REPUBLIC OF KENYA

MINISTRY OF ENVIRONMENT,
CLIMATE CHANGE AND FORESTRY

KENYA'S THIRD NATIONAL GREENHOUSE GAS INVENTORY DOCUMENT

1990-2022

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Acronyms

AD	Activity Data
AFOLU	Agriculture, Forestry, and Other Land Uses
AFREC	African Energy Commission
BUR	Biennial Update Report
BTR	Biennial Transparency Report
CBIT-GSP	Capacity-building Initiative for Transparency - Global Support Programme
CCD	Climate Change Directorate
CH_4	Methane
CKD	Completely Knocked Down
CMA	Conference of the Parties serving as the Meeting of the Parties to the Paris Agreement
CO_2	Carbon dioxide
DRSRS	Directorate of Resource Surveys and Remote Sensing
EOPS	Early Oil Pilot Scheme
EF	Emission Factors
EFDB	Emission Factor Database
ETF	Enhanced Transparency Framework
GDP	Gross Domestic Product
GEF	Global Environment Facility
GHG	Greenhouse Gas
GWP	Global Warming Potential
HFC	Hydrofluorocarbon
ICAO	International Civil Aviation Organization
ICD	Inland Container Depot
IPCC	Intergovernmental Panel on Climate Change
IPPU	Industrial Processes and Product Use
JICA	Japan International Cooperation Agency
KAM	Kenya Association of Manufacturers
KNBS	Kenya National Bureau of Statistics
KPRL	Kenya Petroleum Refineries Ltd.
KPC	Kenya Pipeline Company
LPG	Liquified Petroleum Gas
LULUCF	Land Use, Land-use Change, and Forestry
MoECCF	Ministry of Environment, Climate Change and Forestry
MPGs	Modalities, Procedures and Guidelines
MSD	Medium Speed Diesel
$N_2 0$	Nitrous Oxide
NCV	Net Calorific Values
NDC	Nationally Determined Contribution
NID	National Inventory Document
NIR	National Inventory Report
NMVOC	Non-Methane Volatile Organic Compounds
NTSA	National Transport and Safety Authority
PFCs	Perfluorocarbons
PMU	Project Management Unit
QA/QC	Quality Assurance / Quality Control
SAGAs	Semi-Autonomous Government Agencies
SNC	Second National Communication
SF6	Sulphur Hexafluoride
SO_2	Sulfur Dioxide
SWD	Solid Waste Disposal
TFI	Task Force on National Greenhouse Gas Inventories
TNC	Third National Communication
UN	United Nations
UNFCCC	United Nations Framework Convention on Climate Change
UNEP	United Nations Environment Programme

Chapter 01:

National Circumstances, Institutional Arrangements and Cross-cutting Information

This is Kenya's National Inventory Document (NID) covering the period 1990 to 2022. The inventory estimates emissions of the three mandatory gases (CO2, CH4 and N2O) have been reported, with the country applying the relevant flexibility provisions not to report on the other gases. Mechanisms will be put in place to facilitate data collection and reporting of the rest of the gases to facilitate the estimation of a complete inventory.

Kenya has previously reported two national communications; in 2000 and 2015 but is yet to communicate a Biennial Update Report (BUR). Legal and institutional arrangements are being set up, anchored on the Climate Change Act, to ensure consistent reporting.

1.1. Background information on GHG inventories and climate change

1.1.1. Climate Change

Climate change is one of Kenya's main concerns. Adverse impacts of climate change have led to significant losses in the country's Gross Domestic Product (GDP). Droughts and floods, the main disasters attributed to the adverse impacts of climate change, have become more frequent and intense resulting in significant loss of lives and livelihoods, including damage of infrastructure. The livestock data, for example, demonstrates the impact on livestock populations due to significant losses in livestock in 2021 when Kenya had one of the most severe droughts in the recent past, leading to significant loss of livestock.

1.1.2. GHG Inventory

Kenya has an elaborate policy, legal and institutional framework that provides for the monitoring, reporting and verification of both adaptation and mitigation actions. The inventory is an important piece of the framework since the updated Kenya Nationally Determined Contribution communicated in 2020 has GHG emissions as the main indicator of progress. It is, therefore, imperative for the country to establish an elaborate MRV framework for the inventory to facilitate tracking of the progress of its NDC, the main policy instrument guiding climate change response in the country. Kenya has communicated two GHG inventories as part of the first and second National Communications. This is the third GHG Inventory that is submitted as part of the first Biennial Transparency Report, the initial Biennial Update Report and the third National Communication.

1.2. Description of national circumstances and institutional arrangements

1.2.1. National Entity/Focal Point

The Climate Change Act, 2016 came into force to enable Kenya to meet its international obligations under the UNFCCC. The Act requires that each state department and national government public entity report on greenhouse gas emissions for the national inventory. Under the Act, the Ministry responsible for climate change affairs, which is the Ministry for the Environment, Climate Change and Forestry (MoECCF), is responsible for overall development, compilation, and submission of the greenhouse inventory to the UNFCCC. Specifically, the Act establishes a Climate Change Directorate (CCD) under the MoECCF to coordinate the implementation of Climate Change activities in the Country, including GHG inventories.

The NIR for the Third National Communication (TNC), BUR1 and BTR1 has been developed by inter-ministerial and inter-institutional sector teams. The Project Manager, who is also the GHG Inventory Coordinator, worked closely with Sector Coordinators/sector teams to collect data, estimate emissions, and draft the inventory report.

Five (5) Sector Working Groups were formed under the Technical Working Group on Greenhouse Gas Inventory to support the preparation of the GHG Inventory Report. The sector working groups are.

a. Energy (including Transport) Sector Working Group
b. IPPU Sector Working Group
c. Waste Sector Working Group
d. Agriculture (Crop and Livestock) Sector Working Group
e. FOLU Sector Working Group

The PMU engaged experts/institutions to provide broad technical guidance and will work very closely with the Sector teams in managing the inventory development. The Project Manager worked with sector team leads to develop the required systems and procedures for efficient GHG inventory preparation. Kenya has envisioned a GHG Inventory institutional framework that is yet to be operationalized. The PMU is, therefore, the National GHG Inventory Coordination Unit until the envisioned institutional framework is operationalized. The Project Manager is the GHG Inventory Coordinator. Each Sector Working Group is coordinated by a Sector Coordinator appointed by the Project Manager in consultation with the specific sector team.

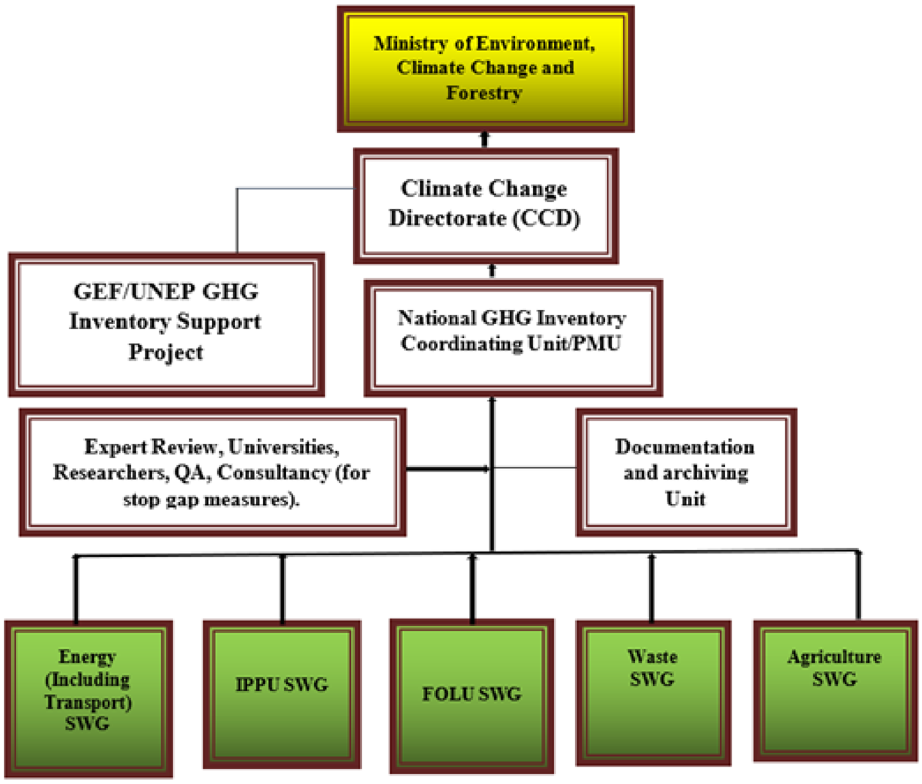


Figure 1-1: Figure Name

1.2.1.1. Project Management Unit

Kenya has not established a national inventory system. The Project Management Unit established to implement the BTR Project doubled as the GHG Inventory Unit. A Project Manager heads the PMU to administer and manage the project and report to the Director of Climate Change. The PMU was responsible for preparing the National Inventory Report. The PMU consists of a Project Manager, a Technical Assistant, and an Administrative Assistant.

1.2.2. Inventory development process

Kenya commenced the GHG Inventory preparation process by convening all sector experts for a planning and capacity-building workshop. The capacity-building workshop was facilitated by an expert supported by CBIT-GSP. The composition of the sector working groups included data providers and compilers to facilitate efficiency due to the limited time the country had to prepare the inventory. The team chose methods based on data availability and identified areas where flexibility provisions would apply.

The sectors proceeded to collect and organize activity data in formats consistent with the common reporting tables. Decisions were made on where to use IPCC default emission factors and where the country-specific emission factors would apply.

After the calculation of the initial estimates, Kenya requested the Transparency Accelerator Initiative to avail experts to QC the initial estimates.

Below is a graphical representation of the GHG inventory cycle

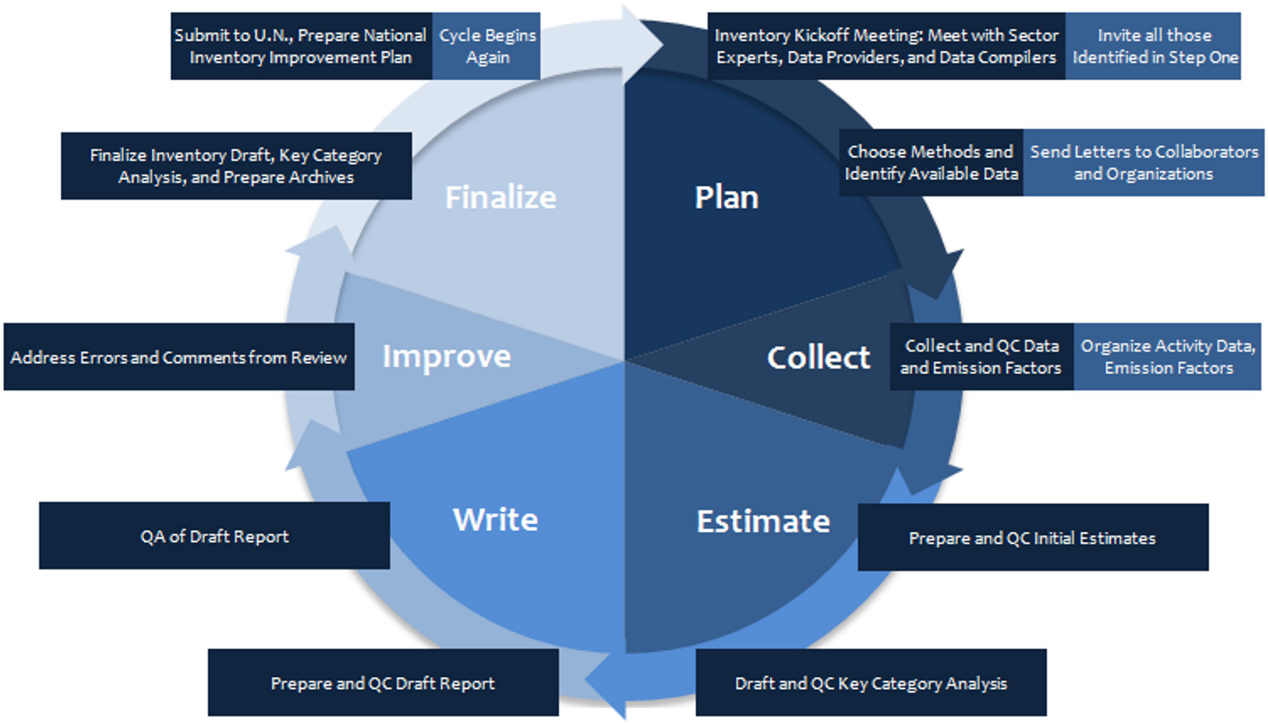


Figure 1. 2: Inventory development process

1.2.3. Archival of Information

Kenya has not institutionalized reporting. Therefore, the information reported in the first and second national communications was not archived to inform the preparation of the third National GHG Inventory Report. The sector working groups collected data for the entire time series and used different methods to address data gaps.

1.2.4. Process for formal inventory review and approval

Kenya has an elaborate process for stakeholder engagement and approval of policy documents and reports. Sectors, the Parliament and other stakeholders reviewed the National GHG Inventory through an elaborate stakeholder engagement process. The team also worked with the IPCC-TFI to support the review of the LULUCF inventory, especially since Kenya used the IPCC software to estimate its emissions for all sectors. At the political level, the inventory was reviewed by the inter-ministerial ETF Reporting Project Steering Committee, which is chaired by the Principal Secretary of the State Department for Environment and Climate Change. The Principal Secretary presented the inventory to the Cabinet Secretary for Environment, Climate Change and Forestry for approval. The Cabinet Secretary then presented the inventory report to the Cabinet chaired by His Excellency the President for final political approval.

1.3. Description of methodologies, methods and sources of information

Kenya updated its national GHG inventory using methodologies recommended under decision 18/CMA.1. The 2006 IPCC guidelines were used to prepare the inventory. The most recent version of the IPCC software was used for emission estimation. The country used the IPCC default emission factors for categories where the country has not developed country-specific emission factors.

1.4. Description of main categories

The IPCC Good practice guidance (IPCC, 2000) identifies a key category as "one that is prioritized within the national inventory system because its estimate has a significant influence on a country's total inventory of direct greenhouse gases in terms of the absolute level of emissions, the trend in emissions, or both". Key categories are identified within the inventory so that the resources available for inventory preparation are prioritized.

The key categories in the Kenya inventory were assessed using the good practice Tier 1 level and trend methodologies (IPCC, 2000; 2003). The good practice methodologies identify sources of emissions and removals that sum to 95 percent of the total emissions or 95 percent of the trend of the inventory in absolute terms. Following GPG-LULUCF (IPCC, 2003) the key category analysis was performed once for the inventory excluding LULUCF categories and then repeated for the full inventory including the LULUCF categories. Non-LULUCF categories that are identified as key in the first analysis but do not appear as key when the LULUCF categories are included were still considered as key. The detailed results for the key category analysis are shown in tables 1.4. 2 to 1.4.5 for the base year and current year respectively.

When the LULUCF sector is included in the analysis, Kenya has identified CH4 emissions from enteric fermentation and FOLU CO2 emissions from Cropland Remaining Cropland (Removals) as the most significant of the key categories (i.e. contributing more than 48 per cent of the level). When the LULUCF sector is excluded from the analysis the most significant key categories are Enteric Fermentation - CH4 and Fuel Combustion Activities - Transport - Road transportation - CO2 contributing 65 % of the emission in 2022.

The key categories identified in the 2022 inventory are summarized in Table 1.4.1. The major contribution to the level analysis is from Agriculture CH4 emissions from enteric fermentation in domestic livestock, and FOLU CO2 emissions from Cropland Remaining Cropland (Removals) being the largest single source of emissions comprising 26% and 22% respectively of total emissions in 2022. The next largest contribution to emissions is Fuel Combustion Activities - Transport – CO2 from Road transportation comprising 9.8 percent of total. This is followed by CO2 emissions from Land Converted to Grassland (Emissions) comprised 7.4 percent of total emissions in 2022. (table 1.4.5). However, due to capacity constrains at national level especially in determination of country specific emission factors, the key categories have been modelled through tier 1 approach.

Table 1-1: Summary of key categories in the 2022 Kenya's Inventory

Quantitative method used: Tier 1 IPCC Source Categories	Gas	Criteria for Identification Level or Trend
Energy Sector		
1.A.3.b - Fuel Combustion Activities - Transport - Road transportation-	CO_2	Level
1.A.4 - Fuel Combustion Activities - Other Sectors - CH_4	CH_4	Level
1.A.2 - Fuel Combustion Activities - Manufacturing Industries and Construction -	CO_2	Level
1.A.4 - Fuel Combustion Activities - Other Sectors	CO_2	Level
1.A.1 - Fuel Combustion Activities - Energy Industries (Liquid Fuel) -	CO_2	Level
Industrial Processes and Product Use (IPPU) Sector		
2.A.1 - Mineral industry - Cement Production	CO_2	Level
Agricultural Sector		
3.A.1 - Enteric Fermentation	CH_4	Level
3.C.4 - Direct N_2O Emissions from Managed Soils	N_2O	Level
3.A.2 - Manure Management	CH_4	Level
LULUCF Sector		
3.B.2.a - Cropland Remaining Cropland (Removals)	CO_2	Level
3.B.3.b - Land Converted to Grassland (Emissions)	CO_2	Level
3.B.2.a - Cropland Remaining Cropland (Emissions)	CO_2	Level
3.B.1.a - Forest Land Remaining Forest Land (Emissions)	CO_2	Level
3.B.1.b - Land Converted to Forest Land (Removals)	CO_2	Level
3.B.5.b - Land Converted to Settlements (Emissions)	CO_2	Level
Waste Sector		
4.D - Wastewater Treatment and Discharge: Domestic	CH_4	Level

Table 1-2: Tier 1 Key Category Level Assessment - excluding LULUCF-Base year

Key Category Tier 1 Level Assessment for the Base Year 1990			
CATEGORIES (the resulting key categories are those categories shaded in green)	**Base Year (1990) Emission Estimate (GgCO2eq)**	**Level assessment**	**Cumulative Percentage**
3.A.1 - Enteric Fermentation - CH4	13,597	0.531	53%
4.D - Wastewater Treatment and Discharge: Domestic - CH4	1,552	0.061	59%
1.A.3.b - Fuel Combustion Activities - Transport - Road transportation - CO2	2,125	0.083	67%
1.A.2 - Fuel Combustion Activities - Manufacturing Industries and Construction - CO2	1,443	0.056	73%
3.C.4 - Direct N2O Emissions from Managed Soils - N2O	904	0.035	77%
1.A.4 - Fuel Combustion Activities - Other Sectors - CH4	1,053	0.041	81%
1.A.4 - Fuel Combustion Activities - Other Sectors - CO2	852	0.033	84%
2.A.1 - Mineral industry - Cement Production - CO2	722	0.028	87%
1.A.3.d - Fuel Combustion Activities - Transport - Domestic Water-borne Navigation - CO2	686	0.027	90%
3.C.5 - Indirect N2O Emissions from Managed Soils - indirect N2O	309	0.012	91%
1.A.1 - Fuel Combustion Activities - Energy Industries (Liquid Fuel) - CO2	436	0.017	93%
3.A.2 - Manure Management - CH4	422	0.016	94%
4.A - Solid Waste Disposal - CH4	246	0.010	95%
4.D - Wastewater Treatment and Discharge: Domestic - N2O	221	0.009	96%
3.A.2 - Manure Management - N2O	195	0.008	97%
1.A.4 - Fuel Combustion Activities - Other Sectors - N2O	150	0.006	97%
1.A.3.c - Fuel Combustion Activities - Transport - Railways - CO2	112	0.004	98%

Table 1-3: Tier 1 Key Category Level Assessment - excluding LULUCF –Current year

Key Category Tier 1 Level Assessment for the Current Year (2022)			
CATEGORIES (the resulting key categories are those categories shaded in green)	**Current Year (2022) Emission Estimate (Gg CO2 eq)**	**Level Assessment**	**Cumulative Percentage**
3.A.1 - Enteric Fermentation - CH4	31,464	0.473	47%
1.A.3.b - Fuel Combustion Activities - Transport - Road transportation - CO2	11,800	0.177	65%
1.A.4 - Fuel Combustion Activities - Other Sectors - CH4	4,460	0.067	72%
2.A.1 - Mineral industry - Cement Production - CO2	3,604	0.054	77%
4.D - Wastewater Treatment and Discharge: Domestic - CH4	3,549	0.053	82%
1.A.2 - Fuel Combustion Activities - Manufacturing Industries and Construction - CO2	2,005	0.030	86%
3.C.4 - Direct N2O Emissions from Managed Soils - N2O	1,617	0.024	88%
3.A.2 - Manure Management - CH4	1,501	0.023	90%
1.A.4 - Fuel Combustion Activities - Other Sectors - CO2	1,331	0.020	92%

Key Category Tier 1 Level Assessment for the Current Year (2022)			
CATEGORIES (the resulting key categories are those categories shaded in green)	Current Year (2022) Emission Estimate (Gg CO2 eq)	Level Assessment	Cumulative Percentage
1.A.1 - Fuel Combustion Activities - Energy Industries (Liquid Fuel) - CO2	901	0.014	94%
4.A - Solid Waste Disposal - CH4	727	0.011	95%
1.A.4 - Fuel Combustion Activities - Other Sectors - N2O	554	0.008	95%
3.C.5 - Indirect N2O Emissions from Managed Soils - indirect N2O	543	0.008	96%
4.D - Wastewater Treatment and Discharge: Domestic - N2O	506	0.008	97%
3.A.2 - Manure Management - N2O	495	0.007	98%

Table 1-4: Tier 1 Key Category Level Assessment - including LULUCF-Base year 1990

	CATEGORIES (the resulting key categories are those categories shaded in green)	Base Year Emission Estimate (Gg CO2 eq)	Level assessment	Cumulative Percentage
	3.A.1 - Enteric Fermentation - CH4	13,597	0.531	53%
	1.A.3.b - Fuel Combustion Activities - Transport - Road transportation - CO2	2,125	0.083	61%
	4.D - Wastewater Treatment and Discharge: Domestic - CH4	1,552	0.061	67%
	1.A.2 - Fuel Combustion Activities - Manufacturing Industries and Construction - CO2	1,443	0.056	73%
	1.A.4 - Fuel Combustion Activities - Other Sectors - CH4	1,053	0.041	77%
	3.C.4 - Direct N2O Emissions from Managed Soils - N2O	904	0.035	81%
	1.A.4 - Fuel Combustion Activities - Other Sectors - CO2	852	0.033	84%
	2.A.1 - Mineral industry - Cement Production - CO2	722	0.028	87%
	1.A.3.d - Fuel Combustion Activities - Transport - Domestic Water-borne Navigation - CO2	686	0.027	90%
	1.A.1 - Fuel Combustion Activities - Energy Industries (Liquid Fuel) - CO2	436	0.017	91%
	3.A.2 - Manure Management - CH4	422	0.016	93%
	3.C.5 - Indirect N2O Emissions from Managed Soils - indirect N2O	309	0.012	94%
	4.A - Solid Waste Disposal - CH4	246	0.010	95%
	4.D - Wastewater Treatment and Discharge: Domestic - N2O	221	0.009	96%
	3.A.2 - Manure Management - N2O	195	0.008	97%

Table 1-5: Tier 1 Key Category Level Assessment - including LULUCF - Current year

Key Category Tier 1 Level Assessment for the Current Year (2022)				
	CATEGORIES (the resulting key categories are those categories shaded in green)	Current Year (2022) Emission Estimate (Gg CO2 eq)	Level assessment	Cumulative Percentage
	3.A.1 - Enteric Fermentation - CH4	31,464	0.260	26%
	3.B.2.a - Cropland Remaining Cropland (Removals) - CO2	26,716	0.221	48%
	1.A.3.b - Fuel Combustion Activities - Transport - Road transportation - CO2	11,800	0.098	58%
	3.B.3.b - Land Converted to Grassland (Emissions) - CO2	9,004	0.074	65%

Key Category Tier 1 Level Assessment for the Current Year (2022)			
CATEGORIES (the resulting key categories are those categories shaded in green)	Current Year (2022) Emission Estimate (Gg CO2 eq)	Level assessment	Cumulative Percentage
3.B.2.a - Cropland Remaining Cropland (Emissions) - CO2	6,609	0.055	71%
3.B.1.a - Forest Land Remaining Forest Land (Emissions) - CO2	6,448	0.053	76%
1.A.4 - Fuel Combustion Activities - Other Sectors - CH4	4,460	0.037	80%
3.B.1.b - Land Converted to Forest Land (Removals) - CO2	-3,767	0.031	83%
2.A.1 - Mineral industry - Cement Production - CO2	3,604	0.030	86%
4.D - Wastewater Treatment and Discharge: Domestic - CH4	3,549	0.029	89%
1.A.2 - Fuel Combustion Activities - Manufacturing Industries and Construction - CO2	2,005	0.017	91%
3.C.4 - Direct N2O Emissions from Managed Soils - N2O	1,617	0.013	92%
3.A.2 - Manure Management - CH4	1,501	0.012	93%
1.A.4 - Fuel Combustion Activities - Other Sectors - CO2	1,331	0.011	94%
1.A.1 - Fuel Combustion Activities - Energy Industries (Liquid Fuel) - CO2	901	0.007	95%
3.B.5.b - Land Converted to Settlements (Emissions) - CO2	747	0.006	96%
4.A - Solid Waste Disposal - CH4	727	0.006	96%
3.B.3.a - Grassland Remaining Grassland (Emissions) - CO2	556	0.005	97%
1.A.4 - Fuel Combustion Activities - Other Sectors - N2O	554	0.005	97%
3.C.5 - Indirect N2O Emissions from Managed Soils - indirect N2O	543	0.004	98%

1.5. Description of the QA/QC plan and its implementation

Quality assurance and quality control are essential to facilitate continuous improvement and guarantee improved inventory quality over time. Decision 18/CMA.1 paragraph 46 provides for Parties to report their QA/QC plans and information on QA/QC procedures already implemented or to be implemented in the future, in accordance with paragraphs 34-36 of the same decision. Kenya has applied flexibility provisions provided in paragraph 34 of the annex to decision 18/CMA.1.

Quality Control

During the preparation of the inventory, the inventory technical working group continued to develop a Tier 1 QC checklist, updating from the one previously used in the preparation of the SNC GHG inventory. General QC procedures were applied routinely to all categories by sector experts responsible for each category and to the inventory report as a whole. In addition, category-specific procedures based on the prioritization identified during the inventory planning process were carried out. General QC procedures include generic quality checks related to calculations, data processing, completeness, and documentation that are applicable to all inventory source and sink categories. Checks were performed on selected sets of data and processes and a representative sample of data and calculations from every category. The Tier 1 QC check sheets were used on all key categories and a selection of non-key categories.

Quality Assurance

Quality assurance of individual sectors is an integral part of the data processing. The sector experts ensured that the activity data, emission factors and parameters used conformed to the principles of completeness and accuracy. The methodologies used in the LULUCF sector were harmonized with those used in other international reporting including the Forest Reference Level and the Forest Resource Assessment 2020 (FRA-2020) submitted to the Food and Agriculture Organization of the UN. A large part of the data in the energy, IPPU and agriculture sectors are compiled using data collected in national surveys. These surveys are conducted and administered by the Kenya National Bureau of Statistics (KNBS). The KNBS conducts its own rigorous quality assurance and quality control procedures on the data.

1.5.1. Criteria for Achievement of Quality Objectives

Kenya elaborates below its criteria for assessing whether the data quality objectives have been met for the GHG inventory submission. National circumstances associated with any given inventory cycle may impact Kenya's inventory development process. Where the data quality objectives for a year cannot be fully met, in accordance with the criteria, Kenya intends to describe the specific national circumstances in the relevant section of the GHG inventory report.

Table 1-6: Criteria for determining whether Kenya's data quality objectives have been met.

Data Quality Objective	Criteria for assessing achievement of objective
Accuracy	Emissions are neither overestimated nor underestimated as far as can be judged. Uncertainty estimates and descriptions for the causes of uncertainties are provided for AD and EF
Comparability	Kenya applies methods from the 2006 IPCC Guidelines taking into account the flexibility provisions in decision 18/CMA.1 and its annex.
Completeness	All categories for which methods are provided in the 2006 IPCC Guidelines are included in the national GHG inventory as appropriate. Emissions estimates cover the entire geographic area of Kenya. Emissions values or notation keys are provided for each category in the relevant reporting table. If, despite the best efforts, emissions for a category for which methods are provided in the 2006 IPCC Guidelines cannot be provided, the relevant flexibility provision applied is clearly referenced.
Consistency	Kenya has applied the same method across the time series for a given category and can explain the trends observed in the time series. If the same method is not used for the entire time series in a category, Kenya can explain (and document in the inventory report) why the selected method(s) ensure time series consistency.
Transparency	Information necessary to reproduce the emissions estimates is either provided in the inventory report or appropriately archived and available for consideration during the technical expert review; The elements to be included in the BTR guided by the MPGs in the annex to decision 18/CMA.1 include, in particular: Methodologies applied, including for country-specific categories. AD used; EFs applied (specifically to be included in the BTR); Emissions on a gas-by-gas basis and in units of mass; GHG emissions to be reported using relevant reporting tables.

1.5.2. QA/QC System

The overall institutional arrangements in Kenya were elaborated earlier in the document. This section focuses on the role(s) of individuals involved with QA/QC activities.

1.5.2.1 Roles and Responsibilities

Everyone involved in the inventory planning, preparation and management process has an obligation to ensure the quality of the GHG emissions information that they gather, process and report. The project manager of the ETF reporting project, who was the inventory coordinator, had a critical role in ensuring the overall quality of the inventory. The coordinator is.

- Responsible for data and document management, which is critical to the long-term improvement of the inventory;
- Act as the receiver of inventory files from the sector experts – is responsible for putting the pieces together into one unified, quality-controlled inventory document;
- Ensures new developments concerning the inventory are thoroughly discussed and implemented.
- Responsible for the planning and implementation of QA/QC activities;

- undertake comprehensive review of available methodological choices on the basis of its applicability to the estimation of GHG emissions;
- Manage spot-checking spreadsheets for correct data entry, consistent formulas and complete documentation for each sector;
- Ensure facilitation of QA process, at least one round of external peer review, for sector reports and draft NIR.
- Together with the sector coordinators, design and oversee the implementation of the QA/QC plan.

The sector coordinators were responsible for sector-level QA/QC. Below are some of their responsibilities

- Perform sector-level QC checks on data being collected and estimations made, guided by the checklists in the QA/QC Plan;
- Submit all processed data and any other supplemental data and QA/QC checklists to the inventory coordinator and maintain backups in the respective organization;
- Liaise with the inventory coordinator to undertake a comprehensive review of available methodological choices and make sound methodological choices on the basis of their applicability to the estimation of GHG emissions;
- Estimate GHG emissions for all categories and gases using appropriate AD/EFs/ GWPs and ensure that the processes/ assumptions for the estimation, including the software used, are consistent with the IPCC guidelines and fully documented;
- Conduct key category analysis for the sector and uncertainty assessment in collaboration with the coordinator/generalist and the uncertainty management lead;
- Collect data using relevant data collection templates, document data sources, check units, and perform other checks in accordance with the annex to decision 18/CMA.1.
- Create and maintain hard and soft copies of all information, data, and estimates at the sector level and for onward transmission to the archive;
- Consult with the inventory coordinator/compiler, as necessary, to discuss and agree on prioritization of activities that can be done within the current inventory cycle;
- Identify prioritised plans for improvements to be incorporated into the national inventory report and inventory improvement plan.

Kenya also reached out to the Transparency Accelerator Initiative to provide sector experts to support the QA/QC process. Six experts came to Kenya under the initiative and work with sector coordinators on the quality assurance for the inventory. The LULUCF team also received additional support from the IPCC-TFI on data QC/QA.

1.6. General Assessment of Uncertainty

According to paragraph 29 of the MPGs each party shall quantitatively estimate and qualitatively discuss the uncertainty of the emission and removal estimates for all source and sink categories, including inventory totals, for at least the starting year and the latest reporting year of the inventory time series. Each Party shall also estimate the trend uncertainty of emission and removal estimates for all source and sink categories, including totals, between the starting year and the latest reporting year of the inventory time series, using at least approach 1, as provided in the IPCC guidelines; those developing country Parties that need flexibility in the light of their capacities with respect to this provision have the flexibility to instead provide, at a minimum, a qualitative discussion of uncertainty for key categories, using the IPCC guidelines, where quantitative input data are unavailable to quantitatively estimate uncertainties, and are encouraged to provide a quantitative estimate of uncertainty for all source and sink categories of the GHG inventory.

In this inventory, Kenya discusses the uncertainty of the emission estimates qualitatively; this is done under each sector.

1.7. Overall Assessment of Completeness

The 2006 IPCC highlights completeness as a critical aspect in ensuring the quality of the inventory. To achieve completeness, national calendar year estimates are reported for all sources and sinks, and gases. Where elements are missing, their absence should be clearly documented, together with a justification for exclusion. Paragraphs 30-33 of the annex to decision 18/CMA.1 provides for the overall assessment of completeness in the inventory submitted as part of the BTR. Paragraph 32 provides flexibility for developing country Parties that need it in light of their capacities.

In the preparation of the inventory, Kenya has indicated the sources and sinks (categories, pools and gases) that are not considered in the national inventory report but for which estimation methods are included in the IPCC guidelines. Notation keys have been used where numerical data are not available when completing common reporting tables, indicating the reasons why emissions from sources and removals by sinks and associated data for specific sectors, categories and subcategories or gases are not reported. The notation keys include:

a. "NO" (not occurring) for categories or processes, including recovery, under a particular source or sink category that do not occur within a Party;
b. "NE" (not estimated) for activity data and/or emissions by sources and removals by sinks of GHGs that have not been estimated but for which a corresponding activity may occur within a Party;
c. "NA" (not applicable) for activities under a given source/sink category that do occur within the Party but do not result in emissions or removals of a specific gas;
d. "IE" (include elsewhere) for emissions by sources and removals by sinks of GHGs estimated but included elsewhere in the inventory instead of under the expected source/sink category;

e. “C” (confidential) for emissions by sources and removals by sinks of GHGs where the reporting would involve the disclosure of confidential information.

1.7.1. Information on completeness

Kenya has provided information and explanation relating to the GHG sources and sinks – categories, reservoirs and gases to the expend possible taking into account the flexibility provisions provided in the annex to decision 18/CMA.1. Below is a summary table for non-estimated GHG sources and sinks and for GHG sources and sinks included elsewhere.

Table 1-7: Table: GHG sources and sinks from Kenya inventory reported as not estimated

GHG	Sector	GHG source and sink categories	Explanation or comment
HFCs	IPPU		
SF_6	IPPU		
Unspecified mixture of HFCs and PFCs			

1.7.2. Aggregated national total of negligible categories

Below is a summary of the negligible categories reported in this report.

Table 1-8: Summary of categories considered to be insignificant

Code	GHG source and sink categories	Last year's emissions or removals (kt CO_2 eq)	Absolute value of emissions and removals	Level evaluation compared to national total (%)	Aggregate total of negligible categories (%)
4C	Incineration and Open Burning of Waste - CO2	321	321	0.2659	0.2659
3C7	Rice Cultivations - CH4	226	226	0.1869	0.1869
3C6	Indirect N2O Emissions from Manure Management - indirect N2O	219	219	0.1815	0.1815
1A3b	Fuel Combustion Activities - Transport - Road transportation - N2O	156	156	0.1293	0.1293
1A3a	Fuel Combustion Activities - Transport - Domestic Civil Aviation - CO2	134	134	0.1104	0.1104
4C	Incineration and Open Burning of Waste - CH4	116	116	0.0959	0.0959
1A3b	Fuel Combustion Activities - Transport - Road transportation - CH4	74	74	0.0614	0.0614
1A3c	Fuel Combustion Activities - Transport - Railways - CO2	61	61	0.0501	0.0501
2B7	Chemical Industry - Soda Ash Production - CO2	44	44	0.0367	0.0367
3C3	Urea Application - CO2	31	31	0.0258	0.0258
2A2	Mineral Industry - Lime Production - CO2	22	22	0.018	0.018
4C	Incineration and Open Burning of Waste - N2O	17	17	0.014	0.014
1A2	Fuel Combustion Activities - Manufacturing Industries and Construction - N2O	7	7	0.0062	0.0062
2A3	Mineral Industry - Glass Production - CO2	7	7	0.0055	0.0055
1A3c	Fuel Combustion Activities - Transport - Railways - N2O	6	6	0.0051	0.0051
1A2	Fuel Combustion Activities - Manufacturing Industries and Construction - CH4	5	5	0.0042	0.0042
3C1	Biomass Burning - CH4	5	5	0.0041	0.0041

Code	GHG source and sink categories	Last year's emissions or removals (kt CO_2 eq)	Absolute value of emissions and removals	Level evaluation compared to national total (%)	Aggregate total of negligible categories (%)
1A3d	Fuel Combustion Activities - Transport - Domestic Water-borne Navigation - CO2	5	5	0.004	0.004
1A1	Fuel Combustion Activities - Energy Industries (Liquid Fuel) - N2O	2	2	0.0015	0.0015
3C2	Liming - CO2	1	1	0.0011	0.0011
3C1	Biomass Burning - N2O	1	1	0.001	0.001
1A3a	Fuel Combustion Activities - Transport - Domestic Civil Aviation - N2O	1	1	0.0008	0.0008
1A1	Fuel Combustion Activities - Energy Industries (Liquid Fuel) - CH4	1	1	0.0008	0.0008
	Total	1,463	1,463	1.2103	1.2103
	Percentage of the national total	1.29%	1.29%		

1.8. Measuring systems

Paragraph 37 of the annex to decision 18/CMA.1 provides for Parties to use the 100-year time-horizon global warming potential (GWP) values from the IPCC Fifth Assessment Report or 100-year time-horizon GWP values from a subsequent IPCC assessment report as agreed upon by the CMA, to report aggregate emissions and removals of GHGs, expressed in CO_2 eq. Kenya inventory was prepared using the 100-year time horizon for the reported gases.

1.9. Summary of applied flexibility provisions

One of the guiding principles of the modalities, procedures and guidelines (MPGs) for the enhanced transparency framework used in the preparation of this inventory document is the provision of flexibility to those developing country Parties that need it in the light of their capacities. Below is a summary table of the flexibility provisions applied.

Table 1-9: Table: Summary of flexibilities applied

MPG flexibility provision (18/CMA.1)	Year	Sector	Category	Gas	Description of the flexibility application	Clarification of capacity limitation	Deadline for capacity improvement	Progress made to address areas for improvement
Para 29	2024	All Sectors	All Categories	CO2, CH4, and N2O	Uncertainty Assessment	Lack of capacity to quantitatively estimate uncertainty	Subject to the availability of support	NA
Para 34 & 35	2024	All Sectors	All Categories	CO2, CH4, and N2O	QA/QC	Lack of capacity to elaborate QA/QC plan. Kenya has implemented and provided general inventory QC procedures.	Subject to the availability of support	NA
Para 48	2024	All Sectors	All Categories		Sectors and Gases	Lack of capacity to collect data and estimate emissions from HFCs, PFCs, SF6, and NF3 gases as applicable.	2028 – Subject to availability of support	NA
Para 57	2024	LULUCF	All Categories		Time series	Lack of capacity to estimate emissions for the entire time series in a consistent manner. Kenya has reported emissions from the LULUCF sector from 2001.	2028 – Subject to availability of support	NA

1.10. Improvement Over Time (Annex 1)

This GHG inventory is the first detailed inventory report that the country has compiled since Kenya started reporting in 2002. It is, therefore, the basis for future improvement in inventory reporting. A detailed improvement plan has been developed to inform future improvements based on the gaps identified during the compilation of this inventory. The timeframes proposed are subject to the availability of adequate support.

Chapter 02:

Trends in Greenhouse Gas Emissions and Removals

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

Kenya's total greenhouse gas emissions were equivalent to 113,366 GgCO_2eq including the Land Use, Land Use Change and Forestry (LULUCF) Sector in 2022. The total greenhouse gas emissions have increased by 343 percent since 1990 (Table 2-1). Total CO_2 emissions for the year 2022 are estimated to be 66,519.7 GgCO_2eq without contribution from LULUCF. Trends in total CO_2eq emissions for the time series 1990 to 2022 are shown in figures 2-1 and 2-2. In general emission have been increasing since 1990 rising to 69,399.5 GgCO_2eq in 2021 without LULUCF and then dropping slightly in 2022.

Table 2-1: Total National Emissions without and with LULUCF

Year	1990	2000	2010	2020	2022	Annual growth rate	~% Change 1990 - 2022
Total emissions without LULUCF (GgCO_2eq)	25,593.7	25,045.0	40,886.2	67,873.6	66,519.7	5%	160%
Total emissions with LULUCF (GgCO_2eq)	25,593.7	25,045.0	55,861.1	108,330.4	113,366.0	10%	343%

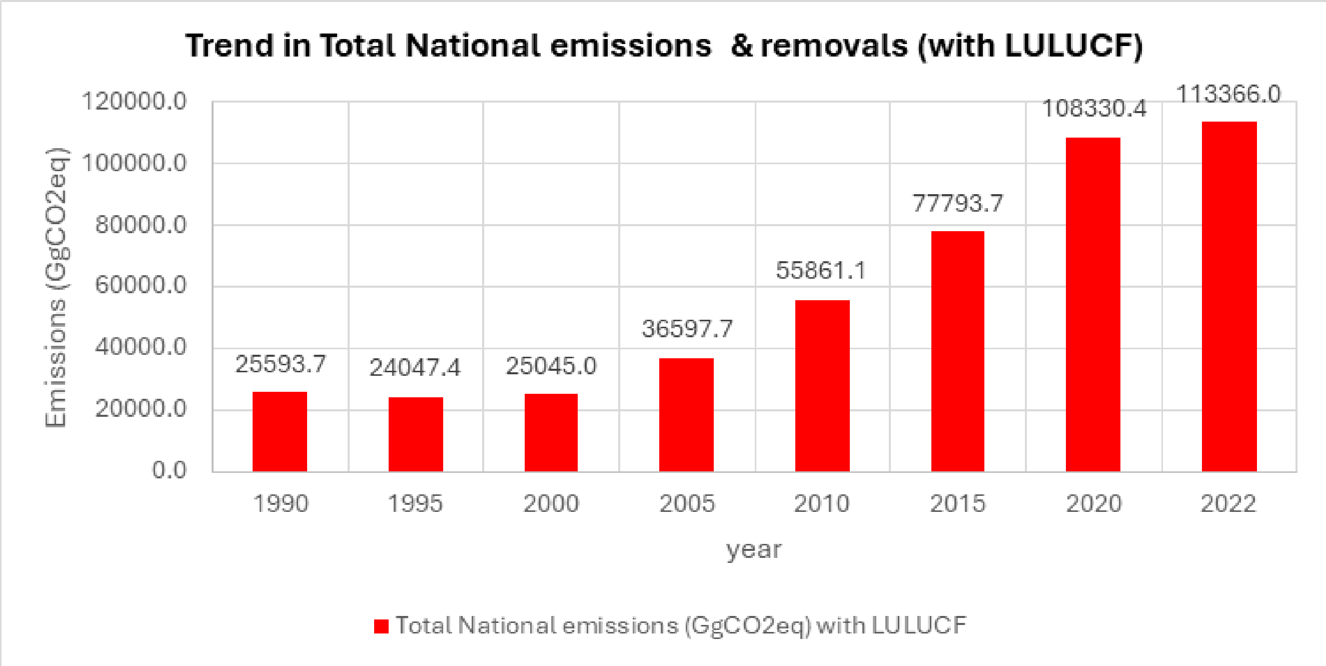


Figure 2-1: Kenya total greenhouse gas emissions trends 1990–2022 with the LULUCF sector

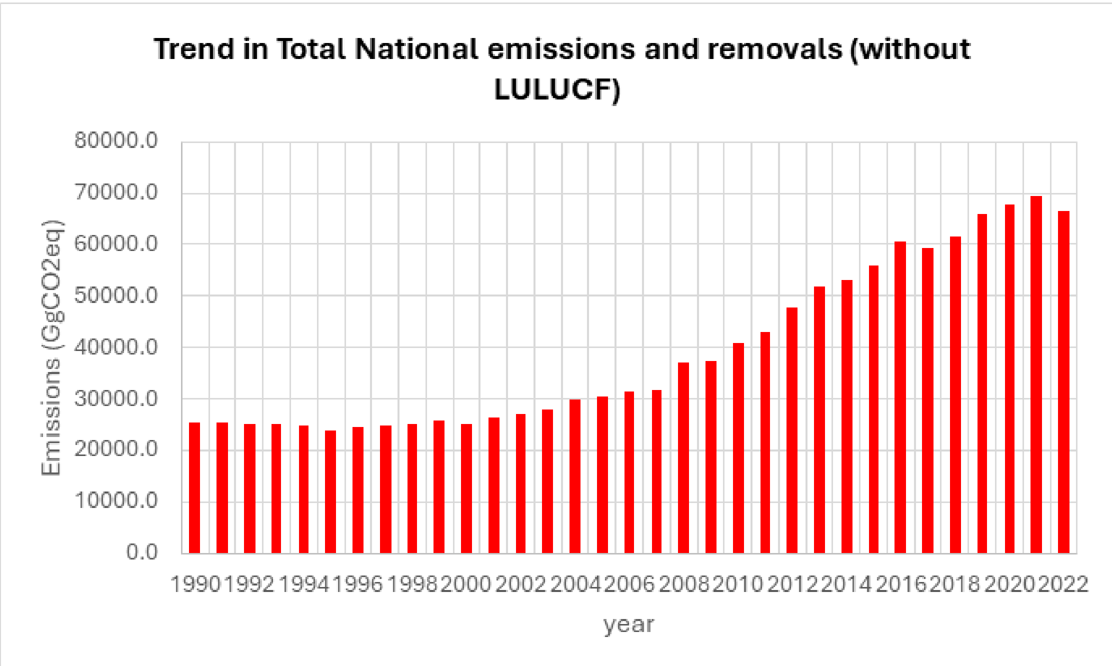


Figure 2-2: Kenya total greenhouse gas emissions trends 1990–2022 without LULUCF

Emission growth is primarily driven by Energy and AFOLU sectors which have remained net emitters, showing deforestation and forest degradation have been exceeding the reforestation rates throughout the period and together with increased consumption of fossil fuels. Other drivers of emissions are due to increased agricultural activities, and demand for fossil fuels in the energy sector. Over the period 1990 to 2022, the average annual growth in overall emissions has been **4** percent per year including the LULUCF sector.

Greenhouse gas emission contributions by sector and by type of greenhouse gas are summarized in section 2.2 below.

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

2.2.1. Emission trends by Source-Sector

Kenya is amongst developing nations in which Agriculture and LULUCF sectors dominates the share of its total greenhouse gas emissions. Tables 2-2 provides a summary of sectoral greenhouse gas emissions results for all sectors, and figure 2-3 shows Emissions trends by sectors without LULUCF, while figure 2-4 shows emissions trends by sector including LULUCF.

Table 2-2: Kenya's sectoral greenhouse gas emissions Summary 1990 - 2022 (Gg- CO2 eq)

Categories	Sectoral greenhouse gas emissions (Gg-CO2eq)					Annual growth rate	~% Change 1990 - 2022
	1990	2000	2010	2020	2022		
3A/C -Agriculture	15,639.7	13,732.7	19,941.1	40,211.6	36,102.2	**4%**	**131%**
1 - Energy	7,018.6	7,767.7	15,185.0	20,625.9	21,503.2	**6%**	**206%**
4 - Waste	2,171.5	2,953.3	4,113.4	5,009.3	5,237.0	**4%**	**141%**
2 - IPPU	764.0	591.2	1,646.7	2,026.9	3,677.2	**12%**	**381%**
3B - LULUCF	-	-	**1,4974.9**	**40,456.8**	**46,846.3**	**20%**	**653%**

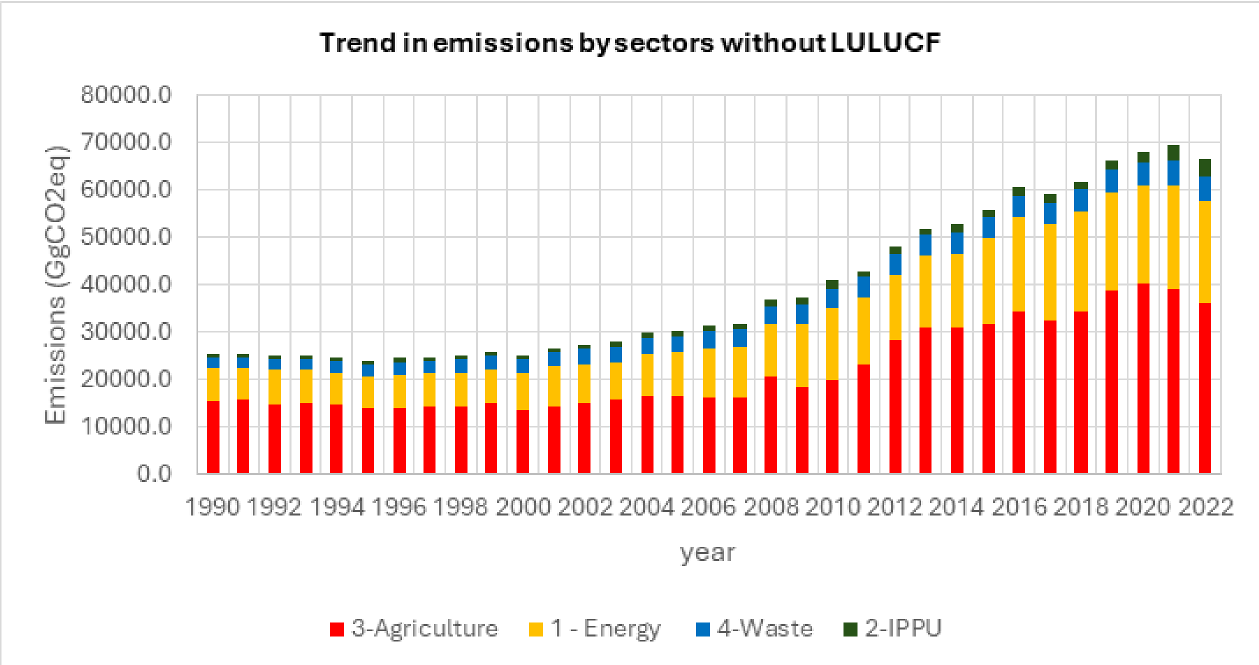


Figure 2-3: Greenhouse gas emission trend by sector in Gg CO2eq, excluding LULUCF

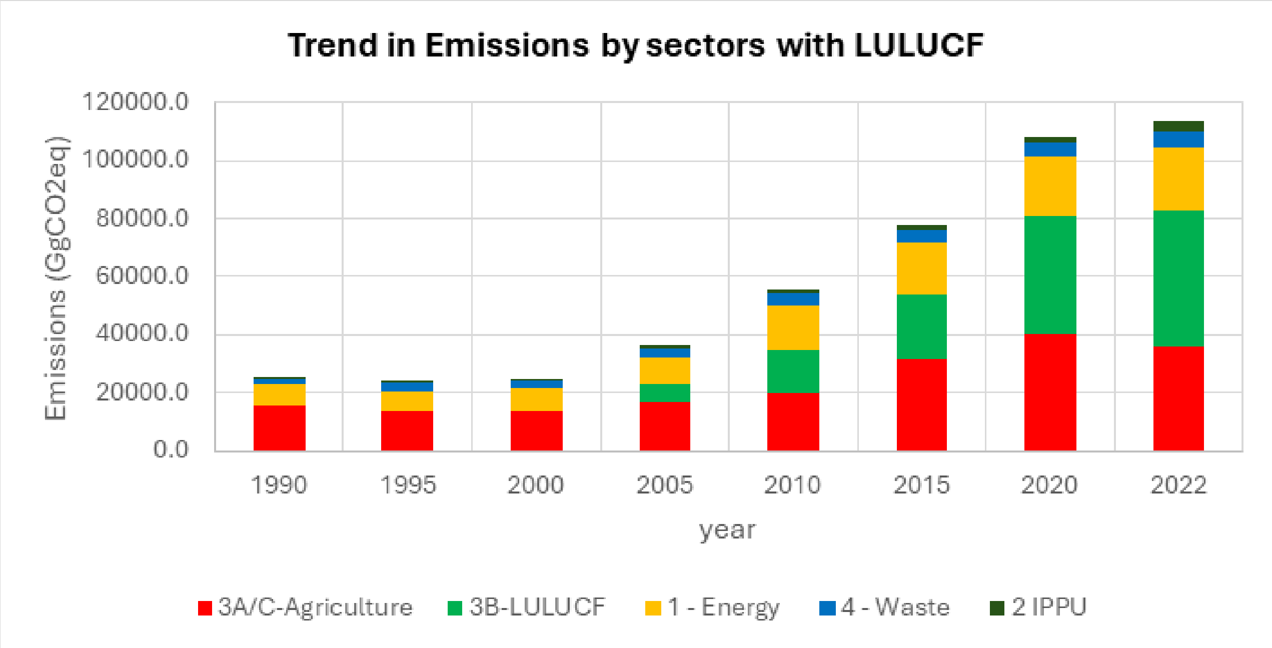


Figure 2-4: ***Greenhouse gas emission trend by sector including LULUCF***

The LULUCF sector emitted **46,846.3** $GgCO_2eq$ in 2022 (41 % of the national emissions). The Agriculture sector was a net emitter in 2022 contributing approximately **36,102.2** $GgCO_2eq$ or 32 percent of the national emissions. Thus AFOLU (combined agriculture, land use change and forestry) is the largest contributor to the total emissions in Kenya having **73%** share. (Tables 2-2 and figure 2-5).

