GOVERNMENT OF
BOTSWANA

NATIONAL GHG INVENTORY DOCUMENT

BOTSWANA

2000 - 2022

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NID ACRONYMS AND ABBREVIATIONS

AD	Activity Data
AFOLU	Agriculture, Forestry and Other Land Use
AFREC	African Energy Commission
AR5	IPCC Fifth Assessment Report
AWMS	Animal Waste Management System
BFDM	Botswana Forest Distribution Map
BOD	Biological Oxygen Demand
BPC	Botswana Power Cooperation
BR	Botswana Railways
BTR	Biennial Transparency Report
BUAN	Botswana University of Agriculture and Natural Resources
BUR	Biennial Update Report
C	Confidential (notation key)
CH_4	Methane
CMA	Conference of the Parties serving as the Meeting of the Parties to the Paris Agreement
CMS	Central Medical Stores
CO	Carbon Monoxide
CO_2	Carbon Dioxide
CO_2 eq	Carbon Dioxide equivalent
COD	Chemical Oxygen Demand
CRT	Common Reporting Tables
DAP	Department of Animal Production
DEP	Department of Environmental Protection
D	Default value for emission factors
DFRR	Department of Forestry and Range Resources
DMS	Department of Meteorological Services
DoE	Department of Energy
DOC	Degradable Organic Compound

DOM	Dead Organic Matter
DVS	Department of Veterinary Services
EF	Emission Factor
ES	Executive Summary
ETF	Enhanced Transparency Framework
FAOSTATS	Food and Agricultural Organization Statistics Database
FR	Forest Reserve
FRA	Forest Resource Assessment
FOD	First Order Decay
GDP	Gross Domestic Product
GEE	Google Earth Engine
GEF	Global Environment Facility
Gg	Gigagram
GHG	Greenhouse Gas
GoB	Government of Botswana
GR	Game Reserve
GWP	Global Warming Potentials
HFC	Hydrofluorocarbons
HWP	Harvested Wood Products
IE	Included Elsewhere (notation key)
IEA	International Energy Agency
IPCC	Intergovernmental Panel on Climate Change
IPPU	Industrial Processes and Product Use (sector)
ISPAAD	Integrated Support Programme for Arable Agriculture Development
JICA	Japan International Cooperation Agency
KBL	Kgalagadi Breweries Limited
kt	Kilotonne
LULUCF	Land Use, Land-Use Change and Forestry (sector)
MCF	Methane Conversion Factor

MDA	Ministries, Departments and Agencies
MET	Ministry of Environment and Tourism
MODIS	MODerate Resolution Imaging Spectroradiometer
MOU	Memorandum Of Understanding
MPG	Modalities, Procedures and Guidelines for the Enhanced Transparency Framework of the Paris Agreement
MSW	Municipal Solid Waste
N_2O	Nitrous Oxide
NA	Not Applicable (notation key)
NARDI	National Agricultural Research and Development Institute
NC	National Communication
NCCC	National Climate Change Committee
NCV	Net Calorific Value
NDC	Nationally Determined Contributions
NE	Not Estimated (notation key)
NF_3	Nitrogen Trifluoride
NFI	National Forest Inventory
NFMS	National Forest Monitoring System
NFS	National Forest Survey
NGHGI	National Greenhouse Gas Inventory
NID	National Inventory Document
NIR	National Inventory Report
NLDSR	National Land Degradation Status Report
NMVOC	Non-Methane Volatile Organic Compound
NO	Not Occurring (notation key)
NO_x	Nitrogen Oxides
NOU	National Ozone Unit
NP	National Park
NPK	Nitrogen, Phosphorous and Potassium
ODS	Ozone Depleting Substances

PFC	Perfluorocarbons
QA/QC	Quality Assurance and Quality Control
RA	Reference Approach
SA	Sectoral Approach
SAR	IPCC Second Assessment Report
SB	Statistics Botswana
SF_6	Sulphur Hexafluoride
SO_x	Sulphur Oxides
SSA	Sub-Saharan Africa
SWDS	Solid Waste Disposal Site
T1, T2, T3	Methodological Tiers; Tier 1, Tier 2 and Tier 3
TERT	Technical Expert Review Team
TJ	Tera Joule
TN	Total Nitrogen
TOW	Total Organics in Wastewater
UB	University of Botswana
UNDP	United Nations Development Program
UNEP	United Nations Environment Program
UNFCCC	United Nations Framework Convention on Climate Change
UPOPs	Unintentional Persistent Organic Pollutants
VS	Volatile Solids
WMA	Wildlife Management Area
WUC	Water Utilities Corporation

ACKNOWLEDGEMENTS AND KEY MESSAGE

The Ministry of Environment and Tourism extends its sincere appreciation to all individuals and institutions whose contributions were vital to the preparation of the 2022 National Inventory Report.

Foremost, the Ministry recognises the dedication and technical expertise of the National Greenhouse Gases Inventory (NGHGI) Team. Their tireless efforts in data collection, analysis, and documentation were fundamental to the successful completion of this report.

We are grateful to the United Nations Development Programme (UNDP) Botswana Office for its continuous guidance and technical oversight, which ensured the report adheres to international standards. The Ministry also acknowledges the Global Environment Facility (GEF) for its essential financial and technical support, which has been instrumental in strengthening national capacities to meet our reporting obligations under the United Nations Framework Convention on Climate Change (UNFCCC).

Furthermore, we appreciate the collaboration of various government ministries, state-owned enterprises, and private sector entities across the Energy, Industrial Processes, Agriculture, Forestry and Other Land Use, and Waste sectors. Their willingness to provide activity data and expert input was crucial to the integrity of this inventory.

Finally, we thank all stakeholders who participated in the review process, as their feedback significantly enhanced the quality and transparency of this submission.

EXECUTIVE SUMMARY

E.S.1. Background Information on GHG Inventories and Climate Change

This is a submission of Botswana's national greenhouse gas (GHG) inventory for the year 2022. The report includes GHG trends for the period 2000 to 2022. It is compiled in accordance with the guidelines provided by the United Nations Framework Convention on Climate Change (UNFCCC), the Paris Agreement's Modalities Procedures and Guidelines (MPGs), the 2006 Intergovernmental Panel on Climate Change (IPCC) Guidelines for National GHG Inventories (IPCC, 2006) and the 2019 Refinement to the 2006 IPCC Guidelines (IPCC, 2019). The report provides an explanation of the methods (Tier 1 approach), activity data and emission factors used to develop the inventory. In addition, it assesses the uncertainty and describes the quality assurance and quality control (QA/QC) activities.

National GHG Inventories and Climate Change

Botswana joined the United Nations Framework Convention on Climate Change (UNFCCC) by signing the agreement in 1992 and completing its ratification in 1994. Under this framework Botswana is mandated to develop, publish, and periodically update detailed national greenhouse gas inventories. The country is also required to control climate change by monitoring and controlling anthropogenic greenhouse gas emissions. Botswana is also a signatory to the Paris Agreement which prescribes the Modalities, Procedures and Guidelines (MPGs) for reporting to the UNFCCC.

The process of national GHG reporting began with the Initial National Communication (INC) in 2001, which established the first baseline inventory for 1994, followed by the Second National Communication (SNC) in 2011, which updated the data to the year 2000. Detailed inventories for the years 2014 and 2015 were prepared during concurrent development of the Third National Communication (TNC) and the First Biennial Update Report (BUR1), both submitted in 2019. The current National Inventory Report of 2022 provides the latest GHG emissions update and contributes to Botswana's first Biennial Transparency Report (BTR1) and Fourth National Communication (4NC).

E.S.2. Summary of Trends Related to National Emissions and Removals

Trend in Aggregated GHG Emissions

In 2022, the emissions (excluding Land Use Land-Use Change and Forestry (LULUCF) sector contribution) were estimated at 11790.67 Gg CO_2 eq, an increase of 24.19% compared to 2000 (9,494.03 Gg CO_2 eq). Figure ES-2, illustrates the trend of emissions from 2000 to 2022 for the total national emissions (excluding LULUCF) and the trends of the individual sectors for the same time series. The energy sector emissions increased from 3952.55 Gg CO2 equivalent in 2000 to 7805.33 Gg CO2 equivalent in 2022. Agriculture sector emissions declined from 3537.39 Gg CO2 equivalent in 2000 to 1935.78 Gg CO2 equivalent in 2022. The IPPU sector emissions decreased from 1768.43 Gg CO2 equivalent in 2000 to 1689.78 Gg CO2 equivalent in 2022. The waste sector maintained a trend just below 400 Gg CO2 equivalent for the entire time series.

In 2022, the Energy sector dominated Botswana's gross emissions (excluding LULUCF), accounting for 66.20% of the national total. The remaining emissions were attributed to Agriculture (16.42%), IPPU (14.33%), and Waste (3.06%), respectively (Figure ES-1).

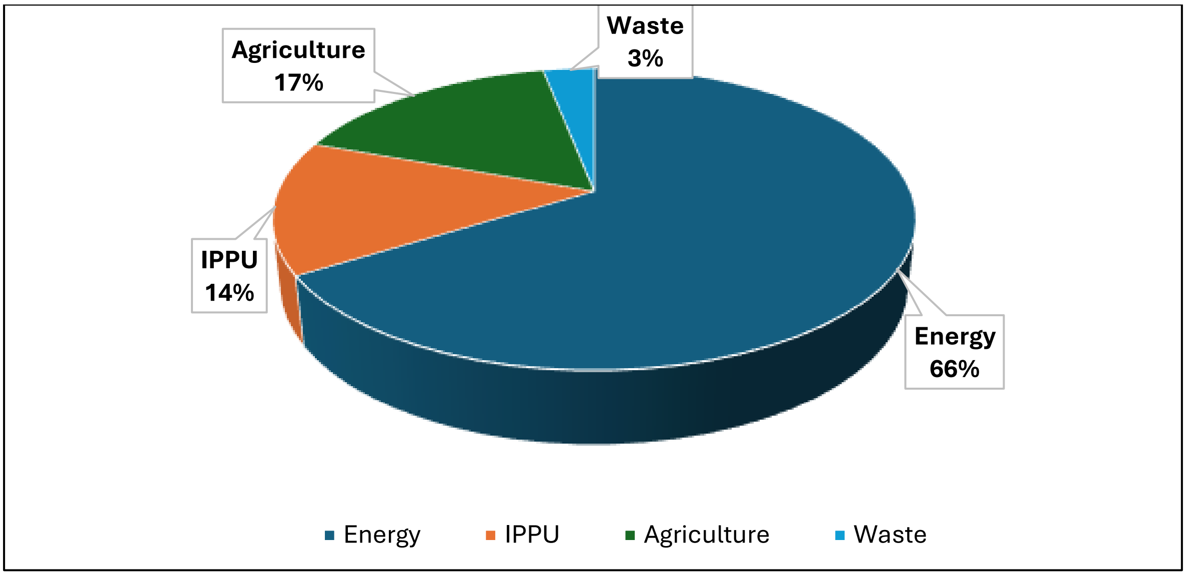

Figure.ES-1: Percent contribution to total national emissions by sector (excluding LULUCF) - 2022

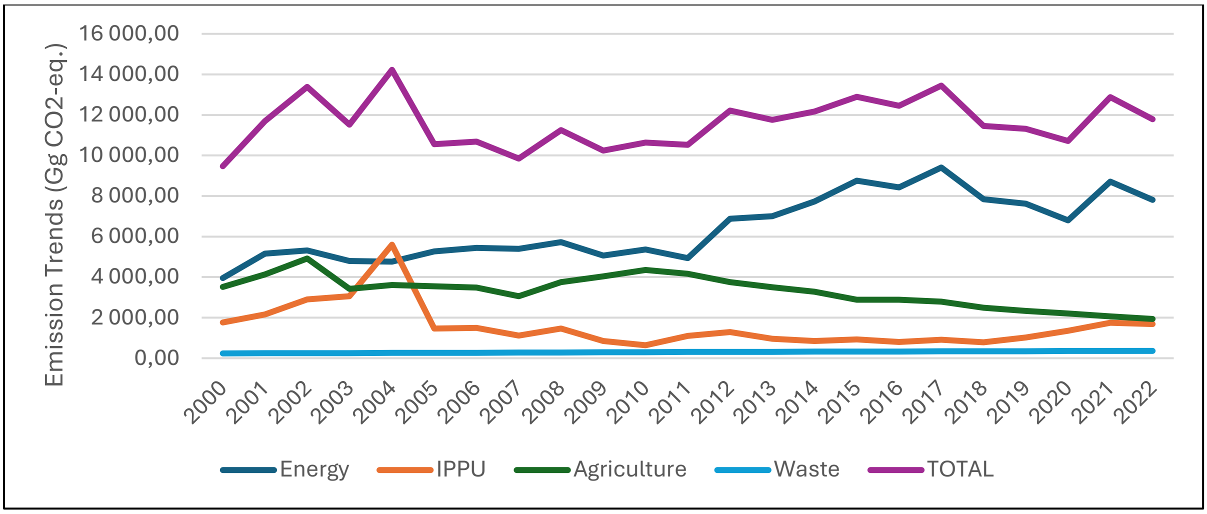

Figure.ES-2: Trend in total national emissions (excluding LULUCF) 2000 - 2022

Figure ES-3 below, illustrates the trend of emissions by greenhouse gas in the time series 2000 – 2022. Carbon dioxide gas emissions increased from 5489.28 Gg CO2 in 2000 to 8897.82 Gg CO2 in 2022. Methane emissions decreased from 2699.05 Gg CO2 eq in 2000 to 2099.39 Gg CO2 eq in 2022. Nitrous oxide emissions remained below 1500 Gg CO2 eq for the entire time series. Hydrofluorocarbons (HFCs) emissions remained below 25 Gg CO2 eq for the time series.

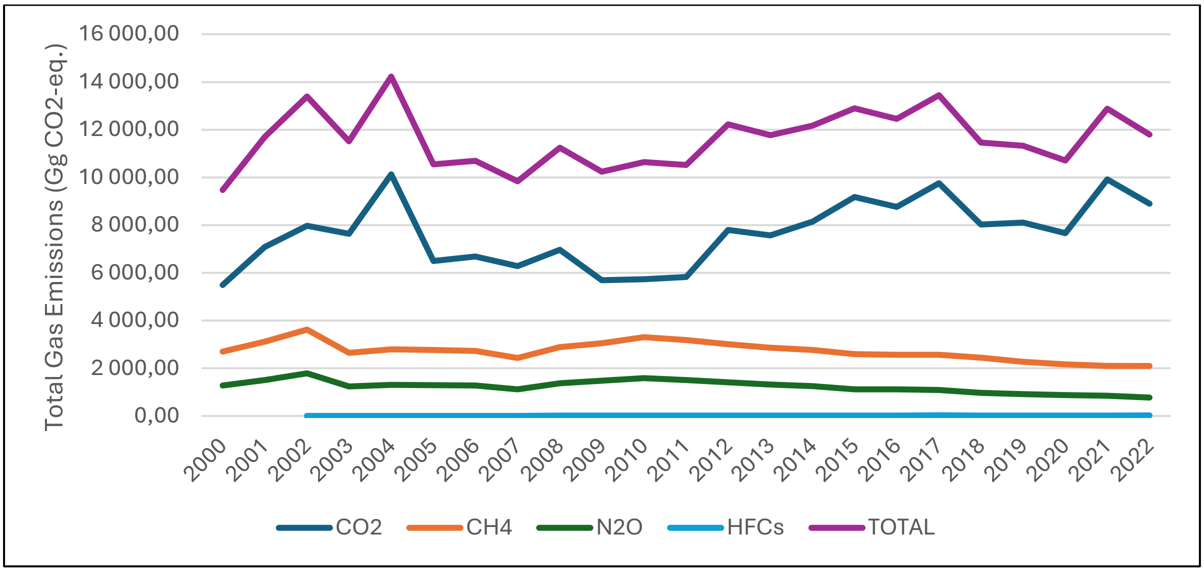

Figure.ES-3: Trend in total emissions by Gas (excluding LULUCF) 2000 - 2022

Trend in GHG Intensity Indicators

There is an obvious decline in emissions per capita and per GDP calculated in local currency (BWP). The figure below shows the trends in GHG emissions per capita and per GDP for the years 2000 to 2022. The per capita emissions do not show a lot of variability. Per capita emissions dropped from 5.65 Tonnes CO2 equivalent in 2000 to 5.00 Tonnes CO2 equivalent in 2022. The emissions per GDP dropped significantly from 301.22 Tonnes CO2 equivalent in 2000 to 46.91 Tonnes CO2 equivalent in 2022. The figure below illustrates the trends in greenhouse gas intensity indicators.

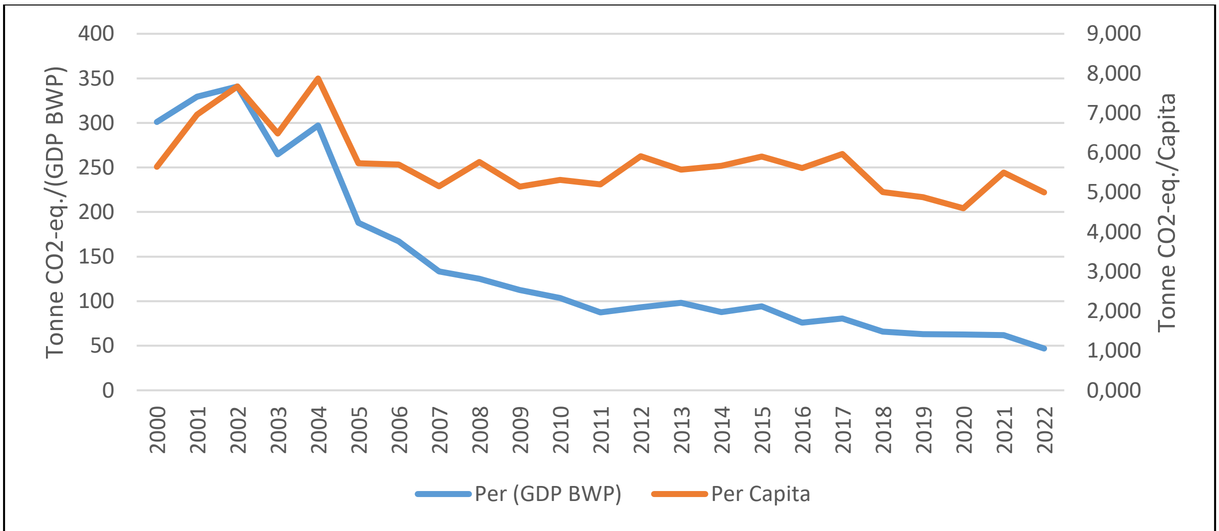

Figure.ES-4: Trend in Total emissions per Capita and per GWP (excluding LULUCF) 2000 - 2022

E.S.3. Overview of Source and Sink Category Emission Estimates and Trends

Energy (CRT 1)

In 2022 the energy sector emitted 7,804.32 Gg CO_2-equivalent, of which fuel combustion contributed 7,299.26 Gg CO_2-eq (93.5%) and fugitive emissions 505.03 Gg CO_2-eq (6.5%). By gas, CO_2 dominated at 7,224.61 Gg CO_2-eq (≈92.6%), methane at 530.15 Gg CO_2-eq (≈6.8%) and N_2O at 49.56 Gg CO_2-eq (≈0.6%). Total energy-sector emissions rose markedly from 3,758.25 Gg CO2-eq in 2000 to 7,299.29 Gg CO_2-eq in 2022 — an increase of 3,541.04 Gg CO_2-eq (94.2%) — with a peak of 8,340.38 Gg CO_2-eq in 2015; 2022 thus represents a 12.5% decline from that peak. Overall, while recent totals are below the 2015 high, 2022 emissions remain substantially above the 2000 baseline.

Industrial Processes and Product Use - IPPU (CRT 2)

Emissions from the IPPU sector in 2022 were 1689.78 Gg $C0_2$ eq. The main contributors were Non-Energy Products from Lubricants and Solvent use (888.93 Gg CO_2 eq.) and Soda Ash Production (777.73 Gg CO_2 eq.). Both subcategories are sources of carbon dioxide emissions. There were emissions from Product Uses as Substitutes for Ozone Depleting Substances (ODS), which amounted to 23.12 Gg CO_2 eq. These are Hydrofluorocarbons (HFCs) from refrigeration and air conditioning. Carbon dioxide emissions account for 98.8% of the sector's total emissions while HFCs account for 1.2% of the sector's emissions for the inventory year 2022. Emissions from this sector dropped by 4.5% from the year 2000 to 2022. However, emissions increased by 82.6% between 2015 (previous inventory year) and 2022.

Agriculture (CRT 3)

The total greenhouse gas emissions from the agriculture sector (CRT 3) in 2022 were 1 935.78 Gg CO_2eq. Agriculture is the second-largest GHG emitting sector in Botswana after the energy sector. Majority of the sector emissions were from enteric fermentation (61.79%), agriculture soils (34.6%) and manure management (3.22%). The main agricultural GHG emitted were methane (64.2%), nitrous oxide (35.7%) and carbon dioxide (0.1%). The emissions from the sector have decreased by 45.27% since 2000. The reduction is attributable to livestock reduction over the years especially other cattle. The period between 2021 and 2022, emissions from the sector decreased by 6.199% due to declining livestock populations.

Land Use, Land-Use Change and Forestry (CRT 4)

The LULUCF sector remained a net sink with a total of -73 642.068 Gg CO_2 eq in 2022. Forest lands amounting to -73 866.304 Gg CO_2 eq, being the largest contributor to the removals. The harvested wood products contributed -98.813 Gg CO_2 eq. Cropland removals were -88.847 Gg CO_2 eq while Biomass burning added emissions of 413.806 Gg CO_2 eq. The smallest sequestration was from the grasslands (-1.086 Gg CO_2 eq). The sector drove the national total emissions in 2022 to -61 851.15 Gg CO_2 eq, resulting in an overall national sink.

Waste (CRT 5)

Total emissions from the Waste sector for the year 2022 were 344.33 Gg CO2eq. Majority of the Waste sector emissions are from solid waste, accounting for 46.57% (160.36 Gg CO2eq) of the emissions, followed by Wastewater Treatment and Discharge accounting for 36.20% (124.63Gg CO2eq) while emissions from Incineration and Open Burning of Waste contributed

17.26% (59.46 Gg CO2eq). Total emissions were 344.33 Gg CO2eq for the inventory year 2022.

The Biological treatment of solid waste was not estimated due to lack of activity data in Botswana.

Solid waste disposal emissions have increased by 69% since 2000. Incineration and open burning of waste emissions increased by 47.1% since 2000, while emissions from Wastewater treatment and discharge increased by 36.20%.

Emissions from all waste categories have increased since the year 2000. Waste Sector emissions have increased by 52.23%.

E.S.5. Analysis of Key Categories

Key categories by level and trend excluding the land category are listed in the following table. Top three categories are from the energy sector. They are then followed by enteric fermentation from the agriculture sector. These are the most significant sources of greenhouse gas emissions in the inventory.

Table ES-1: Inventory Key Categories excluding the land category by level and trend.

CRT Code	CATEGORY	GHG	L,T	Cumulative Total
1.A.1	Energy Industries - Solid Fuels	CO_2	L,T	0,299172549
1.A.3.b	Road Transportation - Liquid Fuels	CO2	L,T	0,494054264
1.A.4	Other Sectors - Liquid Fuels	CO2	L,T	0,595543972
3.A.1	Enteric Fermentation	CH_4	L,T	0,695622578
2.D	Non-Energy Products from Fuels and Solvent Use	CO_2	L,T	0,769944283
2.B.7	Soda Ash Production	CO_2	L,T	0,835017363
3.C.4	Direct N2O Emissions from managed soils	N_2O	L,T	0,890526033
1.B.1.a	Coal mining and handling	CH_4	L,T	0,932629797
4.G	Harvested Wood Products	CO_2	L,T	0,947505247

L = Level Assessment, **T** = Trend assessment

E.S.6. Improvements Introduced

- Botswana has complied with the Modalities, Procedures and Guidelines (MPGs) by adopting the 2006 IPCC guidelines including the 2019 refinements.
- The emissions have been aggregated using the Global Warming Potentials (GWP) of the IPCC Fifth Assessment Report (AR5) to comply with the MPGs.
- Inclusion of the sub-categories of Lubricant and Paraffin Wax Use in the IPPU sector.
- Uncertainties have been assessed per category basis in the Energy, IPPU, Agriculture and Waste sectors as required by the MPGs.
- Key structural changes include splitting Agriculture and LULUCF into separate chapters to comply with the MPGs.
- All non-CO2 emissions from biomass burning associated with other land categories (Forest land, Grassland, Wetland, and Settlement) have been removed from the agriculture sector and are now included under the LULUCF sector.
- In the last inventory (2014/2015) emissions from manure management, and Direct and indirect N2O emissions from managed soils were not estimated, but in 2022 inventory the aforesaid have been incorporated.
- In 2022 inventory, the IPCC default weight of the other cattle (275 Kg) is used, which is more than the weight used in the previous Tier 1 inventory (173 Kg).
- The current inventory includes emissions from open burning of waste (4.C.2 - Open Burning of Waste)
- The current inventory as per the 2006 IPCC guidelines considered the whole population data for Botswana dating back to 1950 to cater for the FOD model.

- In the previous inventory, waste emissions were calculated using a default waste generation rate of 290.0 kg/capita/year (IPCC, 2006), whilst the current inventory used country-specific waste generation rate of 99.519 kg/capita/year which is less than IPCC default.

1. NATIONAL CIRCUMSTANCES, INSTITUTIONAL ARRANGEMENTS AND CROSS-CUTTING INFORMATION

1.1. Background information on GHG inventories and climate change

1.1.1. Climate Change

Botswana formally committed to the United Nations Framework Convention on Climate Change (UNFCCC) by signing the agreement in 1992 and completing its ratification in 1994. As a Party to the Convention, Botswana is mandated to take decisive action against climate change, which includes the rigorous monitoring of anthropogenic greenhouse gas emission trends.

A primary obligation under this international framework is the development, publication, and periodic updating of detailed national greenhouse gas inventories. Beyond tracking emissions, Botswana is also committed to the protection and enhancement of carbon sinks and reservoirs—specifically its forest ecosystems—while implementing comprehensive strategies to support both national and regional climate change adaptation and mitigation efforts.

1.1.2. National Greenhouse Gas Inventories

Botswana's production of National GHG Inventory reports has evolved from isolated snapshots into a comprehensive, multi-year reporting framework designed to meet increasing international standards. The process began with the Initial National Communication (INC) in 2001, which established the first baseline inventory for 1994, followed by the Second National Communication (SNC) in 2011, which updated the data to the year 2000. A significant advancement in technical depth occurred with the concurrent development of the Third National Communication (TNC) and the First Biennial Update Report (BUR1), both submitted in 2019. These reports provided a detailed inventory for the years 2014 and 2015 as part of a continuous 2000–2015 time series and marked Botswana's formal transition from the 1996 to the 2006 IPCC Guidelines. Currently, Botswana is finalizing its First Biennial Transparency Report (BTR1) and an updated National Inventory Report (NIR), which extends the analysis up to 2022 to fulfil the mandatory requirements of the Paris Agreement's Enhanced Transparency Framework (ETF).

1.2. Description of National Circumstances and Institutional Arrangements

1.2.1. National Circumstances

Botswana is a landlocked, semi-arid country in Southern Africa with a land area of 581,730 km². Its climate and geography significantly influence its emission profile, particularly through high solar radiation and structural aridity. As of the 2022 Population and Housing Census, the national population reached 2,359,609, with an urbanization rate of 66.5% (Statistics Botswana, 2022).

Economically, Botswana is an Upper Middle-Income Country (World Bank, 2022). While the economy is historically anchored by diamond mining, the government is currently implementing the Vision 2036 strategy to transition toward a high-income, sustainable, and knowledge-based economy (Vision 2036 Council, 2016). The dependency on the mining sector, particularly diamonds, significantly influences national energy consumption and the GHG emission profiles. In the third quarter of 2025, the nominal Gross Domestic Product was estimated at P67, 538.5 million. This follows a second-quarter nominal GDP of P69, 620.9 million, indicating a period of significant economic activity despite volatility in global mineral markets (Statistics Botswana, 2025a; 2025b). As of late 2025, the Public Administration and Defence sector emerged as a leading contributor to the GDP (18.2%), followed by Wholesale and Retail Trade (12.3%) and Mining and Quarrying (11.9%). On the other hand, the nominal GDP per capita was recorded at P104, 598.33 at the end of 2024, reflecting the country's high-income status relative to the regional average (Statistics Botswana, 2025c).

Implications for GHG inventory: The structure of Botswana's GDP has direct implications for its carbon footprint. The Mining and Quarrying sector is energy-intensive and remains a primary consumer of electricity and fossil fuels. Additionally, the Transport and Storage sector, which grew by 5.2% in the third quarter of 2025, represents a significant and growing source of mobile combustion emissions (Statistics Botswana, 2025b). These economic drivers necessitate robust institutional arrangements for tracking emissions to ensure alignment with national climate targets and international reporting obligations.

In 2015, Botswana's total national greenhouse gas emissions (excluding the LULUCF sink) were estimated at 10,309 Gg CO_2eq (Government of Botswana, 2019). The following sectors were identified as the primary contributors to the national profile:

Energy Sector (Stationary Combustion): Total emissions for the energy sector were recorded at 8,336.95 Gg CO_2eq, representing the largest share of national emissions at approximately 81% (excluding AFOLU). The primary driver was the combustion of domestic coal for centralized power generation, specifically through the Morupule B power station (Government of Botswana, 2019). Botswana's energy supply remains heavily dependent on domestic coal, which accounts for approximately 97-99% of the electricity generation mix, primarily through the Morupule B power station (IEA, 2023). This reliance on fossil fuels for base-load power remains the largest contributor to national CO2 emissions. However, 2022 marked a strategic pivot with the commissioning of the country's first utility-scale solar plant, aligned with the goal to reach 50% renewable energy penetration by 2036 (Ministry of Minerals and Energy, 2022).

Agriculture, Forestry, and Other Land Use Sector (AFOLU): Gross emissions from the AFOLU sector reached 2,803.01 Gg CO_2eq. Within this sector, enteric fermentation from livestock, particularly the national cattle herd, was the most significant source of methane (CH_4), contributing to roughly 12% of total national emissions when excluding LULUCF removals (Government of Botswana, 2019; Statistics Botswana, 2021). Emissions are driven by extensive livestock production, which is a cornerstone of the rural economy. Enteric fermentation from the national cattle herd is the primary sub-sector source. While the cattle population has seen fluctuations due to climate-induced droughts, it remains a significant pillar of the national GHG profile (FAOSTAT, 2022).

Transport Sector (Mobile Combustion): As a critical sub-category of the energy sector, transport accounted for approximately 2,429.52 Gg CO_2eq. Road transport was the overwhelming driver, responsible for over 98% of sectoral emissions due to the consumption of imported liquid fossil fuels (Government of Botswana, 2019). The transport sector has emerged as a critical and rapidly growing source of emissions, accounting for approximately 18% of national energy-related emissions (Climate Analytics, 2023). In 2022, there were 601,081 licensed vehicles in Botswana, with road transport being the dominant mode of travel and freight (Statistics Botswana, 2023). The sector is almost entirely powered by imported petroleum products, making it a priority for mitigation through the proposed Integrated Transport Policy, which encourages a shift toward public rail and bus systems to reduce urban carbon intensity.

1.2.2. Institutional Arrangements (I.A)

Botswana's GHG inventory is managed by the Department of Meteorological Services in its capacity as the UNFCCC National Focal Point, with oversight from the National Committee on Climate Change (NCCC). This collaborative framework ensures the systematic preparation of inventories required for National Communications and Biennial Transparency Reports. Current efforts are directed toward strengthening these arrangements to improve the overall quality and accuracy of national climate data.

The development of the national GHG inventory utilizes a multi-sectoral framework, integrating expertise from government departments, research institutions, and international partners. At the core of this process is the National GHG Inventory Team, a technical body that has been progressively expanded to enhance the practical compilation of data. Led by an Inventory Coordinator, the team is organized by sector, Energy, IPPU, Agriculture, LULUCF, and Waste, with designated Sector Leads and technical experts responsible for data acquisition and verification. This structure, comprised of representatives from various Ministries, Departments, and Agencies (MDAs), ensures comprehensive coverage of the economy, while a dedicated QA/QC Coordinator maintains rigorous quality standards throughout the inventory cycle.

To facilitate the data collection process, the National Focal Point issues formal letters of introduction to team members, granting them the necessary authorization to engage with data providers. Statistics Botswana, the custodian of official statistics, serves as the primary source for activity data. The agency produces environment statistics digests that contain essential data for GHG estimation. Furthermore, Statistics Botswana has established Memoranda of Understanding (MoUs) with various Ministries, Departments, and Agencies (MDAs) to formalize and streamline data-sharing protocols.

Data collection is a cross-sectorial effort involving multiple ministries and departments that provide activity data for their specific sectors. These include:

- Energy sector: Ministries dealing with energy and transport provide data on fuel combustion and other energy-related emissions.
- Agriculture and land use: Departments managing livestock, farming, and land provide data on enteric fermentation, manure management, and land-use changes.
- Research and academic institutions: The University of Botswana, BUAN, and other research entities provide technical expertise, especially in areas like atmospheric physics. International partners and initiatives have also helped build national capacity in specific sectors, such as livestock emissions.
- International partners: The country has received support from international organizations to strengthen its GHG inventory system and transparency (UNDP, UNEP, UNFCCC)

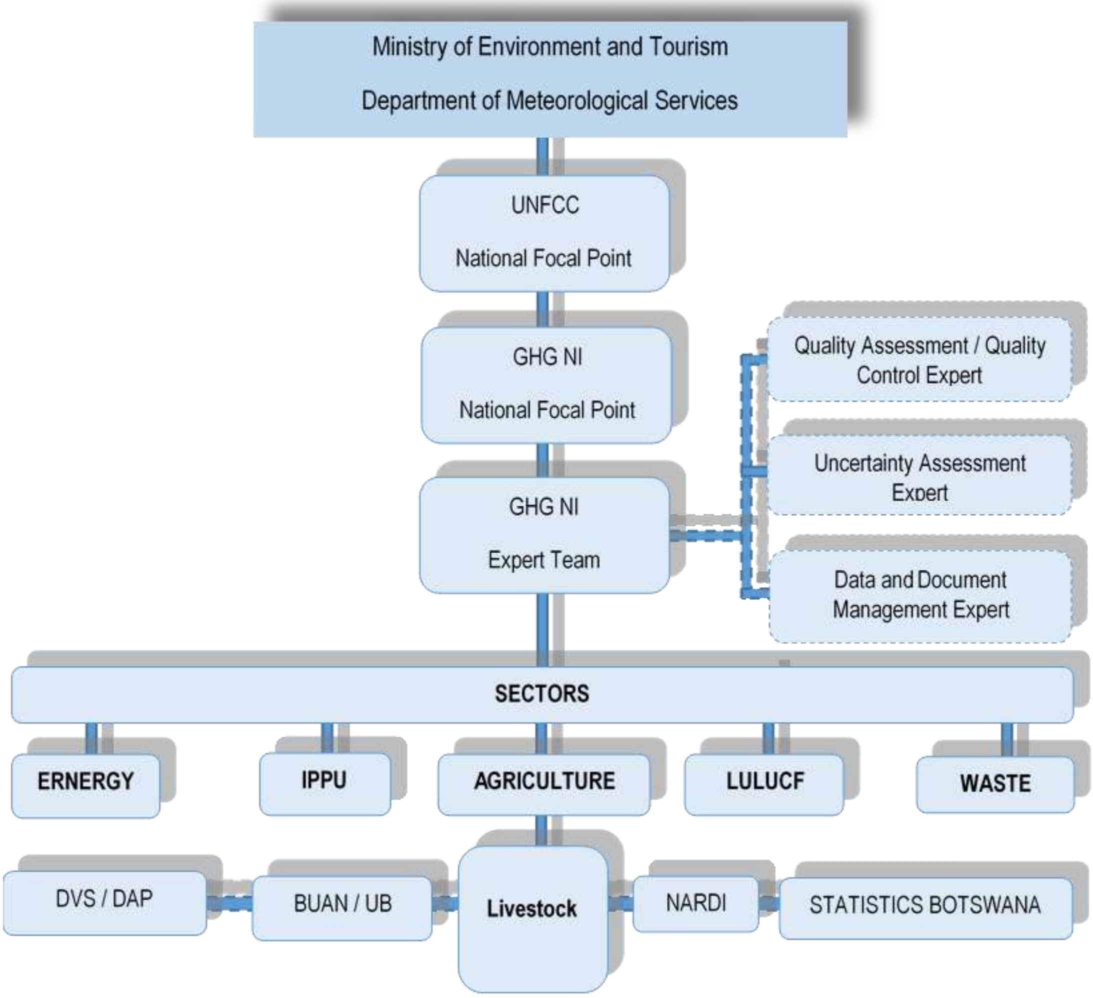

Figure.1-1: Institutional Arrangements for the National GHG Inventory for Botswana

1.2.3. National Entity or National Focal Point

The Department of Meteorological Services (DMS) serves as the national focal point for the UNFCCC on behalf of the Ministry of Environment and Tourism (MET). It houses the office of the National Climate Change Coordinator, who oversees all the inventory preparation and reporting to the UNFCCC.

1.2.4. Inventory Preparation Process

Botswana's greenhouse gas (GHG) inventory cycle was initiated by formalizing governance structures, which involved defining the specific duties of the Inventory and QA/QC Coordinators, Sector leads, and establishing data-sharing requirements for focal points in all sectors (Energy, IPPU, Agriculture, LULUCF, and Waste).

Once planning was completed, the process transitioned to data gathering and harmonization of activity data collected, reconciling sector activity data using IPCC recommended methods to rectify historical data gaps (e.g., using sectoral and approaches under the energy sector). These inputs were subsequently processed using the latest 2006 IPCC Inventory Software, using default Tier 1 methods. Technical integrity was maintained through the QA/QC

Coordinator's execution of internal audits and uncertainty evaluations. The cycle culminated in the development of the National Inventory Document (NID). The Common Reporting Tables (CRTs) are generated utilising the interoperability function of the 2006 IPCC software and the UNFCCC reporting tables tools. The process is followed by a stakeholder validation process that ensured the inventory accurately reflected Botswana's complete GHG estimates.

1.2.5. Archiving of Information

A structured archiving framework, informed by 2006 IPCC Inventory Software and EPA's Inventory Management Plan (IMP) guidance, was implemented to secure data across servers at the Department of Meteorological Services and Statistics Botswana for long-term reliability.

1.2.6. Processes for Official Consideration and Approval of Inventory

The official approval of Botswana's National GHG Inventory follows a multi-tiered cycle designed to ensure data integrity and national ownership, beginning with technical compilation by the National Inventory Team under the guidance of the Department of Meteorological Services (DMS). The process moves through internal Quality Control (QC) by designated coordinators and Quality Assurance (QA) by the National Climate Change Committee (NCCC) to provide inter-ministerial oversight. Following a formal international review by the UNFCCC, the reports are submitted to the Minister of Environment and Tourism for high-level executive sign-off, which serves as the final authorization before the inventory is officially submitted to the UNFCCC Secretariat.

1.3. General description of methodologies and data sources

1.3.1. Data Sources

Energy Sector

The main sources of data for the Energy sector are the energy balance data compiled by International Energy Agency (IEA) and African Energy Commission (AFREC). Data from coal production from Morupule Coal Mine, as well as data on consumption of diesel for locomotives were also considered. Table 1-1 below data sources for the energy sector.

Table 1-1: Data sources for the energy sector

Sub-category	Activity Data	Activity data sources
	1.A.1 - Energy Industries	
1.A.1.a - Main Activity Electricity and Heat Production	Fuel consumption for electricity generation: • Other Bituminous Coal • Gas Diesel/Oil	IEA & AFREC (energy balance) Matshelagabedi Power Station operated by BPC
	1.A.3 - Transport	
1.A.3.a - Civil Aviation	Jet kerosene, Aviation Gasoline, Other Kerosene, Residual Fuel Oil	IEA & AFREC (energy balance)
1.A.3.b - Road Transportation	Diesel/Petrol	IEA & AFREC (energy balance)
1.A.3.c - Railways	Diesel	Botswana Railways (BR)
	1.A.4 - Other Sectors	
1.A.4.a - Commercial/Institutional	Gas/Diesel oil, LPG, Other Bituminous Coal	IEA & AFREC (energy balance)
1.A.4.b - Residential	Gas/Diesel oil, LPG, Other Bituminous Coal	IEA & AFREC (energy balance)

Sub-category	Activity Data	Activity data sources
1.A.4.c – Agriculture /Forestry /Fishing /Fish Farms	Gas/Diesel oil, LPG	IEA & AFREC (energy balance)
	1.B.1 - Solid Fuels	
1.B.1.a - Coal mining and handling	Coal produced	Statistics Botswana

IPPU Sector

The data sources for the IPPU were mainly from Statistics Botswana through International Merchandise Trade Statistics Unit, particularly imports of F-Gases (HFCs), and Non-Energy use products (lubricants and paraffin wax). Botswana Ash (BOTASH) provided on amount of Trona used. (Table 1-2)

Table 1-2: Data sources for the IPPU Sector

Sub-category	Activity Data	Activity data sources
Soda Ash production	Amount trona produced	Botswana Ash (BOTASH)
Non-Energy use products: • lubricants • paraffin wax	Consumption based on imports statistics: • lubricants • Paraffin wax	Statistics Botswana through International Merchandise Trade Statistics Unit
Refrigeration and stationary air conditioning	Imports of F-Gases (HFCs)	Statistics Botswana through International Merchandise Trade Statistics Unit

Agriculture Sector

The main sources of data for Agriculture sector is Statistics Botswana-Agriculture Statistics Unit, which provided data on population of livestock particularly from Agricultural censuses and surveys. Fertilizer and liming data were sourced from Statistics Botswana through International Merchandise Trade Statistics Unit. Data on manure management practices were sources 2019 IPCC Refinements. Table 1-3 provides main data sources for Agriculture sector.

Table 1-3: Data sources for the Agriculture sector

Sub-category	Activity Data	Activity data sources
Livestock (Population)	• Livestock population data (Cattle, sheep, Goats, horses, mules & asses, and swine)	Statistics Botswana-Agriculture Statistics Unit (censuses and surveys)
Livestock (Manure management)	• Manure management systems by livestock type	2019 IPCC Refinements and Expert knowledge
Aggregated & non-CO2 emissions from land	• Liming (dolomite) and urea data (imports) • Fertilizer data (NPK- in-organic/synthetic fertilizers)	Statistics Botswana through International Merchandise Trade Statistics Unit

LULUCF Sector

For the LULUCF sector, data for the sub-categories were sourced from various sources, including Land use transition information derived from FAO, as well as area burnt obtained from the Department of Forestry and Range Resources (DFRR). Harvested wood products (HWP) data were obtained from FAO. (Table 1-4)

Table 1-4: Data sources for the LULUCF sector

Sub-category	Activity Data	Activity data sources
All land types (Forest land, Cropland, Grassland, wetland, Settlements, Other land)	• Land use/cover transition information • Linear interpolation and extrapolation of land cover transitions • Burnt area data	PRAIS4 Report by UNCCD in collaboration with FAO Department of Forestry and Range Resources (DFRR)
Harvest wood products	Production, import/export data	FAOStat (online)

Waste Sector

The main data providers for the Waste sector include Statistics Botswana, Department of Primary Health-Ministry of Local Government and Rural Development, World Bank and published literature on waste management in Botswana. Table 1-6 provides main data sources for the waste sector.

Table 1-5: Data sources for the Waste sector

Sub-category	Activity Data	Activity data sources
Solid waste disposal	• Population data • Waste generation rate (MSW) • GDP	Statistics Botswana- Population and Housing Censuses World Bank & Statistics Botswana (GDP- data)
Open burning of waste	• Population data • Fraction of population burning waste	Statistics Botswana- Population and Housing Censuses UNITAR- source for fraction of population burning waste
Wastewater treatment and discharge	• BOD discharge • Degree of utilisation (fraction of people) • Per capita nitrogen generation rate • Industry Sector(Meat & Poultry): total industry product	IPCC 2006 FAOStat & interpolation and compound annual growth rate

1.3.2. Methodologies

Methodological approaches for each specific category are summarized within the sectoral overview sections of their respective chapters, with more comprehensive technical descriptions available in the dedicated category-level chapters. The GHG inventory employed a Tier 1 methodology, which relies on default emission factors from the IPCC Guidelines.

1.4. Description of key categories

The inventory key categories (excluding land categories) by level and trend are listed in Table 1-6. The energy categories of Energy industries, Road Transportation and Other Sectors are top of the key category list. Enteric Fermentation from the Agriculture sector is also a key category. These are the most significant sources of greenhouse emissions in the inventory.

However due to lack of disaggregated activity data and country specific parameters, these categories are estimated using the Tier 1 methodology. Qualitatively, if we include the land categories in the key category analysis we note that the land categories are also key in the inventory. They significantly provide a sink of the greenhouse gases in the inventory.

Table 1-6: An Overview of Botswana's Key Categories for 2000 to 2022 (excluding land categories)

CRT Code	CATEGORY	GHG	L,T	Cumulative Total
1.A.1	Energy Industries - Solid Fuels	CO2	L,T	0,299
1.A.3.b	Road Transportation - Liquid Fuels	CO2	L,T	0,494
1.A.4	Other Sectors - Liquid Fuels	CO2	L,T	0,596
3.A.1	Enteric Fermentation	CH4	L,T	0,696
2.D	Non-Energy Products from Fuels and Solvent Use	CO2	L,T	0,770
2.B.7	Soda Ash Production	CO2	L,T	0,835
3.C.4	Direct N2O Emissions from managed soils	N2O	L,T	0,891
1.B.1.a	Coal mining and handling	CH4	L,T	0,933
4.G	Harvested Wood Products	CO2	L,T	0,948

L = Level assessment, **T** = Trend assessment

When LULUCF sector is included in the key category analysis using the level assessment, the number of key categories reduce to mainly energy subcategories and Agriculture through enteric fermentation. The forest land remaining forest land become a key sink in the inventory. The table below lists the key categories by level assessment, including LULUCF sector.

Table 1-7: An Overview of Botswana's Key Categories for 2022 (Including LULUCF)

CRT Code	CATEGORY	GHG	L,T	Cumulative Total
4.A.1	Forest land Remaining Forest land	CO_2	L	0,856
1.A.1	Energy Industries - Solid Fuels	CO_2	L	0,898
1.A.3.b	Road Transportation - Liquid Fuels	CO_2	L	0,925
1.A.4	Other Sectors - Liquid Fuels	CO_2	L	0,939
3.A.1	Enteric Fermentation	CH_4	L	0,953

L= Level Assessment

Table 1-8: Key Categories by trend assessment (including LULUCF).

CRT code	IPCC Category	GHG	L,T	Cumulative Total
4.A.1	Forest land Remaining Forest land	CO_2	T	0,499
4.A	Solid Waste Disposal	CH_4	T	0,918
1.A.1	Energy Industries - Solid Fuels	CO_2	T	0,942
1.A.3.b	Road Transportation - Liquid Fuels	CO_2	T	0,957

T = Trend Assessment

1.5. General Description of QA/QC Plan and Implementation

In accordance with IPCC requirements (IPCC, 2006), the national GHG inventory preparation process includes quality assurance and quality control (QA/QC) procedures. The objective of quality checking is to improve the transparency, consistency, comparability, completeness, and accuracy of the national greenhouse gas inventory. QC procedures, performed by the compilers, was carried out at various stages of the inventory compilation process. Quality checks were completed at four different levels, namely (a) inventory data (activity data, EF data, uncertainty, and recalculations), (b) database (data transcriptions and aggregations), (c) metadata (documentation of data, experts and supporting data), and (d) inventory report. Quality assurance was completed through a peer review process, review by National Climate Change Committee members, as well as an independent external review. The inventory was be finalized upon addressing all comments from the quality assurance process.

1.5.1. Quality Control

Quality checks are performed in this phase, which were carried out by the experts during inventory calculation and compilation. After data collection, selection of emission factors and calculation of emissions the quality was checked (e.g., units, sources, methodology, emission factors, transcription, documentation, aggregation, etc.) by performing the general and specific quality checks. Further uncertainty analyses and recalculations were performed, required inventory summary tables were completed and the National Inventory Report and archives were prepared.

1.5.2. Quality Assurance

As per the IPCC Good Practice, Quality Assurance comprises a "planned system of review procedures conducted by personnel not directly involved in the inventory compilation and development process." The quality assurance process includes both expert review and a public review. The comments received during these processes were reviewed and, as appropriate, incorporated into the National Inventory Report (NIR) and reflected in the inventory estimates. The results of the QA activities and procedures were documented and described in the QA/QC sub-chapter in the National Inventory Document (NID).

1.5.3. QA/QC Plans

The dimensions of quality for the inventory, namely, transparency, consistency, comparability, completeness, accuracy and timeliness, form the set of criteria for assessing the output produced by the national inventory system. The principle of continuous improvement was also included through the development of improvement plans.

The phases of the QA/QC process and their timeframes (for Botswana) relative to the GHG Inventory preparation cycle are shown in Figure 1-2.

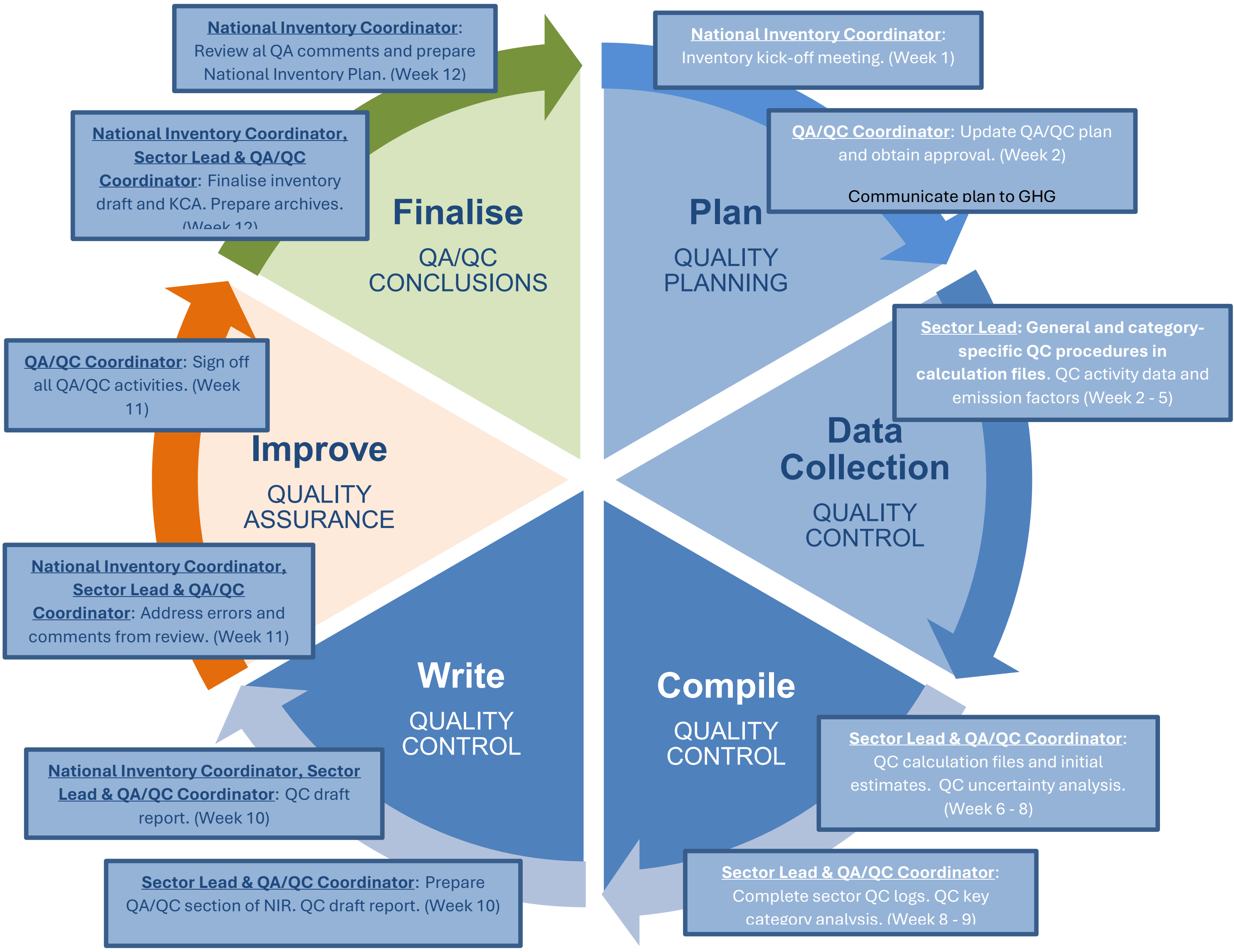

Figure.1-2: Quality control procedures, relative to the GHG Inventory preparation cycle, and timeframes for Botswana.

1.5.4. Quality Control Procedures

The quality control (QC) procedures were performed by the experts during inventory calculation and compilation. QC measures are aimed at the attainment of the quality objectives. The QC procedures conform to the 2006 IPCC Guidelines. General inventory QC checks included routine checks of the integrity, correctness and completeness of data, identification of errors and deficiencies and documentation and archiving of inventory data and quality control actions. Besides the general QC checks, category-specific QC checks including technical reviews of the source categories, activity data, emission factors and methods were applied on a case-by-case basis focusing on key categories and on categories where significant methodological and data revisions have taken place. The general QC checks carried out are provided in Table 1-9.

