



Republic of Malawi

National Greenhouse Gas Inventory Report as part of Malawi's
First Biennial Transparency Report and the Fourth National
Communication



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FOREWORD

Climate change is one of the most pressing global challenges, significantly impacting sustainable development and the management of natural resources. As a Party to the United Nations Framework Convention on Climate Change (UNFCCC), the Kyoto Protocol, and the Paris Agreement, the Government of Malawi is committed to fulfilling its obligations under these frameworks by pursuing pathways for low-carbon and climate-resilient development.

In recent decades, Malawi has experienced an increase in the frequency and intensity of climate-related shocks, such as prolonged dry spells, erratic rainfall patterns, floods, and rising temperatures. These challenges have had a significant impact on key economic sectors, including agriculture, energy, water, transport, forestry, health, and infrastructure development. Recognizing these issues, the Government of Malawi is implementing robust measures and strategies to enhance climate resilience and contribute to achieving the Sustainable Development Goals (SDGs) as well as national development priorities.

This National Inventory Report (NIR), prepared under the Fourth National Communication (NC4) and Biennial Transparency Report (BTR1), provides an updated and comprehensive assessment of greenhouse gas (GHG) emissions and removals in Malawi. The report adheres to the Modalities, Procedures, and Guidelines (MPGs) established under the Enhanced Transparency Framework (ETF) of the Paris Agreement, ensuring compliance with the latest international reporting requirements. It addresses new and emerging issues that were not included in previous reports and highlights both mitigation and adaptation actions based on national circumstances, sectoral developments, and evolving policy frameworks.

The Government of Malawi, through the Ministry of Natural Resources and Climate Change, remains fully committed to implementing the strategies outlined in this report. These efforts are guided by the National Climate Change Management Policy (2016) and the Malawi Vision 2063, which prioritize climate action as a key driver for sustainable development. Achieving these goals requires collective action from government institutions, the private sector, academia, civil society, development partners, and local communities. The government will continue to provide the necessary support for the implementation, monitoring, and evaluation of the Fourth National Inventory Report, ensuring that Malawi's contributions to global climate action are well-documented and impactful.

DR. OWEN CHOMANIKA

MINISTER OF NATURAL RESOURCES AND CLIMATE CHANGE

PREFACE

Malawi's economy is heavily reliant on the agriculture sector, which depends on sufficient and consistent rainfall. Consequently, the country's economic prosperity, food security, and overall well-being are highly vulnerable to the impacts of climate change and climate variability. In recent years, Malawi has faced an increase in climate-related challenges, such as prolonged droughts, erratic rainfall patterns, and floods. These threats adversely affect critical sectors including energy, water, health, transport, forestry, and infrastructure development. In light of these challenges, it is essential to adopt robust strategies and scientific approaches that allow for accurate assessments of climate trends, greenhouse gas (GHG) emissions, and their related impacts on development.

While climate change presents complex challenges that go beyond national borders, it also opens up opportunities for global cooperation to mitigate its adverse effects and enhance resilience. As a Party to the United Nations Framework Convention on Climate Change (UNFCCC), the Kyoto Protocol, and the Paris Agreement, the Government of Malawi reaffirms its commitment to addressing climate change through data-driven policies, measures to reduce emissions, and increased transparency.

This National Inventory Report (NIR), part of the Fourth National Communication (NC4) and Biennial Transparency Report (BTR1), builds upon previous National Communications and assesses Malawi's GHG emissions and removals, mitigation efforts, adaptation strategies, and emerging opportunities for addressing climate change. The report is prepared in accordance with the Enhanced Transparency Framework (ETF) of the Paris Agreement and follows the Modalities, Procedures, and Guidelines (MPGs) to ensure consistency, accuracy, completeness, comparability, and transparency. It provides updated information on:

The preparation of this report is a collaborative effort involving government ministries, agencies, academia, the private sector, civil society, and development partners. I extend my sincere gratitude to all stakeholders who contributed to this process. Special appreciation goes to the Global Environment Facility (GEF) and the United Nations Environment Programme (UNEP) for their financial and technical support in facilitating the development of this report. The Government of Malawi remains committed to transparency, accountability, and climate action, ensuring that the findings and recommendations from this report inform national policies, sectoral strategies, and international reporting obligations under the Paris Agreement. We look forward to continuing our collaboration with all stakeholders to achieve a climate-resilient and sustainable future for Malawi.

DR YUSUF NKUNGULA

PRINCIPAL SECRETARY- MINISTRY OF NATURAL RESOURCES AND CLIMATE CHANGE

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MS TAWONGA MBALE- LUKA

DIRECTOR OF ENVIRONMENTAL AFFAIRS

Table of Contents

FOREWORD	i
PREFACE	ii
CONTRIBUTORS	iii
PROJECT MANAGEMENT TEAM	iv
ACKNOWLEDGEMENTS	v
LIST OF TABLES	xii
LIST OF FIGURES	xvi
ACRONYMS AND ABBREVIATIONS	xix
EXECUTIVE SUMMARY	xxi
ES.1. Background information on GHG inventories and climate change	xxi
ES.2. Summary of trends related to national emissions and removals.....	xxiii
Sectoral Contributions to National GHG Emissions	xxiii
Comparison Across Key Timeframes	xxiv
Trends by Gas	xxiv
ES.3. Overview of source and sink category emission estimates and trends.....	xxv
ES.4. Other information (e.g. indirect GHGs, precursor gases)	xxvii
Scope of Targets and Legislative Framework	xxvii
Other Gases and Precursors	xxviii
Transparency and Continuous Improvement	xxviii
ES.5. Key category analysis	xxix
ES.5.1 Base and Current Year Key Categories – With FOLU	xxix
ES.6. Improvements introduced	xxxi
1. Chapter 1: National circumstances, institutional arrangement	1
1.1 Background information on GHG inventories and climate change	1
1.2 National Circumstances: key drivers of GHG emissions and removals in Malawi	1
1.3 Institutional arrangement	4
1.3.1 National entity or national focal point	4
1.3.2 Inventory preparation process	7
1.3.3 Archiving of information.....	10
1.3.4 Processes for official consideration and approval of inventory	10
1.4 Brief general description of methodologies and data sources used	10
1.4.1 Sector-Specific Methodologies.....	12
1.5 Brief description of key categories	14
1.6 Brief general description of QA/QC plan and implementation.....	17
1.7 General uncertainty assessment	18

1.8	General assessment of completeness.....	19
1.8.1	Information on completeness (including information on non-reported categories or any methodological or data gaps in the inventory).....	19
1.8.2	Description of insignificant categories	22
1.8.3	Total aggregate emissions considered insignificant	22
1.9	Metrics	24
1.10	Summary of any flexibility applied.....	24
2	<i>Chapter 2: Trends in greenhouse gas emissions and removals</i>	28
2.1	Description of emission and removal trends for aggregated GHG emissions and removals	28
2.2	Description of emission and removal trends by sector and by gas	30
2.2.1	Net Greenhouse Gas Emissions by Sector (Kt CO ₂ -e)	32
2.2.2	Trends in Emissions and Removals Based on Annual Growth Rate.....	33
2.2.3	Observations on Socio-economic Influences.....	35
2.2.4	Description of emission and removal trends by gas.....	35
	Carbon Dioxide (CO ₂)	37
	Methane (CH ₄)	37
	Nitrous Oxide (N ₂ O)	38
2.2.5	Comparative Analysis and Sectoral Contributions	39
3	<i>Chapter 3: Energy.....</i>	41
3.1	Overview of the Energy Sector	41
3.2	Fuel Combustion (CRT Category 1.A)	48
	Data Sources and Uncertainty	50
3.2.1	Comparison of the Sectoral and Reference Approaches.....	50
3.2.2	International Bunker Fuels	52
	Jet A-1 Consumption Trends	53
3.2.3	Feedstocks and Non-Energy Use of Fuels.....	54
3.2.4	Energy Industries (CRT Category 1.A.1).....	56
3.2.5	Manufacturing Industries and Construction	58
3.2.6	.Transport (CRT Category 1.A.3)	61
	Category Description	63
	Methodological Approach	64
	Activity Data and Fuel Consumption Trends.....	64
	Emission Trends and Key Drivers	65
	Key Drivers of Emissions Growth	65
	Uncertainty and Time-Series Consistency	66
	Quality Assurance and Control (QA/QC).....	66
	Planned Improvements	66
	Category Description	66
	Methodological Approach	67
	Activity Data and Jet A-1 Consumption Trends	67
	Emission Trends and Analysis	68
	Key Observations	68
	Uncertainty Assessment and Time-Series Consistency	68
	QA/QC and Planned Improvements	68
	Category Description	69
	Methodological Approach	69
	Activity Data and Fuel Use Trends	69

Emission Trends and Interpretation	71
Uncertainty Assessment and Time-Series Consistency	71
QA/QC and Planned Improvements	71
3.2.7 Other Sectors (CRT Category 1.A.4)	72
3.3 Fugitive emissions from fuels (CRT 1.B)	74
3.3.1 Solid Fuels (CRT Category 1.B.1)	74
Category Description	74
3.3.2 Activity Data and Trends	75
Methodological Approach	75
Sector-Specific Developments and Observations	76
Uncertainty and Time-Series Consistency	76
QA/QC and Verification Procedures	77
Recalculations and Planned Improvements	77
3.4 Carbon Dioxide Transport and Storage (CRT Category 1.C)	77
3.4.1 1.4.1 Category Description	77
3.4.2 National Context and Applicability to Malawi	78
3.4.3 Methodological Consistency and Reporting Clarification	78
3.4.4 Sector-Specific QA/QC and Planned Improvements	79
4 Chapter 4: Industrial Processes and Product Use (IPPU)	80
4.1 Overview of the Sector and background information	80
4.2 Mineral Industry (Category 2A)	81
4.2.1 Cement production (2.A.1)	82
4.2.2 Time Series Analysis of CO ₂ Emissions from Cement Production	86
4.2.3 QA/QC and Verification	88
4.2.4 Lime production (2A2)	90
4.3 Chemical Industry (Category 2B)	97
4.4 Other process uses of Carbonates (Category 2A4)	98
5 Chapter 5: Agriculture	98
5.1 Livestock	98
5.2 Overview of the sub sector and background information	98
5.3 Enteric Fermentation (Category 3.A1)	98
5.3.1 Source category description	99
5.3.2 Methodological Issues	100
5.3.3 Activity data	100
5.3.4 Emission factors	105
5.3.5 Calculation of emissions	105
5.4 Enteric fermentation emissions	106
5.4.1 Uncertainties and time-series consistency	107
5.4.2 Source-specific QA/QC and verification	107
5.4.3 Source-specific recalculations	108
5.5 Emissions from manure management (Category 3.A2)	108
5.5.1 Source category description	108
5.5.2 Methodological Issues	109
5.5.3 Activity data	109

5.5.4	Emission factors.....	110
5.6	Methane emission calculations	111
5.7	Methane emissions	111
5.8	Direct N₂O emissions from manure management.....	113
5.8.1	Uncertainties and time-series consistency.....	117
5.8.2	Source-specific QA/QC and verification	117
5.8.3	Source-specific recalculations	118
5.9	Indirect emissions of nitrous oxide from manure management (Category 3.C.6)	118
5.9.1	Source category description.....	118
5.9.2	Methodological issues	119
5.9.3	Activity data.....	119
5.10	Indirect N₂O emissions	120
5.10.1	Uncertainties and time-series consistency.....	122
5.10.2	Source-specific QA/QC and verification.....	122
5.10.3	Source-specific recalculations.....	122
5.11	Direct nitrous oxide emissions from managed soils due to livestock deposit of dung and urine (Category 3.C.4).....	123
5.11.1	Source category description	123
5.11.2	Methodological issues	123
5.11.3	Activity data	123
5.12	Direct N₂O from urine and dung deposited in the pasture.	124
5.12.1	Uncertainties and time-series consistency.....	126
5.12.2	Source-specific QA/QC and verification.....	127
5.12.3	Source-specific recalculations.....	127
5.13	Indirect emissions of nitrous oxide from managed soils due to grazing animals (3.C.5).....	127
5.13.1	Source category description	127
5.13.2	Methodological issues	128
5.13.3	Activity data	128
5.14	Indirect N₂O from pasture deposit.....	128
5.14.1	Uncertainties and time-series consistency.....	129
5.14.2	Source-specific QA/QC and verification.....	129
5.14.3	Reconstructing several the calculations to cross-check the intermediate calculations and results in the inventory spread sheet.	130
5.14.4	Source-specific recalculations.....	130
5.15	Inventory improvement Plan	130
5.15.1	Estimation of specific uncertainty values for activity data	130
5.15.2	Determination of manure management systems.....	130
5.15.3	Determination of evaporation levels for specific ecological zones	130
5.15.4	Recalculation of manure management methane emissions	130
5.15.5	Estimation of country-specific values of TAM	130
5.16	Liming (CRT Category 3.C.2).....	131
5.17	Urea Application (CRT Category 3.C.).....	134
5.18	Direct N₂O Emissions from Managed Soils (CRT Category 3.C.4)	137
5.19	Indirect N₂O Emissions from Managed Soils (CRT Category 3.C.5).....	141

5.20	Rice Cultivation (CRT Category 3.C.7)	145
6	Chapter 6: Forestry and Other Land Use	148
6.1	Overview of the Sector and Background Information	148
6.2	Land Use Definitions and Land Use Change Matrix	152
6.2.1	Land classification and definitions.....	152
6.2.2	Land representation matrix.....	152
6.3	Country Specific Approaches	154
6.3.1	Information on approaches used for representing land areas and land use databases used for the inventory preparation.....	154
6.3.2	Information on approaches used for natural disturbances.....	156
6.3.3	Information on approaches used for reporting harvested wood products.....	156
6.3.4	Quality Assurance and Quality Control (QA/QC) FOLU Subsector	157
6.4	Forestland (CRT Category 4.A)	158
6.4.1	Forestland remaining forestland	158
6.4.2	Land converted to forestland	159
6.4.3	Annual area burnt and net emissions for burning biomass in forestland	160
6.5	Cropland (CRT Category 4.B)	161
6.5.1	Cropland remaining cropland.....	161
6.5.2	Land converted to cropland	162
6.5.3	Annual area burnt and net emissions for burning biomass in cropland.....	163
6.6	Grassland (CRT Category 4.C)	164
6.6.1	Grassland remaining grassland.....	164
6.6.2	Land converted to grassland	165
6.6.3	Annual area burnt and net emissions for burning biomass in grassland.....	166
6.7	Wetland (CRT Category 4.D).....	167
6.7.1	Wetland remaining wetland.....	167
6.7.2	Land converted to wetland	168
6.8	Settlement (CRT Category 4.E).....	168
6.8.1	Settlement remaining settlement	168
6.8.2	Land converted to settlement.....	169
6.9	Other land (CRT Category 4.F)	170
6.9.1	Category description	170
6.10	Harvested Wood Products (CRT Category 4.G).....	170
6.10.1	Category description and net emissions.....	170
6.11	Uncertainty Assessment.....	171
6.11.1	Areas that need improvement.....	172
	Chapter 7:.....	41
7	Chapter 7: Waste	173
7.1	Overview of the sector and background information	173
7.1.1		177
7.1.2	GREENHOUSE GAS SOURCE AND SINK CATEGORIES	187
7.2	Biological treatment of solid waste (5.B.)	189

7.2.1	Composting (5.B.1)	189
7.2.2	5.B.2. Anaerobic digestion at biogas facilities	189
7.3	5.C. Incineration and open burning of waste	189
7.4	5.C.1. Waste incineration	189
7.4.1	5.C.2. Open burning of waste	190
7.5	5.D. Wastewater treatment and discharge	190
7.5.1	5.D.1. Domestic wastewater	193
7.5.2	5.D.2. Industrial wastewater	193
7.5.3	5.D.3. Other (mixed wastewater treatment)	193
7.6	Time-series consistency and recalculations	195
7.7	Assessment of completeness	195
7.8	Planned Improvements for the Waste Sector	197
7.8.1	Status of infrastructure in the four cities and other Urban Areas	198
7.8.2	Status of Wastewater management infrastructure	199
7.9	Governance of GHG inventory in Waste Sector	200
7.10	Other emerging issues.....	201
7.11	Time-series consistency and recalculations	201
7.12	Uncertainty Assessment.....	201
7.13	4.A.1 Managed Waste Disposal Sites (NO).....	202
7.14	Biological Treatment of Solid Waste 4B (NE)	202
7.15	Waste Incineration 4.C.1 (NE).....	202
7.16	Industrial Wastewater and Discharge 4.D.2 (NE)	203
8	<i>Chapter 8: Other</i>	<i>204</i>
9	<i>Chapter 9: Indirect carbon dioxide and nitrous oxide emissions.....</i>	<i>205</i>
10	<i>Chapter 10: Recalculations and Improvements</i>	<i>206</i>
10.1	Explanations and justifications for recalculations, including in response to the review process ..	206
10.2	Areas of improvement and/or capacity-building in response to the review process	208
10.2.1	Summary of Responses to the UNFCCC TTE Review.....	210
10.3	Areas of improvement and/or capacity-building related to the flexibility provisions applied with self-determined estimated time frames for improvements.....	212
REFERENCES/ BIBLIOGRAPHY		215

LIST OF TABLES

Table 1-1: Population trend and intercensal population growth between 1966 and 2022	2
Table 1-2: Sectoral contributions to the national gross domestic product (GDP).....	3
Table 1-3: Roles of government ministries, departments and agencies.....	6
Table 1-4: Sources of data for GHG inventory process	8
Table 1-5: the methodologies used for every sector.....	11
Table 1-6: Summary of Key Categories	16
Table 1-7: summary of completeness across various categories.....	20
Table 1-8:AR5 GWP values	24
Table 1-9:Summary of Flexibility options evaluated by Malawi	26
Table 2-1: Net Greenhouse Gas Emissions by Sector	33
Table 2-2: Annual Growth Rate for Total National Emissions and Removals (1994–2022).....	34
Table 2-3:Table: Net Emissions by Gas (Gg CO ₂ -e)	36
Table 2-4: GHG Emissions and Contribution by Gas and Sector (Gg, 2018 vs 2022).....	39
Table 3-1: Electricity generation by fuel (GWh).....	42
Table 3-2: the total annual GHG emissions in the energy sector 1994 to 2022 by CO ₂ eq	44
Table 3-3: Annual Growth Rate of Net Emissions by Energy Sub-sector	46
Table 3-4: Emissions from Sectoral vs. Reference Approaches.....	51
Table 3-5: Jet A-1 Imports, 2018–2022 (Million Litres)	53
Table 3-6: electricity generation from diesel in terajoules (TJ) with its emissions	57
Table 3-7: GHG Emissions – Food Processing, Beverages, and Tobacco (1994–2022) by gas type	60
Table 3-8: GHG Emissions from Transport Subcategories (Gg CO ₂ -e)	62
Table 3-9: Trends in Petroleum Fuel Imports for Road Transport (2018–2022)	64
Table 3-10: Diesel consumption by waterborne navigation.....	70
Table 3-11: Estimated GHG Emissions from Domestic Navigation	70
Table 3-12: Residential Fuel consumption.....	72
Table 3-13: Amount of Coal Produced (tonne) from Underground Coal Mining	75
Table 3-14: Emissions from Carbon Dioxide Transport and Storage (CRT 1.C), 1994–2022	78
Table 4-1: Volume of cement produced (tonnes)	85
Table 4-2: Estimated uncertainties for Malawi's cement production.....	85
Table 4-3: Production data from the lime industry	91
Table 5-1: Sources of enteric CH ₄ emission from livestock sector	99

Table 5-2: Activity for livestock emissions	100
Table 5-3: Poultry and rabbits population trend 1994 to 2022	100
Table 5-4: Enteric fermentation emission factors (kg CH ₄ head-1 year-1).....	105
Table 5-5: CH ₄ emissions from Enteric fermentation	106
Table 5-6: Source-specific recalculations for methane emissions (Gg CH ₄) from enteric fermentation for the year 2010	108
Table 5-7: Sources of CH ₄ emission from livestock sector.....	108
Table 5-8: Manure management systems used for each livestock species	110
Table 5-9: Meteorological data for Malawi	110
Table 5-10: Methane emission factors from manure management (kg CH ₄ head-1 year-1)	111
Table 5-11: Methane emissions (Gg CH ₄ year-1) from manure management from different livestock species, 1994 – 2022	112
Table 5-12: Trends in methane emissions from poultry and rabbits	112
Table 5-13: Typical animal mass (TAM) values and country-specific number of days alive for each of the livestock sub-category	113
Table 5-14: Default values for nitrogen excretion rate (kg N (1000 kg animal mass) ⁻¹ day ⁻¹)	114
Table 5-15: Emission factors (EF3) used in estimating direct N ₂ O emissions from manure management.....	115
Table 5-16: Trends in N ₂ O emissions from ruminants.....	116
Table 5-17: Source-specific recalculations for methane from manure management (Gg CH ₄ year ⁻¹) for 2010....	118
Table 5-18: Source-specific recalculations for direct N ₂ O from manure management (Gg N ₂ O year ⁻¹) for 2010.	118
Table 5-19: Sources of indirect N ₂ O emissions from manure in the livestock sector.....	118
Table 5-20: Emissions trends for indirect N ₂ O emissions from ruminants	121
Table 5-21: Source categories for direct nitrous oxide emissions from managed soils due to livestock deposit of dung and urine.....	123
Table 5-22: Indirect N ₂ O emissions from dung and urine deposited on pasture by different livestock species	125
Table 5-23: Source categories for indirect nitrous oxide emissions from managed soils due to livestock deposit of dung and urine.....	127
Table 5-24: Emission Trend (1994–2022)	132
Table 5-25: Emission trends	135
Table 5-26: Emissions Trends.....	138
Table 5-27: Emissions Trends.....	142
Table 5-28: Emission Trends	146
Table 6-1: Sources of GHG Emissions/sinks by Category in FOLU Subsector	148
Table 6-2: FOLU Subsector Emissions by Category for the Year 2022 With Changes since, 2018, 2019, 2020, and 2021	149

Table 6-3: Malawi’s land use classes and their definitions.....	152
Table 6-4:Area distribution by land classes and forest sub-classes (in ha) from 2018 to 2022	153
Table 6-5:Malawi Land Use Statistics from 2000 to 2022	153
Table 6-6:Major Land Use Changes (in Hectares) for Malawi	153
Table 6-7:Categorization of wood types for harvested wood products in Malawi.....	157
Table 6-8:Emissions and removals (GgCO ₂ e) from forestland remaining forestland	159
Table 6-9: Annual area in hectares for land converted to forestland	159
Table 6-10: Annual net emissions (GgCO ₂ e) for land converted to forestland	160
Table 6-11: Annual area burnt and net emissions for burning biomass in forestland	161
Table 6-12: Annual Area (hectares) for Land Converted to Cropland.....	162
Table 6-13: Annual net emissions (GgCO ₂ e) for land converted to cropland	163
Table 6-14: Annual area burnt and net emissions for burning biomass in cropland.....	163
Table 6-15: Cumulative area and net emissions for land converted to grassland.....	166
Table 6-16: Annual area burnt and net emissions for burning biomass in grassland.....	166
Table 6-17: Cumulative area in hectares and net emissions for land converted to wetland.....	168
Table 6-18: Area gain and net emissions of sparse woody vegetation, settlements remaining settlements.....	169
Table 6-19: Cumulative area in hectares and net emissions for land converted to settlement	170
Table 6-20: Uncertainty assessment by category in FOLU Sub-sector.....	171
Table 7-1: Population, per capita waste generation and waste composition.....	177
Table 7-2: Statistics on waste disposal type by population category (%)	178
Table 7-3: Sources of emission from waste sector	180
Table 7-4:Source emission factors for waste sector.....	180
Table 7-5: Data sources for the Waste Sector in Malawi for National Communications	186
Table 7-6: Compost Making Data from Cities in Malawi	189
Table 7-7: Activity data for Incineration and Open Burning of Waste	190
Table 7-8: Statistics on access to and type of toilet facility by population category (%).....	191
Table 7-9: Number of people accessing different types of waste water treatment technologies.....	192
Table 7-10: Uncertainty Assessment for the waste sector.....	194
Table 7-11: Completeness status of the estimations under various sub-categories.....	195
Table 7-12: QA/QC procedures in the waste sector	196
Table 10-1: Summary of recalculations in this NIR	207
Table 10-2: Summary of Responses to the UNFCCC TTE Review	210
Table 10-3; Area of flexibilities applied, planned improvement and it's targeted time frame	214

LIST OF FIGURES

Figure 1-1: Kapichira Hydro-power plant damaged by Cyclone Ana in January 2022	4
Figure 1-2: Institutional arrangement for climate change in Malawi	5
Figure 1-3: % share of the categories without FOLU (2022)	15
Figure 1-4: KCA GHG trends without FOLU	15
Figure 1-5: KCA GHG levels with FOLU (2022)	15
Figure 1-6: KCA GHG trend with FOLU	16
Figure 2-1: Total Population Growth, 1994–2022	28
Figure 2-2: GHG Emissions Trend (Gg CO ₂ -e), 1994–2022	29
Figure 2-3: Per Capita GHG Emissions, 1994–2022	30
Figure 2-4: Share of National Emissions by Sector (%)	31
Figure 2-5: Total National Emissions trend for every sector	32
Figure 2-6: Share of National Emissions (Excluding FOLU) by Gas	36
Figure 2-7: Trend of Carbon Dioxide (CO ₂) Emissions, 1994–2022	37
Figure 2-8: Trend of Methane (CH ₄) Emissions, 1994–2022	38
Figure 2-9: Trend of Nitrous Oxide (N ₂ O) Emissions, 1994–2022	39
Figure 3-1: Malawi’s Energy Supply Composition.....	41
Figure 3-2: Electricity Generation by Source	42
Figure 3-3: Activities and sources in the energy sector.....	43
Figure 3-4: Trend of Net GHG Emissions from different sources.....	45
Figure 3-5: Emissions by Fuel combustion Sub-categories	50
Figure 3-6: Emissions from Sectoral vs. Reference Approaches	51
Figure 3-7: Emissions from electricity generation from diesel.....	57
Figure 3-8: GHG Emissions – Food Processing, Beverages, and Tobacco (1994–2022)	60
Figure 3-9: Trends in GHG Emissions from Transport Subcategories	62
Figure 3-10: Vehicle population (2008–2022)	64
Figure 3-11: Road Transport Emissions Trend (1994–2022)	65
Figure 3-12: Domestic Aviation Emissions Trend (1994–2022)	68
Figure 3-13: Domestic Navigation Emissions (1994–2022)	71
Figure 3-14: Emissions from Residential	73
Figure 3-15: Coal Production.....	75
Figure 3-16: Estimated Fugitive CH ₄ Emissions (1994–2022)	76

Figure 4-1: Malawi's IPPU inventory	81
Figure 4-2: Mineral resources in Malawi.....	82
Figure 4-3: Mineral resources in southern Malawi	82
Figure 4-4:Emissions from cement production	87
Figure 4-5:Emissions for the Lime industry.....	94
Figure 5-1: livestock composition (%)	100
Figure 5-2: Population of cow by head	101
Figure 5-3: Population of sheep by head	102
Figure 5-4: Population of goats by head	102
Figure 5-5: Population of pigs by head and type	103
Figure 5-6: Population of chicken by head and type	104
Figure 5-7: Population of rabbits s by head	104
Figure 5-8: CH ₄ emissions from Enteric fermentation	107
Figure 5-9: Methane emissions from manure management (Gg CH ₄ /year)	113
Figure 5-10: Nitrogen excretion (kg N head-1 year-1) for different livestock species	116
Figure 5-11: Direct N ₂ O emissions from manure management, Gg N ₂ O, 1994 - 2022	117
Figure 5-12: Indirect N ₂ O emissions from manure management, Gg N ₂ O, 1994 - 2022	122
Figure 5-13: Direct N ₂ O emissions from dung and urine deposited on pasture by different livestock species, 1994 - 2022 (Gg N ₂ O year-1)	126
Figure 5-14: Indirect N ₂ O emissions from dung and urine deposited on pasture by different livestock species, 1994-2024 (Gg N ₂ O year-1).....	129
Figure 5-15: Emissions from Liming	132
Figure 5-16: CO ₂ -e emissions from urea application	136
Figure 5-17: converted N ₂ O Emissions from Managed Soils	139
Figure 5-18: Indirect N ₂ O Emissions from Managed Soils, 1994–2022 (Gg CO ₂ e)	143
Figure 5-19: Emissions from Rice Cultivation (1994–2022)	147
Figure 6-1:Emission Trends in FOLU Subsector from 2018 to 2022	149
Figure 6-2:FOLU Emissions by Category from 2018 to 2022.....	150
Figure 6-3:Total Contribution of Emissions by Different Categories in FOLU, 2018 to 2022	150
Figure 6-4:Malawi's Land Use/Cover Distribution for the Years 2000, 2010 and 2022	154
Figure 6-5: Net emissions from Cropland remaining Cropland.....	162
Figure 6-6: Net emissions from grassland remaining grassland.....	165
Figure 6-7: Net emissions from wetland remaining wetland	167
Figure 6-8: Net emissions from harvested wood products	171

Figure 7-1: Malawi Population and Adjusted for Urban Population data 1994 to 2022	173
Figure 7-2: Composition of waste going to solid waste disposal sites	176
Figure 7-3: Total GHG emission in waste sector for 1994 to 2022	178
Figure 7-4: GHG emissions for waste sector by gas type for 1994 to 2022.....	182
Figure 7-5: Time series for Incineration and open burning.....	185
Figure 7-6: Malawi Protein per capita intake (g) 1994-2022.....	191
Figure 7-7: Percentage use of sanitation services	192
Figure 7-8: Blantyre City Council's Proposed Landfill Site	199

ACRONYMS AND ABBREVIATIONS

AD	Activity data
ADD	Agriculture Development Division
AFOLU	Agriculture, Forest and Land Use
AR5	Fifth Assessment Report
Av Gas	Aviation Gas
BAU	Business as Usual
BOD	Biological oxygen demand
BRT	Biennial Transparency Report
BUR	Biennial Update Report
CEAR	Central East African Railways Company
CKD	Cement Kiln Dust
EAD	Environmental Affairs Department
CO ₂ e	Carbon Dioxide Equivalent
CoP	Conference of the Party
CMA	Conference of the Party serving as the meeting of the Paris Agreement
CRT	Common Reporting Tables
DAHLD	Department of Animal Health and Livestock Development
EF	Emission factor
EFDB	Emission Factor Data Base
GHG	Greenhouse Gas
GHG-IS	Greenhouse Gas Information System
GoM	Government of Malawi
GWP	Global Warming Potential
HFCs	Hydrofluorocarbons
HWP	Harvested Wood Products
INC	Initial National Communication
INDC	Intended Nationally Determined Contributions
IPCC	Intergovernmental Panel on Climate Change

IPPU	Industrial Processes and Product Use.
JET A1	Jet Kerosene
LEAP	Low Emissions Analysis Platform (formerly it was known as Long- Range Energy Alternatives Planning System)
LPG	Liquefied Petroleum Gas
MAIWD	Ministry of Agriculture Irrigation and Water Development
MERA	Malawi Energy Regulatory Authority
MBS	Malawi Bureau of Standards
MMU	Minimum mapping area
MPGs	Modalities, Procedures and Guidelines
MRV	Monitoring, Reporting and Verification
MSC	Malawi Shipping Company
NAMA	Nationally Appropriate Mitigation Actions
NDC	Nationally Determined Contributions
NPC	National Planning Commission
NE	Not estimated
NIR	National Inventory Report
NTCCC	National Technical Committee on Climate Change
QA/QC	Quality Assurance/Quality Control
SWDs	Solid Waste Disposal Sites
SNC	Second National Communication
SWOT	Strength, Weakness, Opportunity, and Threat
TNC	Third National Communication
TOR	Term of Reference
UN	United Nations
UNDP	United Nations Development Programme
UNFCCC	United Nations Framework Convention on Climate Change
USGS	United States Geological Survey

EXECUTIVE SUMMARY

ES.1. Background information on GHG inventories and climate change

This document presents Malawi's National Inventory Report (NIR) 2022, submitted as part of Malawi's first Biennial Transparency Report (BTR1) and Fourth National Communication (4NC) under the United Nations Framework Convention on Climate Change (UNFCCC) and the Paris Agreement (PA). The accompanying Common Reporting Tables (CRTs) form an integral component of this submission and comply with the standardized reporting requirements established under the Modalities, Procedures, and Guidelines (MPGs) adopted at CMA1 (Decision 18/CMA.1) and operationalized further in Decision 5/CMA.3. This report represents Malawi's first submission under the Enhanced Transparency Framework (ETF), as required by Article 13 of the Paris Agreement.

The inventory includes estimates of greenhouse gas (GHG) emissions and removals from 1994 to 2022, and is classified using the sectoral structure established by the Intergovernmental Panel on Climate Change (IPCC) in its 2006 Guidelines for National Greenhouse Gas Inventories, with updates and clarifications drawn from the 2019 Refinement and, where applicable, the 2013 Wetlands Supplement.

The report covers emissions and removals from the following categories from the following sectors:

- Energy
- Industrial Processes and Product Use
- Agriculture
- Forestry, and Other Land Use
- Waste

The categories of international aviation and marine bunkers are also reported separately in line with IPCC guidance.

All emissions are reported in carbon dioxide equivalent (CO₂-e) using the 100-year Global Warming Potentials (GWPs) presented in Table 8.A.1 of the IPCC Fifth Assessment Report (AR5, 2014). These GWPs were used in accordance with Decision 18/CMA.1, which requires the application of AR5 values to ensure comparability, consistency, and transparency across country submissions.

The preparation of this report was led by the Environmental Affairs Department (EAD) under the Ministry of Natural Resources and Climate Change, with technical support from the National GHG Inventory System of Malawi, comprised of designated sectoral leads and technical teams from line ministries, research institutions, and statistical offices. The system

includes institutional arrangements for the coordination, data collection, compilation, quality assurance/quality control (QA/QC), and timely submission of GHG estimates to the UNFCCC.

Activity data was collected from a wide range of national sources including:

- National Statistical Office (NSO)
- Department of Energy Affairs
- Department of Mines
- Environmental Affairs Department
- Malawi Revenue Authority
- Ministry of Agriculture
- Ministry of Local Government
- Malawi Bureau of Standards
- Electricity Generation Company (EGENCO)
- Electricity Supply Corporation of Malawi (ESCOM)
- Malawi Communications Regulatory Authority (MACRA)
- Waste and sanitation departments in urban assemblies

Where data gaps existed, especially in earlier years of the time series, Tier 1 methodologies and IPCC default values were used to develop proxies or approximations consistent with guidance under the MPGs. This was applied with documented flexibility as allowed under Paragraphs 4 and 6 of the MPGs, reflecting Malawi's status as a developing country party with capacity constraints.

The GHG inventory compilation is guided by the principles of transparency, accuracy, completeness, consistency, and comparability (TACCC). All estimates have undergone internal QA/QC checks, including peer review processes and expert consultations during data processing and interpretation. In addition to this report, Malawi has begun work to establish a centralized GHG data repository and to institutionalize an MRV (Measurement, Reporting and Verification) system to facilitate future submissions under the ETF.

The emissions data in this report is presented on a calendar-year basis (January–December) to align with Malawi's national statistical reporting and budgeting cycles. The use of calendar year reporting also aligns with IPCC guidelines, which allow countries to use the most accurate and nationally appropriate systems for inventory compilation.

This report also provides a detailed analysis of historical trends, sectoral contributions, and gas-specific distributions (CO₂, CH₄, N₂O), supported by extensive graphical and tabular visualizations. Emissions from carbon dioxide (CO₂) dominate the Energy and IPPU sectors, while methane (CH₄) and nitrous oxide (N₂O) are more prevalent in Agriculture and Waste. The

AFOLU sector, while including some removals through forestry and land-use changes, remains a net source due to ongoing deforestation and biomass consumption.

This NIR forms part of Malawi's broader effort to meet its transparency, accountability, and ambition goals under the Paris Agreement. It will serve as a foundational tool for the country's climate policy development, NDC implementation, sectoral mitigation planning, and access to international climate finance. Going forward, Malawi intends to strengthen its inventory capacity through the generation of national emission factors, digitized data flows, subnational inventories, and expanded QA/QC protocols.

ES.2. Summary of trends related to national emissions and removals

Malawi's total greenhouse gas (GHG) emissions, including all sectors and gases (CO₂, CH₄, N₂O), amounted to approximately 25,261.32 Gg CO₂ equivalent (CO₂-e) in 2022. This represents the highest annual emission total since inventory reporting began in 1994. The country's emissions profile has evolved significantly over the reporting period (1994–2022), primarily driven by socio-economic growth, demographic expansion, and increased energy and agricultural demands.

The cumulative national GHG emissions between 1994 and 2022 are estimated at 429,874.01 Gg CO₂-e, reflecting an average annual emission of 14,823.24 Gg CO₂-e. The total emissions rose from 8,604.38 Gg CO₂-e in 1994 to 25,261.32 Gg CO₂-e in 2022, marking a nearly 194% increase over the 28-year period. During the Fourth National Communication (4NC) reporting period (2018–2022) alone, emissions rose by approximately 22%, from 20,144.15 Gg CO₂-e in 2018 to 25,261.32 Gg CO₂-e in 2022.

Figure ES.01 below presents Malawi's emissions profile by sector, highlighting the contributions of Energy, Industrial Processes and Product Use (IPPU), Agriculture, Forestry and Other Land Use (AFOLU), and Waste. Notably, Malawi's AFOLU sector remains a net source of emissions, unlike in some countries where land use activities act as a carbon sink. This reflects sustained pressure on natural resources and land cover through agriculture expansion and forest degradation.

Sectoral Contributions to National GHG Emissions

- **Waste sector:** The Waste sector remains the largest source of emissions, accounting for 63.5% of total emissions in 2022. This is a significant increase from earlier periods and is largely driven by uncontrolled open burning of solid waste and expanding urban populations. The subsector "Incineration and Open Burning of Waste" alone contributed over 53.2% of total national emissions.
- **Agriculture, Forestry, and Other Land Use (AFOLU):** The AFOLU sector contributed 22.9% of total emissions in 2022. The main drivers include enteric fermentation from livestock, manure management, and direct and indirect N₂O emissions from managed soils. These emissions are strongly tied to Malawi's agrarian economy, increasing population pressure on land, and the intensification of fertilizer use.

- Energy sector: Energy-related emissions represented 12.6% of the national total in 2022. This includes fuel combustion in energy industries, transport, and household biomass use. The relative share of Energy sector emissions has decreased over time due to continued reliance on biomass, yet the absolute volume of emissions has grown due to increased consumption of diesel and petrol, particularly in the transport sector.
- Industrial Processes and Product Use (IPPU): The IPPU sector accounted for 1.0% of total emissions in 2022. While modest in share, this sector has exhibited variability tied to cement and lime production, both of which fluctuate with infrastructure development, population growth, and the health of the construction sector.

Comparison Across Key Timeframes

Table ES.02 presents Malawi's total net GHG emissions for selected years aligned with the country's National Communications and Biennial Transparency submissions:

Year	Total Emissions (Gg CO ₂ -e)	% Change from Previous Period
2022	25,261.32	+4.7%
2017	24,129.80	+58.7%
2010	15,197.33	+54.0%
2000	9,864.85	+14.6%
1994	8,604.38	—

The largest increases in emissions occurred between 2000 and 2017, with growth rates exceeding 50%. This period saw extensive land conversion for agriculture, infrastructure development, population growth, and increasing transport fuel consumption. While emissions continued to rise between 2018 and 2022, the pace of growth slightly moderated, potentially due to economic constraints, post-COVID-19 disruptions, and early adaptation efforts.

Trends by Gas

Malawi's emissions profile is predominantly composed of methane (CH₄) and carbon dioxide (CO₂):

- CH₄ (Methane): Constituted 77.3% of total emissions in 2022. Major sources include enteric fermentation, waste decomposition, and flooded rice fields. The growth in CH₄

emissions closely follows trends in agricultural intensification and waste mismanagement.

- CO₂ (Carbon Dioxide): Accounted for 14.2% of emissions. Primary contributors include fossil fuel combustion in transport and manufacturing, and process emissions from cement and lime production.
- N₂O (Nitrous Oxide): Made up 8.5% of emissions, predominantly from synthetic fertilizer application and manure management. Emissions from this gas have been rising steadily due to increased fertilizer usage and intensified cultivation practices.

Further elaboration on gas-specific emissions trends and sub-sectoral dynamics is presented in Chapter 2, with disaggregated estimates and methodological details found in Chapters 3 through 7.

ES.3. Overview of source and sink category emission estimates and trends

ES.3.1 Greenhouse Gas Inventory by Source and Removal Category

This section provides a comprehensive overview of the contributions of individual source and sink categories to Malawi's total national greenhouse gas (GHG) emissions and removals over the time series from 1994 to 2022. The analysis draws upon updated emissions data submitted under the 4th National Communication and Biennial Transparency Report 1 (4NC-BTR1), in accordance with the IPCC 2006 Guidelines and Modalities, Procedures and Guidelines (MPGs) under the Paris Agreement.

Between 1994 and 2022, Malawi's total GHG emissions were estimated at approximately 429,874 Gg CO₂-eq, reflecting an average annual emission of roughly 14,823.25 Gg CO₂-eq. National emissions have grown significantly, rising from 8,604.38 Gg CO₂-eq in 1994 to 25,261.32 Gg CO₂-eq in 2022. This growth trajectory highlights the evolving socio-economic context, characterized by population increase, urbanization, expanding agricultural activities, and rising energy demands.

In terms of contribution by IPCC categories:

- The Waste Sector (CRT Category 4) remains the largest contributor to national emissions, accounting for approximately 62.3% of total GHG emissions in 2022. This is predominantly driven by emissions from solid waste disposal sites and, to a lesser extent, wastewater treatment and discharge. Between 1994 and 2022, emissions from this sector increased by over 265%, largely due to growing urban populations and limited landfill management infrastructure.
- The Agriculture, Forestry and Other Land Use (AFOLU) Sector (CRT Category 3) contributed 22.9% of total emissions in 2022. Within AFOLU, Livestock (3.A) and Direct N₂O Emissions from Soils (3.C.4) are among the leading sources. This reflects a heavy reliance on smallholder farming systems and increasing application of synthetic fertilizers and liming practices to boost productivity.

- The Energy Sector (CRT Category 1) accounted for approximately 12.5% of emissions in 2022. Emissions in this sector are dominated by fuel combustion in transport (especially road transport), manufacturing, and residential biomass use. The sector's contribution has increased as Malawi's transport and manufacturing activities expand, although per capita energy consumption remains comparatively low by regional standards.
- The Industrial Processes and Product Use (IPPU) Sector (CRT Category 2), though relatively small, contributed 1.02% of total emissions in 2022. Emissions in this sector are primarily linked to cement and lime production. While IPPU emissions declined modestly in earlier years, growth resumed in recent periods due to infrastructure development and urban housing demand.

From 2018 to 2022, national GHG emissions increased from 21,861.91 Gg CO₂-eq to 25,261.32 Gg CO₂-eq, indicating an annualized growth of approximately 3.68%. This period alone accounted for nearly 15.4% of total cumulative emissions since 1994, underscoring the intensity of recent development dynamics.

GHG Composition and Sectoral Trends by Gas

Disaggregating by gas, Malawi's emissions profile is dominated by methane (CH₄), followed by carbon dioxide (CO₂) and nitrous oxide (N₂O):

- Methane (CH₄) accounted for approximately 77% of emissions over the time series, with primary sources including enteric fermentation in livestock (3.A.1), manure management (3.B), and waste disposal (4.A and 4.D). Emissions from methane grew sharply due to the increase in livestock populations and unmanaged municipal waste in urban centres.
- Carbon dioxide (CO₂) emissions made up about 14%, primarily from fossil fuel combustion in energy industries and industrial processes. Though modest in share, CO₂ emissions rose steadily with increased road traffic, cement manufacturing, and reliance on firewood and charcoal in household energy use.
- Nitrous oxide (N₂O) emissions contributed 8% and were primarily linked to agricultural soil management, including direct and indirect N₂O emissions from fertilizer use and urea application (3.C.4, 3.C.5, and 3.C.3). These emissions increased in recent years following the intensification of maize and rice production.

Per Capita Emissions Trends

Per capita GHG emissions in Malawi rose from 9.02 Gg CO₂-eq per person in 1994 to 13.75 Gg CO₂-eq per person in 2022. This steady increase reflects a gradual shift toward more carbon-intensive development pathways, particularly in urban areas. The peak of 13.27 Gg/person was recorded in 2018, largely due to surges in fuel consumption and industrial activity.

Drivers of Sectoral Emissions

- In the AFOLU sector, emissions are driven by population pressure on land, increased demand for agricultural outputs, and shifting cultivation practices. The expansion of rice cultivation and fertilizer use, supported by national agricultural subsidy programs, has contributed to the rise in N₂O and CH₄ emissions.
- The Energy sector has seen increased emissions due to growth in road transport and use of fossil fuels, albeit mitigated somewhat by stagnation in industrial energy consumption and the high share of traditional biomass in household energy use.
- Waste sector emissions are on an upward trajectory due to increasing urbanization, inadequate waste segregation, and open dumping of organic solid waste, which contributes to uncontrolled methane release.
- The IPPU sector, though smaller, shows notable increases in recent years as domestic cement and lime demand rises.

ES.4. Other information (e.g. indirect GHGs, precursor gases)

Malawi ratified the Paris Agreement on 22 April 2016, reaffirming its commitment to global efforts to limit the rise in global temperatures and pursue a climate-resilient, low-carbon development pathway. In line with Article 4 of the Paris Agreement, Malawi submitted its updated Nationally Determined Contribution (NDC) in 2021. This updated NDC outlines the country's ambition to reduce greenhouse gas (GHG) emissions by 51 percent by 2040 relative to a business-as-usual (BAU) trajectory, with an interim reduction target of 45 percent by 2030, subject to availability of international support. The targets apply to both conditional and unconditional commitments and cover key emitting sectors including energy, agriculture, forestry and other land use (AFOLU), and waste.

Malawi's mitigation ambition is accompanied by a strong emphasis on adaptation, recognizing the country's heightened vulnerability to climate change impacts, including droughts, floods, and shifting rainfall patterns that adversely affect livelihoods, food security, and infrastructure. The NDC also outlines cross-cutting priorities such as technology transfer, capacity building, and climate finance, which are vital for the full implementation of the proposed interventions.

Scope of Targets and Legislative Framework

Malawi's NDC targets are economy-wide, covering CO₂, CH₄, and N₂O, consistent with the gases included in the national GHG inventory. While the country does not yet have a dedicated climate change act or emissions reduction legislation enshrining these targets, efforts are ongoing under the National Climate Change Management Policy (NCCMP) and the Malawi 2063 development agenda, which emphasizes climate-smart development, environmental sustainability, and disaster risk reduction.

Several national strategies and sector-specific plans reinforce the NDC implementation framework, including:

- The National Energy Policy (2018), which prioritizes renewable energy, energy efficiency, and improved biomass utilization.
- The National Forestry Landscape Restoration Strategy, which supports emissions removals through afforestation and sustainable land use.
- The National Waste Management Strategy (2023–2030), which promotes improved collection, segregation, and disposal practices to reduce emissions from open burning and landfills.

In addition, Malawi is actively participating in multilateral support programs, including the NDC Partnership, the UNFCCC Capacity-Building Initiative for Transparency (CBIT), and technical support from regional entities and development partners to strengthen national inventory systems, enhance data quality, and improve institutional coordination.

Other Gases and Precursors

In accordance with the 2006 IPCC Guidelines, this report focuses on direct greenhouse gases — CO₂, CH₄, and N₂O — that contribute to anthropogenic climate change. Indirect GHGs and precursor gases, such as carbon monoxide (CO), nitrogen oxides (NO_x), non-methane volatile organic compounds (NMVOCs), and sulphur dioxide (SO₂) are not currently reported due to data limitations and institutional capacity constraints. However, efforts are underway through the Department of Climate Change and Meteorological Services (DCCMS) and the Environmental Affairs Department (EAD) to explore potential improvements in tracking and estimating these gases in future submissions.

Transparency and Continuous Improvement

Malawi continues to strengthen its national GHG inventory system in line with the Modalities, Procedures and Guidelines (MPGs) for the Enhanced Transparency Framework (ETF) under the Paris Agreement. While the inventory reported herein is compiled using a Tier 1 approach and largely dependent on national statistical and sectoral data, the country is investing in:

- Enhanced institutional arrangements and capacity building,
- Collection of disaggregated and site-specific activity data,
- Development of country-specific emission factors,
- Digitization of inventory data and archiving systems.

These efforts are aimed at improving the Accuracy, Completeness, Consistency, Transparency, and Comparability (ACCTC) of Malawi's future submissions. This NIR represents an important milestone under the First Biennial Transparency Report (BTR1) and contributes to Malawi's long-term vision of achieving low-emission, climate-resilient development as outlined in Malawi 2063 and successive national development plans.

ES.5. Key category analysis

In accordance with the 2006 IPCC Guidelines for National Greenhouse Gas Inventories (Volume 1, Chapter 4) and its 2019 Refinement, Malawi conducted a Key Category Analysis (KCA) to identify the most significant emission and removal sources influencing the national greenhouse gas (GHG) inventory. A key category is defined as a source or sink that significantly affects total national emissions either through its magnitude, trend, or associated uncertainty. Identifying these categories helps prioritize methodological improvements and enhances transparency, consistency, comparability, completeness, and accuracy, as required under the Enhanced Transparency Framework of the Paris Agreement.

The identification of key categories was based on:

- Approach 1 – Level Assessment for the base year (2018) and current year (2022);
- Approach 1 – Trend Assessment between 2018 and 2022;
- Disaggregated assessments conducted with and without the Forestry and Other Land Use (FOLU) sector.

The level assessment identifies categories that cumulatively contribute 95% of total national emissions, while the trend assessment identifies categories that most significantly influence emission changes over time. The aggregation and disaggregation structure followed was consistent with the uncertainty assessment presented in Annex II.

Malawi's inventory system primarily applies Tier 1 methods across all categories due to data limitations. However, identification of key categories provides the foundation for targeted improvements, including the transition toward higher-tier methodologies where feasible.

ES.5.1 Base and Current Year Key Categories – With FOLU

The Level Assessment for the 2018 base year and the 2022 current year, inclusive of emissions and removals from the Forestry and Other Land Use (FOLU) sector, identified a consistent set of dominant categories driving Malawi's greenhouse gas (GHG) profile (see [Annex Tables A1-1 to A1-3](#)). Total national GHG emissions were estimated at 71,334 kt CO₂e in 2018 and 70,497 kt CO₂e in 2022.

The largest single contributor in both years was Category 4.A – Forest Lands (CO₂), which accounted for 57.1% of total net emissions in 2018 and 51.4% in 2022. This sustained dominance reflects ongoing emissions from deforestation and forest degradation, underlining the critical role of land-use change dynamics in Malawi's national inventory.

Methane emissions from Category 5.A.2 – Solid Waste Disposal at Unmanaged Sites (CH₄) ranked second, rising from 18.8% of total emissions in 2018 to 22.7% in 2022. This trend is consistent with urban population growth and insufficient development of formal waste management systems.

Other land-use categories remained significant. Category 4.B – Croplands (CO₂) contributed approximately 6.9% in 2018 and 7.0% in 2022, while Category 4.D – Wetlands (CO₂) maintained a steady share at around 6%. Emissions from Category 4.C – Grasslands (CO₂) declined slightly but still featured among the key contributors in both years.

Livestock-related methane emissions became increasingly prominent. Category 3.A.1.b – Non-dairy Cattle (CH₄) and Category 3.A.4 – Goats (CH₄) emerged as key categories, jointly contributing over 4.9% of total emissions in 2022. In addition, Category 1.A.3.b – Road Transportation (CO₂), although relatively smaller in absolute terms, crossed the 95% cumulative threshold in both years.

ES.5.2 Base and Current Year Key Categories – Without FOLU

Excluding FOLU emissions and removals from the inventory significantly shifts the emission profile toward anthropogenic sectors. Under this configuration, waste and livestock sectors dominate (see [Annex Tables A1b-1 to A1b-3](#)).

In both the base and current years, the top key categories without FOLU were:

- 5.A.2 – Solid Waste Disposal at Unmanaged Sites (CH₄)
- 5.C – Incineration and Open Burning of Waste (CH₄)
- 3.A.1.b – Non-dairy Cattle (CH₄)
- 3.A.4 – Goats (CH₄)
- 1.A.3.b – Road Transportation (CO₂)

By 2022, emerging contributors also included Category 3.H – Urea Application (CO₂) and 2.A.1 – Cement Production (CO₂), reflecting increasing agricultural intensification and growth in domestic cement use, respectively. These categories now meet the 95% cumulative threshold, indicating a shift in the non-FOLU emissions landscape.

ES.5.3 Trend Assessment Key Categories

The trend assessment examines the relative contribution of each category to the change in national emissions between 2018 and 2022. The total emissions declined by approximately 837 kt CO₂e, a modest 1.2% reduction.

With FOLU included, the most influential category was:

- 4.A – Forest Lands (CO₂), which accounted for 47.3% of the total net change due to reduced deforestation and improved biomass carbon stocks.

Other notable contributors were:

- 5.A.2 – Solid Waste Disposal (CH₄): 27%, due to rising waste generation.
- 4.C – Grasslands (CO₂): 6%, reflecting land use shifts and cover improvement.
- 3.A.4 – Goats (CH₄) and 3.A.1.b – Non-dairy Cattle (CH₄): 6% and 4%, respectively, consistent with increased livestock numbers.

Minor but measurable contributions to the trend came from 1.A.3.b – Road Transportation (CO₂) (2%), 3.H – Urea Application (CO₂) (1%), and 4(IV) – Biomass Burning (CO₂), which showed a decrease, also contributing 1%.

When FOLU is excluded, the trend is primarily driven by:

- 5.A.2 – Solid Waste Disposal (CH₄): 27% of total net change.
- 3.A.4 – Goats (CH₄): 6%
- 3.A.1.b – Non-dairy Cattle (CH₄): 4%
- 1.A.3.b – Road Transportation (CO₂): 2%

This confirms a growing influence of the waste and livestock sectors in driving recent changes in Malawi’s anthropogenic emissions, especially in urban and agricultural areas.

ES.5.4 Implications and Future Improvements

The updated Key Category Analysis underscores three core sectors as pivotal in shaping Malawi’s emissions profile: land-use and forestry, waste, and livestock. The continuing dominance of forest lands in the national inventory points to the need for enhanced forest monitoring systems, including spatially explicit datasets and regular stock assessments.

Rapid growth in waste-related methane emissions calls for a systemic improvement in solid waste management infrastructure, particularly in urban centers. Strengthening data collection and reporting for waste generation, disposal practices, and treatment technologies remains a priority.

Similarly, the consistent emergence of livestock methane emissions as key contributors to both level and trend assessments signals a need for improved livestock census data, emission factor refinement, and promotion of climate-smart livestock practices.

Given the increasing significance of categories such as road transportation, cement production, and urea application, future inventory cycles should aim to apply Tier 2 methodologies for these sources wherever feasible. This may require targeted capacity building, the establishment of sector-specific databases, and stakeholder engagement to improve activity data quality.

Overall, this analysis provides a robust foundation for prioritising improvements and ensuring compliance with the Enhanced Transparency Framework (ETF) under Article 13 of the Paris Agreement.

ES.6. Improvements introduced

Malawi’s emissions inventory is consistently refined to integrate the latest research, data, technologies, and best practices. This is done with an aim to enhance the accuracy and reliability of its environmental reporting.

ES.6.1 Improvements Implemented in 2018-2022

For this report, recommendations from previous UNFCCC Expert Review Team (ERT) submissions have been addressed. The status of these improvements is detailed in [Chapter 0](#), along with a summary of responses to the simplified review for the 2022 inventory submission. Furthermore, the following improvements were incorporated:

- *Method Improvements*: Various method improvements were applied across multiple sectors to increase the accuracy and comparability of Malawi's emissions estimates.
- *Sector-Specific Updates*: Method improvements typically result in recalculations of Malawi's national emissions. The impact of these recalculations is summarized in [ES.6.2 Recalculations](#) and further elaborated in Chapter 10, with specific details provided in sectoral Chapters.

Energy

- Improved estimation of GHG emissions from energy sources through the refinement of energy sector data, ensuring consistency between the reference and sectoral approaches.
- Enhanced institutional arrangements for data-sharing between companies and reporting institutions through formal agreements like MoUs.
- Expansion of reporting methodologies to better capture emissions from fuel combustion and fugitive emissions, aligning with IPCC 2006 Guidelines.
- More details on energy sector improvements are outlined in Chapter 3 of this report.

Industrial Processes and Product Use (IPPU) Sector

- Strengthened documentation of activity data (AD), emission factors (EFs), and estimation methods to improve transparency and accuracy.
- Increased efforts to collect historical data and map emissions from individual industrial processes to improve completeness.

Agriculture, Forestry, and Other Land Use (AFOLU) Sector

- Development of a land representation framework to categorize land-use subcategories more effectively, ensuring compliance with IPCC 2006 Guidelines.
- Introduction of a systematic classification of cropland into perennial and annual categories to refine data accuracy.
- Disaggregation of forest land and cropland by soil type (high-activity and low-activity soil) to align with Malawi's climate and improve carbon stock estimates.
- Improved documentation of uncertainties in GHG estimates across different land use categories.
- *Forest Management and Agriculture*: Methodologies related to forestry and agricultural emissions have been improved. New modelling approaches for forest

carbon stocks and soil carbon sequestration in agricultural lands have been integrated, reflecting more localized climate and land management data.

- *Revised Data on Land Use*: Revisions to crop yield modelling and land use practices have been implemented, particularly in the context of changing climatic conditions that have affected carbon storage in soils and the impact of seasonal changes.
- Further details on FOLU sector improvements are provided in Chapter 6.

Waste

- *Waste Sector Adjustments*: Updates to the modelling of waste disposal practices, particularly related to landfill methane emissions, have been introduced. This includes updated activity data for waste treatment processes and the inclusion of improved reporting methodologies for solid waste emissions.
- More detailed method improvements in the waste sector are found in Chapter **Error! Reference source not found.** There has been an increase in population coverage, leading to a more comprehensive greenhouse gas (GHG) inventory by capturing a broader range of emissions sources and improving data accuracy for reporting and mitigation efforts.
- Establishment of a systematic approach for estimating emissions from municipal solid waste and wastewater using country-specific activity data.
- Identification of key entities responsible for waste management to support data collection and reporting.
- Development of standardized data templates for waste sector reporting to improve consistency and comparability.
- Formalization of data collection mandates for companies involved in waste generation to ensure the availability of accurate data for GHG inventory reporting.

ES.6.2 Recalculations

The implementation of these method improvements and the incorporation of new data have resulted in recalculations across the emissions time series. These recalculations reflect changes in both national totals and sector-specific emissions.

Summary of Improvements Introduced in the Current National Communication – GHG Inventory Report

The current national communication introduces several improvements in Malawi's GHG inventory report, aimed at enhancing data accuracy, methodological consistency, and institutional capacity. These improvements are categorized by sector as follows:

Energy Sector

Cross-Sectoral Improvements

- Strengthening quality assurance/quality control (QA/QC) processes for sector-specific GHG emission reporting.
- Expanding training programs for national experts on the application of the 2006 IPCC Guidelines, including the use of IPCC Inventory Software.
- Developing country-specific emission factors for key categories in all sectors to enhance accuracy.
- Improving the national Measurement, Reporting, and Verification (MRV) system to support comprehensive data collection and reporting on mitigation actions.
- Strengthening institutional arrangements and inter-agency coordination to facilitate sustainable GHG inventory planning and reporting.

Chapter 1:



National circumstances,
institutional arrangements
and
cross-cutting information

1.1 Background information on GHG inventories and climate change

The United Nations Framework Convention on Climate Change (UNFCCC) was adopted in 1992 by 158 countries in Rio de Janeiro Brazil as a global effort to prevent anthropogenic greenhouse gases (GHGs) which are the major cause of global warming from interfering with the climate system (United Nations, 1992). Malawi signed the UNFCCC in 1992 and ratified it in 1994. The Government published its initial, second and third national communications to the UNFCCC in 2003, 2010 and 2021 respectively. The publication of the Nationally Appropriate Mitigation Action (NAMA) report in 2015, Biennial Update report in 2020 and Updated Nationally Determined Contributions (NDC) in 2021 demonstrates the commitment the country has made to contributed towards the global effort to mitigate climate change.

Despite the global GHG mitigation efforts by the United Nations and the Parties, the GHG emission trends showed no sign of decline. After many years of negotiations through Conference of Parties (CoPs), member agreed to limit the increase in global average temperature to below 2 degrees Celsius (C) above pre-industrial level and pursue efforts to limit temperature increase to 1.5°C above pre-industrial levels. During the CoP21 in 2015, the Paris Agreement (PA) was adopted by 196 Parties as a legally binding treaty on climate change. As a Party, Malawi submitted its Intended Nationally Determined Contribution (INDC) in 2015 and the updated Nationally Determined Contribution (NDC) in 2021.

1.2 National Circumstances: key drivers of GHG emissions and removals in Malawi

Malawi's economy is agro-based. The main crops are tobacco, tea and sugar for export while maize and rice are the main food crops. Agriculture contributes to 22.8% of forex, 64% of employment and majority of rural Malawians depend on subsistence agriculture for their livelihoods (Government of Malawi, 2021). The industrial sector involves processing of agricultural produce and to some extend mineral resources especially cement. Although the population is rural-based and accounts for 84% of the total 20.6 million people in 2022, urbanisation rate is high, currently increasing at 4.1% per annum (UNHABITAT, 2023). Poverty level is around 50%. Most Malawians depend on natural resource-based activities for their livelihood i.e. agriculture, fishery, artisanal mining and forest-based activities (firewood, timber, poles, charcoal) (Mphande, 2016; Senganimalunje & Chirwa, 2020). Malawi grid electricity is renewable consisting of hydro and solar photo voltaic. Diesel operated thermal power plants are used for peaking and during maintenance of the hydro power plants. These factors are elaborated further in the respective sectors.

With such social economic and demographic profiling, it has been observed the primary drivers of GHG emissions and removal in Malawi are:

i. Demographic drivers

This factor affects demand for goods and services, land for cultivation and settlement, as well as urbanization, transportation and waste generation amongst others. Malawi's annual population

growth rate has been between 2% and 3.3% per annum. Table 2-1 shows population trend and intercensal population growth between 1966 and 2022 (National Statistical Office, 2018).

Table 1-1: Population trend and intercensal population growth between 1966 and 2022

Year	Population	Intercensal growth rate
1966	4039583	3.3
1977	5547460	2.9
1987	7988507	3.7
1998	9933868	2.0
2008	19077160	2.8
2018	17563749	2.9

Source: National Population Census, 2018 (NSO)

The increase in population directly results in the increase in demand of services such as transport, waste management services for both solid and wastewater, demand for farm inputs such as fertilisers to meet demand for food production, demand for biomass energy, and demand for land for settlement and housing units. These activities directly impact the activity data of the emitting sectors as well as the reduction of forest cover that provide GHG sink.

ii. Economic drivers

The key issues involve agriculture, industry, energy, transport, and natural resources-based livelihood systems of the rural population. Table 1- 2 shows the sectoral contributions to national gross domestic product (GDP).

Table 1-2: Sectoral contributions to the national gross domestic product (GDP).

SECTOR	2019	2020	2021	2022*	2023*
Agriculture, Forestry and Fishing	22.1	22.6	22.5	22.4	22.6
<i>Crop and Animal Production</i>	20.7	21.4	21.4	21.3	21.5
<i>Forestry and Logging</i>	0.1	0.1	0.1	0.1	0.1
<i>Fishing and Aquaculture</i>	1.3	1.1	1.0	1.0	1.0
Mining and Quarrying	0.7	0.7	0.7	0.7	0.8
Manufacturing	11.8	12.2	12.1	11.9	11.9
Electricity, Gas and Water Supply	2.9	3.0	2.8	2.7	2.8
Construction	3.2	3.3	3.2	3.4	3.5
Wholesale and Retail Trade	12.6	12.5	12.4	12.0	12.0
Transportation and Storage	4.7	4.3	4.4	4.4	4.5
Accommodation and Food Services	1.5	1.1	1.1	1.2	1.2
Information and Communication	5.7	5.9	6.1	6.1	6.1
Financial and Insurance Activities	6.0	6.2	6.3	6.6	6.7
Real Estate Activities	6.4	6.6	6.6	6.6	6.7
Professional and Support Services	1.3	1.2	1.2	1.2	1.3
Public Administration and Defence	3.1	3.2	3.2	3.3	3.4
Education	4.3	4.0	4.0	4.1	4.1
Health and Social Work Activities	6.0	5.8	5.6	5.7	5.6
Other Services	1.8	1.8	1.8	1.9	1.9
Sum of All Industries	94.0	94.6	93.9	94.3	95.1
Plus: Taxes less Subsidies on Products	6.0	5.4	6.1	5.7	4.9

Source: Annual Economic Report 2023 (Government of Malawi, 2023).

Malawi is an agro-based economy. As such agro-based emissions from crop and livestock production make a considerable contribution to the total GHG emissions in the country.

Industrial sector is rather low both in types and quantities. The significant industry as far as GHG emission is concerned is cement production. The country clinker production capacity has been growing steadily.

The traditional electricity generation for Malawi has been hydro-based. At one time, hydro power accounted for more than 98%. More recently, solar photovoltaic (PV) is increasingly becoming significant overtaking diesel-based generation. Therefore, GHG emissions from energy generation relate to emissions from diesel generators which are run to meet peak power demand, especially from planned or unplanned power outages. The significant emitter in energy is from road transport sector which meet the demand for freight transport, since Malawi is a landlocked country, and passenger transport. Aviation, marine and rail transport are less significant.

About 85% of Malawian population is rural based. Majority depend on agriculture and natural resources for their livelihood. Districts that surround cities of Blantyre, Lilongwe, Zomba and Mzuzu have seen high rate of deforestation from illegal firewood harvesting and charcoal production to meet energy needs of the urban areas.

iii. Environmental drivers

Extreme climate events have increasingly disrupted Malawi's energy system, particularly its reliance on hydropower. Recurrent droughts, intense rainfall, and tropical cyclones have reduced the reliability of hydropower plants, forcing a greater dependence on fossil-fuel-based generation.

Despite ongoing afforestation and reforestation programmes, the rate of deforestation remains high, driven by the expansion of agricultural land, settlement development, and rising demand for biomass fuels such as firewood and charcoal (often sourced illegally and unsustainably). This land degradation accelerates siltation in rivers and reservoirs, further compromising hydropower capacity. For example, between 2019 and 2022, the Electricity Generation Company (EGENCO) spent approximately MK 10 billion on siltation management alone.

The vulnerability of Malawi's energy system was starkly illustrated in January 2022, when Cyclone Ana caused structural damage to the Kapichira Hydropower Station dam and its associated infrastructure. This event resulted in the immediate loss of 129.6 MW (equivalent to 32% of EGENCO's generation capacity) on the national grid. To mitigate the impact of widespread power rationing, Malawi was compelled to resort to costly diesel-based generation, significantly increasing fossil fuel consumption and associated emissions.

Figure 1-1 shows the devastating effects of Cyclone Ana on one of the country's important infrastructures



Figure 1-1: Kapichira Hydro-power plant damaged by Cyclone Ana in January 2022

Source: <https://www.egenco.mw/outage-of-kapichira-power-station-due-to-damages-caused-by-cyclone-ana/>

1.3 Institutional arrangement

1.3.1 National entity or national focal point

The Environmental Affairs Department (EAD) in the Ministry of Natural Resources and Climate Change (MNRCC), is the National Focal Point (NFP) for managing climate change affairs which includes the national greenhouse gas inventory system. For inquiries on the national GHG inventories, the Department can be reached at:

The Director of Environmental Affairs
Lingadzi House, Robert Mugabe Crescent
Private Bag 394,
Lilongwe 3,
Malawi.
Email: ead@ead.gov.mw
Phone: +265 (0) 1 771 111

The Environmental Affairs Department (EAD), as the national focal point for climate change, collaborates closely with stakeholders across government ministries, departments, and agencies (MDAs), academia, the private sector, and non-governmental organizations (NGOs). This collaboration ensures effective data sourcing and sharing, sectoral studies, technical evaluations, and other support activities.

As a developing country, Malawi prepares its national greenhouse gas (GHG) inventory as part of its National Communications to the UNFCCC (Government of Malawi, 2021b).. Climate change programmes and activities are implemented within a coordinated institutional framework, illustrated in *Figure 1-2*.

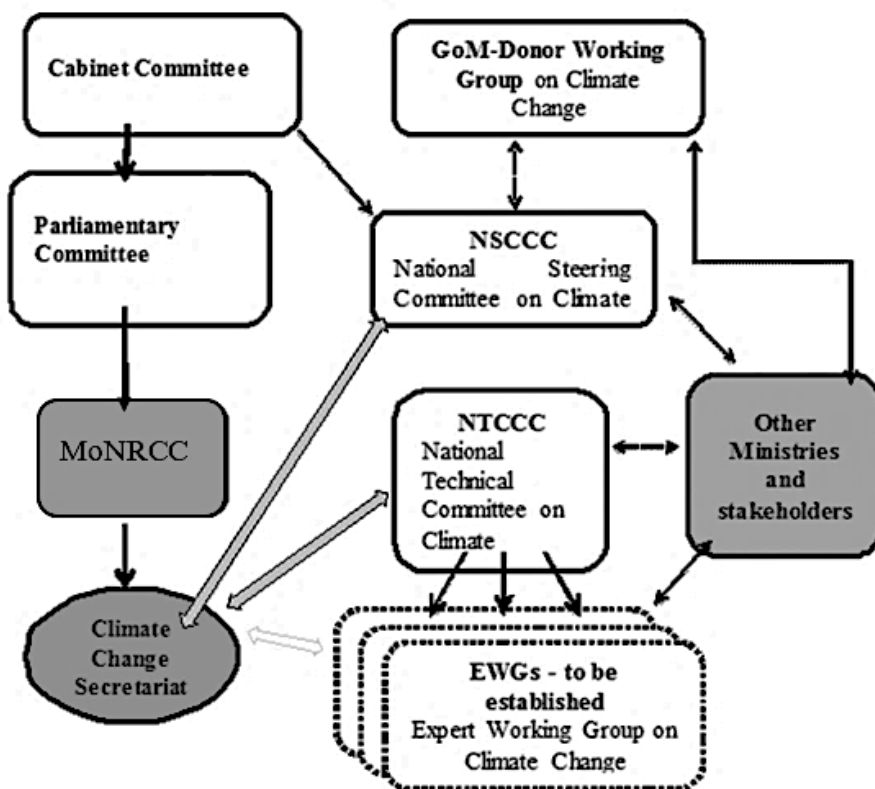


Figure 1-2: Institutional arrangement for climate change in Malawi

Source: Government of Malawi (2021)

The framework comprises of several governance levels:

- **Cabinet Committee on Climate Change** – enables coordination of climate change actions across all arms of government.

- **Parliamentary Committee on Natural Resources and Climate Change** – supports the passage and oversight of environment-related policies and legislation in the National Assembly.
- **National Steering Committee on Climate Change (NSCCC)** – provides policy-level oversight, guidance, and direction on climate change management.
- **National Technical Committee on Climate Change (NTCCC) and Expert Working Groups (EWGs)** – provide technical guidance and advice on climate change issues across sectors.

At the district level, the District Executive Committee (DEC) provides overall leadership and oversight, while the District Environmental Sub-Committee (DESC) addresses environmental management, climate change, forestry, and natural resource issues. The DESC Secretariat, housed within the District Planning and Development Directorate, ensures mainstreaming of climate change into district development programmes.