The energy sector emitted **21,503.2** Gg CO_2eq., contributing **6** percent of the total GHG emissions in 2022. The waste sector emitted **5,237.0 Gg** CO_2eq in 2022, which was **5** percent of the total GHG emission. The Industrial Processes and Product Use emitted **3,677.2** Gg CO_2eq or about **3**% of total GHG emissions. (Tables 2-2 and figure 2-5).

The LULUCF emissions grew at average rate of **20%** per annum which is the highest annual rate by sector, followed by Industrial process emissions at an average rate of **12** % per year. The Energy emissions grew at an average rate of **6%** per year between 1990 and 2022. Waste process and Agriculture emissions grew much more slowly at an average rate of **4%** per year. (Table 2-2).

Emissions from the **AFOLU** sector have been increasing steadily since 1990 to 2022 due steady demand for agricultural land, deforestation activities and use of synthetic fertilizers, and increasing number of livestock. **IPPU** Emissions have continued to grow primarily due to increased CO_2 emissions from cement production (more factories became operational). Emissions from the **Energy** Sector had increased over the years largely due to increased importation of fossil consuming vehicles in the transport sector.

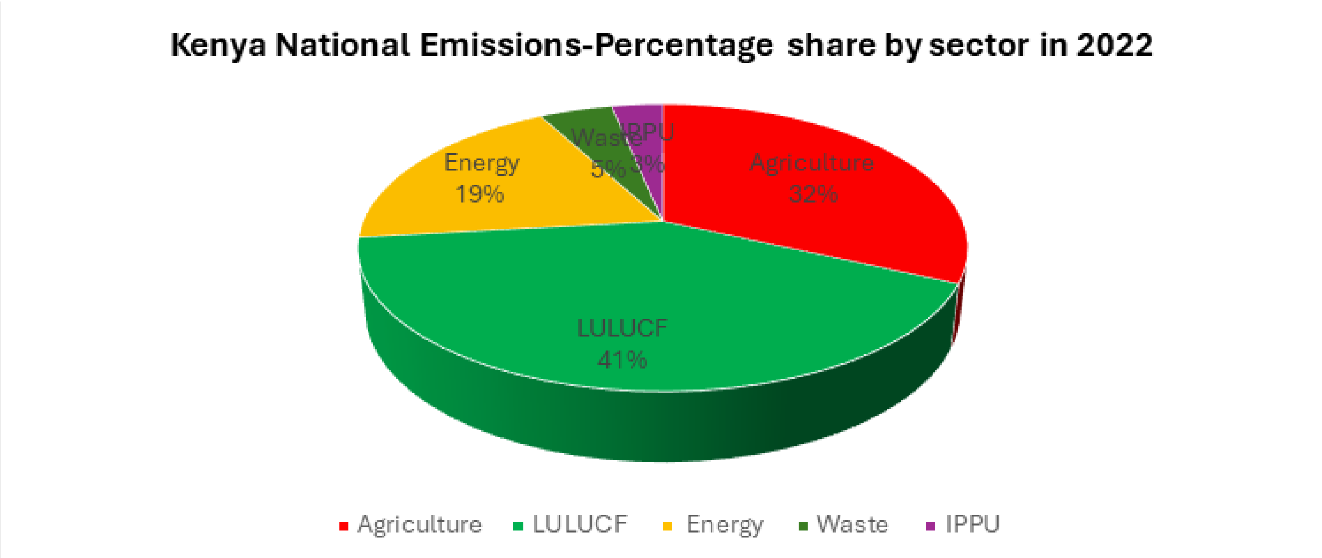


Figure 2-5: ***Kenya`s Sectoral greenhouse gas emissions percentage share of national total emissions in 2022, including LULUCF***

The current level of emissions from LULUCF is **653** percent above the 1990 level, while IPPU **is 381**% above that of the 1990, agriculture sector is **131 percent**, and energy sector is **206**% (table 2-2). Detailed results by sector and source categories for each of the inventory period 1990 to 2022 are provided in chapters 3-6.

2.2.2. Emission trends by gas

Methane and Carbon dioxide dominate Kenya's increase in greenhouse gas emissions (table 2-3 and figure 2-6). In 2022, CO2 comprised **59** percent of total CO_2 equivalent (CO_{2e}) emissions, whereas CH_4 contributed **37** % and N_2O, **4** percent. Therefore, CO_2 and CH_4 remain the major greenhouse gases in Kenya's historical emissions profile. Figure 2-6 illustrate the share of emission by gas type.

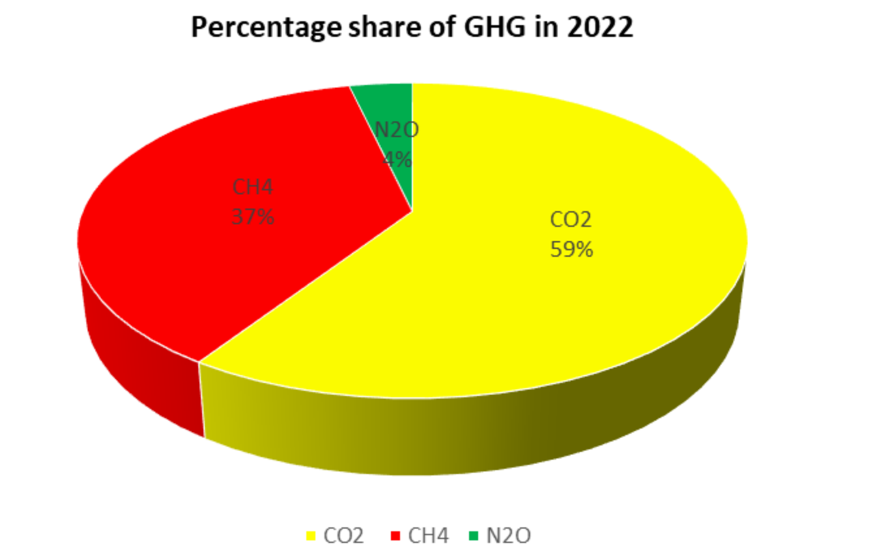


Figure 2-6: Kenya's emissions share by gas in 2022

Table 2-3: Kenya's emissions by gas for selected years between 1990 - 2022 (Gg CO2eq)

GHG Type	Kenya's total emissions by gas					% change 1990 - 2022
	1990	2000	2010	2020	2022	
CO2	6,622.4	7,136.2	29,334.8	58,674.7	67,114.2	913%
CH4	17,036.2	15,865.0	23,843.3	45,599.8	42,127.5	147%
N2O	1,935.2	2,043.8	2,682.9	4,055.9	4,124.4	113%
TOTAL EMISSIONS (Gg CO2eq)	25,593.7	25,045.0	55,861.1	108,330.4	113,366.0	343%

The growth in CH_4 emissions can be associated with an increased number of livestock population. The growth in CO_2 represents the increased emissions from the LULUCF and energy sectors, in particular the transport sub-sector. N_2O emissions have increased due to the increased use of nitrogenous fertilizers in agricultural soils since 1990.

Table 2-3 and figure 2-7 indicate the amounts of emissions of the three main greenhouse gases (i.e., CO_2, CH_4, N_2O) for each of the inventory years and the relative changes from 1990 to 2022. CO_2 relative change in emissions is far the largest changing by **913%** since 1990 to 2022, followed by CH_4 at **147%**, and N_2O at **113 %** change.

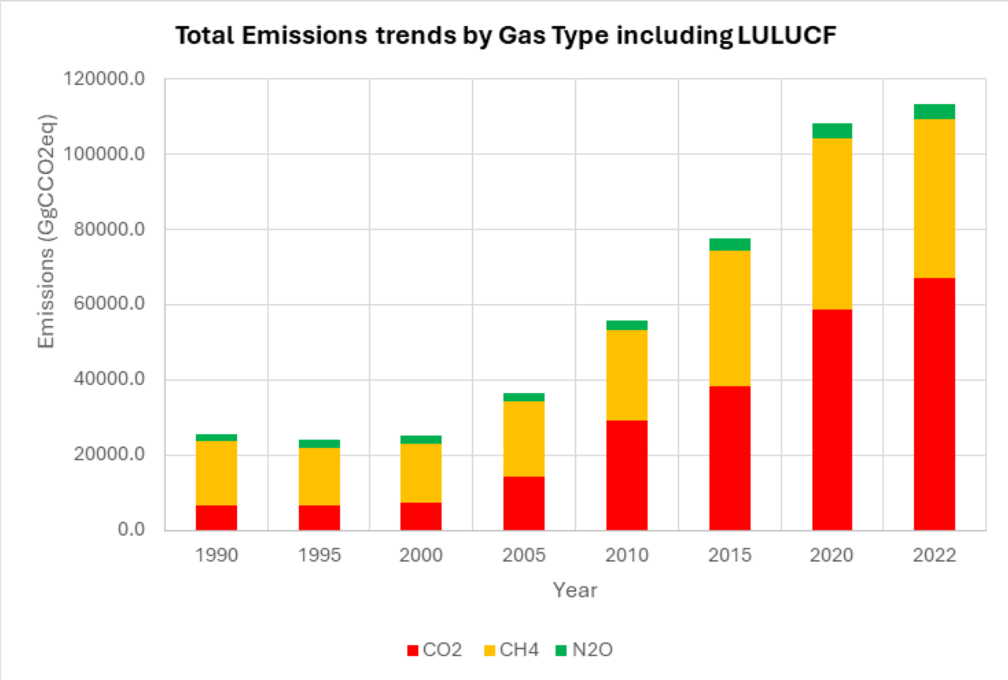


Figure 2-7: Trend in GHG emissions by gas type 1990-2022

Category 2.F product uses as substitutes for ozone depleting substances was not estimated due to insufficient data on Hydrofluorocarbons (HFCs) and, to a very limited extent, perfluorocarbons (PFCs) that are serving as alternatives to ozone depleting substance.

2.2.3. Emission trends for indirect greenhouse gases and SO2

The indirect greenhouse gases CO, NOx, NMVOC as well as SO_2 are not included in the current Kenya`s total greenhouse gas emissions,

Chapter 03:

Energy

3.1. Sector Overview

The 2006 IPCC Guidelines arrange the Energy Sector for greenhouse gas reporting into three (3) distinct subsectors;

i. Fuel Combustion Activities (1.A)
ii. Fugitive Emissions from Fuels (1.B)
iii. Carbon dioxide Transport and Storage (1.C)

In this inventory, Kenya has only estimated emissions originating from fuel combustion activities (1.A). These include emissions from Energy Industries, Manufacturing Industries and Construction, Transport, and Other Sectors as outlined in **table 3-1**.

Table 3-1: Fuel Combustion Activities

Sub-category	Description
1.A.1 Energy Industries	Comprises emissions from fuels combusted by the fuel extraction or energy-producing industries.
1.A.2 Manufacturing industries and construction	Combustion emissions from fuel use during the manufacture of secondary and tertiary products from solid fuels including the production of charcoal
1.A.3 Transport	Emissions from the combustion and evaporation of fuel for all transport activities (excluding military transport)
1.A.4 Other sectors	Emissions from combustion activities as described below, including combustion for the generation of electricity and heat for own use in these sectors
1.A.5 Others	Emissions from combustion activities not captured elsewhere

The Energy sector is the second largest source of emissions in the country accounting for about 25% of total emissions with 21,503 Gg-CO_2e in 2022. These emissions are mainly from transport and other sectors sub-categories, as illustrated in **Figure 3-1**.

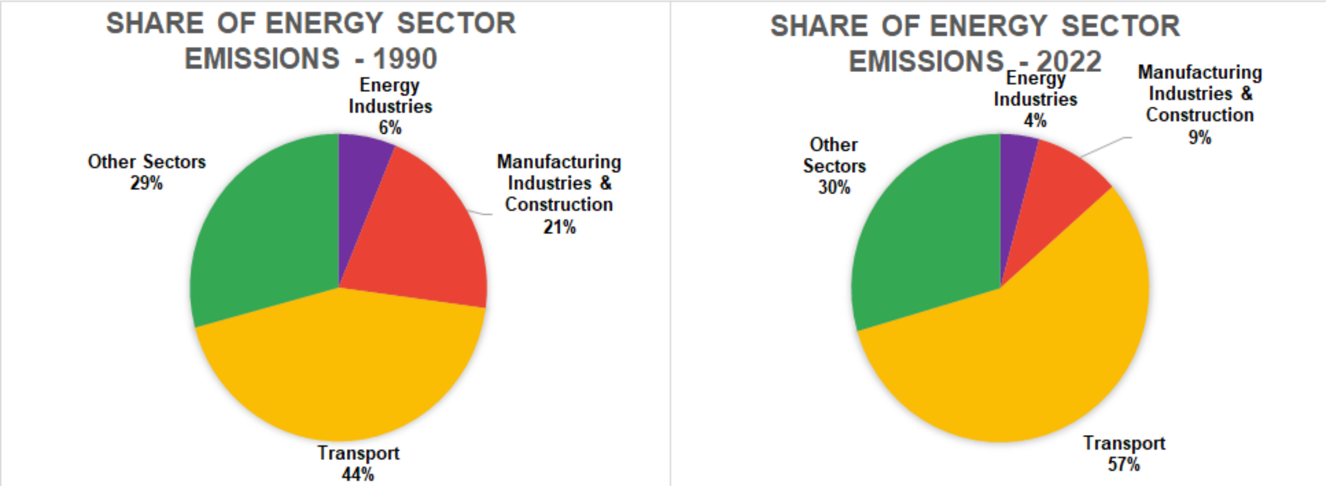


Figure 3-1: Share of energy sector emissions in 1990 and 2022

The transport sub-sector has consistently been the largest source of emissions in the energy sector due to its reliance on fossil fuels. This is followed by Other sectors which comprise of fuel use in the residential, commercial, and agriculture industries, and manufacturing industries, and construction. Energy industries which comprise electricity generation and petroleum refining have always been the smallest contributor sub-category in the energy sector.

There was some activity in exploration for oil and gas in the country in the last decade but emissions from the category Fugitive Emissions from Fuels (1.B) oil and gas exploration were deemed insignificant and thus not estimated. There were coal exploration activities that led to the discovery of coal reserves in the Eastern region of Kenya but no mining activities have been carried out yet.

No emissions occurred under the category, Carbon dioxide transport and storage (1.C) as these activities have not been undertaken anywhere in the country across the time series.

The greenhouse gas emission trends indicated in **Figure 3-2** depict a gradual increase in emissions from 1990 to 2022. The increase is attributed to increased energy demand by the growing population and economic growth leading to increased fuel consumption. The reduction in emissions in the later years is attributed to increased electricity generation from renewable energy technologies, the adoption of lower carbon fuels, and the disruptive effects of the Covid-19 pandemic.

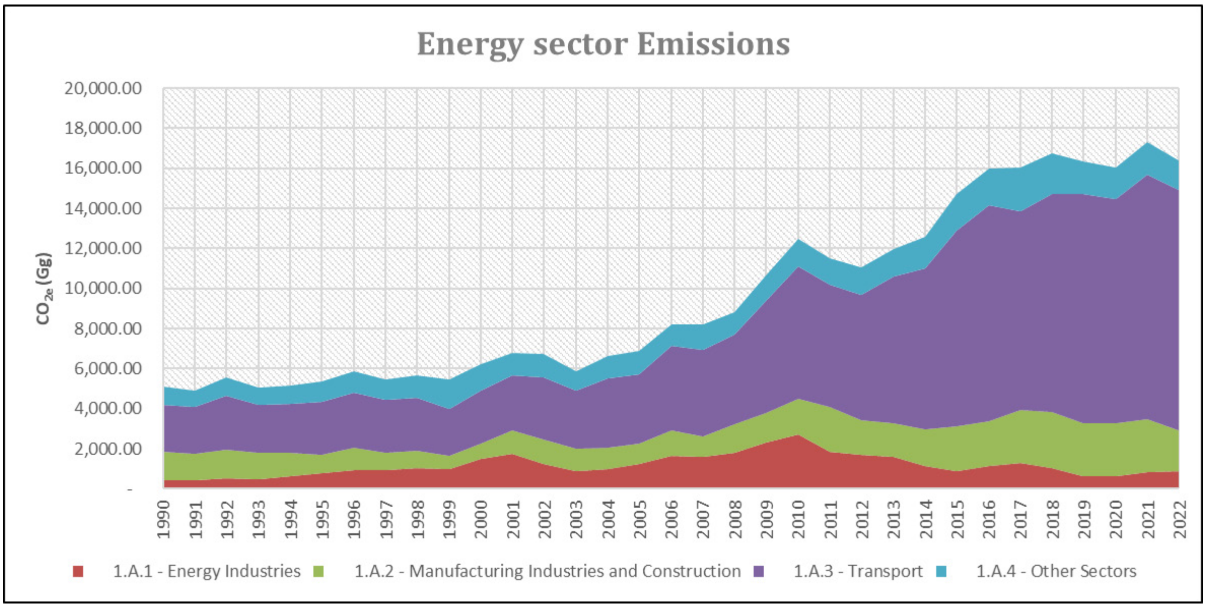


Figure 3-2: Figure 3-2: GHG Emission Trends in the Energy Sector (Gg-CO2e)

1. Transport

Transport has consistently been the most significant source category of emissions, particularly due to its virtually total reliance on petroleum fuels. There has been a sustained increase in the number of motor vehicles driven by population growth, national economy expansion, and urbanisation of society. This has subsequently resulted in an increase in the emissions from the transport sector.

The total length of the rail network in the country is 2,778 km comprising both the metre gauge track and the standard gauge track. In 2017, the construction of Phase I of the Standard Gauge Railway spanning 472 km of track from the port city of Mombasa to Nairobi was completed, this has significantly reduced freight and passenger tariffs and travel time and led to a significant shift of freight and passengers from road to rail. The cargo transported using the railway system increased from 1,380,000 tonnes in 2016 to 6,090,000 tonnes in 2022. The passenger per km increased from 113 million in 2016 to 2,392 million in 2022. (source KNBS Economic Survey 2018 and 2023). This is observed in the trend of emissions for heavy-duty vehicles which declined in 2017.

2. Manufacturing Industries

The Government of Kenya's push towards expansion of industry and manufacturing, coupled with increased population growth has led to increased consumption of fossil fuels, primarily petroleum. In particular, the construction industry has been on a steady growth leading to escalated production of cement by 545% from 1,511,500 tonnes in 1990 to 9,754,000 tonnes in 2022 (KNBS, 2023). Consequently, driving up demand for coal which is the primary fuel in the manufacture of cement.

3. Residential

Kenya's transition to clean cooking is driving an increase in uptake of Liquid Petroleum Gas (LPG) in the residential sector; this has increased since 1990 from 27.4 kt to 333.6 kt. However, about 70% of Kenyans (Ministry of Energy and Petroleum Study, 2019[1]) still use biomass (charcoal and fuel wood) for cooking.

4. Electricity generation

Currently, Kenya has an installed electricity generation capacity of 3,321 MW, against a peak demand of about 2,149 MW (EPRA 2023). Of this, over 70% is from renewable sources, comprising of hydro (838.5 MW), geothermal (950 MW), wind (436.1 MW), biogas (2 MW), and solar (212.6 MW); with thermal medium speed diesel (MSD) contributing 681.9 MW to the interconnected system. This has been driven by deliberate government policy intervention geared towards promotion of renewables in the country which has resulted in the scaling down on the use of diesel thermal generation leading to a drop in greenhouse gas (GHG) emissions.

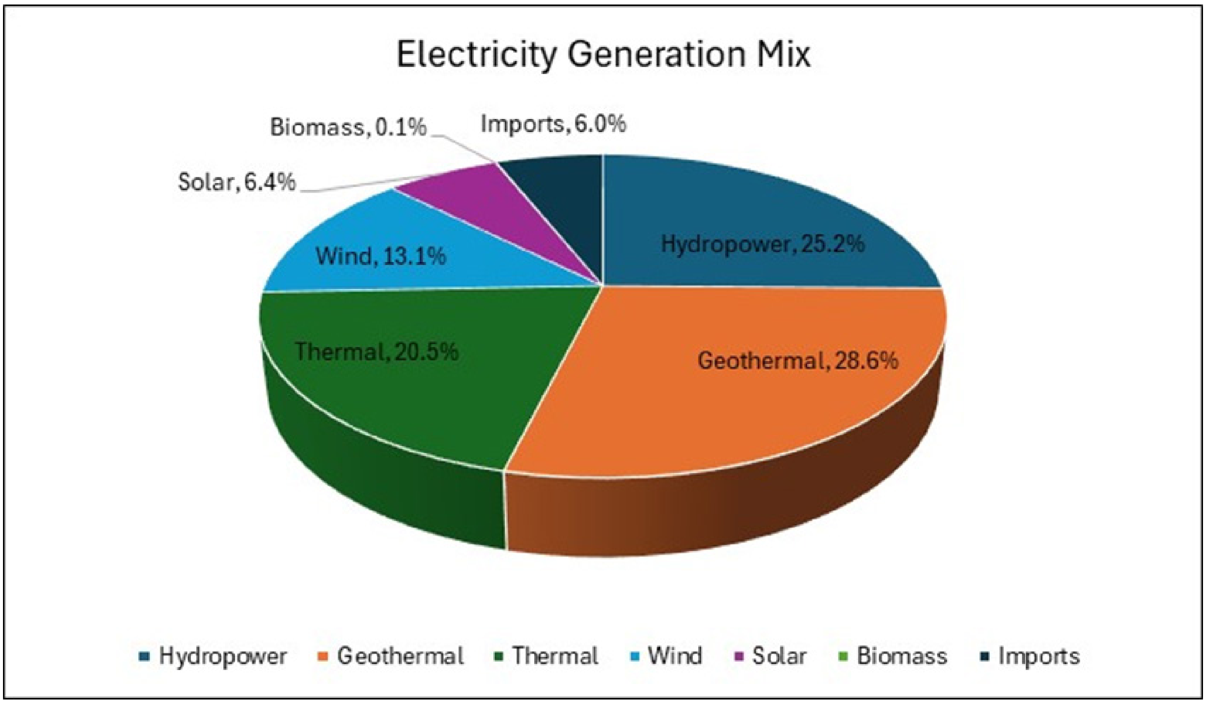


Figure 3-3: Electricity generation mix in Kenya

Energy demand has varied over the years but has been on a general upward trend. This has been due to average sustained economic growth of more than 5% from the year 2003.

1 https://rise.esmap.org/data/files/library/kenya/Electricity%20Access/Kenya_MoE-Kenya%20Cooking%20Sector%20Study_2019.pdf

3.1.1. Description and Trend of GHGs

The energy sector emissions have been generally trending upwards over the reporting period (1990-2022) rising from 7,018 Gg-CO_2e in 1990 to 21,503 Gg-CO_2e in 2022 as illustrated in figure 3-4.

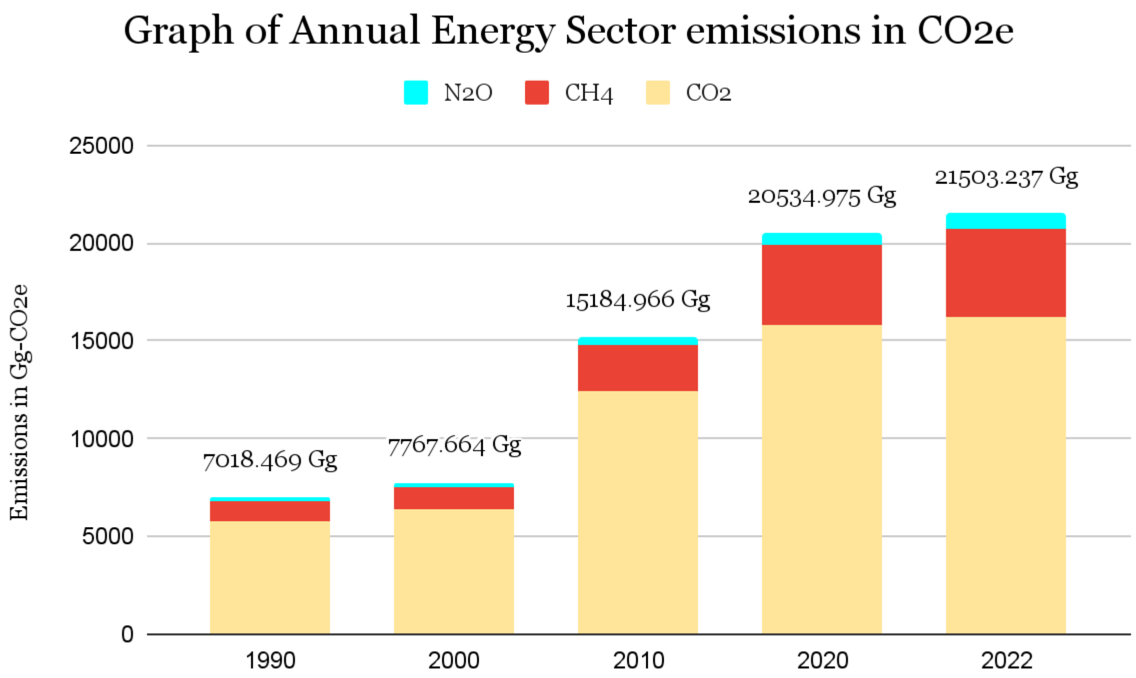


Figure 3-4: Energy sector emissions Gg-CO2e

The growth in emissions is attributed to socio-economic factors such as population and GDP growth which have steadily increased. The emissions stabilize from 2018 to 2022 on account of increased generation from renewable energy technologies and adoption of clean cooking technologies.

3.1.2. Methodological Aspects of the Category

The selection of which tier to apply depends on whether a category is a key category and on the availability of data and methods (e.g. country-specific, plant-specific or models) that would enable the application of the appropriate methodology.

The Energy Sector inventory was estimated based on the tier 1 methodology. This entails the use of default IPCC 2006 emission factors and country activity data to calculate emissions using the formula;

Emissions = AD • EF

Where;

Activity data (AD) is the extent to which human activity takes place, and,

Emission factors (EF) - the coefficients that quantify the emissions or removals per unit activity.

In the energy sector (tier 1 methodology) fuel consumption constituted activity data, and the mass of carbon dioxide (CO2)/ methane (CH_4)/ nitrous oxide (N_2O) emitted per unit of fuel consumed would be an emission factor. The emission factors applied are sourced from the IPCC as embedded in the IPCC inventory software or published in the Emission Factor Database (EFDB). The fuel calorific values used are Net Calorific Values (NCV).

The main sources of Activity Data used for the sector were from the Kenya National Bureau of Statistics (KNBS) as reported in the annual Economic Survey Reports and the Statistical Abstracts. These reports are readily available and compiled information shared by sector representatives/ institutions including the Ministries and their agencies as well as the Kenya Revenue Authority. There was also the use of data from some of the implementing agencies, mostly the Semi-Autonomous Government Agencies (SAGAs) annual reports. In some cases, expert opinion was sought to allocate fuel consumption in some sub-categories.

According to the modalities, procedures and guidelines (MPGs) (Decision 18/CMA.1 Annex II para. 23), the Party shall clearly document why the methodological choice was not in line with the corresponding decision tree of the IPCC guidelines.

Table 3-2:

Sub-category	Tier applied	Reason why a higher tier was not applied
1.A.1.a.i	Tier 1	Lack of country specific emission factors
1.A.1.b	Tier 1	Lack of country specific emission factors
1.A.2.f	Tier 1	Lack of country specific emission factors
1.A.2.m	Tier 1	Lack of country specific emission factors
1.A.3.a.i	Tier 1	Lack of country specific emission factors
1.A.3.a.ii	Tier 1	Lack of country specific emission factors
1.A.3.b.i	Tier 1	Lack of country specific emission factors
1.A.3.b.iii	Tier 1	Lack of country specific emission factors
1.A.3.b.iv	Tier 1	Lack of country specific emission factors
1.A.3.c	Tier 1	Lack of country specific emission factors
1.A.3.d.ii	Tier 1	Lack of country specific emission factors
1.A.4.a	Tier 1	Lack of country specific emission factors
1.A.4.b	Tier 1	Lack of country specific emission factors
1.A.4.c.ii	Tier 1	Lack of country specific emission factors
1.B	Not Estimated (NE)	Emissions from these activities were deemed insignificant and therefore not estimated.
1.C	Not Occurring (NO)	There are no activities that would lead to reportable emissions under this category anywhere in Kenya.

Moving forward, Kenya plans to apply higher tier methodologies in upcoming compilations, particularly for the key categories, in line with the IPCC guidelines.

3.1.3. Comparison of the sectoral approach with the reference approach (related to a non-mandatory provision as per para. 36 of the MPGs)

The Reference Approach is a top-down approach, using a country's energy supply data to calculate the emissions of CO_2 from combustion of mainly fossil fuels. The Reference Approach is a straightforward method that can be applied based on relatively easily available energy supply statistics.

The CO_2 emissions from the combustion of fossil fuels were estimated for the entire period, 1990 – 2022 and the results are as depicted in the graph below

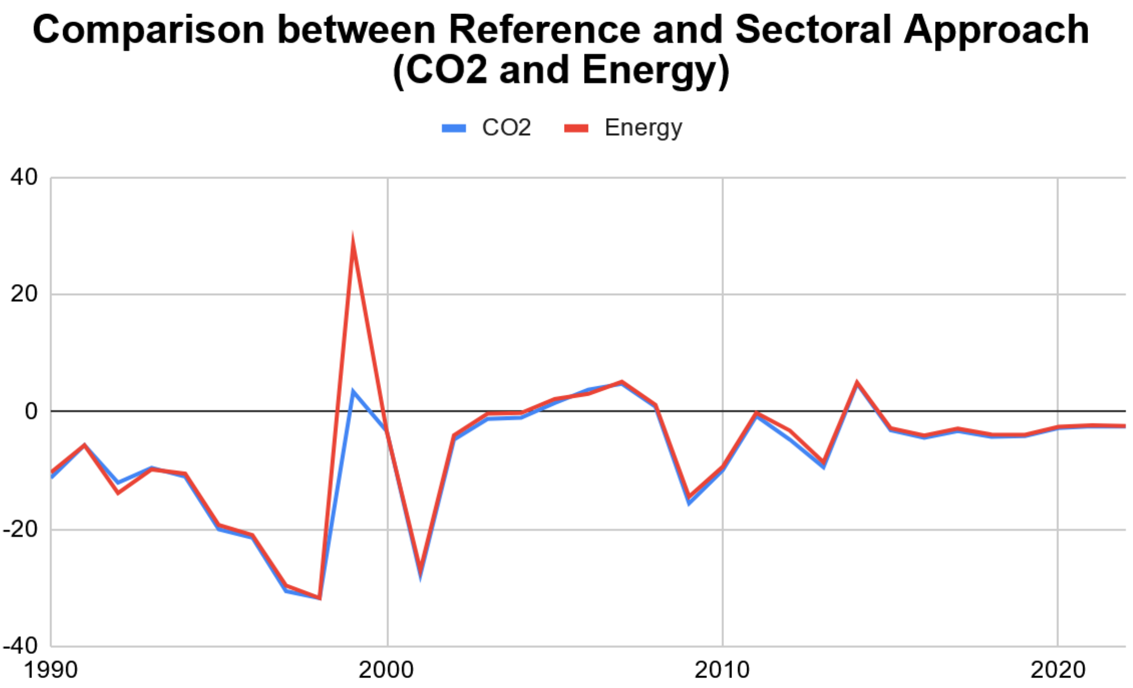


Figure 3-5: Comparison of CO2 and energy consumed between Reference and Sectoral approaches over the time series.

For most of the time series, the comparison returned a negative number, meaning that the sectoral approach estimates are higher than the reference approach estimates and this may be due a number of reasons, including;

i. Poor data collection protocols,
ii. Some material which may have been declared as industrial feedstocks may have been diverted into the fuel streams,
iii. The split of fuel used in international: domestic navigation or aviation might have led to the differences observed,
iv. Kenya is the gateway to the landlocked countries of Uganda, Rwanda, South Sudan or even the Eastern Democratic Republic of Congo. It is possible that some fuels meant for export could have been dumped into the economy and captured in the national fuel statistics.

The trend though seems to be settling to single digit percent difference pointing to better statistics and/or enforcement to prevent material diversion or dumping.

3.1.4. International bunker fuels (related to a non-mandatory provision as per para. 53 of the MPGs)

International bunker fuels are fuel supplied to aeroplanes and ships engaged in international transport. Emissions from international bunker fuels are not included in the national emission totals of individual countries but are reported as memo items.

Kenya has estimated the emissions from international civil aviation under category 1.A.3.a.i but has not estimated the international bunker fuels under water-borne navigation.

3.1.5. Carbon dioxide (CO2) Emissions from Biomass Used for Energy Purposes

CO_2 emissions from biomass used for energy purposes was estimated under the Other sectors (1.A.4) sub-category. This entailed the use of wood/wood waste and charcoal in commercial/institutional (1.A.4.a) and residential sectors (1.A.4.b). The total emissions from biomass were estimated at **61,037.181 Gg-CO_2e** in 2022.

3.1.6. Feedstocks and non-energy use of fuels (related to a non-mandatory provision as per para. 54 of the MPGs)

Non-energy use of fuels for purposes other than generating heat or power included the use of fuels as a feedstock and other purposes such as bitumen production, lubricants, etc. The non-energy use of fuels was not significant in comparison to total fuel consumption. This is all in energy due to lack of data on non-fuel use, except before 2013 where refinery non-fuel products are excluded from fuels.

In the reference approach, the bitumen derived from the refinery was counted as excluded carbon and appropriately accounted for.

3.2. Fuel Combustion Activities

The following sections discuss emissions estimates results of the energy sub-categories whose emissions have been estimated on this inventory.

3.2.1. Energy Industries (1.A.1)

This category comprises emissions from fuels combusted by the fuel extraction or energy-producing industries. Under this category, Kenya estimated emissions from two subcategories; Electricity Generation (1.A.1.a.i) and Petroleum refining (1.A.1.b).

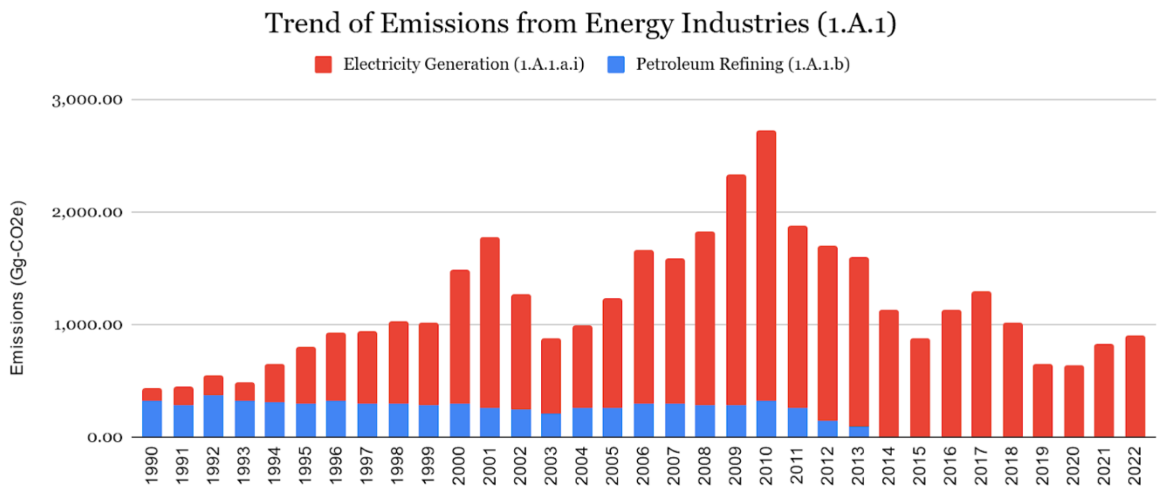


Figure 3-6: GHG emissions from Energy Industries

Electricity generation was the dominant source of emissions in this sub-category throughout the time series. Emissions from Energy industries peaked in 2010 and thereafter generally declined. This was the result of closure of the petroleum refinery in 2013 and a diversification of electricity generation sources to bring on board other options and cushion the sector from the erratic rainfall patterns.

3.2.1.1. Electricity Generation (1.A.1.a.i)

This category comprises emissions estimated from fuel combustion used in electricity generation.

Kenya has a rich portfolio of options and technologies for electricity generation which includes renewable energy options like hydropower, geothermal, wind, solar, and biomass as well as fossil fuel options like medium-speed diesel plants utilizing fuel oil, high-speed diesel plants using diesel and gas turbines that run on kerosene.

Despite a tripling of electricity generation capacity and generation since 1990, the emissions haven't followed a similar trajectory due to the deployment of more renewable energy options to meet the electricity demand.

Table 3-3: Share of Renewable and Thermal electricity generation in Kenya (sample years)

	1990	2000	2010	2020	2022
Total Generation (GWh)	3,359	4,070	6,976	11,611	12,985
Renewable	97.64%	54.31%	68.47%	93.5%	87.79%
Thermal	2.36%	45.69%	31.53%	6.50%	12.21%
Total	100%	100%	100%	100%	100%

Much as the share of electricity from hydropower has gradually diminished, its importance in Kenya's electricity generation mix is still significant. This is seen in the generation trends where there is a spike in emissions from fossil fuels use in electricity generation in the years the country suffered severe drought such as 2009 (KNBS, 2010) which impacted the hydropower output as depicted in Figure 3-3.

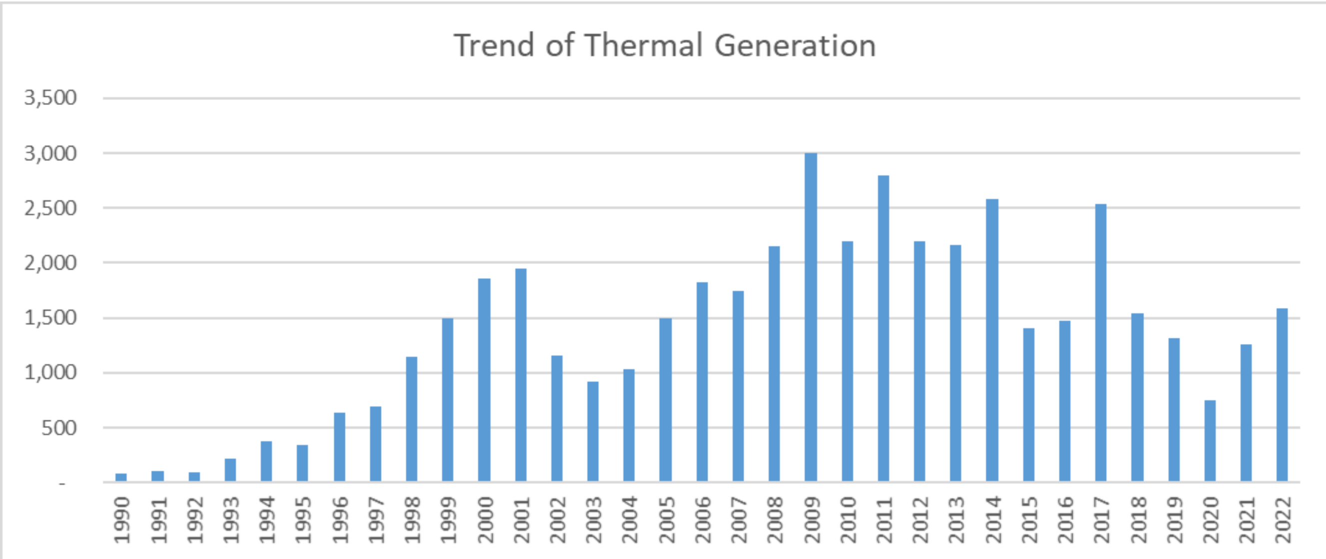


Figure 3-7: Thermal electricity generation (GWh)

This dependence has been addressed by diversifying to other non-hydro RE options such as wind, solar, geothermal as well as investing in regional interconnections and grid strengthening to allow the dispatch. This has subsequently resulted in peaking of emissions in 2010 and reduced emissions from electricity generation in the latter years of the time series as illustrated in figure 3.9

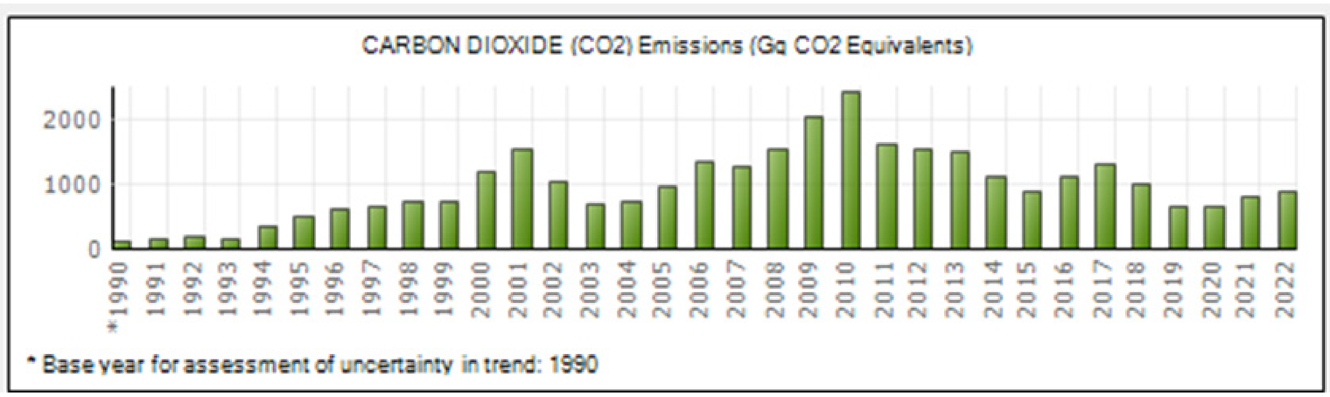


Figure 3-8: CO_2 emissions from Electricity Generation

3.2.1.2. Petroleum refining (1.A.1.b)

This source category comprises all combustion activities supporting the refining of petroleum products including on-site combustion for the generation of electricity and heat for own use.

Kenya Petroleum Refineries Ltd. (KPRL) incorporated in 1960, under the name East African Oil Refineries Limited, operated a petroleum refinery from 1963 to 2013 when its operation was shut down and there have been no refining operations since. The refinery, located in Changamwe in the port city of Mombasa, refined imported crude petroleum sourced from various places, mostly in the Arabian Peninsula to meet part of Kenya's domestic fuel needs. Its storage facilities are currently leased to Kenya Pipeline Company (KPC). The refinery had a capacity to process 70,000 barrels of crude per day

The emissions reported here are from the combustion of fuel, residual fuel oil, as refinery usage from activity data sourced from the Kenya National Bureau of Statistics. The emissions from using the various fractions of fuel emanating from the refinery are reported in the respective use sectors.

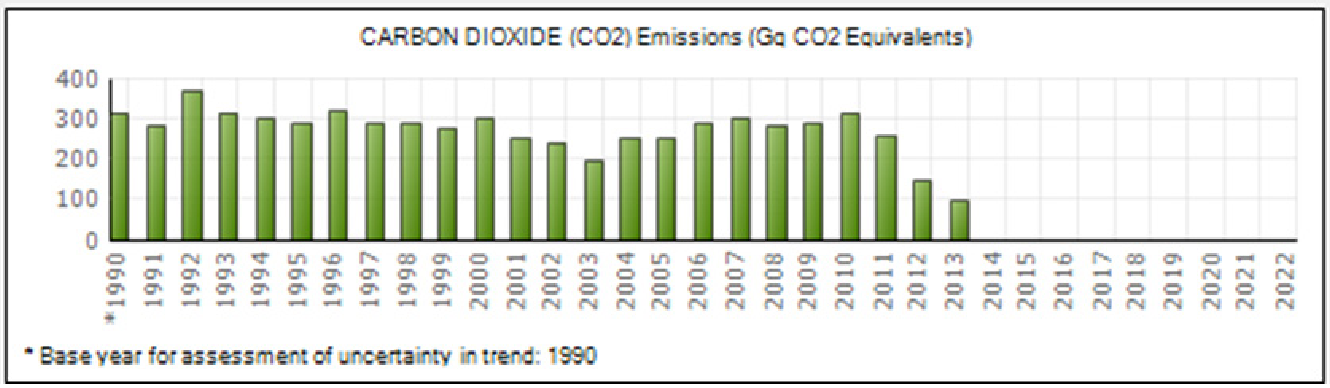


Figure 3-9: C02 Emissions from Petroleum Refining

3.2.2. Manufacturing Industries and Construction (1.A.2)

This category comprises emissions from combustion of fuels in industry. It also includes combustion for the generation of electricity and heat for own use in these industries.

The emissions being reported in this sub-category are those from the fuel used to provide energy for the industrial process but not the emissions from the processing of the materials themselves which are reported under the Industrial Processes and Product Use (IPPU) sector for example the emissions from the burning of coal to provide heat energy in a cement kiln are reported here (Energy > Fuel combustion activities > Manufacturing industries and construction > non-metallic minerals) whereas those from the decomposition of the calcium carbonate are reported in IPPU.

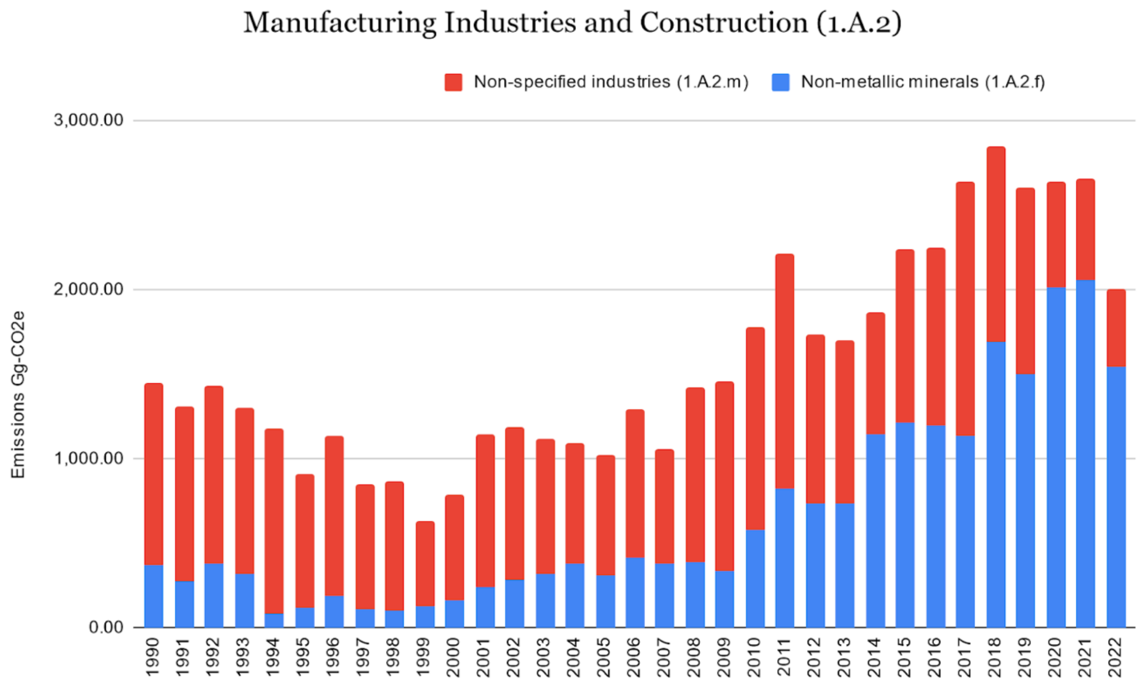


Figure 3-10: Emissions from manufacturing industries and construction

In this category, Kenya has estimated emissions from fuel used to process non-metallic minerals (1.A.2.f) while all other fuel used in industry was reported under the sub-category non-specified industries (1.A.2.m)

3.2.2.1. Non-metallic minerals (1.A.2.f)

This sub-category accounted for emissions from fuel use in non-metallic minerals. Includes products such as glass, ceramic, cement etc.

As of the end of 2022, Kenya had seven (7) cement industries in operation. Four (4) of these produce clinkers that are mainly for in-house cement production. The demand for cement has been increasing mainly driven by infrastructure growth particularly in roads and housing. There are two (2) main lime manufacturers with a total installed capacity of 50,000 tonnes per year. Similarly, there are two (2) major glass producers (mainly dealing in packaging glass products) with an installed capacity of 90,000 tons per annum.

The main fuel used in this category is coal, the main type of coal used was found to be other bituminous coal and it is whose parameters that were used in the estimation of emission from that sub-category. With coal being the main fuel in the manufacture of cement, a graph of coal imports and cement production depicts this relationship as shown in the figure below.

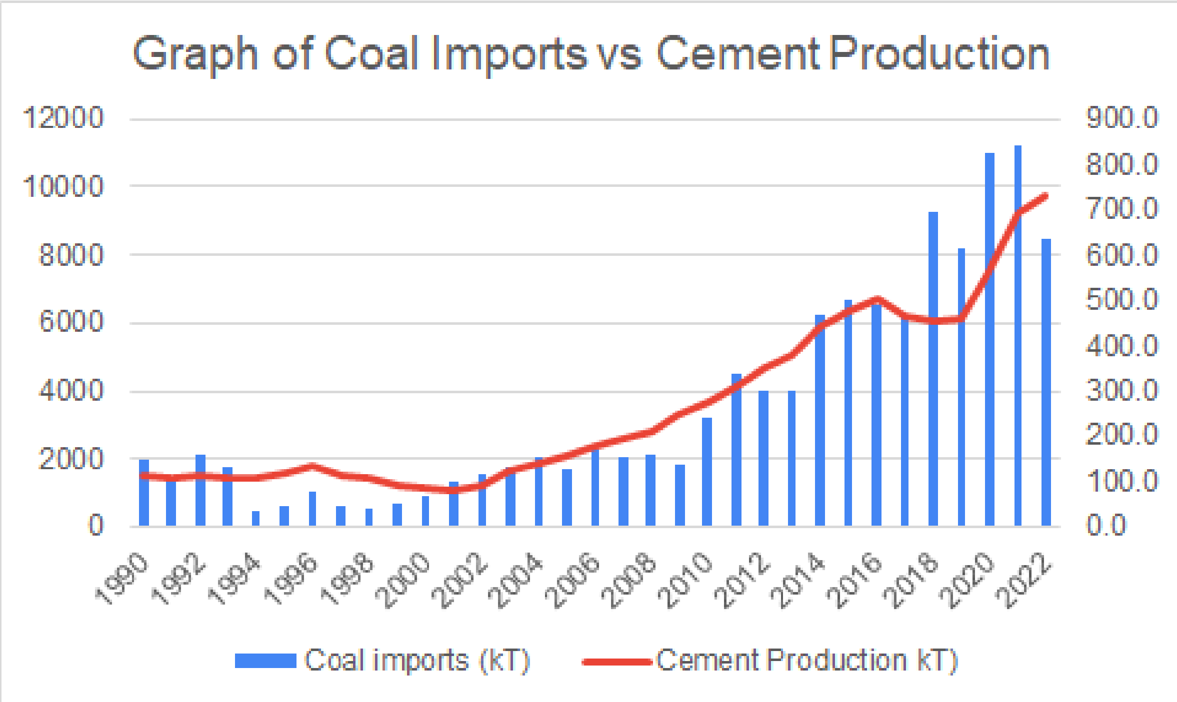


Figure 3-11: Cement production versus 1.A.2.f emissions

Besides coal, it is known that some residual fuel oil and diesel oil are used in this source category but there isn't sufficient data to estimate the quantities consumed in the industry to enable the estimation of emissions. Moreover, some scrap tyres are burnt in some cement kilns, both for energy and as a way of disposal, but it was not possible to estimate what quantity of the tyres were used and neither were there emission factors for the tyres.

It was observed that the emissions have increased substantially from 1990 to 2022, trending with the cement production, which is driven by an improved macroeconomic environment. Cement production in Kenya has increased from 1,511,500 tonnes in 1990 to 9,754,000 tonnes in 2022.

3.2.2.2. Non-Specified Industries (1.A.2.m)

This sub-category accounts for emissions from fuel use in non-specified industries. Any manufacturing industry/construction for which separate data was not available.