1.5.5. Quality Assurance Procedures

The National GHG Inventory included the following QA procedures:

- Peer reviews of specific categories. This was performed by none inventory compiling experts. These reviews were only conducted on selected categories and were often dependent on in-kind contributions from experts and the availability of funds.
- National Climate Change Committee (NCCC) review and comment process. The NCCC participated in the review, particularly members interested in the inventory process.
- External Review of the calculation files and the NIR by external experts. The experts are independent of the inventory preparation. This was done to ensure that the inventory's results, assumptions and methods are reasonable, as judged by those knowledgeable in the specific field. The UNFCCC facilitates the external review process.

1.5.6. QA/QC Process and Verification

The QA/QC measures detailed in Table 1-1 were specifically applied to the calculation files for all the sectors.

Table 1-9: General QA/QC checks completed for all the sectors

QA/QC principle	Check
Accuracy	Activity data source
Accuracy	Correct units
Accuracy	Unit carry through
Accuracy	Calculations check
Accuracy	Uncertainties
Accuracy	Double counting
Accuracy	Correct GWP
Accuracy	Notation keys
Accuracy, Completeness, Consistency, Transparency	Trend check
Accuracy, Transparency	Emission factor applicability
Accuracy, Completeness, Consistency, Transparency	Recalculations
Completeness, Comparability	Sub-category completeness
Consistency	Documentation
Accuracy, Comparability	Cross check data
Accuracy	Spot checks
Transparency, Consistency	Data source referencing
Transparency	Links to source data
Transparency	Raw primary data
Accuracy	QA review

1.6. General assessment of completeness

The inventory covers the entire territory of Botswana. The time series covered is from 2000 to 2022. This National GHG Inventory is a complete inventory of the following direct greenhouse gases: CO2, CH4, N2O and HFCs. The inventory still has some gaps, most being determined by lack of activity data needed to estimate certain emissions and removals such as SF6, NH3 and PFCs (Perfluorocarbons), NMVOC (Non-Methane Volatile Organic Compounds), SOx and CO due to lack of readily available Activity data on their sources. Where time series data is missing, interpolation and extrapolation methods were used to complete the time series.

1.7. Metrics

This inventory employs the Fifth Assessment Report Global Warming Potentials as per the requirements of the Enhanced Transparency Framework (ETF) of the Paris Agreement Modalities, Procedures and Guidelines (MPGs). Global warming potential (GWP) is defined as the time-integrated change in radiative forcing due to the instantaneous release of 1 kg of the gas, expressed relative to the radiative forcing caused by the release of 1 kg of CO2. The following table includes the 100-year time horizon Global Warming Potentials (GWP) relative to CO2 for gases which were estimated in this inventory. This table is adapted from the IPCC Fifth Assessment Report (AR5) (IPCC, 2014):

https://www.ipcc.ch/pdf/assessmentreport/ar5/wg1/WG1AR5_Chapter08_FINAL.pdf

Table 1-10: Global warming potential (GWP) values relative to CO_2 from AR5

GAS	CHEMICAL FORMULA	GWP
Carbon Dioxide	CO_2	**1**
Methane	CH_4	**28**
Nitrous Oxide	N_2O	**265**
HFC - 23	CHF_3	**12400**
HFC - 32	CH_2F_2	**677**
HFC- 134a	CH_2FCF_3	**1300**
HFC – 152a	CH_2CHF_2	**138**

1.8. Summary of Flexibility Provisions Applied

Table 1-11: Summary table on the use of flexibility provisions

MPG Flexibility Provision	Description of the Application of Flexibility	Sector/Category/ GHG	Clarification of Capacity Constraint	Time Frame for Improvement
Para 57 -Time Series Coverage	Botswana applies the time-series coverage flexibility and reports the annual time series starting in 2000.	All sectors	Lack of or very unreliable activity data for the years prior to 2000.	The Flexibility will be maintained throughout all inventories.
Para 58 -Latest Reporting Year	Botswana applies the latest-reporting-year flexibility and reports 2022 as the most recent inventory year.	All sectors	Time, Capacity and lack of latest data constraints.	Estimated BTR3 (2028 submission)
Para 48 - Reported Greenhouse Gases	Botswana applies the reported-greenhouse-gases flexibility and reports CO2, CH4, N2O and HFCs only, excluding NH3, SF6	All sectors	Lack of activity data, Capacity and methodological constraints.	Some gases (SF6) are estimated for BTR2 submission

MPG Flexibility Provision	Description of the Application of Flexibility	Sector/Category/ GHG	Clarification of Capacity Constraint	Time Frame for Improvement
	and precursor gases, in its inventory.			
Para 29 - Uncertainty Assessment	Botswana applies the uncertainty assessment flexibility and provides a qualitative discussion of uncertainties in some sectors and the overall inventory	LLUCF and Overall Inventory uncertainty.	Time constraints and lack of reliable uncertainty estimates for the activity data.	Next submission of BTR2.

2. TRENDS IN GREENHOUSE GAS EMISSIONS AND REMOVALS

2.1. Description of trend for aggregated GHG emissions and removals

This chapter examines and interprets emission trends across various sectors while detailing the trajectory of aggregated national totals.

2.1.1. National trends

2.1.1.1 Overall emissions (excluding LULUCF)

Total national emissions (excl. LULUCF) consist of the Energy, IPPU, Agriculture, and Waste sectors. This total excludes emissions from LULUCF sector, which separately accounts for carbon sources and removals from land-use changes and harvested wood products.

Inventory year- 2022

In 2022, the Energy sector dominated Botswana's gross emissions (excluding LULUCF), accounting for 66% of the national total. The remaining emissions were attributed to Agriculture (17%), IPPU (14%), and Waste (3%), respectively.

Time series 2000 - 2022

In 2022, the emissions (excl. LULUCF) were estimated at 11,790.67 Gg CO_2 eq, an increase of 24.19% compared to 2000 (9,469.03 Gg CO_2 eq).

Table 2-1: Comparative analysis of Botswana's total emissions (with and without LULUCF) for the years 2000, 2015, and 2022 (excl. LULUCF), and years 2003, 2015, and 2022 (incl. LULUCF).

	Emissions (Gg CO_2 eq)			Change between 2000 and 2022		Change between 2015 and 2022	
	2000	2015	2022	Gg CO_2 eq	%	Gg CO_2 eq	%
Emissions (excl. LULUCF)	9 469.03	12 898.36	11 790.67	2 296.64	24.19	1 076.55	10.05
	Emissions (Gg CO_2 eq)			**Change between 2003 and 2022**		**Change between 2015 and 2022**	
	2003	**2015**	**2022**	**Gg CO_2 eq**	**%**	**Gg CO_2 eq**	**%**
Emissions (incl. LULUCF)	-43 467.10	-60 343.74	-61 851.15	-16 876.64	38.83	-1 507.41	2.50

Note: Base year for LULUCF is 2002 and Conversion year for LULUCF is 2003

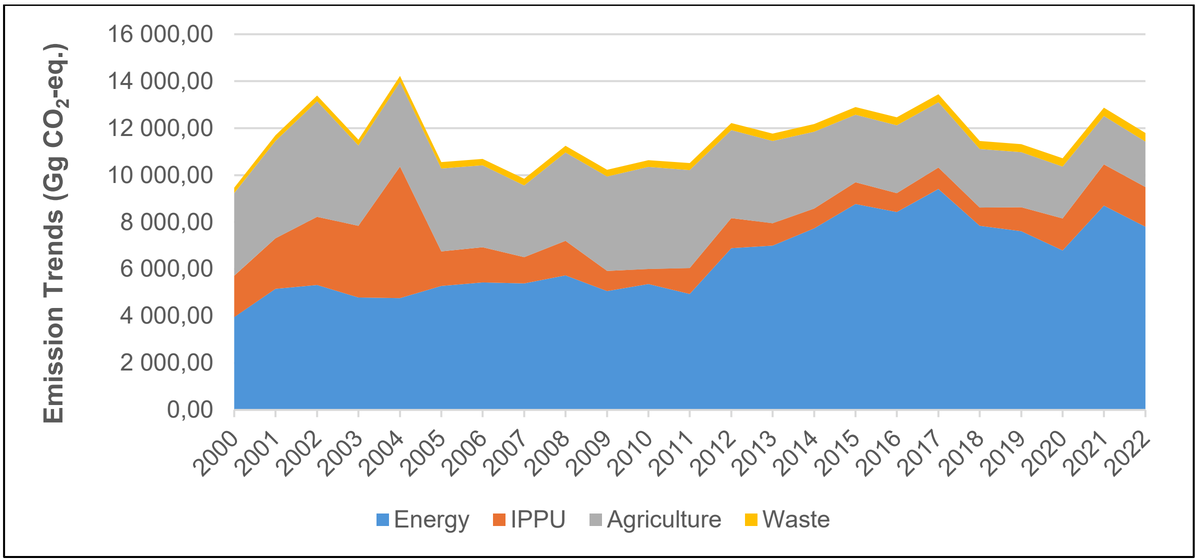

Figure.2-1: National GHG emissions (excluding LULUCF) for Botswana, 2000 – 2022.

Table 2-2: Trends and annual change in emissions (excluding and including LULUCF), 2000 – 2022.

Year	Emissions (excl. LULUCF)		Emissions (incl. LULUCF)	
	Gg CO_2 eq	Annual change (%)	Gg CO_2 eq	Annual change (%)
2000	9 494,03	-	9 494,03	—
2001	11 694,48	23,18	11 694,48	23,18
2002	13 385,13	14,46	13 385,13	14,46
2003	11 513,10	-13,99	-43 467,10*	-424,74
2004	14 224,88	23,55	-37 337,92	-14,10
2005	10 551,84	-25,82	-45 645,26	22,25
2006	10 690,21	1,31	-46 353,79	1,55
2007	9 839,48	-7,96	-55 254,52	19,20
2008	11 244,85	14,28	-20 274,55	-63,31
2009	10 233,91	-8,99	-59 422,89	193,09
2010	10 639,47	3,96	-14 048,43	-76,36
2011	10 519,85	-1,12	-6 910,35	-50,81
2012	12 220,12	16,16	-32 082,78	364,27
2013	11 760,75	-3,76	-32 331,25	0,77
2014	12 172,05	3,50	-52 377,65	62,00
2015	12 898,36	5,97	-60 343,74	15,21
2016	12 457,33	-3,42	-64 454,07	6,81
2017	13 440,99	7,90	-56 316,61	-12,63
2018	11 459,27	-14,74	-63 669,23	13,06
2019	11 322,43	-1,19	-64 237,07	0,89
2020	10 714,11	-5,37	-64 396,49	0,25
2021	12 877,41	20,19	-58 798,69	-8,69
2022	11 790,67	-8,44	-61 851,15	5,19

*Base year for LULUCF emissions is 2003

2.1.1.2 Net emissions (including LULUCF)

Total greenhouse gas emissions (incl. LULUCF) encompass contributions from the Energy, Industrial Processes and Product Use (IPPU), Agriculture, and Waste sectors, alongside all LULUCF-related emission sources and carbon sinks.

2022

In 2022, aggregate greenhouse gas emissions, including the LULUCF sector, were recorded at -73,642.10 Gg CO_2 eq. During this period, the LULUCF sector functioned as a net carbon sink, with Forest lands serving as the primary driver of these removals.

2003-2022

In 2003, Botswana's aggregate greenhouse gas emissions, including the LULUCF sector, stood at -43,467.10 Gg CO_2 eq. By 2022, these levels saw a 38.83 % increase, resulting in an estimated -61,851.15 Gg CO_2 eq (Table 2-1). Throughout this period, the trajectory of emissions including LULUCF closely mirrored the trends observed in emissions excluding the LULUCF sector.

2015-2022

Botswana's aggregate greenhouse gas emissions, including the LULUCF sector in 2015, stood at -60,343.74 Gg CO_2 eq, representing a net sink. By 2022, these levels saw a 2.5 % increase, resulting in an estimated sink of -61,851.15 Gg CO_2 eq (Table 2-1).

2.2. Description of trend by sector and gas

The relative contribution of each gas to Botswana's aggregate emissions from 2000 to 2022 is illustrated in Figures 2-3 and 2-4.

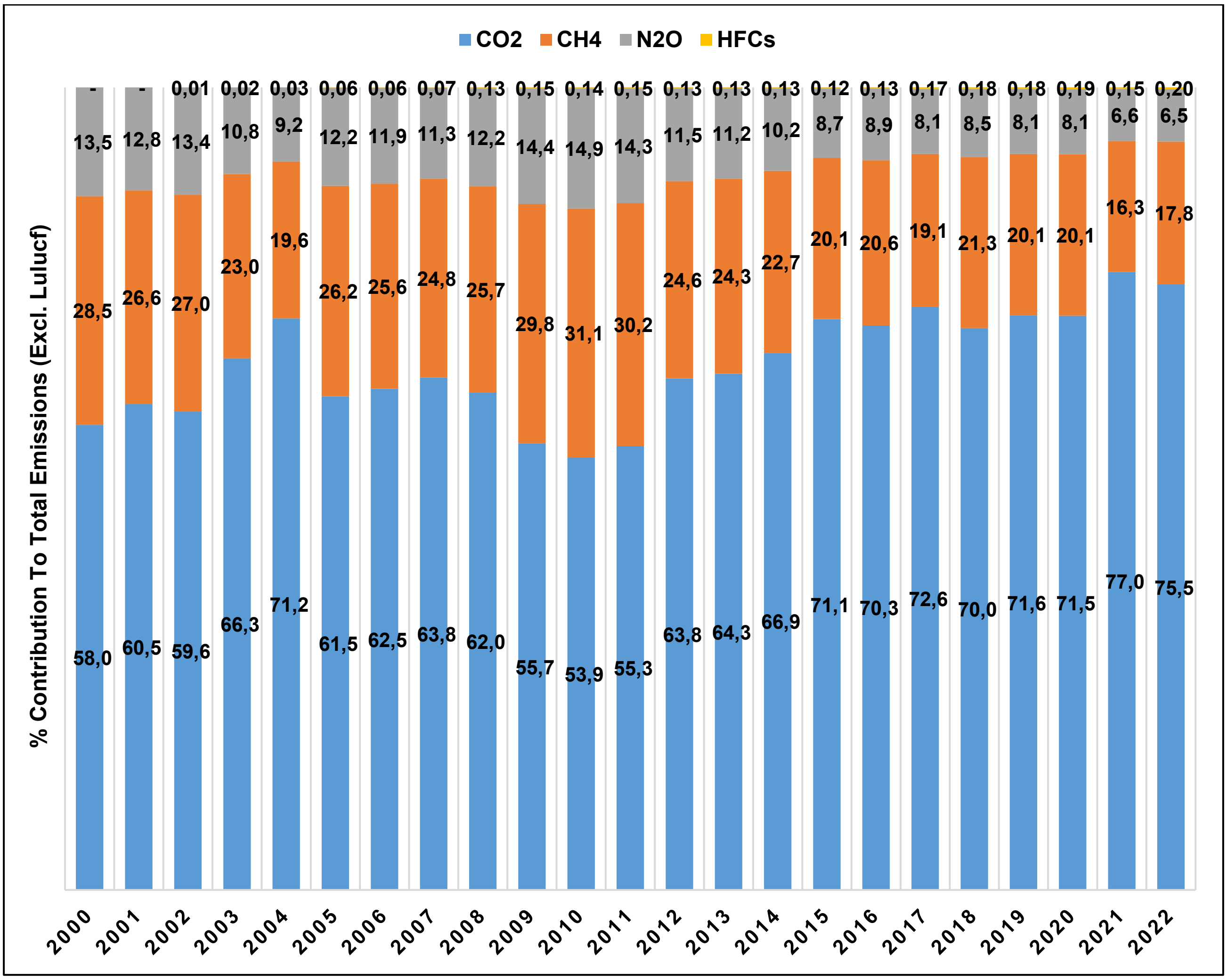

Figure.2-2: Percentage contribution of each gases to Botswana's total emissions (excl. LULUCF), 2000 – 2022

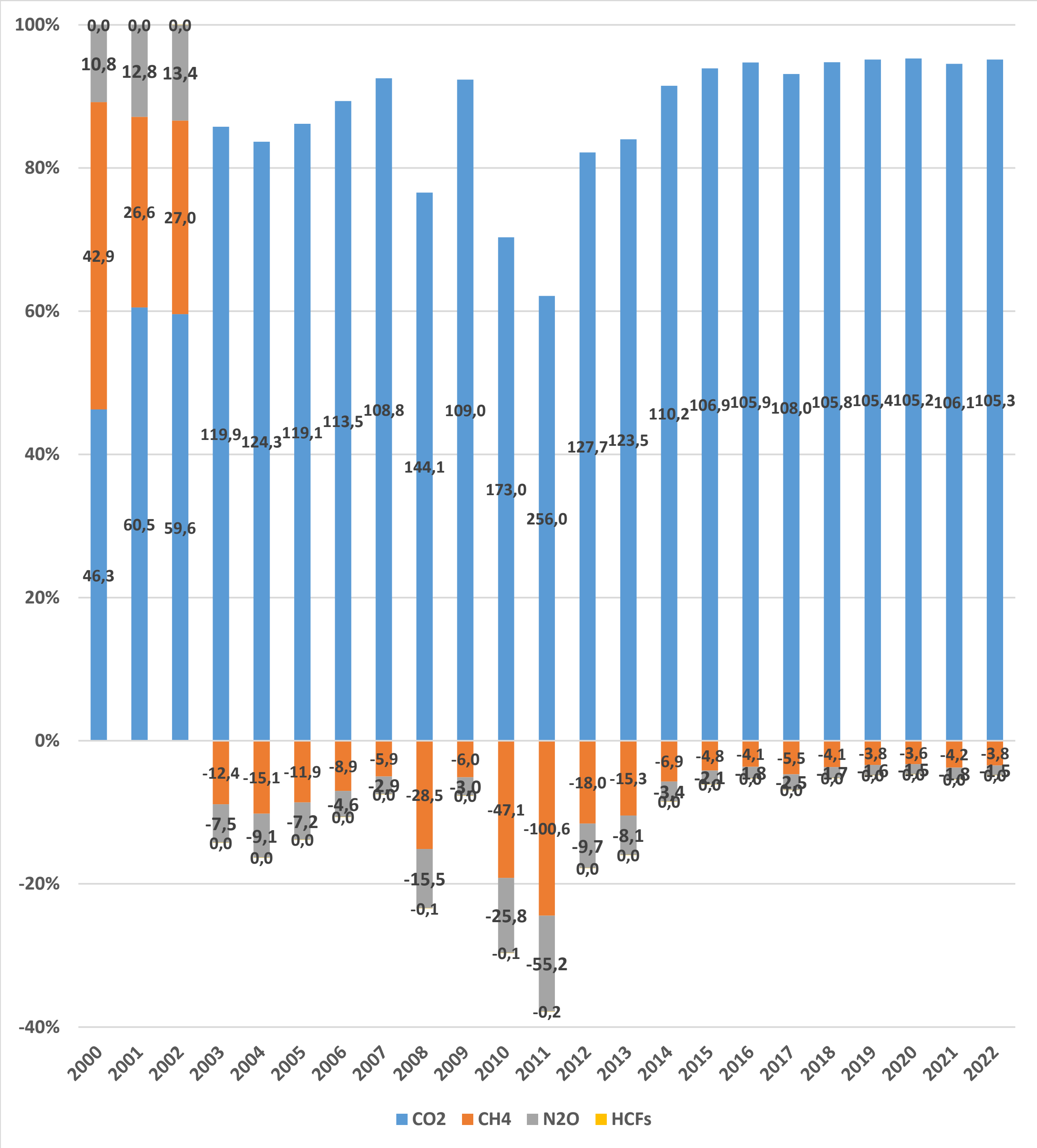

Figure.2-3: Percentage contribution of each gases to Botswana's total emissions (incl. LULUCF), 2000 – 2022

2.2.1. Carbon Dioxide (CO_2)

In Botswana, CO_2 represents the primary source of emissions, followed by CH_4 and N_2O respectively (Figure 2-6). By comparison, CO_2 accounted for 75.46 % of Botswana's total emissions (excluding LULUCF) in 2022. The Energy sector remains the predominant driver of

CO_2 output, responsible for an average of 79.66 % of all carbon dioxide emissions (excluding LULUCF) during the 2000–2022 period.

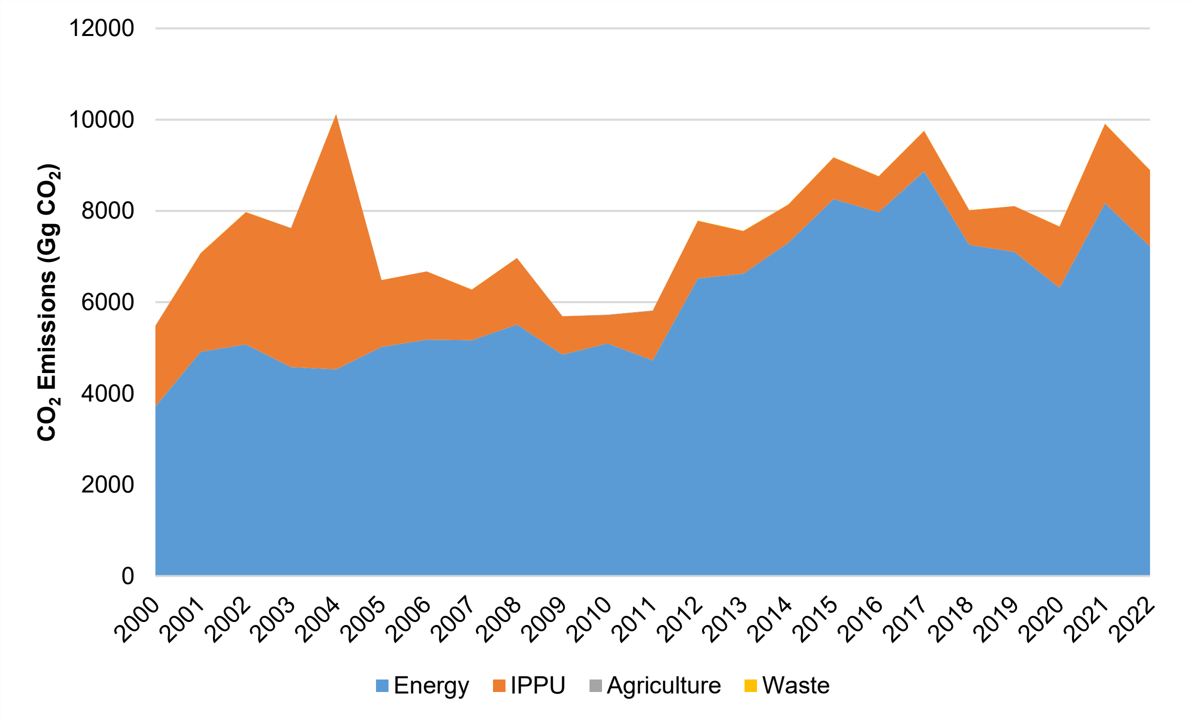

Figure.2-4: Trend and sectoral contribution to CO_2 emissions (excl. LULUCF), 2000 – 2022

2.2.2. Methane (CH_4)

Figure 2-5 illustrates the historical trends and sectoral contributions to Botswana's total CH_4 emissions. CH_4 emissions (excluding LULUCF) fluctuated between 2000 and 2022, with the highest emissions recorded in 2010 (3,305.32 Gg CO_2 eq). As of 2022 (2,099.07 Gg CO_2 eq), the primary drivers of methane output were Enteric Fermentation within the Agriculture sector and Solid Waste Disposal within the Waste sector.

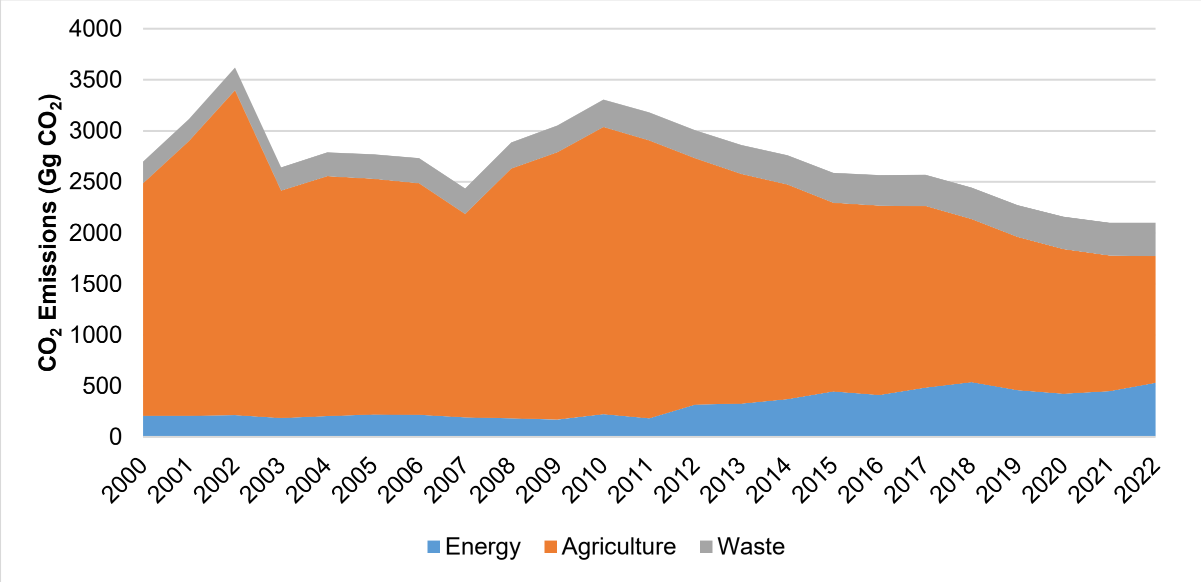

Figure.2-5: Trend and sectoral contribution to CH_4 emissions (excl. LULUCF), 2000 – 2022

2.2.3. Nitrous Oxide (N_2O)

The sectoral distribution of N_2O emissions is depicted in Figure 2-6. Agriculture remains the primary source of these emissions, accounting for 94.5% (excluding LULUCF), followed by the Energy sector at 3.5 %, and Waste sector at 2.0 %. Notably, there were no N_2O emissions from the IPPU sector between 2000 and 2022.

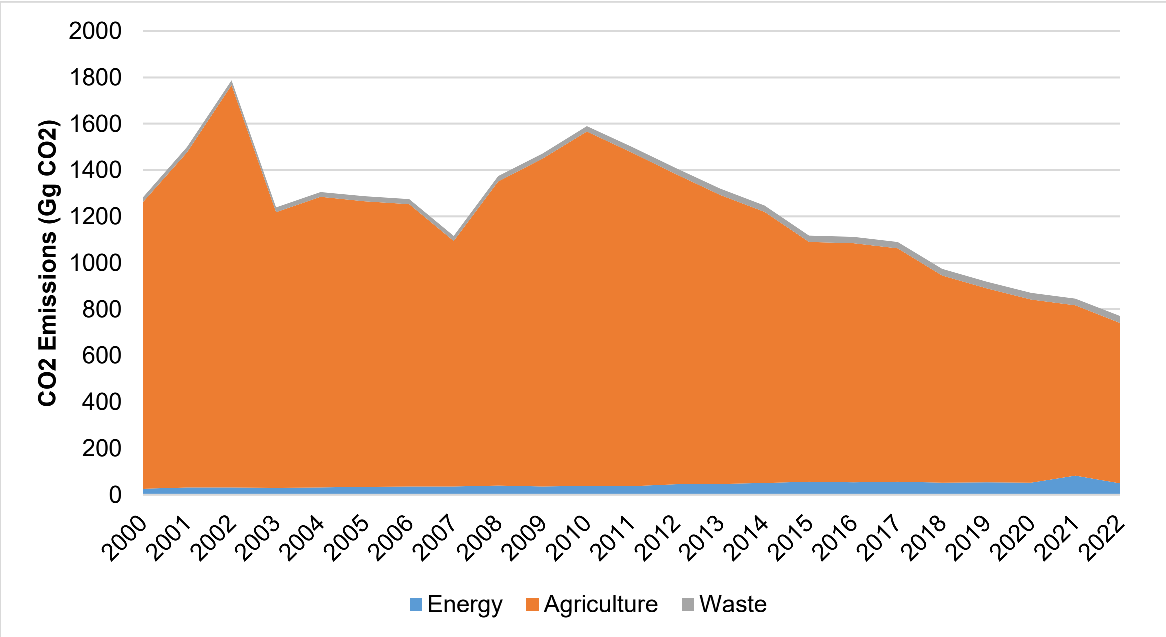

Figure.2-6: Trend and sectoral contribution to N_2O emissions (excl. LULUCF), 2000 – 2022

2.2.4. Hydrofluorocarbons (HFCs)

In Botswana, HFC emissions were calculated exclusively for the Industrial Processes and Product Use (IPPU) sector. These estimates exhibit annual fluctuations, as illustrated in Figure 2-7, and accounted for 0.19% of the total emissions (excluding LULUCF) in 2022.

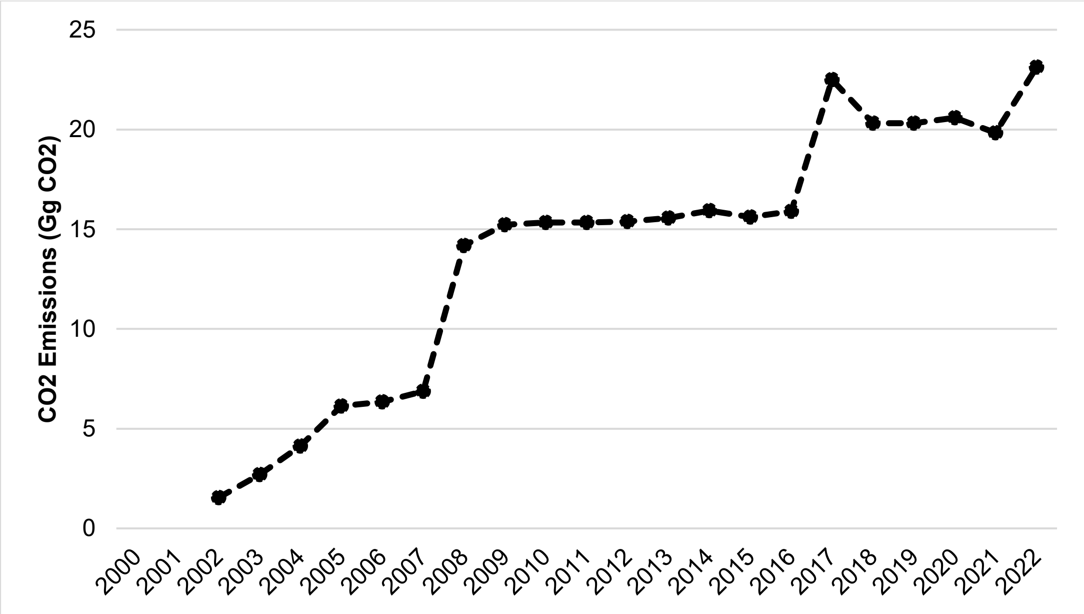

Figure.2-7: Trend and sectoral contribution to HFCs emissions (excl. LULUCF), 2000 – 2022

2.3. Description of trend for GHG intensity indicators

The emissions per capita in tonnes of CO_2 equivalent fluctuated just above 5.0 tonnes of CO_2 equivalent for the time series. The maximum value occurred in 2004 with 7.87 tonnes of CO_2 equivalent emitted per person. Overall, the variability was not that significant over the time series. The figure below shows a time series of the per capita emissions. Annex VI gives the annual population of Botswana from 2000 to 2022.

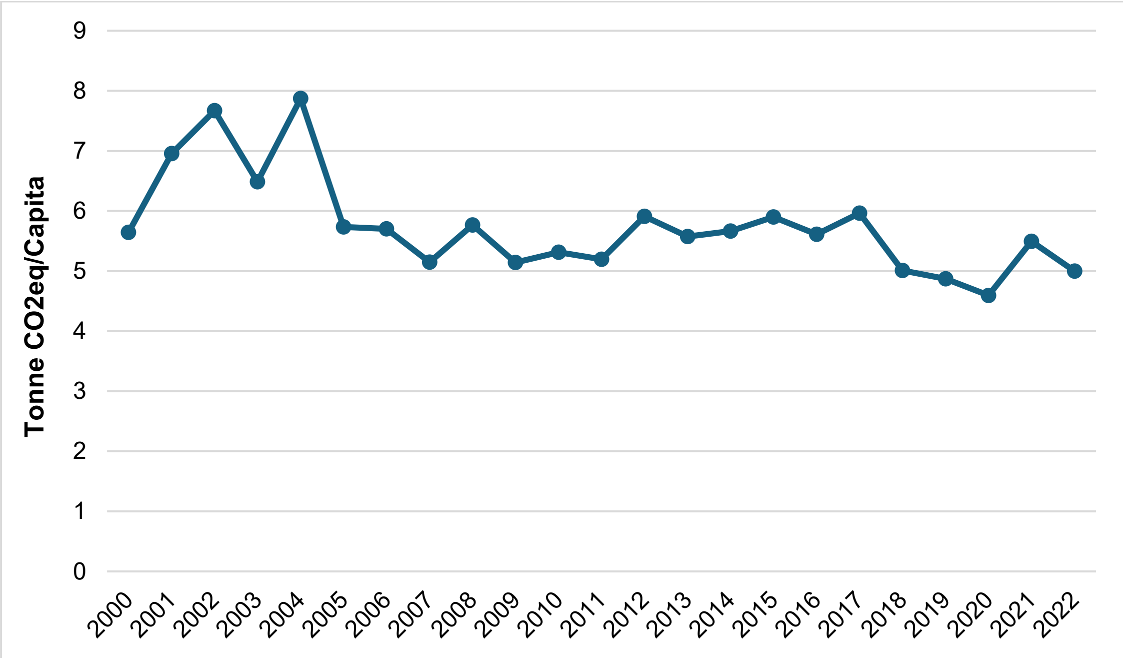

Figure.2-8: Trend of emissions per capita tonne CO2 eq. (excl. LULUCF), 2000 – 2022

The emissions per GDP in local currency, Botswana Pula (BWP) show a significant decline from 301 tonnes CO2 equivalent in 2000 to 47 tonnes CO2 equivalent in 2022. This represents an 84% decline between the two periods of the time series. Annex VI gives the annual GDP for Botswana from 2000 to 2022.

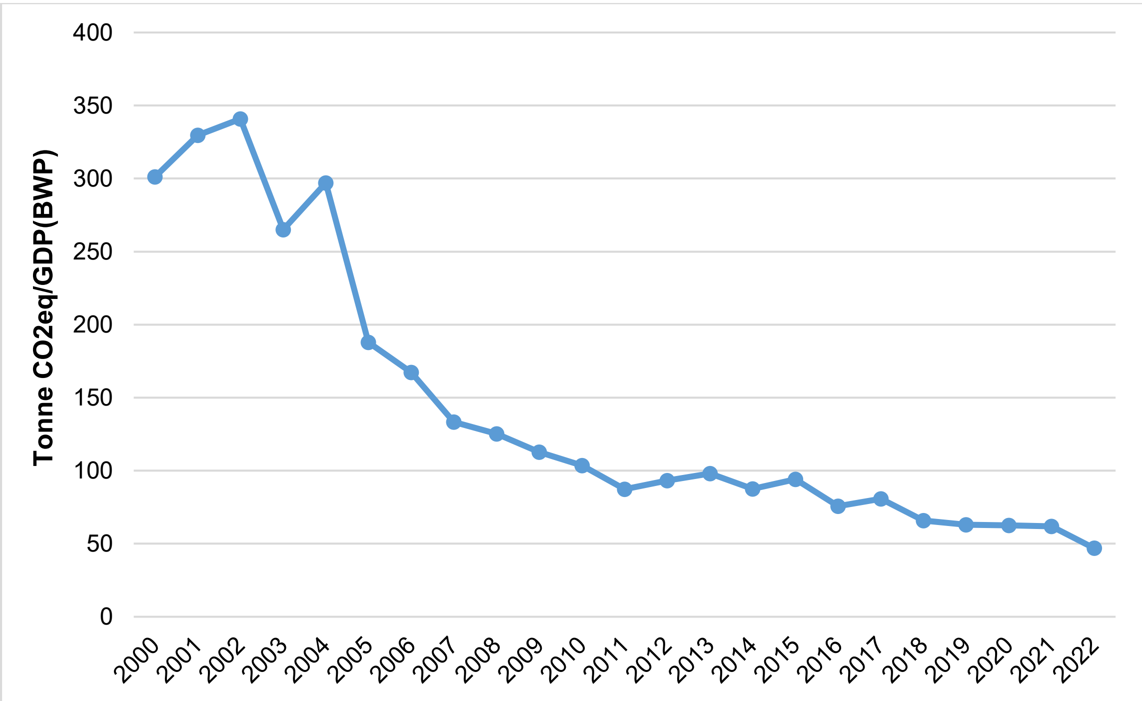

Figure.2-9: Trend in emissions per GDP tonne CO2 eq. (excl. LULUCF), 2000 – 2022

Refer to Annex VI for data on the economic drivers of GHG emissions (population and GDP).

3. ENERGY (CRT SECTOR 1)

3.1. Overview of the sector

The energy sector in Botswana is primarily characterized by the reliance on fossil fuels, mainly coal and imported petroleum products, for electricity generation and transportation. The sector's greenhouse gas (GHG) emissions stem from combustion processes, mainly from power plants and vehicles. Botswana's efforts are aimed at diversifying its energy sources and increasing renewable energy adoption to reduce GHG emissions and enhance energy security.

3.1.1. Description of the sector

In Botswana, energy sector encompasses sources and activities involved in the production, conversion, and use of energy. The main GHG sources include:

1. Emissions resulting from fuel combustion activities (CRT 1.A) and
2. Fugitive emissions associated with fuel production and handling processes (CRT 1.B).

Within the fuel combustion activities:

- Power generation is primarily from coal-fired plants, contributing significant CO2 emissions.
- Transport sector which is characterised by internal combustion engines fuelled by diesel and petrol also contributing significant emissions.
- Renewable energy projects in Botswana are limited: therefore, most emissions are from fossil fuels.

The sector's GHG emissions are concentrated in power generation and transport, with biomass use commonly used for cooking in rural communities, at household level. The energy sector plays a crucial role in Botswana's economy. The inventory covers major categories relevant for national climate reporting, though efforts continue to improve data coverage and accuracy for comprehensive assessment.

3.1.2. Trend in the sector's GHG

The energy sector includes emissions from fuel combustion activities (CRT 1.A) and fugitive emissions related to fuel production and handling processes (CRT 1.B). Of these, fuel combustion accounts for the majority, making up 93.5% of the sector's emissions. It is Botswana's largest source of greenhouse gases, contributing approximately 66.2% to the country's total emissions in 2022, excluding LULUCF.

The sector is the primary source of CO_2 emissions (see Figure 3.1) and the second-largest source of N_2O emissions, mainly due to fuel combustion. These emissions play a significant role in shaping the country's overall greenhouse gas profile and highlight the sector's importance in national climate policies.

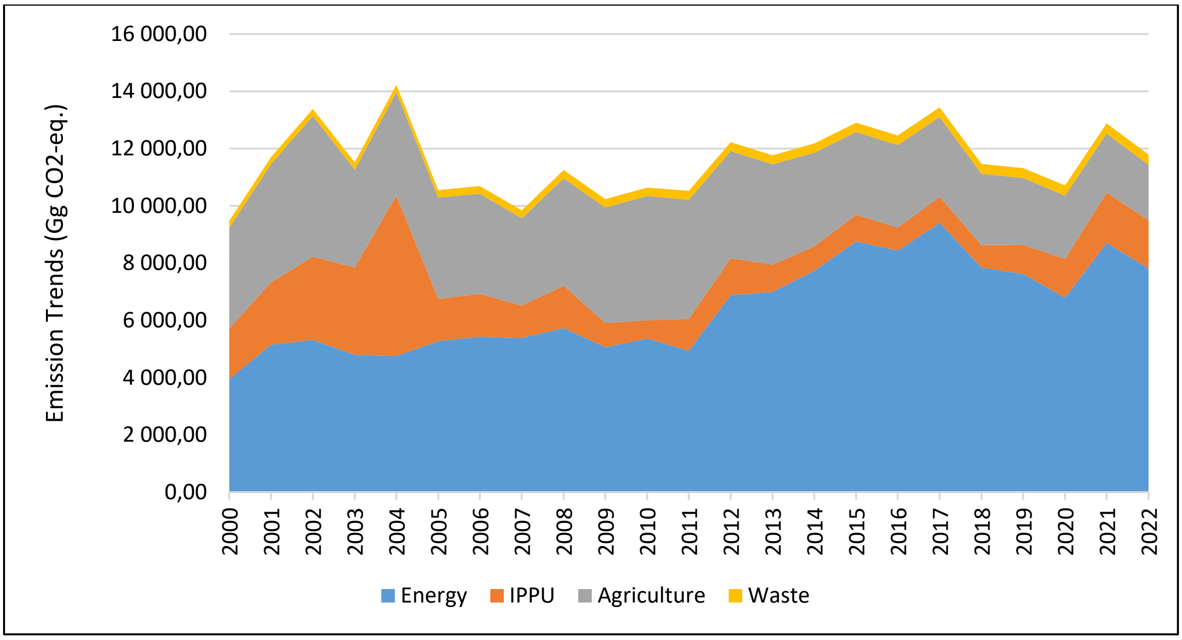

Figure.3-1: Contribution of energy sector gases to the national total (excluding LULUCF) for 2000 - 2022.

The total GHG emissions from Botswana's energy sector in 2022, expressed as both in kilo-tonnes and in Gg CO2-equivalent, are presented in Table 3.1. As indicated in the table, the total GHG emissions for the sector is 7,804.32 Gg CO2-equivalent. Emissions from the energy sector are constituted almost entirely by contributions from Fuel Combustion Activities (1.A) with 7299.26 Gg CO2-eq at 93.5% with the rest (505.03 Gg CO2-eq) coming from Fugitive Emissions from Fuels (1.B) contributing 6.5% to the sector's national total emissions.

By gas, emissions for carbon dioxide were 7224.61 Gg CO2-eq, followed by methane with 530.15 Gg CO2-eq, and nitrous oxide with 49.56 Gg CO2-eq. These account for 92.6%, 6.8%, and 0.6% contributions by gas, for CO2, CH4 and N2O, respectively, to the national total energy emissions.

While emissions of Nitrogen Oxides (NOx), Carbon Monoxide (CO), Non-Methane Volatile Organic Compounds (NMVOCs), and Sulphur Dioxide (SO2) are anticipated due to the combustion of carbon-based fuels in the atmosphere, they were marked as 'NE' because they were undetected in the Fuel Combustion Activities category. The 2006 IPCC Guidelines do not provide their own methodological guidance or default emission factors for estimating NOx, CO, NMVOC, and SO2 under the Energy Sector. Additionally, NOx, CO, and SO2 are not generally expected to occur as fugitive emissions during regular operations. Although these gases can be released during activities like flaring, this practice is not conducted in Botswana. Similarly, NMVOCs, which arise from sources such as leaks from valves and flanges, evaporation during storage, and general oil and natural gas handling, are minimal in Botswana, resulting in their reporting as NE.

Nitrous oxide (N2O) emissions are also noted as NE, as this gas is not a major part of fugitive emissions from underground coal mining. The main greenhouse gases linked to fugitive emissions from coal mining, whether underground or surface, are methane and carbon dioxide.

Table 3-1: Greenhouse Gas Emissions in the Energy Sector (in Gg and total in Gg CO2-eq.): 2022

Categories	Emissions (Gg)							TOTAL Gg CO2-eq
	CO2	CH4	N2O	NOx	CO	NMVOCs	SO2	
1 - Energy	7,224.614	18.934	0.187	NE	NE	NE	NE	**7804.32**
1.A - Fuel Combustion Activities	7,222.803	0.962	0.187	NE	NE	NE	NE	**7299.29**
1.A.1 - Energy Industries	3,575.596	0.038	0.057	NE	NE	NE	NE	**3591.77**
1.A.1.a - Main Activity Electricity and Heat Production	3,575.596	0.038	0.057	NE	NE	NE	NE	**3591.77**
1.A.1.b - Petroleum Refining	NO	NO	NO	NO	NO	NO	NO	**NO**
1.A.1.c - Manufacture of Solid Fuels and Other Energy Industries	NO	NO	NO	NO	NO	NO	NO	**NO**
1.A.2 - Manufacturing Industries and Construction	NA	NA	NA	NA	NA	NA	NA	**NA**
1.A.2.a - Iron and Steel	NA	NA	NA	NA	NA	NA	NA	**NA**
1.A.2.b - Non-Ferrous Metals	NA	NA	NA	NA	NA	NA	NA	**NA**
1.A.2.c - Chemicals	NA	NA	NA	NA	NA	NA	NA	**NA**
1.A.2.d - Pulp, Paper and Print	NA	NA	NA	NA	NA	NA	NA	**NA**
1.A.2.e - Food Processing, Beverages and Tobacco	NA	NA	NA	NA	NA	NA	NA	**NA**
1.A.2.f - Non-Metallic Minerals	NA	NA	NA	NA	NA	NA	NA	**NA**
1.A.2.g - Transport Equipment	NA	NA	NA	NA	NA	NA	NA	**NA**
1.A.2.h - Machinery	NA	NA	NA	NA	NA	NA	NA	**NA**
1.A.3 - Transport	2,368.342	0.730	0.120	NE	NE	NE	NE	**2420.58**
1.A.3.a - Civil Aviation	25.075	0.000	0.001	NE	NE	NE	NE	**25.34**
1.A.3.b - Road Transportation	2,329.152	0.729	0.113	NE	NE	NE	NE	**2379.51**
1.A.3.c - Railways	14.115	0.001	0.005	NE	NE	NE	NE	**15.47**
1.A.3.d - Water-borne Navigation	NO	NO	NO	NO	NO	NO	NO	**NO**
1.A.3.e - Other Transportation	NO	NO	NO	NO	NO	NO	NO	**NO**
1.A.4 - Other Sectors	1,278.865	0.195	0.011	NE	NE	NE	NE	**1287.24**
1.A.4.a - Commercial/Institutional	1,239.839	0.165	0.010	NE	NE	NE	NE	**1247.11**
1.A.4.b - Residential	0.042	0.002	0.000	NE	NE	NE	NE	**0.10**
1.A.4.c - Agriculture/Forestry/Fishing/Fish Farms	38.983	0.027	0.000	NE	NE	NE	NE	**39.74**
1.A.5 - Non-Specified	NO	NO	NO	NO	NO	NO	NO	**NO**
1.A.5.a - Stationary	NO	NO	NO	NO	NO	NO	NO	**NO**
1.A.5.b - Mobile	NO	NO	NO	NO	NO	NO	NO	**NO**

Categories	Emissions (Gg)							TOTAL Gg CO2-eq
	CO2	CH4	N2O	NOx	CO	NMVOCs	SO2	
1.B - Fugitive emissions from fuels	1.811	17.972	NE	NO	NE	NE	NO	**505.03**
1.B.1 - Solid Fuels	1.811	17.972	NE	NO	NE	NE	NO	**505.03**
1.B.1.a - Coal mining and handling	1.811	17.972		NO	NE	NE	NO	**505.03**
1.B.1.b - Uncontrolled combustion and burning coal dumps	NO	NO	NO	NO	NO	NO	NO	**NO**
1.B.2 - Oil and Natural Gas	NO	NO	NO	NO	NO	NO	NO	**NO**
1.B.2.a - Oil	NO	NO	NO	NO	NO	NO	NO	**NO**
1.B.2.b - Natural Gas	NO	NO	NO	NO	NO	NO	NO	**NO**
1.B.3 - Other emissions from Energy Production	NO	NO	NO	NO	NO	NO	NO	**NO**
1.C - Carbon dioxide Transport and Storage	NO			NO	NO	NO	NO	**NO**
1.C.1 - Transport of CO2	NO			NO	NO	NO	NO	**NO**
1.C.1.a - Pipelines	NO			NO	NO	NO	NO	**NO**
1.C.1.b - Ships	NO			NO	NO	NO	NO	**NO**
1.C.1.c - Other (please specify)	NO			NO	NO	NO	NO	**NO**
1.C.2 - Injection and Storage	NO			NO	NO	NO	NO	**NO**
1.C.2.a - Injection	NO			NO	NO	NO	NO	**NO**
1.C.2.b - Storage	NO			NO	NO	NO	NO	**NO**
1.C.3 - Other	NO			NO	NO	NO	NO	**NO**

Categories	Emissions (Gg)							TOTAL Gg CO2-eq
	CO2	CH4	N2O	NOx	CO	NMVOCs	SO2	
Memo Items (3)								
International Bunkers	18.919	0.000	0.001	NE	NE	NE	NE	**19.18**
Information Items								
CO2 from Biomass Combustion	0.759							**0.76**

From 2000 to 2022, greenhouse gas (GHG) emissions in the energy sector more than doubled, rising from 3,952.55 Gg CO2 equivalent in 2000 to 7,805.33 Gg CO2 equivalent in 2022, which equates to a notable percentage increase of 97.5%. This rise in emissions can be linked to several factors, such as the growing energy demand driven by economic expansion and population growth, which escalates the need for energy and results in higher emissions when the energy is derived from fossil fuels. Table 3.2 presents a summary of the total greenhouse gas (GHG) inventory for the sector, covering: 1.A - Fuel Combustion Activities and 1.B - Fugitive Emissions from Fuels, for the years 2000 to 2022. Figure 3.2 illustrates the trend in greenhouse gas emissions from Fuel Combustion Activities (1.A) and Fugitive emissions from fuels (1.B) categories, measured in Gg CO_2-eq. between 2000 and 2022.

Table 3-2: Total energy sector GHG emissions by category (Gg CO2 eq): 2000-2022.

Category	**2000**	**2005**	**2010**	**2015**	**2016**	**2017**
1.A - Fuel Combustion Activities	3,758.56	5,073.71	5,157.15	8,340.36	8,049.34	8,951.83
1.B - Fugitive Emissions from Fuels	194.33	202.11	202.81	423.94	413.96	454.72
Total	3,952.55	5,275.83	5,359.96	8,764.31	8,433.29	9,406.55
% Change over Time from 2000	–	33.5%	35.6%	121.7%	113.4%	138.0%
Category	**2018**	**2019**	**2020**	**2021**	**2022**	
1.A - Fuel Combustion Activities	7,336.92	7,182.80	6,400.28	8,267.42	7,299.30	
1.B - Fugitive Emissions from Fuels	517.42	433.19	394.84	414.80	505.02	
Total	7,846.33	7,616.00	6,795.12	8,702.21	7,805.33	
% Change over Time from 2000	98.5%	92.7%	71.9%	120.2%	97.5%	

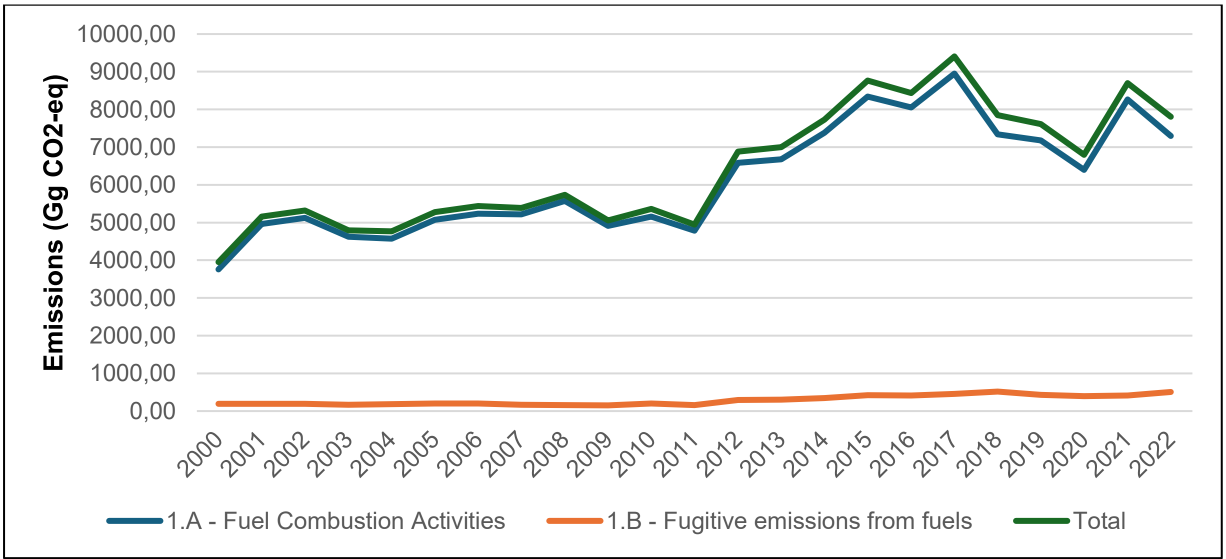

Figure.3-2: Trend in GHG emissions by categories (in Gg CO_2-eq.) between 2000 and 2022.

Table 3.3 and Figure 3.3 illustrate the fluctuations in greenhouse gas (GHG) emissions within the energy sector from the base year (2000) to 2022, specifically focusing on the emissions of CO2, CH4 (methane), and N2O (nitrous oxide), measured in Gg CO2-equivalent.

In year 2000, CO2 emissions totalled 3,718.35 Gg CO2-eq, escalating to 7,224.62 Gg CO2-eq in year 2022, representing an increase of 94.3%. Methane emissions rose by 154.5%, climbing from 208.7 Gg CO2-eq in year 2000 to 531.14 Gg CO2-eq in year 2022. Likewise, nitrous oxide emissions saw a rise from 25.5 Gg CO2-eq in year 2000 to 49.57 Gg CO2-eq in year 2022, marking an increase of 94.9%. Figure 3.3 indicates a strong correlation between the variations in CO2 emissions and the total GHG emissions from the energy sector, highlighting CO2 as the primary contributor to emissions in this sector.

