ZUTARI

PROVINCIAL INVENTORY REPORT 2020 - 2024: GREENHOUSE GAS EMISSIONS IN LIMPOPO

2026

UK PACT

LIMPOPO
PROVINCIAL GOVERNMENT
REPUBLIC OF SOUTH AFRICA

EXECUTIVE SUMMARY

The Limpopo Provincial Greenhouse Gas (GHG) Inventory presents the province's emissions and removals for the 2020 - 2024 period. It covers direct emissions generated within Limpopo (Scope 1), indirect emissions from purchased electricity (Scope 2), electricity transmission and distribution losses (Scope 3), and emissions and removals from Land Use, Land-Use Change and Forestry (LULUCF).

The inventory was compiled in accordance with the 2006 IPCC Guidelines for National Greenhouse Gas Inventories, supplemented by the 2019 Refinement where applicable. The Global Protocol for Community-Scale Greenhouse Gas Emission Inventories (GPC) was used to define the provincial inventory boundary and classify emissions by scope.

Relevant national methodologies and emission factors published by DFFE were applied where available. Emissions were converted to carbon dioxide equivalent (CO_2e) using the 100-year global warming potentials adopted for the inventory (Table ES-1).

Table ES-1: IPCC Global Warming Potentials relative to CO_2

Major greenhouse gases	GWP values for 100-year time horizon
Carbon dioxide (CO_2)	1
Methane (CH_4)	28
Nitrous Oxide (N_2O	265

Limpopo's total GHG emissions, excl. LULUCF increased from 60,906 Gg CO_2e in 2020 to 63,319 Gg CO_2e in 2024. Emissions increased to 62,358 Gg CO_2e in 2021, declined to 60,759 Gg CO_2e in 2022, and subsequently increased in 2023 and 2024 (Table ES-2).

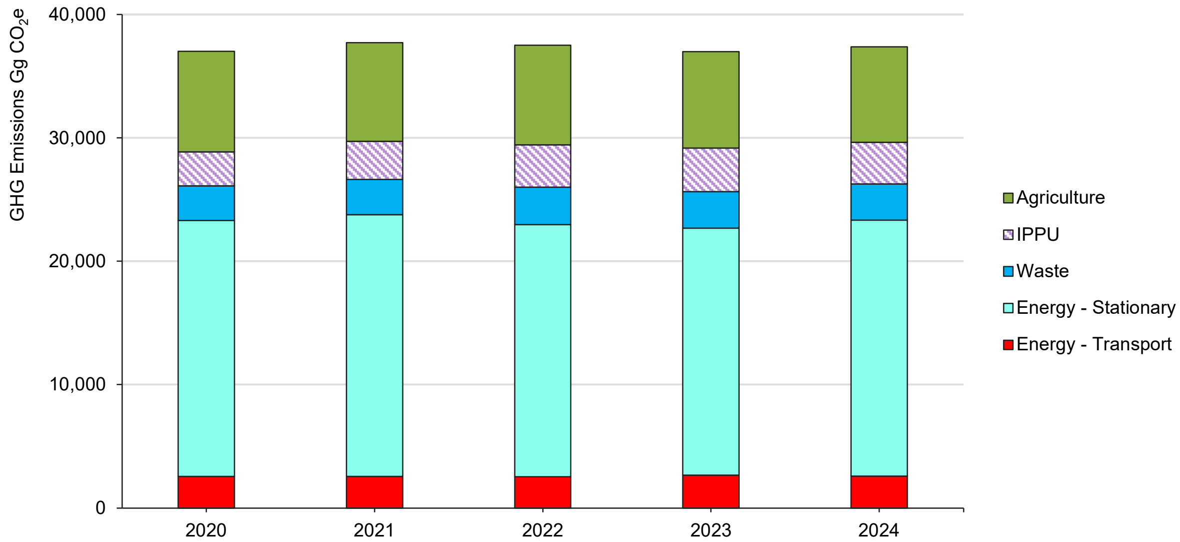
Table ES-2: Emissions by scope, 2020 - 2024

Scope	2020	2021	2022	2023	2024
Scope 1	37,002	37,706	37,500	36,983	37,376
Scope 2	21,247	21,554	20,386	21,434	22,576
Scope 3	2,658	3,098	2,873	3,062	3,367
Total, excl. LULUCF	**60,906**	**62,358**	**60,759**	**61,480**	**63,319**

All values are expressed in Gg CO_2e.

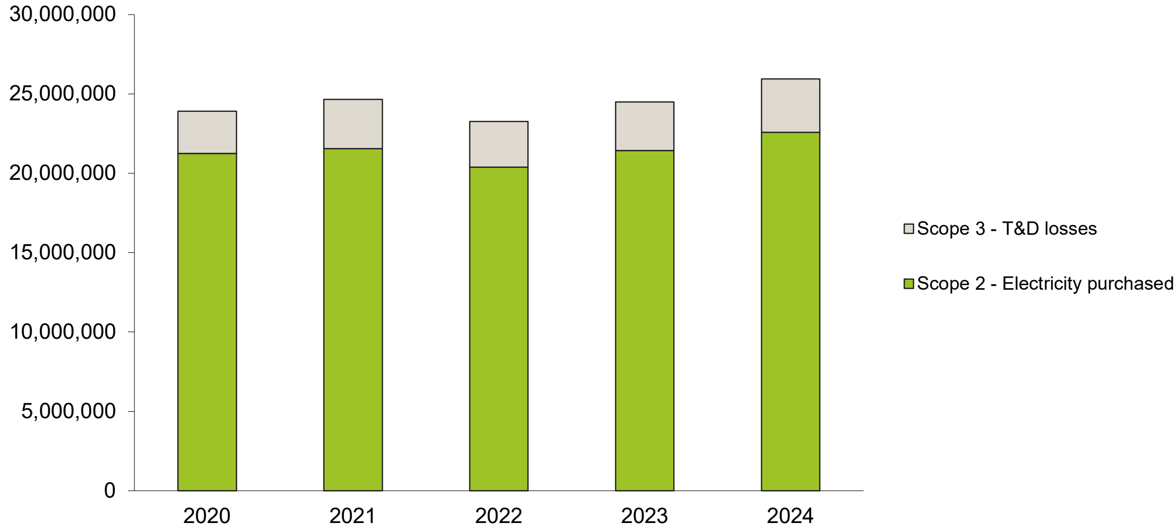
Scope 1 emissions remained relatively stable, ranging from 37,002 Gg CO_2e to 37,706 Gg CO_2e annually. Energy was the largest direct emissions source throughout the inventory period. In 2024, Energy contributed 23.3 $MtCO_2e$, or 62% of Scope 1 emissions, and was dominated by Energy Industries. Agriculture contributed 7.7 $MtCO_2e$, IPPU contributed 3.4 $MtCO_2e$ and Waste contributed 2.9 $MtCO_2e$ (Figure ES-1).

Figure ES-1: Limpopo direct GHG emissions by IPCC sector, 2020 - 2024
Scope 1



Indirect emissions were dominated by purchased electricity. Scope 2 emissions fluctuated from 21.2 $MtCO_2e$ in 2020 to 22.6 $MtCO_2e$ in 2024. Scope 3 emissions ranged from 2.7 to 3.4 $MtCO_2e$ and were entirely associated with electricity transmission and distribution losses (Figure ES-2).

Figure ES-2: Limpopo indirect GHG emissions, 2020–2024
Scope 2 & 3



LULUCF emissions and removals were estimated for 2020 only. The sector recorded net emissions of approximately 2.5 $MtCO_2e$. Emissions from Cropland, Grassland, Settlements and Other Land were largely offset by removals from Forest Land and Wetlands. LULUCF was excluded from the 2021–2024 totals because estimates were unavailable for these years.

The inventory was compiled using Limpopo's existing 2020 GHG inventory, DMRE fuel consumption data, national GHG inventory trends, DFFE methodologies and other provincial and national datasets. In the absence of SAGERS data for 2021–2024, relevant Energy and IPPU emissions were extrapolated using annual changes in the corresponding national sector emissions. Other data gaps were addressed through documented interpolation, extrapolation and assumptions. The results provide an evidence base for tracking emissions and prioritising mitigation measures in electricity generation and consumption, agriculture, industrial processes and waste management.

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Acronyms and abbreviations

AFOLU	Agriculture, Forestry and Other Land Use
CH_4	Methane
CO_2	Carbon dioxide
N_2O	Nitrous Oxide
NH_3	Ammonia
CO_2e	Carbon dioxide equivalent
DALRRD	Department of Agriculture, Land Reform and Rural Development
DFFE	Department of Forestry, Fisheries and the Environment
DMRE	Department of Mineral Resources and Energy
EF	Emission factor
FOLU	Forestry and Other Land Use
GHG	Greenhouse gas
GHGI	Greenhouse gas inventory
GPC	Global Protocol for Community-Scale Greenhouse Gas Emission Inventories
GWP	Global warming potential
IPCC	Intergovernmental Panel on Climate Change
IPPU	Industrial Processes and Product Use
LEDET	Limpopo Economic Development, Environment and Tourism
LPG	Liquefied petroleum gas
LULUCF	Land Use, Land-Use Change and Forestry
MSW	Municipal solid waste
MSWGR	Municipal solid waste generation rate
NCV	Net calorific value
NDC	Nationally Determined Contribution
NH_3	Ammonia
NIR	National Inventory Report
SAGERS	South African Greenhouse Gas Emissions Reporting System
SAWIC	South African Waste Information Centre
T&D	Transmission and distribution
WRI	World Resources Institute

Definitions

Activity data	Quantitative information on an activity that results in GHG emissions or removals, such as fuel consumed, electricity used, livestock numbers, land area or waste generated.
AFOLU	Agriculture, Forestry and Other Land Use. An IPCC sector covering emissions and removals from agriculture, livestock, managed soils, land use and land-use change.
Anthropogenic emissions	GHG emissions resulting from human activities, including fuel combustion, industrial production, agriculture and waste management.
Base year	A historical year against which emissions, removals or changes in emissions may be compared.
Biological treatment of waste	The controlled treatment of organic waste through processes such as composting and anaerobic digestion.
Carbon dioxide equivalent (CO_2e)	A common unit used to express the climate impact of different GHGs by converting them according to their global warming potentials.
Carbon sink	A reservoir or process that removes and stores more carbon from the atmosphere than it releases.
Carbon stock	The quantity of carbon stored within a carbon pool, such as living biomass, dead organic matter or soil.
Direct emissions	Emissions from sources located within the geographical boundary of the province. These are reported as Scope 1 emissions.
Emission factor	A coefficient that relates activity data to the quantity of a GHG emitted or removed.
Emission source	A process or activity that releases a GHG into the atmosphere.
Energy Industries	An IPCC Energy subcategory covering emissions from fuel combustion associated with electricity and heat generation, petroleum refining and other energy-producing activities.
Fugitive emissions	Intentional or unintentional releases of GHGs during the production, processing, storage, transmission and distribution of fuels, excluding combustion emissions.
Geographic boundary	The physical administrative boundary within which the provincial inventory is compiled.
Greenhouse gas	A gas that absorbs and emits infrared radiation and contributes to the greenhouse effect. GHGs covered by the inventory include CO_2, CH_4 and N_2O.
Greenhouse gas inventory	A quantified account of GHG emissions and removals occurring within a defined boundary over a specified reporting period.
Global warming potential (GWP)	A factor that compares the warming effect of a GHG with that of CO_2 over a specified period. This inventory applies 100-year GWPs.
Grid emission factor	The quantity of GHG emissions associated with each unit of electricity supplied by the national electricity grid.
Indirect emissions	Emissions resulting from activities within the province but occurring at sources outside the provincial boundary. These are reported under Scope 2 or Scope 3.
Industrial Processes and Product Use (IPPU)	An IPCC sector covering emissions from industrial processes and product use, excluding emissions from the combustion of fuels for energy.

Inventory year	The calendar year for which GHG emissions and removals are estimated and reported.
IPCC category	A standard classification used to organise emissions and removals by sector, source and subcategory.
Key category	An inventory category that has a significant influence on the total emissions or removals, emissions trend or level of inventory uncertainty.
Land-use change	The conversion of land from one land-use category to another, such as the conversion of Grassland to Settlements.
LULUCF	Land Use, Land-Use Change and Forestry. The sector covering GHG emissions and removals associated with land remaining within a land-use category and land converted between categories.
Mobile combustion	Emissions from fuel combustion in mobile sources, including road transport, aviation and other forms of transportation.
Municipal solid waste	Waste generated by households and similar waste generated by commercial, institutional and other activities.
Net calorific value	The quantity of usable energy released through the combustion of a unit of fuel, excluding the energy required to vaporise water.
Net emissions	Total emissions after subtracting GHG removals from the atmosphere.
Removal	The transfer of a GHG from the atmosphere into a carbon pool through processes such as vegetation growth and carbon sequestration.
Reporting period	The period covered by the inventory. For these reports, the reporting period is 2020–2024.
Scope 1 emissions	GHG emissions from sources located within the provincial geographical boundary. These include direct emissions from Energy, IPPU, Agriculture and Waste, as well as LULUCF where estimated.
Scope 2 emissions	Indirect GHG emissions associated with grid-supplied electricity consumed within the province but generated outside its boundary.
Scope 3 emissions	Other indirect emissions resulting from activities within the province but occurring outside its boundary. In these inventories, this includes electricity transmission and distribution losses and, for Gauteng, imported waste disposed of within the province.
Sequestration	The process through which carbon is captured from the atmosphere and stored in vegetation, soils or other carbon pools.
Stationary combustion	Emissions from fuel combustion in fixed equipment or facilities, such as power stations, boilers, furnaces and industrial plants.
Tier	The methodological level used to estimate emissions. Tier 1 generally uses default IPCC methods and factors, Tier 2 uses country-specific data or factors, and Tier 3 uses detailed models or facility-specific information.
Time series	A consistent set of annual GHG emissions and removals estimated for multiple inventory years.
Transmission and distribution losses	Electricity lost while being transmitted and distributed from generation facilities to consumers. The emissions associated with these losses are reported under Scope 3.
Uncertainty	The degree of confidence associated with an emissions or removals estimate, reflecting limitations in activity data, emission factors, assumptions or calculation methods.
Waste imported	Waste generated outside the provincial boundary but transported into and disposed of within the province.
Wastewater treatment and discharge	Processes used to treat or discharge domestic or industrial wastewater that may generate CH_4 and N_2O emissions.

1 INTRODUCTION

1.1 Background information on climate change

Climate change is one of the most significant environmental, social, and economic challenges facing the world today. The increasing concentration of greenhouse gases (GHGs) in the atmosphere, primarily driven by human activities such as fossil fuel combustion, industrial production, agriculture, and waste management, is driving changes in the global climate system. These changes have far-reaching implications, including rising temperatures, increased frequency and intensity of extreme weather events, water insecurity, biodiversity loss, and adverse impacts on human health and economic development. Limpopo plays an important role in South Africa's transition to a low-carbon and climate-resilient future by implementing renewable energy projects, promoting climate-smart agriculture, conserving natural ecosystems, and supporting green economic development.

South Africa has demonstrated its commitment to addressing climate change through both international and domestic policy frameworks. As one of the 196 Parties to the Paris Agreement, the country has committed to contributing to the global effort to limit the increase in average global temperatures by reducing greenhouse gas emissions and strengthening resilience to climate change. Under the Paris Agreement, Parties are required to prepare, communicate, and periodically update their Nationally Determined Contributions (NDCs), which outline national climate mitigation and adaptation commitments.

South Africa's first Nationally Determined Contribution (NDC), submitted in 2015, committed the country to limiting national GHG emissions to a range of 398–614 $MtCO_2e$ for both 2025 and 2030. In response to increasing scientific evidence and the global ambition to accelerate climate action, South Africa submitted an updated NDC in September 2021, strengthening its mitigation commitments. The revised targets reduced the emissions range for 2025 to 398–510 $MtCO_2e$ and for 2030 to 350–420 $MtCO_2e$, representing a substantial increase in ambition compared to the original commitments. Achieving these targets requires coordinated action across all spheres of government and economic sectors, supported by GHG inventories that enable the monitoring of emissions trends and the identification of mitigation opportunities.