The fuel statistics in Kenya are not sufficiently disaggregated to enable an accurate attribution of the different fuels to the various IPCC emission source categories.

Residual fuel oil is known to be used in a myriad of industries in Kenya besides electricity generation, therefore all residual fuel oil not attributed to electricity generation was counted under this sub category. Diesel oil, small amounts of the other petroleum fuels as well biomass fuels are consumed at varying degrees in the industries, but there is not adequate data with which to estimate the resultant emissions. This therefore left residual fuel oil consumption estimates as the only activity data with which to make emission estimates.

It was observed that the emissions in the non-specified industries (1.A.2.m) sub-category trended with the performance of the national economy. A decline in emissions due to decreased energy demand was observed from 1996 to 2000; this is attributed to the general slowdown in the economy leading to depressed effective demand for manufactured products. (KNBS Economic survey, 2000). Thereafter, there was a recovery in the economy and a general upward trend in the industrial sector performance, albeit with dips in years that had significant political activity

(2005, 2007, 2013) and in 2020, when the COVID-19 pandemic disrupted production.

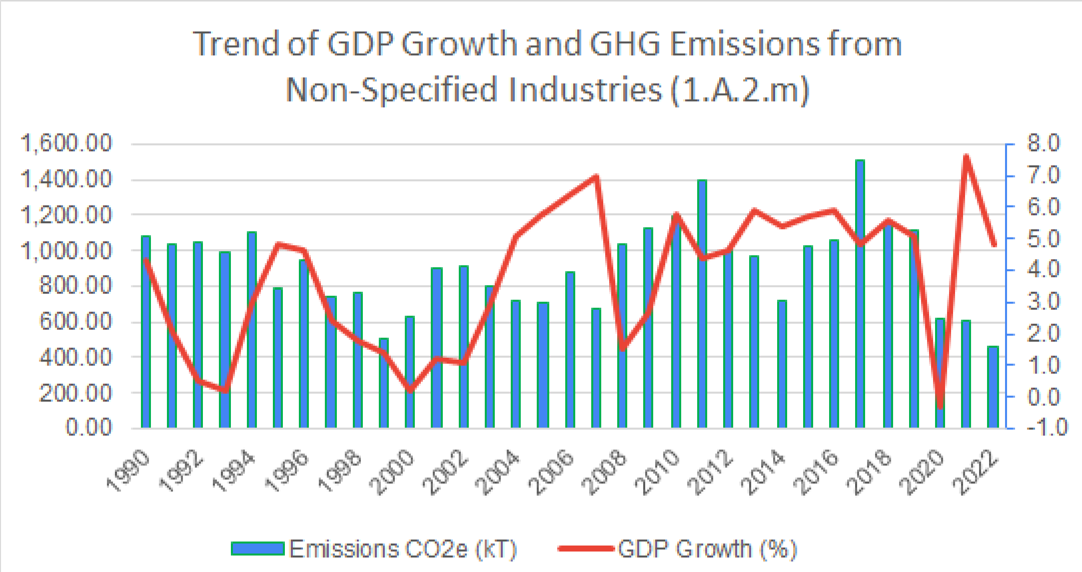


Figure 3-12: GDP growth versus 1.A.2.m emissions

3.2.3. Transport (1.A.3)

Emissions from the combustion and evaporation of fuel for all transport activities

In this category, Kenya reported emissions from civil aviation (1.A.3.a), road transport (1.A.3.b), railways (1.A.3.c) as well as waterborne navigation (1.A.3.d).

Using tier 1 methodology, the quantity of fuel consumed in the various transport vessels was the activity data and the emission factors applied were the appropriate default emission factors as per the category. The fuel used in this sub-category was motor gasoline, diesel, jet kerosene, and aviation gasoline, as tabulated below.

Table 3-4: Fuels used in transport.

Category	Code	Fuel
International civil aviation	1.A.3.a.i	Jet kerosene
Domestic civil aviation	1.A.3.a.ii	Jet kerosene Aviation gasoline
Cars	1.A.3.b.i	Motor gasoline
Heavy duty trucks and buses	1.A.3.b.iii	Gas/diesel oil
Motorcycles	1.A.3.b.iv	Motor gasoline
Railways	1.A.3.c	Gas/diesel oil

Overall emissions from the transport sector indicate a gradual increase from 1990 which stabilised from 2022. This is attributed to growth in the overall vehicle population and population growth.

3.2.3.1. Civil Aviation (1.A.3.a)

This sub-category accounts for emissions from civil aviation and emissions from international and domestic civil aviation, including takeoffs and landings. Comprises civil, commercial use of aeroplanes, including scheduled and charter traffic for passengers and freight, air taxiing, and general aviation. The international/domestic split should be determined on the basis of departure and landing locations for each flight stage and not by the nationality of the airline.

In civil aviation, the type of fuel used was jet kerosene and aviation gasoline. The fuel accounted for was fuel uplifted in the country by both domestic carriers as well as foreign vessels. The distinction between international and domestic civil aviation activities depended on the journey type between two airports.

Table 3-5:

Journey type between two airports	Domestic	International
Departs and arrives in same country	Yes	No
Departs from one country and arrives in another	No	Yes

Kenya has more than fifty-five (55) airports, of which four are classified as international airports[2]. Ten (10) airports have refueling infrastructure utilising either tanker or hydrant refueling systems.

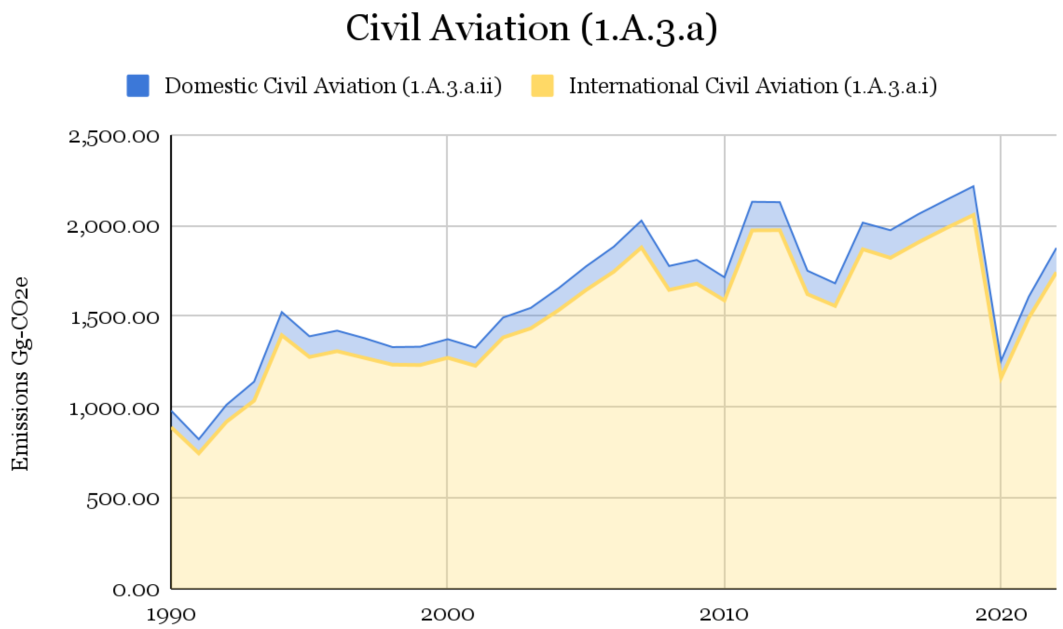


Figure 3-13: Emissions from Civil aviation (1.A.3)

The disruption to aviation, particularly passenger travel occasioned by the covid-19 pandemic in 2020 caused a sharp drop in activities and hence the sharp dip in emissions. This recovered in 2021 and into 2022 as countries and airlines eased travel restrictions allowing the full resumption of air travel.

a. International Aviation (International Bunkers) (1.A.3.a.i)

This sub-category accounted for emissions from International civil aviation.

According to the Feasibility study on the use of sustainable aviation fuels in Kenya by the International Civil Aviation Organization (ICAO) in 2018, 88% of the total aviation fuel requirement in Kenya was used for international aviation, 5% went to regional flights, leaving the 7% for domestic aviation. This split was applied to the jet fuel consumed in the country whereas all the aviation gasoline was attributed to domestic flights.

Emissions from international civil aviation, which includes regional flights, do not add to the national totals, but are reported as memo items as international bunker fuels. The trend is as shown below.

2 Jomo Kenyatta International Airport (Nairobi), Moi International Airport (Mombasa), Kisumu International Airport (Kisumu) and Eldoret International Airport (Eldoret)

b. Domestic Civil Aviation (1.A.3.a.ii)

This sub-category accounted for emissions from domestic civil aviation.

Domestic civil aviation utilized jet kerosene and aviation gasoline. Domestic civil aviation consumed jet kerosene accounting for 7% of the fuel consumed in the country. In addition, all the aviation gasoline imported was utilised in domestic civil aviation.

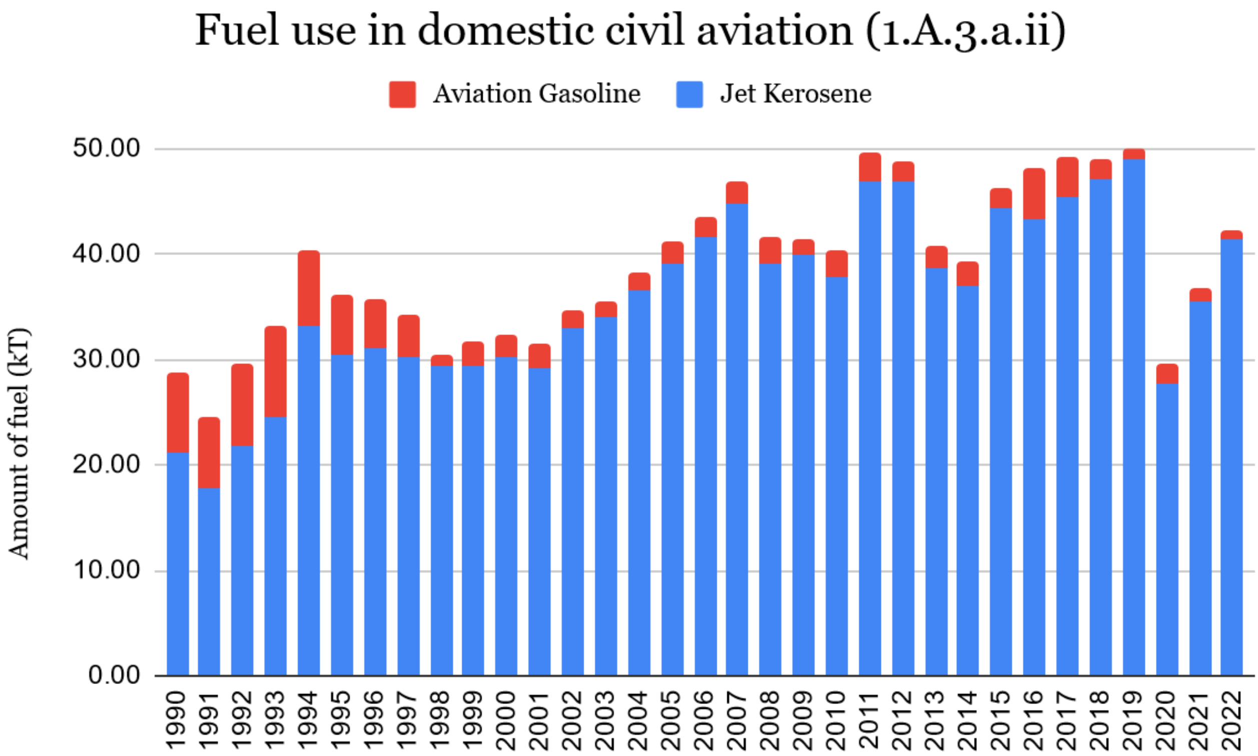


Figure 3-14: Fuel use in Domestic Civil Aviation (1.A.3.a.ii)

Fuel consumption in domestic civil aviation was driven by the consumption of jet kerosene. This is the fuel used in the larger aeroplanes, propelled by gas turbines. The smaller aeroplanes; private, training, agricultural and other small commercial planes are mostly fueled with aviation gasoline. It is known that a tiny amount of aviation gasoline is used by high-performance racing cars, but there was no data to enable a separate estimation of this fraction of the fuel.

3.2.3.2. Road Transport (1.A.3.b)

Road transport is the most important form of mechanized transport in the country. Across the time series, Road transportation has been the most significant sub-category consuming the biggest share of petroleum fuels in the country, further the emissions from the category have been on an accelerating upward trend.

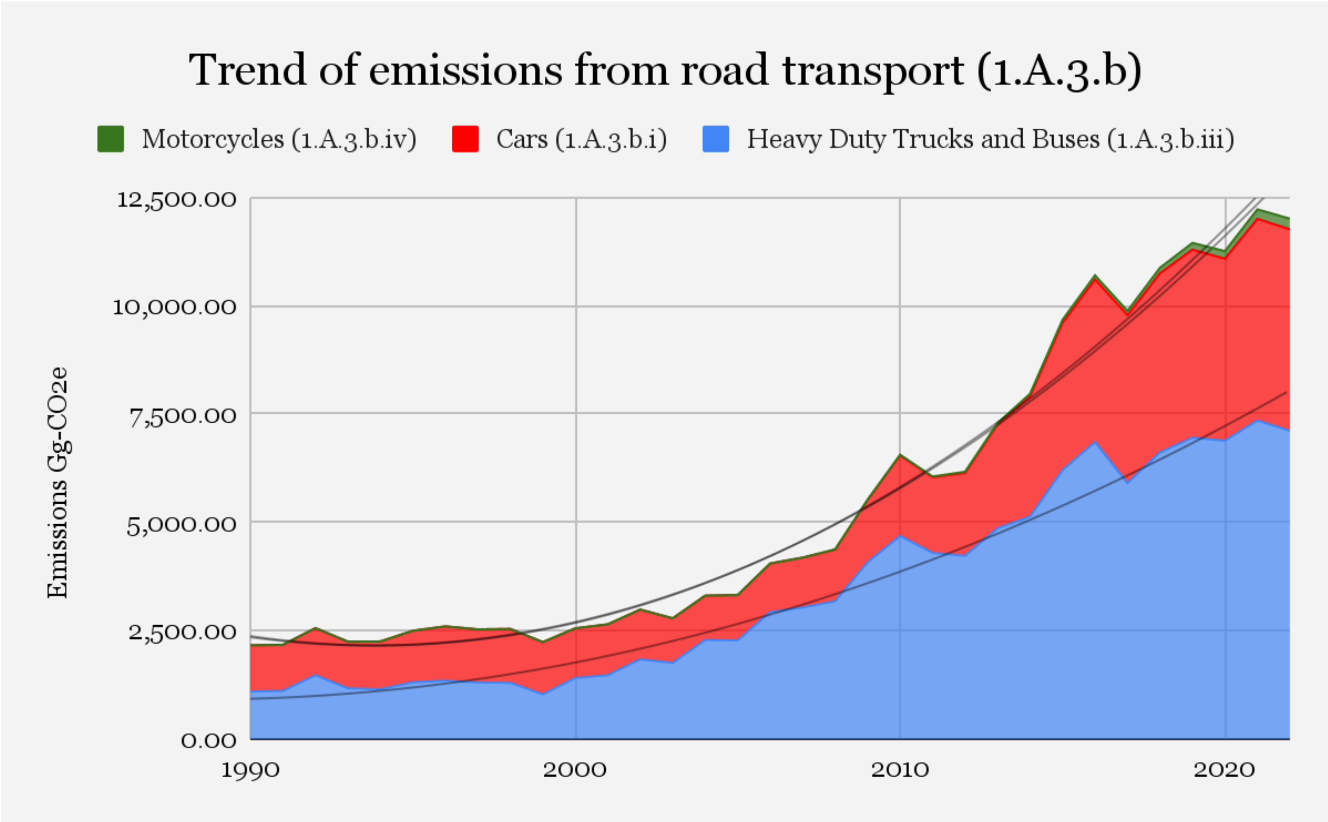


Figure 3-15: Emissions from road transport

Kenya does not manufacture any vehicles but depends on imports of vehicles (new and second-hand/used) sourced largely from Asia and Europe. Other vehicles are imported as completely knocked down (CKD) kits and assembled in the country. Whatever the source or form the vehicles come into the country, they are required to be registered before they are allowed to operate (including off-road vehicles).

Statistics from the road transport sector regulator, the National Transport and Safety Authority (NTSA) and national statistics agency Kenya National Bureau of Statistics (KNBS) give a fairly accurate account of the new registrations. However, there is no data on the actual number of vehicles (and their categories) active on the road at any one time or duration. This therefore only allowed the deployment of fuel-based methodology in estimating the emissions from the sub-category; the lack of country emission factors forced the use of tier 1 methodology.

1. Cars (1.A.3.b.i)

This sub-category reports emissions from cars. These are emissions from automobiles so designated in the vehicle registering country primarily for transport of persons and normally having a capacity of 12 persons or fewer.

It has been assumed that all the motor gasoline sold in the country is consumed in this sub-category in the years 1990 - 2022 and thereafter between 99.5% and 95% with the rest being taken up by motorcycles.

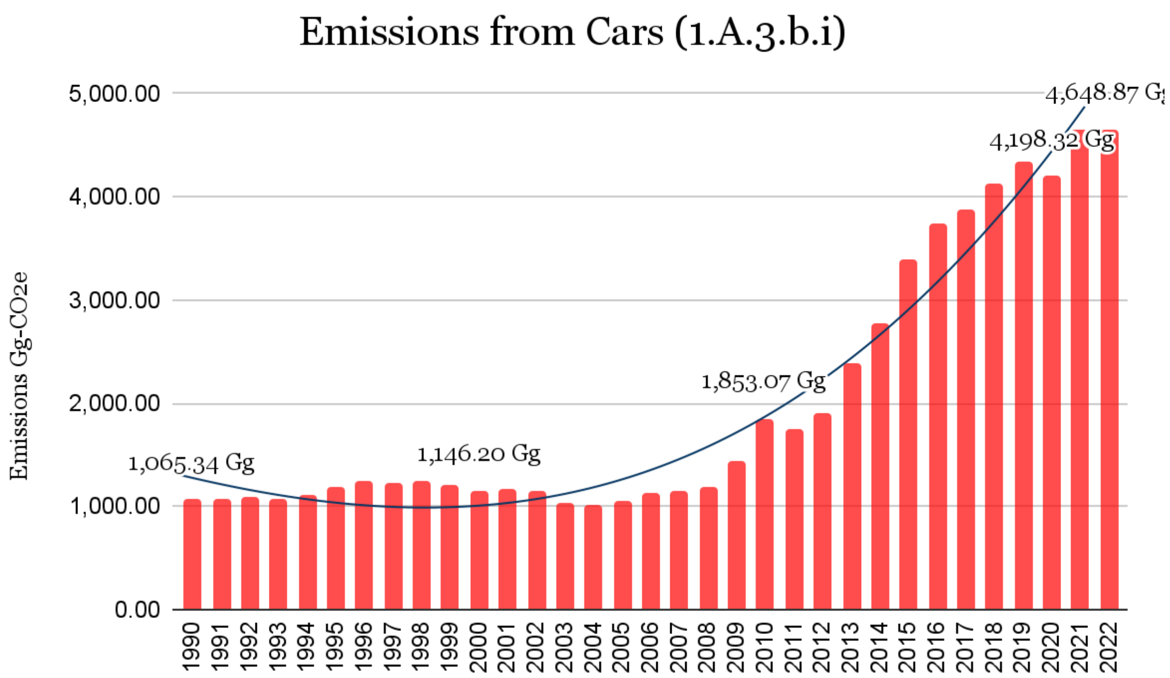


Figure 3-16: Emissions from cars

There has been a rise in car ownership as the society grew more prosperous, and growth in urbanization.

2. Heavy duty trucks and buses (1.A.3.b.iii)

This sub-category reports emissions from heavy duty trucks and buses. These are emissions from any vehicles so designated in the vehicle registering country. Normally the gross vehicle weight ranges from 3,500 - 3,900 kg or more for heavy duty trucks and the buses are rated to carry more than 12 persons.

It has been assumed that all the diesel sold in retail pump outlets was used in this sub-category.

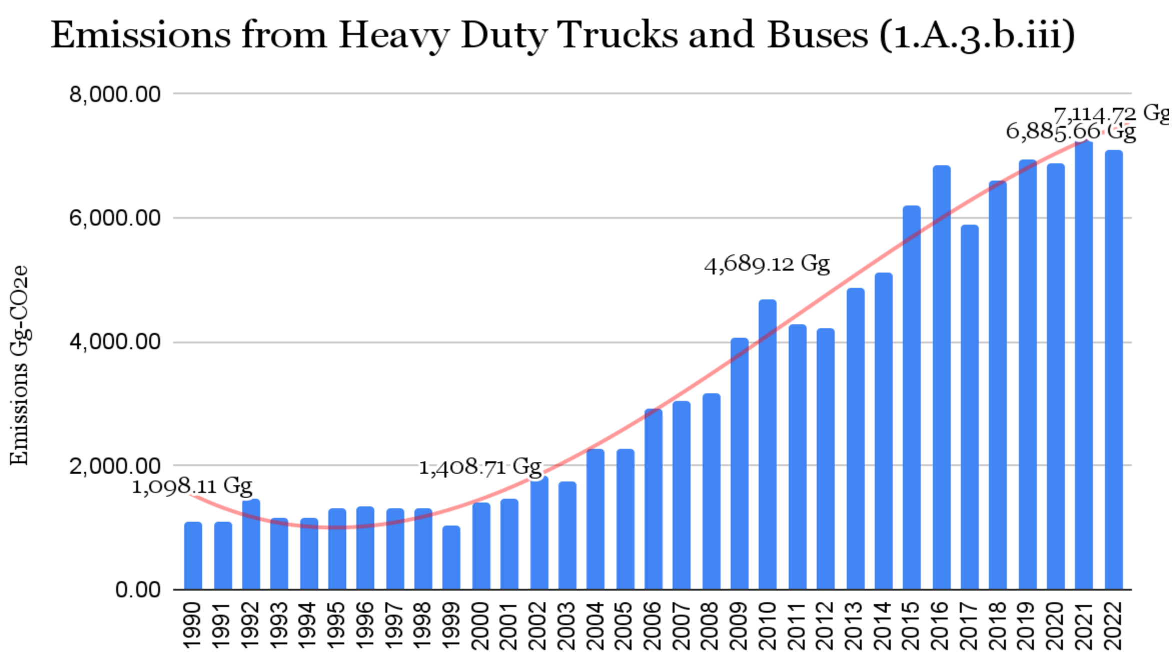


Figure 3-17: Emission from heavy duty trucks and buses.

3. Motorcycles (1.A.3.b.iv)

This sub-category reports emissions from motorcycles. These are any motor vehicles designed to travel with not more than three wheels in contact with the ground and weighing less than 680 kg.

Prior to 2007, there was only a small number of motorcycles in Kenya's traffic mix, mostly used by some government agencies and hobbyists. Thereafter, spurred on by tax incentives from the government, there was an exponential rise in the number of motorcycles imported into the country which found great use in the ***'boda-boda'*** (2-wheeler) and ***'tuk-tuk'*** (3-wheeler) taxi business as well as for private, other commercial and corporate uses. Motorcycles have become a ubiquitous means of transport and an important entrepreneurship/employment opportunity for many.

Emissions from this sub-category are only estimated from 2008 onwards, when there was a rapid growth in motorcycle numbers. The trend in growth of emissions from the sub-category shows a sustained growth in line with the motorcycle numbers.

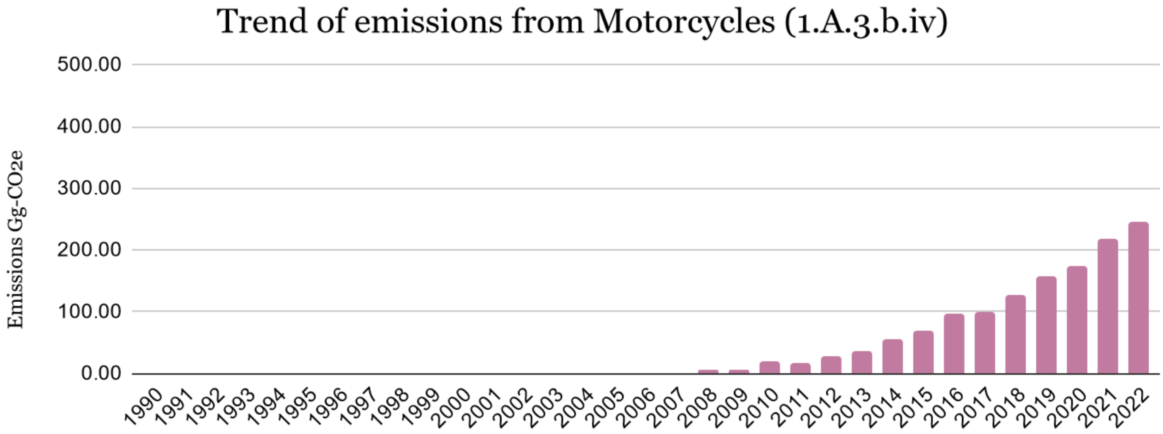


Figure 3-18: Emission estimates from motorcycles

There is a growth in adoption of electric powered motorcycles, but this has only been since 2023 with several companies offering battery swapping models. However, the activity is out of the temporal scope and the numbers are still too low to impact the national fuel statistics.

3.2.3.3. Railways (1.A.3.c)

This sub-category comprises emissions from railway transport for both freight and passenger traffic routes.

Since the early 1900s, Kenya has maintained a railway system. In 1902, the British colonial government commissioned the construction of the East African Railway, famously known as the "lunatic express," in order to connect the Indian Ocean to the East African hinterland, extending up to present-day Uganda.

Diesel locomotives have been the primary choice for railway operation since the retirement of steam engines. The majority of the locomotives are dedicated to long-distance hauling, with only a few serving the Nairobi Commuter Railway system. The newly built (2017) standard gauge railway uses diesel locomotives as well.

In 2017, a new standard gauge railway between Mombasa and Nairobi was commissioned; it was later extended to Suswa in the Rift Valley in Naivasha sub-county of Nakuru County where another inland container depot is planned. This new line enabled more cargo and passengers to be ferried from the port in Mombasa to the Inland Container Depots (ICDs) in Nairobi and Naivasha. This standard gauge railway line is operated alongside the old metre gauge railway line.

Fuel consumption closely aligns with the volume of cargo transported on the railway line. There is a marked increase in fuel consumption in 2015 and 2016 during the construction of the standard gauge railway line probably due to construction activities of the new standard gauge railway between the cities of Mombasa and Nairobi. Notably, a significant shift in this trend occurred after 2017 when the standard gauge railway line became operational. This change may be attributed to the increased utilization of passenger train services and heightened activity in the Nairobi commuter rail network

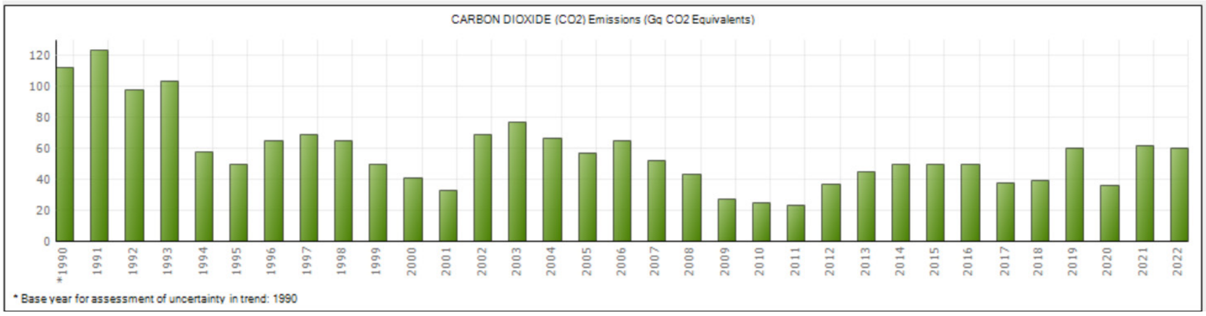


Figure 3-19: CO2 emissions from Railway Transport

3.2.3.4. Water-borne Navigation (1.A.3.d)

This sub-category accounts for emissions from Water-borne navigation activities. It includes emissions from fuels used to propel water-borne vessels, including hovercraft and hydrofoils, but excluding fishing vessels. The international/domestic split should be determined on the basis of port of departure and port of arrival, and not by the flag or nationality of the ship.

The emissions for fuels in this specific category were not estimated because there was no reliable data with which to make an accurate assignment. However, all the fuel used in the country that could be used in waterborne navigation was accounted for elsewhere in the inventory.

a. International Water-borne Navigation (International Bunkers)

The emissions for fuels in this specific category were not estimated because there was no reliable data with which to make an accurate estimate.

Kenya has one major international port in the city of Mombasa. There are a few other seaports and ports in Lake Victoria which are shared by the East African countries of Kenya, Uganda and Tanzania.

However, all the residual fuel oil and diesel oil that may have been used in this sub-category was accounted for elsewhere and this may have led to an overestimation of the country's emissions as these emissions would have been subtracted from the country totals as they are international bunker fuels.

b. Domestic Water-borne Navigation

Kenya has limited activity in the domestic water-borne navigation that is reportable under this sub-category. This category was therefore not estimated.

Kenya Ferry Service has operated ferries across the 0.5 km Likoni channel. It previously operated ferries across the Kilifi creek up to 1992. Additionally, a ferry service operates in Lake Victoria, serving the Homa Bay and Siaya Counties, while some passenger boats are utilized in the coastal islands such as Lamu and Wasini.

3.2.4. Other Sectors (1.A.4)

In this category, Kenya reports emissions from the Commercial/ Institutional (1.A.4.a), Residential (1.A.4.b) and Agriculture/ Forestry/Fishing/Fish farming (1.A.4.c) sub-categories.

Tier 1 methodology was applied in the estimation emissions from the source categories. The activity data were the amounts of fuels consumed (LPG, other kerosene, charcoal, and wood/ wood waste) consumed with the relevant default emission factors applied to estimate the emissions. Some diesel was also used in off-road vehicles and other machinery in agriculture.

This category witnesses the stacking of technology and fuel options deployed motivated by economic, cultural, convenience or other considerations. It is not uncommon to find three or more fuel and technology cooking options deployed in one household. This makes it very difficult to implement higher tier methodologies.

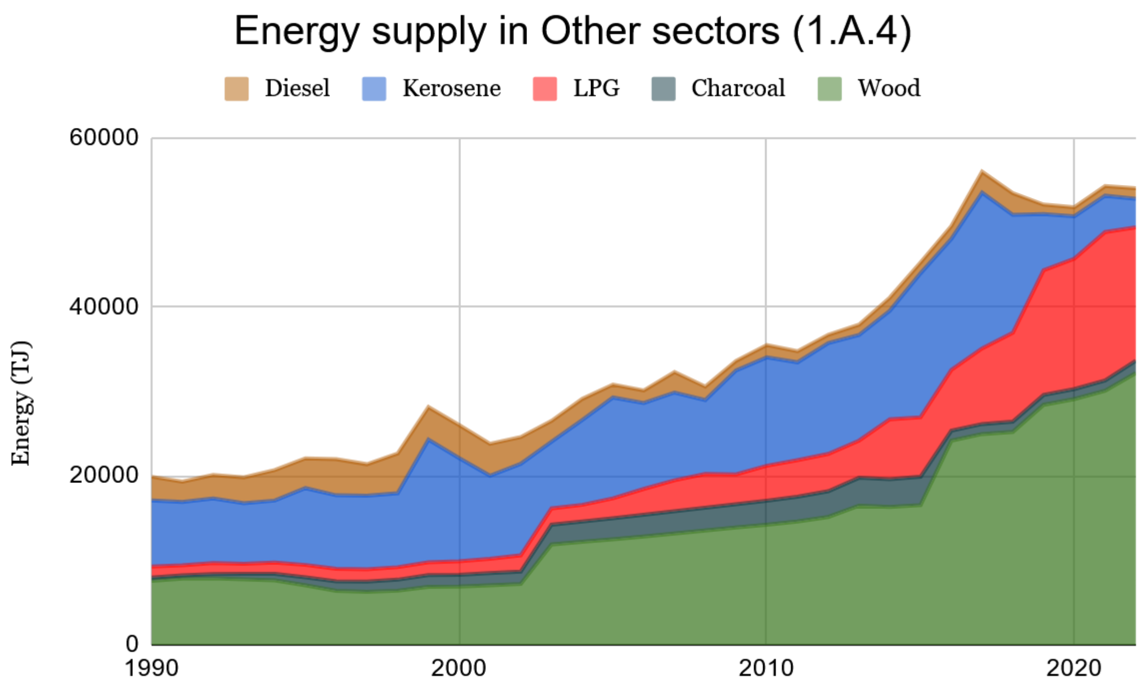


Figure 3-20: Energy supply to other sectors (1.A.4)

The sales of illuminating kerosene (other kerosene) rose sharply in the late 90s before dropping off up to the mid-nineties, then rising steadily up to 2017 when it dropped off sharply to the end of the time series (2022). Kerosene was used for heating in the commercial/institutional sub-category and for cooking and lighting in the residential space. Some kerosene is used as feedstock in industry, but this wasn't excluded as it was not possible to estimate the quantities used. The introduction of anti-adulteration levy in 2017 as well as enhanced quality enforcement by the authorities made it less viable to use kerosene for the adulteration of other petroleum fuels.

The expansion of electricity access, via the national grid, mini-grids or through standalone solar home systems as well as solar lanterns, is thought to have reduced the demand for kerosene as a fuel in residential lighting. Kerosene has been displaced by LPG and more recently bioethanol in the cooking segment.

The consumption of LPG in Kenya was observed to rise steadily throughout the time series as more and more people and commercial enterprises and institutions like hotels, hospitals and schools adopted this modern, clean and convenient fuel. Increased urbanisation and the strengthening of the gas supply chain and raised LPG's profile as a fuel option. LPG is now considered an important clean cooking fuel and an indispensable cog of the energy transition.

Prior to 2018, Kenya National Bureau of Statistics (KNBS) did not publish biomass fuel data in its annual energy statistics, so to fill the time series, international datasets were used. These included data from African Energy Commission (AFREC) and the United Nations Statistics Division, UNData. It is observed that there is a shift in the trend of woody fuels in the years 2003 and 2016, this is was attributed to correction of their models following KNBS household surveys that were conducted in 2002 and 2015.

Of all subcategories in the sector, this sun-category other sectors (1.A.4) has the highest contribution of methane due to the following reasons;

i. There is a significant use of biomass fuels which have a significantly higher emission factor of methane per unit of energy than the fossil fuels
ii. Further, the CO_2 from combustion of the biomass fuels is not counted in the emission totals.

For instance, in 2022, the following were the amounts of GHG emitted in other sectors (1.A>.)

Table 3-6: GHG emitted in 2022

	CO_2	CH_4	N_2O	Total
Mass (Gg)`	1331.16	159.275	2.089	
CO_2e (Gg)	1,331.16	4,459.7	553.585	6,344.445

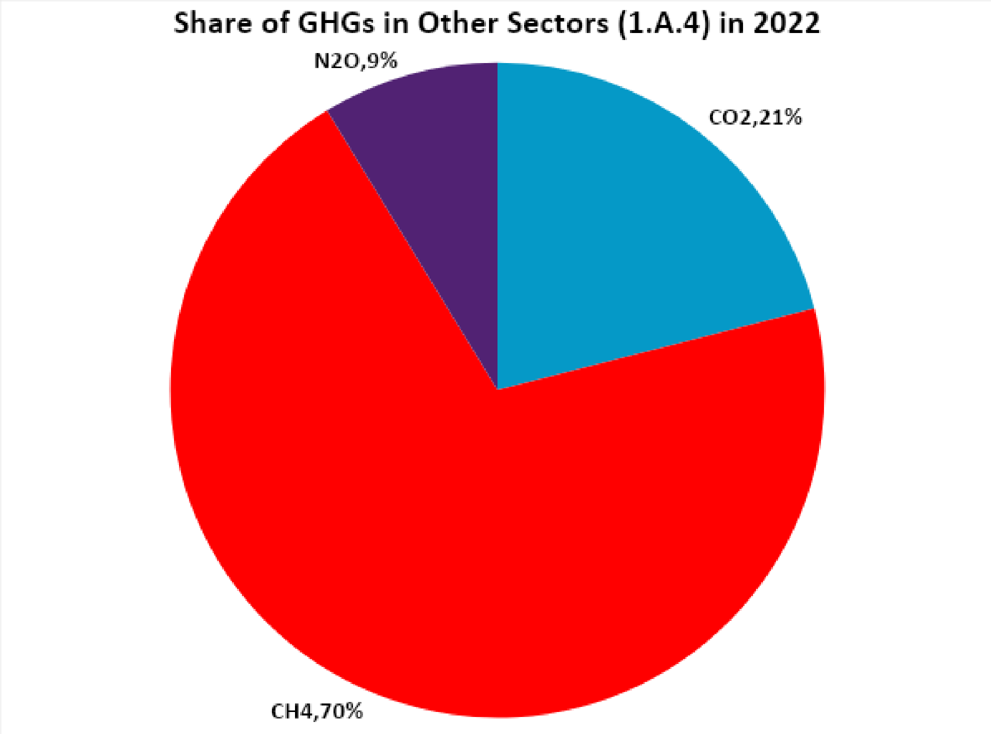


Figure 3-21: Share of GHG emissions in Other Sectors (1.A.4)

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

This sub-category accounts for emissions from fuel combustion in commercial and institutional buildings.

Four (4) fuels were considered here being; liquefied petroleum gas (LPG), other kerosene, wood/wood wastes and charcoal.

10% of all LPG and 10% of other kerosene that were consumed in the country were assumed to have been consumed under this category.

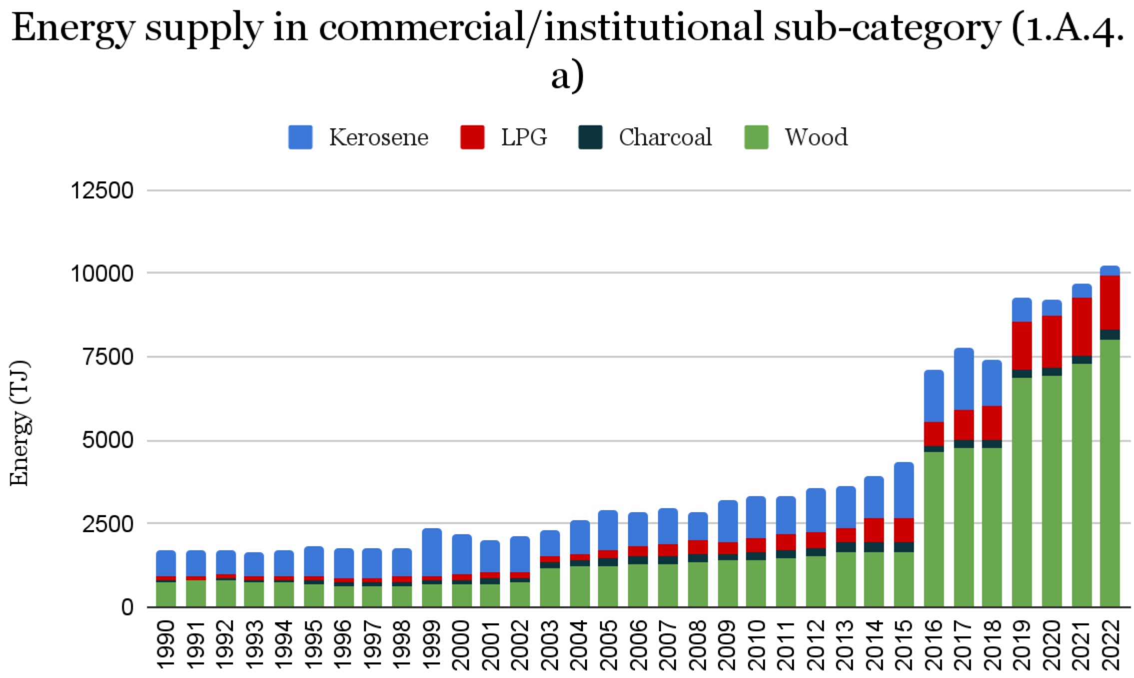


Figure 3-22: Energy supply in commercial/institutional sub-category

3.2.4.2. Residential (1.A.4.b)

This sub-category accounts for emissions from fuel combustion in households.

Similarly, four (4) fuels were considered here: liquefied petroleum gas (LPG), other kerosene, wood/wood wastes, and charcoal. 90% of all LPG as well as 90% of the other kerosene consumed in the country were assumed to have been consumed in this sub-category.

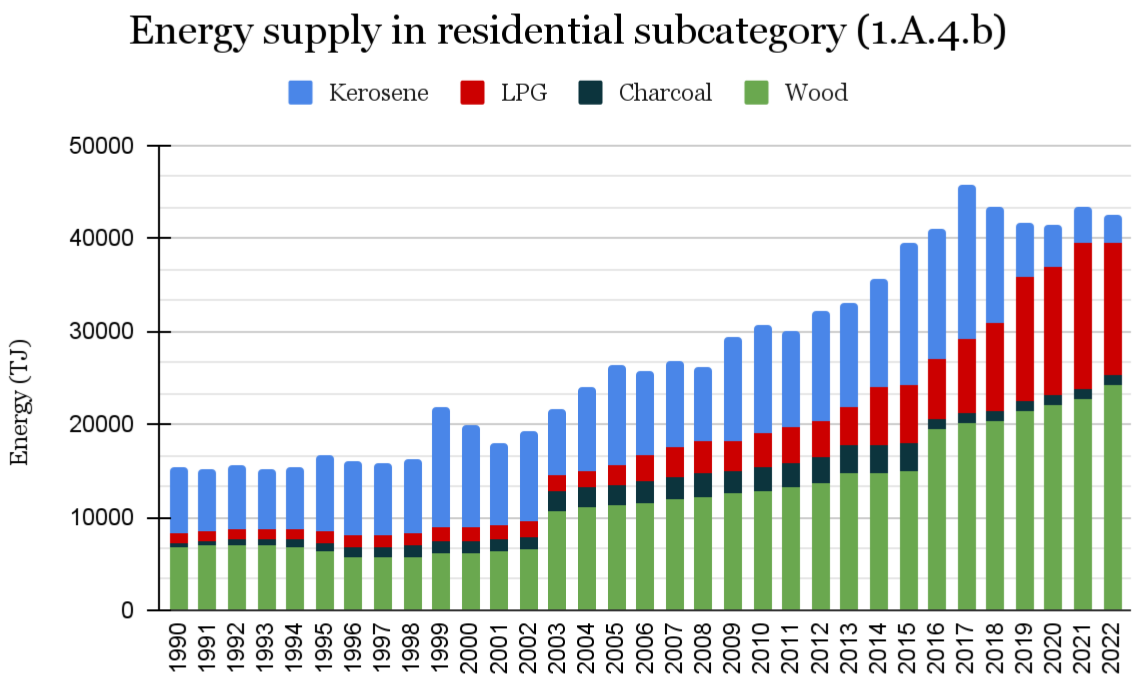


Figure 3-23: Energy supply in residential sub-category

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

This sub-category accounts for emissions from fuels combusted in pumps, grain drying, horticultural greenhouses and other agriculture, forestry or stationary combustion in the fishing industry.

Emissions from fuel combustion in agriculture, forestry, fishing and fishing industries such as fish farms. Under this subcategory emissions were estimated under the mobile division (1.A.4.c.i) where the fuel used was diesel.

3.3. Fugitive emissions from fuels (1.B)

Not Estimated (NE).

There have been exploration activities in the oil and gas sector as well as coal in various parts of Kenya.

Under the Early Oil Pilot Scheme (EOPS) by the government of Kenya and Tullow Oil Company developed five (5) existing wells in the Amosing and Ngamia fields located in Blocks 13T and 10BB in Turkana County in the North of the country which saw the extraction and transportation of 2,000 barrels of oil per day (bopd) by road from Turkana to the port city of Mombasa. The EOPS culminated in the maiden lifting of 240,000 barrels of Kenyan crude in 2019.

Kenya operated a refinery for about 50 years before it was shut down in 2013, emissions from fuel combustion in the refinery were estimated under petroleum refining 1.A.1.b. There are no emission factors for fugitive emissions from petroleum refining for developing countries, and no country emission factors, so the estimation could not be undertaken.

Coal exploration led to the discovery of 400 million tonnes of coal in Mui basin of Kitui County in the Eastern region of Kenya but so far, no mining activities have taken place. Exploration for coal in other parts of the country is yet to encounter any coal reserves.

3.4. Carbon dioxide transport and storage (1.C)

Not Occurring (NO).

There are no activities that would lead to reportable emissions under this category anywhere in Kenya.

3.5. Key Category Analysis

Key category analysis was conducted for this sector, Energy, for the first year (1990) and the latest year (2022) and the following were observed;

A	B	C	D	E	F	G
IPCC Category code	IPCC Category	Greenhouse gas	1990 Ex,t (Gg CO2 Eq)	|Ex,t| (Gg CO2 Eq)	Lx,t	Cumulative Total of Column F
1.A.3.b	Road Transportation - Liquid Fuels	CARBON DIOXIDE (CO2)	2124.919821	2124.919821	0.33573556	0.33573556
1.A.2	Manufacturing Industries and Construction - Liquid Fuels	CARBON DIOXIDE (CO2)	1074.11076	1074.11076	0.169708605	0.505444165
1.A.4	Other Sectors - Biomass - solid	METHANE (CH4)	1055.76277	1055.76277	0.166809637	0.672253802
1.A.4	Other Sectors - Liquid Fuels	CARBON DIOXIDE (CO2)	852.4690652	852.4690652	0.134689402	0.806943204
1.A.1	Energy Industries - Liquid Fuels	CARBON DIOXIDE (CO2)	433.8184026	433.8184026	0.068542946	0.87548615
1.A.2	Manufacturing Industries and Construction - Solid Fuels	CARBON DIOXIDE (CO2)	368.54268	368.54268	0.058229436	0.933715586
1.A.4	Other Sectors - Biomass - solid	NITROUS OXIDE (N2O)	128.1262879	128.1262879	0.020243847	0.953959433

Figure 3-24: Key Category Analysis, Level Assessment, 1990

A	B	C	D	E	F	G
IPCC Category code	IPCC Category	Greenhouse gas	2022 Ex,t (Gg CO2 Eq)	|Ex,t| (Gg CO2 Eq)	Lx,t	Cumulative Total of Column F
1.A.3.b	Road Transportation - Liquid Fuels	CARBON DIOXIDE (CO2)	11799.87979	11799.87979	0.548872709	0.548872709
1.A.4	Other Sectors - Biomass - solid	METHANE (CH4)	4456.386379	4456.386379	0.207289304	0.756162013
1.A.2	Manufacturing Industries and Construction - Solid Fuels	CARBON DIOXIDE (CO2)	1544.95044	1544.95044	0.07186354	0.828025553
1.A.4	Other Sectors - Liquid Fuels	CARBON DIOXIDE (CO2)	1331.16356	1331.16356	0.06191922	0.889944773
1.A.1	Energy Industries - Liquid Fuels	CARBON DIOXIDE (CO2)	901.4811684	901.4811684	0.041932496	0.931877269
1.A.4	Other Sectors - Biomass - solid	NITROUS OXIDE (N2O)	543.2037713	543.2037713	0.025267183	0.957144452

Figure 3-25: Key Category Analysis, Level Assessment, 2022

The key categories mostly remained the same with only Other sectors - Biomass - solid fuels (Nitrous Oxide) falling off the key categories.

Road Transportation - Liquid Fuels (Carbon dioxide) has grown in importance from a third (33.6%) of the sectoral emissions to more than half (54.9%) of the emissions.

3.6. Time series consistency

Most of the areas had activity data throughout the time series (1990 - 2022). Some trends could however not be completely explained pointing to data quality issues. Recalculations will be undertaken once better, more accurate datasets are available.

3.7. Uncertainty Analysis

Activity data used to estimate emissions in the Energy Sector were largely derived from national energy statistics reported in the annual economic survey reports. This data is not disaggregated hence expert judgement was applied which is a source of uncertainties.

The following criteria was applied in attributing the different fuels to the different source categories;

i. The estimation used default emission factors which could be different from those specific to the country's fuels, technologies in use and the combustion efficiencies.

ii. Besides the fuel oil consumed in the refinery as refinery usage, all residual fuel oil consumed in the country is assumed to be used for electricity generation and in industry. The fuel oil used in electricity generation was calculated based on the power generated from the plants using their specific fuel consumption data, and the rest of the fuel oil attributed to non-specified industry (1.A.2.m)

iii. All coal imported into the country was assumed to be used in non-metallic minerals, in the manufacture of cement and lime.

iv. Under civil aviation, 93% of jet kerosene is consumed by international flights while 7% of is consumed by local flights. This split was applied throughout the time series, 1990 - 2022.

v. Motor Gasoline used in road transport is split between cars and motorcycles. It was assumed to be used at 100% by cars between 1990 and 2007 where fuel consumption by motorcycles was considered to be negligible due to their small numbers. From 2008 to 2022 the motor gasoline was apportioned between cars and motorcycles at a gradually increasing share from 0.5 - 5% of the total country's sales.

vi. In other sectors wood and charcoal were consumed in the commercial and residential sectors at 10% and 90% respectively.

vii. Having used the fuel-based tier 1 methodology throughout the sector some of those assumptions are not expected to lead to emission quantification inaccuracies, but rather misallocation of the emissions to the relevant source category.

viii. The following might, however, lead to under- or over-estimation of emissions;

ix. Misallocation of bunker fuels, in case the split does not apply to all the years across the time series;

x. The use of default carbon contents of the various fuels and default emission factors might have led to inaccurate emission estimates;

xi. Not estimating the fuel fraction applied to non-energy uses could have led to an overestimation of emissions;

xii. Incompleteness of the inventory categories;

  a. Fuel used for charcoal making,

  b. Fugitive emissions from oil and gas exploration,

  c. Biogas use in electricity generation, residential and commercial sub-categories

3.8. Areas for Improvement

Several areas of improvement have been identified for the energy sector to aid in the preparation of quality inventory;

i. Train experts on estimation/quantification of uncertainty;

ii. Development of country specific emission factors for the various emission source categories;

iii. Development of frameworks for data collection, sharing and archiving among institutions that handle data and statistics. This will include developing annual national energy balances to improve the accuracy of the inventory

iv. Estimation of fugitive emissions from fuel handling, petroleum exploration activities and pipeline transport;

v. Put in place arrangements for data collection, sharing and archiving in the Waterborne navigation (maritime) sector

vi. Disaggregation of the activity data to the various vehicle categories and technologies

vii. Data collection arrangement for biomass

Chapter 04:

Industrial Processes and Product Use

4.1. Sector Overview

The Industrial Processes and Product Use (IPPU) sector covers greenhouse gas emissions resulting from industrial processes, the use of gases in products, and from non-energy uses of fossil fuels.

In this inventory, the IPPU sub-categories for which emissions were estimated include;

- Mineral Industry (2.A)
  - Cement production (2.A.1),
  - Lime production (2.A.2) and
  - Glass production (2.A.3).
- Chemical Industry (2.B).
  - Soda Ash Production (2.B.7)

4.2. Description of the Sector

Under this sector, cement accounts for the bulk of emissions, typically more than 90% of the sectoral emissions throughout the timeseries.

Under the Mineral industry (2.A), cement manufacturing is one of the most important industries in Kenya contributing 7% of the GDP in 2021 (KNBS 2022). The production of cement is driven by demand from the construction activities in the building and infrastructure sectors of the economy. Kenya currently has seven (7) cement manufacturers, with four (4) producing clinker, mainly used for in-house cement production.

Lime production occurs in Kenya mainly for local consumption.

There are two main glass producers (mainly packaging products) in Kenya presently estimated to have a total production capacity of **90,000 tons/year** glass packaging industry.

Under the chemical industry (2.B), emissions have been estimated from Soda ash production which is mainly for export with only a small fraction consumed in the country. Soda ash is produced from trona, which is mined in Lake Magadi, one of the lakes in the South of the country and the only one of its kind in Africa.

4.3. GHG Trends in the IPPU sector

In 2022, Kenya's emissions from the IPPU sector were equivalent to **3,677.2** Gg-CO_2eq having increased from **764 G**g-CO_2eq (381 percent) since 1990 (Table 4-1 and figure 4-1).