Table 3-3: Total energy sector GHG emissions by gas (Gg CO2 eq): 2000-2022.

Category	2000	2005	2010	2015	2016	2017
Carbon dioxide (CO2)	3,718.35	5,022.77	5,100.91	8,262.34	7,971.22	8,868.02
Methane (CH4)	208.70	219.78	221.58	446.26	409.55	481.99
Nitrous oxide (N2O)	25.50	33.28	37.47	55.71	52.52	56.54
Total	3,952.55	5,275.83	5,359.96	8,764.31	8,433.29	9,406.55
% Change over Time from 2000	–	33.5%	35.6%	121.7%	113.4%	138.0%
Category	**2018**	**2019**	**2020**	**2021**	**2022**	
Carbon dioxide (CO2)	7,256.98	7,104.11	6,321.22	8,172.17	7,224.62	
Methane (CH4)	537.17	458.90	422.54	448.12	531.14	
Nitrous oxide (N2O)	52.18	52.99	51.36	81.92	49.57	
Total	7,846.33	7,616.00	6,795.12	8,702.21	7,805.33	
% Change over Time from 2000	98.5%	92.7%	71.9%	120.2%	97.5%	

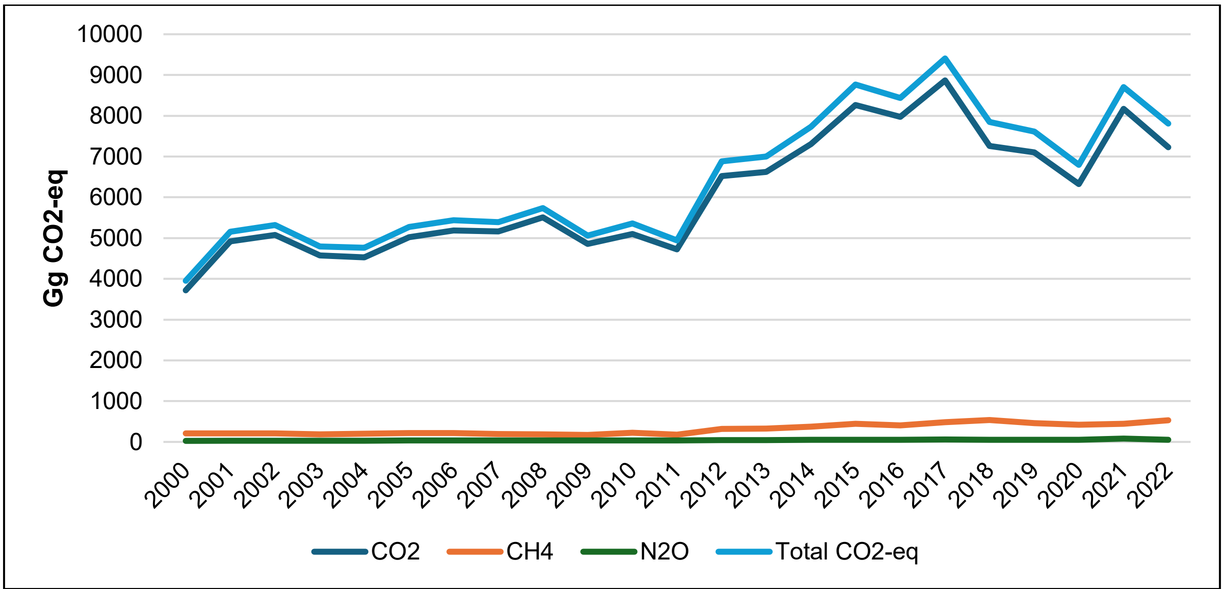

Figure.3-3: Trend in GHG emissions by gas (in Gg CO_2-eq.) between 2000 and 2022.

While the energy sector does release both methane and nitrous oxide gases, their overall contributions to the national totals are comparatively minor. Figure 3.4 illustrates the percentage contributions of CO2, CH4 (methane), and N2O (nitrous oxide) emissions to the national total energy emissions for the year 2022. CO2 contributes 92%, CH4 is the second contributor with 7%, and N2O is the least with 1%.

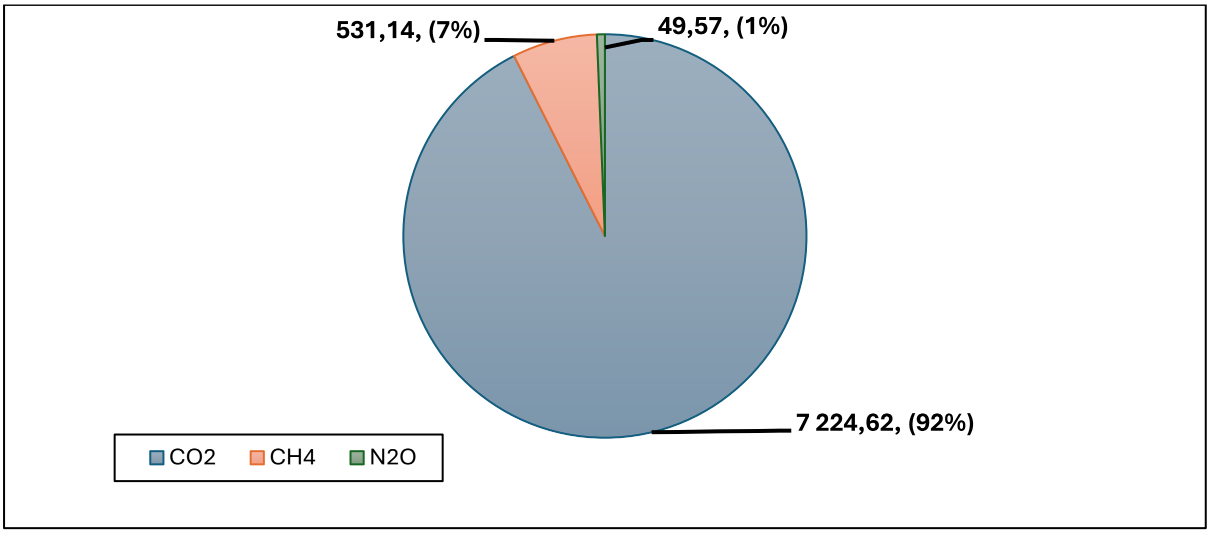

Figure.3-4: Percentage contributions of CO2, CH4, and N2O to national total energy emissions in 2022.

Figure 3.5 illustrates variations in greenhouse gas emissions within the energy sector, emphasizing key factors: (1) fuel combustion activities and (2) fugitive emissions. Total energy emissions surged from 3952.55 Gg CO2-eq in the base year of 2000 to 7805.33 Gg CO2-eq in 2022. Notably, emissions declined from 8764.31 Gg CO2-eq in 2015 to 7805.33 Gg CO2-eq in 2022. This decrease aligns with the initiation of operations at the Morupule B Power Plant around 2012, which increased the capacity by 600 MWh over the existing 132 MWh from Morupule A. However, following its commissioning, the plant experienced numerous downtimes, leading to reduced coal consumption and emissions, which contributed to the decline in emissions between 2015 and 2022. This relationship between capacity growth and operational issues underscores the intricate dynamics influencing emission trends in the energy sector.

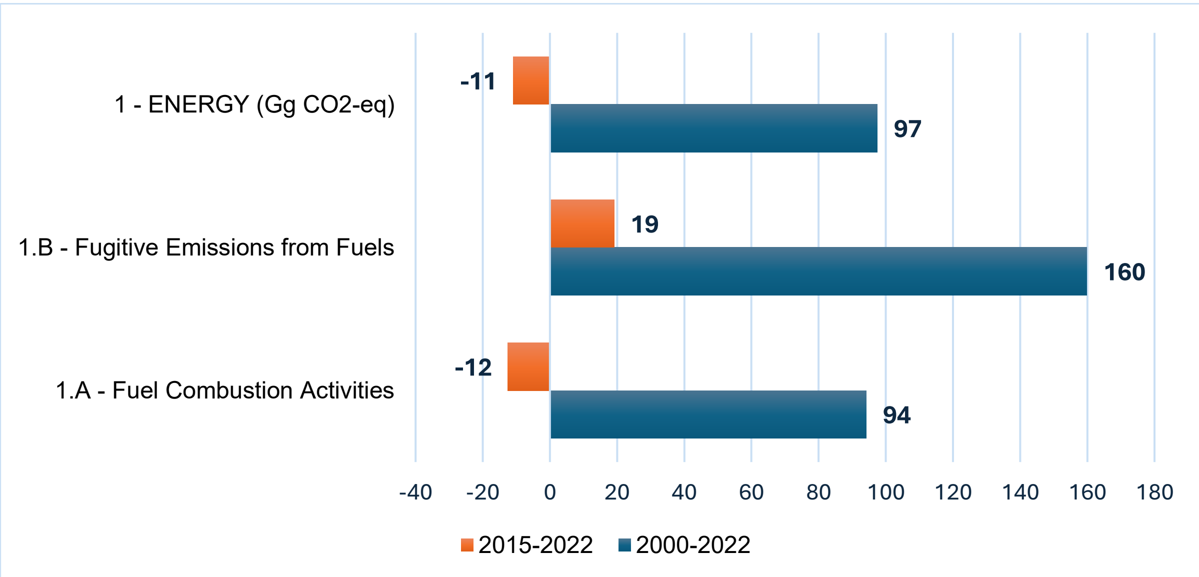

Figure.3-5: Variations (in %) energy emissions between 2000-2022 and 2015-2022.

Emissions of precursors (NOx, CO, NMVOC, and SO2) in the energy sector are considered negligible and are thus reported as NE.

3.1.3. General methodological issues of the sector

The GHG energy sector followed a sectoral approach to calculate emissions by adding emissions from different fuel consumption categories. This was done using default emission factors (D) and the Tier 1 (T1) methodology, which estimates emissions based on fuel usage and standard activity data. A summary of the methods and emission factors for the energy sector (1.A - Fuel Combustion Activities and 1.B - Fugitive emissions from fuels), along with an evaluation of the completeness of its emissions, is given in Table 3.4.

Table 3-4: Summary of methods and emission factors for the Energy Sector (1.A - Fuel Combustion Activities and 1.B - Fugitive emissions from fuels), along with an assessment of emission completeness.

Category	CO_2		CH4		N_2O		NOx	CO	NMVOC	SO_2
	Method applied	Emission factor	Method applied	Emission factor	Method applied	Emission factor				
1.A - Fuel Combustion Activities										
1.A.1 - Energy Industries	T1	D	T1	D	T1	D	NE	NE	NE	NE
1.A.2 - Manufacturing Industries and Construction	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
1.A.3 - Transport	T1	D	T1	D	T1	D	NE	NE	NE	NE
1.A.4 - Other Sectors	T1	D	T1	D	T1	D	NE	NE	NE	NE
1.A.5 - Non-Specified	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
1.B - Fugitive emissions from fuels										
1.B.1 - Solid Fuels	T1	D	T1	D	T1	D	NE	NE	NE	NE

3.2. Fuel combustion (CRT 1.A)

Emissions resulting from fuel combustion are directly linked to the burning of fossil fuels for energy. The main categories under Fuel Combustion Activities (1A) in the Energy Sector are: 1.A.1 - Energy Industries, 1.A.3 - Transport, and 1.A.4 - Other Sectors.

In terms of their contribution to fuel combustion emissions (Figure 3.6), the energy industries emit 3,591.77 Gg CO2-eq, followed by the transport sector with 2,420.58 Gg CO2-eq, and "Other Sectors" with 1,287.24 Gg CO2-eq. The respective contributions by percentage to fuel combustion activities are 49.2%, 33.2%, and 17.6%.

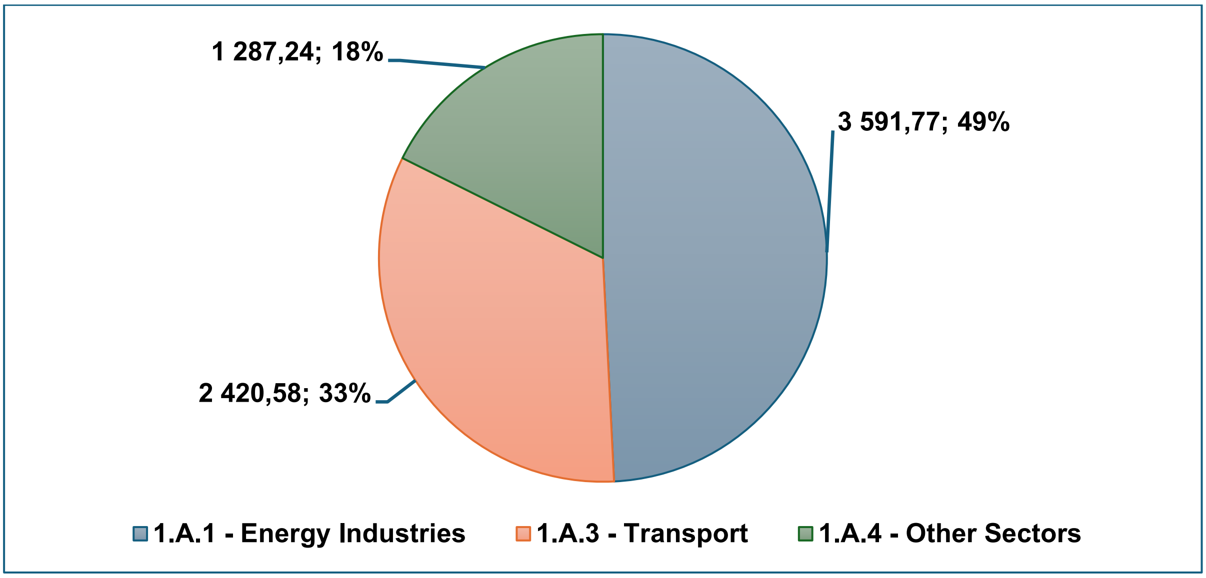

Figure.3-6: Primary national GHG emitter categories within Fuel Combustion Activities.

3.2.1 Description and trend of GHGs in the category

The emissions profile in Botswana clearly shows that the energy industries are the primary source of greenhouse gas emissions, largely due to the increased consumption of fossil fuels for electricity generation, a trend observed since year 2000. Notably, emissions from the energy industries have risen significantly, peaking in year 2015 due to the high carbon intensity of Botswana's electricity production sector; despite some fluctuations, these industries have consistently contributed the most to the country's overall emissions. Moreover, an analysis of greenhouse gas (GHG) emissions from fuel combustion activities reveals distinct trends across key sectors, as indicated in Table 3.6 and Figure 3.8, emphasizing the main factors driving the country's emission profile during the periods 2000-2022 and 2015-2022.

Botswana's Energy Industries (1.A.1) are the predominant source of rising fuel combustion emissions, primarily driven by an increased reliance on fossil fuels for electricity generation. This sector saw a 174.3% surge in emissions from 1,309.28 Gg CO2-eq in 2000 to 3,591.77 Gg CO2-eq in 2022. However, analysis from 2015 to 2022 reveals a 29.4% reduction, with emissions falling from 5,088.95 Gg CO2-eq. This reduction in emissions from energy production was a due persistent downtime episode in electricity production during this specific seven-year interval, despite the long-term increase.

Table 3-5: Percentage contribution of the category to the sector's total emissions in the latest inventory year and its percentage change over time (Gg CO2 eq): 2000-2022.

Category	2000	2005	2010	2015	2016	2017
1.A.1 - Energy Industries	1309.19	2414.88	2422.23	5111.71	3971.69	4501.25
1.A.3 - Transport	1315.57	1592.67	2054.81	2444.09	2489.18	2569.62
1.A.4 - Other Sectors	1133.49	1066.16	680.11	784.58	1688.47	1880.96
Total	3758.25	5073.71	5157.15	8340.38	8149.34	8951.83
% Change over time from 2000	–	35.0%	37.2%	121.9%	116.8%	138.2%

Category	2018	2019	2020	2021	2022
1.A.1 - Energy Industries	2843.93	3738.78	2657.60	2924.82	3591.68
1.A.3 - Transport	2823.20	2774.93	2996.66	3252.35	2420.43
1.A.4 - Other Sectors	1669.80	669.11	746.03	2090.24	1287.18
Total	7336.93	7182.82	6400.29	8267.41	7299.29
% Change over time from 2000	95.2%	91.1%	70.3%	120.0%	94.2%

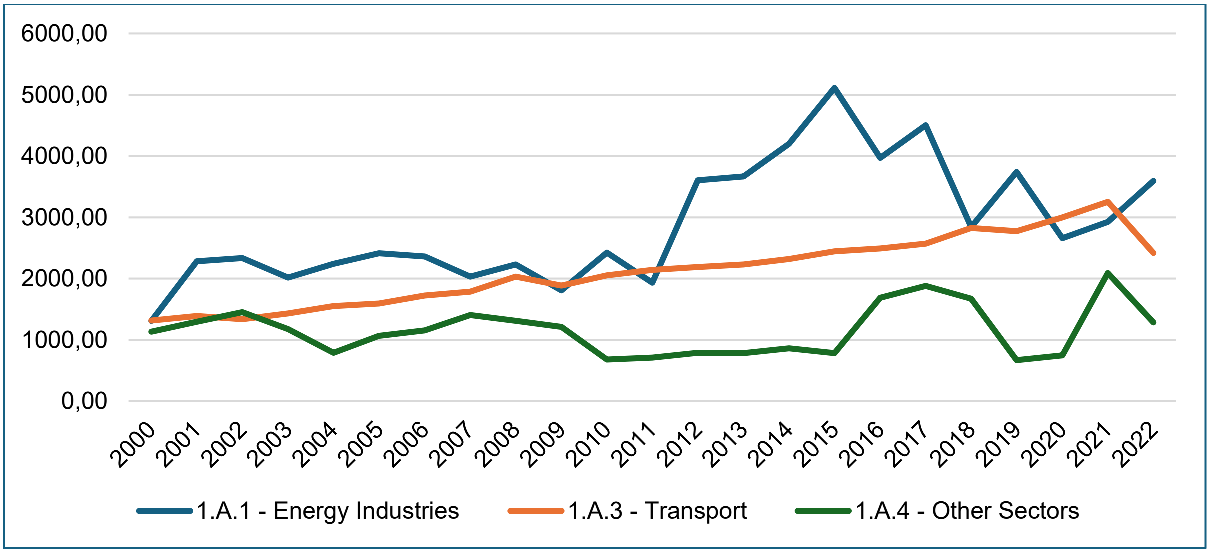

Figure.3-7: Trends in total GHG emissions (in CO2-eq.) from sub-sectors within the Fuel Combustion Activities: 1.A.1 - Energy industries, 1.A.3 - Transport, and 1.A.4 - Other sectors.

The Transport sector (1.A.3) also demonstrates considerable growth in emissions. Between 2000 and 2022, the sector's emissions increased by 84.0%, from 1,315.65 Gg CO2-eq to 2,420.58 Gg CO2-eq. This consistent rise is largely attributed to factors such as an increase in the number of vehicles, particularly parallel imports of older, less fuel-efficient models, driven by affordability. In contrast to the Energy Industries, the Transport sector showed a marginal increase of 1.1% from 2015 to 2022, growing from 2,394.15 Gg CO2-eq. This indicates a more stable, albeit still upward, trend in recent years, likely influenced by sustained road transportation activities.

Emissions from “Other Sectors" (1.A.4) showed a 13.6% increase from 1,133.53 Gg CO2-eq in 2000 to 1,287.24 Gg CO2-eq in 2022. This gradual rise often reflects energy insecurity issues, such as insufficient electricity supply and distribution, alongside climate-sensitive agricultural activities like irrigation and machinery use, which are impacted by irregular rainfall and droughts. Notably, between 2015 and 2022, "Other Sectors" experienced a significant 65.3% increase in emissions, rising from 778.78 Gg CO2-eq.

Table 3-6: Variation between the latest inventory year of the previous inventory and the latest inventory year of the current inventory

Categories	EMISSIONS (Gg CO2-eq) OVER INVENTORY YEARS							
	Base Year	Latest Year	Current Year (2022)				% VARIATION	
	2000	2015	CO2	CH4	N2O	TOTAL	2000-2022	2015-2022
1.A - Fuel Combustion Activities	3,758.16	8,261.88	7,222.80	26.94	49.56	7,299.29	94.2%	-11.7%
1.A.1 - Energy Industries	1,309.28	5,088.95	3,575.60	1.06	15.11	3,591.77	174.3%	-29.4%
1.A.2 - Manufacturing Industries and Construction	NA	NA	NA	NA	NA	NA	NA	NA
1.A.3 - Transport	1,315.65	2,394.15	2,368.34	20.44	31.80	2,420.58	84.0%	1.1%
1.A.4 - Other Sectors	1,133.53	778.78	1,278.87	5.46	2.92	1,287.24	13.6%	65.3%
1.A.5 - Non-Specified	NO	NO	NO	NO	NO	NO	NO	NO

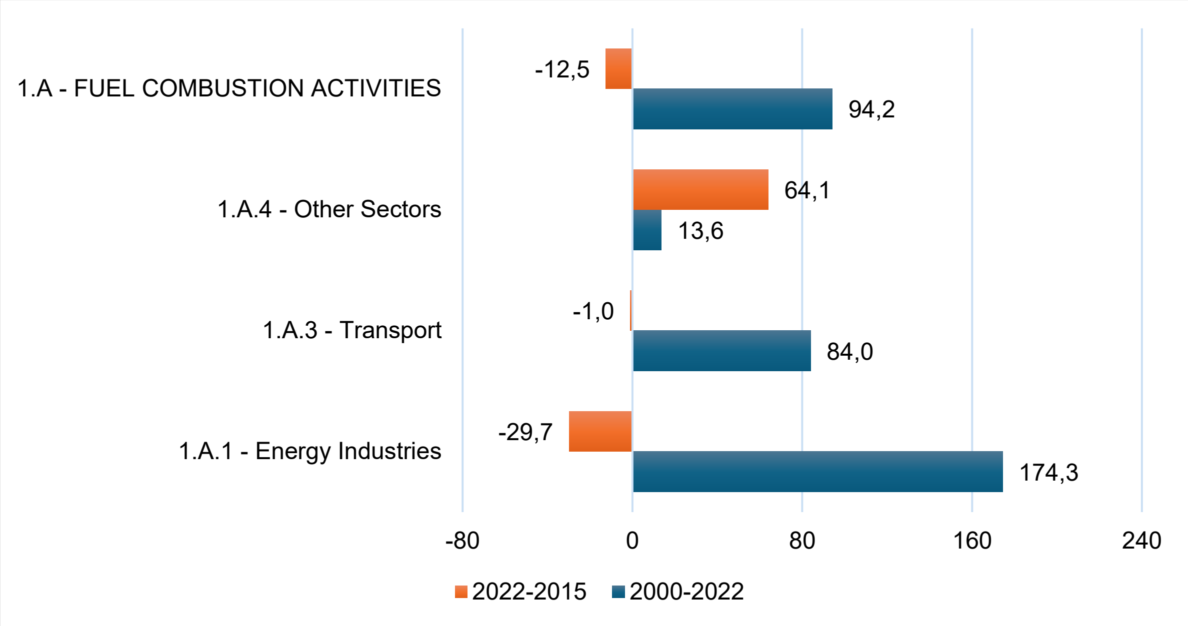

Figure.3-8: Variation (in %) between the latest inventory year of the previous inventory and the latest inventory year of the current inventory.

It is important to recognize that the main contributors to Botswana's "Other Sectors" are the Commercial /Institutional, Residential, and Agriculture /Forestry /Fishing /Fish Farms subcategories. Notably, the Agriculture/Forestry/Fishing/Fish Farms segments are highly influenced by climatic factors like fluctuations in rainfall, while the Commercial/Institutional and Residential subsectors tend to react more to developments in the energy sector.

Botswana's total emissions from fuel combustion activities (1.A) nearly doubled between 2000 and 2022, rising by 94.2% from 3,758.16 Gg CO2-eq to 7,299.29 Gg CO2-eq. However, a more recent period from 2015 to 2022 saw an 11.7% decline, largely attributed to reduced emissions from the Energy Industries. Despite this short-term reduction, the long-term upward trajectory of Botswana's fuel combustion emissions is predominantly driven by the expansion of electricity generation within the energy sector and the consistent growth of the transport sector. Additionally, evolving dynamics within "Other Sectors" illustrate how factors like energy access, agricultural practices, and climate vulnerability contribute to the national greenhouse gas inventory.

3.2.2 Methodological issues of the category

Emissions from the Fuel Combustion Activities category were calculated using default emission factors and the Tier 1 methodology. Table 3.7 provides a summary of the methods and emission factors for the subcategories (1.A.1 - Energy Industries, 1.A.3 - Transport, and 1.A.4 - Other Sectors), as well as an assessment of the completeness of these emissions.

Table 3-7: Methods and emission factors for the Fuel Combustion Activities category.

Category	CO_2		CH4		N_2O		NOx	CO	NMVOC	SO_2
	Method applied	Emission factor	Method applied	Emission factor	Method applied	Emission factor				
1.A.1 - Energy Industries										
a - Main Activity Electricity and Heat Production a.i - Electricity Generation	T1	D	T1	D	T1	D	NE	NE	NE	NE
1.A.3 - Transport										
a - Civil Aviation a.ii - Domestic Aviation	T1	D	T1	D	T1	D	NE	NE	NE	NE
b - Road Transportation b.i - Cars	T1	D	T1	D	T1	D	NE	NE	NE	NE
c - Railways	T1	D	T1	D	T1	D	NE	NE	NE	NE
1.A.4 - Other Sectors										
a - Commercial/Institutional	T1	D	T1	D	T1	D	NE	NE	NE	NE
b - Residential	T1	D	T1	D	T1	D	NE	NE	NE	NE
c - Agriculture/Forestry/Fishing/Fish Farms c.i - Stationary	T1	D	T1	D	T1	D	NE	NE	NE	NE

3.2.2.1 Activity data of the category

Table 3.8 summarizes Energy Industries activity data, reporting total fuel combustion consumption of 88,542.212 TJ, comprising liquid fuels 50,041.838 TJ, solid fuels 38,493.6 TJ and biomass 6.774 TJ, all expressed using NCV for inventory reporting.

Table 3-8: Activity data of the Fuel Combustion Activities category

GHG Source and Sink	Aggregate Activity Data	
	Consumption (in TJ)	Conversion Factor Type
1.A - Fuel Combustion Activities	88,542.2	Net Calorific Value (NCV)
Liquid Fuels	50,041.8	Net Calorific Value (NCV)
Solid Fuels	38,493.6	Net Calorific Value (NCV)
Biomass	6.7	Net Calorific Value (NCV)
1.A.1 - Energy Industries	38,164.22	Net Calorific Value (NCV)
Liquid	367.22	Net Calorific Value (NCV)
Solid	37.80	Net Calorific Value (NCV)
1.A.3 - Transport	33,004.39	Net Calorific Value (NCV)

GHG Source and Sink	Aggregate Activity Data	
	Consumption (in TJ)	Conversion Factor Type
Liquid	33,004.39	Net Calorific Value (NCV)
1.A.3.a - Domestic aviation	44.1	Net Calorific Value (NCV)
1.A.3.b - Road transport	32,760.8	Net Calorific Value (NCV)
Gasoline	20,643.8	Net Calorific Value (NCV)
Diesel oil	12,126	Net Calorific Value (NCV)
1.A.3.c - Railways	190.49	Net Calorific Value (NCV)
Liquid	190.49	Net Calorific Value (NCV)
1.A.4 - Other Sectors	17,067.00	Net Calorific Value (NCV)
Liquid fuels	16,363.63	Net Calorific Value (NCV)
Solid fuels	696.60	Net Calorific Value (NCV)
Biomass	6.77	Net Calorific Value (NCV)
1.A.4.a - Commercial /Institutional	16,547.9	Net Calorific Value (NCV)
Liquid fuels	15,928.7	Net Calorific Value (NCV)
Solid fuels	619.2	Net Calorific Value (NCV)
1.A.4.b - Residential	7.4	Net Calorific Value (NCV)
Liquid fuels	0.628	Net Calorific Value (NCV)
Biomass	6.774	Net Calorific Value (NCV)
1.A.4.c - Agriculture /Forestry /Fish	511.7	Net Calorific Value (NCV)
Liquid fuels	434.3	Net Calorific Value (NCV)
Solid fuel	77.4	Net Calorific Value (NCV)
1.A.4 - Other	306.6	Net Calorific Value (NCV)
Liquid fuels	306.3	Net Calorific Value (NCV)

Table 3.9 provides a list of the Energy Industries activity data of by fuel (or GHG source) for the time series: 2000 to 2022.

Table 3-9: Fuel Combustion activity data of fuel for the time series: 2000 to 2022 (in TJ)

Year	Liquid Fuels (TJ)	Solid Fuels (TJ)	Biomass (TJ)
2000	23,255.7	21,723.6	24.5
2001	24,920.9	33,204.6	24.5
2002	26,366.6	33,798.0	24.5
2003	27,788.4	27,451.2	24.5
2004	26,351.6	27,993.0	23.6
2005	27,424.4	32.379.0	8.8
2006	29,695.6	32,353.2	8.8
2007	31,223.4	30.908.4	8.8
2008	35,075.8	31.656.6	8.8
2009	32,552.6	26,625.6	8.8
2010	35.373.7	27,064.2	8.8
2011	36,645.6	22,033.2	8.9
2012	37,790.0	40,144.8	7.7
2013	38,231.9	40.789.8	8.6
2014	39.906.4	46,852.8	8.9
2015	41,309.5	55,908.6	9.2
2016	54,605.3	42,492.6	6.5
2017	58,856.7	48,710.4	11.6
2018	60,307.4	30,624.6	25.4
2019	46,649.6	40,015.8	5.3
2020	51,273.1	28,638.0	5.5
2021	54.853.8	45,562.8	6.2
2022	50,041.8	38,493.6	6.8

3.2.2.2 Emission factors applied in the category

Table 3.10 lists implied CO2, CH4 and N2O emission factors for liquid fuels, solid fuels and biomass,

Table 3-10: Emission factors applied in the Fuel Combustion Activities category

GHG Source and Sink	Implied Emission Factors		
	CO2 (in Ton/TJ)	CH4 (in kg/TJ)	N2O (in kg/TJ)
1.A - Fuel Combustion Activities			
Liquid Fuels	71.7	17.8	2.6
Solid Fuels	94.6	1.7	1.5
Biomass	112	300	4
1.A.1 - Energy Industries			
Liquid fuels	NE	NE	NE
Solid fuels	94.6	1	1.5
1.A.3 - Transport			
Liquid	71.09	22.1	3.6
1.A.3.a - Domestic aviation			
1.A.3.b - Road transport			
Gasoline	69.3	33.0	3.2
Diesel oil	74.1	3.9	3.9
1.A.3.c - Railways			
Liquid Fuels	74.1	4.15	28.6
1.A.4 - Other Sectors			
Liquid fuels	74.13	9.97	0.6
Solid fuels	94.6	42.22	1.5
Biomass	112	300	4
1.A.4.a - Commercial / Institutional			
Liquid fuels	74.16	9.99	0.6
Solid fuels	94.6	10	1.5
1.A.4.b - Residential			
Liquid fuels	66.97	7.2	0.32
Biomass	112	300	4
1.A.4.c - Agriculture / Forestry / Fish			
Liquid fuels	72.9	9.46	0.55
Solid fuel	94.6	300	1.5
1.A.4 - Other			
Liquid fuels	71.5	0.5	2

3.2.3 Comparison of the sectoral approach with the reference approach

The reference approach (RA) is a top-down method using national fuel supply statistics multiplied by default or country-specific implied emission factors to estimate CO2 emissions; it captures fuel flows across the whole economy. The sectoral approach (SA) is bottom-up, summing emissions from individual end-use sectors (energy industries, transport, residential, etc.) using activity data and sector-specific emission factors. The reference approach provides completeness and consistency with national fuel balances but can mask sectoral allocation issues; sectoral approach yields more detailed sectoral attribution and supports policy analysis but depends on the quality and coverage of sectoral activity data. Comparing them assesses consistency, identifies missing sources, and helps quantify uncertainty.

Table 3.11 compares the national CO2 emissions from fuel combustion with the estimates produced using the reference approach for 2022.

Table 3-11: CO2 Emissions by Reference and Sectoral Approaches 2022

Fuel Type	Reference Approach			Sectoral Approach		Difference	
	Apparent Consumption (TJ)	Apparent Consumption (excluding non-energy use, reductants and feedstocks) (TJ)	CO2 Emissions (Gg)	Energy Consumption (TJ)	CO2 Emissions (Gg)	Energy Consumption (%)	CO2 Emissions (%)
Liquid Fuels	42,390.80	42,337.30	3,004.79	50,041.84	3,581.31	-15.29	-16.10
Solid Fuels	28,142.64	28,142.64	2,609.05	38,493.60	3,641.49	-26.89	-28.35
Gaseous Fuels	NA	NA	NA	NA	NA	NA	NA
Other Fossil Fuels	NA	NA	NA	NA	NA	NA	NA
Peat	NA	NA	NA	NA	NA	NA	NA
Total	**70,533.44**	**70,533.44**	**5,613.83**	**88,535.44**	**7,222.80**	**-20.33**	**-22.28**

3.2.3.1 Description and trend of CO2 from the approaches comparison

Emissions from fuel combustion were estimated using the Sectoral Approach, with the Reference Approach calculated as a secondary check. Energy balance data for 2000–2015 were taken from IEA, while for 2016–2022, energy balance data was sourced from AFREC.

From 2000–2022 both approaches show rising CO2 emissions, but the Sectoral Approach (SA) is consistently higher than the Reference Approach (RA). From 2000–2011 the gap is moderate; from 2012–2015 both rise sharply while SA exceeds RA by a growing margin. SA peaks around 2016–2017 then fluctuates, whereas RA increases more steadily. Post-2017 the gap narrows somewhat but SA remains above RA through 2022.

Table 3.12 summarizes CO2 emissions (Gg CO2) estimated by the sectoral and reference approaches, and Figure 3.9 illustrates the time series of these estimates from 2000 to 2022.

Table 3-12: CO2 emissions obtained using reference and sectoral approaches (Gg CO2)

Method	**2000**	**2005**	**2010**	**2015**	**2016**	**2017**
Reference Approach	4,015.20	4,438.35	4,975.54	7,951.99	5,072.27	6,198.38
Sectoral Approach	3,717.66	5,022.04	5,100.18	8,260.81	7,969.85	8,866.39
Difference	297.54	-583.69	-124.64	-308.82	-2,897.58	-2,668.01
% Difference	8.00	-11.62	-2.44	-3.74	-36.36	-30.09
Method	**2018**	**2019**	**2020**	**2021**	**2022**	
Reference Approach	4,830.36	5,505.05	5,549.37	5,887.81	5,613.83	
Sectoral Approach	7,255.16	7,102.55	6,319.80	8,170.68	7,222.80	
Difference	-2,424.80	-1,597.50	-770.43	-2,282.87	-1,608.97	

Method	2000	2005	2010	2015	2016	2017
% Differences	-33.42	-22.49	-12.19	-27.94	-22.28	

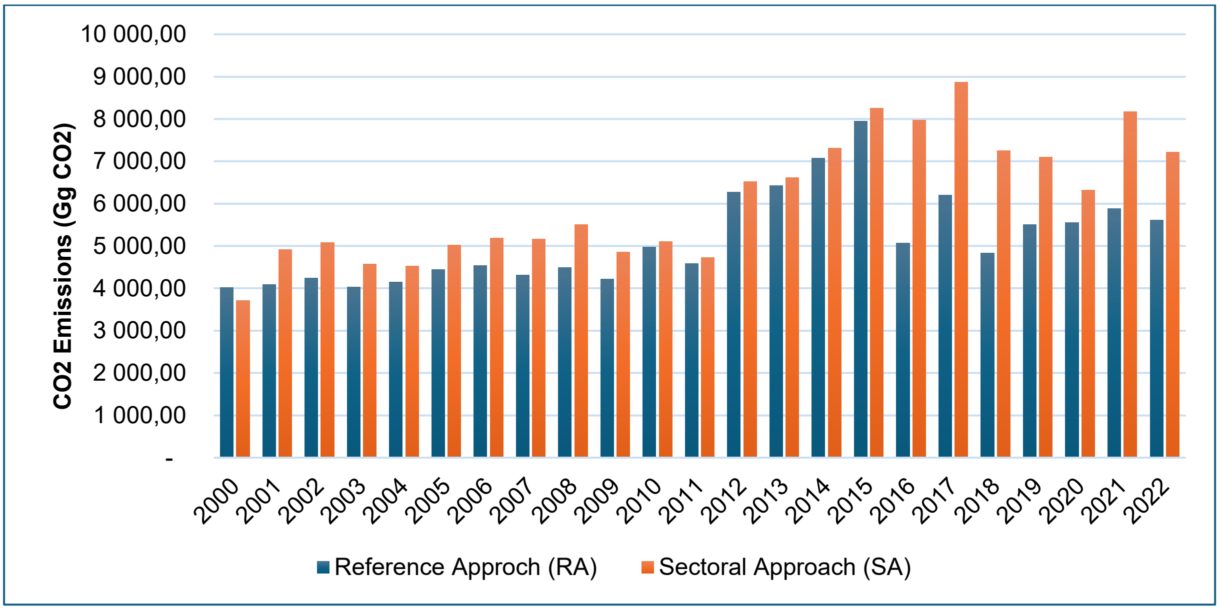

Figure.3-9: Time series of CO_2 emissions obtained using reference and sectoral approaches (estimates Gg CO_2) for 2000 to 2022.

3.2.3.2 Methodological issues of the reference approach

The differences in energy consumption and CO_2 emissions between Reference and Sectoral Approach are calculated within the IPCC inventory software and the data is obtained from table 1.A(c) (comparison of CO_2 emissions from fuel consumption). The energy consumption and CO_2 emissions gap between the reference and sectoral approaches is calculated as $[(RA - SA) / SA] \times 100\%$, where RA = Reference Approach and SA = Sectoral Approach (refer to Figure 3.10).

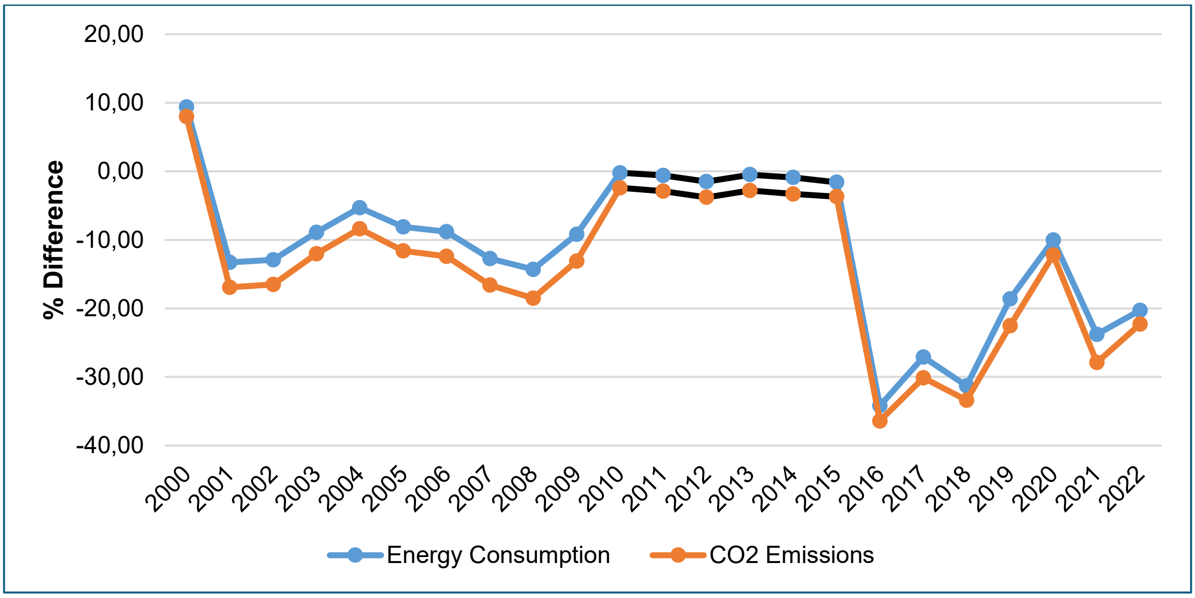

Figure.3-10: Time series of energy consumption and CO2 emissions % differences between Reference and Sectoral Approaches, for 2000 to 2022.

According to the 2006 IPCC Guidelines, the difference between the two methods is usually small (about 5% or less). If the approaches diverge by more than 5%, a description of the fuel-combustion subsector and comparisons between CO2 emissions calculated by the sectoral approach with those from the reference approach are given.

The two approaches agree only in the 2010–2015 window; before and especially after 2015 the Sectoral approach reports substantially lower emissions than the Reference approach, indicating methodological and/or input-data changes (most likely linked to energy balance source differences and production reporting). The discrepancies between the approaches (of more than 5 per cent) are possibly due to:

- A significant change in how data was captured or reported between the IEA and AFREC energy balances; production figures dropped notably from 2016–2022, especially bituminous coal.
- Lack of data on end-user fuel stock fluctuations; stock treatment varies by method within the Sectoral Approach.
- Inconsistencies from changing activity data sources across the time series and occasional use of extrapolation.
- Errors in allocating fuel volumes (fuels converted to secondary products or consumed within the energy sector).

The comparison data

Approach comparison of apparent consumption by fuel type is given in Table 3.13.

Table 3-13: Comparison of consumption by fuel types (in TJ)

Year	Liquid Fuels (TJ)		Solid Fuels (TJ)	
	Reference	Sectoral	Reference	Sectoral
2000	24,784.00	23,255.7	21,723.6	21,723.60

Year	Liquid Fuels (TJ)		Solid Fuels (TJ)	
	Reference	Sectoral	Reference	Sectoral
2001	26,398.50	24,920.9	33,204.6	33,204.60
2002	27,799.70	26,366.6	33,798.0	33,798.00
2003	29,248.10	27,788.4	27,451.2	27,451.20
2004	27,941.80	26,351.6	27,993.0	27,993.00
2005	29,545.20	27,424.4	32.379.0	32,379.00
2006	31,741.90	29,695.6	32,353.2	32,353.20
2007	32,874.80	31,223.4	30.908.4	30,908.40
2008	36,989.00	35,075.8	31.656.6	31,656.60
2009	34,684.10	32,552.6	26,625.6	26,625.60
2010	36,829.90	35.373.7	27,064.2	27,064.20
2011	38,060.00	36,645.6	22,033.2	22,033.20
2012	39,259.10	37,790.0	40,144.8	40,144.80
2013	40,063.30	38,231.9	40.789.8	40,789.80
2014	41,818.70	39.906.4	46,852.8	46,852.80
2015	42,337.30	41,309.5	55,908.6	55,908.60
2016	39,140.34	54,605.3	42,492.6	42,492.60
2017	49,119.03	58,856.7	48,710.4	48,710.40
2018	44,002.36	60,307.4	30,624.6	30,624.60
2019	47,220.18	46,649.6	40,015.8	40,015.80
2020	51,062.41	51,273.1	28,638.0	28,638.00
2021	55,302.73	54.853.8	45,562.8	45,562.80
2022	42,390.80	50,041.8	38,493.6	38,493.60

3.2.4 International bunkers

Emissions from international bunkers for aviation are excluded from the national total and are reported separately as a memo item in CRT 1.D, following the IPCC Guidelines.

3.2.5 Feedstocks and no-energy use of fuels

Feedstocks and non-energy use of fuels are reported under the IPPU sector (CTR 2).

3.2.6 Energy industries (CRT 1.A.1)

The Energy Industries sub-category encompasses fuel combustion activities from the Main Activity of Electricity and Heat Production (1.A.1.a), which is exclusively fuelled by the Electricity Generation disaggregation (1.A.1.a.i).

Table 3.7 presents the methods and emission factors applied to all categories within the Fuel Combustion Activities, including at the sub-category level. The emissions listed were identified as key categories in the 2000-2022 inventory. Emissions from 1.A.1.a - Electricity and Heat Production (solid) were assessed using a Tier 1 method for the inventories of 2000-2015 and 2000-2015. Therefore, there is a necessity to enhance the methodology to adopt a higher tier for these sub-categories in future inventories. Activity data and emission factors of the Energy Industries sub-category are reported in tables 3.8 and 3.10, respectively, under the Fuel Combustion Activities category section.

The activity data for the Energy industries sub-category was primarily sourced from the International Energy Agency (IEA) online data service for the emission calculations from 2000 to 2015, and from the African Energy Commission (AFREC) for the emissions from 2000 to

2022. This data pertains to 1.A.1.a.i - Electricity Generation (solid fuels) and the Botswana Power Corporation for 1.A.1.a.i - Electricity Generation (liquid fuels).

3.2.6.1 Uncertainty assessment and time-series consistency of the subcategory

The uncertainties assigned to the Activity Data (AD) and Emission Factors (EF) for CO2, CH4 and N20 for source category 1A Fuel combustion are presented in the Table 3.14. Uncertainties were based on expert judgement.

Table 3-14: Uncertainty levels assigned for Fuel Consumption Activities

2006 IPCC Categories	Gas	Uncertainty assigned (%): Liquid Fuels	
		AD	EF
1.A.3.a.i International Aviation	CO2	±5.0	±15.0
	CH4	±5.0	±50.0
	N2O	±5.0	±75.0
1.A.3.a.ii Domestic Aviation	CO2	±5.0	±15.0
	CH4	±5.0	±50.0
	N2O	±5.0	±75.0
1.A.3.b.i Cars	CO2	±5.0	±15.0
	CH4	±5.0	±50.0
	N2O	±5.0	±75.0
1.A.3.c Railways	CO2	±5.0	±15.0
	CH4	±5.0	±50.0
	N2O	±5.0	±75.0

3.2.6.2 Subcategory-specific recalculations

Not applicable.

3.2.6.3 Subcategory-specific planned improvements

No planned improvement is envisaged.

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

No Manufacturing industries and construction are reported in this submission.

3.2.8 Transport (CRT 1.A.3)

The Transport sub-category encompasses fuel combustion activities from various transportation modes, including:

- 1.A.3.a - Civil aviation, which covers domestic flights, with international aviation noted as a memo item.
- 1.A.3.b - Road transportation, incorporating agricultural vehicles on paved roads, as well as off-road and mobile machinery.
- 1.A.3.c - Railways, which includes both freight and passenger services.

Emissions from military aviation and navigation have not been calculated and are not represented in the inventory due to insufficient data.

Table 3.7 outlines the methods and emission factors utilized across all categories within the Transport sector, including at the sub-category level. The emissions reported were classified as key categories in the 2000-2022 inventory. Emissions from 1.A.3.b - Road transportation were evaluated using a Tier 1 method for the **2000-2015 and 2015-2022** inventories. Consequently, there is a need to improve the methodology to implement a higher tier for these sub-categories in future inventories. Activity data and emission factors of the Transport sub-category are reported in tables 3.8 and 3.10, respectively, under the Fuel Combustion Activities category section.

The activity data for the Transport sub-category was mainly sourced from the International Energy Agency (IEA) online data service for calculating emissions from 2000 to 2015, and from the African Energy Commission (AFREC) for emissions calculations from 2000 to 2022, covering both 1.A.3.a.ii - Domestic Aviation and 1.A.3.b.i - Cars. For the 1.A.3.c - Railways section, the activity data was obtained from fuel consumption records supplied by the Botswana Railway services.

3.2.9 Other sectors (CRT 1.A.4)

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

- 1.A.4.a - Commercial/Institutional, which covers all fuel combustion in commercial and institutional facilities.
- 1.A.4.b - Residential, which includes all fuel combustion from households.
- 1A.4.c - Agriculture/Forestry/Fishing/Fish Farms, which incorporates fuel combustion related to agriculture, forestry, fishing, and fish farming.

Table 3.7 details the methods and emission factors utilized across all categories within the 1.A.4 - Other Sectors category, including at the sub-category level. The activity data for the Transport sub-category was primarily sourced from the International Energy Agency (IEA) online data service for the calculation of emissions from 2000 to 2015, and from the African Energy Commission (AFREC) for emissions calculations from 2000 to 2022. This data encompasses all disaggregated sectors: 1.A.4.a - Commercial/Institutional, 1.A.4.b - Residential, and 1.A.4.c - Agriculture/Forestry/Fishing/Fish Farms, with contributions solely from the Stationary (1.A.4.c.i) sources. Activity data and emission factors of the Other Sectors sub-category are reported in tables 3.8 and 3.10, respectively, under the Fuel Combustion Activities category section.

3.2.10 Other (not specified elsewhere) (CRT 1.A.5)

None for the category are reported in this submission.

3.3. Fugitive emissions from fuels (CRT 1.B)

Botswana's emissions from 1.B - Fugitive emissions from fuels are solely associated with the release of CO2 and CH4 gases from Solid Fuels (1.B.1). When examined in more detail, these emissions stem primarily from Mining (1.B.1.a.i.1) and the underground mining method of coal handling, along with a minimal amount of CH4 emissions from post-mining seam gas emissions (1.B.1.a.i.2). Together, these emissions represent about 7% of the national energy sector's emissions for the 2022 inventory.

Regarding their impact on fugitive emissions from fuels (Figure 3.11), Mining (1.B.1.a.i.1) produces 463.48 Gg CO2-eq, while post-mining seam gas emissions (1.B.1.a.i.2) contribute 41.55 Gg CO2-eq. Their respective contributions to fugitive emissions from fuels are 91.8% and 8.2%.

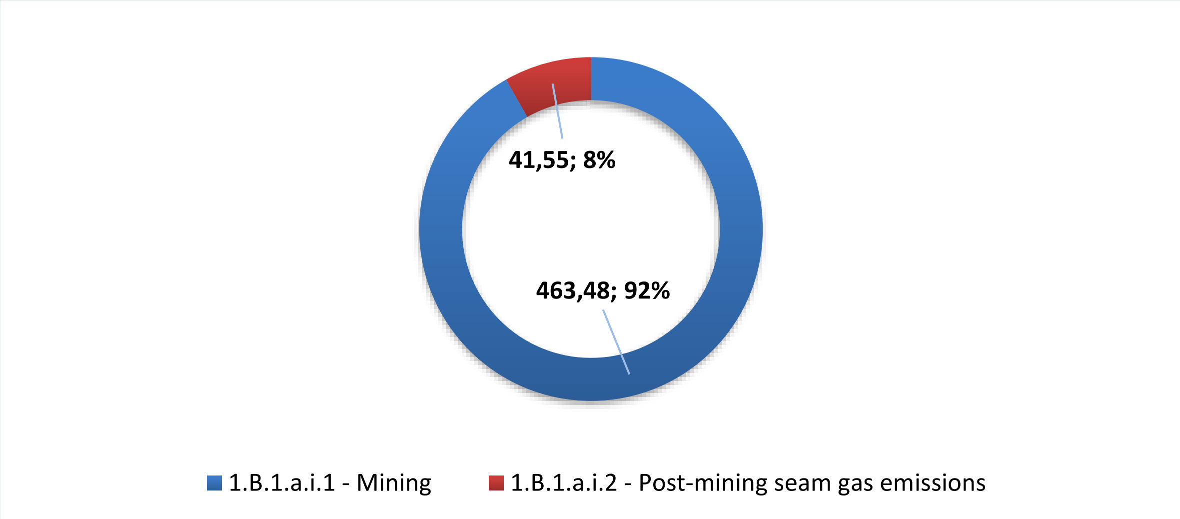

Figure.3-11: Contributions of the Mining and the Post-mining seam gas emissions to Fugitive emissions from fuels for 2022.

3.3.1. Description and trend of GHGs in the category

Fugitive emissions from fuels in Botswana, which are mainly from the mining subsector (1.B.1.a.i.1) from 2000 to 2022, reveals distinct trends and variations. According to Table 3.15 and Figure 3.12, emissions from mining exhibited initial stability followed by fluctuations.

Table 3-15: Fugitive emission from fuels (Gg CO2 eq): 2000-2022.

Category	2000	2005	2010	2015	2016	2017
1.B.1.a.i.1 – Mining	178.34	185.48	186.12	389.06	382.37	417.31
1.B.1.a.i.2 - Post-mining seam gas emissions	15.99	16.63	16.69	34.88	31.59	37.41
Total	194.33	202.11	202.81	423.94	413.96	454.72
% Change over time from 2000	–	4.0%	4.4%	118.2%	113.0%	134.0%
Category	**2018**	**2019**	**2020**	**2021**	**2022**	
1.B.1.a.i.1 – Mining	467.51	397.55	362.36	380.67	463.47	
1.B.1.a.i.2 - Post-mining seam gas emissions	49.91	35.64	32.48	34.13	41.55	
Total	517.42	433.19	394.84	414.80	505.02	
% Change over time from 2000	166.3%	122.9%	103.2%	113.5%	159.9%	

From 2000 to 2011, there was a gradual decrease in emissions from 178.34 Gg CO2-equivalent to 148.48 Gg CO2-equivalent. However, in 2012, emissions sharply increased to 273.92 Gg CO2-equivalent, marking a pivotal change. The subsequent years demonstrated varying trends, with emissions reaching a peak of 467.51 Gg CO2-equivalent in 2018. This peak reflected a significant rise of 166.3% compared to 2000. The emissions then fluctuated, showing decreases and increases, ending in 463.47 Gg CO2-equivalent by 2022.

Figure 3.12 clearly shows that the trends in Fugitive emissions from fuels are influenced by those in the Energy Industries. This correlation is due to Botswana's heavy reliance on coal burning for energy, resulting in emissions patterns that align with the fugitive emissions from coal mining and handling.