A significant milestone in South Africa's climate governance framework was the promulgation of the Climate Change Act, 2024 (Act No. 22 of 2024) in July 2024. The Act establishes a comprehensive legal framework to support an effective national climate change response and facilitate South Africa's transition towards a low-carbon, climate-resilient economy and society. Building upon the principles and provisions of the National Environmental Management Act, the Climate Change Act provides for integrated climate change governance across national, provincial, and municipal spheres of government. It also promotes GHG emissions reduction, climate risk assessment, and coordinated planning to ensure that climate considerations are incorporated into development planning and decision-making processes.

1.2 Background information on GHG Inventories

Within the Climate Change Act context, provincial GHG inventories have become increasingly important. They contribute to improving the quality of national GHG reporting by providing more detailed and accurate sub-national data. The primary objective of this inventory is to establish a transparent, consistent, and credible estimate of Limpopo's GHG emissions and removals for the 2020–2024 period. This GHG Inventory presents an assessment of GHG emissions and removals for Limpopo Province using activity data for the period 2020 to 2024. The inventory has been compiled using the 1996 Intergovernmental Panel on Climate Change (IPCC) Guidelines for National GHG Inventories. The 1996 IPCC Good Practice Guidelines were adopted to ensure methodological consistency with previous provincial GHG inventories and to facilitate the comparison of emissions trends over time.

Limpopo province compiled and published the Limpopo GHG Emissions Inventory for 2020. The inventory accounts exclusively for Scope 1 (direct) GHG emissions and Scope 2 emissions associated with purchased electricity occurring within the provincial boundary. As such, it excludes FOLU (Forest and Other Land Use) and indirect emissions (Scope 3). The inventory therefore provides a baseline assessment of direct emissions generated by activities within Limpopo Province, forming the foundation for future emissions tracking, reporting, and climate change mitigation planning.

Building on this baseline, the current Limpopo provincial GHG Inventory covering the period 2020–2024 has been developed using the same methodological approach and IPCC Guidelines to ensure consistency and comparability with the previous inventory. However, the scope of the inventory has been significantly expanded to include FOLU, Scope 2 emissions from purchased electricity and Electricity losses (Distribution and Transmission), as well as imported: Landfilled. The inclusion of indirect emissions provides a more comprehensive representation of Limpopo's GHG footprint by capturing emissions associated with energy consumption and other activities that occur outside the provincial boundary but are driven by economic activities within the province.

1.3 Institutional arrangements for Limpopo GHG Inventory preparations

The Limpopo Economic Development, Environment and Tourism (LEDET) is responsible for the coordination and management of the provincial GHG Inventory as part of the province's climate change mitigation planning, monitoring, reporting, and evaluation functions. The Department leads the compilation, quality assurance, and publication of the provincial GHG inventory, ensuring that the inventory is developed in accordance with nationally approved methodologies and international good practice.

Although the LEDET plays the lead role in compiling and reporting the provincial GHG inventory, the successful preparation of the inventory relies on collaboration with a range of provincial departments, municipalities, state-owned entities, and other relevant institutions. Moreover, the Department coordinates data collection, engaging with data providers and undertaking quality control. This collaborative institutional arrangement strengthens the transparency, consistency, completeness, and accuracy of the inventory.

1.4 Objective of the project

The primary objective of the project is to develop a Limpopo Provincial GHG Inventory. This includes compiling and analysing activity data to estimate provincial GHG emissions and removals, preparing a comprehensive and transparent inventory, and identifying data gaps and opportunities for improving future inventory development and reporting.

1.5 Purpose of the Report

The purpose of this report is to present a comprehensive assessment of GHG emissions and removals within Limpopo Province by quantifying emissions across the relevant IPCC sectors (Energy, IPPU, AFOLU and Waste sectors). The report provides the province's emissions profile using approved GHG inventory methodologies and activity data. It identifies the sources and sinks of emissions and highlights areas where data quality and reporting can be improved. The GHG inventory serves as an important evidence base for emissions reduction planning and the monitoring of mitigation interventions. Furthermore, it supports compliance with the requirements of the Climate Change Act, strengthens provincial GHG monitoring and reporting systems, and contributes to South Africa's national GHG inventory and climate change commitments.

2 LIMPOPO INVENTORY REPORT, 2020 – 2024

2.1 Inventory Boundary

The GHG emissions inventory for the Limpopo province over the 2020 - 2024 period follows the 2006 IPCC Guidelines[1], and the Global Protocol for Community-Scale Greenhouse Gas Emission Inventories: An accounting and Reporting Standard for Cities which was developed by the World Resources Institute (WRI 2014)[2].

The inventory provides an overview of the provincial GHG footprint by emission scope and sector. Scope 1, Scope 2 and Scope 3 emissions are presented to illustrate the relative contribution of direct and indirect emission sources to the overall provincial GHG footprint. Scope 1 emissions are further disaggregated by IPCC sector and source category to identify the dominant contributors to direct GHG emissions within the province. A summary of the emission scopes and source categories included in the inventory is presented below:

Table 2-1: Emission scopes and sources included in the inventory

Scope 1	Scope 2	Scope 3
Agriculture, forestry and other land use	Grid-supplied electricity (delivered / consumed in Limpopo)	Transmission and distribution losses
Stationary and mobile fuel combustion (in-boundary transportation)		
Industrial processes and product use (IPPU)		
Waste generated and disposed inside Limpopo		

A detailed description of the methodologies, activity data, emission factors, assumptions and equations applied to estimate emissions for each source category is provided in Chapter 2: Methodology for Calculating GHG Emissions for the Limpopo Province.

2.2 Overview of Limpopo GHG Emissions

The Limpopo GHG footprint consisted of direct (Scope 1), indirect electricity-related (Scope 2) and selected value chain (Scope 3) emissions. Total GHG emissions by scope over the 2020 - 2024 inventory period are presented in Table 2-2**Error! Reference source not found.** and **Error! Reference source not found.**.

Scope 1 emissions accounted for the largest share of Limpopo's GHG emissions throughout the inventory period, contributing approximately 59% to 62% of total emissions, excl. LULUCF. These emissions include emissions from the energy, industrial processes and product use (IPPU), agriculture and waste sectors. Scope 2 emissions were the second largest contributor, accounting for approximately 34% to 36% of total emissions, which represent emissions from electricity purchased and consumed within the province but generated outside its boundary. Scope 3 emissions represented the smallest share ranging from 4% to 5% of total emissions, excl. LULUCF and were primarily associated with electricity transmission and distribution losses.

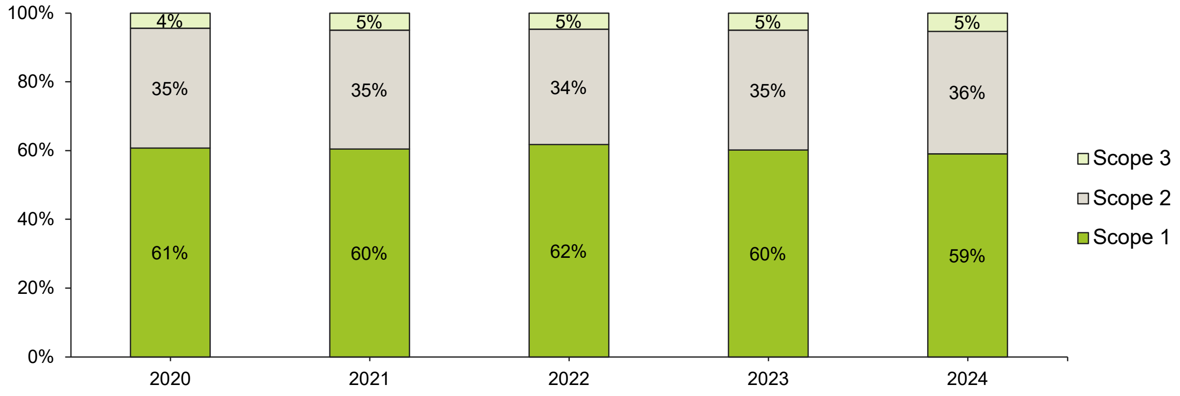
Table 2-2: Limpopo greenhouse gas emissions by scope, excl LULUCF (tCO_2e)

Scope	2020	2021	2022	2023	2024
Scope 1	37,002,000	37,706,187	37,500,013	36,983,208	37,376,059
Scope 2	21,246,840	21,554,000	20,385,840	21,434,260	22,576,320

[1] 2006 IPCC Guidelines for National Greenhouse Gas Inventories (Volume 1-5)
[2] World Resources Institute (WRI), Global Protocol for Community-Scale Greenhouse Gas Emission Inventories: An Accounting and Reporting Standard for Cities, 2014.

Scope 3	2,657,573	3,097,520	2,873,106	3,062,443	3,366,786
Total	**60,906,413**	**62,357,706**	**60,758,959**	**61,479,911**	**63,319,165**

Figure 2-1: Limpopo Greenhouse Gas Emissions by Scope (%) excl. LULUCF, 2020 - 2024



2.2.1 Emissions breakdown by sector

In 2024, Limpopo's GHG emissions totalled 63.3 $MtCO_2e$, excl. LULUCF. Scope 1 emissions represented the largest share, accounting for 59% of total emissions. Scope 2 emissions from purchased electricity contributed 36%, while Scope 3 emissions from electricity transmission and distribution (T&D) losses accounted for the remaining 5%.

Scope 1 emissions were primarily generated by stationary energy sources, which contributed 33% of total emissions. Agriculture was the second-largest Scope 1 source at 12%, followed by Waste and IPPU at 5% each and transport at 4%. Fugitive emissions contributed less than 1% of the total emissions (Figure 2-2). As shown in Table **2-3Error! Reference source not found.**, the overall emissions profile remained broadly consistent throughout the 2020-2024 inventory period, with Scope 1 representing the largest share in each year.

Figure 2-2: Breakdown of total GHG emissions by scope and Scope 1 emission sources, 2024.

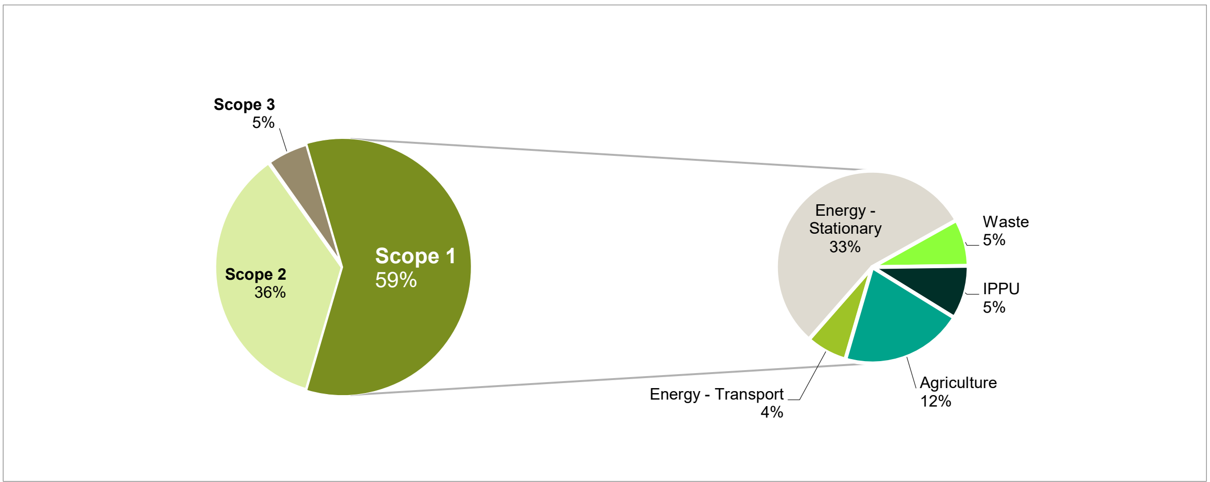


Table 2-3: Annual GHG emissions by scope and emission source, 2020–2024 (tCO_2e).

Scope	Emission source	2020	2021	2022	2023	2024
Scope 1	Energy Transport	2,558,289	2,571,704	2,548,302	2,657,740	2,592,851
	Energy - Stationary	20,744,288	21,190,456	20,405,041	20,015,140	20,726,075
	Energy – Fugitive sources	6,960	7,125	6,872	6,732	6,969

	Waste	2,795,495	2,855,635	3,030,843	2,951,559	2,948,814
	IPPU	2,759,530	3,090,728	3,439,643	3,528,898	3,371,703
	Agriculture	8,137,438	7,990,539	8,069,312	7,823,139	7,729,647
Scope 2	Electricity consumed	21,246,840	21,554,000	20,385,840	21,434,260	22,576,320
Scope 3	T&D losses	2,657,573	3,097,520	2,873,106	3,062,443	3,366,786
Total		**37,002,000**	**37,706,187**	**37,500,013**	**36,983,208**	**37,376,059**

2.3 Scope 1 GHG Emissions

Scope 1 emissions are all direct emissions sources located within the geographical boundary of the Limpopo province. The direct sources of emissions include agriculture (excl. LULUCF), stationary and mobile fuel combustion (in-boundary transportation), industrial processes and product use, and waste generated and disposed inside Limpopo. The Scope 1 emissions presented in this section are reported in accordance with the IPCC sector codes and categories and represent only direct emissions occurring within the provincial boundary. Indirect emissions, including Scope 2 and Scope 3 emissions, are presented in the subsequent sections of this chapter.

2.3.1 GHG Emissions and Trends by IPCC sector

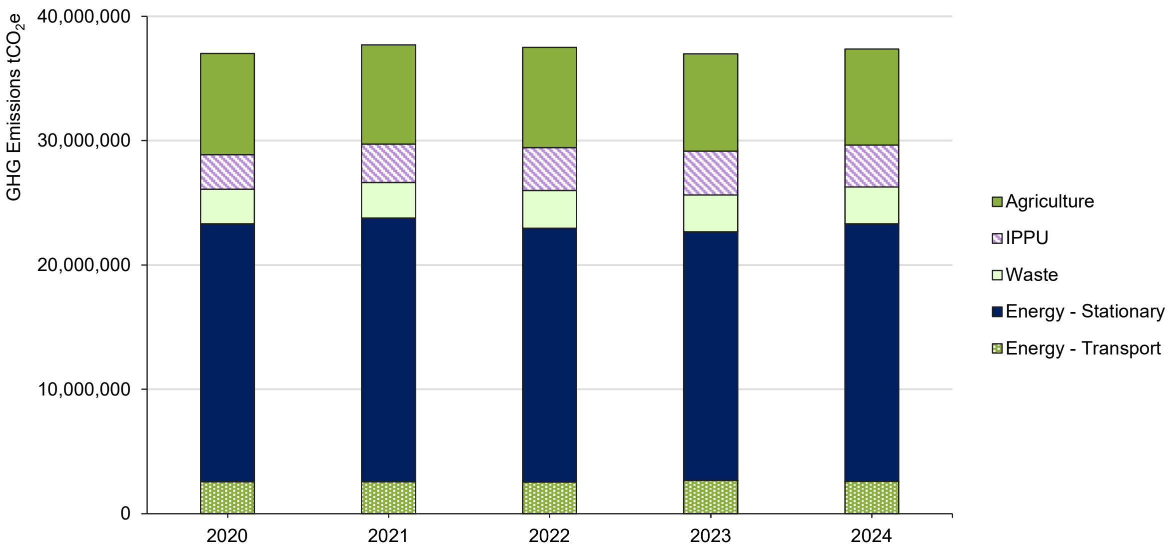
Table 2-4 and Figure 2-3 present Limpopo's Scope 1 emissions by IPCC sector from 2020 to 2024, excl. LULUCF. Energy was the largest contributor throughout the period, followed by Agriculture. IPPU emissions increased overall, while Waste emissions remained relatively stable. Total Scope 1 emissions ranged from approximately 37.0 to 37.7 $MtCO_2e$ annually.