At the community level, various committees play a role in addressing climate change. The most notable is the Village Natural Resources Management Committee (VNRMC), which focuses on protecting the environment to promote both climate change mitigation and adaptation. These committees are legally mandated to enforce environmental protection measures through established by-laws.

Table 1-3 provides the summary of roles played by the lead government institutions in facilitating and aiding inventory preparation process.

Table 1-3: Roles of government ministries, departments and agencies.

Institution	Responsibilities
Environmental Affairs Department in the Ministry of Natural Resources and Climate Change	Overall planning, coordination, training, QA/QC, approval process, publication and submission to the UNFCCC
Ministry of Finance and Economic Planning	Overall economic and fiscal policies and economic development. It manages data portal with lots of sectoral data*
Ministry of Energy (MoE)	MoE has been developing capacity to prepare national Energy balances
Malawi Energy Regulatory Authority (MERA)	Manages petroleum import data and issues licenses for energy generators
Department of Mines	The Department manages mineral production statistics- coal and cement production data
Ministry of Trade and industry	The Ministry receives industrial production statistics from the registered industries
Ministry of Agriculture	Produces data on crop production (including paddy and upland rice), fertiliser usage, livestock statistics and land use data.

Department of Forestry	Provides data on forestry cover and land use change
Ministry of Transport and Infrastructure Development Road Transport, Aviation, Rail and Marine	Provides statistics on registered motor vehicles, registered ships and boats, fuels usage by rail and aviation.
Ministry of Local Government and Rural development (city, municipal, town and district councils) Water Boards	Management of municipal solid waste is delegated to local government Malawi has five water boards who have the responsibility of management of wastewater treatment and discharge.
National Statistical Office (NSO)	NSO manages collection and archiving of various demographic, social and economic data for the country. It manages data portal on various data **
Malawi Revenue Authority (MRA)	MRA collects revenue for the government through duties and taxes

* <https://psip.malawi.gov.mw/reports/economic.php>; ** <https://malawi.opendataforafrica.org/>

Malawi, through the EAD, has been developing a robust and sustainable system of national GHG inventory preparation. In the past few years, climate change focal persons in government ministries, departments and agencies (MDAs) were trained in data collection and archiving to support the national GHG inventory preparation. The MDAs involved came from energy, agriculture, forestry, trade and industry, local government, transport, NSO, MRA, mining, and water, amongst others. EAD assembled a team of experts from various sectors for data collection, entry, methodology improvement, emissions estimation, report preparation, and review. The collected data was used in compiling the inventory report.

1.3.2 Inventory preparation process

As a developing country, Malawi produced the national GHG inventory report as part of its national communication to the UNFCCC. The national GHG inventory preparation process involves a well-structured approach that includes the following: planning at Secretariat level, setting up the GHG inventory team, reviewing and selecting methodologies, engagement of data sources, collecting and entering data, implementing quality control and assurance measures, estimating emissions and associated uncertainties, preparing reports, reviewing emissions data and reports with stakeholders and experts, identifying areas for improvement, data archiving and publishing the final reports Table 1-4 summarises the lead institutions in the data sourcing and inventory preparation.

Table 1-4: Sources of data for GHG inventory process

Sector	Institutions	Responsibilities	Remarks
All sectors	Environmental Affairs Department in the Ministry of Natural Resources and Climate Change	Overall planning, coordination, training, QA/QC, approval process, publication and submission to the UNFCCC	EAD is the custodian of previous inventory studies. Efforts are underway to archive these sources of data.
	Ministry of Finance and Economic Planning	Overall economic and fiscal policies and economic development	Publishes Annual Economic Review Report- contains lots of sectoral data.*
	National Statistical Office (NSO)	NSO manages collection and archiving of various demographic, social and economic data for the country	Publishes regular statistics based on various surveys such Integrated Household Surveys (IHS) NSO manages Malawi Data Portal** that could potentially be able to integrate and host GHG relevant activity data
Energy sector	Transport Road Transport Aviation Rail Marine	Provides statistics on registered motor vehicles, registered ships and boats, fuels usage by rail and aviation.	Department of Road Traffic and Safety Services is the custodian of Malawi Transport Information System (MALTIS) Data on fuel usage by the aviation, rail and marine industries should ideally be available at MERA or Ministry of Transport and Public Works. This information could be checked with fuel distributors, airline, marine and railway operators.
IPPU sector Energy sector	Ministry of Mining (Department of Mines)	The Department manages mineral production statistics- coal and cement production data	Activity data is regularly produced in Annual Economic Reports- but in aggregated format. This information should be presented in disaggregated format in the future
IPPU sector Energy sector	Trade and industry	The Ministry receives industrial production statistics	Most of the data is managed by private sector

		from the registered industries	Submitted data is often in aggregated format and not easily accessible.
Agriculture sector	Ministry of Agriculture and Food Security	Produces data on crop production (including paddy and upland rice), fertiliser usage, livestock statistics and land use data.	The Ministry has recently launched a management information system that could support GHG inventory preparation (National Agriculture Information Management System)
FOLU	Ministry of Natural Resources and Climate Change (Forestry Research Institute,)	Provides data on forestry cover and land use change	Forestry Research Institute of Malawi is the custodian of forestry data
Waste sector (Resource sector)	Ministry of Local Government and Rural Development (city, municipal, town, urban areas, and district councils) Ministry of Water and Sanitation Water Boards	Management of municipal solid waste is delegated to local government Malawi has five water boards who have the responsibility of management of wastewater treatment and discharge.	Some challenges in the data collection Some challenges in the data collection. There will be need to specify data requirements Lack of engineered waste treatment sites

Data portals:

* <https://psip.malawi.gov.mw/reports/economic.php>

* * <https://malawi.opendataforafrica.org/>

Malawi, through the EAD, has been working to develop a robust and sustainable system of national GHG inventory preparation. In the past few years, focal persons in government ministries, departments and agencies (MDAs) considered as custodians of data sources were trained and sensitized on data collection and archiving to support the national GHG inventory preparation. The MDAs involved came from energy, agriculture, forestry, trade and industry, local government, transport, NSO, MRA, Mining, and Water. EAD assembled a team of experts from various sectors for data collection, entry, methodology improvement, emissions estimation, report preparation, and review. The collected data was analysed using the IPCC GHG Inventory software.

1.3.3 Archiving of information

Malawi has published and disseminated its National GHG Inventories as part of the National Communications through online platforms, electronic formats, and print media. However, detailed sectoral datasets and supporting reports have not been systematically archived, limiting accessibility for stakeholders. The absence of an efficient and robust archiving system has made it difficult to verify historical data, ensure consistency, and enhance methodologies over time. This gap has posed challenges in achieving the principles of transparency, accuracy, consistency, comparability, and completeness in the national GHG inventory process.

Despite these challenges, the Government of Malawi and its development partners have made efforts to strengthen data collection, management, and archiving systems—for instance, through initiatives such as the USAID PERFORM Project. Recognizing the critical importance of a reliable data repository, work is currently underway to establish a comprehensive archiving system as part of the Fourth National Communication deliverables.

This repository will function as a centralized platform for storing and managing emissions data, enabling improved data retention, consistency, and accessibility. Ultimately, the system will enhance institutional memory, support verification of past submissions, and facilitate continuous improvement in inventory methodologies.

1.3.4 Processes for official consideration and approval of inventory

Once the GHG inventory was produced, it went through a number of review stages to ensure accuracy and consistency of the reported information. The first step involves internal review by the team of experts within EAD to ensure that all aspects of the terms of reference were fulfilled. The second stage involved the presentation of the report to the sectoral stakeholders who offered critical reviews in their respective sectors and offered additional checks on the accuracy and consistency of the data that was used in the inventory. Initial estimates and methodologies were peer-reviewed by experts drawn from various sectors, including stakeholders from MDAs, academia, and industry. There were two government committees that reviewed the report, namely, the Technical Committee on Climate Change (TCCC) and National Steering Committee on Climate Change (NSCCC). The TCCC and NSCCC reviewed the report at technical and policy levels respectively. These steps are essential to improve the credibility and accuracy of the data. The finalised inventory was subsequently submitted to the UNFCCC Secretariat by the Environmental Affairs Department.

1.4 Brief general description of methodologies and data sources used

Malawi's GHG inventory was compiled following the 2006 IPCC Guidelines for National Greenhouse Gas Inventories and associated revisions and amendments (IPCC 2019 refinement) and MPGs. This comprehensive framework ensures consistency and comparability in reporting across sectors, for all parties. Tier 1 approaches (Table 2) were predominantly used due to the lack of country-specific emission factors and data limitations.

Table 1-5: the methodologies used for every sector

GREENHOUSE GAS SOURCE AND SINK CATEGORIES	Method
1A1. Energy industries	Tier 1
1A2. Manufacturing industries and construction	Tier 1
1A 3. Transport	Tier 1
1A 4. Other sectors	Tier 1
1A 5. Other	NO
1B 1. Fugitive emissions from Solid fuels	Tier 1
1B 2. Fugitive emissions from Oil and natural gas	NE
1C. CO ₂ transport and storage	NE
2A. Mineral industry	Tier 1
2B. Chemical industry	NO
2C. Metal industry	NO
2F. Product uses as ODS substitutes	NO
3A. Enteric fermentation	Tier 1
3B. Manure management	Tier 1
3C. Rice cultivation	Tier 1
3D. Agricultural soils	Tier 1
3E. Prescribed burning of savannas	Tier 1
3F. Field burning of agricultural residues	Tier 1
3G. Liming	Tier 1
3H. Urea application	Tier 1
3I. Other carbon-containing fertilizers	Tier 1
3J. Other	Tier 1
4A. Forest land	Tier 1
4B. Cropland	Tier 1
4C. Grassland	Tier 1
4D. Wetlands	Tier 1
4E. Settlements	Tier 1
4F. Other land	Tier 1
4G. Harvested wood products	Tier 1
4H. Other	Tier 1
5A. Solid waste disposal	Tier 1
5B. Biological treatment of solid waste	NO
5C. Incineration and open burning of waste	Tier 1
5D. Waste water treatment and discharge	Tier 1
5E. Other	NO

Data was sourced from institutional records, national surveys, expert consultations, and international reports. Below is an outline of the methodologies used for key sectors:

1.4.1 Sector-Specific Methodologies

Energy Sector

The GHG inventory for the Energy sector was developed using the 2006 IPCC Guidelines for National Greenhouse Gas Inventories, specifically covering Category 1: Energy. Subcategories analysed include fuel combustion (1A) and fugitive emissions (1B). The Tier 1 approach was applied due to the unavailability of country-specific emission factors, and emissions were estimated by multiplying activity data (fuel consumption) by IPCC default emission factors. The sectoral approach provided insights into emissions by societal and economic activity levels.

- **Categories Covered:**

- 1A: Fuel Combustion Activities (Energy industries, Manufacturing industries, Transport, Other sectors)
- 1B: Fugitive Emissions (YES for solid fuels and NO oil/natural gas in Malawi).

- **Data Sources:**

Activity data was gathered through data collection sheets, structured questionnaires, desk reviews, and consultations with key stakeholders, including the Department of Energy Affairs (DEA), Malawi Energy Regulatory Authority (MERA), Ministry of transport, and public works, MRA, online resources, and publications, and NSO. Furthermore, previous National Communications (INC, SNC and TNC) and other government reports supplemented the datasets.

Industrial Processes and Product Use (IPPU)

Industrial Processes and Product Use is in Category 2 of the 2006 IPCC Guidelines. The Tier 1 approach was utilized, with emissions estimated by applying default emission factors to activity data (e.g., production volumes of cement and lime). Recalculations were made where refined activity data and emission factors were available.

- **Categories Covered:**

- 2A: Mineral Industry (Cement and Lime production)

- **Data Sources:**

Data was obtained from cement producers, the Department of Mines, the Malawi Revenue Authority (MRA), Ministry of Trade and Industry, and the NSO. Additional data was collected from the United States Geological Survey (USGS) publications.

Agricultural Sector

The 2006 IPCC Guidelines, Category 3: Agriculture, were employed to estimate emissions from agricultural activities. The Tier 1 approach was applied, relying on default IPCC emission factors due to the lack of local data. Key subcategories analyzed include enteric fermentation, manure management, and rice cultivation.

- Categories Covered:
 - 3A: Enteric Fermentation (CH₄ from livestock digestion)
 - 3B: Manure Management (CH₄ and N₂O)
 - 3C: Rice Cultivation (CH₄ from flooded fields)
 - 3D: Agricultural Soils (N₂O emissions).
 - 3G: Liming
 - 3H: Urea application
 - 3I: Other carbon-containing fertilizers

- Data Sources:

Data was sourced from the Ministry of Agriculture (Departments of Livestock Development, Crop Development, and Land Resources and Conservation), the NSO, and other institutional stakeholders. Further data on crop production and livestock production were obtained from Food and Agriculture Organisation (FAO) online databases. In addition, data was sourced from online technical reports and publications.

Forestry and Other Land Use (FOLU)

The FOLU inventory followed the 2006 IPCC Guidelines, Category 4: FOLU, employing a combination of Tier 1 and Tier 2 approaches. Emissions and removals were estimated using Approach 1 for total land-use area and Approach 2 for land-use conversions. Recalculations were based on refined activity data and emission factors, particularly for Miombo woodlands and wetlands (2019 IPCC Refinement).

- Categories Covered:
 - 4A: Forest Land
 - 4B: Cropland
 - 4C: Grassland
 - 4E: Settlements
 - 4F: Other Land.
 - 4G: Harvested wood products

- Data Sources:

Data was primarily derived from the JICA-Malawi Government land-cover mapping initiative, with epochs (1990, 2000, 2010) used for interpolation and extrapolation.

Waste Sector

The waste sector inventory was prepared following Category 5: Waste in the 2006 IPCC Guidelines, using the Tier 1 approach. Emissions were calculated from solid waste disposal, wastewater treatment, and open burning based on activity data and default IPCC emission factors.

- Categories Covered:
 - 5A: Solid Waste Disposal
 - 5C: Incineration and Open Burning of Waste
 - 5D: Wastewater Treatment and Discharge.
- Data Sources:

Data was collected from municipal authorities, the NSO, Water boards international secondary sources, and reports on waste management practices. In cases of missing local data, IPCC parameters were applied.

1.5 Brief description of key categories

Key categories are those sources or sink categories that have a significant influence on a country's total greenhouse gas (GHG) inventory, either in terms of the absolute level of emissions or removals, the trend over time, or the associated uncertainty. In line with the Modalities, Procedures, and Guidelines (MPGs) under the Paris Agreement, Malawi undertook a key category analysis (KCA) consistent with the 2006 IPCC Guidelines (Volume 1, Chapter 4).

The analysis was conducted using Approach 1 and covered both the base year (2018) and the most recent reporting year (2022). Categories were identified that together contribute to at least 95 percent of national emissions or to the most significant trends in emissions growth. To provide a more comprehensive perspective, the analysis was performed twice: first excluding the Land Use component of the FOLU sector, and then including it.

When FOLU emissions and removals were excluded, the Waste and Agriculture sectors dominated Malawi's emissions profile. Within Waste, incineration and open burning of waste (category 5.C) and unmanaged solid waste disposal sites (category 5.A.2) consistently ranked highest in terms of emission levels. In Agriculture, enteric fermentation from non-dairy cattle (3.A.1.b) and goats (3.A.4) emerged as significant contributors. Energy-related categories such as road transportation (1.A.3.b) and fuel combustion in manufacturing industries (1.A.2) also featured prominently across both level and trend assessments. Key emerging categories showing increasing importance were urea application (3.H) and cement production (2.A.1), reflecting recent growth in agricultural inputs and industrial activity.

When FOLU was included, the picture shifted considerably. Forest land (4.A) became the single largest contributor, displacing the Waste sector and accounting for approximately 51.4% of national emissions by level and 47.2% by trend. This underscores the central role of land use and forestry dynamics in shaping Malawi's overall emissions profile.

The findings are illustrated in Table 1-3 and Figures 1-2 to 1-5, which present the key categories by level and trend for both cases (with and without FOLU). These results confirm that a relatively small

number of categories dominate Malawi's emissions and removals, highlighting the priority areas for improvements in data collection, methodological refinement, and mitigation planning.

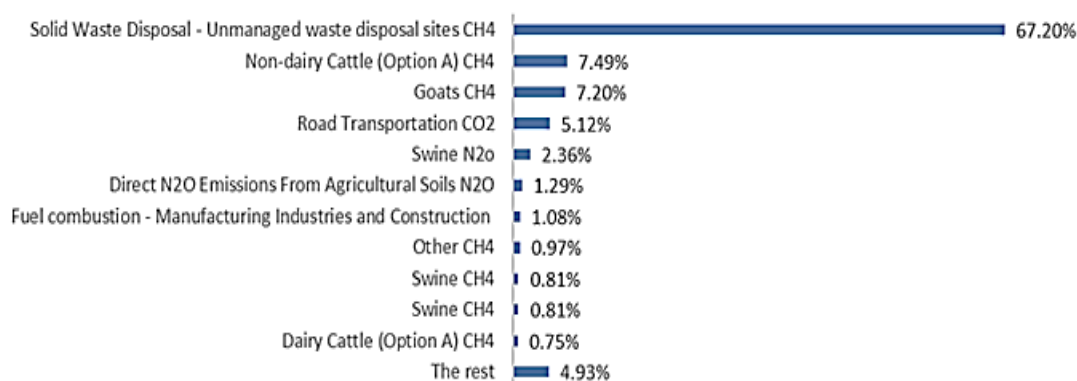


Figure 1-3: % share of the categories without FOLU (2022)

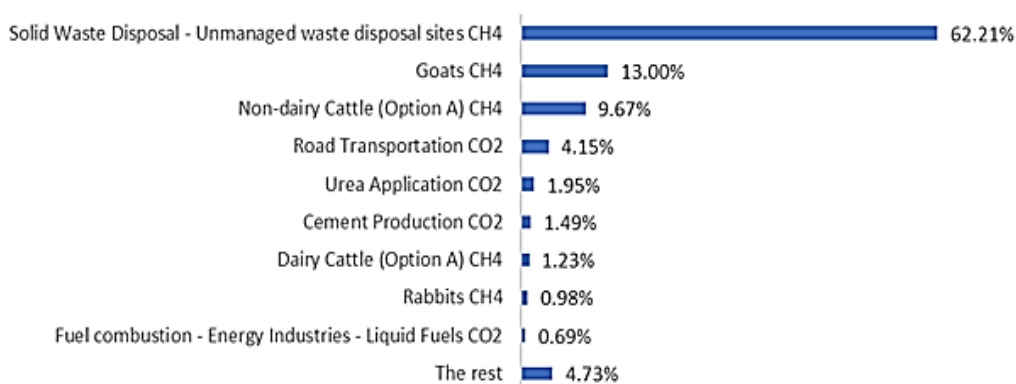


Figure 1-4: KCA GHG trends without FOLU

Figure 1-5 show the key category analysis that included the categories under FOLU.

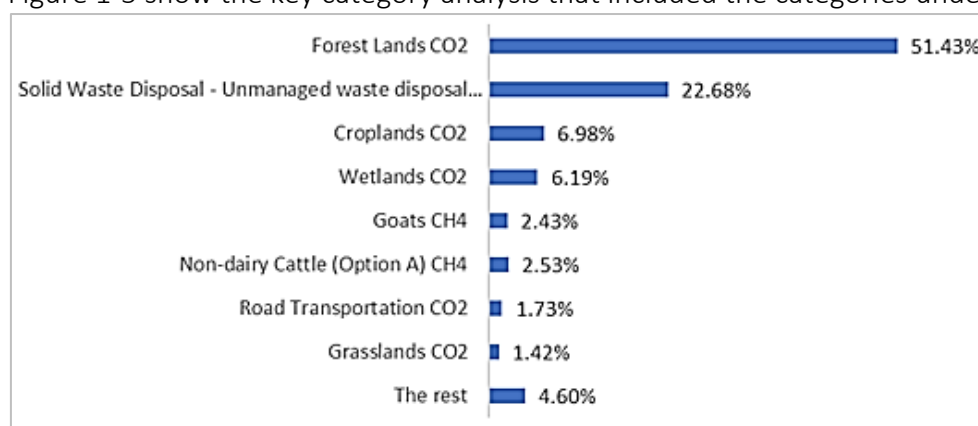


Figure 1-5: KCA GHG levels with FOLU (2022)

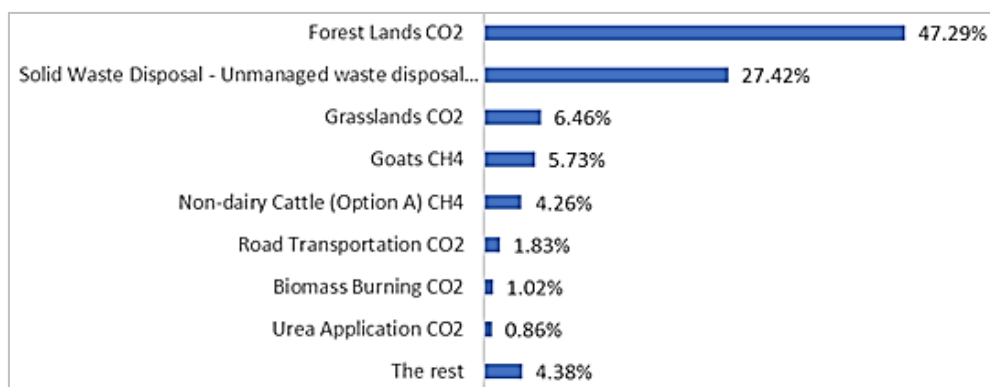


Figure 1-6: KCA GHG trend with FOLU

Table 1-6: Summary of Key Categories

CRT Code	Category Description	GHG	Base Year KCA	Current Year KCA	Trend KCA
4.A	Forest Lands	CO ₂	✓ (FOLU)	✓ (FOLU)	✓ (FOLU)
5.C	Incineration and Open Burning of Waste	CH ₄	✓	✓	✓
4.B	Croplands	CO ₂	✓ (FOLU)	✓ (FOLU)	
4.D	Wetlands	CO ₂	✓ (FOLU)	✓ (FOLU)	✓ (FOLU)
3.A.1.b	Non-dairy Cattle	CH ₄	✓	✓	✓
3.A.4	Goats	CH ₄	✓	✓	✓
5.A.2	Solid Waste Disposal – Unmanaged Sites	CH ₄	✓	✓	✓
1.A.3.b	Road Transportation	CO ₂	✓	✓	✓
3.H	Urea Application	CO ₂		✓	✓
2.A.1	Cement Production	CO ₂		✓	✓

Note: ✓ indicates the category was identified as a key category in the respective analysis. “FOLU” in brackets indicates categories relevant only in analyses inclusive of FOLU.

A complete summary of the key category analysis, including rankings and disaggregated data by gas and source category, is provided in **Error! Reference source not found.** of this Report.

1.6 Brief general description of QA/QC plan and implementation

Malawi has established a Quality Assurance/Quality Control (QA/QC) framework in accordance with the 2006 IPCC Guidelines for National Greenhouse Gas Inventories, as prescribed by Decision 18/CMA.1 under the Paris Agreement. The implementation of QA/QC is a central component of the national inventory system and is aimed at enhancing the accuracy, transparency, consistency, comparability, completeness, and reduction of uncertainty in greenhouse gas (GHG) estimates.

The QA/QC Plan is fully described in Annex IV: Quality Assurance and Quality Control (QA/QC) of this report and outlines the systematic procedures and responsibilities that guide inventory compilation and review. The QA/QC processes are designed to ensure that the inventory is both technically robust and well-documented, supporting the overall integrity of the reporting system.

Quality Control (QC)

Quality control comprises routine technical activities implemented during the preparation of the GHG inventory. Malawi’s Tier 1 QC procedures include:

- Verification of data entry accuracy through consistency checks,
- Cross-referencing activity data with source documentation,
- Reviewing calculations for emissions estimates against IPCC formulas and default values,
- Ensuring that source-specific emission factors are appropriately referenced and used,
- Documentation and archiving of datasets, calculation files, and QA/QC checklists.

QC activities are conducted internally by sector experts during each stage of inventory development and are repeated at the compilation stage by the National Inventory Coordination Team, housed at the Environmental Affairs Department (EAD).

Quality Assurance (QA)

Quality assurance consists of independent reviews and evaluations of the inventory by personnel not directly involved in its preparation. For Malawi, QA is implemented through:

- Peer review of draft reports and datasets by external consultants or local academic institutions,
- Validation workshops with stakeholders, including government departments, research bodies, and sectoral experts,
- Review sessions under the National Technical Committee on Climate Change (NTCCC),

- Regional and international technical support, including informal consultations with UNFCCC roster experts and IPCC regional capacity-building initiatives.

The QA process also includes the reception of feedback from past UNFCCC technical review teams during the BUR and NIR review cycles, and these inputs are systematically addressed in subsequent inventory improvements.

Inventory Improvements and Risk Management

Malawi's QA/QC plan identifies key risks to inventory integrity—such as data gaps, methodological uncertainties, and institutional coordination challenges—and outlines mitigation measures. These include:

- Prioritizing improvements in key categories as identified through key category and uncertainty analyses,
- Strengthening institutional arrangements for data sharing with agencies such as the National Statistical Office (NSO), Ministry of Agriculture, Malawi Energy Regulatory Authority (MERA), and local councils,
- Transitioning from Tier 1 to Tier 2 methodologies in priority subcategories, where feasible.

Public Engagement and Transparency

In keeping with Malawi's commitment to transparency, the National Inventory Report and its supporting documents, including the QA/QC framework, are publicly disseminated through the Environmental Affairs Department.

International Review and Continuous Improvement

Malawi's submission of the CRTs and NIR as part of its BTR1 will undergo technical expert review under the Paris Agreement Enhanced Transparency Framework. The findings from this review will guide future improvements to Malawi's QA/QC systems. The country continues to benefit from capacity-building support through regional initiatives led by the UNFCCC, IPCC, and supporting partners, and integrates lessons from peer countries into its QA/QC updates.

The detailed QA/QC plan is presented in: [Error! Reference source not found.](#)

1.7 General uncertainty assessment

Uncertainty analysis is a natural part of all estimations, such as greenhouse gas (GHG) inventories. The task is more complicated in Malawi due to dynamic national data system development, infrastructural constraints, and dependency on Tier 1 approaches. The 2006 IPCC Guidelines focus on managing uncertainty as a central component of building inventories, especially for developing nations.

Sources of uncertainty include variability in measurement instruments, assumptions in emissions modeling, and incomplete data coverage—especially in sectors with high biological or spatial variability such as agriculture, FOLU, and waste. Emissions from CO₂ combustion in the energy and

industrial sectors generally exhibit lower uncertainty due to the availability of structured fuel and production data. In contrast, estimates from agricultural soils, forest conversions, and unmanaged waste streams display higher uncertainty due to natural heterogeneity and methodological constraints.

In accordance with the Tier 1 approach under the IPCC Guidelines, Malawi has applied error propagation methods to quantify uncertainty. The national uncertainty in total GHG emissions for the latest inventory year (2022) is estimated at $\pm 0.545\%$, while the uncertainty in the trend across the full time series (1994–2022) is estimated at $\pm 2.241\%$. These estimates assume no correlation between uncertainty sources and reflect conservative bounds of national inventory reliability.

As documented in [Error! Reference source not found.](#), sectoral uncertainties vary significantly. For example, the energy sector exhibits strong confidence in CO₂ emissions due to reliable fuel import data, while emissions from CH₄ and N₂O in both the energy and waste sectors are marked by high uncertainties resulting from the use of default emission factors and inconsistent activity data. Similarly, the IPPU sector has moderate uncertainty, especially in clinker import estimates for cement production, while agriculture and FOLU face higher uncertainty due to data gaps, biological variability, and limitations in geospatial monitoring.

These uncertainty levels are largely consistent with those expected under IPCC guidelines for Tier 1-based inventories. Ongoing improvements in national data systems, institutional arrangements, and stakeholder coordination are expected to reduce uncertainty over future reporting cycles.

1.8 General assessment of completeness

The (MPGs under the Paris Agreement require national inventories to evaluate the completeness of reported GHG emissions sources and removals. Achieving full completeness is a challenge for all inventory systems, including Malawi's, due to the complexity and diversity of emission sources. Accurately estimating many sources demands significant human and financial resources, and limitations in data availability and methodological guidance can further complicate efforts. Although continuous improvements are made to enhance completeness, some minor omissions may occur. These omissions are documented for transparency and to improve future reporting cycles. This section assesses the completeness of Malawi's key activity datasets and the coverage of GHG emissions and removals sources within the national inventory system.

1.8.1 Information on completeness (including information on non-reported categories or any methodological or data gaps in the inventory)

Malawi's GHG inventory is nearly complete, with most major emission sources estimated according to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories (IPCC, 2006). However, some minor sources remain unestimated due to a lack of country-specific data or insufficient methodological guidance applicable to Malawi's context.

The National Statistical Office (NSO) plays a crucial role in providing national-level activity data, which is essential for many inventory calculations. Nonetheless, data gaps exist in certain sectors, particularly in informal and small-scale activities, where comprehensive data collection is challenging. In these cases, proxy data, regional estimates, or expert judgment are used to enhance completeness while ensuring consistency within the national inventory framework.

Unlike some developed countries that employ extensive facility-level reporting mechanisms, Malawi relies heavily on secondary data sources, sectoral surveys, and consultations with stakeholders. Therefore, completeness is achieved through a combination of national data sources, extrapolated estimates, and the best available scientific methodologies. Future improvements, such as expanding data collection efforts and collaborating with key industry stakeholders, will further strengthen the robustness of the inventory.

To ensure transparency, [Table 1-7](#) summarizes how completeness is achieved across various categories, particularly where direct measurement or facility-level reporting is not available.

Table 1-7: summary of completeness across various categories

Category	Sources for Completeness
1.A.1 Energy Industries	Activity data obtained from MERA, ESCOM, and key electricity generation reports. Emission factors applied using IPCC Tier 1 defaults. Fuel consumption statistics were confirmed through national energy balance data.
1.A.2 Manufacturing Industries and Construction	Energy use data derived from Ministry of Energy reports and economic activity data in the Annual Economic Report (AER). Verified through industrial energy surveys.
1.A.3.a Civil Aviation	Included under Domestic Aviation. Data on aviation fuel consumption sourced from Civil Aviation Department and MERA. Tier 1 methods applied.
1.A.3.b Road Transportation	Fuel consumption data from MERA disaggregated by transport sector. Adjusted for non-energy use. Local emission factors used where applicable.
1.A.3.c Railways	Emissions not estimated due to lack of active rail fuel use data; considered Not Estimated (NE) based on the absence of railway transport activity.
1.A.3.d Navigation	Domestic navigation included. Fuel data from MERA and port authorities. National method used for fuel allocation.
1.A.3.e Other Transportation	Not separately reported; included within 1.A.3.b or 1.A.3.d. Assumed negligible based on national transport profile.
1.A.4 Other Sectors	

1.A.4.a Commercial/Institutional	Estimated using aggregate energy consumption data split by economic sector in Malawi Government Annual Economic Reports. Tier 1 methods applied.
1.A.4.b Residential	Fuel consumption data (biomass and LPG) from IHS surveys and MERA. Emission factors derived from IPCC defaults.
1.A.4.c Agriculture/Forestry/Fishing	Energy use derived from disaggregated fuel statistics and agricultural surveys. Included within overall fuel consumption totals.
1.A.5 Non-Specified	Not Reported (NR); all fuel uses are disaggregated across known sectors.
1.B.1 Solid Fuels	Fugitive emissions from coal considered. Activity data sourced from mining reports; emission factors from IPCC defaults.
1.B.2 Oil and Natural Gas	Not Occurring (NO) as Malawi has no oil or natural gas extraction infrastructure.
1.C Carbon Dioxide Transport and Storage	Not Occurring (NO) due to lack of CO2 transport infrastructure.
2.A.1 Cement Production	Activity data from Lafarge Cement Malawi. CO2 emissions estimated using clinker production and IPCC default emission factors.
2.A.2 Lime Production	Production data collected from local lime producers and industry surveys. Tier 2 applied using carbonate content.
2.A.3 Limestone and Dolomite Use	Not Reported (NR); no national data currently available. Planned improvement noted.
2.A.4 Other Process Uses of Carbonates	Not Occurring (NO); no evidence of these activities in Malawi.
2.A.5 Glass Production	Not Occurring (NO); no glass manufacturing plants in operation.
2.A.6 Other Mineral Products	Not Reported (NR); no verified activity.
2.B.3 Adipic Acid Production	Not Occurring (NO); no domestic production.
2.D.3 Consumption of Halocarbons and SF6	Estimated using import statistics and servicing records. Applied Tier 1 methods.
2.F Product Uses as Substitutes for ODS	Data obtained from Environmental Affairs Department. Refrigerant data from customs, surveys, and maintenance records.
3.A.1 Enteric Fermentation	Estimated using livestock population data from Department of Animal Health. Tier 1 methodology applied.
3.A.2 Manure Management	Emissions from methane and nitrous oxide estimated using livestock data and IPCC parameters.
3.C Rice Cultivation	Emissions estimated using harvested area from MoAFS and IPCC default emission factors. Tier 1 used.

3.D Agricultural Soils	Activity data for fertilizer and lime use from MoAFS and FAOSTAT. Direct and indirect N ₂ O emissions estimated.
3.F Field Burning of Agricultural Residues	Data on area and type of crops burned obtained from MoAFS. Default burning fractions used.
4.A Forest Land	Activity data from National Forest Inventory and satellite land cover assessments. Emissions/removals modelled using IPCC Tier 1.
4.B Cropland	Land area and change data from MoAFS and Land Resources. Default soil carbon stock change factors applied.
4.C Grassland	Similar methodology and data sources as cropland. Grassland conversion data from MoNREM.
4. D	
4.E Settlements	Included in land use change data from national land use assessments. Estimated using Tier 1 defaults.
5.A Solid Waste Disposal	Emissions from solid waste disposal estimated using data from local councils and NSO. Waste generation modelled by population.
5.B Biological Treatment of Solid Waste	Not Reported (NR); no composting or anaerobic digestion infrastructure currently accounted.
5.C Incineration and Open Burning of Waste	Data from EAD and district councils. Includes open burning practices and Tier 1 factors applied.
5.D Wastewater Treatment and Discharge	Emissions from domestic wastewater estimated using population and per capita BOD load. Tier 1 applied.

1.8.2 Description of insignificant categories

In line with the flexibility outlined in paragraph 32 of the MPGs, the NIR designates certain emission sources as "NE" (not estimated) if they are considered insignificant. For Malawi, a source is classified as insignificant when its estimated emissions are less than 0.05% of the national total of greenhouse gas (GHG) emissions (excluding land use, land-use change, and forestry - FOLU) or if the emissions from the individual source do not exceed 500 kilotons of CO₂ equivalent (kt CO₂-e). Additionally, the cumulative emissions from all "NE" sources should remain below 0.1% of the national GHG total.

1.8.3 Total aggregate emissions considered insignificant

In accordance with paragraph 32 of the MPGs, Malawi has identified emission source categories that are quantitatively insignificant in terms of their contribution to the national greenhouse gas inventory. These sources individually contribute less than 0.05% of the total emissions in the inventory and are not influential in terms of trend or uncertainty. Their identification allows for a focused application of resources to more significant categories, in line with good inventory practice.

Based on the 2022 Key Category Analysis (Approach 1 – Level and Trend), the following categories are considered insignificant for the 2022 submission:

1.A.3.d – Domestic Navigation (CO₂, CH₄, N₂O)

Malawi's domestic navigation activity is minimal, consisting mainly of small passenger boats and canoes used on Lake Malawi and other inland water bodies. The associated fuel consumption is extremely low, resulting in estimated CO₂ emissions of just 1.1 kt CO₂ in 2022—equating to less than 0.005% of the national total. CH₄ and N₂O emissions were below measurable levels. Due to the very limited scale and impact, this source is considered insignificant.

1.A.1 – Fuel Combustion in Energy Industries (CH₄, N₂O)

While CO₂ emissions from fuel combustion in energy industries are included in the inventory, CH₄ and N₂O emissions from this source are negligible. In 2022, CH₄ and N₂O from this category contributed less than 0.0001% of total emissions. The dominance of hydroelectric power and limited fossil fuel use in centralized electricity generation explain the minimal levels observed.

1.A.2 – Manufacturing Industries and Construction (CH₄, N₂O)

Emissions of CO₂ from this source are included due to the presence of some fuel combustion in industrial facilities. However, CH₄ and N₂O emissions remain marginal. In 2022, CH₄ and N₂O emissions from this category were less than 1 kt CO₂-e combined, contributing less than 0.01% to total national emissions. The insignificant contribution is attributed to the reliance on biomass and low-emission fuels in these sectors.

3.B.4 – Rabbits (CH₄, N₂O)

Livestock population data indicates that rabbit rearing in Malawi is practiced at a very small scale. In 2022, CH₄ emissions from rabbits amounted to only 8.7 kt CO₂-e, and N₂O emissions were just 2.1 kt CO₂-e—both contributing far below 0.01% to the total inventory. As such, these sources are categorized as insignificant for the purposes of prioritization in inventory improvement.

3.B.2 – Sheep (CH₄, N₂O)

Sheep farming in Malawi is limited, and as a result, emissions from this category are minimal. In 2022, CH₄ emissions were 2.3 kt CO₂-e and N₂O emissions were less than 0.3 kt CO₂-e. These represent less than 0.01% of national emissions and are not material to the inventory's overall uncertainty or trend.

3.B.5 – Indirect N₂O Emissions from Manure Management

This category captures volatilization and leaching pathways from manure. Given Malawi's low-input livestock management systems and limited synthetic feed use, the indirect emissions are estimated at just 7.7 kt CO₂-e in 2022—less than 0.03% of the total. This contribution is minimal and not expected to influence trend analyses.

3.G – Liming

While liming is reported under the agricultural category, national data indicates that its application is limited, and the total emissions reported in 2022 were 14.3 kt CO₂-e, amounting to just 0.06% of total

GHG emissions. While this falls close to the reporting threshold, it remains a low priority category in terms of inventory improvement, given its limited national relevance and minor trend contribution.

3.H – Urea Application

Emissions from the application of urea in agricultural soils have grown slightly over time due to increased fertilizer use. However, in 2022, total emissions were approximately 138.8 kt CO₂-e, contributing 0.55% to total emissions. Although this is slightly above the traditional threshold for insignificance, the low trend impact and data limitations support its classification here, pending further development of agricultural emission data in future inventories.

1.B.1 – Fugitive Emissions from Solid Fuels

Malawi does not have large-scale coal processing operations. The limited coal use for industrial purposes results in fugitive CH₄ emissions of only 29.2 kt CO₂-e in 2022—well below 0.12% of total national emissions. This source is not considered influential to the inventory’s trend.

1.9 Metrics

Malawi has used the 100-year time-horizon global warming potential (GWP) values from the IPCC Fifth Assessment Report [Table 1-8](#), or 100-year time-horizon GWP values from a subsequent IPCC assessment report as agreed upon by the CMA to report the aggregate emissions and removals of GHGs, expressed in CO₂ eq.

Table 1-8:AR5 GWP values

Industrial designation or common name	Chemical formula	GWP AR5
Carbon dioxide	CO ₂	1
Methane	CH ₄	28
Nitrous oxide	N ₂ O	265

1.10 Summary of any flexibility applied

In line with the flexibility provisions outlined in paragraphs 46 and 47 of the MPGs, Malawi has implemented tailored measures to address data limitations and capacity constraints within its national greenhouse gas (GHG) inventory. Due to its current reliance on Tier 1 methodologies across all key sectors, these flexibility measures allow Malawi to ensure transparent, consistent, and comparable reporting. At the same time, they recognize the areas where country-specific data and higher-tier methods can be developed in the future.

provides a detailed summary of the flexibility measures that were utilised, including adjustments

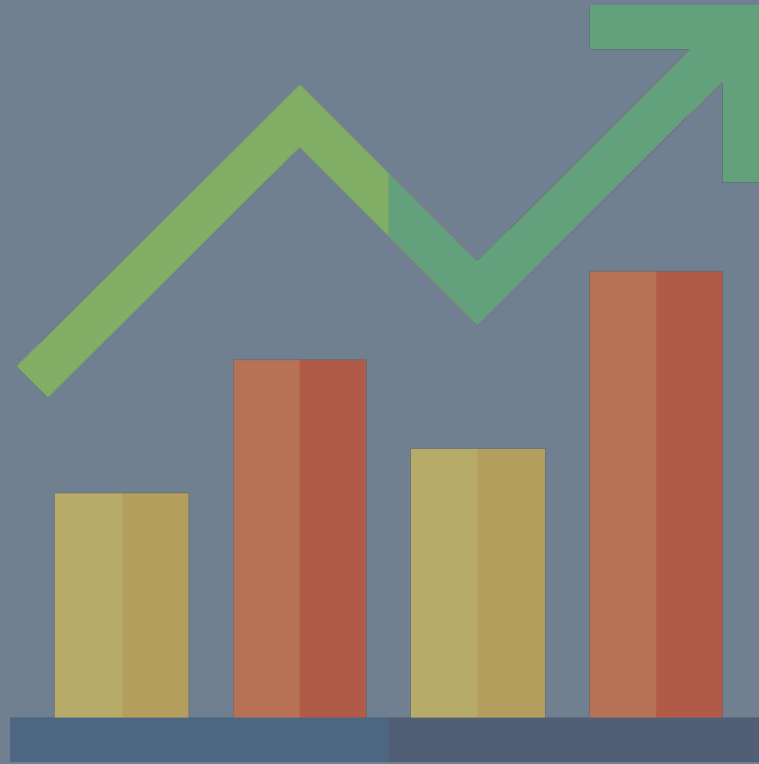
Flexibility provision	Reference paragraph	Status	Provision used
Key categories	25	No	Did not utilize the flexibility provision that allows for the identification of fewer key categories or the use of less complex methodologies for non-key categories. Instead, the inventory maintained a rigorous approach, considering and reporting all categories comprehensively in line with the full IPCC guidelines.
Uncertainty analysis	29	No	Despite the challenges related to data availability, every effort was made to collect the most accurate data possible, and uncertainty was assessed and reported wherever feasible, in line with the full requirements of the MPGS.
Completeness	32	No	The flexibility to omit estimation of more insignificant categories was not applied.
QA/ QC	34, 35	No	Flexibility not applied regarding the development of a QA/QC plan. A formal QA/QC plan has been reported.
Gases	48	Yes	Option to report fewer gases was used. Due to data limitations, Malawi reported only CO ₂ , CH ₄ and N ₂ O.
Time series	57, 58	Yes	Malawi made attempt to report all the time series from 1994 to 2022, but due to data challenge reported shorter series (2018 to 2022) for the FOLU sector. Extrapolation was applied where data was missing to complete, ensuring consistency and transparency in the inventory's temporal coverage.

made to emission factors, activity data, and methodological assumptions to better reflect national circumstances.

Table 1-9: Summary of Flexibility options evaluated by Malawi

Flexibility provision	Reference paragraph	Status	Provision used
Key categories	25	No	Did not utilize the flexibility provision that allows for the identification of fewer key categories or the use of less complex methodologies for non-key categories. Instead, the inventory maintained a rigorous approach, considering and reporting all categories comprehensively in line with the full IPCC guidelines.
Uncertainty analysis	29	No	Despite the challenges related to data availability, every effort was made to collect the most accurate data possible, and uncertainty was assessed and reported wherever feasible, in line with the full requirements of the MPGS.
Completeness	32	No	The flexibility to omit estimation of more insignificant categories was not applied.
QA/ QC	34, 35	No	Flexibility not applied regarding the development of a QA/QC plan. A formal QA/QC plan has been reported.
Gases	48	Yes	Option to report fewer gases was used. Due to data limitations, Malawi reported only CO ₂ , CH ₄ and N ₂ O.
Time series	57, 58	Yes	Malawi made attempt to report all the time series from 1994 to 2022, but due to data challenge reported shorter series (2018 to 2022) for the FOLU sector. Extrapolation was applied where data was missing to complete, ensuring consistency and transparency in the inventory's temporal coverage.

Chapter 2:



Trends in greenhouse
gas emissions and
removals

2.1 Description of emission and removal trends for aggregated GHG emissions and removals

Malawi's GHG emissions profile is shaped by the interaction of socio-economic dynamics, demographic change, and the structural evolution of its economy. With a population of 18.37 million (Figure 2-1) in 2022—up from 9,539,665 in 1994—the country has experienced a population increase of approximately 92.5% over the 28-year period, with an average annual growth rate of around 2.6%. This demographic expansion has exerted growing pressure on the environment, natural resources, and infrastructure, and has directly influenced consumption and production trends that drive greenhouse gas emissions.

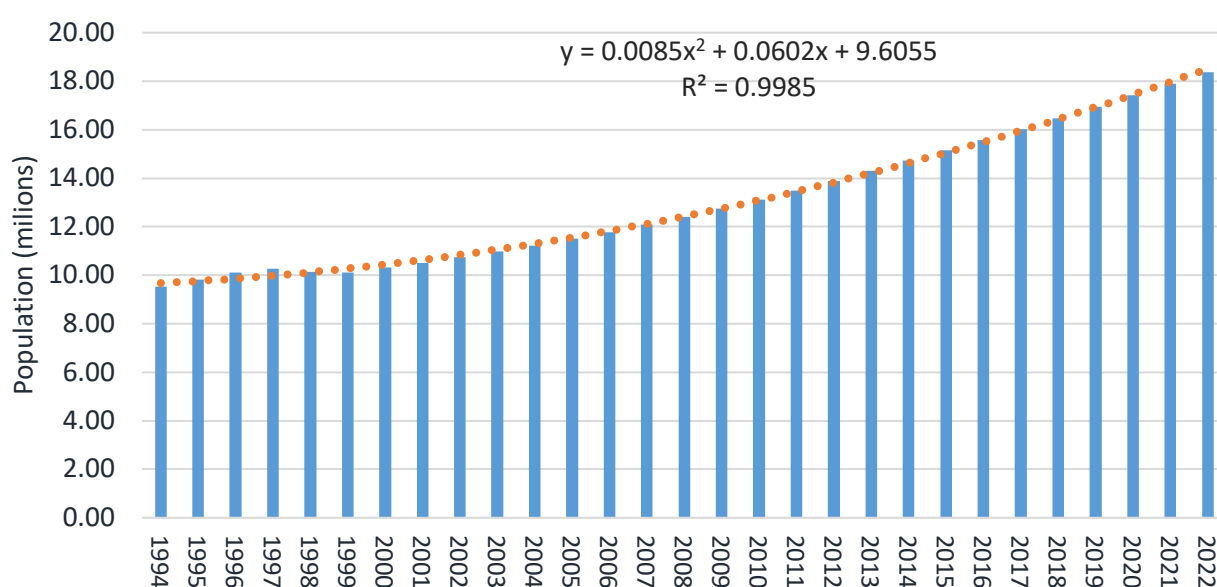


Figure 2-1: Total Population Growth, 1994–2022

Malawi remains predominantly rural, with 84% of its population residing in rural areas as of 2022. The rural population is heavily reliant on natural resources for subsistence and energy, particularly through biomass-based cooking fuels and smallholder agriculture. These rural dynamics have implications for emissions from land-use change, agriculture, and the continued dependence on traditional energy sources.

The economic backbone of the country is agriculture, which supports livelihoods, drives export earnings—particularly through crops like tobacco, tea, and sugar—and supplies staple food crops such as maize and rice for domestic consumption. Growth in agriculture has led to increased emissions from fertilizer application, land clearance, and methane emissions from rice paddies and livestock.

Malawi's total GHG emissions have grown steadily from 1994 to 2022, in line with the population trajectory and the expansion of key economic activities. In 1994, the country's emissions were estimated at 8,604.38 Gg CO₂-e. By 2022, this figure had increased to 25,261.32 Gg CO₂-e, representing a 193.6% increase over the 28-year period. The consistent upward trajectory reflects rising energy consumption, increased transport activities, agricultural intensification, and urban expansion. [Figure 2-2](#) presents a time series of total emissions measured in gigagrams of CO₂ equivalent (Gg CO₂-e) from 1994 to 2022.

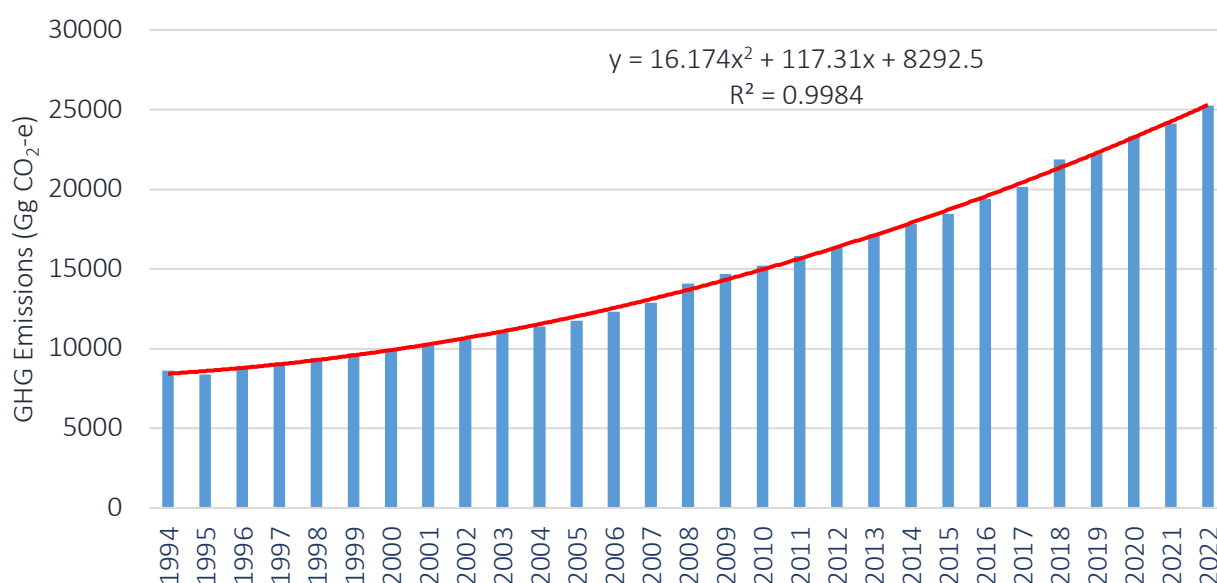


Figure 2-2: GHG Emissions Trend (Gg CO₂-e), 1994–2022

The cumulative emissions over the 1994–2022 period is estimated at approximately 429,874.02 Gg CO₂-e, averaging 15,352.64 Gg CO₂-e per year. Analysis of the five-year period from 2018 to 2022 reveals a particularly pronounced increase in emissions, rising from 21,861.91 Gg CO₂-e in 2018 to 25,261.32 Gg CO₂-e in 2022. This represents a 15.5% increase within a short timeframe, consistent with the broader trends of accelerated development, urbanization, and population growth.

Parallel to the growth in total emissions, per capita emissions have also exhibited an upward trend. In 1994, per capita GHG emissions stood at 0.00090 Gg CO₂-e per person ([Figure 2-3](#)). By 2022, this figure had increased to 0.00138 Gg CO₂-e per person, representing a 53% increase over the period. The highest per capita emissions level was recorded in 2020 at 0.00133 Gg CO₂-e per person, followed by a continued increase in subsequent years, in part due to emissions from fossil-fuel-based energy generation during climate-related hydropower disruptions.

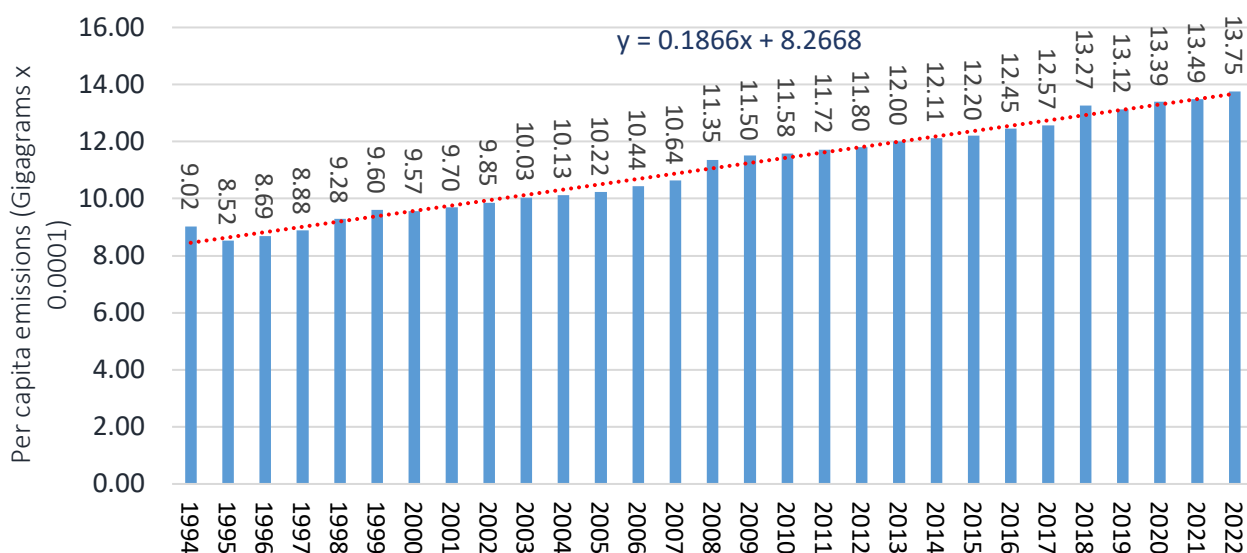


Figure 2-3: Per Capita GHG Emissions, 1994–2022

This rising per capita emissions trend underscores the compounding effect of population growth and economic development on environmental outcomes. Although Malawi's per capita emissions remain low in global terms, the persistent upward trend signals a shift in production and consumption patterns that are increasingly carbon-intensive.

The interaction between demographic trends and emission patterns provides critical context for understanding the drivers of GHG emissions in Malawi. The combination of high population growth, urban expansion, increasing economic activity, and a reliance on carbon-intensive technologies continues to define the country's emissions trajectory.

The emission and removal patterns outlined in this section provide the foundation for the sector-specific discussions in subsequent chapters of this report.

2.2 Description of emission and removal trends by sector and by gas

The greenhouse gas (GHG) emissions trends by sector—Energy, Industrial Processes and Product Use (IPPU), Agriculture, Forestry and Other Land Use (AFOLU), and Waste—reflect the structure of Malawi's economy and the underlying drivers of emissions over the period 1994 to 2022.

Figure 2-4 illustrates the relative contribution of each sector to national net emissions. The Waste sector emerged as the largest contributor, followed by AFOLU, Energy, and IPPU. Unlike some nations where the land use and forestry sector acts as a carbon sink, in Malawi, the AFOLU category remains a net source of emissions due to sustained land clearing, agricultural expansion, and biomass harvesting.

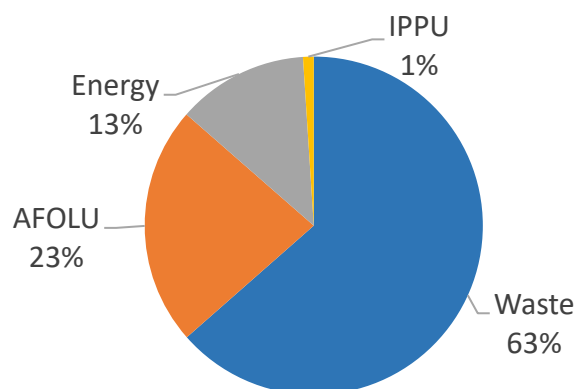


Figure 2-4: Share of National Emissions by Sector (%)

Energy Sector

Emissions from the Energy sector totaled 34,575.20 Gg CO₂-e over the period, accounting for 12.55% of national emissions. These arise from fuel combustion in electricity generation, manufacturing, transport, and residential sectors, as well as fugitive emissions from coal handling. A modest long-term growth trend has been observed, influenced by:

- Expansion in road transport, which dominates fuel consumption.
- Intermittent diesel power generation, especially during hydro outages caused by cyclones and flooding (e.g., 2015, 2019, and 2022).
- Heavy reliance on biomass fuels in households, although these are often not fully captured in CO₂ totals due to being considered carbon-neutral under IPCC guidance.

IPPU Sector

The IPPU sector contributed 2,842.30 Gg CO₂-e, with emissions primarily from cement (2,219.62 Gg) and lime production (622.65 Gg). This reflects activity in Malawi's growing construction and infrastructure sectors. Emissions fluctuated depending on industrial output and cement demand, which is highly sensitive to macroeconomic variables such as currency stability, public infrastructure investment, and fuel imports.

AFOLU Sectors

The Agriculture, Forestry and Other Land Uses sector contributed 58,080.83 Gg CO₂-e of methane and 10,637.90 Gg CO₂-e of nitrous oxide over the time series, reflecting both livestock and soil-related emissions. Agriculture remains the backbone of Malawi's economy, and this sector's emissions are driven by:

- Enteric fermentation and manure management from cattle and goats.
- Nitrogen fertilization in crop production (urea and liming).
- Rice cultivation, which remains a significant CH₄ source due to flooded irrigation practices.

Despite the presence of reforestation and afforestation projects, these have not fully offset emissions from deforestation and shifting cultivation, keeping the net balance positive.

Waste Sector

Emissions from the Waste sector reached 267,099.14 Gg CO₂-e in methane and 24,917.16 Gg CO₂-e in nitrous oxide over the period, making it the largest source of national GHG emissions. Key contributors include:

- Open burning of waste in urban and peri-urban areas, which alone accounted for over 215,995 Gg CO₂-e.
- Landfills and unregulated dumpsites, which generate large volumes of methane from anaerobic decomposition.
- Wastewater treatment, which contributes to both CH₄ and N₂O emissions.

Although solid waste regulations have improved slightly in cities such as Lilongwe and Blantyre, rural and informal settlements continue to rely on open burning and unmanaged disposal.

The trends (Figure 2-5) in emissions from each sector are further discussed in Chapters 3 to 7.

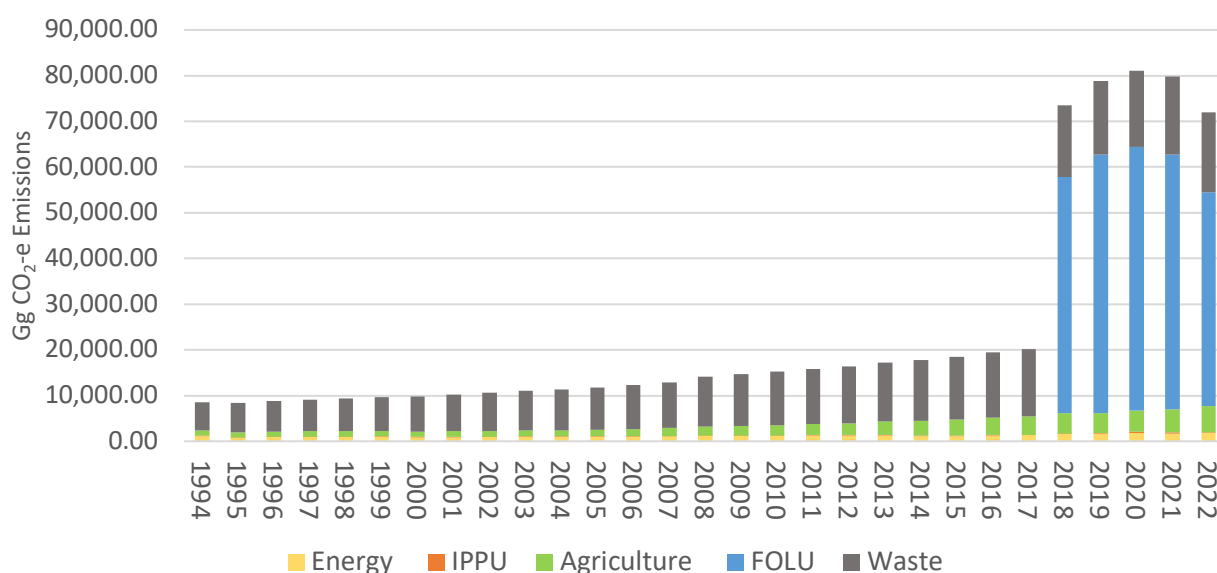


Figure 2-5: Total National Emissions trend for every sector

2.2.1 Net Greenhouse Gas Emissions by Sector (Kt CO₂-e)

The following table (Table 2-1) provides a disaggregated summary of emissions from 1994 to 2022, including breakdowns for each National Communication (NC) period. The data are consistent with the updated Tier 1 methodology applied throughout this inventory cycle.

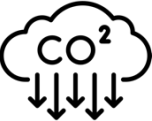
Table 2-1: Net Greenhouse Gas Emissions by Sector

Categories	1994-22	2018-22	(2001-17)	(1995-00)	1994
Total National Emissions and Removals	429,874.02	116,777.04	249,231.41	55,261.19	8,604.38
1 - Energy	34,575.21	8,690.44	19,111.37	5,594.89	1,178.51
1.A - Fuel Combustion Activities	33,841.92	8,562.63	18,658.47	5,458.55	1,162.27
1.A.1 - Energy Industries	245.97	171.8	52.26	18.78	3.13
1.A.2 - Manufacturing Industries and Construction	5,643.77	1,233.63	3,308.80	968.16	133.18
1.A.3 - Transport	19,955.87	5,877.72	10,696.40	2,761.98	619.77
1.A.4 - Other Sectors	7,996.45	1,279.80	4,600.80	1,709.66	406.19
1.B - Fugitive emissions from fuels	733.3	127.82	452.91	136.33	16.24
1.B.1 - Solid Fuels	733.3	127.82	452.91	136.33	16.24
2 - Industrial Processes and Product Use	2,842.31	816.19	1729.44	247.97	48.71
2.A - Mineral Industry	2,842.31	816.19	1729.44	247.97	48.71
2.A.1 - Cement production	2,219.61	619.81	1,312.92	240.26	46.62
2.A.2 - Lime production	622.62	196.37	416.47	7.69	2.09
3 - Agriculture, Forestry, and Other Land Use	70,928.18	24,214.50	38,562.47	7,047.49	1,103.72
3.A - Livestock	61,354.51	21,118.63	32,960.59	6,269.81	1,005.48
3.A.1 - Enteric Fermentation	51,114.27	16,958.63	27,395.25	5,825.25	935.14
3.A.2 - Manure Management	10,240.29	4,160.03	5,565.35	444.56	70.35
3.C - Aggregate sources and non-CO2 emissions sources on land	9,574.25	3,096.18	5,602.15	777.95	97.97
3.C.2 - Liming	323.50	77.28	196.58	43.34	6.30
3.C.3 - Urea application	1,885.98	493.8	1,199.53	170.27	22.38
3.C.4 - Direct N2O Emissions from managed soils	3189.08	1326.34	1750.11	97.26	15.37
3.C.5 - Indirect N2O Emissions from managed soils	1355.83	563.67	744.17	41.36	6.63
3.C.6 - Indirect N2O Emissions from manure management	101.55	32.08	54.63	12.72	2.12
3.C.7 - Rice cultivation	2,718.28	602.79	1,657.01	413.04	45.44
4 - Waste	321,528.08	83,055.87	189,827.90	42,370.86	6,273.45
4.A - Solid Waste Disposal	50,585.81	16,280.46	31,493.89	2,811.46	0.00
4.C - Incineration and Open Burning of Waste	270,078.27	66,471.36	157,866.57	39,478.11	6,262.23
4.D - Wastewater Treatment and Discharge	863.41	303.80	467.39	81.02	11.20
International Bunkers	518.42	25.76	347.69	101.79	43.18
1.A.3.a.i - International Aviation (International Bunkers)	518.42	25.76	347.69	101.79	43.18

2.2.2 Trends in Emissions and Removals Based on Annual Growth Rate

Malawi adopted the Compound Annual Growth Rate (CAGR) approach to assess the evolution of national greenhouse gas (GHG) emissions over different inventory periods. This method offers a consistent and comparative annualized rate of change, particularly useful for tracking long-term trends. The analysis covers all GHG emissions and removals from 1994 to 2022, as presented in [Error! Not a valid bookmark self-reference..](#)

Table 2-2: Annual Growth Rate for Total National Emissions and Removals (1994–2022)

Categories	Annual Growth Rate over Different periods				
	Overall (1994-2022)	(2018-22)	(2001-17)	(1995-2000)	(1994)
 Total National Emissions	3.92%	3.68%	10.22%	1.65%	--
	↑ +	↑ +	↑ +	↑ +	
 Energy	1.54%	2.67%	6.39%	0.93%	--
	↑ +	↑ +	↑ +	↑ +	
 IPPU	1.54%	2.62%	6.44%	0.77%	--
	↑ +	↑ +	↑ +	↑ +	
 Agriculture, Forestry, and Other Land Use	6.05%	6.22%	18.46%	0.66%	--
	↑ +	↑ +	↑ +	↑ +	
 Waste	3.74%	2.93%	8.96%	1.91%	--
	↑ +	↑ +	↑ +	↑ +	

Note: Icons in this figure are sourced from Freepik, and Uniconlabs on flaticon.com.

The 3.92% overall growth rate in total national emissions (including removals) demonstrates a consistent increase in emissions from 1994 to 2022. However, the growth dynamics vary by sector and reporting period:

- **Energy (CRT 1):** Despite remaining one of the most stable sectors in terms of emissions, the energy sector registered an average rate of 1.54% from 1994 to 2022. Recent increases are driven by transport and manufacturing industries, with slight moderation due to growth in renewables and energy efficiency investments.
- **Industrial Processes and Product Use (CRT 2):** IPPU emissions grew steadily at 1.54% annually, largely from cement and lime production. The expansion of construction and industrial activity sustained this growth, particularly between 2001 and 2017 (6.44%).
- **Agriculture (CRT 3):** This sector exhibited the fastest long-term growth rate of 6.05%, reflecting intensifying agricultural activities such as fertilizer use, rice irrigation, and livestock production. The sector's 18.46% growth rate during 2001–2017 was driven by rapid land conversion and growing demand for food and cash crops.
- **Waste (CRT 4):** The waste sector's growth has moderated in recent years, declining from 8.96% during 2001–2017 to 2.93% during 2018–2022, although emissions from open burning and landfills remain significant.

2.2.3 Observations on Socio-economic Influences

The emission patterns reflect Malawi's socio-economic trajectory—an economy rooted in agriculture but transitioning toward agro-processing and service-based industries (GoM, 2023). Key national trends influencing GHG emissions include:

- Agricultural expansion and intensification, including greater reliance on nitrogen-based fertilizers and irrigation systems, contributing to rising N₂O and CH₄ emissions.
- Deforestation and land-use change in response to population growth and fuelwood demand.
- Urbanization and increased waste generation, exacerbated by limited waste treatment infrastructure.
- Infrastructure constraints, such as limited electricity supply, which increase reliance on biomass and diesel generators.
- Cyclonic disturbances, such as Cyclones Ana and Freddy, led to temporary disruptions in hydropower generation, increasing reliance on diesel-based energy sources, particularly between 2018 and 2022.

The Annual Economic Reports confirms that these factors, coupled with foreign exchange constraints and logistical bottlenecks, have shaped sector-specific emission pathways.

2.2.4 Description of emission and removal trends by gas

Greenhouse gases (GHGs) absorb infrared radiation and contribute to atmospheric warming, with varying degrees of influence depending on their Global Warming Potentials (GWPs). Malawi's national GHG inventory tracks emissions of three key gases: carbon dioxide (CO₂), methane (CH₄), and nitrous

oxide (N₂O). Each gas contributes differently to total emissions, largely depending on the source sector.

The following section presents a disaggregated analysis of national emissions by gas type from 1994 to 2022. These trends provide insights into the evolving structure of the Malawian economy, emission drivers, and potential areas for targeted mitigation. Figure 2-6 below presents the proportional share of each gas in total emissions (excluding emissions and removals from the Forestry and other Land Use (FOLU) sector).

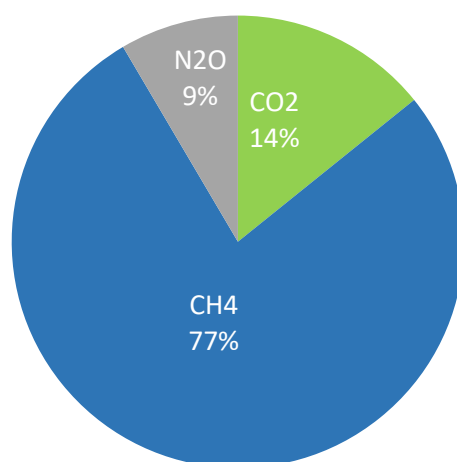


Figure 2-6: Share of National Emissions (Excluding FOLU) by Gas

Error! Reference source not found. provides historical data on total net emissions (in Gg CO₂-e) by gas type for the reporting period. These values are categorized by the major National Communication periods to reflect progress over time.

Table 2-3: Table: Net Emissions by Gas (Gg CO₂-e)

Categories	Overall (1994–22)	2018–22	2001–17	1995–00	1994
CO₂					
Total National Emissions	61,101.36	15,782.40	34,832.75	8,817.09	1,669.11
1 - Energy	26,537.79	7,185.91	14,414.95	4,031.17	905.76
2 - IPPU	2,842.30	816.19	1,729.43	247.98	48.71
3 - Agriculture	2,209.48	571.08	1,396.12	213.60	28.68
CH₄					
Total National Emissions	332,330.12	90,175.48	193,514.80	42,357.00	6,282.84
1 - Energy	7,150.19	1,320.62	4,191.07	1,397.03	241.48
3 - Agriculture	58,080.83	19,216.34	31,317.55	6,521.45	1,025.48
4 - Waste	267,099.14	69,638.49	158,006.21	34,438.54	5,015.89
N₂O					
Total National Emissions	36,442.54	10,819.16	20,883.86	4,087.10	652.43

1 - Energy	887.22	183.91	505.36	166.69	31.27
3 - Agriculture	10,637.90	4,427.09	5,848.82	312.44	49.56
4 - Waste	24,917.16	6,208.16	14,529.42	3,607.98	571.61

The trends in emissions by individual gas type are elaborated below.

Carbon Dioxide (CO₂)

Carbon dioxide emissions in Malawi are primarily associated with fossil fuel combustion in energy industries, road transportation, and industrial processes. Between 1994 and 2022, CO₂ emissions exhibited an overall increasing trend, reflecting growing energy demand, vehicle fleet expansion, and industrial activities. This has been indicated on [Figure 2-7](#).