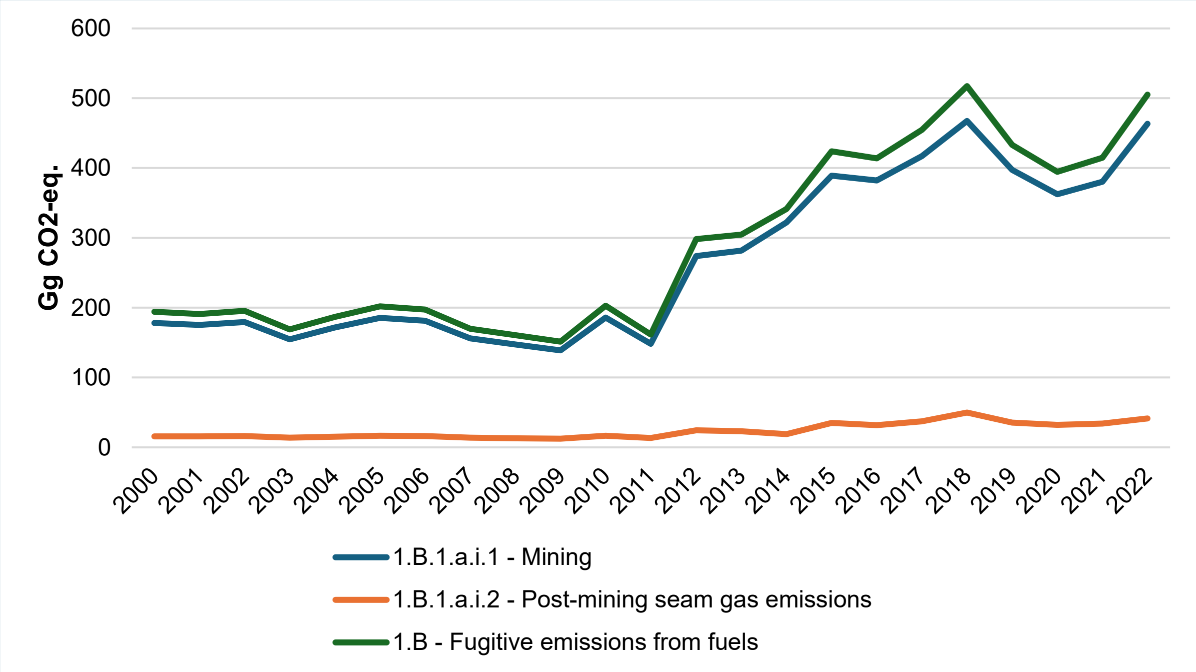

Figure.3-12: Trends in total GHG emissions from the Mining and the Post-mining seam gas emissions to Fugitive emissions from fuels: 2000-2022.

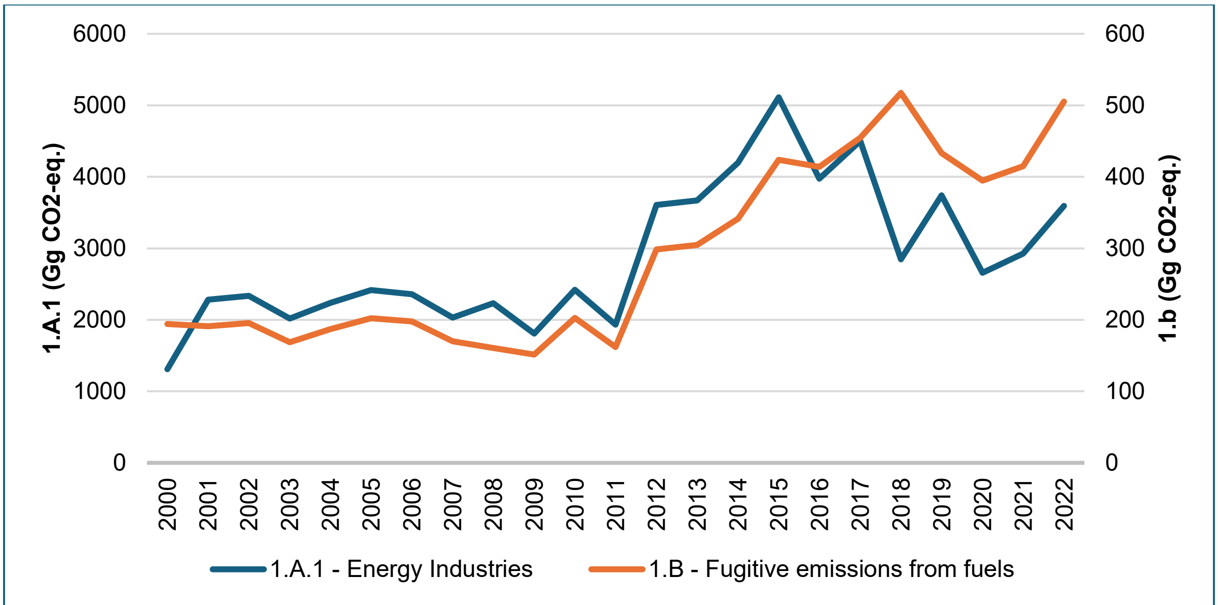

Figure.3-13: Comparisons in emissions trends for the Energy Industries and the Fugitive emissions from fuels: 2000-2022.

Table 3.16 displays the differences between the latest inventory year of the previous inventory and that of the current inventory for fugitive emissions.

Table 3-16: Differences between the most recent inventory year of the previous data and the latest inventory year of the current data.

Categories	EMISSIONS (Gg CO2-eq) OVER INVENTORY YEARS							
	Base Year	Latest Year	Current Year (2022)				% VARIATION	
	2000	2015	CO2	CH4	N2O	TOTAL	2000-2022	2015-2022
1.B - Fugitive emissions from fuels	194.32	16.61	1.81	503.22	NE	505.03	159.9%	2,941.2%
1.B.1 - Solid Fuels	194.32	16.61	1.81	503.22	NE	505.03	159.9%	2,941.2%
1.B.2 - Oil and Natural Gas	NO	NO	NO	NO	NO	NO	NO	NO
1.B.3 - Other emissions from Energy Production	NO	NO	NO	NO	NO	NO	NO	NO

The examination of greenhouse gas (GHG) emissions from fugitive emissions related to solid fuels reveals significant variations over two timeframes (Figure 3.14). Between 2000 and 2022, emissions increased moderately by 159.9%, while the period from 2015 to 2022 saw a dramatic rise of 2,941.2%. Additionally, Figure 3.11 highlights that these fugitive emissions trends are closely tied to the Energy Industries, reflecting Botswana's heavy dependence on coal, which influences the emissions patterns tied to coal mining and handling.

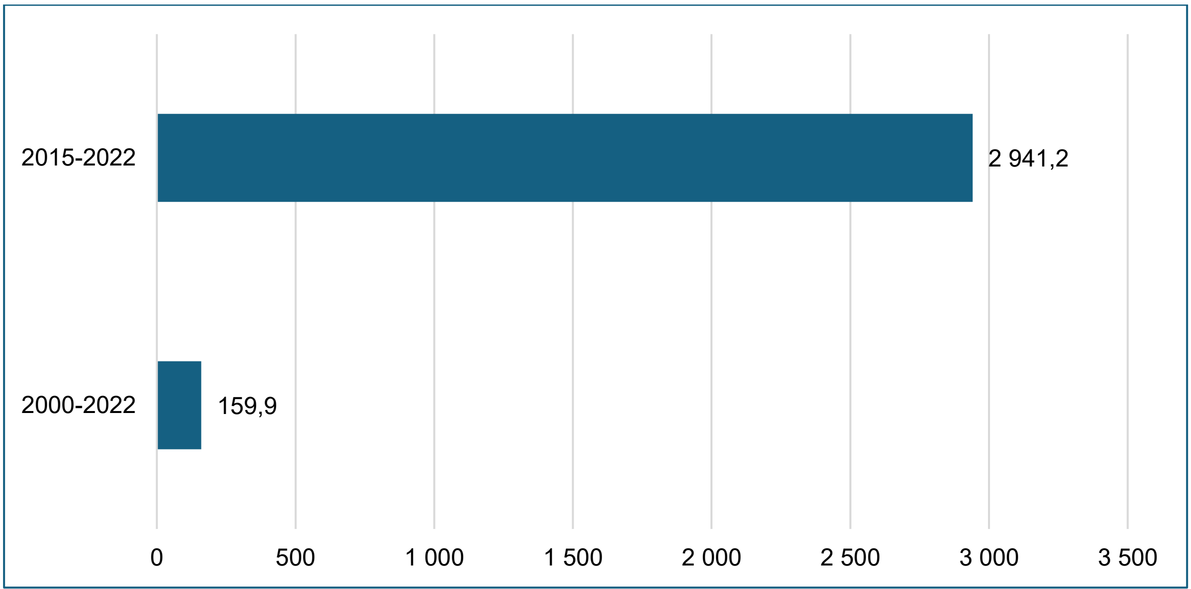

Figure.3-14: Variation (in %) between the latest inventory year of the previous inventory and the latest inventory year of the current inventory.

3.3.2. Methodological issues of the category

Emissions from the Fugitive Emissions from Fuels category were determined using default emission factors and the Tier 1 methodology. Table 3.17 summarizes the methods and emission factors for the 1.B.1 – Solid Fuels subcategories, along with an evaluation of the completeness of these emissions.

Table 3-17: Methods and emission factors for the Fugitive Emissions from Fuels.

Category	CO_2		CH4		N_2O		NOx	CO	NMVOC	SO_2
	Method applied	Emission factor	Method applied	Emission factor	Method applied	Emission factor				
1.B.1 - Solid Fuels										
a - Coal mining and handling a.i - Underground mines a.i.1 - Mining a.i.2 - Post-mining seam gas emissions c.i - Stationary	T1	D	T1	D	T1	D	NO	NE	NE	NO

3.3.3. Solid fuels (CRT 1.B.1)

The Solid Fuels category consists of the 1.B.1.a.i.1 – Mining and 1.B.1.a.i.2 – Post-mining seam gas emissions at disaggregated levels. Table 3.10 outlines the methods and emission factors used within this category. The activity data for emissions calculations from 2000 to 2015 was primarily obtained from the International Energy Agency (IEA) online data service, while data for emissions calculations from 2000 to 2022 came from the African Energy Commission (AFREC). This data includes all disaggregated sectors: 1.B.1.a.i.1 – Mining and 1.B.1.a.i.2 – Post-mining seam gas emissions.

3.3.4. Oil and natural gas and other emissions from energy production (CRT 1.B.2)

None for the category are reported in this submission.

3.4. CO2 transport and storage (CRT 1.C)

None for the category are reported in this submission.

3.5. Comparison of trends between previous total-energy inventory and current inventory

This subsection compares energy-sector emission trends in the earlier total-energy inventory (2000–2015) with those in the current inventory (2000–2022). The overall trends, shown in Table 3.8 and Figure 3.15, are broadly similar, but reported emissions in the 2000–2015 series are consistently higher than in the current series, with the difference decreasing from 16% in 2000 to 6% in the final year of the previous inventory. The higher values in the earlier series are likely due to the use of higher GWP100 factors for N_2O from the Second Assessment Report (SAR), whereas the current inventory applies AR5 values. The narrowing gap from 16% to 6% may indicate a gradual increase in national energy-sector emissions over time.

Table 3-18: Comparison of total energy-sector emission trends between the 2000–2015 and 2000–2022 GHG inventory submissions.

Total Energy Inventories (Gg-CO2-eq)	**2000**	**2001**	**2002**	**2003**	**2004**	**20005**
CRT 1 Total Energy (2000-2015) Inventory	4574.3	5807.18	5954.59	5423.09	5319.21	5850.53
CRT 1 Total Energy (2000-2022) Inventory	3952.55	5155.97	5321.64	4793.87	4763.89	5275.83
% Difference	16%	13%	12%	13%	12%	11%
Total Energy Inventories (Gg-CO2-eq)	**2006**	**2007**	**2008**	**2009**	**2010**	**20011**
CRT 1 Total Energy (2000-2015) Inventory	6017.78	5971.85	6320.37	5676.71	5979.11	5576.13
CRT 1 Total Energy (2000-2022) Inventory	5434.59	5391.62	5733.08	5060.78	5359.96	4944.47
% Difference	11%	11%	10%	12%	12%	13%
Total Energy Inventories (Gg-CO2-eq)	**2012**	**2013**	**2014**	**2015**	**2016**	**20017**
CRT 1 Total Energy (2000-2015) Inventory	7503.63	7597.17	8351.6	9310.72		
CRT 1 Total Energy (2000-2022) Inventory	6881.37	6998.68	7730.76	8764.31		
% Difference	9%	9%	8%	6%		

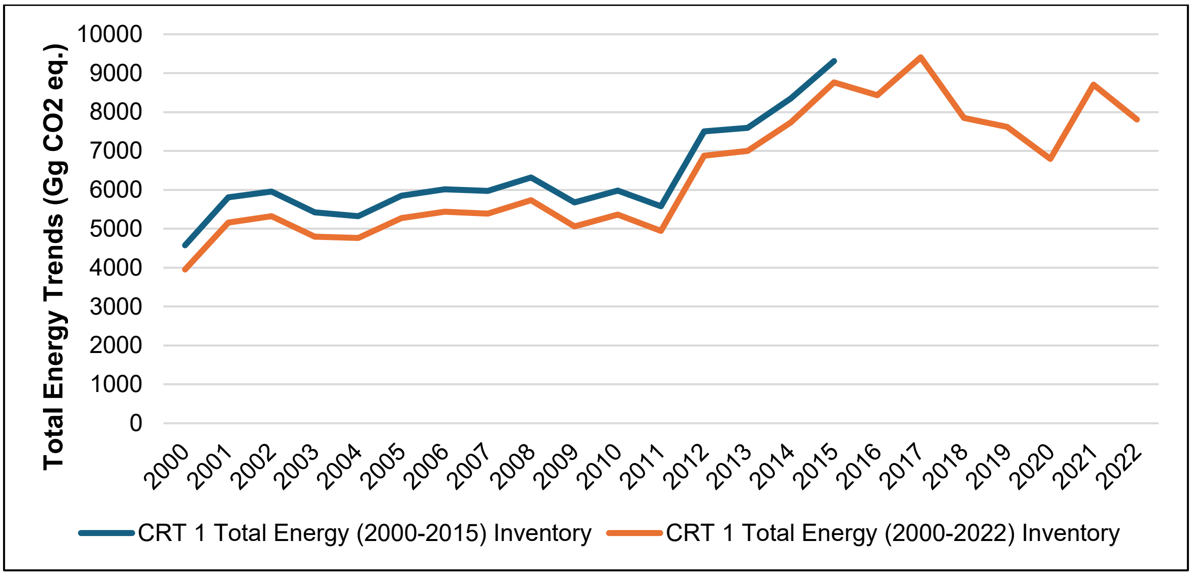

Figure.3-15: Comparison of total energy-sector emission trends from the 2000–2015 and 2000–2022 GHG inventory submissions.

4. INDUSTRIAL PROCESSES AND PRODUCT USE (CRT 2)

4.1. Overview of the sector

The IPPU sector involves non-energy related emissions from industrial processing plants and use of products containing greenhouse gases. The main emission sources are released from industrial processes that chemically or physically transform raw materials and thereby release GHGs, (e.g., products manufactured from fossil fuels), GHG emissions released during these processes are CO_2, CH_4, N_2O, HFCs, PFCs, NH_3 and SF_6, which are direct gases. Indirect gases, NO_X, CO, NMVOC and SO_2 are emitted from some processes in this sector.

4.1.1. Description of the sector

Botswana is not a heavily industrialized country. Most of the industries and process associated with emissions in this sector are mostly either not occurring (NO) or very insignificant to quantify and therefore not estimated (NE). However, there are some production processes which do not result in emissions, like cement production/packaging in Botswana.

It must be noted that the previous inventories (2011, 2012, 2014 and 2015) included emissions from cement production which is under the IPCC category 2A – **Mineral Industry**. It has been established that, both masonry cement and Portland cement are primarily blended and packaged in Botswana. Up to the current inventory year (2022) there is no production of clinker in Botswana, all clinker is imported. Therefore, the emissions for cement production cannot be accounted for in Botswana. For this inventory cycle emissions from cement production are not applicable (NA) in Botswana.

There is significant clay brick production in Botswana. There are three main clay brick producing companies; Makoro Brick & Tile (PTY) LTD, Panda and Lobatse Clay Works. Efforts are underway to collect activity data from these manufacturers. At present emissions from this sub-category are not estimated (NE). The other mineral industry processes, including limestone and lime production do not occur in Botswana.

The **Chemical Industry** in Botswana is mainly insignificant and most of the subcategories are not occurring. The sub-category that is applicable and significant is soda ash production under IPCC subcategory 2.B.7. Botswana Ash (Pty) Ltd (BotAsh), a minerals beneficiation and manufacturing company located on the Sua Pan in the north-eastern part of Botswana produces soda ash. The company has a nameplate production capacity of 300 000 tonnes per annum for Soda Ash (Botash Integrated annual Report, 2021 @https://www.botash.bw/reports-2/). Under the chemical industry category, only soda ash production is applicable.

In the **Metal Industry** category, steel manufacturing takes place by recycling scrap metal to produce steel. Reliance Foundries/Rhino Steel Rolling Mills (Pty) Ltd recycles various mix of scrap metal. The company uses the Electric Induction Furnace (EIF) instead of the Basic Oxygen Furnace (BOF) and the Open Hearth Furnace (OHF) technologies, which have well documented methodologies in the 2006 guidelines. However, the emissions from this subcategory (iron and steel production – 2.C.1) are not yet estimated pending the right methodology for the EIF technology. Efforts are ongoing for collection of the relevant activity data. Other subcategories under metal industry do not occur in Botswana.

The **Non-Energy Products from Fuels and Solvent Use** is one of the significant categories in the IPPU sector. Lubricant use, paraffin wax use and other (Asphalt Road paving) are the subcategories whose emissions are estimated in this category. However, carbon dioxide emissions from asphalt road paving are insignificantly small and will not be included in this inventory.

The emissions from **Electronic Industry** do not occur in Botswana. For **Products Uses as Substitutes for Ozone Depleting Substances (ODS)** emissions from refrigeration and stationary air-conditioning are estimated. Imports of HFC's are sourced through Statistics Botswana (SB).

Emissions occur under **Other Product Manufacture and Use.** Botswana Power Cooperation (BPC) installs switchgears that use sulphur hexafluoride (SF_6) in their electrical equipment. Collection of activity data from BPC is on-going. The Central Medical Stores (CMS) procures nitrous oxide (N_2O) for use in medical applications. Efforts are underway to collect activity data for estimation of those emissions. Activity data collection are underway for estimates under the **Other** category for food and beverages industry. Kgalagadi Breweries Limited (KBL), an alcohol producing company is assisting in compilation of data for the alcoholic beverages industry.

Emissions from the following IPCC categories and associated sub-categories of industrial processes are included in Botswana's IPPU sector:

- 2.B - Chemical Industry
    - 2.B.7 – Soda Ash Production
- 2.D - None-Energy Products from Fuels and Solvent Use
    - 2.D.1 – Lubricant Use
    - 2.D.2 – Paraffin Wax Use
- 2.F - Product Uses as Substitutes for Ozone Depleting Substances
    - 2.F.1 – Refrigeration and Air Conditioning
        - 2.F.1.a – Refrigeration and Stationary Air Conditioning

4.1.2. Trend in the sector's GHG

Table 4-1: IPPU Sector: Emissions by GHG, category and sub-category (Gg) - 2022

	(Gg)			Gg CO2-eq.
Categories	**CO2**	**CH4**	**N2O**	**HFCs**
2 - Industrial Processes and Product Use	1 665.994	NE	NE	23.122
2.B - Chemical Industry	777.729	NO	NO	NO
2.B.7 - Soda Ash Production	777.729			
2.D - Non-Energy Products from Fuels and Solvent Use	888.265	NO	NO	
2.D.1 - Lubricant Use	880.931			
2.D.2 - Paraffin Wax Use	7.333			
2.D.4 - Other (Asphalt Road Paving)	NE	NE	NE	
2.F - Product Uses as Substitutes for Ozone Depleting Substances				23.122

	(Gg)			Gg CO2-eq.
Categories	CO2	CH4	N2O	HFCs
2.F.1 - Refrigeration and Air Conditioning				23.122
2.F.1.a - Refrigeration and Stationary Air Conditioning				23.122

The main contributing emissions in this sector are from emissions of carbon dioxide from soda ash production (777.729 Gg) and lubricant use (880.931 Gg). Paraffin wax use has 7.33 Gg while Other (Asphalt Road Paving) emissions are insignificant. There is a considerable amount of emissions of HFCs (23.12 Gg CO_2eq). Carbon dioxide emissions account for 98.8% of the sector's total emissions while HFCs account for 1.2% for the inventory year 2022.

The emissions from this sector dropped by 4.5% between 2000 and 2022. However, emissions increased by 82.6% between 2015 (previous inventory year) and 2022. Table 4-2 below summarises the time series emissions by category, calculated during the current inventory cycle, and the total emissions for 2000, 2005, 2010, 2015, 2020, 2021 and 2022.

Table 4-2: IPPU Sector: Total GHG emissions by category (Gg CO2 eq)

CRT Category	2000	2005	2010	2015	2020	2021	2022
2.B – Chemical Industry	493.63	708.97	415.53	639.44	726.78	824.66	777.73
2.D – Non-Energy Products from Fuels and Solvent Use.	1274.80	754.72	208.58	270.29	606.98	910.24	888.93
2.F – Product Uses as Substitutes for ODS	NE	6.139	15.336	15.601	20.588	19.827	23.12
Total	**1768.43**	**1469.83**	**639.45**	**925.33**	**1354.35**	**1754.73**	**1689.78**

Figure 4-1 below gives a time series of total GHG emissions by category for the sector.

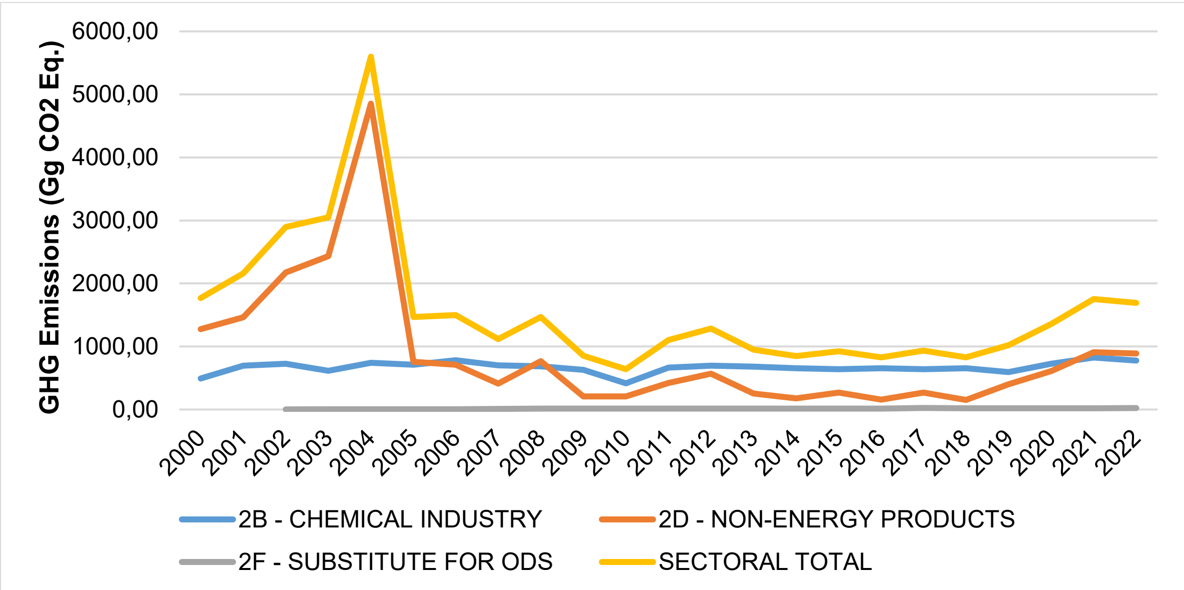

Figure.4-1: IPPU Sector: Total GHG emissions by category (Gg CO_2. Eq), 2000-2022

There was a significant increase in the import of the non-energy products from 2000 to 2004. This drove the sector emissions to above 5000 Gg CO_2 eq in 2004. The emissions fell to below 2000 Gg in 2005 and they fluctuated steadily up to 2022 maintaining values below 2000 Gg.

Carbon dioxide emissions in 2022 were 1666 Gg. These were combined emissions from the Chemical Industry (Soda Ash Production) and Non-Energy Products from Fuels and Solvent Use (Lubricant Use and Paraffin Wax Use). Carbon dioxide emissions contributed around 99% of the entire sector emissions. In 2000 the CO_2 emissions were 1768.4 Gg. This represents a 6% fall in the CO_2 emissions from the base year to the current inventory year. In the previous inventory year of 2015, the CO_2 emissions were 909.7 Gg. This represents an increase of 45% in CO_2 emissions in the current inventory year. This rise was driven by the fluctuations in the imported non-energy products (lubricants and paraffin wax). Most of the interannual variation is driven by imports of non-energy products. All these products are imported and some years there is over subscription.

Contribution from HFCs in 2022 were 23.12 Gg CO_2 eq. These were combined emissions for air conditioning and stationary refrigeration with the use of HFC-23, HFC-32, HFC-134a and HFC-152a. The emissions were first estimated in 2002 as the start year and were 1.55 Gg CO_2 eq. This represents around 1400% increase in emissions for the current inventory year. This is driven by increase in equipment consuming the substitutes for Ozone Depleting Substances (ODSs). The previous inventory year, 2015, the HFCs emissions were 15.60 Gg CO_2 eq. This represents a 48% increase in emissions for the current inventory year. The trend shows a rapid increase in emissions from the start year up to the current year. This is mainly driven by increase in equipment that uses the substitutes for ODSs. In the individual chemicals, the HFC-134a is the main contributor, with 13.71 Gg CO_2 eq in 2022. This represents a 59% contribution to the sector's HFCs' emissions. The least contributor is HFC-152a, with 0.029 Gg CO_2 eq in 2022. This represents a 0.1% contribution to the sector's HFCs' emissions. Table 4-3 below summarises the time series emissions by gas for 2000, 2005, 2010, 2015, 2020, 2021 and 2022.

Table 4-3: IPPU Sector: Total GHG emissions by GHG (Gg CO_2 eq)

Green House Gas	2000	2005	2010	2015	2020	2021	2022
Carbon dioxide	1768.43	1463.69	624.11	909.73	1333.76	1734.9	1666.0
HFCs (total)	**NE**	**6.14**	**15.34**	**15.60**	**20.59**	**19.83**	**23.12**
HFC-23	NE	1.61	1.68	2.15	3.79	4.49	5.32
HFC-32	NE	0.09	0.34	1.03	3.03	3.54	4.07
HFC-134a	NE	3.49	12.0	12.0	13.74	11.77	13.71
HFC-152a	NE	0.94	1.33	0.44	0.03	0.03	0.03
Total	**1768.43**	**1469.83**	**639.45**	**925.33**	**1354.35**	**1754.73**	**1689.78**

Figure 4-2 below gives a time series of total emissions by GHG for the sector.

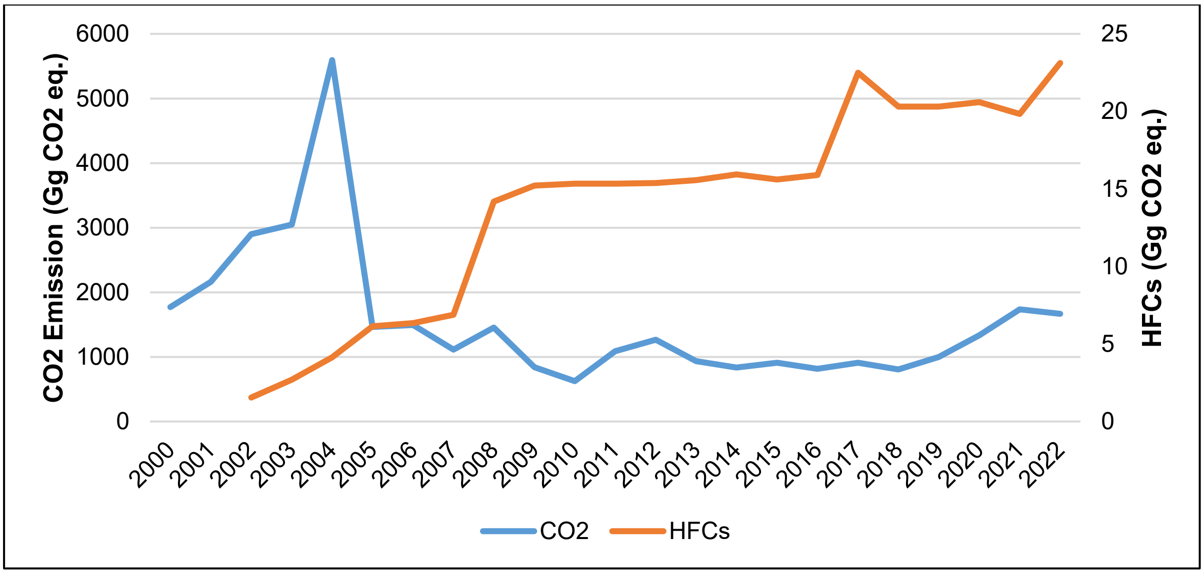

Figure.4-2: IPPU Sector: Total GHG emissions by gas (Gg CO_2. Eq), 2000 – 2022

In the carbon dioxide emissions, there is a significant increase from 2000 to 2004. This is driven by imports of the non-energy products such as lubricants and paraffin wax use. The emissions drop to below 2000 Gg in 2005 and thereafter the annual variability maintains the emissions below 2000 Gg. We note the sharp increase in the non-energy products from 2000 to 2004. It is difficult to account for the imports, since sometimes there is oversubscription.

The HFCs shows some steady increase from about 2 Gg CO_2 equivalent in 2002 to around 23 Gg CO_2 equivalent in 2022. This is driven by increase in air-conditioning and refrigeration equipment overtime.

Figure 4-3 below shows trend in GHG emissions by hydrofluorocarbon (HFC) type for 2002 to 2022. The HFCs estimated are HFC-23, HFC-32, HFC-134a and HFC-152a.

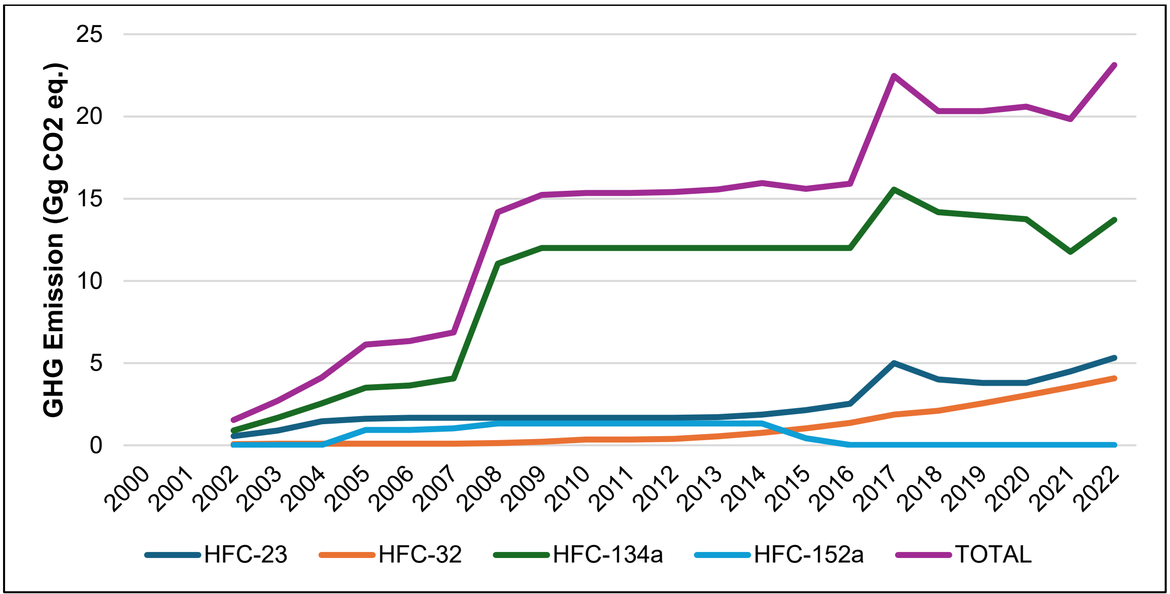

Figure.4-3: IPPU Sector: Total GHG emissions by HFC type (Gg CO_2. Eq), 2002 - 2022

All the HFCs started with emissions below 5 Gg CO_2 equivalent in 2002, then there was a steady increase in HFC-13a over the time series to about 15 Gg CO_2 equivalent in 2022. This was driven by increase in automobile air conditioning systems, domestic refrigerators and commercial cooling systems. The other HFCs remained below or around 5 Gg CO2 equivalent for the entire time series. These are controlled under the Montreal Protocol and the Kigali amendment.

4.1.3. General methodological issues of the sector

Emissions in the IPPU sector were estimated using TIER 1 approach throughout the entire sector. The main reason is lack of the disaggregated activity data and lack of country specific parameters and emission factors. Table 4-4 provides a summary of the methods and emission factors applied to each estimated category and sub-categories.

Table 4-4: Summary of methods and emission factors for the IPPU sector.

Code	GHG source and sink categories	CO_2		CH_4		N_2O		HFC	
		Method	EF	Method	EF	Method	EF	Method	EF
2.	**Industrial processes and product use**	**T1**	**D**					**T1**	**D**
2.B.	Chemical industry	T1	D						
2.B.7	Soda Ash Production	T1	D						
2.D.	Non-energy products from fuels and solvent use	T1	D						
2.D.1	Lubricant Use	T1	D						
2.D.2	Paraffin Wax Use	T1	D						
2.F.	Product uses as substitutes for ODS							T1	D
2.F.1.a	Refrigeration and Stationary Air Conditioning							T1	D

T1 – Tier 1 methodology, **D** – Default Factor

Activity data for this sector were obtained from BotAsh (Pty) LTD, for soda ash production. BotAsh is a company based in the north-eastern Botswana, that produces soda ash. Data for non-energy products from fuels, lubricants and paraffin wax use, were acquired from International Merchandise and Trade Statistics (IMTS) unit of Statistics Botswana (SB). They are all imported. The activity data for substitutes for ozone depleting substances were also acquired from the IMTS unit of Statistics Botswana. They are also all imported into the country.

The emission factors used in this sector were the defaults provided in the 2006 IPCC software for the TIER 1 methodologies. There are no country specific factors for this sector. Lack of country specific factors and lack of disaggregated data led to the use of TIER 1 method in this sector.

4.2. Mineral industry (CRT 2.A)

It must be noted that the previous inventories (2011, 2012, 2014 and 2015) included emissions from cement production which is under the IPCC category 2A – **Mineral Industry**. It has been established that, both masonry cement and Portland cement are primarily blended and packaged in Botswana. Up to the current inventory year (2022) there is no production of clinker in Botswana, all clinker is imported. Therefore, the emissions for cement production cannot be accounted for in Botswana. For this inventory cycle emissions from cement production are not applicable (NA) in Botswana.

There is significant clay brick production in Botswana. There are three main clay brick producing companies; Makoro Brick & Tile (PTY) LTD, Panda and Lobatse Clay Works. Efforts are underway to collect activity data from these manufacturers. At present emissions from this sub-category are not estimated (NE). The other mineral industry processes, including limestone and lime production do not occur in Botswana.

4.3. Chemical industry (CRT 2.B)

4.3.1. Description and trend of GHGs in the category

The chemical industry in Botswana is mainly very insignificant and most of the subcategories do not occur. The only source covered in reporting this category is Soda Ash Production (2.B.7). Most of the other subcategories do not occur or they exist in very insignificant quantities in Botswana. Table 4-5 below summarises the time series of emissions from soda ash production subcategory for 2000, 2005, 2010, 2015, 2020, 2021 and 2022. From the start year of 2000, the emissions have been increasing steadily such that by 2022 there was about 58% increase in emissions from soda ash production.

Table 4-5: Chemical Industry: Total GHG emissions by subcategory (Gg CO_2 eq)

Subcategory	2000	2005	2010	2015	2020	2021	2022
2.B.7 – Soda Ash Production	493.63	708.97	415.54	639.44	726.78	824.66	777.73
Total	**493.63**	**708.97**	**415.54**	**639.44**	**726.78**	**824.66**	**777.73**

The following figure shows the time series of emissions from soda ash production for 2000 to 2022. There is a steady increase from below 500 Gg CO_2 in 2000 to around 800 Gg CO_2 in

2022. There is a significant decline to about 400 Gg CO_2 in 2010. However, the trend then recovers in the following year to a steady increase.

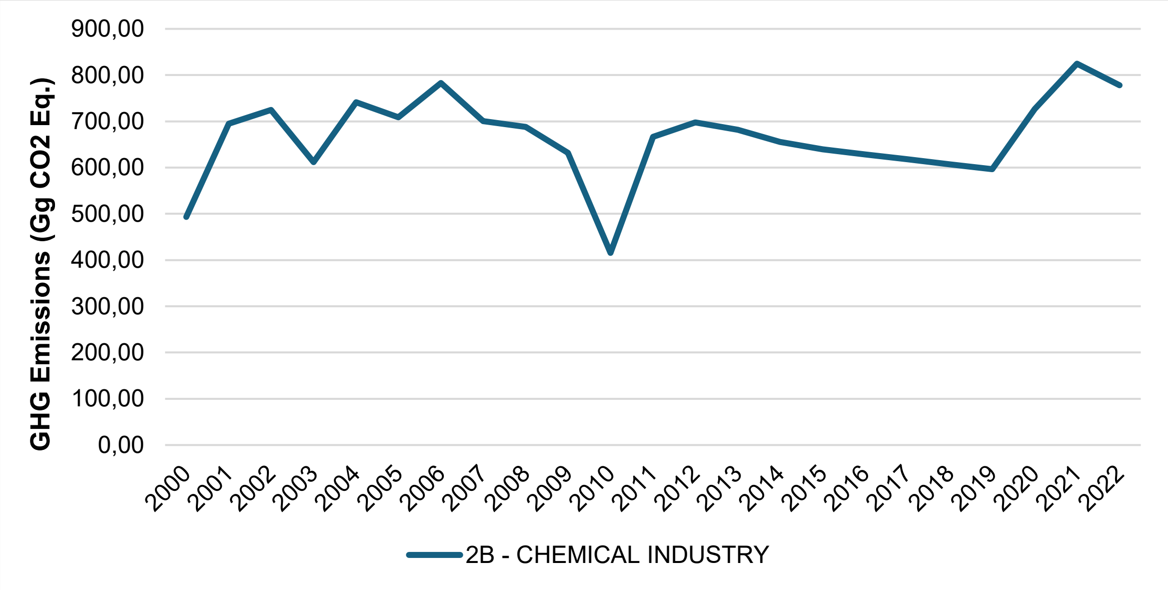

Figure.4-4: IPPU Sector: Total GHG Soda Ash Production (Gg CO_2. Eq), 2002 - 2022

The figure shows a general gentle upward trend from 2000 to 2022. The decline in 2010 is the only point which shows low production of the Trona-brine used during soda ash production. The company reports that the 2010 production was constrained by downstream processes. Processes like compaction and utilities, which had several downtimes resulting in low consumption of trona-brine.

4.3.2. Methodological issues of the category

The 2006 IPCC guidelines and 2006 IPCC software version 2.98 was used to estimate emission for the sub-category of soda ash production. The amount of Trona-brine used in tonnes per annum was entered into the 2006 IPCC software and the default emission factor was used to calculate the emissions. The Tier 1 methodology was used to calculate the emissions.

4.3.2.1 Activity data of the category

Activity data in this category, which is only estimating emissions from soda ash production, were obtained directly from Botswana Ash (Pty) LTD (BotAsh). The amount of Trona-Brine utilized was obtained from the company in units of volume (m^3). The volume data was converted to mass in tonnes (1000 kg) using the average value of specific gravity for trona-brine which is 1.25 (acquired from BotAsh Pty LTD). This value indicates the density of trona-brine solutions with respect to water.

The activity data is from 2000 to 2022. The years 2016, 2017 and 2018 had missing data. The missing data were estimated by using a simple linear interpolation technique. The interpolation formula used is as follows;

$$Y_t = Y_{start} + \frac{(T_t - T_{start})}{(T_{end} - T_{start})} * (Y_{end} - Y_{start})$$

Where: Y_t - Emissions to be estimated for the year t (2016, 2017,2018),

Y_{start} – Emissions in the year 2015,

Y_{end} - Emissions in the year 2019,

T_t - year to be estimated (2016, 2017,2018),

T_{start} - Year 2015,

T_{end} - Year 2019

Table 4-6: Chemical Industry: Activity Data for Soda Ash Production

Year	Amount of Trona-Brine Utilized (m3)	Amount of Trona-Brine Utilized (Tonnes)
2000	4071142	5088928
2001	5729234	7161543
2002	5974482	7468103
2003	5047167	6308959
2004	6114261	7642826
2005	5847160	7308950
2006	6453923	8067404
2007	5779079	7223849
2008	5672386	7090483
2009	5209403	6511754
2010	3427094	4283868
2011	5495373	6869216
2012	5753208	7191510
2013	5622653	7028316
2014	5608314	6760393
2015	5273730	6592163
2016	XXX	6480722
2017	XXX	6369282
2018	XXX	6257841
2019	4917120	6146400
2020	5994060	7492575
2021	6801285	8501606
2022	6414257	8017821

Note: Trona Brine quantities were given in units of volume (m^3). They were converted to units of mass (Tonnes) using the average specific gravity value of 1.25 for trona-brine.

Source: Botswana Ash Pty LTD. (BotAsh).

4.3.2.2 Emission factors applied in the category

The default emission factor from the 2006 IPCC software was used under a TIER 1 methodology for estimation of emissions from soda ash production.

Table 4-7: Chemical Industry: Emission factors for Soda Ash Production

GHG source	GHG	Value	Unit
2.B.7 – Soda Ash Production	CO_2	0.097	Tonnes CO_2/tonne trona used

Note: This emission factor is for trona utilized in soda ash production. The source: The IPCC 2006 software.

4.3.3. Uncertainty assessment and time-series consistency of the category

Activity data uncertainty of ±5% was taken from the default value of the IPPCC 2006 guidelines, Volume 3, Chapter 3. The emission factor uncertainty of ±10% is also default from the guidelines.

The time-series for GHG of this category was reviewed. There was a significant drop in the emissions from soda ash production in 2010. The company, however attributed that low production to downstream processes such as compaction and utilities, which had several downtimes and resulted in low consumption of trona-brine. There were missing activity data for the years 2016, 2017 and 2019. A simple linear interpolation technique was used to fill the data gap, since the time series did not have a lot of annual variability. The time-series was therefore considered to be consistent.

4.3.4. Category-specific recalculations

No Category-specific recalculations were carried out.

4.4. Metal industry (CRT 2.C)

In the **Metal Industry** category, steel manufacturing takes place by recycling scrap metal to produce steel. Reliance Foundries/Rhino Steel Rolling Mills (Pty) Ltd recycles various mix of scrap metal. The company uses the Electric Induction Furnace (EIF) instead of the Basic Oxygen Furnace (BOF) and the Open Hearth Furnace (OHF) technologies, which have well documented methodologies in the 2006 guidelines. However, the emissions from this subcategory (iron and steel production – 2.C.1) are not yet estimated pending the right methodology for the EIF technology. Efforts are ongoing for collection of the relevant activity data. Other subcategories under metal industry do not occur in Botswana.

4.5. Non-energy products from fuels and solvent use (CRT 2.D)

4.5.1. Description and trend of GHGs in the category

Non-energy products from fuels include Grease, lubricating oils, paraffin wax and asphalt for road paving. The sources covered in reporting this category are lubricant use (2.D.1) and paraffin wax use (2.D.2). Solvent use (2.D.3) is not covered due to lack of activity data.

Other (2.D.4, asphalt road paving) was found to be too insignificant to be included in the inventory. For example, in 2022, Activity Data, AD = 8.56 Gg, Emission Factor, EF = 0.00004 and Emissions, E = AD X EF = 0.00038 Gg. This value is insignificant as per the guidelines to be included in the total inventory. Therefore the subcategory is reported as Not Estimated (NE).

Table 4-8 below summarises the time series of emissions from lubricant use and paraffin wax use subcategories for 2000, 2005, 2010, 2015, 2020, 2021 and 2022. There was a 30% drop in the emissions between 2000 and 2022. It Must be noted that all these non-energy products are imported into the country by various suppliers and contractors.

Table 4-8: Non-Energy Products: Total GHG emissions by subcategory (Gg CO_2 eq)

Subcategory	2000	2005	2010	2015	2020	2021	2022
2.D.1 – Lubricant Use	975.15	657.24	187.22	312.36	606.06	909.17	880.93
2.D.2 – Paraffin Wax Use	299.66	97.48	21.36	11.72	0.92	1.07	7.33
Total	**1274.80**	**754.72**	**208.58**	**324.08**	**606.98**	**910.24**	**888.26**

The following figure shows the time series of emissions from lubricant use, Paraffin wax use and total emissions for the category for 2000 to 2022. There is a rapid increase from about 1300 Gg CO_2 in 2000 to around 5000 Gg CO_2 in 2004. The emissions then drop to below 1000 Gg CO_2 in 2005 and maintains that lower trend up to 2022. The rapid rise between 2000 and 2004 may be attributed to over subscription of importers.

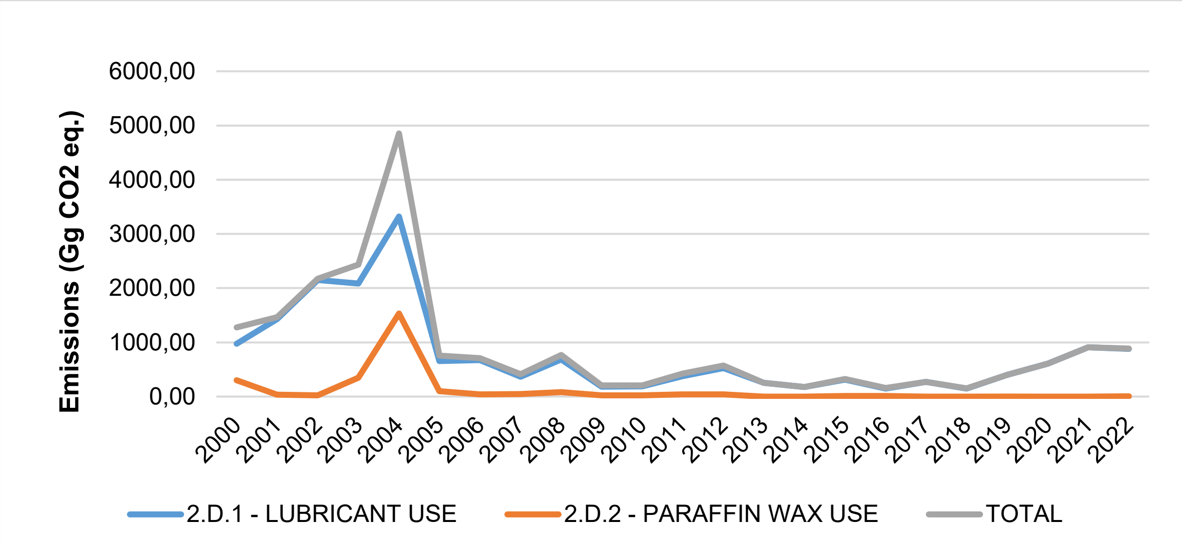

Figure.4-5: Non-Energy Use: Total GHG emissions by subcategory 2000 - 2022(Gg CO_2. Eq)

4.5.2. Methodological issues of the category

The 2006 IPCC guidelines and 2006 IPCC software version 2.98 was used to estimate emissions for this category. The consumption of lubricants (Grease and lubricating oils) was entered into the 2006 IPCC software and the default emission factors were used to calculate the emissions. Consumption of wax was used as activity data as well. Activity data were in units of energy. The Tier 1 methodology was used to calculate the emissions.

4.5.2.1 Activity data of the category

Activity data in this category, which is lubricant use and paraffin wax use, were obtained from the International Merchandise Trade Statistics (IMTS) unit of Statistics Botswana. Table 4-9 shows the activity data from 2000 to 2022 in units of energy (TJ).

Table 4-9: Non-Energy Products: Activity Data for sub-categories

Year	Lubricant Use (TJ)		Paraffin Wax Use (TJ)
	Grease	Lubricating Oils	
2000	240113	6459	xxxx
2001	355230	8540	2545
2002	570259	3930	1649
2003	455212	28520	23766
2004	814136	22885	104459
2005	161420	4457	6646
2006	156016	6711	2580
2007	87183	3223	3028
2008	158947	6875	5757
2009	30901	4810	1524
2010	27272	5947	1456
2011	62929	10153	2940
2012	55260	22133	2940
2013	41214	6931	49
2014	26049	5451	130
2015	40393	11199	799
2016	27980	3066	723
2017	34320	9797	52
2018	36450	1103	114
2019	27223	20611	18
2020	43340	30487	63
2021	22320	56409	73
2022	27930	53081	500

4.5.2.2 Emission factors applied in the category

The default emission factors from the 2006 IPCC software were used under the TIER 1 methodology for estimation of emissions from this category.

Table 4-10: Non-Energy Products: Emission Parameters for the subcategories

GHG source	Lubricant Type	GHG	Carbon Content of lubricant type (tonne C/TJ)	Oxidised During Use (Fraction)
2.D.1 – Lubricant Use	Grease	CO_2	20	0.05
	Lubricating Oils	CO_2	20	0.2
2.D.2 – Paraffin Wax Use		CO_2	20	0.2

Source: 2006 IPCC Software.

4.5.3. Uncertainty assessment and time-series consistency of the category

Uncertainty for lubricant use activity data was taken from the 2006 guidelines, Volume 3, Chapter 5, where a range of 10 – 20% is given as default. The midway value of ±15% was used for uncertainty of the Lubricant Use AD. For the emission factor the uncertainty was the default ±50%. The Paraffin Wax activity data uncertainty was taken as ±15% as the mid-point value of the default range of 10 – 20%. The emission factor uncertainty is set at the default value of ±50%.

The time-series for GHG of this category was reviewed. There was a rapid increase in imported non-energy products from fuels, especially lubricants, from 2000 to 2004. The trend lowered from 2005 and stabilised until 2022. This may be attributed to oversubscription by importers of the products. The time-series was considered to be consistent.

4.5.4. Category-specific recalculations

There were no recalculations for this category.

4.6. Electronic industry (CRT 2.E)

No industrial processes occur in this category. Therefore, the emissions are reported as Not Occurring (NO) for this category.

4.7. Product uses as substitutes for ODS (CRT 2.F)

4.7.1. Description and trend of GHGs in the category

Product uses as substitutes for Ozone Depleting Substances (ODS) covered under this category are from refrigeration and air conditioning (2.F.1). The source covered in reporting this category is refrigeration and stationary air conditioning (2.F.1.a). Other sub-categories are not covered due to lack of activity data. The gases covered under the ODSs are HFC-23, HFC-32, HFC-134a and HFC152a. Table 4-11 below summarises the time series of emissions from refrigeration and stationary air conditioning for 2002, 2005, 2010, 2015, 2020, 2021 and 2022. It Must be noted that all these chemicals are imported into the country by various suppliers and contractors. The first year of estimation is 2002 for this category. No data was found prior to 2002.

Table 4-11: Substitutes for ODS: Total GHG emissions by HFCs (Gg CO_2 eq

2.F.1.a – Refrigeration and stationary Air Conditioning	***2002***	***2005***	***2010***	***2015***	***2020***	***2021***	***2022***
HFC – 23	0.56	1.61	1.68	2.15	3.79	4.49	5.32
HFC – 32	0.07	0.09	0.34	1.03	3.03	3.54	4.07
HFC – 134a	0.90	3.49	12.0	12.0	13.74	11.77	13.71
HFC – 154a	0.01	0.94	1.33	0.44	0,03	0.03	0,03
Total	**1.54**	**6.14**	**15.34**	**15.60**	**20.59**	**19.83**	**23.12**

The following figure shows the time series of the total emissions from refrigeration and air conditioning for 2002 to 2022 (See also figure 4-3 for trend in the individual chemicals). There is a steady but significant increase from about 1.5 Gg CO_2 eq in 2002 to around 23 Gg CO_2 eq in 2022. The increase represents around 1400% growth. The steady increase in emissions is due to the increase in automobile air conditioning systems, domestic refrigeration and commercial cooling systems.