Table 2-4: Limpopo's GHG emissions by IPCC sectors, 2020 - 2024

IPCC categories		GHG Emissions (tCO_2e)				
		2020	2021	2022	2023	2024
TOTAL (excl. LULUCF)		**37,002,000**	**37,706,187**	**37,500,013**	**36,983,208**	**37,376,059**
TOTAL (incl. LULUCF)		**39,519,210**	**37,706,187**	**37,500,013**	**36,983,208**	**37,376,059**
1	**ENERGY**	**23,309,537**	**23,769,285**	**22,960,215**	**22,679,612**	**23,325,895**
1A1	Energy Industries	19,667,480	20,134,296	19,419,860	19,022,520	19,692,031
1A2	Manufacturing Industries & Construction	901,030	922,416	889,686	871,482	902,155
1A3	Transportation	2,558,289	2,571,704	2,548,302	2,657,740	2,592,851
1A4	Other Industries	175,778	133,743	95,495	121,137	131,889
1B	Fugitive Emissions	6,960	7,125	6,872	6,732	6,969
2	**IPPU**	**2,759,530**	**3,090,728**	**3,439,643**	**3,528,898**	**3,371,703**
2A3	Glass Production	938,000	1,050,578	1,169,179	1,199,518	1,146,086
2A4	Other Process Uses of Carbonates	16,510	18,492	20,579	21,113	20,173
2C2	Ferroalloys Production	1,805,020	2,021,658	2,249,885	2,308,267	2,205,445
3	**AGRICULTURE**	**8,137,438**	**7,990,539**	**8,069,312**	**7,823,139**	**7,729,647**
3A1	Enteric Fermentation	7,852,307	7,687,269	7,727,703	7,487,361	7,427,430
3A2	Manure Management	101,840	99,797	97,232	100,323	97,109
3C2	Liming	49,297	56,907	67,376	65,895	57,695
3C4	Direct N2O Emissions from Managed Soils	43,186	54,139	78,976	72,364	56,860
3C5	Indirect N2O Emissions from Managed Soils	13,652	16,840	23,669	21,857	17,250
3C6	Indirect N2O Emissions from Manure Management	77,158	75,588	74,356	75,339	73,303

	LULUCF	2,517,210	NE	NE	NE	NE
4A	Forest Land	-37,861,313				
4B	Cropland	29,130,999				
4C	Grassland	4,564,570				
4D	Wetlands	- 480,644				
4E	Settlements	4,477,190				
4F	Other land	2,686,407				
5	**WASTE**	**2,795,495**	**2,855,635**	**3,030,843**	**2,951,559**	**2,948,814**
5A	Solid Waste Disposal	805,720	817,758	872,167	842,377	854,963
5B	Biological Treatment of Solid Waste	6	6	7	4	2
5C	Incineration and Open Burning of Waste	706,655	717,213	764,932	738,804	749,843
5D	Wastewater Treatment and Discharge	1,283,113	1,320,658	1,393,737	1,370,373	1,344,006

Figure 2-3: Limpopo GHG emissions by IPCC sectors, excl. LULUCF (2020 – 2024)

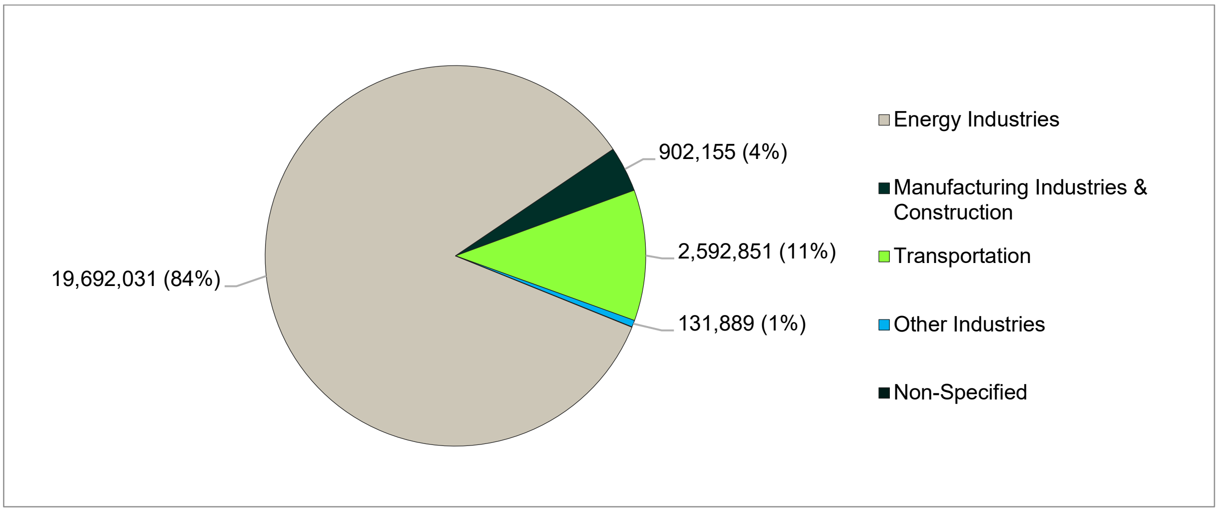


2.3.1.1 Energy GHG Emissions (2024)

The Energy sector includes GHG emissions from stationary fuel combustion, mobile fuel combustion, fugitive emissions and other fuel combustion activities occurring within the provincial boundary. In 2024, the energy sector emitted 23.3 MtCO_2e, accounting for 62% of total Scope 1 emissions and 37% of Limpopo's total GHG footprint. The contribution of each Energy source category is presented in Figure 2-4.

- Energy Industries were the largest source, contributing approximately 19.7 MtCO_2e, or 84% of Energy sector emissions. These emissions were almost entirely as a result of electricity generation.
- Transportation contributed 2.6 MtCO_2e (11% of energy sector emissions), with road transport representing the main source.
- Manufacturing Industries and Construction contributed approximately 4%, primarily from non-metallic minerals, iron and steel, and residual fuel oil use.

Figure 2-4: Energy GHG Emissions, 2024 (tCO_2e, %)

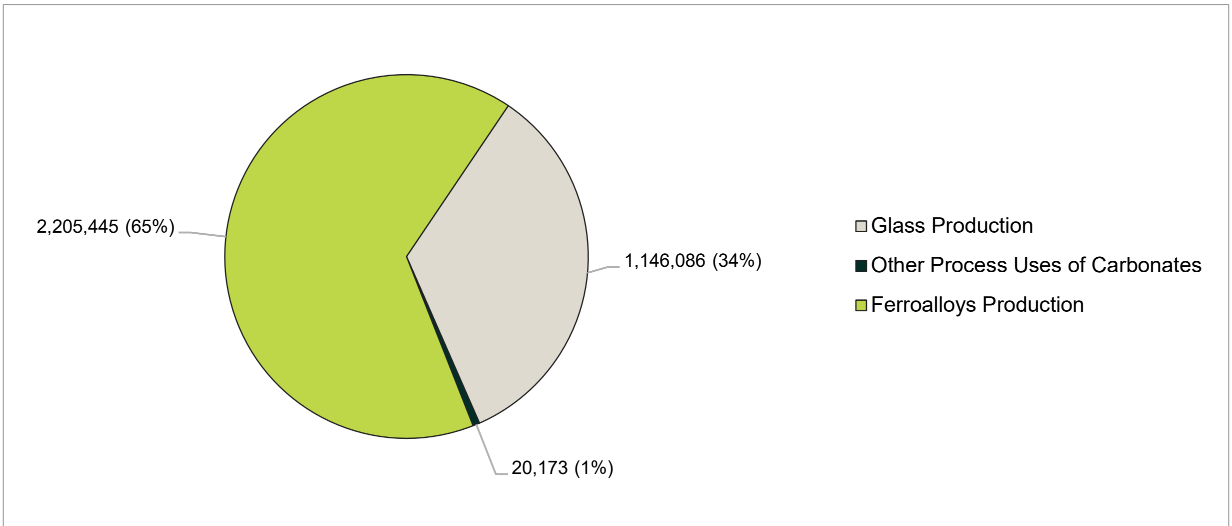


2.3.1.2 IPPU GHG Emissions (2024)

The Industrial Processes and Product Use (IPPU) sector includes GHG emissions from industrial processes and product use, excluding fuel-combustion emissions. In 2024, the IPPU sector emitted approximately 3.4 $MtCO_2e$, accounting for 9% of Scope 1 emissions and 5% of Limpopo's total GHG footprint (Figure 2-5).

- Ferroalloys Production was the largest source, contributing approximately 2.2 $MtCO_2e$, or 65% of IPPU emissions.
- Glass Production contributed approximately 1.1 $MtCO_2e$, accounting for 34%.
- Other Process Uses of Carbonates contributed approximately 0.02 $MtCO_2e$, or 1%.

Figure 2-5: IPPU GHG Emissions, 2024



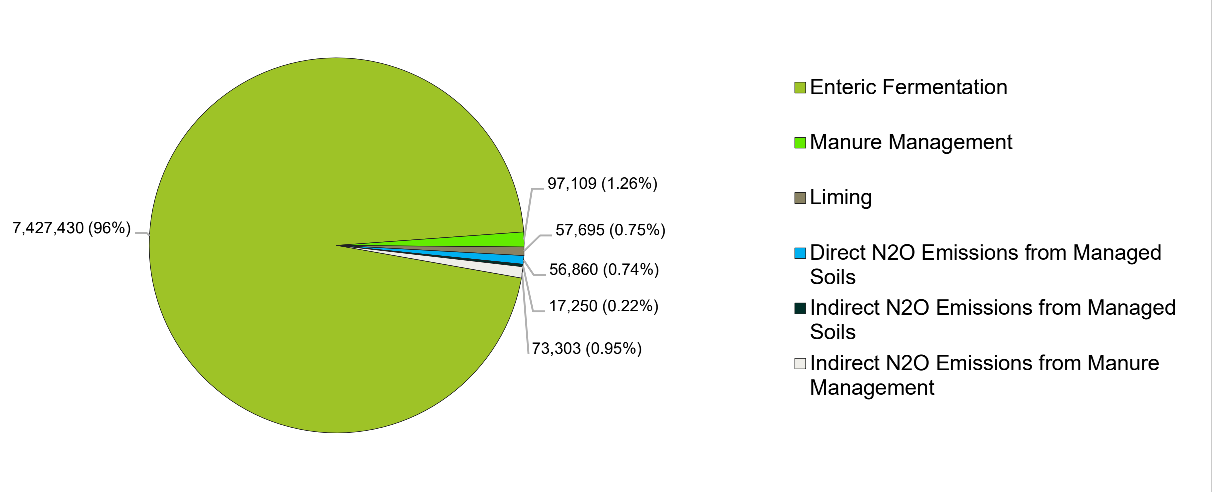
2.3.1.3 Agriculture, excl LULUCF GHG Emissions (2024)

The agriculture sector includes GHG emissions from livestock production and managed agricultural soils. In 2024, the sector emitted approximately 7.7 $MtCO_2e$, accounting for 21% of Scope 1 emissions and 12% of Limpopo's total GHG footprint (Figure 2-6).

- Enteric Fermentation was the dominant source, contributing approximately 7.4 $MtCO_2e$, or 96% of agricultural emissions.
- Manure Management contributed approximately 0.10 $MtCO_2e$, or 1.3%.

- Indirect N_2O emissions from Manure Management contributed approximately 1%.
- Liming and Direct N_2O emissions from Managed Soils each contributed approximately 0.7%.
- Indirect N_2O emissions from Managed Soils contributed the remaining 0.2%.

Figure 2-6: Agriculture GHG Emissions, 2024 (tCO_2e, %)



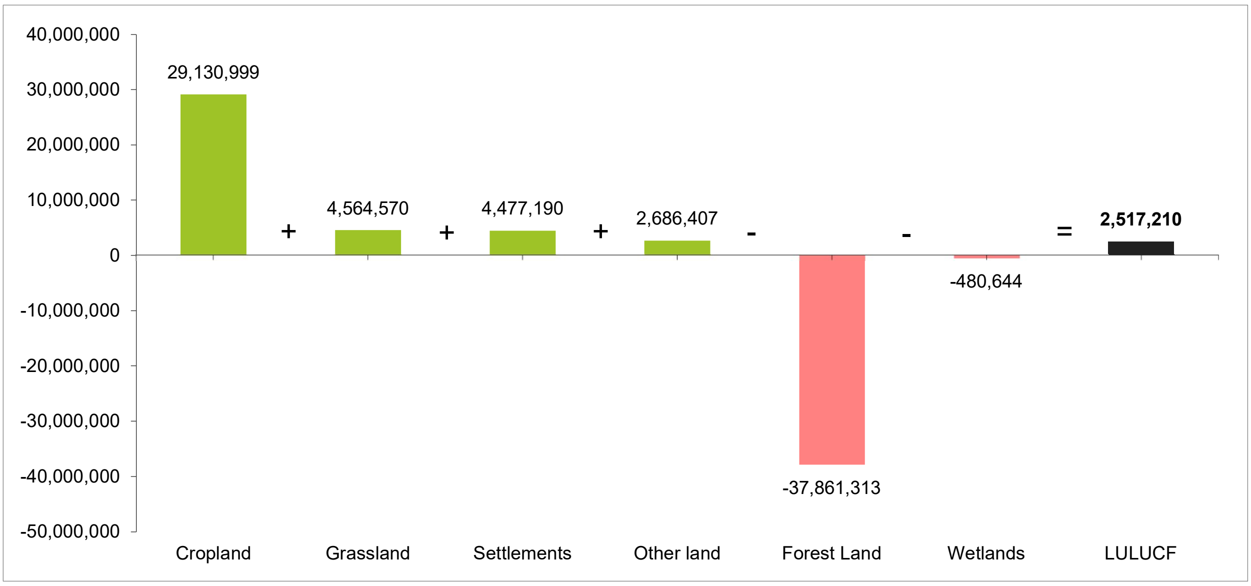
2.3.1.4 Land Use and Land Use Change (2020)

In 2020, the LULUCF sector was a net source of approximately 2.5 $MtCO_2e$. Figure 2-7 presents the contribution of each land-use category. Positive values represent emissions, while negative values represent removals from the atmosphere.

Cropland was the largest emissions source, contributing approximately 29.1 $MtCO_2e$. Grassland, Settlements and Other Land contributed a further 4.6 $MtCO_2e$, 4.5 $MtCO_2e$ and 2.7 $MtCO_2e$, respectively. These emissions were largely offset by removals from Forest Land of approximately 37.9 $MtCO_2e$ and Wetlands of 0.5 $MtCO_2e$.

The GHG emissions and removals in the LULUCF are calculated using a minimum of 20 years data. Collection of these data is done periodically and is aligned with the DFFE reporting. The last reporting used the 2020 data. In the interim between the reporting periods, the emissions and removals for the latest reporting can be assumed.

Figure 2-7: Limpopo LULUCF emissions and removals by land-use category (tCO2e)

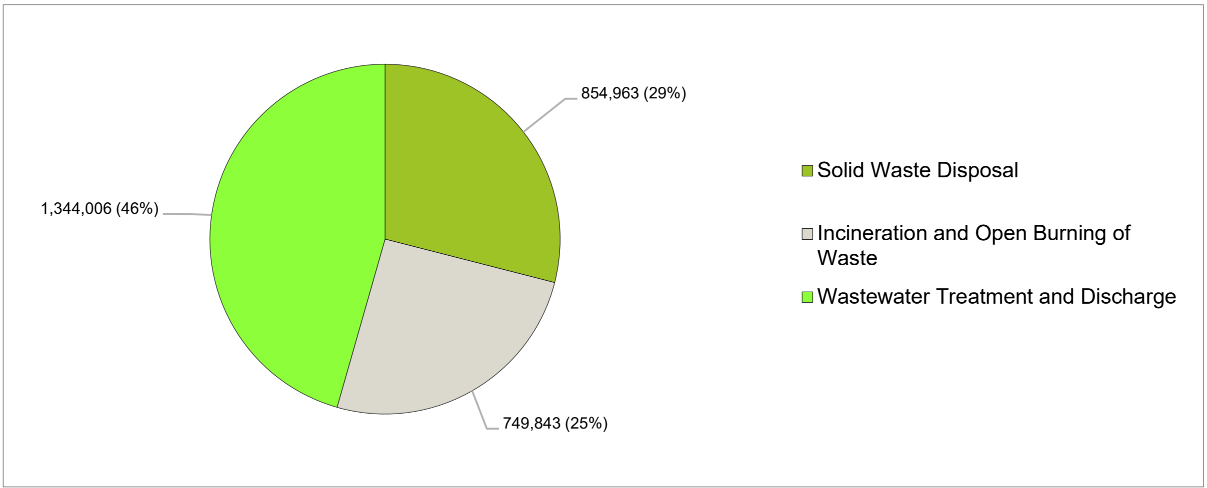


2.3.1.5 Waste GHG Emissions (2024)

The Waste sector includes GHG emissions from solid waste disposal, biological treatment, incineration and open burning, and wastewater treatment and discharge. In 2024, the sector emitted approximately 2.9 $MtCO_2e$, accounting for 8% of Scope 1 emissions and 5% of Limpopo's total GHG footprint (Figure 2-8).