Table 4-1: Summary IPPU emissions 1990-2022

Year	1990	2000	2010	2020	2022
Cement production (2.A.1)	721.5	547.1	1,346.8	1,963.2	3,604.4
Lime production (2.A.2)	10.4	11.3	35.3	21.8	21.8
Glass Production (2.A.3)	0.0	0.0	3.4	7.0	6.7
Soda Ash Production (2.B.7)	32.0	32.9	65.4	35.1	44.4
Total IPPU (Gg-CO_2eq)	**764.0**	**591.2**	**1,450.8**	**2,027.1**	**3,677.2**

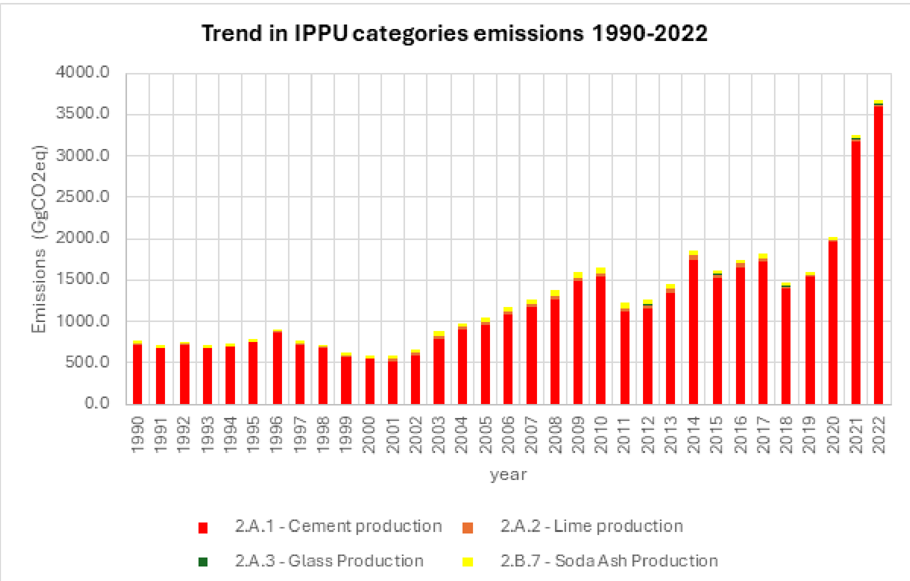


Figure 4-1: Trend in IPPU emission 1990-2022

The sectoral greenhouse gas emissions were a result of emissions from the production of cement, soda ash, lime and glass (in descending order). The largest source of emissions in the IPPU sector emissions in Kenya was from cement production, accounting for nearly 97% share of all IPPU emissions in 2022. The other sub-categories, lime production soda ash production and, contributed 1% each, while glass production accounted for 0.16%.

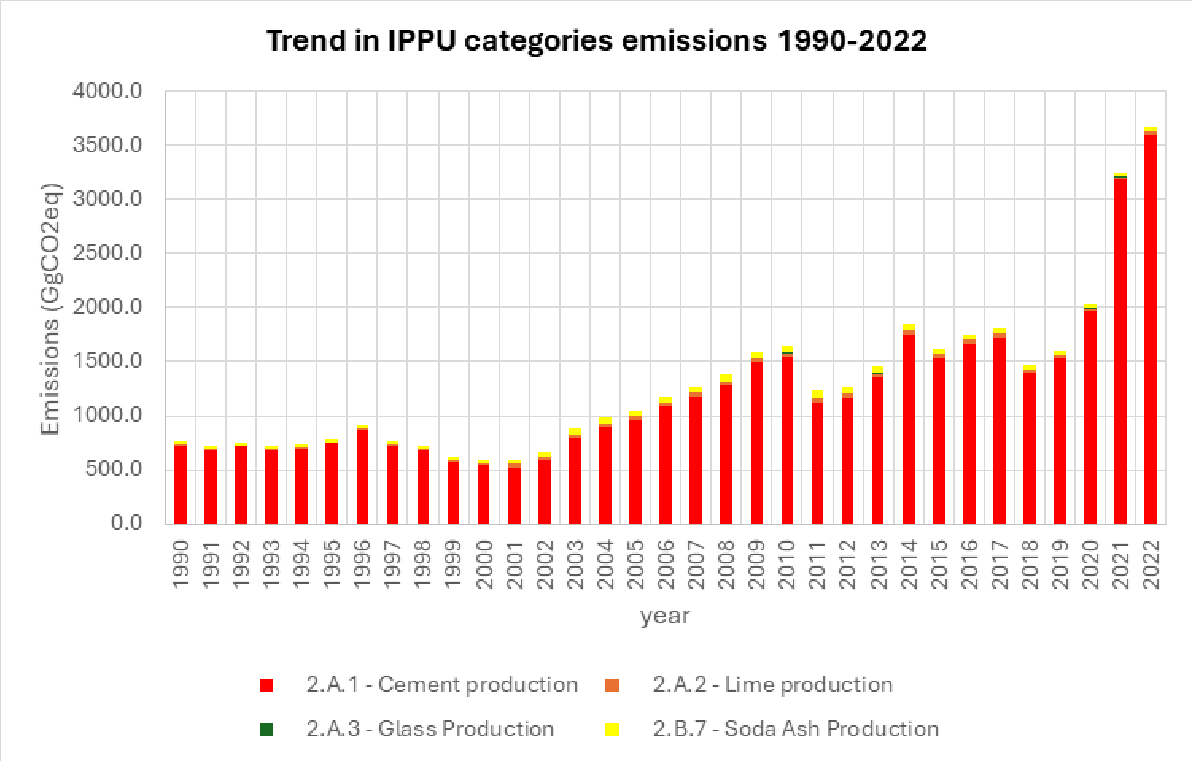


Figure 4-2: ***Percentage share contribution by sub-category in 2022.***

4.4. General Methodological Aspects of the Sector

Tier 1 approach of the 2006 IPCC Guidelines was used to estimate emissions from the different sub-categories of the IPPU sector. This is due to a lack of country specific emission factors meaning the inventory was estimated using the IPCC default emission factors as are published in the or as embedded in the IPCC inventory software. Activity data for the sector were derived from national statistics and data supplied from specific industries; there was also the use of international datasets particularly for lime production statistics.

Greenhouse gas is produced from a wide variety of industrial activities. The main emission sources are releases from industrial processes that chemically or physically transform materials. During these processes, many different greenhouse gases, including carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs) and sulphur hexafluoride (SF_6) can be produced. Emissions from fuel use in the industries is reported under energy in accordance with the guidelines

The following are the greenhouse gases whose emissions are estimated from the sub-categories reported in this inventory under IPPU.

Table 4-2: ***greenhouse gases estimated under IPPU***

Category	Sub-category	Gas
Mineral Industries (2.A)	Cement production (2.A.1)	CO_2
	Lime production (2.A.2)	CO_2
	Glass production (2.A.3)	CO_2
Chemical Industries (2.B)	Soda ash production (2.B.7)	CO_2

Table 4-3 below summarises the emission factors and coefficients for the IPPU sector used in this inventory.

Table 4-3: Emission factors and coefficients for select minerals

Mineral	Description of Emission Factor / Coefficient	Value
Cement	Fraction of clinker in cement (%/Mt)	OPC; 0.95, PPC; 0.75, PLC; 0.75
	CO_2 Emission Factor per ton of Clinker produced	0.52 t CO_2; / t Clinker
	SO_2 emission factor per ton of cement produced	0.3 kg SO_2 / t cement
Lime	Stoichiometric Ratio (CO_2 / CaO)	0.79
	CaO Content	0.85
	MgO Content	0.85
Soda Ash	CO_2 emission factor per ton of trona utilized	0.097 tCO_2 / t trona
	CO_2 emission factor per ton of soda ash used	0.138 tCO_2 / t soda ash used
Glass	CO_2 emission factor per ton of glass(flint)	0.210 tCO_2/t of glass

4.5. Mineral Industry (2.A)

This section outlines methodologies for estimating process-related carbon dioxide (CO_2) emissions resulting from the use of carbonate raw materials in the production and use of a variety of mineral industry products.

In this inventory, Kenya reports the following sub-categories under the mineral industry;

i. Cement production (2.A.1)
ii. Lime production (2.A.2)
iii. Glass production (2.A.3)

4.5.1. Cement Production (2.A.1)

4.5.1.1. Description and Trends of GHGs

In cement manufacture, CO_2 is produced during the production of clinker. During the production of clinker, limestone, which is mainly calcium carbonate ($CaCO_3$), is heated, or calcined, to produce lime (CaO) and CO_2 as a by-product. The CaO then reacts with silica (SiO_2), alumina (Al_2O_3), and iron oxide (Fe_2O_3) in the raw materials to make the clinker minerals (chiefly calcium silicates).

GHG emissions from cement production increased from **721.5** Gg-CO_2eq in 1990 to **3,535.05 Gg-CO_2eq** in 2022, as shown in figure 4-3. Cement production in Kenya increased significantly due to growth in the real estate sector and big infrastructure projects undertaken by the government. The cement production increase was also as a result of rising domestic and regional consumption.

Between 1990 - 2010, Kenya produced two types of cement, ordinary portland cement (OPC) and pozzolana-modified cement (PMC). Up to the year 2005 OPC made up 75% of the cement production with the rest being PMC; this sharing was evenly split (50:50) between 2006 - 2010. From 2011, a third type of cement came into the market, Portland Pozzolana Cement (PPC) altering the share to settle at OPC (3%), PMC (7%) and PPC (90%)

Cement production has been gradually increasing over the time series as the economy grew from 1.5 million tonnes in 1990 to 9.7 million tonnes in 2022. The growth is driven by increased activity in the real estate and infrastructure sector, which are the main drivers of demand.

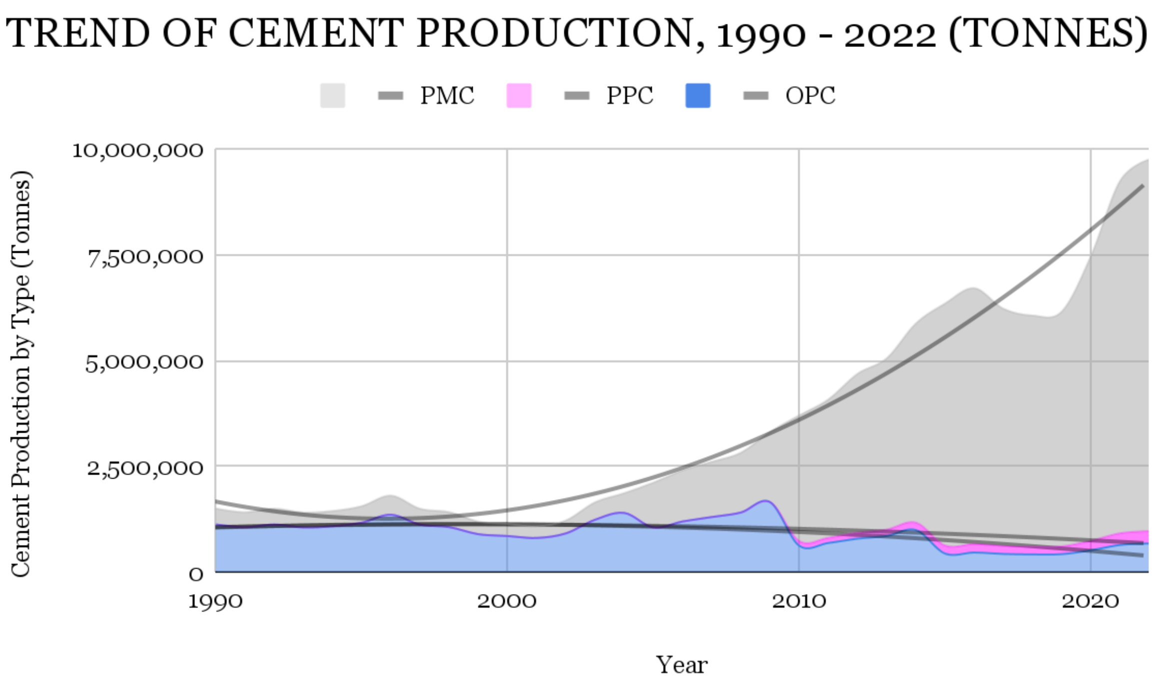


Figure 4-3: Trend of cement production, 1990 – 2022

4.5.1.2. Methodological Aspects of the Cement Production

Tier 1 approach was used to estimate emissions from this sub-category, applying equation 2.1 of the 2006 IPCC Guidelines for estimating emissions from cement production.

EQUATION 2.1 TIER 1: EMISSIONS BASED ON CEMENT PRODUCTION

$$CO_2\ Emissions = \{[\sum_i (M_{ci} \bullet C_{cl_i})] - \mathrm{Im} + Ex\} \bullet EF_{clc}$$

Where:

CO_2 Emissions - Emissions of CO_2 from cement production, tonnes

M_{ci} - Weight (mass) of cement produced, of type i, tonnes,

C_{cli} - Clinker fraction of cement of type i, fraction,

I_m - Imports for consumption of clinker, tonnes,

Ex - Exports of clinker, tonnes,

EF_{clc} - Emission factor for clinker in the particular cement, tonnes CO_2/tonne clinker, (The default clinker emission factor (EF_{clc}) is corrected for CKD).

Kenya supplemented her clinker production capacity to meet her needs with imports from 2011 to 2022. These clinker imports were considered in the estimation of the emissions from the industry. Table 4-4 shows the activity data used in deriving cement production emission estimates.

Table 4-4: Cement production 1990 - 2022.

Year	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
OPC	1,133,625	1,066,950	1,130,475	1,062,150	1,089,225	1,174,500	1,362,000	1,129,500	1,069,500	903,000	859,500
PMC	377,875	355,650	376,825	354,050	363,075	391,500	454,000	376,500	356,500	301,000	286,500
PPC	0	0	0	0	0	0	0	0	0	0	0
Cement Total	1,511,500	1,422,600	1,507,300	1,416,200	1,452,300	1,566,000	1,816,000	1,506,000	1,426,000	1,204,000	1,146,000
Clinker Imports	0	0	0	0	0	0	0	0	0	0	0

Year	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
OPC	813,750	921,750	1,243,500	1,404,975	1,061,600	1,202,950	1,307,550	1,414,800	1,660,150	630,666	694,960
PMC	271,250	307,250	414,500	468,325	1,061,600	1,202,950	1,307,550	1,414,800	1,660,150	2,967,840	3,270,400
PPC	0	0	0	0	0	0	0	0	0	0	0
Cement Total	1,085,000	1,229,000	1,658,000	1,873,300	2,123,200	2,405,900	2,615,100	2,829,600	3,320,300	3,709,800	4,088,000
Clinker Imports	0	0	0	0	0	0	0	0	0	0	1,087,623

Year	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
OPC	797,929	860,047	1,000,025	444,703	470,078	436,121	424,893	431,410	523,152	647,339	682,780
PMC	3,754,960	4,047,280	4,706,000	5,717,610	6,043,860	5,607,270	5,462,910	5,546,700	6,726,240	8,322,930	8,778,600
PPC	140,811	151,773	176,475	190,587	201,462	186,909	182,097	184,890	224,208	277,431	292,620
Cement Total	4,693,700	5,059,100	5,882,500	6,352,900	6,715,400	6,230,300	6,069,900	6,163,000	7,473,600	9,247,700	9,754,000
Clinker Imports	1,489,245	1,427,115	1,307,225	1,973,231	2,002,865	1,504,627	2,016,670	1,813,898	2,008,427	1,065,709	656,499

The emissions from the sub-category were estimated using Tier 1 methodology and yielded the results as depicted in the graph below (figure 4-4).

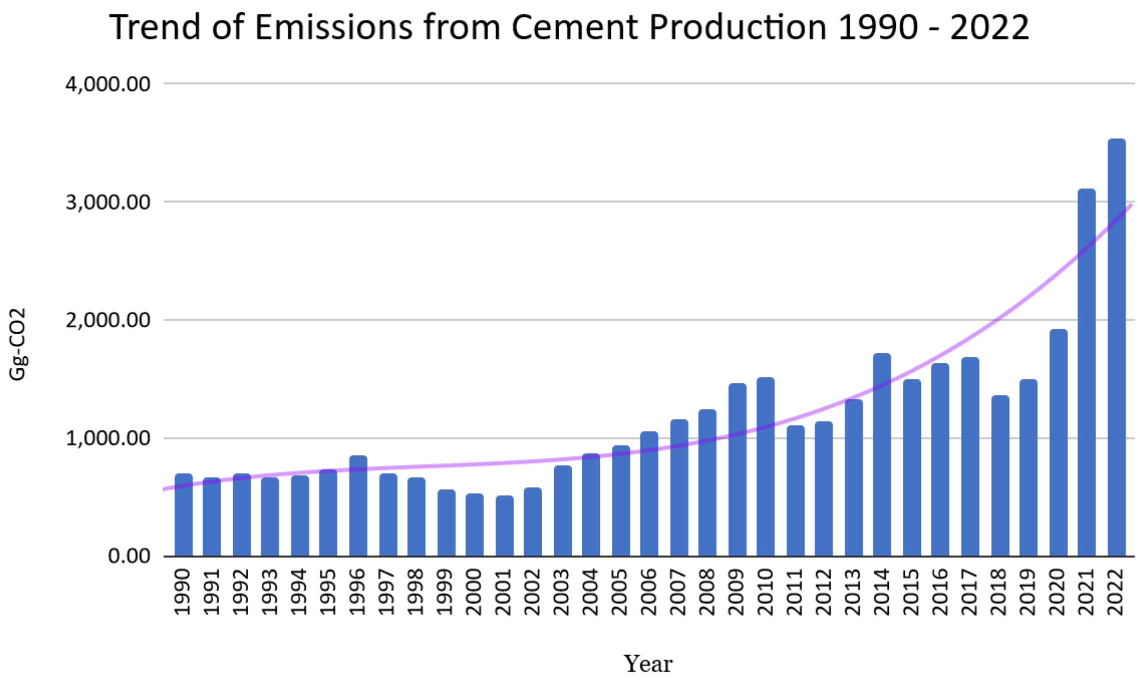


Figure 4-4: *Trend of GHG emission from cement production*

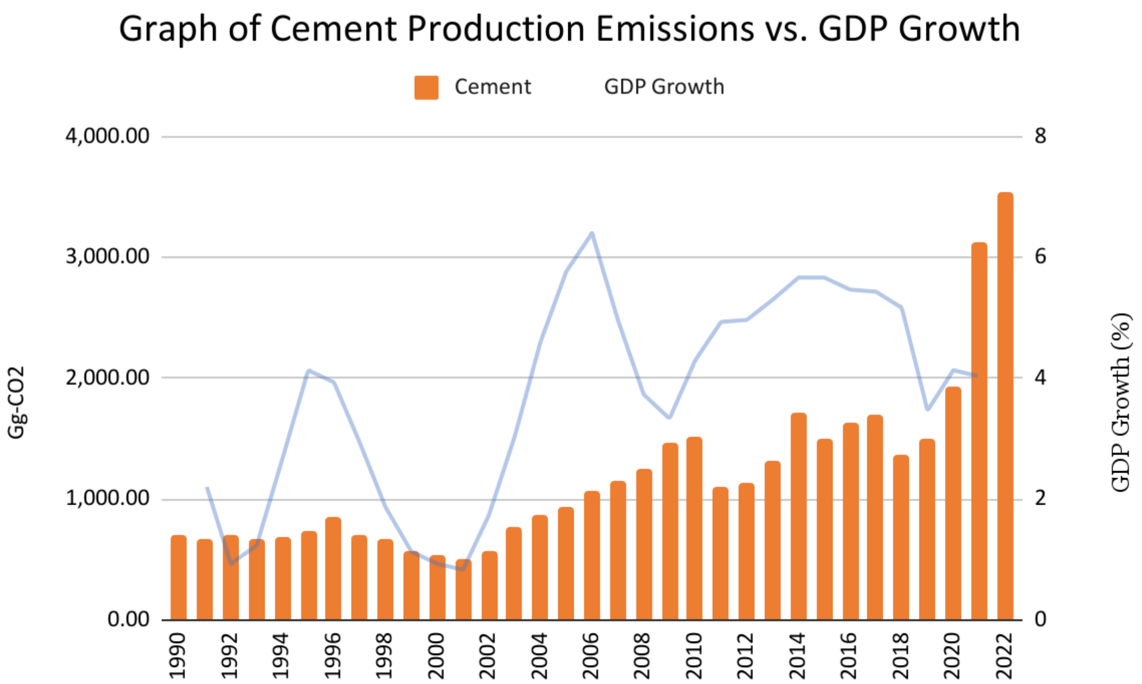


Figure 4-5: *Comparison of emission from Cement production and GDP growth*

Considering a 3-year moving average of GDP growth, it is apparent that cement production. and consequently emissions, trend with the economic performance of the country. Since the year 2000, Kenya has witnessed an accelerated growth in real estate and infrastructure development.

Cement manufacturing plants have increased their capacities and even new ones opened in response to this demand. Plants have also upped their clinker production capacities to boost their production. As at the end of 2022, there were seven (7) cement manufacturing companies with a total production capacity of 10 million tonnes, up from four 4 million tonnes in 1990.

From 2000 - 2010 there was a steady increase in the production of cement. This trend was disrupted in 2011 probably due to the availability of clinker import data that was factored in the estimation of emissions. It is possible then that there could have been an overestimate of emissions from this subcategory for the earlier years where there isn't any clinker import data.

4.5.2. Lime Production (2.A.2)

4.5.2.1. Description and Trends of GHG

This sub-category accounts for process emissions from the production of lime.

Lime is an important industrial mineral product produced from limestone that has many industrial, chemical, and environmental applications. It is a widely used chemical alkali in the world. The major uses in Kenya are in construction and agricultural applications, as well as for water purification.

Lime refers to a variety of chemical compounds that include calcium oxide or high–calcium quicklime (CaO),; calcium hydroxide ($Ca(OH)_2$), or hydrated lime; dolomitic quicklime ([CaO.MgO]); and dolomitic hydrate ($[Ca(OH)_2.MgO]$ or $[Ca(OH)_2.Mg(OH)_2]$).

Lime production involves three main processes: limestone preparation, calcination, and hydration. Carbon dioxide is released during the calcination process, when limestone (mostly calcium carbonate - $CaCO_3$) is baked (calcined) in a kiln at high temperatures to produce CaO and CO_2.

Heat

$CaCO_{3\ (High\ purity\ limestone)}$ —-------------------> CaO $_{(quicklime)}$ + CO_2

The CO_2 is given off as a gas and is normally emitted to the atmosphere.

Figure 4-6 shows the emissions trend from Lime production. GHG emissions from Lime production increased from **10.4 Gg-CO_2eq** in 1990 to **42.8 Gg-CO_2eq** in 2015 and dropped to **21.84 Gg-CO_2eq** in 2022. The emissions increased significantly in 2000 with the introduction of a new lime production plant bringing up emissions to over **40 Gg-CO_2eq.**

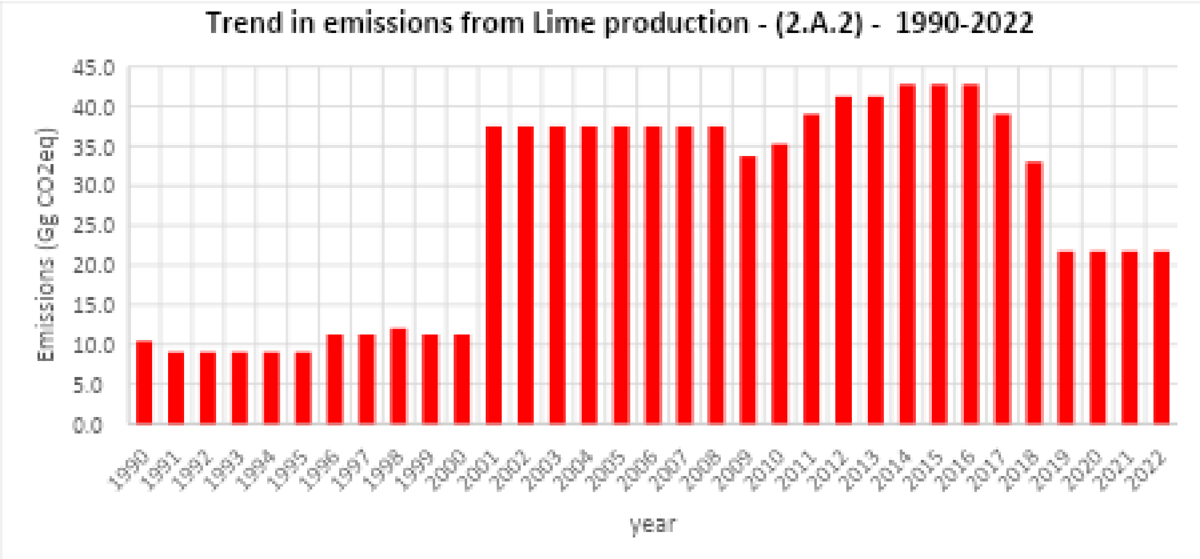


Figure 4-6: Trend In lime Production emissions 1990-2022

Between 1995 and 1999 the country had only one major lime production plant (and many smaller, essentially artisanal, facilities). Lime production increased in 2000 with the introduction of a new lime production plant at Athi River Mining Company. The production bumped up from 15,000 tonnes in the year 2000 to 50,000 tonnes in 2001, following an increase in production capacity.

The data then depicts a steady increase in production from 2008 to 2016 succeeded by a steady drop until 2019, which is attributed to the diminishing performance and eventual closure of the Athi River Mining (ARM) company limited. There were two main lime manufacturers in Kenya, Homa Lime and Athi River Mining (ARM) with the latter having two plants near Nairobi. The drop in emissions in 2018-2022 could be attributed to the closure of the Athi River Mining (ARM) Limited.

4.5.2.2. Methodological Aspects of Lime Production

The lime activity data was derived from the United States Geological Survey (USGS) Minerals Yearbook, volume III, Kenya Reports for the years 1990 - 2019 and Kenya and Uganda Reports for the years 2000 - 2003. Where there was a variance between the two publications, the higher was selected as a conservative approach and will be corrected with the accurate values in subsequent inventories.

Due to lack of data beyond 2019, the 2019 values were assumed for the years 2020 - 2022 as placeholder values; these will be replaced with actual production data in subsequent inventories.

The IPCC's Tier 1 approach was used to calculate emissions from lime production using equation 2.6. The Tier 1 method is based on applying a default emission factor to national-level lime production data.

EQUATION 2.6 TIER 2: EMISSIONS BASED ON NATIONAL LIME PRODUCTION DATA BY TYPE

$$CO_2\ Emissions = \sum_i (EF_{lime,i} \bullet M_{l,i} \bullet CF_{lkd,i} \bullet C_{h,i})$$

Where:

$EF_{lime,i}$ - Emissions factor for lime of type 'i' (see Equation 2.8)

$M_{l,i}$ - Lime production of type 'i' (tonnes)

$CF_{lkd,i}$- Correction factor for lime kiln dust (LKD) for each type of lime 'i'.

This correction can be accounted for in a similar way as for CKD (Equation 2.5, but omitting the factor (Efc/EFcl))

$C_{h,i}$ - Correction factor for hydrated lime of the respective type of lime (see

Table 4-3 and accompanying text for description and default values)

i - each of the specific lime types listed in Table 4-3.

According to the IPCC guidelines, In the absence of country specific data, it is good practice to assume 85 percent production of high calcium lime and 15 percent production of dolomitic lime (Miller, 1999). Based on this, Equation 2.8 illustrates how to calculate the Tier 1 emission factor for lime production. The IPCC 2006 default emissions factor of 0.75 tonnes of CO_{2eq} per tonne of lime was used to calculate emissions. Activity data on lime production (table 4.5) were obtained from Kenya National Bureau of Statistics reports, Kenya Association of Manufacturers, with data built up from Kenya's second national communication (NC2) and published reports from the U.S Geological Survey (USGS).[3] However, some uncertainty could have been caused by inadequate and inconsistent data from the Lime industry.

EQUATION 2.8
TIER 1 DEFAULT EMISSION FACTOR FOR LIME PRODUCTION

$$\begin{aligned} EF_{Lime} &= 0.85 \bullet EF_{high\ calcium\ lime} + 0.15 \bullet EF_{dolomitic\ lime} \\ &= 0.85 \bullet 0.75 + 0.15 \bullet 0.77^{a} \\ &= 0.6375 + 0.1155 \\ &= 0.75 \text{tonnes } CO_2 / \text{tonne lime produced} \end{aligned}$$

Where the factor of 0.77 for the dolomitic lime is applied as Kenya is a developing country.

3 United States Geological Survey (US Department of the Interior), "The Mineral Industry of Kenya", yearly publications from 1996 to 2017, secondary data drawn from KNBS (Statistical Abstracts, etc.), mining industry sources, banking sources, industry interviews, industrial trade information, etc..

Table 4-5: Lime production tonnes (time series)

Year	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
Lime production (tonnes)	12,000	12,000	12,000	12,000	12,000	12,000	15,000	15,000	16,000	15,000	50,000
Year	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**
Lime production (tonnes)	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	45,000	47,000	52,000
Year	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**
Lime production (tonnes)	55,000	58,000	61,000	64,000	67,000	70,000	73,000	76,000	79,000	82,000	85,000

***Source: US Geological Survey Minerals Yearbook 2023 and from Kenya Country profile accessed on July, 2024 at** http://minerals.usgs.gov/minerals*

4.5.3. Glass Production (2.A.3)

4.5.3.1. Description and Trend of GHG

This sub-category accounts for emissions from the production of glass including emissions from the production of containers, flat (window) glass, fibre glass, and specialty glass as well as glass wool.

Glass is made from a combination of silica sand, soda ash, limestone, and dolomite. Furnace used for glass production is heated at very high temperatures to melt the ingredients forming molten concoction that is shared into various glass products by blowing, pressing and rolling.

Due to constraints in the acquisition of data in the earlier years, Kenya estimated emissions from this category from the year 2009 onwards. GHG emissions from glass production were reported for the period between 2009 and 2015 based on the available data in the country. There were only two main glass manufacturers in Kenya as most of the glass was imported.

Emissions in glass production rose from around **3.3 Gg-CO_2eq** in 2009 to doubling to **6.7** Gg-CO_2eq in 2022 as depicted in figure 4-7.

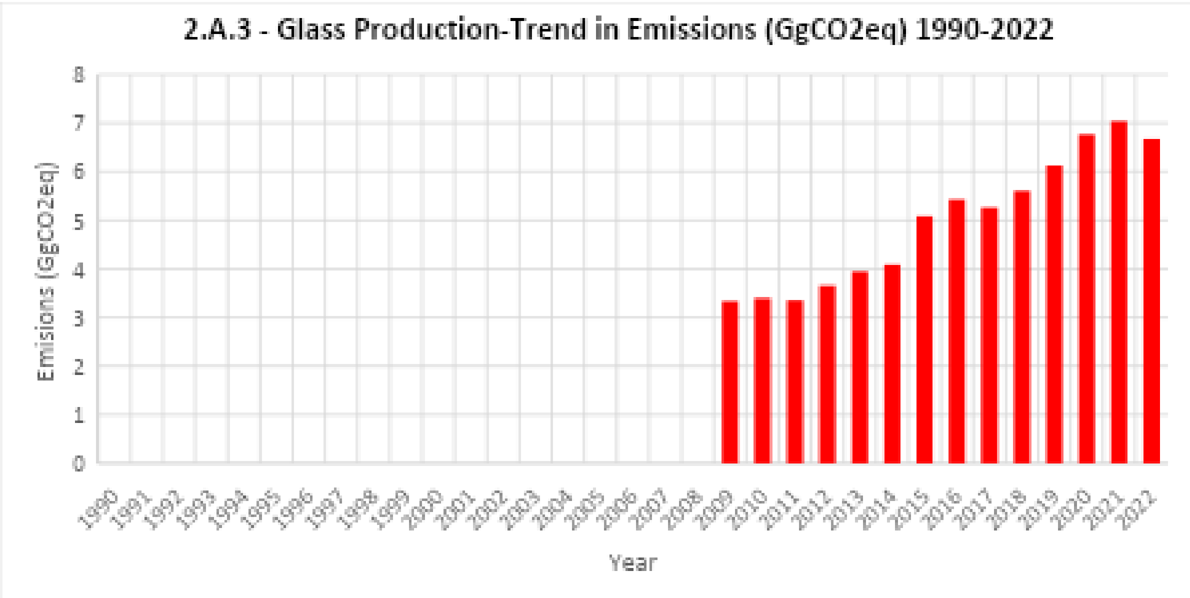


Figure 4-7: Emissions trend Glass Production 2010-2022.

4.5.4. Methodological aspects of Glass Production

The tier 1 approach was used to determine estimates of the GHG emissions from glass production. The default IPCC emission factor of 0.21 tonne CO_2/tonne glass was used to calculate emissions. Activity data for glass production was obtained from the two glass manufacturing companies in Kenya through the Kenya Association of Manufacturers (KAM). Activity data was only available for the period 2009 - 2022. (Table 4.6)

Tier 1 methodology was applied, using equation 2.10, default emission factor and cullet ratio to national-level glass production statistics.

EQUATION 2.10 TIER 1: EMISSIONS BASED ON GLASS PRODUCTION

$$CO_2\ Emissions = M_g \bullet EF \bullet (1 - CR)$$

Where:

CO_2 emissions - emissions of CO_2 from glass production, tonnes;

M_g - mass of glass produced, tonnes;

the data was sourced directly from the glass manufacturers in the country.

EF - default emission factor for manufacturing of glass, tonnes CO_2/tonne

glass;

CR - cullet ratio for process (either national average or default), fraction.

Table 4-6: Glass Production Data time series 2009 - 2022: Source (Kenya glass manufacturers)

Year	2009	2010	2011	2012	2013	2014	2015
Glass production (tonnes)	33,372	33,979	33,558	36,567	39,495	40,908	50,834
Year	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**
Glass production (tonnes)	54,291	52,620	29,797	32,538	35,950	37,388	35,482

4.6. Chemical Industry (2.B)

4.6.1. Soda Ash Production (2.B.7)- Description and Trend of GHGs

This category accounts for greenhouse gas emissions that result from the production of various inorganic and organic chemicals. Under this category, Kenya reports emissions from Soda ash (2.B.7).

This sub-category accounts for emissions from the production of soda ash, also known as sodium carbonate (Na_2CO_3). It exists in various hydrates and forms, including anhydrous soda ash, monohydrate, heptahydrate, and decahydrate. It is used in glass manufacture where the soda ash is used to lower the melting point of silica and improve glass quality. It's also a common water softener and used in water treatment, in household detergents, and as a food additive. Other Applications include cleaning agents, pulp and paper production.

Kenya produces soda ash from natural sodium carbonate-bearing deposits found in Lake Magadi in the South of the country. During the production process, Trona (the principal ore from which natural soda ash is made) is calcined in a rotary kiln and chemically transformed into a crude soda ash. Carbon dioxide and water are generated as by-products of this process. Carbon dioxide emissions can be estimated based on the following chemical reaction:

$$2Na_2CO_3.NaHCO_3.2H_2O\ (Trona) \rightarrow 3Na_2CO_3\ (Soda\ Ash) + 5H_2O + CO_2$$

CO_2 is emitted from using soda ash and these emissions are accounted for as a source under the relevant using industry. CO_2 is also emitted during production with the quantity emitted dependent on the industrial process used to manufacture soda ash.

Approximately 97% of the soda ash produced in Kenya is exported to other countries and the remainder (3% of the total) is used for different uses in the country. However, emissions under the soda ash use (sub-category 2.A.4.b) was not estimated due to inadequate data.

Figure 4-8 demonstrates the trend in emissions from Soda Ash. GHG emissions from soda ash production (2.B.7) increased from **32 Gg-CO_2eq** in 1990 to highest value of **69.4 Gg-CO_2eq** in 2008 then dropped gradually to **44.4 Gg-CO_2eq** in 2022, (figure 4-8).

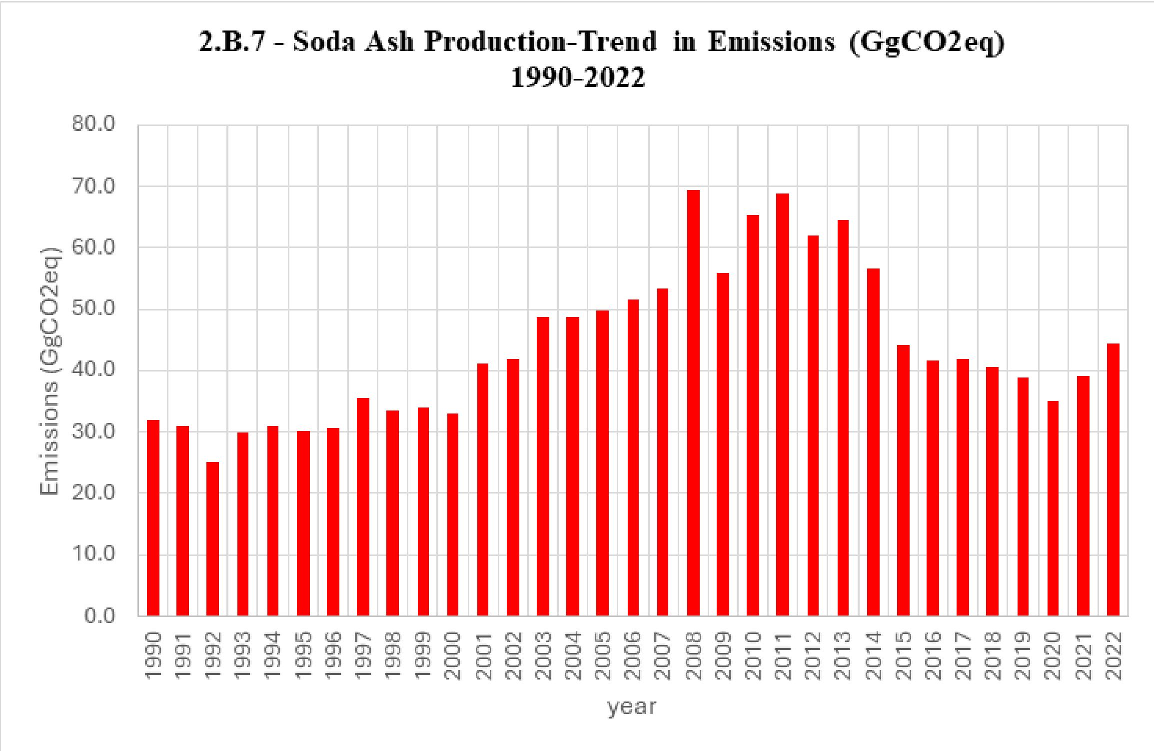


Figure 4-8: Trend in Emissions from Soda Ash Production 1990-2022

4.6.1.1. Methodological aspects of the Soda Ash sub-category (2.B.7)

The Tier 1 approach was used to determine estimates of the GHG emissions from soda ash production as provided in the 2006 IPCC guidelines, equation 3.14 below. The default emission factors used were derived from the stoichiometric ratio between soda ash produced and purified sodium sesquicarbonate obtained from trona.

Activity data from soda ash production was obtained from Kenya National Bureau of Statistics (1990 - 2022) and from Tata Chemicals, Magadi, through the Kenya Association of Manufacturers (KAM), supplemented by data form USGS. ***Table 4.7*** shows soda ash production data that were used to estimate emissions in Kenya. Lake Magadi in Kenya is one of the largest naturally occurring soda ash reserves in the world and plays a significant role in the world's production of natural soda ash.

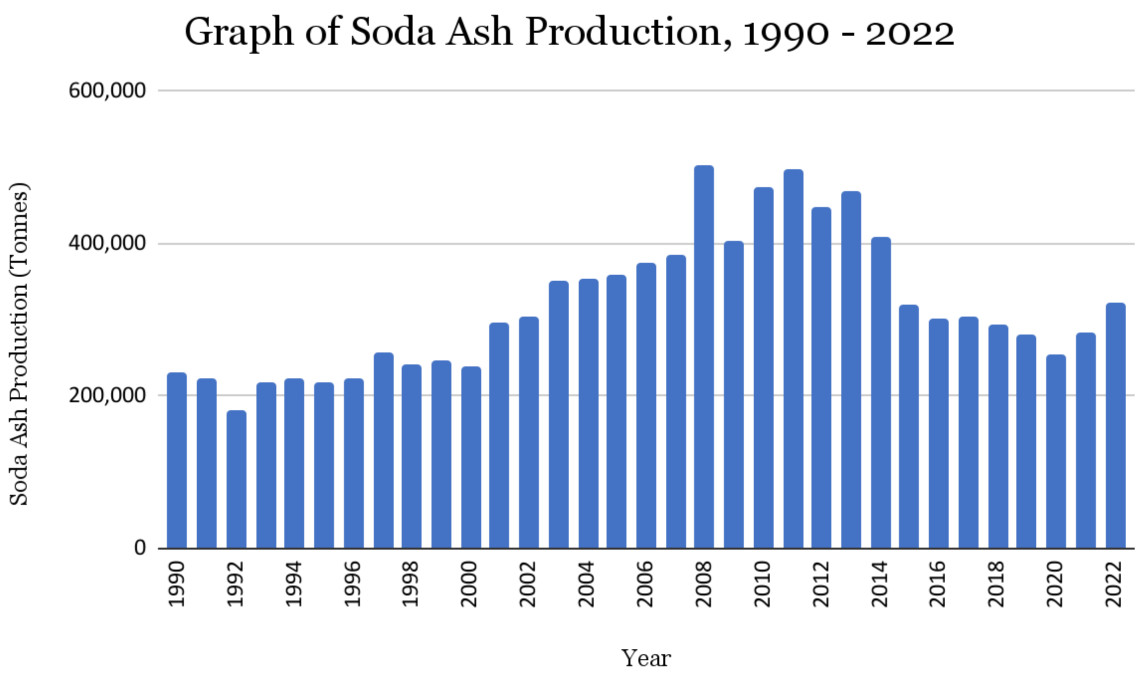


Figure 4-9: Trend in Soda ash production

Equation 3.14 from the 2006 IPCC guidelines which is used to estimate emissions from natural soda ash production was applied.

EQUATION 3.14: CO_2 EMISSIONS FROM NATURAL SODA ASH PRODUCTION – TIER 1

$$E_{CO2} = AD \bullet EF$$

$$EF_{Trona} = 0.097 \text{ tonne } CO_2 \text{ / tonne of Trona}$$

$$EF_{Soda\ Ash} = 0.138 \text{ tonne CO2/tonne natural soda ash}$$

Where:

E_{CO2} - emissions of CO_2, tonnes;

AD - quantity of soda ash produced;

EF - emission factor per unit of natural soda ash output, tonnes CO_2/tonne natural soda ash produced:

$EF_{Soda\ Ash}$ - 0.138 tonnes CO_2/tonnes natural soda ash produced.

The default emission factors used were derived from the stoichiometric ratio between soda ash produced and purified sodium sesquicarbonate obtained from trona.

Table 4-7: Soda Ash production data: Source Kenya National Bureau of Statistics. 1990 - 2022

Year	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
Soda ash production (tonnes)	231,900	223,770	181,330	216,890	224,200	218,450	223,000	257,640	242,910	245,680	238,190
Year	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**
Soda ash production (tonnes)	297,780	304,110	352,560	353,835	360,161	374,210	386,578	502,846	404,904	473,689	499,052
Year	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**
Soda ash production (tonnes)	449,269	468,215	409,845	319,761	301,719	303,580	294,856	282,049	254,579	283,621	321,779

4.6.1.2. Description of any Flexibility applied in Mineral industry

Quantitative estimates and qualitative discussion on the uncertainty of the emission and removal estimates for all sources in this category could not be done, due to insufficient time to engage with the actual data providers. Thus, flexibility in the light of our capacities with respect to this provision was applied to have the flexibility to instead provide, at a minimum, a qualitative discussion of uncertainty for this key category.

Though cement production is among the key categories in Kenya, (thus requiring a higher tier approach for estimation of its emissions), tier 1 approach was used to determine estimates of the GHG emissions from cement production, due to lack of country specific emission factors. Tier 2, approach would require clinker production data (rather than clinker production inferred from cement production) and a national emission factor, while tier 3 approach relies on plant specific data, the weights and compositions of all carbonate inputs from all raw material and fuel sources, the emission factor(s) for the carbonate(s), and the percentage of calcination achieved. All these data requirements for tier 2 or 3 approach are not currently available.

4.7. Quality Assurance and Quality Control (QA/QC)

QA/QC procedures were performed in accordance with the general QA/QC principles and the QA/QC plan (in Annex??). Additional source-specific quality control checks were undertaken to assess international comparability.

Verification on the following was conducted:

- Emission source documentation,
- Homogeneity of the source data and methods used for the entire time series.

4.8. Description of any Flexibility applied in IPPU Sector

Paragraph 29 of the MPGs on flexibility has been applied on uncertainty. Quantitative estimates and qualitative discussion on the uncertainty of the emission and removal estimates for all sources in this category could not be done, due to insufficient time to engage with the actual data providers. Thus, flexibility in the light of our capacities with respect to this provision was applied to instead provide, at a minimum, a qualitative discussion of uncertainty for this key category.

4.9. Uncertainty and consistency of the time series in IPPU sector

Below is a set of information that could impact the certainty and consistency of the IPPU sector inventory

- Cement and soda ash had production data across the time series, however in cement, data on clinker imports is only available from 2011 onwards,
- The sharing of the various types of cement was based on expert opinions, this could have resulted in an inaccurate apportionment and hence errors,
- Some of the sub-categories do not have data across the time series; glass production only had data from one of the two companies producing glass and only for the years from 2006;
- Lime data used in the estimation was derived from statistics published by the USGS. Their estimates are based on the production capacities of the plants. It is unlikely that the plants were operating at full capacity every year. A sample of data from one of the companies confirmed that that was a gross overestimation
- Soda ash production data has relatively low associated uncertainty because reliable and accurate data sources are available across the time series.

4.10. Category Specific recalculations for IPPU sector

No recalculations were performed for any of the sub-categories under this sector.

4.11. Planned Improvements for IPPU Sector

Below are some of the identified areas of improvement for the IPPU sector

1. Capacity building for inventory experts to build a team of competent inventory experts to enable the development of quality inventories.
2. Many of the data providers in the sector are privately owned and without any obligation to provide data for estimation of GHG emissions. Therefore, there is need to institutionalise data collection arrangements to allow the private sector to be obligated to provide the data.
3. There is a need to collect data to enable the estimation of more sub-categories reportable under this sector.
4. Determination of country specific emission factors for the various sub-categories to facilitate reporting using higher tier methodologies.

Chapter 05:

Agriculture

5.1. Agriculture

5.1.1. Description of the Sector

This chapter provides information on the estimation of the greenhouse gas emissions from the agriculture sector. Based on the IPCC 2006 guidelines, the following categories are reported:

- Livestock
  - Enteric fermentation (3A1), CH4 emissions from domestic livestock
  - Manure management (3A2), emissions of CH4, and N2O
- Aggregate sources on non-CO2 emissions on land
  - Biomass burning in croplands (3.C.1.b), emissions of CH4, and N2O
  - Liming (3C2), emissions of CO2,
  - Urea application (3C3), emissions of CO2
  - Direct N_2O emission from managed soils (3C4)
  - Indirect N_2O emission from managed soils (3C5)
  - Indirect N_2O emission from manure management (3C6)
  - Rice cultivations (3.C.7), CH4 emissions

Emissions from fuel combustion in this sector are not included here as these fall under ***agriculture/forestry/fisheries*** (see section 3.3.6) in the energy sector.

The agriculture sector has been identified as one of the key sectors to contribute to the projected annual national economic growth as per the National Development Blueprint "The Kenya Vision 2030". The sector is envisaged to ensure food security, provision of raw materials for agro-industries, creation of employment opportunities, generation of income and foreign exchange earnings.

The sector, however, is among the most vulnerable to impacts of climate change and extreme weather events. Enhanced temperatures and change in precipitation regimes have lowered the appropriateness of the agro-based enterprises; reduced crops and livestock yields due to temperature and water stresses and increased production costs. The increased frequency and intensity of extreme weather events such as droughts, floods and strong winds have resulted in the loss of investments, income/revenue and livelihoods, as well as the damage of agricultural infrastructure. Because of these challenges, the government is cognisant of the needs and has created interventions to strengthen agricultural resilience to climate change and extreme weather events while reducing its contribution to greenhouse gas emissions (GHG).

Livestock contributes about 42 percent, 19.6 percent and 14 percent of Agricultural, AFOLU and national Gross Domestic Product (GDP), respectively. The sub-sector employs 50 percent of the agricultural labour force and is the main source of livelihood for most rural Kenyans living in the ASALs (Arid and Semi-Arid Lands) of Kenya. The largest proportion (about 80 percent) of livestock populations are kept in the ASALs.

The livestock category consists of various sub-categories (species) namely Cattle, Sheep, Goats, Camels, Donkeys (asses), Poultry and Pigs (swine). Cattle subcategory is further classified into dairy and other cattle (beef) populations. The livestock populations are dynamic from one year to another and are distributed across diverse ecological zones. For example, in 2022 there were 15.8 million indigenous (beef) cattle, 5.1 million dairy cattle, 30.6 million goats, 21.3 million sheep, 3.5 million camels, 0.8 million pigs, 61.7 million chickens and 1.7 million donkeys. The dynamism of livestock populations and production is mainly dependent on the weather patterns and availability of forage.

Under the crop sub-sector, a total of eleven (11) Crops value chains drawn from cereals, pulses, root and tubers, and industrial crops were selected namely Maize, Wheat, Rice, Millet, Sorghum, Beans, Potatoes, Coffee, Tea, Sugar cane, Cotton for modelling of the GHG inventory based on the on government policy of the crops included in the fertiliser subsidy program and total acreage under production provided by the National Agriculture Statistics Unit (ASU). The GHG activity data was accessed from the Agricultural Statistics Unit, KALRO coupled with extensive consultative technical expert judgement.

Where there were gaps outlier detection was conducted and data filling was done using statistical methods.

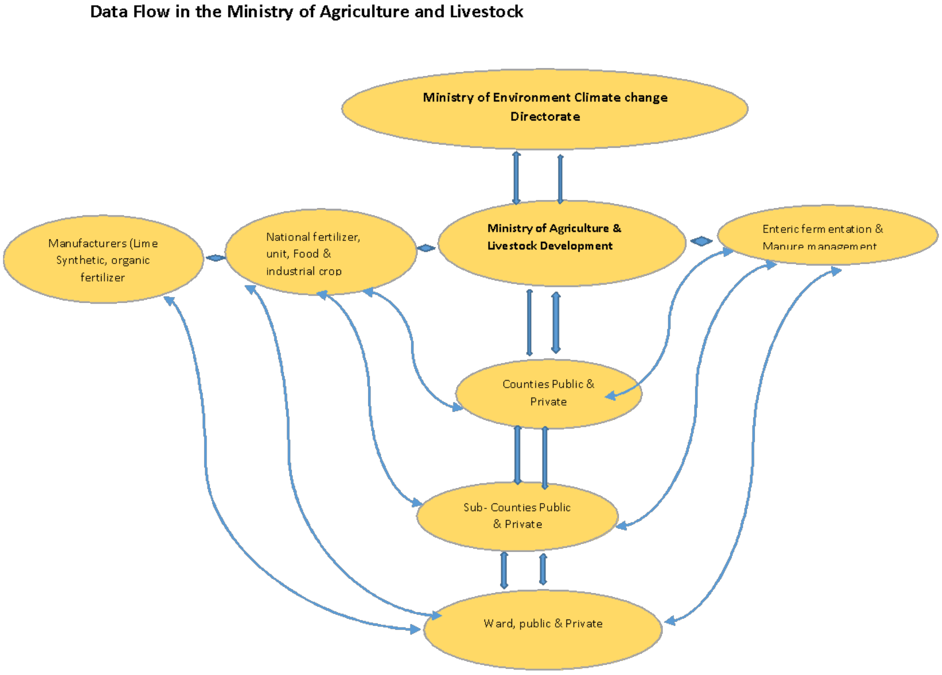


Figure 5-1: Illustration of Data flow in the agriculture sector

5.1.2. GHG Trends in the Agriculture Sector

Table 5-1 and figure 5-2, present summary and trend of GHG emission in the agriculture sector. Total greenhouse gas emissions from the agriculture sector in 2022 were **36,102.2** Gg CO_2eq which is a contribution 32% to the total of Kenya greenhouse gas emissions. This is a 131% rise from the 1990 level of 1990 of **15,639.7 Gg** (CO_2eq). Main agricultural sources of greenhouse gases were 3A Enteric fermentation, emitting **87** % of all agricultural Greenhouse gases, followed by Agricultural soils (3.C.4 +3.C.5) with **6** % and 3B Methane (CH_4) emissions from Manure management at ***4.2%,*** 3B Nitrous Oxide (N2O) emissions from Manure Management at **1.4** %. It was noted that 3.C.6 - Indirect N2O Emissions from manure management and 3.C.7 - Rice cultivation (CH4) contributed about 0.6% each, while Liming, Urea application and burning of crop land contributed well below 0.1 % each. (Table 5-1)

Table 5-1: Summary of Greenhouse gas emissions of the agricultural sector categories in Gg CO2 equivalent.