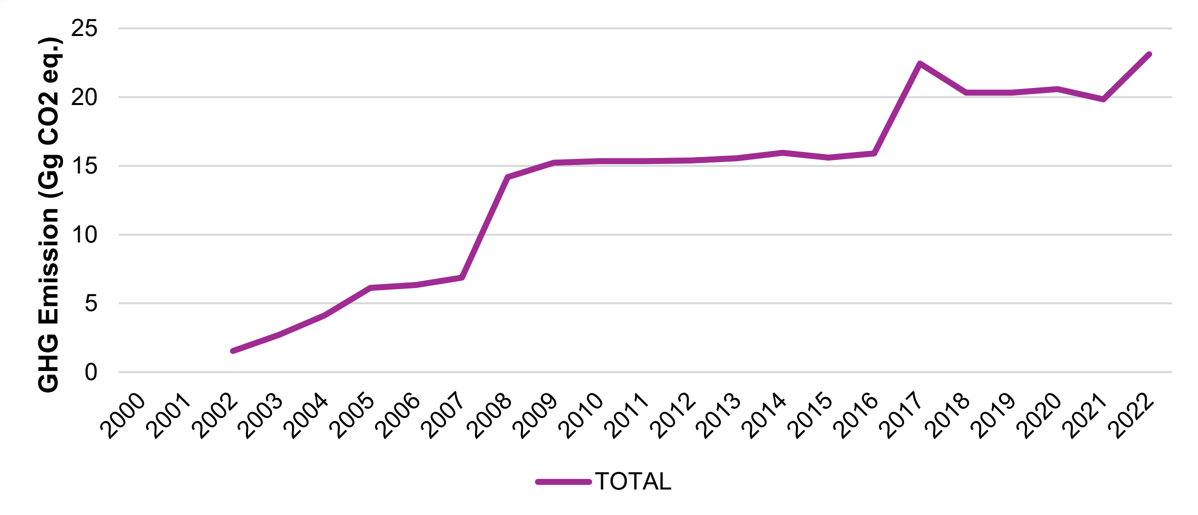

Figure.4-6: Substitutes for ODS: Total GHG emissions by HFCs 2000 - 2022(Gg CO_2. Eq)

4.7.2. Methodological issues of the category

The 2006 IPCC guidelines and 2006 IPCC software version 2.98 was used to estimate emissions for this category. The amount of chemicals (agents) were entered into the 2006 IPCC software. The Tier 1 methodology was used to calculate the emissions.

4.7.2.1. Activity data of the category

Activity data in this category, were obtained from the International Merchandise Trade Statistics (IMTS) unit of Statistics Botswana. Table 4-12 shows the activity data from 2002 to 2022 in units of mass (Tonnes).

Table 4-12: Substitutes for ODS: Activity Data for sub-categories

Year	HYDROFLUOROCARBONS (Tonnes)			
	HFC-23	HFC-32	HFC-134a	HFC-152a
2002	0.30	0.68	4.61	0.46
2003	0.23	0.35	4.70	0.47
2004	0.37	0.014	5.75	0.42
2005	0.20	0.03	6.80	44.29
2006	0.17	0.04	3.40	1.78
2007	0.13	0.05	5.00	11.64
2008	0.10	0.54	38.90	21.50
2009	0.07	1.03	13.40	0.09
2010	0.04	1.52	6.20	3.42
2011	0.002	0.09	3.60	2.57
2012	0.076	1.03	0.20	1.72
2013	0.15	1.97	1.68	2.20

Year	HYDROFLUOROCARBONS (Tonnes)			
	HFC-23	HFC-32	HFC-134a	HFC-152a
2014	0.23	2.91	3.16	1.19
2015	0.30	3.85	4.64	0.18
2016	0.37	4.79	6.12	0.18
2017	0.45	5.73	7.60	0.19
2018	0.52	6.68	9.08	0.19
2019	0.60	7.61	10.56	0.19
2020	0.67	8.56	12.04	0.20
2021	0.75	9.50	15.00	0.20
2022	0.82	10.44	15.30	0.21

4.7.2.2. Emission factors applied in the category

The default emission factors from the 2006 IPCC software were used under the TIER 1 methodology for estimation of emissions from this category.

Table 4-13: Substitutes for ODS: Emission Parameters/factors for the subcategory

GHG source	HFC Type	Emission Factor (%)	Percentage Of Gas Destroyed (%)	Equipment Growth Rate (%)	Equipment Lifetime (years)
2.F.1.a – Refrigeration and Stationary Air conditioning.	HFC - 23	15	0	2	15
	HFC - 32	15	0	2	15
	HFC – 134a	15	0	2	15
	HFC – 152a	15	0	2	15

Source: 2006 IPCC Software.

4.7.3. Uncertainty assessment and time-series consistency of the category

An uncertainty of ±10% was assumed for activity data following the IPCC guidelines. For emission factors, ±5% uncertainty was assumed.

The time series shows a gradual increase in emissions from substitutes for ozone depleting substances from 2002 to 2022. This is mainly due to growth in domestic refrigeration, automobile air conditioning and commercial cooling systems. The time-series shows some consistency.

4.7.4. Category-specific recalculations

There were no recalculations in this category

4.8. Other product manufacture and use (CRT 2.G)

Emissions occur under **Other Product Manufacture and Use.** Botswana Power Cooperation (BPC) installs switch-gears that use sulphur hexafluoride (SF_6) in their electrical equipment. Collection of activity data from BPC is on-going.

The Central Medical Stores (CMS) procures nitrous oxide (N_2O) for use in medical applications. Efforts are underway to collect activity data for estimation of those emissions.

4.9. Other (specify) (CRT 2.H)

Activity data collection are underway for estimates under the **Other** category for food and beverages industry. Kgalagadi Breweries Limited (KBL), an alcohol producing company is assisting in compilation of data for the alcoholic beverages industry.

4.10. Sector-Specific Planned Improvements

- Include emissions from clay brick production.
- Include emissions from steel production.
- Include emissions of SF_6 from electrical equipment.
- Include emissions of N_2O from medical applications.
- Include emissions from alcoholic beverages industry.

5. AGRICULTURE (CRT 3)

5.1. Overview of the sector

This chapter comprises GHG emissions from Agriculture sector. The main categories included in the emission estimates for the agriculture sector include: 3.A Enteric Fermentation, 3.B Manure Management, 3.D Agricultural Soils, 3.G Liming, and 3.H Urea application.

5.1.1. Description of the sector

Agriculture serves as a foundational pillar of Botswana's rural economy, providing essential nutrition, employment, and livelihoods for approximately 70% of the rural population. Despite its social importance, the sector's economic performance has recently remained below 5% of GDP, leading to reduced farm incomes and increased vulnerability (Masocha et al. 2024). The sector is characterized by a dual production system: a dominant traditional (subsistence) sector and a smaller, technology-intensive commercial sector. While crop production- focused on sorghum, maize, millet, sunflower, and pulses, accounts for 20% of agricultural income, the sector is primarily defined by extensive livestock production. Livestock farming, which involves the rearing of cattle, goats, sheep, horses, and poultry, contributes 80% of total agricultural income. Notably, while crop production involves both genders, cattle rearing remains a largely male-dominated activity (Matopote et al. 2025).

Environmentally, the agriculture sector is a significant driver of climate change in Botswana, primarily through greenhouse gas (GHG) emissions from livestock (enteric fermentation and manure management) and agricultural soils. In the 2015 GHG emissions profile, the Agriculture, Forestry, and Other Land Use (AFOLU) sector was identified as the second-largest contributor to national emissions (Government of Botswana, 2021). Given the country's semi-arid climate and sensitivity to climate-induced shocks, current national priorities emphasize a transition toward Climate-Smart Agriculture (CSA). This transition is guided by the National Agricultural Resilience Strategy (2020–2030) and the Revised National Policy on Agricultural Development. These frameworks aim to harmonize rural livelihoods with the mitigation and adaptation targets set forth in Botswana's updated Nationally Determined Contributions (NDC), Third National Communication (TNC), and First Biennial Transparency Report (BTR) (GoB, 2019; GoB, 2023).

5.1.2. Trend in the sector's GHG

The total emissions from agriculture sector in 2022 were 1,935.77 Gg CO_2eq as shown in Table 5.1. The emissions showed a decrease of 45.28% when compared to total emissions from 2000 (3,537.39 Gg CO_2eq). Table 5.2 and Figure 5.1 illustrate that enteric fermentation was the main contributor (61.79%) followed by agriculture soils (34.86%) and manure management (3.22%). The overall decrease in total agriculture sector emissions during the 2000-2022 period is attributed to a decline in livestock population over the years. This decline is driven by climate-induced factors, specifically recurrent and severe droughts that have degraded rangelands and reduced calving rates, alongside transboundary animal disease outbreaks, such as Foot and Mouth Disease (FMD), which led to mandatory culling and restricted herd growth (MENT, 2021; MoH, 2023). Furthermore, rural-to-urban migration has reduced available labour for traditional farming, resulting in a structural shift that reinforces this persistent reduction in livestock population (Statistics Botswana, 2024).

Table 5-1: Emissions from Agriculture categories between 2000 and 2022 (Gg CO_2 equivalent)

Categories	2000 Emissions Gg CO_2eq			2022 Emissions Gg CO_2eq		
	CO_2	CH_4	N_20	CO_2	CH_4	N_2O
3 - Agriculture	**0.393**	**2,278.20**	**1,258.80**	**2.49**	**1,241.81**	**691.48**
3.A - Livestock		**2,193.68**			**1,196.10**	
3.A.1 - Enteric Fermentation		2,193.68			1,196.10	
3.A.1.a - Cattle		1,823.54			930.10	
3.A.1.a.i - Dairy Cows		1.6126			1.6216	
3.A.1.a.ii - Other Cattle		1,821.93			928.475	
3.A.1.c - Sheep		35.84			37.485	
3.A.1.d - Goats		220.64			180.04	
3.A.1.f - Horses		24.192			6.678	
3.A.1.g - Mules and Asses		89.32			41.606	
3.A.1.h - Swine		0.1492			0.1951	
3.B - Manure Management		**84.51411**	**54.37815**		**45.69**	**16.785**
3.B.2.1 - Cattle		58.84211	11.43469		29.988	1.59
3.B.1.a - Dairy cows		58.80706	11.24472		0.028	0.265
3.B.2.b - Other cattle		0.035056	0.189965		29.96	1.325
3.B.2 - Sheep		1.4336	1.338465		1.512	1.325
3.B.3 - Swine		0.2984	NE		0.392	NE
3.B.4 - Other						
3.B.4.d - Goats		9.716	11.395		7.924	9.275
3.B.4.e - Horses		2.94	0.795		0.812	0.265
3.B.4.f - Mules and Asses		10.724	0.53		4.984	0.265
3.B.4.g - Poultry		0.56	26.5		0.47	2.21
3.C.6 - Indirect N2O Emissions from manure management			2.385			1.855
3.D - Agriculture soils		**NE**	**1,204.43**		**NE**	**674.69**
3.D.1 - Direct N2O Emissions from managed soils			1186.935			663.295
3.D.2 - Indirect N2O Emissions from managed soils			17.49			11.395
3.G - Liming	**0.038**			**0.103**		
3.H - Urea application	**0.355**			**2.387**		

Table 5-2: Emissions from Agriculture categories between 2000 and 2022 (Gg CO_2 equivalent)

Category	2000	2005	2010	2015	2016	2017	2018	2019	2020	2021	2022
Enteric Fermentation	2,193.68	2,221.96	2,713.8	1,783.10	1,790.59	1,719.8	1,540.46	1,445.59	1366.12	1279.46	1,196.12
Manure Management	138.89	108.05	137.87	81.49	83.86	83.75	78.16	68.37	66.29	63.26	62.48
Liming	0.04	0.04	0.03	0.10	0.10	0.02	0.30	0.10	0.02	0.10	0.10
Urea application	0.36	0.10	1.00	0.90	0.70	0.20	0.30	2.5	4.70	1.30	2.40
Agricultural soils	1,204.43	1,211.46	1,492.99	1,018.77	1,015.63	983.63	872.63	822.35	775.75	719.87	674.69
Total	3,537.39	3,541.57	4,345.66	2,884.32	2,890.89	2,787.36	2,491.59	2,338.91	2,212.89	2,064.03	1,935.77

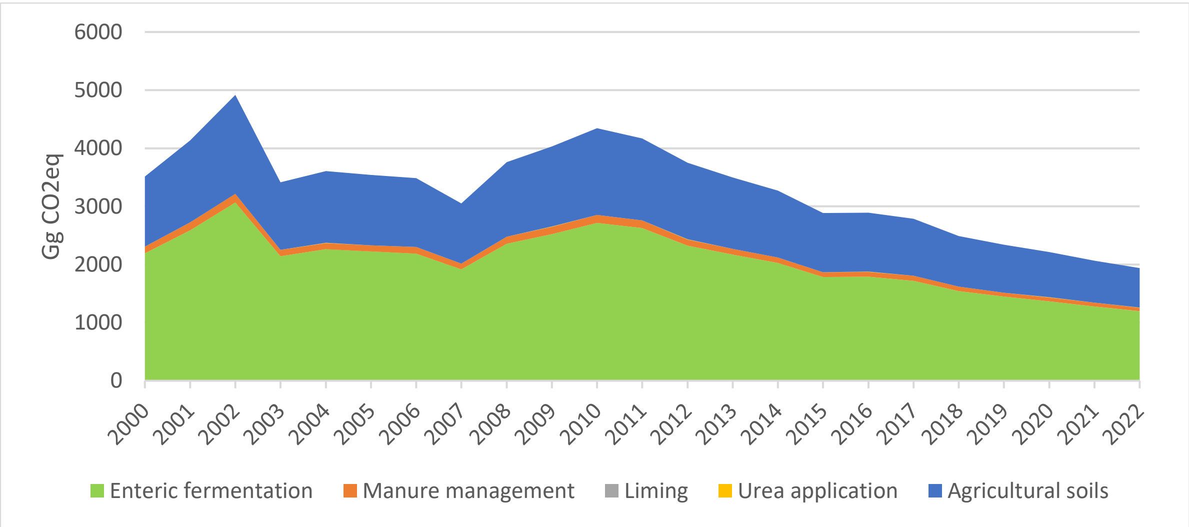

Figure.5-1: Emissions from Agriculture categories, 2000 - 2022 (Gg CO_2 equivalent)

5.1.2.1. Enteric Fermentation

The trend line for enteric fermentation was irregular as shown in Table 5.2 and Figure 5.2. Enteric fermentation emissions increased between the years 2000 (2,193.69 Gg CO_2eq) and 2002 (3,068.09 Gg CO_2eq). This coincided with increase on population of other cattle, goats and, mules and asses. From year 2002 the emissions declined and plateaued up to 2006 in response to decrease and stabilisation in livestock population especially for other cattle and goats. Other cattle and goats dropped by 42% and 3% respectively between year 2002 and 2007. However, from 2010 there was a continuous decline on emissions up to 2022. This is attributable to decrease of other cattle (59%) and goats (34%) during the same period as shown in Figure 5.3. Key drivers for this downward trend include severe climate-induced droughts that negatively impacted rangeland productivity and birth rates. Additionally, the sector faced significant pressure from animal diseases such as FMD, which resulted in mandatory culling and capped the growth of the national livestock population (MENT, 2021; MoA, 2023).

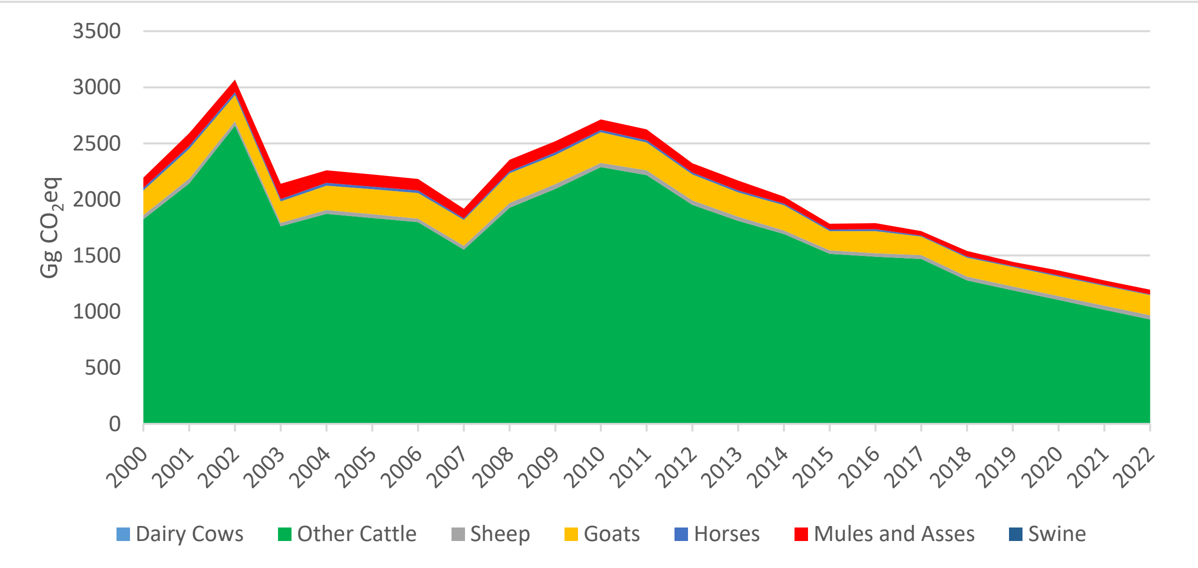

Figure.5-2: Enteric fermentation emission trends, 2000 - 2022 (Gg CO_2 equivalent)

Table 5-3: Enteric fermentation emission trends, 2000 - 2022 (Gg CO_2 equivalent)

Livestock	2000	2005	2010	2015	2016	2017	2018	2019	2020	2021	2022
	Gg CO_2eq										
Dairy Cows	1.61	1.88	1.75	1.50	1.64	2.0621	2.06	1.74	1.58	1.85	1.62
Other Cattle	1,821.93	1,833.30	2,286.00	1,512.92	1,487.69	1,470.04	1,276.91	1,189.81	1,102.70	1,015.59	928.48
Buffalo	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
Sheep	35.84	33.11	39.06	33.88	32.83	32.90	32.87	34.02	35.18	36.33	37.49
Goats	220.64	222.60	271.32	168.70	196.77	168.00	169.40	172.06	174.72	177.38	180.04
Horses	24.19	22.43	20.66	16.13	14.87	7.56	11.21	10.08	8.95	7.81	6.68
Mules and Asses	89.32	108.36	94.92	49.84	56.70	39.20	47.95	37.80	42.88	40.34	41.61
Swine	0.15	0.28	0.08	0.12	0.09	0.04	0.06	0.09	0.13	0.16	0.20
Other	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
Total	**2,193.69**	**2,221.68**	**2,713.71**	**1,782.97**	**1,790.50**	**1,717.70**	**1,540.40**	**1,445.51**	**1,365.99**	**1,279.29**	**1,195.91**

Figure 5.3 shows livestock categories that were directly related to enteric fermentation emissions. Horses and Dairy cattle were less variable in population during the period of 2000 - 2022 when compared to other livestock populations. Dairy cattle are usually intensively managed and provided with livestock feeds to meet their nutrient requirements hence they are less affected by droughts when compared to other cattle that rely on natural pastures for feeding.

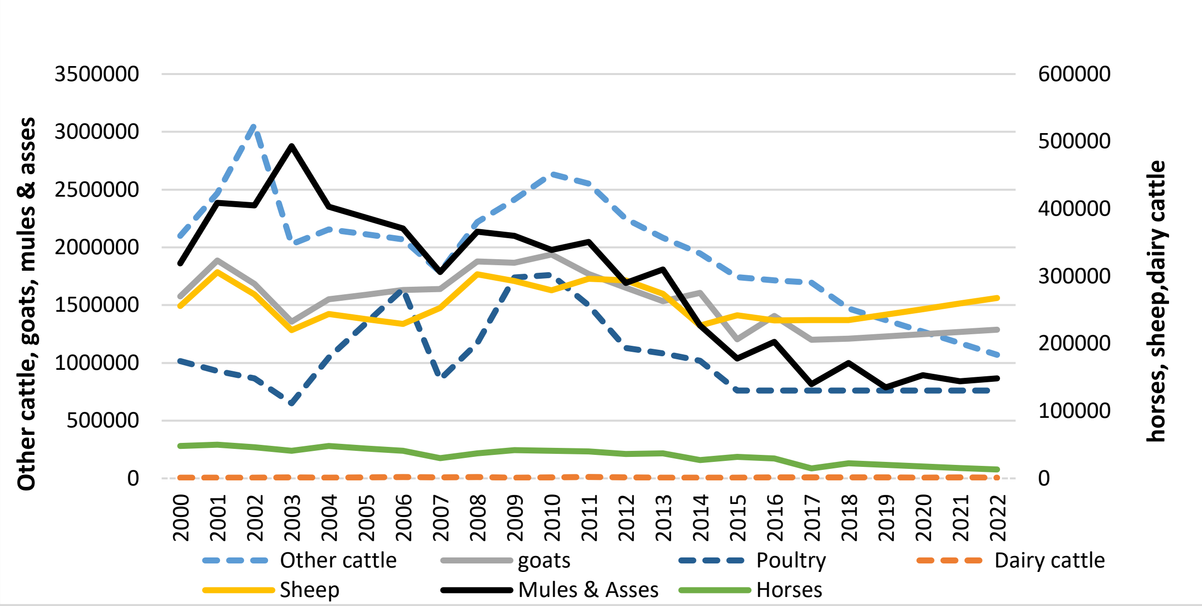

Figure.5-3: Population size of livestock 2000 – 2022

Table 5.4 presents the variations in enteric fermentation emissions from 2000 to 2022, as well as the proportional contributions of different livestock categories to the overall enteric fermentation emissions. The table shows that the share of dairy cows, sheep, goats, and swine enteric fermentation emissions to the total enteric fermentation emissions showed an increase over the period from 2000 to 2022. Amongst the livestock categories, other cattle contributed the most to the total enteric fermentation emissions in 2022, accounting for 77.63% of the total enteric fermentation emissions, followed by goats, mules and asses, and sheep, with 15.05%, 3.48%, and 3.13%, respectively.

Table 5-4: Enteric fermentation emission trends, 2000 - 2022 (Gg CO_2 equivalent)

Livestock	Emissions (Gg CO_2eq)		Change (2000-2022)		Share of enteric fermentation (%)	
	2000	2022	Diff	%	2000	2022
Dairy Cows	1.61	1.62	0.01	0.56	0.07	0.14
Other Cattle	1821.93	928.48	-893.46	-49.04	83.06	77.63
Buffalo	NO	NO				
Sheep	35.84	37.49	1.65	4.59	1.63	3.13
Goats	220.64	180.04	-40.60	-18.40	10.06	15.05
Horses	24.19	6.68	-17.51	-72.40	1.10	0.56
Mules and Asses	89.32	41.61	-47.71	-53.42	4.07	3.48
Swine	0.15	0.20	0.05	30.07	0.01	0.02
Other	NO	NO				
Total	2193.54	1196.10	-997.44	-45.47	**100**	**100**

5.1.2.2. Manure Management

Emissions from manure management declined by 55.02% between 2000 and 2022 (Table 5.5 and Figure 5.4). Both CH_4 and N_2O emissions saw a decrease between 2000 and 2022. The table further shows that CH_4 emissions decreased by 45.94% between 2000 and 2022, while N_2O decreased by 69.13% during the same period. In 2022, CH_4 emissions (73.13%) contributed the most to the total manure management emissions. Trend differentials show that CH_4 emissions dropped drastically (55.36% decrease) between 2010 and 2022 and in the same period nitrous oxide declined by 52.75%. The drop in manure management emissions is directly related to livestock population and it therefore declines as livestock population goes down.

Table 5-5: Trends and changes in manure management emissions, 2000 - 2022 (Gg CO_2 equivalent)

Gas	Emissions (Gg CO_2eq)		Change (2000-2022)		Share of manure management (%)	
	2000	2022	Diff	%	2000	2022
Methane	84.51	45.69	-38.82	-45.94	60.85	73.13
Nitrous Oxide	54.38	16.79	-37.59	-69.13	39.15	26.87
Total manure management	138.89	62.48	-76.42	-55.02	**100**	**100**

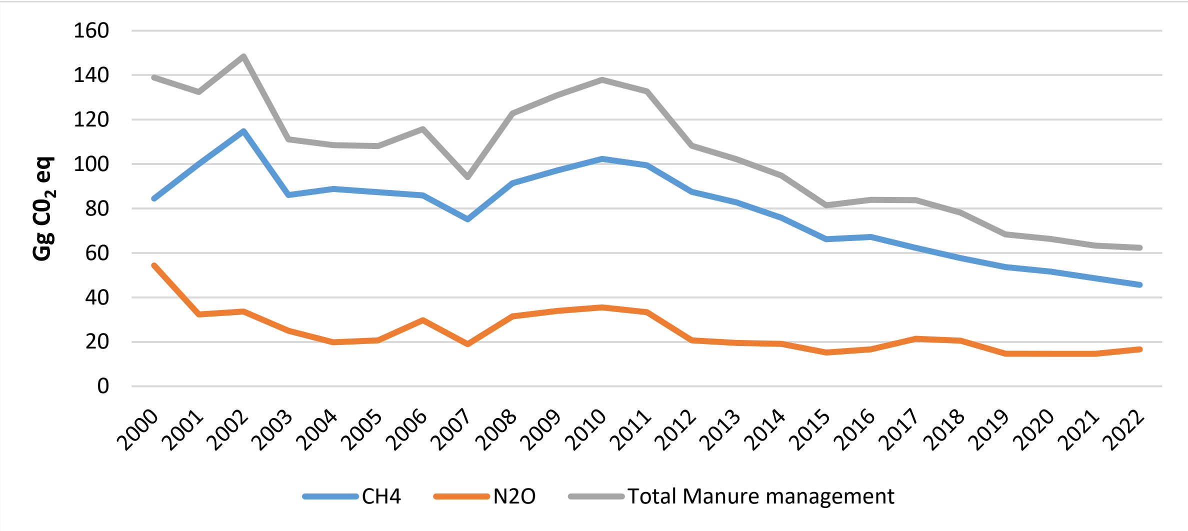

Figure.5-4: Trends in manure management emissions 2000 – 2022

Indirect N_2O emissions from manure management (3.B.5)

Table 5.6 presents the indirect N_2O emissions from manure management across different livestock types. Table 5.6 includes N_2O emissions resulting from volatilization. N_2O emissions due to leaching/runoff was not estimated due lack of country-specific information on the fraction of nitrogen loss due to leaching. In 2022, indirect N_2O emissions from manure management due to volatilization amounted to 1.85 Gg CO_2eq, a 22.6% reduction from 2.39 Gg CO_2eq recorded in 2000. Generally, the contribution of indirect N_2O emissions to the total Agriculture emissions is not substantial.

Table 5-6: Trends and changes in manure management emissions, 2000 - 2022 (Gg CO_2 equivalent)

2000	2005	2010	2015	2016	2017	2018	2019	2020	2021	2022
N_2O Emissions due to Volatilization (Gg CO_2eq)										
2.3869	3.2738	2.988	2.641	2.589	1.8447	1.698	2.1554	2.067	1.9197	1.855

5.1.2.3. Agricultural Soils- CRT 3.D

Table 5.7 presents a summary of emissions from Agricultural soils, emanating from Direct N_2O from managed soils (CRT 3.D.1), and Indirect N_2O from managed soils (CRT 3.D.2). It is evident from the table that, Direct N_2O from managed soils contributed the most towards this category. The table further shows that both categories 3.D.1 and 3.D.2 decreased between 2000 and 2022 by 44.12% and 35.06%, respectively. Trend line differentials show that Direct N_2O emissions from managed soils increased substantially from 2008 to 2010 (Fig 5.5). This is attributable to increased uptake of Integrated Support Programme for Arable Agriculture Development (ISPAAD) that aimed at improving arable farming by provision of agricultural inputs such as fertilizers to the farmers. ISPAAD was introduced by the government in 2008.

Table 5-7: Changes in emissions related to agricultural soils between 2000 and 2022

Category	Emissions (Gg CO_2eq)		Change (2000-2022)	
	2000	2022	Diff	%
3.D.1 - Direct N_2O from managed soils	1,186.94	663.295	-523.640	-44.12
3.D.2 - Indirect N_2O from managed soils	17.547	11.395	-6.152	-35.06

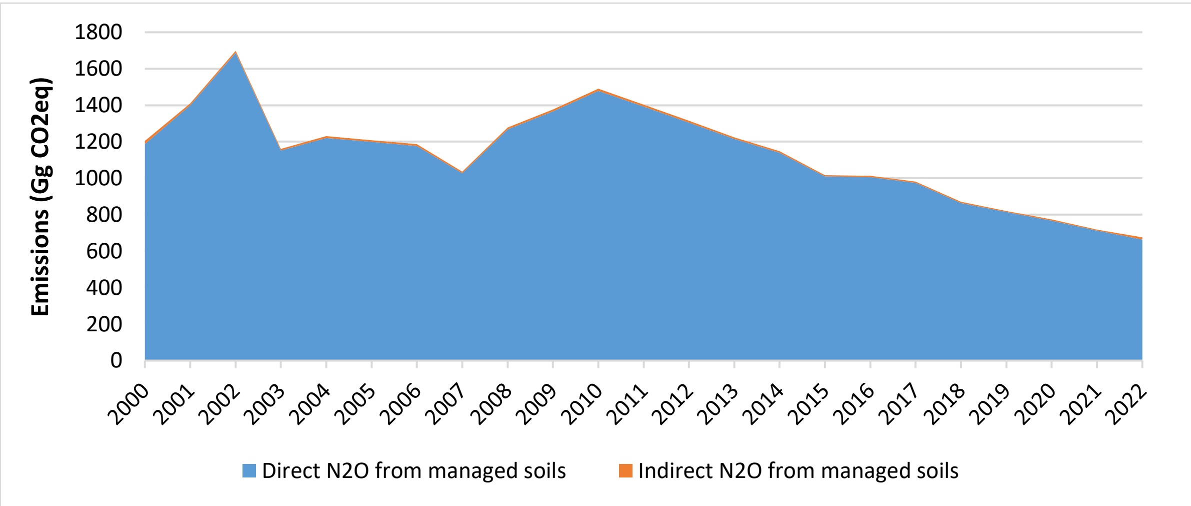

Figure.5-5: Trends in emissions related to agricultural soils 2000 – 2022

5.1.2.4. Liming- CRT 3.G

Total greenhouse gas emissions from liming, specifically from dolomite, rose from 0.038 Gg CO_2eq in 2000 to 0.143 Gg CO_2eq in 2022 (Table 5-8). This represents an absolute increase of 0.105 Gg CO_2eq, or a substantial percentage growth of 276.32% over the twenty-year period. While the sector's growth is high in percentage terms, the low absolute values (well below 1 Gg) indicate that Liming is a non-key category for Botswana.

Table 5-8: Changes in emissions related to liming (dolomite) between 2000 and 2022

Category	Emissions (Gg CO_2eq)		Change (2000-2022)	
	2000	2022	Diff	%
3.G - Liming	0.038	0.143	0.105	276.32

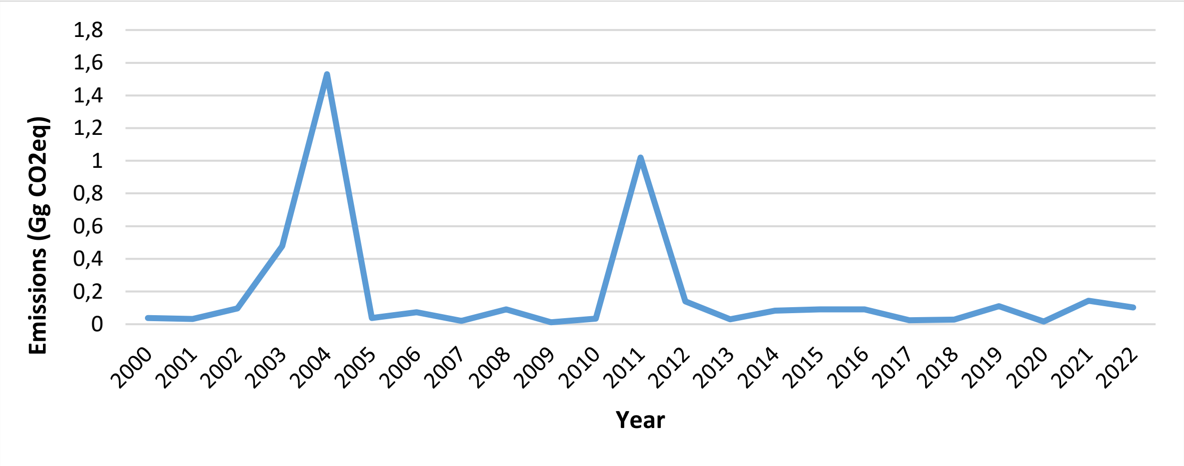

Figure.5-6: Trends in emissions related to liming 2000 – 2022

5.1.2.5. Urea application- CRT 3.H

Table 5-9 shows that emissions related to urea application increased from 0.355 Gg CO_2eq in the base year (2000) to 1.3 Gg CO_2eq in the 2022 inventory year. This reflects an absolute growth of 0.945 Gg CO_2eq, representing a total increase of 266.20%. Urea application emissions increased significantly in 2019 when the government introduced Impact Accelerator Subsidy (2019) that offered several grants such as inputs (seeds, fertilizers, seedlings), shade houses and water infrastructure to horticultural farmers.

Table 5-9: Changes in emissions related to Urea application between 2000 and 2022

Category	Emissions (Gg CO_2eq)		Change (2000-2022)	
	2000	2022	Diff	%
3.H - Urea application	0.355	1.3	0.945	266.20

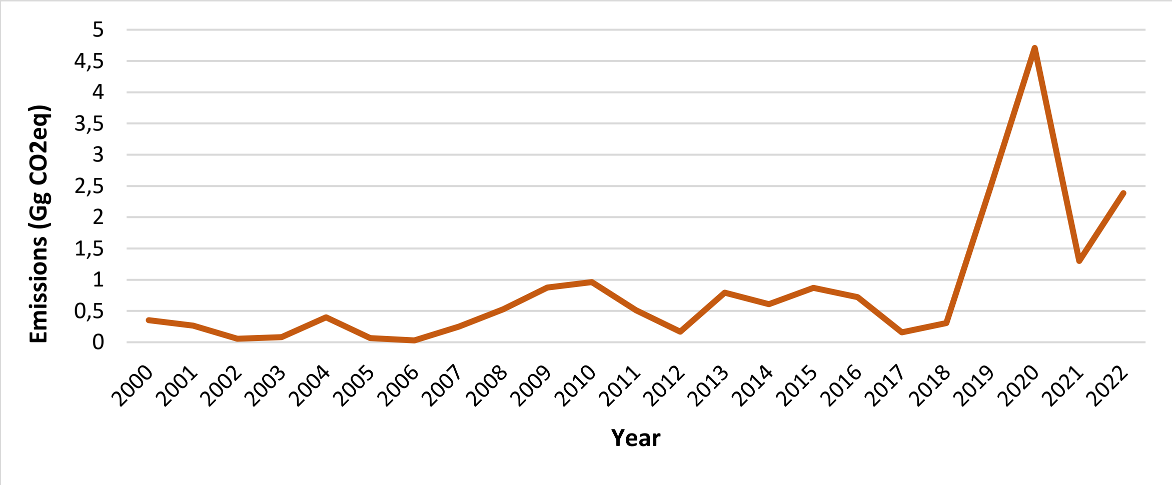

Figure.5-7: Trends in emissions related to Urea application 2000 – 2022

5.1.3. General methodological issues of the sector

This sector primarily utilizes the Tier 1 IPCC 2006 methodology (IPCC, 2006), incorporating several updated methods derived from the IPCC 2019 Refinement of the 2006 Guidelines (IPCC, 2019). Both guideline documents serve as the source for the IPCC default constants and emission factors applied here. Further details on their use are presented in the methodology sections of the respective categories. Table 5.10 shows the methods and types of EF used in the Agriculture inventory.

Table 5-10: Summary of methods and emission factors for the Agriculture sector and an assessment of the completeness of the Agriculture sector emissions

	GHG Source and sink category	CO_2		CH_4		N_2O		NOx	CO	NMVOCs
		Method applied	Emission factor	Method applied	Emission factor	Method applied	Emission factor			
LIVESTOCK										
	3.A.1.a - Cattle	NA	NA	T1	D	NA	NA	NA	NA	NA
	3.A.1.a.i - Dairy Cows	NA	NA	T1	D	NA	NA	NA	NA	NA
	3.A.1.a.ii - Other Cattle	NA	NA	T1	D	NA	NA	NA	NA	NA
	3.A.2 - Sheep	NA	NA	T1	D	NA	NA	NA	NA	NA
	3.A.3 - Swine	NA	NA	T1	D	NA	NA	NA	NA	NA
	3.A.4 - Other									
	3.A.4.a - Buffalo	NA	NA	NO	NO	NA	NA	NA	NA	NA
	3.A.4.b - Camels	NA	NA	NO	NO	NA	NA	NA	NA	NA
	3.A.4.d - Goats	NA	NA	T1	D	NA	NA	NA	NA	NA
	3.A.4.e - Horses	NA	NA	T1	D	NA	NA	NA	NA	NA
	3.A.1.h - Mules and Asses	NA	NA	T1	D	NA	NA	NA	NA	NA
	3.B - Manure Management									
	3.B.1- Cattle									
	3.B.1.a - Dairy cows	NA	NA	T1	D	T1	D	NE	NA	NA
	3.B.1.b - Other cattle	NA	NA	T1	D	T1	D	NE	NA	NA
	3.B.2 - Sheep	NA	NA	T1	D	NO	NO	NE	NA	NA
	3.B.3 - Swine	NA	NA	T1	D	T1	D	NE	NA	NA
	3.B.4 - Other									
	3.B.4.a - Buffalo	NA	NA	NO	NO	NO	NO	NE	NA	NA
	3.B.4.b - Camels	NA	NA	NO	NO	NO	NO	NE	NA	NA
	3.B.4.d - Goats	NA	NA	T1	D	NO	NO	NE	NA	NA

	GHG Source and sink category	CO_2		CH_4		N_2O		NOx	CO	NMVOCs
		Method applied	Emission factor	Method applied	Emission factor	Method applied	Emission factor			
	3.B.4.e - Horses	NA	NA	T1	D	NO	NO	NE	NA	NA
	3.B.4.f – Mules and Asses	NA	NA	T1	D	NO	NO	NE	NA	NA
	3.B.4.g - Poultry)	NA	NA	T1	D	T1	D	NE	NA	NA
	3.B.5-Indirect N2O emissions									
	3.C – Rice cultivation	NO		NO		NO				
AGRICULTURAL SOILS	**3.D - Agricultural soils**									
	3.D.1 – Direct N2O Emissions from managed soils	NA		NA		T1	D			
	Synthetic fertilizers	NA		NA		T1	D		NA	NA
	Urine and dung deposited by grazing livestock	NA		NA		T1	D		NA	NA
	3.D.2 – Indirect N2O Emissions from managed soils									
	Atmospheric deposition	NA		NA		T1	D			
	Nitrogen leaching and runoff	NA		NA		T1	D			
	3.E – Prescribed burning of savannas	NE		NE		NE		NE	NE	
	3.F – Field burning of Agricultural residues	NE		NE		NE		NE	NE	
	3.G – Liming									
	Liming (Dolomite)	T1	D	NA		NA		NA	NA	NA
	3.H - Urea application									
	Urea application	T1	D	NA		NA		NA	NA	NA
	3.I – Other carbon containing fertilisers									
	Other carbon containing fertilisers	NE		NE		NE				
	3.J - Other									
	Other	NO		NO		NO				

5.1.4. Flexibility applied in the agriculture sector

In accordance with MPG para. 6, which indicates that "The developing country Party shall clearly indicate the provision to which flexibility is applied, concisely clarify capacity constraints, noting that some constraints may be relevant to several provisions, and provide self-determined estimated time frames for improvements in relation to those capacity constraints" (UNFCCC, 2018), and addressing the TERT feedback regarding the need for explicit clarification of capacity hurdles, Botswana applies the flexibility provision for time-series consistency (paragraph 57 of the MPGs) across the Agriculture sector (Categories 3.A, 3.B, 3.D, 3.G, and 3.H) (Table 5-11). This application is necessitated by specific capacity constraints in accessing and digitizing historical activity data prior to 2020. While a robust annual time series has been established from 2020 through 2022 to meet current NDC tracking requirements, gaps in archived national statistics and shifts in historical data-collection methodologies currently hinder the retrospective application of 2006 IPCC Guidelines back to 1990. To address these constraints, the country has initiated a data-recovery roadmap and institutionalized reporting protocols within the Thematic Working Groups, with a self-determined goal to deliver a fully consistent, recalculated time series by the submission of BTR 2.

Table 5-11: Flexibility applied in the agriculture sector

Year	Sector	Category	Gas	Explanation for using flexibility provision (MPG provision)	Timeframe for improvement
2022	Agriculture	Enteric fermentation (CRT 3A)	CH_4	Provision 57 on Time Series: The standard requirement for reporting a continuous annual time series starting in 1990 has been replaced with a more flexible approach. Parties have the flexibility to instead report data for their NDC reference period and provide a consistent annual time series beginning from at least 2020. However, because Botswana currently lacks sufficient data extending back to 1990, the country is actively working to collect data from 1990 to the present.	BTR 2 (NIR 3)
2022	Agriculture	Manure management (CRT 3B)	CH_4, N_2O	Provision 57 on Time Series: The standard requirement for reporting a continuous annual time series starting in 1990 has been replaced with a more flexible approach. Parties must now report data for their NDC reference period and provide a consistent annual time series beginning from at least 2020. However, because Botswana currently lacks sufficient data extending back to 1990, the country is actively working to collect data from 1990 to the present.	BTR 2 (NIR 3)
2022	Agriculture	Direct and indirect N_2O emissions from managed soils (CRT 3D1 and 3D2)	N_2O	Provision 57 on Time Series: The standard requirement for reporting a continuous annual time series starting in 1990 has	BTR 2 (NIR 3)

Year	Sector	Category	Gas	Explanation for using flexibility provision (MPG provision)	Timeframe for improvement
				been replaced with a more flexible approach. Parties must now report data for their NDC reference period and provide a consistent annual time series beginning from at least 2020. However, because Botswana currently lacks sufficient data extending back to 1990, the country is actively working to collect data from 1990 to the present.	
2022	Agriculture	Liming (CRT 3G)	CO_2	Provision 57 on Time Series: The standard requirement for reporting a continuous annual time series starting in 1990 has been replaced with a more flexible approach. Parties must now report data for their NDC reference period and provide a consistent annual time series beginning from at least 2020. However, because Botswana currently lacks sufficient data extending back to 1990, the country is actively working to collect data from 1990 to the present.	BTR 2 (NIR 3)
2022	Agriculture	Urea application (CRT 3H)	CO_2	Provision 57 on Time Series: The standard requirement for reporting a continuous annual time series starting in 1990 has been replaced with a more flexible approach. Parties must now report data for their NDC reference period and provide a consistent annual time series beginning from at least 2020. However, because Botswana currently lacks sufficient data extending back to 1990, the country is actively working to collect data from 1990 to the present.	BTR 2 (NIR 3)

5.1.5. General Category-specific recalculations

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

- The agriculture sector is undergoing continuous refinement, necessitating recalculations of its data. Key structural changes include splitting Agriculture and LULUCF into separate chapters. Furthermore, all non-CO_2 emissions from biomass burning associated with other land categories (Forest land, Grassland, Wetland, and Settlement) have been removed from the agriculture sector and are now included under the LULUCF sector.
- Non-CO_2 emissions from biomass burning associated with cropland (Category 3.F) have not been estimated (NE) in the 2022 NID, in accordance with the flexibility and significance thresholds outlined in the MPGs (UNFCCC, 2018). This exclusion is primarily due to a lack

of robust national activity data regarding the fraction of crop residues burned in-situ. Furthermore, based on national circumstances, this category is considered insignificant; in Botswana's semi-arid agricultural system, crop residues are traditionally prioritized as essential livestock fodder during the dry season rather than being disposed of through fire (GoB, 2021). Following the 2006 IPCC Guidelines (IPCC, 2006), estimating these emissions without verified burning fractions would introduce disproportionate uncertainty. Botswana plans to enhance future agricultural surveys to capture residue management practices, aiming for completeness in future BTR cycles.

- In the last inventory (2014/2015) emissions from manure management, and Direct and indirect N_2O emissions from managed soils were not missed out, but in 2022 inventory the aforesaid have been incorporated.
- In 2022 inventory, the IPCC default weight of the cows (275 Kg) which is more than the weight used in the previous Tier 1 inventory (173 Kg).

Specific details regarding these improvements are presented in the relevant category or sub-category sections of this report. Although the recalculations maintained the overall consistent emission trend, they also revealed a shift in that trend across the entire time series. Consequently, the emissions recorded are now higher than those reported in the previous inventory (Figure 5-8).

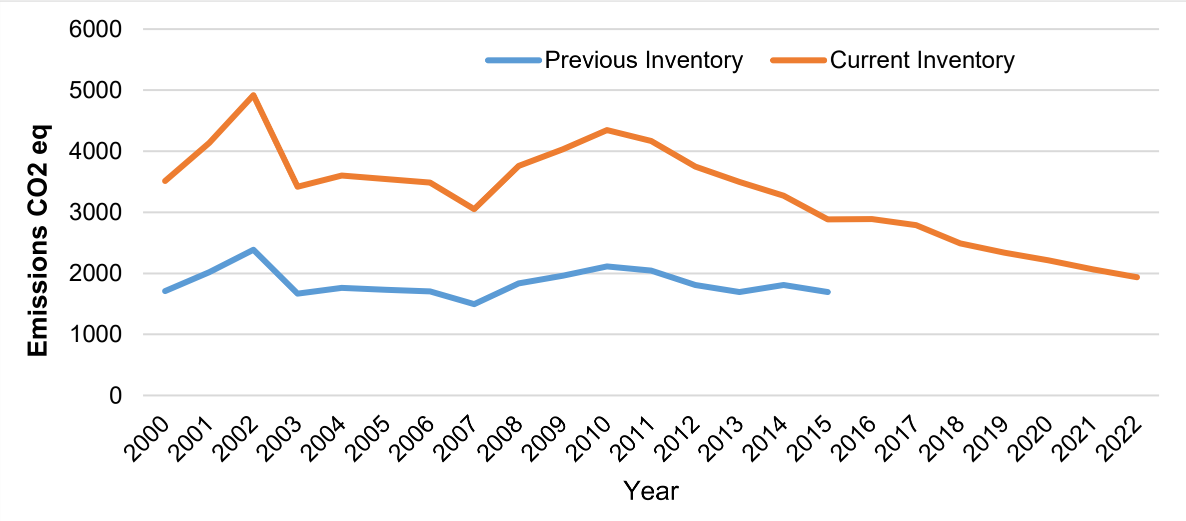

Figure.5-8: Change in Agriculture emission estimates due to recalculations since 2015 submission

5.1.6. QA/QC process and verification

Details of the QA/QC processes are found in the subsequent category sections. Additionally, the QA/QC measures detailed in Table 5.12 were specifically applied to the calculation files for the agriculture sector.

Table 5-12: Category-specific QA/QC checks completed for the agriculture sector

QA/QC principle	Check
Accuracy	Activity data source
Accuracy	Correct units
Accuracy	Unit carry through
Accuracy	Calculations check
Accuracy	Uncertainties
Accuracy	Double counting
Accuracy	Correct GWP
Accuracy	Notation keys
Accuracy, Completeness, Consistency, Transparency	Trend check
Accuracy, Transparency	Emission factor applicability
Accuracy, Completeness, Consistency, Transparency	Recalculations
Completeness, Comparability	Sub-category completeness
Consistency	Documentation
Accuracy, Comparability	Cross check data
Accuracy	Spot checks
Transparency, Consistency	Data source referencing
Transparency	Links to source data
Transparency	Raw primary data
Accuracy	QA review

5.1.7. Planned improvements and recommendations

The planned improvements and recommendations for the agriculture sector, aimed at enhancing future estimates, are outlined below:

a) As Enteric Fermentation is a Key Category for Botswana, the country is transitioning from Tier 1 to a Tier 2 approach. This involves collecting enhanced activity data, beginning with the Dairy Cattle and Other Cattle sub-categories, to develop country-specific emission factors (EFs). This shift ensures higher accuracy and better reflects national livestock characteristics as required by the 2006 IPCC Guidelines.

b) Encourage farmers should to keep records on growth performance, milk production and reproductive performance in preparation for Tier 2 methodology.

c) Improve on data collection dealing with manure management because there is currently lack of national data set on manure management systems. To enhance the accuracy of manure-related emissions, it is recommended that a system be established to track manure management practices or systems used across Botswana. This would allow for the inclusion of dynamics driven by shifts in management regimes.

d) Engage Ministry of Lands and Agriculture and Statistics Botswana to resuscitate annual agricultural surveys.

e) Collect data for Tier 2 approach on cattle manure management category and develop country-specific emission factors. The intention is to start with dairy cattle and other cattle.

5.2. Enteric Fermentation (CRT 3.A)

5.2.1. Source category description

According to 2006 IPCC, the important end product from ruminal fermentation is methane (CH_4). The amount of CH_4 produced from enteric fermentation depends on animal species, production level, quantity and quality of feed ingested and environmental conditions. In Botswana enteric fermentation emissions reduced by 45.47% from 2,193.55 Gg CO_2eq in 2000 to 1,196.10 Gg CO_2eq in 2022. This is attributed to the decrease of other cattle which is associated with periodic livestock diseases, drought, stock theft and other factors. Tier 1 level and trend assessments reveal that enteric fermentation is a key source category in Botswana (Table 5.13). According to IPCC good practice requirements, there is need to use Tier 2 methods to estimate enteric fermentation emissions from the major livestock sub-categories.

Table 5-13: Summary of source category description, CRT 3.A, according to approach 1.

CRT	Gas	Key Category Assessment (excluding LULUCF)		Method	EF	All sources estimated
		Level	Trend			
3.A.1.a Dairy cattle	CH_4	X	X	T1	D	Yes
3.A.1.b Other cattle	CH_4	X	X	T1	D	Yes
3.A.2 Sheep	CH_4	-	-	T1	D	Yes
3.A.4.b Goats	CH_4	-	-	T1	D	Yes
3.A.4.d Horses	CH_4	-	-	T1	D	Yes
3.A.4.e Mules and Asses	CH_4	-	-	T1	D	Yes
3.A.3 Swine	CH_4	-	-	T1	D	Yes

T1 - Tier 1. D – Default

5.2.2. Methodological Issues of the Category

A Tier 1 methodology is used to calculate CH_4 emissions from enteric fermentation in dairy cattle, other cattle, sheep, goats, horses, mules and asses by multiplying the population data by IPCC default emissions factors (IPCC Equation 10.19, IPCC 2019 Refinement). The livestock population for each category (Table 5.8) is multiplied by default emission factor and the total emission is calculated as (Equation 10.19, Chapter 1, 2006 IPCC Guidelines):

$$emissions = \sum_i population_i \times EF_i$$

5.2.2.1. Activity data: Livestock population

The livestock population data were sourced from Statistics Botswana agricultural censuses and annual survey reports. Where population data were missing, simple linear interpolation and extrapolation were performed to estimate the missing population data. Table 5.14 shows the total livestock populations for the time series 2000-2022, respectively.

Table 5-14: Population size of livestock

Livestock	2000	2001	2002	2003	2004	2005	2006	2007	2008
Dairy	1 252	1 271	1 233	1 308	1 159	1 459	1 754	1 425	1 750
Other Cattle	2 099 000	2 468 000	3 060 000	2 028 000	2 155 000	2 112 096	2 069 191	1 786 575	2 218 250
Sheep	256 000	306 000	273 000	220 000	244 000	236 500	229 000	253 000	303 000
Goats	1 576 000	1 887 000	1 683 000	1 355 000	1 550 000	1 590 000	1 630 000	1 640 000	1 879 000
Horses	48 000	50 000	46 000	41 000	48 000	44 500	41 000	30 000	37 000
Mules and Asses	319 000	409 000	405 000	493 000	403 000	387 000	371 000	306 000	366 000
Swine	5 329	5 000	4 671	4 000	7 000	10 000	12 000	16 614	13 664
Poultry	1 015 000	928 000	866 000	650 000	1 046 000	1 324 500	1 639 000	858 000	1 170 000

Table 5-12 (continued)

Livestock	2009	2010	2011	2012	2013	2014	2015	2016	2017
Dairy	973	1 358	2 091	1 703	1 101	1 135	1 166	1 276	1 601
Other Cattle	2 412 043	2 633 642	2 551 909	2 245 297	2 082 746	1 948 000	1 743 000	1 713 926	1 693 595
Sheep	293 000	279 000	296 000	294 000	274 000	227 000	242 000	234 500	235 000
Goats	1 867 000	1 938 000	1 770 000	1 650 000	1 533 000	1 606 000	1 205 000	1 405 500	1 200 000
Horses	42 000	41 000	40 000	36 000	37 000	27 000	32 000	29 500	15 000
Mules and Asses	360 000	339 000	351 000	290 000	310 000	227 000	178 000	202 500	140 000
Swine	13 320	3 000	4 865	2 437	3 023	4 113	4 398	3 303	1 437
Poultry	1 739 000	1 761 000	1 499 000	1 130 000	1 081 000	1 017 000	760 000	1 011 710	710 000

Table 5.12 (continued).

Livestock	2018	2019	2020	2021	2022
Dairy	1596	1352	1225	1435	1259
Other Cattle	1471100	1370743	1270386	1170029	1069672
Sheep	234750	243000	251250	259500	267750
Goats	1210000	1229000	1248000	1267000	1286000
Horses	22250	20000	17750	15500	13250
Mules and Asses	171250	135000	153125	144063	148594
Swine	2094	5 000	4 671	4 000	7 000
Poultry	846 000	848 000	864 000	814 000	842 000

Source: *Statistics Botswana; FAOSTAT*

5.2.2.2. Emission Factors

Tier 1 IPCC default emission factors in Table 5-15 were applied to dairy cattle, other cattle, sheep, goats, horses, mules and asses, respectively (IPCC 2006, Tables 10.10 & 10.11). Botswana's livestock sector is characterized by a dual production structure consisting of Traditional (Communal) and Commercial (Freehold) systems (MoA, 2021). For greenhouse gas reporting, approximately 80-90% of the national herd is managed under the traditional communal system, which is characterized by extensive grazing on natural rangelands, minimal supplementary feeding, and significant energy expenditure for water access (Mahabile, 2006). Conversely, the commercial sector, including specialized dairy farms and beef feedlots, utilizes intensive management and higher-quality feed concentrates.

Table 5-15: Methane from animals, emission factors used.