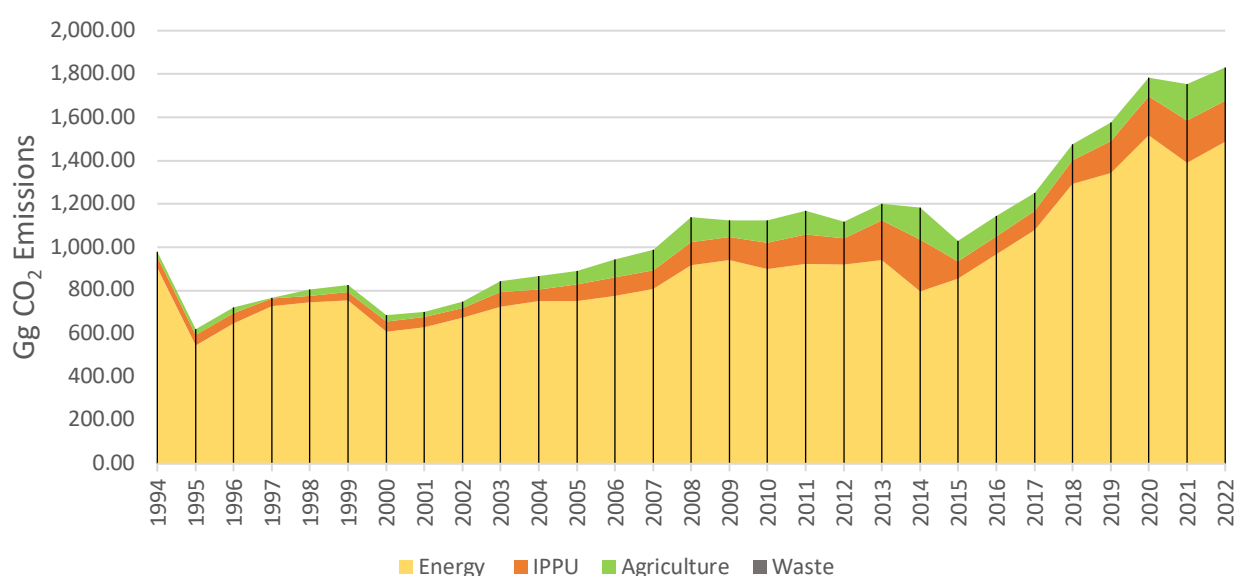


Figure 2-7: Trend of Carbon Dioxide (CO₂) Emissions, 1994–2022

In 2018, CO₂ emissions from the Energy sector accounted for approximately 82% of all national CO₂ emissions excluding FOLU. This share slightly increased to 83% by 2022, indicating continued reliance on fossil fuels and limited uptake of low-carbon alternatives. Emissions from the Industrial Processes and Product Use (IPPU) sector also increased significantly, more than doubling from 107.5 Gg in 2018 to 188.3 Gg in 2022.

Methane (CH₄)

Methane remains the dominant greenhouse gas in Malawi's national inventory, largely driven by agricultural sources such as enteric fermentation, rice cultivation, and manure management, as well as solid waste disposal. This has been indicated on [Figure 2-8](#).

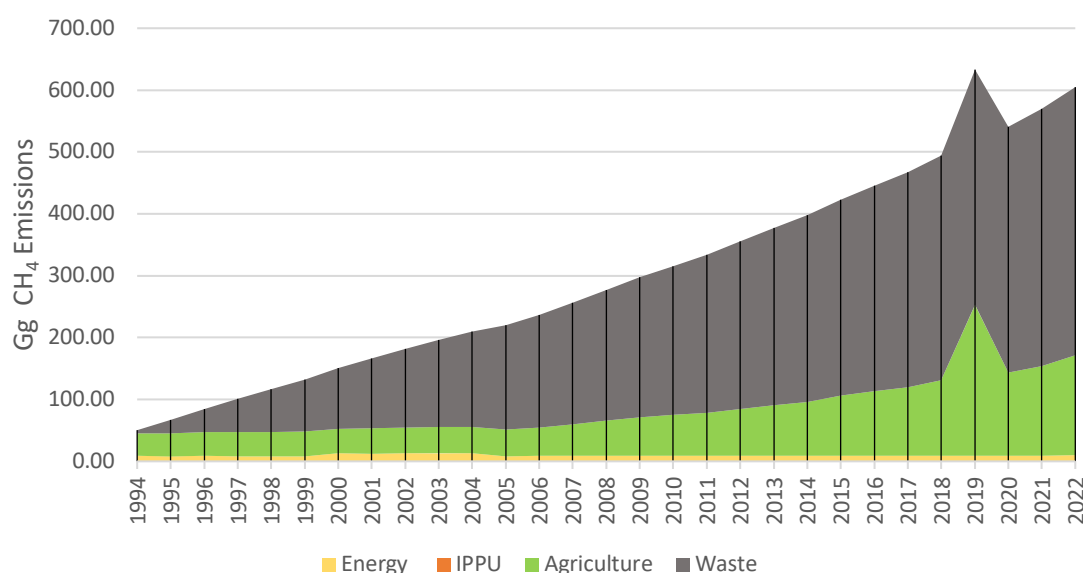


Figure 2-8: Trend of Methane (CH₄) Emissions, 1994–2022

From 1994 to 2022, CH₄ emissions rose steadily, nearly doubling from 50.0 Gg CO₂-e to over 604.4 Gg CO₂-e. The most pronounced growth occurred after 2015, linked to increased livestock populations, rice farming, and urban waste generation. In 2022, agriculture and waste combined accounted for over 160 Gg of CH₄ emissions, representing more than 84% of total CH₄ emissions, underscoring the need for interventions in these sectors.

Nitrous Oxide (N₂O)

Nitrous oxide emissions, though relatively small in volume compared to CO₂ and CH₄, have a high GWP ([Metrics](#)) and thus contribute significantly to Malawi's total emissions in CO₂-equivalent terms. Key sources include agricultural soils, manure management, and wastewater treatment. Trends in N₂O are shown in Figure 29.

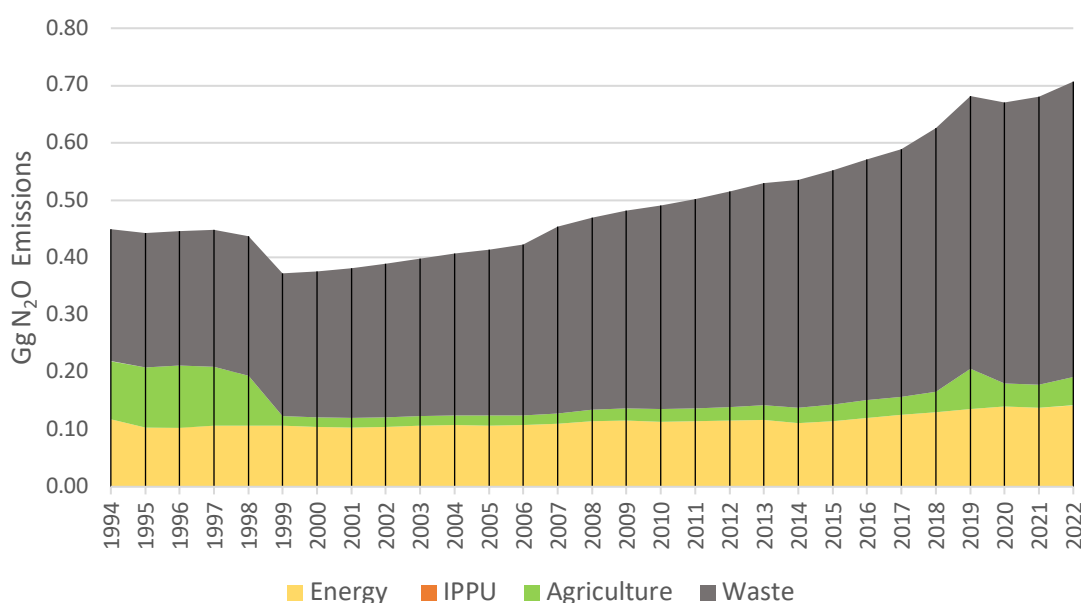


Figure 2-9: Trend of Nitrous Oxide (N₂O) Emissions, 1994–2022

Over the inventory period, N₂O emissions increased gradually from 0.449 Gg in 1994 to 0.700 Gg in 2022. Most of these emissions originated from the agriculture sector, particularly due to the application of nitrogen-based fertilizers and crop residue management.

2.2.5 Comparative Analysis and Sectoral Contributions

The combined analysis of 2018 and 2022 emissions shows that methane remains the leading contributor to Malawi's total GHG emissions (excluding FOLU), largely due to agricultural and waste-related activities. In contrast, CO₂ emissions dominate in the energy and industrial sectors, while N₂O emissions remain concentrated in agriculture.

Table 2-4: GHG Emissions and Contribution by Gas and Sector (Gg, 2018 vs 2022)

Sector		2018 Emissions				2022 GHG Emissions			
		CO ₂	CH ₄	N ₂ O	CO ₂ e	CO ₂	CH ₄	N ₂ O	CO ₂ e
Energy	Gg	1,335.35	9.22	0.13	1,629.07	1502.0892	9.65843	0.142	1,810.16
No FOLU	%	81.97%	15.85%	2.18%	7.45%	82.98%	14.94%	2.08%	7.17%
With FOLU					2.22%				2.52%
IPPU	Gg	107.54	0.00	0.00	107.54	188.31578	0	0	188.32
No FOLU	%	100.00%	0.00%	0.00%	0.49%	100.00%	0.00%	0.00%	0.75%
With FOLU					0.15%				0.26%
Agriculture	Gg	75.74	121.77	3.79	4,489.38	153.02	162.14	3.86	5,714.96

No FOLU	%	1.69%	75.95%	22.37%	20.54%		2.68%	79.44%	17.88%	22.62%
With FOLU					6.11%					7.94%
FOLU	Gg	51,631.71	0.00	0.00	51,631.71		46,705.41			46,697.30
	%				70.25%					64.50%
Waste	Gg	1,381.74	467.22	4.42	15,635.91		1,454.29	527.89	4.95	17,547.87
No FOLU	%	8.84%	83.67%	7.50%	71.52%		8.29%	84.23%	7.48%	69.47%
With FOLU					21.28%					24.78%

These trends indicate Malawi’s unique emissions profile—highly agricultural, with emerging emissions growth in transport and energy. The data calls for a sector-specific mitigation approaches.

Chapter 3:



Energy

3.1 Overview of the Energy Sector

The energy sector is a critical pillar of Malawi's socio-economic development. It drives industrial production, powers essential services, supports livelihoods, and underpins efforts to enhance climate resilience and meet national mitigation commitments under the Paris Agreement. In alignment with the Intergovernmental Panel on Climate Change (IPCC) 2006 Guidelines and the MPGs under the Enhanced Transparency Framework, this chapter provides a comprehensive overview of the energy landscape, consumption patterns, and associated GHG emissions.

Energy Supply and Consumption Profile

Malawi's energy supply is heavily dominated by traditional biomass, reflecting the country's continued dependence on wood-based fuels for cooking and heating, especially in rural communities. Figure 3-1 shows Malawi's energy mix. In 2022, biomass fuels—comprising fuelwood, charcoal, and crop residues—accounted for 87.6% of total energy consumption. This is followed by petroleum products (9.4%), electricity (2.4%), and coal (0.6%) (Government of Malawi, 2023).

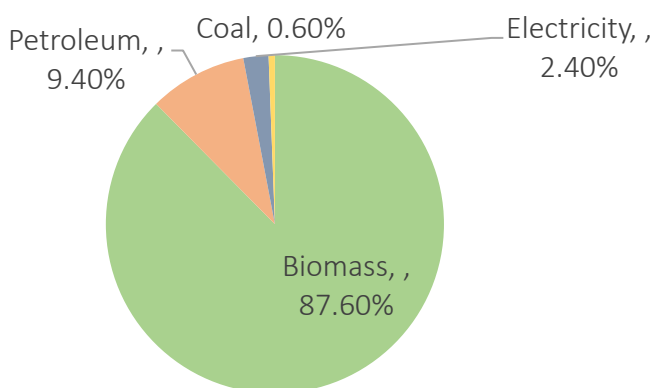


Figure 3-1: Malawi's Energy Supply Composition

The residential sector remains the largest energy consumer, primarily through the use of firewood and charcoal for cooking. Meanwhile, the transport sector dominates fossil fuel consumption, largely dependent on diesel and petrol. The manufacturing and construction sectors are notable users of coal and biomass for industrial thermal energy, particularly in cement, tobacco, and sugar industries.

The report on electricity supply and demand by the Ministry of Energy showed that electricity generation capacity increased from 475.4 MW to 533.4MW. The change net increase was attributed to:

- Hydro power generation increased from 358.7 MW to 398.9 MW
- Thermal power from diesel generators reduced from 115.4 MW to 51.4 MW due to end of contract with Aggreko and increase in solar PV from 1.4 MW to 83.1 MW by 2022 (Figure 3-2).

Access to Modern Energy Services

Despite ongoing investments in electricity infrastructure, access to modern energy remains low. Nationally, only 18% of the population had access to electricity as of 2022, with urban access at 42% and rural access below 10% (World Bank, 2023). The national grid is primarily powered by hydropower, which constitutes 75% of electricity generation (Table 3-1). However, hydropower remains vulnerable to climate-induced variability, with recurring droughts and declining water levels disrupting generation capacity (MERA, 2022). Figure 3-2 shows changes in the electricity generation by sources between 2018 and 2022.

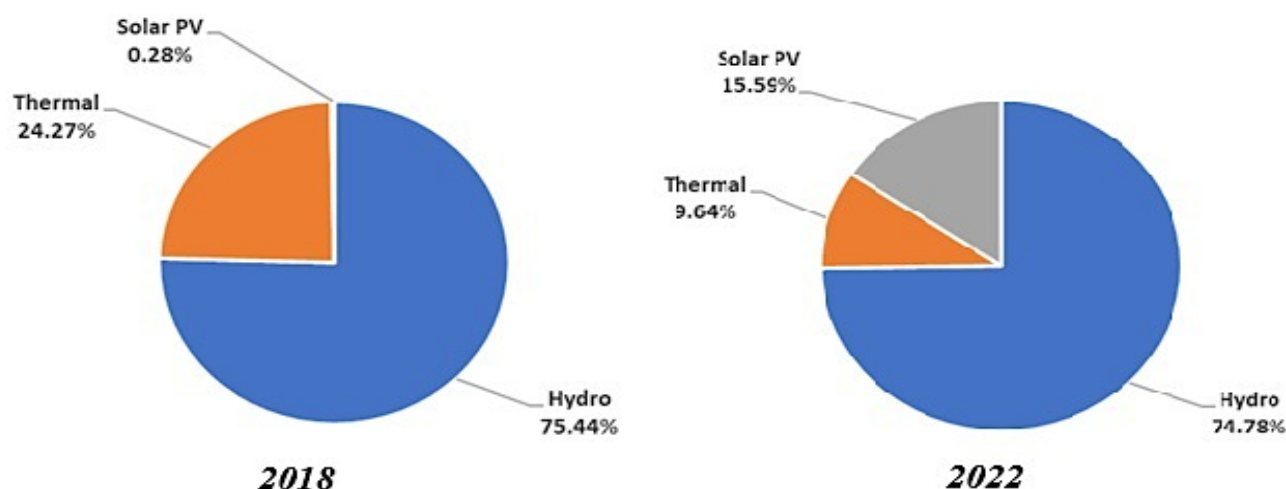


Figure 3-2: Electricity Generation by Source

Source: Ministry of Energy, 2022

To address access challenges, the Government of Malawi, through the Ministry of Energy, has initiated various rural electrification and renewable energy programs, including the Malawi Rural Electrification Programme (MAREP) and off-grid solar initiatives.

Table 3-1: Electricity generation by fuel (GWh)

Years	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
Hydro	1877.1	1864.5	1969.5	1952.3	1850.6	1757.1	1696.9	1758.4	1870.6	2197.1	1523.5
Diesel	0.0	0.0	0.0	0.0	5.6	14.2	170.5	207.3	159.6	42.0	62.6
Solar	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.1	0.1	39.7	165.4
Bagasse	148.2	106.0	106.3	140.1	133.4	130.7	98.0	71.8	108.9	0.0	0.0
Petrol	0	0	0	0	0	1.8	1.8	1.8	1.8	0.0	0.0
Other biomass	0	0	0	0	0	0.1	0.1	0.1	0.1	0.0	0.0
Total	2025.3	1970.5	2075.8	2092.4	1989.6	1904.0	1967.4	2039.5	2141.1	2278.8	1751.5

Source: Government of Malawi, 2023

GHG Emissions Energy Sector in

The energy sector is a major contributor to Malawi's total GHG emissions, primarily through fuel combustion in transport, industry, and households. Figure 3-3 is a Flowchart indicating categories and sub-categories, colour-coded to show inventory coverage for this report.

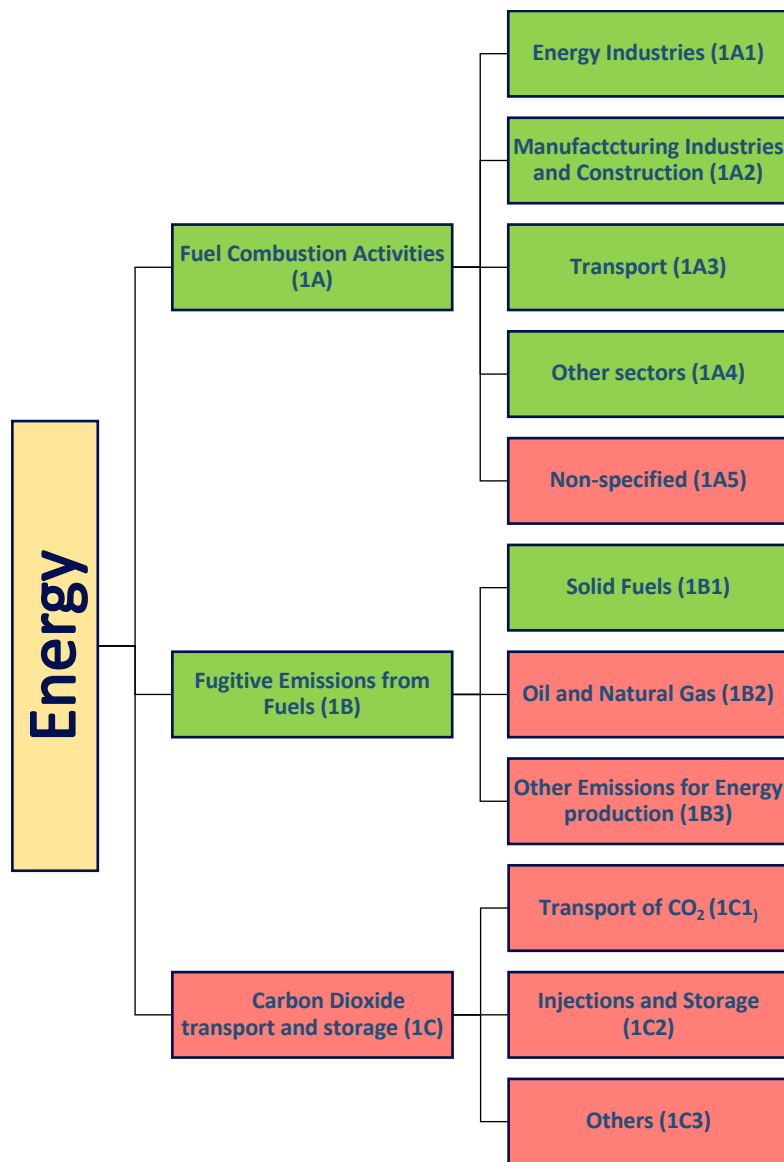


Figure 3-3: Activities and sources in the energy sector



Source: (IPCC, 2006) Guidelines, Volume 2

Transport is the largest fossil fuel consumer, and thus the largest CO₂ emitter in the energy sector. In 2022, Malawi imported over 370 million litres of diesel and 230 million litres of petrol, mainly for use

in passenger and freight vehicles (MRA Import Data, 2022). Meanwhile, emissions from the residential sector arise mainly from the incomplete combustion of firewood and charcoal, resulting in substantial CH₄ and N₂O emissions.

Emission Trends in the Energy Sector (1994–2022)

Greenhouse gas emissions from fuel combustion have exhibited a consistent upward trend over the period 1994–2022 (Figure 3-4). Total emissions from the energy sector increased from approximately 1,178.5 Gg CO₂e in 1994 to 1,796.5 Gg CO₂e in 2022, marking a 52% rise over the inventory period. The growth in emissions correlates with increased energy demand from the transport and manufacturing sectors, population growth, and urbanization.

Table 3-2: the total annual GHG emissions in the energy sector 1994 to 2022 by CO₂ eq

Years	1.A.1 - Energy Industries	1.A.2 - Manufacturing Industries and Construction	1.A.3 - Transport	1.A.4 - Other Sectors	1.B.1 - Solid Fuels	1.A.3.a.i - International Aviation (International Bunkers)
1994	3.13	133.06	619.85	406.19	16.24	133.18
2000	3.13	155.40	582.87	231.34	21.06	155.43
2010	3.13	247.87	633.42	265.89	37.14	247.85
2017	1.50	177.51	912.10	251.73	21.21	177.50
2018	3.81	239.11	1,067.91	253.10	23.33	239.21
2019	55.47	239.10	1,120.63	252.81	25.67	239.18
2020	42.71	268.71	1,266.98	255.46	25.74	268.74
2021	11.23	228.89	1,174.95	258.88	23.92	229.01
2022	16.75	257.47	1,247.28	259.49	29.16	257.49

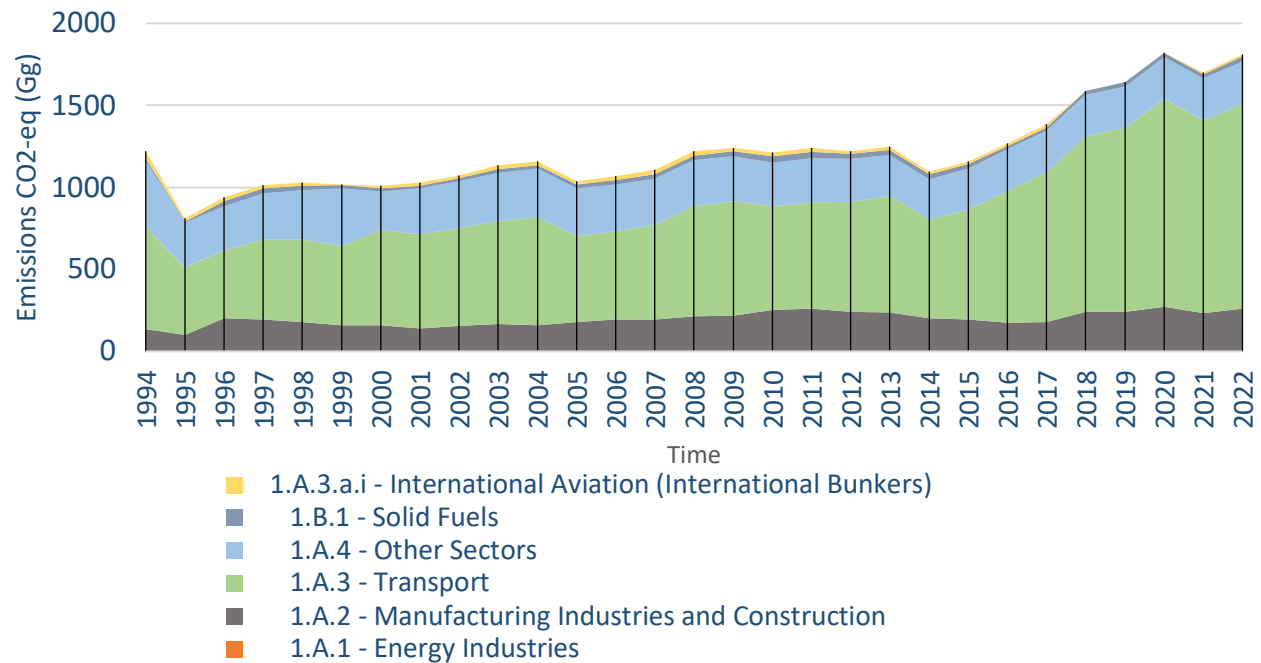


Figure 3-4: Trend of Net GHG Emissions from different sources

Key Observations

The national trend in GHG emissions from the energy sector continued to increase between 2018 and 2022, driven primarily by growth in the transport and manufacturing sectors, while other subsectors experienced variable or declining trends. The annual average growth rate in emissions from selected energy sector categories during this period is summarized in Table 3-3 and discussed below.

Table 3-3: Annual Growth Rate of Net Emissions by Energy Sub-sector

Subsectors	ANNUAL CHANGE PER REPORTING PERIOD				
	Overall 1994-2022	2018-22 Emissions	2001-2017	1995-2000	1994
 Energy industries 1.A.1	6.17% ↑	-22.15% ↓	2.82% ↑	--	--
 Manufacturing Industries and Construction 1.A.2	2.39% ↑	1.87% ↑	3.85% ↑	4.88% ↑	--
 Transport 1.A.3	2.53% ↑	3.96% ↑	6.82% ↑	3.52% ↑	--
 Other 1.A.4	-1.59% ↓	0.63% ↑	-1.48% ↓	-1.66% ↓	--
 Fugitive emissions 1B	2.11% ↑	5.73% ↑	3.98% ↑	11.87% ↑	--

Note: Icons in this figure are sourced from Freepik, and Uniconlabs on flaticon.com.

- Energy industries 1.A.1

Between 2018 and 2022, GHG emissions from this category declined at an average annual rate of -22.15%, a significant reversal from the 2.82% growth recorded between 2001 and 2017. The recent decline is attributed to a reduction in diesel-based thermal electricity generation, as hydropower and solar energy installations increased their share in the national energy mix.

According to the 2023 Annual Economic Report, diesel-based electricity generation dropped, following the restoration of key hydropower stations such as Kapichira. Despite these short-term reductions, the long-term trend (1994–2022) shows an overall growth of 6.17%, primarily reflecting the surge in thermal power use during crisis years (e.g., 2017–2020) due to droughts and cyclone-induced infrastructure damage. The strong fluctuations underscore the vulnerability of Malawi’s energy sector to climate extremes and the importance of diversifying the energy portfolio.

- **Manufacturing Industries and Construction (1.A.2):**

During the 2018–2022 period, GHG emissions from this category increased at an average annual rate of 1.87%. This is a slight moderation compared to the 3.85% average annual growth observed between 2001 and 2017. The slower growth reflects stabilizing output in cement and other industrial sectors, partially linked to intermittent energy supply disruptions and fluctuating demand. However, activity in the cement and lime industries remained a significant emissions driver.

- **Transport (1.A.3):**

This subcategory experienced the most substantial increase in emissions, with an average annual growth rate of 3.96% between 2018 and 2022. The rise reflects an expansion in the national vehicle fleet and increasing fuel consumption. According to the 2023 Malawi Economic Report, fuel sales for petrol increased from 154.8 million litres in 2018 to 183.2 million litres in 2022, while diesel sales rose from 271.4 million litres to 351.7 million litres in the same period. These trends underscore a growing reliance on fossil-fuel-powered transport modes.

- **Other Sectors (1.A.4):**

GHG emissions from residential, commercial, and institutional sectors grew at an annual average of 0.63% during 2018–2022. This is a rebound from the -1.48% decline recorded during 2001–2017. The current positive trend may be attributed to increased biomass use in peri-urban and rural households, offsetting gains from the uptake of electricity and LPG in urban centres.

- **Fugitive Emissions from Solid Fuels (1.B):**

Fugitive emissions from coal mining activities grew significantly at an annual average rate of 5.73% between 2018 and 2022. This surge corresponds with the increased coal production in Karonga and Rumphi Districts, where coal output rose from 171,236 metric tons in 2018 to over 220,000 metric tons in 2022. The expansion of domestic coal demand in manufacturing industries, including tobacco processing and textiles, is a major contributing factor.

Long-Term Trend Comparison

When compared to the 2001–2017 period, which recorded more accelerated growth across most subcategories (e.g., 6.82% for transport), the 2018–2022 period reflects relatively stabilized emission growth. This could be a signal of economic maturity in some categories or the beginning of a shift towards more energy-efficient practices, though this remains limited in scope and scale.

Efforts to Improve Emission Estimation and Mitigation

Recognizing the significance of the energy sector in national GHG emissions, Malawi has undertaken measures to improve both data quality and mitigation outcomes. These include:

- **Adoption of Tier 2 methodologies** for key emission categories where sufficient disaggregated activity data is available.
- **Development of local emission factors** for biomass and coal combustion in industrial applications.
- **Enhancement of data systems** such as digital fuel import tracking by MRA and improved Energy Balance reporting by the Department of Energy Affairs.
- **Promotion of energy efficiency and renewable energy technologies**, including off-grid solar PV and clean cookstoves.

Continued investment in data systems, stakeholder engagement, and policy implementation will be key to reducing uncertainty and supporting Malawi's climate commitments under the UNFCCC.

The integrated analysis of these subcategories provides a comprehensive picture of Malawi's energy sector emissions. While transport emissions dominate the sector, industrial and residential activities also contribute substantially. The stability in energy industries underscores the limited reliance on fossil-fuel-based electricity generation. However, the marked increases in transport and manufacturing sectors highlight areas where energy efficiency improvements and policy interventions could yield significant GHG mitigation benefits.

3.2 Fuel Combustion (CRT Category 1.A)

Fuel combustion remains a significant source of GHG emissions in Malawi, resulting from the oxidation of carbon-based fuels across various energy-consuming sectors. Emissions under this category primarily include CO₂, CH₄, and N₂O, emitted during the use of fossil fuels and biomass in energy generation, industry, transport, residential, and commercial applications.

Overview of Fuel Use and Emission Trends

Malawi's energy mix is dominated by traditional biomass, which accounts for approximately 87.6% of total energy consumption (Government of Malawi, 2021). The main forms include fuelwood and

charcoal, especially within the residential and commercial sectors. Despite the dominance of biomass, fossil fuel combustion, though comparatively limited in volume, contributes disproportionately to CO₂ emissions due to its higher carbon intensity.

According to the 2022 Energy Balance, petroleum products constitute to 9.4% of total energy supply, while electricity (mostly hydropower) contributes 2.4% (Government of Malawi, 2023). The remaining 0.6% is made up of coal, primarily consumed in manufacturing industries. Diesel and petrol are the primary fuels used in the transport sector, while coal and biomass are dominant in the industrial and residential sectors respectively.

GHG emissions from fuel combustion have shown a gradual increase over the inventory period (1994–2022), driven primarily by population growth, expansion in road transport, and growing demand in industrial production. The increase in fossil fuel imports (particularly diesel and petrol) and the increased deployment of diesel-based power generators during hydropower shortages also contributed to emission growth in recent years.

Sectoral Contributions to Fuel Combustion Emissions

Emissions from fuel combustion are disaggregated based on stationary and mobile sources (Figure 3-5) following the IPCC 2006 Guidelines:

- 1.A.1 – Energy Industries: Includes emissions from electricity generation (grid-connected and off-grid), petroleum refining (minimal), and other energy-related facilities. Malawi's national electricity generation is largely hydro-based, with minimal emissions. However, increasing reliance on diesel gensets in off-grid and emergency contexts has raised emissions under this subcategory.
- 1.A.2 – Manufacturing Industries and Construction: Encompasses emissions from fuel used in cement, tobacco, sugar, and tea production, where coal and biomass are the main energy sources. In 2021, coal consumption in industry stood at 105,000 tonnes, while biomass remained significant in small-scale artisanal processing (Government of Malawi, 2021).
- 1.A.3 – Transport: This is the largest contributor to fossil fuel CO₂ emissions. Diesel accounts for over 78% of total liquid fuel consumption in this category, used predominantly in freight and passenger vehicles. Between 2018 and 2022, fuel imports for transport increased by 24.5%, aligned with the growth in vehicle registrations (Government of Malawi, 2023).
- 1.A.4 – Other Sectors: Includes residential, commercial, and agricultural sectors, which are heavily reliant on fuelwood and charcoal. Over 97% of households use biomass for cooking, contributing to CH₄ and N₂O emissions through incomplete combustion.

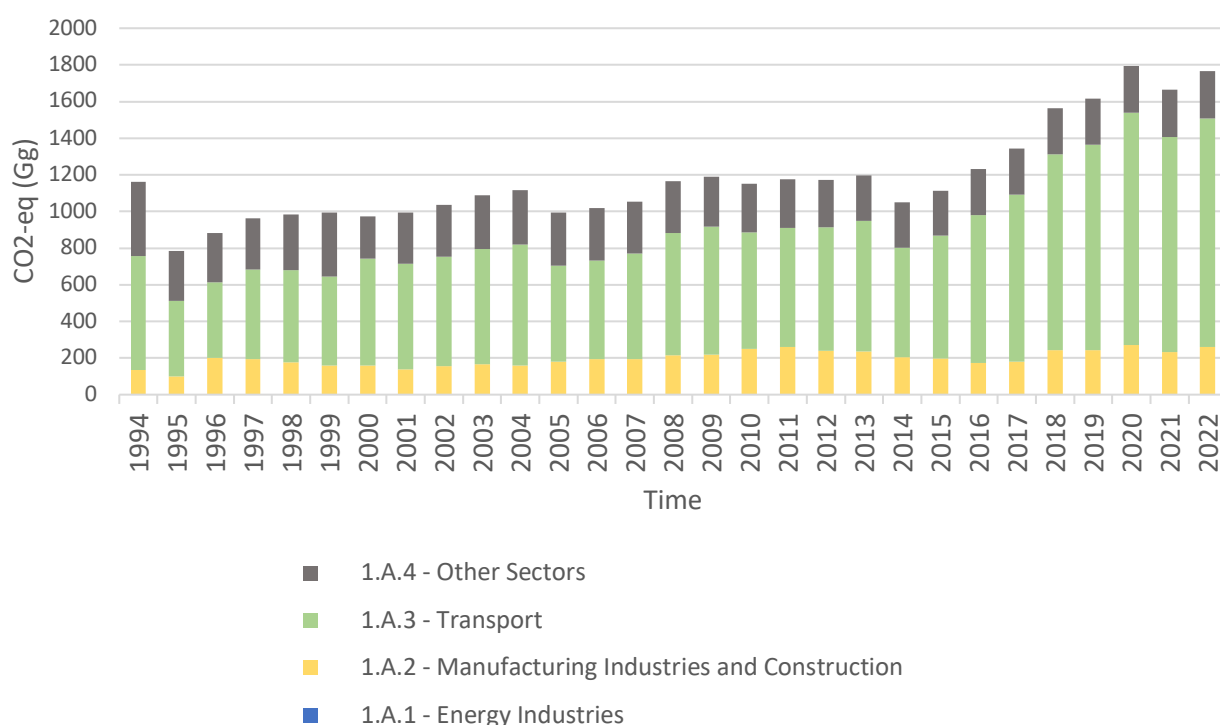


Figure 3-5: Emissions by Fuel combustion Sub-categories

Data Sources and Uncertainty

Activity data were primarily obtained from the Department of Energy Affairs, the National Statistical Office, fuel import records from the Malawi Revenue Authority (MRA), and the 2022 Malawi Energy Balance. Emission factors used are IPCC Tier 1 defaults.

Key sources of uncertainty include:

- Incomplete or inconsistent data on biomass use and fuelwood production.
- Challenges in sectoral allocation of petroleum product consumption.
- Use of default rather than country-specific emission factors.

Efforts to improve data accuracy include digitization of fuel import statistics, updates to the Energy Balance, and engagement with sectoral agencies and operators to improve reporting granularity.

3.2.1 Comparison of the Sectoral and Reference Approaches

In accordance with Volume 2, Chapter 6 of the 2006 IPCC Guidelines, Malawi has applied both the sectoral and reference approaches for estimating CO₂ emissions from fuel combustion. The sectoral approach (CRT 1.AA) estimates emissions based on reported fuel consumption across specific sub-sectors, while the reference approach (CRT 1.AB) provides a top-down estimate using total national fuel supply data (imports, exports, and stock changes). These two methods serve as cross-verification

tools, and while perfect alignment is not expected, significant differences may indicate inconsistencies in fuel statistics or assumptions used in the estimation process.

For Malawi, the comparison of reference and sectoral approaches for combined liquid and solid fuels. Figure 3-6 shows an average difference well within the $\pm 2\%$ tolerance range for most recent years (post-2005), with higher discrepancies observed in earlier years, particularly for liquid fuels.

Table 3-4: Emissions from Sectoral vs. Reference Approaches

Inventory Year	Reference Approach	Sectoral Approach	Difference (%)
1994	948.44	905.76	4.50%
2000	623.98	609.75	2.28%
2010	923.53	900.23	2.52%
2017	1016.01	996.97	1.87%
2018	1334.97	1335.35	-0.03%
2019	1394.65	1395.01	-0.03%
2020	1556.39	1556.81	-0.03%
2021	1408.04	1396.64	0.81%
2022	1515.54	1502.09	0.89%

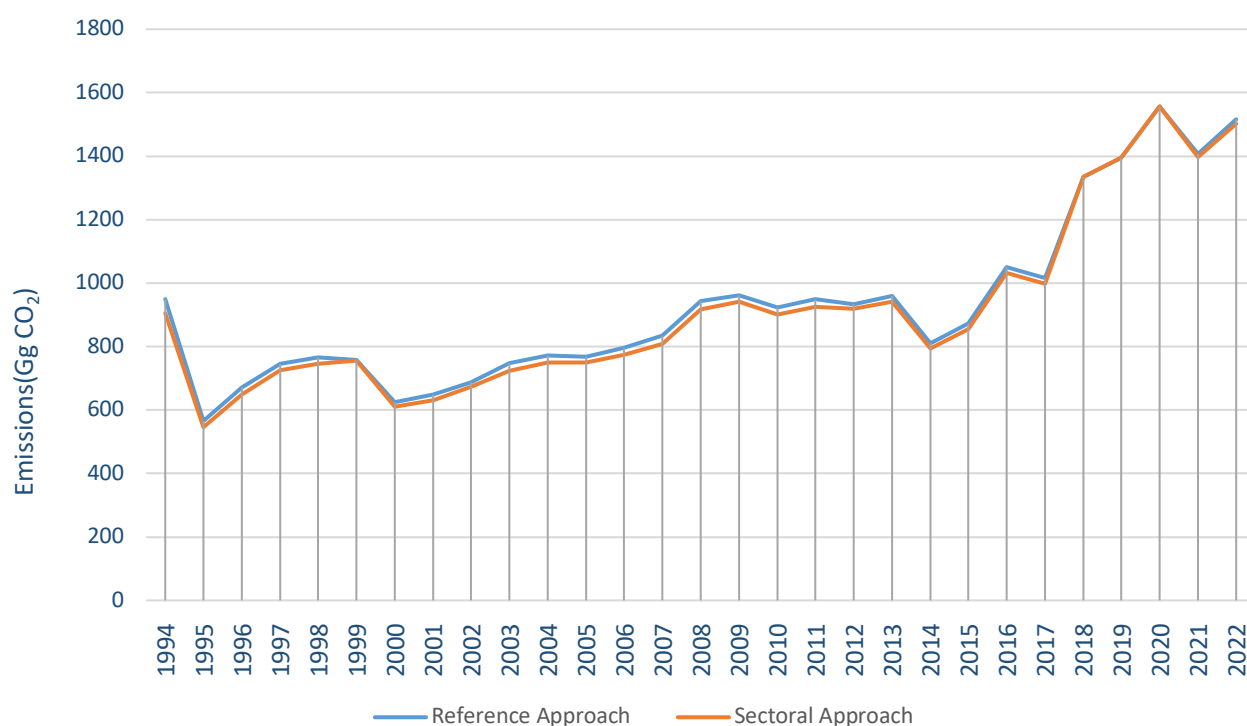


Figure 3-6: Emissions from Sectoral vs. Reference Approaches

Differences between the sectoral and reference approaches for liquid fuels exceeded 2% in several years between 1994 and 2017, with a maximum difference of 4.82% in 1994. These discrepancies are

primarily attributed to Uncertainty in early fuel trade statistics, Variability in average energy content and fuel density values, Inconsistencies in fuel allocation across sectors.

From 2018 onwards, the difference between the two approaches for liquid fuels was below $\pm 1\%$, and even marginally negative in some years (e.g., -0.03% in 2020), indicating a high level of consistency in national energy statistics.

For solid fuels, the differences between the reference and sectoral approaches remained consistently minimal across all years—approximately -0.035% , reflecting high alignment between production-based estimates and sector-level usage data. This consistency is expected given that domestic coal production is the sole source of solid fuel emissions in Malawi, with well-documented production figures from the Department of Mines and minimal stock change or export activity.

At the total level, the difference between the reference and sectoral approaches for the combined fuels has remained within acceptable bounds for all years. Differences exceeded 2% only in earlier inventory years (e.g., 4.50% in 1994 and 3.48% in 1995), consistent with the higher discrepancies noted for liquid fuels. From 2018 onwards, differences dropped below $\pm 1\%$, confirming improved data quality and methodological consistency.

These comparisons affirm that while early-year discrepancies were primarily linked to data system limitations and reliance on generalized assumptions, recent inventory years show convergence between both estimation approaches, enhancing confidence in the completeness and accuracy of the reported GHG emissions.

3.2.2 International Bunker Fuels

As stipulated under the 2006 IPCC Guidelines (Vol. 2, Chapter 1, Section 1.3.2) and Paragraph 53 of the MPGs, emissions from international bunker fuels—comprising fuels used in international aviation and marine transport—must be reported separately from national totals and are included as *memo items* in the Common Reporting Tables (CRT Table 1.D.1). These emissions are also referenced in the carbon balance (CRT Table 1.A(b)) as part of the reference approach for inventory consistency and quality control.

In the context of Malawi, international bunker fuels are primarily associated with aviation fuel (Jet A-1) used in aircrafts engaged in international routes.

Status of Data and Estimation Challenges

As of the current inventory period, Malawi has not reported estimates for emissions from international bunker fuels, primarily due to limited data availability and the lack of segregation between domestic and international fuel sales. The 2023 Annual Economic Report confirms that although Jet A-1 imports are consistently recorded, fuel sales data are not disaggregated by end-use or final destination—making it difficult to differentiate between domestic and international consumption.

Petroleum products such as Jet A-1, petrol, and diesel continue to be imported through road and rail networks, with Jet A-1 used predominantly at the Kamuzu and Chileka International Airports. The

aviation fuels are reported in aggregated form, i.e. domestic and international bunkers are not separated. However official published reports often do not segregate (Annual Economic Report 2023).

Malawi's marine transport activities remain minimal, concentrated on Lake Malawi and thus largely domestic. The Department of Marine Services does not currently track marine fuel consumption by international vs. domestic use. International aviation is serviced primarily through Kamuzu International Airport (Lilongwe) and Chileka International Airport (Blantyre), but fuel supply records from the Petroleum Importers Limited (PIL) and local fuel retailers do not yet differentiate flight destinations.

This lack of data granularity hampers the ability to apply even Tier 1 estimates as per the IPCC guidelines, which require at minimum a breakdown of activity data (fuel consumed by international aviation/marine) and default emission factors.

Jet A-1 Consumption Trends

According to data from the Malawi Energy Regulatory Authority (MERA), Jet A-1 fuel imports in Malawi fluctuated significantly between 2018 and 2022, reflecting dynamic shifts in aviation activity. Imports dropped sharply from 7.87 million litres in 2018 to just 1.87 million litres in 2020, largely due to the global COVID-19 pandemic, which led to restricted air travel.

However, by 2022, imports had rebounded to 6.96 million litres, suggesting a strong recovery in aviation fuel demand. Despite not fully returning to 2018 levels, the post-pandemic resurgence was notable—highlighting resumed activity in both domestic and international flights.

Table 3-5: Jet A-1 Imports, 2018–2022 (Million Litres)

Year	Jet A-1 Imports (Litres)
2018	7,871,569
2019	5,570,403
2020	1,865,837
2021	5,914,856
2022	6,956,643

Source: Malawi Energy Regulatory Authority (MERA)

The trend illustrates a steep decline from 2018 to 2020, followed by a gradual but strong recovery. This aligns with global patterns, where aviation demand sharply fell during the peak of COVID-19 and then began to normalize thereafter.

Still, a critical limitation persists—the lack of data disaggregation between fuel used for domestic versus international aviation. This makes it difficult to accurately allocate Jet A-1 fuel emissions between the domestic aviation category (1.A.3.a) and international bunkers. As a result, all Jet A-1 fuel imports are provisionally assumed under international bunkers in the inventory, with a

recommendation to engage the Civil Aviation Authority and airline operators to enable better reporting in future cycles.

Methodological Notes

Given the current limitations, no GHG emissions from international bunker fuels are reported in this inventory submission. This is in accordance with the MPGs (Para. 53), which state that reporting of international bunker fuels is a *memo item* and not mandatory in national totals.

Efforts will continue to focus on aligning data systems and methodologies with IPCC-recommended good practice. The intention is to transition toward Tier 1 or higher approaches once suitable disaggregated fuel consumption data become available.

Planned Improvements

To improve the completeness and transparency of future GHG inventories, the following measures are being prioritized:

- Establishment of a national fuel data tracking system that distinguishes between international and domestic aviation and marine transport fuel sales.
- Stakeholder engagement with the Department of Civil Aviation, Petroleum Importers Limited (PIL), and airport operators to define a methodology for fuel allocation by destination.
- Capacity building for data management within energy and transport regulatory bodies to facilitate continuous, disaggregated fuel data collection.
- Integration of aviation statistics (e.g., number of international flights, average fuel consumption per flight) into energy statistics to support proxy-based estimation where direct data are unavailable.
- Collaboration with regional SADC initiatives to harmonize aviation GHG data frameworks.

3.2.3 Feedstocks and Non-Energy Use of Fuels

In accordance with the 2006 IPCC Guidelines for National Greenhouse Gas Inventories (Volume 2, Chapter 1, Section 1.4.1 and Chapter 5), the category of feedstocks and non-energy use of fuels refers to fossil fuels consumed for purposes other than energy production, where carbon is either stored in products or later released in other sectors. Such fuels include lubricants, bitumen, paraffin waxes, and some types of kerosene, and their emissions are treated differently in energy balance tables to avoid double-counting or omission.

3.2.3.1 Current Status in Malawi

In Malawi, fossil fuels are imported primarily for energy purposes, with limited utilization in non-energy applications such as bitumen for road surfacing or lubricants for industrial machinery and automotive maintenance. The 2023 Annual Economic Report highlights that petroleum imports remain dominated by diesel, petrol, and Jet A-1, with minimal mention of feedstock-related products.

Diesel and petrol continued to dominate the country's total fuel imports, followed by Jet A-1 and paraffin. Other products such as bitumen and lubricants were imported in much smaller quantities, primarily for road construction and mechanical applications (Annual Economic Report 2023).

The data constraints—particularly for paraffin wax, kerosene breakdown, and waste oil recovery—continue to limit the accurate estimation of emissions from this category.

3.2.3.2 Current Estimation Status and Reporting

Given the unavailability of detailed disaggregated data, the following assumptions and reporting approaches have been adopted in line with Paragraph 54 of the MPGs:

- **Bitumen:** Assumed to result in no emissions due to lack of combustion; treated as *Not Occurring (NO)*.
- **Lubricants:** Treated as *Not Estimated (NE)* due to lack of structured data on end-use and disposal practices.
- **Paraffin Wax:** Marked as *NE* as imports or usage data is not recorded in official national statistics.
- **Kerosene:** Some quantities likely contribute to non-energy use, but disaggregation between lighting, cooking, and possible industrial or solvent uses is not available; non-energy portion marked as *NE*.
- **Waste Oils:** Treated as *NE* as no systematic tracking or recovery framework exists.

3.2.3.3 Linkages to Other Sectors

Although emissions from the disposal or use of non-energy fuels such as lubricants and bitumen may occur in other IPCC sectors (such as Waste or IPPU), they are not currently captured due to data limitations. For instance, waste oils could contribute to emissions through informal burning or dumping, but no emissions have been reported due to lack of data.

3.2.3.4 Planned Improvements

To improve the completeness and methodological transparency of future GHG inventory submissions, the following measures are proposed:

- **Stakeholder Engagement:** Engage with the Roads Authority, Malawi Bureau of Standards (MBS), Department of Energy Affairs, and private oil companies to initiate discussions on tracking non-energy use of fuels.
- **Data System Enhancement:** Integrate fuel import and consumption statistics across construction, manufacturing, and transportation sectors with disaggregated classifications for feedstock usage.
- **Capacity Building:** Support the development of methodologies to estimate emissions and carbon storage from lubricants, bitumen, and paraffin wax in line with IPCC Tier 1 guidance, including default storage fractions.

- **Inclusion in Energy Balance:** Work with the National Statistical Office (NSO) and the Department of Energy to explicitly include non-energy fuel uses in future energy balance tables.

As this category is considered a *memo item* under the MPGs, emissions from feedstocks and non-energy fuel use are not included in the national totals, but are recorded to enhance completeness and transparency in line with good practice.

3.2.4 Energy Industries (CRT Category 1.A.1)

Category Description

The Energy Industries category (CRT 1.A.1) in Malawi refers primarily to Public Electricity and Heat Production (1.A.1.a), specifically 1.A.1.a.i - Electricity Generation, given that the country lacks oil refining, natural gas infrastructure, or coal-based transformation industries. Emissions under this category are largely attributed to diesel combustion in thermal power plants, especially during periods when hydroelectric generation capacity is compromised.

As of December 2022, Malawi had an installed electricity generation capacity of 618.4 MW, with 441.65 MW (71.4%) from hydropower, 102.3 MW (16.5%) from solar PV, and 45.6 MW (7.4%) from diesel thermal sources. Diesel thermal plants are used intermittently, mainly during droughts or emergencies such as natural disasters.

Emissions Estimation Approach

A Tier 1 approach under the 2006 IPCC Guidelines was used to estimate emissions from diesel-based electricity generation. The estimation is based on the following formula:

$$\text{Emissions} = \text{Activity Data} \times \text{Emission Factor}$$

Equation 3-1

Where:

- *Activity Data refers to diesel fuel consumed (in TJ), based on electricity generated.*
- *Emission Factors (EFs) are IPCC defaults:*
 - *CO₂: 74,100 kg/TJ*
 - *CH₄: 3 kg/TJ*
 - *N₂O: 0.6 kg/TJ*

For years 1994–2016, due to a lack of disaggregated data, the diesel-based generation is assumed to be constant. The estimated annual diesel-based emissions over this period are:

- CO₂: 3.123 kt

- CH₄: 0.00013 kt
- N₂O: 0.00003 kt

Updated Activity Data and Emissions (2015–2022)

From 2016 onward, Malawi began utilizing diesel generators to offset hydropower disruptions, particularly after extreme weather events like Cyclones Ana and Dumako, which damaged the Kapichira Hydropower Plant (129.6 MW) in January 2022. This led to increased diesel generation.

Table 3-6 and Figure 3-7 present electricity generation from diesel in terajoules (TJ) based on an 8-hour daily operation and a 23.3% load factor:

Table 3-6: electricity generation from diesel in terajoules (TJ) with its emissions

Year	Diesel Generation (TJ)	CO ₂ (Gg)	CH ₄ (Gg)	N ₂ O (Gg)
2016	20.24	1.50	0.00006	0.00001
2017	51.19	3.79	0.00015	0.00003
2018	613.77	45.45	0.00184	0.00037
2019	746.37	55.26	0.00224	0.00045
2020	574.61	42.56	0.00172	0.00034
2021	151.03	11.19	0.00045	0.00009
2022	225.46	16.71	0.00068	0.00014

Source: Ministry of Energy

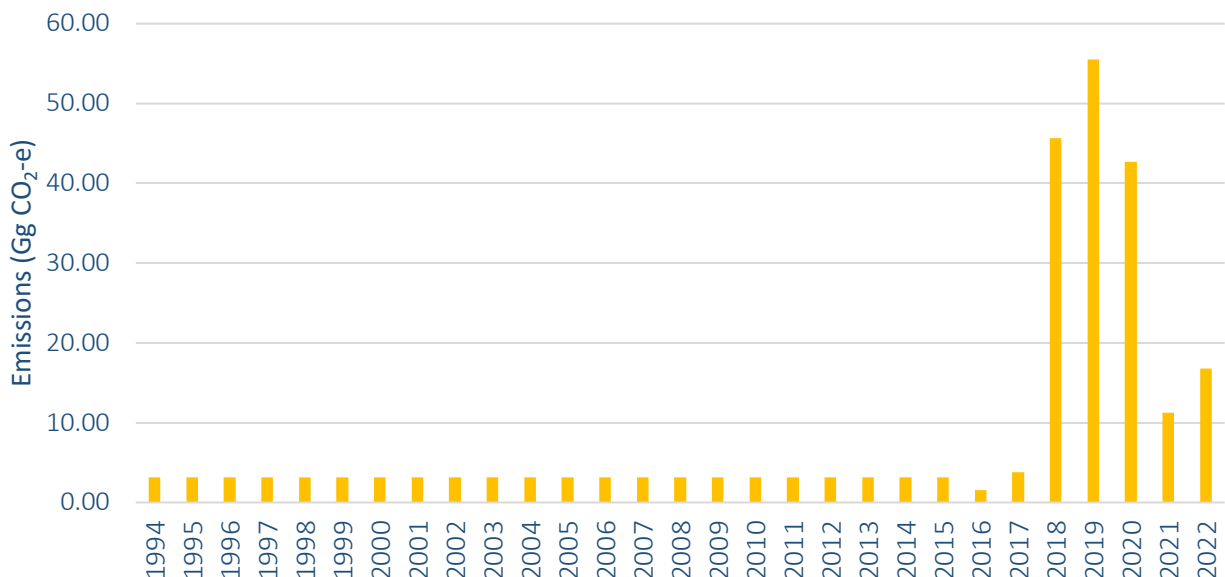


Figure 3-7: Emissions from electricity generation from diesel

The spike in 2018–2019 and again in 2022 directly correlates with the failure of hydropower infrastructure and the need for diesel backup. In particular:

- In 2018, diesel generation surged to 613.77 TJ, emitting over 45 Gg CO₂.
- After recovery in 2020, Cyclone Ana in January 2022 again disrupted hydro production, leading to 225.46 TJ of diesel generation.

Trends and Observations

Despite Malawi's reliance on hydropower, the vulnerability of hydro infrastructure to climate-related shocks has made diesel backup essential, albeit carbon-intensive. Import data from MERA confirms a 22% increase in diesel imports in 2022, highlighting the strain on the system and the corresponding rise in fossil fuel emissions.

The 2023 Annual Economic Report also attributes the 4.7% contraction in the electricity sector in 2021, and -0.3% in 2022, to outages stemming from extreme weather impacts and the termination of the 78MW Aggreko rental plant in March 2022.

3.2.4.1 Methodological Challenges and QA/QC

The main methodological constraints include:

- Inadequate plant-level reporting on diesel consumption.
- Reliance on assumed generation efficiencies and operational hours.
- Use of IPCC default emission factors, which may not fully represent local fuel combustion characteristics.

Quality control included cross-checking reported diesel generation with fuel imports and triangulating with hydropower availability from ESCOM and EGENCO records. No recalculations were made for pre-2015 years.

Planned Improvements

Future inventory cycles will:

- Adopt Tier 2 methodologies where plant-specific data becomes available.
- Establish a centralized database linking generation data with fuel use.

Incorporate real-time reporting from diesel generation sites to capture year-on-year variability.

3.2.5 Manufacturing Industries and Construction

3.2.5.1 (CRT Category 1.A.2.e – Food Processing, Beverages and Tobacco)

Category Description

This subcategory under the energy sector covers fuel combustion emissions from manufacturing industries and construction, with a focus on food processing, beverages, and tobacco production—one of Malawi's most economically important sectors. Fuel types used include diesel, coal, and

liquefied petroleum gas (LPG). These fuels power boilers, generators, and other thermal processes within the sector.

As of 2022, the manufacturing sector remains a vital contributor to GDP. According to the 2023 Annual Economic Report by the Ministry of Finance and Economic Affairs, manufacturing accounted for 10.1% of Malawi's GDP in 2022, a marginal increase from 9.7% in 2021, with major contributors being tobacco processing, sugar, beverages, and bakery products (Government of Malawi, 2023). This industrial activity directly correlates with fuel consumption and, consequently, GHG emissions.

Methodological Issues

Emissions from fuel combustion in this sector were calculated using the following IPCC equations:

For CO₂:

$$\text{Emissions}_{\text{CO}_2} = \text{Activity Data} \times \text{Emission Factor (CO}_2\text{)}$$

Equation 3-2

For CH₄ and N₂O:

$$\text{Emissions}_{\text{GHG}} = \text{Activity Data} \times \text{Emission Factor}_{\text{GHG}}$$

Equation 3-3

Where:

- *Activity data = fuel consumption in TJ*

**Emission factors were sourced from IPCC 2006 Guidelines, Vol. 2.*

Fuel Allocation Assumptions:

- Diesel use in manufacturing industries is assumed to be 10% of national diesel imports, plus diesel used for self-generation.
- Conversion from litres to tonnes used a density of 0.832 kg/litre.

Emission trend

Emissions in this subcategory are estimated using the IPCC Tier 1 methodology, based on fuel consumption and IPCC default emission factors. The activity data for this category is derived from national fuel import records from the Malawi Energy Regulatory Authority (MERA) and includes assumptions about industrial fuel use.

The emissions trend from 1994 to 2022 shows notable variability, reflecting shifts in industrial productivity and fuel usage patterns over the years. A summary of estimated emissions (in Gg CO₂-e) for selected years is shown in Figure 3-8.

Table 3-7: GHG Emissions – Food Processing, Beverages, and Tobacco (1994–2022) by gas type

Years	CO ₂	CH ₄
1994	132.391	0.009
2000	154.581	0.011
2010	246.519	0.019
2017	176.625	0.012
2018	237.987	0.015
2019	237.942	0.016
2020	267.461	0.017
2021	227.794	0.015
2022	256.200	0.018

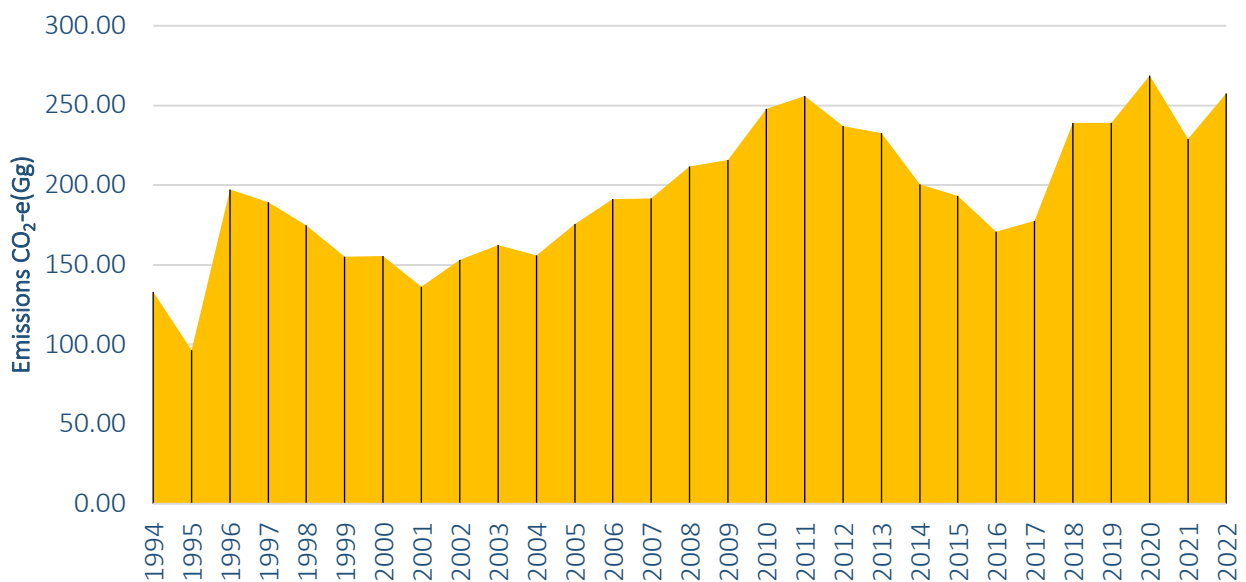


Figure 3-8: GHG Emissions – Food Processing, Beverages, and Tobacco (1994–2022)

The annual growth rate in emissions for the period 2018–2022 was 1.87%, slightly lower than the average of 3.85% observed between 2001–2017, indicating a more stable consumption pattern in recent years despite economic fluctuations.

Uncertainties and Time Series Consistency

Key uncertainties include:

- Lack of disaggregated fuel consumption data by industry.

- Use of Tier 1 default emission factors, which may not fully reflect local combustion technologies or fuel quality.
- Potential underreporting or overlap with emissions from the general energy industries subcategory.

To maintain time-series consistency:

- The same methodological assumptions and emission factors have been applied uniformly across all years.
- All fuel conversion factors and sectoral proportions remained fixed, except where updated activity data were available.

Quality Assurance, Quality Control and Verification

This category follows the general QA/QC framework described in Annex IV, including:

- Verification of fuel imports through MERA and MRA.
- Cross-checking with industry data from the National Statistical Office and Ministry of Industry.
- Peer review by inventory experts to validate consistency and transparency.

Recalculations and Planned Improvements

Recalculations: No recalculations were made during this cycle, though updates may be considered upon availability of new industrial fuel use surveys.

Planned Improvements:

- Develop sector-specific surveys to collect disaggregated industrial fuel use.
- Introduce country-specific emission factors based on measured combustion characteristics.
- Work with industry associations (e.g., MCCI) to enhance the transparency of fuel use reporting.

3.2.6 .Transport (CRT Category 1.A.3)

Category Description

The Transport Sector (CRT Category 1.A.3) captures greenhouse gas (GHG) emissions resulting from fuel combustion in various modes of transport, including road, domestic aviation, and domestic water-borne navigation. As per the 2006 IPCC Guidelines, emissions are disaggregated by mode and function, and in Malawi's context, three subcategories are relevant:

- 1.A.3.a.ii – Domestic Aviation
- 1.A.3.b – Road Transportation
- 1.A.3.d.ii – Domestic Water-borne Navigation

Among these, road transportation remains the most significant contributor to emissions, accounting for over 90% of internal freight and passenger movement in 2022 (Government of Malawi, 2023).

Fuel combustion in the transport sector is primarily based on diesel and petrol (gasoline), with negligible shares from alternative fuels such as ethanol or biodiesel, despite existing potential for biofuel production in Malawi. The reliance on second-hand vehicles, predominantly imported from Japan and South Africa, further exacerbates emissions due to outdated technologies and lower fuel efficiency.

Figure 3-9 presents the long-term trend in emissions across the three transport subcategories between 1994 and 2022:

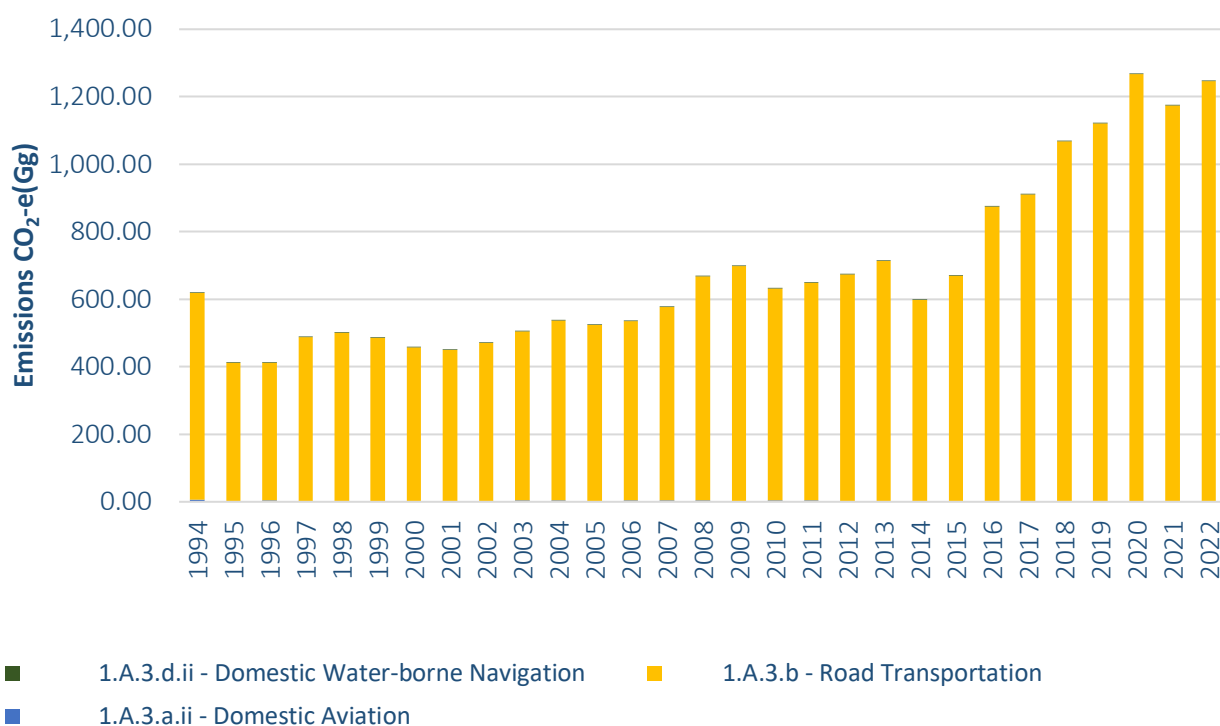


Figure 3-9: Trends in GHG Emissions from Transport Subcategories

Emission Trends Summary (1994–2022)

Table 3-8: GHG Emissions from Transport Subcategories (Gg CO₂-e)

Year	Domestic Aviation (1.A.3.a.ii)	Road Transport (1.A.3.b)	Water Transport (1.A.3.d.ii)
1994	6.86	611.76	1.22
2000	2.30	455.29	0.71
2010	3.77	628.90	0.64
2015	2.80	666.98	0.64
2020	0.00	1,265.67	1.32
2022	2.21	1,243.94	1.13

Key Observations:

- Road Transport (1.A.3.b) demonstrates a steady and significant increase in emissions over the reporting period. From 611.76 Gg in 1994 to 1,243.94 Gg in 2022, road transport nearly doubled its contribution to total transport emissions. This growth mirrors increased fuel consumption, expanding vehicle fleet, and urbanization.
- Domestic Aviation (1.A.3.a.ii) exhibits a fluctuating but overall low emissions profile, with noticeable impacts from the COVID-19 pandemic, including zero emissions recorded between 2018–2020. Post-pandemic recovery is visible, but emissions have yet to return to pre-2010 levels.
- Domestic Water-borne Navigation (1.A.3.d.ii) remains the least significant emitter in the transport subcategories, consistently below 2 Gg CO₂e annually, but demonstrates a modest increase post-2015, which may reflect improvements in fleet operations and fuel use tracking.

3.2.6.1 Road Transportation (CRT Category 1.A.3.b)

Category Description

Road transportation in Malawi forms the backbone of the national transport system, accounting for over 90% of domestic freight and passenger movement as reported in the 2023 Annual Economic Report. It connects both rural and urban centres and supports key sectors such as agriculture, manufacturing, and trade. Consequently, it is also the largest source of greenhouse gas (GHG) emissions within the transport sector.

The vehicle fleet in Malawi is predominantly composed of imported second-hand vehicles, primarily from Japan and South Africa, many of which lack modern emissions controls. According to the Malawi Revenue Authority (MRA), vehicle registrations surpassed 300,000 units by 2022, up from under 160,000 in 2010— a sharp increase that correlates directly with the upward emissions trend. This has been indicated on Figure 3-10. The absence of vehicle emission standards and fuel efficiency regulations further increases GHG emissions.

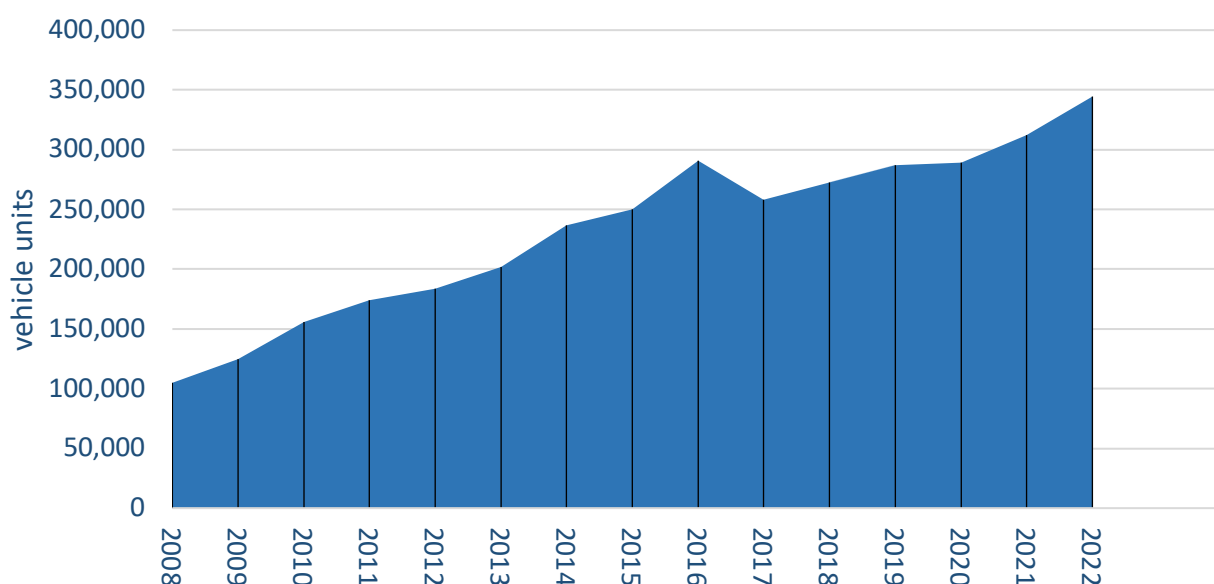


Figure 3-10: Vehicle population (2008-2022)

Methodological Approach

The estimation of GHG emissions from this subcategory follows the Tier 1 approach, in accordance with the 2006 IPCC Guidelines (Volume 2: Energy, Chapter 3). The method applies national-level fuel consumption data and IPCC default emission factors (EFs).

For CO₂ emissions:

$$\text{Emissions}_{\text{CO}_2} = \text{Activity Data} \times \text{Emission Factor (CO}_2\text{)}$$

Equation 3-4

For CH₄ and N₂O emissions:

$$\text{Emissions}_{\text{GHG}} = \text{Activity Data} \times \text{Emission Factor}_{\text{GHG}}$$

Equation 3-5

Where:

- Activity data = fuel consumption in TJ
- Emission factor is the IPCC default emission factor for the specific gas and fuel type

Activity Data and Fuel Consumption Trends

Fuel data used in this inventory was sourced from MERA, cross-verified with MRA import statistics, and includes quantities of petrol and diesel used for road transport.

Table 3-9: Trends in Petroleum Fuel Imports for Road Transport (2018–2022)

Year	Petrol (litres)	Diesel (litres)
2018	209,053,949	273,288,621

2019	247,234,190	256,553,903
2020	290,605,042	310,417,905
2021	275,606,073	250,310,332
2022	292,872,565	265,253,077

Source: MERA

Total petrol and diesel imports increased by approximately 17% between 2018 and 2022. This growth aligns closely with the observed rise in emissions from road transport.

Emission Trends and Key Drivers

Despite the global assumption that COVID-19 would lower emissions, Malawi recorded a peak in road transport emissions in 2020 (1,266.98 Gg CO₂-e) as indicated on Figure 3-11. This contradicts the international trend and reflects Malawi's resilient transport fuel demand, likely influenced by continued goods movement, informal transport activities, and limited lockdown enforcement.