Sub category (Gas emitted) Year	Year 1990	2000	2010	2020	2022	% change 1990 - 2022 % change 1990-2022	% share 2022 & share 2022
3.A.1 - Enteric Fermentation (CH_4)	13,597.4	11,472.5	17,038.2	35,516.6	31,463.6	**131%**	**87.2%**
3.A.2 - Manure Management (CH_4)	421.9	595.8	819.9	1,649.0	1,500.6	**256%**	**4.2%**
3.A.2 - Manure Management (N_2O)	195.2	208.5	261.8	532.7	494.7	**153%**	**1.4%**
3.C.1.b - Burning in Cropland (CH_4) sugarcane	1.6	2.3	2.7	3.5	4.9	210%	0.01%
3.C.1.b - Burning in Cropland (N_2O) sugarcane	0.4	0.6	0.7	0.9	1.2	**210%**	**0.003%**
3.C.2 - Liming (CO_2)	0.66	0.7	2.2	1.4	1.4	**109%**	**0.004%**
3.C.3 - Urea application (CO_2)	6.3	11.2	28.3	31.1	31.2	**394%**	**0.1%**
3.C.4 - Direct N_2O Emissions from managed soils	904.3	915.0	1160.7	1611.5	1616.7	**79%**	**4.5%**
3.C.5 - Indirect N_2O Emissions from managed soils	309.3	292.8	361.5	541.9	542.7	75%	1.5%
3.C.6 - Indirect N_2O Emissions from manure management	98.9	121.8	119.0	204.0	219.4	**122%**	**0.6%**
3.C.7 - Rice cultivation (CH_4)	103.7	111.6	146.2	118.9	225.9	**118%**	**0.6%**
TOTAL AGRICULTURE EMISSIONS (Gg CO_2eq)	**15,639.7**	**13,732.7**	**19,941.1**	**40,211.6**	**36,102.2**	131%	

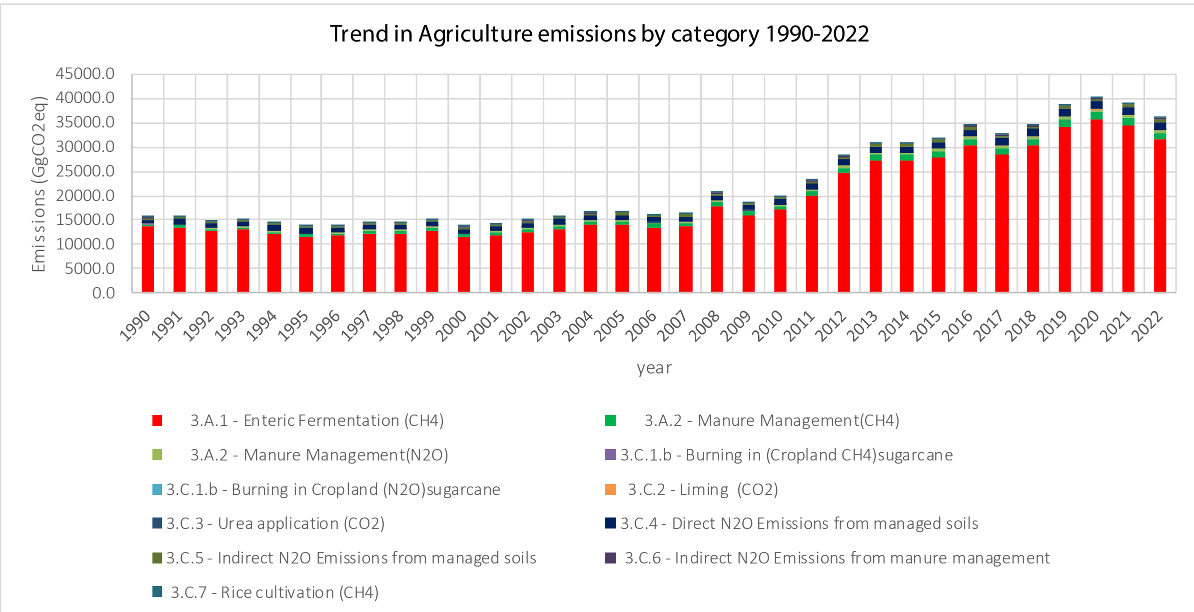


Figure 5-2: Trend in Greenhouse gas emissions of the agricultural sector in Gg CO_2 equivalent.

Since 1990, emissions in the agricultural sector have shown an increasing trend, reaching a peak of **40,211.6 Gg-CO_2eq** in 2020 (figure 5-3) due to the increasing number of livestock, demand for agricultural land by the ever-increasing national population, and applications of synthetic fertilizers for improved food production.

Figure 5-3 show that Methane (CH_4) dominated the agriculture sector emissions contributing about **92 percent**, Nitrous Oxide (N_2O) about **8 percent**, while Carbon dioxide (CO_2) is well below 0.1%.

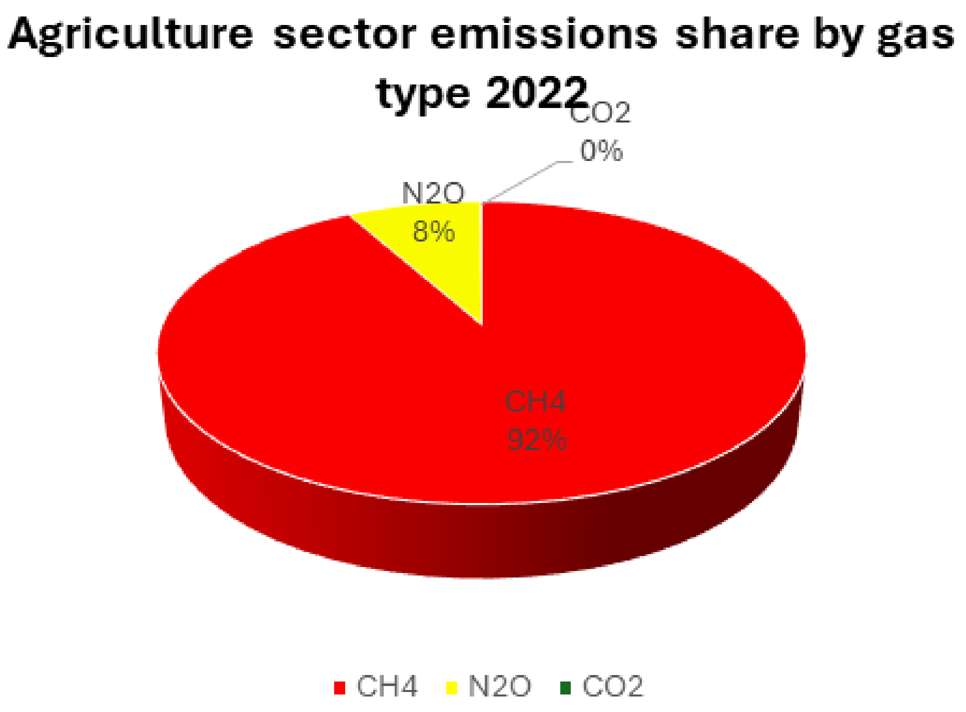


Figure 5-3: Share of agricultural sector GHG emissions in 2002

5.1.3. General Methodological Aspects of the Agriculture Sector

The estimation of Livestock emissions was completed using the Tier 1 methodology, except for dairy cattle, where Tier II methodology was applied using IPCC ***2006*** Revised IPCC Guidelines.

Category 3.C (Aggregate sources and non-CO_2 emissions) deals with GHG emissions related to activities other than livestock and land. They include CH_4 and N_2O from biomass burning, CO_2 from Urea application, direct and indirect N_2O from managed soils and indirect N_2O from manure management as well as CH_4 emissions from rice cultivation. Sub-category 3.C.1 deals with non-CO_2 emissions from biomass burning in all land use types but only losses from biomass burning from Cropland (3.C.1.b), (in which only biomass burning from Sugarcane was considered), is included since other land types lacked any consistent data. Tier 1 approach was used to estimate emissions under Category 3.C. Based on the availability of data for the sub-categories mentioned, the data input was: (a) areas of crop land affected by fire (b) annual crop area and yield from major staple crops (c) Liming application, (d) nitrogen fertilizers and urea consumption and mode of application, (e) rice cultivation. The main source of the data under this category was obtained from the Ministry of Agriculture and Livestock Development.

More detailed information on specific categories is discussed in the following sections.

5.2. Enteric fermentation (3.A.1)

5.2.1. Description and Trend of GHGs in Enteric fermentation

Methane (CH_4) is the main greenhouse gas produced as a by-product of digestion in ruminants, e.g. cattle, and some non-ruminant animals such as pigs and camels. Ruminants are the largest source of CH_4 as they are able to break down cellulose into simple sugars through anaerobic fermentation of fibrous feedstuffs. The amount of CH_4 released depends on the type, age and weight of the animal, the quality and quantity of feed and the energy expenditure of the animal. CH_4 emissions from enteric fermentation is the second largest key category in the country level assessment. Tier 1 modelling approach for enteric fermentation has been used for all years except for dairy cattle where Tier II approach has been applied.

Table 5-2 below shows the amount of methane emission from enteric fermentation for all livestock species from the year 1990 to 2022 (Tier 1 for the other livestock type, adjusted with dairy cows Tier 2 approach), while Figure 5-4 shows the trend in enteric fermentation over the period 1990-2022.

In 2022, emissions from enteric fermentation comprised **31,463.6 GgCO_2eq of Methane** (CH_4).

Table 5-2: Methane emission from enteric fermentation 1990 to 2022

Category	1990	2000	2010	2020	2022	% change 1990-2022	% share 2022
3.A.1 - Enteric Fermentatio	13597.4	11472.5	17038.2	35516.6	31463.6	131%	
3.A.1.a - Cattle	10006.5	7849.1	10808.4	20537.6	19229.1	92%	61%
3.A.1.a.i - Dairy Cows (tier2	3808.0	3725.2	3904.4	6179.8	5920.3	55%	19%
3.A.1.a.ii - Other Cattle	6198.5	4123.9	6904.0	14357.8	13308.8	115%	42%
3.A.1.c - Sheep	1375.2	1111.5	1517.0	3548.4	2986.7	117%	9%
3.A.1.d - Goats	1398.9	1458.1	2448.0	5043.0	4278.2	206%	14%
3.A.1.e - Camels	766.4	924.2	1977.7	6014.6	4452.0	481%	14%
3.A.1.g - Mules and Asses	45.0	116.5	277.0	345.7	484.4	976%	2%
3.A.1.h - Swine	5.4	13.0	10.1	27.3	33.3	519%	0.1%

The trend of enteric methane fermentation was fairly stable from the year 1990 to 2006. However, from the year 2009 emissions have consistently increased over the years as indicated in the graph (Figure 5-3). The drastic increase is attributed to the actual livestock population as indicated in the 2009 census report. Previously, livestock population numbers have been reported as estimates.

Enteric fermentation constitutes the largest source of CH_4 emissions in the agricultural sector in Kenya. It is the highest source of total carbon dioxide equivalent emissions accounting for 87.2**%** and 28**%** shares in agriculture and total national emissions respectively.

This source category in 1990 resulted in a value of **13,597.4 Gg CO_2 eq**., decreased to **11,472.5 Gg CO_2eq** by 2000 then steadily increased to **35,516.6 Gg CO_2eq** by 2020. CH_4 emissions from enteric fermentation, which are presented by main livestock species in Table 5-2, fluctuate over time.

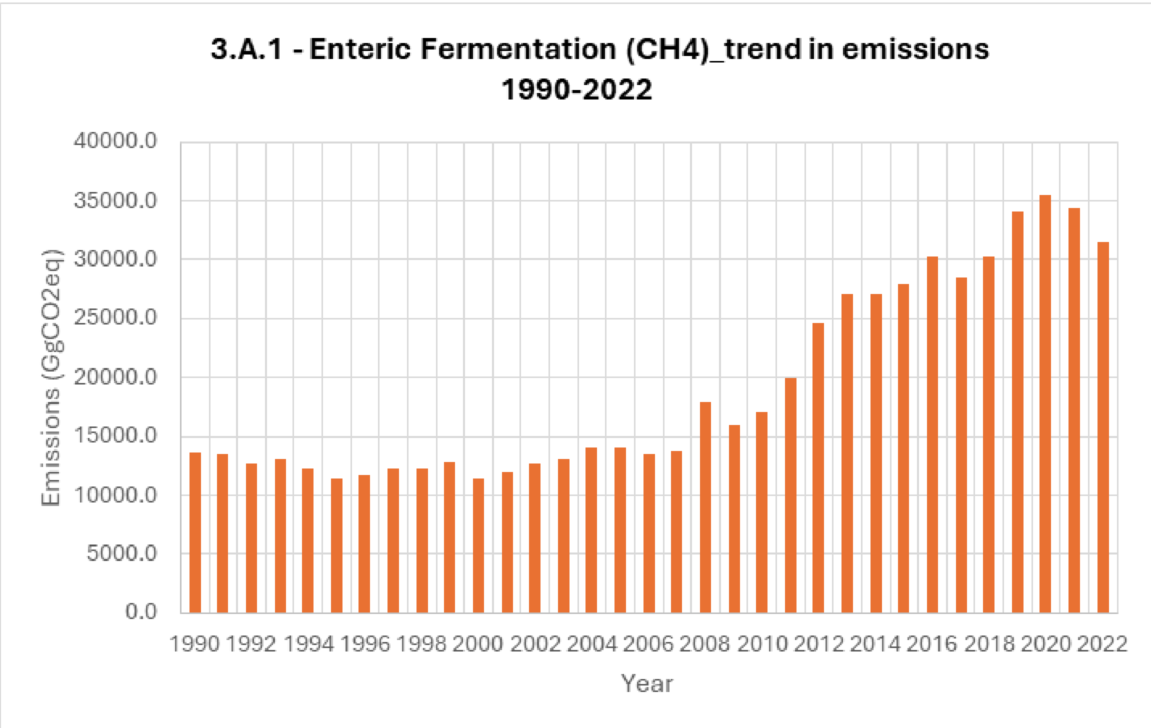


Figure 5-4: Trends in Livestock Methane Enteric fermentation emissions for livestock

In 2022, non-dairy cattle produced **13308.8. Gg** CO_2 eq., which increased by 6309.93 Gg CO_2 eq. (**115**%) from the 1990 level of **6198.5** GCO_2 eq. An increase of 85.94% in dairy cattle population for the period of 1990-2022, led to a spike in CH_4 emissions from **3808.02** Gg CO_2 eq. in 1990 to **5920.3Gg** CO_2 eq. in 2022, translating to **55**% increase.

A closer look at the changes in the composition of the population of dairy cattle (improved breeds, and pure exotic dairy cattle) revealed a reasonable explanation for the same period. The dairy cattle population was 2.9 million in total for 1990, while the respective figures for the year 2022 were 5.5 million in total. Population numbers of livestock species for the period 1990-2022 are shown in Table 5-3.

Figure 5-4 shows that there was a drastic increase in CH_4 emission from enteric fermentation for the years 2010 to 2020. The year 2020 recorded the highest emission. This can also be attributed to a high increase in ruminant livestock numbers mainly cattle, sheep, goats and camels. However, there was a decline in emission in 2021 and 2022 due to decline in livestock numbers orchestrated by severe droughts and the government interventions in offtake, and improvement in pasture/fodder quality. Quality pastures/fodder require shortened time for enteric fermentation hence reduced emission from such processes.

Dairy and non-dairy cattle contribution accounted for **61**% of emissions to the enteric fermentation category while sheep (wool and hair) accounted for 9% share of emissions to this category. Goats, camels, donkeys and swine (pigs) contributed 14%, 14%, 2% and 0.01% respectively of the total enteric fermentation in 2022 as presented in Figure 5-5 for the latest reporting year 2022, therefore, donkeys and pigs' contribution was insignificant.

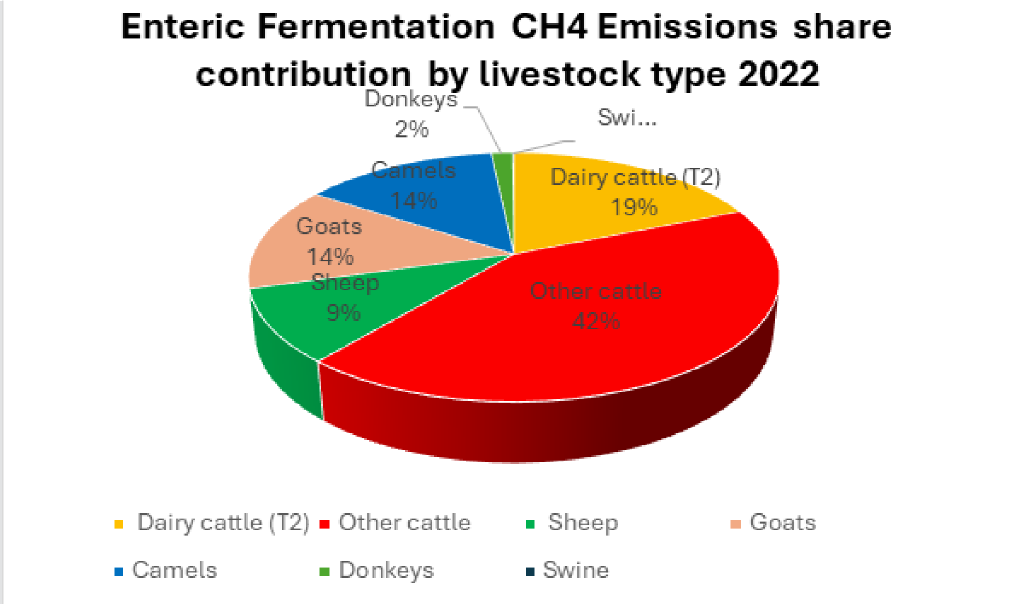


Figure 5-5: Share contribution of livestock type to enteric fermentation CH4 Emissions 2022

5.2.2. Methodological aspects of the Enteric Fermentation

a. Methodology

Methane is produced in herbivores as a by-product of enteric fermentation, a digestive process by which complex carbohydrates (Cellulose) are broken down by micro-organisms (methanogens) into simple molecules for absorption into the bloodstream.

The calculation of methane emissions from enteric fermentation was completed using the Tier 1 methodology for all livestock types except the dairy cattle, where a tier 2 country-specific EF were used (2006 Revised IPCC Guidelines). This method relies on default emission factors drawn from previous studies and the only country specific data required are the populations of different livestock.

Methane Emissions (kg/yr) = Σ Population of Livestock (head) x Emission Factor (kg CH_4 per head per year)

b. Activity Data

The Ministry of Agriculture and Livestock Development, the State Department for Livestock Development, and FAOSTAT were the primary sources of data that were collected on livestock populations. The livestock populations data were estimated using data from two censuses (KNBS 2009 and 2019) and annual updates from national livestock statistics (MoALD).

The annual population numbers for livestock species are summarized in Table 5-3 below.

Table 5-3: Total Livestock population 1990 to 2022

Year	Total Cattle	Total Dairy	Other cattle	Sheep	Goats	Camels	Donkeys	Swine	Total Chicken
1990	10,097,630	2,956,540	7,141,090	9,823,120	9,991,791	595,000	160,843	128,168	19,161,000
1991	10,082,192	2,828,752	7,253,440	10,034,555	10,203,240	560,000	217,702	147,014	23,233,000
1992	9,058,500	2,930,570	6,127,930	10,396,990	10,039,037	525,000	250,495	217,084	22,312,000
1993	9,614,120	3,095,340	6,518,780	9,507,496	9,951,003	507,290	201,620	195,860	21,038,000
1994	8,664,696	3,182,893	5,481,803	8,641,139	10,071,765	533,750	231,990	247,038	22,454,000
1995	12,805,528	3,255,479	9,550,049	8,812,624	10,396,000	787,700	314,000	230,600	27,296,000
1996	12,742,890	3,355,192	9,387,698	8,509,298	10,229,985	795,600	425,000	302,042	28,332,000
1997	11,738,240	3,281,525	8,456,715	8,580,804	10,856,261	791,600	358,000	313,100	29,296,000
1998	11,823,349	3,442,446	8,380,903	8,166,291	9,674,381	799,500	339,000	358,462	29,718,000
1999	12,020,634	3,435,140	8,585,494	8,521,111	10,967,320	845,561	352,134	317,115	26,446,153
2000	11,411,297	3,335,920	8,075,377	7,939,546	10,004,367	717,524	416,136	310,647	26,291,238
2001	11,630,289	3,442,755	8,187,534	7,609,086	10,804,245	819,123	478,818	332,512	27,030,572
2002	11,985,459	3,551,160	8,434,299	9,288,633	11,319,430	846,555	521,289	336,161	27,871,224
2003	12,723,301	3,665,398	9,057,903	8,157,048	11,945,492	895,094	423,980	415,194	28,282,792
2004	13,179,647	3,605,505	9,574,142	10,298,464	13,390,504	1,193,618	515,045	379,797	25,905,570
2005	13,100,947	3,579,461	9,521,486	10,033,881	13,882,605	931,308	716,614	320,020	26,856,693
2006	12,756,942	3,639,018	9,117,924	8,276,848	10,210,434	1,058,330	785,071	318,547	27,771,847
2007	12,988,653	3,667,746	9,320,907	9,428,666	13,966,023	1,006,337	631,895	304,161	27,495,209
2008	13,522,466	3,403,347	10,119,119	9,907,304	14,478,257	1,132,476	786,804	330,020	29,614,970
2009	11,549,015	3,310,898	8,238,117	9,261,531	13,871,840	1,163,090	751,661	272,105	27,538,493
2010	13,683,788	3,376,478	10,307,309	10,835,364	18,178,379	1,535,473	989,189	342,585	30,207,795
2011	14,127,745	3,739,609	10,388,135	10,938,910	17,988,345	1,787,379	946,319	344,155	32,307,891
2012	16,223,123	4,158,377	12,064,746	15,420,793	21,033,477	2,824,688	1,342,722	380,225	33,974,144
2013	18,138,500	4,505,574	13,632,918	16,600,911	24,637,393	2,899,244	1,713,382	432,979	39,868,802
2014	17,811,845	4,316,153	13,495,692	17,420,207	25,430,058	2,937,262	1,882,785	430,844	42,076,110
2015	18,753,179	4,242,131	14,511,047	16,808,470	25,128,075	3,066,998	1,676,267	462,037	42,185,323
2016	20,529,191	4,505,731	16,023,458	18,983,760	26,745,916	3,222,593	1,965,632	504,395	44,618,658
2017	18,747,286	4,982,348	13,764,938	18,759,073	25,684,489	3,338,757	2,182,193	554,301	48,124,578
2018	18,134,580	5,153,875	12,980,705	18,983,760	26,320,559	3,273,457	2,233,309	580,843	48,124,578
2019	17,906,677	4,536,551	13,370,126	27,294,639	35,172,749	4,721,900	1,664,345	596,414	49,568,315
2020	21,653,595	5,112,340	16,541,255	25,345,927	36,021,177	4,669,739	1,232,630	649,273	58,556,440
2021	21,200,347	5,017,991	16,182,356	24,801,605	33,681,560	4,427,881	1,393,628	647,746	60,373,418
2022	20,830,135	5,497,412	15,332,722	21,333,288	30,588,620	3,456,483	1,729,940	792,906	61,708,876

Figure 5-6 shows the trend in population of all the livestock species namely dairy cattle, non-dairy cattle, sheep, goats, camels, swine (pigs), donkey and poultry. The general trend is that there has been increase in population across all the livestock species. However, donkeys and swine have recorded very low growth compared to the other livestock species.

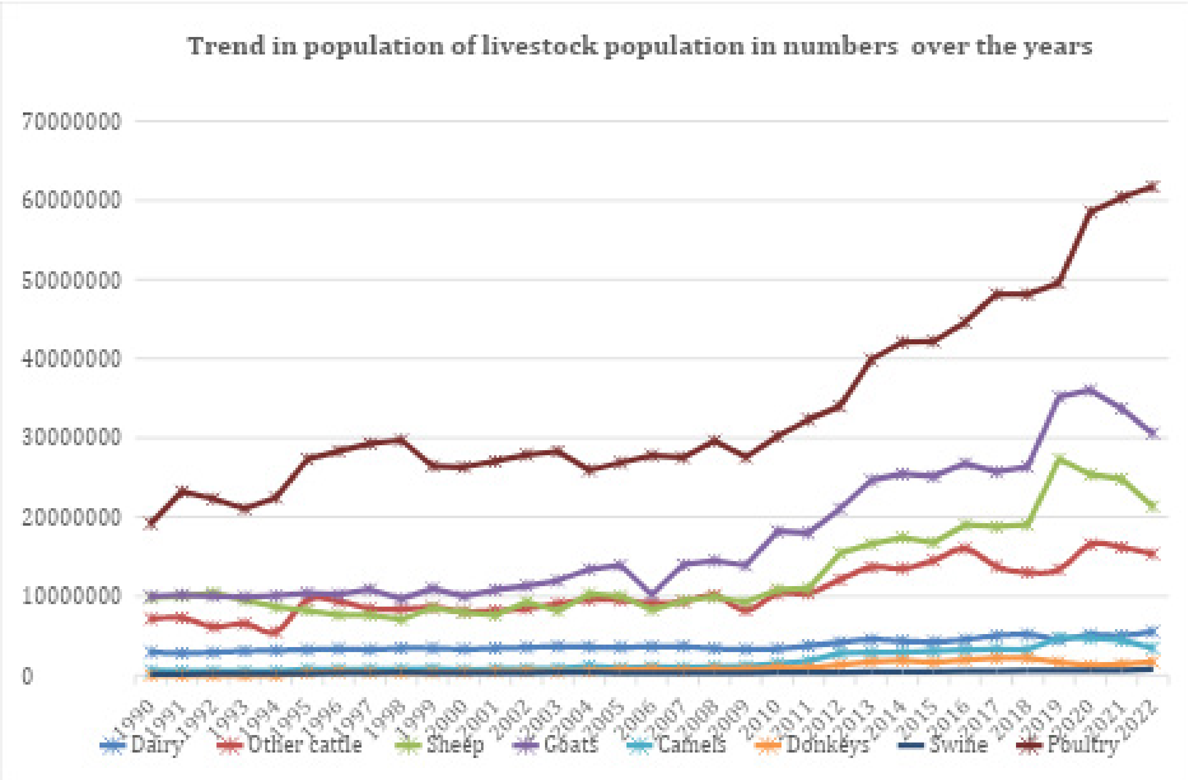


Figure 5-6: Trend of livestock population for all the livestock species by number

Livestock populations particularly other cattle, sheep and goats heavily rely on rainfall patterns. The increase in such populations is due to conducive weather conditions that promoted forage regrowth hence feeds availability to support fertility, growth and development. Declines in populations are due to drought and flood cycles that wipe substantial population sizes mainly in ASALs. After several weather cycles, the governments (National and Counties) and NGOs do enhance the resilience of affected communities by promoting livestock interventions such as pasture and fodder improvement and production. Hence causing a significant increase in livestock populations, consequently increasing CH_4 emissions for these subcategories. The largest increase occurred from non-dairy cattle emissions due to an increase in its population numbers.

c. Emission Factors and Coefficients in Enteric Fermentation CH_4

Default emission factors were drawn from the 2006 Revised IPCC Guidelines Volume 4, Chapter 10, Table 10.1 and 10.11. Table 5-4: summarizes the enteric fermentation emission factors that were used.

Table 5-4: Enteric Fermentation Emission Factors for Different Types of Livestock

Type of livestock	Dairy cattle	Non-Dairy cattle	Sheep	Goats	Pigs	Donkeys	Camels
Emission Factor Enteric Fermentation	Provided under dairy tier 2 section	31	5	5	1	10	46

Source: 2006 IPCC Guidelines, Chapter 10 Emissions from Livestock and Manure Management, Table 10.10 and 10.11 Volume 4

5.2.3. Description of any Flexibility applied

No flexibility was applied for tier 1 calculations.

5.2.4. Uncertainty and consistency of the time series

The uncertainty of activity data for both tier 1 and 2 was set at ± 10 as actual data was used. This uncertainty arises due to the fact that this actual data on livestock census was conducted only for two years (2009 and 2019) over the report period. Further, annual national livestock populations are estimated based on small sample sizes that may not capture livestock population variability spread across various production environments in the country. The uncertainty in livestock population numbers is greater than is commonly assumed. There may have been systematic biases in the reporting of animal populations during the national census.

The uncertainty for emission factors for tier 1 was set at -25 to +30 for all livestock categories (except dairy cattle), with a combined EF calculated at ± 31.6%. This was due to the use of default emission factors derived from an assumption that all animals in particular livestock class have the same body-mass (2006 IPCC Guidelines for National Greenhouse Gas Inventories, Vol. 4 table 10.10). For the dairy cattle class, where tier 2 was applied, the EF uncertainty was set at a range of ±20 with a combined EF of ±22.4%. This uncertainty arose due to dynamics in dairy herd structures, inconsistency in performance records for parameters such as body weights and milk production.

5.2.5. QA/QC in Enteric Fermentation

QA/QC procedures were performed in accordance with the general QA/QC principles and the QA/QC plan (in Annex 2). Additional source specific quality control checks were undertaken to assess international comparability.

5.2.6. Enteric Fermentation Category Specific recalculations

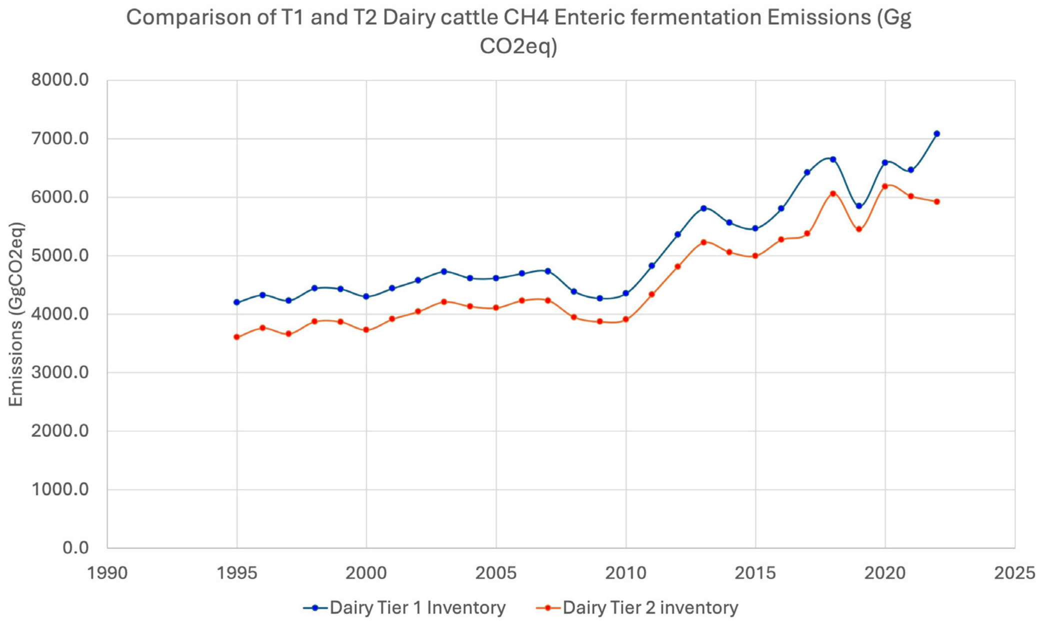
Recalculations of dairy cattle emissions was performed following the change in methodology from T1 to T2 approach, for the period 1995 to 2022, thus affecting emissions from both enteric and manure management for the dairy cattle. The T2 Dairy cattle inventory was prepared by the State Department of Livestock of the Ministry of Agriculture and Livestock Development with support from UNIQUE forestry and land use GmbH, the Global Research Alliance on Agricultural Greenhouse Gases and the New Zealand Government, and the CGIAR Research Programme on Climate Change, Agriculture and Food Security (CCAFS).

Both the activity data and emission factors used in this T2 inventory differ from those used in Kenya's Second National Communication (2012). The reason is that the official dairy cattle population time series has been revised through numerous efforts of the State Department of Livestock, particularly in light of the data from the 2009 agricultural census. The table below compares the activity data, implied emission factors and total enteric fermentation emissions calculated using the Tier 2 approach with the previous time series that was calculated using the Tier 1 approach. With a lower implied emission factor than the IPCC Tier 1 default value for the entire time series, total dairy cattle enteric fermentation CH4 emissions are lower than those estimated using the Tier 1 approach for all years. The figure below provides a visual comparison of estimates using a Tier 1 approach and using a Tier 2 approach with the revised activity data.

Table 5-5: Comparison Dairy Cattle Enteric fermentation of T1 time series with Tier 2 inventory time series (1995-2022)

Year	Population	EF (kg CH_4 hd^{-1} yr^{-1})	Gg CH_4 (CO_2eq)	Population	IEF (kg CH_4 hd^{-1} yr^{-1})	Gg CH_4 (CO_2eq)
1995	3,255,468	46	4193.1	3,255,468	39.51	3601.7
1996	3,355,181	46	4321.5	3,355,181	39.99	3756.9
1997	3,281,542	46	4226.6	3,281,542	39.82	3659.1
1998	3,442,423	46	4433.9	3,442,423	40.12	3867.0
1999	3,435,120	46	4424.5	3,435,120	40.18	3864.2
2000	3,335,902	46	4296.7	3,335,902	39.88	3725.2
2001	3,442,732	46	4434.3	3,442,732	40.56	3910.2
2002	3,551,137	46	4573.9	3,551,137	40.63	4039.7
2003	3,665,375	46	4721.0	3,665,375	40.97	4205.0
2004	3,605,486	46	4610.3	3,605,486	40.88	4127.0
2005	3,579,440	46	4610.3	3,579,440	40.93	4102.7
2006	3,638,996	46	4687.1	3,638,996	41.48	4226.6
2007	3,667,724	46	4724.1	3,667,724	41.19	4229.9
2008	3,403,321	46	4383.5	3,403,321	41.38	3943.7
2009	3,310,877	46	4264.4	3,310,877	41.72	3867.3
2010	3,386,594	46	4348.9	3,386,594	41.3	3904.4
2011	3,739,604	46	4816.6	3,739,604	41.35	4329.4
2012	4,158,353	46	5356.0	4,158,353	41.31	4809.5
2013	4,505,582	46	5803.2	4,505,582	41.37	5219.3

Year	Population	EF (kg CH_4 hd^{-1} yr^{-1})	Gg CH_4 (CO_2eq)	Population	IEF (kg CH_4 hd^{-1} yr^{-1})	Gg CH_4 (CO_2eq)
2014	4,316,152	46	5559.2	4,316,152	41.83	5054.9
2015	4,242,108	46	5463.9	4,242,108	42.05	4994.1
2016	4,505,731	46	5803.4	4,505,731	41.75	5267.8
2017	4,573,848	46	6417.3	4,573,848	41.98	5376.4
2018	5,153,875	46	6638.2	5,153,875	41.97	6056.6
2019	4,536,551	46	5843.1	4,536,551	42.91	5450.8
2020	5,112,340	46	6584.7	5,112,340	43.17	6179.8
2021	5,017,991	46	6463.2	5,017,991	42.79	6011.8
2022	5,145,240	46	7080.7	5,145,240	43.28	5920.3



5.2.7. Planned Improvements for enteric fermentation

All data and methodologies should be periodically reviewed and an upgrade from T1 to T2 for the specific livestock category will be considered for the future. The T1 default emission factors for camels and dairy cattle should therefore be upgraded to T2 for camels in order to get the country emission factor for camels. There is a need to have regular census, surveys and capacity building to improve the methodologies of data collection. The respective AD used for calculations are also published as official statistics by KNBS, which has its own QA/QC procedures. Emission trends are analysed. If there is a high fluctuation in the series, then AD and emission calculations are re-examined.

5.3. Manure Management

5.3.1. Description and Trend of GHGs of Manure Management

Based on the IPCC 2006 guidelines, the following categories are reported:

Table 5-6:

IPCC code	category	Gas
3.A.2	Manure management all livestock direct	CH4
3.A.2	Manure management all livestock direct	N2O
3.C.6	Indirect N2O Emissions from manure management	N2O

Livestock manure is composed principally of organic material. When the manure decomposes in the absence of oxygen, methanogenic bacteria produce methane ($CH_{4)}$. These conditions often occur when large numbers of animals are managed in a confined area (e.g., dairy farms, beef feedlots, and swine and poultry farms), where manure is typically stored in large piles or disposed of in lagoons. The emissions of CH_4 are related to the amount of manure produced and the amount that decomposes anaerobically.

This category also includes emissions of Nitrous Oxide (N_2O) related to manure handling before the manure is added to the soil. The amount of N_2O released depends on the system of waste management and the duration of storage. **Direct N_2O emissions** from manure management systems (MMS) can occur via combined nitrification and denitrification of ammoniacal nitrogen contained in the wastes. The amount released depends on the systems and duration of waste management. **Indirect N_2O emissions** occur via runoff and leaching, and the atmospheric deposition of Nitrogen (N) volatilised from the MMS.

a. Trend in 3.A.2 Manure Management Livestock direct CH_4

Figure 5-7 shows the trend in direct methane (CH_4) emissions from Manure Management, while table 5.6 shows the methane (CH_4) emissions by livestock type. Manure management produced a total of **1,500.6** Gg-CO_2.eq in 2022 which was an increase from **421.9** Gg-CO_2eq produced in 1990. This was as an increase in emission by **256**% from 1990 levels.

Table 5-7: Manure Management CH4 Emission (Gg-CO_2eq)

Year	1990	1995	2000	2005	2010	2015	2020	2022	% change 1990-2022	& share 2022
3.A.2 - Manure Management (CH4)-Total	**421.9**	**577.6**	**595.8**	**715.5**	**819.9**	**1286.9**	**1649.0**	**1500.6**	**256%**	
3.A.2.a - Cattle	282.7	445.1	438.2	518.1	562.2	853.1	1038.8	979.8	**247%**	**65%**
3.A.2.a.i - Dairy cows (tier2)	82.8	288.1	305.2	348.8	339.4	446.7	575.6	550.5	**565%**	**37%**
3.A.2.a.ii - Other cattle	200.0	157.0	133.0	169.4	222.7	406.3	463.2	429.3	**115%**	**29%**
3.A.2.c - Sheep	41.3	34.5	33.3	42.1	45.5	70.6	106.5	89.6	**117%**	**6%**
3.A.2.d - Goats	47.6	25.7	49.6	63.1	83.2	119.6	171.5	145.5	**206%**	**10%**
3.A.2.e - Camels	32.0	42.3	38.6	50.1	82.5	164.9	251.0	185.8	**481%**	**12%**
3.A.2.g - Mules and Asses	4.1	7.9	10.5	18.1	24.9	42.2	31.1	43.6	**976%**	**3%**
3.A.2.h - Swine	3.6	7.2	8.7	9.0	6.7	12.9	18.2	22.2	**519%**	**1%**
3.A.2.i - Poultry	10.7	14.8	16.9	14.9	14.8	23.6	32.0	34.0	**217%**	**2%**

The highest amount of methane emission under manure management was **1,649 Gg CO_2eq** in the year 2020, while the lowest was **380.9 Gg CO_2eq** in the year 1994. (Figure 5-5 shows trends of methane Emission from manure management from the year 1990 to 2022. The emission trends have been fairly constant from 1990 to 2007. However, in the year 2008 to 2020 there was a significant increase in emissions. In the year 2021 and 2022 there was a decline in emissions. And this may be due to interventions in improved feed for livestock mainly enhanced quality pasture developed. In general, from 1990-2022 there has been a consistent increase in methane emission from manure and this may be attributed to increase in livestock numbers across all the livestock sub category. This increase could be attributed to increasing population and intensification of production systems especially in dairy cattle, poultry and pig management. Changes in production system affects manure management system, with high tendency of solid storage.

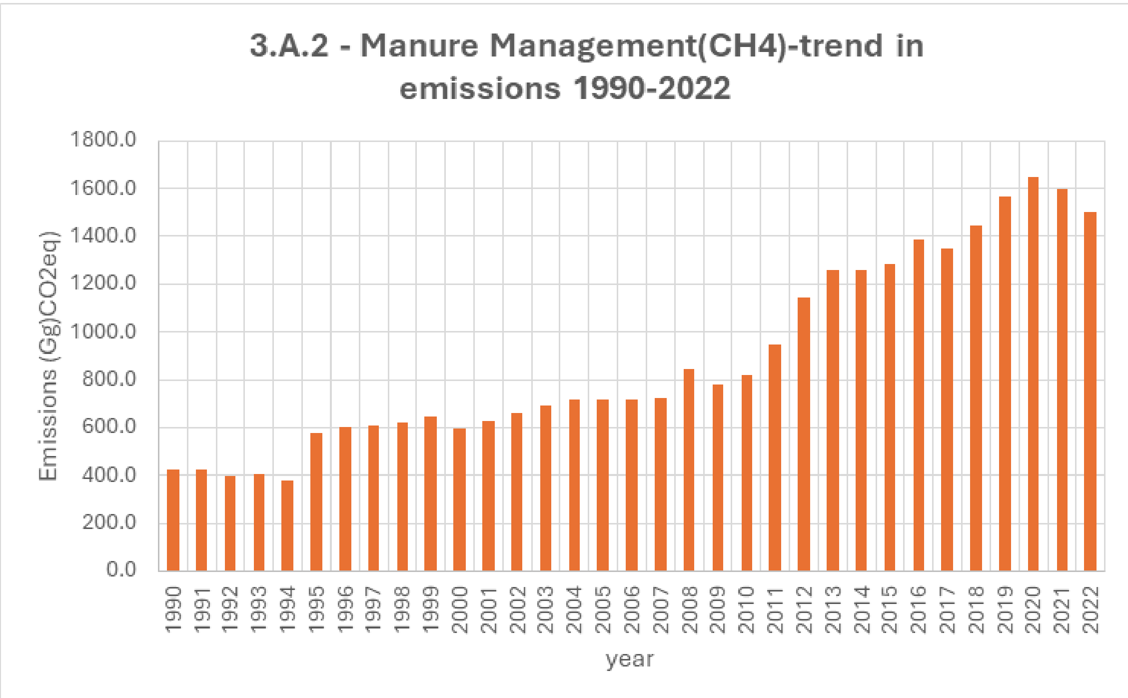


Figure 5-7: Trend in Livestock Manure Management CH4 emissions 1990 - 2022

Figure 5-8 presents the percentage shares for the subcategories of manure management Methane (CH_4) emission sources for the latest reporting year 2022.The figure shows that Dairy Cows are the largest contributors to manure management CH_4 emissions with 37 % followed by other- cattle (non-dairy cattle) at 29 %. Camels contributed 12%, Goats 10%, Sheep 6%, and donkeys 3% share of manure management emissions in 2022.

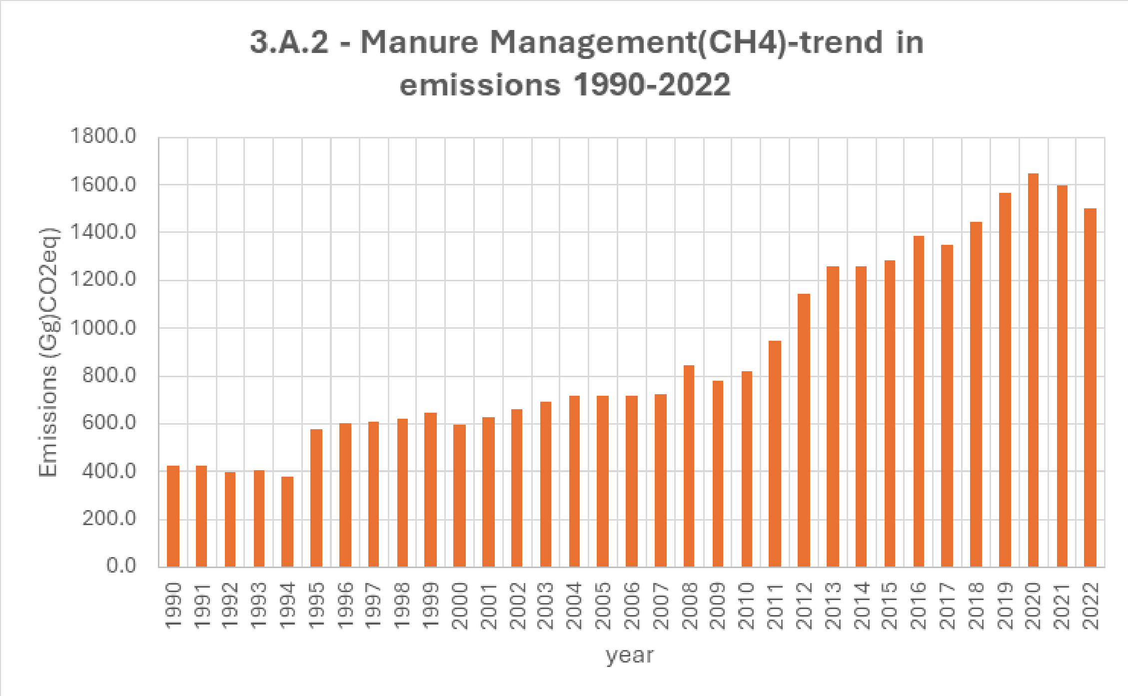


Figure 5-8: Share contribution of livestock type to Manure Management CH4 Emissions 2022

b. Trend in 3.A.2 Manure management all livestock direct N_2O

Table 5-9 shows the trend in direct manure management N_2O emission for all the livestock species from the year 1990 to 2022. Manure management direct N_2O produced a total of **494.7 Gg-CO_2eq** in 2022 from the 1990 level of **195.2 Gg-CO_2eq**, a significant increase in emissions of 153**%.** In general, with Kenya extensive use of all year-round production systems, this category is relatively low in emissions.

Table 5-8: Summary Emissions Trends in N2O from Manure Management 1990 - 2022

Category	Year					% change 1990 - 2022	% share 2022
	1990	2000	2010	2020	2022		
3.A.2 - Manure Management Methane (CH4) - total	421.9	595.8	819.9	1,649.0	1,500.6	256%	
3.A.2.a - Cattle	282.7	438.2	562.2	1,038.8	979.8	247%	65%
3.A.2.a.i - Dairy cows (tier 2)	82.8	305.2	339.4	575.6	550.5	565%	37%
3.A.2.a.ii - Other cattle	200.0	133.0	222.7	463.2	429.3	115%	29%
3.A.2.c - Sheep	41.3	33.3	45.5	106.5	89.6	117%	6%
3.A.2.d - Goats	47.6	49.6	83.2	171.5	145.5	206%	10%
3.A.2.e - Camels	32.0	38.6	82.5	251.0	185.8	481%	12%
3.A.2.g - Mules and Asses	4.1	10.5	24.9	31.1	43.6	976%	3%
3.A.2.h - Swine	3.6	8.7	6.7	18.2	22.2	519%	1%
3.A.2.i - Poultry	10.7	16.9	14.8	32.0	34.0	217%	2%

Table 5-7 also presents Manure Management N_20 emissions percent increase from 1990 to 2022 by livestock species. The highest increase by 519 % is in Swine and lowest in Dairy cattle by 96%. Although the percent increase is high in Swine, Poultry and Camels, the amount of Manure Management N_20 emissions from Swine, Poultry, and Camels is significantly low compared to other cattle, Dairy Cattle, Goat and Sheep.

Figure 5-9 illustrates the trend in direct N_2O emissions from livestock manure management. In general, from 1990-2022 there has been a consistent increase in N_2O emission from manure management, and this may be attributed to increase in livestock numbers across all the livestock types.

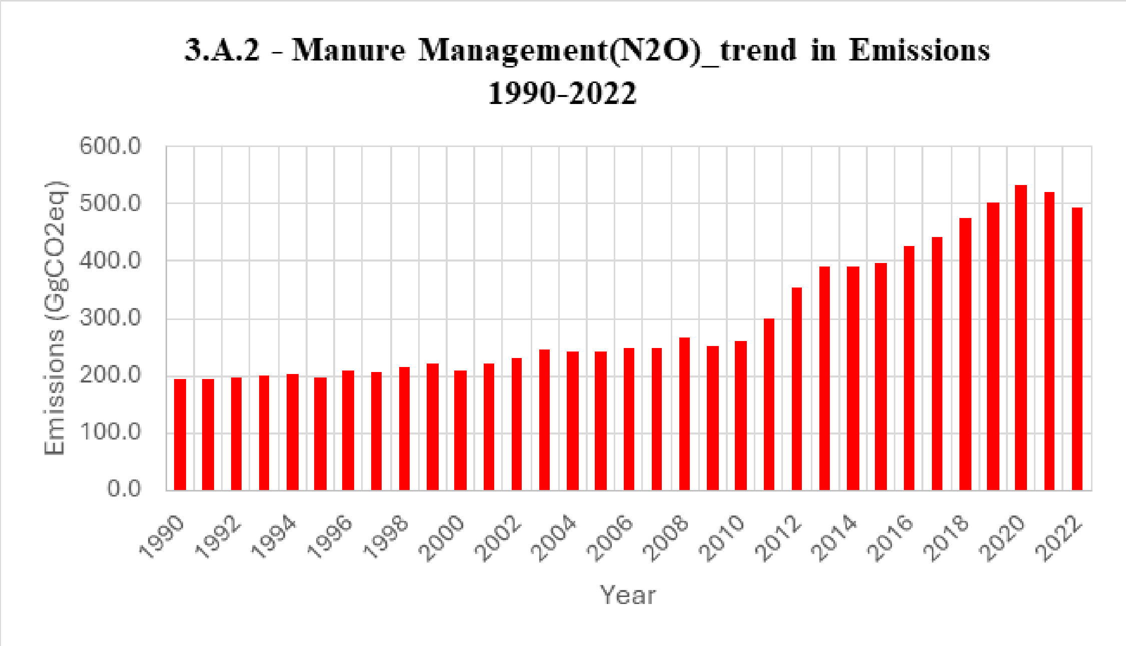


Figure 5-9: ***Direct N2O emissions trends from livestock manure management***

Figure 5-10 illustrate the contribution by livestock types to manure management direct N_2O Emissions in 2022. The largest contributor to the N_2O emissions from manure management were Dairy cattle, at **44** %, followed by other cattle **15** %, Camels at **11**%, Goats **10**%, Swine **10**% and Sheep **5**%. Poultry contributed the lowest at **2**% share. The larger proportion of N_20 emission in Dairy cattle is due to more organised production system practices for dairy cattle compared to other livestock which are more often kept on free range.

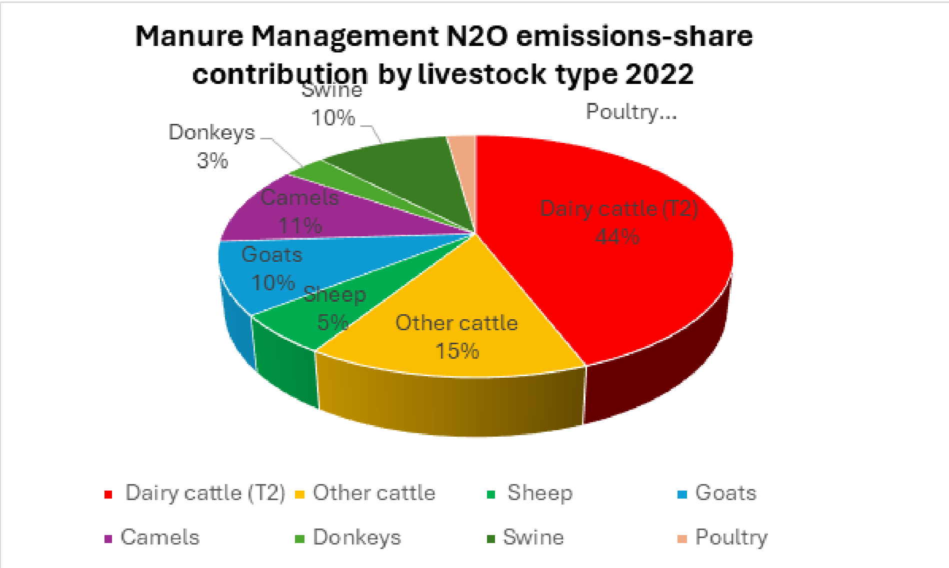


Figure 5-10: ***Share Contribution by Livestock Types to N2O Emissions from Manure Management 2022***

c. Trend in 3.C.6 Indirect N_2O Emissions from manure management

Table 5-8 Figure 5-11 shows the trend in Indirect N_2O manure management. Manure management indirect N_2O produced a total of **219.4** Gg-CO_2.eq in 2022 from the 1990 level of **98.9** Gg-CO_2.eq, representing increase in emissions of **122**%, though emissions remain relatively low.