Livestock	kg CH_4/head/year	Method
Dairy	36	IPCC 2006
Other Cattle	31	
Sheep	5	
Goats	5	
Horses	18	
Mules and Asses	10	
Swine	1	

5.2.3. Uncertainties and time-series consistency

Uncertainty was estimated using the method described below. The uncertainty of activity data was estimated at ±10% for dairy cattle and swine, and ±5% for other cattle, sheep, goats, horses, and mules and asses in 2000 to 2022. The relatively large uncertainty for dairy and swine is attributed to a lot of missing data in comparison to other livestock. The questionnaire for commercial farmers was self-administered (Statistics Botswana Report, 2011), which is likely to increase uncertainties due to different interpretations of the questions. The uncertainty of emission factors for all the livestock was ±30% (IPCC, 2006, Vol 4, Ch. 10, p33). In accordance with the 2006 IPCC Guidelines (Volume 4, Chapter 10, Table 10.10), which provides an uncertainty range of 30-50% for default emission factors, Botswana has applied a 30% uncertainty values based on the high level of confidence in the national livestock population data provided by Statistics Botswana. The selection of the lower-bound criterion is justified by the use of annual agricultural censuses and a rigorous characterization of the national herd into traditional and commercial sectors, which reduces the potential for activity data errors typically associated with the higher 50% uncertainty margin (IPCC, 2006).

Uncertainty of total enteric fermentation emissions is a simple error propagation of activity data uncertainty and emission factor uncertainty:

The uncertainty of activity data (AD) and emission factor (EF) are ΔAD and ΔEF respectively, the simple error propagation for the emission is given by;

$$\Delta EM = \mathrm{EM} \times \sqrt{\left(\left(\frac{\Delta AD}{AD}\right)^2 + \left(\frac{\Delta EF}{EF}\right)^2\right)}$$

This is further simplified to: $\Delta EM = \sqrt{\Delta \mathrm{AD}^2 + \Delta \mathrm{EF}^2}$

Which yields uncertainties of emissions as follows: dairy at ±22.4%; other cattle at ±20.6%; sheep at ±20.6%; goats at ±20.6%; horses at ±20.6%; mules and asses at ±20.6%.; swine at ±20.6%.

5.2.4. Source-specific QA/QC and verification

Quality control activities have been implemented. Quality control activities included:

- Used data from Statistics Botswana, an organisation charged with the responsibility of collecting and disseminating all official statistics in Botswana.
- Data were checked and verified several times.
- To verify the cattle population data, comparisons were made with FAOSTAT data. The data were comparable.

Since Tier 1 IPCC default emission factors were used, there was no need to compare them with any other emissions factors because they were the only factors available for the country to use. There are no country-specific emission factors.

5.2.5. Source-Specific Recalculations

The same data were used for both current Tier 1 and previous Tier 1, hence a similar trend was observed as reflected in Figure 5.9. Current Tier 1 reported emissions for the period 2000-2022. The difference in emissions is attributed to the use of GWP from Fifth Assessment Report in the current as opposed to the Second Assessment Report used in the previous inventory.

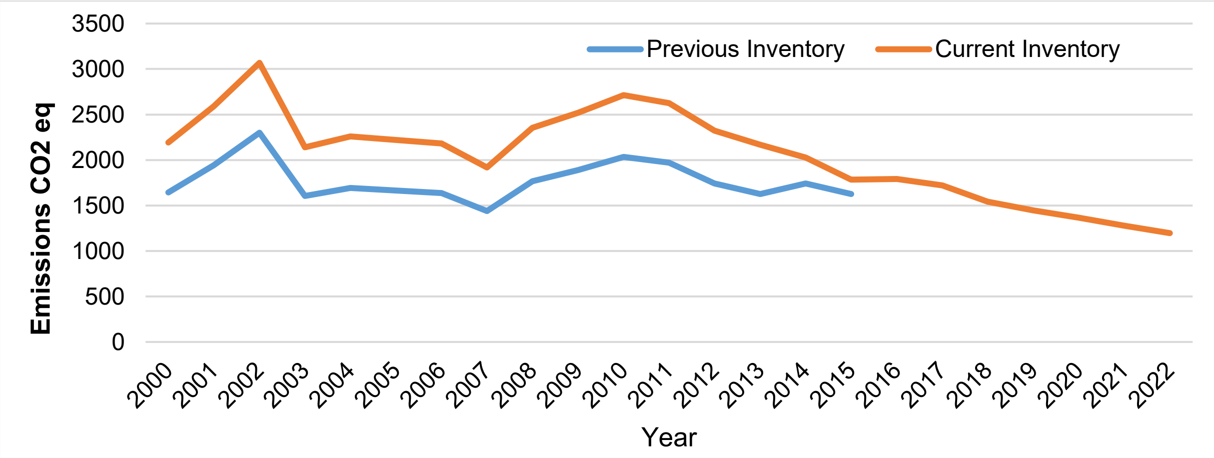

Figure.5-9: Comparison of current Enteric Fermentation Tier 1 (2000-2022) time series with the previous Tier 1 (2000-2015) time series

5.2.6. Source-Specific Planned Improvements

For cattle enteric fermentation emissions, priorities for improvements include:

- Generate country-specific emission factors.
- Improve quality and reliability of data produced nationally.
- Data captured in readily available format.

5.3. Manure Management (CRT 3.B)

The relevant greenhouse gases emitted from this source category are CH_4 (IPCC 3.B.a) and N_2O (IPCC 3.B.b). For Botswana, the emission from both gases are important.

5.3.1. CH_4 emissions from manure management (CRT 3.Ba)

5.3.1.1. Source category description

Livestock manure is mainly composed of organic matter. When this material decomposes in an anaerobic environment (without oxygen), methanogenic bacteria produce CH_4. The volume of CH_4 emissions depends on both the total manure produced and the proportion that decomposes anaerobically. To estimate these CH_4 emissions from manure management, the IPCC methodology requires the following steps:

- Collection of activity data- livestock population
- For CH_4 emissions- multiply the livestock emission factors by livestock populations to estimate livestock CH_4 emissions.

In 2022, the contribution of manure management to the total agriculture sector emissions was 62.48 Gg CO_2eq (3.23%). Methane emissions contributed about 73.13% to the total manure management emissions.

5.3.1.2. Methodological issues

A Tier 1 methodology is used and it requires livestock population data by animal species/category and climate region or temperature, in combination with IPCC default emission factors, to estimate emissions. The Tier 1 method entails multiplying the total amount of VS excreted (from all livestock species/categories) in each type of manure management system by an emission factor for that type of livestock category in the specified climate zone and manure management system (using IPCC 2019 Refinement, Equation 10.22). Emissions are summed over all manure management systems and livestock categories. The Tier 1 method is applied using IPCC default VS excretion rates (IPCC 2019 Refinement, Table 10.13a), default typical animal mass (IPCC 2019 Refinement, Table 10A.5), default CH_4 Emission Factors (IPCC 2019 Refinement, Table 10.14), and default animal waste management systems (AWMS).

Activity data

The two main types of activity data for estimating CH_4 and N_2O emissions from manure management are animal population data and manure management system usage data. Livestock population data is presented in section 5.2.2.1. The manure management system usage data for livestock was sourced mainly from 2006 IPCC and IPCC 2019 Refinement (SSA default) guidelines.

Table 5-16: Manure management systems for the various livestock types and their data sources

Livestock	Liquid /Slurry	Dry lot /Kraals	Solid storage	Compost-static pile	Poultry manure with litter	Poultry manure without litter	Pasture, Range, Paddock (PRP)	Burned for fuel	Data sources
Dairy		29%	5%*				60%*	6%	IPCC 2006; IPCC 2019
Other Cattle		1%					96%	3%	
Sheep		1%	17%				82%		

Livestock	Liquid /Slurry	Dry lot /Kraals	Solid storage	Compost-static pile	Poultry manure with litter	Poultry manure without litter	Pasture, Range, Paddock (PRP)	Burned for fuel	Data sources
Goats		1%	19%				80%		Refinement (SSA default)
Horses		1%	19%				80%		
Mules and Asses		1%					99%		
Swine		30%***	70%****						
Poultry	10%	56%		9%	15%**	10%**			

* ARC Report (2021), ** Moeletsi &Tongwane (2015), ***Nsoso et al. (2006), ****Moreki (2012)

Emission factors

Methane emissions from manure management were estimated in accordance with IPCC Equation 10.22 (IPCC, 2006). The Tier 1 method calculates emissions using the population of each livestock category and a corresponding regional default emission factor ($EF_{(T)}$), as defined in Table 10.14 and Table 10.15 of the 2006 Guidelines. For Botswana, the default emission factors for the Africa region were selected to reflect national management practices and the semi-arid (warm) climate. The following factors were used for a warm climate (IPCC 2006, Tables 10.14 & 10.15):

- Dairy Cattle: 1 Kg CH_4/head/year
- Other Cattle: 1 Kg CH_4/head/year
- Sheep: 0.20 Kg CH_4/head/year
- Goats: 0.22 Kg CH_4/head/year
- Horses:1.56 Kg CH_4/head/year
- Mules & Asses: 0.84 Kg CH_4/head/year

Annual volatile solid (VS) excretion for all livestock categories including dairy cattle, other cattle, sheep, goats, horses, and mules/asses, is determined using a Tier 1 methodology in accordance with IPCC 2006, Equation 10.22 (Volume 4, Chapter 10). The calculation utilizes default VS excretion rates (kg VS per 1000 kg animal mass per day) for the Africa region as provided in the 2006 IPCC Guidelines, Annex 10A.1 (formerly Table 10.13a):

- Dairy cattle: 6.10 kg VS (1000 kg animal mass)$^{-1}$ day^{-1}
- Other cattle: 6.10 kg VS (1000 kg animal mass)$^{-1}$ day^{-1}
- Sheep: 12.0 kg VS (1000 kg animal mass)$^{-1}$ day^{-1}
- Goats: 12.0 kg VS (1000 kg animal mass)$^{-1}$ day^{-1}
- Horses: 7.5 kg VS (1000 kg animal mass)$^{-1}$ day^{-1}
- Mules/Asses: 5.4 kg VS (1000 kg animal mass)-1 day-1

5.3.1.3. Time-series consistency

The time-series presented is only for the current inventory (period 2000-2022) because the previous inventory did not estimate CH_4 emissions from manure management.

5.3.1.4. Uncertainty

Activity data uncertainty: The population data uncertainties are discussed in section 5.2.3. For manure management data, the IPCC 2006 default uncertainty for N excretion for all the livestock is ± 50%.

The 2006 IPCC guidelines assign uncertainty of ±30 Tier 1 emission factors for CH_4 emissions from manure management (Table 5.17).

Table 5-17: Uncertainty data for livestock manure CH_4 emission factors

Animal category	Emission factor uncertainty	Reference
3.B.1.a - Dairy cattle	± 30	IPCC 2006
3.B.1.b - Other cattle	± 30	
3.B.2 - Sheep	± 30	
3.B.4.d - Goats	± 30	
3.B.4.e - Horses	± 30	
3.B.4.f - Mules & asses	± 30	
3.B.3 - Swine	± 30	
3.B.4.g - Poultry	± 30	

5.3.1.5. Category specific QA/QC and verification

Tier 1 QA/QC activities have been implemented. Activity data for this inventory was compiled in an excel spreadsheet and data verification was done as a quality control measure before being entered into the IPCC software. Quality control activities included:

- Checking that the equations programmed in the software were correctly inputted.
- 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 from the inventory software.

5.3.1.6. Source-specific recalculations

There is no comparative data from the previous inventory because CH_4 emissions from manure management were not estimated. Hence, recalculation was not done. The emission for the current inventory is for the period 2000-2022.

5.3.1.7. Category-specific planned improvements

This category is not expected to undergo any improvements over the next year.

5.3.2. N_2O emissions from manure management (CRT 3.Bb)

5.3.2.1. Source category description

The Manure Management category accounts for N_2O emissions generated during the handling and storage of manure before it is applied to agricultural soil. The quantity of N_2O released varies based on the waste management system and the storage time. N_2O emissions are classified as either direct or indirect:

- Direct emissions occur during manure handling, storage, and application. They are primarily caused by microbes breaking down nitrogen compounds and releasing N_2O when manure is stored under anaerobic conditions (lack of oxygen).
- Indirect emissions of N_2O-N occur in two ways (IPCC, 2006): through the volatilization of nitrogen (N) as ammonia (NH_3) and various nitrogen oxides, and through runoff and leaching from the land where the nitrogen was applied.

To estimate direct N_2O emissions from manure management IPCC methodology requires the following steps:

1. Collection of activity data- livestock population
2. For N_2O emissions the following IPCC default parameters are used and are sourced from IPCC 2019 Refinement:
   a) Determine average annual nitrogen excretion rate per head for each livestock subcategory.
   b) Determine the fraction of total annual nitrogen excretion for each livestock category that is managed in each manure management system.
   c) Determine N_2O emission factors for each manure management system.
   d) Multiply the emission factor by the total nitrogen managed in the system and sum over all manure management systems.

Direct N_2O emissions from manure management dropped by 71.29% from 51.99 Gg CO_2eq in 2000 to 14.93 Gg CO_2eq in 2022. It contributed 88.95% of the total Manure management emissions in 2022.

Indirect N_2O emissions from manure management decreased by 22.22% from 2.39 Gg CO_2eq in 2000 to 1.86 Gg CO_2eq in 2022. It contributed 11.05% of the total Manure management emissions in 2022 (Table 5-1).

5.3.2.2. Methodological issues

Direct N_2O emissions from manure management are calculated using the IPCC Tier 1 method, specifically following Equation 10.25 (IPCC, 2006, Volume 4, Chapter 10). For indirect N_2O emissions resulting from the volatilization of nitrogen (N) in the forms of NH_3 and NO_x, the Tier 1 approach is applied using Equations 10.26 and 10.27 (IPCC, 2006). This methodology involves estimating the fraction of managed manure nitrogen that volatilizes from each management system, utilizing default values from Table 10.22, and subsequently applying the indirect emission factor (EF_4) for atmospheric deposition as defined in the 2006 Guidelines

Activity data

Direct N_2O emissions calculations depend on three key inputs: livestock population (section 5.2.2.1), manure management details (section 5.3.1.2), and the annual (N) excretion rate per animal ($N_{ex(T)}$). The ($N_{ex\,(T)}$) for all the livestock is calculated using a Tier 1 method. Table 5.18 presents the applied IPCC default N excretion rate (IPCC 2006, Chapter1, Vol. 4, Table 10.19 & Table 10A-9). The fraction of managed manure that volatilises and that is leached are taken from the IPCC 2019 Refinement (volume 4, chapter 11, Table 10.22).

Table 5-18: IPCC default N excretion rate and typical animal mass

Animal	IPCC default N excretion rate (kg N (1000 kg animal mass)$^{-1}$ day^{-1})	Typical animal mass, Kg (IPCC Default)
Dairy cattle	0.60	275
Other cattle	0.63	275*
Sheep	1.17	28
Goats	1.37	30
Horses	0.46	238
Mules and Asses	0.46	130
Poultry	0.82	1.8

*Typical Average Mss for Other cattle= 275 Kg (based on expert judgement)

For the 2022 Inventory, Botswana applied a country-specific Typical Animal Mass (TAM) of 275 kg for Other Cattle, deviating from the IPCC (2006) regional default of 173 kg. This adjustment is based on expert judgment from the National GHG Inventory Team, Animal Scientists from NARDI and supported by Botswana Meat Commission (2015) slaughter records, which indicate that the average mass of the national herd consistently exceeds 250 kg. BMC slaughter data typically shows Cold Dressed Weights (CDW) ranging between 229 and 248 Kg, that when converted back to live weight using a standard 50-55% killing-out percentage, support a live mass >250 kg. Using the 173 kg default would lead to a significant underestimation of Volatile Solids (VS) and Nitrogen (N) excretion. By utilizing a mass of 275 kg, Botswana ensures accuracy and completeness in reflecting the emissions profile of its national herd, as encouraged by the 2006 IPCC Good Practice Guidance.

Emission factors

Direct N_2O emission factors for all identified manure management systems, including Liquid/Slurry, Dry lot/Kraals, Solid storage, Compost, Poultry manure (with and without litter), Pasture/Range/Paddock (PRP), and manure Burned for fuel, are sourced from Table 10.21 of the 2006 IPCC Guidelines (Volume 4, Chapter 10). For indirect N_2O emissions, the inventory focuses specifically on losses due to atmospheric nitrogen (N) deposition resulting from volatilization. The default emission factors for these processes are drawn from Table 11.3 (Volume 4, Chapter 11) of the same guidance as shown below in Kg N_2O – N per Kg N:

- Pasture, Range, Paddock (PRP): 0.02 (Cattle/Poultry) / 0.01 (Others)
- Dry Lot / Kraals: 0.02
- Solid Storage: 0.005
- Compost (Static Pile): 0.005
- Liquid / Slurry: 0.005

5.3.2.3. Time-series consistency

The time-series presented is only for the current inventory (period 2000-2022) because the previous inventory did not estimate CH_4 emissions from manure management.

5.3.2.4. Uncertainty

Activity data uncertainty: The population data uncertainties are discussed in detail in Section 5.2.3. For manure management calculations, the IPCC 2006 Tier 1 default uncertainty for nitrogen (N) excretion across all livestock categories is estimated at ±50%. Additionally, the uncertainty ranges for the fraction of managed manure nitrogen that volatilizes as NH_3 and

NO_x ($Frac_{GASMS}$) are adopted from the 2006 IPCC Guidelines (Volume 4, Chapter 10, Section 10.5.5). These values account for the high variability in manure handling practices and environmental conditions within Botswana's agricultural sector. Consistent with the focus on atmospheric pathways, uncertainties related to leaching ($Frac_{LEACHMS}$) are noted as being significantly higher, often exceeding ±100%, though the inventory prioritizes volatilization data. This inventory focuses on these volatilization pathways while omitting leaching (EF_5) due to data limitations, ensuring that the uncertainty assessment remains consistent with the prioritized emission sources and the 2006 IPCC methodological framework.

Emission factor uncertainty: The IPCC 2006 default N_2O emission factor for manure management has an associated uncertainty ranging from -50% to +100%. For indirect emissions, the uncertainty for the emission factor associated with atmospheric nitrogen deposition (EF_4) is identified as ranging from -100% to +120%, according to Table 11.3 (Volume 4, Chapter 11) of the 2006 IPCC Guidelines. These broad uncertainty ranges reflect the complex nature of nitrogen transformation and deposition processes. This inventory strictly utilizes these 2006 default ranges, focusing on the volatilization pathway while excluding leaching (EF_5) assessments.

5.3.2.5. Category specific QA/QC and verification

Refer to section 5.3.1.5 Category specific QA/QC and verification, for category specific QA/QC and verification.

5.3.2.6. Source-specific recalculations

There is no comparative data from the previous inventory because N_2O emissions from manure management were not estimated. Hence, recalculation was not done. The emissions for the current inventory is for the period 2000-2022.

5.3.2.7. Category-specific planned improvements

This category is not expected to undergo any improvements over the next year.

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

5.4.1. N_2O emissions from managed soils (CRT 3.Ba)

Agricultural soils can generate greenhouse gases (GHGs) through three pathways, though not all are relevant to this section:

1. *CO_2 from soil organic matter loss*: This is linked to land-use change and is addressed in the land sector, not here.
2. *CH_4 from anaerobic soils*: Since Botswana does not practice anaerobic cultivation (like rice paddies), CH_4 emissions from agricultural soils are excluded from this inventory.
3. *N_2O from fertilizer and intensive cultivation*: This is a major source of non-carbon agricultural emissions and is the primary focus of this inventory section.

The IPCC (2006) identifies several nitrogen (N) inputs to agricultural soils that lead to direct N_2O emissions:

- N inputs from: synthetic and organic fertilizers (including manure/compost), and crop residue (including N-fixing crops).
- Soil organic matter loss from mineral soils due to land-use change.

- Organic soils that are drained or managed for agriculture.
- Animal manure deposited on pastures, rangelands, and paddocks.

It is worth noting that in this inventory, emissions from management changes in mineral soils (Category 3.D.1.e) are currently not estimated (NE) due to a lack of spatially explicit historical land-use data and soil carbon stock measurements. Organic soils are excluded from this inventory as they are considered negligible in Botswana, where the landscape is dominated by mineral soils with low organic carbon content. Botswana recognizes these gaps and is prioritizing the development of a land-use change matrix and soil monitoring framework to enable the quantification of these management-related fluxes in future reporting cycles, in accordance with IPCC 2006 (Volume 4, Chapter 11). On the other hand, sewage sludge is not applied to agricultural crops in Botswana because it presents high contamination risk.

In 2022 Direct N_2O from managed soils amounted to 663.295 Gg CO_2 eq, 44.12% decrease from 1,186.94 Gg CO_2 eq recorded in 2000 (Table 5-7). The emission contribution of N inputs from Inorganic N fertiliser and Urine and dung from grazing animals is shown in Table 5.19.

Table 5-19: Emission trends for the sub-category (Inorganic N fertilisers & urine and dung from grazing animals) of direct N_2O emissions from managed soils.

Category	Emissions (Gg CO_2eq)						Change (%)	
	2000	% Agric.	2015	% Agric.	2022	% Agric.	2000-2015	2000-2022
Inorganic N fertilizers	1.029	0.029	4.283	0.148	5.069	0.262	316.23	392.61
Urine and dung from grazing animals	1,185.91	33.76	971.81	33.66	631.348	32.61	-18.06	-46.76

5.4.2. Methodological issues

Tier 1 approach was used to calculate Direct N_2O emission from managed soils. The sub-categories under managed soils calculated include N inputs emissions from Inorganic N fertiliser and Urine and dung from grazing animals. Tier 1 followed the IPCC 2006 Equation 11.1 (IPCC, 2006, Volume 4, Chapter 11).

Inorganic fertiliser N inputs (FN) (CRT 3.D.1.a)

IPCC Tier 1 methodologies and default emission factors (IPCC 2006) are used for estimating direct N2O emissions from managed soils. The amount of inorganic N applied to soils is multiplied with the IPCC default emission factor (IPCC 2006).

Urine and dung N deposited by grazing animals (F_{PRP}) (CRT 3.D.1.c)

Manure nitrogen (N) deposited by grazing animals on pastures, rangelands, and paddocks is categorized as F_{PRP} and calculated using Equation 11.5 (IPCC 2006, Volume 4, Chapter 11). Given that the majority of Botswana's livestock graze extensively, these emissions are highly significant. It is important to distinguish F_{PRP} from Daily Spread systems; the latter is considered a managed manure system. Consequently, N associated with managed systems is first accounted for under Category 3.B, and any subsequent application to soils, after deducting losses such as $Frac_{LossMS}$, is reported under Category 3.D.1.b.i (F_{AM}). This distinction ensures no double-counting between unmanaged grazing deposition and nitrogen intentionally managed and applied to agricultural soils, as specified in Section 10.5.4 and Section 11.2.1.3 of the IPCC 2006 Guidelines.

5.4.2.1. Activity data

Regarding category 3.D.1.b.i, nitrogen inputs from animal manure applied to soils are currently reported as Not Estimated (NE). This is due to a lack of specific data on the fractions of managed manure that are collected and applied to croplands versus other end-uses. Botswana is working to improve future agricultural surveys to capture these manure management flows, ensuring better completeness and transparency in accordance with the 2006 IPCC Guidelines.

Inorganic fertiliser N inputs

The mostly used synthetic N fertilizer in Botswana is Nitrogen Potassium and Phosphorus (NPK) compound with 15% nitrogen content, and a balanced ratio of 15-15-15. The activity data was sourced from FAOSTAT, and data covered the period 2000-2022 (Table 5-20).

Table 5-20: Imports of Nitrogen Potassium and Phosphorus (NPK) in tons, 2000-2022

Item	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
NPK fertilizers	2,160.61	1,532.82	905.03	277.24	278.17	227.29	65.16	191.17	3,582.48	5,387.60	5,013.71	2,521.87

Item	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
NPK fertilizers	866.79	975.74	4,507.39	12,583.29	4,609.75	6,058.42	4,232.29	7,053.45	5,457.82	5,845.00	7,813.92

Source: FAOSTAT (https://www.fao.org/faostat/en/#data)

Urine and dung deposited by grazing animals

Activity data for this sub-category are livestock population (refer to section 5.2.2.1) and manure management (refer to section 5.3.1.2) data.

5.4.2.2. Emission Factors

Inorganic N fertiliser

The annual amount of synthetic (inorganic) N fertiliser applied to soils is calculated using the Tier 1 approach. The IPCC 2006 default emission factor of 0.01 kg N_2O-N/kg N applied is utilized, as specified in Table 11.1 (Volume 4, Chapter 11). This factor accounts for direct nitrous oxide emissions resulting from the application of all synthetic nitrogen sources.

Urine and dung deposited by grazing animals

The annual amount of N deposited on pasture, range, and paddock (F_{PRP}) by grazing animals is calculated using the IPCC 2006 default emission factors from Table 11.1. A default factor of 0.02 kg N_2O-N (kg N)$^{-1}$ is applied for cattle (dairy, non-dairy), poultry, and pigs, while a factor of 0.01 kg N_2O-N (kg N)$^{-1}$ is applied for sheep, goats, and other animals. These values represent the direct emissions from unmanaged manure during grazing in accordance with Chapter 11.

5.4.2.3. Uncertainty

Activity data uncertainty

The activity data uncertainty for Inorganic N fertiliser, suggests that the N consumption would likely be within 15% based on 15% nitrogen content in NPK compound.

The activity data for urine and dung deposited by grazing animals (F_{PRP}) carries an uncertainty estimate derived from the combined uncertainties of livestock population data and the nitrogen excretion rates (N_{ex}). In accordance with the 2006 IPCC Guidelines (Volume 4, Chapter 11), the $Frac_{LossMS}$ factor is not applied to this category, as grazing emissions occur from unmanaged excretions deposited directly onto rangelands. The $Frac_{LossMS}$ uncertainty (±50% per IPCC 2006, Table 10.23) is instead strictly applied to the activity data for Category 3.D.1.b.i (Animal manure applied to soils), where it accounts for nitrogen lost during the storage and transport of managed manure before it reaches agricultural land.

Emission factor uncertainty

Inorganic N fertiliser: The uncertainty associated with the default emission factor (EF_1) for synthetic (inorganic) N fertiliser application is estimated at -70% to +300%, as specified in the 2006 IPCC Guidelines (Volume 4, Chapter 11, Table 11.1). This wide range reflects the high variability of N_2O emissions across different soil types and management conditions.

Urine and dung deposited by grazing animals: The uncertainty for the default emission factors applied to urine and dung deposited by grazing animals (EF_{3PRP}) is also adopted from Table 11.1 of the 2006 IPCC Guidelines. For cattle, poultry, and pigs, the uncertainty range is -70% to +300%. For sheep and other animals (including goats and horses), the uncertainty is similarly estimated at -70% to +300%.

5.4.2.4. Time-series consistency

The time-series presented is only for the current inventory (period 2000-2022) because the previous inventory did not estimate direct N_2O emissions from managed soils.

5.4.2.5. Category specific QA/QC and verification

The general QA/QC measures in Table 5.9, section 5.15 were used for this category since there were no category specific quality control checks.

5.4.2.6. Category-specific recalculations

There is no comparative data from the previous inventory because direct N_2O emissions from managed soils were not estimated. Hence, recalculation was not done. The emissions for the current inventory is for the period 2000-2022.

5.5. Liming (CRT 3.G)

5.5.1. Source category description

Liming is a practice used in managed agricultural systems to reduce soil acidity and enhance plant growth. This involves adding carbonate compounds (limestone or dolomite) to the soil. As these carbonate limes dissolve, they release bicarbonate, resulting in the emission of CO_2. Activity data for the annual amount of lime applied to agricultural soils was sourced from Statistics Botswana import records. In Botswana, dolomite is identified as the primary liming agent used to improve soil alkalinity, and import volumes are utilized as a proxy variable for total national application. Regarding the use of limestone, current national statistics and agricultural surveys do not indicate significant limestone application within the sector. To ensure transparency, this inventory focuses exclusively on dolomite; however, Botswana intends to further investigate the potential use of limestone in future reporting cycles to ensure full coverage of all liming agents, as per the 2006 IPCC Guidelines (Volume 4, Chapter 11).

Liming produced 0.103 Gg CO_2 eq in 2022, a two-fold increase from 0.038 Gg CO_2 eq emitted in 2000.

5.5.2. Methodological issues

Annual CO_2 emissions resulting from lime application were calculated using the Tier 1 approach outlined in the IPCC 2006 Guidelines (Equation 11.12, IPCC 2006).

5.5.2.1. Activity data

The activity data on the annual amount of lime (dolomite) mostly used in Botswana was sourced from Statistics Botswana. The imports of dolomite into the country were used as proxy variable.

5.5.2.2. Emission Factors

The IPCC default emission factor of 0.13 t C (t dolomite)$^{-1}$ was used to calculate the CO_2 emissions from Liming.

5.5.2.3. Uncertainty

Activity data uncertainty

The activity data uncertainty for dolomite is -25% to 10%, because of the assumption that the quantities imported are all used.

Emission factor uncertainty

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

5.5.2.4. Time-series consistency

The entire time-series is consistent and complete.

5.5.2.5. Category specific QA/QC and verification

The general QA/QC measures in Table 5.9, section 5.15 were used for this category.

5.5.2.6. Category-specific recalculations

The methodology did not change in the current inventory. Hence, the recalculation was not done.

5.5.2.7. Category-specific Planned Improvements

There are no planned improvements for this category.

5.6. Urea application (CRT 3.H)

5.6.1. Source category description

The application of urea to soils during fertilization results in the release of CO_2 that was initially fixed during the industrial production process.

Urea application produced 2.387 Gg CO_2 eq in 2022, a two-fold increase from 0.355 Gg CO_2 eq emitted in 2000.

5.6.2. Methodological issues

A Tier 1 approach of the IPCC 2006 Guidelines is used to calculate CO_2 emissions from urea fertilization (Equation 11.13, IPCC 2006).

5.6.2.1. Activity data

The activity data on the annual amount of carbonate N-fertilizer (tonnes/year) mostly used in Botswana was sourced from Statistics Botswana. The imports of urea into the country were used as proxy variable.

5.6.2.2. Emission Factors

In accordance with section 11.4.1, Chapter 11, Volume 4 (IPCC, 2006), Urea emission factor is 0.20 tonne of C (tonne of urea)$^{-1}$. This emission factor was applied to calculate the CO_2 emissions.

5.6.2.3. Uncertainty

Activity data uncertainty

The activity data uncertainty for dolomite is -25% to 10%, because of the assumption that the quantities imported are all used.

Emission factor uncertainty

The urea default emission factors has an uncertainty of -50% (IPCC 2006 Guidelines, p. 11.32).

5.6.2.4. Time-series consistency

The entire time-series is consistent and complete.

5.6.2.5. Category specific QA/QC and verification

The general QA/QC measures in Table 5.9, section 5.15 were used for this category.

5.6.2.6. Category-specific recalculations

The methodology did not change in the current inventory. Hence, the recalculation was not done.

5.6.2.7. Category-specific Planned Improvements

There are no planned improvements for this category.

5.7. Other carbon-containing fertilizers (CRT 3.I)

Regarding Category 3.I (Other Carbon-Containing Fertilizers), Botswana has applied the notation key NO (Not Occurring) for this submission. A review of national import statistics and agricultural supply data indicates that, while urea and dolomite are utilized, other specialized synthetic carbon-containing fertilizers are not currently used in the national agricultural sector. Botswana will continue to monitor import records from Statistics Botswana in future inventory cycles to ensure that any introduction of these fertilizers is captured and reported in accordance with the 2006 IPCC Guidelines.

5.8. Other (specify) (CRT 3.J)

None for the category are reported in this submission.

6. LAND USE, LAND-USE CHANGE AND FORESTRY (CRT 4)

6.1. Overview of the sector

In Botswana all lands have been classified under the six (6) IPCC land categories and treated as managed lands. Therefore, they have been used in the estimation of emissions and removals. In this inventory LULUCF sector is a stand-alone as per the Common Reporting Tables (CRT) and the requirements of Enhanced Transparency Framework (ETF). Previously it was part of the AFOLU (Agriculture, Forestry and Other Land Use) sector as per the IPCC guidelines (2006). Botswana reports on the emissions (positive) and removals (negative) of CO_2 from the entire land area of 57,960,139.464 ha and all lands are considered managed. Land use changes were derived from the National Land Degradation Status Report (2022).

These six land classes are:

- 4.A. Forestland
- 4.B. Cropland
- 4.C. Grassland
- 4.D. Wetlands
- 4.E. Settlements
- 4.F. Other land

6.1.1. Description of the sector

The LULUCF sector also include emissions from gain and loss of biomass when a particular land class changes use such as Forestland being converted to Grassland or settlements, burning of biomass caused by wildfires and emissions or removals estimated for Harvested Wood Products (HWP).

The carbon pools are reported for the following land-use categories; Forest land (4.A.), Cropland (4.B.), Grassland (4.C.), Wetlands (4.D.), Settlements (4.E.) and Other land (4.F.). As well as the relevant land-use changes between these categories. A distinction is made between areas which, during the reporting period undergo no land-use changes, and thus remain, in unchanged form, in the land-use category they are in ("land remaining" categories 4.A.1 – 4.F.1), undergo land-use changes. From the time of conversion onward, these areas are reported in the category to which they were converted. Within those land-use categories, the converted areas are then reported in conversion categories ("land conversion" categories 4.A.2 – 4.F.2) for a total of 20 years. Trends in land-use change estimates are impacted by lack of data from 1980 to 1999 needed for the mineral soils.

The country only reports burning in the forestlands and grasslands. Other lands, except Cropland which is unavailable, are assumed not to burn due to the absence of combustible material. Wetlands also include the emissions of CH_4 from wetlands and flooded lands.

6.1.2. Trend in the sector's GHG

The LULUCF sector remained a net sink with a total of -73 642,068 Gg CO_2 eq as shown in Table 6.1 in 2022. Forest lands amounting -73 866.304 Gg CO_2 eq, being the largest contributor to the sink. The smallest sequestration was from the grasslands (-1.086 Gg CO_2 eq).

Table 6-1: LULUCF sector: emissions and removals by GHG, category and subcategory (Gg) for 2022.

Greenhouse gas source and sink categories	CO_2	CH_4	N_2O	Total
4. LULUCF	**- 74 055.874**	**256.616**	**157.190**	**-73 642.068**
4.A. Forest land	- 73 866.304	NA	NA	**-73 866.304**
4.B. Cropland	- 88.487	NA	NA	**- 88.487**
4.C. Grassland	-1.086	NA	NA	**- 1.086**
4.D. Wetlands	0	NA	NA	**0**
4.E. Settlements	- 1.184	NA	NA	**- 1.184**
4.F. Other land	0	NA	NA	**0**
4.G. Harvested wood products	- 98.813	NA	NA	**- 98.813**
4.IV. Biomass Burning		256.616	157.190	**413.806**

Note: NA = not applicable

Figures 6-1 and 6-2, and Table 6-2 provides an overview of the LULUCF emission trends for Botswana over the time-series 2003-2022. Specifically, Figure 6-1 depicts time series for GHG emissions and removals by land type in the LULUCF sector in Botswana, 2003 – 2022 (incl. biomass burning), while Figure 6-2 presents time series for GHG emissions and removals by land type in the LULUCF sector in Botswana, 2003 – 2022 (incl. biomass burning).

Across the time-series (Table 6-2), it indicated the Forest lands were the largest contributor to the sink in the country. The widely dense forest and woodlands contributed to this high carbon sink. The Forest land carbon sink increased between 2014 and 2022 is due to an increasing sparse dense forest (woodland) sink resulting from the conversion of grassland to sparse dense forests. The decrease in sink was found between 2010 and 2013 due to wildland fires which burnt lot of forests and grasslands. The fires reduced the Forestlands and Grasslands. It is evidenced that the variation in the Forest lands and Grasslands categories follow is liner correlated with the area burnt. For example, the years 2010 and 2011 were high burnt periods which meant an increase in emissions and disturbance losses in Forest lands, thus a reduction sink in 2010 and 2011 amounting -29,898.4143 Gg CO_2 eq and -23,353.279 Gg CO_2 eq correspondingly.

There was an increment of emissions in Croplands between 2018 and then constant until 2022, resulting from the conversion of perennial crops to annual crops and the conversion of sparse dense forests to subsistence crops. A steady of emissions was noticed between 2004 and 2017 as the same conversions of annual crops to perennial crops. The change in Grasslands is what was causing the reduced sink between 2017 and 2022. Between 2004 and 2017 there is an increase in the conversion of low shrublands to grasslands leading to an increase sources, while between 2018 and 2022 there is an increase in the conversion of sparse to grassland leading to an increased sink. Grasslands changed from a small source in 2004 to a small sink in 2022. Forest land increased in this inventory due to classification of woodlands under sparse dense forests, hence leading to a large net sink across the time-series.

Converted lands were the largest contributors to all land categories except Wetlands (Table 6-2) where non-CO2 emissions from wetlands play a role. The sector remained a net sink throughout the time series 2003 to 2022 as shown in Figure (6-2).

Generally, the LULUCF sector increased its sink by 23.95% since 2003 (Table 6-4) due to factor such as an increase in area burnt. Forest land increased in this inventory due to classification of woodlands under sparse dense forests, hence leading to a large net sink across the time-series

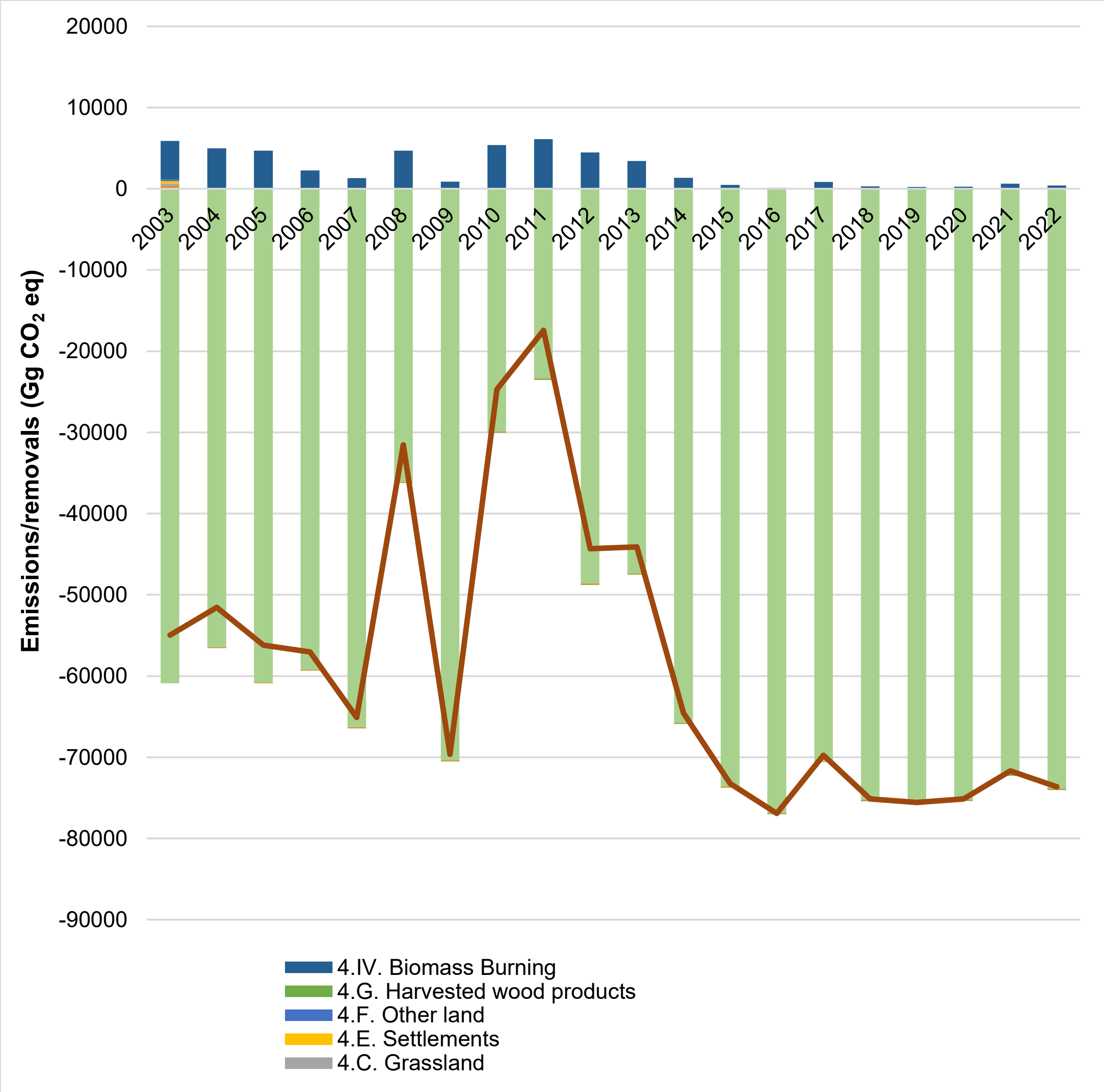

Figure.6-1: Time series for GHG emissions and removals by land type in the LULUCF sector in Botswana, 2003 – 2022 (incl. biomass burning)

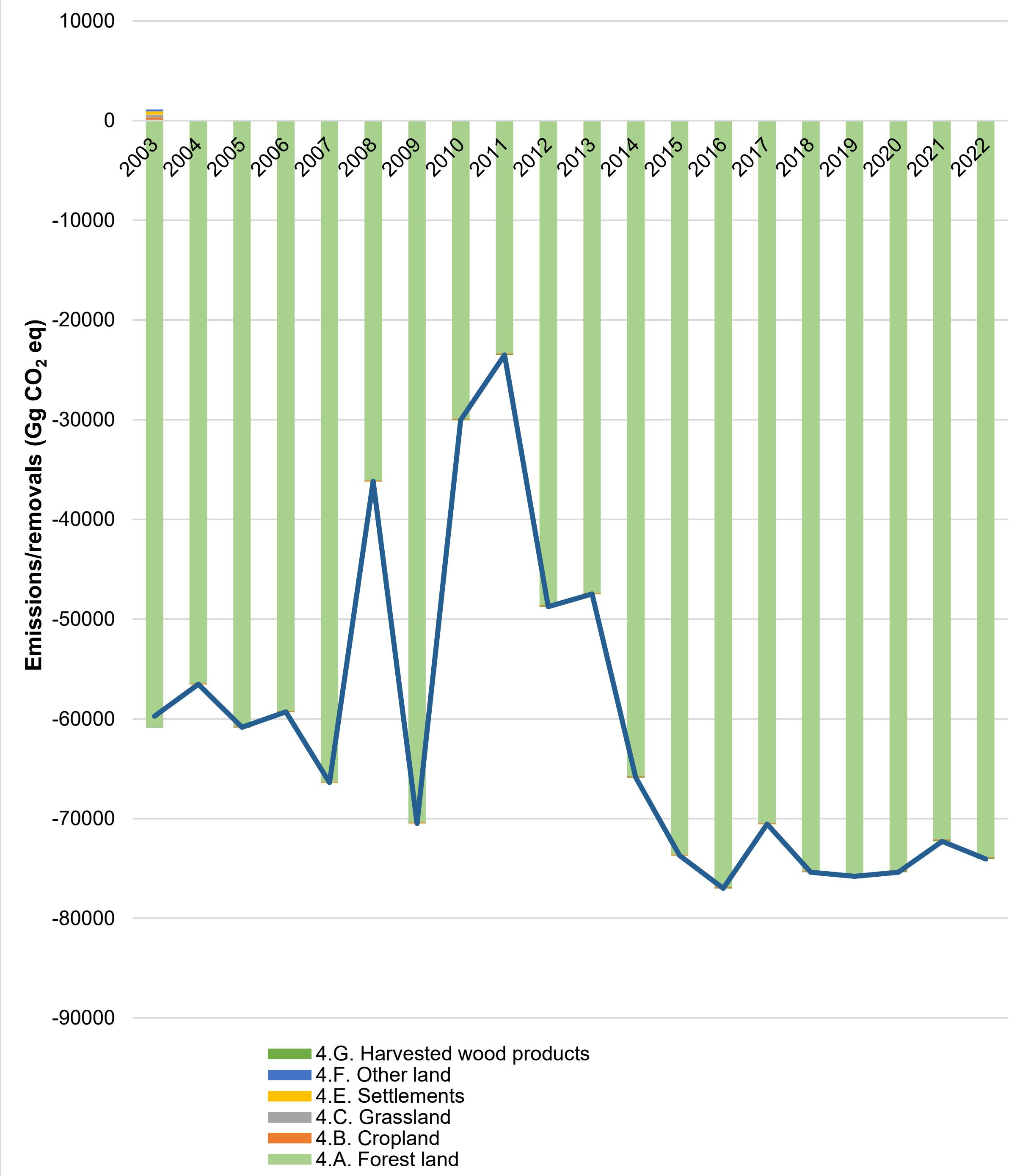

Figure.6-2: Time series for GHG emissions and removals by land type in the LULUCF sector in Botswana, 2003 – 2022 (excl. biomass burning)

Table 6-2: Time series for GHG emissions and removals by land type in the LULUCF sector in Botswana, 2003 - 2022 (CO_2 eq) All gases

GHG source and sink categories	2003	2005	2010	2015	2016	2017	2018	2019	2020	2021	2022
4. LULUCF	-54980,2	-56197,1	-24687,9	-73242,1	-76911,4	-69757,6	-75128,5	-75559,5	-75110,6	-71676,1	-73642,1
4.A. Forest land	-60846,8	-60782,5	-29898,4	-73617	-76879,5	-70464,6	-75223	-75605,7	-75186,4	-72094,8	-73866,3
4.B. Cropland	341,4154	-79,7686	-79,7686	-79,7686	-79,7686	-79,7686	-88,4816	-88,4816	-88,4816	-88,4816	-88,4871
4.C. Grassland	261,3418	5,9459	5,9459	5,9459	5,9459	5,9459	-1,1034	-1,1034	-1,1034	-1,1034	-1,0859
4.D. Wetlands	0	0	0	0	0	0	0	0	0	0	0
4.E. Settlements	330,5156	-1,9834	-1,9834	-1,9834	-1,9834	-1,9834	-1,1823	-1,1823	-1,1823	-1,1823	-1,1841
4.F. Other land	185,6688	14,9294	14,9294	14,9294	14,9294	14,9294	0	0	0	0	0
4.G. Harvested wood products	-20,7659	-16,059	-70,6369	-23,6028	-66,6543	-42,2009	-90,1194	-93,2524	-107,784	-106,828	-98,8129
4.IV. Biomass Burning	4768,419	4662,306	5342,021	459,3741	95,6977	810,0972	275,4171	230,2442	274,4114	616,2857	413,8051

Table 6-3: Summary of the change in emissions from the LULUCF sector over the time-series 2003-2022.

GHG source and sink categories	Emission (Gg CO2 eq)		Difference (Gg CO2 eq)	Change (%)
	2003	2022	2003-2022	2003-2022
4. LULUCF	**-59748.6475**	**-74055.8744**	**-14307.2269**	**23.95**
4.A. Forest land	**-60846.8232**	**-73866.3044**	**-13019.4812**	**21.40**
4. A.1. Forest land remaining forest land	-57943.1668	-73852.2979	**-15909.1311**	**27.46**
4. A.2. Land converted to forest land	-2903.6564	-14.0065	**2889.6499**	**-99.52**
4.B. Cropland	**341.4154**	**-88.4871**	**-429.9025**	**-125.92**
4. B.1. Cropland remaining cropland	-94.6731	-94.6731	**0**	**0.00**
4. B.2. Land converted to cropland	436.0885	6.186	**-429.9025**	**-98.58**
4.C. Grassland	**261.3418**	**-1.0859**	**-262.4277**	**-100.42**
4. C.1. Grassland remaining grassland		0	**0**	**0.00**
4. C.2. Land converted to grassland	261.3418	-1.0859	**-262.4277**	**-100.42**
4.D. Wetlands	**0**	**0**	**0**	**0.00**
4. D.1. Wetlands remaining wetlands	0	0	**0**	**0.00**
4. D.2. Land converted to wetlands	0	0	**0**	**0.00**
4.E. Settlements	**330.5156**	**-1.1841**	**-331.6997**	**-100.36**
4. E.1. Settlements remaining settlements	0	0	**0**	**0.00**
4. E.2. Land converted to settlements	330.5156	-1.1841	**-331.6997**	**-100.36**
4. F. Other land	**185.6688**	**0**	**-185.6688**	**-100.00**
4. F.1. Other land remaining other land	0	0	**0**	**0.00**
4. F.2. Land converted to other land	185.6688	0	**-185.6688**	**-100.00**
4.G. Harvested wood products	**-20.7659**	**-98.8129**	**-78.047**	**375.84**

Presented in Table 6-4 is a summary of the methodological tier levels and the specific types of emission factors utilized throughout this inventory.

Table 6-4: Summary of Methodologies, Emission Factors, and Completeness Assessment for the LULUCF Sector.

GHG source and sink categories	CO2		CH4		N2O	
	Method Applied	Emission Factor	Method Applied	Emission Factor	Method Applied	Emission Factor
4.A. Forest land	**T1**	**D**	**NA**	**NA**	**NA**	**NA**
4. A.1. Forest land remaining forest land	T1	D	NA	NA	NA	NA
4. A.2. Land converted to forest land	T1	D	NA	NA	NA	NA
4.B. Cropland	**T1**	D	NA	NA	NA	NA
4. B.1. Cropland remaining cropland	T1	D	NA	NA	NA	NA
4. B.2. Land converted to cropland	T1	D	NA	NA	NA	NA
4.C. Grassland	**T1**	D	NA	NA	NA	NA
4. C.1. Grassland remaining Grassland	T1	D	NA	NA	NA	NA
4. C.2. Land converted to grassland	T1	D	NA	NA	NA	NA
4.D. Wetlands	T1	D	NE	NE	NA	NA
4. D.1. Wetlands remaining wetlands	T1	D	NE	NE	NA	NA
4. D.2. Land converted to wetlands	T1	D	NA	NA	NA	NA
4.E. Settlements	T1	D	NA	NA	NA	NA
4. E.1. Settlements remaining settlements	T1	D	NA	NA	NA	NA
4. E.2. Land converted to settlements	T1	D	NA	NA	NA	NA
4. F. Other land	T1	D	NA	NA	NA	NA
4. F.1. Other land remaining other land	T1	D	NA	NA	NA	NA
4. F.2. Land converted to other land	T1	D	NA	NA	NA	NA
4.G. Harvested wood products	T1	D	NA	NA	NA	NA
4. IV. Biomass Burning	IE	IE	T1	D	T1	D

NA = Not applicable; NO = Not occurring; NE = Not estimated; IE = Included elsewhere; T1 = Tier 1; D = IPCC default factor

6.1.3. Key categories in the LULUCF sector

Botswana conducted a key category analysis following the approach of the 2006 IPCC Guidelines (Vol. 1), using both Level and Trend assessments for the LULUCF sector. The analysis was performed using the IPCC Inventory Software, applying Tier 1 methods and national activity data where available. Table 6-6 provides a breakdown and ranking of the key categories within Botswana's LULUCF sector. Forest Land (4.A) is identified as the dominant key category in both Level (L) and Trend (T) terms, driven by its role as the country's largest carbon sink and the category with the greatest inter-annual variability due to biomass growth, fuel wood harvesting and fire disturbance. Table 6-6 further depicts that the second dominant key category is HWP in both Level and Trend analysis. Other categories (Cropland (4.B), Grassland (4.C), Wetlands (4.D), Settlements (4.E) and Other Land (4.F)) contribute small or negligible emissions/removals under Tier 1 and are not key categories in the national analysis. Their influence on overall sector trends is minor due to limited biomass stocks and low levels of land-use change.

Table 6-5: Key categories in the LULUCF sector in 2022

CRT Code	CATEGORY	Greenhouse gas	Criteria (Lx,t)
4.A.1	Forest land Remaining Forest land	CO_2	L, T
4.G	Harvested Wood Products (HWP)	CO_2	L,T

6.2. Land-Use Definitions, Land Representation Approach and Data Sources

6.2.1. Land-Use Definitions and Representation Approach

The land-cover legend and associated information in the National Land Degradation Status (2022) dataset are based primarily on the newly gazetted national land-cover classification standard, with adjustments made to ensure comparability and compatibility with earlier NLDS datasets. The dataset was generated using Google Earth Engine, and the Botswana team received technical support from FAO experts in producing both the land-cover maps and the land-cover conversion matrices for the periods 2003–2015 and 2016–2019. The Botswana Forest Distribution Map (BFDM) classifies national land-cover types, which were first aggregated for land-change assessment and then further consolidated into the six IPCC land-use categories for greenhouse gas reporting. In line with IPCC reporting practice, Botswana aggregates national land-cover classes to the six IPCC land-use categories used for LULUCF reporting, as listed below:

CRT 4.A Forest Land

The Forest land category includes indigenous forests such as riparian and typical forests and woodland (NFMS 2020). The forest definition is given as “a minimum area of land of 0.05 hectares with tree crown cover of more than 10 per cent with trees with the potential to reach a minimum height of 5 metres at maturity in situ” (Forest Policy, 2011).

CRT 4.B Cropland

Cropland includes arable and tillable land and agroforestry systems where the vegetation structure falls below the thresholds used for the Forest Land category and is not expected to exceed those thresholds at a later time. Cropland includes all annual and perennial crops as well as temporary fallow land (i.e., land set at rest for one or several years before being cultivated again). Annual crops include cereals, oils seeds, vegetables, root crops and forages. Perennial crops include trees and shrubs, in combination with herbaceous crops (e.g., agroforestry) or as orchards.