- Wastewater Treatment and Discharge was the largest source, contributing approximately 1.3 $MtCO_2e$, or 46% of Waste sector emissions.
- Solid Waste Disposal contributed approximately 0.85 $MtCO_2e$, accounting for 29%.
- Incineration and Open Burning of Waste contributed approximately 0.75 $MtCO_2e$, or 25%.

Figure 2-8: Waste GHG Emissions, 2024 (tCO_2e, %)



2.4 Scope 2 GHG Emissions

Scope 2 emissions are indirect GHG emissions associated with electricity purchased within the Limpopo province. Annual electricity consumption and the corresponding Scope 2 emissions for the 2020–2024 inventory period are presented in Table 2-5.

Scope 2 emissions were the second-largest contributor to Limpopo's GHG footprint throughout the inventory period. Emissions fluctuated from 21.2 $MtCO_2e$ in 2020 to 21.6 $MtCO_2e$ in 2021, before declining to 20.4 $MtCO_2e$ in 2022. Emissions subsequently increased to 21.4 $MtCO_2e$ in 2023 and reached their highest level of 22.6 $MtCO_2e$ in 2024. Electricity consumption followed a broadly similar trend, increasing overall from 19,673 GWh in 2020 to 20,904 GWh in 2024.

Table 2-5: Limpopo Scope 2 Emissions, 2020 - 2024

Parameter	Unit	2020	2021	2022	2023	2024
Electricity consumption	GWh	19,673	20,725	20,184	20,221	20,904
Scope 2 GHG emissions	tCO_2e	21,246,840	21,554,000	20,385,840	21,434,260	22,576,320

2.5 Scope 3 GHG Emissions

The only source of Scope 3 GHG emissions included in the Limpopo inventory was electricity transmission and distribution (T&D) losses. These are indirect emissions associated with electricity lost during its transmission and distribution from the point of generation to end users within the province. Annual T&D losses and the corresponding Scope 3 emissions for the 2020 - 2024 inventory period are presented in Table 2-6.

Scope 3 emissions fluctuated over the inventory period, increasing from 2.7 $MtCO_2e$ in 2020 to 3.1 $MtCO_2e$ in 2021 before declining to 2.9 $MtCO_2e$ in 2022. Emissions subsequently increased to 3.1 $MtCO_2e$ in 2023 and reached their highest level of 3.4 $MtCO_2e$ in 2024. T&D losses followed a broadly similar pattern, increasing overall from 2,461 GWh in 2020 to 3,117 GWh in 2024.

Table 2-6: T&D Losses and Scope 3 GHG Emissions, 2020 - 2024

Parameter	Unit	2020	2021	2022	2023	2024
T&D losses	GWh	2,461	2,978	2,845	2,889	3,117
Scope 3 (Fuel & Energy related activities)	tCO_2e	2,657,573	3,097,520	2,873,106	3,062,443	3,366,786

METHODOLOGY FOR CALCULATING GHG EMISSIONS FOR THE LIMPOPO PROVINCE

1 ENERGY

This section describes the methodology and assumptions used to estimate emissions for energy. The energy sector includes emissions from fuel combustion and fugitive emissions from fuels. This covers fuel combustion activities across all sectors, as well as fugitive emissions related to the production, processing, transmission, storage, and distribution of fuels. IPCC Energy Categories Included in the Limpopo GHG Inventory:

- 1A1 Energy Industries
- 1A2 Manufacturing Industries and Construction
- 1A3 Transportation
- 1A4 Other Industries
- 1B Fugitive Emissions

1.1 Methodology

Limpopo Energy sector emissions were estimated using the province's existing 2020 GHG inventory and annual fuel consumption data obtained from the Department of Mineral Resources and Energy (DMRE). Energy sector emissions are estimated using a combination of emissions data reported through the South African Greenhouse Gas Emissions Reporting System (SAGERS) and fuel consumption data from the Department of Mineral Resources and Energy (DMRE).

As SAGERS data were not available for Limpopo for 2020 - 2024, the SAGERS-related component of the 2020 inventory was extrapolated using annual changes in Energy sector emissions reported in the national GHG inventory. The percentage change in national Energy emissions relative to 2020 was calculated for each year and applied to the corresponding Limpopo 2020 emissions:

Equation 1-1: Calculation of Energy sector GHG emissions

$$\boldsymbol{E_{Limpopo,y} = E_{Limpopo,y-1} \times (1 + r_y)}$$

$E_{Limpopo,y}$	=	estimated Limpopo Energy emissions for the current year
$E_{Limpopo,2020}$	=	Limpopo Energy emissions for the preceding year
r_y	=	annual percentage change in national Energy emissions

The annual percentage movements in national Energy sector emissions presented in Table 1-1 were used to estimate Limpopo's Energy sector emissions for 2021–2024.

Table 1-1: Data used for extrapolating Limpopo Energy sector emissions, 2020–2024

Bases of extrapolation	2020	2021	2022	2023	2024
SA Energy emissions (GgCO2e)	374,748	383,643	370,030	362,459	375,216
% Changes	0.0%	2.4%	-3.5%	-2.0%	3.5%

DMRE fuel consumption data were disaggregated by fuel type and allocated to the relevant IPCC source categories. Total Energy sector emissions were therefore derived as the sum of emissions reported through SAGERS and emissions calculated from the DMRE fuel consumption data.

Emissions from fuel consumption reported by the DMRE were estimated by applying the relevant net calorific values, emission factors and GWPs to the quantity of fuel consumed, as shown below:

Equation 1-2: Calculation of Energy sector GHG emissions

$$\boldsymbol{GHG\ Emissions} = \sum_{i} (\boldsymbol{Fuel\ consumption} \times \boldsymbol{NCV} \times \boldsymbol{EF_i}) \times \boldsymbol{GWP_i}$$

i	=	Greenhouse gas type
$Fuel\ consumption$	=	Quantity of fuel consumed (litres)
NCV	=	Net Calorific Value of the fuel (TJ/litre)
EF_i	=	Emission factor for the greenhouse gas type i (kg gas/TJ)
GWP_i	=	Global Warming Potential of the greenhouse gas type i (1 for CO_2, 28 for CH_4 and 265 for N_2O)

Following the classification and calculation steps described above, emissions derived from DMRE fuel consumption data and emissions extrapolated from the 2020 reported Energy emissions in Limpopo's Climate Change Response Strategy were aggregated by inventory year and IPCC source category to determine total Energy sector emissions for Limpopo. The resulting emissions were reported as carbon dioxide equivalent (CO_2e) using the global warming potentials adopted for the inventory.

1.2 Activity Data

- DMRE contains fuel consumption data by province, region, and fuel type. For this inventory, the data was grouped under the appropriate IPCC classifications within the Energy sector, while regional records were mapped to the corresponding districts for reporting purposes. Emissions were then estimated following the methodology in 1.1.

Table 1-2: Fuel consumption used for estimating energy-related emissions in Limpopo, 2020 – 2023 (liters)

Province	Year	Jet Fuel	Aviation Gasoline	Diesel	Furnace Oil	LPG	Paraffin	Petrol
Limpopo	2020	955,001	296,248	216,123,996	36,810,446	2,265,606	1,646,191	276,512,089
	2021	17,619	311,318	210,257,732	24,022,486	1,022,327	1,425,021	276,417,065
	2022	-	410,266	221,987,440	13,790,494	-	582,732	273,644,045
	2023	9,936	296,468	263,555,946	21,898,501	-	1,393,147	284,655,319

1.3 Emission Factors

- For DMRE fuel consumption data, the applicable net calorific values, fuel densities, and Tier 1 default or Tier 2 country-specific emission factors were applied to convert fuel quantities to energy units and estimate CO_2, CH_4 and N_2O emissions. The resulting emissions were converted to CO_2e using the global warming potentials adopted for the inventory. Table 1-3 below shows the fuel properties and emissions factors used to calculate energy sector emissions.

Table 1-3: Fuel properties and emission factors applied to DMRE fuel consumption data

Fuel		NCV MJ/L	DF Kg CO_2/TJ	CS Kg CO_2/TJ	DF Kg CH_4/TJ	DF Kg N_2O/TJ
Liquid	Jet fuel	34.4	71,500	-	3	0.6
	Aviation Gasoline	33.9	70,000	-	0.5	2
	Diesel	35.5	74,100	74,638	3	0.6
	Furnace Oil	41.60	77,400	73,090	3	0.6
	LPG	46.29	63,100	64,852	1	0.1
	Paraffin	37.5	71,900	64,640	3	0.6
	Petrol	32.5	69,300	72,430	3	0.6

NCV: Net Calorific Value, DF: Default Factor, CS: Country Specific Factor

1.4 Assumptions and Limitations

- DMRE fuel consumption data were disaggregated by fuel type, including jet fuel, aviation gasoline, diesel, petrol, furnace oil, LPG and paraffin. Jet fuel and aviation gasoline were classified under 1A3a Domestic Aviation; diesel and petrol were classified under 1A3b Road Transport; LPG was classified under 1A4a Commercial/Institutional; paraffin was classified under 1A4b Residential; and furnace oil was included under 1A1ai Electricity Generation.
- Extrapolation of SAGERS-related emissions: The 2020 emissions from Limpopo's existing GHG inventory were used as the base year. Emissions for 2021–2024 were estimated by applying the annual percentage changes in national Energy sector emissions.
- Extrapolations (DMRE): Fuel consumption data were available for 2020–2023. 2024 fuel quantities were estimated using the arithmetic mean of the available annual fuel consumption, after which emissions were calculated using the applicable emission factors.

2 INDUSTRIAL PROCESSES AND PRODUCT USE (IPPU)

This section describes the methodology and assumptions used to estimate emissions from Industrial Processes and Product Use (IPPU). The IPPU sector includes emissions that arise from industrial processes and the use of products, excluding emissions from fuel combustion. This covers process-related emissions from activities such as mineral, chemical and metal production, as well as emissions from product use, including refrigerants and other industrial products where applicable. IPCC IPPU Categories included in the Limpopo GHG inventory:

- 2A1 Cement Production
- 2A4 Other Process Uses of Carbonates
- 2C2 Ferroalloys Production

2.1 Methodology

Limpopo's existing 2020 GHG inventory, presented in the Limpopo Climate Change Response Strategy, was used as the base year for estimating IPPU emissions. The 2020 inventory included emissions originally reported through SAGERS.

As SAGERS data were unavailable for 2021–2024, emissions were extrapolated using annual changes in IPPU emissions reported in the national GHG inventory:

Equation 2-1: Calculation of Energy sector GHG emissions

$$\boldsymbol{E_{Limpopo,y} = E_{Limpopo,y-1} \times (1 + r_y)}$$

$E_{Limpopo,y}$	=	estimated Limpopo IPPU emissions for the current year
$E_{Limpopo,2020}$	=	Limpopo IPPU emissions for the preceding year
r_y	=	annual percentage change in national IPPU emissions

The annual percentage movements in national IPPU sector emissions presented in Table 2-1 were used to estimate Limpopo's Energy sector emissions for 2021–2024.

Table 2-1: Data used for extrapolating Limpopo IPPU emissions, 2020 - 2024

Bases of extrapolation	2020	2021	2022	2023	2024
SA Energy emissions (GgCO2e)	24,857	27,841	30,984	31,788	30,372
% Changes	0.0%	12.0%	11.3%	2.6%	-4.5%

2.2 Assumptions and Limitations

- Extrapolation of SAGERS-related emissions: Limpopo's existing 2020 IPPU inventory was used as the base year. Emissions for 2021–2024 were estimated by applying the annual percentage changes in national IPPU emissions.
- The approach assumes that changes in Limpopo's IPPU emissions broadly followed national IPPU trends over the inventory period.
- The estimates should be updated when complete SAGERS or facility-level data for Limpopo become available.

3 AGRICULTURE

This section describes the methodology and assumptions used to estimate emissions from the agriculture sector. The agriculture sector includes emissions from livestock and agricultural land management activities, excluding emissions from fuel combustion, which are reported under the Energy sector. This covers emissions from activities such as enteric fermentation, manure management, managed soils, crop residues, and the application of lime, where applicable. IPCC Agriculture Categories included in the inventory:

- 3A1 Enteric Fermentation
- 3A2 Manure Management
- 3C2 Liming
- 3C4 Direct N2O emissions from managed soils
- 3C5 Indirect N2O emissions from managed soils
- 3C6 Indirect N2O emissions from manure management

3.1 Enteric Fermentation and Manure Management

Enteric fermentation emissions refer to methane emissions generated during the digestive process of livestock, particularly ruminant animals such as cattle, sheep and goats. In this inventory, enteric fermentation emissions were calculated for cattle, sheep, goats and swine.

3.1.1 Methodology

Enteric fermentation emissions were estimated using a Tier 2 approach, consistent with the 2006 IPCC Guidelines for National Greenhouse Gas Inventories. The approach applies livestock category-specific emission factors that reflect the characteristics of different animal types, including herd composition.

Annual livestock population data for each livestock category were used as the activity data. South Africa-specific Tier 2 enteric fermentation emission factors, expressed in kg CH_4/head/year, developed by the Department of Forestry, Fisheries and the Environment (DFFE), were applied to the corresponding livestock populations. Methane emissions were estimated separately for each livestock category and year by multiplying the livestock population by the applicable emission factor, using the following equation:

Equation 3-1: Calculation of Enteric Fermentation Methane Emissions

$$\boldsymbol{CH_4\ emissions = \sum(Livestock\ population \times EF_{CH_4}) \times GWP_{CH_4}}$$

$Livestock\ population$	=	Number of animals in each livestock category (head)
EF_{CH_4}	=	Enteric fermentation emission factor (kg CH_4/head/year)
GWP_{CH_4}	=	28, the 100-year Global Warming Potential of methane
$CH_4\ emissions$	=	Annual methane emissions expressed as tonnes of carbon dioxide equivalent

3.1.2 Activity Data

- The main activity data used to estimate enteric fermentation emissions are livestock population numbers by animal category. The Department of Agriculture publishes provincial livestock numbers for cattle, sheep, goats, swine and other livestock categories for the 2020–2024 period. These data provide the total number of animals per province but do not provide the full level of detail required to distinguish between herd composition and breed composition[3].

- To further disaggregate the provincial livestock totals, national herd and breed composition data were applied. For cattle, the national herd composition was used to estimate the share of bulls, dairy cows, other cows, dairy heifers, other heifers, calves, young oxen and oxen. For sheep and goats, national breed composition data were used to estimate the share of Merino sheep, Karakul sheep, other woolled sheep, non-woolled sheep, Angora goats and other goats[4].