Table 5-9: Summary of Indirect N2O emissions from manure management

Year	1990	1995	2000	2005	2010	2015	2020	2022
3.C.6 - Indirect N_2O Emissions from manure management (Gg-CO_2eq)	98.9	115.5	121.8	126.2	119.0	161.8	204.0	219.4

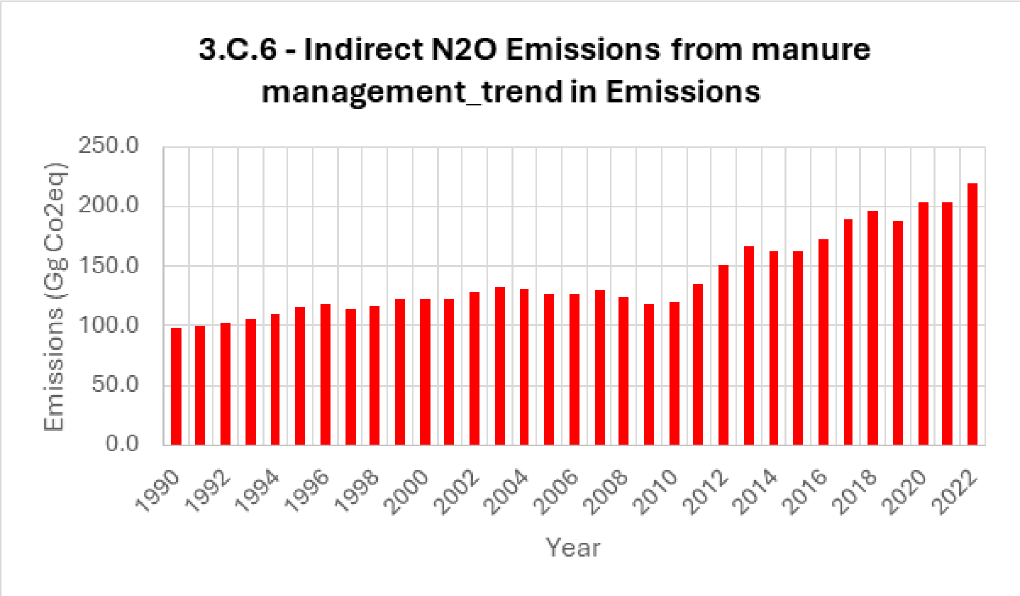


Figure 5-11: Trend in emission in indirect N2O emissions from manure management

5.3.2. Methodological aspects of the Manure Management category

a. Methodology

Methodology - Direct CH_4 from Manure management

The calculation of methane emissions from manure management was completed using the Tier 1 methodology from the 2006 Revised IPCC Guidelines (except for dairy cattle). This method relies on default emission factors drawn from previous studies and the only country specific data required are the populations of different livestock types.

Methane Emissions (kg/yr) = Σ Population of Livestock (head) x Emission Factor (kg CH_4 per head per year)

IPCC default emission factors for manure management are available for different categories of livestock based on the climate region. Livestock population data is similar to what was used in enteric fermentation in **table 5.4**. In addition to livestock population, data is required on the climatic region where livestock populations are raised as this impacts on manure management emissions. In our case an average temperature of 25°C was assumed for the entire country.

b. Activity Data

Livestock population data is similar to what was used in enteric fermentation in table 5-4. In addition to livestock populations, data is required on the climatic region where livestock populations are raised as this impacts on manure management emissions. In our case an average temperature of 25°C was assumed for the entire country.

c. Emission Factors and Coefficients in Manure management CH_4

Default emission factors were drawn from the 2006 Revised IPCC Guidelines Volume 4, Chapter 10, Table 10.14 and 10.15 and are presented in Table 5-9.

Table 5-10: ***Manure Management Emission Factors for Different Livestock Types***

(Default emission factors for T1)

Type of livestock	Dairy cattle	Non-dairy cattle	Sheep	Goats	Swine (Pigs)	Donkeys	Camels	Chick-en
Emission Factor Manure Management CH_4/head/yr	**1**	**1**	**0.15**	**0.17**	**1**	**0.9**	**1.92**	**0.02**

Methodology-Direct N_2O from Manure management

Proportions for Manure Management Systems were developed using expert judgement as shown in Table 5-.10. Direct N_2O emissions from manure management were calculated from animal populations, applying IPCC 2006 Guidelines, Volume 4, and Chapter 10 using equations 10.25 and 10.30 as defined in the IPCC guidelines.

EQUATION 10.25
DIRECT N_2O EMISSIONS FROM MANURE MANAGEMENT

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

EQUATION 10.30
ANNUAL N EXCRETION RATES

$$Nex_{(T)} = N_{rate(T)} \bullet \frac{TAM}{1000} \bullet 365$$

Nitrogen excretion rates (Nrate) were obtained from the Africa default values (IPCC, 2006, Table 10.19) while the annual nitrogen excretion for livestock Nex was estimated using the equation 10.30 from the guidelines (IPCC 2006). Default IPCC values from 2006 guidelines were used for Typical Animal Mass (TAM) for the various livestock categories. IPCC 2006 default Nitrous Oxide emission factors were used for the various manure management systems (IPCC 2006 Table 10.21).

Nitrogen excretion rates (Nrate) were obtained from the Africa default values (IPCC, 2006, Table 10.19), while the annual nitrogen excretion for livestock Nex was estimated using equation 10.30 from the guidelines (IPCC 2006). Default IPCC values from 2006 guidelines were used for Typical Animal Mass (TAM) for the various livestock categories. IPCC 2006 default Nitrous Oxide emission factors were used for the various manure management systems (IPCC 2006 Table 10.21).

Table 5-11: ***Livestock Manure Management Percentage Usage for Different Livestock Categories and Associated N2O Emission Factors***

Livestock type	% of MMS	Emission factors for N_2O for MMS tier 1
Dairy Cows (tier1)		
Pasture / Range/ Paddock	50%	0
Solid Storage	30%	0.005
Daily Spread	20%	0
Non-dairy		
Pasture / Range/ Paddock	95%	0
Solid Storage	5%	0.02
Sheep and Goats		
Pasture / Range/ Paddock	95%	0
Solid Storage	5%	0.005
Swine		
Cattle and swine deep bedding	100%	0.01
Poultry		
Poultry manure with litter	50%	0.001
Dairy Spread	20%	0
Poultry manure without litter	30%	0.001

Livestock type	% of MMS	Emission factors for N_2O for MMS tier 1
Camels		
Pasture/ Range/ Paddock	95%	0
Dry lot	5%	0.02
Donkey		
Pasture/ Range/ Paddock	95%	0
Dry lot	5%	0.02

d. Methodology-Indirect N_2O Emissions from Manure Management

The Tier 1 calculation of N volatilisation in forms of NH3 and NOx from manure management systems is based on multiplication of the amount of nitrogen excreted (from all livestock categories) and managed in each manure management system by a fraction of volatilised nitrogen. Equation 10.26 and 10.27 as defined in the IPCC guidelines were used. N losses are then summed over all manure management systems. The Tier 1 method is applied using default nitrogen excretion data, default manure management system data, and default fractions of N losses from manure management systems due to volatilisation (see Table 10.22):

EQUATION 10.26
N LOSSES DUE TO VOLATILISATION FROM MANURE MANAGEMENT

$$N_{volatilization-MMS} = \sum_{S}\left[\sum_{T}\left[\left(N_{(T)} \bullet Nex_{(T)} \bullet MS_{(T,S)}\right) \bullet \left(\frac{Frac_{GasMS}}{100}\right)_{(T,S)}\right]\right]$$

EQUATION 10.27
INDIRECT N_2O EMISSIONS DUE TO VOLATILISATION OF N FROM MANURE MANAGEMENT

$$N_2O_{G(mm)} = \left(N_{volatilization-MMS} \bullet EF_4\right) \bullet \frac{44}{28}$$

In addition, indirect N2O emissions from leaching and runoff could be added to this that volatises. However, the indirect N2O emissions from leaching and run-off of nitrogen from manure management systems was not calculated due to lack of representative values of fraction (in percentage) of managed livestock manure nitrogen N that leaches.

e. Data

The manure management system usage data used to estimate N_2O emissions from manure management was the same as those that are used to estimate CH_4 emissions from manure management. The portion of manure managed in each manure management system was also as used for each representative livestock category (as in table 5-9 above)

Emission factors for Indirect N_2O Emissions from Manure Management used were default as per IPCC guidelines default value EF4 = 0.01 kg N_2O-N/kg.

5.3.3. Description of any Flexibility applied

Flexibility was applied on Manure Management System ratios for all livestock categories based on experts drawn from relevant multifaceted disciplines and data collected from sampled farms across all production systems. Further, flexibility was also applied on herd structures considering the dynamics observed in the dairy cattle enterprises.

5.3.4. Uncertainty and consistency of the time series

The uncertainty for activity data for tier 1 and 2 was established at ±10%. Livestock populations had a lower degree of uncertainty of ±10%. Many of the calculations in this sector require livestock numbers. Only 2009 and 2019 represent actual census data, while all the other years used estimates collected from small sample sizes. The uncertainty in livestock population data is larger than typically recognized. There may well be systematic biases in the reporting of the livestock population to the national census (positive and negative). The population data should be examined in cooperation with the national statistical agencies.

Uncertainty for emission factors ranged from -50 and +30%, with a combined EF of 50.9% (Revised 2006 IPCC Guidelines for National Greenhouse Gas Inventories: Reference Manual, Table 4.5) The Tier 1 default emission factor values employed may have a large uncertainty for Kenya, because the African region values used may not reflect conditions within the country.

Data on manure management storage systems under different livestock categories was not available, with estimates being based on expert opinion and information from the various livestock industries. Country average temperature was collected from the default values, and this leads to some inaccuracy in estimates as the country has varied climate zones. To reduce this uncertainty, the percentage of animal populations, and thus manure management systems, in different temperature zones needs to be determined so that a more specific Methane Conversion Factor (MCF) can be used and a weighted average emission factor determined.

5.3.5. QA/QC for Manure Management category

QA/QC procedures were performed in accordance with the general QA/QC principles.

5.3.6. Manure Management category Specific recalculations

There was no recalculation exercised regarding emission estimates from this source category in this submission**.**

5.3.7. Planned Improvements for manure management category

In order to improve the accuracy and reduce the uncertainty of the manure management data, it would be important to improve the monitoring of the manure management systems. N_2O emissions data from manure management systems would also be improved if N excretion rates for cattle in Kenya were determined so that actual data could be used instead of the IPCC 2006 default values.

Indirect N_2O emissions from leaching and runoff will have to be added to the indirect N_2O emission that volatize by determining representative values of fraction (in percentage) of managed livestock manure nitrogen (N) that leaches.

5.4. Rice Cultivation (3.C.7)

5.4.1. Description and Trend of GHGs in Rice cultivation

Description

Rice is Kenya's third staple after maize and wheat. Kenyan rice production is estimated at 33,000 – 50,000 metric tons, whereas consumption is 180,000–250,000 tons. Kenya grows 70.1% of its rice in government-run irrigation projects and 29.9 & in rain-fed systems. The total rice cultivation area increased from 11,000 ha in 1995 to 29,438 ha in 2015.

Anaerobic decomposition of organic material in flooded rice fields produces methane. Upland rice fields which are not flooded do not produce significant methane emissions. CH_4 is released into the atmosphere through diffusion loss across the water surface, bubbles and rice plants themselves which is the most common.

Methane emissions potential from rice cultivation depend on the percent share of the total rice cultivation areas under rain fed upland, rain fed lowland and irrigated areas. It is also a function of the period the cultivated area is flooded. Data on annual rice cultivation area and percentage area under different systems were obtained from Ministry of Agriculture and Livestock Development (MoALD).

Emission Trends from Rice Cultivation

Methane emissions from rice cultivation increased by **88.2 Gg-CO_2 eq** between 1990 to 2022 (table 5-11 and Figure 5-12).

Table 5-12: Summary emissions from rice cultivation

Year	1990	1995	2000	2005	2010	2020	2022
3.C.7 - Rice cultivation emissions (GgCO2eq)	103.7	87.8	111.6	107.9	146.2	118.9	225.9

The emissions from rice cultivation contributed one percent of the total emissions from aggregated sources and non-CO_2 emissions from lands.

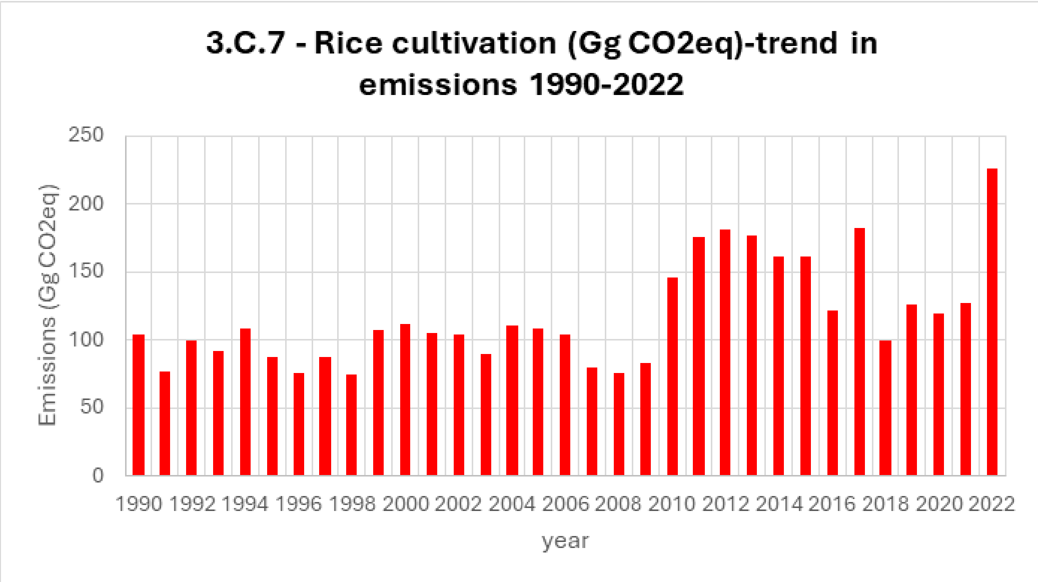


Figure 5-12: Emissions trends from Rice Cultivation, 1990 – 2022 (Gg CO2 Eq)

The observed increase in methane emissions can be attributed to the expansion in the area of irrigated rice schemes in Kenya. Generally, from 2016 there was a general decrease in emissions from rice production which can be attributed to the introduction of intermittent irrigation in some rice growing regions of Kenya.

5.4.2. Methodological Aspects of Rice Cultivation Category

Methodology

The IPCC Tier 1 methodology and default emission factors for rice cultivation were used. Emissions of methane from rice fields were estimated using IPPC equations 5.1, 5.2 and 5.3 as defined in the IPCC guidelines: -

EQUATION 5.1
CH_4 EMISSIONS FROM RICE CULTIVATION

$$CH_{4\ Rice} = \sum_{i,j,k} (EF_{i,j,k} \bullet t_{i,j,k} \bullet A_{i,j,k} \bullet 10^{-6})$$

EQUATION 5.2
ADJUSTED DAILY EMISSION FACTOR

$$EF_i = EF_c \bullet SF_w \bullet SF_p \bullet SF_o \bullet SF_{s,r}$$

EQUATION 5.3
ADJUSTED CH_4 EMISSION SCALING FACTORS FOR ORGANIC AMENDMENTS

$$SF_o = \left(1 + \sum_i ROA_i \bullet CFOA_i\right)^{0.59}$$

Activity Data

The MoALD provided annual harvested areas of rice from 1990 to 2022, disaggregated into different rice water regimes associated with varied levels of methane emissions. Table 5-12 summaries the harvested areas of rain-fed and irrigated rice water regimes.

Table 5-13: Activity data for rice cultivation 1990-2022

Rice ecosystem	Water regime	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
Upland	Rainfed (area (ha)	208.8	257.6	376.4	240.5	137.6	236	297	254	144	279	432
Irrigated	Continuously flooded (area ha)	12500	9210	12050	11030	13100	10580	9100	10570	9004	12950	13450
Irrigated	Intermittend (area ha)	0	0	0	0	0	0	0	0	0	0	0

Rice ecosystem	Water regime	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
Upland	Rainfed(area (ha)	530	420	1157.65	2143.89	3924	10605	6831	7642.4	9978	11488	6933
Irrigated	Continuously flooded (area ha)	12670	12580	10781	13322	13000	12501	9626	9092	10072	17611	21101
Irrigated	Intermittend (area ha)	0	0	0	0	0	0	0	0	0	0	0

Rice ecosystem	Water regime	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
Upland	Rainfed (area (ha)	7758.4	10036	8979.2	9279	14315	8842.8	4965.6	3991.8	7116.5	4548.1	8615
Irrigated	Continuously flooded (area ha)	21872	21313	19411	19411	14586	21949	4307	6614	5680	7002	18685
Irrigated	Intermittend (area ha)	0	0	0	0	0	0	23076	25710	25911	25026	25570

Emission Factors and Coefficients for Rice

Default scaling factors for methane emissions, correction factors for organic amendments and seasonally integrated emission factors were drawn from the 2006 IPCC Guidelines Tables 4-10 and 4-11 and are presented in Table 5-13.

Table 5-14: Rice Water Management Regime Emission Factors and Coefficients

Water Management Regime	Baseline Emission Factor, EF_c	(SF_w)	(SF_p)	(ROAi)	(CFOAi)	(SF_o)	$(SF_{s/r})$	Cultivation Period (days)
Irrigated – Continuously Flooded	1.30	0.52	1.9	2	1	1.9	1	120
Rainfed – Drought Prone	1.30	0.27	1.22	2	1	1.9	1	120

5.4.3. Description of any Flexibility applied

Paragraph 29 of the MPGs on flexibility has been applied on uncertainty due to lack of harmonised data from the sector. Thus, at a minimum, a qualitative discussion of uncertainty for this key category is provided.

5.4.4. Uncertainty and consistency of the time series

Uncertainty exists in the annual harvested areas of rice as well as default emission factors used. Uncertainty is estimated to be ±10 percent from expert judgement in the rice activity data, while the default Methane (CH_4) baseline emission factor of 1.3 has an error range of 0.8 to 2.2 (Volume 4, Chapter table 5.11 IPCC guidelines).

5.4.5. QA/QC for Rice cultivation category

QA/QC procedures were performed in accordance with the general QA/QC principles.

5.4.6. Rice cultivation category specific recalculations

There was no recalculation exercised regarding emission estimates from this source category in this submission.

5.4.7. Planned Improvements for Rice cultivation category

The quality of activity data for rice fields in Kenya is average and improved surveys could help to identify the crop areas that are continuously flooded, intermittent and rainfed. In order to reduce uncertainty in rice cultivation activity data. it is crucial to develop monitoring systems to capture areas under different water management regimes and clearly determine annual harvested hectares.

5.5. 3C– Agricultural soils

5.5.1. Description and Trend of GHGs in Agriculture Soils

Description

The source category Agriculture soils include direct and indirect N2O emissions from managed soils (Table 5-14).

Table 5-15: Categories of Agricultural soils

IPCC Code	IPCC category	Gas
3.C.4	Direct N2O Emissions from managed soils	N2O
3.C.5	Indirect N2O Emissions from managed soils	N2O

Direct N2O Emissions from managed soils are derived from: -

- Inorganic N fertilisers
- Organic N fertilisers*
- Urine and dung deposited by grazing animals,
- Crop residues that remain in soils
- Mineralisation of soil organic matter*
- Cultivation of organic soils

However, for Kenya data, the application of organic manure, Urine and dung deposited by grazing animals, and Nitrogen in mineral soils that are mineralised was unavailable, and modelling depending on the other factors listed above.

Indirect N_2O Emissions from managed soils are derived from; -

- Volatilisation of nitrogen included in synthetic fertilizers and animal manure (used as fertilizers) as NO_x and NH_3, followed by atmospheric deposition as NO_x, HNO_3 and NH_4 on soils and surface waters and subsequent N_2O formation.
- Leaching and runoff of nitrogen contained in applied fertilizers (synthetic and animal manure).

Trend of emissions from Agricultural soils

Table 5-15 and Figure 5-13 below illustrates both direct and indirect N2O emissions from managed soils.

The direct and Indirect N_2O Emissions from managed soils in Kenya rose from **1213.6** Gg-CO_2 eq in 1990 to **2159.3** Gg-CO_2 equivalent in 2022 representing an increase of 78 percent. This could be associated with increase in land under cultivation and fertilizer application.

Table 5-16: Summary of Agricultural Soil Emissions 1990-2022

Year	1990	2000	2010	2020	2022	% change 1990-2022	% share 2022
3.C.4 - Direct N2O Emissions from managed soils	904.3	915.0	1160.7	1611.5	1616.7	79%	75%
3.C.5 - Indirect N2O Emissions from managed soils	309.3	292.8	361.5	541.9	542.7	75%	25%
Year	1990	2000	2010	2020	2022		
Total Agriculture soils (Direct + Indirect) N2O emissions from Managed soils	1213.6	1207.8	1522.2	2153.4	2159.3	78%	

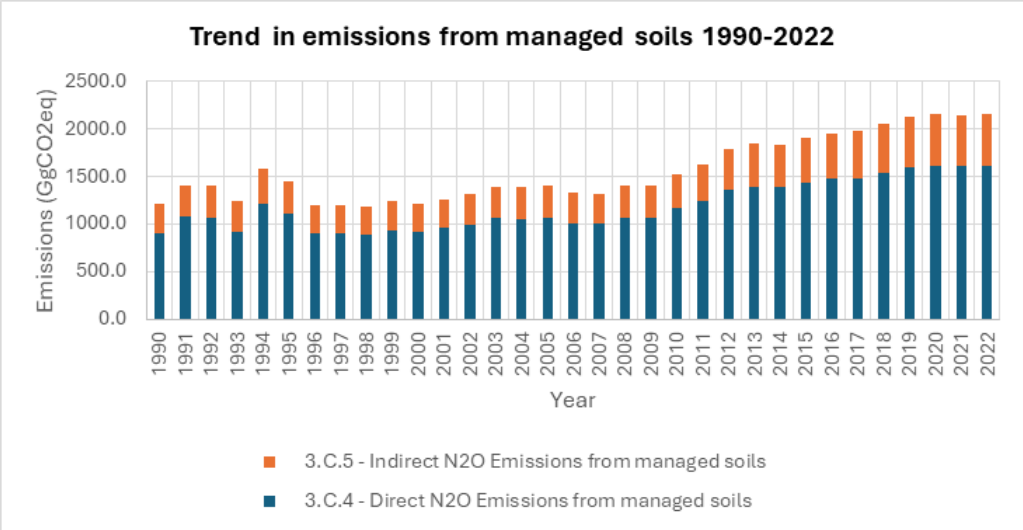


Figure 5-13: Trends in Direct and Indirect N2O emissions from managed soils (Gg-CO2eq) 1990-2022.

Figure 5-14 illustrates the contribution of direct and indirect N2O emissions from managed soils in 2022. The largest contributor to the N_2O emissions to agricultural soils is from direct sources at **75** percent, followed by indirect sources at **25** percent.

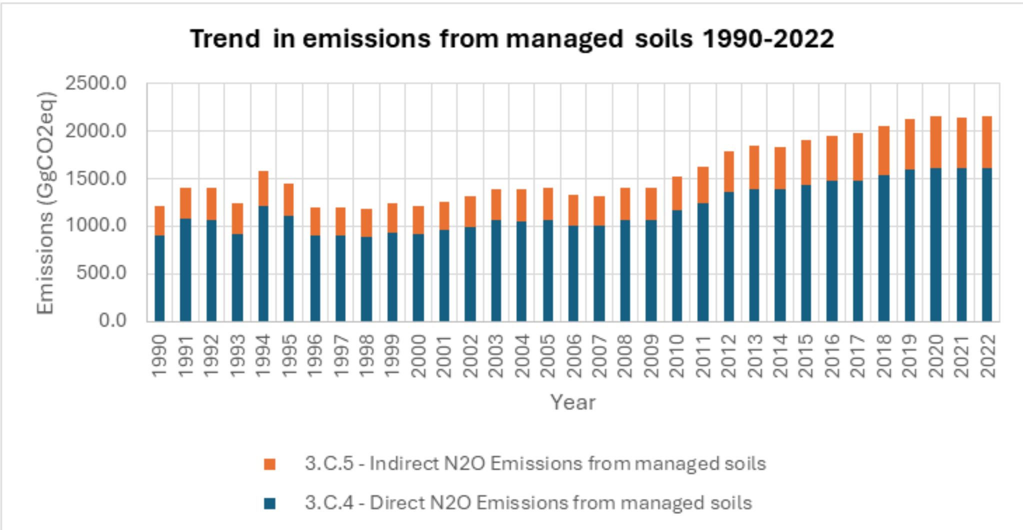


Figure 5-14: contrition of direct and indirect from managed soils.

5.5.2. Methodological aspects of the agriculture soils category

Methodological Issues of Direct N_2O emissions from Managed Soils (3.C.4)

For the calculation of N2O emissions from Agricultural soils a Tier 1 method was applied based on IPCC 2006 guidelines, and default emission factors. Direct N_2O emissions from managed soils were determined using the IPCC tier 1 approach using Equation 11.1 as defined in the IPCC guidelines.The estimation of N_2O emissions relied heavily on the use of synthetic fertilizers, and N in crop residues,

EQUATION 11.1
DIRECT N_2O EMISSIONS FROM MANAGED SOILS (TIER 1)

$$N_2O_{Direct}-N = N_2O-N_{N\,inputs} + N_2O-N_{OS} + N_2O-N_{PRP}$$

Where:

$$N_2O-N_{N\,inputs} = \begin{bmatrix} [(F_{SN} + F_{ON} + F_{CR} + F_{SOM}) \bullet EF_1] + \\ [(F_{SN} + F_{ON} + F_{CR} + F_{SOM})_{FR} \bullet EF_{1FR}] \end{bmatrix}$$

$$N_2O-N_{OS} = \begin{bmatrix} (F_{OS,CG,Temp} \bullet EF_{2CG,Temp}) + (F_{OS,CG,Trop} \bullet EF_{2CG,Trop}) + \\ (F_{OS,F,Temp,NR} \bullet EF_{2F,Temp,NR}) + (F_{OS,F,Temp,NP} \bullet EF_{2F,Temp,NP}) + \\ (F_{OS,F,Trop} \bullet EF_{2F,Trop}) \end{bmatrix}$$

$$N_2O-N_{PRP} = [(F_{PRP,CPP} \bullet EF_{3PRP,CPP}) + (F_{PRP,SO} \bullet EF_{3PRP,SO})]$$

Methodological Issues of Indirect N_2O Emissions from Managed Soils (3.C.5)

Indirect N_2O emissions from agricultural soils is derive from:

- Volatilisation of nitrogen included in synthetic fertilizers and animal manure (used as fertilizers) as NO_x and NH_3, followed by atmospheric deposition as NO_x, HNO_3 and NH_4 on soils and surface waters and subsequent N_2O formation.
- Leaching and runoff of nitrogen contained in applied fertilizers (synthetic and animal manure).

The N_2O emissions from atmospheric deposition of N volatilised from managed soil are estimated using Equation 11.9 as defined in the IPCC guidelines.

EQUATION 11.9
N_2O FROM ATMOSPHERIC DEPOSITION OF N VOLATILISED FROM MANAGED SOILS (TIER 1)

$$N_2O_{(ATD)}-N = [(F_{SN} \bullet Frac_{GASF}) + ((F_{ON} + F_{PRP}) \bullet Frac_{GASM})] \bullet EF_4$$

Leaching/Runoff, $N_2O_{(L)}$

The N_2O emissions from leaching and runoff were estimated using tier 1 approach Equation 11.10:

EQUATION 11.10
N_2O FROM N LEACHING/RUNOFF FROM MANAGED SOILS IN REGIONS WHERE LEACHING/RUNOFF OCCURS (TIER 1)

$$N_2O_{(L)}-N = (F_{SN} + F_{ON} + F_{PRP} + F_{CR} + F_{SOM}) \bullet Frac_{LEACH-(H)} \bullet EF_5$$

However, $F_{PRP,}$ and F_{SOM} values could not be calculated from the available data, so the emissions' relied on the other default parameters and data.

Data sources

The amount of synthetic fertilizers consumed in the country was provided by MoALD from 1990 to 2022 and is presented in Table **5-16.** Crop area and production data for major crops including maize, coffee, Irish potatoes, sugarcane, tea and wheat were provided by the Ministry of Agriculture.

Data for missing years was filled by use of statistical techniques. Annual crop residues were derived from FAOSTAT, while annual amount of urine and dung inputs to grazed soils was derived from livestock population data provided by Kenya`s State Department of Livestock.

Table 5-17: Activity data for agricultural soils

Synthetic fertilizer applied (Tonnes / yr)	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
Ammonium sulphate	3151.78	2347.97	3081.75	2795.08	3282.93	2682.37	2330.46	2684.35	2268.70	2567.05	3275.98
Calcium Ammonium Nitrate	218721.55	219940.85	227917.33	227771.60	250962.34	239718.53	247137.53	249414.50	234033.18	253446.01	251581.74
Di-Ammonium Phosphate	218465.19	219602.00	227586.57	226919.14	250177.02	238737.70	246072.42	248606.55	233087.59	252711.00	251254.93
NPK compound-N	7342.59	7167.22	7410.06	7522.62	7736.80	7806.13	7989.28	7951.17	8077.64	8063.58	8439.40

Synthetic fertilizer applied (Tonnes / yr)	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
Ammonium sulphate	2331.45	2613.60	2960.79	3835.54	4197.15	5730.29	4081.34	4150.13	4972.40	7216.55	6952.43
Calcium Ammonium Nitrate	268383.40	273528.63	302825.91	294100.83	304405.36	275221.41	262483.68	284700.72	307835.99	333197.67	349742.02
Di-Ammonium Phosphate	267631.34	275746.78	302482.15	293871.57	304351.44	276532.77	263516.95	286071.54	309573.16	336007.87	352371.11
NPK compound-N	8416.78	8727.80	8719.46	8874.03	9187.11	9014.08	8639.68	8798.78	8839.19	8534.40	8989.60

Synthetic fertilizer applied (Tonnes / yr)	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
Ammonium sulphate	7348.34	7774.55	7040.77	7115.12	7167.45	7636.37	6439.47	6197.97	6972.89	6335.93	7344.52
Calcium Ammonium Nitrate	350773.74	346399.38	348336.36	374225.09	387546.17	357385.45	371295.33	393210.53	370102.57	370989.79	371877.01
Di-Ammonium Phosphate	353551.73	349341.43	350862.47	376739.32	390037.51	360062.20	373324.58	395069.98	372300.44	372820.12	374162.59
NPK compound-N	8530.55	9062.03	9317.31	9617.15	9774.70	9830.79	10274.45	10391.95	10062.60	10145.11	10227.62

Emissions Factors:

All emissions factors used were default derived from Table 11.1 and Table 11.3, IPCC guidelines Volume 4 Chapter 11.

Table 5-18: Emission factors for calculating direct and Indirect N2O emissions from managed soils

Direct N_2O emission factors		Indirect N_2O emission factors	
EF_1 Inorganic N fertilisers (kg N_2O-N/kg)	(for CAN, DAP, NPK) 0.003 (for AS)	EF_5 = emission factor for N_2O emissions from N leaching and runoff, kg N_2O-N	0.0075
EF1 Crop residue (kg N2O-N/kg)	0.01	$Frac_{LEACH)}$ kg N / (kg of N additions)	0.03
EF1 Emission Factor for organic matter applied fertilisers (kg N_2O-N/kg N applied)	0.01		
EF2 Cultivation of organic soils (kg N_2O-N/ha)			
EF_3 Urine and dung deposited by grazing animals (kg N_2O-N/kg)	0.01		
EF_4- emission factor for N_2O emissions from atmospheric deposition of N on soils and water surfaces (kg N_2O-N/kg)	0.01		

5.5.3. Description of any Flexibility applied in Agriculture soils category

Paragraph 29 of the MPGs on flexibility has been applied on uncertainty due to inadequate harmonised data from the sector. Thus, at a minimum, a qualitative discussion of uncertainty for this key category is provided.

5.5.4. Uncertainty and consistency of the time series

Activity data for Direct N2O emissions from managed soils have uncertainty of ±10%. EF_1, emission factor for N_2O emissions from N inputs value of 0.01 has an error range of 0.003 to 0.03 (IPCC guidelines volume 4, Chapter 11, table 11.1).

5.5.5. QA/QC for Agriculture soils

QA/QC procedures were performed in accordance with the general QA/QC principles.

5.5.6. Agriculture soils category Specific recalculations

There was no recalculation exercised regarding emission estimates from this source category in this submission. No data on emissions from organic soils.

5.5.7. Planned Improvements for Agriculture soils

Planned improvements for Direct and Indirect N_2O Emissions

- Crop area data collection could be enhanced by MoALD working closely with the devolved governments
- In future the accurate amount of fertiliser used in irrigated rice cultivation should be determined by MoALD.
- Other improvements include Data on: -

N_2O-N_{OS} = annual direct N_2O-N emissions from managed organic soils, kg N_2O-N yr^{-1}

F_{OS} = annual area of managed/drained organic soils, hectares

F_{SOM} = annual amount of N in mineral soils that is mineralised, in association with loss of soil C from soil organic matter as a result of changes to land use or management

N_2O-N_{PRP} = annual direct N_2O-N emissions from urine and dung inputs to grazed soils, kg N_2O-N yr^{-1}

(since we could not determine the fraction of N from N sources deposited within land use subcategory F(Ns,LU), Fraction of N excreted in Urine F_u and Fraction of N excreted in dung Fd)

- Surveys on animal manure, compost, sewage sludge and organic manure and other organic N additions added to soils need to be considered.

5.6. Biomass burning in croplands (3.C.1.b)

5.6.1. Description and Trend of GHG Biomass burning in croplands

Non-CO2 emissions from ***Cropland remaining Cropland*** (particularly CH4, CO, NOx and N2O) are usually associated with burning of agriculture residues, which vary by country, crop, and management system. CO2 emissions from biomass burning do not have to be reported, since the carbon released during the combustion process is assumed to be reabsorbed by the vegetation during the next growing season.

In the section we report on emissions resulting from burning of agricultural residues which include methane (CH4), nitrous oxide (N_2O). Due to a lack of sufficient data, the estimation of non-CO_2 emissions from biomass burning on crop land use (Category 3.C.1b) was based on modelled results from **sugar cane** only, where burning is still practised to ease harvesting. Annual and biennial crops such as cereals, pulses, and root and tubers are rarely **burned** because of the guidance provided by agriculture extension advisories, as most of the crop **residues** are used as feeds for livestock in the country**.**

Trend of GHG in the biomass burning in cropland

Both CH_4 and N_2O emissions from biomass burning from sugarcane for the period 1990-2022 is summarized in Table 5-18, while the trend is shown in figure 5-15, (specifically sugarcane). Emissions from biomass burning in cropland have risen from **2 Gg CO_2eq** in 1990 to **6.1 Gg**-CO_2eq in 2022 representing **210%** rise in emissions in the sub-category. **80%** of emissions from biomass burning in sugarcane result in CH_4 emissions, while N_2O is about **20%.**

Table 5-19: Summary emissions from burning in cropland (sugarcane)

Year	1990	1995	2000	2005	2010	2015	2020	2022	Change 1990-2022	% Share 2022
3.C.1.b - Burning in (Cropland CH4) sugarcane	1.6	2.2	2.3	2.2	2.7	3.1	3.5	4.9	210%	80%
3.C.1.b - Burning in Cropland (N2O) sugarcane	0.4	0.5	0.6	0.5	0.7	0.8	0.9	1.2	210%	20%
Total 3.C.1.b - Burning in Cropland (GgCO2eq)	2.0	2.7	2.9	2.7	3.4	3.9	4.4	6.1	210%	

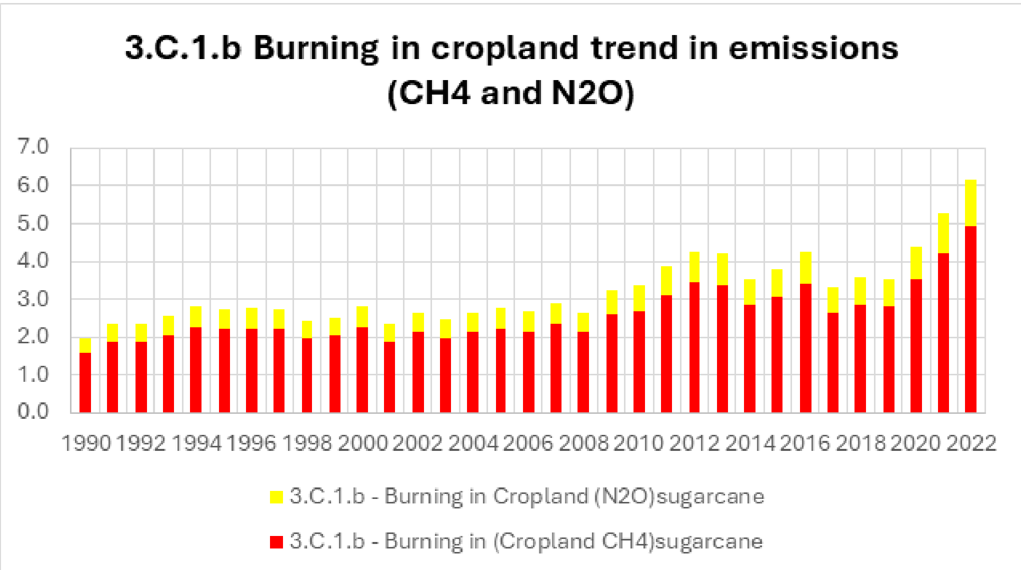


Figure 5-15: Trends analysis of biomass burning (sugarcane)

5.6.2. Methodological aspects of Biomass burning in cropland category

Methodology

Emissions from biomass burning were estimated using **equation 2.27** as defined in the IPCC guideline:

EQUATION 2.27
ESTIMATION OF GREENHOUSE GAS EMISSIONS FROM FIRE

$$L_{fire} = A \bullet M_B \bullet C_f \bullet G_{ef} \bullet 10^{-3}$$

Emission factors: used were default as provided in IPPCC guidelines Volume 4, chapter 2 (tables 2.4, 2.5, and 2.6).

Area burned A: was assumed to be 60% of area under sugarcane cultivation per year by expert judgment (some farmers use the sugarcane residues for other purposes)

Activity data

Activity data for area burned for different crops was sourced from FAOSTAT. Table 5-19 summarises the data on Area burned for sugarcane in Kenya (Source FAOSTAT)

Table 5-20: Area burned for sugarcane (Source FAOSTAT)

Year	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
Biomass burned (dry matter) (Tonnes)	26321.10	31122.65	30954.30	33762.95	37304.80	36494.25	37050.00	36400.00	32572.15	33691.45	37207.95
Area (Ha)	40494	47881	47622	51943	57392	56145	57000	56000	50111	51833	57243
60% of area burnt	24296.4	28728.6	28573.2	31165.8	34435.2	33687	34200	33600	30066.6	31099.8	34345.8

Year	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
Biomass burned (dry matter) (Tonnes)	56771.00	55807.05	46917.00	50589.50	56469.40	44010.20	47502.00	46735.00	58371.95	70008.9	81645.9
Area (Ha)	87340	85857	72180	77830	86876	67708	73080	71935	89800	92436	116500
60% of the area burnt	52404	51514.2	43308	46698	52125.6	40624.8	43848	43161	53880	55461.6	69900
Year	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
Biomass burned (dry matter) (Tonnes)	31066.10	35106.50	32804.20	35224.15	36749.05	35503.65	38480.65	35402.25	42753.10	44679.70	51350.00
Area (Ha)	47794	54010	50468	54191	56537	54621	59201	54465	65774	68738	79000
60% of area burnt	28676.4	32406	30280.8	32514.6	33922.2	32772.6	35520.6	32679	39464.4	41242.8	47400

5.6.3. Description of any Flexibility applied

Paragraph 29 of the MPGs on flexibility has been applied on uncertainty due to inadequate harmonised data from the sector. Thus, at a minimum, a qualitative discussion of uncertainty for this category is provided.

5.6.4. Uncertainty and consistency of the time series

Crop area data is a source of uncertainty especially after devolution of agricultural function in 2013. Lack of area burned data for different crops from national statistics result in bias and uncertainty in the data, hampering the determination of accurate emissions from biomass burning in cropland.

5.6.5. QA/QC for Biomass burning in cropland

QA/QC procedures were performed in accordance with the general QA/QC principles.

5.6.6. Biomass burning in cropland category Specific recalculations

There was no recalculation exercised regarding emission estimates from this source category in this submission

5.6.7. Planned Improvements for Biomass burning in cropland

Collaboration with institutions providing data on area burned using high-resolutions satellites. Country data collection mechanism on biomass burning in all land classes should be put in place.

5.7. Liming Category (3.C.2)

5.7.1. Description and Trend of GHGs in Liming Category

In Kenya, liming is a beneficial practice that helps in the regulation of soil acidity and promotes growth in different agricultural lands. A national soil fertility assessment conducted in 2014/2015 (KALRO 2015) indicated that 47% of soils in high potential areas are acidic and Lime application is key to address this situation. When soils are limed, with carbonates, such as lime (e.g., calcic limestone (CaCO3), or dolomite (CaMg(CO3)2), CO2 emissions are generated as the carbonates dissolve and release bicarbonate ($2HCO_3$) which evolves into CO_2 and water (H_2O).

Emission trends in Liming

Emissions from liming for the period 1990-2022 is summarized in Table **5-20**, while the trend is shown in figure 5-.16

Table 5-21: Summary emissions from liming 1990-2022

Year	1990	1995	2000	2005	2010	2015	2020	2020	2022
3.C.2 - Liming (Gg CO2eq)	0.7	0.6	0.7	2.4	2.2	2.7	1.4	1.4	1.4

Emissions in this category rose from **0.7 Gg** in 1990 to **2.7** Gg CO_2 in 2016 and dropping gradually to **1.4** Gg CO_2eq in 2022. There was a significant rise in lime use on agricultural soils between 1995 and 2015 associated with agricultural research, awareness creation through extension technical advisories on agricultural lime benefits on soils. Between 1995 and 1999 the country had only one major lime production plant (and many smaller, essentially artisanal, facilities). Lime production increased in 2000 with the introduction of a new lime production plant at Athi River. In addition, some companies (e.g. Omnia) were importing granulated dolomitic lime. An NGO (One Acre Fund) has also promoted lime usage in its area of operation in Western Kenya. That explains the increase in lime usage between 1995 and 2016. However, from 2019, there has been a steady drop in lime production which is attributed to the closure of the Athi River Mining (ARM) Limited.

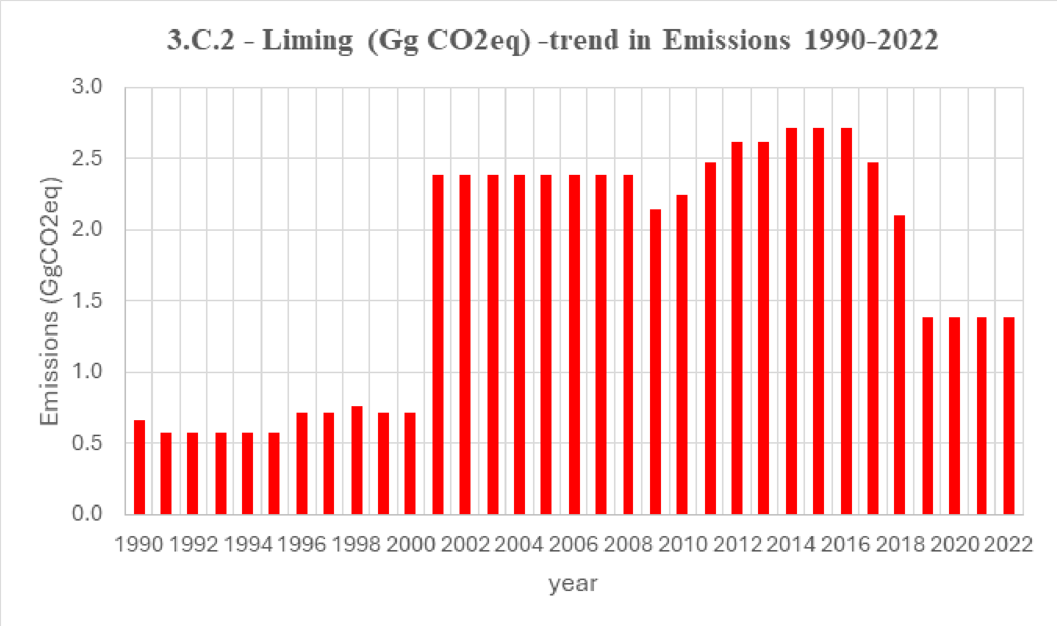


Figure 5-16: Trend in lime emissions 1990-2022

5.7.2. Methodological aspects of the Liming Category

Methodology

CO_2 Emissions from additions of carbonate limes to soils can be estimated with Equation 11.12 as per the IPCC guidelines.

EQUATION 11.12
ANNUAL CO_2 EMISSIONS FROM LIME APPLICATION

$$CO_2\text{–}C\ Emission = (M_{Limestone} \bullet EF_{Limestone}) + (M_{Dolomite} \bullet EF_{Dolomite})$$

Default Emission factor for Dolomite lime, EF=0.13 (tonnes C/ tonne of lime) was used.

Activity Data

To calculate emissions from lime application, activity data on lime production were obtained from Kenya National Bureau of Statistics reports (1990-2022), Kenya Association of Manufacturers, with data built up from Kenya's second national communication (NC2). Lime for agricultural use was estimated to 10% of the lime production in Kenya used in the IPPU category. The 10% figure was based on sector experts 'consultations and judgement.

Table 5-22: Activity data for Liming 1990-2022 (Lime Production data Source KNBS, USGS)

Year	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
Agriculture lime use (tonnes)	1390	1200	1200	1200	1200	1200	1500	1500	1600	1500	3200
Year	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**
Agriculture lime use (tonnes)	5000	5000	5000	5000	5000	5000	5000	5000	4500	4700	5200
Year	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**
Agriculture lime use (tonnes)	5500	5500	5700	5700	5700	5200	4400	2900	2900	2900	2900

United States Geological Survey (US Department of the Interior), "The Mineral Industry of Kenya", yearly publications from 1990 to 2022, secondary data drawn from KNBS (Statistical Abstracts, etc.), mining industry sources, banking sources, industry interviews, industrial trade information, etc.

5.7.3. Description of any Flexibility applied

Paragraph 29 of the MPGs on flexibility has been applied on uncertainty due to lack of harmonised data from the sector leading to assumptions where 10% of production data is used to calculate emissions from liming. Thus, at a minimum, a qualitative discussion of uncertainty for this key category is provided.

5.7.4. Uncertainty and consistency of the time series

Activity data uncertainty is estimated to be -7% and +10%, while default emission factor uncertainty is -50% and +10% with combined uncertainty of +50.99. The activity data uncertainties are informed by the nature of soils and climate conditions in regions where liming is predominant. The major causes of uncertainties are from amount of carbonate lime applied to soils and in the net amount of carbonate-C from liming applications that is emitted as CO2 The lime activity data is similar to that used in IPPU, and it was assumed that 10 % of lime production is used in agriculture, which may not be the actual case every year. Thus, uncertainties in both the amount of lime available for application and the amount applied in a particular inventory year is a source of concern. There is also a likelihood that the country also has many smaller, essentially artisanal, facilities that produce lime which may not be captured in the national statistics. Given the high uncertainty in liming activity data, there is need to harmonise data collection and clearly determined actual use of lime in agricultural soils.

5.7.5. QA/QC for Liming Category

QA/QC procedures were performed in accordance with the general QA/QC principles.

5.7.6. Liming Category-Specific recalculations

There was no recalculation exercised regarding emission estimates from this source category in this submission.

5.7.7. Planned Improvements for Liming Category

To enhance transparency and instil confidence in the data provided, it may be necessary for future inventory development to establish direct collaboration with lime producing companies. Given the high uncertainty in liming activity data, there is a need to harmonise data collection. It is crucial to develop monitoring systems to capture lime application on agricultural soils and clearly determine actual use of lime in agricultural soils.

5.8. Urea application (3.C.3)

5.8.1. Description and Trend of GHGs in Urea application

Description of Urea Application

Adding urea to soils during fertilization leads to a loss of CO_2 that was fixed in the industrial production process. Urea ($CO(NH_2)_2$) is converted into ammonium (NH_4^+), hydroxyl ion (OH^-), and bicarbonate ($HCO3^-$), in the presence of water and urease enzymes. Similar to the soil reaction following addition of lime, bicarbonate that formed evolves into is CO_2 and water. This source category is included because the CO_2 removal from the atmosphere during urea manufacturing is estimated in the Industrial Processes and Product Use Sector.

Emission trends from Urea Application

Emissions from liming for the period 1990-2022 is summarized in Table **5-22**, while the trend is shown in figure 5-.17. Urea emissions have risen from **6.3** Gg- CO_2eq in 1990 to **31.1 GgCO_2**eq in 2022, representing 394% rise in emissions in in the sub-category as shown in Figure 5-17, though overall emissions remain low. The increase is primarily attributable to increased uptake of urea fertilizer application coupled with government sourcing of urea.

Table 5-23: Summary emissions for Urea Application 1990-2022

Year	1990	1995	2000	2005	2010	2015	2020	2020
3.C.3 - Urea application emissions (GgCO2eq)	6.3	7.9	11.2	18.3	28.3	31.0	31.1	31.1

Urea emissions fluctuate over time, there is a steady rise from 1990 to 2011 and then a drop in urea application in 2012, then a bump (rise) in application in 2014. In 2014 there was a government fertilizer subsidy programme aimed at increasing agriculture productivity, cushioning farmers by making fertilizer affordable and as a fertilizer price stabilization mechanism that could have resulted in high supply of urea in 2014. There has been an increase in Urea application to enhance productivity, access to Urea for application, cushion farmers through fertilizer affordability, fertilizer price stabilization mechanism that could have resulted in gentle high supply of urea from 2013.

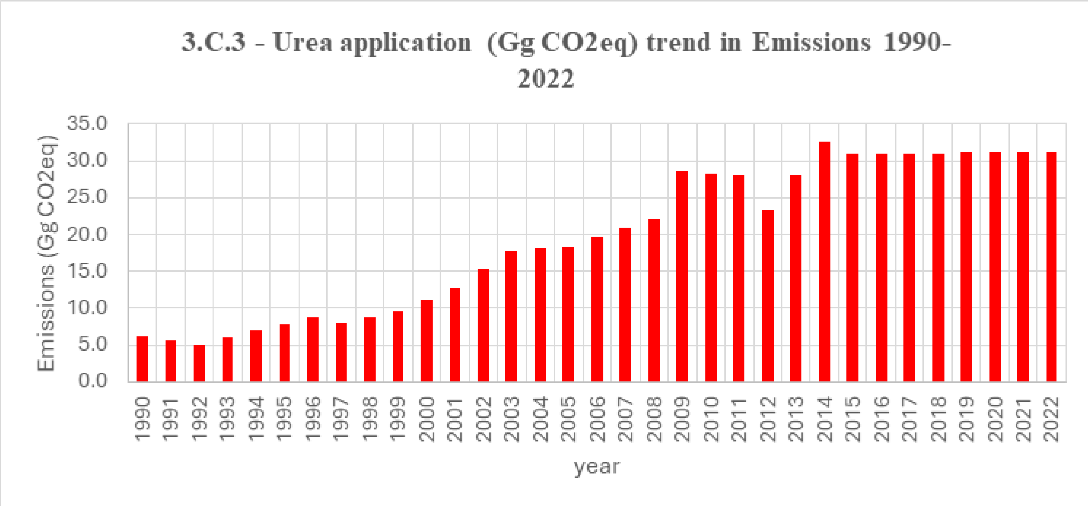


Figure 5-17: Trend in emissions in Urea application 1990-2022

5.8.2. Methodological aspects of Urea application category

CO_2 emissions from urea fertilization were estimated using tier 1 approach with Equation 11.13 as defined in the IPCC guidelines.

EQUATION 11.13
ANNUAL CARBON EMISSIONS FROM UREA APPLICATION (CO_2)

$$CO_2 - C\ Emission = M \bullet EF$$

Default Emission factor EF-0.2(tonnes of C/tonne of carbonate) was applied under tier 1 approach.

Activity Data:

Urea consumption data was sourced from the Ministry of Agriculture fertiliser division, supplemented with United States Geological Survey (US Department of the Interior), "The Mineral Industry of Kenya", yearly publications from 1990 to 2022, secondary data drawn from KNBS (Statistical Abstracts, etc.), In order to address the missing years (1990-1994), splicing statistical techniques were employed to fill in the gaps. However, these methods introduced a considerable level of uncertainty in the resulting modelled data. The amount of Urea applied to agricultural soils is presented in Tables 5-23.