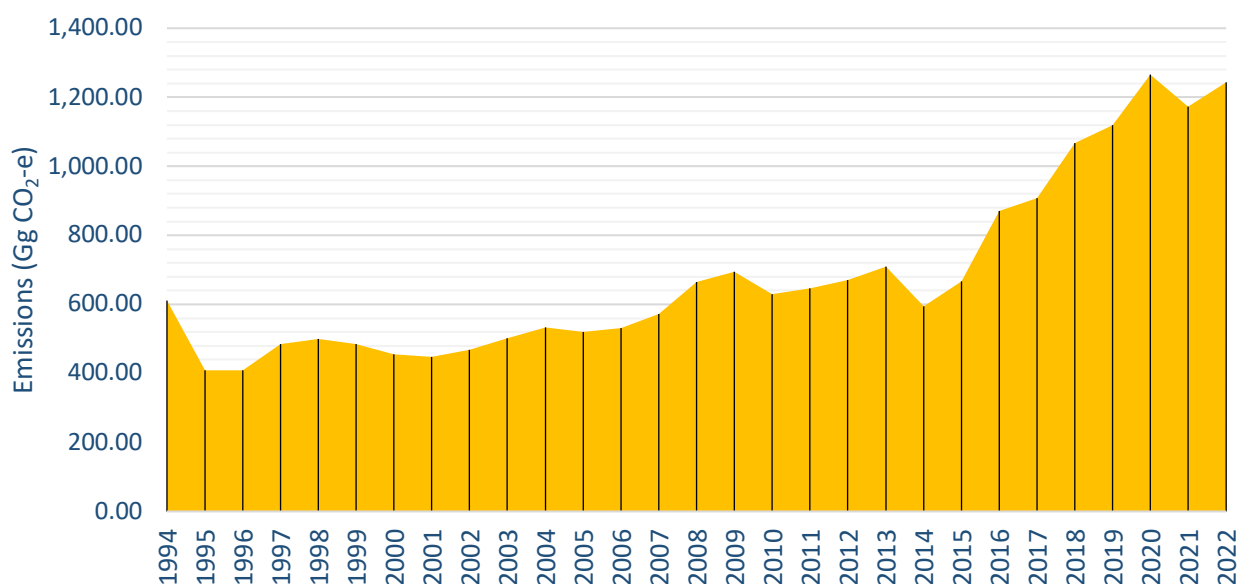


Figure 3-11: Road Transport Emissions Trend (1994–2022)

Key Drivers of Emissions Growth

- **Vehicle Fleet Expansion:** MRA data shows a more than twofold increase in registered vehicles from 2010 to 2022.
- **Urbanization:** Growing urban centres such as Lilongwe, Blantyre, and Mzuzu have increased fuel demand for personal and commercial transport.

- Inadequate Regulatory Framework: Malawi lacks fuel economy standards and vehicle emission testing.
- Importation of Used Vehicles: These contribute heavily to emissions due to poor engine performance and high fuel consumption.

Uncertainty and Time-Series Consistency

- **Uncertainties:**
 - Use of Tier 1 default EFs instead of Malawi-specific factors.
 - Lack of disaggregated fuel consumption by vehicle type.
 - Possible under-reporting or over-estimation in earlier years due to data gaps.
- **Consistency Measures:**
 - Cross-validation using MERA and MRA data.
 - Use of linear interpolation to fill minor data gaps.
 - Engagement with stakeholders through the GHG Inventory Enhancement Programme to improve emission factor accuracy.

Quality Assurance and Control (QA/QC)

- Internal QA conducted through:
 - Verification of fuel imports against MRA and MERA reports.
 - Regional benchmarking with SADC Transport Sector Trends.
 - External peer reviews by independent national and international experts.

Planned Improvements

In alignment with Malawi's NDCs and the MPGs, future improvements include:

- Development of Malawi-specific EFs for petrol and diesel.
- Enhanced fuel data collection disaggregated by vehicle type, age, and geographic area.
- Integration of alternative fuels into the emission estimation framework.
- Digitalization of the vehicle registry to capture fuel economy and emissions characteristics.
- Pilot studies in cities to monitor and model urban transport emissions.

3.2.6.2 Domestic Aviation (CRT Category 1.A.3.a.ii)

Category Description

This category includes greenhouse gas (GHG) emissions from fuel combustion in aircraft operating on domestic flight routes within Malawi. Domestic aviation emissions are primarily from the use of Jet A-

1 aviation fuel for scheduled passenger and freight transport between airports such as Kamuzu International Airport (Lilongwe), Chileka International Airport (Blantyre), and regional hubs like Mzuzu and Karonga.

Unlike international aviation, which is treated as a memo item under IPCC 2006 Guidelines, domestic aviation emissions are included in the national GHG total. Although this subsector is smaller in scale compared to road transport, it remains an important part of the inventory due to its role in facilitating internal mobility and trade.

Methodological Approach

Emissions from domestic aviation are estimated using the Tier 1 methodology outlined in the 2006 IPCC Guidelines (Vol. 2, Ch. 3). This approach utilizes fuel consumption data and IPCC default emission factors for Jet A-1.

For CO₂ emissions:

$$\text{Emissions}_{\text{CO}_2} = \text{Activity Data} \times \text{Emission Factor (CO}_2\text{)}$$

Equation 3-6

Where:

- *Activity Data = Jet A-1 fuel consumption (in TJ)*
- *Emission Factor (CO₂) = IPCC default emission factor for Jet A-1 (73,500 kg CO₂/TJ)*

For CH₄ and N₂O:

$$\text{Emissions}_{\text{GHG}} = \text{Activity Data} \times \text{Emission Factor}_{\text{GHG}}$$

Equation 3-7

Where:

- *Emission Factor (CH₄) = 2 kg/TJ (Tier 1 default)*
- *Emission Factor (N₂O) = 0.6 kg/TJ (Tier 1 default)*

**Fuel consumption is derived from MERA petroleum import statistics, while emission calculations follow the IPCC guidelines for civil aviation.*

Activity Data and Jet A-1 Consumption Trends

Jet A-1 import data from MERA for the period 2018–2022 is shown (Table 3-5). Although the total volumes do not differentiate between domestic and international use, expert judgement and sector consultations suggest that a fraction of the imports serves domestic routes.

Fuel imports dropped significantly in 2020 due to COVID-19 disruptions but rebounded sharply in 2021 and 2022, highlighting a quicker-than-anticipated recovery of domestic aviation activity. This contradicts earlier assumptions that pandemic-related travel restrictions would lead to a sustained decline in fuel demand in this sector.

Emission Trends and Analysis

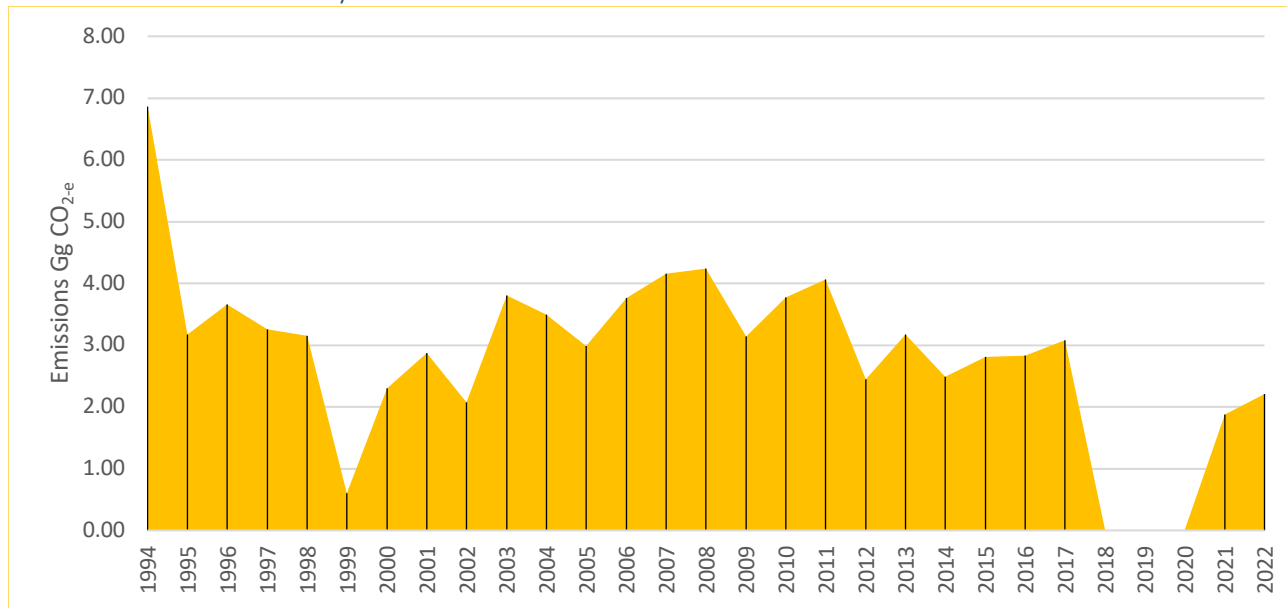


Figure 3-12: Domestic Aviation Emissions Trend (1994–2022)

Key Observations

- **COVID-19 Impact:** Malawi's domestic aviation sector experienced a temporary collapse in emissions during 2018–2020, corresponding to low Jet A-1 imports.
- **Post-COVID Recovery:** Emissions resumed in 2021 and grew modestly in 2022, consistent with a rise in domestic air travel and sector recovery.
- **Long-Term Stability:** Historically, emissions in this category have been low and stable, reflecting the limited scale of domestic aviation operations.

Uncertainty Assessment and Time-Series Consistency

- **Key Uncertainties:**
 - Lack of disaggregated fuel use data (domestic vs. international).
 - Default emission factors not tailored to aircraft types operating in Malawi.
- **Time-Series Measures:**
 - Estimates are based on consistent data sources and methods.
 - Gaps for 2018–2020 were addressed using fuel import trends and expert consultation.

QA/QC and Planned Improvements

- **Data cross-checks:** Jet A-1 volumes validated using MERA and MRA sources.
- **Verification:** Consistency checks with flight data from Civil Aviation Department (if accessible in future).

Future Improvements:

- Collaboration with airport authorities and aviation stakeholders to obtain disaggregated consumption data.
- Development of Malawi-specific Tier 2 methodologies for this category.
- Tracking of aircraft movements and passenger volumes to support bottom-up estimates.

3.2.6.3 Domestic Water-borne Navigation (CRT Category 1.A.3.d.ii)

Category Description

This category includes GHG emissions resulting from the combustion of fuels used in water-borne vessels operating within Malawi's inland waters, particularly Lake Malawi and the Shire River. It covers emissions from domestic ferries, cargo boats, fishing vessels, and small passenger crafts. These operations are important for connecting remote lakeshore communities and supporting both tourism and local commerce.

While the domestic water-borne navigation sector is relatively small in terms of fuel consumption, it remains a relevant category under the IPCC 2006 Guidelines and is reported separately for completeness and transparency.

Methodological Approach

The estimation of emissions follows the Tier 1 approach as prescribed by the IPCC 2006 Guidelines (Vol. 2, Ch. 3). This method relies on total fuel consumption data for inland navigation and applies default emission factors for diesel, the dominant fuel type used in this category.

For CO₂ emissions:

$$\text{Emissions}_{\text{CO}_2} = \text{Activity Data} \times \text{Emission Factor (CO}_2\text{)}$$

Equation 3-8

Where:

- *Activity Data = TJ of diesel consumed*
- *Emission Factor (CO₂) = Emission factor for diesel = 74,100 kg CO₂/TJ*

For CH₄ and N₂O:

$$\text{Emissions}_{\text{GHG}} = \text{Activity Data} \times \text{Emission Factor}_{\text{GHG}}$$

Equation 3-9

Where:

- *Emission Factor (CH₄) = 3.9 kg/TJ (Tier 1 default)*
- *Emission Factor (N₂O) = 0.6 kg/TJ (Tier 1 default)*

**Activity data is derived from diesel fuel allocations provided in the Annual Economic Report (2023) and from past inventory estimates.*

Activity Data and Fuel Use Trends

Although Malawi does not publish disaggregated fuel statistics specifically for water-borne navigation, estimates are derived by allocating a proportion of national diesel imports to inland water transport

based on historic sector analysis and consultations with stakeholders such as Malawi Shipping Company and the Department of Marine Services.

Table 3-11 shows the Estimated GHG Emissions from Domestic Navigation.

Table 3-10: Diesel consumption by waterborne navigation

YEAR	Consumption (Mass (Gg))
	Gas/Diesel Oil
1994	0.38
2000	0.22
2010	0.2
2017	0.23
2018	0.36
2019	0.33
2020	0.41
2021	0.33
2022	0.35

Table 3-11: Estimated GHG Emissions from Domestic Navigation

Year	CO ₂ (Gg)	CH ₄ (Gg)	N ₂ O (Gg)	CO ₂ -e
1994	1.22	~0.00004	~0.00001	~1.22
2000	0.71	~0.00002	~0.00001	~0.71
2010	0.64	~0.00002	~0.00001	~0.64
2015	0.64	~0.00002	~0.00001	~0.64
2018	1.16	~0.00004	~0.00001	~1.16
2020	1.32	~0.00004	~0.00001	~1.32
2022	1.13	~0.00004	~0.00001	~1.13

Note: CH₄ and N₂O values are negligible under Tier 1 and have minimal impact on the overall total.

Emission Trends and Interpretation

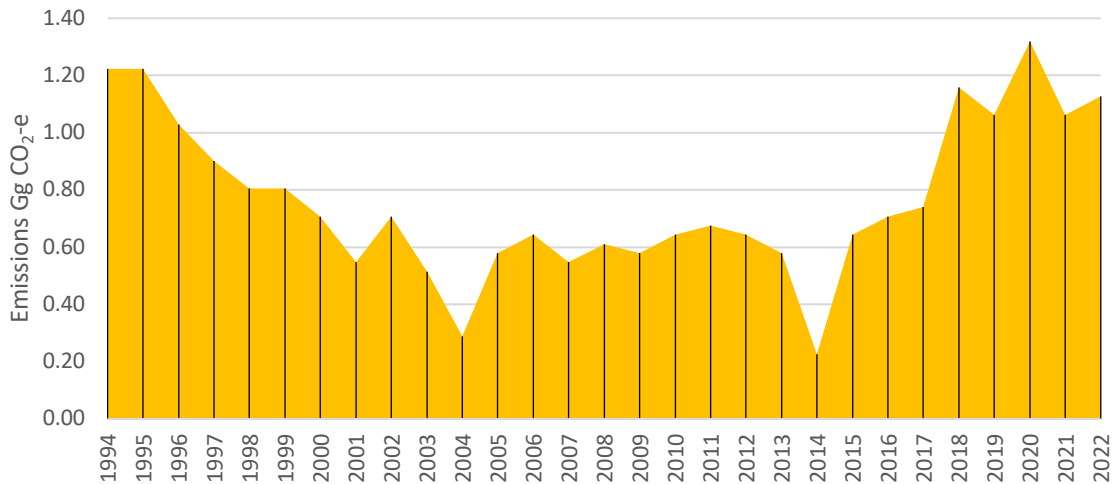


Figure 3-13: Domestic Navigation Emissions (1994–2022)

Observations:

- Emissions from this category are very low and stable across the time series, never exceeding 1.5 Gg CO₂e annually.
- A slight increase is observed from 2016 onward, likely reflecting increased operations of passenger and cargo services on Lake Malawi.
- Despite these increases, the category remains insignificant in overall national totals but remains important for completeness and tracking sectoral shifts.

Uncertainty Assessment and Time-Series Consistency

- **Uncertainty Sources:**
 - Lack of direct fuel allocation data specific to inland water transport.
 - Use of IPCC default emission factors that may not reflect vessel engine conditions or operational patterns in Malawi.
- **Time-Series Measures:**
 - A consistent allocation methodology has been applied across the years to ensure comparability.
 - Minor fluctuations are addressed using sector-informed assumptions and proxy data from stakeholders.

QA/QC and Planned Improvements

- **Validation:** Data cross-checked with trends in fuel imports and transport operations from the Annual Economic Report and Maritime Authority sources.
- **Stakeholder Consultation:** Input from the Department of Marine Services and Malawi Shipping Company is planned to enhance activity data.

Planned Enhancements:

- Incorporate vessel-specific fuel use data as it becomes available.
- Conduct fuel consumption surveys for vessels operating on Lake Malawi and the Shire River.
- Explore potential Tier 2 methodologies using vessel classification and operational profiles.

3.2.7 Other Sectors (CRT Category 1.A.4)

3.2.7.1 Residential (1.A.4.b)

Category Description

The residential sector in Malawi is one of the most energy-consuming sectors and is highly reliant on biomass-based fuels for daily household energy needs. According to the 2023 Annual Economic Report, biomass accounts for over 85% of total energy consumption in Malawi, predominantly from firewood, charcoal, and agricultural residues used for cooking, heating, and lighting purposes. These fuels are typically combusted under low-efficiency conditions, contributing significantly to non-CO₂ GHG emissions, particularly methane (CH₄) and nitrous oxide (N₂O).

Despite government initiatives to promote alternative energy solutions such as liquefied petroleum gas (LPG) and electricity, accessibility and affordability remain critical barriers in rural and peri-urban areas, leading to continued heavy reliance on traditional biomass.

Methodology

In line with the IPCC 2006 Guidelines (Volume 2, Chapter 2), a Tier 1 approach was applied. Emissions were calculated using default IPCC emission factors and national-level activity data. The approach assumes complete oxidation of CO₂ in biomass and includes the estimation of CH₄ and N₂O, which vary with combustion conditions.

For CO₂ emissions:

$$\text{Emissions}_{\text{CO}_2} = \text{Activity Data} \times \text{Emission Factor (CO}_2\text{)}$$

Equation 3-10

Where:

- Activity Data = TJ of fuel consumed
- Emission Factor = kg/TJ (Tier 1 default)

Emission Trends and Observations

The following updated GHG emissions data (in Gg CO₂e) reflect changes in the residential energy use over time, incorporating data for CO₂, CH₄, and N₂O:

Table 3-12: Residential Fuel consumption

YEAR	Consumption (Mass (Gg))				Consumption (Energy Unit (TJ))
	Other Kerosene	Liquefied Petroleum Gases	Wood/Wood Waste	Other Primary Solid Biomass	Charcoal
1994	28.47	24.8	0.00048	1623.08	10855
2000	0.42	0.452	0.00043	1466.01	11557
2017	0.78	0.884	0.00039	1336.2	17048
2018	0.39	1.308	0.00039	1328.04	17429
2019	0.27	1.032	0.00039	1315.51	17819
2020	0.56	1.109	0.00038	1307.83	18218
2021	0.75	1.528	0.00038	1299.97	18633
2022	0.25	2.258	0.00038	1299.97	18633

Source: FAOSTAT(2024)

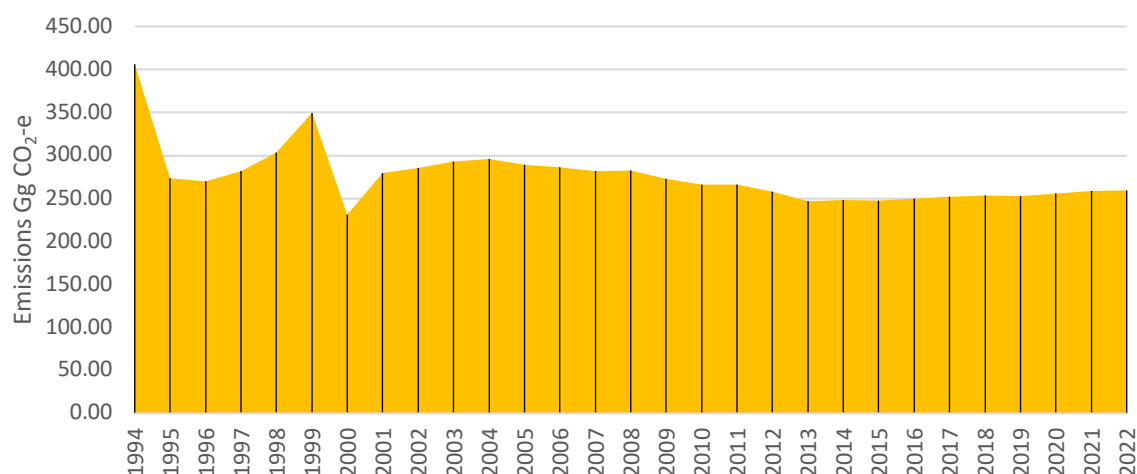


Figure 3-14: Emissions from Residential

Trend analysis:

- Between 1994 and 2022, CO₂ emissions declined by approximately 36%, from 406.19 Gg to 259.49 Gg.
- While CO₂ emissions reflect declining firewood and charcoal combustion (or improved cooking practices), non-CO₂ emissions (CH₄ and N₂O) remain relevant due to inefficient combustion practices.
- The data indicates stabilized emissions post-2010, with slight increases aligned to population growth and urban expansion.

Discussion

Despite Malawi's efforts to reduce reliance on biomass, especially through improved cookstove dissemination and LPG promotion, the residential category remains a key emitter in the “Other

Sectors” category. The National Energy Policy of Malawi (2018) calls for diversification and efficiency improvements; however, implementation has faced challenges.

The GHG Transport Analysis Report (2021) also notes that shifting urban energy use and promoting alternative fuels is a strategic mitigation opportunity, yet this remains underutilized in rural areas.

Furthermore, the IPCC’s good practice guidance highlights that biomass combustion under incomplete conditions (as in traditional three-stone fires and basic charcoal stoves) leads to significant non-CO₂ emissions. This points to an urgent need for fuel substitution and clean cooking technologies.

QA/QC, Uncertainty and Consistency

- **QA/QC:** All estimates were validated using national energy balances and cross-referenced with household energy survey data where applicable.
- **Uncertainty:** The major uncertainty source lies in fuel use estimates, especially biomass. The Tier 1 emission factors used are not Malawi-specific.
- **Consistency:** A uniform approach was applied throughout the time series to maintain comparability.

Planned Improvements

- Development of country-specific emission factors for biomass combustion in rural and urban settings.
- Enhancement of household energy surveys, especially to capture disaggregated fuel use patterns (by region, gender, and income level).
- Integration of improved cookstove uptake data and LPG penetration statistics into the emissions framework.
- Promotion of electrification and solar energy adoption as alternatives to biomass.

3.3 Fugitive emissions from fuels (CRT 1.B)

3.3.1 Solid Fuels (CRT Category 1.B.1)

Category Description

This category covers fugitive methane (CH₄) emissions from solid fuel production in Malawi, specifically coal mining and handling. In accordance with the 2006 IPCC Guidelines (Volume 2, Chapter 4), fugitive emissions are unintentional releases of CH₄ during the mining process and post-mining operations.

1.B.1.a - Coal mining and handling

1.B.1.a.i - Underground mines

1.B.1.a.i.1 - Mining

Coal remains Malawi’s only significant solid fossil fuel, and there is no oil or natural gas production in the country. Coal mining in Malawi is concentrated in Karonga and Rumphi districts in the Northern Region. The main active mines are Mchenga, Kaziwiziwi, Kasikizi, and Chombe, which primarily

produce sub-bituminous coal used in tobacco curing, cement manufacturing, food processing, and beverage industries.

Table 3-13: Amount of Coal Produced (tonne) from Underground Coal Mining

YEAR	Amount of Coal Produced (tonne)
Sub-Bituminous Coal	
1994	34630
2000	44900
2017	45230
2018	49753
2019	54728
2020	54875.8
2021	51000
2022	62166

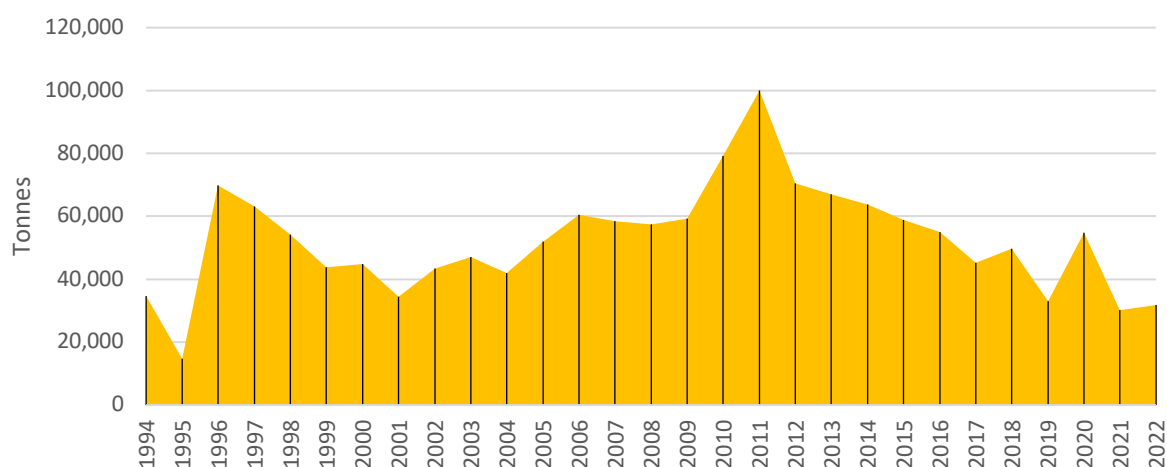


Figure 3-15: Coal Production

3.3.2 Activity Data and Trends

According to the 2023 Annual Economic Report, coal production more than doubled from 30,250.8 tonnes in 2021 to 62,166.1 tonnes in 2022, representing a 106% increase in annual output. This spike is attributed to the post-COVID-19 economic recovery, increased industrial demand, and operational improvements at mining sites, including acquisition of more efficient equipment.

Methodological Approach

Methodological Tier and Parameters

- **Approach:** Tier 1 (IPCC 2006 Guidelines, Vol. 2, Ch. 4)
- **Activity Data Source:** Department of Mines (Annual Coal Production Reports)
- **Emission Factor:** 1 m³ CH₄ per tonne of coal (IPCC default for surface mining)

- **Conversion Factor:** $1 \text{ m}^3 \text{ CH}_4 = 0.0007168 \text{ tonnes of CH}_4$
- **GHG Reported:** Methane (CH_4) only (CO_2 not included as per IPCC guidance)

Formula:

$$\text{Emissions (CH}_4\text{)} = \text{Coal Production (tonnes)} \times 1 \text{ m}^3/\text{tonne} \times 0.0007168 \text{ tCH}_4/\text{m}^3$$

Equation 3-11

Estimated Fugitive CH_4 Emissions (1994–2022)

As shown on Figure 3-16, fugitive CH_4 emissions display significant interannual variability. However, the long-term trend from 1994–2022 suggests a gradual increase, particularly in the post-2010 period where industrial use of coal has expanded due to increased energy demands.

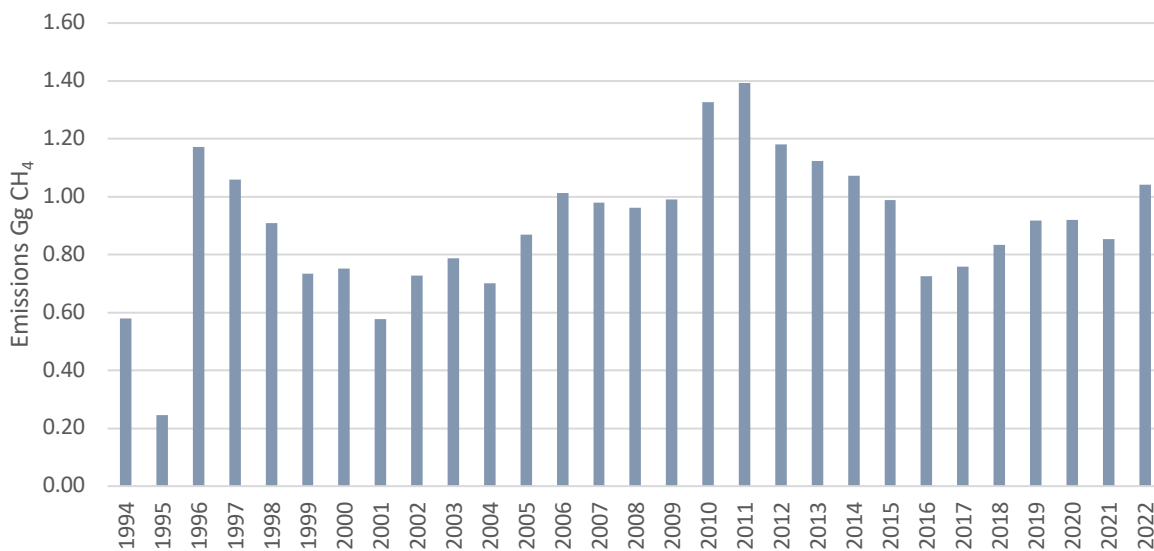


Figure 3-16: Estimated Fugitive CH_4 Emissions (1994–2022)

Sector-Specific Developments and Observations

- **Increased Production in 2022:** The 106% rise in coal production in 2022 is reflective of improved mine output and rising domestic industrial demand due to continued efforts to substitute imported fuels.
- **Coal Reserve Potential:** Malawi has over 22 million tonnes of proven coal reserves, with Livingstonia and Ngana identified as the most viable coalfields.
- **Export Limitations:** Despite increased production, no coal was exported in 2022, indicating domestic consumption accounted for all output.

Uncertainty and Time-Series Consistency

Uncertainty Assessment

- The IPCC estimates a $\pm 50\%$ uncertainty range for fugitive emissions using Tier 1.

- Emission estimates are influenced by potential underreporting of small-scale coal mining operations and lack of continuous methane measurement.

Time-Series Consistency

- Methodological consistency has been maintained for the entire series (1994–2022).
- Year-to-year changes reflect actual production trends, with data sourced from Department of Mines.

QA/QC and Verification Procedures

- **Tier 1 QA/QC:** Data cross-verified with production figures from MERA and industrial users.
- **Peer Review:** Reviewed internally and by third-party GHG inventory consultants.
- **Data Archiving:** All supporting documents and emission factor sources are archived and traceable.

Recalculations and Planned Improvements

No recalculations were conducted for this reporting period, but future improvements will focus on:

- **Development of Country-Specific Emission Factors** – Pilot methane measurement projects at Kaziwiziwi and Mchenga mines.
- **Monthly Data Collection** – Digitization and real-time tracking of production figures by the Department of Mines.
- **Enhanced Private Sector Engagement** – Encouraging reporting compliance and technical cooperation from private operators.

3.4 Carbon Dioxide Transport and Storage (CRT Category 1.C)

3.4.1 1.4.1 Category Description

This category refers to emissions and removals associated with Carbon Capture and Storage (CCS), defined under the 2006 IPCC Guidelines (Volume 2, Chapter 5) as a system involving four major components:

- Capture and compression of CO₂ at point sources (e.g., power plants or industrial facilities),
- Transportation of the captured CO₂, typically via pipeline or tanker,
- Injection of CO₂ into a long-term geological storage site (such as depleted oil/gas reservoirs or deep saline formations),
- Monitoring and verification to ensure containment and prevent leakage.

The principal purpose of CCS is to reduce CO₂ emissions from fossil-fuel-based or industrial processes, particularly in sectors with high point-source emissions.

3.4.2 National Context and Applicability to Malawi

As of the latest reporting period (2022), Malawi has no operational or planned CCS infrastructure. The country does not have:

- Any CO₂ capture and compression facilities,
- CO₂ pipeline networks or transportation systems for captured carbon,
- Identified geological storage formations for CO₂ injection and sequestration,
- Any ongoing research or pilot-scale CCS demonstration projects.

The industrial profile of Malawi is characterized by low-emission intensity industries, small-scale fuel combustion systems, and the absence of large fossil-fuel-based electricity generation plants, which typically serve as primary candidates for CCS. As reported in the 2023 Annual Economic Report, renewable hydropower and solar contributed more than 88% to the total installed electricity capacity, with thermal generation making up only 7.4%, thus limiting the existence of high-volume point sources of CO₂.

In addition, no fossil-fuel-based industrial activities in the cement or lime sectors currently include CO₂ capture as part of production, and carbon dioxide emissions from process sources are reported under IPPU Sector 2 rather than Category 1.C.

Given these conditions, CRF Category 1.C is considered “Not Occurring (NO)” in Malawi for the 1994–2022 inventory time series. This designation is consistent with reporting under paragraph 54 of the Modalities, Procedures, and Guidelines (MPGs) where parties are permitted to indicate the non-occurrence of an activity where it is not relevant to the national context.

3.4.3 Methodological Consistency and Reporting Clarification

No CO₂ emissions or removals have been reported under this category from 1994 to 2022, and no activity data exist to support the use of Tier 1 or higher-level estimation methodologies as indicated in Table 3-14.

Table 3-14: Emissions from Carbon Dioxide Transport and Storage (CRT 1.C), 1994–2022

Year	1.C.1 Capture and Compression	1.C.2 Transport	1.C.3 Injection and Storage	Total Emissions	Notation Key
1994–2022	NO	NO	NO	0	NO = Not Occurring

This treatment is consistent with Annex II of the MPGs on uncertainty assessment, which requires the inventory compiler to exclude categories that are irrelevant to the national emission context while ensuring methodological transparency.

3.4.4 Sector-Specific QA/QC and Planned Improvements

QA/QC

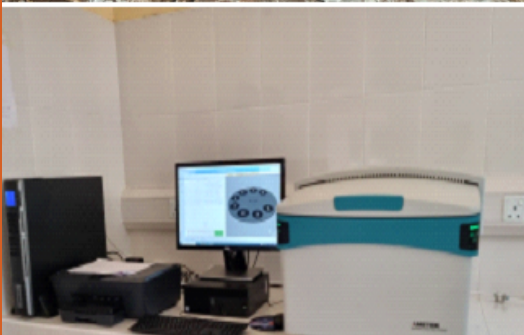
- Data Review: This category was reviewed as part of the broader energy sector QA/QC exercise. The absence of relevant activities was confirmed with sectoral stakeholders, including the Department of Mines, Department of Energy Affairs, and industrial operators.
- Peer Review: Verified through internal consistency checks and third-party sectoral consultation.

Planned Improvements

While CCS is not applicable to Malawi at present, the following actions are proposed to maintain transparency and enable future improvements:

1. Tracking International Developments: Monitor regional CCS advancements (e.g., Southern Africa) to assess long-term feasibility.
2. Integrating CCS in Low-Carbon Pathways: Assess its inclusion in Malawi's Long-Term Strategy (LTS) for carbon neutrality and green growth scenarios.
3. Institutional Readiness: Build institutional knowledge and capacity in CCS methodologies to ensure readiness for potential future technology uptake.
4. Inventory Documentation: Maintain "Not Occurring" status in future submissions unless national developments warrant re-evaluation

Chapter 4:



Industrial Processes and Product Use

4.1 Overview of the Sector and background information

Industrial Processes and Product Use (IPPU) sector is made up of emissions from industries that do not involve fuel consumption but result from chemical and physical processes in production and transformation of materials. In the context of this inventory for Malawi, key subsectors include:

- Mineral Industry (Category 2A): Emissions arise from the production of cement (2A1) and lime (2A2), where carbonate decomposition during clinker and lime production releases carbon dioxide (CO₂).
- Other Uses of Carbonates (Category 2A4): The manufacturing of ceramics involves high-temperature processing, leading to CO₂ emissions from raw material decomposition and firing processes.
- Chemical Industry (Category 2B): Emissions from processes involved in the production and application of paints and coatings (2B10), which may release volatile organic compounds (VOCs) and other greenhouse gases.

These activities all form part of Malawi's industrial process emissions, which are separate from energy-related emissions. These emissions are estimated using methodologies from the 2006 IPCC Guidelines for National Greenhouse Gas Inventories. Future work will attempt to enhance data quality for more accurate accounting for emissions in these subsectors. The [Figure 4-1](#): Malawi's IPPU inventory shows a Summary of Malawi's IPPU inventory.

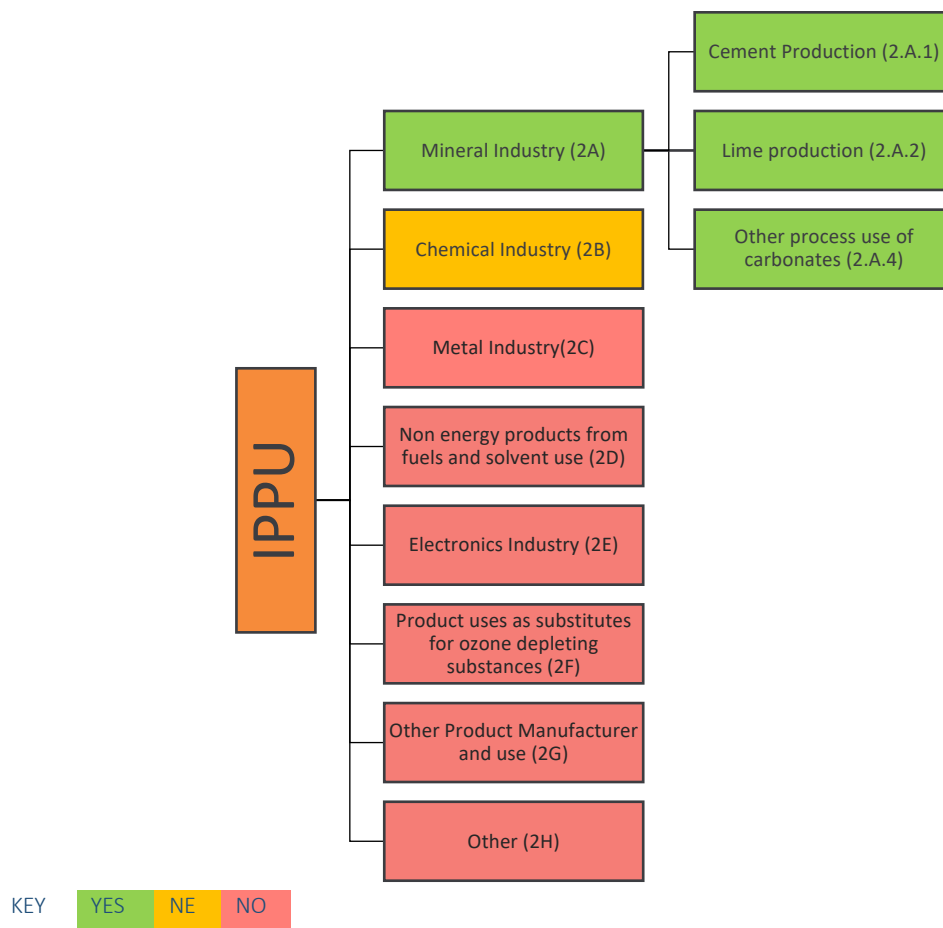


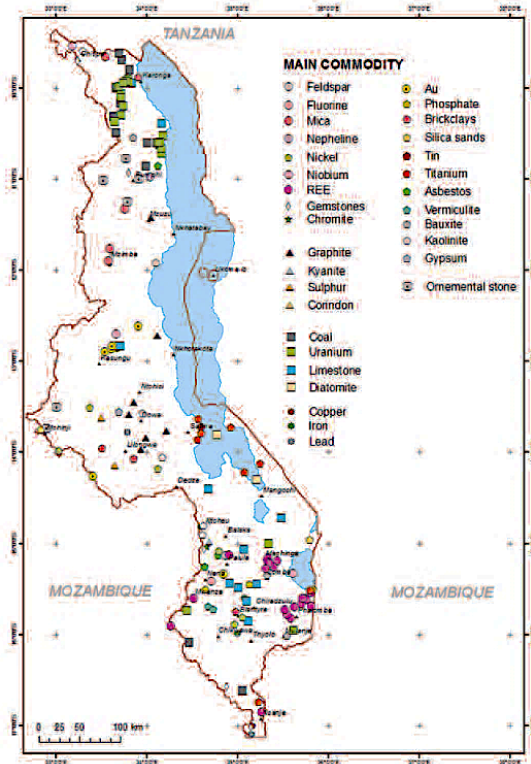
Figure 4-1: Malawi's IPPU inventory

In 2017, the industrial sector accounted for approximately 15.6% of Malawi's Gross Domestic Product (GDP) (Government of Malawi, 2018). Despite recent investments in cement production, particularly in local clinker manufacturing, Malawi remains a net importer of cement. In 2022, the country imported \$22.5 million worth of cement, primarily from Zambia, Oman, Singapore, Tanzania, and the United Arab Emirates. In contrast, Malawi's cement exports were minimal, valued at only \$2,060, indicating a significant trade imbalance (Government of Malawi, 2023).

Lime production is categorized under the mining sector, which contributes about 1% to Malawi's GDP (Government of Malawi, 2023). Although the sector is expected to grow by about 8% in 2023 and 2024, its overall contribution is anticipated to remain below 1% (Government of Malawi, 2023). Lime is essential for various industries, including agriculture, water treatment, and construction. Increasing the efficiency of local lime production could reduce dependency on imports while also mitigating emissions.

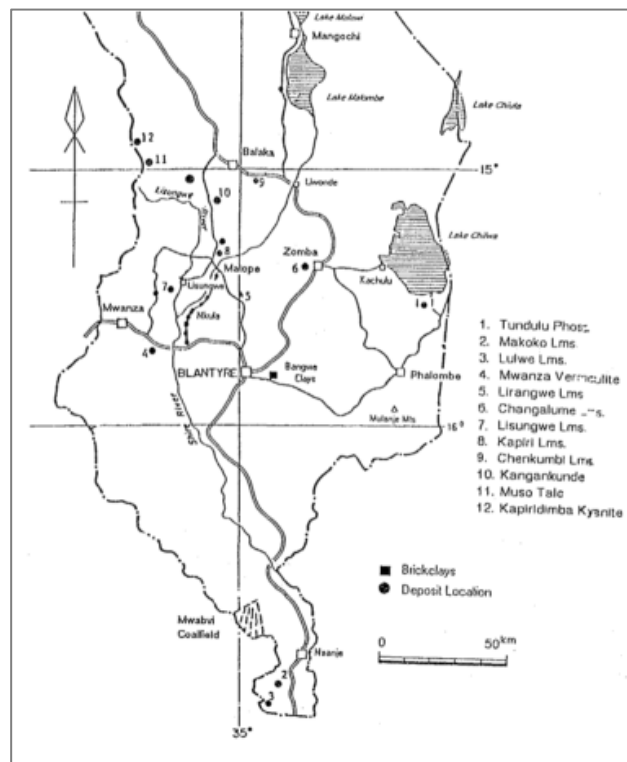
4.2 Mineral Industry (Category 2A)

The Mineral Industry (Category 2A) includes greenhouse gas (GHG) emissions resulting from the processing and transformation of minerals, primarily due to chemical reactions that release carbon dioxide (CO₂). These emissions are distinct from those arising from fuel combustion and are primarily attributed to carbonate decomposition during high-temperature processing (IPCC, 2006).



■ Limestone

Figure 4-2: Mineral resources in Malawi



● Deposit location

Figure 4-3: Mineral resources in southern Malawi

4.2.1 Cement production (2.A.1)

Cement production, classified under Category 2A1 in the Industrial Processes and Product Use sector, primarily involves the calcination of limestone (CaCO_3) to produce clinker. This process entails heating crushed limestone in rotary kilns, where calcium carbonate decomposes into calcium oxide and releases CO_2 . The calcination process is the largest single source of greenhouse gas emissions in the industry, as CO_2 is emitted directly from the chemical reaction and from the fuel combustion required for kiln operation.

The first limestone quarrying site for the production of Portland cement was Changanlume in Zomba district. The site was closed in 2003 after being in operation from the 60's.

There are two current cement production plants. These are in Kasungu and Mangochi districts.

Malawi's cement plants consistently operate to meet domestic demand, producing high-quality clinker with calcium oxide (CaO) content that closely aligns with the IPCC (2006) guidelines. These guidelines recommend a CaO range of 60% to 65% for optimal clinker composition. Clinker production levels have steadily increased, reflecting the sector's growth and the rising demand for cement in the Malawian construction market. Although a few plants dominate local production, the sector adheres to international standards and is regulated by national quality and environmental standards. Additionally, the reliance on Tier 1 methodology for greenhouse gas inventory provides a simplified

and efficient approach to estimating emissions based on national production data, average clinker content, and default emission factors, as outlined in IPCC guidelines (IPCC, 2006).

Malawi's cement industry, although relatively small, plays a vital role in supporting national economic growth. Rising demand for infrastructure has led to an upward trend in cement production, driven by urbanization and increased construction activity. The sector faces challenges, including data limitations and uncertainties in GHG reporting, often relying on Tier 1 methodology, which incorporate national activity data and default emission factors, as site-specific data remains scarce (Government of Malawi, 2020).

Cement production in Malawi is primarily centered around producing Ordinary Portland Cement (OPC) and follows national standards (MS 29:2001) to ensure quality. Recent expansion in this sector aligns with infrastructure-focused government initiatives, which fuel demand for cement in projects such as road construction, school buildings, and healthcare facilities (National Statistical Office of Malawi, 2023). The industry relies heavily on clinker, the main ingredient produced by calcining limestone, which makes the industry a substantial GHG emitter. While energy-intensive processes remain common, there are efforts underway to adopt energy-efficient technologies to reduce emissions (Government of Malawi, Ministry of Natural Resources and Climate Change, 2022).

4.2.1.1 Methodological issues

The methodology for estimating greenhouse gas (GHG) emissions in Malawi's cement production sub-sector, follows Tier 1 guidelines from the 2006 IPCC Guidelines for National Greenhouse Gas Inventories. The approach utilizes generalized default emission factors along with basic activity data. This is primarily due to challenges in obtaining detailed data at the plant level. Under Tier 1, emissions are calculated based on default emission factors provided by the IPCC and standard activity data that reflect national production levels. This method assumes average clinker content in cement and typical CaO content in clinker, establishing a consistent and accessible baseline for emissions estimation.

The emission equation for Tier 1 is given as:

$$CO_2 \text{ Emissions} = \left[\sum_i (M_{ci} \cdot C_{di}) - Im + Ex \right] EF_{dc}$$

Equation 4-1

Where:

- CO₂ Emissions : Emissions of CO₂ from cement production, measured in tonnes.
- M_{ci} : Weight (mass) of cement produced of type i, measured in tonnes.
- C_{cli} : Clinker fraction of cement of type i, expressed as a fraction.
- Im : Imports for consumption of clinker, measured in tonnes.
- Ex : Exports of clinker, measured in tonnes.
- EF_{clc} : Emission factor for clinker in the particular cement, measured in tonnes CO₂/tonne clinker.

Source: IPCC (2006)

With the Clinker fraction of cement = 0.75, emission factor for clinker in the particular cement in tonnes CO₂/tonne clinker = 0.52

4.2.1.2 Description of any flexibility applied

For cement production, emissions were estimated using the Tier 1 approach, which relies on default emission factors provided by the 2006 IPCC Guidelines (Vol. 3, Ch. 2). One notable flexibility applied was the absence of differentiation among cement types. The inventory did not break down data by clinker content, blended cements, or other specific formulations since plant-specific composition data was unavailable. Instead, a default emission factor for cement production was used to maintain consistency and comparability in emissions estimates. This approach aligns with IPCC guidance, which permits default assumptions when detailed input data is lacking, particularly in countries with limited reporting capacity.

While this flexibility introduces some uncertainty in emissions estimates—since different cement types have varying clinker-to-cement ratios—it ensures that the inventory remains methodologically consistent over time while still capturing broad emission trends in the sector. Future efforts will focus on improving data collection at the plant level to refine these estimates.

4.2.1.3 Uncertainty Assessment for Malawi's Cement Production Sector

The Tier 1 uncertainty assessment for Malawi's cement production sector focuses on key sources of uncertainty, including chemical composition, production data, and trade data for clinker imports and exports. Given Malawi's reliance on aggregated data and assumptions, particularly in a context with limited data infrastructure, these uncertainties are essential to address for accurate GHG emissions reporting. Below is an analysis of the main uncertainty sources using the IPCC (2006) guidelines and available data from Malawi's cement plants.

Chemical Analysis/Composition

The primary uncertainty in chemical composition for Tier 1 methodology arises from the assumption that 95% of cement production is Portland cement with a clinker content of around 65%, contributing an uncertainty range of 2-7% (IPCC, 2006). Malawi's two main cement plants, Plant A and Plant B, each conducted a chemical analysis of their clinker to determine CaO content. For Plant A, the CaO content analysis has a higher uncertainty of 2%, attributed to a fixed range of 65% to 65.5% for all years. In contrast, Plant B reports CaO content as measured values, with an uncertainty of 1.5%. These variations in reporting practices contribute to an overall emission factor uncertainty of 4.5% for Plant A and 4% for Plant B.

Production Data

Uncertainty in production data is influenced by factors such as the assumption of complete reporting and the reliability of plant-level weighing of raw materials. For Tier 1, the uncertainty associated with reported cement production data is 1-2% (IPCC, 2006). Malawi's activity data uncertainty was estimated at 4% for both Plant A and Plant B due to reported complete data

from plant sources, which are generally reliable. However, there may still be minor errors related to instrument accuracy or operator-related measurement errors. Additionally, a significant assumption in Tier 1 is that 100% of the cement output is Portland cement, which could introduce up to a 35% uncertainty. The lack of differentiation between cement types in Malawi's aggregated national production data contributes to this high uncertainty.

Table 4-1: Volume of cement produced (tonnes)

YEAR	Volume of Cement Produced (tonne)
1994	119500
2000	111800
2010	241100
2017	163100
2018	202351.52
2019	294366.59
2020	347977.69
2021	382706.55
2022	361247.37

Imports/Exports

Trade data for clinker presents one of the highest sources of uncertainty. A 10% uncertainty is assigned to trade data accuracy if clinker imports are isolated correctly. Furthermore, the potential overestimation of import tonnage by up to 50% stems from the difficulty in accounting for net clinker imports in national statistics. This is critical because the Tier 1 approach does not allow detailed tracking of import and export data at the level of clinker and Portland cement, leading to potential overestimations or underestimations in total clinker consumption.

4.2.1.3.1 Summary of Uncertainties

The overall Tier 1 uncertainty for Malawi's cement production is influenced by assumptions regarding clinker content, cement type, and data completeness. The estimated uncertainties for emission factors and activity data for Plants A and B are as indicated on [Table 4-2](#).

Table 4-2: Estimated uncertainties for Malawi's cement production

Uncertainty	Plant A	Plant B
Emission Factor Uncertainty	4.5%	4%
Activity Data Uncertainty	4%	4%

CKD Uncertainty	3.5%	3.5%
-----------------	------	------

These uncertainties indicate that while plant-level data collection has reduced some sources of error, significant uncertainties remain due to assumptions in national-level data and clinker trade reporting. Moving forward, refining country-specific data, especially on clinker imports and exports, would help Malawi transition to a more accurate Tier 2 methodology, which relies less on broad assumptions.

4.2.2 Time Series Analysis of CO₂ Emissions from Cement Production

The cement sector has experienced fluctuations in net CO₂ emissions (measured in Gg CO₂) over the years (

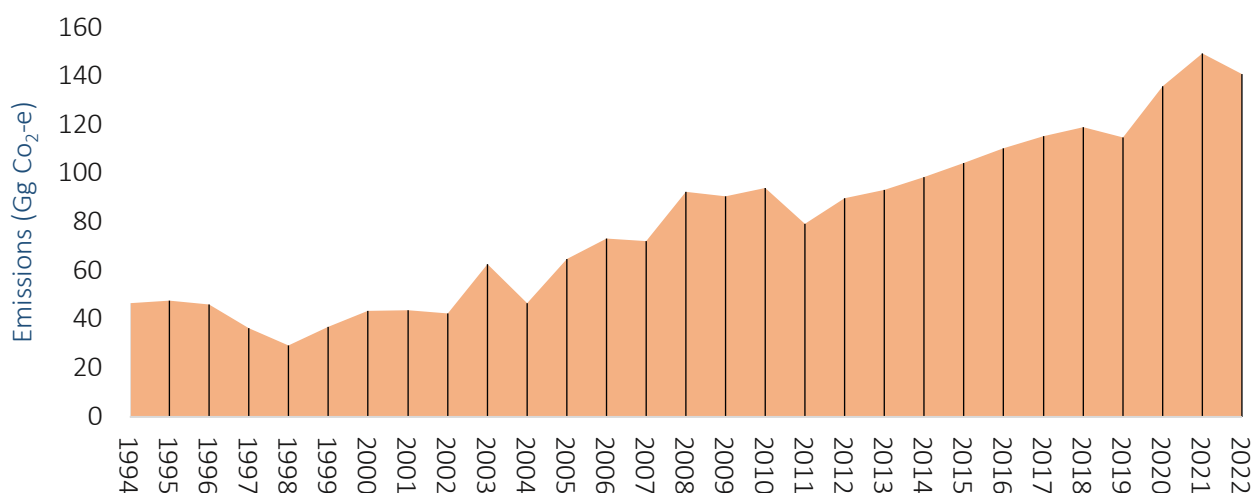


Figure 4-4), largely influenced by variations in production levels, industrial demand, and economic conditions.

From 1994 to the early 2000s, emissions showed significant variability, starting at 2.09 Gg CO₂ in 1994 before dropping to 0.15 Gg CO₂ in 1996. A substantial increase occurred between 1997 and 2000, with emissions rising from 0.63 Gg CO₂ in 1997 to 3.64 Gg CO₂ in 2000, indicating growth in cement

production.

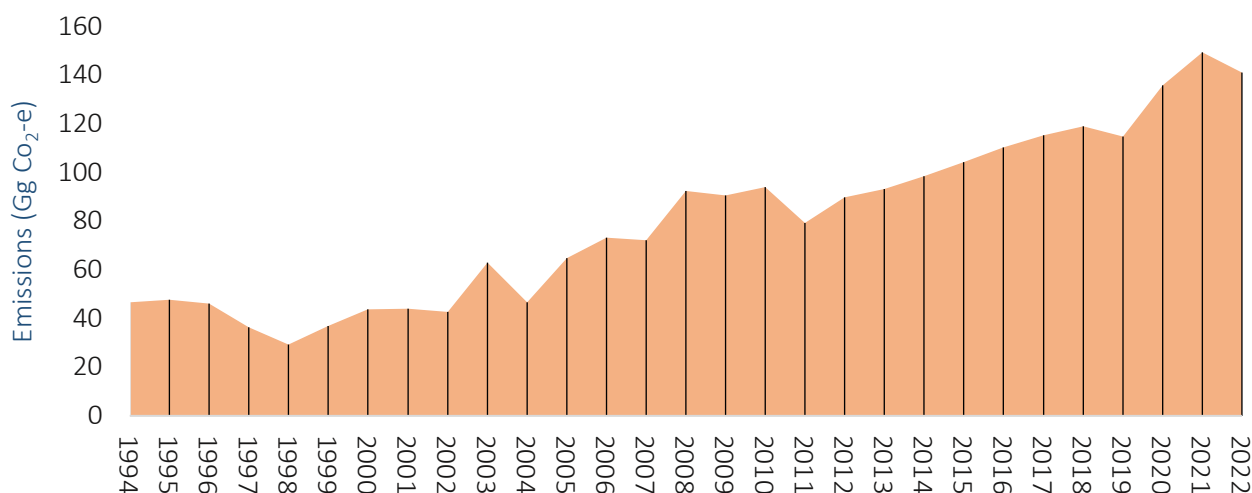


Figure 4-4: Emissions from cement production

Malawi's cement industry has experienced significant changes over the years, with fluctuations in CO₂ emissions corresponding to shifts in clinker production and import practices. The closure of the Chungalume clinker plant in 2003 led to a period during which cement mills primarily relied on imported clinker. Around the same time, a new clinker plant was commissioned in Kasungu, which utilized a vertical shaft kiln. This marked the beginning of a gradual recovery in local clinker production.

From 2006 to 2011, emissions showed an increasing trend, rising from 73.19 Gg CO₂ in 2006 to a peak of 94.07 Gg CO₂ in 2010, before slightly declining to 79.28 Gg CO₂ in 2011. This upward trend can be attributed to rising cement demand and increased production capacities (Government of Malawi, 2020).

Between 2013 and 2014, emissions rose significantly, increasing from 93.16 Gg CO₂ in 2013 to 98.51 Gg CO₂ in 2014. This coincided with the commissioning of modern rotary clinker kiln plants in Kasungu and Mangochi. This expansion was driven by growing infrastructure projects and construction activities throughout the country. By 2015, emissions had reached 104.30 Gg CO₂, reflecting enhanced production capabilities.

From 2018 to 2022, emissions continued to rise significantly, starting at 119.05 Gg CO₂ in 2018 and peaking at 149.31 Gg CO₂ in 2021, before declining slightly to 140.94 Gg CO₂ in 2022. The elevated emissions during this period align with the commissioning of additional production facilities and a surge in construction activities aimed at addressing housing and infrastructure deficits. This sustained growth indicates robust expansion in the cement manufacturing sector, driven by both rising domestic demand and improved production capabilities.

4.2.3 QA/QC and Verification

In developing the national greenhouse gas (GHG) inventory for the cement industry, quality assurance and quality control (QA/QC) procedures were implemented to ensure the accuracy, completeness, and consistency of emissions estimates as follows;

Data validation

The first step in the QA/QC process involved validating data and conducting consistency checks across multiple years. Historical cement production data from 1994 to 2023 was reviewed to ensure completeness and to identify any potential anomalies in the reported values. A trend analysis was performed to detect unexpected fluctuations in emissions estimates, which were then cross-checked with production trends. Any discrepancies were flagged for further review, and additional verification measures were taken when necessary to confirm data integrity.

Comparability

Emissions estimates from the cement industry were cross-referenced with previously reported values from past National Communications and Biennial Reports. This approach ensured that the methodology remained aligned with earlier inventories, while also facilitating improvements in data quality. Efforts were made to harmonize national data with international reporting standards, ensuring that emissions estimates could be benchmarked against regional and global trends.

Completeness

In instances where data gaps were identified, proxy data methods were employed to maintain the completeness of the inventory. For example, when direct production figures were unavailable for specific years, estimates were derived from industry reports, stakeholder consultations, and trend extrapolation from existing data points. These estimates were carefully documented to ensure transparency in the reporting process.

Data verification

The cement production data was reviewed in collaboration with key stakeholders, including government agencies, cement manufacturers, and industry associations. This peer review process ensured that the reported activity data accurately represented actual sector performance and allowed for addressing any inconsistencies before finalizing emissions estimates. Furthermore, the emission factors used in calculations were validated against IPCC default values to ensure compliance with international guidelines.

Traceability

traceability of sources was maintained by organizing all references, reports, and datasets in a structured data repository. This organization provided easy access and supported future updates, thereby enabling consistency across reporting cycles.

By implementing these QA/QC and verification measures, the national GHG inventory for the cement industry ensures credible, transparent, and reproducible emissions estimates. Moving forward, efforts will focus on improving data collection mechanisms, increasing industry engagement, and exploring higher-tier methodologies to enhance inventory accuracy.

4.2.3.1 National/Site-Specific Activity Data Check

Both plants are equipped with well-established laboratories to ensure that product data complies with national standards. Cement products from these facilities are certified under the Malawi Bureau of Standards (MBS) MS 29: 2001 cement standard, which sets stringent sampling and testing requirements. This standard serves as an external validation mechanism, establishing robust QA/QC systems at both plants to confirm that each certified product meets quality specifications (IPCC, 2006).

However, differences were noted in how each plant reports Calcium Oxide (CaO) content, a crucial factor for estimating clinker emissions. Plant B reports an annual average value for CaO content, while Plant A uses a control limit approach, indicating whether values fall within a predefined range without providing precise averages. Although these differences do not directly impact compliance with MS 29: 2001, they introduce variability in emission factor calculations, underscoring the need for site-specific data checks.

4.2.3.2 Emission Factor Consistency Checks

To minimize uncertainty in emission factors, both plants carry out chemical analyses to determine CaO content in clinker. However, due to discrepancies in reporting (fixed ranges in Plant A vs. average values in Plant B), the estimated uncertainty varies—4.5% for Plant A and 4% for Plant B. This variation highlights the necessity for standardized reporting practices that would facilitate consistent data interpretation and reduce measurement errors (IPCC, 2006).

4.2.3.3 Activity Data Verification and Reporting Completeness

Activity data from each plant is directly sourced and reported to regulatory bodies, which helps maintain low uncertainty (4% for both plants). However, instrument-related errors and operator-related measurement issues present potential sources of error, emphasizing the importance of regular calibration of measurement equipment and training for personnel involved in data collection. Additionally, assumptions about clinker kiln dust (CKD) composition—specifically, that it is equivalent to raw meal and entirely composed of CaCO_3 —introduce an uncertainty of 3.5% for CKD estimates (IPCC, 2006).

In line with the Paris Agreement's MPGs and IPCC guidelines, Malawi's cement industry has made significant progress in implementing QA/QC measures that align with national standards. Although the industry faces capacity constraints, continued improvements in data reporting standards—such as standardized reporting for CaO content—could help reduce uncertainty. The flexibility in QA/QC practices allows for progressive refinement, contributing to more reliable GHG emission inventories while supporting the country's broader environmental goals.

4.2.3.4 *Category-specific planned improvements*

To enhance the transparency and accuracy of greenhouse gas (GHG) emissions accounting in Malawi's cement production industry (Category 2A1), the country is developing specific emission factors and activity data tailored to local production practices. This initiative aligns with the non-mandatory provisions of paragraph 7 in the IPCC's MPGs, which provide flexibility for developing countries with limited data capacities (IPCC, 2006). Transitioning from Tier 1 to Tier 2 methodologies is essential for Malawi, as national emission factors have historically relied on default IPCC values that may not accurately reflect local conditions.

Currently, the framework is in the final stages of development and has produced preliminary findings, including insights into clinker production volumes and the calcium oxide (CaO) content specific to Malawi's cement industry. For instance, initial data indicates that Plant B produces an average of approximately 199,741 tonnes of clinker annually, with the CaO content consistently within the IPCC's recommended range of around 65% (Gondwe, Chiotha, & Mkandawire, 2017; IPCC, 2006). These findings contribute to a more accurate emissions profile by aligning with the actual material composition and production processes unique to Malawi's cement sector.

However, the framework is still undergoing critical review by local experts, and further refinements are anticipated. Both data collection methodologies and calculation procedures are being evaluated to ensure their reliability. Once this review phase concludes, additional peer assessments will be necessary before the final data and methodology are integrated into Malawi's national GHG inventory and approved by the UNFCCC. These planned improvements are a vital step toward more accurate GHG accounting and effective policy-making within Malawi's IPPU sector (IPCC, 2006).

4.2.4 *Lime production (2A2)*

The lime production industry, categorized under the Industrial Processes and Product Use (IPPU) sector as CRT category 2.A.2, is primarily characterized by the calcination of limestone (CaCO_3) to produce quicklime (CaO) and subsequently hydrated lime (Ca(OH)_2). This process is a significant source of carbon dioxide (CO_2) emissions due to the thermal decomposition of limestone, which releases CO_2 as a byproduct (IPCC, 2006). The industry typically comprises various production methods, including vertical kilns, rotary kilns, and other advanced technologies, each with varying emission profiles based on operational efficiency and fuel types utilized (Fearnside, 2012).

Lime is widely used across multiple sectors, including construction, agriculture, and environmental management, serving purposes such as soil stabilization, water treatment, and as a raw material in cement production (Limestone Resources Limited, 2016). The key characteristics of sources within the lime production category involve diverse operational practices, raw material characteristics, and end-use applications. Each of these factors contributes to the variability of emissions and necessitates tailored approaches for GHG inventory reporting (WMO, 2020).

4.2.4.1 Methodological Issues

For lime production in Malawi, the Tier 1 methodology was adopted due to the limited availability of detailed activity data and emission factors specific to the country. The Tier 1 approach, provided by the IPCC, which uses default emission factors and simplified calculations, making it suitable for countries like Malawi where lime production is largely informal and data collection remains challenging.

4.2.4.1.1 Activity Data:

The activity data required for lime production reporting include the total amount of lime produced annually. In Malawi, the production is predominantly artisanal, with limited formal record-keeping, so estimates will rely on secondary data, surveys, or proxy measures of lime production volumes.

Table 4-3: Production data from the lime industry

YEAR	Mass of Lime Produced (tonne)	Net CO ₂ (Gg)
1994	3544	2.09
2000	6177	3.64
2010	45851	15.21
2017	43650	25.75
2018	48461	28.59
2019	52817	31.16
2020	74075.71	43.70
2021	77186.26	45.54
2022	80296.82	47.38

4.2.4.1.2 Emission Factors:

The IPCC default emission factor for lime production, which is 0.75 tonnes of CO₂ per tonne of lime produced, will be used. This factor assumes complete conversion of limestone to lime, with no carbon dioxide capture or sequestration during production. The equation is as follows;

4.2.4.1.3 Estimation of carbon dioxide emission from lime Production

The estimation of Carbon dioxide from the lime production, Tier 1 Equation, 2.8 from the IPCC guidelines was adopted based on tonnage of lime produced as follows:

$$EF_{lime} = 0.85 * EF_{high\ calcium\ lime} + 0.15 * EF_{dolomitic\ lime}$$

Equation 4-2:

$$\begin{aligned} &= 0.85 * 0.75 + 0.15 * 0.77 \\ &= 0.6375 + 0.1155 \\ &= 0.75\ tonne\ CO_2 / tonne\ lime\ produced \end{aligned}$$

Assumptions and Parameters:

- It is assumed that all lime produced results in full CO₂ release based on the chemical reaction of calcium carbonate calcination.
- Due to the lack of national-specific emission factors, the default values provided by IPCC are used. This ensures consistency with international reporting guidelines.
- For fuel combustion emissions, the default emission factors for the type of fuel commonly used (biomass or coal) in artisanal kilns will also be applied.

Carbon Dioxide Capture:

There are no technologies currently in use in Malawi's artisanal lime production sector for carbon dioxide capture and storage, so no deductions for CO₂ sequestration were made.

The rationale for using these methods is to provide a simple, consistent, and internationally recognized means of estimating emissions in a sector where formal data collection mechanisms are not yet established.

4.2.4.2 Description of any flexibility applied for the lime industry

For lime production, the inventory utilized secondary data sources, including national reports, industry estimates, and historical production records. This approach was necessary due to the limited direct reporting from lime manufacturers. The 2006 IPCC Guidelines (Vol. 3, Ch. 2) recommend using national activity data where available; however, in cases of missing or incomplete data, secondary sources and proxy estimates can be employed to fill the gaps.

To ensure consistency and completeness, historical production trends were used to estimate emissions for certain years when direct data was unavailable. Additionally, the default IPCC emission factor for lime production was applied because plant-specific emission factors could not be obtained. This method aligns with the IPCC Tier 1 methodology, which permits the use of default parameters and secondary data sources when country-specific data is lacking.

While relying on secondary data introduces some uncertainty in emissions estimates, this approach allowed for the inclusion of lime production emissions across the entire time series without significant data gaps. Future efforts will focus on engaging industry stakeholders to improve direct data reporting and enhance transparency.

4.2.4.3 Uncertainty assessment and time-series consistency

4.2.4.3.1 National/Site-Specific Activity Data Check

Both plants are equipped with well-established laboratories to ensure that product data complies with national standards. Cement products from these facilities are certified under the Malawi Bureau of Standards (MBS) MS 29: 2001 cement standard, which sets stringent sampling and testing requirements. This standard serves as an external validation mechanism, establishing robust QA/QC systems at both plants to confirm that each certified product meets quality specifications (IPCC, 2006).

However, differences were noted in how each plant reports Calcium Oxide (CaO) content, a crucial factor for estimating clinker emissions. Plant B reports an annual average value for CaO content, while Plant A uses a control limit approach, indicating whether values fall within a predefined range without providing precise averages. Although these differences do not directly impact compliance with MS 29: 2001, they introduce variability in emission factor calculations, underscoring the need for site-specific data checks.

4.2.4.3.2 Emission Factor Consistency Checks

To minimize uncertainty in emission factors, both plants carry out chemical analyses to determine CaO content in clinker. However, due to discrepancies in reporting (fixed ranges in Plant A vs. average values in Plant B), the estimated uncertainty varies—4.5% for Plant A and 4% for Plant B. This variation highlights the necessity for standardized reporting practices that would facilitate consistent data interpretation and reduce measurement errors (IPCC, 2006).

4.2.4.3.3 Activity Data Verification and Reporting Completeness

Activity data from each plant is directly sourced and reported to regulatory bodies, which helps maintain low uncertainty (4% for both plants). However, instrument-related errors and operator-related measurement issues present potential sources of error, emphasizing the importance of regular calibration of measurement equipment and training for personnel involved in data collection. Additionally, assumptions about clinker kiln dust (CKD) composition—specifically, that it is equivalent to raw meal and entirely composed of CaCO_3 —introduce an uncertainty of 3.5% for CKD estimates (IPCC, 2006).

In line with the Paris Agreement's MPGs and IPCC guidelines, Malawi's cement industry has made significant progress in implementing QA/QC measures that align with national standards. Although the industry faces capacity constraints, continued improvements in data reporting standards—such as standardized reporting for CaO content—could help reduce uncertainty. The flexibility in QA/QC practices allows for progressive refinement, contributing to more reliable GHG emission inventories while supporting the country's broader environmental goals.

4.2.4.4 Time Series Analysis of CO₂ Emissions from Lime Production (1994–2022)

The emissions from lime production in Malawi have fluctuated over the years, reflecting changes in production levels and potentially shifts in industrial activity (

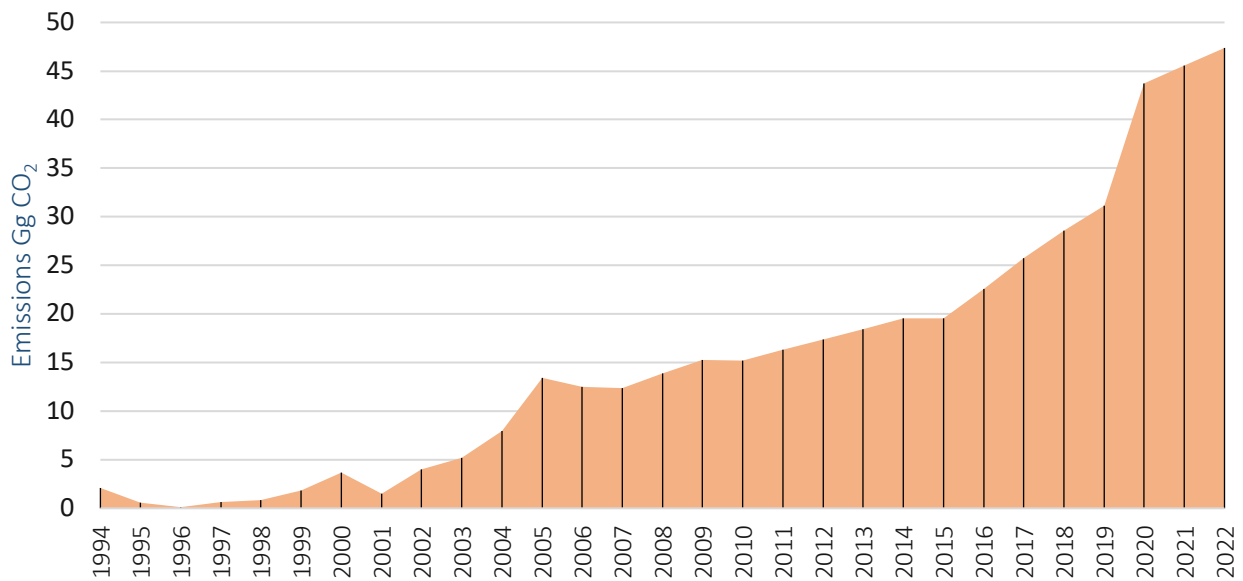


Figure 4-5).