- The national composition shares were applied to the provincial livestock totals to derive a more detailed breakdown of livestock categories per province. This approach assumes that the national herd and breed composition is representative of the livestock composition within each province. The resulting disaggregated livestock data were then used as the activity data for estimating enteric fermentation emission, as shown in Table 3-1 below:

Table 3-1: Activity data used for estimating enteric fermentation emissions in Limpopo

Limpopo									
Cattle									
Year	Bulls	Cows over 2 years		Heifers 1 to 2 years		Calves	Young oxen	Oxen	Total
		Dairy	Other	Dairy	Other				
2020	21,304	110,071	297,072	26,038	82,849	253,281	37,874	31,956	**860,444**
2021	21,001	108,505	291,680	25,668	80,504	246,178	37,335	30,335	**841,204**
2022	23,171	99,635	287,319	27,805	84,574	234,026	47,500	33,598	**837,628**
2023	23,102	112,045	266,829	34,653	82,012	241,417	45,049	30,033	**835,140**
2024	23,683	106,008	259,381	32,704	84,581	212,015	56,387	40,599	**815,357**

Limpopo							
Year	Sheep					Goat	Swine
	Merino	Karakul	Other woolled sheep	Non-woolled sheep	Total	Angora	Swine
2020	104,444	231	38,555	55,824	**199,054**	902,057	328,633
2021	100,923	215	37,246	53,947	**192,330**	898,835	328,627
2022	100,920	215	37,250	53,945	**192,330**	895,518	322,307
2023	113,034	241	41,712	60,423	**215,410**	878,621	319,403
2024	113,661	244	41,951	60,751	**216,607**	865,636	319,213

3.1.3 Emission Factors

- South Africa-specific enteric fermentation emission factors developed by the Department of Forestry, Fisheries and the Environment (DFFE) were applied for each livestock category. The emission factors used in the inventory to estimate emissions from enteric fermentation are shown in the table below
- :

[3] Department of Agriculture: Livestock numbers from 1996 to current
[4] National Development Agency: Abstract of Agricultural Statistics 2025

Table 3-2: Enteric fermentation emission factors and sources per livestock category

Livestock		Enteric Emission Factor *kg CH_4 per head*	Reference
Dairy cattle	Mature cows	141.07	DFFE 2022, NIR 2000 - 2022
	Heifers	70.91	DFFE 2022, NIR 2000 - 2022
Other cattle	Commercial bulls	113	DFFE 2022, NIR 2000 - 2022
	Commercial cows	118.41	DFFE 2022, NIR 2000 - 2022
	Commercial heifers	118.41	DFFE 2022, NIR 2000 - 2022
	Commercial calves	51.6	DFFE 2022, NIR 2000 - 2022
	Commercial young ox	89.4	DFFE 2022, NIR 2000 - 2022
	Commercial ox	65.23	DFFE 2022, NIR 2000 - 2022
Sheep	Commercial wool	9.95	DFFE 2022, NIR 2000 - 2022
	Commercial meat	13.8	DFFE 2022, NIR 2000 - 2022
Goat - Angora	Commercial mohair	6.64	DFFE 2022, NIR 2000 - 2022
	Commercial dairy	19.99	DFFE 2022, NIR 2000 - 2022
Swine	Commercial swine	1.09	DFFE 2022, NIR 2000 - 2022

3.1.4 Emission Factors

- South Africa-specific manure management emission factors developed by the Department of Forestry, Fisheries and the Environment (DFFE) were applied for each livestock category. The emission factors used in the inventory to estimate emissions from enteric fermentation are shown in Table **3-2** table below:

Table 3-3: Emission factors for manure management (DFFE)

Livestock	Lagoon (%)	Liquid / slurry (%)	Dry lot / Kraals (%)	Solid storage (%)	Daily spread (%)	Compost (%)	Pasture Range Paddock (%)	Ash content of manure	Urinary Energy (% of GE)	Gross Energy (MJ/day)	Feed digestibility (%)	Max CH4 capacity (m3 CH4/kg of VS excreted)	Daily volatile solid excreted (kg dm
Dairy Mature cows	5	5	20	5	5		60	0.08	0.04	358.9	0.7	0.24	18.49
Dairy Heifers			2				98	0.08	0.04	183.57	0.7	0.13	9.46
Commercial Other cattle			3				97	0.08	0.04	255.3	0.6	0.18	13.16
Sheep			2				98	0.08	0.04	20.11	0.6	0.19	1.04
Goats			2				98	0.08	0.04	27.9	0.6	0.18	1.44
Swine	71	11	13		3	2		0.17	0.02				

3.1.5 Assumptions and Data Limitations

- Provincial livestock data were available only as total livestock numbers by animal type and no breakdown of herd or breed composition. National herd and breed compositions were therefore applied to disaggregate provincial livestock totals into the animal subcategories required for the emissions calculations. This assumes that the national livestock composition is broadly representative of the composition within Limpopo.
- Provincial goat population data were available only as total goat numbers, with no national composition available to distinguish between commercial mohair and commercial dairy goats. The provincial goat population was therefore assumed to include 50% commercial mohair goats and

50% commercial dairy goats for the application of emission factors. This assumption should be reviewed if more detailed goat composition data become available.

- These assumptions should be reviewed and updated when province-specific herd and breed composition data become available.

3.2 Liming

Liming emissions refer to carbon dioxide (CO_2) emissions released following the application of carbonate - containing lime to agricultural soils. Lime, including limestone and dolomite, is commonly applied to reduce soil acidity and improve nutrient availability and crop productivity. When these carbonate materials are applied to soil, they dissolve and release carbon dioxide.

3.2.1 Methodology

Liming emissions were estimated as direct carbon dioxide (CO_2) emissions resulting from the application of carbonate-containing lime materials to agricultural soils. Calculations were undertaken for maize, sunflower, soybeans, groundnuts, dry beans, sorghum and wheat for each inventory year from 2020 to 2024.

For each crop, the quantity of lime applied was estimated by multiplying the planted area by the relevant crop-specific lime application rate as determined by Tongwane et al (2016)[5]. The estimated lime quantity was then apportioned between limestone and dolomite using the assumed share of each material as used by the DFFE.

Separate carbon emission factors were applied to the estimated quantities of limestone and dolomite. The resulting carbon emissions were converted to CO_2 emissions using the molecular weight conversion factor of 44/12, as shown in Equation 3-2 below:

Equation 3-2: Calculation of Enteric Fermentation Methane Emissions

$$\boldsymbol{CO_2\ emissions} = \sum_{c} (\boldsymbol{Area_c} \times \boldsymbol{Application\ rate_c} \times (\boldsymbol{Limestone\ share} \times \boldsymbol{EF_{Limestone}} + \boldsymbol{Dolomite\ share} \times \boldsymbol{EF_{Dolomite}}) \times {}^{\boldsymbol{44}}/_{\boldsymbol{12}})$$

c	=	Crop type (e.g. maize, wheat, soybeans, sunflower, etc.)
$CO_2\ emissions$	=	Total annual carbon dioxide emissions from liming, expressed as (tCO_2e).
$Area_c$	=	Area planted for crop c (ha)
$Application\ rate_c$	=	Lime application rate for crop c (t lime/ha)
$Limestone\ share$	=	Fraction of agricultural lime applied as limestone (37%)
$Dolomite\ share$	=	Fraction of agricultural lime applied as dolomite (63%)
$EF_{Limestone}$	=	Carbon emission factor for limestone (t C/t limestone)
$EF_{Dolomite}$	=	Carbon emission factor for dolomite (t C/t dolomite)
${}^{44}/_{12}$	=	Molecular weight ratio used to convert carbon (C) to carbon dioxide (CO_2)

Emissions from limestone and dolomite were added to determine total liming emissions for each crop. Crop-level emissions were then aggregated to determine total liming emissions for the province and inventory year.

3.2.2 Activity Data

- Planted area data were used as the primary activity data for estimating liming emissions. Annual planted area data for maize, sunflower, soybeans, groundnuts, dry beans, sorghum and wheat were obtained for Limpopo for the 2020–2024 inventory period[6].

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[5] Tongwane, M., Mdlambuzi, T., Moeletsi, M., Tsubo, M., Mliswa, V. and Grootboom, L., 2016. Greenhouse gas emissions from different crop production and management practices in South Africa. *Environmental Development*, *19*, pp.23-35.

[6] crop estimates committe

- The data were sourced from the Department of Agriculture, Land Reform and Rural Development (DALRRD) Crop Estimates Committee annual area planted and final production estimate reports. Planted area, expressed in hectares, was used to estimate the quantity of lime applied to each crop using the applicable crop-specific lime application rate.

Table 3-4: Area planted by crop type, 2020 - 2024

Province	Crop type	Area planted per crop type (ha)				
		2020	2021	2022	2023	2024
Limpopo	Maize	33,000	37,500	40,500	39,600	26,000
	Sunflower	65,000	76,500	110,000	100,000	90,000
	Soybeans	15,500	20,500	22,500	26,000	21,000
	Groundnuts	2,900	3,000	2,000	2,000	1,700
	Dry beans	8,400	8,000	10,400	8,000	12,200
	Sorghum	16,000	17,000	15,000	15,500	18,000
	Wheat	23,000	26,500	29,000	30,000	20,500

3.2.3 Emission Factors

- Carbon emission factors were applied to estimate direct CO_2 emissions from the application of limestone and dolomite to agricultural soils. The factors were expressed in tonnes of carbon per tonne of lime material and were applied separately to the estimated quantities of limestone and dolomite.

Table 3-5: Carbon emission factors applied for liming emissions estimates

Lime material	Carbon emission factor	Unit	Sources
Limestone	0.12	tC/t	Literature[7]
Dolomite	0.13	tC/t	Literature

3.2.4 Assumptions and Data Limitations

- Crop-specific lime application rates, expressed in tonnes of lime per hectare per year, were applied to the planted area data to estimate the total quantity of lime applied to each crop. This assumes that the applicable planted area receives lime at the assumed crop-specific application rate.

Table 3-6: Crop-specific lime application rates applied in the liming emissions calculation

Crop	Lime application rate	Unit	Sources
Maize	0.50	t/ha/year	Literature[8]
Sunflower	0.57	t/ha/year	Literature
Soybeans	0.90	t/ha/year	Literature
Groundnuts	0.40	t/ha/year	Literature
Drybeans	0.60	t/ha/year	Literature
Sorghum	1.15	t/ha/year	Literature
Wheat	0.63	t/ha/year	Literature

- In the absence of province-specific data on the composition of lime products applied, total estimated lime application was assumed to be 37% limestone and 63% dolomite.
- The emissions estimated under this category represent direct CO_2 emissions from lime application to agricultural soils.

[7] GHG emissions from different crop production and management practices in South Africa
[8] GHG emissions from different crop production and management practices in South Africa

3.3 Synthetic Fertilizer Application

Synthetic fertiliser application contributes to nitrous oxide (N_2O) emissions from managed agricultural soils. These emissions arise when nitrogen applied to soils is transformed through microbial processes following fertiliser application.

Direct N_2O emissions from synthetic fertiliser application are estimated under IPCC category 3C4, while indirect N_2O emissions associated with nitrogen losses through volatilisation and leaching or runoff are estimated under IPCC category 3C5.

The following sections describe the activity data, methodology, emission factors, assumptions and data limitations applied to estimate emissions from synthetic fertiliser use.

3.3.1 Methodology

Synthetic fertiliser application emissions were estimated for the crops included in the inventory using a Tier 1 approach consistent with the 2006 IPCC Guidelines. The methodology covered both direct N_2O emissions from nitrogen applied to managed soils and indirect N_2O emissions resulting from nitrogen losses through volatilisation and leaching.

3.3.1.1 Direct N_2O Emissions from Synthetic Fertiliser Application

Direct N_2O emissions were estimated by first calculating the quantity of nitrogen applied to each crop. This was determined by multiplying the planted area by the applicable nitrogen application rate.

The estimated nitrogen applied was then multiplied by the direct emission factor (EF1) to estimate N_2O-N emissions. These emissions were converted to N_2O using the molecular weight conversion factor of 44/28 and subsequently converted to CO_2e using the global warming potential adopted for the inventory.

Equation 3-3: Calculation of Direct N_2O from Synthetic fertilizer application

$$\boldsymbol{N_2O\ emissions} = \sum_c \left(\boldsymbol{Area_c} \times \boldsymbol{N\ Application\ rate_c} \times \boldsymbol{EF_1} \times {}^{\mathbf{44}}/_{\mathbf{28}} \times \boldsymbol{GWP_{N_2O}}\right)$$

c	=	Crop type (e.g. maize, wheat, soybeans, sunflower, etc.)
$N_2O\ emissions$	=	Total annual direct nitrous oxide emissions from nitrogen application, expressed as tCO_2e
$Area_c$	=	Area planted for crop c (ha)
$N\ Application\ rate_c$	=	Nitrogen application rate for crop c (kg N/ha).
EF_1	=	Direct emission factor for nitrogen inputs to managed soils (kg N_2O–N/kg N applied)
${}^{44}/_{28}$	=	Molecular weight ratio used to convert N_2O–N to N_2O.
GWP_{N_2O}	=	**265**, the 100-year Global Warming Potential of nitrous oxide.

Direct emissions were calculated separately for each crop, province and inventory year, and then aggregated to determine total direct N_2O emissions from synthetic fertiliser application.

3.3.1.2 Indirect N_2O Emissions from Synthetic Fertiliser Application

Indirect N_2O emissions were estimated from nitrogen losses associated with volatilisation and leaching. These losses occur after nitrogen fertiliser is applied to agricultural soils and a portion of the applied nitrogen is transferred to other environmental pathways.

Volatilisation

For volatilisation, the quantity of nitrogen lost as ammonia and nitrogen oxides was estimated by applying the volatilisation fraction (FracGASF) to total nitrogen applied. The resulting nitrogen loss was multiplied by the volatilisation emission factor (EF4) to estimate indirect N_2O–N emissions. These emissions were converted to N_2O using the molecular weight conversion factor of 44/28 and subsequently converted to CO_2e using the global warming potential adopted for the inventory.

Equation 3-4: Calculation of Indirect N_2O Emissions from Volatilisation of Synthetic Fertilizers

$$N_2O\ emissions = \sum_c (Area_c \times N\ Application\ rate_c \times Frac_{GASF} \times EF_4 \times {}^{44}/_{28} \times GWP_{N_2O})$$

c	=	Crop type (e.g. maize, wheat, soybeans, sunflower, etc.)
N_2O emissions	=	Total annual indirect nitrous oxide emissions from atmospheric deposition of nitrogen, expressed as tCO_2e
$Area_c$	=	Area planted for crop c (ha)
$N\ Application\ rate_c$	=	Nitrogen application rate for crop c (kg N/ha)
$Frac_{GASF}$	=	Fraction of applied nitrogen that volatilises as NH_3 and NO_x (kg N volatilised/kg N applied)
EF_4	=	Emission factor for N_2O emissions from atmospheric deposition of volatilised nitrogen (kg N_2O–N/kg NH_3–N and NO_x–N volatilised)
$^{44}/_{28}$	=	Molecular weight ratio used to convert N_2O–N to N_2O.
GWP_{N_2O}	=	**265**, the 100-year Global Warming Potential of nitrous oxide.

Indirect emissions from nitrogen losses associated with volatilisation were calculated separately for each crop, province and inventory year, and then aggregated to determine total indirect N_2O emissions from synthetic fertiliser application.

Leaching

For leaching, the proportion of nitrogen lost through leaching and runoff was estimated by applying the leaching fraction FracLEACH-(H) to total nitrogen applied. The resulting nitrogen loss was multiplied by the leaching emission factor (EF5) to estimate indirect N_2O–N emissions. These emissions were converted to N_2O using the molecular weight conversion factor of 44/28 and subsequently converted to CO_2e using the global warming potential adopted for the inventory.

Equation 3-5: Calculation of Indirect N_2O Emissions from Leaching of Synthetic Fertilizers

$$N_2O\ emissions = \sum_c (Area_c \times N\ Application\ rate_c \times Frac_{LEACH} \times EF_5 \times {}^{44}/_{28} \times GWP_{N_2O})$$

c	=	Crop type (e.g. maize, wheat, soybeans, sunflower, etc.)
N_2O emissions	=	Total annual indirect nitrous oxide emissions from nitrogen lost through leaching and runoff, expressed as tCO_2e
$Area_c$	=	Area planted for crop c (ha)
$N\ Application\ rate_c$	=	Nitrogen application rate for crop c (kg N/ha)
$Frac_{LEACH}$	=	Fraction of applied nitrogen lost through leaching and runoff (kg N leached and runoff/kg N applied)
EF_5	=	Emission factor for N_2O emissions resulting from nitrogen lost through leaching and runoff (kg N_2O–N/kg N leached and runoff)
$^{44}/_{28}$	=	Molecular weight ratio used to convert N_2O–N to N_2O.
GWP_{N_2O}	=	265, the 100-year Global Warming Potential of nitrous oxide.

Indirect emissions from nitrogen losses associated with leaching were calculated separately for each crop, province and inventory year, and then aggregated to determine total indirect N_2O emissions from synthetic fertiliser application.

3.3.2 Activity Data

- Planted area data was used as the primary activity data for estimating direct and indirect emissions from synthetic fertiliser application. Annual planted area data for maize, sunflower, soybeans, groundnuts, dry beans, sorghum and wheat were obtained for Limpopo for the 2020–2024 inventory period.

- The data is sourced from the Department of Agriculture, Land Reform and Rural Development (DALRRD)[9] Crop Estimates Committee annual area planted and final production estimate reports. Planted area, expressed in hectares, was used to estimate the quantity of synthetic fertiliser applied to each crop using the applicable crop-specific N-application rate
- The planted area data used in the synthetic fertiliser calculations are presented in Table 3-4.