Table 5-24: Tables 5-23: Activity data for Urea application in Kenya (source: Ministry of Agriculture, USGS)

Year	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
Urea (Tonnes)	8600	7750	6900	8175	9450	10725	12000	10800	12000	13200	15238
Year	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**
Urea (Tonnes)	17276	20782	24288	24652.5	25017	26785.5	28554	29982	38944	38547.47	38150.94
Year	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**
Urea (Tonnes)	31810.8	38150.94	44491.07	42339.94	42360.95	42381.96	42402.97	42423.99	42445	42466.01	42487.02

5.8.3. Description of any Flexibility applied

No flexibility has been applied.

5.8.4. Uncertainty and consistency of the time series

Activity data uncertainty is estimated to be -10% and +10%, while default emission factor uncertainty is -50% and +10% with a combined uncertainty of +50.99. Sources of uncertainty in estimating CO_2 emissions from urea could have come from the gaps in activity data The splicing statistical techniques were employed to fill the gaps. Introduced a considerable level of uncertainty in the resulting modelled data.

5.8.5. QA/QC for Urea application

QA/QC procedures were performed in accordance with the general QA/QC principles.

5.8.6. Urea application Category Specific recalculations

There was no recalculation exercised regarding emission estimates from this source category in this submission

5.8.7. Planned Improvements for Urea Application Category

Given the high uncertainty in urea activity data, there is a need to harmonise data collection. It is crucial to develop a multi-stakeholder/sectoral monitoring system to capture urea importation and clearly determine the actual use of urea in agricultural soils. There is also a need to establish direct collaboration with urea-importing companies to enhance transparency and instil confidence in the data provided.

Chapter 06:

Land Use, Land Use Change and Forestry

6.1. Overview of the Sector

Kenya spans a total land area of approximately 59.2 million hectares, with forest cover accounting for 5.9% of this area, as reported in the Forest Reference Level (FRL) of 2020. The Land Use, Land Use Change, and Forestry (LULUCF) sector holds significant importance for the country's environmental sustainability and economic development. This sector plays a dual role: contributing to climate change mitigation through carbon sequestration while supporting livelihoods, biodiversity, and water regulation.

Anthropogenic activities, such as deforestation, land degradation, and unsustainable agricultural and rangeland practices in the sector. These pressures lead to significant environmental impacts, including increased greenhouse gas emissions and diminished carbon sequestration.

In response to these challenges, Kenya has developed a robust framework of policies, strategies, and institutions at both national and county levels, tailored to address the key categories within the LULUCF sector; frameworks which underscore Kenya's commitment to mitigating climate risks and fostering a resilient, low-carbon economy.

This section highlights GHG emissions (and removals) of CO_2 occurring in managed ecosystems. Emissions from the Land (IPCC category 3.B) resulting from deforestation, forest degradation, afforestation/reforestation as well as sustainable management of forests. Changes in land use for the other non-forest classes have also been estimated. Therefore, emissions from the land category have been analysed under six land representations, namely;

1. 3.B.1 - Forestland
2. 3.B.2 - Cropland
3. 3.B.3 - Grassland
4. 3.B.4 - Wetland
5. 3.B.5 - Settlement
6. 3.B.6 - Other Lands

This report has been prepared in line with decision 18/CMA.1, which outlines the Modalities, Procedures, and Guidelines (MPGs) for the transparency framework under Article 13 of the Paris Agreement. It covers data collection, uncertainty calculations, key category analysis, methodological choices, recalculations, and quality control and quality assurance.

The GHG emissions were estimated using the 2006 Intergovernmental Panel on Climate Change (IPCC) Guidelines for national GHG inventories, which provide standardised methods for assessing GHG emissions and removals.

This reporting covers only the above-ground biomass (AGB), below-ground biomass (BGB), and soil organic carbon (SOC) pools. Due to limited data availability, the dead wood and litter carbon pools were excluded. Comprehensive studies on the carbon dynamics within the dead wood and litter pools are necessary to assess their significance as emission sources in Kenya. Such research would enable their inclusion in the future through the stepwise approach.

Calculation of CO_2 emissions/removals were further based on two main activities namely; (a) land use remaining the same over a given period and (b) lands converted to another land use type over a given period. Activity data consisting of area in hectares of change from one land use or land use sub-category to another as well as land remaining the same were multiplied by country-specific emission factors or default emissions factors (where country specific data was unavailable) to calculate CO_2 emissions.

The key category analysis indicated that Land conversion to Cropland had the greatest contribution as a source followed by land converted to Grassland, Cropland remaining Cropland, and Forestland remaining Forestland respectively. Land converted to Forestland on the other hand had the greatest contribution as a sink as highlighted in Figure 6.1 below.

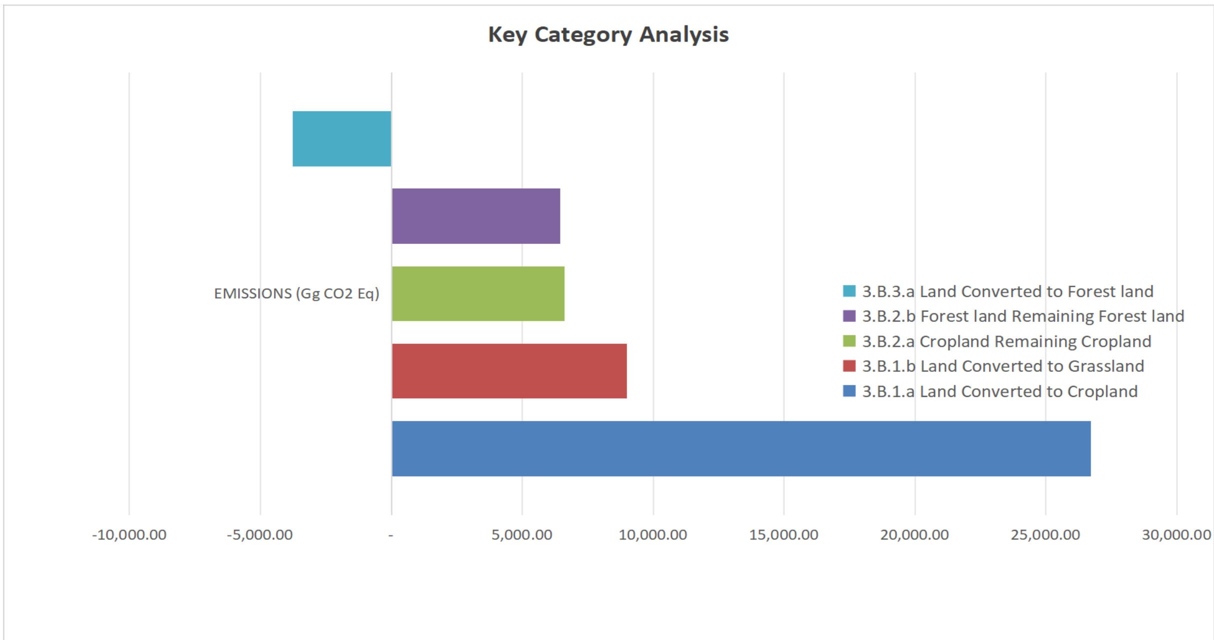


Figure 6-1: Contribution of sources and sink categories to total Emissions

6.1.1. Description of the Sector

The main data sets used in this report include (a) land use representations for each sub-category and land use change matrix (transitions in land use representations) generated through remote sensing and ground verification (b) biomass carbon stocks for each land use subcategory and (c) soil organic carbon default values for mineral soils derived from the 2006 IPCC Guidelines.

Land use representation data was generated from remote sensing where mapping for area estimation was undertaken through a multi-stakeholder process by government institutions, learning institutions, and the private sector. The data generation process involved a thorough QA/QC process both internally and externally. This also involved the documentation of the processes involved in generating the activity data.

The emission factors were generated from a pilot forest inventory that was undertaken since the country has not undertaken a National Forest Inventory (NFI). Where country-specific data were non-existent, data from reliable sources were used. Table 6.1 indicates the data sources used in this reporting.

Table 6-1: FOLU data sources

	Category	Type of Data	Data Source
1.	**Land Remaining Land**	Total area in (ha) of a specific land remaining the same	Sample-based area estimation method using remote sensing data
2.	**Land converted to another land category**	Changes in area (ha) converted from one category to another	Sample-based area estimation method using remote sensing data
3.	**All land categories and their conversions**	Above Ground Biomass	Pilot forest inventory; 2006 IPCC guidelines default values where data was lacking (for grassland, annual cropland, wetland, settlement and otherland); Owate A.O et al (2018) for Perennial cropland
		Below ground Biomass	Root to shoot ratio derived from table 4.4 of the 2006 IPCC guidelines
4.	**All land categories and their conversions**	Soil Organic Carbon	2006 IPCC guidelines default values

6.1.2. GHG Trends in the Sector

GHG emissions and removals were reported from Forestland, Cropland, Grassland, Wetland, Settlement, and Otherland categories. The general trend of emissions in the sector indicates an increasing trend over the reporting period (Figure 6.2). The analysis depicts that the sector is a net emitter with an estimated average emission of 17, 838.76 Gg $C0_2$ equivalent per year. It is noted that due to an assumption of no land use change between the periods 1990 and 2000, there were no emissions generated within the period and therefore, emissions only occurred from 2001 when land conversions were experienced.

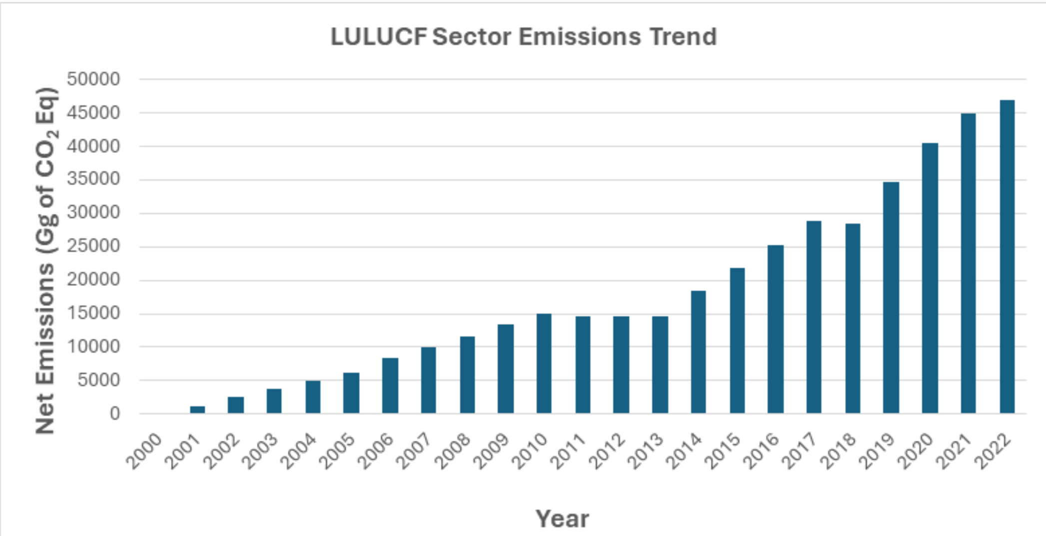
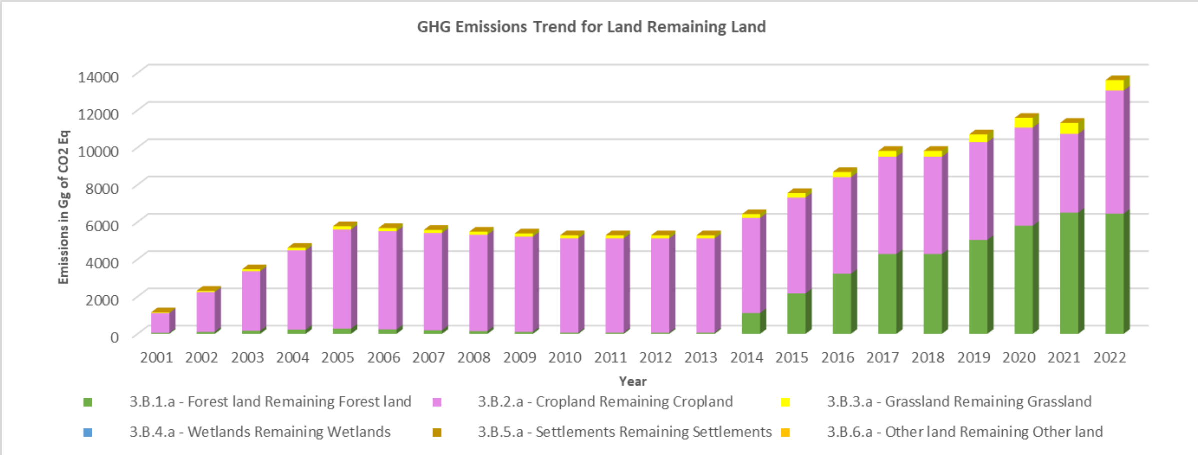


Figure 6-2: Trends of emissions in the LULUCF sector

Land conversions to Forestland were majorly reported from Cropland and Grassland while conversions to Cropland were mostly from Forestland, Wetland, and Grassland with conversions from the Grassland category being converted more to Cropland. On the other hand, conversions to Grassland were from Forestland, Cropland, Wetland, and Otherland with conversions from Forestland having the greatest contribution (Figure 6.3). Emissions were also reported from Grassland converted to Settlements and Grassland converted to Otherland. Figure 6.3 shows the overall trend in GHG emissions and removals for land remaining in the same land category and land converted to another land category for the period 2001 to 2022.



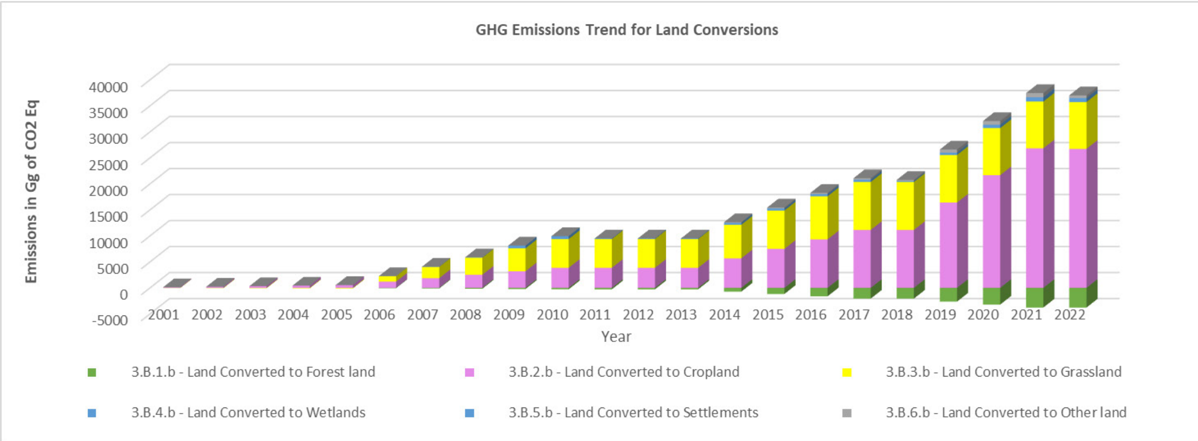


Figure 6-3: Emissions and Removals Trend for the period 2001-2022

6.1.3. General Methodological Aspects of the Category

This section highlights choices of methods and assumptions used to categorise land use/land cover classes, generation of activity data, and emission factors for the LULUCF sector. The inventory was guided by the 2006 IPCC guidelines, specifically on data identification and selection, methods and use of emission factors. Expert judgement and application of underlying assumptions in a consistent and transparent manner were applied where data was limited.

Kenya adopted a complete representation of lands to monitor its land cover classes over time and reported at the tier two level. The six IPCC land cover classes were further sub-categorised based on national circumstances. The forestland category was subdivided based on canopy cover (Table 6.2). In addition, the forestland was further subdivided into 6 strata, namely, Montane, Western Rain, Dryland, Coastal, Mangroves and Plantation forests.

Using Approach 2 (consistent representation of lands), data collected through a sample-based methodology was utilized to generate activity data. The Sample-Based Area Estimation (SBAE) approach represents an enhanced methodology adopted by the country to improve accuracy and reduce uncertainties. This builds on the limitations highlighted by the Technical Expert Review team in Kenya's first Forest Reference Level (FRL) report submitted to the UNFCCC in 2020.

The data used for this inventory was collected to support the second Forest Reference Level reporting, with intensified sampling points within forest strata zones. Stratified sampling data collected for the periods 2000–2005, 2005–2010, 2013–2017, and 2018–2021 was used as-is. However, transitioning to a systematic sampling approach for future Greenhouse Gas Inventory (GHGI) reporting has been strongly recommended to enhance methodological consistency and data quality.

For years with data gaps—specifically 1990–1999—it was assumed that the land area remained unchanged until 2000 (land areas for 2000 were used all through to 1990). Similarly, for 2011, 2012, and 2022, the land area was assumed to have remained consistent with the previous year. Consequently, activity data collection ensured a consistent representation of lands for both land remaining in the same use and land-use conversions for the period 2000–2022.

To calculate emissions, activity data on land-use change transitions over various time periods and the corresponding carbon stocks for each land-use subcategory were utilized. The stock change method was applied, with a one-year interval used for assessing deforestation and forest degradation, and a 20-year interval for other land-use conversions. Emission factors for each subcategory were derived from country-specific data when available; otherwise, default values from the IPCC were applied.

Emission estimates in this report were generated using a combination of Tier 1 and Tier 2 methods, depending on the availability of country-specific data. In cases where no data existed at the national, sub-regional, or international levels, expert judgment was applied, with underlying assumptions carefully documented. For above-ground biomass, emission factors were derived from published and pilot forest inventory data for select land-use strata. In line with IPCC good practice guidelines, default emission factor values were used to address data gaps where information from other sources was unavailable.

Table 6-2: Kenya land categorization

IPCC Class	First Level Sub-categorization	Canopy Cover	Second Level Sub-categorization
Forestland	Montane/Western rainforest	Dense Forest (> 65%)	Montane Forest - Dense
			Montane Forest - Moderate
		Moderate Forest (40%-65%)	Montane Forest - Open
			Western Rain Forest - Dense
			Western Rain Forest - Moderate
		Open Forest (15%-40%)	Western Rain Forest - Open
	Coastal and Mangrove forests		Coastal Forest - Dense
			Coastal Forest - Moderate
			Coastal Forest - Open
			Mangrove Forest - Dense
			Mangrove Forest - Moderate
			Mangrove Forest - Open
	Dryland forest		Dryland Forest - Dense
			Dryland Forest -Moderate
			Dryland Forest - Open
	Plantation Forest		Public Plantation
			Private Plantation
2. Grassland			Wooded Grassland
			Open Grassland
3. Cropland			Perennial Cropland
			Annual Cropland
4. Wetland			Vegetated Wetland
			Open Water
5. Settlements			Settlements
6. Otherland			Otherland

Box 6.1: Land cover classes for Kenya adopted from the IPCC land cover categories

1. **Forestland**: This is based on Kenya's definition of forests (KFS, 2013). ***Forestlands are areas occupied by forests and characterised by tree crown cover ≥ 15%, an area ≥ 0.5 ha and a tree height ≥ 2m. It also includes areas managed for forestry where trees have not attained 2m height but with potential to do so, and areas that are temporarily destocked.*** Forestlands include Plantation forests (Public and private plantations), Natural forests (Coastal forests, Mangrove forests, Bamboo forests, Dryland forests, Montane and Western rain forests), categories which describe forests with different carbon dynamics.
2. **Cropland**: This refers to land that is purposely managed for agricultural activities. Though this definition assumes a-priori defined area that can be captured with ancillary data, such land is characterised by presence of agricultural crops or with evidence of tillage. It includes agroforestry systems (Nair, 1992 defined agroforestry as the deliberate growing of woody perennials/trees on the same unit of land as agricultural activity). The tree cover in these agroforestry systems shall fall below the thresholds used for the forest land category. Cropland also includes areas with annual herbaceous crops where crops grow in one or more seasons in a year and at times such land are bare due to tillage. This category also includes areas with perennial shrub crops like tea and sisal and which remain on the same land unit for many years but undergo management systems that influence carbon dynamics.
3. Grassland: This refers to rangelands and pasture land of Kenya which do not qualify as forestland and cropland. They may have sparse trees and woody vegetation but the tree cover falls below the threshold used in the forestland category. The category includes grassland in wildlands, moorlands, shrub savannah, recreational areas, glades and silvo-pastoral systems, in managed and unmanaged systems. KFS (2013) describes these as the most extensive land cover types of Kenya covering over 70% of the country. They are areas rich in wildlife, dominated by shrubs and woody trees, some of which are deciduous (Beentje 1994). Some of these areas are also prone to degradation activities like fires and charcoal burning.
4. Wetlands: This refers to areas covered or saturated by water that is observable by remote sensing. It includes lakes, dams, reservoirs, and rivers. There is also vegetation associated with these water bodies including papyrus and reeds and river line trees.
5. Settlements: This refers to developed land. It includes transportation infrastructure and human settlements where buildings exceed 50% of the land use (which could be in croplands, forestland, grassland, or Wetlands), unless they are already included under other categories.
6. Other land: This category includes unidentified land. It could be bare soil, rock, ice, and all unmanaged land areas that do not fall into any of the other five categories at a specific time

6.2. Definitions of Land Use and Land Representation Approaches

6.2.1. Land use definitions

A. Forestland: This is based on a national forest definition which has been agreed through a broad stakeholder consensus as a minimum 15% canopy cover; minimum land area of 0.5 ha and potential to reach a minimum height of 2 metres at maturity in situ (Republic of Kenya, 2020). Perennial tree crops like coffee and tea are not considered as forests under this definition irrespective of whether they meet the definition of forests. The subcategories under this category are as follows as demonstrated in Figure 6.4:

1. **Montane forest**- These are forests in high altitude regions of Kenya (above 1,500m). They are the most extensive and have been described as water towers due to their support to water catchments (***Akotsi, Ndirangu, & Gachanja, 2006***). They include the Mau, Mt. Kenya, Aberdares, Cherangany, and Mt Elgon blocks, as well as Leroghi, Marsabit, Ndotos, the Matthews Range, Mt Kulal, the Loita Hills, The Chyulu Hills, the Taita Hills, Mt. Kasigau among others. These forests have different patches of species association which are influenced by climate and altitude. For example, the moist broad-leaved forests occur on the windward sides while the drier coniferous mixed forests are found on the leeward sides. At higher altitudes, the forests are dominated by the highland bamboo (***Yushania alpina***). Bamboo is a common forest type in Kenya and their biomass stocks have been estimated as comparable to those of the adjacent montane natural forests.
2. **Western Rain forests**- These are forests with characteristics of the Guineo-Congolean forests and include Kakamega forest, the North and South Nandi Forest and Nyakweri forest in Transmara Sub-County (Peter Wass, 1995). The trees are significantly taller and larger as compared to the other forests of Kenya.
3. Coastal forests- These are the forests found in the coastal region of Kenya within a 30km strip from the shore line (Peter Wass, 1995). They are part of the larger coastal belt including, Arabuko-Sokoke forest, Shimba hills forest and the forests of Tana River region and Boni-Dodori forest

complex. They are dominated by species of Combretum, Afzelia, Albizia, Ekerbergia, Hyphaene, Adansonia and Brachestegia woodlands and are biodiversity hotspots. Delineation of this zone is based on a 30 km buffer from the shoreline and captures forests in public and private lands.

4. Mangrove forests- Mangroves have been defined as trees and shrubs that have adapted to life in saline environments. They are characterised by a strong assemblage of species according to geomorphological and salinity gradients, and tidal water currents. There are nine species of mangroves in Kenya which occur on a typical zonation pattern with the seaward side occupied by ***Sonneratia alba***, followed by ***Rhizophora mucronata***, then ***Bruguiera gymnorrhiza***, ***Ceriops taga***l, ***Avicennia marin***a, ***Lumnitzera racemosa*** and ***Heritiera littoralis*** respectively (Kokwaro, 1985; Kairo, 2001). Other mangrove species include ***Xylocarpus granatum*** and ***Xylocarpus mollucensis.***

5. **Dryland forests**- These are the forests found in the arid and semi-arid regions of Kenya. Their tree composition is dominated by Acacia-Commiphora species but also include Combretum, ***Platycephelium voense***, Manilkara, Lannea, ***Balanites aegyptiaca***, ***Melia volkensii***, ***Euphorbia candelabrum*** and ***Adansonia digitata***. The category also includes riverine forests in dry areas. This forest stratum has unique characteristics from the other forest strata. First, they shed leaves and provide a challenge for time series mapping and therefore require special attention during mapping. Secondly, they have extensive root systems due to water stress and their below ground biomass component varies from other forests. Thirdly, the harsh conditions of their growth imply higher specific wood densities though these have not been researched on.

6. Public plantation forests - Refers to public forest areas with even-aged monocultures managed by KFS for commercial purposes. Their boundaries are also clearly defined by compartments and sub compartments and it is possible to delineate them from the other natural forests. The trees are mainly planted for commercial purposes and undergo a series of silvicultural activities like pruning and thinning which affect their carbon stocks. Plantations may be divided based on commonly grown species and the areas where these species are grown. They include ***Cupressus lusitanic***a, Eucalyptus sp. and several pine species (***P. patula*** in montane areas and, ***P. caribeae*** in coastal forests)

7. **Private plantation forests**- These are commercial plantations of various tree species outside gazetted forest areas. They are grown for commercial purposes. Private plantation forest sub-category is found across all the forest strata.

Further, the natural forest strata have been sub-categorised into:

a. **Forest dense**: These are forests within the five forest strata of Montane forests, Western rainforests, Coastal forests, Mangroves, and Dryland forests that have a canopy closure of 65% and above.

b. **Forest moderate**: These are forests within the five forest strata of Montane forests, Western rainforests, Coastal forests, Mangroves, and Dryland forests that have a canopy closure between 40% and 65%.

c. Forest open: These are forests within the five forest strata of Montane forests, Western rainforests, Coastal forests, Mangroves, and Dryland forests that have a canopy closure between 15% and 40%.

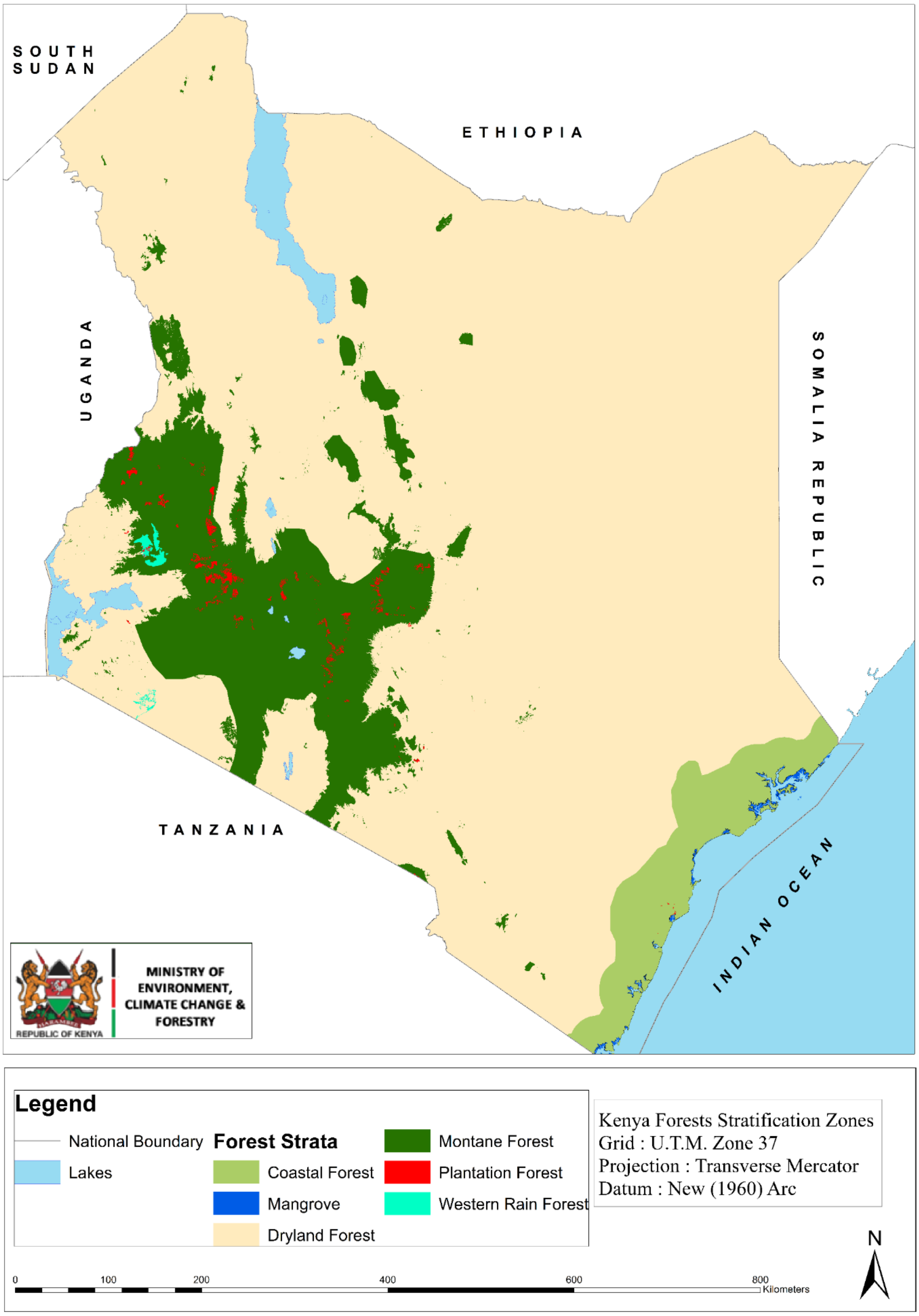


Figure 6-4: Forest strata in Kenya

B. Grassland: This category includes rangelands and pasture lands that are not considered Cropland. This also includes systems with woody vegetation and other non-grass vegetation such as herbs and brushes that fall below the thresholds of the Forest Land category. This further includes all grasslands ranging from wild lands to recreational areas as well as agricultural and silvo-pastoral systems that are consistent with national definitions.

1. **Open Grassland:** This refers to grasslands devoid of trees. They are grasses in wildlands, moorlands, recreational areas, and glades. They include areas that support nomadic pastoralism in the rangelands of Kenya.
2. **Wooded Grassland:** This refers to woodlands that do not qualify as forestlands. They will be defined as grasslands with a tree canopy ≥10%. These are mainly the woodlands that support wildlife in the rangelands of Kenya and have a mixture of trees, shrubs and grasses. The tree component here influences the biomass content and associated GHG fluxes. Due to the canopy closure of the woody component, it is possible to differentiate these areas from the open grasslands.

C. Cropland: This category includes cropped lands, including rice fields, and lands with an agro-forestry system where the vegetation structure falls below the thresholds used for the Forest Land category.

1. **Perennial Cropland:** This category specifically refers to tea farms, coffee farms, sugar cane farms, cotton farms, sisal farms, agroforestry systems, among others whose spectral characteristics can easily be delineated from the rest of the agricultural areas. Their areas of growth are also clearly known. Tea farms are found in high-potential areas and are normally adjacent to large forest blocks. They have unique management systems that influence GHG fluxes. Sisal farms are found in areas of moderate rainfall and the coastal region while sugar farms are found in western and coastal regions of Kenya. On a single image, it may be difficult to assign tea, coffee, cotton, sugar cane and sisal farms into a single land cover category. However, working on different images, the perennial shrub crop can always be assigned to the specific crop type after land cover classification.
2. **Annual Cropland:** Refers to the treeless agricultural fields. They comprise mechanised farms in the bread baskets of Kenya (wheat and maize growing areas of the Rift Valley), extensive irrigation farms largely dominated by rice and other mixed farming systems, and other small-scale crop farming where the crop growth season does not exceed one year.

D. Wetland: This category includes areas of peat extraction and lands that are covered or saturated by water for all or part of the year (e.g. peatlands) and do not fall into the five categories of Forest Land, Cropland, Grassland, Settlements and Other land. This includes reservoirs, natural rivers and lakes.

1. **Vegetated Wetland**: Wetland areas with vegetation
2. **Open Water**: Open water bodies without vegetation

E. Settlements: This category includes all developed lands, including transportation infrastructure and human settlements regardless of size, unless they are already included in the other categories. This should be consistent with national definitions.

F. Other lands: This category includes bare soil, rock, ice, and all land areas that do not fall into any of the other five categories.

6.2.2. Land representation approaches

Kenya implemented approach 2 for land use representation, which enabled the tracking of land use changes within and between specific land use categories. Annual matrices were developed to document both land that remained unchanged and land that underwent conversion during the period from 2000 to 2021. This data was then utilised to create the land representation matrix (Figure 6.5) for input into the IPCC software.

ID	Category_P	Subcategory_P	Subdivision_P	Category_C	Subcategory_C	Subdivision_C	2005	2006	2007	2008	2009	2010
FL_FL_1	Forest Land	Managed Forest Land	Coastal Forest-Dense	Forest Land	Managed Forest Land	Coastal Forest-Dense	347462.9	347462.9	347462.864	347462.864	347462.9	347462.9
FL_FL_2	Forest Land	Managed Forest Land	Coastal Forest-Moderate	Forest Land	Managed Forest Land	Coastal Forest-Moderate	242895.8	242895.8	242895.848	242895.8475	242895.8	242895.8
FL_FL_3	Forest Land	Managed Forest Land	Coastal Forest-Open	Forest Land	Managed Forest Land	Coastal Forest-Open	20703.31	18779.57	16855.8329	14932.09311	13008.35	11084.61
FL_FL_4	Forest Land	Managed Forest Land	Dryland Forest-Dense	Forest Land	Managed Forest Land	Dryland Forest-Dense	308818.5	307861	306903.388	305945.8196	304988.3	304030.7
FL_FL_5	Forest Land	Managed Forest Land	Dryland Forest-Moderate	Forest Land	Managed Forest Land	Dryland Forest-Moderate	742956	742956	742955.98	742955.9801	742956	742956
FL_FL_6	Forest Land	Managed Forest Land	Dryland Forest-Open	Forest Land	Managed Forest Land	Dryland Forest-Open	47624.5	47029.25	46434.006	45838.76084	45243.52	44648.27
FL_FL_7	Forest Land	Managed Forest Land	Mangrove Forest-Dense	Forest Land	Managed Forest Land	Mangrove Forest-Dense	0	0	0	0	0	0
FL_FL_8	Forest Land	Managed Forest Land	Mangrove Forest-Moderate	Forest Land	Managed Forest Land	Mangrove Forest-Moderate	6807.058	6807.058	6807.05796	6807.057957	6807.058	6807.058
FL_FL_9	Forest Land	Managed Forest Land	Mangrove Forest-Open	Forest Land	Managed Forest Land	Mangrove Forest-Open	0	0	0	0	0	0
FL_FL_10	Forest Land	Managed Forest Land	Montane Forest-Dense	Forest Land	Managed Forest Land	Montane Forest-Dense	1034774	1033556	1032338.4	1031120.565	1029903	1028685
FL_FL_11	Forest Land	Managed Forest Land	Montane Forest-Moderate	Forest Land	Managed Forest Land	Montane Forest-Moderate	97782.71	96229.9	94677.0822	93124.26843	91571.45	90018.64
FL_FL_12	Forest Land	Managed Forest Land	Montane Forest-Open	Forest Land	Managed Forest Land	Montane Forest-Open	89371.08	89371.08	89371.0805	89371.08049	89371.08	89371.08
FL_FL_13	Forest Land	Managed Forest Land	WesternRain Forest-Dense	Forest Land	Managed Forest Land	WesternRain Forest-Dense	9575.686	9575.686	9575.68592	9575.685918	9575.686	9575.686
FL_FL_14	Forest Land	Managed Forest Land	WesternRain Forest-Moderate	Forest Land	Managed Forest Land	WesternRain Forest-Moderate	0	0	0	0	0	0
FL_FL_15	Forest Land	Managed Forest Land	WesternRain Forest-Open	Forest Land	Managed Forest Land	WesternRain Forest-Open	0	0	0	0	0	0
FL_FL_16	Forest Land	Managed Forest Land	Private Plantations	Forest Land	Managed Forest Land	Private Plantations	41911.36	41911.36	41911.3568	41911.3568	41911.36	41911.36
FL_FL_17	Forest Land	Managed Forest Land	Public Plantations	Forest Land	Managed Forest Land	Public Plantations	113726	112768.5	111810.907	110853.338	109895.8	108938.2
CL_CL_1	Cropland	Managed Cropland	Perennial Cropland	Cropland	Managed Cropland	Perennial Cropland	1860172	1859651	1859130.9	1858610.373	1858090	1857569
CL_CL_2	Cropland	Managed Cropland	Annual Cropland	Cropland	Managed Cropland	Annual Cropland	5253902	5201642	5149382.87	5097123.308	5044864	4992604
GL_GL_1	Grassland	Managed Grassland	Wooded Grassland	Grassland	Managed Grassland	Wooded Grassland	27243177	27234472	27225766.7	27217061.39	27208356	27199651
GL_GL_2	Grassland	Managed Grassland	Open Grassland	Grassland	Managed Grassland	Open Grassland	16227223	16129071	16030918.9	15932767.05	15834615	15736463
WL-WL_1	Wetland	Managed Wetland	Open Water	Wetland	Managed Wetland	Open Water	511853.6	511853.6	511853.603	511853.6027	511853.6	511853.6
WL_WL_2	Wetland	Managed Wetland	Vegetated Wetland	Wetland	Managed Wetland	Vegetated Wetland	93222.65	93222.65	93222.6509	93222.65093	93222.65	93222.65
SL_SL_1	Settlements	Managed Settlements	Settlement	Settlements	Managed Settlements	Settlement	351516.9	351516.9	351516.876	351516.8755	351516.9	351516.9
OL_OL_1	Otherland	Managed Otherland	Otherland	Otherland	Managed Otherland	Otherland	4223731	4223731	4223731.04	4223731.041	4223731	4223731
FL_FL_2001_1	Forest Land	Managed Forest Land	Dryland Forest-Dense	Forest Land	Managed Forest Land	Dryland Forest-Moderate	1361.412	1361.412	1361.41159	1361.411591	1361.412	1361.412
FL_FL_2001_2	Forest Land	Managed Forest Land	Dryland Forest-Moderate	Forest Land	Managed Forest Land	Dryland Forest-Open	595.2452	595.2452	595.245198	595.2451978	595.2452	595.2452
CL_CL_2001_3	Cropland	Managed Cropland	Annual Cropland	Cropland	Managed Cropland	Perennial Cropland	1217.835	1217.835	1217.83451	1217.834511	1217.835	1217.835
CL_CL_2001_4	Cropland	Managed Cropland	Perennial Cropland	Cropland	Managed Cropland	Annual Cropland	49749.18	49749.18	49749.1789	49749.17889	49749.18	49749.18
GL_CL_2001_5	Grassland	Manged Grassland	Wooded Grassland	Cropland	Managed Cropland	Annual Cropland	6034.378	6034.378	6034.37814	6034.378138	6034.378	6034.378
GL_GL_2001_6	Grassland	Manged Grassland	Open Grassland	Grassland	Managed Grassland	Wooded Grassland	1361.412	1361.412	1361.41159	1361.411591	1361.412	1361.412
WL_GL_2001_7	Wetland	Managed Wetland	Vegetated Wetland	Grassland	Managed Grassland	Wooded Grassland	1950.143	1950.143	1950.14336	1950.143364	1950.143	1950.143
GL_GL_2001_8	Grassland	Managed Grassland	Wooded Grassland	Grassland	Managed Grassland	Open Grassland	4646.563	4646.563	4646.56297	4646.562965	4646.563	4646.563

Figure 6-5: Sample of the Land representation matrix

A time series analysis of land use representation was conducted using available national data, segmented into 5-year intervals from 2000 to 2010, a 4-year interval from 2013 to 2017, and a 3-year interval from 2018 to 2021 (Figure 6.6). This data was presented on an annual basis to monitor both land that remained unchanged and land conversions.

2000/2005	Forestland	Cropland	Grassland	Wetlands	Settlement	Otherlands	Total
Forestland	3,114,192.31	-	-	-	-	-	3,114,192.31
Cropland	-	7,368,909.03	-	-	-	-	7,368,909.03
Grassland	-	30,171.89	43,500,439.88	-	-	-	43,530,611.77
Wetlands	-	-	9,750.72	605,076.25	-	-	614,826.97
Settlement	-	-	-	-	351,516.88	-	351,516.88
Otherlands	-	-	-	-	-	4,223,731.04	4,223,731.04
Total	3,114,192.31	7,399,080.92	43,510,190.60	605,076.25	351,516.88	4,223,731.04	59,203,788.00

2005/2010	Forestland	Cropland	Grassland	Wetlands	Settlement	Otherlands	Total
Forestland	3,093,739.61	1,301.33	19,151.37	-	-	-	3,114,192.31
Cropland	6,089.17	7,380,095.51	12,896.23	-	-	-	7,399,080.92
Grassland	11,052.05	264,119.89	42,990,311.20	235,131.78	9,575.69	-	43,510,190.60
Wetlands	-	-	-	605,076.25	-	-	605,076.25
Settlement	-	-	-	-	351,516.88	-	351,516.88
Otherlands	-	-	-	-	-	4,223,731.04	4,223,731.04
Total	3,110,880.83	7,645,516.74	43,022,358.80	840,208.03	361,092.56	4,223,731.04	59,203,788.00

2013/2017	Forestland	Cropland	Grassland	Wetlands	Settlement	Otherlands	Total
Forestland	3,315,206.72	14,567.20	27,313.50	1,820.90	-	-	3,358,908.32
Cropland	41,080.29	7,749,652.72	16,898.34	-	28,228.13	-	7,835,859.49
Grassland	28,333.98	88,537.90	43,284,202.84	-	5,462.70	26,407.23	43,432,944.66
Wetlands	-	-	3,641.80	931,496.35	-	1,820.90	936,959.05
Settlement	-	-	-	-	324,225.16	-	324,225.16
Otherlands	-	-	1,820.90	-	-	3,313,070.42	3,314,891.32
Total	3,384,620.99	7,852,757.83	43,333,877.38	933,317.25	357,916.00	3,341,298.55	59,203,788.00

2018/2021	Forestland	Cropland	Grassland	Wetlands	Settlement	Otherlands	Total
Forestland	3,460,391.22	35,307.67	5,884.61	1,961.54	-	-	3,503,545.04
Cropland	39,230.74	7,580,607.07	13,730.76	-	12,137.42	-	7,645,705.99
Grassland	9,807.69	116,345.59	43,425,218.78	3,923.07	37,147.71	39,109.25	43,631,552.08
Wetlands	-	1,961.54	1,961.54	710,096.92	-	-	714,020.00
Settlement	-	-	-	-	382,633.30	-	382,633.30
Otherlands	-	-	80,915.48	1,961.54	-	3,243,454.57	3,326,331.59
Total	3,509,429.65	7,734,221.87	43,527,711.17	717,943.07	431,918.43	3,282,563.82	59,203,788.00

Figure 6-6: Figure 6.6 IPCC categories land use matrices for the reporting period

To generate consistent time series data, the process involved sequentially comparing changes in activity data between two time periods (e.g., 2000–2005, 2005–2010, 2013–2017, and 2018–2021). This comparison produced a change matrix indicating areas that remained within the same land-use type and areas that transitioned to different land-use types (conversions) for all land-use categories.

The resulting data was utilized to create a change matrix for stable land and conversions across 25 land-use subcategories for each year (Figure 6.7). This information was subsequently used to compile comprehensive time series datasets.

	2010																									
2005	Coastal Forest-Dense	Coastal Forest-Moderate	Coastal Forest-Open	Dryland Forest-Dense	Dryland Forest-Moderate	Dryland Forest-Open	Mangrove Forest-Dense	Mangrove Forest-Moderate	Mangrove Forest-Open	Montane Forest-Dense	Montane Forest-Moderate	Montane Forest-Open	Western Rain Forest-Dense	Western Rain Forest-Moderate	Western Rain Forest-Open	Private Plantations	Public Plantations	Perennial Cropland	Annual Cropland	Wooded Grassland	Open Grassland	Open Water	Vegetated Wetland	Settlement	Otherland	2000 Totals
Coastal Forest-Dense		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Coastal Forest-Moderate	0		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.00
Coastal Forest-Open	1923.74	0		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1923.74
Dryland Forest-Dense	0	0	0		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	957.568592	0	0	0	0	0	957.57
Dryland Forest-Moderate	0	0	0	0		0.00	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.00
Dryland Forest-Open	0	0	0	0	595.2452		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	595.25
Mangrove Forest-Dense	0	0	0	0	0	0		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.00
Mangrove Forest-Moderate	0	0	0	0	0	0	0		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.00
Mangrove Forest-Open	0	0	0	0	0	0	0	0		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.00
Montane Forest-Dense	0	0	0	0	0	0	0	0	0		0	0	0	0	0	0	0	0	260.265919	957.568592	0	0	0	0	0	1217.83
Montane Forest-Moderate	0	0	0	0	0	0	0	0	0	595.2452		0	0	0	0	0	0	0	0	0	957.56859	0	0	0	0	1552.81
Montane Forest-Open	0	0	0	0	0	0	0	0	0	0	0		0	0	0	0	0	0	0	0	0	0	0	0	0	0.00
WesternRain Forest-Dense	0	0	0	0	0	0	0	0	0	0	0	0		0	0	0	0	0	0	0	0	0	0	0	0	0.00
WesternRain Forest-Moderate	0	0	0	0	0	0	0	0	0	0	0	0	0		0	0	0	0	0	0	0	0	0	0	0	0.00
WesternRain Forest-Open	0	0	0	0	0	0	0	0	0	0	0	0	0	0		0	0	0	0	0	0	0	0	0	0	0.00
Private Plantations	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		0	0	0	0	0	0	0	0	0	0.00
Public Plantations	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		0	0	0	957.56859	0	0	0	0	957.57
Perennial Cropland	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	260.26592	0		0	260.265919	0	0	0	0	0	520.53
Annual Cropland	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	957.56859	0	48983.01		2318.98018	0	0	0	0	0	52259.56
Wooded Grassland	0	0	0	0	0	1950.14	0	0	0	0	0	0	0	0	0	0	0	1923.74	3873.883146		0	0	0	957.568592	0	8705.33
Open Grassland	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	260.26592	0	0	47026.35571	2881.30837		47026.36	0	957.568592	0	98151.85
Open Water	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		0	0	0	0.00
Vegetated Wetland	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		0	0	0.00
Settlement	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		0	0.00
Otherland																										0.00
2005 Totals	1923.74	0.00	0.00	0.00	595.25	1950.14	0.00	0.00	0.00	595.25	0.00	0.00	0.00	0.00	0.00	1478.10	0.00	50906.75	51160.50	7375.69	1915.14	47026.36	0.00	1915.14	0.00	

Figure 6-7: Land conversion matrix between 2005-2010

6.3. Country Specific Approaches

6.3.1. Information on approaches used for representing land areas and on land-use databases used for the inventory preparation

Kenya implemented approach 2 for land representation, assessing both net gains and losses in land use. This method tracked areas that remained within the same land use category and those that transitioned between categories. The representation incorporated top-level land use categories, further subdivided to address national circumstances critical for estimating emissions and removals, as outlined in the 2006 IPCC guidelines. These sub-categories were analysed to ensure robustness in emissions and removals estimations, representing the various ecological regions of the country and ensuring comprehensive reporting.

To input the data into the IPCC software, the entire country was treated as a single climate region (Tropical dry) with one soil type of High Activity Clay, as per Table 3.1 of the 2006 IPCC Guidelines. Land representation data was generated annually for each sub-category, capturing both land that remained unchanged and land conversions throughout the reporting period.

In the forestry sector, the primary sources of greenhouse gas (GHG) emissions—predominantly carbon dioxide (CO_2) arise from land transitions such as conversion to agriculture, grassland, or settlements. While CO_2 is the main GHG in this sector, other gases like methane (CH_4) and nitrous oxide (N_2O) can be emitted from biomass burning; and methane (CH_4) from mangrove forests (combustion of soils). However, for this inventory, only CO_2 emissions were reported.

Further, the soil types found throughout the country are very diverse. However, when classified based on IPCC classes, there are two dominant soil types in the country; High Activity Clay (HAC) soil and Low Activity Clay soil. Kenya is 80% ASAL and the dryland part of Kenya mostly has HAC. Therefore, an assumption was made on applying HAC clay for the entire country since a tropical dry climate was assigned for the entire country. In accordance with the IPCC Guidelines, and based on the soil types found in Kenya, Kenya was assumed to be having only mineral soils with no organic soils since the wetland areas are insignificant.

6.3.2. Information on approaches used for natural disturbances

This is not applicable.

6.3.3. Information on approaches used for reporting harvested wood products

Harvested wood products were not included in this inventory due to a lack of sufficient country-specific data. Addressing this limitation has been recognized as an essential area for future improvements to ensure more comprehensive reporting with key proposals being to develop a system for Data collection on HWP in the country and to determine wood density values for the major species for timber and other major forest products for use in estimating Emission Factors for this category.

6.4. 6.4 LULUCF Categories

6.4.1. Category Description and Trend of GHGs

3.B.1-Forest Land

Emissions in this category have been reported for stable land—forestland remaining forestland—and for land converted to forestland (enhancements), primarily from grassland and cropland. Overall, the forestland category shows an increasing trend in emissions, measured in gigagrams of CO2 equivalent, rising from 56.18 Gg CO2 eq in 2001 to 2,680.76 Gg CO2 eq in 2022, as illustrated in Figure 6.8.

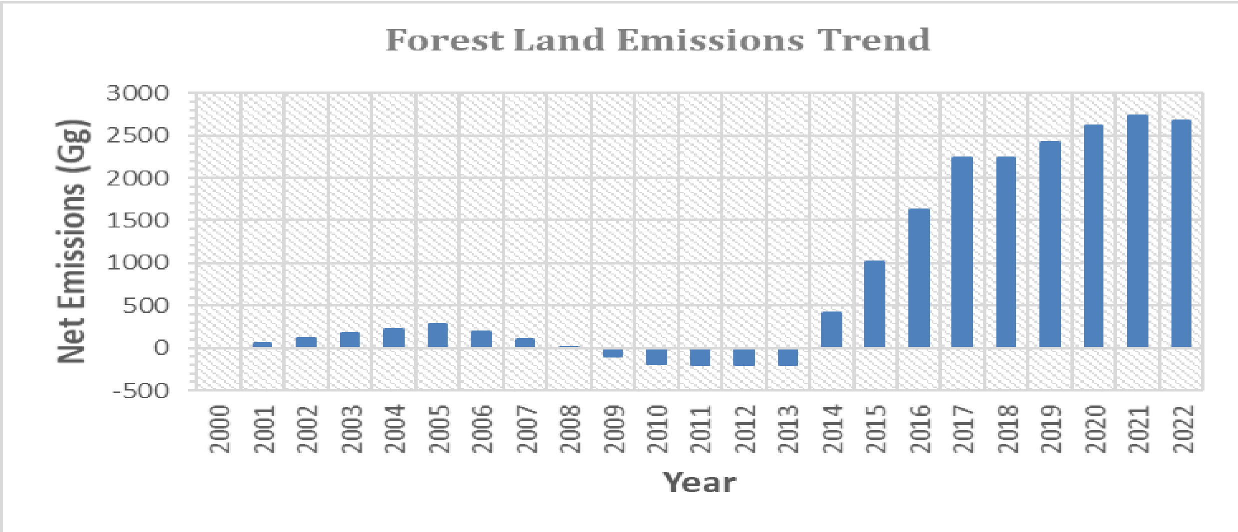


Figure 6-8: Emissions trend for forestland category

The trend of emissions depicts a significant increase in forestland remaining forestland compared to the trend of removals within the same period (Figure 9).