CRT 4.C Grassland

Grassland includes grasslands, low shrub lands, bush land, degraded land, range and pasture lands not considered cropland. The category covers all grasslands from wild lands to recreational areas as well as agricultural and silvi-pastural systems.

CRT 4.D Wetlands

Wetlands include natural rivers, waterbodies, perennial and non-perennial water systems, natural lakes, dams, flooded pans and related water features.

CRT 4.E Settlements

Settlements cover transportation infrastructure and human settlements, including built-up areas, towns, villages, commercial/industrial areas, smallholdings, and mines.

CRT 4.F Other Land

Other land includes barren land, bare soils, natural rock surfaces, sand dunes, dry pans and long-term fallow or abandoned fields that are predominantly non-vegetated.

6.2.2. Relationship between National Classes and IPCC Classes

The relationships between the Botswana Forest Distribution Map (BFDM) classes, the Land Degradation Status Map (LDSM) classes, and the IPCC categories used in this inventory are presented in Table 6-7. These datasets provide full national coverage and form the basis for the aggregation of national land-cover categories into the six IPCC land-use categories used for greenhouse gas reporting

Table 6-6: Relationship between the IPCC categories, land change categories and the BFDM and Botswana Land Degradation Status Map (LDSM) datasets in the 2022 inventory.

BFDM classes	LDSM classes	IPCC sub-category	IPCC sub-category
Riparian forest	Forestland	Moderately dense forest	Forestland
Typical forest	Forestland	Widely dense forest	Forestland
Woodland	Forestland	Sparse forest	Forestland
Grassland	Grassland	Grassland	Grassland
Bushland	Grassland	Grassland	Grassland
Shrubland	Grassland	Grassland	Grassland
Seasonal/permanent Mine water seasonal/permanent Waterbodies/	Wetland	Wetland	Wetland
Sand dunes /Bareland /Rocky	Otherland	Otherland	Otherland
Cultivated orchards /cultivated Rainfed dry land /Commercial /subsistence crops	Cropland	Cropland	Cropland
Built up/residential areas	Settlement	Settlement	Settlement

In Botswana, three national forest subcategories, namely Riparian Forest, Typical Forest, and Woodland, are all classified under the Forest Land category for LULUCF reporting. The national forest definition is aligned with the FAO approach, in which Riparian and Typical Forests generally have top-canopy heights greater than 8 metres and exhibit multi-layered canopy structure, while Woodlands typically have top-canopy heights below 8 metres and a predominantly single-layer canopy. These categories form the basis of the Botswana Forest Distribution Map (BFDM), which provides the official national forest classification.

The BFDM 2015 and BFDM 2020 datasets were produced using Landsat-8 satellite imagery (2013 and 2015 acquisitions) with a 30-metre spatial resolution, enabling consistent mapping of forest extent and distribution and supporting aggregation to the six IPCC land-use categories used in this inventory. The National Forest Inventory (NFI) under the National Forest Monitoring System (NFMS) complements these datasets through recurring assessments of forest structure and biomass.

Vegetation patterns in Botswana are closely linked to climatic conditions. Hardwood forests in the northern regions represent an important resource, while sparse savannah woodland and scrub formations cover more than 60% of the national land area. These patterns are reflected consistently in the BFDM and LDSM classifications used to derive the national-to-IPCC mapping.

6.3. Land-Use Change and Transition Matrices

6.3.1. Development of Land-Use Transition Matrices

Annual land-use transition matrices were developed for the period 2000–2022 to ensure time-series consistency and complete representation of land-use change, in line with the 2006 IPCC Guidelines (Vol. 4) and the 2019 Refinement. The annual matrices were derived from the National Land Degradation Status (NLDS, 2022) land-cover conversion matrices (2000–2015 and 2016–2019), with 2020 category totals used as constraints. These datasets were harmonised to a common land-use classification, and national land area was held constant across all years

The multiyear matrices were first annualised by converting them into average annual transition probabilities, assuming constant change rates within each observed period. These annualised matrices were then applied sequentially to derive year-to-year transitions. Differences in total land area among source datasets were corrected using proportional scaling to maintain a consistent national land area, consistent with IPCC good practice for land representation.

For years where no observed matrix existed, gap-filling procedures were applied. The transition between 2015 and 2016 was derived through linear interpolation of transition probabilities, ensuring a smooth evolution of change patterns. For the 2019–2020 period, observed 2020 land-use totals were used to constrain the estimation, with adjustments made to retain the structure of the 2016–2019 transition probabilities. For 2020–2022, transition probabilities from the 2016–2019 period were extrapolated consistently to produce annual estimates.

This approach provides a complete, methodologically consistent annual time series of land-use transitions, allowing all “land remaining” and “land converted” categories to be reported in accordance with IPCC requirements and without introducing artificial discontinuities into the dataset.

The full multiyear land-cover conversion matrices (2000–2015 and 2016–2019) from the National Land Degradation Status (NLDS, 2022) dataset underpin the annualised series described above. For transparency, this section presents the derived annual transition matrix for the most recent reporting period (2021–2022), while the original NLDS matrices remain available in the source dataset.

Table 6-7: Derived Annual Land change (ha) matrix for the reporting year (2022)

	LULUC 2022							
	LULUC Type	**FL**	**CL**	**GL**	**OL**	**WL**	**SL**	**Total**
LULUC 2021	**FL**	20 812 496.6	2 308.2	1 405.7	0.0	0.0	4 248.3	20 820 458.8
	CL	1 910.9	1 204 264.0	464.0	0.0	0.0	464.0	1 207 102.9
	GL	463.6	437.4	33 103 492.0	0.0	463.6	0.0	33 104 856.6
	OL	0.0	0.0	463.3	1 490 848.1	0.0	0.0	1 491 311.4
	WL	0.0	0.0	431.8	457.6	859 257.6	0.0	860 147.0
	SL	0.0	0.0	0.0	0.0	0.0	476 262.9	476 262.9
	Total	20 814 871.0	1 207 009.6	33 106 256.8	1 491 305.7	859 721.1	480 975.2	**57 960 139.5**

6.3.2. Categories' Conversion Losses and Gain

6.3.2.1. Category specific QA/QC and verification

Forest Land in Botswana, which accounts for 26 -27% of the national land area (FAO), is subdivided into Moderately Dense Forest (25%), Widely Dense Forest (4%), and Sparse Forest (71%) to reflect the country's dominant vegetation structures. For reporting purposes, only Sparse Forest is treated as susceptible to land-use pressures, whereas Moderately Dense and Widely Dense Forests are considered relatively stable formations. As a result, all forest-related land-use conversions are attributed to changes within the Sparse Forest subcategory. This approach prevents overstating losses in ecologically stable forest types and aligns the reporting with the subcategory most likely to undergo conversion, while remaining consistent with IPCC guidance on allocating land-use change to the most affected strata.

6.3.2.2. Grassland conversions

Grassland in Botswana comprises a range of savanna formations that include grass-dominated and shrub-dominated systems. For inventory purposes, these formations are grouped under the IPCC Grassland category but are internally disaggregated into closed savanna grassland, closed savanna shrubland, open savanna grassland, and open savanna shrubland. Based on observed national land-use dynamics, only the open savanna subcategories are treated as susceptible to land-use conversion within the time series, while closed savanna systems are considered more structurally stable.

All conversions from Grassland to other land-use categories are therefore allocated to the open savanna subcategories using fixed proportions of 30% (grassland) and 70% (shrubland). Inflows to Grassland are distributed using the same proportions to ensure internal consistency. This approach reflects Botswana's ecological conditions and is applied consistently across the time series.

6.3.2.3. Cropland conversions

In Botswana's land-use classification, Cropland is internally disaggregated into two national subcategories to reflect the structure of agricultural production: annual crops (field crops) and perennial crops (orchards). Annual crops account for approximately 99% of total cropland area and represent the dominant land-use system, while perennial crops make up a small and relatively stable portion of the landscape. Based on national agricultural practices, land-use dynamics, and available datasets, only the annual-crop subcategory is considered susceptible to land-use conversion within the inventory time series. Perennial crops are characterized by long-term establishment, higher investment requirements, and low turnover, and are therefore treated as unchanged across the time series. Accordingly, all conversions to and from Cropland are allocated exclusively to the annual-crop subcategory, while the perennial-crop subcategory is held constant for all inventory years. This ensures that reported land-use change reflects Botswana's actual agricultural patterns and avoids artificially attributing changes to perennial systems that are not subject to regular conversion.

6.3.2.4. Natural Disturbances (Fires)

Fire is a natural and recurring feature of Botswana's ecosystems and is included in the inventory as a source of emissions and disturbance-related carbon losses. Due to data limitations, the inventory does not distinguish between natural wildfires and controlled burns; therefore, all detected fire activity is reported as wildfire emissions under the LULUCF sector.

Burnt-area activity data are obtained from MODIS satellite observations, and emissions are estimated for Forest Land and Grassland, which are the only land categories with combustible biomass and available activity data. Other land categories are assumed not to burn, while Cropland burning is not reported due to lack of data.

The estimation method incorporates above-ground biomass as the primary fuel load, with dead organic matter included for relevant forest types. Combustion factors and emission factors for CH_4 and N_2O follow the 2006 IPCC Guidelines, applying dry tropical forest parameters for moderately and densely stocked forests and savanna values for sparse forests; and, in the absence of country-specific data on the fraction of biomass lost during fire disturbances, the inventory applies a combustion fraction of 0.2 for Forest Land, consistent with the 2019 Refinement's recommended value for tropical dry forests.

Fire emissions contribute substantially to year-to-year variability in the national LULUCF balance. For example, in 2010 the net sink was −24,688 Gg CO_2-eq with fires compared to −70,492 Gg CO_2-eq without fires, indicating fire emissions exceeding 45,000 Gg CO_2-eq in that year. Similar impacts are observed in 2011–2012, while 2015–2020 show smaller differences, and by 2019–2022 the sink remains strong even with fires included. The implementation is consistent with the Gain–Loss methodology applied elsewhere in the sector, ensuring no double counting between disturbance-related losses and land-use conversions. Planned improvements include distinguishing wildfires from controlled burns, developing country-specific combustion and emission factors, and incorporating seasonal burned-area analyses to refine future estimates.

Generally, fires are the dominant source of variability in Botswana's LULUCF emissions and removals. Excluding fires reveals the underlying sequestration potential of forests and land-use systems. Large fire years (2010–2012) significantly weaken the sink, underscoring the need for fire management strategies. The long-term trend shows that forest carbon sequestration is robust, but its effectiveness is reduced during years of substantial fire activity. The impacts of fire on total LULUCF emissions and removals are summarised in Table 6-8 for the period 2002–2022

Table 6-8: Impacts of emissions from biomass burning on total LULUCF emissions/removals

Year	Total emissions with fires (Gg CO_2 e)	Total emissions excluding fires (Gg CO_2 e)
2002	-59147,9404	-63352,5085
2003	-54980,2285	-59748,6475
2004	-51562,8322	-56524,0513
2005	-56197,0868	-60859,3924
2006	-57043,9631	-59291,4476
2007	-65094,0167	-66389,9962
2008	-31519,3618	-36177,259
2009	-69656,7893	-74055,8744
2010	-24687,9073	-70492,2737
2011	-17430,1993	-30029,9279
2012	-44302,857	-48756,5808
2013	-44092,0407	-48756,5808
2014	-64549,674	-65887,5946
2015	-73242,0895	-73701,4636
2016	-76911,3506	-77007,0483
2017	-69757,5984	-70567,6956
2018	-75128,4892	-75403,9063
2019	-75559,4959	-75789,7401
2020	-75110,5711	-75384,9825
2021	-71676,1257	-72292,4114

Year	Total emissions with fires (Gg CO_2 e)	Total emissions excluding fires (Gg CO_2 e)
2022	-73642,0693	-74055,8744

6.4. Forest Land (CRT 4.A)

This category reports emissions and removals from above-ground biomass, below-ground biomass, litter, deadwood, mineral soils, and from Harvested Wood Products (HWP). Changes in biomass reflect wood removals, fuelwood collection, and disturbance-related losses. Fuelwood harvesting, which could not be disaggregated by forest type, is included under Woodlands, while emissions from the burning of fuelwood for energy use are reported under the Energy sector. Emissions and removals from HWP are reported under category 4.G. Forest Land includes both forest land remaining forest land and land converted to forest land, with the latter subject to a 20-year transition period in accordance with IPCC guidance. In this inventory, CH_4 and N_2O emissions from biomass burning occurring on forest land are reported directly under category 4.A (rather than under Agriculture 3C1, as was done previously) to align with the Common Reporting Tables required under the ETF.

Trend context. Forest Land is the principal contributor to Botswana's LULUCF sink across the time series. Inter-annual variability is influenced by fire activity, with weakened sinks observed in 2010–2012, and stronger removals in years with limited burned area (e.g., 2015–2020). The dominance of woodlands (reported within Forest Land sub-classes) strengthens the sectoral sink over the long term.

Biomass

Forest Land estimates are prepared using Tier 1 methods in accordance with the 2006 IPCC Guidelines (Volume 4). A Gain–Loss method is applied across Forest Land categories

Carbon gains.

Natural forest lands remaining forest lands are classed as either undisturbed (primary) or disturbed (secondary) to apply different growth rates. In the absence of data on specific areas of primary and secondary forests, a protected-area proxy was used to infer primary-forest areas. According to NFMS (2020), approximately Moderately dense Forest: 25%, Sparse Forest: 71%, Widely dense Forest: 4% of indigenous forests were protected over 2003–2022. Annual above-ground biomass growth in primary indigenous forests is taken as zero (IPCC, 2019), which is consistent with NFMS (2020) findings. For secondary forests, the growth rates in the internal table were applied and assumed to grow until maximum biomass; root-to-shoot ratios were used to include below-ground biomass; the IPCC 2006 default value of 0.47 t C per t dm^{-1} was used for the carbon fraction of dry matter of all Forest lands.

Carbon losses (harvest and fuelwood).

Harvest losses.

Harvested wood data were obtained from FAOSTAT. The harvested wood included fuelwood and other removals, and all harvest losses were allocated to Forest land remaining forest land, assuming recently converted land would not be harvested due to longer harvest cycles.

Fuelwood collection.

Carbon losses from fuelwood removals were estimated using Equation 2.13 (IPCC 2006). Due to limited information on the distribution of removals by vegetation type, the entire amount was allocated to sparse forests, with no removals assigned to moderately or densely stocked forests. Fuelwood-collection losses were reported across forest land remaining forest land and land converted to forest land; values attributed to converted lands were minimal compared with forest land (sparse) remaining forest land (sparse). FAOSTAT indicates household fuelwood consumption declined compared to 2003 (electrification), then stabilised from 2015 as many electrified households continued to rely on wood; charcoal production increases in 2013 and 2020 led to spikes in total fuelwood consumption. Future inventories will investigate the FAO fuelwood data more closely and identify improved country-specific datasets.

Biomass burning on Forest Land.

Annual burnt-area data are used to estimate non-CO_2 emissions from biomass burning within Forest Land. Fuel-load assumptions are based on above-ground biomass, with DOM included for relevant forest types following IPCC defaults; combustion factors and emission factors for CH_4 and N_2O are taken from the 2006 IPCC Guidelines (dry tropical forest parameters for moderately/densely stocked forests; savanna values for sparse forests). A combustion fraction of 0.2 is applied for tropical dry forests per the 2019 Refinement.

Note on DOM (cross-cutting).

DOM stock-change estimates for Forest Land are not estimated (NE) in this cycle due to insufficient country-specific DOM stock data for a stock-difference method.

Emission Factors

Emission factors applied in the Forest Land category follow the 2006 IPCC Guidelines (Volume 4), using default Tier 1 parameters in the absence of country-specific values. Combustion and emission factors for biomass burning on Forest Land were taken from Table 2.6 (combustion factors) and Table 2.5 (CH_4 and N_2O emission factors) of the 2006 IPCC Guidelines. For biomass burning in moderately and densely stocked tropical dry forests, dry-tropical-forest parameters were applied, while savanna-type parameters were used for sparse forest formations, consistent with Botswana’s dominant vegetation types.

The carbon fraction of dry matter (CF = 0.47 t C per t dm^{-1}) recommended by the IPCC 2006 Guidelines was applied across all Forest Land strata. Root-to-shoot ratios were used to estimate below-ground biomass following IPCC defaults. Where emission factors for any activity or forest type were not available for Botswana, IPCC default factors were adopted

6.5. Cropland (CRT 4.B)

6.5.1. Description of the category

The Cropland category covers perennial crops (orchards) and annual crops (field crops). Reporting covers emissions and removals of CO_2 from above- and below-ground biomass, litter, and mineral soils, and includes both cropland remaining cropland and land converted to cropland. Calculations apply a 20-year transition period, whereby once a land area is converted it remains in the converted category for 20 years.

Trend context: In the time series, Cropland emissions were broadly stable during 2004–2017, then increased in 2018 and remained relatively constant through 2022, driven by transitions between annual and perennial systems and inflows from sparse forest categories. Changes in annual vs. perennial cropping explain most of the variability; perennial areas are small and relatively stable, while annual crops (~99% of cropland) dominate the trend.

Note on burning: Cropland burning is not reported due to lack of data (consistent with the fire discussion, where burning is estimated only for Forest Land and Grassland)

6.5.2. Methodological issues of the category

Approach and tiers: Estimates are prepared using Tier 1 methods of the 2006 IPCC Guidelines (Vol. 4) and the 2006 IPCC Inventory Software, together with country-specific activity data and IPCC default factors. A Gain–Loss method is applied to above-/below-ground biomass and litter; mineral soils are included under Tier 1 default parameters.

Category disaggregation: In Botswana's land-use classification, Cropland is internally disaggregated into annual crops (field crops) and perennial crops (orchards). Annual crops (~99% of cropland) are treated as susceptible to conversion, while perennial crops are held constant across the series. Accordingly, all conversions to and from Cropland are allocated exclusively to the annual-crop subcategory. This reflects national agricultural patterns and avoids attributing changes to perennial systems that are not subject to regular turnover.

Land conversion treatment: Conversions into Cropland (e.g., from Grassland or sparse Forest sub-classes) follow the 20-year transition rule. Immediate carbon losses at conversion are treated consistent with Gain–Loss methods; subsequent years reflect stock changes in the converted land until transition completion.

Results (summary for the time series)

Consistent with the sector overview, Cropland shows modest net emissions with limited inter-annual variability compared with Forest Land. Emissions were broadly stable from 2004–2017, followed by an increase in 2018 linked to annual/perennial transitions and inflows from sparse forest categories, then relatively constant through 2022.

6.6. Grassland (CRT 4.C)

6.6.1. Description of the category

The Grassland category includes natural and semi-natural grasslands, shrublands, bushlands and savanna systems that fall below the national forest definition. These systems cover a substantial proportion of Botswana's land base and show strong ecological variability driven by annual rainfall and long-term climatic gradients. Reporting in this category covers CO_2 emissions and removals from above-ground biomass, below-ground biomass, and mineral soils, for both Grassland remaining Grassland and land converted to Grassland. A 20-year transition period is applied for all land-use conversions in accordance with IPCC guidance.

Trend context: Grassland contributes a relatively small sink or low emissions compared with Forest Land, with most inter-annual variability linked to shifts between grass- and shrub-dominated savanna types and transitions from sparse forest formations. Grassland areas often act as transitional landscapes between forest, cropland and mixed savanna systems, and the category exhibits modest fluctuations across the 2002–2022 period.

6.6.2. Methodological issues

Approach and tiers: Grassland estimates are prepared using Tier 1 methods from the 2006 IPCC Guidelines (Vol. 4) and the 2006 IPCC Inventory Software, consistent with the approach applied across all land categories. A Gain–Loss method is used to estimate carbon stock changes in biomass and soils, using IPCC default biomass growth rates, turnover parameters, and carbon fractions.

Category disaggregation: Grassland is internally disaggregated into closed savanna grassland, closed savanna shrubland, open savanna grassland and open savanna shrubland. Based on observed land-use change patterns, only the open savanna subcategories are considered susceptible to conversion, while closed savanna systems are treated as more stable. Conversions from Grassland to other categories are allocated 30% to grassland and 70% to shrubland, with inflows distributed using the same proportions. These proportions reflect Botswana's ecological patterns and are applied consistently across the time series.

Land conversion treatment: All land converted to Grassland is assigned a 20-year transition period, after which the land class is considered to have fully transitioned to the Grassland category. Immediate changes at conversion are treated according to the Gain–Loss method, and subsequent years reflect stock-change dynamics until the end of the transition period.

Note on burning. Grassland burning is included in the inventory, with CH_4 and N_2O emissions estimated using MODIS burnt-area data and 2006 IPCC Guidelines combustion/emission factors, as described in Section 6.3.3 Natural disturbances (fires). Fire disturbance significantly shapes year-to-year variation in Grassland emissions.

Results (summary for the time series)

Grassland shows modest net emissions or small removals through the time series, with limited long-term directional change compared with Forest Land. The category's behaviour reflects both ecological dynamics in Botswana's semi-arid savanna systems and the inflows/outflows associated with conversions to and from grassland and shrubland formations. Fire patterns play a key role in short-term variability, with higher emissions observed in years of extensive burnt area.

6.7. Wetland (CRT 4.D)

6.7.1. Description of the category

The Wetlands category includes natural and human-made waterbodies such as natural rivers, perennial and non-perennial streams, natural lakes, dams, flooded pans, mine pits, and tailings ponds, as represented in the NLDS/LDSM (2022) land-cover classification. These areas generally contain little or no woody biomass and do not accumulate significant above- or below-ground biomass under Botswana's semi-arid conditions. Consequently, Wetlands typically exhibit very limited carbon stock changes and therefore contribute negligible emissions or removals in the LULUCF sector.

Trend context: Wetland area shows minimal year-to-year change over the 2002–2022 time series, and variations that do occur reflect hydrological fluctuations rather than land-use change. As a result, emissions and removals from Wetlands remain close to zero across the entire period.

6.7.2. Methodological issues

Approach and tiers: Wetlands are estimated using Tier 1 methods from the 2006 IPCC Guidelines (Volume 4). Under Tier 1, only managed wetland systems with measurable biomass dynamics or drainage impacts are reported. Botswana does not have drained organic soils in this category and does not manage wetlands for peat extraction or aquaculture; therefore, estimation is limited to assessing whether biomass carbon stock changes occur. Based on national land-cover classes (NLDS/LDSM), no significant biomass stock-change activity occurs in these systems.

Land conversion treatment: Land converted to Wetlands (e.g., creation of dams or mine ponds) is reported under Wetlands converted to another category using the 20-year transition rule where applicable. However, these conversions are rare, tend to involve non-biomass land, and therefore do not result in measurable carbon stock changes under Tier 1. Similarly, conversions from Wetlands are uncommon and generally do not involve biomass pools.

Results (summary for the time series)

Wetlands show no significant emissions or removals over the 2002–2022 period. Category values remain zero or close to zero due to absence of woody or herbaceous biomass accumulation, negligible land-use conversion involving wetlands, and no fire activity detected in these areas. The Wetlands category therefore contributes negligibly to Botswana's net LULUCF emissions/removals.

6.8. Settlements (CRT 4.E)

6.8.1. Description of the category

The Settlements category includes built-up areas, towns, villages, commercial and industrial areas, major road corridors and related infrastructure, as classified in the NLDS/LDSM (2022) national land-cover dataset. Settlements generally contain little or no biomass and therefore exhibit negligible carbon stock changes under Tier 1 methods. Changes in reported area are mainly due to expanding urban and peri-urban development, particularly around Gaborone, Francistown, and other growing centres. These changes, however, occur mostly on land types with already low biomass stocks, resulting in negligible emissions or removals.

Trend context: Across the 2002–2022 time series, the Settlements category shows a gradual increase in area, reflecting national population and infrastructure growth. Despite this expansion, total emissions from Settlements remain close to zero because the conversions originate mostly from low-biomass savanna and shrubland classes and because built-up areas do not accumulate or lose biomass under Tier 1 accounting.

6.8.2. Methodological issues

Approach and tiers: Settlements are estimated using Tier 1 methods from the 2006 IPCC Guidelines (Volume 4). Reporting covers CO_2 emissions/removals from biomass and soils where applicable. In Botswana's context, Settlements carry no substantive biomass pools, and soil organic carbon changes are negligible under Tier 1 default factors, given the dryland environment and the nature of built-up land.

Land conversion treatment: Conversions to Settlements from other land-use categories (e.g., Grassland or sparse Forest subclasses) are reported using the 20-year transition rule in accordance with IPCC guidance. However, these conversions involve minimal above-ground or below-ground biomass, resulting in very small or zero carbon stock changes at conversion and over the transition period. Conversions from Settlements are extremely rare and generally do not involve biomass accumulation.

Results (summary for the time series)

The Settlements category contributes negligible CO_2 emissions or removals across the time series. Category totals remain at or near zero, with minor numerical movement reflecting small annual changes in land-use area rather than meaningful carbon stock changes. This behaviour is consistent with Botswana's land-cover characteristics and the Tier 1 assumption of negligible biomass in built-up landscapes.

6.9. Other Land (CRT 4.F)

6.9.1. Description of the Category

The Other Land category includes areas with very sparse or no vegetation, such as barren land, bare soils, rock outcrops, sand dunes and dry pans, based on the NLDS/LDSM (2022) classification. These areas contain negligible biomass, do not accumulate carbon, and therefore generate no measurable emissions or removals under Tier 1 methods. Area changes over 2002–2022 are minor and reflect mapping variation rather than true land-use shifts.

6.9.2. Methodological issues

Approach (Tier 1): Under the 2006 IPCC Guidelines (Vol. 4), Other Land is assumed to have no biomass or soil carbon stock changes unless evidence of management or vegetation growth exists—neither of which apply in Botswana. Consequently, CO_2 emissions/removals are reported as zero across the time series.

Land conversions: Conversions to or from Other Land are rare and involve areas with no biomass, so conversion-related carbon stock changes are zero under Tier 1. A 20-year transition period is maintained for consistency with IPCC rules.

Results summary

Other Land contributes zero emissions or removals for all years 2002–2022.

6.10. Harvested Wood Products (CRT 4.G)

6.10.1. Description of the Category

Harvested Wood Products (HWP) in this inventory refer to wood harvested from Forest Land, Cropland, and other land-use categories. The HWP pool includes all woody material present at removal. In this cycle, Botswana reports HWP in line with the 2006 IPCC Guidelines (Volume 4), consistent with UNFCCC advice for ETF reporting.

Historical note: HWP were not reported in the 2014–2015 inventory cycle. Inclusion in the current inventory represents a methodological improvement; the estimates draw on internationally available activity data while national HWP statistics are being developed.

Trend summary: HWP constitute a net sink across the series, with removals beginning around –20 Gg CO_2-eq in the early 2000s, strengthening through the 2010s and peaking near –108 Gg CO_2-eq around 2020, then remaining strongly negative by 2022. Inter-annual variability reflects changes in wood product production, imports/exports, and use.

6.10.2. Methodology and activity data

Estimates use the 2006 IPCC Guidelines (Vol. 4) Tier 1 approach for HWP, implemented with the IPCC Inventory/ETF tools and FAOSTAT activity data for production, imports and exports of relevant commodities (e.g., Roundwood, sawn wood, panels, paper/paperboard, pulp, residues, charcoal). Table 6-10 presents FAOSTAT Activity data for the components of Harvested Wood Products (2018–2022)

Table 6-9: Activity data for the different components of Harvested Wood Products (2018 – 2022)

ComponentYear		2018	2019	2020	2021	2022
Fuelwood/Wood Fuel	Production	699,385	699,472	699,563	699,644	699,729
	Import	73	74	149	117	41
	Export	0	0	0	0	5
Sawn Wood	Import	109,950	99,553	102,760	115,466	100,144
	Export	133	35	0	0	312
Wood-Based Panels	Import	5165	3653	17,272	21,139	12,468
	Export	202	21	711	53	78
Paper+Paperboard	Import	26,046	31,898	44,514	37,740	51,784
	Export	149	271	1809	1140	308
Wood Pulp	Import	1	3	0	0	1
	Export	0	0	0	0	0
Recycled Paper	Import	106	75	3493	7	238
	Export	9461	3406	5674	5957	9950
Wood Pulp + Recycled Paper	Import	1	109	75	0	0
	Export	9461	3406	5674	5957	9950
Industrial Roundwood	Import	42,405	77,242	69,140	64,703	38,949
	Export	132	40	35	0	33
Chips and particles	Import	4305	2463	5127	804	599
	Export	11	0	0	0	0
Wood charcoal	Import	0	22	93	89	117
	Export	0	66	1	17	0
Wood residues	Import	842	89	1022	872	357
	Export	0	0	0	2	0
Roundwood (Fuelwood+Industrial Roundwood)	Import	42,478	77,316	69,289	64,820	58,990
	Export	132	40	35	0	38

Source: FAOSTAT

Results summary

HWP are a persistent net sink over the time series. Removals were modest in the early 2000s (≈ –20 to –70 Gg CO_2-eq), then strengthened through 2015–2020 (to ≈ –108 Gg CO_2-eq), and remained strongly negative in 2022, consistent with activity-data patterns for wood commodities.

6.11. Biomass Burning (CRT 4.IV)

Biomass burning emissions under CRT 4.IV include CH_4 and N_2O from fires on Forest Land and Grassland, estimated using MODIS burnt-area data and 2006 IPCC default combustion and emission factors (dry-tropical and savanna parameters). No emissions are reported for Cropland (lack of data), Wetlands, Settlements or Other Land, as these categories show no combustible biomass and no MODIS-detected fire activity. Table 6-10 presents national area burnt for the period 2002-2022.

In Botswana, prescribed burning is **insignificant**, and fire management activities are almost entirely focused on wildland fires. Consequently, the reported emissions predominantly reflect wildfires. MODIS burnt-area products do not provide reliable disaggregation by fire type for Botswana. Prescribed burning is minimal and not systematically recorded, making it impractical to separate emissions at this stage. We acknowledge this limitation and explicitly note that emissions reported under fire are overwhelmingly from wildland fires. Botswana commits to exploring options for disaggregation in future submissions, including collaboration with FAO and regional fire monitoring initiatives, to improve reporting consistency with MPGs.

Fire drives inter-annual variability in CRT 4.IV, with higher emissions in large-burn years and lower values in recent years. The following table below gives the area burnt for the time series 2002 – 2022.

Table 6-10: Annual Area Burnt (ha)

YEAR	AREA BURNT(ha)
2002	4 210 000,000
2003	5 690 000,000
2004	6 120 000,000
2005	4 880 000,000
2006	5 716 201,000
2007	3 296 165,000
2008	11 846 790,000
2009	2 124 952,000
2010	13 586 774,000
2011	15 439 034,980
2012	11 327 500,000
2013	8 620 279,000
2014	3 402 837,000
2015	1 168 361,770
2016	243 395,428
2017	2 060 382,940
2018	700 489,700
2019	585 597,900
2020	697 931,700
2021	1 567 446,900
2022	1 052 462,464

6.12. Planned Sectoral Improvements

Planned improvements for the LULUCF sector are summarised in Table 6 11, covering methodological refinements, data system enhancements and remaining gaps identified during the preparation of this inventory. These actions address sector wide priorities as well as category specific needs and are aligned with Botswana's long term capacity building and transparency objectives under the ETF.

Table 6-11: LULUCF-specific planned improvements

Area	Planned improvement	Status	Notes / Source
Forest pools & factors	Obtain deadwood and litter data; strengthen verification of biomass and emission factors	Outstanding	NFMS/NFI, FRA
Biomass burning	Integrate seasonal burnt-area information; develop country-specific combustion/emission factors for Tier 2	Outstanding	Fire methods (6.3.3)
Other disturbances	Compile information on non-fire disturbances affecting Forest Land	Outstanding	NFMS/NFI
DOM (Dead Organic Matter) pools	Implement estimation of DOM stock changes using IPCC 2006 GL equations **2.20–2.22** once available; explore Tier 1 stock-difference method using FRA/NFMS datasets	Outstanding	Software limitation (DOM_{IN}/ DOM_{OUT} not implemented)
DOM activity data	Develop national datasets for dead wood and litter carbon stocks; integrate DOM measurements into NFMS/NFI permanent plots	Outstanding	Required for Tier 1/2 DOM estimation
Land-cover and land-use data	Continue improving accuracy and consistency of NLDS/LDSM and transition matrices; enhance quality checks	Ongoing	NLDS/LDSM, FAO support
HWP data	Develop country-specific statistics for wood-product production, imports and exports	Outstanding	HWP now included; FAOSTAT used as AD source
Transparency & data systems	Improve transparency and structure of estimation files and reporting; consider automation as data volume grows	Outstanding	Internal QA/QC review

7. WASTE (CRT 5)

7.1. Overview of the sector

The waste sector covers greenhouse gas emissions from the following sources:

- Solid Waste Disposal
- Incineration and Opening Burning of Waste
- Wastewater Treatment and Discharge

7.1.1. Description of the sector

The waste management in Botswana is currently insufficient. The sector faces challenges in waste collection services, where some settlements both in rural and urban areas receive insufficient to no collection at all, mainly in rural areas where waste is disposed in dumping sites or illegally dumped. Moreover, population distribution is a contributing factor, it is sparse making collection of waste in every settlement difficult. The uptake of the initiative for recycling and recovery of waste is slow resulting from inadequate waste separation at source. Botswana government however, has a national waste management strategy and a regulatory framework, whose implementation and enforcement are a challenge (GoB, 2021).

Waste generation growth in the country exceeds the capacity of existing infrastructure for treatment and disposal of waste which is a challenge. Furthermore, these facilities operate inadequately and there is generally poor maintenance which could result in their reduced lifespan as well as non-compliance to environmental statutes. In addition, there are no hazardous waste treatment facilities except a few incinerators both in some landfills and privately owned, for the treatment of clinical waste. Majority of the hazardous waste is exported to other countries (GoB, 2021).

The wastewater sector is managed by Water Utilities Corporation (WUC), a parastatal fully owned by Botswana government. Just as solid waste, this section of the sector faces challenges, there is lack of operational and maintenance of these facilities. These facilities receive both industrial and household wastewater. Most facilities pre-treat their wastewater prior to disposal into the sewer lines. Most households are not connected to the sewer lines, especially in villages and therefore use wastewater bowsers to transport waste to the treatment plants. The waste from the pit latrines are also disposed at these wastewater treatment facilities. Sludge from the treatment plants, of unknown volumes is kept in drying beds. Therefore, their emissions couldn't be estimated due to lack of activity data.

7.1.2. Trend in the sector's GHG

The total emissions from the Waste sector for the year 2022 were 344.33 Gg CO_2eq, as shown in Table 7-1. The majority of the Waste sector emissions are from solid waste, accounting for 46.57% (160.36 Gg CO_2eq) of the emissions, followed by Wastewater and Discharge accounting for 36.20% (124.64 Gg CO_2 eq) while emissions from Incineration and Open Burning of Waste contributed 17.26% (59.46 Gg CO_2 eq). Total emissions were 360.837 Gg CO_2 eq (Figure 7-1). Solid waste contributed 160.36 Gg CO_2 eq (46.57%) of the total waste sector, which accounts for most of these emissions. The Biological treatment of solid waste was not estimated due to lack of activity data.

Solid waste disposal emissions have increased by 69% since 2000. Incineration and open burning of waste emissions increased by 47.1% since 2000, while emissions from Wastewater treatment and discharge increased by 36.20%.

The emissions of the Waste sector for the period 2000-2022 are shown in Figure 7-1.

Waste Sector emissions have increased by 52.23%. Emissions from all waste categories have increased since the year 2000 as shown in Table 7-1 below.

Table 7-1: The emissions of the Waste sector for the period 2000-2022

Source Category	Emissions (Gg CO_2eq)		Change (%)
	2000	2022	2000-2022
4 - Waste	**225.12**	**344.33**	**52.23%**
4.A - Solid Waste Disposal	94.88	160.356	69.0%
4.B - Biological Treatment of Solid Waste	NO	NO	NO
4.C - Incineration and Open Burning of Waste	40.42	59.457	47.1%
4.D - Wastewater Treatment and Discharge	89.82	124.64	36.20%.
4.E - Other	NA	NA	NA

Table 7-2 below presents the greenhouse gas emissions in the Waste Sector for the inventory year 2022. It is evident that solid waste subcategory constituted majority of the sector. Table 7-3 and Figure1 depicts the GHG trend for the waste sector from 2000 to 2022. A linear growth is evident resulting from population growth.

Table 7-2: Greenhouse Gas Emissions in the Waste Sector (in Gg and total in Gg CO_2-eq.): 2022

	Emissions (Gg)							TOTAL (Gg CO2-eq)
Categories	CO2	CH4	N2O	NOx	CO	NMVOCs	SO2	
4 - Waste	4.705	11.65	0.112	NE	NE	NE	NE	344.33
4.A - Solid Waste Disposal		5.727		NE	NE	NE	NE	160.356
4.A.1 - Managed Waste Disposal Sites		2.092		NE	NE	NE	NE	58.576
4.A.2 - Unmanaged Waste Disposal Sites		2.874		NE	NE	NE	NE	80.472
4.A.3 - Uncategorised Waste Disposal Sites		0.761		NE	NE	NE	NE	21.308
4.B - Biological Treatment of Solid Waste		NO	NO	NO	NO	NO	NO	NO
Composting		NO	NO	NO	NO	NO	NO	NO
Anaerobic digestion at biogas facilities		NO	NO	NO	NO	NO	NO	NO
Other		NO	NO	NO	NO	NO	NO	NO
4.C - Incineration and Open Burning of Waste	4.705	1.697	0.027	NE	NE	NE	NE	59.457
4.C.1 - Waste Incineration	NE	NE	NE	NE	NE	NE	NE	NE
4.C.2 - Open Burning of Waste	4.705	1.697	0.027	NE	NE	NE	NE	59.457

	Emissions (Gg)							TOTAL (Gg CO2-eq)
Categories	**CO2**	**CH4**	**N2O**	**NOx**	**CO**	**NMVOCs**	**SO2**	
4.D - Wastewater Treatment and Discharge	NO	**3.644**	0.085	NE	NE	NE	NE	124.557
4.D.1 - Domestic Wastewater Treatment and Discharge	NO	3.364	0.085	NE	NE	NE	NE	116.717
4.D.2 - Industrial Wastewater Treatment and Discharge	NO	0.28	NE	NE	NE	NE	NE	7.84
4.E - Other (please specify)	NE	NE	NE	NE	NE	NE	NE	NE

Table 7-3: Total GHG emissions by category (Gg CO_2 eq)

Category	2000	2005	2010	2015	2020	2021	2022
Solid Waste Disposal	94.88	109.33	124.21	139.09	154.48	157.47	160.36
Incineration and Open burning of waste	40.42	45.3	49.8	54.24	58.09	59.13	59.34
Wastewater Treatment and Discharge	89.81	98.581	108.188	117.377	124.43	124.9	124.557
Total Waste	**225.117**	**253.211**	**282.198**	**310.707**	**337.023**	**341.641**	**344.257**

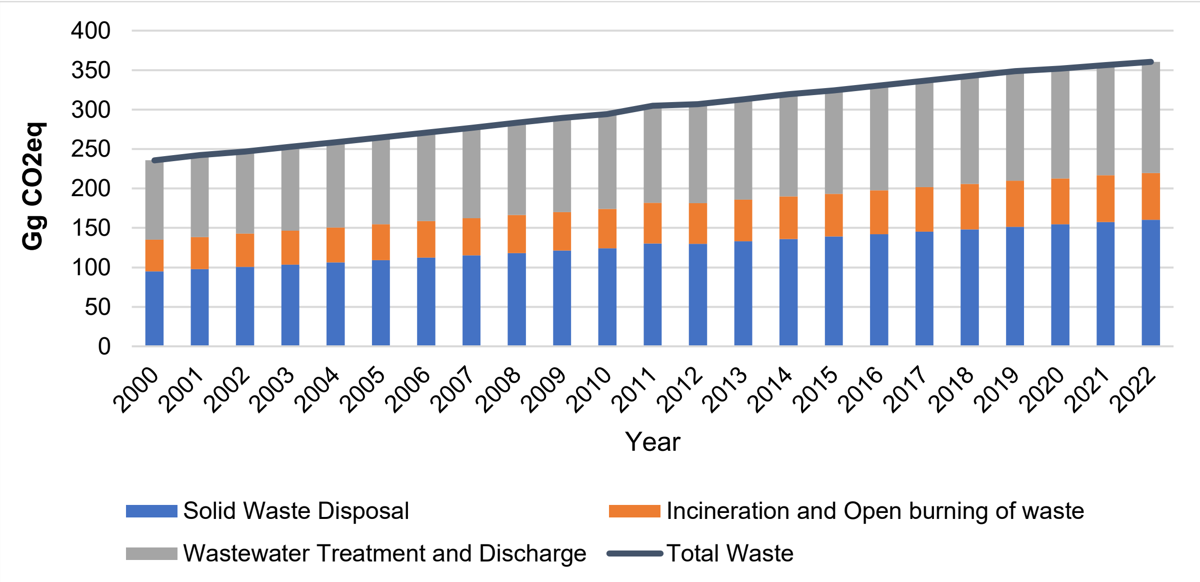

Figure.7-1: Total GHG emissions by category or subcategory (GgCO_2 eq), 2000-2022

Table7-4 below presents total GHG emissions by gas from the year 2000 to 2022. It shows that the main gas emitted from waste throughout the entire time series was methane.

Table 7-4: Emissions by GHG (Gg CO2 eq)

GHG	2000	2005	2010	2015	2020	2021	2022
CO_2	2.11	2.88	3.38	3.72	3.97	4.50	4.71
CH_4	201.10	227.09	253.83	278.23	302.48	306.37	309.91
N2O	21.9	23.23	24.99	28.76	30.60	30.77	29.71
Total CO_2eq	**225.11**	**253.20**	**282.20**	**310.71**	**337.05**	**341.64**	**344.3**

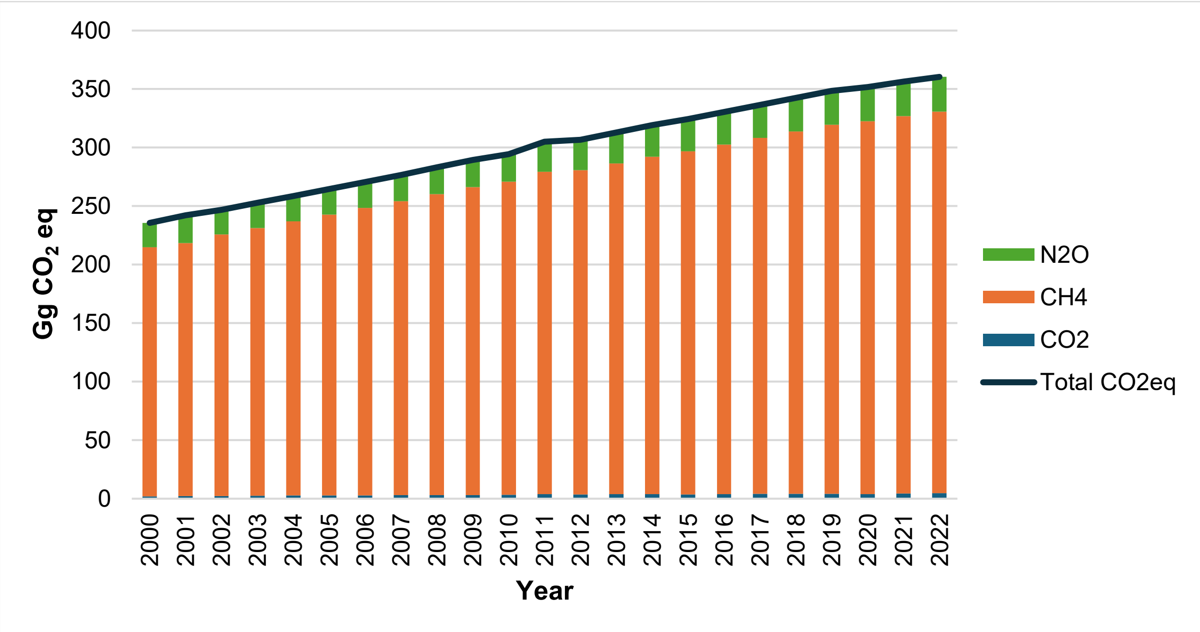

Figure.7-2: Total GHG emissions by gas from the year 2000 to 2022

7.1.3. General methodological issues of the sector

Table 7-5 summarises methods and emission factors used to calculate the GHG emissions from the waste sector. Tier 1 method and IPCC default emission factors were applied for all categories since the country does not have country specific emission factors.

Table 7-5: Summary of methods and emission factors for the Waste sector and an assessment of the completeness of the waste emissions

GHG Source and sink category		CO_2		CH_4		N_2O		Details
		Method Applied	*Emission factor*	*Method Applied*	*Emission factor*	*Method Applied*	*Emission factor*	
A	Solid waste disposal	NA	NA	T1	D	T1	D	Tier FOD method was used
B	Biological treatment of waste	NA	NA	NA	NA	NA	NA	NA
C	Incineration and Open Burning of Waste	T1	D	T1	D	T1	D	2006 IPCC GL
D	Wastewater Treatment and Discharge	NA	NA	T1	D	T1	D	2006 IPCC GL

7.1.4. QA/QC process and verification

QA/QC measures in Table 7-6 were used for the waste sector calculation.

Table 7-6: General QA/QC checks completed for Waste sector

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

QA/QC principle	Check
Accuracy	QA review

7.1.5. Improvements and recalculations

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

- The current inventory included emissions from open burning of waste (4.C.2 - Open Burning of Waste)
- There was an error in population data entry in the previous inventory. It was assumed that higher population in urban areas generate more waste than rural population and hence a small segment of the rural population was included in the estimation of GHG emissions in waste sector. The current inventory as per the 2006 IPCC guidelines considered the whole population data for Botswana dating back to 1950.
- The previous inventory waste emissions were calculated using a default waste generation rate of 290.0 kg/capita/year (IPCC, 2006), whilst the current inventory used country-specific waste generation rate of 99.519 kg/capita/year which is less than IPCC default. This value was derived from 224,320.91 tonnes of waste generated in Botswana in 2017 (Statistics Botswana, 2020). The 224,320 tonnes of waste generated was converted to 224,320,000 Kg. This annual waste generation was divided by the 2017 population of figure of 2,254 021 to get a per capita waste generation rate of 99.519 kg waste/capita/year rounded to 100 kg/capita/year. Rate was divided by 365 days to get a per day rate = 0.273 kg waste/capita/day.

The recalculations show a change in the trend throughout the time series (Figure 7-3). The emissions are lower after the recalculations compared to the previous inventory.

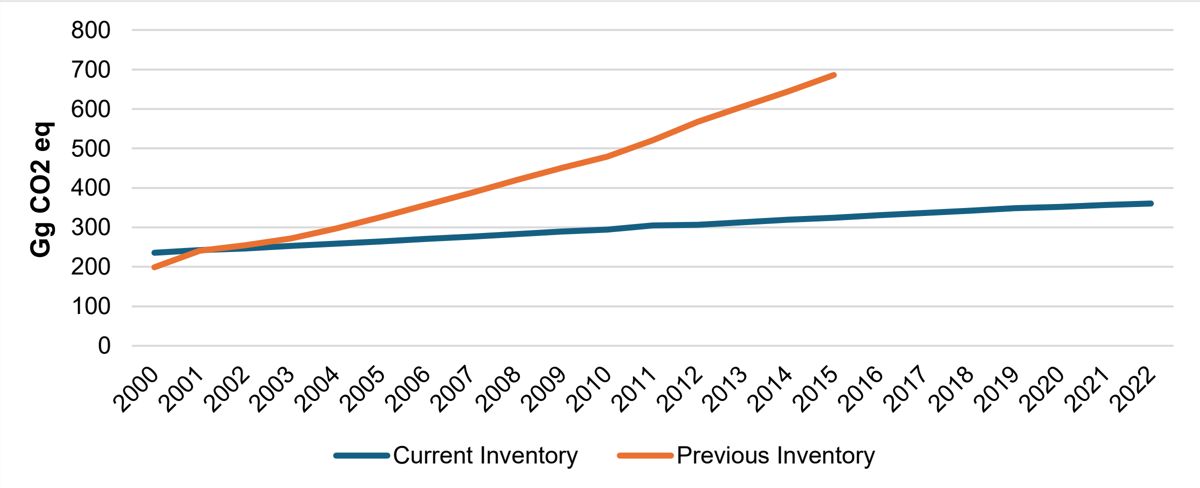

Figure.7-3: Change in Waste emission estimates due to recalculations since 2000 submission.

7.2. Solid waste disposal (CRT 5.A)

Solid waste disposal in Botswana is challenged by inadequate infrastructure, leading to illegal dumping, and limited waste collection, especially in urban areas. The country faces difficulties with frequent waste collection, inadequate separation of waste, and environmental risks like water contamination and fire hazards. The Government of Botswana has enacted a Waste Management Act to address the aforesaid issues through regulated collection, treatment, and disposal, and is exploring new strategies and technologies (GoB, 1998).

Waste streams deposited into landfills in Botswana are from households, commercial businesses, institutions, and industry. In this report only the organic fraction of the waste in solid disposal sites was considered as other waste stream components were assumed to generate insignificant quantities in landfills. The waste categories included are municipal waste and industrial waste. The GHGs generated from managed disposal sites, unmanaged and uncategorised waste management disposal sites were included. Waste is managed at the landfills through daily compaction and separation into designated cells for different waste types, like general, garden, rubble, and scrap metal (GoB, 2018). However, operations face challenges including leachate management, poor waste segregation at the source, lack of a landfill gas monitoring system, and inadequate maintenance and equipment. Unmanaged waste management disposal sites include dumping sites where there is minimal to no management of waste deposited. Botswana has several dumping sites across the country.

Data on the amount of waste generated is poor and where available, there are inconsistencies and gaps. For municipal waste generation, population data was used instead to estimate emissions, and industrial waste generation, GDP in US$ million was used to estimate industrial waste generation.

From Table 7-7 and Figure 7-4 below, it is evident that unmanaged waste disposal sites generate and emits more GHGs compared to other sub-categories. These are mainly found in rural areas where the majority the population is located.

Table 7-7: Total GHG emissions by subcategory (Gg CO2 eq)

Sub-Category							
4.A - Solid Waste Disposal	**2000**	**2005**	**2010**	**2015**	**2020**	**2021**	**2022**
4.A.1 - Managed Waste Disposal Sites	34.66	39.94	45.38	50.81	56.44	57.53	58.58
4.A.2 - Unmanaged Waste Disposal Sites	47.62	54.87	62.34	69.80	77.53	79.02	80.48
4.A.3 - Uncategorised Waste Disposal Sites	12.61	14.52	16.50	18.48	20.52	20.92	21.30
Total	**94.89**	**109.33**	**124.22**	**139.09**	**154.48**	**157.47**	**160.36**

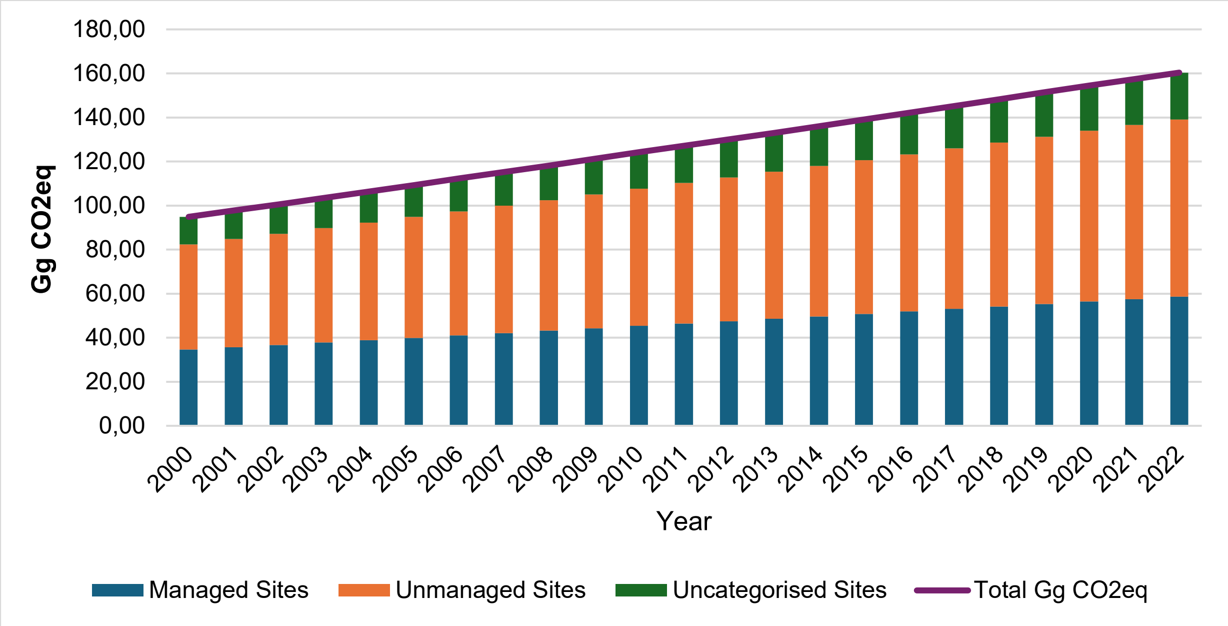

Figure.7-4: Total CH_4 emissions by Waste Disposal Sites (Gg CO2 eq)

Figure 7-5 below demonstrates the distribution of or municipal solid waste pathways. For Africa, the default fraction of municipal solid waste that goes to the landfill is estimated to be 69% (IPCC, 2006). The rest is incinerated, open burned and some recycled (expert judgement).