3.3.3 Emission Factors

- Default emission factors and nitrogen-loss fractions from the 2006 IPCC Guidelines were applied to estimate direct and indirect N_2O emissions from synthetic fertiliser application.

- For direct emissions, the estimated quantity of nitrogen applied to agricultural soils was multiplied by the direct N_2O emission factor, EF1. For indirect emissions, the relevant nitrogen-loss fractions and emission factors were applied to estimate N_2O emissions resulting from volatilisation and leaching or runoff. The emission factors and nitrogen-loss fractions used in the inventory to estimate direct and indirect emissions from synthetic fertiliser application are shown in Table 3-7 below:

Table 3-7: Emission factors and nitrogen-loss fractions applied for synthetic fertiliser application

Emission type	Parameter	Description	Factor	Unit	Source
Direct	EF1	Direct N2O emission factor for N2 applied to managed soild	0.01	(kg N_2O–N) (kg N applied)-1	IPCC 2006 Guidelines, Chapter 11, Table 11.3
Indirect (Volatilisation)	FracGASF	Fraction of applied nitrogen volatilised as NH3 and NOx	0.11	(kg NH3–N + NOx–N) (kg N applied)–1	IPCC 2006 Guidelines, Chapter 11, Table 11.3
	EF4	N2O emission factor for volatilised nitrogen	0.01	(kg NH3–N + NOx–N) (kg N applied)–1	IPCC 2006 Guidelines, Chapter 11, Table 11.3
Indirect (Leaching)	FracLEACH	Fraction of applied nitrogen lost through leaching and runoff	0.24	(kg NH3–N + NOx–N) (kg N applied)–1	IPCC 2006 Guidelines, Chapter 11, Table 11.3
	EF5	N_2O emission factor for nitrogen lost through leaching and runoff	0.011	(kg NH3–N + NOx–N) (kg N applied)–1	IPCC 2006 Guidelines, Chapter 11, Table 11.3

3.3.4 Assumptions and Data Limitations

- Crop-specific nitrogen application rates, expressed in kilograms of nitrogen per hectare, were applied to planted area data to estimate the total quantity of synthetic nitrogen fertiliser applied to each crop.

Table 3-8: Nitrogen application rates in South Africa

Crop	N-application rate	Unit	Sources
Maize	52.8	kg N/ha	Literature[10]
Sunflower	15.0	kg N/ha	Literature
Soybeans	19.0	kg N/ha	Literature
Groundnuts	180.0	kg N/ha	Literature
Drybeans	24.9	kg N/ha	Literature
Sorghum	30.0	kg N/ha	Literature
Wheat	30.0	kg N/ha	Literature

3.4 Crop Residues

Crop residue emissions refer to nitrous oxide (N_2O) emissions from managed soils resulting from the decomposition of crop residues following harvest. Crop residues include both above-ground plant material, such as stalks, leaves and husks, and below-ground biomass, including roots. As crop

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residues decompose, nitrogen contained within the plant material is returned to managed soils, where microbial processes of nitrification and denitrification produce direct N_2O emissions. Indirect N_2O emissions also occur where nitrogen released from crop residues is lost through leaching and runoff.

In this inventory, crop residue emissions were estimated for maize, sunflower, soybeans, groundnuts, dry beans, sorghum and wheat cultivated in Limpopo for the 2020–2024 inventory period.

3.4.1 Methodology

Crop residue emissions were estimated using a Tier 1 approach in accordance with the 2006 IPCC Guidelines for National Greenhouse Gas Inventories (Volume 4, Chapter 11). The methodology is based on estimating the annual amount of nitrogen in crop residues returned to managed soils (F_{CR}), which represents the nitrogen input from crop residues available for nitrification and denitrification. F_{CR} forms the basis for estimating both direct and indirect nitrous oxide (N_2O) emissions from crop residues.

The annual amount of nitrogen in crop residues returned to managed soils (F_{CR}) was estimated separately for each crop type using IPCC Equation 11.6. The calculation accounts for nitrogen contained in both above-ground and below-ground crop residues and incorporates crop-specific production, residue-to-crop production ratios, dry matter fractions, nitrogen contents and residue management parameters.

The estimated FCR per crop is subsequently used to estimate direct and indirect N_2O emissions. Direct emissions were estimated by applying the IPCC default direct emission factor (EF_1) to the total nitrogen input from crop residues, while indirect emissions were estimated by applying the default fraction of nitrogen lost through leaching and runoff (FracLEACH-(H)) together with the corresponding indirect emission factor (EF_5). Nitrous oxide emissions were converted to carbon dioxide equivalent (CO_2e) using a Global Warming Potential (GWP) of 265.

The annual amount of nitrogen in crop residues returned to managed soils (FCR) was estimated using Equation 3-6 below. A summary of the variables and parameters used in the calculation is provided in Table 3-9.

Equation 3-6: Calculation of the annual amount of nitrogen in crop residues returned to soils

$$\boldsymbol{F_{CR}} = \sum_{c} (\boldsymbol{Crop_c} \times \boldsymbol{Frac_{Renew(c)}} \times ((\boldsymbol{Area_c} - \boldsymbol{Area\ burnt_c} \times \boldsymbol{C_f}) \times \boldsymbol{R_{AG(c)}} \times \boldsymbol{N_{AG(c)}} \times (\boldsymbol{1} - \boldsymbol{Frac_{Removed(c)}}) + \boldsymbol{Area_c} \times \boldsymbol{R_{BG(c)}} \times \boldsymbol{N_{BG(c)}})$$

c	=	Crop type (e.g. maize, wheat, soybeans, sunflower, etc.)
F_{CR}	=	Annual amount of N in crop residues (above and below ground) returned to soils (kg N)
$Crop_c$	=	Harvested annual dry matter yield for crop c, kg d.m. per ha
$Area_c$	=	Total annual area harvested of crop c, ha
$Area\ burnt_c$	=	Annual area of crop c burnt, ha yr-1
C_f	=	Combustion factor
$Frac_{Renew(c)}$	=	Fraction of total area under crop c that is renewed annually
$Frac_{Remove(c)}$	=	Fraction of above-ground residues of crop c removed annually for purposes such as feed, bedding and construction (kg N)
$R_{AG(c)}$	=	Ratio of above-ground residues dry matter
$N_{AG(c)}$	=	N content of above-ground residues for crop c (kg N (kg d.m)-1)
$R_{BG(c)}$	=	Ratio of below-ground residues harvested yield for crop c
$N_{BG(c)}$	=	N content of below-ground residues for crop c (kg N (kg d.m)-1)

Table 3-9: Variables Used in the Calculation of F_{CR}

#	Variable	Description	Units	Source
a	*Area planted*	Total area planted under crop c, during the inventory year.	Ha	Literature
b	*Production*	Annual production of crop c, calculated from the planted area and crop yield.	t	Literature
c	*Yield*	Harvested fresh yield for crop c	t/ha	Calculated $(b \div a)$
d	*DRY*	Dry matter fraction of harvested crop c	kg d.m	2019R IPCC, Chapter 11, Table 11.1A

e	$Crop_c$	Harvested annual dry matter yield for crop c	kg/ha	Calculated $(c \times d)$
f	$R_{AG(c)}$	Ratio of above-ground residue dry matter to harvested yield for crop c	kg d.m. ha-1(kg d.m. ha-1)-1	2019R IPCC, Chapter 11, Table 11.1A
g	$R_{S(c)}$	Ratio+ of below-ground root biomass to above-ground shoot biomass for crop c	kg d.m. ha-1(kg d.m. ha-1)-1	2019R IPCC, Chapter 11, Table 11.1A
h	$Frac_{Renew(c)}$	Fraction of total area under crop c that is renewed annually	Dimensionless	Expert judgment
i	$AG_{DM(c)}$	Above-ground residue dry matter for crop c	kg d.m. ha-1	Calculated $(e \times f)$
j	BGR_c	annual total amount of belowground crop residue for crop c	kg d.m	Calculated $\{(e+i) \times g \times a \times h)\}$
k	$N_{AG(c)}$	N content of above-ground residues for crop c	kg N (kg d.m.) -1	2019R IPCC, Chapter 11, Table 11.1A
l	$N_{BG(c)}$	N content of below-ground residues for crop c	kg N (kg d.m.) -1	2019R IPCC, Chapter 11, Table 11.1A
m	$Frac_{burnt}$	Fraction of above-ground crop residues for crop c that are burnt in the field following harvest.	Dimensionless	Expert judgment
n	$Frac_{removed}$	Fraction of above-ground residues of crop c removed annually for purposes such as feed, bedding and construction	Dimensionless	Expert judgment
o	$R_{BG(BIO)}$	Ratio of below-ground biomass (roots) to harvested crop biomass for crop *i*.	kg d.m. (kg d.m.)-1	2006 IPCC, Chapter 11, Table 11.2
p	$R_{BG(c)}$	Ratio of below-ground residues harvested yield for crop c	kg d.m. (kg d.m.)-1	Calculated $\{(o \times (i \times 1000 + e)/e\}$
q	C_f	Combustion factor	Dimensionless	2019R IPCC, Chapter 2, Table 2.1

3.4.1.1 Direct N_2O Emissions from Crop Residues

Direct N_2O emissions from crop residues were estimated by applying the IPCC default direct emission factor (EF_1) to the annual amount of nitrogen in crop residues returned to managed soils (FCR). The resulting N_2O-N emissions were converted to N_2O using the molecular weight ratio of 44/28 and subsequently expressed as carbon dioxide equivalent (CO_2e) using a Global Warming Potential (GWP) of 265.

Equation 3-7: Calculation of Direct N_2O Emissions from Crop Residues

$$\boldsymbol{N_2O\ emissions} = \sum_{c} (\boldsymbol{F_{CR}} \times \boldsymbol{EF_1} \times \boldsymbol{{}^{44}/_{28}} \times \boldsymbol{GWP_{N_2O}})$$

c	=	Crop type (e.g. maize, wheat, soybeans, sunflower, etc.)
$N_2O\ emissions$	=	Total direct nitrous oxide emissions from crop residues, expressed as tCO_2e
F_{CR}	=	Annual amount of nitrogen in crop residues returned to managed soils (kg N/year)
EF_1	=	IPCC default direct emission factor for nitrogen inputs to managed soils
${}^{44}/_{28}$	=	Molecular weight ratio used to convert N_2O–N to N_2O.
GWP_{N_2O}	=	**265**, the 100-year Global Warming Potential of nitrous oxide.

Direct emissions were calculated separately for each crop, province and inventory year, and then aggregated to determine total direct N_2O emissions from crop residues.

3.4.1.2 Indirect N_2O Emissions from Crop Residues

Indirect N_2O emissions from crop residues were estimated by applying the IPCC default fraction of nitrogen lost through leaching and runoff FracLEACH and the corresponding indirect emission factor (EF_5) to the annual amount of nitrogen in crop residues returned to managed soils (FCR). This accounts for N_2O emissions resulting from nitrogen that is transported from managed soils through leaching and runoff before undergoing further transformation. The resulting N_2O-N emissions were converted to N_2O and expressed as carbon dioxide equivalent (CO_2e).

Equation 3-8: Calculation of Indirect N_2O Emissions from Crop Residues

$$\boldsymbol{N_2O\ emissions} = \sum_{c} (\boldsymbol{F_{CR}} \times \boldsymbol{Frac_{LEACH}} \times \boldsymbol{EF_5} \times \boldsymbol{{}^{44}/_{28}} \times \boldsymbol{GWP_{N_2O}})$$

c	=	Crop type (e.g. maize, wheat, soybeans, sunflower, etc.)
$N_2O\ emissions$	=	Total direct nitrous oxide emissions from crop residues, expressed as tCO_2e
F_{CR}	=	Annual amount of nitrogen in crop residues returned to managed soils (kg N/year)
$Frac_{LEACH}$	=	Fraction of applied nitrogen lost through leaching and runoff (kg N leached and runoff/kg N applied)
EF_5	=	IPCC default indirect emission factor for nitrogen losses through leaching and runoff
$^{44}/_{28}$	=	Molecular weight ratio used to convert N_2O–N to N_2O.
GWP_{N_2O}	=	**265**, the 100-year Global Warming Potential of nitrous oxide.

Indirect emissions from nitrogen losses associated with leaching were calculated separately for each crop, province and inventory year, and then aggregated to determine total indirect N_2O emissions from crop residues.

3.4.2 Activity Data

- The primary activity data used to estimate crop residue emissions were the annual area planted (ha) and crop production (tonnes) for each crop included in the inventory. Area planted data were used to estimate annual crop production, which, together with crop-specific IPCC default parameters, formed the basis for estimating the annual amount of nitrogen in crop residues returned to managed soils (F_{CR}).
- Crop-specific planted area data and production for maize, sunflower, soybeans, groundnuts, dry beans, sorghum and wheat were obtained from the Department of Agriculture for Limpopo for the 2020 - 2024 inventory period. The planted area is presented in Table 3-4 and production data is presented in the table below:

Table 3-10: Production by crop type, 2020 - 2024

Province	Crop type	Production per crop type (tonne)				
		2020	2021	2022	2023	2024
Limpopo	Maize	231,000	284,400	304,800	301,705	194,800
	Sunflower	65,000	76,500	77,000	75,000	63,000
	Soybeans	48,050	71,750	76,500	88,500	72,450
	Groundnuts	5,220	6,900	4,600	4,700	4,590
	Dry beans	13,440	16,000	18,200	16,000	23,790
	Sorghum	41,950	61,200	26,250	33,325	35,100
	Wheat	147,200	176,220	185,600	195,000	135,300

3.4.3 Emission Factors

- Default emission factors and nitrogen-loss fractions from the 2006 IPCC Guidelines were applied to estimate direct and indirect N_2O emissions from crop residues.
- For direct emissions, the estimated quantity of nitrogen applied to agricultural soils was multiplied by the direct N_2O emission factor, EF1. For indirect emissions, the relevant nitrogen-loss fractions and emission factors were applied to estimate N_2O emissions resulting from volatilisation and leaching or runoff. The emission factors and nitrogen-loss fractions used in the inventory to estimate direct and indirect emissions from crop residues are shown in Table 3-7.

3.4.4 Assumptions and Data Limitations

- Crop residue emissions were estimated using the IPCC Tier 1 methodology, with crop-specific default parameters for residue-to-crop production ratios, dry matter fractions, nitrogen contents and residue management factors. These default values may not fully reflect local crop varieties and management practices in Limpopo.

- In the absence of province-specific residue management data, the following assumptions were applied based on expert judgement:
    - $Frac_{RENEW}$ = 1.0, assuming complete annual renewal of the crops included in the inventory.
    - $Frac_{BURNT}$ = 0.0, assuming that crop residues were not burnt in the field following harvest.
    - $Frac_{REMOVED}$ = 0.90, assuming that 90% of above-ground crop residues were removed from the field.
- All the above assumptions were applied consistently across all crop types assessed.

4 LULUCF

The LULUCF sector looks at the changes of carbon stocks in a land use. The 2006 IPCC guidelines recommend that emissions and removals from this sector be calculated using data for at least 20 years. The emissions and removals are calculated for the land use remaining in the same land use and from the land use changes that might have occurred during the period.

4.1.1 Methodology

Emissions and removals were estimated for Forest Land, Cropland, Grassland, Wetlands, Settlements and Other Land. Changes in land area and associated carbon stocks were calculated for land remaining in the same category and land converted between categories. Positive values represent emissions, while negative values represent removals from the atmosphere.

4.1.2 Activity Data

The land use change matrix for the period 1990 – 2020 (**Error! Reference source not found.**) was used to calculate emissions and removals from this sector. The calculations were made for both land use remaining in the same land use, and the land use changes from one land use to the other.

4.1.3 Emission Factors

The sector emission factors were obtained from DFFE and the 1996 IPCC Good Practice Guidelines (**Error! Reference source not found.**)

4.1.4 Assumptions and Data Limitations

- Land-use changes were assessed using the most recent available land-use matrix.
- Emissions and removals were assumed to remain constant after 2020 until updated land-use data become available.
- Default or nationally derived factors were applied where province-specific factors were unavailable.
- The results are subject to uncertainty associated with land classification, mapping accuracy and the availability of province-specific carbon-stock data.