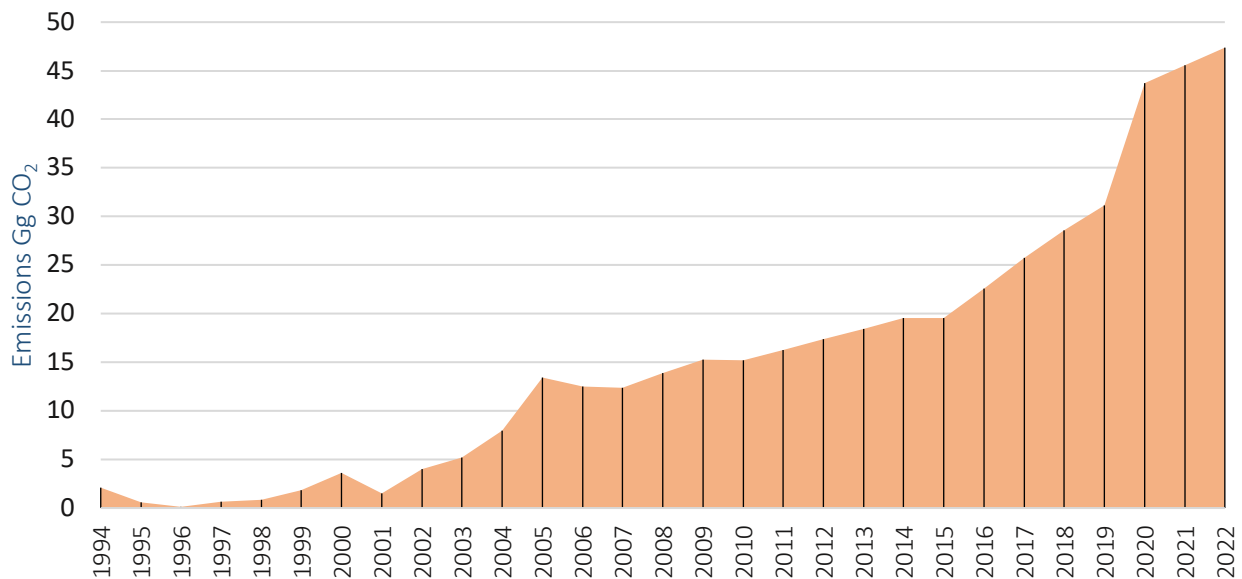


Figure 4-5: Emissions for the Lime industry

From 1994 to 2000, CO₂ emissions from lime production in Malawi fluctuated significantly. Emissions began at 2.09 Gg CO₂ in 1994, dropped sharply to 0.59 Gg CO₂ in 1995, and reached a low of 0.15 Gg CO₂ in 1996. This decline may indicate a reduction in lime production during this period. However,

emissions started to rise again, reaching 3.64 Gg CO₂ by 2000, which suggests a gradual recovery in production.

Between 2000 and 2002, emissions showed a steady increase, growing from 3.64 Gg CO₂ to 3.99 Gg CO₂. This indicates a period of relatively stable and gradually rising lime production.

From 2003 to 2005, emissions increased significantly, rising from 5.16 Gg CO₂ in 2003 to 13.41 Gg CO₂ in 2005. This sharp rise points to a substantial expansion in lime production capacity or increased demand for lime during those years.

During the period from 2006 to 2014, emissions continued to grow steadily. They increased from 12.48 Gg CO₂ in 2006 to 19.54 Gg CO₂ in 2014, demonstrating a consistent upward trend. This rise can be attributed to higher demand in sectors such as construction and agriculture, which rely on lime.

In 2015, emissions remained relatively stable at 19.56 Gg CO₂ but experienced a noticeable increase to 22.58 Gg CO₂ in 2016 and further to 25.75 Gg CO₂ in 2017, indicating ongoing expansion in production capacity.

From 2018 to 2022, there was a significant and steady rise in emissions, increasing from 28.59 Gg CO₂ in 2018 to a peak of 47.38 Gg CO₂ in 2022. This surge corresponds with heightened lime production activities and increasing demand from infrastructure projects.

4.2.4.5 Category-specific QA/QC and verification for the Lime Industry

The development of the national greenhouse gas (GHG) inventory for the lime industry followed a structured quality assurance and quality control (QA/QC) process to ensure the accuracy, completeness, and consistency of emissions estimates. Due to the limited availability of plant-level data, the Tier 1 methodology was applied, relying on default emission factors from the 2006 IPCC Guidelines and national lime production data. The QA/QC and verification processes focused on validating data sources, ensuring comparability across time series, and applying consistency checks to maintain transparency.

Data validation and consistency checks

Historical production data was reviewed carefully to detect inconsistencies or missing values. A trend analysis of lime production and associated CO₂ emissions was conducted to identify any irregularities, such as sudden increases or decreases in emissions. Any anomalies were flagged and cross-checked with available industry reports, stakeholder feedback, and contextual economic factors that could explain variations in production.

Completeness

Data gaps were addressed using proxy estimations where direct production figures were not available. In these cases, historical production trends and industry reports were used to interpolate missing values, ensuring a continuous and reliable dataset for emissions

calculations. All assumptions and estimations were documented to maintain transparency in the inventory process.

Comparability

The reported emissions data were cross-referenced with previous National Communications and Biennial Reports to ensure alignment with past methodologies. Additionally, national figures were benchmarked against regional and global trends to identify potential inconsistencies and refine estimation approaches when necessary.

Verification

Key industry stakeholders—including lime producers, government regulatory bodies, and sector experts—were engaged to review and validate activity data. Peer reviews were conducted to ensure that the reported lime production figures accurately reflected industry operations, thereby reducing the risk of under- or over-estimating emissions. Furthermore, the default emission factors used in the calculations were reviewed against IPCC guidelines to confirm their applicability to the Malawian context.

Traceability

All datasets, references, and reports were systematically stored in a structured data repository. This ensured that all inventory inputs and assumptions were well-documented, facilitating future updates and consistency in subsequent reporting cycles.

4.2.4.6 *Category-specific recalculations*

For cement production, recalculations were made primarily due to updates in activity data, where more recent and reliable production figures were obtained from industry sources. Additionally:

- Previous inventories did not specify the type of cement produced (e.g., clinker-based cement, blended cement, etc.). This lack of distinction meant that a default emission factor (Tier 1) for clinker-based cement was applied. However, given that some cement in Malawi may involve partial clinker substitution, future refinements may require disaggregating production data into cement types and adjusting emission factors accordingly (IPCC, 2006).
- Improved production data for recent years required recalculations of historical trends to ensure consistency and comparability across time series. The changes mainly impacted estimates from 2015 onward, where refined production data was integrated into the inventory.

Methodological Consistency

Despite data updates, the methodology remained consistent with the Tier 1 approach, using the IPCC default emission factor of 0.51 t CO₂ per tonne of clinker produced (IPCC, 2006). Since clinker

production data was not directly available, the cement production data was used as a proxy, assuming typical clinker ratios from regional or global default values.

For lime production, recalculations were required due to the following reasons:

- Previous inventories relied on limited data sources, leading to potential underestimation of emissions. For this reporting cycle, secondary data sources were used to estimate production trends more accurately.
- Activity data adjustments were made based on additional industry reports and production statistics. This update refined the time series for lime production emissions, particularly for the period 2015-2023, where more detailed production figures were available.
- Correction of minor inconsistencies in historical trends by ensuring a smooth transition between reporting years, avoiding abrupt fluctuations that were due to data limitations rather than actual production trends.

Methodological Consistency

- The default Tier 1 emission factor of 0.79 t CO₂ per tonne of lime produced was maintained (IPCC, 2006).

Since no direct plant-level data was available, production figures were extracted from secondary sources, meaning there is still room for improvement through primary data collection in future inventories.

4.3 Chemical Industry (Category 2B)

The Chemical Industry (Category 2B) under the Industrial Processes and Product Use (IPPU) sector addresses greenhouse gas (GHG) emissions resulting from chemical transformations in industrial production. These emissions differ from those caused by fuel combustion; they arise from the chemical reactions involved in manufacturing various industrial products (IPCC, 2006). Typical activities in this category include the production of ammonia, nitric acid, carbide, and other chemical manufacturing processes that release carbon dioxide (CO₂), methane (CH₄), nitrous oxide (N₂O), and other greenhouse gases (IPCC, 2019).

Exclusion from This Inventory

For this national inventory cycle, Category 2B (Chemical Industry) was not included due to the lack of identified industrial chemical production activities that contribute significantly to process-related GHG emissions in Malawi. The absence of reported data on ammonia, nitric acid, or other relevant chemical manufacturing processes hindered the inclusion of this category in the emissions estimates. This approach is consistent with the flexibility provisions of the Paris Agreement, which allow countries with limited data availability to focus on key emission sources (UNFCCC, 2018).

Future inventories may consider evaluating the potential emergence of chemical industries in Malawi and improving data collection methods to determine whether this category should be included in subsequent reporting cycles.

4.4 Other process uses of Carbonates (Category 2A4)

The Non-Metallic Mineral Products category (2A4) under the Industrial Processes and Product Use (IPPU) sector includes emissions generated during the manufacturing of ceramics, glass, gypsum, and other mineral-based products. These emissions result from chemical reactions that occur during production processes, such as the decomposition of carbonates and the high-temperature processing of raw materials (IPCC, 2006). Key sources of emissions in this category include clay bricks, tiles, glass production, and gypsum-based products, where carbon dioxide (CO₂) is primarily released due to the heating of mineral compounds.

Exclusion from This Inventory

For this reporting cycle, emissions from Category 2A4 (Non-Metallic Mineral Products) were not accounted for due to limited data availability on industrial production activities in Malawi related to ceramics, glass, and gypsum manufacturing. No verified data sources were identified to support the estimation of emissions from this category. As a result, greenhouse gas (GHG) emissions from this sector were not included in the inventory calculations.

Given the increasing industrialization and potential growth of non-metallic mineral product manufacturing, future inventory reports may explore data collection mechanisms to assess emissions from this category and evaluate its significance within Malawi's overall GHG profile.

Chapter 5:



Agriculture

5.1 Livestock

5.2 Overview of the sub sector and background information

The Malawi livestock subsector contributes 11% of Gross Domestic Product (GDP) and about 36% of agriculture GDP (Ministry of Agriculture, 2021). Livestock rearing plays pivotal roles in Malawi as source of income, food, and nutrition security, create employment along value chains and resilience buffering effect from rampant climatic shocks that Malawi has been exposed to in the recent past 10 years. The main livestock species reared are cattle, goats, sheep, pigs, poultry and other non-conventional species like guinea fowls, ducks, rabbits and pigeons. Most of these livestock are indigenous owned by smallholder farmers applying extensive management practices.

Livestock production in Malawi is predominantly smallholder farmer based with few commercial farms. GHG emission estimation in the SNC and TNC used Tier 1 default values from 2006 IPCC Guidelines (referred to as the Guidelines henceforth). All the species covered in the GHG calculations are in abundance in Malawi whereas some animals like buffalos are considered as wildlife therefore not constituting livestock category in Malawi. Activity data reports for livestock in Malawi do not include horses, hence are not reported in the report. For all livestock species Tier 1 using 2006 IPCC default values have been used in all the GHG estimates in the report. Thus, the report covers emissions estimated from dairy cattle, other cattle, sheep, goats, pigs (breeding and marketed pigs), poultry (dual purpose, broilers, layers), and rabbits. The main livestock emission sources being enteric fermentation CH₄ (reporting category 3A1; cattle, sheep, goat, pigs and rabbits); manure management CH₄ and N₂O (reporting category 3A2, all livestock species); direct N₂O emissions from dung and urine deposit on pasture (which contributes to reporting category 3C4, cattle, sheep, goats, chicken), indirect N₂O emissions from dung and urine deposit on pasture (which contributes to reporting category 3C5) and indirect N₂O emissions from manure management (reporting category 3C6).

For each of the above mentioned GHG emission sources, the text describes the following:

1. Source category description, including the estimated total emissions for the category; and key input data used. Details of data sources and methods used to calculate the key input data are given in the [Annex 5.3](#).
2. Methodological issues include choice of methods, activity data, emission factors, assumptions, and other methodological issues.
3. Uncertainty analysis
4. Source-specific QAQC and verification.
5. Source-specific recalculations

For each source category, the main text further describes the results of inventory compilation, the methodologies and key input data used.

5.3 Enteric Fermentation (Category 3.A1)

Enteric emissions from poultry were not estimated because the 2006 IPCC Guidelines and the 2019 Refinement did not provide methodologies for doing this. The emissions were calculated using 2006

IPCC Equation 10.19 (sheep, goat, pigs, rabbits) and Equation 10.20 (dairy and other cattle) as follows:

$$Emissions = EF_{(T)} \left(\frac{N_{(T)}}{10^6} \right)$$

Equation 5-1

Emissions = methane emissions from Enteric Fermentation, Gg CH₄ yr⁻¹

EF_(T) = the emission factor of livestock species/category T in the country

N_(T) = the number of head of livestock species/category T in the country

T = species/category of livestock.

$$Total CH_{4Enteric} = \sum_i E_i$$

Equation 5-2

Total CH_{4Enteric} = total methane emissions from Enteric Fermentation, Gg CH₄ yr⁻¹

E_i = is the emissions for the *i*th livestock category.

The resulting emission for each year and livestock sub-category is shown in **Error! Reference source not found..**

5.3.1 Source category description

Table 5-1 shows summary descriptions of the sources of enteric methane from the livestock sector.

Table 5-1: Sources of enteric CH₄ emission from livestock sector

Emissions sources	Sources included	Method	Emission factors
3.A.1.a.i	Dairy cattle enteric fermentation	Tier 1	IPCC (2006) Table 10.11
3.A.1.a.ii	Other cattle enteric fermentation	Tier 1	IPCC (2006) Table 10.11
3.A.1.C	Sheep enteric fermentation	Tier 1	IPCC (2006) Table 10.10
3.A.1.D	Goat enteric fermentation	Tier 1	IPCC (2006) Table 10.10
3.A.1.H.i	Breeding pigs enteric fermentation	Tier 1	IPCC (2006) Table 10.10
3.A.1.H.ii	Marketed pigs enteric fermentation	Tier 1	IPCC (2006) Table 10.10
3.A.1.J	Rabbits enteric fermentation	Tier 1	IPCC (2006) Table 10.10
Gases reported	CH ₄		
Completeness	All major livestock species (except poultry) are covered. Donkeys and horses were not included because they are not considered major livestock (because of their low numbers) and are not widely distributed in the country. They may be included in future revisions.		
Improvements since last submission	This is the first inventory for that includes rabbits in response to a 2019 QA review finding		

5.3.2 Methodological Issues

The IPCC Tier 1 Method was applied for dairy and other cattle, sheep, goats, pigs and rabbits.

5.3.3 Activity data

5.3.3.1 Livestock population

The activity data for enteric fermentation emissions were for the major livestock species: cattle (dairy and other), sheep, goats, pigs and rabbits (Figure 5-1). Livestock data sources were Agriculture Production Estimates Survey (APES) reports from the 28 agricultural districts in Malawi covering the 8 Agricultural Development Divisions (ADD) that represent agroecological zones of Malawi. The data are collected by agriculture field staff twice a year (January and June).

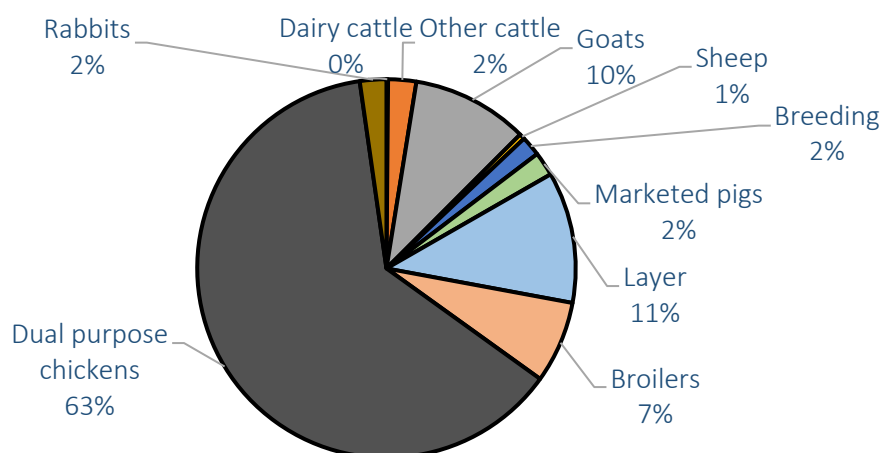


Figure 5-1: livestock composition (%)

Table 5-2: Activity for livestock emissions

Years	Dairy Cattle	Other Cattle	Sheep	Goats	Mature Swine	Growing Swine
1994	26,407	767,693	81,286	1,534,104	123,921	149,618
2000	37,243	773,231	131,140	1,767,000	131,626	158,922
2010	55,303	1,027,397	214,230	3,893,922	873,881	1,055,097
2017	90,355	1,449,552	302,090	7,672,737	2,700,501	3,260,501
2018	98,144	1,590,730	317,491	8,374,006	3,102,541	3,745,912
2019	105,637	1,620,610	331,272	9,147,837	2,133,024	2,575,346
2020	113,885	1,711,058	351,458	10,028,678	2,431,095	2,935,228
2021	125,943	1,790,018	373,715	11,104,382	2,700,501	3,260,501
2022	137,885	2,054,208	404,956	12,238,382	3,102,541	3,745,912

Table 5-3 show the population trends of poultry and rabbits in Malawi for the period 1994 to 2022.

Table 5-3: Poultry and rabbits population trend 1994 to 2022

Years	Broiler chickens	Layer chickens	Dual purpose chickens	Rabbits
-------	------------------	----------------	-----------------------	---------

1994	4,165,277	816,030	7,833,183	36,938
2000	3,828,821	2,550,930	8,294,935	124,406
2010	3,268,061	5,442,430	21,168,556	894,025
2017	4,628,592	6,737,380	53,076,214	1,735,875
2018	6,496,873	7,443,847	60,676,441	2,285,239
2019	9,124,592	8,132,924	69,107,661	2,577,733
2020	10,392,520	8,804,436	77,690,553	3,096,033
2021	13,850,596	9,803,012	86,170,934	3,458,230
2022	14,039,674	11,088,264	96,956,612	3,861,884

5.3.3.1.1 Cattle (diary and other cattle)

Cattle populations kept increasing from 2018 to 2022. Dairy cattle increased from 26,407 to 137,885, representing a 422.2 percent increase (Figure 5-2). Most of these dairy cattle herd are half crosses of Indigenous Malawi zebu and Friesian dairy animals. On the other hand, other cattle (predominantly Malawi Zebu) increased from 767,693 in 1994 to 2,054,208 in 2022, registering a 167.6 percent jump.

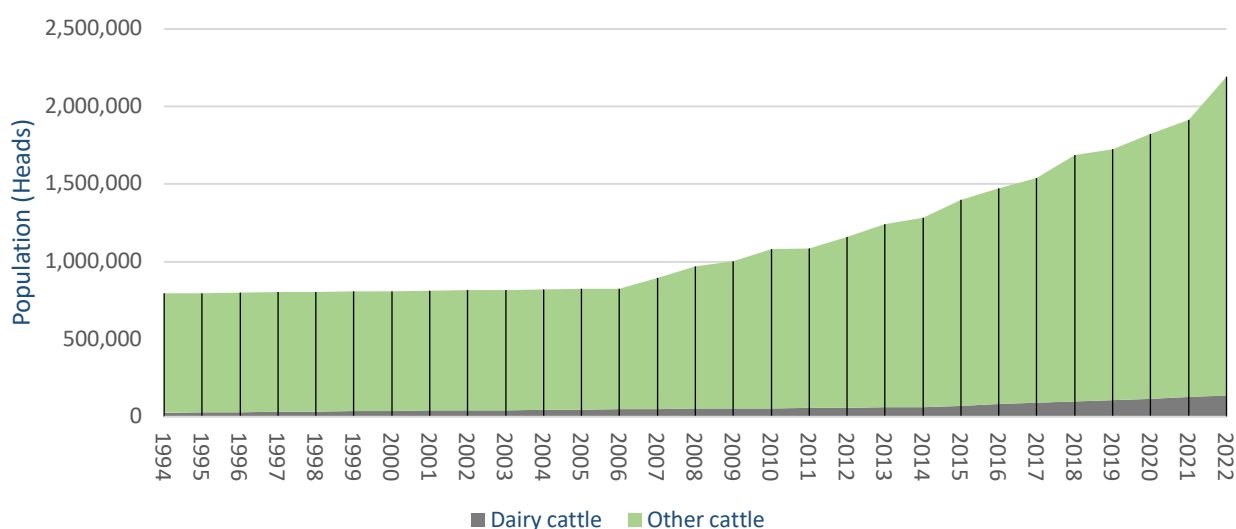


Figure 5-2: Population of cow by head

Source: District and Agriculture Development Divisions reports

5.3.3.1.2 Sheep

Sheep increased from 81,286 in 1994 to 404,956 in 2022, a 398.2 percent increase (Figure 5-3). Most of these sheep are of indigenous breeds.

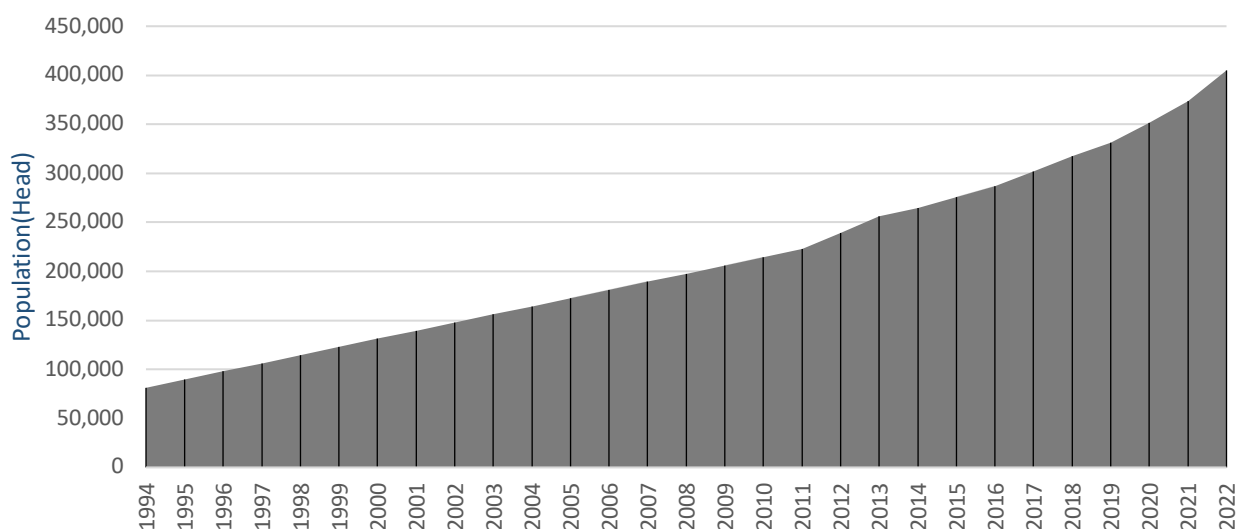


Figure 5-3: Population of sheep by head

Source: District and Agriculture Development Divisions reports

5.3.3.1.3 Goats

Goats also increased from 1, 534,104 in 1994 to 12,238,382 in 2022, representing 697.7 percent increase (Figure 5-4). Government program and non-governmental organizations efforts in issuing goats to vulnerable farmers to broaden ownership and enhance food security are the primary reason why goats number skyrocketed in the period under review.

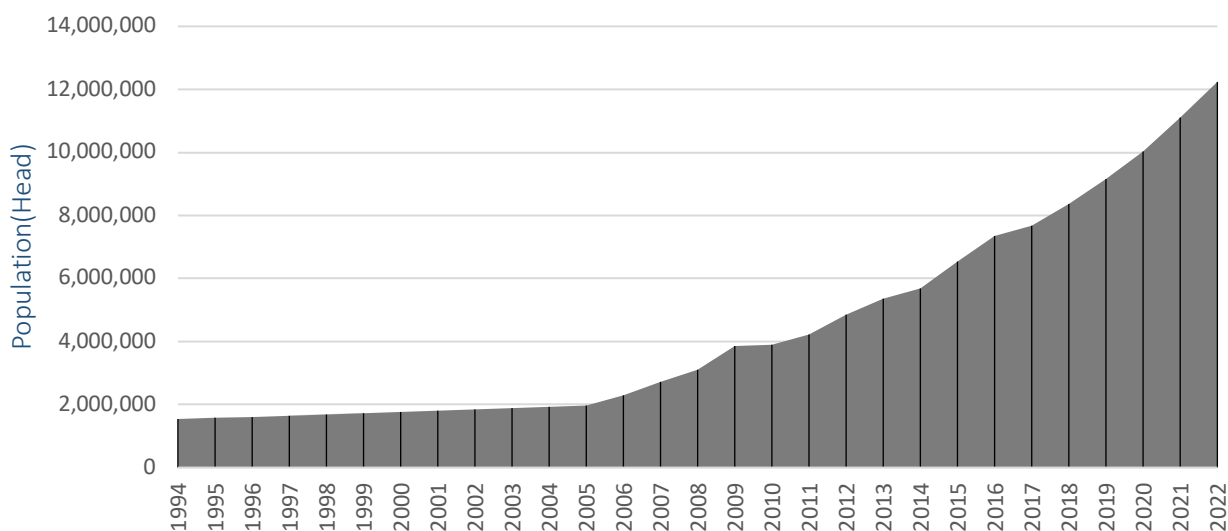


Figure 5-4: Population of goats by head

Source: District and Agriculture Development Divisions reports

5.3.3.1.4 Pigs (breeding and marketed pigs)

Pigs in Malawi are categorized into breeding pigs that live longer than one year (approximately 71 percent), and those that are slaughtered as porkers within 6 to 7 months of age (approximately 29 percent). The annual average of slaughtered porker population (living shorter than a year) was estimated using Equation 5-3 :

$$AAP = days_alive * \left(\frac{NAPA}{365} \right)$$

Equation 5-3

where:

AAP = annual average population

NAPA = number of animals produced annually

Breeding pigs increased from 73,112 in 1994 to 3,102,541 in 2022 recording a 4,143.5% increase. Fattening pigs increased from 88,274 in 1994 to 3,745,912 in 2022, also translating like breeding pig's percent increase (Figure 5-5). The drivers for the increases were good response of farmers to good husbandry practices and promotions from Government and non-governmental organisations in a quest to broaden livestock ownership.

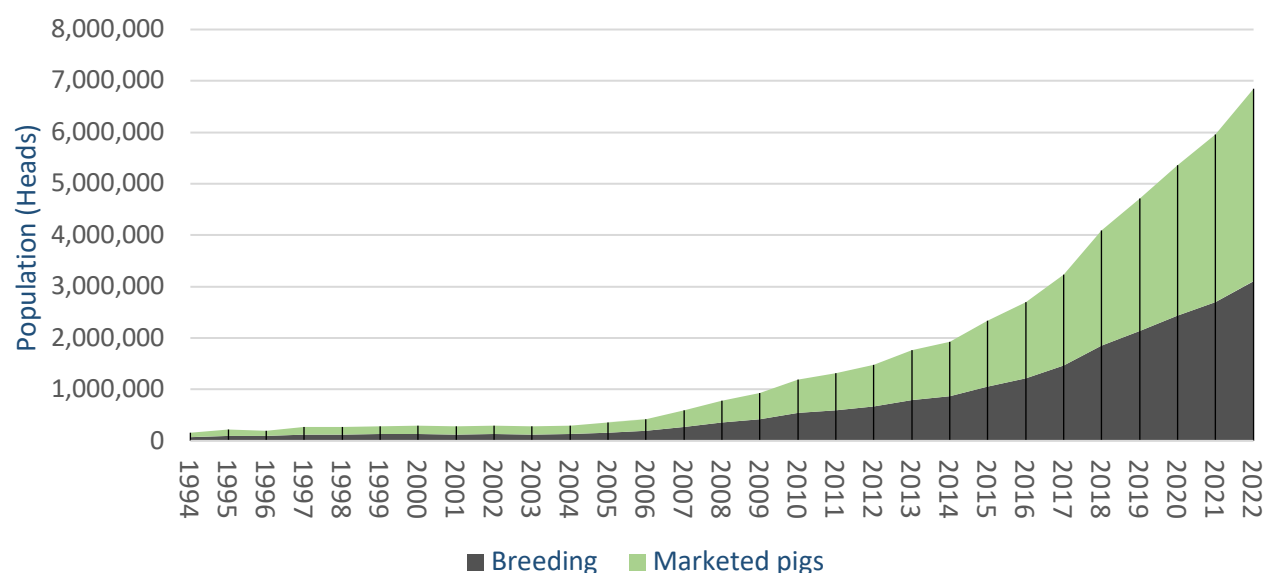


Figure 5-5: Population of pigs by head and type

Source: District and Agriculture Development Divisions reports

5.3.3.1.5 Poultry (dual purpose, broiler; layer)

Poultry in Malawi are mainly dual-purpose chicken constituting Black Australorps and indigenous chickens. A similar procedure as in section 1.2.1.14 was also applied to estimate the annual average population of broilers and layers. Dual-purpose chicken registered the biggest jump from 7,833,183 in 1994 to 96,956,612 in 2022 representing a 1,137.7 percent increase (Figure 5-6). Government programs and Non-Governmental Organization efforts in issuing chicken to vulnerable farmers to

broaden ownership and enhance food security are the major reasons why dual-purpose chicken number skyrocketed in the period under review.

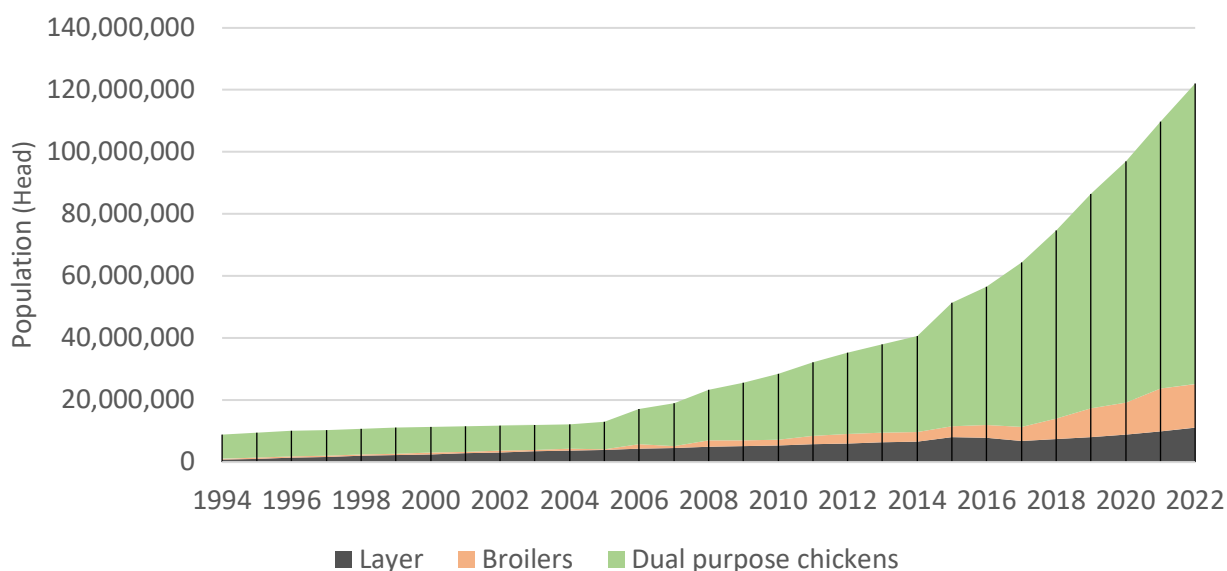


Figure 5-6: Population of chicken by head and type

Source: District and Agriculture Development Divisions reports

5.3.3.1.6 Rabbits

In 2022 there were 3,861,884 rabbits compared to 36,938 rabbits in 1994, which translates to a 105,108.4% increase (Figure 5-7) due to Government programs and Non-Governmental Organization efforts in issuing rabbits to vulnerable farmers to broaden ownership and enhance food security.

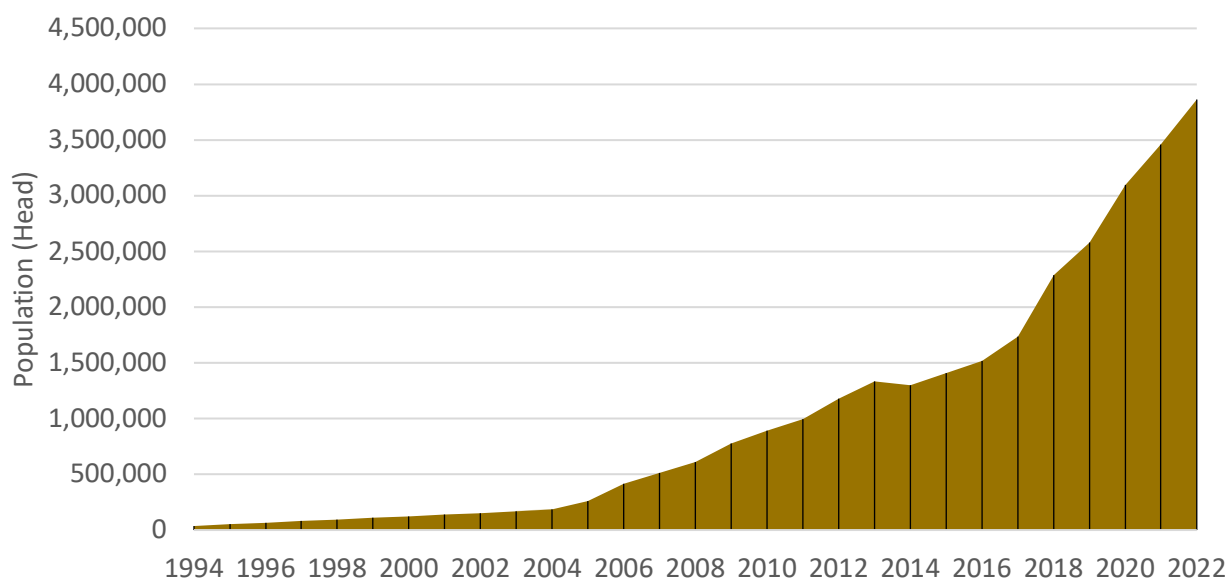


Figure 5-7: Population of rabbits by head

In summary, all livestock subcategories population increased because of increased adoption of good agricultural practices such as good housing, feeding, parasite and disease control and good breeding and due to increased livestock ownership programmes mostly through pass-on programmes implemented by the Malawi Government and Non-Governmental Organizations.

5.3.4 Emission factors

Table 5-4 details enteric fermentation emission factors derived from the Guidelines that have been used for the GHG calculation for each livestock subcategory.

Table 5-4: Enteric fermentation emission factors (kg CH₄ head-1 year-1)

Species	Emission factors	Reference
Dairy cattle	46	IPCC 2006 Table 10.11
Other cattle	31	IPCC 2006 Table 10.11
Sheep	5	IPCC 2006 Table 10.10
Goat	5	IPCC 2006 Table 10.10
Breeding pigs	1	IPCC 2006 Table 10.10
Marketed pigs	1	IPCC 2006 Table 10.10
Rabbits*	0.92	Estimated based on approximate emission factors (p.32, IPCC 2019).

*The approach for developing the approximate emission factors for rabbits was to use the Tier 1 emissions factor for an animal with a similar digestive system (horse) and to scale the emissions factor using the ratio of the weights of the animals raised to the 0.75 power. Approximate emissions factor = [(Rabbit weight, 4.5 kg)] / (Horse weight, 235 kg)]^{0.75} * Horse IPCC emission factor (18 kg CH₄/head/year).

5.3.5 Calculation of emissions

Emissions from enteric fermentation were estimated with the Tier 1 method, using equations 10.19 and 10.20 from the 2006 IPCC guidelines:

$$Emissions = EF_T * \left(\frac{N(T)}{10^6} \right)$$

Equation 5.-5-4

where:

Emissions= methane emission from Enteric Fermentation, Gg CH₄ yr⁻¹

EF_(T)=the emission factor of livestock species/category T in the country

N_(T)=the number of head of livestock species/category T in the country; T=species/category of livestock.

$$TotalCH_{4Enteric} = \sum_i E_i$$

Equation 5.-5-5

where:

Total CH_{4Enteric}= total methane from Enteric fermentation, Gg CH₄ yr⁻¹

E_i = the emissions for the i^{th} livestock categories and subcategories

5.4 Enteric fermentation emissions

The emission values are presented in Figure 5-8. The 1994 and 2022 enteric fermentation emissions were 31.8 and 144 Gg, respectively, representing a 351 percent increase. The large increase in emissions is attributed to the increased number of livestock due to increased livestock ownership and adoption of recommended livestock husbandry practices. The key source categories were other cattle and goats, which together contributed between 96 percent and 87 percent of all enteric methane emissions in 1994 and 2022, respectively. The contribution of other cattle has been going down, while that of goats has been going up in the last decade. Pigs and rabbits showed the most increase in emissions between 1994 and 2022, due to the high increase in their numbers. Table: Methane emission from enteric fermentation by sub-categories (Gg CH₄ year⁻¹)

The GHG emission values are given in Table 5-5.

Table 5-5: CH₄ emissions from Enteric fermentation

Years	Dairy Cattle	Other Cattle	Sheep	Goats	Mature Swine	Growing Swine	Rabbits
1994	1.21	23.80	0.41	7.67	0.12	0.15	0.03
2000	1.71	23.97	0.66	8.84	0.13	0.16	0.11
2010	2.54	31.85	1.07	19.47	0.87	1.06	0.82
2017	4.16	44.94	1.51	38.36	2.70	3.26	1.60
2018	4.51	49.31	1.59	41.87	1.84	5.01	2.10
2019	4.86	50.24	1.66	45.74	1.47	3.24	2.37
2020	5.24	53.04	1.76	50.14	1.61	3.76	2.85
2021	5.79	55.49	1.87	55.52	1.74	4.22	3.18
2022	6.34	63.68	2.02	61.19	2.07	4.77	3.55

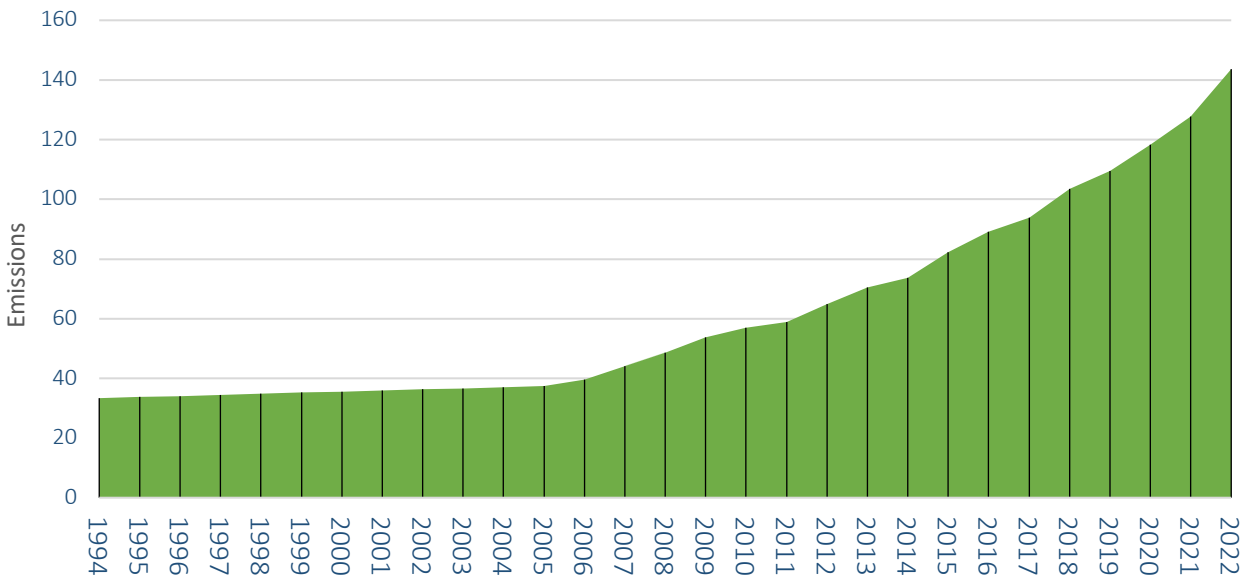


Figure 5-8: CH₄ emissions from Enteric fermentation

5.4.1 Uncertainties and time-series consistency

The activity data for enteric fermentation emissions were from the major livestock species: cattle (dairy and other), sheep, goats, pigs (breeding and marketed pigs) and rabbits.

For 1994, due to lack of information on the sampling procedure used to collect activity data, the uncertainty (UNC) of livestock numbers is assumed to be around 10 percent based on expert judgment by the inventory task force members. For 2022, the uncertainty of the activity data is assumed to be nearly 0% because the data were obtained via census (head count of the livestock) and not through sampling. The uncertainty values for activity data are the same for all livestock categories. The UNC value for the emission factors is assumed to be ± 50 percent for Tier 1 (according to the Guidelines Section 10.3.4). Using error propagation as $UNC_{Comb} = \sqrt{UNC_{AD}^2 + UNC_{EF}^2}$, the combined UNC for 1994 was $\sqrt{10^2 + 50^2} = \sqrt{2600}$ which is ($\pm 51\%$) while that for 2022 was the same as UNC for the EFs ($\pm 50\%$). A summary of uncertainty values for all source categories is given in Annex II.

For each livestock sub-category, consistent methods have been used to estimate the time series for enteric fermentation emissions.

5.4.2 Source-specific QA/QC and verification

Tier 1 and Tier 2 QA/QC activities have been implemented. This inventory was compiled in an Excel spread sheet. Quality control activities included:

- Checking that the equations programmed in the spreadsheet were correctly input.
- Checking that inputs to summed totals were obtained from the correct fields.
- Checking that all data sources were fully documented.
- Checking that the figures in the inventory spreadsheet were correctly transcribed from prior worksheets.

- Checking that the figures in the inventory report were correctly transcribed.
- Reconstructing several calculations to cross-check the intermediate calculations and results in the inventory spread sheet.

The population time-series used in this inventory are slightly lower (3%) in the early 1994 's and higher (8%) in 2000's than the FAOSTAT series because the series in this inventory are mostly based on actual livestock headcounts, while the FAOSTAT figures are extrapolated values. For instance, the FAO series number of cattle in 2021 is 2,036,980 while the official figure is 1,915,961 (representing a difference of about 6%).

5.4.3 Source-specific recalculations

This inventory used the same emission factors as those used in the (previous) TNC (Malawi Government, 2021). However, the emission values calculated in this inventory for the year 2010 are different from those calculated in the TNC. Emission values were higher for dairy cattle, sheep and pigs in the TNC than in this inventory. The 2010 total enteric fermentation emissions amounted to 59.36 Gg CH₄ according to the TNC and 56.95 Gg CH₄ according to this inventory. This translates into a difference of 2.41 Gg CH₄, which may be due to that fact that

- rabbits were not included in the TNC, and
- the average annual population (number of days alive) were not calculated for pigs, resulting in differences in numbers of livestock used for calculation between the two inventories.

Table 5-6: Source-specific recalculations for methane emissions (Gg CH₄) from enteric fermentation for the year 2010

Inventory	Dairy cattle	Other cattle	Goats	Sheep	Pigs*	Rabbits**	Total
TNC	4.16	31.85	19.47	1.51	2.37	-	59.36
This inventory	2.54	31.85	19.47	1.07	1.19	0.82	56.95
Change (%)	-39	0	0	-29	-50	N/A	-4

* Pigs were not disaggregated into marketed and breeding pigs in the TNC.

** Rabbits were not included in the TNC.

5.5 Emissions from manure management (Category 3.A2)

This chapter describes the estimation of CH₄ and direct N₂O emissions from animal manure management systems.

5.5.1 Source category description

The sources of CH₄ emission from livestock sector is shown in **Error! Reference source not found.**

Table 5-7: Sources of CH₄ emission from livestock sector

Emissions sources	Sources included	Method	Emission factors
3.A.2.a.i	Dairy cattle manure management	Tier 1	IPCC (2006) Table 10.14

3.A.2.a.ii	Other cattle manure management	Tier 1	IPCC (2006) Table 10.14
3.A.2.c	Sheep manure management	Tier 1	IPCC (2006) Table 10.15
3.A.2.d	Goat manure management	Tier 1	IPCC (2006) Table 10.15
3.A.2.h.i	Breeding pigs manure management	Tier 1	IPCC (2006) Table 10.14
3.A.2.h.ii	Marketed pigs manure management	Tier 1	IPCC (2006) Table 10.14
3.A.2.i.i	Layers	Tier 1	IPCC (2006) Table 10.15
3.A.2.i.ii	Broilers	Tier 1	IPCC (2006) Table 10.15
3.A.2.i.iii	Dual purpose chickens	Tier 1	IPCC (2006) Table 10.15
3.A.2.j	Rabbits manure management	Tier 1	IPCC (2006) Table 10.16
Gases reported	CH ₄ , N ₂ O		
Completeness	All major livestock species covered		
Improvements since last submission	This is the first inventory for sheep, goat, pigs, rabbits that uses a Tier 1 approach to estimate direct N ₂ O emissions. Indirect N ₂ O from manure management is reported separately according to the IPCC 2006 Guidelines.		

5.5.2 Methodological Issues

The IPCC Tier 1 default values were applied for dairy and other cattle, sheep, goats, pigs, rabbits, and poultry (**Error! Reference source not found.**).

5.5.3 Activity data

5.5.3.1 Livestock population

The livestock numbers used here are the same as the ones used for enteric fermentation.

5.5.3.2 Manure management systems

Most households in Malawi practise some form or another of mixed crop-livestock production. Almost all ruminant livestock graze on traditional communal lands. The area available for grazing increases from South to North in Malawi (Reynolds, 2006). During the rainy season, grazing is restricted to dambos, roadsides or hillsides, especially in the Central and the Southern Regions. Cattle and sheep are generally herded while goats are tethered by the roadside or around dambos. When crops have been harvested and through most parts of the dry season, animals are given free access to crop residues. This means that there is substantial deposition of urine and dung on pastures, range and paddocks by cattle, sheep, and goats. Pig and rabbits are generally confined in their pens, so there is minimal deposition of urine and dung on pastures, range, and paddocks. Actual data on the proportion of manure managed in different manure management systems (MMS %) in Malawi is very limited. Using expert judgment,¹ estimates of MMS % were made for each livestock species (Table 5-8). .

¹ Estimates of MMS% were elicited by the inventory task force members from a small sample of experts from a few EPAs.

Table 5-8: Manure management systems used for each livestock species

Manure Management System	Dairy cattle (3.A.2.a.i)	Other cattle (3.A.2.a.ii)	Sheep (3.A.2.c)	Goats (3.A.2.d)	Breeding Pigs (3.A.2.h.i)	Marketed pigs (3.A.2.h.ii)	Layer (3.A.2.i.i)	Broilers (3.A.2.i.ii)	Dual purpose chickens (3.A.2.i.iii)	Rabbits (3.A.2.j)
Lagoon	0	0	0	0	0	0	0	0	0	0
Liquid/slurry	0	0	0	0	6%	6%	0	0	0	0
Pit storage	0	0	0	0	1%	1%	0	0	0	0
Dry lot	0	1%	0	0	87%	87%	0	0	0	0
Solid storage	1%	0	0	0	6%	6%	0	0	0	20%
Daily spread	10%	1%	15%	15%	0	0	0	0	0	80%
Burned for fuel or waste – sun dried dung burned for fuel	6%	3%	0	0	0	0	0	0	0	0
Digester	0	0	0	0	0	0	0	0	0	0
Poultry manure with litter	0	0	0	0	0	0	60%	60%	60%	0
Poultry manure without litter	0	0	0	0	0	0	39%	39%	39%	0
Pasture/range/paddock	83%	95%	85%	85%	0	0	1%	1%	1%	0
Total	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%

5.5.4 Emission factors

In the Tier 1 method, the Guidelines give default emission factors based on cool, temperate and warm climates for each livestock species, so no additional data is required on the proportion of manure managed in different manure management systems. The **Error! Reference source not found.** climate data to justify the choice of temperate values for Africa.

Table 5-9: Meteorological data for Malawi

ADD	Agroecological zone	Mean annual temperature (°C) *	Mean annual precipitation (mm) *	Mean annual evaporation (mm)
Karonga	High altitude plateau and hilly areas	22.9	963	1170
Mzuzu	High altitude plateau and hilly areas	22.7	819	1170
Kasungu	Medium altitude areas	23.0	745	1170
Salima	Lakeshore and low-lying rain shadow areas	22.1	1160	1170
Lilongwe	Medium altitude areas	23.2	832	1170
Machinga	Medium altitude areas	24.1	917	1170

Blantyre	High altitude plateau and hilly areas	24.3	1120	1170
Shire Valley	Lower Shire Valley	25.4	794	1170

* Computed from data from Department of Climate Change and Meteorological Services (<https://www.metmalawi.gov.mw/>)

Table 5-10: Methane emission factors from manure management (kg CH₄ head⁻¹ year⁻¹)

Species	Emission factors*	Reference
Dairy cattle	1	IPCC 2006 Table 10.14
Other cattle	1	IPCC 2006 Table 10.14
Sheep	0.2	IPCC 2006 Table 10.15
Goat	0.22	IPCC 2006 Table 10.15
Breeding pigs	1	IPCC 2006 Table 10A-8
Marketed pigs	1	IPCC 2006 Table 10A-7
Layers	0.02	IPCC 2006 Table 10.15
Broilers	0.02	IPCC 2006 Table 10.15
Dual Purpose chickens	0.02	IPCC 2006 Table 10.15
Rabbits	0.08	IPCC 2006 Table 10.16

*These emission factors are for developing countries in the tropical, warm and dry climates.

5.6 Methane emission calculations

Methane is produced by the decomposition of manure under anaerobic conditions. When stored in liquid or slurry form, anaerobic decomposition is greater and more methane is released, and when stored as a solid, less methane is released. Therefore, the manure management system used affects methane emission rates. The default Tier 1 emission factors for manure management were taken from the Guidelines (**Error! Reference source not found.**) and calculated using the following Equation 10.22:

$$CH_{4Manure} = \sum_T \left(\frac{EF_T \cdot N_T}{10^6} \right)$$

Equation 5-6

where:

$CH_{4manure}$ = CH₄ emissions from manure management, for a defined population, (Gg CH₄ year⁻¹)

$EF_{(T)}$ = emission factor for the defined livestock population, kg CH₄ head⁻¹ yr⁻¹

$N_{(T)}$ = the number of head of livestock species/category T in the country

T = species/category of livestock

The emission factors presented were multiplied by population numbers of the relevant sub-category in each year.

5.7 Methane emissions

The time series results for methane emissions from manure management are shown in **Error! Reference source not found.**

Methane emissions from manure in other cattle were nearly 50 percent of the total methane emission from the manure management systems in the 94 's and early 2000's, but their proportion of the total has been declining ever since to about 12 percent in 2022. Methane emissions from manure in goats have remained roughly close to 20 percent, with a noticeable dip to 16 percent after 2017. Methane emissions from manure management in pigs and poultry (broiler and dual-purpose) have been going up steadily in the last decade. As of 2022, the most significant sources of methane from manure management were pigs (41%) and poultry (28%).

Table 5-11: Methane emissions (Gg CH₄ year⁻¹) from manure management from different livestock species, 1994 – 2022

	Dairy cattle	Other cattle	Goats	Sheep	Breeding pigs	Market pigs
	Gg CH ₄ year ⁻¹	Gg CH ₄ year ⁻¹	Gg CH ₄ year ⁻¹	Gg CH ₄ year ⁻¹	Gg CH ₄ year ⁻¹	Gg CH ₄ year ⁻¹
1994	0.026	0.768	0.338	0.016	0.073	0.088
2000	0.037	0.773	0.389	0.026	0.136	0.164
2010	0.055	1.027	0.857	0.043	0.540	0.652
2017	0.090	1.450	1.688	0.060	1.465	1.769
2018	0.098	1.591	1.842	0.063	1.853	2.237
2019	0.106	1.621	2.013	0.066	2.133	2.575
2020	0.114	1.711	2.206	0.070	2.431	2.935
2021	0.126	1.790	2.443	0.075	2.701	3.261
2022	0.138	2.054	2.692	0.081	3.103	3.746

Table 5-12: Trends in methane emissions from poultry and rabbits

	Layers	Broilers	Dual-purpose poultry	Rabbits
	Gg CH ₄ year ⁻¹	Gg CH ₄ year ⁻¹	Gg CH ₄ year ⁻¹	Gg CH ₄ year ⁻¹
1994	0.016	0.006	0.157	0.003
2000	0.051	0.009	0.166	0.010
2010	0.109	0.036	0.423	0.072
2017	0.135	0.093	1.062	0.139
2018	0.149	0.130	1.214	0.183
2019	0.163	0.182	1.382	0.206
2020	0.176	0.208	1.554	0.248
2021	0.196	0.277	1.723	0.277
2022	0.222	0.281	1.939	0.309

Figure 5-9 shows methane emissions from manure management for the period 1994 to 2022.

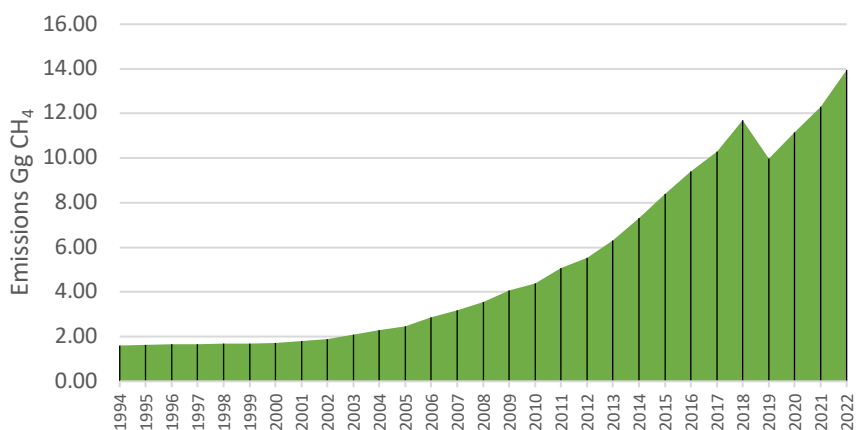


Figure 5-9: Methane emissions from manure management (Gg CH₄ /year)

5.8 Direct N₂O emissions from manure management

Manure also releases nitrous oxide with different rates in the different manure management systems. This section only covers the nitrous oxide released during the storage and treatment of manure before it is applied to the land or used elsewhere. Therefore, this section does not include the nitrous emissions from manure deposited directly to pasture. Instead, this is covered in 3.C.4 and 3.C.5. Emissions of direct N₂O emissions were calculated using the IPCC Tier 1 approach by applying IPCC (2006) Equation 10.25:

$$N_2O_{D(mm)} = \left[\sum_S \left[\sum_T (N_T \times Nex_T \times MS_{T,S}) \right] \times EF_{3(S)} \right] \times \frac{44}{28}$$

Equation 5-7

where:

$N_2O_{D(mm)}$ is direct N₂O emissions from manure management, kg N₂O year⁻¹

N_T is number of head of sub-category T

Nex_T is average nitrogen excretion per head of sub-category T, kg N head⁻¹ year⁻¹

$MS_{T,S}$ is fraction of total annual nitrogen excretion for sub-category T that is managed in manure management system S, dimensionless

$EF_{3(S)}$ is emission factor for direct N₂O emissions from manure management system S, kg N₂O-N/kg N

44/28 is the conversion of N₂O-N emissions to N₂O emissions.

To derive the annual N excretion for each livestock species, the default nitrogen excretion rate (Table 5-14) was multiplied by the corresponding default typical animals mass (TAM) values provided in IPCC (2006) Tier 1 guideline Tables 10A-4 to 10 A-9 in Annex 10A.2 (Table 5-13) and calculated annually by multiplying the result by 365.

Table 5-13: Typical animal mass (TAM) values and country-specific number of days alive for each of the livestock sub-category

Livestock species	Sub-category	TAM (kg)	Number of days alive in a year (days)
Cattle*	Dairy	275	365
	Other	173	365
Pigs*	Breeding	28 (100)	365
	Marketed	28 (50)	180
Goats		27	365
Sheep		30	365
Rabbits**		4.5	365
Chickens	Layers	1.5	365
	Broilers	1.9	42
	Dual purpose chickens	1.5	365

* 2006 IPCC

** Expert judgement by inventory task force members.

The resulting annual nitrogen excretion for each livestock species are presented in

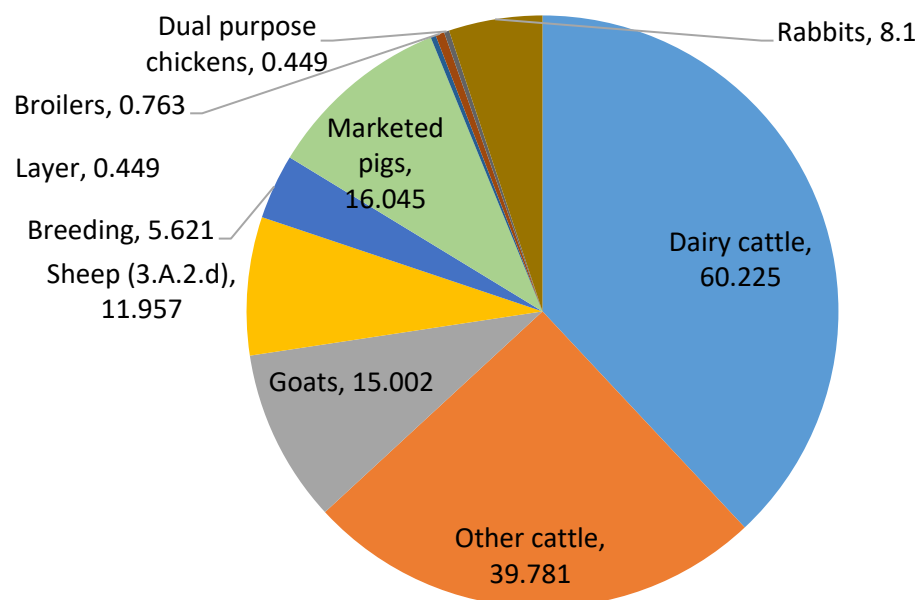


Figure 510. This inventory used IPCC default values for all the parameters in this equation, except livestock populations (**Error! Reference source not found.**) and fraction of manure managed in different manure management systems .

The values for Nitrogen excretion rate in Table 5-14 for cattle, sheep, goats, pigs, poultry, and rabbits are the values from IPCC (2006. Table 10.19). The values for TAM are the values from the IPCC default values for cattle, sheep, goat, pigs except for layer, broilers, dual purpose chicken, and rabbits, which used information from the Food and Agriculture Organization of the United Nations (FAO) Domestic Animal Diversity Information System (DAD-IS) database (FAO, 2022).

Table 5-14: Default values for nitrogen excretion rate (kg N (1000 kg animal mass)⁻¹ day⁻¹)

Livestock type	kg N/1000 kg animal mass/day	Source
Dairy cattle	0.6	IPCC (2006) Table 10.19

Other cattle	0.63	IPCC (2006) Table 10.19
Goats	1.37	IPCC (2006) Table 10.19
Sheep	1.17	IPCC (2006) Table 10.19
Breeding pigs	0.55	IPCC (2006) Table 10.19
Market pigs	1.57	IPCC (2006) Table 10.19
Layers	0.82	IPCC (2006) Table 10.19
Broilers	1.10	IPCC (2006) Table 10.19
Dual purpose chickens	0.82	IPCC (2006) Table 10.19
Rabbits	8.1 kg/head/year	IPCC (2006) Table 10.19

The MMS% activity data used for N₂O is the same as was used for CH₄ for each livestock species. The emission factors, EF₃, used were the IPCC default emission factors from IPCC (2006) Table 10.21 and Table 10.22 (Table 5-15). The resulting time series for direct N₂O emissions is shown in Figure 5-10.

Table 5-15: Emission factors (EF₃) used in estimating direct N₂O emissions from manure management.

Manure management system	EF ₃ [kg N ₂ O-N (kg Nitrogen excreted) ⁻¹]	Source
Uncovered anaerobic lagoon	0	IPCC 2019 Table 10.21
Liquid/slurry	0	IPCC 2019 Table 10.21
Pit Storage	0.002	IPCC 2019 Table 10.21
Dry lot	0.02	IPCC 2019 Table 10.21
Solid storage	0.005	IPCC 2019 Table 10.21
Daily spread	0	IPCC 2019 Table 10.21
Burned as fuel/waste	unavailable	The emissions associated with the burning of the dung are to be reported under the IPCC category 'Fuel Combustion' if the dung is used as fuel.
Anaerobic digester	0	IPCC 2019 Table 10.21
Pasture/range/paddock	NO*	Direct and indirect N ₂ O emissions associated with the manure deposited on agricultural soils and pasture, range, paddock systems are covered in the category 3.C.6 and 3.C.4
Poultry manure with litter	0.001	IPCC 2019 Table 10.21
Poultry manure without litter	0.001	IPCC 2019 Table 10.21

*NO indicates not occurring in this GHG emission source.

N excretion per head per year was highest in dairy cattle (60.2 kg), followed by other cattle (39.8 kg) and goats (15.0 kg).

Direct N₂O from manure management (Figure 5-11) was highest in pigs, at 0.034 Gg N₂O and 2.159 Gg N₂O in 1994 and 2022, respectively, representing 65% and 87%, respectively.

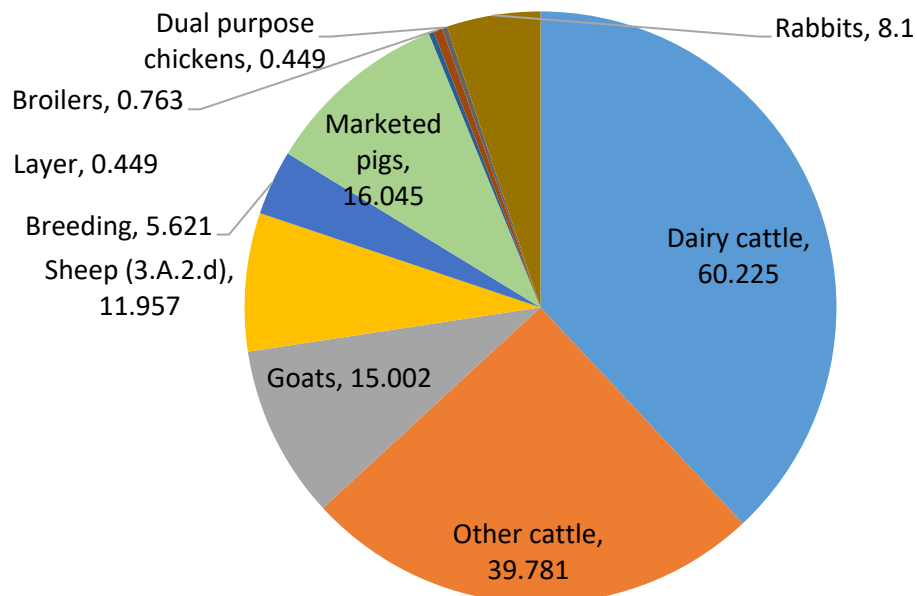


Figure 5-10: Nitrogen excretion (kg N head-1 year-1) for different livestock species

Table 5-16: Trends in N₂O emissions from ruminants

Year	Dairy cattle	Other cattle	Goats	Sheep	Breeding pigs	Market pigs
	Gg N ₂ O/year	Gg N ₂ O/year	Gg N ₂ O/year	Gg N ₂ O/year	Gg N ₂ O/year	Gg N ₂ O/year
1994	0.015	0.290	0.218	0.009	0.007	0.023
2000	0.021	0.292	0.252	0.015	0.007	0.024
2010	0.032	0.388	0.555	0.024	0.047	0.161
2017	0.052	0.547	1.093	0.034	0.144	0.497
2018	0.061	0.649	1.289	0.039	0.106	0.825
2019	0.060	0.612	1.303	0.038	0.079	0.493
2020	0.067	0.668	1.477	0.041	0.089	0.592
2021	0.069	0.650	1.521	0.041	0.089	0.619
2022	0.080	0.791	1.776	0.047	0.113	0.741

	Layers	Broilers	Dual-purpose poultry	Rabbits
	Gg N ₂ O/year	Gg N ₂ O/year	Gg N ₂ O/year	Gg N ₂ O/year
1994	0.0006	0.0049	0.0055	0.0047
2000	0.0018	0.0045	0.0058	0.0157
2010	0.0038	0.0039	0.0148	0.1129
2017	0.0047	0.0055	0.0371	0.2193

2018	0.0052	0.0077	0.0424	0.3119
2019	0.0057	0.0108	0.0483	0.3256
2020	0.0061	0.0123	0.0543	0.4045
2021	0.0068	0.0164	0.0602	0.4200
2022	0.0077	0.0167	0.0677	0.4971

Figure 5-11 shows the N₂O emissions from manure management.

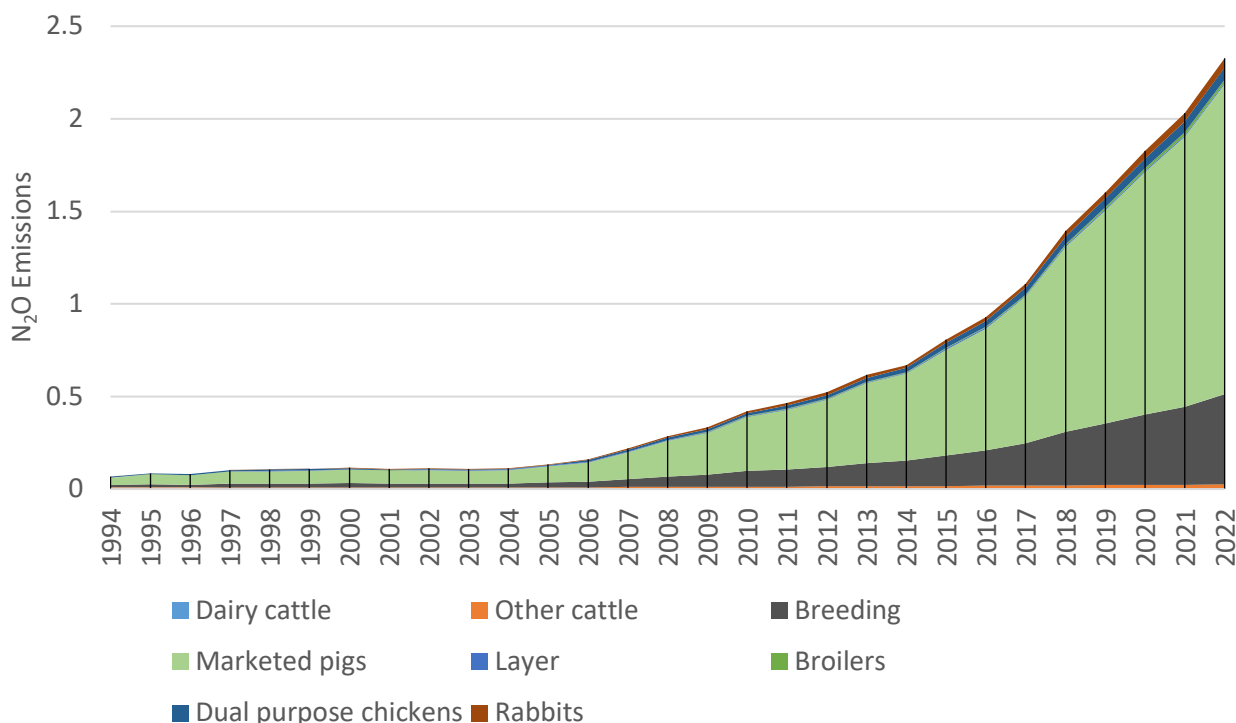


Figure 5-11: Direct N₂O emissions from manure management, Gg N₂O, 1994 - 2022

5.8.1 Uncertainties and time-series consistency

Uncertainty values were computed using the procedure explained in Section 0 and a summary of uncertainty values for all source categories is given in Annexe II. Uncertainty values of 1994 and 2022 total methane emissions from manure management for each livestock species were ($\pm 59\%$) and ($\pm 58\%$), respectively. The uncertainties for direct N₂O emissions were both ($\pm 71\%$).

A consistent method was used to estimate emissions in each year of the time series.

5.8.2 Source-specific QA/QC and verification

Tier 1 QA/QC activities have been implemented. This inventory was compiled in an Excel spreadsheet. Quality control activities included:

- Checking that the equations programmed in the spreadsheet were correctly input.
- Checking that inputs to summed totals were obtained from the correct fields.
- Checking that all data sources were fully documented.

- Checking that the figures in the inventory report were correctly transcribed.
- Reconstructing a number of the calculations to cross-check the intermediate calculations and results in the inventory spreadsheet.

5.8.3 Source-specific recalculations

For methane from manure management, the recalculations for 2010 (to compare the TNC and the current inventory). This inventory found significantly lower emissions from goats and pigs, most likely due to differences in MMS proportions between the two inventories or differences in the tools used to compile the inventories. The TNC report did not give the MMS proportions used in the report. Direct nitrous oxide emissions for 2010 are lower by 33% in this inventory compared to the TNC.

Table 5-17: Source-specific recalculations for methane from manure management (Gg CH₄ year⁻¹) for 2010

Inventory	Dairy cattle	Other cattle	Goats	Sheep	Pigs*	Poultry*	Rabbits**	Total
TNC	0.04	1.03	1.69	0.06	2.37	-	-	5.19
This inventory	0.06	1.03	0.86	0.04	1.19	0.8	0.07	4.04
Change (%)	+38	-0.25	-49	-29	-50	N/A	N/A	-22

* Pigs and poultry population figures were not disaggregated in the TNC.

** Rabbits were not included in the TNC.

Table 5-18: Source-specific recalculations for direct N₂O from manure management (Gg N₂O year⁻¹) for 2010

Inventory	Dairy cattle	Other cattle	Goats*	Sheep*	Pigs*	Poultry*	Rabbits**	Total
TNC2010	0.0200	0.6400						0.6600
This Inventory	0.0003	0.0128	0.0000	0.0000	0.3757	0.0356	0.0187	0.4431
Diff (%)	-99	-98	N/A	N/A	N/A	N/A	N/A	-33

* Direct nitrous oxide was not estimated for goats, sheep, pigs and poultry in the TNC.

** Rabbits were not included in the TNC.

5.9 Indirect emissions of nitrous oxide from manure management (Category 3.C.6)

This category reports indirect emissions of N₂O from management of manure from different livestock species.

5.9.1 Source category description

The descriptions of sources of indirect N₂O emissions from manure in the livestock sector are given in Table 5-19.

Table 5-19: Sources of indirect N₂O emissions from manure in the livestock sector

Emissions sources	Sources included	Method	Emission factors
3.C.6.a.i	Dairy cattle manure management	Tier 1	IPCC (2006)

3.C.6.a.ii	Other cattle manure management	Tier 1	IPCC (2006)
3.C.6.c	Sheep		
3.C.6.d	Goats		
3.C.6.h.i	Breeding pigs manure management	Tier 1	IPCC (2006)
3.C.6.h.ii	Marketed pigs manure management	Tier 1	IPCC (2006)
3.C.6.i.i	Layers	Tier 1	IPCC (2006)
3.C.6.i.ii	Broilers	Tier 1	IPCC (2006)
3.C.6.i.iii	Dual purpose chickens	Tier 1	IPCC (2006)
3.C.6.j	Rabbits manure management	Tier 1	IPCC (2006)
Gases reported	N ₂ O		
Completeness	All major livestock species covered.		
Improvements since last submission	This is the first inventory for pigs, rabbits that uses a Tier 1 approach.		

This category reports indirect emissions of N₂O from management of manure from cattle (dairy and other); pigs (breeding and marketed); chickens (broilers, layers and dual purposed) and rabbits. Indirect N₂O emission from sheep and goat are included, but the value of volatilization losses equals zero because no default values of $Frac_{GasMS}$ are presented for the MMS systems for sheep and goats.

5.9.2 Methodological issues

The section describes the indirect N₂O emissions due to volatilization and leaching to soil from manure management systems for different livestock species category. However, the meteorological data (**Error! Reference source not found.**) revealed that evaporation is greater than precipitation thus, N₂O emissions via leaching was not considered.

5.9.3 Activity data

5.9.3.1 Livestock population

Livestock population data are the same as for enteric fermentation (**Error! Reference source not found.**).

5.9.3.2 Manure management systems

The manure management systems data are the same as for direct N₂O emission.