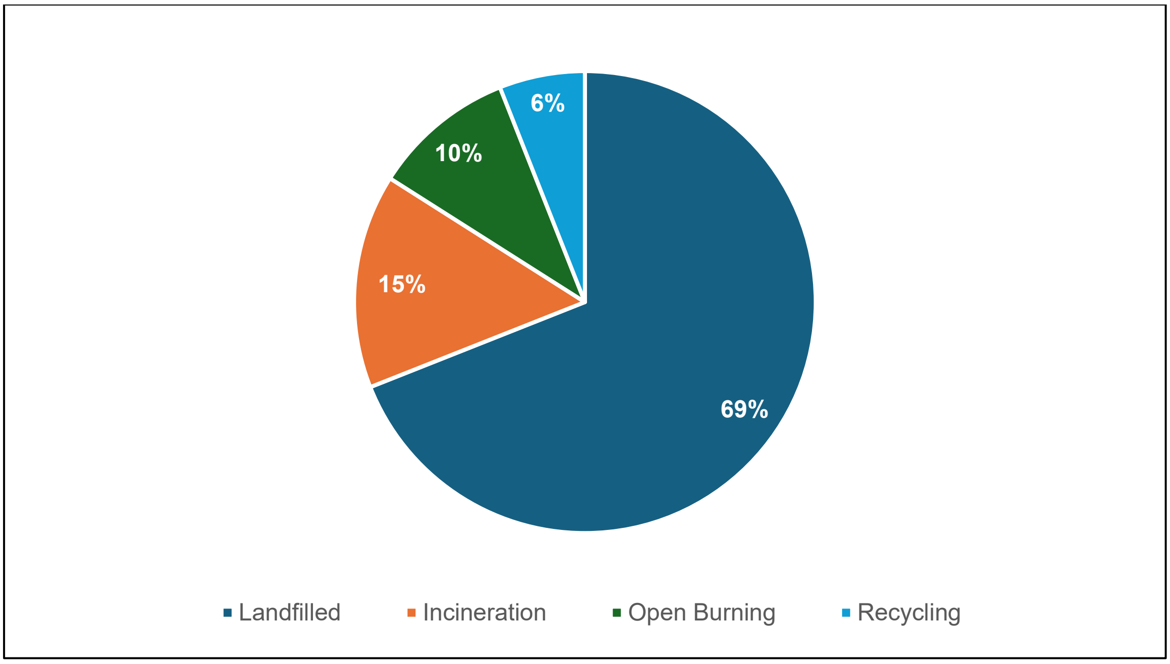

Figure.7-5: Percent distribution of Municipal Solid Waste Pathways.

7.2.1. Methodological issues

Botswana does not have country specific emission factors; therefore, the default emission factors were used instead. The methodology for calculating GHG emissions from *Solid waste* is consistent with the IPCC Tier 1 First Order Decay (FOD) Model (IPCC, 2006). This method uses a dynamic model driven by landfill data (IPCC, 2006). The FOD Model assumes that the degradable organic component (degradable organic carbon, DOC) in waste decays slowly throughout a few decades, during which CH_4 and CO_2 are formed. With constant conditions, the rate of CH_4 production depends solely on the amount of carbon remaining in the waste. As a result, emissions of CH_4 from waste deposited in a disposal site are highest in the first few years after deposition, then gradually decline as the degradable carbon in the waste is consumed by the bacteria responsible for the decay.

To estimate a year's CH_4 emissions from solid waste disposal, Equation 3.1(IPCC, 2006) below was applied. Methane (CH_4) is created when organic waste decomposes without oxygen. The amount actually released is less than the amount generated because some is oxidized in the landfill cover or captured for energy or burning. In this case, there is no methane recovery, therefore the only reduction is due to oxidation.

$$\boldsymbol{CH_4\,Emissions} = \left[\sum_x CH_4\,generated_{x,T} - R_T\right] * (1 - OX_T)$$

Where:

CH_4 Emissions= CH_4 emitted in year T, Gg

T= inventory year

x = waste category or type/material

R_T= recovered CH4 in year T, Gg

OX_T = oxidation factor in year T, (fraction)

7.2.2. Activity data

Activity data includes population data (*World Bank; Statistics Botswana, 2015 & 2024*), waste generation rates, GDP (World Bank), annual waste generation, population growth rates, emission rates, half-lives of bulk waste stream (default value for the half-live is 14 years), rate constants, Methane correction factor (MCF), degradable carbon fraction (DCF), as well as other factors described in the IPPC Guidelines, Volume 5, Chapter (IPPC, 2006). Due to lack of published specific-activity data for many of these parameters in Botswana, the default values suggested in the IPCC Guidelines were applied (Table 7-8).

The FOD method requires data to be collected or estimated for historical disposals of waste over a period of 3 to 5 half-lives in order to achieve an acceptably accurate result (IPCC, 2006). It is therefore good practice to use disposal data for at least 50 years as this time frame provides an acceptably accurate result for most typical disposal practices and conditions. Therefore, the activity data used comprised waste quantities disposed of into managed and unmanaged landfills with uncategorised waste from 1950 to 2022, covering a period of about 75 years (satisfying the condition for a period of five half-lives). Population data for the period 1950 to 1990 was sourced from World Bank. Statistics Botswana population data was used for the period 1991 to 2022 (Statistics Botswana, 2015 & 2024). Waste generation rates for industrial waste were estimated using GDP values sourced from the World Bank for period 2000 to 2022

7.2.3. Emission Factors

The emission factors for the FOD Model are presented in Table 7-8

Table 7-8: IPCC default factors utilized in the FOD Model to estimate emissions from solid waste disposal

Parameter	Sub-category	Value	Unit
DOC (degradable organic carbon)	Bulk MSW	0.18	Weight fraction (wet basis)
	Industrial waste	0.15	
	Sludge waste		
DOC_f (fraction of DOC dissimilated)		0.5	Fraction
Methane generation rate constant	Bulk MSW	0.05	$Year^{-1}$
	Industrial waste		
	Sludge waste		
Methane Correction Factor (MCF)	Unmanaged shallow	0.4	Unitless
	Unmanaged deep	0.8	
	Managed aerobic	1	
	Managed well semi aerobic	0.5	
	Uncategorised	0.6	
Fraction of Methane in generated landfill gas		0.5	Fraction
Oxidation Factor		0.1	Unitless

7.2.4. Uncertainty

A typical uncertainty margin of more than a factor of two was estimated based on the fact that the country has poor quality data (IPPC, 2006). The uncertainty stems from the demographic dynamic factors such as population age composition, household size, urban density and food, which means inaccurate projections of these metrics lead to high uncertainties. Further uncertainty arises because methane production is calculated using bulk waste estimates due to a lack of detailed data on specific waste composition; the country (Botswana) is classified under tropical dry climate zone for these bulk estimates.

Table 7-9: Uncertainties associated with emissions from solid waste

Gas	Activity data and emission factors	Uncertainty	
		%	Source
CH4	Total municipal solid waste	±30	IPCC 2006
	Fraction of MSW sent to SWDS	More than a factor of two	
	Total uncertainty of waste composition	More than a factor of two	
	DOC	±20	
	DOC_f	±20	
	MCF	±10	
	Fraction of CH_4 in generated landfill gas	±5	

7.2.5. Time series consistency

The FOD methodology for calculating methane emissions from solid waste necessitates at least 48 years of historical data, which is unavailable in Botswana. Due to lack of consistent waste disposal statistics and the non-continuous nature of periodic waste baseline studies, population data from sources like the World Bank and Statistics Botswana (2015 & 2024) were used instead to provide a consistent time-series dataset for solid waste disposal activity.

Time series consistency in emissions estimates is maintained by using the same model parameters and datasets for all calculations. If any changes to the datasets or parameters become necessary, the entire time series is fully recalculated to ensure uniformity

7.2.6. Category specific QA/QC and verification

Refer to section 7.1.4 QA/QC process and verification, for category specific QA/QC and verification

7.2.7. Category specific recalculations

In the previous inventory, waste emissions were calculated using a default waste generation rate of 290.0 kg/capita/year (IPCC, 2006), whilst the current inventory used country-specific waste generation rate of 99.519 kg/capita/year which is less than IPCC default. This value was derived from 224,320.91 tonnes of waste generated in Botswana in 2017 (Statistics Botswana, 2020). The 224,320 tonnes of waste generated was converted to 224,320,000 Kg. This annual waste generation was divided by the 2017 population of figure of 2,254 021 to get a per capita waste generation rate of 99.519 kg waste/capita/year rounded to 100 kg/capita/year. Rate was divided by 365 days to get a per day rate = 0.273 kg waste/capita/day.

The recalculations show a change in the trend throughout the time series (Figure 7-6). The previous inventory emissions remain higher after the recalculations compared to the current inventory.

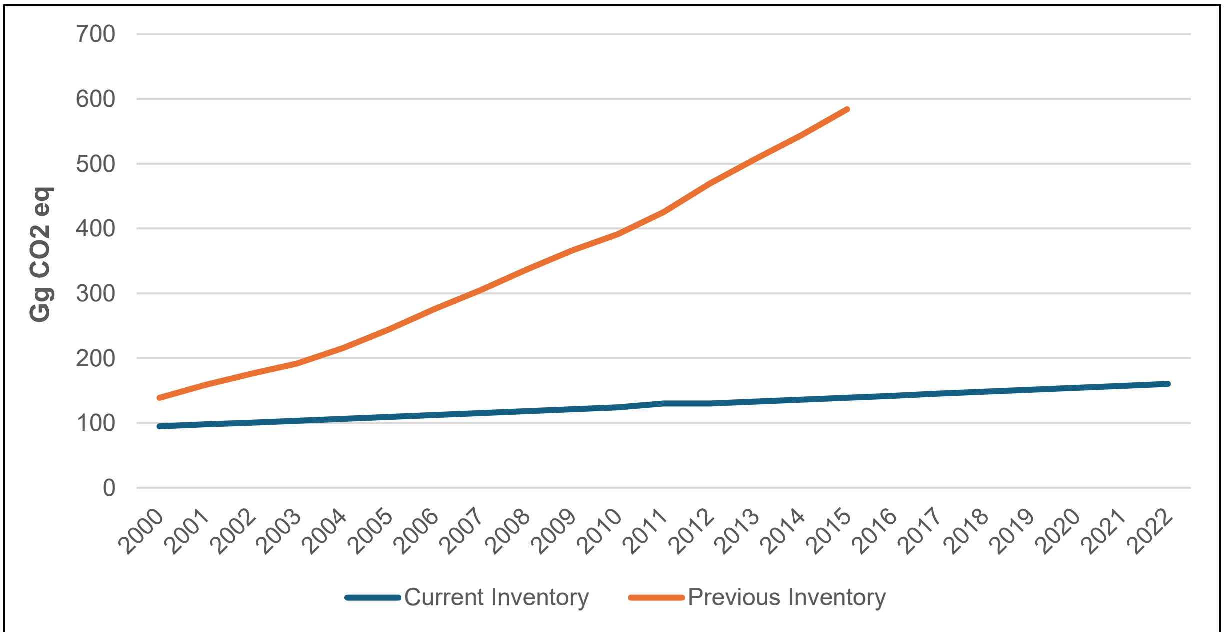

Figure.7-6: Change in MSW emission estimates due to recalculations since 2000 submission.

7.2.8. Category specific planned improvements

No planned improvements for this category

7.3. Biological treatment of solid waste (CRT 5.B)

No emissions are reported under this sector because there is no concrete information on the existence of such treatment facility in Botswana.

7.4. Incineration and open burning of waste (CRT 5.C)

7.4.1. Category description

The 2006 IPCC guidelines define waste incineration as the combustion of solid and liquid waste in controlled incineration facilities (IPCC,2006). Waste incineration in Botswana is performed at some landfills and some privately-owned incinerators. Emissions from incineration however were not estimated as there was no activity data. Waste incineration in Botswana is done without energy recovery. The type of waste incinerated is mainly clinical waste.

On the other hand, open burning of waste according to the 2006 IPCC guidelines is defined as "the combustion of unwanted combustible materials such as paper, wood, plastics, textiles, rubber, waste oils and other debris in nature (open-air) or in open dumps, where smoke and other emissions are released directly into the air without passing through a chimney or stack." This waste management is mainly practiced in rural areas than in urban areas.

Both incineration and open burning of waste produce greenhouse gas emissions and these include CO_2, methane (CH_4) and nitrous oxide (N_2O). In incineration, CO_2 emissions are more significant than CH_4 and N_2O emissions (IPCC, 2006).

Table 7-10 and Figure 7-6 present a trend in the open burning of waste GHG emissions throughout the entire time (2000 to 2022).

Table 7-10: Trend in GHG emissions from Open Burning of Waste by Gas, (Gg CO2 eq)

	2000	2005	2010	2015	2020	2021	2022
CO2	2.11	2.88	3.38	3.72	3.97	4.5	4.71
CH4	33.32	36.89	40.36	43.93	47.06	47.5	47.51
N2O	4.99	5.53	6.06	6.59	7.06	7.13	7.12
Total CO2eq	**40.42**	**45.3**	**49.8**	**54.24**	**58.09**	**59.13**	**59.34**

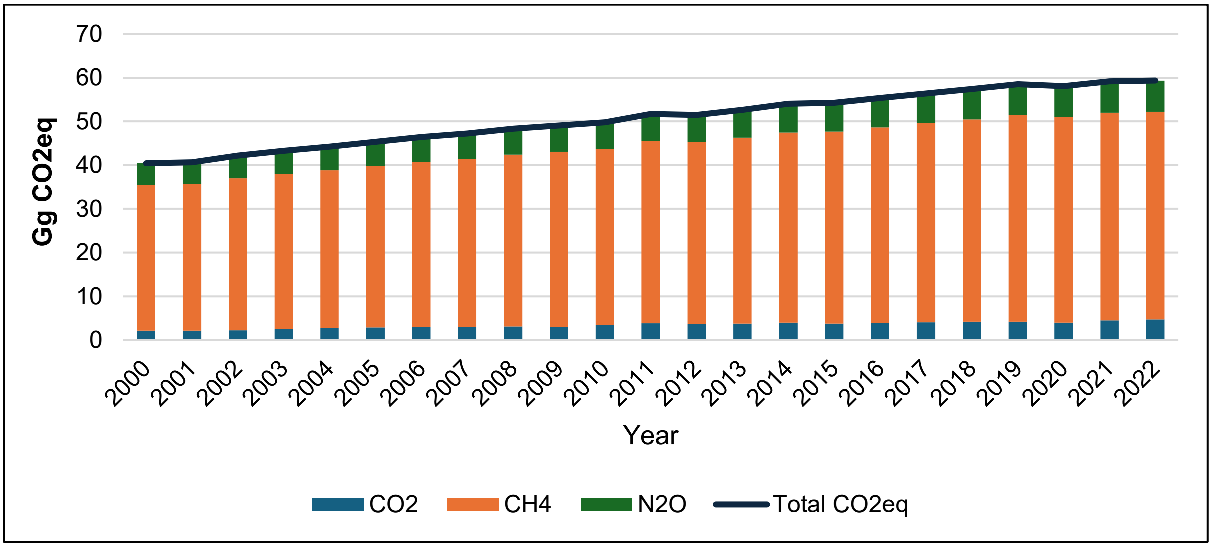

Figure.7-7: Total GHG emissions from Open Burning by Gas, (Gg CO_2 eq)

7.4.2. Methodological issues

As previously mentioned, Botswana has no country specific emission factors, as a result, the default IPCC 2006 emission factors were used. A Tier 1 approach was applied in the calculation of CO_2, CH_4 and N_2O emissions from open burning. The amount of MSW open-burned was determined using Equation 5.7 of the IPCC 2006 Guidelines (IPCC, 2006; vol 5, chapter. 5; pg. 5.16)

$$\boldsymbol{MSW_B} = P \cdot P_{frac} \cdot MSW_P \cdot B_{frac} \cdot 365 \cdot 10^{-6}$$

Where;

MSW_B = Total amount of municipal solid waste open-burned, Gg/yr

P = population (capita)

P_{frac} = fraction of population burning waste, (fraction)

MSW_P = per capita waste generation, kg waste/capita/day

B_{frac} = fraction of the waste amount that is burned relative to the total amount of waste treated,

(fraction)

365 = number of days by year

10^{-6} = conversion factor from kilogram to gigagram

7.4.3. Activity data

Data on the amount of waste open burned is not available, therefore, population data was used to estimate emissions. The fraction of population carrying out open-burning was assumed to be 7.8% (GoB, 2019). IPCC default breakdown were used to calculate CO_2 emissions for the different waste types.

7.4.4. Emission Factors

The default emission factors from the IPCC 2006 Guidelines were used to estimate CO_2 emissions from Open Burning (IPCC, 2006). Refer to Table 7-11 below.

TABLE 7-11: CO_2 default emission factors for incineration and Open Burning of waste

Default Data CO2 Emission Factors for Incineration and Open Burning of Waste						
Parameters	Management Practice	MSW	Industrial Waste (%)	Clinical Waste (%)	Sewage Sludge (%)	Fossil Liquid Waste (%)
Dry matter content in % wet weight	NA	NA	NA	NA	NA	NA
Total carbon content in % of dry weight	NA	NA	50	NE	NE	NE
Fossil carbon fraction in % of total carbon content	Incineration	NE	NE	NE	NE	NE
Oxidation factor in % of carbon input	NA	58%	NO	NO	NO	NO

7.4.5. Uncertainty

7.4.5.1. Activity data uncertainty

A typical uncertainty margin of ±35 was estimated. Uncertainties can be particularly high for the amount of waste generated per capita and the fraction of waste burned (IPPC, 2006).

7.4.5.2. Emission factor uncertainty

Uncertainties associated with CO_2 emission factors for Open burning of waste are dependent on uncertainties related to fraction of dry matter in waste open-burned, fraction of carbon in the dry matter, fraction of fossil carbon in the total carbon, combustion efficiency, and fraction of carbon oxidized and emitted as CO_2 (IPCC,2006). 2006 IPCC guidelines suggest a default value of ±40%, which was used. Uncertainties on default N_2O and CH_4 emission factors have been estimated to be ±100% (IPCC, 2006).

7.4.6. Time series consistency

The time series is consistent as the activity data source is the same throughout the time series. Time series consistency in emissions estimates is maintained by using the same model parameters and datasets for all calculations. If any changes to the datasets or parameters become necessary, the entire time series is fully recalculated to ensure uniformity

7.4.7. Category specific QA/QC and verification

Refer to section 7.1.4 QA/QC process and verification, for category specific QA/QC and verification.

7.4.8. Category specific recalculation

For the current inventory, Open burning of waste was introduced. Activity data includes population data (World Bank; Statistics Botswana, 2015 & 2024), waste generation rates, GDP (World Bank), annual waste generation, population growth rates and emission rates. The IPCC Software equations and default parameters were used to calculate emissions. This contributed to the increase in total waste emissions compared to the previous inventory.

7.4.9. Category specific planned improvements

- Planned improvement for this category are collection of activity data on amounts of waste incinerated and the technologies used in Botswana.
- Development of country specific emission factors.

7.5. Wastewater treatment and discharge (CRT 5.D)

7.5.1. Category description

In Botswana, wastewater mainly comes from domestic and industrial sources, where urban areas generate the largest volumes. Wastewater is managed through treated effluent reuse for irrigation and landscaping, and discharge into rivers and streams. Mining is also another source of wastewater; it generates both industrial wastewater and domestic wastewater from its operations and workers. Minor contribution also is realized from rural areas mainly through the use of pit latrines.

Sources of wastewater in areas where there are wastewater treatment plants, connect to the Water Utilities Corporation (WUC) sewer line which conveys wastewater to the plant. Industrial wastewater is released into domestic sewer systems; therefore, the emissions are included with the domestic wastewater emissions. In some places, waste is collected using bowsers and disposed of at the nearest treatment plant.

The anthropogenic emissions from wastewater treatment are mainly CH_4 and N_2O. The CH_4 generated results from anaerobic degradation of organic matter in wastewater. The biological oxygen demand (BOD) values are used for quantifying organic matter. Organic carbon from wastewater sources produces low CH_4 quantities compared to solid waste. This is because oxygen severely inhibits the anaerobic bacteria responsible for CH_4 generation, even at very low concentrations. Meanwhile, N_2O is generated from the nitrification and denitrification of sewage nitrogen, which is a consequence of human protein consumption and discharge.

Table 7-12 and Figure 7-8 show a trend in GHG emissions from Wastewater Treatment and Discharge. The main gas emitted in the wastewater category is Methane.

Table 7-12: Trend in GHG emissions from Wastewater Treatment and Discharge by Gas, (Gg CO2 eq)

GHG	2000	2005	2010	2015	2020	2021	2022
CH_4	72.8961	80.8746	89.2576	95.2118	100.9419	101.403	102.0343
N_2O	16.9207	17.7072	18.9302	22.1648	22.22	23.497	22.5922
Total CO_2eq	**89.8168**	**98.5818**	**108.1878**	**117.3766**	**123.1619**	**124.9**	**124.6265**

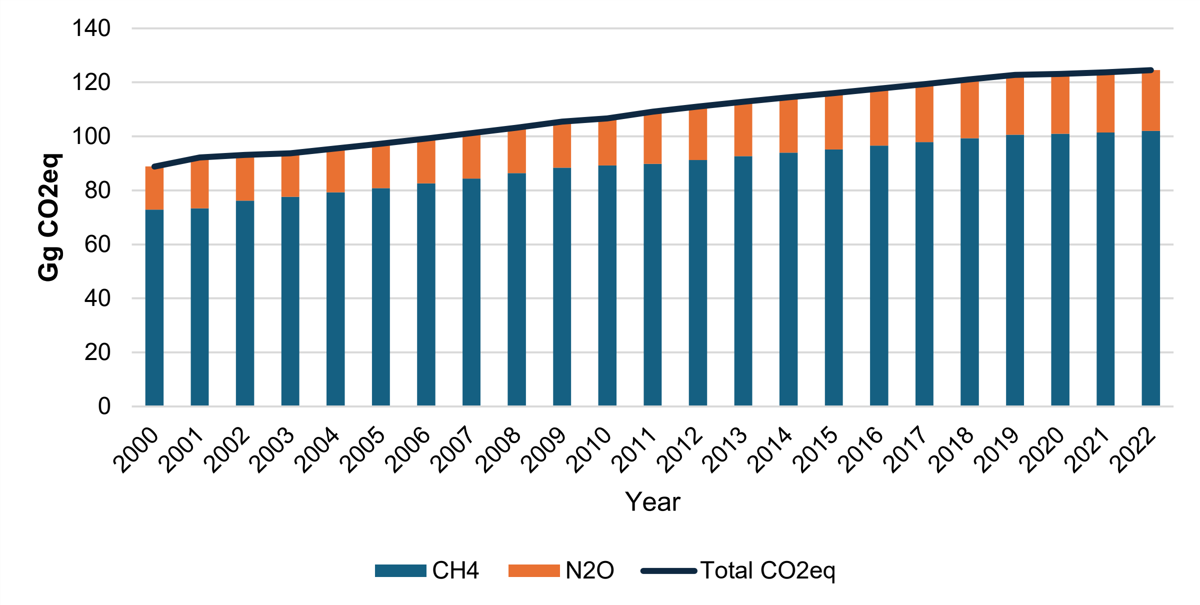

Figure.7-8: Trend in emissions from Wastewater Treatment and Discharge by Gas, (Gg CO2 eq)

7.5.2. Methodological issues

The majority of domestic and industrial wastewater is processed via Water Utilities Corporation (WUC) wastewater treatment plants. Methane (CH_4) emissions from these sources primarily come from septic tank systems and the sewer line. Due to lack of national data regarding the annual quantity of Biological Oxygen Demand (BOD) produced by domestic and industrial sources in Botswana, annual estimates were calculated using the default Tier 1 method outlined in the 2006 Intergovernmental Panel on Climate Change (IPCC) guidelines.

The equation below was used to estimate emissions from domestic wastewater and discharge.

$$CH_4 Emissions = \left[\sum_{i-j} \left(U_i \cdot T_{i-j} \cdot EF_j \right) \right] (TOW - S) - R$$

Where:

CH4 Emissions = CH4 emissions in inventory year, kg CH4/yr

TOW = total organics in wastewater in inventory year, kg BOD/yr

S = organic component removed as sludge in inventory year, kg BOD/yr

Ui = fraction of population in income group *i* in inventory year

Ti,j = degree of utilisation of treatment/discharge pathway or system, *j*, for each income group, fraction *i* in inventory year

i = income group: rural, urban high income and urban low income

j = each treatment/discharge pathway or system

EFj = emission factor, kg CH4 / kg BOD

R = amount of CH4 recovered in inventory year, kg CH4/yr, however in this case there is no methane recovery

Total Organically Degradable Material in Domestic Wastewater

The equation below was used to estimate total organics in wastewater.

$$TOW = P.BOD.0.001.I.365$$

Where:

TOW = total organics in wastewater in inventory year, kg BOD/yr

P = country population in inventory year (person)

BOD = country- specific per capita BOD in inventory, g/person/day

0.01 = conversion from grams BOD to kg BOD

I = correction factor for additional industrial BOD discharged into sewers

BOD was estimated as 37(2006, IPCC)

I was estimated as 1.25 (2006, IPCC), default value for collected

The factor I values in the above equation in the 2006 IPCC guidelines are based on expert judgment by the authors. It is said to expresses the BOD from industries and establishments (e.g., restaurants, butchers or grocery stores) that is co-discharged with domestic wastewater (2006, IPCC).

7.5.3. Activity data

To determine the total amount of organically degradable material in the wastewater, activity data was gathered using population statistics provided by Statistics Botswana and standard values for Biochemical Oxygen Demand (BOD) outlined in the 2006 IPCC guidelines. A default IPCC correction factor of 1 was used.

7.5.4. Emission Factors

The emissions factors required for various wastewater treatment and discharge systems were sourced from of the 2006 IPCC Guidelines.

Since Botswana lacked specific data on N_2O emissions from wastewater treatment, estimations were made using the default values established by the IPCC Guidelines. Additionally, a consistent value of 20.805 kg/person/yr. was used for per capita protein consumption across the entire time series, based on 2022 data from the FAO (Food and Agriculture Organization of the United Nations).

7.5.5. Activity Data Uncertainty

A typical uncertainty margin of ±5 was estimated using human population uncertainty which is expert judgement (IPPC, 2006).

7.5.5.1. Emission factor uncertainty

Uncertainties on default CH_4 emission factors have been estimated to be ±30% (IPCC, 2006). The uncertainty range is also technology dependent. The uncertainty range is determined by expert judgement.

7.5.5.2. Time series consistency

The time series is consistent as the activity data source is the same throughout the time series. Time series consistency in emissions estimates is maintained by using the same model parameters and datasets for all calculations. If any changes to the datasets or parameters become necessary, the entire time series is fully recalculated to ensure uniformity

7.5.5.3. Category specific QA/QC and verification

Refer to section 7.1.4 QA/QC process and verification, for category specific QA/QC and verification.

7.5.5.4. Category specific recalculations

There is no comparative data from the previous inventory because emissions from Wastewater and Discharge were not recalculated. The emissions for the current inventory are for the period 2000-2022.

7.5.5.5. Planned improvements

- Botswana plans to report wastewater treatment systems and discharge pathways by fraction of population income group, or the degree of utilization of treatment/discharge pathway or system for each income group.

7.5.6. Industrial wastewater treatment and discharge (CRT 5.D.2)

7.5.6.1. Category description

Botswana is not highly industrialized; some existing industries have on-site wastewater treatment systems for purposes of compliance with regulatory standards for wastewater treatment and discharge. Industrial and commercial wastewater treated on-site is later discharged to a centralized treatment plant together with domestic wastewater.

The current inventory's industrial wastewater treatment and discharge is mainly driven by meat and poultry industry, dominated by beef, which is a key export and the largest source of agricultural income. Poultry industry faces challenges of high production costs. There is a slight growth in production. The proxy indicator is the production of meat in tonnes from FAO. The composition of meat is as follows: meat/chicken; meat/pig; meat/cattle, & Other. (https://openknowledge.fao.org/server/api/core/bitstreams/8dde9b01-6771-45bc-ad39-cf194b616f9f/content)

Table 7-13 and Figure 7-9 below show a trend in GHG emissions from Industrial Wastewater Treatment and Discharge throughout the entire time series (2000 to 2022). The main gas emitted in the wastewater category is Methane. A decline in the trend is observed from the year 2011. This change could have resulted from a reduction in animal slaughter due to a Foot and Mouth Disease outbreak that occurred in 2011 resulting in cattle slaughter (Kabelo et. al 2023).

Table 7-13: Trend in GHG emissions from Industrial Wastewater Treatment and Discharge by Gas, (Gg CO_2 eq)

GHG	2000	2005	2010	2015	2020	2021	2022
CH_4	5.9323	7.4238	9.2902	7.947	7.8669	7.851	7.8351
N_2O	0.9949	1.245	1.558	1.3328	1.322	1.3167	1.314
Total CO_2eq	6.9272	8.6688	10.8482	9.2798	9.1889	9.1677	9.1491

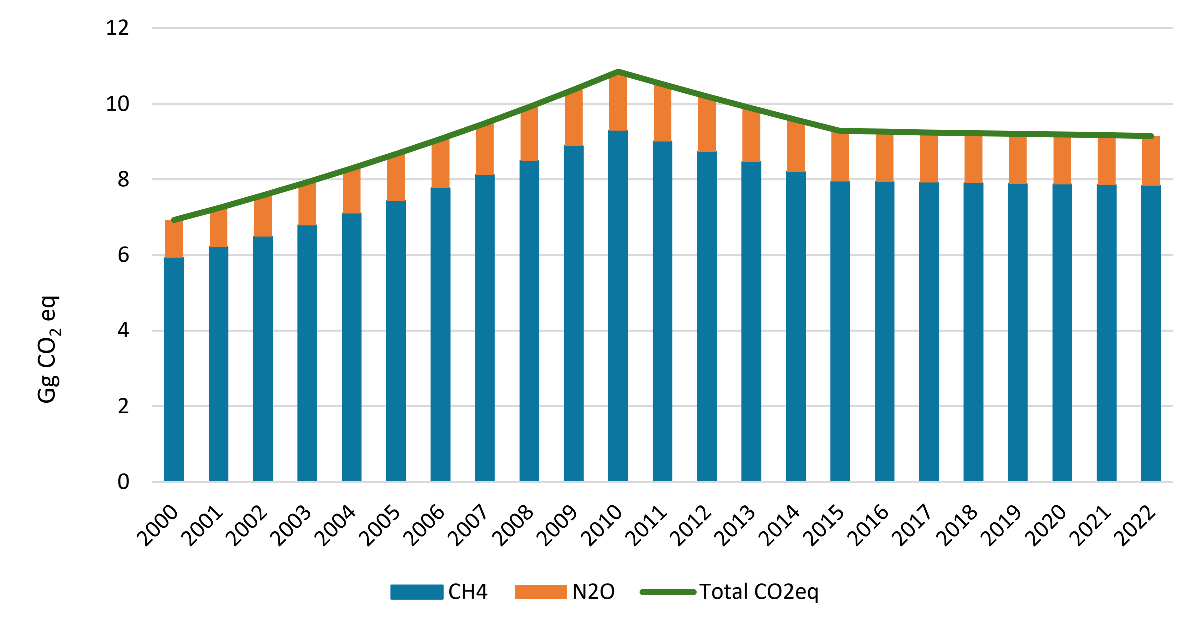

Figure.7-9: Trend in emissions from Industrial Wastewater Treatment and Discharge by Gas, (Gg CO2 eq), 2000-2022

7.5.6.2. Methodological issues

The tier 1 default IPCC methodology was used to estimate CH_4 and N_2O emissions from industrial wastewater treatment. Data were only available for the years 2000, 2010, 2015, & 2022. Compound annual growth rate was used to fill the data gaps.

7.5.6.3. Activity data

To determine the total amount of organically degradable material in the industrial wastewater, activity data was gathered from Meat & poultry industry (the only industry with available activity data). The 2006 IPCC default values of waste generation W (m^3/t) = 13 and COD (kg/m^3) = 4.1 were used.

7.5.6.4. Emission Factors

Methane emissions from Domestic Wastewater Treatment

The emissions factors (EF) required for various wastewater treatment and discharge systems were sourced from of the 2006 IPCC Guidelines. The value of EF was calculated from equation: Bo× MCF_j, the calculation used the default B0 value of 0.25 g CH_4 / g COD (IPCC, 2006). MCF_j of 0.3 was used since the treatment and discharge system in Botswana is mainly aerobic and the treatment plants are not well managed / overloaded (IPCC, 2006; https://dumas.ccsd.cnrs.fr/dumas-01668380/file/MARTIN_Natacha_rapport.pdf)

Nitrous oxide emissions from Wastewater Treatment Plants

Since Botswana lacked specific data on N_2O emissions from wastewater treatment, estimations were made using the default values established by the IPCC Guidelines. Additionally, a consistent value of 20.805 kg/person/yr. was used for per capita protein consumption across the entire time series, based on 2022 data from the FAO (Food and Agriculture Organization of the United Nations).

7.5.6.5. Uncertainty

A typical uncertainty margin of ±1.25 was estimated to allow for co-discharge of industrial nitrogen into sewers. It is based on expert judgement (IPPC, 2006).

7.5.6.6. Emission factor uncertainty

Uncertainties on default CH_4 emission factors have been estimated to be ±30% whilst for N_2O is ±3.2% (IPCC,2006). The uncertainty range is also technology dependent. The uncertainty range is determined by expert judgement.

7.5.6.7. Time series consistency

The time series is consistent as the activity data source is the same throughout the time series. Time series consistency in emissions estimates is maintained by using the same model parameters and datasets for all calculations. If any changes to the datasets or parameters become necessary, the entire time series is fully recalculated to ensure uniformity

7.5.6.8. Category specific QA/QC and verification

Refer to section 7.1.4 QA/QC process and verification, for category specific QA/QC and verification.

7.5.6.9. Category specific recalculations

There is no comparative data from the previous inventory because emissions from Wastewater and Discharge were not recalculated. The emissions for the current inventory are for the period 2000-2022.

7.5.6.10. Planned improvements

No improvements planned for this category

7.6. Other (specify) (CRT 5.E)

No emission data have been documented for this specific IPCC category.

8. OTHER (CRT 6)

This sector is Not Applicable.

ANNEXES TO THE NATIONAL INVENTORY DOCUMENT

Annex I: Key categories

This is covered and discussed under Chapter 1, Section 1.4

Annex II: Uncertainty assessment

The uncertainty of activity data and emission factors for this inventory were largely drawn from the IPCC default values available for various categories and sub-categories. The sectors with quantitative uncertainty estimates are Energy, IPPU, Agriculture and Waste. Effort is on-going on how to determine reliable methods of estimating uncertainties in the LULUCF sector by consulting other documentation/literature, such as Petrescu et. al, 2020, McGlynn et. al, 2022 etc.

The uncertainties for each estimated sub-category category are listed below in Table A-1. Combined uncertainty of emissions from each sub-category is a simple error propagation of a product of activity data uncertainty and emission factor uncertainty.

If emissions (EMS) are a product of activity data (AD) and emission factors (EF), then the following equation suffices:

$$EMS = AD \times EF.$$

The uncertainty of AD and EF are ΔAD and ΔEF respectively, the simple error propagation for the emission is given by:

$$\Delta EMS = \sqrt{\Delta \mathrm{AD}^2 + \Delta \mathrm{EF}^2}$$

This uses approach 1 following, equation 3.1 in Volume 1, Chapter 3 of the 2006 IPCC guidelines.

This method yields a total inventory uncertainty of 15.36%, excluding LULUCF. Quantitative uncertainties in the LULUCF sector are complicated by the highly uncertain land conversions. It is planned to include the quantitative assessment of the uncertainties in the LULUCF sector in the next National Inventory Report (NIR).

Table A-1: Uncertainty Estimates, Activity Data and Emission Factors summary -2022

CRT Categories	Gas	Activity Data Uncertainty (%)	Emission Factor Uncertainty (%)	Combined Uncertainty (%)
1.A - Fuel Combustion Activities				
1.A.1.a.i - Electricity Generation - Solid Fuels	CO2	5	5	7,07
1.A.1.a.i - Electricity Generation - Solid Fuels	CH4	5	5	7,07
1.A.1.a.i - Electricity Generation - Solid Fuels	N2O	5	5	7,07
1.A.4.a - Commercial/Institutional - Liquid Fuels	CO2	5	5	7,07
1.A.4.a - Commercial/Institutional - Liquid Fuels	CH4	5	5	7,07
1.A.4.a - Commercial/Institutional - Liquid Fuels	N2O	5	5	7,07
1.A.4.a - Commercial/Institutional - Solid Fuels	CO2	5	5	7,07
1.A.4.a - Commercial/Institutional - Solid Fuels	CH4	5	5	7,07
1.A.4.a - Commercial/Institutional - Solid Fuels	N2O	5	5	7,07

CRT Categories	Gas	Activity Data Uncertainty (%)	Emission Factor Uncertainty (%)	Combined Uncertainty (%)
1.A.4.b - Residential - Liquid Fuels	CO2	5	5	7,07
1.A.4.b - Residential - Liquid Fuels	CH4	5	5	7,07
1.A.4.b - Residential - Liquid Fuels	N2O	5	5	7,07
1.A.4.b - Residential - Biomass - solid	CH4	5	5	7,07
1.A.4.b - Residential - Biomass - solid	N2O	5	5	7,07
1.A.4.c.i - Stationary - Liquid Fuels	CO2	5	5	7,07
1.A.4.c.i - Stationary - Liquid Fuels	CH4	5	5	7,07
1.A.4.c.i - Stationary - Liquid Fuels	N2O	5	5	7,07
1.A.4.c.i - Stationary - Solid Fuels	CO2	5	5	7,07
1.A.4.c.i - Stationary - Solid Fuels	CH4	5	5	7,07
1.A.4.c.i - Stationary - Solid Fuels	N2O	5	5	7,07
1.A.3.a.i - International Aviation (International Bunkers) - Liquid Fuels	CO2	5	15	15,81
1.A.3.a.i - International Aviation (International Bunkers) - Liquid Fuels	CH4	5	50	50,25
1.A.3.a.i - International Aviation (International Bunkers) - Liquid Fuels	N2O	5	75	75,17
1.A.3.a.ii - Domestic Aviation - Liquid Fuels	CO2	5	15	15,81
1.A.3.a.ii - Domestic Aviation - Liquid Fuels	CH4	5	50	50,25
1.A.3.a.ii - Domestic Aviation - Liquid Fuels	N2O	5	75	75,17
1.A.3.b.i - Cars - Liquid Fuels	CO2	5	15	15,81
1.A.3.b.i - Cars - Liquid Fuels	CH4	5	50	50,25
1.A.3.b.i - Cars - Liquid Fuels	N2O	5	75	75,17
1.A.3.c - Railways - Liquid Fuels	CO2	5	15	15,81
1.A.3.c - Railways - Liquid Fuels	CH4	5	50	50,25
1.A.3.c - Railways - Liquid Fuels	N2O	5	75	75,17
1.B.1 - Fugitive Emissions from Fuels - Solid Fuels				
1.B.1.a.i.1 - Mining	CO2	5	100	100,12
1.B.1.a.i.1 - Mining	CH4	5	100	100,12
1.B.1.a.i.2 - Post-mining seam gas emissions	CH4	5	200	200,06
2.B - Chemical Industry				
2.B.7 - Soda Ash Production	CO2	0,5	10	10,01
2.D - Non-Energy Products from Fuels and Solvent Use				
2.D.1 - Lubricant Use	CO2	15	50	52,20
2.D.2 - Paraffin Wax Use	CO2	15	50	52,20
2.F - Product Uses as Substitutes for Ozone Depleting Substances				
2.F.1.a - Refrigeration and Stationary Air Conditioning	CHF3	10	5	11,18
2.F.1.a - Refrigeration and Stationary Air Conditioning	CH2F2	10	5	11,18
2.F.1.a - Refrigeration and Stationary Air Conditioning	CH2FCF3	10	5	11,18
2.F.1.a - Refrigeration and Stationary Air Conditioning	CH3CHF2	10	5	11,18
3.A - Livestock				
3.A.1.a.i - Dairy Cows	CH4	5	30	30,41
3.A.1.a.ii - Other Cattle	CH4	10	30	31,62

CRT Categories	Gas	Activity Data Uncertainty (%)	Emission Factor Uncertainty (%)	Combined Uncertainty (%)
3.A.1.c - Sheep	CH4	10	30	31,62
3.A.1.d - Goats	CH4	10	30	31,62
3.A.1.f - Horses	CH4	10	30	31,62
3.A.1.g - Mules and Asses	CH4	10	30	31,62
3.A.1.h - Swine	CH4	10	30	31,62
3.A.2.a.i - Dairy cows	N2O	10	50	50,99
3.A.2.a.ii - Other cattle	N2O	10	50	50,99
3.A.2.c - Sheep	N2O	10	50	50,99
3.A.2.d - Goats	CH4	10	30	31,62
3.A.2.d - Goats	N2O	10	50	50,99
3.A.2.f - Horses	CH4	10	30	31,62
3.A.2.f - Horses	N2O	10	50	50,99
3.A.2.g - Mules and Asses	CH4	10	30	31,62
3.A.2.g - Mules and Asses	N2O	10	50	50,99
3.A.2.h - Swine	CH4	10	30	31,62
3.A.2.h - Swine	N2O	10	50	50,99
3.A.2.i - Poultry	CH4	10	30	31,62
3.A.2.i - Poultry	N2O	10	50	50,99
3.C - Aggregate sources and non-CO2 emissions sources on land				
3.C.2 - Liming	CO2	0,8	5	5,06
3.C.3 - Urea application	CO2	0,5	8	8,02
3.C.4 - Direct N2O Emissions from managed soils	N2O	50	3	50,09
3.C.5 - Indirect N2O Emissions from managed soils	N2O	0,4	2	2,04
3.C.6 - Indirect N2O Emissions from manure management	N2O	50	80	94,34
5.A - Solid Waste Disposal				
5.A.1 - Managed Waste Disposal Sites	CH4	35	30	46,10
5.A.2 - Unmanaged Waste Disposal Sites	CH4	35	30	46,10
5.A.3 - Uncategorised Waste Disposal Sites	CH4	35	30	46,10
5.C - Incineration and Open Burning of Waste				
5.C.2 - Open Burning of Waste	CO2	35	40	53,15
5.C.2 - Open Burning of Waste	CH4	35	100	105,95
5.C.2 - Open Burning of Waste	N2O	35	100	105,95
5.D - Wastewater Treatment and Discharge				
5.D.1 - Domestic Wastewater Treatment and Discharge	CH4	5	30	30,41
5.D.2 - Industrial Wastewater Treatment and Discharge	CH4	5	30	30,41
Total - Uncertainty in total inventory (excluding LULUCF): 15,357%				

LULUCF Uncertainty Analysis (Qualitative)

Based on IPCC Good Practice Guidance for Land Use, Land-Use Change and Forestry (GPG-LULUCF), using qualitative uncertainty analysis is essential because the sector often relies on default parameters, complex models, and diverse land-use data that cannot be always be fully quantified with simple statistical models. For Botswana's National Inventory Document (NID), the LULUCF qualitative uncertainty analysis highlights a high reliance on expert judgment and international datasets to bridge significant local data gaps. To describe the quality of data consistently, the following scale was applied to both Activity Data (AD) and Emission Factors (EF):

Table A-2: Standardized Reliability Scale for AD and EF

Reliability Level	Description
High (1)	Nationally validated, recent, and consistent data (e.g., continuous Forest Inventory).
Medium (2)	Direct data with some gaps, or proxy data from reliable international sources (e.g., FAO).
Low (3)	Data based on heavy assumptions, old statistics, or Tier 1 default values.
Very Low (4)	Expert judgment with no empirical backing or significant omitted pools (e.g., SOC/DOM).

Uncertainty for data sources and emission factors

The analysis of uncertainty for data sources and emission factors is provided below. The reliability scale presented in Table A-2 above is applied here.

- **Activity Data (AD)**:
  - _Burnt Area_: Sourced from DFRR using MODIS. Reliability is Medium; while local, satellite-derived burnt area data often struggles with small-scale fires and cloud cover.
  - _Land Use Change_: Based on PRAIS4 with linear interpolation/extrapolation (2002–2022). Reliability is Low; linear trends do not capture abrupt annual changes (e.g., sudden clearing or drought impacts).
  - _Harvested Wood Products & Fuel wood consumption_: Sourced from FAO. Reliability is Medium; these are estimates based on national submissions but may not capture informal/unregulated harvesting.
- **Emission Factors (EF)**:
  - _Tier 1 Method_: Uses IPCC default values. Reliability is Low; default values are global/regional averages and do not reflect Botswana's specific semi-arid ecosystems or vegetation density.
  - _Missing Pools_: DOM, SOC, Deadwood, Litter, and Below-ground Carbon are omitted. This creates a systematic Underestimation/Completeness Error.

Presented in Table A-3 is the qualitative uncertainty matrix for LULUCF sector for Botswana's 2022 GHG inventory focusing on category, gas, uncertainty level, and key drivers of uncertainty.

Table A-3: Qualitative Uncertainty Matrix for LULUCF sector for Botswana's 2022 GHG inventory

Category	Gas	Uncertainty	Key Drivers of Uncertainty
Forest Land	CO_2	High	Reliance on FAO for fuel wood; Tier 1 defaults; missing DOM/SOC.
Cropland	CO_2	High	Linear interpolation of land area; lack of soil carbon data.
Grassland	CO_2, CH_4, N_2O	Medium-High	DFRR (MODIS) burnt area accuracy; lack of country-specific biomass density.
HWP	CO_2	High	Uncertainty in FAO trade data versus actual domestic consumption.

The *expert judgement synthesis* concludes that the 2002–2022 LULUCF inventory for Botswana is characterized by High Uncertainty. While the involvement of experts from DFRR, Ministry of Land and Agriculture, University of Botswana, NARDI, and Statistics Botswana ensures that the best available national knowledge was utilized to refine activity data, the methodological foundation remains at Tier 1. The absence of five major carbon pools (SOC, DOM, etc.) and the use of linear extrapolation for land-use transitions likely result in an inventory that captures general trends but lacks the precision needed for year-on-year mitigation tracking. The current estimates should be viewed as a conservative baseline.

Annex III: Detailed description of the reference approach

Botswana utilizes the Tier 1 Reference Approach as a top-down verification tool to cross-check sectoral fuel combustion estimates. The process involves aggregating national energy supply data, accounting for production, imports, and exports to determine the Apparent Consumption for each fuel type. These mass or volume balances are converted to energy units using IPCC default Net Calorific Values (NCVs) and then multiplied by default Carbon Emission Factors. To ensure accuracy, the carbon stored in non-energy products (such as bitumen in roads, lubricants in engines, or plastic feedstocks) is subtracted before the final conversion to CO_2 equivalents. In this current inventory there was no data on carbon stored, and this is common in many Non Annex I parties where detailed data on the specific end-use of imported lubricants or bitumen is not yet captured in national energy balances. Because this carbon was not 'excluded,' the CO_2 emissions calculated via the Reference Approach will likely be slightly higher than they actually are. In the current inventory, this contributes to the statistical difference when comparing the Reference Approach to the Sectoral Approach.

This standardized approach (Reference approach) provides a transparent baseline to identify potential gaps or statistical differences within the national energy balance. Provided in the table below is the IPCC Tier 1 Default Factors table for Botswana's Reference Approach. It incorporates fuel types as identified in the IEA/AFREC energy balances for Botswana.

Table A-4: IPCC Tier 1 Default Factors for Botswana's Reference Approach

Sector / Sub-category	Fuel Type	NCV (TJ/Gg)	Carbon EF (t C/TJ)	CO_2 EF (kg CO_2/TJ)
Electricity Generation	Other Bituminous Coal	25.8	25.8	94,600
	Gas/Diesel Oil	43.0	20.2	74,100
Domestic Aviation	Jet Kerosene	44.1	19.5	71,500
	Aviation Gasoline	44.3	19.1	70,000
	Other Kerosene	43.8	19.6	71,900
	Residual Fuel Oil	40.4	21.1	77,400
Road Transport	Motor Gasoline (Petrol)	44.3	18.9	69,300
	Gas/Diesel Oil	43.0	20.2	74,100
Commercial / Stationary	LPG	47.3	17.2	63,100
	Other Bituminous Coal	25.8	25.8	94,600
Residential	Wood / Wood Waste*	15.6	30.5	112,000
	Other Kerosene	43.8	19.6	71,900

***Note**: Under IPCC guidelines, CO_2 from biomass (Wood/Wood Waste) is reported as a memo item and is not included in national totals to avoid double-counting with the LULUCF sector.

Table A-5: CO_2 Emissions by Reference and Sectoral Approaches 2000-2022

Approach	2000	2001	2002	2003	2004	2005	2006	2007
Reference	4,015.20	4,084.67	4,237.99	4,028.23	4,146.49	4,438.35	4,539.56	4,308.31
Sectoral	3,717.66	4,916.78	5,076.57	4,577.11	4,527.83	5,022.04	5,182.35	5,164.95

Table A-5: CO_2 Emissions by Reference and Sectoral Approaches 2000-2022 cont'd…

Approach	2008	2009	2010	2011	2012	2013	2014	2015
Reference	4,491.90	4,219.44	4,975.54	4,588.96	6,270.62	6,429.89	7,070.15	7,951.99
Sectoral	5,511.14	4,853.62	5,100.18	4,726.00	6,517.38	6,614.80	7,307.99	8,260.81

Table A-5: CO_2 Emissions by Reference and Sectoral Approaches 2000-2022 cont'd…

Approach	2016	2017	2018	2019	2020	2021	2022
Reference	5,072.27	6,198.38	4,830.36	5,505.05	5,549.37	5,887.81	5,613.83
Sectoral	7,969.85	8,866.39	7,255.16	7,102.55	6,319.80	8,170.68	7,222.80

Annex IV: Quality Assurance and Quality Control Plan

This is covered and discussed under Chapter 1, Section 1.5

Annex V: Inventory Planned Improvements

Table A-6: List of planned inventory improvements.

Sector	Improvement	Challenges	Timeline
Energy	Collection and verification of fuel consumption data from Botswana Railways.	Availability of the activity data.	Next submission – BTR2
IPPU	Include emissions from Clay-Bricks production	The manufactures don't seem to be aware of the carbonate composition of their clay.	Next submission – BTR2
IPPU	Include emissions from steel production	The methodological issue of the Electric Induction Furnace (EIF).	Next submission – BTR2
IPPU	Include emissions of SF6 from electrical equipment.	The availability of activity data from the utility company.	Next submission – BTR2
IPPU	Include emissions of N2O from medical applications.	Access to activity data from the government medical procurement entity.	Next submission – BTR2
IPPU	Include emission from alcoholic beverages industry.	There are legal requirements to access the company data.	Next submission – BTR2
Agriculture	Collect data for Tier 2 approach on enteric fermentation. The intention is to start with dairy cattle and other cattle.	Development and approval of country specific factors and parameters.	Submission of BTR3
Agriculture	Improve collection of data dealing with manure management systems.	Limited resources for data collection	Next submission – BTR2
Agriculture	Engage Ministry of Lands and Agriculture and Statistics Botswana to resuscitate annual agricultural surveys.	It is highly dependent on the priorities of the Ministry and organizations concerned.	Cannot be established.
Agriculture	Collect data for Tier 2 approach on cattle manure management category and develop country-specific emission factors. The intention is to start with dairy cattle and other cattle.	Limited resources for data collection and development of CS factors.	Submission of BTR3
Waste	Collection of activity data on amounts of waste incinerated and the incineration technologies used in Botswana	Availability of the activity data and resources for data collection.	Next submission – BTR2

Sector	Improvement	Challenges	Timeline
Waste	Development of country specific emission factors in the waste sector.	Lack of capacity and resources to develop the CS factors and parameters.	Long term (Beyond BTR3)
Waste	Botswana plans to report wastewater treatment systems and discharge pathways by fraction of population income group, or the degree of utilization of treatment/discharge pathway or system for each income group.	Availability of the disaggregated waste-water treatment pathways.	Submission of BTR2/3
LULUCF	Include quantitative uncertainty estimates.	Uncertain land conversions (activity data)	Next submission – BTR2
LULUCF	Compile information on non-fire disturbances affecting Forest Land	Data collection resources availability	Next submission – BTR2
LULUCF	Implement estimation of DOM stock changes	Capacity challenges	Next submission – BTR2
LULUCF	Develop country-specific statistics for wood-product production, imports and exports	Capacity and resources for data collection.	BTR3 submission
LULUCF	Develop national datasets for dead wood and litter carbon stocks	Resources and capacity	Next submission – BTR2

Annex VI: Economic Drivers

Table A-7: Botswana's economic drivers of GHG emissions, 2000-2022

Year	Population	GDP in Million BWP
2000	1,677,382	31,438.20
2001	1,680,863	35,479.10
2002	1,744,763	39,271.80
2003	1,775,736	43,456.30
2004	1,807,146	47,883.60
2005	1,839,877	56,128.50
2006	1,874,516	63,894.20
2007	1,911,201	73,767.10
2008	1,949,970	89,756.20
2009	1,990,673	90,833.00
2010	2,003,111	102,640.40
2011	2,024,904	120,496.00
2012	2,068,529	131,061.20
2013	2,110,050	119,867.00
2014	2,149,255	138,860.80
2015	2,185,903	137,052.80

Year	Population	GDP in Million BWP
2016	2,219,732	164,418.20
2017	2,254,021	166,646.80
2018	2,288,651	173,725.40
2019	2,323,493	179,901.60
2020	2,331,445	171,388.30
2021	2,343,396	207,888.10
2022	2,359,609	251,348.40

Source: Statistics Botswana

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