Table 4-1: Land change (ha) for Limpopo for 2020 (including 20-year conversion periods)

		1990 Limpopo	Indigenous Forest	Thicket / dense Bush	Natural Wooded Land	Planted Forest	Shrubland	Grasslands	Waterbodies	Wetlands	Barren Land	Eroded Lands	Cultivated commercial permanent orchards	Cultivated commercial permanent vines	Commercial annuals pivot irrigated	Commercial annuals Non-pivot	Cultivated subsistence	Built-up Residential All	Built-up Smallholdings	Built-up Commercial	Built-up Industrial	Mines	**Total 2020**	**Total Land Reductions**
2020 Limpopo			1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20		
FL	Indigenous Forest	1	**18,243**	204	1,681	1,784	36	411	16	636	7	-	5	-	-	1	0	5	-	-	-	-	**23,030**	**4,788**
	Thicket / dense Bush	2	18,410	**99,662**	27,606	4,268	154	2,511	425	4,481	35	1	1,070	-	27	285	2,487	733	10	14	7	9	**162,194**	**62,532**
	Natural Wooded Land	3	9,378	1,346,049	**4,479,576**	4,694	428,659	2,043,587	3,750	38,593	2,215	16,941	11,614	-	7,812	176,790	179,769	17,777	1,819	491	402	8,500	**8,778,414**	**13,195**
	Planted Forest	4	682	2,766	4,879	**84,385**	308	2,505	154	306	24	7	516	-	25	829	77	33	43	1	0	40	**97,580**	**13,195**
GL	Shrubland	5	0	10	69	4	**31**	28	5	0	2	0	3	-	0	4	8	1	-	-	-	62	**228**	**196**
	Grasslands	6	1,057	169,718	620,068	1,577	186,930	**532,059**	1,083	3,566	1,855	11,853	443	-	1,555	30,865	13,922	2,881	370	111	126	6,276	**1,586,316**	**1,054,257**
OL	Waterbodies	7	71	5,789	5,694	88	778	2,107	**9,292**	2,447	1,518	89	34	-	31	441	122	52	15	1	0	601	**29,172**	**19,880**
	Wetlands	8	21	5,024	10,415	204	1,359	4,497	235	**23,857**	34	63	42	-	92	935	107	122	10	1	3	123	**47,145**	**23,288**
	Barren Land	9	41	6,427	20,085	56	17,617	20,572	848	399	**2,526**	326	22	-	84	399	429	207	7	2	3	95	**70,146**	**67,620**
	Eroded Lands	10	-	1,136	4,442	1	10,054	4,553	23	41	145	**19,523**	10	-	5	88	247	167	0	-	-	136	**40,572**	**21,050**
CL	Commercial Permanent Orchards	11	420	6,391	6,773	3,393	879	2,258	63	425	10	0	**53,354**	-	4,640	8,178	560	119	89	0	1	8	**87,563**	**34,209**
	Commercial Permanent Vines	12	-	-	-	-	-	-	-	-	-	-	-	**-**	-	-	-	-	-	-	-	-	**-**	**-**
	Commercial Annuals Pivot Irrigated	13	0	1,942	27,869	20	5,659	22,546	4	1,303	14	28	782	-	**50,010**	58,975	569	13	230	-	-	3	**169,968**	**119,958**
	Commercial Annuals Non-Pivot	14	70	8,563	47,824	623	10,937	46,526	60	2,385	122	64	6,906	-	12,505	**422,255**	2,184	220	599	1	-	70	**561,914**	**139,660**
	Cultivated Subsistence	15	33	11,237	42,516	213	48,973	26,856	17	992	118	3,109	1,313	-	529	4,329	**256,666**	2,007	6	0	-	88	**399,002**	**142,336**
SL	Built-up Residential All	16	34	12,671	51,153	1,133	18,247	48,568	37	257	314	834	274	-	286	1,221	6,864	**294,850**	506	41	6	176	**437,474**	**142,624**
	Built-up Smallholdings	17	0	442	5,034	43	747	5,464	4	32	12	141	13	-	2	5,174	138	777	**23,816**	1	3	30	**41,873**	**18,057**
	Built-up Commercial	18	4	114	398	16	110	310	1	5	18	0	1	-	0	14	5	830	41	**1,308**	24	25	**3,224**	**1,916**
	Built-up Industrial	19	1	330	1,620	16	302	899	1	34	40	4	1,339	-	690	1,666	14	1,074	11	8	**937**	376	**9,362**	**8,425**
	Mines	20	0	2,417	5,577	9	1,081	3,818	264	65	141	247	2	-	34	324	1,271	515	34	1	10	**11,193**	**27,002**	**15,809**
Total 1990			**48,467**	**1,680,894**	**5,363,280**	**102,527**	**732,862**	**2,770,075**	**16,282**	**79,825**	**9,150**	**53,230**	**77,742**	**-**	**78,327**	**712,774**	**465,440**	**322,383**	**27,608**	**1,980**	**1,524**	**27,810**		
Total Land Lost			**30,224**	**1,581,232**	**883,704**	**18,142**	**732,830**	**2,238,016**	**6,990**	**55,967**	**6,624**	**33,708**	**24,388**	**-**	**28,317**	**290,519**	**208,774**	**27,533**	**3,792**	**673**	**586**	**16,617**		

Table 4-2: Biomass growth or accumulation rates for the forest land (DFFE, 2024) categories

Land Class	Forest type	Biomass growth rate	Root: Shoot ratio	AGB	Dead Wood & litter	Total biomass	Litter	FLU	FMG	FI	Fuel density	Combustion factor	Fuel consumption	Accumulation rate	Half life	Average lifetime	Decay rate	Conversion factor	Total biomass
Indigenous forest	Primary (undisturbed)	0	0.27	178	4.67			1	1	1		0.45							
	Secondary ≥ 20 yrs (disturbed)	1.7																	
	Secondary ≤ 20 yrs (disturbed)	2.9																	
Thicket / dense bush	Primary (undisturbed)	0	0.35	28.2	1.35			1	1	1		0.45							
	Secondary ≥ 20 yrs (disturbed)	1.2																	
	Secondary ≤ 20 yrs (disturbed)	2.4																	
Woodlands	Primary (undisturbed)	0	0.25	27.2	1.01			1	1	1		0.56							
	Secondary ≥ 20 yrs (disturbed)	0.9																	
	Secondary ≤ 20 yrs (disturbed)	1.9																	
Plantations				83.2	2.38			1	1	1									
Annual non-pivot crops			0.22	8.6		10	3.4												5.83
Annual pivot crops			0.22	8.6		10	2.72												9.94
Subsistence crops			0.22	6.5		7.8	1.36												7.2
Orchards		1.8	0.42	80.9		114.88	6.86	0.72	1	1									17.45
Vineyards		0.66	0.42	29.8		42.32	9.8	0.72	1	1									12.89
Grasslands			2.6	1.86		6.7	1.55	1	0.85	1	3.5	0.88	3.1						
Low shrubland			0.8	8.7		15.8	2.72	1	1	1	11.4	0.91	10.4						
Eroded land				0				1	0.85	1									
Degraded lands																			
Residential				5.44			2.96				5.73	0.89	5.1	2.9					
Smallholdings				4.77			2.4				6.03	0.89	5.47	2.9					
Commercial							2.35												
Industrial							4.3												
Settlements & mines								1	1	1									

5 WASTE

This section describes the methodology, data sources, assumptions, and emission factors used to estimate greenhouse gas (GHG) emissions from the waste sector in the provincial inventory. The waste sector includes emissions associated with the treatment and disposal of solid waste and wastewater. The assessment covers methane (CH_4) and nitrous oxide (N_2O) emissions generated from solid waste disposal, biological treatment of solid waste, wastewater treatment and discharge, and waste incineration, where applicable.

The IPCC waste categories included in the inventory are listed below:

- 4A Solid Waste Disposal
- 4B Biological Treatment of Solid Waste
- 4C Incineration and Open Burning of Waste
- 4D Wastewater Treatment and Discharge

5.1 Solid Waste Disposal

Solid waste disposal emissions arise from the anaerobic decomposition of biodegradable organic material contained in solid waste disposed of at managed disposal sites. As organic waste decomposes in the absence of oxygen, methane (CH_4) is generated and released to the atmosphere over many years. The quantity of methane produced depends on the amount and composition of waste disposed, climatic conditions, waste management practices, and the extent of methane recovery or oxidation occurring at the disposal site.

5.1.1 Methodology

Methane (CH_4) emissions from solid waste disposal were estimated using the Tier 1 methodology described in the 2006 IPCC Guidelines for National Greenhouse Gas Inventories (Volume 5: Waste). Annual municipal solid waste disposal quantities were first estimated using a population-based approach, whereby district population data were used to estimate the quantity of municipal solid waste generated and disposed of at landfill sites. These estimated waste disposal quantities formed the activity data for the emissions calculations.

Annual methane emissions were calculated using the IPCC equation below. A summary of the variables and parameters used in the calculation is provided in Table 5-1,

Equation 5-1: Calculation of CH_4 emissions from solid waste disposal

$$\boldsymbol{CH_4\ emissions} = ((\boldsymbol{MSW_T} \times \boldsymbol{MSW_F} \times \boldsymbol{L_O}) - \boldsymbol{R})\ \times (\boldsymbol{1} - \boldsymbol{OX}))\ \times \boldsymbol{GWP_{CH_4}}$$

$CH_4\ emissions$	=	Annual methane emissions from solid waste disposal expressed as tCO_2e
MSW_T	=	Total municipal solid waste generated (tonne waste/year)
MSW_F	=	Fraction of municipal solid waste disposed at solid waste disposal sites
L_O	=	Methane generation potential
R	=	Quantity of methane recovered through landfill gas collection systems (Gg CH_4/year)
OX	=	Oxidation factor, representing the fraction of methane oxidised as it passes through the landfill cover (dimensionless)
GWP_{CH_4}	=	28, the 100-year Global Warming Potential of methane.

Table 5-1: Variables used in the calculation of CH4 emissions from solid waste disposal

#	Variable	Description	Units	Source
a	MSW_T	Total municipal solid waste generated	Tonnes / year	Calculated using per capita rate (c) and provincial population data.
b	MSW_F	Fraction of municipal solid waste disposed at solid waste disposal sites	%	NIR 2019 (2000-2015)/ IPCC 2006 Table 2A.1

c	MSW_{GR}	Municipal Solid Waste generation rate, Africa	Tonnes / cap / year	(DFFE)/IPCC 2006 Table 2A.1
d	L_O	Methane generation potential	Dimensionless	SA national GHG inventory 2019
e	R	Methane recovered	Dimensionless	SA national GHG inventory 2019
f	OX	Oxidation factor	Dimensionless	SA national GHG inventory 2019

5.1.2 Activity Data

- The activity data required for estimating methane emissions from solid waste disposal consist of annual quantity of municipal solid waste disposed at solid waste disposal sites (MSW_T.) As historical records of waste disposal quantities are not consistently available within the Limpopo Province, annual waste disposal quantities were estimated using district population data and a municipal solid waste generation rate (MSW_{GR}).
- District population data were obtained from the following sources:
    - 2022: Census 2022 Municipal Factsheets (Statistics South Africa).
    - 2020 - 2021 and 2023 - 2024: *Municipal Socio-Economic Profiles*.
- District population data is presented in Table 5-2 below:

Table 5-2: Population by district, 2020 - 2024

Province	District	Population				
		2020	2021	2022	2023	2024
Limpopo	Mopani	1,268,279	1,287,228	1,372,873	1,325,980	1,345,792
	Vhembe	1,527,135	1,549,952	1,653,077	1,596,614	1,620,469
	Capricorn	1,336,854	1,356,827	1,447,103	1,397,675	1,418,558
	Waterberg	704,743	715,272	762,862	736,805	747,814
	Sekhukhune	1,234,959	1,253,410	1,336,805	1,291,144	1,310,435

- Where district population data were unavailable for a reporting year, population values were extrapolated using the available time series to produce a complete dataset for the inventory period.
- Annual municipal solid waste generation was estimated by multiplying the district population by the municipal solid waste generation rate (MSW_{GR}), expressed in tonnes of waste generated per capita per year. The MSW_{GR} values were obtained from the Department of Forestry, Fisheries and the Environment (DFFE), which are based on the 2006 IPCC Guidelines for National Greenhouse Gas Inventories. MSW_{GR} used in this inventory is 0.398 tonnes/cap/year.
- The resulting activity data (municipal solid waste in tonnes per year) obtained by multiplying the population by the MSW_{GR} is presented in the table below.

Table 5-3: Total Municipal waste generated (MSW_T), 2020 - 2024

Province	District	Municipal Solid Waste (tonnes)				
		2020	2021	2022	2023	2024
Limpopo	Maize	129,727	131,665	140,426	135,629	137,656
	Sunflower	153,166	155,454	165,797	160,134	162,527
	Soybeans	213,359	216,547	230,955	223,066	226,399
	Groundnuts	148,939	151,164	161,222	155,715	158,041
	Dry beans	112,065	113,739	121,307	117,164	118,914

5.1.3 Emission Factors

- Methane emissions from solid waste disposal were estimated using the default emission factors and model parameters provided in the 2006 IPCC Guidelines for National Greenhouse Gas

Inventories (Volume 5: Waste). Where South African or provincial-specific values were unavailable, IPCC default values were applied in accordance with the Tier 1 methodology.

- The emission factors and variables used in the estimation are presented in Table 5-1.

5.1.4 Assumptions and Data Limitations

- Annual municipal solid waste disposal quantities were estimated using district population data and a municipal solid waste generation rate (MSW_{GR}) due to the limited availability of historical waste disposal records at the district level.
- Missing annual population estimates and municipal solid waste generation data were estimated using the average of the available annual values. These estimates were subsequently used to derive activity data for all population-dependent waste source categories.
- Where district population data were unavailable for a reporting year, population values were extrapolated using the available population time series.
- The municipal solid waste generation rate (MSW_{GR}) was assumed to be representative of waste generation across all districts and reporting years.
- IPCC default emission factors and model parameters were applied in accordance with the Tier 1 methodology where provincial- or country-specific values were unavailable.

5.2 Biological Treatment of Solid Waste

Biological treatment of solid waste includes the controlled biological decomposition of organic waste through processes such as composting and anaerobic digestion. These treatment methods reduce the amount of biodegradable waste disposed of at landfill sites and are used to recover nutrients and, in some cases, energy. Greenhouse gas emissions from biological treatment arise primarily from methane (CH_4) generated during the decomposition of organic waste.

5.2.1 Methodology

Emissions from biological treatment of solid waste were estimated using the Tier 1 methodology described in the 2006 IPCC Guidelines for National Greenhouse Gas Inventories (Volume 5: Waste). Annual quantities of organic waste treated through biological processes were obtained from the South African Waste Information Centre (SAWIC). In the absence of granular information on treatment technologies, it was assumed that 50% of the reported organic waste was treated through composting and 50% through anaerobic digestion. These quantities formed the activity data for the emissions calculations. The equations below were used to estimate the CH_4 emissions and N_2O emissions from biological treatment of waste respectively.

Equation 5-2: Calculation of CH_4 emissions from biological treatment of solid waste

$$\boldsymbol{CH_4\ emissions} = (((\mathbf{0.5} \times \boldsymbol{M} \times \boldsymbol{EF_{CH_4,C}}) + (\mathbf{0.5} \times \boldsymbol{M} \times \boldsymbol{EF_{CH_4,AD}})) \times \mathbf{10^{-3}} - \boldsymbol{R}) \times \boldsymbol{GWP_{CH_4}}$$

$CH_4\ emissions$	=	Annual methane emissions from biological treatment of waste expressed as tCO_2e
M	=	Total quantity of organic waste treated biologically (tonnes/year)
$EF_{CH_4,AD}$	=	Methane emission factor for anaerobic digestion (kg CH_4/tonne waste treated)
$EF_{CH_4,C}$	=	Methane emission factor for composting (kg CH_4/tonne waste treated)
R	=	Quantity of methane recovered (Gg CH_4/year)
GWP_{CH_4}	=	28, the 100-year Global Warming Potential of methane.