5.9.3.3 N losses from volatilization

Nitrous oxide emissions due to volatilization were calculated using IPCC Equations 10.26 and 10.27:

$$N_{volatilization-MMS} = \left[\sum_S \left[\sum_T (N_T \times Nex_T \times MS_{T,S}) \right] \times \frac{Frac_{GasMS}}{100} \right]_{(T,S)}$$

Equation 5-8

where:

$N_{volatilization - MMS}$ is amount of manure nitrogen lost due to volatilization of NH₃ and NO_x, kg N year⁻¹

N_T is number of head of cattle sub-category T

N_{exT} is average nitrogen excretion per head of sub-category T, kg N head⁻¹ year⁻¹

$MS_{T,S}$ is fraction of total annual nitrogen excretion for sub-category T that is managed in manure management system S, dimensionless

$Frac_{GasMS}$ is percent of managed manure nitrogen for each sub-category that volatilizes as NH₃ and NO_x in manure management system S, %.

$$N_2O_{G(mm)} = (N_{volatilization-MMS} \times EF_4) \times \frac{44}{28}$$

where

$N_2O_{G(mm)}$ is indirect N₂O emissions due to volatilization of N from manure management, kg N₂O year⁻¹

EF_4 is emission factor for N₂O emissions from atmospheric deposition of nitrogen on soils and water surfaces, kg N₂O-N (kg NH₃-N + NO_x-N volatilised)⁻¹

N excretion data is the same as for direct N₂O emission (Section 1.11,

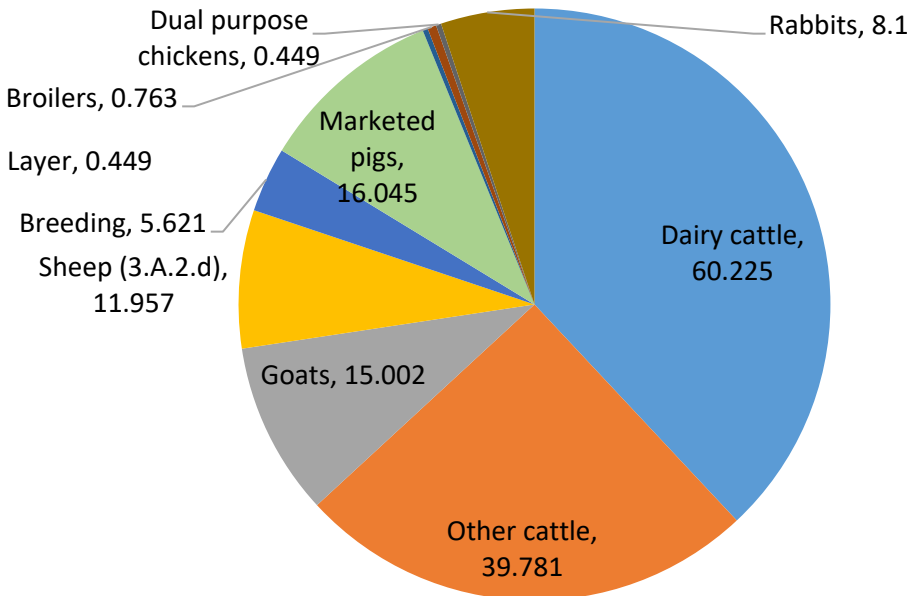


Figure 5). Manure management system activity data are the same as those used to estimate direct N₂O manure management emissions. For EF_4 , the value used was 0.01 taken from IPCC (2006, Table 11.3). $Frac_{GasMS}$ was taken from IPCC (2006) Table 10.22. It is worth noting that $Frac_{GasMS}$ values vary with manure management systems for each livestock species category.

5.10 Indirect N₂O emissions

The time series for indirect N₂O emissions (including N losses from volatilization) is shown in Figure 5-12. Indirect N₂O emission from manure management were high in broiler and dual-purpose chickens, which accounted for about 0.978 Gg N₂O in 2022. Between 1994 and 2022, chickens accounted for 72-89% of indirect N₂O emissions, with an average of 81%.

Emissions trends for indirect N₂O emissions are given in Table 5-20.

Table 5-20: Emissions trends for indirect N₂O emissions from ruminants

	Market pigs	Layers	Broilers	Dual-purpose poultry	Rabbits
	Indirect N2O	Indirect N2O	Indirect N2O	Indirect N2O	Indirect N2O
	Gg N2O/year	Gg N2O/year	Gg N2O/year	Gg N2O/year	Gg N2O/year
1994	0.009035159	0.002617	0.022694027	0.025117	0.000293
2000	0.009596958	0.008179	0.020860887	0.026597	0.000985
2010	0.063715198	0.017451	0.017805652	0.067876	0.007081
2017	0.196895174	0.021603	0.025218347	0.170187	0.013749
2018	0.277178358	0.023868	0.035397456	0.194557	0.014906
2019	0.195374703	0.026078	0.04971428	0.221591	0.020417
2020	0.221741999	0.028231	0.056622438	0.249112	0.02419
2021	0.25998081	0.031433	0.075463359	0.276304	0.028507
2022	0.286112236	0.035554	0.076493532	0.310888	0.031004

	Dairy cattle	Other cattle	Goats	Sheep	Breeding pigs
	Indirect N2O	Indirect N2O	Indirect N2O	Indirect N2O	Indirect N2O
	Gg N2O/year	Gg N2O/year	Gg N2O/year	Gg N2O/year	Gg N2O/year
1994	0.005961519	0.095289985	0.013701232	0.000578659	0.002621554
2000	0.008407803	0.09597739	0.015781249	0.00093356	0.00278456
2010	0.012484943	0.127525775	0.034776995	0.001525061	0.018486985
2017	0.020398116	0.179925814	0.068525959	0.002150519	0.057129197
2018	0.021814184	0.183257731	0.061590991	0.001861304	0.035654163
2019	0.023848108	0.201158409	0.081700221	0.00235826	0.031162365
2020	0.025491498	0.214081426	0.088351254	0.002467996	0.033291565
2021	0.028544675	0.223001471	0.103213087	0.002768745	0.03745871
2022	0.03102014	0.259216535	0.110785918	0.002921934	0.043542715

Figure 5-12 shows emissions trends for indirect N₂O emissions

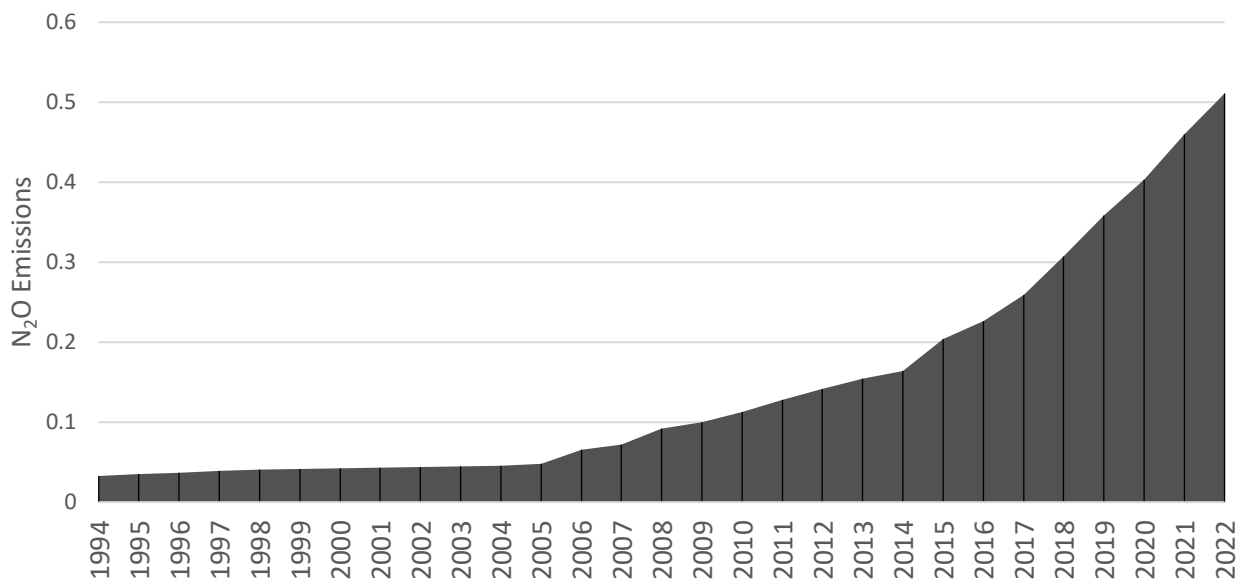


Figure 5-12: Indirect N₂O emissions from manure management, Gg N₂O, 1994 - 2022

5.10.1 Uncertainties and time-series consistency

Uncertainty values were computed using the procedure explained in Section 0 and a summary of uncertainty values for all source categories is given in Annexe 2.

Uncertainty of 1994 and 2022 for the indirect nitrous oxide emissions was ($\pm 77\%$) and ($\pm 77\%$), respectively. The most sensitive factors affecting emissions were the manure management system itself (MMS) and the fraction of total annual nitrogen excretion for sub-category T that is managed in manure management system S ($MS_{T,S}$).

A consistent method was used to estimate emissions in each year of the time series.

5.10.2 Source-specific QA/QC and verification

Tier 1 QC activities have been implemented. This inventory was compiled in an Excel spread sheet. Quality control activities included:

- Checking that the equations programmed in the spreadsheet were correctly input.
- Checking that inputs to summed totals were obtained from the correct fields.
- Checking that all data sources were fully documented.
- Checking that the figures in the inventory report were correctly transcribed.
- Reconstructing several the calculations to cross-check the intermediate calculations and results in the inventory spreadsheet.

It was found that N excretion for rabbits had been wrongly calculated and this was recalculated.

5.10.3 Source-specific recalculations

The TNC did not estimate N₂O from manure management, so there was no basis for comparison with this inventory.

5.11 Direct nitrous oxide emissions from managed soils due to livestock deposit of dung and urine (Category 3.C.4)

Direct N₂O emissions from urine and dung N deposited on pasture, range and paddock by grazing animals is categorized under reporting category 3C4.

5.11.1 Source category description

The descriptions of the source categories for direct nitrous oxide emissions from managed soils due to livestock deposit of dung and urine are given in Table 5-21.

Table 5-21: Source categories for direct nitrous oxide emissions from managed soils due to livestock deposit of dung and urine

Emissions sources	Sources included	Method	Emission factors
3.C.4.a.i	Dairy cattle manure management	Tier 1	IPCC (2006)
3.C.4.a.ii	Other cattle manure management	Tier 1	IPCC (2006)
3.C.4.c	Sheep manure management	Tier 1	IPCC (2006)
3.C.4.d	Goat manure management	Tier 1	IPCC (2006)
3.C.4.h.i	Breeding pigs manure management	Tier 1	IPCC (2006)
3.C.4.h.ii	Marketed pigs manure management	Tier 1	IPCC (2006)
3.C.4.i.i	Layers	Tier 1	IPCC (2006)
3.C.4.i.ii	Broilers	Tier 1	IPCC (2006)
3.C.4.i.iii	Dual purpose chickens	Tier 1	IPCC (2006)
3.C.4.j	Rabbits manure management	Tier 1	IPCC (2006)
Gases reported	N ₂ O		
Completeness	All the major animals were included.		
Improvements since last submission	This is the first inventory for sheep, goat, pigs, rabbits that uses a Tier 1 approach.		

Direct N₂O emissions from urine and dung N deposited on pasture, range and paddock by grazing animals is categorized under reporting category 3C4.

5.11.2 Methodological issues

This section describes the methodological aspects of direct N₂O emissions from urine and dung N deposited on pasture, range and paddock by grazing animals including choice of methods, activity data, emission factors, assumptions and any other methodological issues.

5.11.3 Activity data

5.11.3.1 Livestock population

Livestock population data are the same as for enteric fermentation.

5.11.3.2 Manure management systems

The manure management system was as explained in Table 5.5.3.2.

5.12 Direct N₂O from urine and dung deposited in the pasture.

Emissions were calculated using the IPCC Tier 1 approach using equations modified from IPCC (2006) Equations 11.1 and 11.5:

$$N_2O - N_{PRP} = [(F_{PRP,CPP} \times EF_{3,PRP,CPP}) + (F_{PRP,SO} \times EF_{3,PRP,SO})]$$

Equation 5-9

where

$N_2O - N_{PRP}$ are annual direct N₂O-N emissions from urine and dung inputs to grazed soils, kg N₂O-N year⁻¹

F_{PRP} is annual amount of urine and dung N deposited by grazing animals on pasture and paddock, kg N year⁻¹. The subscripts CPP and SO refer to Cattle, Poultry and Pigs, and Sheep and Other animals, respectively)

$EF_{3,PRP}$ is the emission factor for N₂O emissions from urine and dung N deposited by grazing animals on pasture and paddock, kg N₂O-N (kg N input)⁻¹ (Note: the subscripts CPP and SO refer to Cattle, Poultry and Pigs, and Sheep and Other animals, respectively)

and

$$F_{PRP,(CPP)SO} = \sum [(N_{(T)} \times Nex_{(T)}) \times MS_{(T,PRP,CPP(SO))}]$$

Where;

$F_{PRP,(CPP)SO}$ is the amount of urine and dung deposited by grazing animals on pasture and paddock, kg N year⁻¹. The subscripts CPP and SO refer to Cattle, Poultry and Pigs, and Sheep and Other animals, respectively).

$N_{(T)}$ is the number of animals in each sub-category

$Nex_{(T)}$ is annual average nitrogen excretion per head of sub-category T, kg N head⁻¹ year⁻¹

$MS_{(T,PRP)}$ is the fraction of annual N excretion for sub-category T that is deposited on pasture or paddock. The subscripts CPP and SO refer to Cattle, Poultry and Pigs, and Sheep and Other animals, respectively.

$N_2O - N_{PRP,CPP(SO)}$ was then converted to N₂O by multiplying it by (44/28).

The same values for N excretion were used as for direct N₂O emissions and manure management. A value of 0.02 was used for the emission factor, $EF_{3,PRP,CPP}$ for cattle, pigs and poultry, taken from IPCC (2006) Table 11.1, whereas a value of 0.01 for the emission factor, $EF_{3,PRP,SO}$ for sheep and other animals including goats, taken from IPCC (2006) Table 11.1. The proportion of manure deposited on pasture is given in .

This inventory estimates the amount of N deposited on pasture (F_{PRP}) separately for cattle, poultry and pigs ($F_{PRP,CPP}$) and for sheep and other animals, i.e. goats ($F_{PRP,SO}$).

The resulting time series data for direct N₂O emissions from pasture deposit of dung and urine are given in **Error! Reference source not found.** Goats are the most significant contributors of direct N₂O, followed by other cattle. Direct N₂O from goats has been going up steadily in the last decade.

Table 5-22: Indirect N₂O emissions from dung and urine deposited on pasture by different livestock species

	Dairy cattle	Other cattle	Goats	Sheep	Breeding pigs	Market pigs
	Gg N ₂ O	Gg N ₂ O	Gg N ₂ O	Gg N ₂ O	Gg N ₂ O	Gg N ₂ O
1994	0.000606934	0.011655009	0.008782841	0.000370935	0.00026583	0.000916181
2000	0.000855987	0.011739086	0.009005065	0.000408852	0.000276447	0.000952773
2010	0.001271075	0.0155978	0.010338409	0.000636352	0.000346011	0.001192525
2017	0.002076704	0.022006899	0.024198504	0.00101552	0.002267928	0.007816389
2018	0.002202649	0.023582003	0.046813665	0.001414728	0.003852748	0.029951574
2019	0.002427942	0.024603878	0.052371936	0.001511705	0.003159918	0.019811333
2020	0.002617513	0.025977047	0.057414806	0.00160382	0.003453482	0.023002282
2021	0.002860597	0.026856091	0.062825357	0.001685323	0.003682738	0.025559911
2022	0.003057273	0.030085996	0.067592599	0.001782728	0.004292243	0.028203647

	Layers	Broilers	Dual-purpose poultry	Rabbits
	Gg N2O	Gg N2O	Gg N2O	Gg N2O
1994	1.15E-05	9.99E-05	0.000110525	0.000187547
2000	3.60E-05	9.18E-05	0.00011704	0.000631651
2010	7.68E-05	7.84E-05	0.000298685	0.004539266
2017	9.51E-05	0.000110972	0.000748898	0.008813621
2018	0.000105032	0.000155764	0.000856136	0.011329917
2019	0.000114754	0.000218765	0.000975099	0.013088017
2020	0.000124229	0.000249164	0.001096203	0.015719601
2021	0.000138319	0.000332072	0.00121586	0.017352025
2022	0.000156454	0.000336605	0.001368044	0.018916034

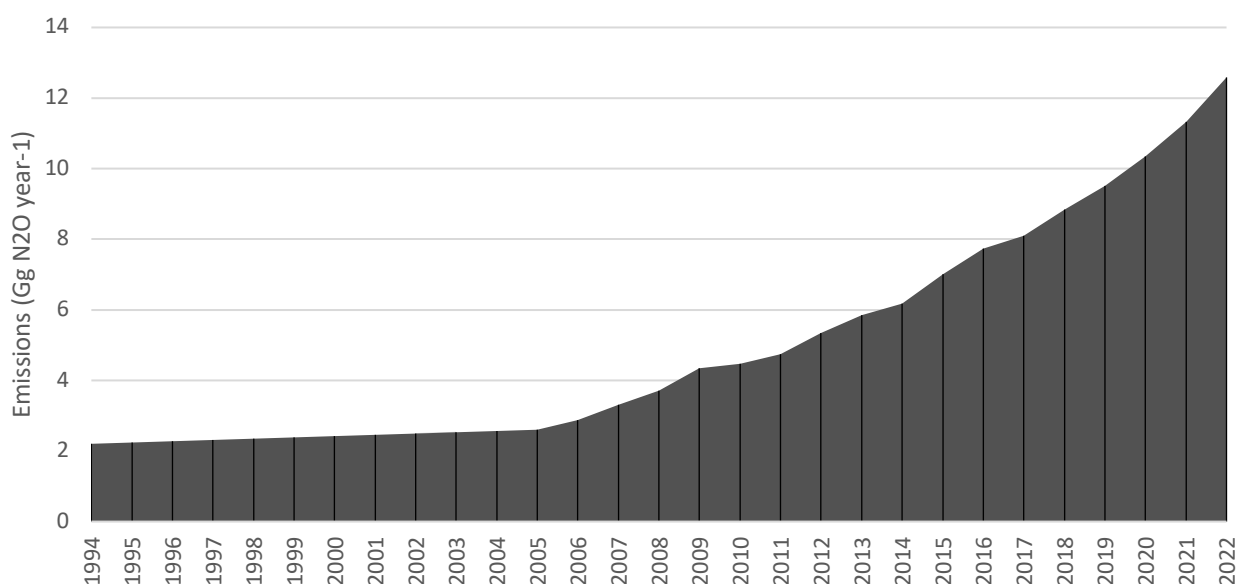


Figure 5-13: Direct N₂O emissions from dung and urine deposited on pasture by different livestock species, 1994 - 2022 (Gg N₂O year-1)

5.12.1 Uncertainties and time-series consistency

Uncertainty values were computed using the procedure explained in Section 1.4 and a summary of uncertainty values for all source categories is given in Annexe 2. Uncertainty of 1994 and 2022 for the direct N₂O emissions from urine and dung deposited by grazing animals was (±92%) and (±92%), respectively. For direct nitrous oxide emissions from manure management the most sensitive factors affecting emissions were proportion of manure deposited on pasture, range and paddocks (MS_(T)) and

the proportion of nitrogen (N) deposited to the soil through ruminant excreta, which is emitted as N₂O.

A consistent method was used to estimate emissions in each year of the time series.

5.12.2 Source-specific QA/QC and verification

Tier 1 QC activities have been implemented. This inventory was compiled in an Excel spreadsheet. Quality control activities included:

- Checking that the equations programmed in the spreadsheet were correctly input.
- Checking that inputs to summed totals were obtained from the correct fields.
- Checking that all data sources were fully documented.
- Checking that the figures in the inventory report were correctly transcribed.
- Reconstructing a number of the calculations to cross-check the intermediate calculations and results in the inventory spreadsheet.

5.12.3 Source-specific recalculations

The TNC did not estimate direct N₂O emissions from dung and urine deposited on pasture, so there was no basis for comparison with this inventory.

5.13 Indirect emissions of nitrous oxide from managed soils due to grazing animals (3.C.5)

This category reports indirect emissions of N₂O from dung and urine deposited on pasture by grazing animals. Indirect N₂O emissions from urine and dung N deposited on pasture, range and paddock by grazing animals is categorized under reporting category 3C5.

5.13.1 Source category description

The descriptions of the source categories for indirect nitrous oxide emissions from managed soils due to livestock deposit of dung and urine are given in Table 5-23.

Table 5-23: Source categories for indirect nitrous oxide emissions from managed soils due to livestock deposit of dung and urine

Emissions sources	Sources included	Method	Emission factors
3.C.5.a.i	Dairy cattle manure management	Tier 1	IPCC (2006)
3.C.5.a.ii	Other cattle manure management	Tier 1	IPCC (2006)
3.C.5.c	Sheep manure management	Tier 1	IPCC (2006)
3.C.5.d	Goat manure management	Tier 1	IPCC (2006)
3.C.5.h.i	Breeding pigs manure management	Tier 1	IPCC (2006)

3.C.5.h.ii	Marketed pigs manure management	Tier 1	IPCC (2006)
3.C.5.i.i	Layers	Tier 1	IPCC (2006)
3.C.5.i.ii	Broilers	Tier 1	IPCC (2006)
3.C.5.i.iii	Dual purpose chickens	Tier 1	IPCC (2006)
3.C.5.j	Rabbits manure management	Tier 1	IPCC (2006)
Gases reported	N ₂ O		
Completeness	All the major animals were included in this analysis.		
Improvements since last submission	This is the first inventory for sheep, goat, pigs, rabbits that uses a Tier 1 approach. This is the third time that dairy and other cattle use a Tier 1 approach.		

5.13.2 Methodological issues

This section describes the methodological aspects of indirect N₂O emissions from urine and dung deposited on pasture, range and paddock by grazing animals including choice of methods, activity data, emission factors, assumptions and any other methodological issues.

5.13.3 Activity data

5.13.3.1 Livestock population

Livestock population data are the same as for enteric fermentation.

5.13.3.2 Manure management systems

The manure management system is as described in Section 1.8.1.2 above.

5.14 Indirect N₂O from pasture deposit

Indirect N₂O emissions from deposit of dung and urine on pasture by grazing animals were calculated by modifying IPCC equation 11.9 (for volatilization):

$$N_2O_{ATD} - N = (F_{PRP} \times Frac_{GASM}) \times EF_4$$

Equation 5-10

where

$N_2O_{ATD} - N$ is annual amount of N₂O-N produced from atmospheric deposition of N volatilized from pasture and paddock, kg N₂O-N year⁻¹

F_{PRP} is annual amount of urine and dung N deposited by grazing animals on pasture and paddock, kg N year⁻¹

$Frac_{GASM}$ is fraction of urine and dung N deposited by grazing animals that volatilizes as NH₃ and NO_x, kg N volatilized (kg N input)⁻¹

EF_4 is emission factor for N₂O emissions from atmospheric deposition of N on soils and water surfaces, [kg N-N₂O (kg NH₃-N + NO_x-N volatilised)⁻¹]

The values of Nex(T) and MS(T,PRP) used in calculating F_{PRP} were the same values used for calculating direct nitrous oxide emissions from manure management and deposit of urine and dung on pasture. Default emission factors for EF₄ (0.010) and EF₅ (0.0075) and default fractions for Frac_{GASM} (0.20) were

used (IPCC 2006, Table 11.3). Figure 5-14 presents the resulting estimated indirect N₂O emissions from deposit of dung and urine on pasture by the different livestock categories.

Cattle and goats are the most significant contributors of indirect nitrous oxide. The goat contribution has been steadily going up in the last decade.

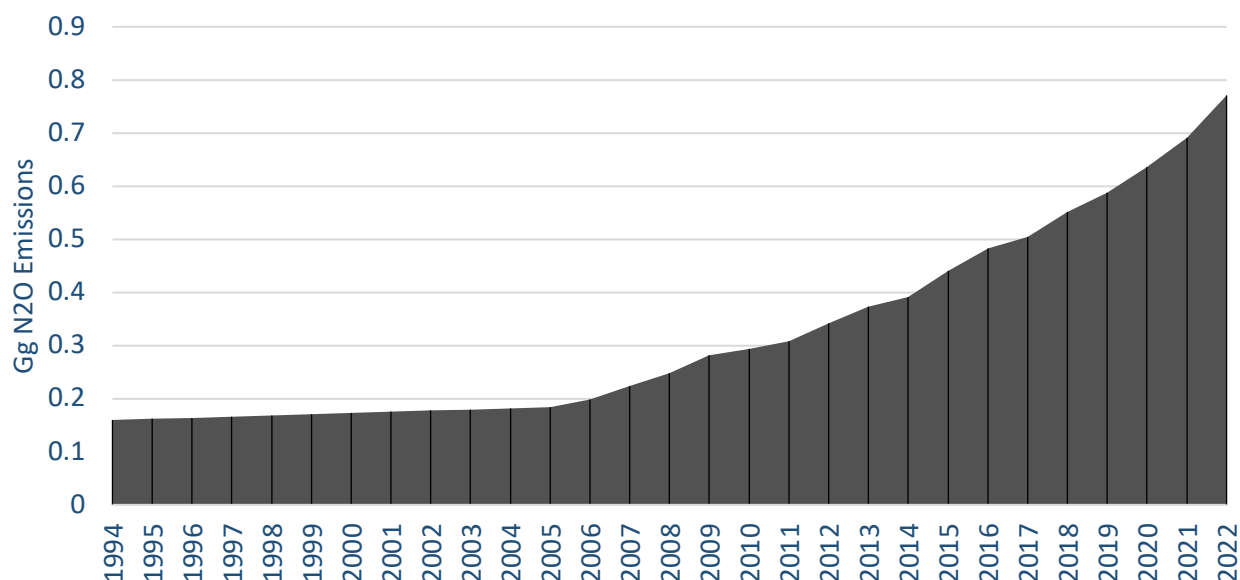


Figure 5-14: Indirect N₂O emissions from dung and urine deposited on pasture by different livestock species, 1994-2024 (Gg N₂O year⁻¹)

5.14.1 Uncertainties and time-series consistency

The summary of uncertainty values for all source categories is given in Annexe 2. Uncertainty of 1994 and 2022 for the indirect N₂O emissions from urine and dung deposited by grazing animals was (±92%) and (±92%), respectively. For direct nitrous oxide emissions from manure management the most sensitive factors affecting emissions were proportion of manure deposited on pasture, range and paddocks (MS_(T)) and the proportion of nitrogen (N) deposited to the soil through animal excreta which is emitted as N₂O.

A consistent method was used to estimate emissions in each year of the time series.

5.14.2 Source-specific QA/QC and verification

Tier 1 QC activities have been implemented. This inventory was compiled in an Excel spreadsheet. Quality control activities included:

- Checking that the equations programmed in the spreadsheet were correctly input.
- Checking that inputs to summed totals were obtained from the correct fields.
- Checking that all data sources were fully documented.
- Checking that the figures in the inventory report were correctly transcribed.

5.14.3 Reconstructing several the calculations to cross-check the intermediate calculations and results in the inventory spread sheet.

5.14.4 Source-specific recalculations

The TNC did not estimate indirect N₂O emissions from dung and urine deposited on pasture, so there was no basis for comparison with this inventory.

5.15 Inventory improvement Plan

The proposed Tier 1 livestock improvements are in the following areas:

- a. Estimation of specific uncertainty values for activity data i.e., population data.
- b. Determination of manure management systems.
- c. Determination of evaporation, precipitation and temperature at each ecological zone.
- d. Recalculation of manure management methane emissions.
- e. Estimation of country-specific values of TAM.

5.15.1 Estimation of specific uncertainty values for activity data

Activity data whose uncertainties need to be estimated more accurately include livestock population and proportions of different manure management systems.

For instance, as indicated in Section 0, the uncertainty for livestock population is assumed to be 0 because the data are collected through a census. However, it is not correct to assume that the data collected are exact at the time of collection because some animals may be missed while others may be counted more than once. There is need to estimate the likelihood of these events happening to come up with more accurate uncertainty values. Similarly, there is need to come up with more specific uncertainties for the manure management systems data.

Where uncertainty ranges are estimated using expert judgement, the protocol for expert elicitation presented in the 2006 IPCC Guidelines Vol 1 Annex 2A.1 should be used.

5.15.2 Determination of manure management systems

The manure management systems data used in this study were based on a small sample of experts from a few EPAs. There is need to carry out a more comprehensive survey to ensure that the MMS data are more representative of the different agroecological zones (AEZ) in the country.

5.15.3 Determination of evaporation levels for specific ecological zones

There is need to determine AEZ-specific levels of precipitation and evaporation to verify whether leaching needs to be quantified.

5.15.4 Recalculation of manure management methane emissions

There is need to try to divide the country in homogenous climate zones to increase the accuracy of estimations.

5.15.5 Estimation of country-specific values of TAM

There is need for estimating typical animal masses at country level.

5.16 Liming (CRT Category 3.C.2)

This reports carbon dioxide (CO₂) emissions resulting from the application of lime—primarily dolomitic lime (CaMg(CO₃)₂)—to agricultural soils. Liming is a critical soil management strategy employed across smallholder and commercial farms to correct soil acidity, enhance nutrient availability, and boost overall crop productivity. The practice is particularly common in high-value crop zones such as tobacco-growing regions, where acidic soils are prevalent due to intensive cultivation and prolonged use of ammonium-based fertilizers.

Over the past three decades, Malawi's reliance on lime application has grown in response to observed soil degradation and national efforts to promote integrated soil fertility management (ISFM). The Fertilizer Association of Malawi and Ministry of Agriculture extension programs have actively supported the use of lime as a complementary input alongside inorganic fertilizers, especially in soil-sensitive regions such as Central and Southern Malawi.

Dolomitic lime is the dominant liming material in the country, given its dual benefits of neutralizing soil acidity and supplying magnesium—an essential secondary nutrient often deficient in degraded soils. Calcitic lime (CaCO₃) is used to a lesser extent and lacks consistent reporting in available datasets. Consequently, national estimates for GHG emissions from liming primarily reflect dolomitic lime usage.

Methodological Issues

Emissions from lime application are estimated using the Tier 1 methodology from the 2006 IPCC Guidelines (Vol. 4, Ch. 11). CO₂ is emitted when carbonate compounds in lime react with acidic components in soil, resulting in the formation of CO₂ and water.

Equation Used:

$$CO_2 \text{ emissions (Gg)} = \text{Lime Applied (Gg)} \times EF$$

Where:

- *EF = 0.13 for dolomitic lime (default IPCC 2006 emission factor)*
- *Lime Applied is in gigagrams (Gg) = tonnes ÷ 1,000*

Data Sources & Assumptions:

- Activity data (1994–2022) on dolomitic lime application were compiled from national fertilizer suppliers, agricultural input distributors, and Ministry of Agriculture extension services.

- In the absence of reliable disaggregated data on calcitic lime use, all reported lime is assumed to be dolomitic.
- This approach is consistent with historical procurement and application patterns observed in Malawi.

Emission Trends Analysis (1994–2022)

Between 1994 and 2022, emissions from dolomitic lime application rose from 1.72 Gg CO₂ to 3.89 Gg CO₂, (Figure 5-15) with an average annual growth rate of 2.83%. The peak was in 2019 (5.46 Gg CO₂), mainly due to increased lime use under donor-supported soil fertility programs and favorable agro-climatic conditions (MoAFS, 2020; World Bank, 2020).

Table 5-24: Emission Trend (1994–2022)

YEAR	Annual amount of lime (tonnes / yr)	Emissions CO ₂ (Gg)
1994	13,225.10	6.30
2000	16,641.78	7.93
2010	31,790.00	15.15
2017	33,158.00	15.81
2018	38,278.00	18.25
2019	42,000.00	20.02
2020	24,725.59	11.79
2021	27,198.15	12.96
2022	29,917.96	14.26

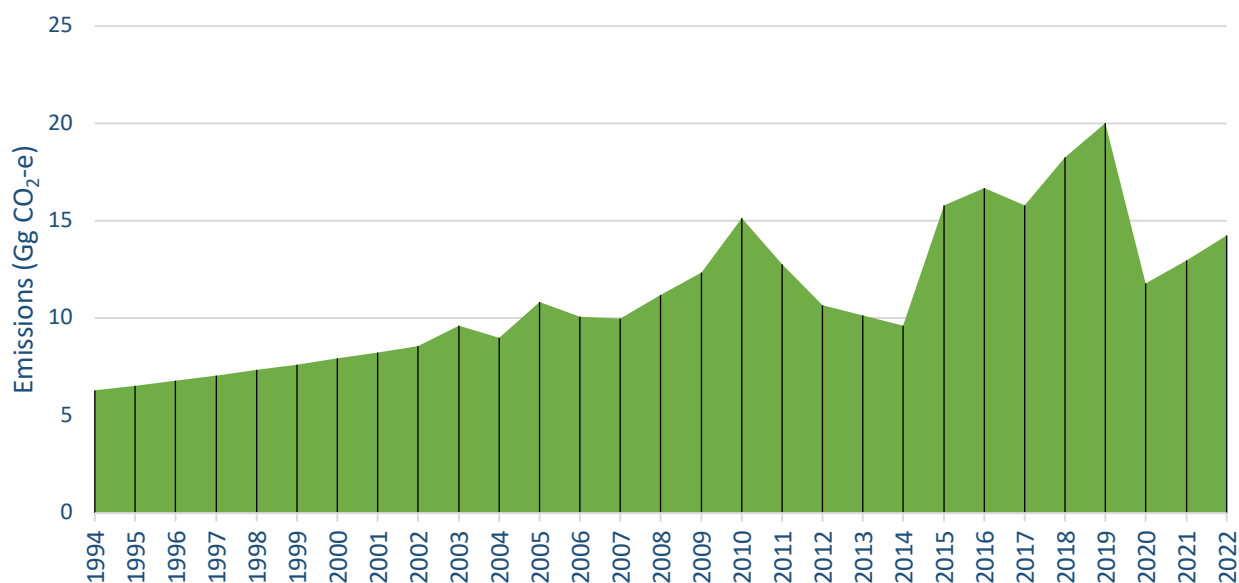


Figure 5-15: Emissions from Liming

A decline followed between 2020 and 2022, attributed to COVID-19-related disruptions, reduced import capacity, and supply chain challenges that affected the availability of agricultural inputs like lime (MoFEPD, 2023; World Bank, 2022). This trend reflects how emissions from liming are influenced by both agricultural policy and broader economic shocks.

Flexibility Applied

No Flexibility has been applied due to limited national capacity in distinguishing lime types by mass and purity. A Tier 1 method using default IPCC emission factors and assumptions was adopted, reflecting practical data availability limitations.

Uncertainty Assessment and Time-Series Consistency

Uncertainty is primarily driven by:

- Variability in reported lime imports and actual usage
- Assumptions regarding exclusive use of dolomitic lime
- The absence of country-specific emission factors

Quantitative Estimates:

- Activity data uncertainty: $\pm 50\%$
- IPCC Tier 1 default EF uncertainty: $\pm 10\%$

Despite these uncertainties, a consistent approach has been applied across the full time series (1994–2022), ensuring time-series comparability.

QA/QC and Verification

QA/QC procedures implemented include:

- Cross-checking activity data with annual input procurement records and FAOSTAT data
- Review and validation by national agricultural experts and the National Inventory Review Team
- Consistency checks against past GHG inventory submissions

Recalculations

No recalculations have been made for this reporting period. However, future updates may incorporate disaggregated lime data, including calcitic lime, once available.

Planned Improvements

- Conduct field-level surveys to determine actual lime types and application rates

- Develop district-level lime use reporting templates
- Conduct laboratory analysis of lime samples to establish country-specific emission factors for calcitic and dolomitic lime

5.17 Urea Application (CRT Category 3.C.)

This sub-category captures direct carbon dioxide (CO₂) emissions resulting from the application of urea-based nitrogen (N) fertilizers to agricultural lands. Urea is extensively used in Malawi's agricultural sector, especially under the Affordable Inputs Programme (AIP), to support the cultivation of major crops such as maize, rice, and tobacco.

Upon application, urea undergoes chemical hydrolysis in soil, converting into ammonium and bicarbonate. The bicarbonate subsequently decomposes into water and carbon dioxide, releasing CO₂ into the atmosphere. This transformation is a purely chemical process, occurring independently of microbial or biological activity.

In Malawi, urea usage spans across two major sub-categories of cropland:

- **Cropland – General (Unspecified):** Covers non-flooded agricultural land used for a variety of crops such as maize, tobacco, legumes, and horticultural crops.
- **Cropland – Flooded Rice Fields:** Covers areas under permanent or seasonal flooding where rice cultivation occurs, particularly in lakeshore and lowland districts (e.g., Salima, Zomba, and parts of Karonga and Chikwawa).

Over the inventory period (1994–2022), the use of urea fertilizer has shown substantial growth, in part driven by government input subsidies, improvements in logistics, and intensified farming practices.

Methodological Issues

The Tier 1 approach in line with the 2006 IPCC Guidelines (Volume 4, Chapter 11) was applied to estimate emissions from urea application. The approach uses a default emission factor (EF) of 0.20 tonnes of CO₂ per tonne of urea applied.

- *Emission Factor (EF): 0.20 t CO₂/t urea applied*
- *Estimation Method:*
$$\text{Emissions (CO}_2\text{)} = \text{Urea Applied (tonnes)} \times \text{EF}$$
- *Activity Data Source:*

Ministry of Agriculture fertilizer import and distribution records, national agricultural surveys, and FAOSTAT data. For recent years, data disaggregation by land use sub-category was derived from national reports and fertilizer usage patterns from MoA, MRA, and NSO surveys.

Emission Trends

Urea usage has increased significantly over the time series. The annual application rate of urea in Malawi rose from 30,514 tonnes in 1994 to a peak of 196,255 tonnes in 2021.

- Flooded rice fields began recording distinct urea usage starting in 2020, with over 6,500 tonnes in 2020 and rising to over 18,700 tonnes in 2022, suggesting increasing intensification in rice farming supported by AIP and irrigation programs.
- For general cropland, a sharp rise in usage was recorded between 2018 and 2021, in line with increased AIP coverage and price subsidies.

The Annual Growth Rate for total urea-based emissions between 2018 and 2022 was 4.52%, driven by:

- Increased input subsidies.
- Expanded irrigation schemes.
- Intensified fertilizer demand, especially in the maize-growing central region.

Table 5-25: Emission trends

YEAR	Annual amount of Carbonate N-fertilizer (tonnes / yr)		Emissions
	Cropland - Flooded ricefields	Cropland	
1994		30514	8,604.38
2000		41150	9,864.85
2010		120967	15,197.33
2017		89852.18	20,144.15
2018	6507.848	71890.06	73,493.61
2019	6826.956	83239.76	22,223.66
2020	7479.586	93162.97	23,300.35
2021	18784.82	196255.3	24,129.80
2022	15365.5	173851.1	71,958.88

Figure 5-16 below presents annual CO₂ emissions from urea application for both cropland categories between 1994 and 2022.

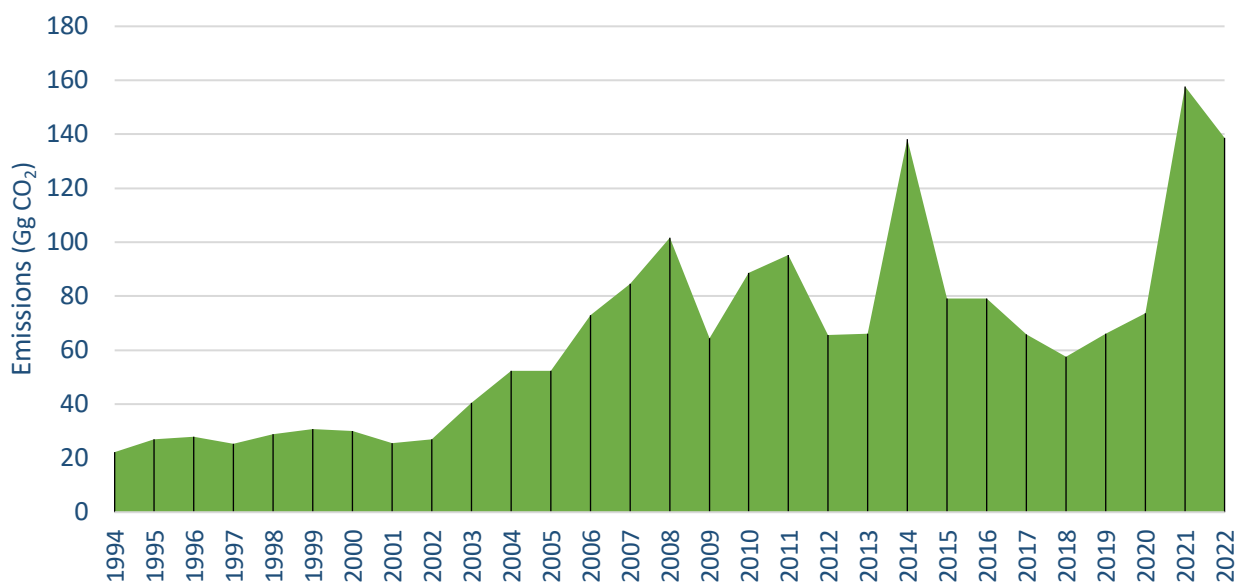


Figure 5-16: CO₂-e emissions from urea application

Description of Flexibility Applied

Flexibility was applied under due to:

- Lack of detailed historical records disaggregating fertilizer use by crop or region.
- Limited availability of country-specific emission factors.

As such, the IPCC default EF was used throughout the series.

Uncertainty Assessment and Time-Series Consistency

- **Uncertainty Level: Moderate**
 - Primarily arises from estimation of activity data, especially in earlier years and disaggregation by land-use subcategories.
 - Use of import data as a proxy for application introduces potential uncertainty where stockpiling or cross-border trade occurred.
- **Time-Series Consistency: Maintained using:**
 - Harmonized methodology (Tier 1, same EF)
 - Consistent data sources from MoA, FAOSTAT, and national reports.

Category-Specific QA/QC and Verification

- **QA/QC Procedures:**
 - Cross-referenced fertilizer volumes with MRA import statistics.
 - Data validated through interviews with key stakeholders (e.g., agro-dealers, district agricultural officers).

- **Verification:**
 - Urea usage trends reviewed by sectoral experts including agricultural economists and soil scientists.

Category-Specific Recalculations

- No recalculations were carried out for this submission.
- However, activity data for earlier years (1994–2005) were verified and updated through triangulation with historical national budget allocations to farm inputs, FAOSTAT trends, and archived Ministry reports.

Category-Specific Planned Improvements

- **Improved Disaggregation:** Develop region- and crop-specific fertilizer use statistics through periodic agricultural censuses and surveys.
- **Country-Specific Emission Factor (EF) Development:** Initiate collaborations with LUANAR and research institutions to derive Malawi-specific CO₂ emission factors from urea application.
- **Monitoring Enhancements:** Institutionalize fertilizer consumption tracking through integration of agro-dealer distribution networks into national monitoring systems (e.g., through NSO and e-voucher systems).

5.18 Direct N₂O Emissions from Managed Soils (CRT Category 3.C.4)

This category accounts for direct emissions of nitrous oxide (N₂O) from nitrogen (N) inputs to managed agricultural soils. These emissions are the result of microbial processes—primarily nitrification and denitrification—that occur following the application of nitrogen in various forms. The nitrogen inputs include synthetic fertilizers, organic amendments, crop residue returns, and biological nitrogen fixation by legumes.

Nitrogen Input Sources in Malawi

In Malawi, the major pathways of nitrogen addition to soils include:

- Synthetic fertilizers, particularly urea, calcium ammonium nitrate (CAN), and NPK blends, widely used under national agricultural programs.
- Animal manure, mostly from smallholder livestock systems.
- Biological nitrogen fixation, primarily by leguminous crops such as groundnuts, pigeon peas, and soybeans.
- Crop residue incorporation, notably from maize and tobacco.

Fertilizer application is particularly intensive in maize and tobacco cultivation systems, which have consistently received priority under government-led programs such as the Affordable Inputs

Programme (AIP). According to the 2023 Annual Economic Report (MoFEPD, 2023), maize remained the dominant crop receiving nitrogen-based inputs.

Methodological Approach

Direct N₂O emissions from managed soils are estimated using the Tier 1 methodology outlined in the 2006 IPCC Guidelines for National Greenhouse Gas Inventories (Vol. 4, Chapter 11). This approach uses a default emission factor applied to the total annual nitrogen input to soils.

- **Emission Factor (EF):** 0.01 kg N₂O–N / kg N input (equivalent to 1%)
- **Total N Input Sources:**
 - Inorganic fertilizers (urea, CAN, NPK)
 - Organic manure
 - Crop residue returns
 - Biological nitrogen fixation (BNF)

Activity Data Sources:

- **Ministry of Agriculture (MoA) and Malawi Revenue Authority (MRA):** Fertilizer distribution and import records
- **FAOSTAT:** Estimates of biological nitrogen fixation and crop residue returns
- **National Statistical Office (NSO):** Crop production surveys, land area under cultivation, and livestock numbers

Estimation Equation:

$$N_2O\ Emissions\ (Gg\ CO_2e) = (N_{input} \times 0.01) \times \frac{44}{28}$$

Where:

- *N_{input}* = Total nitrogen applied (in Gg)
- *0.010* = Default Tier 1 EF for direct N₂O emissions
- $\frac{44}{28}$ = Molecular weight ratio for converting N₂O–N to N₂O

Emissions Trend

Between 1994 and 2022, direct N₂O emissions from managed agricultural soils in Malawi exhibited a gradual upward trend, primarily driven by increased nitrogen inputs associated with the intensification of crop production. Emissions increased from approximately 0.32 Gg CO₂e in 1994 to 1.12 Gg CO₂e in 2022 (Figure 5-17).

Table 5-26: Emissions Trends

YEAR	Emissions CO ₂ e(Gg)
------	---------------------------------

1994	15.37
2000	16.43
2010	87.98
2017	260.495
2018	298.655
2019	212.265
2020	241.15
2021	267.65
2022	306.605

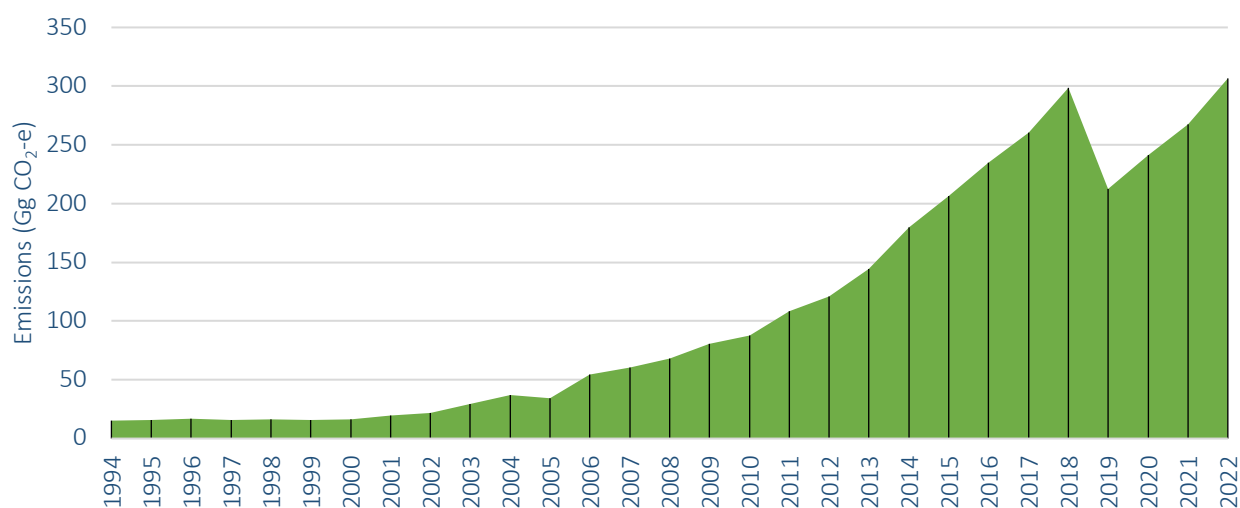


Figure 5-17: converted N₂O Emissions from Managed Soils

The overall trend is explained by the following key drivers:

- Expansion of fertilizer use: The most significant contributor to increased nitrogen inputs has been the wider distribution and usage of synthetic fertilizers, notably urea, CAN, and NPK. This expansion was particularly evident during years when government subsidy programs, such as the Affordable Inputs Programme (AIP) and its predecessor initiatives, were implemented at scale.
- Intensification of maize and tobacco cultivation: These two crops continued to dominate fertilizer consumption, in line with national priorities and food security objectives. Maize, as the staple crop, has consistently received the highest share of subsidized fertilizer.
- Growth in legume production: The increase in legume cultivation, particularly groundnuts and soybeans under crop diversification strategies, has also contributed to elevated nitrogen levels through biological nitrogen fixation.
- Increased crop residue incorporation: Changes in conservation agriculture and sustainable land management practices have promoted the return of crop residues to soils, adding further nitrogen input over time.

Description of Any Flexibility Applied

Flexibility were applied in the following cases:

- Assumptions were made where crop-specific residue returns and BNF estimates were not available due to data constraints.
- Country-specific emission factors have not yet been developed; hence, default IPCC values were used.

Uncertainty Assessment and Time-Series Consistency

- **Uncertainty:** Classified as high, especially in estimating the proportion of nitrogen returned via crop residues and manure application rates. BNF estimates from FAOSTAT also include some uncertainty due to modeling assumptions.
- **Time-series consistency:** All years from 1994 to 2022 used a consistent Tier 1 approach and emission factor. Activity data were harmonized across sources and cross-validated where possible.

Category-Specific QA/QC and Verification

- **Quality Assurance/Quality Control (QA/QC):** Triangulation of data was conducted using national fertilizer records, FAOSTAT datasets, and agricultural survey reports. Expert judgment was incorporated to validate estimates.
- **Verification:** Emission estimates underwent review during stakeholder consultation workshops with representation from academia, agricultural extension officers, and climate change experts.

Category-Specific Recalculations

No major recalculations were made in this reporting cycle. However, fertilizer usage data from 2018 to 2022 were refined based on improved import records and distribution reports from MRA and the MoA. This led to minor adjustments in nitrogen input values at the upper end of the time series.

Category-Specific Planned Improvements

Planned actions to enhance this category include:

- Disaggregation of nitrogen inputs by crop type and region, particularly for residues and manure.
- Development of country-specific emission factors through national research collaborations.
- Expansion of nitrogen balance data collection, including crop nutrient uptake and nitrogen output coefficients.

- Improved survey design to capture more accurate data on livestock manure management and legume cultivation practices at district level.

5.19 Indirect N₂O Emissions from Managed Soils (CRT Category 3.C.5)

This accounts for indirect nitrous oxide (N₂O) emissions resulting from nitrogen (N) that is initially volatilized as ammonia (NH₃) and nitrogen oxides (NO_x) or leached/run off as nitrate (NO₃⁻) following application to managed soils. These forms of nitrogen are subsequently deposited in other ecosystems—such as water bodies, wetlands, and adjacent soils—where they undergo microbial nitrification and denitrification, leading to delayed N₂O emissions.

Source Description

In Malawi, the main sources contributing to indirect N₂O emissions include:

- Volatilization losses from synthetic and organic fertilizers, particularly urea and ammonium-based compounds.
- Leaching and runoff during the rainy season, especially in high rainfall regions such as Thyolo, Mulanje, Nkhatabay, Mzimba, and parts of Dedza.

The consistent rise in nitrogen-based fertilizer use, supported by government-led initiatives such as the Farm Input Subsidy Programme (FISP) and the Affordable Inputs Programme (AIP), has led to increased nitrogen input to soils, especially under maize and tobacco production systems, further driving indirect N₂O emissions.

Methodological Issues

Estimates were developed using the Tier 1 methodology of the 2006 IPCC Guidelines (Vol. 4, Ch. 11). This approach uses default emission factors and nitrogen loss fractions to estimate indirect N₂O emissions from volatilization and leaching pathways.

- **Default Nitrogen Loss Fractions:**
 - Frvol (fraction of N volatilized): 0.10 (10%)
 - Frleach (fraction of N leached/runoff): 0.30 (30%)
- **Emission Factor (EF) for Indirect N₂O:**
 - 0.0075 kg N₂O-N per kg N volatilized or leached
- **Activity Data Sources:**
 - Fertilizer import and distribution statistics from the Ministry of Agriculture, MRA, and FAOSTAT
 - Crop production and land use data from NSO and FAOSTAT

Calculation Formula:

$$N_2O_{Indirect} = (N_{vol}) + N_{leach}) \times EF_{indirect} \times \frac{44}{28}$$

Where:

- N_{vol} = 10% of total nitrogen input (volatilized N)
- N_{leach} = 30% of total nitrogen input (leached/runoff N)
- $EF_{indirect}$ = 0.0075
- $\frac{44}{28}$ = molecular weight ratio to convert N_2O -N to N_2O

Emissions Trend

Direct N_2O emissions from managed soils in Malawi have exhibited a consistent upward trend over the period 1994 to 2022, increasing from 15.37 Gg CO_2 eq. in 1994 to 306.61 Gg CO_2 eq (Figure 5-18).

Table 5-27: Emissions Trends

YEAR	Emissions CO_2 e(Gg)
1994	2.12
2000	2.12
2010	3.18
2017	5.035
2018	5.565
2019	5.83
2020	6.36
2021	6.625
2022	7.685

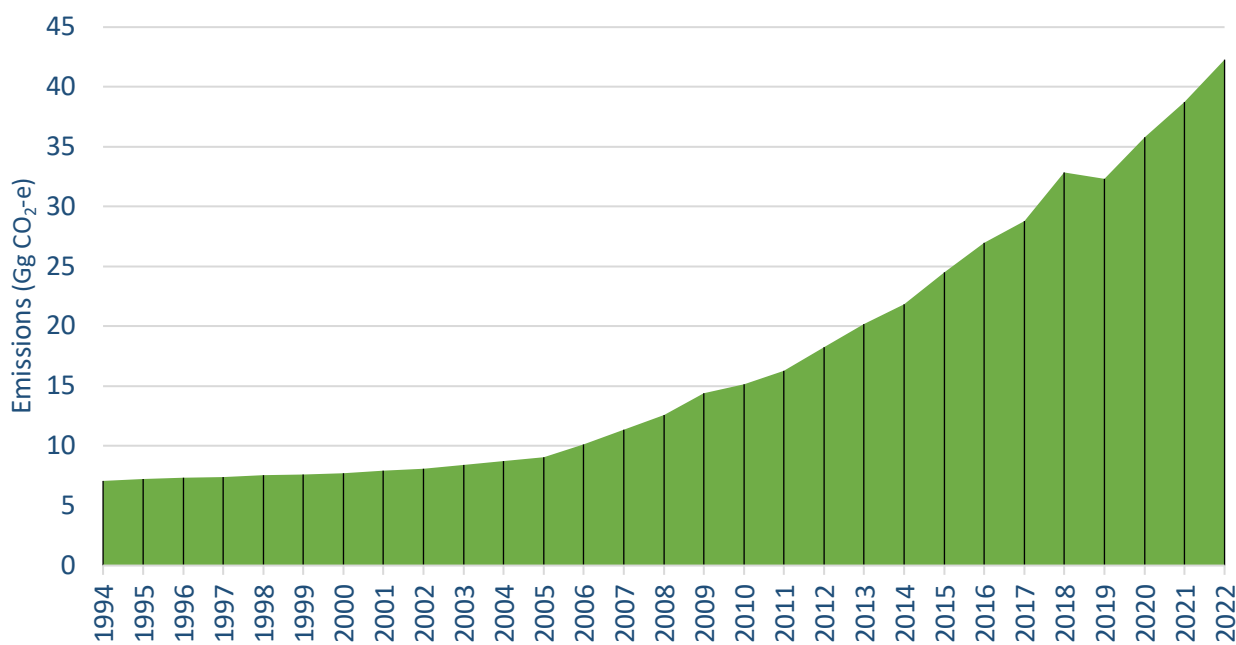


Figure 5-18: Indirect N₂O Emissions from Managed Soils, 1994–2022 (Gg CO₂e)

The trend can be divided into three distinct phases:

- 1994–2005 (Stable Low Emissions Phase):

During this period, emissions fluctuated within a relatively narrow range, averaging approximately 16 Gg CO₂ eq. annually. Limited use of nitrogen-based fertilizers, constrained by affordability and access, contributed to the low and stable emission levels.

- 2006–2010 (Transitional Growth Phase):

Emissions began to rise more noticeably, from 22 Gg CO₂ eq. in 2006 to 37.1 Gg CO₂ eq. in 2010, driven by the implementation and scale-up of the Farm Input Subsidy Programme (FISP), which significantly expanded smallholder access to nitrogen-based fertilizers, particularly for maize and tobacco cultivation.

- 2011–2022 (Accelerated Growth Phase):

From 2011 onwards, direct N₂O emissions increased steeply, reaching 298.66 Gg CO₂ eq. by 2020 and 306.61 Gg CO₂ eq. in 2022. This acceleration corresponds with:

- Expanded fertilizer use under FISP and later the Affordable Inputs Programme (AIP).
- Intensification of rain-fed crop production, especially in high-fertilizer-demand crops such as maize and tobacco.
- Gradual increases in cropland area under cultivation, particularly in high rainfall zones conducive to nitrogen loss through nitrification and denitrification.

A temporary dip in 2020 (212.27 Gg CO₂ eq.) was observed, likely linked to COVID-19-related disruptions, including delays in input distribution, reduced farmer mobility, and logistical constraints in fertilizer supply chains. However, the post-pandemic recovery period showed a swift rebound in fertilizer application, contributing to a renewed rise in emissions in 2021 and 2022.

The observed trend underscores the growing significance of direct N₂O emissions from agricultural soils in Malawi's national GHG profile, highlighting the need for enhanced nitrogen use efficiency and the development of mitigation strategies such as precision fertilization, soil health improvements, and improved crop management practices.

Description of Flexibility Applied

Flexibility has been applied to this category. Due to data limitations, default IPCC emission factors and nitrogen loss fractions were used consistently across the time series. No country-specific factors have been developed to date.

Uncertainty Assessment and Time-Series Consistency

- **Uncertainty Level: High**
Key uncertainties arise from:
 - Absence of spatially disaggregated leaching and volatilization data
 - Assumption of uniform climatic and soil drainage conditions across agroecological zones
- **Time-Series Consistency:**
A uniform Tier 1 methodology has been applied from 1994 to 2022. Variations in annual fertilizer inputs due to programmatic and economic factors (e.g. changes in FISP/AIP reach or import levels) have been accounted for in year-specific activity data.

Category-Specific QA/QC and Verification

- **Quality Assurance (QA):**
 - Reviewed fertilizer consumption trends from the Annual Economic Report, MRA, and FAOSTAT
 - Input data validated through consultation with national agricultural experts
- **Quality Control (QC):**
 - Peer review of nitrogen input assumptions and applied fractions (Fr_{vol}, Fr_{leach})
 - Cross-checks with national fertilizer use and crop distribution datasets

Category-Specific Recalculations

No formal recalculations were undertaken in this inventory cycle. However, activity data for the period 2018–2022 was updated using recent fertilizer import statistics from MRA and distribution data from MoAFS, leading to refinements in upper-end estimates of the time series.

Category-Specific Planned Improvements

Planned improvements to enhance the accuracy of this category include:

- Development of country-specific nitrogen loss rates through collaboration with agricultural research institutions
- Pilot studies in major maize and tobacco-growing regions to quantify nitrogen leaching and volatilization under different management practices
- Integration of remote sensing, rainfall, and soil data to develop spatially explicit models of nitrogen flow and associated N₂O emissions

5.20 Rice Cultivation (CRT Category 3.C.7)

Rice cultivation in Malawi is an important agricultural activity and a key contributor to food security. It predominantly occurs in the central and southern regions, with major production hubs in the Shire Valley, Salima, Nkhosha, and parts of Karonga. The majority of rice is grown under irrigated or semi-irrigated conditions using flooded paddy systems, which are conducive to methane (CH₄) emissions.

The principal greenhouse gas emitted from rice cultivation is methane (CH₄), generated through the anaerobic decomposition of organic matter in water-saturated soils. The anaerobic conditions created by continuous flooding stimulate methanogenic bacteria, leading to CH₄ production throughout the growing season. Although nitrous oxide (N₂O) emissions may also occur due to fertilizer application, they are typically minor compared to methane in flooded systems.

Factors influencing methane emissions include soil type, water management, fertilizer use, and the length of the growing season. Most smallholder farmers in Malawi employ traditional practices, but recent years have seen an expansion of irrigation schemes, supported by government and donor investments, aimed at increasing productivity and crop resilience to climatic variability.

Methodological Issues

A Tier 1 method has been applied, in accordance with Volume 4, Chapter 5 of the 2006 IPCC Guidelines, using the default emission factors and scaling coefficients for rice systems without organic amendments.

Activity

Data:

Annual harvested area data from the Ministry of Agriculture and FAO is used for the 1994–2022 period. The rice ecosystem is classified under deep-water, continuously flooded paddy fields.

Emission Factor and Scaling Coefficients:

- *EF_c (Baseline EF): 1.19 kg CH₄/ha/day*
- *SF_w (Water regime during cultivation): 1 (continuously flooded)*
- *SF_p (Pre-season water regime): 0.89 (non-flooded)*
- *SFO (Organic amendment): 1 (synthetic fertilizers used)*
- *Growing season length: 150 days*

$$\text{Rice EF} = 1.19 \times 150 \times 1 \times 0.89 \times 1 = 158.9 \text{ kg CH}_4/\text{ha/season}$$

Annual emissions are calculated as:

$$\text{Emissions (Gg CH}_4\text{)} = \frac{\text{Harvested area (ha)} \times 158.9}{10^6}$$

Emission Trends

Emissions from rice cultivation have increased significantly over the past three decades, rising from 0.107 Gg CH₄ (2.67 Gg CO₂e) in 1994 to 1.205 Gg CH₄ (30.12 Gg CO₂e) in 2022 (Figure 5-19). This trend closely follows the expansion in harvested area, which nearly tripled from 27,067 ha in 1994 to 75,787 ha in 2022.

This growth reflects:

- Increased government investment in irrigation infrastructure.
- Rising domestic demand for rice as a staple food.
- Favorable prices and market access driven by public and private sector support.

The largest jumps in emissions were recorded during:

- 2006–2009, coinciding with expansion of irrigation schemes under the Farm Input Subsidy Programme (FISP).
- 2017–2022, following climate-smart agriculture initiatives and irrigation investments in Karonga, Salima, and Nsanje.

Table 5-28: Emission Trends

YEAR	Annual harvested area (ha/yr)	Emissions
1994	27067	45.43532
2000	43523	73.05872
2010	59098	99.20316
2017	64881	108.91076
2018	63971	107.38308
2019	70573	118.46548
2020	72763	122.1416
2021	76000	127.57528
2022	75787	127.21772

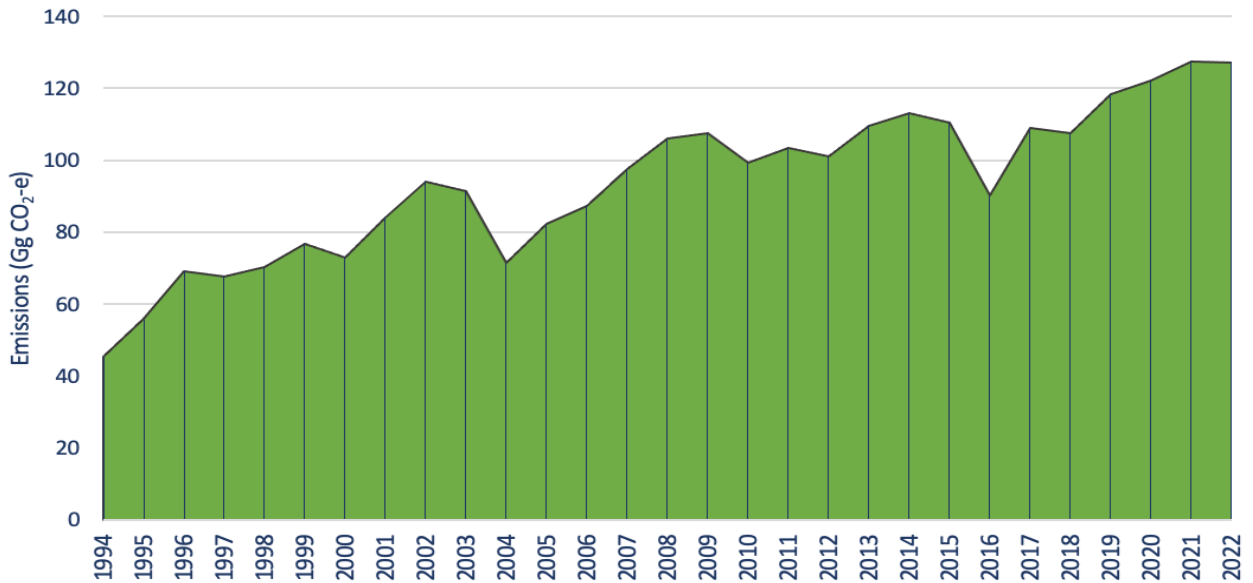


Figure 5-19: Emissions from Rice Cultivation (1994–2022)

The figure will display a time-series plot of CO₂e emissions derived from the harvested area and EF.

Uncertainty and Time-Series Consistency

- Uncertainty in emission estimates arises from assumptions on water management, uniform growing season length, and the absence of country-specific EFs.
- Time-series consistency is ensured through the consistent application of the Tier 1 method and use of annual harvested area statistics.

While emissions are likely underestimated or overestimated in years with highly variable rainfall and irrigation implementation delays, the general trend remains robust.

QA/QC and Verification

- The activity data was validated against national crop estimates from the Ministry of Agriculture and FAOSTAT.
- QA/QC procedures involved cross-verification of annual harvested area figures with the Annual Economic Report and the Agricultural Production Estimates (APES) system.
- IPCC Tier 1 spreadsheet tools were used to verify emission estimates.

Category-Specific Recalculations

No recalculations were necessary for this inventory submission. All updates reflect the application of consistent methodologies with updated activity data.

Category-Specific Planned Improvements

- Transition to Tier 2 methods, including seasonal water management data and country-specific emission factors.
- Field studies to monitor methane emissions under varying water regimes in rice-growing zones.
- Integration of AWD practices into emission modeling as adoption expands.
- Improved tracking of input use, particularly organic amendments and irrigation frequencies, for higher-tier estimation.

Chapter 6:



Forestry and Other Land Uses

6.1 Overview of the Sector and Background Information

The FOLU sector covers greenhouse gas (GHG) emissions and sinks associated with forestry and land management practices that impact carbon stored in vegetation and soils. The GHGs emissions and sink sources reported in this report are presented in Table 6-1. It further entails FOLU emissions by category for the year 2022, thus depicting changes in the years; 2018, 2019, 2020, and 2021. Overall, for the reporting period (2018 to 2022), there has been a noticeable fluctuation in emissions which registered a decreased of 5,347.13 GgCO₂e (10.29%) averaging to -2.06% annually (Figure 6-1; Figure 6-2). Furthermore, for the period 2018 to 2022 the greatest contribution of the emissions emanated from the forestland (79.08%), followed by cropland (9.70%) and Wetland (8.50%). Grassland and settlement contributed the lowest, 2.60% and 0.12%, respectively (Figure 6-3).

The 95% confidence level uncertainty results for GHG emissions show varying levels of reliability across FOLU categories (Table 6-20). Cropland (0.20%), wetland (0.64%), and settlements (0.69%) bear the lowest uncertainties. These epitomise the availability of improved or robust data and well-documented emission factors. Grassland (6.05%) has the highest uncertainty due to challenges in measuring emissions associated with fire management, though it remains within the allowable 30-50% threshold of the 2006 IPCC guidelines. Forestland (4.92%) has moderate uncertainty, likely influenced by variations in deforestation rates and biomass loss estimates. The overall uncertainty (4.16%) suggests a reasonably reliable GHG inventory. Nevertheless, improvements in land-use monitoring, particularly biomass burning in grasslands are needed to enhance accuracy.