Equation 5-3: Calculation of N_2O emissions from biological treatment of solid waste

$$\boldsymbol{N_2O\ emissions} = ((\mathbf{0.5} \times \boldsymbol{M} \times \boldsymbol{EF_{N_2O,C}}) \times \mathbf{10^{-3}}) \times \boldsymbol{GWP_{N_2O}}$$

$N_4O\ emissions$	=	Annual nitrous oxide emissions from biological treatment of waste expressed as tCO_2e

M	=	Total quantity of organic waste treated biologically (tonnes/year)
$EF_{N_2O,C}$	=	Nitrous Oxide emission factor for composting (kg N_2O/tonne waste treated)
GWP_{N_2O}	=	265, the 100-year Global Warming Potential of methane.

The total greenhouse gas emissions (tCO_2e) from biological treatment of solid waste were calculated by summing the methane (CH_4) and nitrous oxide (N_2O) emissions estimated using the equations above.

5.2.2 Activity Data

- The activity data required for estimating emissions from biological treatment of solid waste is the annual quantity of organic waste treated through biological processes. Activity data were obtained from the South African Waste Information Centre (SAWIC).
- Total quantities of waste treated through biological treatment is presented in Table 5-4Table **5-4**Table **5-2** below:

Table 5-4: Waste treated through biological treatment

Province	District	Waste treated through biological treatment (kg)				
		2020	2021	2022	2023	2024
Limpopo	Mopani	1,536	1,425	1,690	978	530
	Vhembe	1,814	1,683	1,996	1,154	625
	Capricorn	2,527	2,344	2,780	1,608	871
	Waterberg	1,764	1,636	1,941	1,122	608
	Sekhukhune	1,327	1,231	1,460	845	458

- The activity data presented above represent the variable M used in the methane (CH_4) and nitrous oxide (N_2O) emission equations.

5.2.3 Emission Factors

- Methane (CH_4) and nitrous oxide (N_2O) emissions from biological treatment of solid waste were estimated using the default emission factors provided in the 2006 IPCC Guidelines for National Greenhouse Gas Inventories (Volume 5: Waste). Separate emission factors were applied for composting and anaerobic digestion to reflect the different emission characteristics of each biological treatment process. Where South African or provincial-specific emission factors were unavailable, the IPCC default values were applied in accordance with the Tier 1 methodology.
- The emission factors used in the estimation are presented below:

Table 5-5: Emission factors used to estimate emissions from biological treatment of waste

Biological treatment	Variable	Carbon emission factor	Unit	Sources
Anaerobic digestion	$EF_{CH_4,AD}$	2	g CH_4/kg waste treated	DFFE, 2024
Composting	$EF_{CH_4,C}$	10	g CH_4/kg waste treated	DFFE, 2024
	$EF_{N_2O,C}$	6	g N_2O/kg waste treated	DFFE, 2024

5.2.4 Assumpetions and Data Limitations

- Annual quantities of organic waste treated through biological processes were obtained from the South African Waste Information Centre (SAWIC).

- The SAWIC only reports the total mass of waste that is biologically treated which is the sum of composting and anaerobic treatment. Owing to this, it was assumed that of the total amount of biologically treated waste, 50% is composted and 50% is treated through anaerobic treatment.
- Methane recovery from anaerobic digestion (R) was assumed to be zero

5.3 Incineration and Open Burning of Waste

Incineration and open burning of waste generate greenhouse gas (GHG) emissions through the combustion of municipal solid waste. Emissions are dependent on the quantity of waste burned and its composition, with different waste fractions producing varying amounts of carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O). This category includes emissions from the uncontrolled open burning of municipal solid waste where waste collection services are unavailable.

5.3.1 Methodology

Emissions from incineration and open burning of waste were estimated using the Tier 1 methodology described in the 2006 IPCC Guidelines for National Greenhouse Gas Inventories (Volume 5: Waste). In the absence of district-level data on the quantity of waste openly burned, a population-based approach was adopted to estimate the quantity of municipal solid waste subject to open burning.

The methodology consists of the following steps:

- **Step 1:** Estimate the population without access to municipal waste collection services by multiplying the annual district population (Table 5-6) by the district-specific percentage of the population without waste collection, obtained from the literature (Table 5-7). The resulting population represents the estimated number of people without access to municipal waste collection services and forms the basis for estimating the quantity of municipal solid waste subject to open burning.

Table 5-6: Percentage of population without access to municipal waste collection services

Province	District	No waste collection (%)
Limpopo	Mopani	74.3%
	Vhembe	74.8%
	Capricorn	59.9%
	Waterberg	46.9%
	Sekhukhune	77.2%

- **Step 2:** Estimate the quantity of municipal solid waste generated by the population without waste collection services by applying the municipal solid waste generation rate (MSWGR) (0.398 tonnes/capita/year) adopted from the DFFE methodology, which is based on the 2006 IPCC Guidelines.
- **Step 3:** Apply the municipal solid waste composition fractions presented in Table 5-7 to disaggregate the estimated total quantity of municipal solid waste subjected to open burning into the individual waste types (e.g., food, garden waste, paper, wood, textiles, nappies, and plastics). The resulting quantities of each waste type were used as activity data in the emissions calculations.

Table 5-7: Municipal solid waste composition

Waste type	Waste Fraction
Food	0.2
Garden	0.1
Paper	0.12
Wood	0.04
Textile	0.03

Nappies	0.18
Plastics, Other inert	0.33

- **Step 4:** Estimate greenhouse gas emissions from each waste type by applying the Tier 1 equations and emission factors provided in the 2006 IPCC Guidelines, Volume 5: Waste, to the activity data derived in Steps 1 - 3. The IPCC equations used to estimate emissions are presented below. Total emissions were calculated by summing the emissions across all waste types and greenhouse gases.

Equation 5-4: Calculation of CO_2 emissions from incineration and open burning of waste

$$\boldsymbol{CO_2\ emissions = MSW \times \sum_i (WF_i \times dm_i \times CF_i \times FCF_i \times OF_i) \times {}^{44}/_{12}}$$

i	=	Type of waste open-burned
$CO_2\ emissions$	=	Annual carbon dioxide emissions from incineration and open burning of waste, expressed as tCO_2e
MSW	=	Mass of municipal solid waste open-burned
WF_i	=	Waste fraction
dm_i	=	Dry matter content in the component i of the MSW open-burned, (fraction)
CF_i	=	Fraction of carbon in the dry matter (i.e., carbon content) of component i
FCF_i	=	Fraction of fossil carbon in the total carbon of component i
OF_i	=	Oxidation factor, (fraction) of component i
${}^{44}/_{12}$	=	Molecular weight ratio used to convert carbon (C) to carbon dioxide (CO_2)

Equation 5-5: Calculation of N_2O emissions from incineration and open burning of waste

$$\boldsymbol{N_2O\ emissions = \sum_i (IW_i \times EF_i) \times 0.000001}$$

i	=	Type of waste open-burned
$N_2O\ emissions$	=	Annual N_2O emissions from incineration and open burning of waste, expressed as tCO_2e
IW	=	Amount of solid waste of type i open-burned, Gg/year
EF_i	=	Emission factor for waste type i, kg N_2O/Gg of waste
0.00001	=	Conversion factor from kilogram to gigagram

Equation 5-6: Calculation of CH_4 emissions from incineration and open burning of waste

$$\boldsymbol{CH_4\ emissions = \sum_i (IW_i \times EF_i) \times 0.000001}$$

i	=	Type of waste open-burned
$CH_4\ emissions$	=	Annual CH_4 emissions from incineration and open burning of waste, expressed as tCO_2e
IW	=	Amount of solid waste of type i open-burned, Gg/year
EF_i	=	Emission factor for waste type i, kg CH_4/Gg of waste
0.00001	=	Conversion factor from kilogram to gigagram

The total greenhouse gas emissions (tCO_2e) from incineration and open burning of waste were calculated by summing the methane (CH_4) and nitrous oxide (N_2O) emissions estimated using the equations above.

5.3.2 Activity Data

- The activity data required for estimating emissions from incineration and open burning of waste is the annual quantity of open-burned waste. This is identified by applying the proportion of South African population that has no access to waste collection services to total population from Census, it is assumed that this population fraction practices open burning of waste for Limpopo (Table X)

- The proportions in the table above are applied to total populations in Limpopo, which results in population with no access to waste collection services. To calculate the tonnes of waste burned, a municipal solid waste generation rate of 0.398 tonnes/cap/year was applied.

- The tonnes of waste burned (tonnes) is the primary activity data used in this category.

- Total quantities of waste burned is presented in theTable **5-2** below:

Table 5-8: Waste treated through biological treatment

Province	District	Incineration and open-burned waste (tonnes)				
		2020	2021	2022	2023	2024
Limpopo	Mopani	375,048	380,651	405,978	392,111	397,969
	Vhembe	454,634	461,427	492,128	475,318	482,420
	Capricorn	318,709	323,470	344,992	333,209	338,187
	Waterberg	131,549	133,514	142,397	137,534	139,588
	Sekhukhune	379,449	385,118	410,741	396,712	402,639

- The activity data presented above represent the variable M used in the methane (CH_4) and nitrous oxide (N_2O) emission equations.

5.3.3 Emission Factors

- GHG emissions from burned waste were estimated using the default emission factors and model parameters provided in the 2006 IPCC Guidelines for National Greenhouse Gas Inventories (Volume 5: Waste). Where South African or provincial-specific values were unavailable, IPCC default values were applied in accordance with the Tier 1 methodology.

5.3.4 Assumptions and Data Limitations

- Annual municipal solid waste disposal quantities were estimated using district population data and a municipal solid waste generation rate (MSW_{GR}) due to the limited availability of historical waste disposal records at the district level.

- Missing annual population estimates and municipal solid waste generation data were estimated using the average of the available annual values. These estimates were subsequently used to derive activity data for all population-dependent waste source categories.

- Where district population data were unavailable for a reporting year, population values were extrapolated using the available population time series.

- The municipal solid waste generation rate (MSW_{GR}) was assumed to be representative of waste generation across all districts and reporting years.

- IPCC default emission factors and model parameters were applied in accordance with the Tier 1 methodology where provincial- or country-specific values were unavailable.

6 SCOPE 2

Scope 2 emissions are indirect GHG emissions associated with grid-supplied electricity purchased and consumed within the province. Although the emissions occur at electricity-generation facilities, they are attributed to the province because they result from electricity consumption within its boundary.

6.1 Methodology

Scope 2 emissions were calculated by multiplying annual provincial electricity consumption by the Eskom-reported grid emission factor (Equation 6-1). As the grid emission factor is expressed in tonnes of carbon dioxide equivalent per megawatt-hour (tCO_2e/MWh), electricity consumption reported in gigawatt-hours (GWh) was converted to megawatt-hours (MWh) before applying the grid emission factor. The calculation produces emissions directly in tCO_2e. Therefore, no additional conversion using global warming potentials (GWPs) was required.

Equation 6-1: Calculation of Scope 2 GHG emissions from purchased electricity

$$\boldsymbol{Scope\ 2\ emissions = Electricity\ consumption \times Grid\ Emission\ Factor}$$

$Scope\ 2\ emissions$	=	Indirect electricity-related emissions, expressed in tCO_2e
$Electricity\ consumption$	=	Grid-supplied electricity consumed within the province, expressed in MWh
$Grid\ emissions\ factor$	=	Eskom-reported grid emission factor, expressed in tCO_2e/MWh

6.2 Activity Data

- The activity data used to estimate Scope 2 emissions were monthly electricity consumption data by province, obtained from Statistics South Africa's Electricity Generated and Available for Distribution (P4141) dataset.
- Monthly electricity consumption, reported in gigawatt-hours (GWh), was aggregated to determine the total annual electricity consumed within the province for each year from 2020 to 2024.
- The annual electricity consumption was converted from GWh to megawatt-hours (MWh) before applying the corresponding annual Eskom grid emission factor. The annual electricity consumption values used in the calculations are presented in the table below.

Table 6-1: Limpopo annual electricity consumption

Parameter	Unit	2020	2021	2022	2023	2024
Electricity consumption	GWh	19,673	20,725	20,184	20,221	20,904

6.3 Emission Factors

- Annual grid emission factors reported by Eskom were used to estimate Scope 2 emissions. The applied factors are based on Eskom's total electricity sales and the total electricity available for distribution after excluding technical transmission and distribution (T&D) losses.
- A separate emission factor was applied to each inventory year to reflect annual changes in the emissions intensity of grid-supplied electricity (Table 6-2). The factors are expressed in tCO_2e/MWh and therefore produce Scope 2 emissions directly in tCO_2e, with no additional GWP conversion required.

Table 6-2: Eskom grid emission factors

Year	Eskom Factor 1: Based on total electricity sales by Eskom, total available for distribution, after excluding technical losses through T&D		
	Units	Emission Factor	Source
2020	tCO_2e/MWh	1.080	Eskom Integrated Report 2021
2021	tCO_2e/MWh	1.040	Eskom Integrated Report 2022
2022	tCO_2e/MWh	1.010	Eskom Integrated Report 2023
2023	tCO_2e/MWh	1.060	Eskom Integrated Report 2024
2024	tCO_2e/MWh	1.080	Eskom Integrated Report 2025

6.4 Assumptions and Data Limitations

- Electricity consumption data were available only at the provincial level and were not disaggregated by district municipality. Scope 2 emissions could therefore not be estimated separately for each district within the province.

7 SCOPE 3

Scope 3 emissions are indirect GHG emissions associated with activities occurring outside the provincial boundary but attributable to activities within the province. The Scope 3 sources included in this inventory were electricity transmission and distribution (T&D) losses.

7.1 Electricity Transmission and Distribution Losses

Electricity transmission and distribution (T&D) losses occur when a portion of the electricity supplied through the national grid is lost before reaching end users. The emissions associated with generating this lost electricity occur outside the provincial boundary and are therefore reported as Scope 3 emissions.

7.1.1 Methodology

Scope 3 emissions from electricity T&D losses were calculated by multiplying annual provincial electricity consumption by the applicable annual electricity loss rate and Eskom grid emission factor. Electricity consumption was converted from gigawatt-hours (GWh) to megawatt-hours (MWh) before applying the emission factor.

Equation 7-1: Calculation of Scope 3 emissions from electricity transmission and distribution losses

$$\boldsymbol{Scope\ 3\ emissions\ (T\&D\ losses) = Electricity\ consumption\ \times T\&D\ loss\ rate\ \times Grid\ Emission\ Factor}$$

$T\&D\ loss\ emissions$	=	emissions associated with electricity lost during transmission and distribution (tCO_2e)
$Electricity\ consumption$	=	Grid-supplied electricity consumed within the province, expressed in MWh
$T\&D\ loss\ rate$	=	Grid-supplied electricity consumed within the province, expressed in MWh
$Grid\ emissions\ factor$	=	Eskom-reported grid emission factor, expressed in tCO_2e/MWh

The grid emission factor is expressed in tCO_2e/MWh; therefore, the calculation produces emissions directly in tCO_2e and no GWP is applied.

7.1.2 Activity Data

- Annual provincial electricity consumption was used as the primary activity data. The annual T&D factors presented in the table below were calculated by dividing Eskom's total electricity available for distribution by its total electricity sold.

Table 7-1: Eskom energy losses

Year	Distribution	Transmission	Total available for distribution GWh	Total electricity sold (GWh)	Source	Total Dist / Total Sold
2019	7.6	2.2	237,215	214,121	Eskom IR 2024	1.108
2020	7.7	2	235,486	212,190	Eskom IR 2024	1.110
2021	8.5	2.2	234,407	208,319	Eskom IR 2024	1.125
2022	8.8	2.2	231,356	205,635	Eskom IR 2024	1.125
2023	10.1	2.3	219,423	191,852	Eskom IR 2024	1.144
2024	9.6	2.3	226,226	198,281	Eskom IR 2024	1.141
2025	9.7	2.3	215,319	188,401	Eskom IR 2024	1.143
2026	9.9	2.2	210,648	183,311	Eskom IR 2024	1.149

- Each factor was applied to provincial electricity consumption to estimate the total electricity supplied, including losses. Electricity lost during transmission and distribution was then calculated as the difference between the estimated total electricity supplied and the electricity consumed. The calculated energy losses are shown below:

Table 7-2: T&D losses

Parameter	Unit	2020	2021	2022	2023	2024
T&D losses	GWh	2,461	2,978	2,845	2,889	3,117

7.1.3 Emission Factors

- Annual Eskom grid emission factors were applied to the estimated quantity of electricity lost during transmission and distribution.

7.1.4 Assumptions and Data Limitations

- Electricity consumption data were available at the provincial level and could not be disaggregated by district municipality.

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