Table 6-1: Sources of GHG Emissions/sinks by Category in FOLU Subsector

No.	Category	GHG's emission sources
1	Forestland	1) Forestland remaining forestland 2) Land converted to forestland 3) Harvested wood products 4) Biomass burning in forestland
2	Cropland	1) Cropland remaining cropland 2) Land converted to cropland 3) Biomass burning in cropland
3	Grassland	1) Grassland remaining cropland 2) Land converted to cropland 3) Biomass burning in grassland
4	Wetland	1) Wetland remaining wetland 2) Land converted to wetland
5	Settlement	1) Settlement remaining settlement 2) Land converted to settlement

Table 6-2: FOLU Subsector Emissions by Category for the Year 2022 With Changes since, 2018, 2019, 2020, and 2021

Category	Change in 2022 emissions (GgCO ₂ -e) since:				2022 emissions (GgCO ₂ -e)
	2018	2019	2020	2021	
Forestland	-4464.27	-5031.02	-5547.68	-4862.49	36258.53
	-11 %	-12.2 %	-13.3 %	-11.8 %	--
Cropland	-28.1	-21.08	-14.06	-7.03	4922.24
	-0.6 %	-0.4 %	-0.3 %	-0.1 %	--
Grassland	-610.5	-502.02	-302.17	-196.26	1002.89
	-37.8 %	-33.4 %	-23.2 %	-16.4 %	--
Wetland	80.16	60.12	39.08	20.04	4366.06
	+1.9 %	+1.4 %	+0.9 %	+0.5 %	--
Settlement	-1.4	-0.8	-0.4	-0.6	58.42
	-1.4 %	-0.8 %	-0.4 %	-0.6 %	--
overall	-5023.57	-5494.49	-5825.09	-5045.38	46608.15
	-9.7 %	-10.5 %	-11.1 %	-9.8 %	--

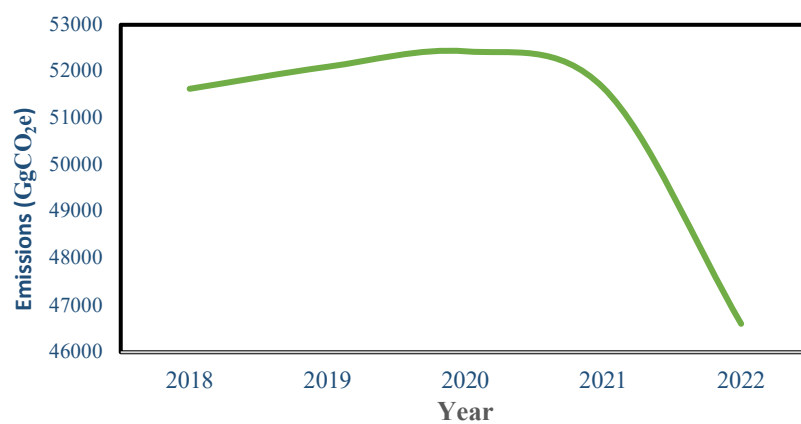


Figure 6-1: Emission Trends in FOLU Subsector from 2018 to 2022

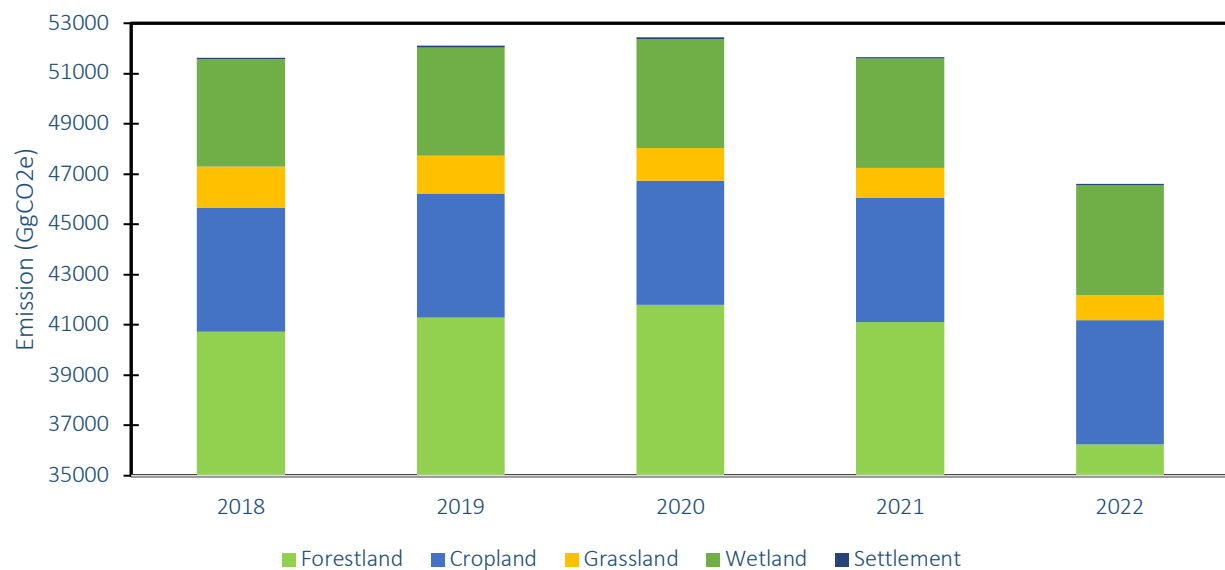


Figure 6-2: FOLU Emissions by Category from 2018 to 2022

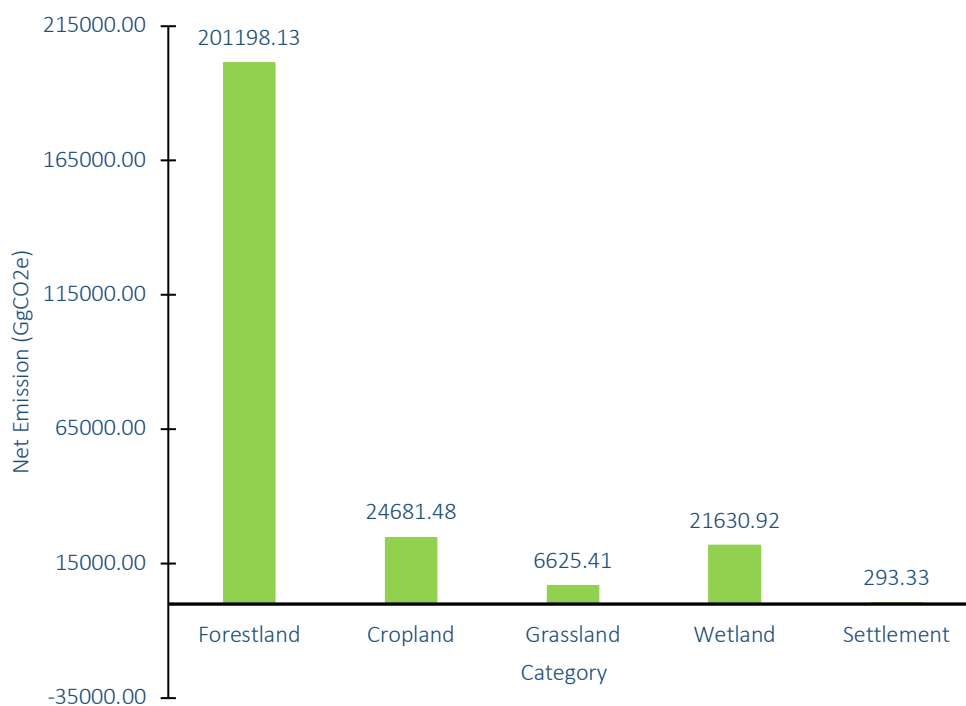


Figure 6-3: Total Contribution of Emissions by Different Categories in FOLU, 2018 to 2022

As depicted in Table 6-2, Figure 6-1 and Figure 6-2, the underlying trend of declining emissions in the FOLU subsector from 2018 to 2022 is primarily, though not exclusively, attributed to the following.

- i. The decline in emissions from forestland conversion to other land uses,
- ii. The increase in removals through forest regrowth on previously cleared land.

These have ultimately resulted to a decline in net emissions from the harvest of indigenous (Miombo) forests.

Nevertheless, emissions remained relatively stable in 2022 as increasing sink in croplands and grasslands due to the La Niña conditions (wetter conditions that enhanced plant growth) were offset by increases in emissions in forest lands due to wildfires and increased rates of soil carbon decay also caused by the wetter conditions.

Principally, the mitigation scenario predicts GHG emission trends under interventions to curtail their emissions. In as far as Malawi's Nationally Determined Contributions (NDCs) and Nationally Appropriate Mitigation Actions (NAMA) are concerned, the FOLU subsector showed greatest mitigation potential (GoM, 2021a; GoM, 2015). Coincidentally, the mitigation options identified also in Malawi's Third National Communication NC3 apply for this study (GoM, 2021b). They further agree with the recommendations of the Food and Agricultural Organization (FAO) which recognised them as the GHG reduction options under the FOLU subsector. Selection of these mitigation interventions was carried out through a screening process by the stakeholders which prioritised the following in their criteria; (i) the cost of implementation, (ii) potential to reduce emissions, (iii) ease of implementation, and (iv) compatibility with government programmes and plans. The optimal mitigation options selected are briefly enshrined in policy framework and implementation. In this regard, the country is implementing, sector-specific policies to enhance mainstreaming of adaptation and mitigation measures within the FOLU context, and *inter-alia*, these include.

- i. National Forest Landscape Restoration Strategy-2018,
- ii. Reducing Emissions from Degradation and forest Degradation (REDD+) Strategic Plan,
- iii. Malawi REDD+ Forest Reference Level-2018,
- iv. Malawi National Charcoal Strategy 2017-2027,
- v. Tree planting (afforestation and reforestation) Initiatives.
- vi. National Greenhouse Gas Inventory Systems (GHG-IS) 2019.
- vii. Towards Healthy Forests for a Better Malawi (2021)

Additionally, there are technological options in FOLU sector aimed at mitigating GHG emissions and the key ones are not limited to.

- i. Tree survival campaigns,
- ii. Breeding and screening drought tolerant tree species,
- iii. Pest and disease control, and
- iv. Sustainable management of forest resources,
- v. Increase in concessions of protected areas though under the Department of National Parks and Wildlife (i.e., Majete, Liwonde and recently Nkhotakota Wildlife Reserves under the African Parks Programme).

In addition, Malawi has also engaged in the international Carbon Trade and the key carbon market schemes under the FOLU subsector so far include;

- i. The 'Reducing Deforestation and forest Degradation (REDD+), and

ii. The Voluntary Carbon Markets (VCM).

Advocated by the UNFCCC, the REDD+ includes the conservation and sustainable management of forests and enhancement of forest carbon stocks, thus the 'Plus' (Bellassen & Leguet, 2007; Berry et al., 2008; Skole et al., 2021).

In June 2023 country officially launched the Malawi Carbon Markets Initiative (MCMI) to champion the implementation of the frameworks, action plans, and ongoing efforts that support carbon markets. In the country, carbon trading is deemed as a source of revenue that will bolster the economy by supporting, foreign exchange shortages caused by a large trade imbalance and being buffeted by several shocks, including the climate crisis. In economic terms, the country's carbon potential estimated to be around 19 million metric tons annually.

The advantage of carbon trading is that it will provide incentives for managing trees and forests and all other initiatives that enhance carbon sequestration and are aimed at avoiding greenhouse gases. This is deemed a key mitigation option under FOLU.

6.2 Land Use Definitions and Land Use Change Matrix

6.2.1 Land classification and definitions

Six Land classes based on current or potential use are nationally defined in Malawi as indicated in Table 6-3. Their distribution for the reporting periods are presented in Table 6-4.

6.2.2 Land representation matrix

The total area covered under each land-use within the designated two 10-year epochs are reported in Table 6-5, and Table 6-6; and Figure 6-4. The findings indicate that "forestland to cropland," and "wetland to cropland," were the major land use changes from the year 2000 to the year 2022. Forestland steadily declined at a rate of 13,591 ha (0.5%) per annum. Similarly, grassland declined at the rate of 1,651 ha (0.5%) per annum. On the other hand, cropland, wetland, and settlements steadily increased at the rate of 8,228 ha (0.14%); 5,257 ha (0.17%); and 1,941 ha (8.1%) per annum, respectively. Furthermore, these results indicate that the "grassland to forestland" changes were higher than the "forestland to grassland" changes, suggesting forest regeneration was occurring.

Table 6-3: Malawi's land use classes and their definitions

No.	Land use class	Definition
1	Forestland	Land with woody vegetation consistent with thresholds used to define forest land. These thresholds are minimum mapping area or unit (MMU), minimum crown closure at maturity, minimum height, and minimum width of linear features. Recommended definition thresholds for the GoM are a minimum mapping area of 0.5 hectare, a minimum 10% crown closure, a minimum height of 5 meters, and a minimum linear feature width of 20 meters.

2	Cropland	Arable and tillage land, and agroforestry systems where vegetation falls below the thresholds used to define forest land. The FAO Land Cover Classification System (LCCS) calls these Agriculture Lands.
3	Grassland	Rangelands and pastureland that is not considered cropland.
4	Wetland	Land that is covered or saturated by water for all or part of the year and that does not fall into the previous categories or settlements.
5	Settlements	developed land, including transportation infrastructure and human settlements of any size unless they are already included under other categories
6	Other land	Bare ground, rock, and all unmanaged land not in the previous categories.

Source: MFNR (2021)

Table 6-4:Area distribution by land classes and forest sub-classes (in ha) from 2018 to 2022

Year	Miombo	Pine	Eucalyptus	Cropland	Grassland	Wetlands	Settlements	Other Lands
2018	2071558.1	69827.8	186207.5	6008600.0	304606.7	3117143.3	62880.0	11216.7
2019	2061533.7	69489.9	185306.4	6016982.5	302927.5	3120510.0	64325.0	10965.0
2020	2051509.3	69152.0	184405.3	6025365.0	301248.3	3123876.7	65770.0	10713.3
2021	2041485.0	68814.1	183504.3	6033747.5	299569.2	3127243.3	67215.0	10461.7
2022	2031460.6	68476.2	182603.2	6042130.0	297890.0	3130610.0	68660.0	10210.0

Table 6-5:Malawi Land Use Statistics from 2000 to 2022

Year	2000		2010		2022	
Classes	Area (ha)	%	Area (ha)	%	Area (ha)	%
Forest Land	2595140	21.9	2417700	20.4	2282540	19.3
Cropland	5852880	49.5	5941540	50.2	6042130	51.1
Grassland	335860	2.8	318040	2.7	297890	2.5
Wetland	3009710	25.4	3090210	26.1	3130610	26.5
Settlements	24010	0.2	51320	0.4	68660	0.6
Other Land	14440	0.1	13230	0.1	10210	0.1

Table 6-6:Major Land Use Changes (in Hectares) for Malawi

Land use cover change	2000- 2010	2010-2022
Forest land to Cropland	368060	220840
Forest land to Grassland	25509	15360
Cropland to Forest land	187070	112240
Grassland to Forest land	22060	31240
Wetland to Forest land	39240	23540
Wetland to Cropland	147930	88770
Forest land to Settlement	2730	2480

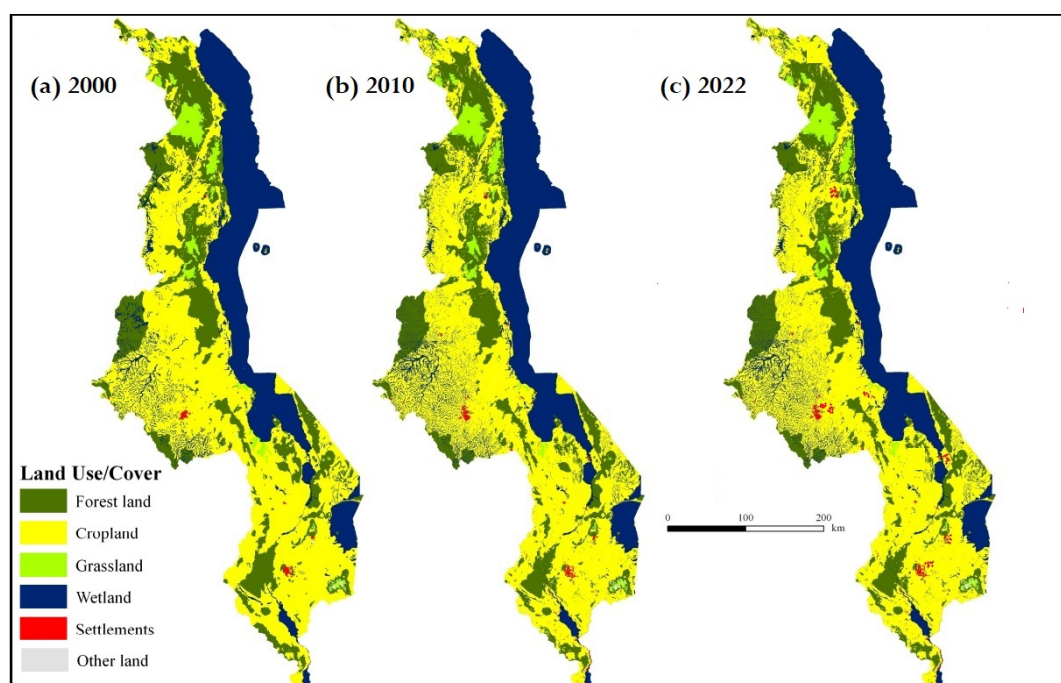


Figure 6-4: Malawi's Land Use/Cover Distribution for the Years 2000, 2010 and 2022

6.3 Country Specific Approaches

6.3.1 Information on approaches used for representing land areas and land use databases used for the inventory preparation

Activity data

Malawi uses Approaches 1 and 2 as described in the 2006 IPCC Guidelines for National Greenhouse Gas Inventories (Eggleston et al., 2006) to monitor forestry and other land use (FOLU). The principal monitoring system is a remote sensing programme used to identify forestlands and changes in forest cover. Malawi's land cover maps for the year 2022 were produced to supplement the land cover maps for the years 2000, and 2010 that were produced by Air Asia Survey (AAS, 2012). A more detailed production of Malawi's land cover maps for the year 2022 is available in Missanjo and Kadzuwa (2024). Data between the three epochs was linearly interpolated while extrapolation was conducted for the period 2018 to 2021.

Emission factor

The emission factor was developed using Forest Inventory techniques. Essentially, the Carbon Stock Change approach was used. In the Carbon Stock Change approach, carbon stocks are measured at two-time intervals and the difference between those two intervals determines the carbon stock change. Equation 6.1 was used in the Carbon Stock Change approach (IPCC, 2019).

$$\Delta C = \frac{C_{t2} - C_{t1}}{t_2 - t_1} \quad \text{Equation 6-1}$$

Where: ΔC is annual carbon stock change in pool (tC/ha/yr); C_{t_2} is carbon stock in pool at time t_2 (tC/ha); and C_{t_1} is carbon stock in pool at time t_1 (tC/ha). In this reporting period, Forest Inventory data collected by the JICA project in the year 2011 was used as time (t_1). On the other hand, Forest Inventory data collected by the Modern Cooking for Healthy Forests (MCHF) Project in the year 2022 was used as time (t_2). Both datasets were obtained from the Department of Forestry Headquarters, National Forest Monitoring Unit. However, the time (t_2) dataset was supplemented by a forest inventory conducted in Lilongwe Urban Forest in November 2022.

Above-ground biomass (AGB) and Below-ground biomass (BGB) were estimated using the site-specific allometric equation 6.2 and equation 6.3, respectively, developed by Kachamba et al. (2016).

$$AGB = 0.103685 \times (DBH)^{1.921719} \times ht^{0.844561} \quad \text{(Equation 6-2)}$$

$$BGB = 0.284615 \times (DBH)^{1.992658} \quad \text{Equation 6-3}$$

where: AGB and BGB are above-ground biomass and below-ground biomass (kg dry matter per tree), respectively; DBH is a diameter at breast height (1.3 m above the ground level), measured in centimetres (cm); and ht is the total tree height, measured in metres (m).

The total living biomass of a tree (TLB) was calculated as the sum of AGB and BGB, while carbon stock (C) was calculated using equation 6.4:

$$C = TLB \times CF \quad \text{(Equation 6.4)}$$

where: CF is the carbon factor and varies from 0.45 to 0.50 (Hirita et al., 2012). In this reporting period, a value of 0.47 was used as informed by previous key studies (Missanjo and Kadzuwa, 2021).

Soil organic carbon (SOC) was calculated using equation 6.5 as recommended by Pan et al. (2011).

$$SOC = 0.571 \times (AGC + BGC) \quad \text{(Equation 6.5)}$$

where: SOC is soil organic carbon (tC/ha), AGC and BGC are above-ground carbon stock and below-ground carbon stock (tC/ha), respectively. Therefore, the developed emission factor for Miombo (indigenous trees) used for the estimation of emissions was $13.66 \text{ tCO}_2\text{eha}^{-1}\text{yr}^{-1}$, with an uncertainty of 2.44%. The UNFCCC guidelines require the use of five carbon pools when estimating emission factors. These pools include above-ground biomass, below-ground biomass, deadwood (DW), litter, and soil organic carbon (SOC) (IPCC, 2019). The developed emission factor used three carbon pools, above ground biomass, below ground biomass, and soil organic carbon. It should be noted that Malawi's populace is highly dependent on fuel wood and less wood is left lying for longer periods in the forestlands unlike in other highly significant areas like peatlands. Furthermore, litter is burned in the dry season to achieve ecosystem goals (Nieman, 2021). Therefore, the assumption is that the carbon stocks in deadwood and litter do not significantly change over time. The default emission

factors were used for the Pine plantation, Eucalyptus plantation, cropland, grassland, wetland, and settlement categories.

Uncertainty Assessment

Carbon stock or biomass estimates are usually associated with uncertainties from sources such as sampling error, measurement error, and estimation error (FAO, 2005). It is a good practice to quantify uncertainties to understand the accuracy of the Carbon Stock Estimations (FAO, 2015). Therefore, the Monte Carlo procedure, well-explained by other researchers (Sierra et al., 2007) was used to estimate the uncertainty of the parameters studied at a 95% confidence interval.

Estimation of Greenhouse Gases

The GHGs were estimated using Approach 1 (reporting total land-use area without conversions between land uses) and partly approach 2, where land use conversions and data between land cover classes is available. The classes involved include Forestland, Cropland, Grasslands, Wetlands, Settlements, and Other Land. Except for the Wetlands, the rest of the five classes are considered as managed in the country's context. The six land classes are nationally defined as indicated in Table 6.3.

6.3.2 Information on approaches used for natural disturbances

Fire (biomass burning) is the principal form of natural disturbance which impacts carbon stocks on land in Malawi. Therefore, only losses of carbon stocks due to fires were considered in this inventory. Other disturbances such as wind, and pest and disease outbreaks were considered insignificant. The statistics of the burnt areas were acquired from Global Forest Resource) Assessment (FRA) and distributed proportionately to forest sub-types and other land classes. Biomass burning utilized combustion values and fuel loads from regionally existing studies (MNFR, 2021).

6.3.3 Information on approaches used for reporting harvested wood products

Malawi applies Approach 1 from the 2019 Refinement (IPCC 2019) to the 2006 IPCC Guidelines (Eggleston et al., 2006), also known as the stock-change approach. Statistics for timber harvests in the form of round wood, sawn wood, wood-based panels and industrial round wood were obtained from FAOSTAT. The FAO data was consolidated into harvested wood products/types as indicated in Table 6-7. Simple decay approach was used in the estimation of the emissions for the reporting period. Further information is provided in Chapter 6.10.

Table 6-7: Categorization of wood types for harvested wood products in Malawi

No.	Wood type	Sub-categories
1	Round wood	Wood fuel, coniferous; Wood fuel, non-coniferous; and Wood fuel, all species.
2	Sawnwood	Sawnwood, coniferous; and Sawnwood, non-coniferous
3	Wood based panels	Veneer sheets; Plywood; Particle board and OSB; Particle board; OSB; Hardboard; MDF/HDF; Other fibreboard; and Fibreboard, compressed
4	Wood pulp and recovered paper	Mechanical wood pulp; Semi-chemical wood pulp; Chemical wood pulp; Chemical wood pulp, sulphate, bleached and unbleached; Dissolving wood pulp; Pulp from fibres other than wood; Recovered fibre pulp; Recovered paper; Newsprint; Printing and writing papers; Printing and writing papers, uncoated, mechanical; Printing and writing papers, uncoated, wood free; and Printing and writing papers, coated.
5	Paper and paperboard	Other paper and paperboard; Household and sanitary papers; Wrapping and packaging paper and paperboard; Case materials; Carton board; Wrapping papers; Other papers mainly for packaging; and other paper and paperboard not elsewhere specified
6	Industrial roundwood	Industrial roundwood, coniferous; Industrial roundwood, non-coniferous; Sawlogs and veneer logs, coniferous; Sawlogs and veneer logs, non-coniferous; Other industrial roundwood, coniferous; Other industrial roundwood, non-coniferous; and Other industrial roundwood, all species
7	Chips and particles	Wood chips and particles
8	Wood charcoal	Wood charcoal
9	Wood residues	Wood residues

6.3.4 Quality Assurance and Quality Control (QA/QC) FOLU Subsector

Quality assurance, quality control (QA/QC), and verification of data for estimating emissions in the Forestry and Other Land Use (FOLU) Subsector in Malawi involve a structured approach to ensure accuracy, consistency, and reliability. QA processes involve implementing standardized data

collection methodologies, capacity-building for data collectors, and adherence to the Intergovernmental Panel on Climate Change (IPCC) 2006 Guidelines. On the other hand, QC measures include routine checks on data entry, error identification, and cross-validation with historical datasets to detect anomalies. Furthermore, National Forest inventories, remote sensing data, and land use change assessments are systematically compared against ground-truthed field measurements to enhance data integrity.

Verification involves independent reviews and validation by third-party experts, government institutions, and international organizations to ensure alignment with international reporting standards such as the United Nations Framework Convention on Climate Change (UNFCCC) and the Global Forest Observations Initiative (GFOI). Comparative analyses with regional datasets, sensitivity assessments of emission factors, and uncertainty analysis further strengthen the robustness of estimates. Additionally, stakeholder engagement, including academia, civil society, and local communities, is essential in verifying deforestation rates, forest degradation trends, and carbon stock changes.

6.4 Forestland (CRT Category 4.A)

6.4.1 Forestland remaining forestland

6.4.1.1 Category description

There are two broad sub-divisions to forest land remaining forestland, namely, the Miombo woodland, and the plantations. Plantations are further sub-divided into two: Pines and Eucalyptus plantations. The distribution of Miombo woodland, Pine plantations and Eucalyptus plantations is 89%, 3%, and 8%, respectively.

Miombo woodland in Malawi is defined as a tropical and subtropical dry forest ecosystem dominated by tree species from the *Brachystegia*, *Julbernardia*, and *Isoberlinia* genera. It is characterized by a mix of deciduous and semi-evergreen trees, with an understory of grasses and shrubs (Gondwe et al., 2021). Plantations included within forest land remaining forest land are commercial plantations (Pine and Eucalyptus).

6.4.1.2 Emissions and removals from forestland remaining forestland

Summary of emissions and removals from forestland remaining forestland are depicted in Table 6-8 decline from 33,830.53 GgCO₂e in 2018 to 33,494.63 GgCO₂e in 2022. This downward trend suggests a steady reduction in net emissions, which could be attributed to improved forest conservation efforts, enhanced carbon sequestration, or reduced deforestation and degradation. The consistent decrease, averaging around 84 GgCO₂e per year, indicates that forest management strategies, such as afforestation, reforestation, and reduced logging, may be having a positive impact. However, the decline is relatively small, implying that while progress is being made, additional efforts may be needed to accelerate carbon sequestration or further minimize emissions from forest degradation. Continuous monitoring and strengthening of sustainable forest management practices will be crucial to maintaining and enhancing this trend. Mitigation interventions implemented in areas hit-hard by the climate-induced catastrophes (cyclones Freddy, Idai and Chido) such as tree planting and conservation of regeneration would go a long way in enhancing carbon increase.

Table 6-8: Emissions and removals (GgCO₂e) from forestland remaining forestland

Year	Miombo woodland	Pine plantations	Eucalyptus plantations	Total
2018	-26652.02	-1133.17	-6045.34	-33830.53
2019	-26585.86	-1130.36	-6030.33	-33746.55
2020	-26519.70	-1127.55	-6015.33	-33662.58
2021	-26453.55	-1124.73	-6000.32	-33578.60
2022	-26387.39	-1121.92	-5985.32	-33494.63

6.4.2 Land converted to forestland

6.4.2.1 Category description

Land converted to forestland includes the sub-categories;

- i. grassland converted to forest land,
- ii. cropland converted to forest land, and
- iii. wetlands converted to forest land.

Grassland converted to forestland contains forest established on land that was previously non-forest. These conversions include (a) commercial plantations and environmental plantings, (b) forest that has regrown on land that was previously converted from a forest to grassland, and (c) regeneration from natural seed sources on land protected by State or Territory vegetation management policies. *Cropland* converted to forest land contains forest that has regrown on land that was previously converted from forest land to the land use identified. *Wetlands* converted to forestland comprises land on marsh has been detected to emerge with trees.

6.4.2.2 Annual area (ha) for land converted to forestland

The annual area in hectares for the land converted to forestland category are shown in Table 6-9.

Table 6-9: Annual area in hectares for land converted to forestland

Year	Cropland converted to forestland	Grassland converted to forestland	Wetlands converted to forestland	Total
2018	137183.36	28180.00	28773.36	194136.70
2019	130947.53	28945.00	27465.03	187357.60
2020	124711.70	29710.00	26156.70	180578.40
2021	118475.87	30475.00	24848.37	173799.20
2022	112240.00	31240.00	23540.00	167020.00

6.4.2.3 Annual net emissions for land converted to forestland

The annual net emissions for land converted to forestland category are shown in Table 6-10. The emissions data for land converted to forestland from 2018 to 2022 show a steady decline from 2,995.90 GgCO₂e in 2018 to 2,577.44 GgCO₂e in 2022, indicating a reduction of approximately 104 GgCO₂e per year. This downward trend suggests that newly established forests are increasingly acting as carbon sinks, sequestering more carbon over time as trees mature and accumulate biomass. The decline in emissions may also reflect improved afforestation and reforestation efforts, natural regeneration, or better land-use practices that enhance carbon absorption. However, the gradual decrease suggests that while progress is being made in converting land to forest, the rate of carbon sequestration is still limited, possibly due to factors such as species selection, soil conditions, or initial land degradation. Strengthening forest restoration initiatives and ensuring sustainable management of newly forested areas could further enhance carbon sequestration and contribute to long-term climate mitigation goals.

Table 6-10: Annual net emissions (GgCO₂e) for land converted to forestland

Year	Cropland converted to forestland			Grassland converted to forestland			Wetlands converted to forestland			Total
	Miombo	Pine	Eucalyptus	Miombo	Pine	Eucalyptus	Miombo	Pine	Eucalyptus	
2018	1667.79	70.91	378.30	342.60	14.57	77.71	349.81	14.87	79.35	2995.90
2019	1591.98	67.69	361.10	351.90	14.96	79.82	333.90	14.20	75.74	2891.28
2020	1516.17	64.46	343.90	361.20	15.36	81.93	318.00	13.50	72.13	2786.67
2021	1440.36	61.24	326.71	370.50	15.75	84.04	302.09	12.84	68.52	2682.05
2022	1364.55	58.02	309.51	379.80	16.15	86.15	286.19	12.17	64.91	2577.44

6.4.3 Annual area burnt and net emissions for burning biomass in forestland

The annual area burnt and net emissions for burning biomass in forestland are presented in Table 6-11. The emissions data for burning biomass in forestland from 2018 to 2022 show significant fluctuations, with a peak at 5,227.17 GgCO₂e in 2020. This is followed by a decline to 4,755.77 GgCO₂e in 2021, and a drastic drop to 96.27 GgCO₂e in 2022. The increase from 2018 to 2020 suggests intensified forest fires, slash-and-burn practices, or increased biomass burning due to deforestation or land clearing. However, the sharp reduction in 2022 indicates a major shift, potentially due to improved fire management strategies, stricter regulations, or favourable climatic conditions that reduced fire occurrences. Arguably, this could also typify the less anthropogenic activities subjected to forest (wood harvesting, forest fires for forest produce's extraction) due to the lockdown that was imposed during the peak of the COVID 19 pandemic (Bowa et al., 2024). The extreme variability highlights the sensitivity of forest emissions to human activities and environmental factors, emphasising the need for sustainable forest fire management, early warning systems, and policies that mitigate biomass extraction and burning to maintain forest carbon stocks and reduce emissions.

Table 6-11: Annual area burnt and net emissions for burning biomass in forestland

Year	Area burnt (ha)	Emissions from CO ₂ (GgCO ₂ e)	Emissions from CH ₄ (GgCO ₂ e)	Emissions from N ₂ O (GgCO ₂ e)	Emissions from CO (GgCO ₂ e)	Total Emissions (GgCO ₂ e)
2018	581898.33	3520.48	14.55	0.42	234.72	3770.18
2019	694899.00	4204.14	17.37	0.51	280.30	4502.32
2020	806773.33	4880.98	20.17	0.59	325.43	5227.17
2021	734017.07	4440.80	18.35	0.54	296.08	4755.77
2022	14857.93	89.89	0.37	0.01	5.99	96.27

6.5 Cropland (CRT Category 4.B)

6.5.1 Cropland remaining cropland

6.5.1.1 Category description

The cropland remaining cropland sub-category includes continuous cropping lands and lands that are cropped in rotation with pastures. Croplands are of high land value with a high return on production and moderate to high soil nutrient status and are therefore not generally converted to forest land or grassland but remain as cropland.

Anthropogenic emissions and removals on croplands occur because of changes in management practices from changes in crop type and from changes in land use. Permanent changes in management practices generate changes in the levels of soil carbon or woody biomass stocks over the longer term. Changes in carbon stock levels during the transition period to a new stock equilibrium are recorded under croplands.

6.5.1.2 Net emissions (GgCO₂e) from cropland remaining cropland

Summary of net emissions from cropland remaining cropland are given in Figure 6-5. The emissions data for cropland remaining cropland from 2018 to 2022 show a very gradual decline from 2,999.91 GgCO₂e in 2018 to 2,994.96 GgCO₂e in 2022, indicating a minor annual reduction of approximately 1 GgCO₂e per year. This stability suggests that agricultural practices, soil carbon dynamics, and land-use management have remained largely unchanged over the years. The slight decrease in emissions could be attributed to marginal improvements in sustainable farming techniques, such as conservation agriculture, reduced tillage, or enhanced soil carbon sequestration. However, the minimal reduction implies that more significant interventions such as large-scale adoption of agroforestry, cover cropping, or improved fertilizer management, are needed to achieve substantial emission reductions. Continuous monitoring and investment in climate-smart agricultural practices

could further enhance carbon sequestration and improve the sustainability of cropland management.

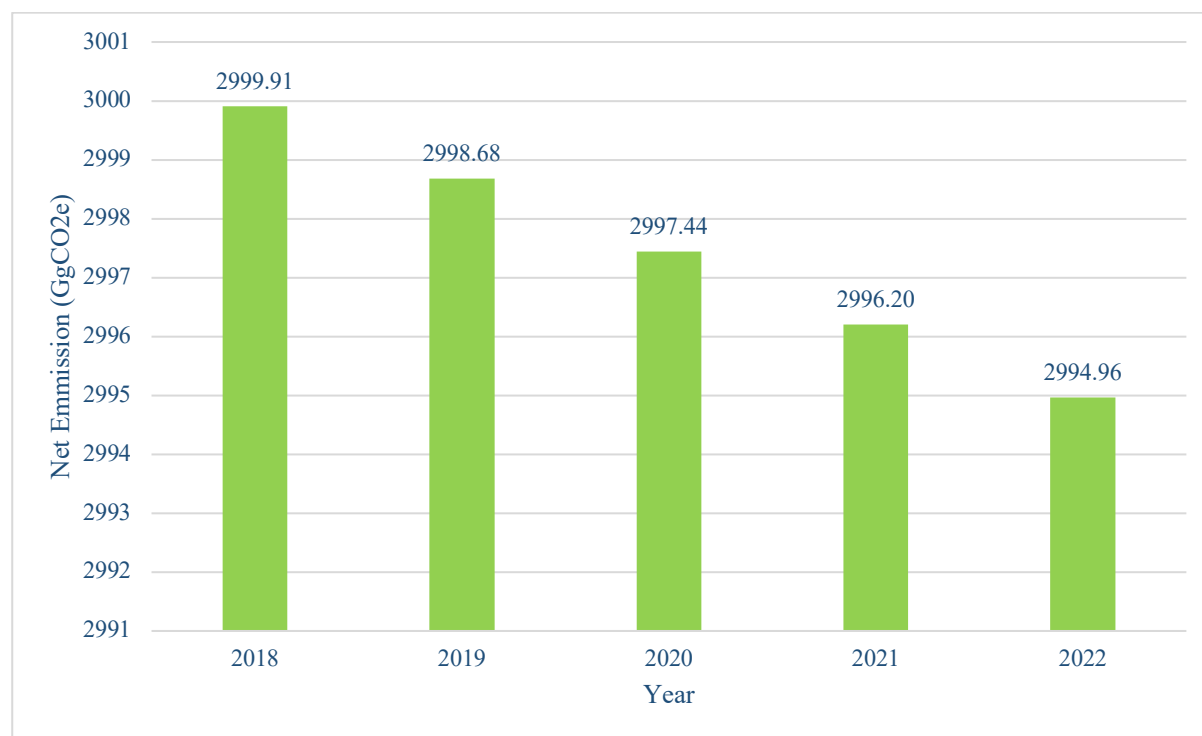


Figure 6-5: Net emissions from Cropland remaining Cropland

6.5.2 Land converted to cropland

6.5.2.1 Category description

Within the land converted to cropland sub-category, Malawi reports emissions for forestland converted to cropland, and wetlands converted to cropland subcategories. The wetland converted to cropland subcategory includes the conversion of wetlands to cropping, and irrigated cropping.

6.5.2.2 Annual area (ha) for land converted to cropland

The annual area in hectares for the land converted to cropland category are shown in Table 6-12.

Table 6-12: Annual Area (hectares) for Land Converted to Cropland

Year	Forestland converted to cropland	Wetlands converted to cropland	Total
2018	269913.6	108490.0	378403.6
2019	257645.3	103560.0	361205.3
2020	245377.0	98630.0	344007.0
2021	233108.7	93700.0	326808.7
2022	220840.0	88770.0	309610.0

6.5.2.3 Annual net emissions for land converted to cropland

The annual net emissions for the land converted to cropland category are shown in Table 6-13. The emissions data for land converted to cropland from 2018 to 2022 show a steady decline from 181.63 GgCO₂e in 2018 to 148.61 GgCO₂e in 2022, reflecting an annual reduction of approximately 8 GgCO₂e. This declining trend suggests a decrease in land conversion to cropland, possibly due to reduced deforestation for agricultural expansion, improved land-use planning, or a shift towards more sustainable farming practices. The decrease may also indicate better soil management and conservation measures that help maintain or enhance soil carbon stocks. However, while this reduction is positive in terms of emission control, it could also be linked to factors such as land degradation, reduced agricultural expansion, or shifts in economic priorities affecting land use. Strengthening sustainable agricultural policies, promoting agroforestry, and enhancing soil carbon sequestration strategies could further reduce emissions while ensuring food security and productive land use.

Table 6-13: Annual net emissions (GgCO₂e) for land converted to cropland

Year	Forestland converted to cropland	Wetlands converted to cropland	Total
2018	129.56	52.08	181.63
2019	123.67	49.71	173.38
2020	117.78	47.34	165.12
2021	111.89	44.98	156.87
2022	106.00	42.61	148.61

6.5.3 Annual area burnt and net emissions for burning biomass in cropland

The annual area burnt and net emissions for burning biomass in cropland are presented in Table 6-14. The emissions data for burning biomass in cropland from 2018 to 2022 show a slight, but consistent increase from 1,768.80 GgCO₂e in 2018 to 1,778.67 GgCO₂e in 2022, with an average annual rise of approximately 2–3 GgCO₂e. This upswing trend suggests that agricultural biomass burning, such as the burning of crop residues, has remained a common practice. This could possibly be due to traditional land-clearing methods, limited access to alternative residue management techniques, or increasing agricultural activity.

The steady increase in emissions highlights the need for improved sustainable practices, such as residue incorporation, mulching, or bioenergy production, to reduce carbon release and enhance soil fertility. Without interventions, continued biomass burning could contribute to long-term soil degradation and air pollution. Encouraging farmers to adopt climate-smart agriculture and promoting policies that regulate biomass burning could help curb emissions while maintaining agricultural productivity.

Table 6-14: Annual area burnt and net emissions for burning biomass in cropland

Year	Area burnt (ha)	Emissions from CO ₂ (GgCO ₂ e)	Emissions from CH ₄ (GgCO ₂ e)	Emissions from N ₂ O (GgCO ₂ e)	Emissions from CO (GgCO ₂ e)	Total Emissions (GgCO ₂ e)
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2018	300430.00	1664.38	2.97	0.08	101.37	1768.80
2019	300849.13	1666.70	2.98	0.08	101.51	1771.27
2020	301268.25	1669.03	2.98	0.08	101.65	1773.73
2021	301687.38	1671.35	2.99	0.08	101.79	1776.20
2022	302106.50	1673.67	2.99	0.08	101.93	1778.67

6.6 Grassland (CRT Category 4.C)

6.6.1 Grassland remaining grassland

6.6.1.1 Category description

The grassland remaining grassland category encompasses all grassland areas not classified under land converted to grassland. Areas that undergo rotational use between grassland and cropland are recorded under either forestland converted to cropland or cropland remaining cropland.

Anthropogenic emissions and removals in grasslands result from shifts in management practices, particularly in pasture and grazing management, savanna fire management, and changes in sparse woody vegetation that do not qualify as forests. Grassland remaining grassland is categorized into three components corresponding to these practices. Long-term alterations in management can lead to changes in soil carbon levels or woody biomass stocks. As these changes occur, carbon may either be emitted or sequestered. However, these effects are temporary rather than permanent. Over time, the net emissions or removals from a modified management practice stabilise, reaching an equilibrium of approximately zero emissions, unless further changes disrupt the balance.

6.6.1.2 Net emissions (GgCO₂e) from grassland remaining grassland

Summary of net emissions from grassland remaining grassland are provided in Figure 6-6. The emissions data for grassland remaining grassland from 2018 to 2022 show a gradual decline from 814.15 GgCO₂e in 2018 to 777.78 GgCO₂e in 2022, with an average annual reduction of approximately 9 GgCO₂e. This decreasing trend suggests improved management of grasslands, potentially through better grazing practices, fire management, or natural regeneration that enhances carbon sequestration. The reduction in emissions could also indicate a shift towards more sustainable land-use strategies, such as rotational grazing or reduced biomass burning. However, the decline may also be influenced by changes in land cover, such as grassland degradation or conversion to other land uses, which could have long-term ecological consequences. To sustain and further reduce emissions, it is essential to strengthen grassland conservation efforts, promote ecosystem restoration, and implement policies that encourage carbon-friendly land management practices.

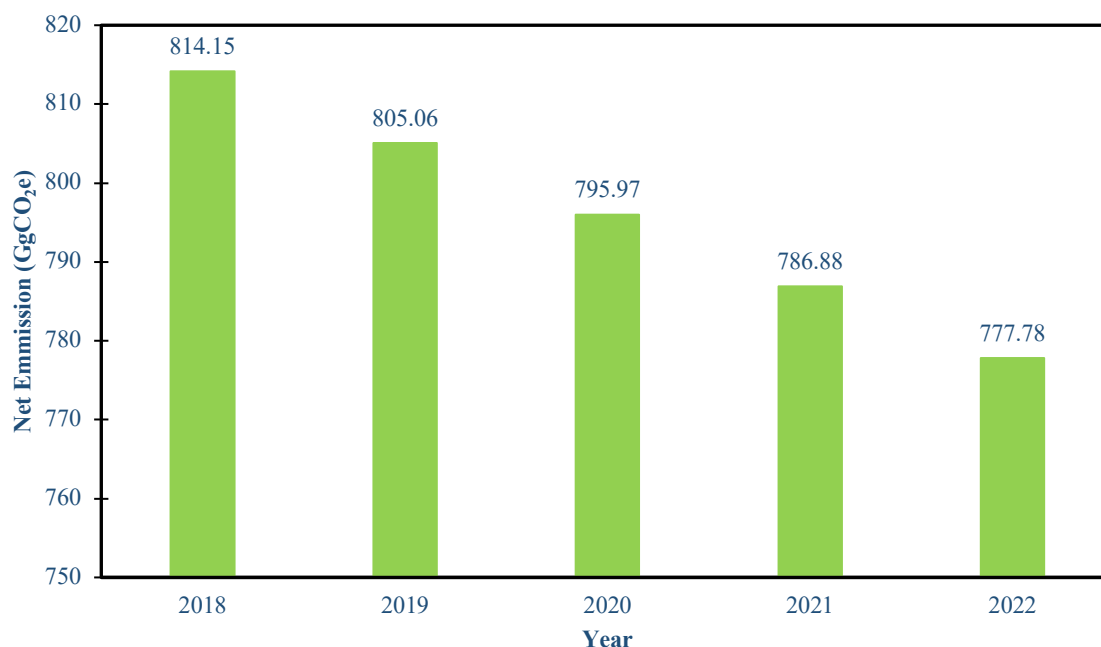


Figure 6-6: Net emissions from grassland remaining grassland

6.6.2 Land converted to grassland

6.6.2.1 Category description

In the land converted to grassland subcategory, Malawi reports emissions from forestland converted to grassland and wetlands converted to grassland. Net emissions resulting from conversions between croplands and grasslands are accounted for under croplands remaining croplands, as pasture and grazing rotations are commonly integrated into cropping systems.

6.6.2.2 Annual area (ha) and net emissions for land converted to grassland

The annual area in hectares and net emissions for the land converted to grassland category are shown in Table 6-15. The emissions data for land converted to grassland from 2018 to 2022 show a steady decline from 51.77 GgCO₂e in 2018 to 42.36 GgCO₂e in 2022, reflecting an annual reduction of approximately 2–3 GgCO₂e. This drop off trend suggests a decrease in land conversion to grassland, which may be due to reduced deforestation, shifts in land-use policies, or improved land management practices that enhance soil carbon sequestration. The declining emissions could also indicate a transition toward more stable ecosystems with lower carbon release from soil disturbance. However, this trend may also reflect a reduction in available land for grassland expansion, potentially due to competing land uses such as agriculture or urbanisation. To maximize the climate benefits of grasslands, further efforts in sustainable grazing, fire control, and soil restoration should be encouraged to enhance carbon storage and mitigate emissions.

Table 6-15: Cumulative area and net emissions for land converted to grassland

Year	Cumulative area (ha) of forestland converted to grassland	Emissions (GgCO ₂ e) forestland to grassland
2018	18770.0	51.77
2019	17917.5	49.42
2020	17065.0	47.07
2021	16212.5	44.71
2022	15360.0	42.36

6.6.3 Annual area burnt and net emissions for burning biomass in grassland

The annual area burnt and net emissions for burning biomass in grassland are presented in Table 6-16. The emissions data for biomass burning in grassland from 2018 to 2022 show a significant and consistent decline from 747.48 GgCO₂e in 2018 to 182.75 GgCO₂e in 2022. This sharp reduction suggests a decrease in the frequency or intensity of grassland fires, likely due to improved fire management practices, reduced human-induced burning, or changes in climate conditions affecting fire occurrence. The decline may also be attributed to shifts in land-use practices, such as better grazing management or policies discouraging uncontrolled burning. While the reduction in emissions is a positive indicator for climate mitigation, it is important to assess whether it has any unintended ecological consequences, such as excessive fuel buildup that could lead to more intense wildfires in the future. Strengthening controlled burning strategies, promoting sustainable grazing, and enhancing natural firebreaks could help maintain the ecological balance while minimizing carbon emissions.

Table 6-16: Annual area burnt and net emissions for burning biomass in grassland

Year	Area burnt (ha)	Emissions from CO ₂ (GgCO ₂ e)	Emissions from CH ₄ (GgCO ₂ e)	Emissions from N ₂ O (GgCO ₂ e)	Emissions from CO (GgCO ₂ e)	Total Emissions (GgCO ₂ e)
2018	121842.67	705.47	1.74	0.05	40.21	747.48
2019	106024.63	613.88	1.52	0.05	34.99	650.44
2020	75312.08	436.06	1.08	0.03	24.86	462.02
2021	59913.83	346.90	0.86	0.03	19.77	367.56
2022	29789.00	172.48	0.43	0.01	9.83	182.75

6.7 Wetland (CRT Category 4.D)

6.7.1 Wetland remaining wetland

6.7.1.1 Category description

The estimates in this category are guided by the Environment Management Act No. 19 of 2017 and the 2019 Refinement to the 2006 IPCC Guidelines (IPCC 2006). In this category, the Malawi inventory includes estimates for biomass burning on tropical savannas that are categorised as wetlands.

6.7.1.2 Net carbon dioxide emissions ($GgCO_2e$) from wetland remaining wetland

Summary of net emissions from wetland remaining wetland are given in Figure 6-7. The emissions data for wetland remaining wetland from 2018 to 2022 show a gradual increase in emissions, rising from 3,763.59 $GgCO_2e$ in 2018 to 3,814.20 $GgCO_2e$ in 2022. This steady upward trend suggests that the wetlands are releasing more carbon over time, potentially due to factors such as increasing degradation, changes in water levels, or disturbances from land-use practices like drainage or agriculture. Wetlands are significant carbon sinks, but when disturbed, they can become net carbon emitters due to the release of stored carbon from organic soils. The consistent rise in emissions could reflect increased human activity in these areas, such as land conversion, or natural factors like climate change affecting water regimes. To mitigate this, effective wetland conservation strategies, including improved water management and restoration projects, are crucial to preserving their carbon sequestration capacity and reducing future emissions.

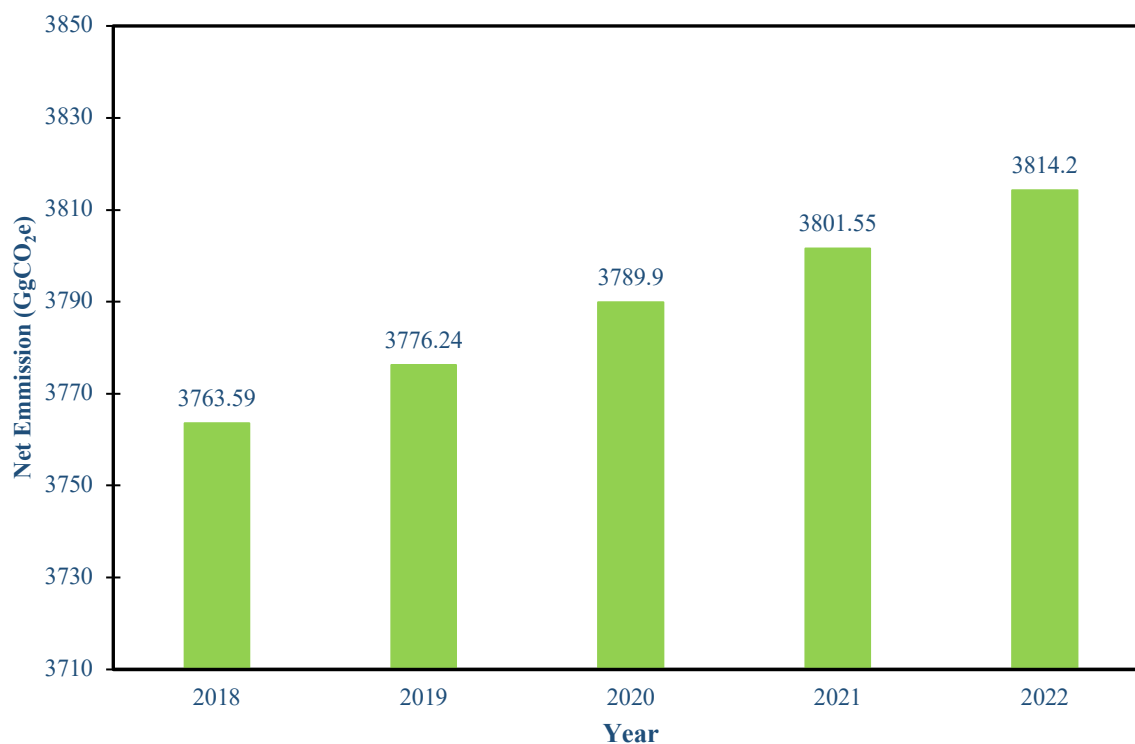


Figure 6-7: Net emissions from wetland remaining wetland

6.7.2 Land converted to wetland

6.7.2.1 Category description

This category includes the subcategory forest land converted to wetlands (flooded land). Forest conversion occurs when forests are cleared for the construction of reservoirs or other areas classified as flooded lands under the forest land converted to wetlands subcategory in the IPCC 2006 Guidelines (Eggleston et al., 2006). Emissions are reported for land clearing activities associated with flooding.

6.7.2.2 Annual area (ha) and net emissions for land converted to wetland

The annual area in hectares and net emissions for the land converted to wetland category are shown in Table 6-17. The emissions data for land converted to wetland from 2018 to 2022 show a steady increase, rising from 522.31 GgCO₂e in 2018 to 551.86 GgCO₂e in 2022. This consistent upward trend suggests that land conversions to wetlands, possibly driven by human activities such as drainage or reclamation for agricultural or developmental purposes, are leading to higher carbon emissions. Wetland conversions can release significant amounts of stored carbon from organic soils, as draining or disturbing these areas exposes previously sequestered carbon to oxidation, contributing to greenhouse gas emissions. The gradual increase in emissions highlights the need for better land-use planning and stronger regulations to prevent the degradation of wetlands. Additionally, promoting the restoration and preservation of wetlands can mitigate emissions, as healthy wetlands function as critical carbon sinks, contributing to climate change mitigation.

Table 6-17: Cumulative area in hectares and net emissions for land converted to wetland

Year	Cumulative Area (ha) forestland converted to wetland	Emissions (GgCO ₂ e) forestland to wetland
2018	38236.7	522.31
2019	38777.5	529.70
2020	39318.3	537.09
2021	39859.2	544.48
2022	40400.0	551.86

6.8 Settlement (CRT Category 4.E)

6.8.1 Settlement remaining settlement

6.8.1.1 Category description

The settlements remaining settlements subcategory encompasses urban areas and infrastructure that have not undergone land use conversion. To prevent double counting, it excludes woody vegetation classified as forest land. This subcategory accounts only for net emissions from changes in sparse woody vegetation, such as those resulting from modifications in urban parks and gardens.

6.8.1.2 Area and net emissions of sparse woody vegetation, settlements remaining settlements

The key input data and estimated net emissions for settlement remaining settlements are presented in Table 6-18. The emissions data for settlement remaining settlement from 2018 to 2022 show minimal fluctuations, with emissions ranging from 19.47 GgCO₂e to 20.15 GgCO₂e over the five-year period. The slight variation in emissions indicates a stable level of emissions from settled areas, with relatively consistent land use and low changes in land cover. Settlements, being largely urbanized, tend to have stable emissions because the land-use patterns in these areas do not change significantly, and the main emission sources are typically from energy consumption, waste management, and transportation rather than land conversion. The small increase in 2022 could reflect urban expansion or increased emissions from infrastructure development or changes in waste management practices. This stability highlights the need for continued efforts in promoting sustainable urban planning, energy efficiency, and low-carbon technologies to keep emissions in settlement areas under control while supporting urban growth.

Table 6-18: Area gain and net emissions of sparse woody vegetation, settlements remaining settlements

Year	Area gain (ha)	Net emission (GgCO ₂ e)
2018	1443	19.71
2019	1440	19.67
2020	1447	19.77
2021	1425	19.47
2022	1475	20.15

6.8.2 Land converted to settlement

6.8.2.1 Category description

The land converted to settlements category includes forestland converted to settlements.

6.8.2.2 Annual area (ha) for land converted to settlement and annual net emissions for land converted to settlement

The annual area in hectares for the land converted to wetland category and annual net emissions for land converted to settlement are given in Table 6-19. The emissions data for land converted to settlement from 2018 to 2022 show a consistent decline, decreasing from 39.55 GgCO₂e in 2018 to 38.27 GgCO₂e in 2022. This gradual decrease suggests a reduction in the amount of land being converted into settlements or potentially more sustainable urban development practices being implemented. Lower emissions could reflect urban planning initiatives that focus on reducing land use change, improving building designs, and using energy-efficient technologies, which mitigate emissions typically associated with land conversion, such as those from vegetation clearing or soil disturbance. The reduction might also indicate a shift towards higher-density developments rather than extensive sprawl. However, the decreasing trend in emissions is modest, so it is important to continue promoting sustainable land-use policies and smart growth strategies to minimize the environmental impact of urban expansion while accommodating population growth.

Table 6-19: Cumulative area in hectares and net emissions for land converted to settlement

Year	Cumulative Area (ha) forestland converted to settlement	Emissions (GgCO ₂ e) forestland (Miombo) to settlement	Emissions (GgCO ₂ e) forestland (Pine plantation) to settlement	Emissions (GgCO ₂ e) forestland (Eucalyptus plantation) to settlement	Total Emissions (GgCO ₂ e) forestland to settlement
2018	2563.3	31.16	1.32	7.07	39.55
2019	2542.5	30.91	1.31	7.01	39.23
2020	2521.7	30.66	1.30	6.95	38.91
2021	2500.8	30.40	1.29	6.90	38.59
2022	2480.0	30.15	1.28	6.84	38.27

6.9 Other land (CRT Category 4.F)

6.9.1 Category description

Malawi does not report emissions and removals from the reporting category of other lands remaining other lands. Other lands typically occur in regions with minimal anthropogenic impacts on biomass, dead organic matter, and soil carbon. Because of this land converted to other land is not observed.

6.10 Harvested Wood Products (CRT Category 4.G)

6.10.1 Category description and net emissions

Malawi applies the stock-change approach for harvested wood products (HWP) in use. The net emissions from harvested wood products are presented in Figure 6-8. The emissions data for harvested wood products in forestland from 2018 to 2022 exhibit fluctuations, with emissions rising from 126.2 GgCO₂e in 2018 to 149.4 GgCO₂e in 2019, then decreasing to 90.2 GgCO₂e by 2022. This trend suggests variability in the amount of wood harvested, with higher emissions in years of increased logging or timber extraction, followed by a reduction as harvesting activity decreased or more sustainable practices were implemented. The spike in 2019 could reflect an increase in timber demand or forest management practices that emphasized harvesting. Conversely, the subsequent decline may indicate a reduction in wood extraction, possibly due to changes in the market, improved forest management, or the adoption of policies promoting reforestation and sustainable timber harvesting. The overall reduction in emissions by 2022 highlights the potential for forest management strategies to limit carbon release from harvested wood products, underlining the importance of promoting sustainable forestry practices to balance economic needs with environmental goals.

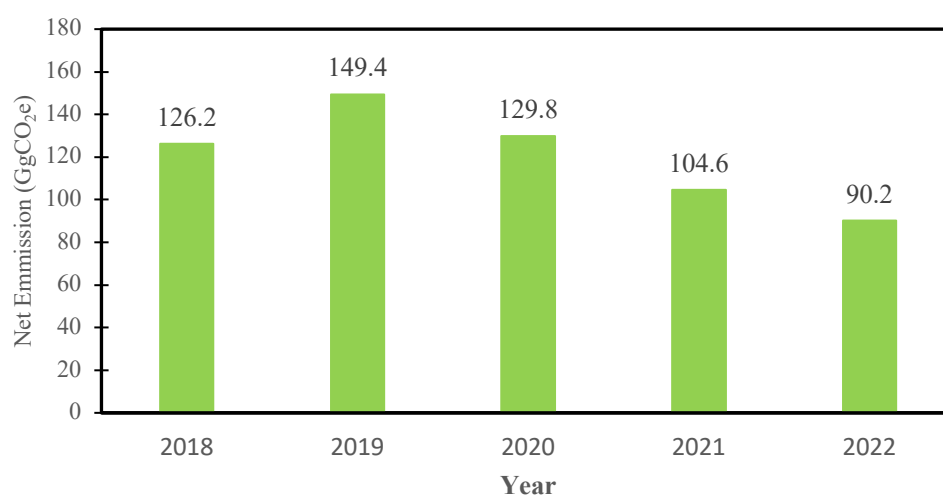


Figure 6-8: Net emissions from harvested wood products

6.11 Uncertainty Assessment

The results on uncertainty assessment for the reporting period are presented in Table 6-20. The uncertainty results, at 95% confidence level, for GHG emissions indicate varying levels of assurance in the estimates across different land categories. Cropland (0.20%) and wetland (0.64%) have the lowest uncertainties, suggesting that data availability, emission factors, and estimation methodologies for these categories are relatively robust and well-documented. Similarly, settlements (0.69%) show a low level of uncertainty, likely due to stable land-use patterns and well-defined emission sources. In contrast, grassland (6.05%) exhibits the highest uncertainty, reflecting challenges in measuring emissions from fire management (biomass burning), which are influenced by management variations. However, the uncertainty value for grassland is within the allowable value (9.0%) as indicated in 2006 IPCC guidelines. Forestland (4.92%) has moderate uncertainty, which may be attributed to variability in deforestation rates, carbon stock estimates, and biomass loss calculations. The overall uncertainty (4.16%) represents a balanced measure of all land categories, indicating a reasonably reliable national GHG inventory. This suggests that while some land categories have reliable estimates, land-use monitoring, especially for biomass burning in grassland is needed to enhance accuracy.

Table 6-20: Uncertainty assessment by category in FOLU Sub-sector

No.	Category	Uncertainty (%)
1	Forestland	4.92
2	Cropland	0.20
3	Grassland	6.05
4	Wetland	0.64
5	Settlement	0.69
Overall		4.16

6.11.1 Areas that need improvement

Malawi's FOLU sector plays a significant role in greenhouse gas (GHG) emissions reporting. Improving LULUCF reporting requires addressing gaps in data, methodology, and institutional frameworks for each category: forestland, cropland, grassland, wetland, and settlements. Here are the potential areas of improvement for each category:

1. Forestland

- Incorporate and improve tracking of biomass loss due to charcoal production.
- Improve reporting on community woodlots, natural regeneration, and forest conservation efforts.

2. Cropland

- Implement better methodologies to track soil organic carbon changes
- Enhance reporting on emissions from biomass burning and promote residue management practices.

3. Grassland

- Improve assessment of land degradation due to overgrazing and unsustainable livestock management.
- Enhance monitoring of emissions from grassland burning, particularly in savanna ecosystems.

4. Wetlands

- Establish monitoring systems for methane fluxes from dambos and floodplain ecosystems.
- Strengthen tracking of deforestation and restoration projects along Lake Malawi and coastal areas.

5. Settlements

- Enhance data collection on household charcoal and firewood consumption, as well as alternative energy adoption.
- Incorporate carbon sequestration from urban tree planting and green spaces in emission reporting.

General Cross-Cutting Improvements

- Shift from default Tier 1 emission factors to country-specific factors where possible.
- Strengthen institutional and technical capacity for data collection, analysis, and reporting.
- Align LULUCF reporting with Malawi's Nationally Determined Contributions (NDCs) and climate action plans.
- Leverage local knowledge for improved data collection in remote areas.
- Enhance appropriate archiving of data for easy retrieving and use

Chapter 7:



Waste

7.1 Overview of the sector and background information

In Malawi, urban areas include the four major cities—Blantyre, Lilongwe, Mzuzu, and Zomba—as well as towns, Bomas, and gazetted town planning areas. As of 2018, only 16 percent of the national population resided in these urban areas. Of this urban population, 12 percent lived in the four major cities, while 4 percent lived in other towns and Bomas.

The urban population in Malawi has steadily increased over the years—from approximately 850,000 in 1987, to 1.4 million in 1998, 2.0 million in 2008, and 2.8 million in 2018. However, its share of the total national population has only marginally increased: from 14.4 percent in 1998 to 15.3 percent in 2008, and 16 percent in 2018. The population data for this period is illustrated in [Figure 7-1](#).

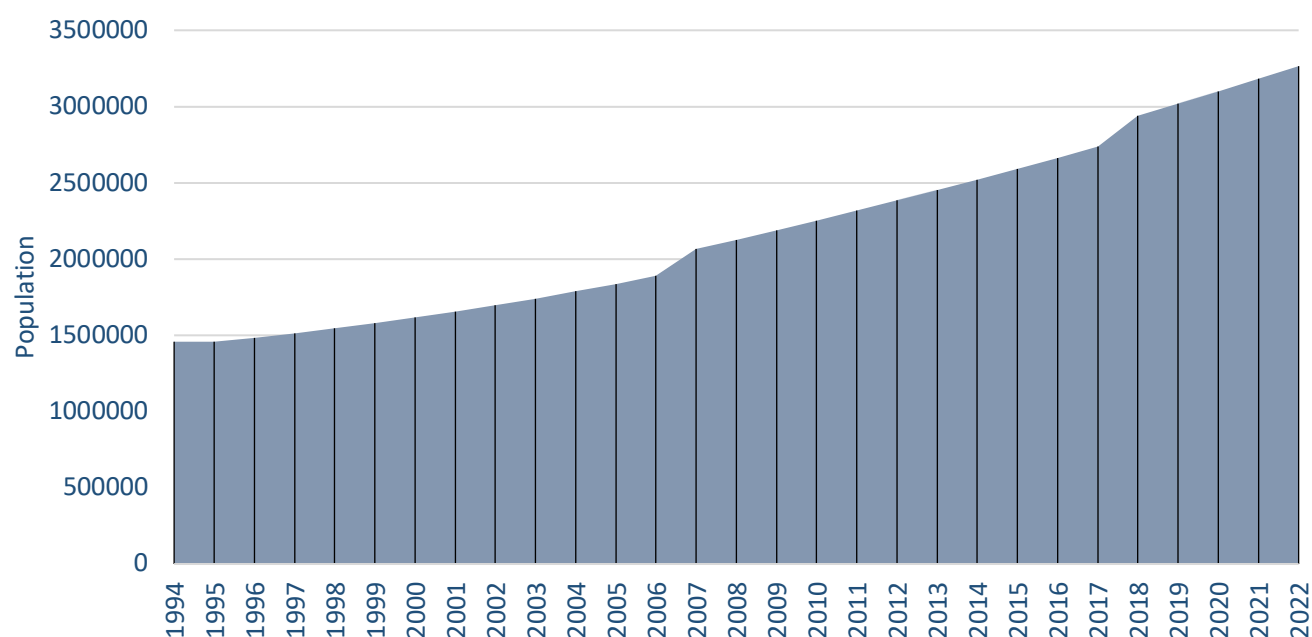


Figure 7-1: Malawi Population and Adjusted for Urban Population data 1994 to 2022

Solid waste (SW) in Malawi is generated from households, gardens and parks, offices, shops, markets, restaurants, public institutions, industrial facilities, waterworks, sewage systems, construction and demolition sites, and agricultural operations (IPCC, 2006). Solid waste is generally categorized into:

- i. municipal solid waste (MSW),
- ii. sludge, and
- iii. industrial and other waste.

MSW includes household waste, garden and park waste, and waste from commercial and institutional sources. Sludge refers to materials from domestic and industrial wastewater treatment

plants. Industrial waste includes organic solids such as construction debris, while “other waste” includes clinical, hazardous, and agricultural waste.

Municipal solid waste is composed mainly of food waste, organic matter from gardens and parks, paper, cardboard, wood, textiles, rubber, leather, plastics, metals, and glass (including pottery and china) (IPCC, 2006). However, systematic data collection on waste generation in Malawi has been limited over the years, with various studies conducted sporadically.

Recent studies have assessed waste generation in low-, medium-, and high-density residential areas within the four major cities. Per capita waste generation was found to be 0.457 kg, 0.493 kg, 0.479 kg, and 0.433 kg per day in these areas, respectively. The composition of waste was found to be approximately 70% food waste, 6% plastics, 4% paper and nappies, 3% textiles/wood/rubber/leather, 1% metals/glass, and 3% ceramics/others. Since this characterization does not align with IPCC software guidelines, the default composition provided in the IPCC software has been applied.

In 2017, the National Commission for Science and Technology (NCST) conducted a baseline study on waste composition and greenhouse gas emissions in Lilongwe City. The study determined an average waste generation rate of 0.493 kg/capita/day.

An updated study by Research/Share/Malawi reported an average waste generation rate of 0.471 kg/capita/day across the cities, with organic waste comprising about 68% of the total, and the remainder consisting of other waste types.

The treatment and disposal of municipal, industrial, and other solid waste generates significant amounts of methane (CH₄) (IPCC, 2006). Methane emissions from solid waste disposal sites contribute approximately 3–4% of annual global anthropogenic GHG emissions (IPCC, 2001). This occurs when degradable organic carbon (DOC) is broken down by bacteria, producing methane—a process that typically begins one to two years after the waste is deposited in landfills (Chipofya, 2003).

A 2013 study by Research/Share/Malawi on *Challenges and Opportunities in Solid Waste Management in Malawian Cities* found that waste from households, commercial entities, industries, markets, educational and health institutions is typically stored temporarily in containers such as plastic bins and metal drums. From there, waste is either collected by municipal authorities, taken to communal dump sites, or disposed of in designated rubbish pits.

Sorting of solid waste at the source is low: about 30% at the household level and 35% at the commercial level. Sorting at educational, health, and market facilities is virtually non-existent. However, in Lilongwe, some areas operate waste transfer stations where sorting takes place. Waste reuse and recycling is more common for materials such as glass, plastics, cardboard, metal, and paper. Plastic is the most reused material, with a 76% reuse rate at the household level. PET bottles,

for instance, are repurposed by small-scale businesses for bottling traditional beverages made from maize, millet, or finger millet flour. Agricultural waste is sometimes used to make compost at the community level.

Waste collection services are mainly available to high- and medium-income residential areas, as well as commercial, industrial, health, and market institutions. These services are provided primarily by city, municipal, and town councils, with some involvement from private operators. Overall, mixed waste collection rates are low—averaging only 30% across cities—with over 70% of solid waste originating from households. Disposal methods vary, including burning (most common at 63% among households), open dumping, burying, and disposal at city dumpsites. At these sites, scavengers often recover reusable materials.

Composting is becoming increasingly common in Malawian cities. Private waste collectors and NGOs often collaborate with city councils to separate organic waste for composting using aerobic methods. The resulting compost is sold to gardeners, nurseries, and commercial farmers growing tea, coffee, and macadamia. These groups have recognized the benefits of compost for flower beds, lawns, and potted plants. Moreover, customer demand for organic products has encouraged commercial farmers to adopt compost use. New initiatives include commercial organic fertilizer production using MSW-derived organic waste, and biochar production—a process that combines char, animal manure or compost, and water.

Since 2019, compost production has increased steadily in urban areas. As of 2022, more than 800,000 kg of compost had been produced. Some composting operations use accelerated methods, producing compost within 30 days, while others use passive or semi-passive methods requiring 60 to 90 days. The table below shows population, waste generation based on per capita waste generation ([Table 7-1](#)) and waste composition data over the period 1994 to 2022 ([Error! Reference source not found.](#)).

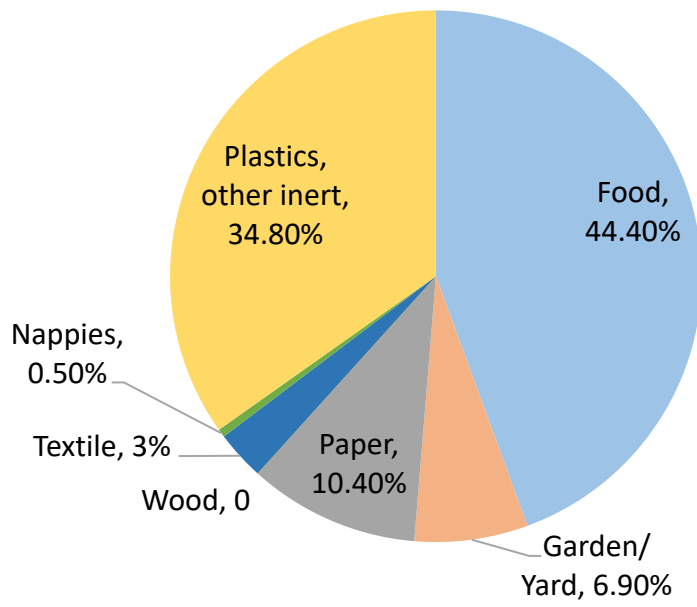


Figure 7-2: Composition of waste going to solid waste disposal sites

Table 7-1: Population, per capita waste generation and waste composition

Year	Urban Population	Waste per capita	Total MSW
		kg/cap/yr	Gg
1994	1458979	0.18	262616.2
1995	1456246	0.18	262124.3
1996	1484716	0.18	267248.9
1997	1513826	0.18	272488.7
1998	1545474	0.18	278185.3
1999	1580250	0.18	284445
2000	1617032	0.18	291065.8
2001	1655830	0.18	298049.4
2002	1696968	0.18	305454.2
2003	1740667	0.18	313320.1
2004	1787233	0.18	321701.9
2005	1836813	0.18	330626.3
2006	1889036	0.18	340026.5
2007	2064806	0.18	371665.1
2008	2125082	0.18	382514.8
2009	2187737	0.18	393792.7
2010	2251919	0.18	405345.4
2011	2317352	0.18	417123.4
2012	2383931	0.18	429107.6
2013	2451791	0.18	441322.4
2014	2521129	0.18	453803.2
2015	2591658	0.18	466498.4
2016	2663060	0.18	479350.8
2017	2735819	0.18	492447.4
2018	2938861	0.18	528995
2019	3018774	0.18	543379.3
2020	3100330	0.18	558059.4
2021	3182359	0.18	572824.6
2022	3264851	0.18	587673.2

7.1.1

Figure 7-3 shows GHG emissions in the waste sector by category type for the period 1994 to 2022.

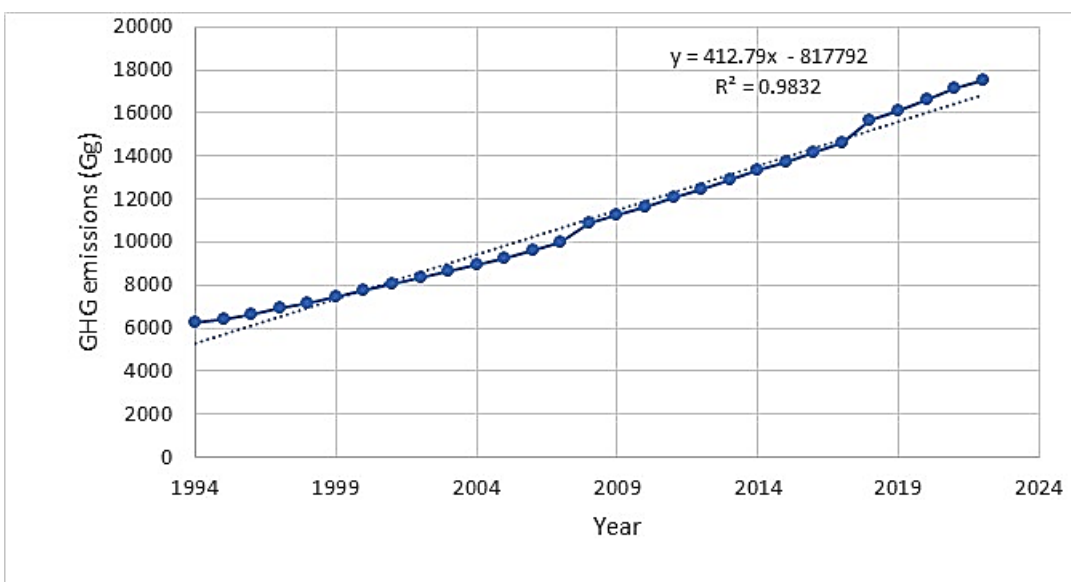


Figure 7-3: Total GHG emission in waste sector for 1994 to 2022

Challenges in MSW Management

Municipal solid waste management in Malawi faces significant challenges, categorized as follows:

7.1.1.1 1. Sociological Challenges

Public attitudes and perceptions towards waste significantly affect management efforts. Waste generation rates are largely influenced by lifestyle, particularly in urban centers. The urban poor often lack access to organized waste collection services, which are typically limited to high- and middle-income planned areas—comprising only about 30% of the urban population. Consequently, approximately 70% of urban residents are excluded from formal waste management services provided by city, municipal, town, and urban councils.

Table 7-2: Statistics on waste disposal type by population category (%)

Population category	Type of waste disposal						Total
	Waste bin	Waste pit	Burning	Public heap	Other	None	
Malawi	3.8	59.2	4.9	8.5	1.4	22.2	100
Rural	2.1	58.6	4.9	8.6	1.3	24.5	100
Urban	12.4	62.2	5.2	7.8	1.9	10.5	100
Northern Region	8.1	63.9	0.7	2.1	1.7	23.5	100
Central Region	3.1	59.5	5.7	10.7	1.1	19.9	100
Southern Region	3.2	57.6	5.4	8.2	1.6	24.0	100

7.1.1.2 2. Economic Challenges

Local authorities operate under severe financial constraints, with competing demands for essential municipal services such as roads, health care, water supply, and education. These core services consume the bulk of local government budgets, leaving waste management underfunded—often receiving only 10–15% of total budget allocations. This underfunding persists due to limited revenue-generating capacity at the local level.

7.1.1.3 3. Human Resource Capacity Constraints

The environmental management sector suffers from critical staff shortages. Most local authorities lack professionally trained personnel, relying instead on unskilled workers who often handle waste without adequate training or protective equipment. This not only endangers their health but also limits the sector's capacity for planning, innovation, and implementation of efficient waste management systems.

With support from the World Bank, there has been a gradual transfer of sewerage liquid waste management to water boards. Lilongwe City Council has handed over this responsibility to Lilongwe Water Board, while Blantyre and Mzuzu city councils are in the process of doing the same.

7.1.1.4 4. Technological Challenges

Improved incomes have led to increased consumption of modern goods, resulting in a greater diversity and volume of waste—particularly plastics and electronic waste (e-waste). Plastics are non-biodegradable, clog drainage systems, and become breeding grounds for vermin. Managing e-waste requires advanced infrastructure such as shredders, recyclers, or incinerators—equipment that is expensive and scarce in Malawi.

The high cost of waste management equipment, such as compactors, presents further obstacles. When these machines break down, spare parts often must be imported, causing service delays and accumulation of waste in households, commercial centers, and markets. There is an urgent need to explore cost-effective and context-appropriate waste management technologies.

7.1.1.5 5. Regulatory Challenges

Regulatory limitations also hinder effective MSW management. Outdated legal frameworks, such as the Local Government Act, restrict municipalities from enacting and enforcing bylaws with sufficient punitive measures for non-compliance. Furthermore, delays by central government in approving proposed local bylaws exacerbate enforcement challenges, leading to widespread disregard for waste-related regulations.

7.2. Category-specific Emissions

This study assesses greenhouse gas (GHG) emissions from the following waste management categories:

- Solid waste disposal,
- Incineration and open burning of waste, and
- Wastewater treatment and discharge.

The sources of emission from waste sector are shown in Table 7-3

Table 7-3: Sources of emission from waste sector

Emissions sources	Sources included	Method	Emission factors reference
5.A.1.a.ii	Solid waste disposal – unmanaged shallow sites	Tier 1	IPCC (2006) Table 3.2
5.A.1.b.	Solid waste disposal – uncategorised sites	Tier 1	IPCC (2006) Table 3.2
5.C.2.	Open burning – solid waste	Tier 1	IPCC (2006) Table 5.1
5.D.1.a.i	Domestic wastewater – centralized treatment	Tier 1	IPCC (2006) Table 6.2
5.D.1.a.ii	Domestic wastewater – septic systems	Tier 1	IPCC (2006) Table 6.2
5.D.1.a.iii	Domestic wastewater – latrines	Tier 1	IPCC (2006) Table 6.2

Globally, methane (CH₄) emissions from solid waste disposal sites (SWDS) and wastewater treatment plants (WWTPs) are the primary contributors from the waste sector, accounting for approximately 3.0–4.0% of total annual anthropogenic GHG emissions (IPCC, 2001; 2006).

In Malawi, the main GHGs emitted from the Waste Management Sector (WMS) include:

- Methane (CH₄) – primarily from anaerobic decomposition of organic waste in SWDS and WWTPs,
- Carbon dioxide (CO₂) – from incineration and fossil-based materials, and
- Nitrous oxide (N₂O) – from biological processes during wastewater treatment.

The summary of emission factors applied in the waste sector are shown in Table 7-4.

Table 7-4:Source emission factors for waste sector

Emissions sources	Sources included	Tier-1 Default Emission Factor / Parameter	Emission factors reference
5.A.1.a.ii	Solid waste disposal – unmanaged shallow sites	Methane Correction Factor (MCF) = 0.4	IPCC (2006) Table 3.1
5.A.1.b.	Solid waste disposal – uncategorised sites	MCF = 0.6	IPCC (2006), Table 3.1
5.C.2.	Open burning – solid waste	CH ₄ EF = 6,500 g CH ₄ / tonne MSW (wet weight) N ₂ O EF = 150 g N ₂ O / tonne waste Oxidation factor for CO ₂ = 58% of carbon input	IPCC (2006) Tables 5.2 & 5.6
5.D.1.a.i	Domestic wastewater – centralized treatment	CH ₄ maximum producing capacity (Bo) = 0.0 kg CH ₄ / kg BOD + MCF varies by treatment pathway; N ₂ O EF (effluent discharge) = 0.005 kg N ₂ O-N / kg N	IPCC (2006), Chapter 6, Table 6.2 & Section 6.3.1.2
5.D.1.a.ii	Domestic wastewater – septic systems	MCF for septic systems = 0.5 (used in combination with Bo above) N ₂ O EF=0.3 kg/person/year	IPCC (2006), Chapter 6
5.D.1.a.iii	Domestic wastewater – latrines	MCF for latrines = 0.1 CH ₄ EF calculation uses that with Bo; N ₂ O EF =0.06kg CH ₄ /kg BOD	IPCC (2006), Chapter 6

Figure 7-4 shows total GHG emissions by gas type contributions.

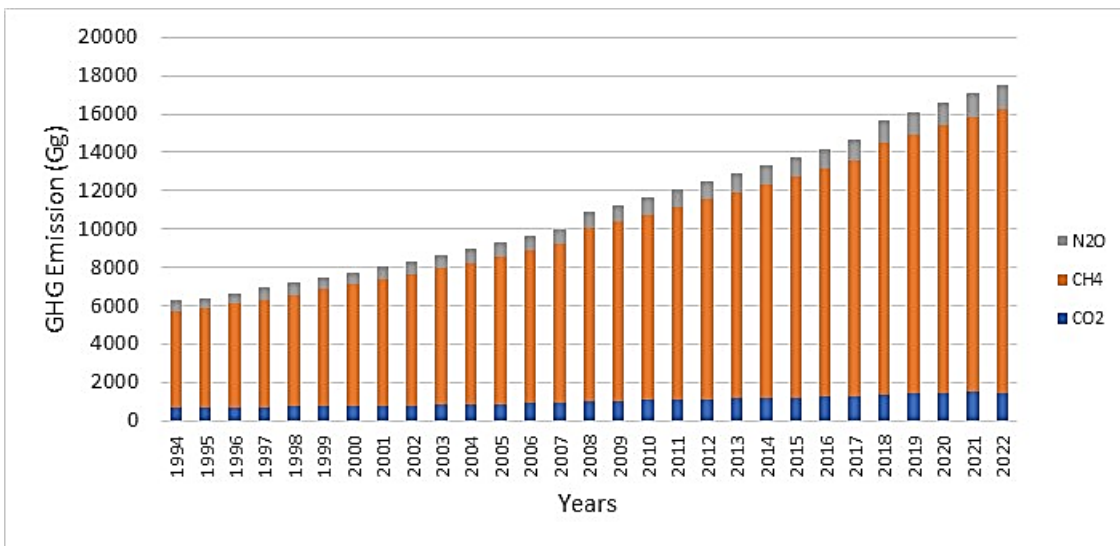


Figure 7-4: GHG emissions for waste sector by gas type for 1994 to 2022.

7.2.1. Solid waste disposal

Carbon dioxide (CO₂) emissions from municipal solid waste (MSW) originate from both biogenic and fossil sources. Biogenic CO₂ is considered climate-neutral because it is reabsorbed by vegetation through photosynthesis and is therefore accounted for in the Agriculture sector. Nitrous oxide (N₂O) emissions from solid waste disposal sites (SWDS), arising from anaerobic digestion of organic matter or mechanical–biological (MB) treatment, are considered negligible (IPCC, 2006).

Composting, however, can emit N₂O in amounts ranging from 0.5% to 5% of the initial nitrogen content of the feedstock (Peterson et al., 1998; Hellebrand, 1998; Vesterinen, 1996). Despite this, emission estimates remain uncertain due to limited data availability, variations in organic matter composition, and the lack of systematic data collection on composting activities. Additionally, waste composition and quantities vary widely, further complicating consistent emissions quantification. As such, N₂O emissions accounted for in this report primarily arise from open burning of waste and domestic wastewater treatment.

7.2.2. Biological treatment of solid waste.

The biological treatment of organic components of solid waste is generally conducted through two main processes:

- i. Anaerobic digestion, and
- ii. Composting.

Anaerobic digestion is associated with methane (CH₄) recovery and combustion, primarily for energy generation. As a result, GHG emissions from this process are reported under the Energy Sector, in

accordance with IPCC 2006 Guidelines. The mechanical-biological (MB) treatment process aims to reduce the volume of waste and minimize emissions from disposal sites by combining composting and anaerobic digestion, alongside processes such as shredding and separation (Kaartinen, 2004). This treatment typically reduces organic content by 40–60% and is more common in developed countries, particularly in Europe, and less so in developing contexts.

In Malawi, however, the use of composting is gradually increasing. Compost is being used to enrich soil organic matter (SOM) and is applied in farming, plant nurseries, landscaping, and even in the commercial production of organic macadamia, potting mixes, and biochar. Despite this, biological treatment of solid waste is currently not assessed for GHG emissions in the national inventory due to data limitations.

7.2.3. Incineration and open burning of waste.

Incineration and open burning are significant sources of GHG emissions. Incineration involves controlled combustion of waste in designated facilities. While incineration of hazardous and medical waste is known to occur in some facilities, this report does not include these emissions due to insufficient activity data.

Open burning, on the other hand, refers to uncontrolled combustion of waste at open dumpsites. This process leads to the release of CO₂, CO, and N₂O, mainly as a result of incomplete combustion.

i. Methane (CH₄) Emissions

Methane emissions from open burning and incineration were estimated using the 2006 IPCC default methodology:

$$CH_4 \text{ emissions} = IW \times EF \times 10^{-6}$$

Equation 7-1

Where:

- *IW* = Amount of solid waste incinerated (Gg/year)
- *EF* = Emission factor (kg CH₄/Gg waste)
- *Pfrac* = Fraction of the population whose waste is burned
- *Bfrac* = Fraction of waste that is actually burned (taken as 0.5 to reflect incomplete combustion)

A CH₄ emission factor of 6,500 g/tonne of MSW (wet weight) was applied, in line with IPCC guidelines. Due to limited local data, default parameters were used.

ii. Carbon Dioxide (CO₂) and Nitrous Oxide (N₂O) Emissions

CO₂ emissions were calculated as follows:

$$CO_2 \text{ emissions} = \text{Total amount of waste open burnt} \times DM \times CF \times FCF \times OF \times \text{conversion factor}$$

Equation 7-2

Where:

DM = dry matter CF = fraction of carbon in dry matter

FCF = Fraction of Fossil fuel carbon in total carbon

OF = Oxidation Factor

$$\text{Conversion factor} = \frac{44}{12} \left(= \frac{11}{3} \right)$$

N₂O emissions were calculated using:

$$N_2O \text{ emissions} = \text{Total amount of waste open burnt} \times EF$$

Equation 7-3

Where:

$$EF = \frac{150 \text{ kg } N_2O}{t_{\text{dry waste}}}$$

7.1.1.6 Emissions Summary

The uncollected fraction of MSW, which constitutes approximately 70% of total waste generated in Malawi, is not included in these estimates due to a lack of data.

For the period 2018–2022, open burning of waste resulted in estimated GHG emissions of:

- 7,209.2 Gg CO₂
- 1,900.3 Gg CH₄
- 22.8 Gg N₂O

This yields a total of 13,932.97 Gg CO₂-eq for the five-year period. Time series emissions from 1994 to 2022 are presented in Figure 7-5.

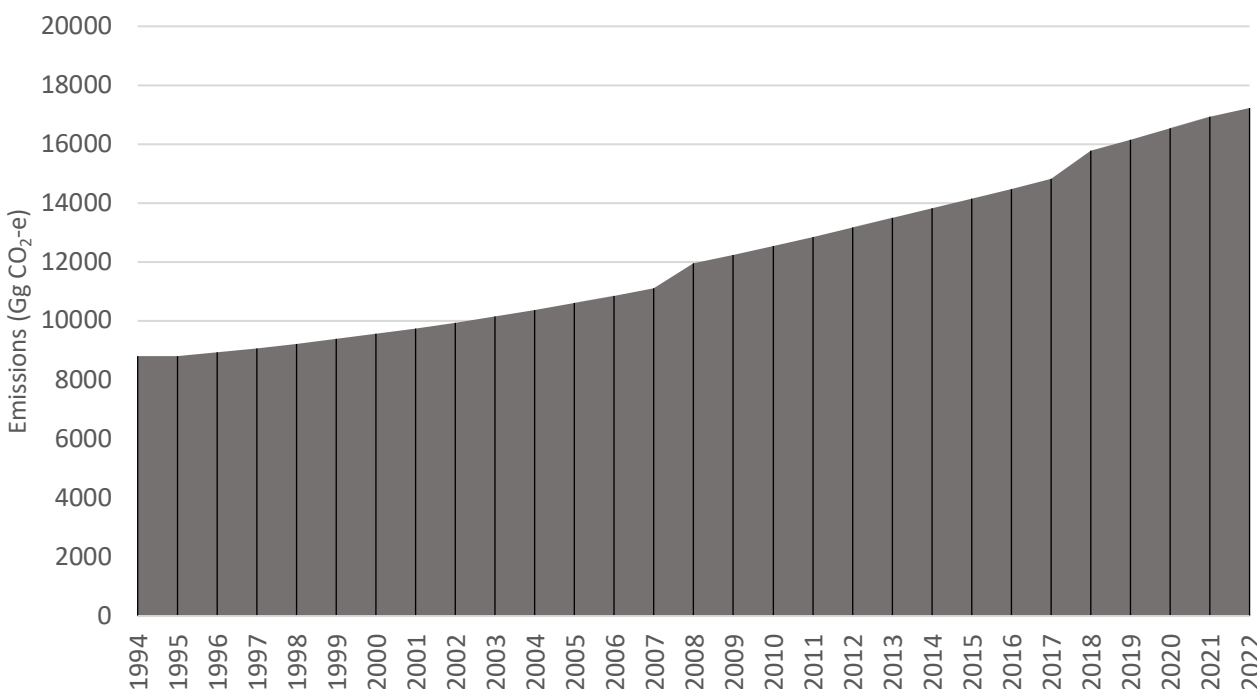


Figure 7-5: Time series for Incineration and open burning

7.2.4. Wastewater treatment and discharge.

Wastewater in Malawi originates from domestic, municipal, and industrial activities. This combined wastewater is treated at various sewage treatment facilities where flow-measuring devices are installed (Chipofya, 2003). Methane (CH₄) emissions arise when wastewater is treated or discharged under anaerobic conditions. The configuration of wastewater discharge systems varies by country, region, and user, comprising either open or closed systems, including closed pipe networks, open canals, gutters, and ditches. These systems transport wastewater containing varying concentrations of organic compounds depending on their source.

Rivers and streams that receive wastewater rich in organic matter—especially from food processing industries—often experience rapid depletion of dissolved oxygen due to microbial decomposition. This oxygen demand is quantified by the biochemical oxygen demand (BOD₅), which measures the amount of oxygen required by microorganisms to oxidize organic matter. When oxygen becomes depleted, anaerobic conditions prevail, leading to the production and emission of methane.

Both wastewater and its associated sludge are sources of methane, with emissions increasing at higher ambient temperatures. Under such conditions, open sewers typically emit more methane than closed systems (Doorn et al., 1997). Domestic wastewater that is not collected in centralized systems—such as that treated in pit latrines, septic systems, or disposed of in unmanaged lagoons or waterways—is also a significant source of methane emissions. In Malawi, domestic and industrial wastewaters are generally not separated at treatment facilities, resulting in mixed sludge streams.

From 2018 to 2022, domestic wastewater treatment and discharge in Malawi resulted in emissions of 5.3 Gg CO₂, 0.6 Gg CH₄, and 5.0 Gg N₂O, corresponding to 308.8 Gg CO₂-equivalents.

Methodology

The GHG estimates in this section follow the 2006 IPCC Guidelines for National Greenhouse Gas Inventories (Waste Volume). Activity data were obtained for municipal solid waste (MSW) and wastewater from Malawi's four cities, municipalities, towns, designated urban areas, and district headquarters as defined in the Malawi Integrated Household Survey (IHS, 2017). Data was collected from cities, municipalities, towns, urban areas and district headquarters as shown in the table below.

Table 7-5: Data sources for the Waste Sector in Malawi for National Communications

National Communication	Local Government area providing MSW data and Wastewater Treatment and Discharge
Initial National Communication (INC)	Cities of Mzuzu, Lilongwe, Blantyre and Zomba, Municipalities of Kasungu and Luchenza, Towns: Karonga, Dedza, Salima, Mangochi and Balaka,
Second National Communication (SNC)	Cities of Mzuzu, Lilongwe, Blantyre and Zomba, Municipalities of Kasungu and Luchenza, Towns: Karonga, Dedza, Salima, Mangochi and Balaka,
Third National Communication (TNC)	Cities of Mzuzu, Lilongwe, Blantyre and Zomba, Municipalities of Kasungu and Luchenza, Towns: Karonga, Dedza, Salima, Mangochi and Balaka,
Fourth National Communication (NC 4)	Cities of Mzuzu, Lilongwe, Zomba and Blantyre. District headquarters of Likoma, Chitipa, Nkhatabay, Mzimba, and Karonga town and Chintheche urban in the north. Kasungu municipality, Mponela urban, Chipoka urban, Salima and Dedza towns and district headquarters of Mchinji, Nkhotakota, Ntchisi, Dowa, and Ntcheu in central region, Mangochi, Balaka and Liwonde towns, district headquarters of Machinga, Neno, Mwanza, Chiradzulu, Phalombe, Mulanje, Chikwawa and Nsanje in the South. Data for Wastewater Treatment and Discharge was provided by Blantyre Water Board, Lilongwe Water Board and Southern Region Water Board.

Data Sources and Collection:

Data were collected using structured questionnaires and interviews targeting key aspects of waste management value chain, including:

- Waste management practices
- Solid waste disposal
- Biological treatment of solid waste
- Incineration and open burning
- Wastewater treatment and discharge

Secondary data sources included the 2018 National Population and Housing Census, Malawi Demographic and Health Survey (2017), and FAOSTAT per capita protein intake data and other publications.

Due to the absence of country-specific emission factors and a systematic data collection system, Tier 1 default emission factors were applied. Waste generation rates specific to Malawi (0.18 kg/capita/day) were derived from the 2019 IPCC Refinement. As per this refinement, the urban population (16% of the total) was used to estimate GHG emissions, and default waste composition data for the East Africa region was applied (

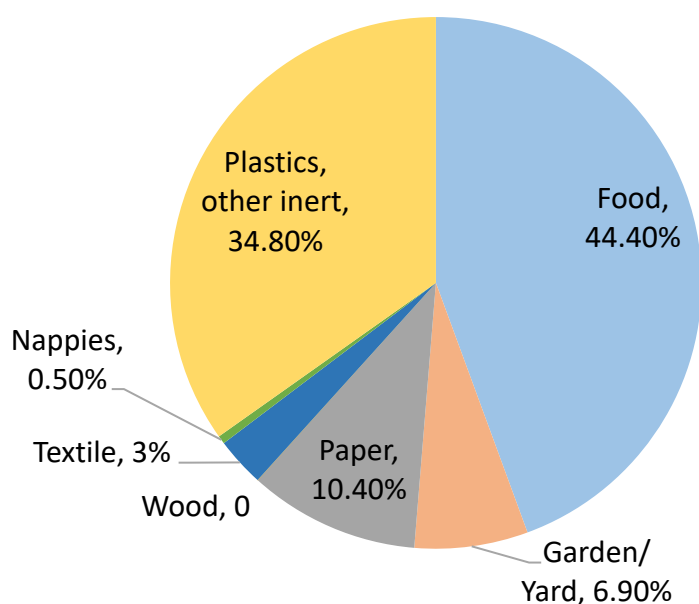
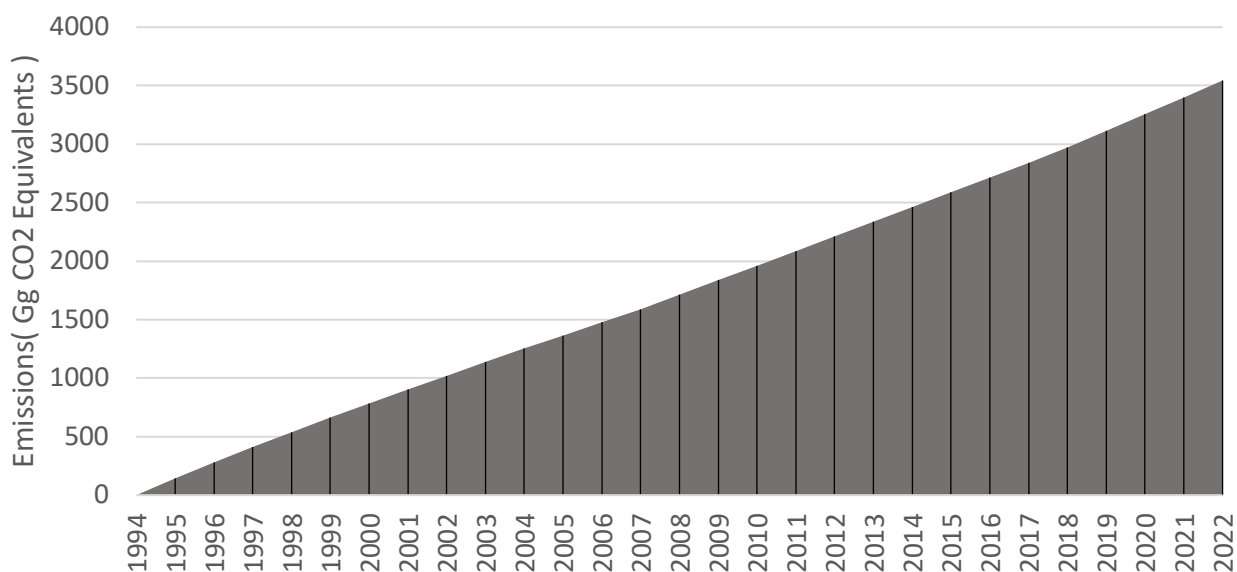


Figure 7) because local data were incompatible with IPCC software requirements.

7.1.2 GREENHOUSE GAS SOURCE AND SINK CATEGORIES

7.1.2.1 1.1.1 Solid Waste Disposal (5.A.)

Solid waste disposal refers to the process of managing solid waste from its generation to its final disposal in Solid Waste Disposal Sites (SWDS). The waste can be categorized as either sorted or mixed, and disposal sites may vary from engineered facilities to unmanaged sites. In the waste management process, some materials are reused or recycled before they reach the disposal site, including plastics, glass, and metal waste.



7.1.2.2 Managed waste disposal sites (5.A.1)

Managed waste disposal sites are engineered facilities that are lined with an impermeable layer to protect the surrounding environment. These sites are typically deeper than 2 meters, and the waste brought to the site is covered with soil or other materials in layers. Anaerobic decomposition of organic matter occurs, which results in methane (CH₄) emissions. This methane can either be captured for waste-to-energy recovery or flared. In the case of waste-to-energy recovery, the emissions are accounted for under the energy sector. As of now, emissions from managed waste disposal sites have not been estimated (NE).

7.1.2.3 Unmanaged waste disposal sites (5.A.2)

Unmanaged waste disposal sites are typically shallow (less than 5 meters deep) and lack an impermeable lining. Waste is simply dumped and left unmanaged. At these sites, aerobic decomposition occurs in the upper layers, while anaerobic decomposition takes place in deeper layers. GHG emissions from these sites include CO₂, CH₄, and N₂O. CO₂ emissions are biogenic in origin and are assumed to be absorbed by plants via photosynthesis in the same year.

7.1.2.4 Uncategorized waste disposal sites (5.A.3.)

Uncategorized waste disposal sites are informal dumping areas such as drains, manholes, riverbanks, road junctions, parks, and open spaces. Some materials, including plastics, rubber, glass bottles, and metal, may be informally recovered at these sites. GHG emissions of CO₂, CH₄, and N₂O occur here, and waste is commonly burned, particularly during the dry season. It is assumed that 50% of the waste decomposes anaerobically, while the remaining 50% is burned. However, due to a lack of

reliable data sources, GHG emissions from this category have not been estimated in this communication.

7.2 Biological treatment of solid waste (5.B.)

7.2.1 Composting (5.B.1)

Composting has become increasingly common in Malawi, particularly in urban areas (see Table 7-3). Organic waste from markets is composted through aerobic or anaerobic processes and sold to gardeners, plant nurseries, and commercial farmers growing tea, coffee, and macadamia. While composting, both CH₄ and N₂O are released into the atmosphere. Compost application to farmland contributes to carbon sequestration, with a range of 12–45% of carbon for every tonne applied over 4 to 12 years. Every tonne of soil organic carbon holds the equivalent of approximately 3.67 tons of atmospheric CO₂ (Bhogal et al., 2016).

Table 7-6: Compost Making Data from Cities in Malawi

Year	Blantyre	Lilongwe	Zomba	Mzuzu
2018	220	150	25	25
2019	260	180	30	28
2020	280	200	40	34
2021	300	220	43	40
2022	400	300	50	48

Despite these developments, activity data on composting, organic fertilizer production, and biochar production, as well as associated GHG emissions, are not systematically recorded.

7.2.2 5.B.2. Anaerobic digestion at biogas facilities

Biogas facilities are spread across Malawi, mostly in domestic settings, with a few located in institutional settings. Comprehensive records of these facilities are lacking, preventing the estimation of GHG emissions for this process. Emissions from biogas facilities are reported under the energy sector.

7.3 5.C. Incineration and open burning of waste

7.4 5.C.1. Waste incineration

Waste incineration is primarily used in hospital establishments for medical waste and by industries for hazardous chemical waste. In both cases, incineration is conducted at designated sites with

permission from Fire Brigade Services, specifically in the cities of Blantyre and Lilongwe. No data is currently collected for this activity.

7.4.1 5.C.2. Open burning of waste

Open burning of waste is commonly practiced at unmanaged solid waste disposal sites and uncategorized waste sites. CO₂ and N₂O are released during this process, contributing to global warming. Open burning is particularly prevalent in towns and market centers that lack waste collection services and have unmanaged waste disposal sites. Activity data for this process is collected for MSW collection in cities and selected urban centers, with population data used to estimate per capita waste generation.

Table 7-7: Activity data for Incineration and Open Burning of Waste

YEAR	Total Amount of Waste open-burned (Gg Waste)						
	Food waste	Garden and park	Disposable nappies	Paper and cardboard	Wood	Textile	Rubber and leather
1994	17490.25	2718.08	196.9623	4096.81584	0	1181.774	1825.98233
2000	19384.99	3012.532	218.29946	4540.62866	0	1309.797	2023.79312
2010	26996	4195.325	304.00907	6323.38855	0	1824.054	2818.38292
2017	32797.01	5096.833	369.3357	7682.18256	0	2216.014	3424.00786
2018	35231.07	5475.098	396.74624	8252.32169	0	2380.477	3678.12326
2019	36189.07	5623.978	407.53463	8476.7202	0	2445.208	3778.1394
2020	37166.76	5775.915	418.54455	8705.72664	0	2511.267	3880.20933
2021	38150.12	5928.735	429.61847	8936.06407	0	2577.711	3982.8725
2022	39139.05	6082.419	440.75502	9167.70442	0	2644.53	4086.11638

7.5 5.D. Wastewater treatment and discharge

Wastewater treatment and discharge involve the management of liquid waste through either open or closed sewer systems. This wastewater may be of domestic or industrial origin, and in Malawi,

some sewer systems are mixed. Through conveyance, treatment, and discharge, GHGs such as CH₄ and N₂O are emitted. The sludge from wastewater treatment is 100% reused by farmers in gardens after drying. Emissions from wastewater treatment and discharge are influenced by per capita protein intake. Figure 7-6 below shows the per capita protein intake for Malawi based on data from FAOSTAT.

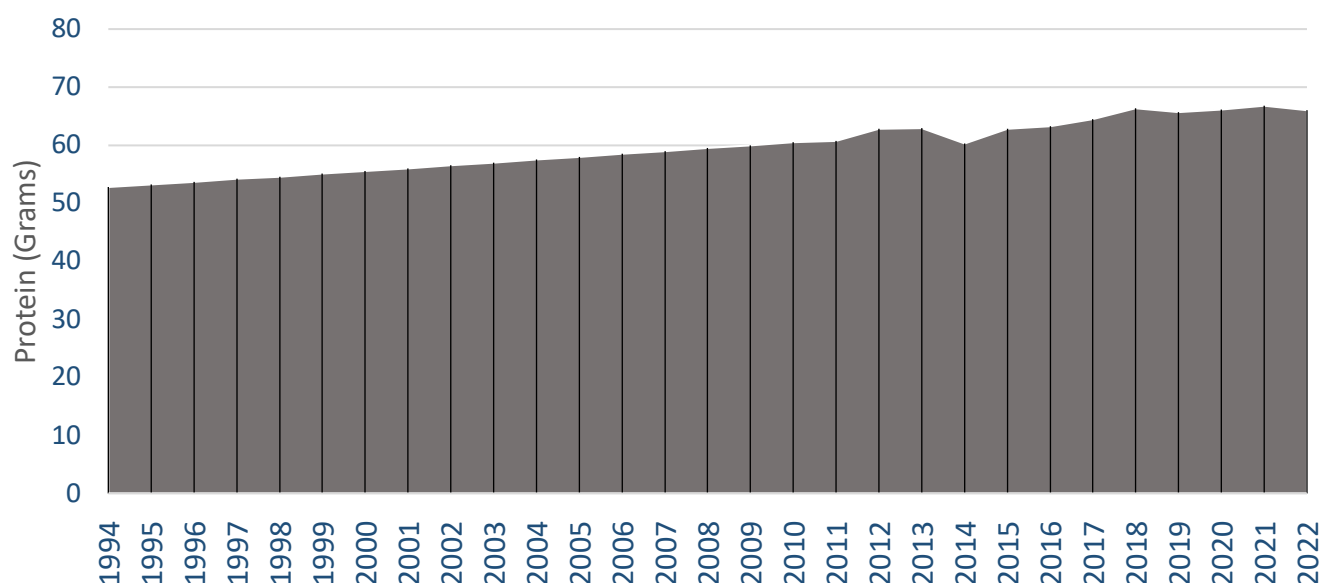


Figure 7-6: Malawi Protein per capita intake (g) 1994-2022

Source: FAOSTAT portal, Malawi

Wash data for sewerage, septic tank and improved latrines was obtained for the calculating GHG emissions in wastewater treatment and discharge. Due to data limitations, some extrapolations were done for the years 1994 to 1999. The Figure 7-7 shows the relationship between the different sanitation systems with improved latrines being the most common sanitation methodology followed by septic tanks and lastly sewerage sanitation.

Table 7-8: Statistics on access to and type of toilet facility by population category (%)

Population category	Access to improved toilet	Type of toilet facility						
		Flush toilet	VIP latrine	Pit latrine with slab	Pit latrine without slab	None	Other	Total
Malawi	35.4	2.3	1.2	31.7	54.7	8.9	1.2	100
Rural	29.3	0.4	1.2	27.7	59.1	10.2	1.4	100
Urban	65.5	11.7	1.3	52.5	32.0	1.9	0.6	100
Northern Region	43.7	2.7	0.6	40.4	46.6	9.3	0.4	100
Central Region	38.0	2.3	0.5	35.2	52.7	8.6	0.7	100

Southern Region	30.2	2.1	2.0	26.0	58.8	9.0	2.1	100
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Source: Adapted from the Fifth Integrated Household Survey (IHS 5), NSO (2020)

Table 7-9: Number of people accessing different types of waste water treatment technologies

YEAR	Population - P (Capita)/ Waste water treatment technologies		
	Sewered	Septic Tank	Improved Latrine
1994	100984.3	151198.43	224178.6058
2000	101582.8	184277.84	407679.6087
2010	138230.2	275705.38	894746.677
2017	177440.4	379192.34	1673462.453
2018	184236.1	397540.59	1816988.538
2019	191408.5	417011.99	1970671.301
2020	198969.8	437659.1	2135180.291
2021	206847.8	459348.86	2310271.856
2022	215078	482183.55	2496829.913

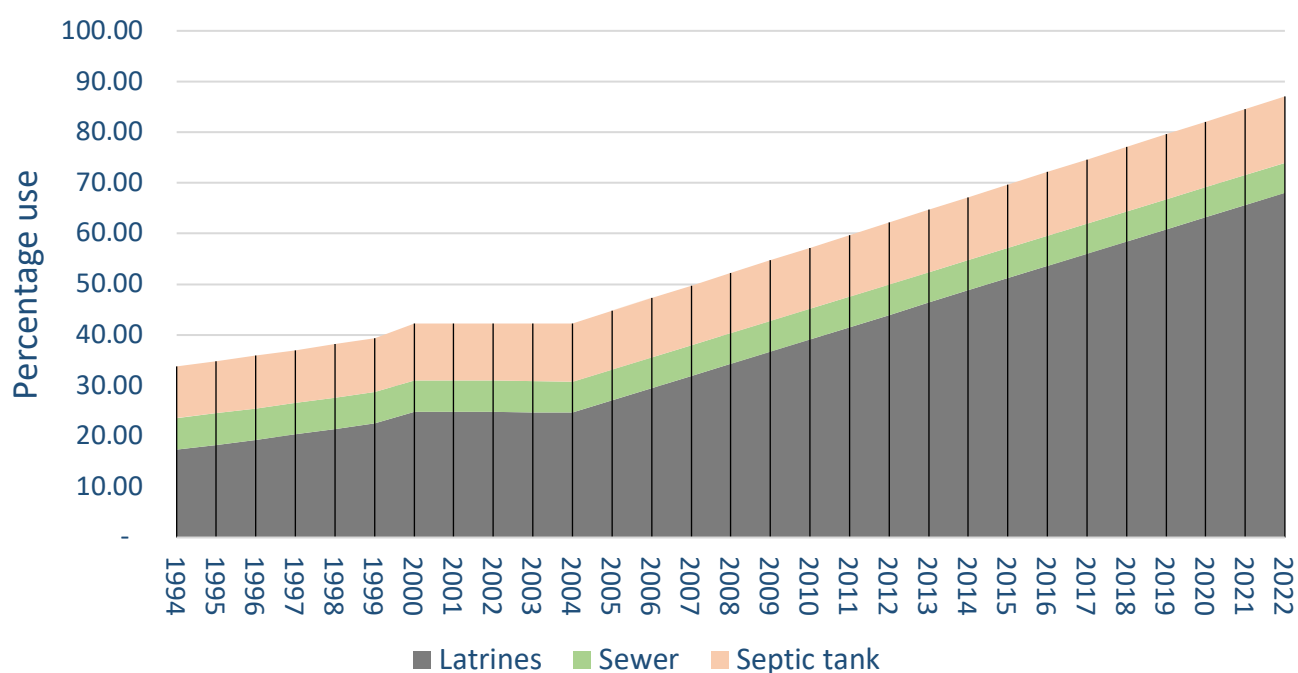


Figure 7-7: Percentage use of sanitation services

7.5.1 5.D.1. Domestic wastewater

Domestic wastewater treatment occurs at three plants in Blantyre and one plant in Zomba. Activity data for these sites has been recorded.

7.5.2 5.D.2. Industrial wastewater

There is one industrial wastewater treatment plant in Blantyre, which is currently non-functional.

7.5.3 5.D.3. Other (mixed wastewater treatment)

Two mixed wastewater treatment plants are located in Lilongwe (Kawuma) and Blantyre (Nkhumbwe). These plants release GHGs, including CH₄ and N₂O, into the atmosphere during the treatment process.

7.2.3. Uncertainty assessment and time series

The importance of assessing uncertainty in data collection, collation, emission factors, and other relevant variables cannot be overstated.

Population data for urban areas in Malawi is largely based on estimates from the 2018 national population census. Since the census is conducted every 10 years, the interim periods between census sessions rely on estimated figures. Population projections are provided by the National Statistical Office (NSO), but these projections do not always align with actual census data. The designation of urban areas in Malawi is fluid, as there are unplanned areas and urban sprawl. Population growth rates are typically produced in the year of the census and applied between subsequent census periods. However, this approach does not capture the true growth rate over a 10-year period.

To address this challenge, research was conducted to compare Malawi's population data with sources like FAOSTAT, Micro-Trends, and various research papers for triangulation purposes.

Waste generation and management present another challenge. In all urban areas, the weight of waste collected is only an estimate due to the lack of detailed records. Additionally, machinery downtime is not accounted for, and factors like moisture content of the waste and the weight of loads are not measured. Most waste surveys in the country's cities do not specify the stage of the waste life cycle at which the assessments were conducted. Furthermore, the waste characterization methods are not standardized according to UNEP guidelines, which complicates the direct use of survey results for accurate reporting. This introduces uncertainty, as MSW generation, which waste surveys cover, differs from MSW disposal.

To improve the accuracy of reporting, Malawi will need to use national-level waste generation and sanitation data. This initiative will help develop national-specific emission factors for the waste sector.

Wastewater treatment and disposal facilities in Malawi operate under varying conditions, further complicating the accuracy of emissions estimates. All sewerage sludge is collected by farmers for use as organic fertilizer, and this has been incorporated into our calculations to ensure the estimates reflect the true status of the situation. However, some wastewater treatment plants are in poor repair, meaning that final discharges are not fully processed.

Uncertainty in emissions data is critical, as incorrect inputs lead to inaccurate GHG emissions estimates. Urban sanitation data, sourced from the WHO/UNICEF joint report for 1999 to 2022 and other reports like IHS, have been used. Emission factors for non-consumption protein were applied: zero for sewered systems, 0.3 for septic tanks, and 0.06 for improved pit latrines, based on a range of values. Protein data was obtained from FAOSTAT for the period 2010–2022, and extrapolated data was used for earlier years, though this introduces challenges in ensuring accuracy.

Table 7-10: Uncertainty Assessment for the waste sector

Data Sources	Uncertainty assessment	Remarks
Waste collection data	30%	The weights of waste are only assumed based on the vehicle capacity. The disposal sites do not have weighbridges to ascertain the weight. moisture content is not known.
Population	10%	Population extrapolation has its own challenges. The interval between population censuses is long. When actual surveys have been done, there is always a difference with projected figures. Urban areas are fluid places as city sprawl and unplanned areas within may be included or not in population counts.
Per capita Protein data	5.0%	FAOSTAT data may be just as good. But extrapolation and interpolation make the whole exercise more challenging.
Sanitation data	20%	Sanitation data has been obtained from HIS reports. Sewered sanitation is not separated from flush toilets which are on

septic tanks. This makes it difficult to be 100% sure that the figures are correct.

Annual Emission periods for solid wastes	30%	Malawi has tropical dry climate with clear demarcation of wet and dry seasons. During the dry months, there are more fires at solid waste disposal sites than during the wet season. During the wet season, more waste accumulate at solid waste disposal sites as there are few fire incidences. The more the wastes accumulate, the more anerobic decomposition takes place releasing Methane gas that during the dry season when there are more fires and there is less Methane generated because there is less anerobic decomposition.
Overall Assessment	15.8%	

7.6 Time-series consistency and recalculations

To ensure credible time series for the waste sector, the 2006 IPCC guidelines, along with the 2019 refinement, were used for default per capita municipal solid waste (MSW) generation. For Malawi, the per capita MSW generation is set at 0.18 kg, and the methane emission factor for MSW in unmanaged shallow solid waste dump sites is 0.4. Recalculations were made due to the inclusion of new data sources, such as per capita protein intake in wastewater treatment and discharge. data coverage has changed tremendously as data sources have increased from 10 to 31 urban areas. Population growth over the years has significantly contributed to the increased data volume compared to previous national communications.

7.7 Assessment of completeness

The completeness of emission estimates in the Waste sector is assessed below. Completeness refers to the coverage of gases, categories, and time series. Additional details are provided on the status of emission estimates across all sub-categories:

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

Table 7-11: Completeness status of the estimations under various sub-categories

IPCC Category	Time series Completeness		Status of Gas
	1994-2017 (Previous Estimates)	2018-2022 (Latest Estimates)	

	E	NE	NO	IE	E	NE	NO	IE	CO ₂	CH ₄	N ₂ O
Solid Waste Disposal	X				X				NO	X	NO
Biological Treatment of Solid Waste		NE									
Incineration		NE				NE					
Open Burning	X				X				X	X	X
Domestic wastewater treatment and discharge	X				X				NO	X	X
Industrial wastewater treatment and discharge			NO								

Quality Assurance (QA) and Quality Control (QC) in the waste sector

The QA/QC procedures followed in the Waste sector are outlined in the table below.

Table 7-12: QA/QC procedures in the waste sector

Data Type	QA/QC procedure	Remarks/Comment/Examples
Activity data check	Check for transcription, typographical errors and errors.	Division of tasks among the inventory team to ensure that one or two team members always focus on double checking and that data errors associated with those described in the column are avoided.
	Consistency checks of categories and sub-categories with totals	Ensuring that disaggregated figures at the category and sub-categories levels add to the overall totals.
	Identify and fix outliers in data inputs	Data that deviate unrealistically from the trends and spikes beyond ranges are suspected as inaccurate and replaced with expert judgment.
	Documentation of all data sources, data format and assumptions for easy reference	A record of all data, their sources and assumptions made in admitting the data used were kept to help easy cross-referencing.
	Ensure reduction in data redundancy	Logical sequence data flow according to the IPCC methodology for the GHG emission estimation was designed for: • easy understanding and further probing of how the final results in the IPCC software would like, • easy cross-referencing and avoidance of mistakes, • easy transmission into the IPCC software and
Calculation by the approved	Cross-checks all steps involved in the calculation.	Ensure that steps used for determining, estimating and deriving data are accurate, transparent internally consistent

2006 IPCC software	Documentation of sources and correct use of units.	Use of the documentation template to record all data sources and assumptions. Check for transcription, typographical errors and error transposition.
	Check mistakes and errors in data entry into the software	Checked completeness of data coverage Ensuring all the relevant gases for the specific activity were covered. Results) Check of recalculation differences to identify and pinpoint changes, revisions and reallocation to improve the accuracy and transparency of the estimates. Identify and fix outliers in the results checking for dips and spikes in trends and levels
	Documentation Assumptions, corrections, data and sources.	Ensure consistency, transparency, facilitate repeatability and easy retrieval Improvement list (internal and external findings) Help prioritise areas that require action.

7.8 Planned Improvements for the Waste Sector

Data collection remains a significant challenge across most sources, and there is an urgent need to implement more robust mechanisms for collecting and maintaining records in waste management from a wider range of sites. The following improvements are proposed:

- **Data Collection:** There is a lack of continuous data collection in the waste sub-sectors. To address this, personnel should be trained and empowered to collect and submit data as part of their monthly reports to the relevant offices.
- **Emission Factors:** Currently, Malawi relies on regional default emission factors for estimating GHG emissions in the waste sector. Studies should be undertaken to develop country-specific emission factors, which will require significant resources.
- **Waste Separation and Agriculture:** The waste sector has the potential to contribute to agricultural production. By implementing waste separation at waste transfer stations (WTS), compost can be produced, improving soil organic matter and promoting carbon sequestration. This aligns with the growing organic farming movement and the increasing demand for organically produced products, particularly in commercial tea, coffee, and macadamia farming for export.
- **Composting Standards:** The composting sub-sector is experiencing new developments, with market waste now being used for compost production. International compost-making companies have supported the development of composting standards based on the process and final product characteristics. These standards should be popularized, and the associated methane (CH₄) and nitrous oxide (N₂O) emissions should be assessed. This will enrich data collection and help refine emission factors.
- **Waste Management Investment:** Investment in waste management infrastructure for rapidly growing urban areas is essential. With the introduction of attractive valorization models,

waste management can become a sustainable and profitable sector. By expanding data collection efforts, more accurate and representative data can be obtained, reducing errors and uncertainties.

7.8.1 Status of infrastructure in the four cities and other Urban Areas

Solid waste management infrastructure in Malawi is currently limited and outdated, significantly affecting waste collection efficiency. Only 30% of the total waste generated in the major cities—Blantyre, Lilongwe, Mzuzu, and Zomba—is collected.

Key infrastructure components include:

- **Collection Vehicles:** Waste collection is primarily carried out using 5-ton skips and skip-lifting vehicles, as well as waste compaction vehicles, tractors, and tractor-drawn trailers, especially in towns and municipal councils.
- **Transfer Stations:** In Lilongwe, three waste transfer stations are located in high-density, unplanned areas where waste collection services are lacking. In other towns and municipalities, waste bunkers are strategically placed at markets, traffic junctions, and hospitals, with additional waste receptacles placed in residential areas, schools, and central business districts (CBDs).
- **Waste Disposal Sites:** Currently, all local authorities in Malawi use open dump sites for final waste disposal. These sites are unmanaged, shallow, and lack proper infrastructure such as security walls and weighbridges, making it difficult to measure the amount of waste being disposed. Open burning is common, particularly due to methane emissions or deliberate fires set by scavengers. During the rainy season, mixed waste accumulation at these sites creates anaerobic conditions that contribute to CO₂ and CH₄ emissions.

The figure below shows the proposed 50-hectare landfill site for Blantyre City Council.

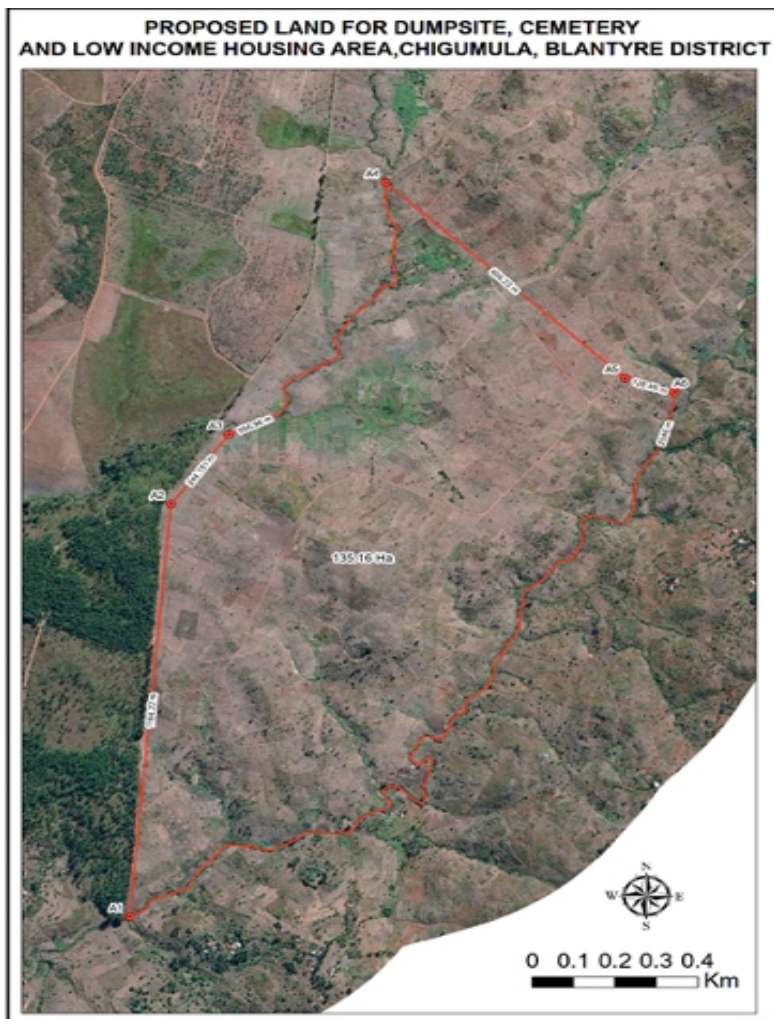


Figure 7-8: Blantyre City Council's Proposed Landfill Site

Waste is not sorted at the residential level, which complicates handling and undermines recycling initiatives.

7.8.2 Status of Wastewater management infrastructure

Malawi's wastewater infrastructure is predominantly onsite, with most urban residents relying on water closet toilets with septic tanks. As of 2020, only 14.4% of the urban population had direct access to sewer lines, and the existing sewer network operates at only 10% capacity. In peri-urban areas, 83.8% of residents use VIP and pit latrines, which pose risks for groundwater and surface water contamination. These systems are characterized by anaerobic decomposition, leading to CH₄ and N₂O emissions. There is a need to expand sewerage networks and move away from septic tanks.

7.8.2.1 Initiatives and Projects in various councils and Key concerns affecting cities in Malawi

- *Lilongwe City:* The city has benefited from a water and sanitation project supported by the World Bank (2020-2024), which has upgraded the wastewater treatment plant and extended the sewer network. The solid waste management diagnostic study and promotion of organic waste composting are key initiatives to reduce illegal waste disposal and open burning, subsequently mitigating emissions from uncontrolled decomposition.
- *Blantyre City:* The World Bank-supported waste and sanitation project (2023-2028) aims to establish the first engineered landfill and improve the wastewater treatment plant, alongside extending the sewer line network. A 135-hectare site in Chigumula has been identified for the project, which will include a class-one cemetery, landfill site, forestry, and high-density housing.
- *Mzuzu City:* The construction of the Nsilo Waste Facility encountered operational challenges due to technical limitations. However, the World Bank is supporting the city in the development of an engineered solid waste disposal site, with the project now in the procurement stage.
- *Zomba City:* A waste composting shelter is under construction to reduce the amount of waste directed to open dumps and contribute to greenhouse gas reduction.

Planned Projects in Need of Funding

There are several key waste management projects in Malawi that are urgently in need of funding, including the construction of engineered solid waste landfills in Lilongwe and Zomba. These projects, which are part of Malawi's Nationally Determined Contributions (NDCs), will significantly improve waste management practices and reduce methane and N₂O emissions.

7.9 Governance of GHG inventory in Waste Sector

The development of a national greenhouse gas (GHG) inventory for the waste sector in Malawi has been a gradual and challenging process, primarily due to persistent issues in data collection. Compared to sectors such as Agriculture, Forestry and Other Land Use (AFOLU) and Energy, the waste sector is relatively underdeveloped. Data sources remain localized, and there is currently no centralized government department mandated to manage or store waste-related data. This issue is compounded by limited funding allocated to waste management initiatives.

In addition to data availability, lack of standardization across local councils presents another major barrier. Different research studies on solid waste management conducted in Malawi have employed varying waste characterization methods and assessed waste at different stages along the value chain. For instance, the composition of waste at collection points differs from that at disposal sites. These inconsistencies—caused by non-standardized data capture methods—make harmonization and comparison of data difficult.

To address this challenge, it is recommended that a designated government department—such as the Environmental Affairs Department (EAD), Ministry of Local Government, or Ministry of Sanitation—be tasked with developing and enforcing a standardized data collection methodology. This department should also be responsible for data storage and ensure traceability for verification purposes.

7.10 Other emerging issues.

Currently, four major urban councils—Lilongwe, Blantyre, Mzuzu, and Zomba—are the primary contributors to municipal waste and regularly report their waste generation data. However, there is a growing need to incorporate data from emerging municipalities such as Luchenza, Mangochi, Kasungu, Salima, Dedza, Balaka, Chintheche, Mponela, Chipoka, and Liwonde, which are becoming significant waste generation hotspots.

Additionally, areas with unique waste management challenges—particularly tourist destinations like lakeshore towns and mountainous regions such as Mponela and Mulanje—should be deliberately considered in the national inventory. Though these areas are classified as non-urban, they experience seasonal urban-like waste generation due to heavy visitor traffic.

7.11 Time-series consistency and recalculations

To ensure time-series consistency in the waste sector, the 2006 IPCC Guidelines, supplemented with the 2019 Refinement, were applied. Malawi's per capita municipal solid waste (MSW) generation rate is estimated at 0.18 kg/day. A methane emission factor of 0.4 was used for unmanaged, shallow solid waste dump sites.

7.12 Uncertainty Assessment

Uncertainty in data collection, collation, and use of emission factors is a critical consideration. Urban population estimates in Malawi are primarily based on the 2018 national census, which occurs every ten years. The projections between censuses are approximations and often differ from actual figures when a new census is conducted. Additionally, urban boundaries are fluid due to unplanned settlements and urban sprawl. The same population growth rate is typically applied across intercensal years, which may not accurately reflect true growth trends.

To mitigate these uncertainties, triangulation was done using population data from other sources such as FAOSTAT, MacroTrends, and relevant academic studies.

Waste generation data also carries a high degree of uncertainty. Most urban councils estimate the amount of waste collected, as actual weights are not recorded due to lack of weighing facilities and frequent equipment breakdowns. Moisture content is not measured, and the stage of assessment

along the waste life cycle is often not clearly defined. Moreover, waste characterization methods are inconsistent and do not follow UNEP guidelines, making the data difficult to standardize or compare.

Importantly, MSW generation and MSW disposal are distinct activities, and conflating them introduces further inaccuracies. Therefore, national-level waste and sanitation data are being prioritized to facilitate the development of country-specific emission factors.

Wastewater treatment plants also exhibit considerable variability. While sewer sludge is often collected by farmers for use as organic fertilizer—a fact considered in calculations—some plants are poorly maintained, resulting in partial treatment before discharge.

Emission estimates are highly sensitive to data quality; inaccurate inputs inevitably lead to inaccurate GHG estimations. Sanitation data from Integrated Household Surveys (IHS) include flush toilets and onsite sanitation (VIPs and pit latrines) but do not distinguish between sewered and septic tank systems. Consequently, protein excretion factors used were 1.4 for flush toilets and 1.1 for pit latrines, selected from within accepted ranges.

Protein consumption data was sourced from FAOSTAT for the years 2010–2022, with earlier years (1994–2009) filled through interpolation—a standard but inherently uncertain method.

7.13 4.A.1 Managed Waste Disposal Sites (NO)

This sub-category was not estimated as Malawi currently lacks any engineered solid waste disposal sites in its urban centers.

7.14 Biological Treatment of Solid Waste 4B (NE)

No estimation was made for this sub-category due to a lack of credible data on composting practices. Composting standards in Malawi are voluntary, and methods and timelines vary significantly among operators. Unlike agricultural waste, urban MSW varies by season and composition, complicating standardization.

7.15 Waste Incineration 4.C.1 (NE)

Medical waste incineration occurs at healthcare facilities, but no data is available since records are not maintained. Hazardous waste, such as plastic bottles and electronic waste, also contributes to emissions when burned. While some paint-related waste is incinerated under supervision, this data is not systematically recorded. As a result, waste incineration emissions could not be reliably estimated.

7.16 Industrial Wastewater and Discharge 4.D.2 (NE)

Most wastewater treatment plants in Malawi handle mixed effluent streams from both residential and industrial sources, regardless of their original design. The growth of cottage industries in residential areas has further blurred the lines between domestic and industrial wastewater. City authorities have introduced guidelines for pre-treatment, but the mixed nature of inflows persists.

As per IPCC guidelines, treatment plants receiving mixed wastewater are considered part of the domestic category. Therefore, no separate estimation was made for industrial wastewater.

Chapter 8: Other

Malawi does not report any emissions under CRT sector 6, 'Other'.

Chapter 9: Indirect carbon dioxide and nitrous oxide emissions

In accordance with paragraph 29 of Decision 24/CP.19, Malawi has elected not to report indirect carbon dioxide (CO₂) and nitrous oxide (N₂O) emissions in this submission of its National Inventory Report (NIR). This decision has been made in view of current technical and institutional capacity constraints, and the limited availability of reliable, disaggregated data necessary to quantify these emissions with sufficient accuracy.

While indirect CO₂ and N₂O emissions are not explicitly reported as a separate category in this inventory, relevant emissions and associated activity data are included under the direct sources reported in the Energy and Agriculture, in Chapters 3 and 5 respectively. Specifically, these chapters address the use of nitrogen-based fertilizers and the combustion of fuels that may give rise to precursor emissions of CO, and NO_x, which may in turn contribute indirectly to the formation of CO₂ and N₂O in the atmosphere.

Malawi remains committed to improving the comprehensiveness and accuracy of its greenhouse gas inventory over time. As part of its continuous improvement strategy and subject to available resources, future submissions may explore options for reporting indirect emissions, guided by advancements in national data collection systems and recommendations of the IPCC and the UNFCCC reporting framework.

Until then, this report provides a complete and transparent account of all direct emissions and removals consistent with the 2006 IPCC Guidelines for National GHG Inventories and the MPGs adopted under Article 13 of the Paris Agreement.

Chapter 10:

Recalculations and Improvements

Estimating GHG emissions is an ongoing process that requires continuous refinement to improve its accuracy, completeness, and reliability. In Malawi, the national inventory system regularly updates emissions estimation methods and data sources to align with advancements in scientific understanding, better data availability, and international best practices.

The process of recalculating and improving emissions data is guided by Malawi's Inventory Improvement Plan. This plan aims to enhance transparency, accuracy, consistency, comparability, and completeness (TACCC) in emissions reporting. Efforts are focused on refining key categories that significantly impact national emissions estimates. Furthermore, these improvement initiatives consider feedback from international expert reviews, adapt to evolving IPCC guidelines, and respond to national circumstances such as policy developments and changes in sectors that affect emissions.

10.1 Explanations and justifications for recalculations, including in response to the review process

Recalculations are carried out to improve the accuracy of emissions estimates and to ensure the consistency of the time series. These adjustments may arise from updated activity data, refined emission factors, methodological advancements, or the inclusion of new data sources.

The main reasons for recalculations in this inventory are detailed in the sector-specific chapters and summarized in Table 10-1. Recalculations are applied retro-actively across the entire time series to maintain the consistency and comparability of emissions trends. By updating past estimates, Malawi aims to ensure that its inventory reflects the most current and scientifically sound methodologies, thereby increasing confidence in the reported emissions figures.

The recalculation process also considers recommendations from expert peer reviews, regional collaborations, and national institutional frameworks that support emissions monitoring. Ongoing improvements in data collection, stakeholder engagement, and sectoral assessments are essential for enhancing the overall quality of Malawi's NIR.

Table 10-1: Summary of recalculations in this NIR

	Subsector	NIR Chapter	Reason for Recalculation
Energy			
Energy: Fuel Combustion (1A)	Energy industries	3.2.1	No recalculation
Energy: Fuel Combustion (1A)	Manufacturing industries	3.2.2	No recalculation
Energy: Fuel Combustion (1A)	Transport	3.2.3	No recalculation
Energy: Fuel Combustion (1A)	Other sectors	3.2.4	No recalculation
Energy: Fugitive Emissions from Fuels (1B)	Solid fuels	3.3	No recalculation
IPPU			
IPPU: Mineral Industry (2A)	Cement production	4.2.1	Change of clinker fraction in cement from 0.95(assumed to be ordinary Portland) to 0.75(Portland cement with significant blends).
IPPU: Mineral Industry (2A)	Lime production	4.2.4	
Agriculture:			
Agriculture: Enteric Fermentation (3A)	CH ₄ from livestock digestion	5.4.3	Rabbits were excluded from the previous inventory. The pig population was not averaged annually, leading to inconsistencies in livestock data between inventories.
Agriculture: Manure Management (3B)	CH ₄ and N ₂ O	5.8.3 5.10.3 5.12.3	Lower emissions for goats and pigs were likely due to differing MMS proportions or methods used. The previous report did not include details on the MMS proportions applied. The previous report did not estimate N ₂ O from manure management, so there was no basis for comparison with this inventory. The previous report did not estimate direct N ₂ O emissions from dung and urine

deposited on pasture, so there was no basis for comparison with this inventory.

Agriculture:Rice Cultivation (3C)	CH4 from flooded fields	No recalculation
Agriculture: Agricultural Soils (3D)	N2O emissions	No recalculation
Agriculture: Liming (3G)	Liming	No recalculation
Agriculture: Urea application (3H)	Urea application	No recalculation
Agriculture: Other carbon-containing fertilizers (3I)	Other carbon-containing fertilizers	No recalculation

FOLU

FOLU: Forest Land (4A)	Forest Land	No recalculation
FOLU: Cropland (4B)	Cropland	No recalculation
FOLU: Grassland (4C)	Grassland	No recalculation
FOLU: Settlements (4E)	Settlements	No recalculation

Waste:

Waste: Solid waste disposal (5A)	Solid waste disposal	7.6	This assessment included uncategorised solid waste disposal. Population growth and urbanisation significantly increased data volume.
Waste: Biological treatment of solid waste (5B)	Composting		
Waste: Incineration and open burning of waste (5C)	Open burning of waste	7.6	This was not reported in the previous inventory
Waste: Wastewater treatment and discharge (5D)	Domestic wastewater	7.6	New data sources like protein intake in wastewater prompted recalculations.

10.2 Areas of improvement and/or capacity-building in response to the review process

The review process conducted by the Technical Team of Experts (TTE) within the UNFCCC framework has provided valuable insights into the areas needing improvement in Malawi's National GHG Inventory. In line with the MPGs established under Decision 18/CMA.1, particularly as outlined in paragraphs 7(a) and (d), Malawi has identified key areas for enhancement to

improve the transparency, accuracy, completeness, comparability, and consistency of its reporting.

The priority areas for developing the inventory are based on important findings from this review, as well as an ongoing assessment of data gaps and advancements in methodology. The planned enhancements will be integrated into the national inventory system and aim to strengthen institutional arrangements and technical capacity to ensure compliance with the reporting requirements under the Enhanced Transparency Framework (ETF).

Malawi has acknowledged the need to bolster its technical capacity, improve institutional coordination, and enhance data management systems.

Specifically, the planned improvements include:

- *Enhancing Technical Capacity:* National experts need additional training to recalibrate greenhouse gas (GHG) emission estimates across time series, using methodologies from the 2006 IPCC Guidelines, while ensuring consistency throughout the time series. Efforts are currently underway to build capacity for estimating emissions from key sectors, including energy, Industrial Processes and Product Use (IPPU), Agriculture, Forestry and Other Land Use (AFOLU), and waste management.
- *Developing Country-Specific Emission Factors (EFs) and Activity Data (AD):* The review identified gaps in data availability, particularly regarding waste management, livestock emissions, and emissions from industrial processes. Creating localized EFs and improving the collection of AD will enhance the accuracy of emission estimates.
- *Improving Data Collection and Reporting Systems:* The review noted inconsistencies in reported time series across various sectors. Malawi plans to establish legally binding data-sharing agreements between relevant government institutions and private sector stakeholders to streamline data collection.
- *Enhancing Quality Assurance/Quality Control (QA/QC) Procedures:* The review found that QA/QC measures were not fully aligned with the good practice guidance provided by the IPCC. Malawi intends to develop sector-specific QA/QC protocols and implement systematic checks throughout the inventory development process.
- *Strengthening Institutional Arrangements:* Although Malawi has made progress in establishing institutional frameworks for inventory compilation, further efforts are needed to formalize roles and responsibilities within the national system. Initiatives are underway to improve coordination between the Environmental Affairs Department and sectoral agencies.
- *Adapting the Monitoring, Reporting, and Verification (MRV) System:* The review recommended enhancing MRV capabilities, especially in tracking the effectiveness of mitigation actions. Malawi is currently reviewing its National Monitoring and Evaluation Master Plan to integrate climate reporting and ensure consistency with IPCC guidelines.

10.2.1 Summary of Responses to the UNFCCC TTE Review

Malawi has taken steps to address issues raised in previous technical reviews, with ongoing efforts focused on improving transparency, addressing data limitations, and strengthening institutional arrangements. Table 10-2 indicate a summary of the Key responses to the TTE review.

Table 10-2: Summary of Responses to the UNFCCC TTE Review

Sector	TTE Recommendation	Malawi's Response and Planned Actions	Reference Chapters	Capacity-Building Needs Identified
General	Establish formal data-sharing agreements for GHG inventory data.	Initial consultations with key agencies completed; formal Memoranda of Understanding (MoUs) under development.	Chapter 1	Training on legal frameworks and inter-agency coordination for data sharing.
	Improve QA/QC procedures in line with IPCC guidelines.	Developing sector-specific QA/QC protocols and piloting automated data consistency checks.	Annex IV	Training on QA/QC methodologies and uncertainty analysis.
	Address time series inconsistencies across reporting years.	Recalculations performed to ensure consistent time series from 1994–2022.	Chapters 2-7	Training on recalculation methods and time series consistency.
Energy	Improve consistency in emissions estimates from coal and biomass combustion.	Revising energy data collection processes and developing country-specific emission factors.	Chapter 3.2	Capacity building on energy sector inventory development.
	Enhance transparency for fugitive methane emissions estimation.	Full documentation of assumptions and data sources initiated.	Chapters 3.3.1	Training on fugitive emissions monitoring and methane leak detection.
Industrial Processes and Product Use (IPPU)	Develop country-specific emission factors for cement and lime production.	Engagement with industry stakeholders initiated; laboratory analyses planned.	Chapter 4.3	Training on GHG accounting frameworks for industrial emissions.

	Improve data availability for fluorinated gases and industrial process emissions.	Strengthened institutional coordination with industry bodies for better data access.	Chapter 4.5	Development of reporting templates and training on fluorinated gases estimation.
Agriculture	Disaggregate livestock emissions by species.	Updated livestock categorization system and collaboration with Ministry of Agriculture underway.	Chapter 5.3.1	Capacity building on livestock sector emissions estimation.
	Develop country-specific emission factors for key crops (e.g., maize, rice, tobacco).	Field research and emission factor development initiated for targeted crops.	Chapter 5.4	Training on agricultural emissions modeling and EF development.
Forestry and Other Land Use (FOLU)	Enhance documentation of forestry and land-use methodologies and assumptions.	Improved land representation and detailed reporting included in inventory annexes.	Chapter 6	Training on IPCC land-use methodologies and field data collection.
Waste	Strengthen data collection systems for wastewater and solid waste management.	Engagements with municipal authorities initiated; national capacity-building workshops planned.	Chapter 7	Training on IPCC methodologies for waste inventories.
	Improve methane recovery reporting from landfill sites.	Assessment of landfill management practices initiated to improve methane capture data.	Chapter 7	Training on waste sector MRV and methane recovery estimation.
Uncertainty and Data Management	Expand and document uncertainty analysis methodologies.	Sectoral uncertainty analysis expanded, with plans for full incorporation in the next submission.	Annex II	Training on statistical methods for uncertainty quantification.
	Develop structured archiving and database systems for	Centralized database development underway to	--	Training on data management and archiving systems.

inventory management.	facilitate data storage and retrieval.
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Monitoring, Reporting and Verification (MRV) System	Strengthen MRV systems for mitigation actions and impacts.	Integration of GHG MRV elements into the National Monitoring and Evaluation Master Plan.	--	Training on MRV frameworks and indicator tracking.
	Develop systems to track financial support for climate initiatives.	Establishment of a reporting mechanism for climate finance tracking underway.	--	Training on climate finance tracking and reporting mechanisms.

Malawi is dedicated to continuously improving its GHG inventory. The country will align its efforts with the latest guidelines and best practices set by the IPCC to ensure high-quality and transparent reporting. Additionally, Malawi will seek further international support and technical assistance to address the capacity-building needs identified during the review process.

10.3 Areas of improvement and/or capacity-building related to the flexibility provisions applied with self-determined estimated time frames for improvements

In accordance with Decision 18/CMA.1, Annex, paragraph 9 and 10, Malawi has applied flexibility provisions in specific areas where capacity constraints persist, as permitted for developing country Parties under the Enhanced Transparency Framework (ETF) of the Paris Agreement. These flexibilities are necessary due to limitations in data availability, institutional arrangements, technical expertise, and resource allocation.

Malawi remains committed to progressively enhancing its national inventory capacity, data quality, methodological rigor, and reporting transparency over time. A self-determined roadmap for addressing capacity gaps and phasing out reliance on flexibility provisions is presented below.

Flexibility was applied mainly in the following areas:

- Use of Tier 1 methodologies across all sectors, particularly where disaggregated national data or country-specific emission factors are lacking.
- Limited disaggregation of fuel types in energy statistics.
- Challenges in compiling key category analysis fully aligned with Approach 2 due to uncertainty quantification constraints.
- Incomplete time series for some activity data, necessitating interpolation or expert judgment.

- Constraints in land representation systems for complete, consistent, and comparable FOLU estimates at Tier 2/3 levels.

A targeted capacity-building plan has been formulated to address these gaps within self-determined timeframes, as outlined in Table 10.3 below:

Table 10-3; Area of flexibilities applied, planned improvement and it's targeted time frame

Area of Flexibility	Current Limitation	Planned Improvement	Target Time Frame
Methodological Tiers	Tier 1 methodologies used across Energy, IPPU, Agriculture, Waste, and FOLU sectors	Gradual transition to Tier 2 for Energy (CO ₂) and IPPU (cement and lime) through national data collection	2027–2028
Disaggregation of Fuel Types	Aggregated liquid fuel and biomass statistics in energy data	Enhance energy balance statistics with MERA, NSO and sectoral reporting collaboration	2026
Key Category Analysis (Approach 2)	Key category analysis mainly based on Approach 1; no full uncertainty-integrated Approach 2 analysis	Strengthen uncertainty data collection and implement Approach 2 by next inventory cycle	2027
FOLU Land Representation	Limited satellite monitoring and periodic land-use survey data; reliance on Tier 1 default factors	Establish Tier 2/3 system using remote sensing, national forest inventories, and geospatial models	2028–2029
Waste Data Systems	Inconsistent urban waste generation and wastewater management data	National standardisation of waste surveys and adoption of IPCC waste model tools	2026–2027
Industrial Process Data	Limited clinker trade data and lack of plant-specific emission factor data for IPPU	Develop sector-specific reporting protocols with major industries (cement, lime)	2027
Agriculture Activity Data	Use of regional default emission factors for livestock and soils	Conduct national livestock survey and fertilizer use studies to update emission factors	2026–2028

Malawi acknowledges that meeting these milestones will depend on the availability of international support, including financial resources, capacity-building initiatives, and technology transfer under Articles 13 and 14 of the Paris Agreement. The country remains committed to continuously improving its national inventory system, ultimately aiming for higher-tier methods, full time series consistency, and broader sectoral coverage in future submissions.

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