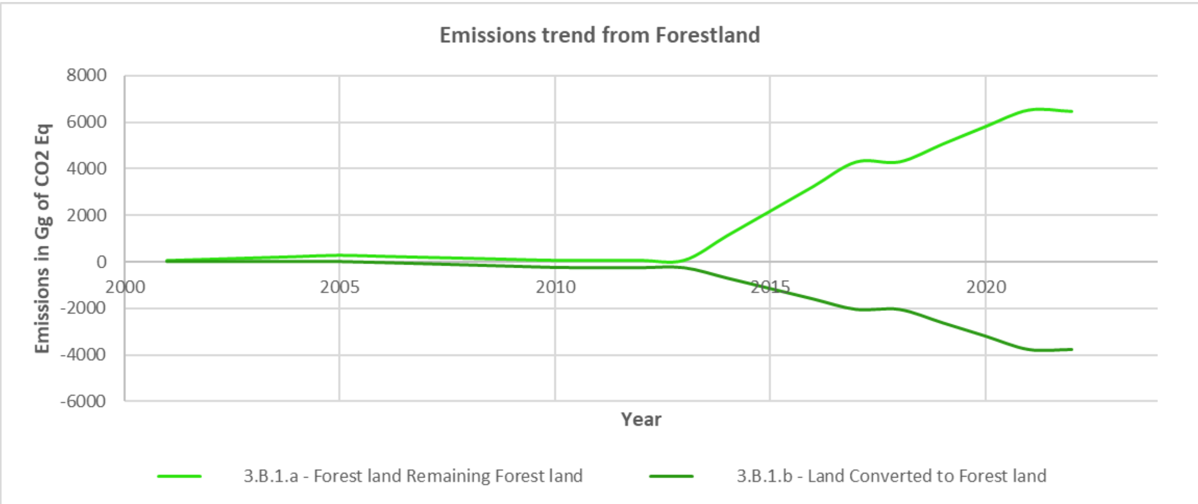


Figure 6-9: Emission trends for Forestland remaining forestland and land converted to forest land

Conversions of land to forestland could be attributed to various policy reforms in the forest sector during the period. There was a review of the forest law that established the Kenya Forest Service as a semi-autonomous government agency responsible for forest conservation and management. Through the law, participatory forest management was entrenched and communities living adjacent to the forest (through community forest associations) worked with the forest agency in co-management of forest resources. This, together with the creation of the Mau Taskforce in 2008 may have resulted in reduced illegal activities which are drivers of forest degradation and deforestation.

On the other hand, the establishment of the Kenya Forest Service (KFS) in 2005, through the Forest Management and Conservation Act of 2005 (revised in 2016), also marked a significant milestone in Kenya's forest conservation efforts. While the KFS initially contributed to an increase in forest cover, the Government imposed a moratorium on logging in all Public and Community Forests in 2018 which led to a shift in deforestation patterns to private lands. To address this, the government launched a National Landscape and Ecosystem Restoration Strategy 2023-2032 to support the 15B tree-growing initiative. These activities started back in 2021 after the presidential directive and launch and have significantly contributed to the rise in tree and forest cover across the country mappable through remote sensing.

3.B.2 - Cropland

Overall analysis shows increasing emissions from the cropland category (Figure 6.10) with an average of 11,575.22 Gg CO_2 Eq. The leading expansion of agricultural activities into formerly marginal areas may be associated with encroachment into former grassland areas and at the same time, agricultural expansion may also be a contributing factor to decrease in Forestlands and Grassland areas as there is need for more land to grow food for the increasing population.

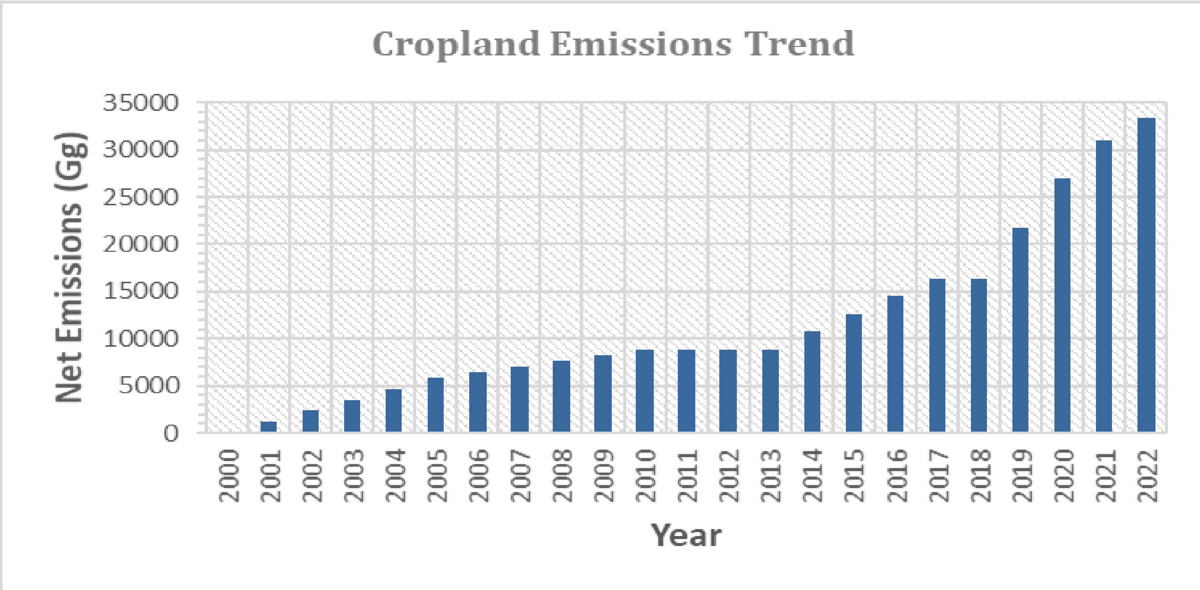


Figure 6-10: ***Emissions trend for the cropland category***

The Figure 6.11 shows the trend in emissions from cropland remaining cropland and land converted to cropland. From the results, cropland remaining cropland category considers emissions/removals due to the carbon stock changes attributed to conversions within the cropland sub-categories (annual cropland and perennial cropland).

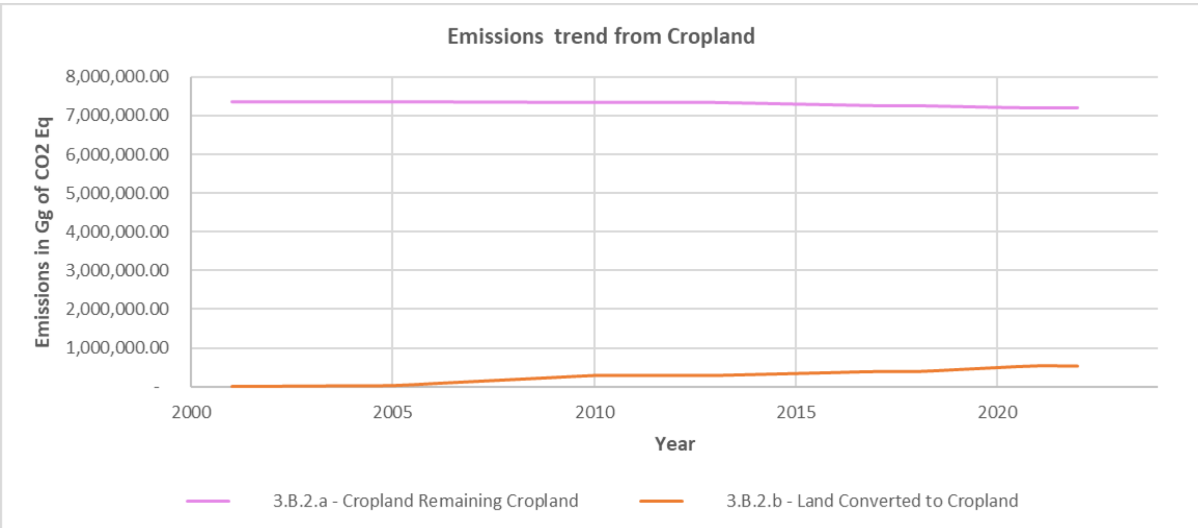


Figure 6-11: ***Emissions trend from cropland remaining cropland and land converted to cropland***

3.B.3 - Grassland

This category contributed significant emissions across the time series with an average emission level of 4,988.7 Gg CO_2 eq. Conversions to grassland were reported from forestland, cropland, wetlands and other lands with greatest emissions being reported from forestland. Figure 6.12 shows the overall trend in net emissions.

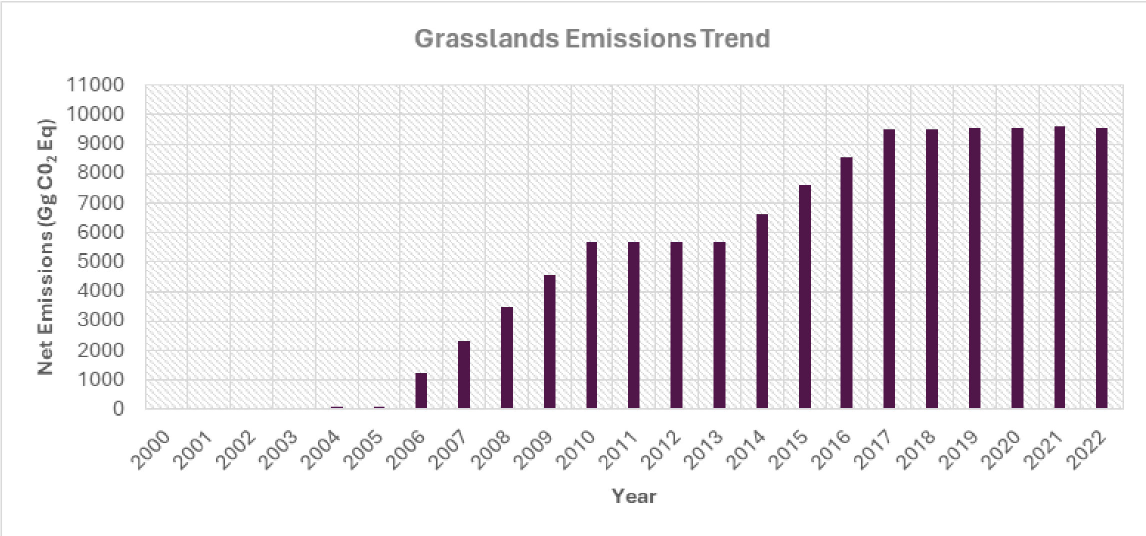


Figure 6-12: Emissions trend for the grassland category

3.B.4 - Wetlands

Default emission factor values were applied to the wetlands category, resulting in no reported emissions from wetlands remaining wetlands. However, conversions from grassland to wetlands during the periods 2006–2010, 2014–2017, and 2018–2021 contributed to notable emissions. These emissions, though showing a decreasing trend, remained consistent across the periods due to similar conversion patterns within each timeframe, as illustrated in Figure 6.13.

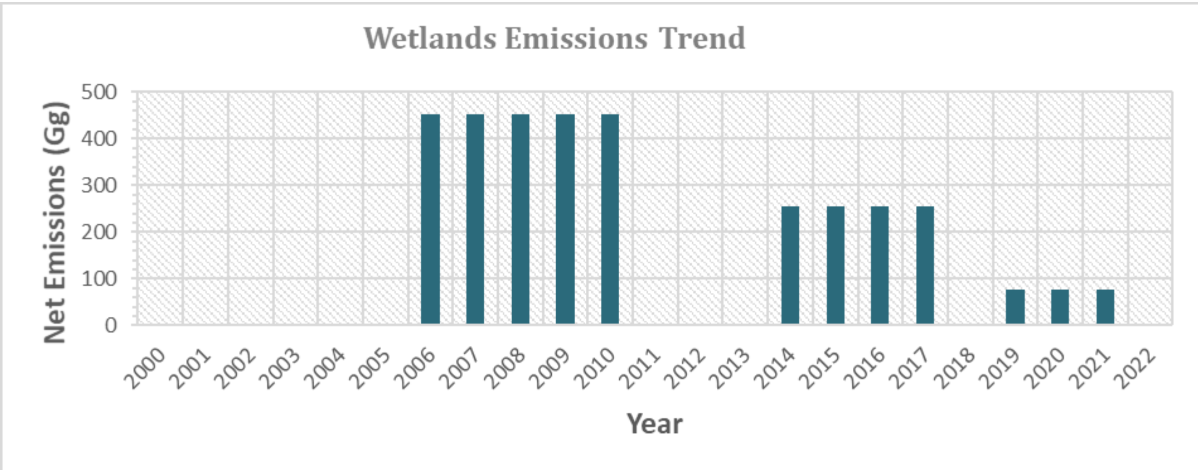


Figure 6-13: Emissions trend for the wetlands category

3.B.5 - Settlements

Default emission factor values were applied to the settlements category, resulting in no reported emissions from land remaining unchanged. However, emissions began to increase from 2006 onwards, driven by land-use conversions, as shown in Figure 6.14. These conversions were primarily from grassland to settlements, attributed to population growth and accelerated urbanization across the country, particularly after 2012 when Kenya's devolution framework was implemented.

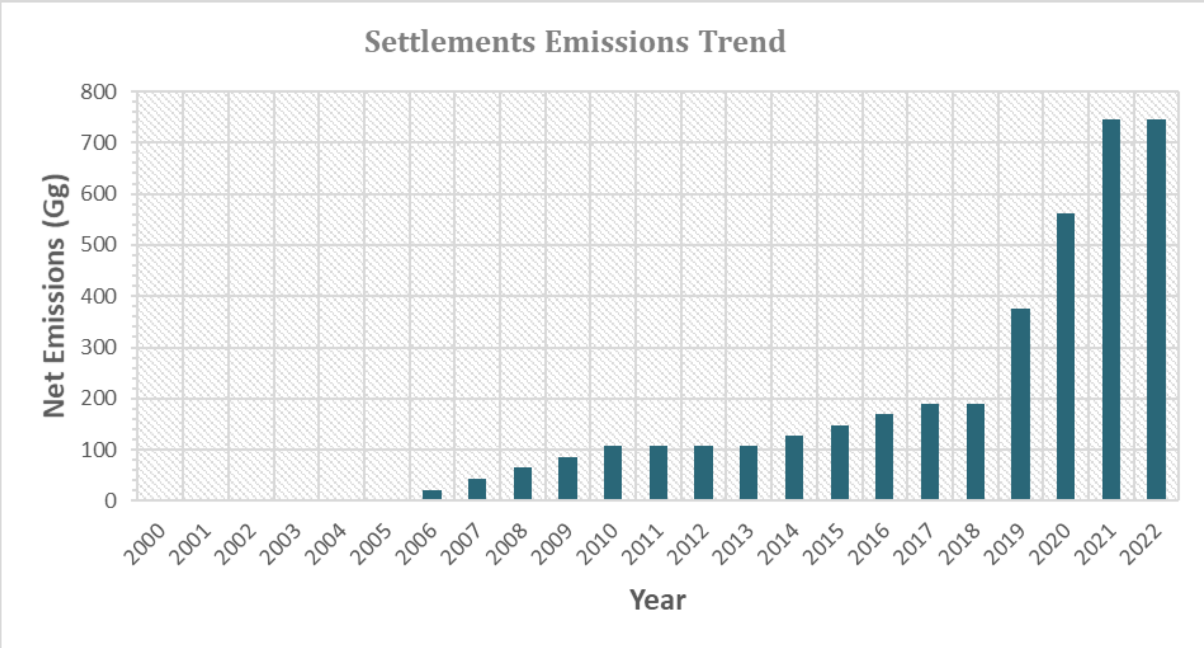


Figure 6-14: Emissions trend for the settlement category

3.B.6 - Other Land

For the other land category, default emission factor values were also applied, resulting in no reported emissions from land remaining in this category. However, emissions were observed from conversions of grassland to other land, as shown in Figure 6.15. The trend reveals sporadic emissions associated with land-use changes, with no consistent pattern across the reporting period. This suggests that these conversions occurred irregularly rather than as part of a continuous or large-scale process. The conversions to Other Land are primarily attributed to quarrying and road construction, activities that have fluctuated since 2014.

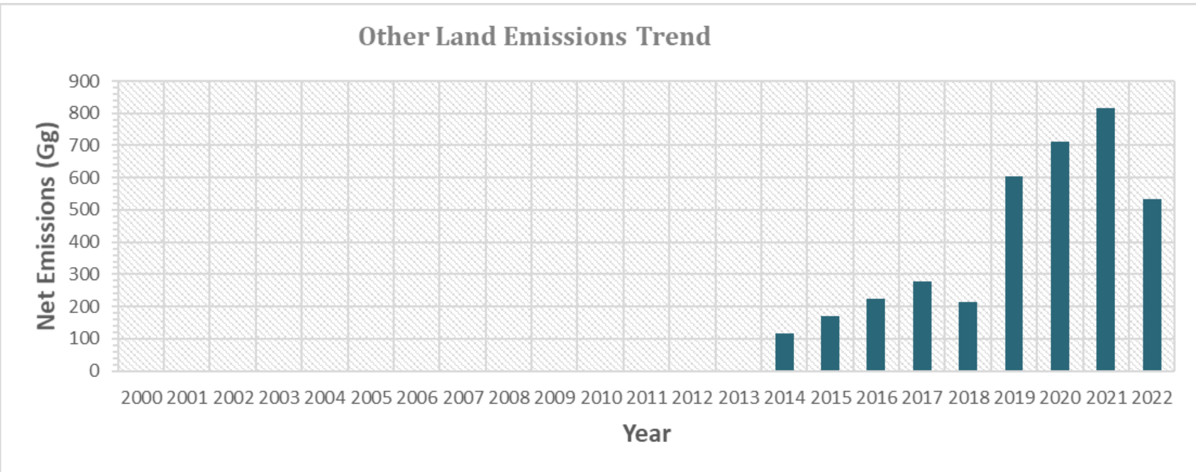


Figure 6-15: Emissions trend for the other land category

6.4.2. Methodological aspects

The National Mapping team developed Activity Data for the period 2000–2022 using an innovative methodology known as Ensemble Sample-Based Area Estimation (eSBAE). This approach involved generating 2 km grids across the entire country, resulting in a total of 149,460 data points. The grid size was carefully chosen following a simulation exercise that tested grid densities ranging from 500 meters to 50 kilometers, utilizing both systematic and random sampling designs.

Machine Learning-Based Time Series Analysis was applied to the dataset to identify potential areas of change. Using probability-based change detection, a subset of the 149,460 points was selected for further analysis. Visual interpretation of these points was conducted through Collect Earth Online (CEO), leading to the detailed assessment of 7,313 samples.

Each interpreted point was classified into one of several categories: Deforestation (Forest to Non-Forest), Forest Degradation (Reduction in canopy density), No Change (Land remaining in the same category), Forest Enhancement (Non-Forest to Forest), Sustainable Forest Management, or Transitions within Non-Forest categories. This methodology provided data that was used for Activity data as described in section 6.2.2.

Data from Kenya's pilot forest inventory was used to calculate above-ground biomass for forestland categories (dense, moderate, and open) in each stratum. Below-ground biomass was calculated using the shoot/root ratio as per IPCC default values as shown below in Table 6.3.

Table 6-3: Table 6.3: Specific Root/Shoot ratios for the different strata

Forest type	R [tonne root d.m. (tonne shoot d.m.)-1]	Reference
Montane	0.27	Table 4.4 IPCC 2006 Guidelines Vol 4 Ch 4 (Tropical Mountain systems)
Western Rain Forest	0.37	Table 4.4 IPCC 2006 Guidelines Vol 4 Ch 4 (Tropical rain forests)
Coastal	0.24	Table 4.4 IPCC 2006 Guidelines V4 Ch 4 (Tropical moist deciduous forests for above-ground biomass >125 tonnes/ha)
	0.2	Table 4.4 IPCC 2006 Guidelines Vol 4 Ch 4 (Tropical moist deciduous forests for above-ground biomass <125 tonnes/ha)
Mangroves	0.24	Table 4.4 IPCC 2006 Guidelines V4 Ch 4 (Tropical moist deciduous forests for above-ground biomass >125 tonnes/ha)
	0.2	Table 4.4 IPCC 2006 Guidelines Vol 4 Ch 4 (Tropical moist deciduous forests for above-ground biomass <125 tonnes/ha)
Dryland	0.28	Table 4.4 IPCC 2006 Guidelines Vol 4 Ch 4 (Tropical dry forests for above-ground biomass >20 tonnes/ha)
	0.56	Table 4.4 IPCC 2006 Guidelines Vol 4 Ch 4 (Tropical dry forests for above-ground biomass <20 tonnes/ha)
Plantation	0.27	Table 4.4 IPCC 2006 Guidelines Vol 4 Ch 4 (Tropical Mountain systems)
Wooded Grassland	0.4	Table 4.4 IPCC 2006 Guidelines Vol 4 Ch 4 (shrubland)

Total above and below-ground biomass was converted to carbon stocks and CO_2 emissions using the IPCC 2006 default values, as outlined in Table 6.4. Additionally, IPCC default values were applied to determine biomass stock factors for grassland categories. Specifically, wooded grasslands were assigned the default value for grasslands, while open grasslands were assigned half this value, based on expert judgement. An emission factor for perennial croplands was derived from research data by Owate A.O et al. (2018), while the IPCC default values were used for annual croplands, wetlands, settlements, and other land types. To convert tree biomass to carbon stocks, the IPCC default value (multiplying biomass by 0.47) was used, followed by conversion to CO2 equivalent (multiplying by 44/12), as shown in Table 6.4.

Table 6-4: Table 6.4: Emission Factors for Various Land Use Categories

Forest stratum	Canopy Cover	AGB Biomass stock (Tonnes/ha)	BGB Biomass stock (Tonnes/ha)	TOTAL Biomass stock (Tonnes/ha)	Carbon Stock (Tonnes/ha)	CO2 (Tonnes/ha)
Montane forest	Dense	255.32	68.93	324.25	152.40	558.80
	Moderate	92.11	24.86	116.97	54.97	201.58
	Open	33.01	8.91	41.92	19.70	72.25
Western Rainforest	Dense	452.84	167.55	620.39	291.58	1069.14
	Moderate	159.10	58.86	217.96	102.44	375.62
	Open	40.03	14.81	54.84	25.77	94.52
Coastal forest	Dense	185.20	44.44	229.64	107.93	395.75
	Moderate	58.12	11.62	69.74	32.78	120.19
	Open	32.56	6.51	39.08	18.36	67.35
Mangroves	Dense	82.97	16.59	99.55	46.79	171.57
	Moderate	46.00	9.20	55.20	25.94	95.13
	Open	15.44	3.08	18.53	8.70	31.93
Dryland forest	Dense	42.43	11.88	54.31	25.52	93.59
	Moderate	34.52	9.66	44.18	20.76	76.15
	Open	14.26	7.98	22.25	10.45	38.34
Plantation forest	Plantation	324.79	87.69	412.47	193.86	710.83

To calculate the change in carbon stocks due to afforestation, IPCC 2006 growth rate values for forests less than 20 years were applied (Table 6.5). The method also applies to growth rates due to enhancement (where default IPCC values for forests greater than 20 years were applied).

Table 6-5: Afforestation and Enhancement Emission Factors

Forest type	Above-ground biomass growth (tonnes d.m. ha-1 yr-1)	Reference
Montane	5	Table 4.9 IPCC 2006 Guidelines Vol 4 Ch 4 (Tropical Mountain systems ≤20 y)
	1.5	Table 4.9 IPCC 2006 Guidelines Vol 4 Ch 4 (Tropical Mountain systems >20 y)
Western Rain Forest	10	Table 4.9 IPCC 2006 Guidelines Vol 4 Ch 4 (Tropical rainforest ≤20 y)
	3.1	Table 4.9 IPCC 2006 Guidelines Vol 4 Ch 4 (Tropical rainforest >20 y)
Coastal	5	Table 4.9 IPCC 2006 Guidelines Vol 4 Ch 4 (Tropical moist deciduous forest ≤20 y)
	1.3	Table 4.9 IPCC 2006 Guidelines Vol 4 Ch 4 (Tropical moist deciduous forest >20 y)
Mangroves	5	Table 4.9 IPCC 2006 Guidelines Vol 4 Ch 4 (Tropical moist deciduous forest ≤20 y)
	1.3	Table 4.9 IPCC 2006 Guidelines Vol 4 Ch 4 (Tropical moist deciduous forest >20 y)
Dryland	2.4	Table 4.9 IPCC 2006 Guidelines Vol 4 Ch 4 (Tropical dry forest ≤20 y)
	1.8	Table 4.9 IPCC 2006 Guidelines Vol 4 Ch 4 (Tropical dry forest >20 y)
Plantation Montane	10	Table 4.10 IPCC 2006 Guidelines Vol 4 Ch 4 (Tropical Mountain systems)

Forest type	Above-ground biomass growth (tonnes d.m. ha-1 yr-1)	Reference
Plantation-Western Rain	6	Table 4.10 IPCC 2006 Guidelines Vol 4 Ch 4 (Tropical rain forests Africa other ≤20 y)
Plantation-Coastal	9	Table 4.10 IPCC 2006 Guidelines Vol 4 Ch 4 (Tropical moist deciduous forest Africa other ≤20 y)
Plantation-Dryland	10	Table 4.10 IPCC 2006 Guidelines Vol 4 Ch 4 (Tropical dry forest Africa other ≤20 y)
Wooded Grassland	0.5	Table 4.9 IPCC 2006 Guidelines Vol 4 Ch 4 (Tropical shrubland ≤20 y)

Emissions for this reporting period were estimated using a combination of Tier 1 and Tier 2 methodologies. For the Forestland category, country-specific emission factors were applied to determine carbon stock changes across various sub-categories within forestland. Where country-specific data was unavailable, default IPCC values were utilized. Conversions both to and from all sub-categories have been accounted for in the report.

To calculate annual activity data, it was assumed that the rate of conversion remains consistent. Additionally, for assigning emission factors, instantaneous oxidation was assumed for all forest degradation and deforestation activities.

For the cropland category, emissions from the perennial crops were estimated based on carbon stock changes in the biomass of perennial crops, using country-specific emission factors derived from a study on ***Grevillea*** conducted in Kenya by Owate et al. These calculations incorporated data on the annual area (ha) under perennial crops and changes in these areas compared to the previous year. For annual cropland, default IPCC values were applied.

Carbon stock changes in cropland soils were estimated using the Tier 1 methodology outlined in the 2006 IPCC Guidelines for National Greenhouse Gas Inventories. This involved applying Equation 2.25 (2006 IPCC Guidelines, Vol. 4, Part 1, Chapter 2, p. 2.35) for mineral soils, using default reference soil organic carbon stocks from Table 2.3 (Vol. 4, Part 1, Chapter 5, p. 2.37) for mineral soils with high-activity clay (HAC) in a dry climatic region. Stock change factors for different cropland management activities were derived from Table 5.5 (pp. 5.20–5.21). Conversion of stored carbon to CO_2-equivalent (CO_2-eq) units was achieved by applying the conversion factor (-44/12).

Default IPCC emission factors were used for the Grassland category. For wooded grasslands, a carbon stock of 8.7 tonnes of carbon per hectare, as specified in the 2006 IPCC Guidelines, was adopted. It was assumed that open grasslands accumulate half the carbon stock of wooded grasslands.

To estimate emissions from grasslands, carbon stock changes in soils were calculated using the Tier 1 methodology of the 2006 IPCC Guidelines for National Greenhouse Gas Inventories. This involved applying Equation 2.25 (2006 IPCC Guidelines, Vol. 4, Part 1, Chapter 2, p. 2.35 for mineral soils) with default factors from Table 6.2. Reference soil organic carbon stocks were selected from Table 2.3 (Vol. 4, Part 1, Chapter 5, p. 2.37) for mineral soils with high-activity clay (HAC). Conversion of carbon stocks to CO_2-equivalent (CO_2-eq) units was performed using the conversion factor (-44/12).

For the Wetland, Settlement, and Other Land categories, default emission factors from the 2006 IPCC Guidelines were applied. It was assumed that all land converted to these categories resulted in a carbon stock of zero. However, significant emissions were observed from conversions to these specific land categories.

6.4.3. Description of flexibility applied

The following flexibility provisions have been applied in this reporting, in light of Kenya's capacities:

Key Category Analysis was conducted only for level assessment, not for trend assessment, in line with Paragraph 25 of Decision 18/CMA.1, annex. This limitation arose from the assumption of unchanged land areas between 1990 and 2000, resulting in a lack of data to perform a trend assessment for the period 1990 to 2022.

- Uncertainty assessment was carried out qualitatively, following Paragraph 29 of Decision 18/CMA.1, annex, due to the unavailability of quantitative input data.
- In accordance with Paragraph 48 of Decision 18/CMA.1, annex, only CO_2 emissions have been reported in this inventory. Non-CO_2 gases from forest fires and the decomposition of organic matter have not been included.

6.4.4. Uncertainty assessment and time-series consistency

The activity data used in this inventory exhibited some inconsistencies, which may have significantly contributed to uncertainties. The primary sources of uncertainty in activity data estimation stemmed from variations in the number of sample points interpreted for different reporting periods and differences in the interval between these periods.

For the Forestland category, emission factors were calculated based on representative sample points derived from the Pilot Forest Inventory (NFI). However, the small sample size likely resulted in relatively high uncertainty in these emission factors.

In the case of perennial cropland, emission factors were adopted from a study focused exclusively on agroforestry systems, specifically ***Grevillea*** species. These values were applied across all perennial cropland types, potentially introducing uncertainties when extrapolated to other types of perennial cropland.

For grasslands, uncertainties in emission factors arose from the adoption of tropical shrubland default values from Table 4.9 of the 2006 IPCC Guidelines (Vol. 4, Chapter 4). Additionally, for the Open Grassland category, an expert judgment-based assumption was made to apply half of the tropical shrubland value, further contributing to uncertainty.

6.4.5. Category specific QA/QC and verification

QA/QC procedures for data collection were conducted in accordance with the 2006 IPCC Guidelines for National Greenhouse Gas Inventories, ensuring international comparability and consistency. To guarantee data accuracy and consistency, rigorous quality control measures were implemented to ensure the precise classification of land use categories. Additionally, the procedures for quality control were documented for transparency.

Data validation was carried out through both internal and external processes. The external validation involved a multi-stakeholder Technical Working Group, which reviewed the activity and emission factor data analysis to verify the accuracy and reliability of the results. The process also included an evaluation by external experts to identify potential errors and inconsistencies, ensuring the data's overall accuracy and reliability.

Data was stored securely and organized, with regular backups to prevent loss. Data quality control procedures were also put in place to detect and correct any errors or inconsistencies. Detailed documentation of data collection, processing, and analysis methods was maintained through Standard Operating Procedures (SOPs), ensuring transparency and traceability.

This report was prepared in line with UNFCCC reporting principles, ensuring transparency, accuracy, clarity, completeness, and consistency.

6.4.6. Category-specific recalculations

No recalculations were applied to any of the categories.

6.4.7. Category-specific planned improvements

The following improvement plan (Table 6.7) is proposed to enable subsequent reporting from the different categories.

Table 6-6: Improvement plan for the LULUCF sector

Land Category	Identified Gaps	Improvement Actions
Forestland	Insufficient data on country-specific emission factors. Sampling method and the number of sample points. Limited data for reporting on the non-CO2 gases.	Implementing an NFI to allow provision of site specific (based on strata and substrata) emission factors. This enhances the certainty of reporting and allows for calculation of uncertainty assessment. The NFI will avail data that have not been reported and also data estimated by use of the IPCC default values: growth rates arising from afforestation and canopy improvement, root-to-shoot ratios for estimating below-ground biomass, estimation of non-covered pools-dead wood, litter, and soil organic carbon and developing country-specific allometric equations for the estimation of biomass stocks. Use of a systematic grid to enhance land cover mapping methodology and increase the number of samples that should be interpreted across the entire reporting period for Activity Data generation. Performing recalculation backwards for the entire country using the Sample Based Area Estimation methodology. Developing a system for data collection to allow for the estimation of the harvested wood products (post deforestation factors) because the use of instantaneous oxidation for all deforestation may exaggerate emissions. Developing a system for monitoring non-CO2 emissions e.g. CH4 from decomposing organic matter and N2O from forest fires. Developing a method for monitoring private plantations in a similar manner as has been done for public plantations. This requires georeferencing these forests and providing information about changes occurring just as is being done for public plantations. In such forests, it is proposed that species-specific or site-specific emission factors be developed. Improvement on uncertainty calculations with additional activity data and sample plots for EF calculations.
Cropland	Sampling method and the number of sample points. Emission factors for different perennial crop types.	Use of systematic grid to enhance land cover mapping methodology and increase the number of samples which should be interpreted across the entire reporting period for Activity Data generation. Performing recalculation backwards for the entire country using the Sample Based Area Estimation methodology. Improving the emission factors for the different types of the perennial cropland category through collection of data on AGB, BGB and annual increment.
Grassland	Sampling method and the number of sample points. Country specific emission factors.	Use of systematic grid to enhance land cover mapping methodology and increase the number of samples which should be interpreted across the entire reporting period for Activity Data generation. Performing recalculation backwards for the entire country using the Sample Based Area Estimation methodology. Improving country specific EF for wooded grassland and open grassland through collection of data on AGB and BGB and annual increment.
Wetland	Sampling method and the number of sample points.	Use of systematic grid to enhance land cover mapping methodology and increase the number of samples which should be interpreted across the entire reporting period for Activity Data generation. Performing recalculation backwards for the entire country using the Sample Based Area Estimation methodology.

Land Category	Identified Gaps	Improvement Actions
Settlement	Sampling method and the number of sample points. Emission factors for treed settlements.	Use of systematic grid to enhance land cover mapping methodology and increase the number of samples which should be interpreted across the entire reporting period for Activity Data generation Performing recalculation backwards for the entire country using the Sample Based Area Estimation methodology. Data collection for determining emission factors for treed settlements.
Otherland	Sampling method and the number of sample points.	Use of systematic grid to enhance land cover mapping methodology and increase the number of samples which should be interpreted across the entire reporting period for Activity Data generation. Performing recalculation backwards for the entire country using the Sample Based Area Estimation methodology.

Chapter 07:

Waste

7.1. Sector Overview

The Constitution of Kenya (2010) provides the rights to a clean and healthy environment for each of her citizens and the responsibility to safeguard it is further elaborated in Kenya's development blueprint, Vision 2030. The Environment Management and Coordination Act, Sustainable Waste Management Act 2022 and the Public Health Act are the main legal frameworks key to waste management in Kenya. The Devolved Governance system has provided the management of waste as a function of the County Governments thus allowing them to enact laws that address their unique circumstances and needs including waste management. Besides these, there are other sectoral laws that address waste management such as in Water, Health and Forest sectors. Notably, the Sustainable Waste Management Act, 2022 establishes legal frameworks and provisions to enable Kenya harness large scale investment in waste recovery and recycling to reduce her GHG emissions and to ensure a healthy, safe and secure environment for all.

The Sustainable Waste Management Act, 2022 provides that NEMA establish a national waste information system for recording, collecting, management and analysis of data and information including, data on the quantity and type or classification of waste generated, stored, transported, treated, transformed, reduced, reused, recycled, recovered or disposed of. The County Governments are responsible for implementing the devolved function of waste management by establishing the financial and operational conditions for the effective performance of this function including maintaining data on waste management activities and sharing it with NEMA.

Other institutions identified to provide data for GHG reporting in the waste sector include the Ministry of Health's Public Health Department, and the Water and Sanitation Service Providers as well as the private sector entities that are required to provide actual quantities of waste generated. Solid waste management practices include collection, recycling, disposal on land, biological treatment, incineration and open burning of waste.

7.1.1. Description of the Sector

This section presents emissions from the management of both solid and wastewater in Kenya. According to the Sustainable Waste Management Policy (GoK, 2021), Kenya's populace generates an estimated 22,000 tons of waste per day calculated with the assumption of an average per capita waste generation of 0.5 kilogrammes for a population of 45 million people both from rural and urban settings which translates to approximately 8 million tonnes of solid waste annually. The main sources of waste are households, manufacturing, commerce, healthcare, agriculture and construction industries. Management practices of solid waste in Kenya includes disposal at the Municipal Solid Waste landfills, open burning, biological treatment and incineration. Approximately 3% of landfills can be classified as unmanaged deep while the rest are unmanaged shallow. Kenya's Second National Communication indicates a national average estimate of waste composition as 60% - 70% of waste being organic, 20% plastic, 10% paper, 1 % medical waste and 2% metal. The GHGs are emitted into the atmosphere from solid waste disposal sites, clinical waste incineration, open burning of waste and wastewater treatment systems.

Methane is the main GHG generated as a result of anaerobic decomposition of degradable organic waste in solid waste disposal sites. Clinical waste incineration emits CO_2 gas and N_2O while open burning of waste results in CO_2, CH_4 and N_2O gases. Wastewater treatment and discharge emits CH_4 and N_2O gases.

Kenya's Sustainable Waste Management Policy (GoK, 2021) indicates that only 40% of the population receive waste management services in major cities. Low income and informal settlements do not have waste collection systems.

Wastewater in Kenya emanates from domestic, commercial and industrial sources. This waste stream is either treated ***on-site*** (uncollected), sewered to a centralised plant (collected) or disposed untreated to a nearby or via an outfall such as a river, lake or sea.

Waste Management Policies

Kenya's waste sector is governed by various policies at the National and Sub-National levels. The Constitution of Kenya (CoK), 2010 and EMCA, 1999 lay a basis for management of the environment in a manner that guarantees citizens a clean and healthy environment for all. EMCA, 1999 and the Sustainable Waste Management Act, 2022 further give guidance on how waste is managed in Kenya. These legislations provide guidelines, procedures and standards for waste management. The legislations also give provision for the creation of institutions such as the National Environment Management Authority (NEMA) and county-based departments that ensure compliance to these national laws. County Governments have been developing individual policies that govern the waste sector.

7.1.2. GHG Trends in the Sector

Kenya's GHG emissions by source and sub-categories from the waste sector for the period 1990 - 2022 are presented in Table 7.1. Figure 7.1 gives the trends of total emissions for the same period. The total Waste sector emissions for the year 2022 were **5,237** $GgCO_{2eq}$. Most of these emissions were from domestic wastewater that contributed **4,055.19** Gg CO_{2eq} (79%) of the total Waste sector emissions.

Municipal solid waste disposal contributed a further 14% of waste emissions while open burning of waste contributed 5% together with clinical waste incineration which were deemed as negligible (0.05205 $GgCO_{2eq}$). Waste GHG emissions increased from **2,171.4** $GgCO_{2eq}$ in 1990 to **5,237** $GgCO_{2eq}$ in 2022. This increase is a result of growth in population size, urbanisation and industrial growth.

This GHG trend is attributed to Kenya's population, which has continued to expand exponentially over the years, as well as the country's economy, which has equally continued to grow throughout the inventory period. These factors, coupled with a favourable macro-economic environment continue to influence waste generation and management dynamics. In contrast to the past, there are policies that guide different actors in the waste sector. Generally, GHG emissions have significantly risen over the years with some slight variations in some years. In the year 2018, for instance, there was a drop in the consumption of plastic bags owing to the implementation of a policy that banned the use of single-use plastic bags towards the end of 2017. It is equally notable that the percentage of waste deposited in dumpsites in the year 2020 was slightly higher. This could be attributed to the curfew/ban on travel that saw many people under lockdown at home during the COVID-19 pandemic outbreak and the ability of county governments to ferry more waste to the dumpsites owing to the reduced road traffic flow, hence more trips. In addition to this, the emissions were also dictated by the adoption of new policies on waste management by county governments post-devolution kick-off and resultant interventions.

Table 7-1: Waste GHG Emissions (Gg CO_{2eq}) by categories from 1990-2022

Category	Year					% increase 1990 - 2022	% share 2022
	1990	2000	2010	2020	2022		
4.A - Solid Waste Disposal	246.1	394.3	609.6	701.3	727.4	196%	11%
4.C - Incineration and Open Burning of Waste	105.7	125	240.9	279.1	321.4	199%	7%
4.D - Wastewater Treatment and Discharge	1,773.5	2,379.4	3,165.6	3,910.9	4,055.2	129%	79%
Total 4 - Waste Emissions in Gg CO2eq	2,171.5	2,953.3	4,113.3	5,009.3	5,237.0	139%	

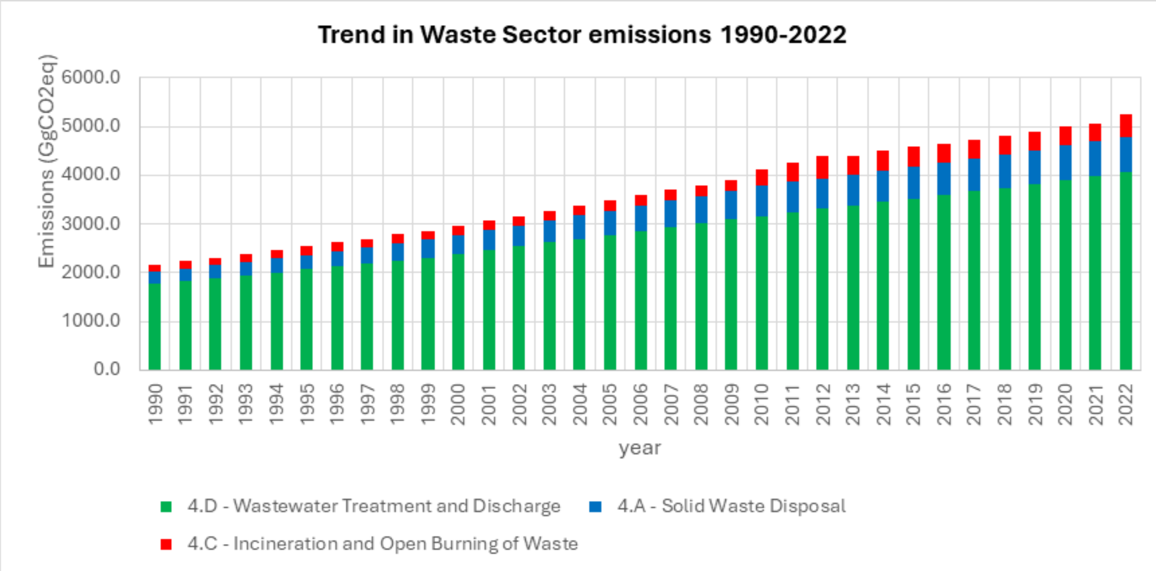


Figure 7-1: Emission Trends in Waste by Source Categories from 1990-2022

Solid waste disposal's contribution to the total waste sector emissions in 2022 is 14% (**727.4** Gg CO_{2eq}). Incineration of Clinical waste and open burning of waste is 9 % (321.4 $GgCO_{2eq}$). Contribution of wastewater treatment and discharge to the total waste emissions is 77% (4,055.1 Gg CO_{2eq}) as shown in Figure 7-2 while Figure 7-3 depicts the percentage share of waste emissions by gas type in the year 2022.

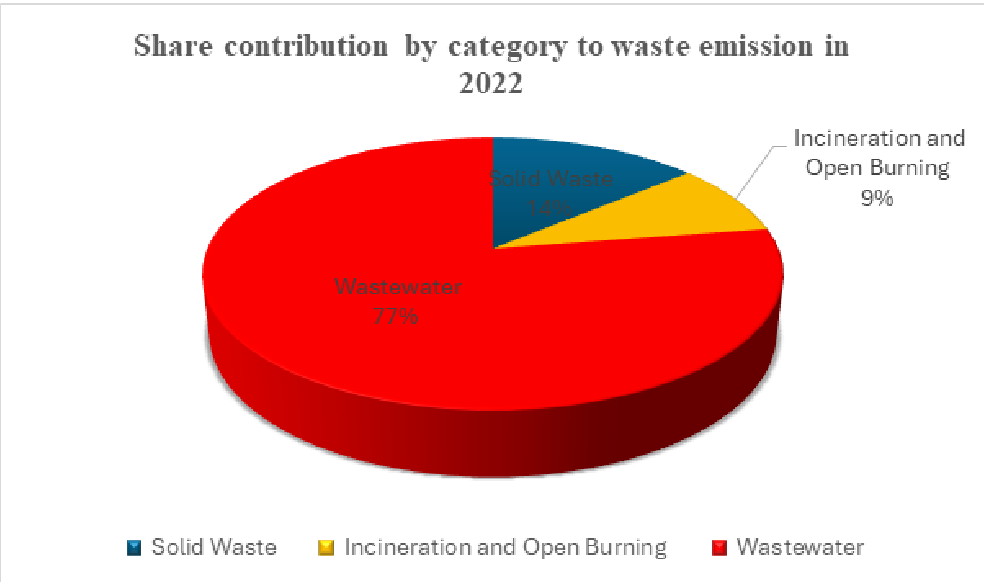


Figure 7-2: Percentage share in Waste by Source Categories in 2022

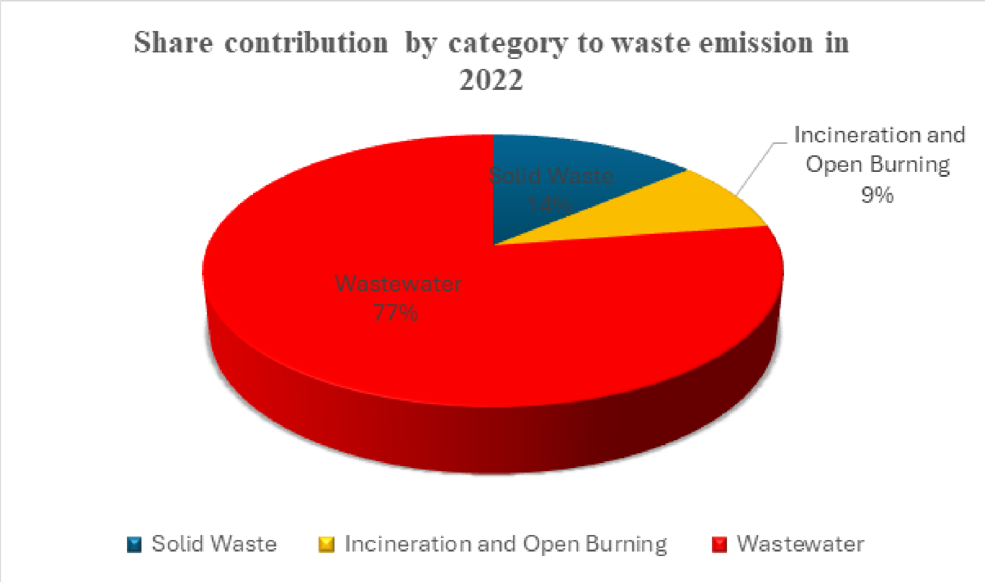


Figure 7-3: Percentage share in Waste by gas type in 2022

7.1.3. General Methodological Aspects of the Waste sector

The GHG emissions estimates from the waste sector in Kenya for the inventory period 1990 – 2022 were based on the 2006 IPCC Guidelines under different methodologies. The primary data sources for the analysis of GHG emissions for each category of waste are illustrated in Table 7-3. Table 7-2 shows a summary of approaches used to estimate the waste sector categories.

Table 7-2: Methodologies used by categories

GHG Source and Sink Category		CO_2		CH_4		N_2O		Details
Tier		E.F	Tier	E.F	Tier	E.F		
4.A	Solid waste disposal			T2	Default value			FOD model
4.B	Clinical waste incineration	T2a	DV					2006 IPCC GL
4.C	Open burning of waste	T2	DV	**T2**	**DV**			Country Specific data used with IPCC default values
4.D	Wastewater treatment			T2	DV	T2	DV	CS data used with IPCC default values

Table 7-3: Data Sources for each Waste Category

Waste Category	Activity Data	Data Source
Solid Waste Disposal	Population data	KNBS
	Waste Composition	JICA, UN-HABITAT
	Waste Generation	JICA, IPCC
Clinical Waste Incineration	Amount of Waste	DHIS2 MoH 2019
Open Burning of Waste	Population	KNBS
	Amounts of Waste open-burned (15% of waste not collected is open-burned)	Expert judgement

Waste Category	Activity Data	Data Source
Wastewater Treatment and Discharge	Population	KNBS
	Split of population by income group	Economic Survey, Expert Judgement
	BOD rates	IPCC 2006
	Per capita protein consumption	IPCC 2006

Detailed results for each of the waste source categories for the inventory period 1990 to 2022 are discussed in the sections below. The categories include Solid Waste Disposal (SWD), Incineration and Open Burning of Waste, and Wastewater Treatment and Discharge.

7.2. Solid Waste Disposal

7.2.1. Description and Trend of GHGs

Municipal solid waste in Kenya is not uniformly disposed of across the country. Under the Constitution of Kenya 2010, the solid waste management function is devolved and is, as such, decentralised and undertaken by county governments. It is worth noting that some counties are largely urban-based while others are a blend of rural and urban setups. Nairobi City County is the only sub-national government that weighs municipal solid waste as it is hauled into the solely designated dumpsite (Dandora dumpsite). Other county governments rely on estimated figures and other statistical methods to determine the volumes of waste that find its way to their dumpsites. Residents in rural areas prefer burning their waste within their precincts or just bury the same in shallow pits. The Sustainable Management Act, 2022 provides for the measures and actions for waste collection, segregation and disposal. However, in the current urban settings, waste is collected from designated and other sites on scheduled days or as may be dictated by resource availability and dispatch. Waste is generally disposed of in its unsegregated form with waste picking happening at the transfer stations or the final disposal sites. Dumpsites are either officially designated or illegal, and levels of management vary from one site to another. Often, there are pockets of open waste burning in selected areas of the country. The depth of the disposal sites is not standard, and neither is the mode of management of the facilities.

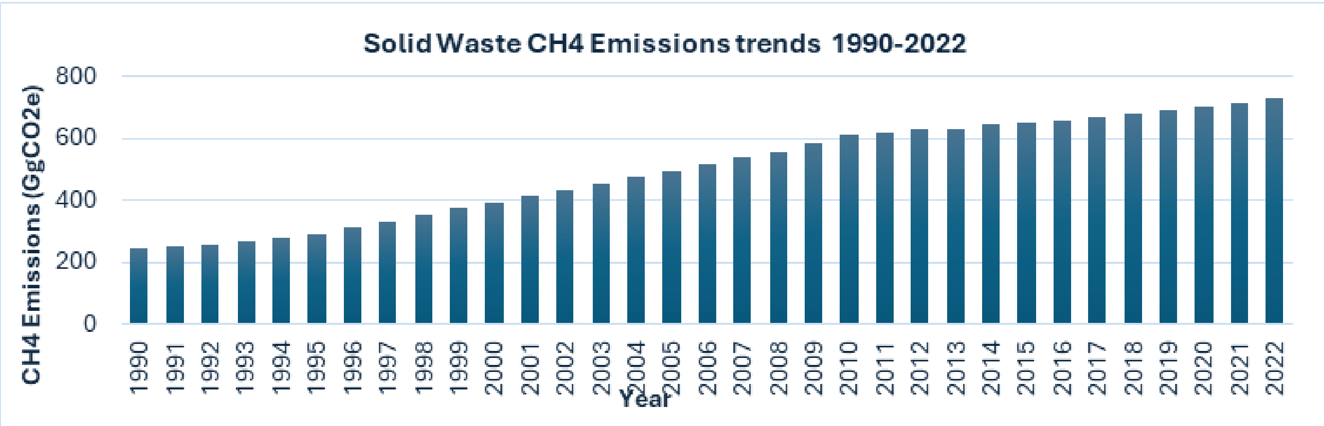


Figure 7-4: Emissions from municipal solid waste (1990-2022)

Total solid waste disposal emissions have increased by 139% from 246 Gg CO_{2eq} in 1990 to 727.4 Gg CO_{2eq} (Table 7-1). The reasons for this observation are due to the use of the FOD method which introduces an in-built lag-effect which means that the reported emissions from solid waste disposal sites in a given year could be a result of solid waste disposed over a few decades ago hence constantly degrading over time depending on their composition and individual decomposition rates. There is no documented CH_4 captured for energy or flaring purposes in the country. Likewise, the percentage of recycled organic waste is low; hence another reason for the observed increase in emissions.

Waste is closely linked to population, urbanisation and the standards of living. Urban and rural populations have increased significantly during the inventory period. The increase in income levels of the growing middle-income class has spurred change in consumer behaviour, which has also resulted in the rise in both liquid and solid waste production.

7.2.2. Methodological aspects of SWD

Data on solid waste collected and disposed of in dumpsites was collected from 22 out of 47 counties in Kenya. It included the volumes deposited in the designated sites and other characterisations of the waste sites, which were unmanaged and uncategorised solid waste sites. Types of disposal sites were either unmanaged shallow or unmanaged deep. The weights were based on real-time scales while in other situations, they were based on estimates obtained through expert judgement. It is the City County of Nairobi that is currently able to weigh its waste before disposing of it at the dump site.

Waste stream composition data such as food, garden, paper, plastics, metal, wood, glass and their mixtures were informed by surveys and publications that are publicly accessible. Regional averages from countries with similar conditions were used as well.

Emission estimation was done using the First Order Decay (FOD) method (Tier 2) as provided in the IPCC software to estimate CH_4 emissions from solid waste disposal. The method was based on historical to current data on volumes of waste collected at the disposal sites, climatic conditions of Kenya, composition of waste (fractions) and disposal practices for several decades. Historical data was used backdating to 1950 in order to record more accurate CH_4 emissions and also to avoid underestimation of the emissions.

The estimates of emissions were calculated using IPCC equation 3.1 below;

EQUATION 3.1
CH_4 EMISSION FROM SWDS

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

Where:

CH_4 emissions = CH_4 emitted in year T, Gg

T = inventory year

X = waste category or type/material

RT = recovered CH_4 in year T, Gg

OX_T = oxidation factor in year T, (fraction)

The CH_4 recovered must be subtracted from the amount of CH_4 generated. Only the fraction of CH_4 that is not recovered will be subject to oxidation in the SWDS cover layer. However, in Kenya there is no quantified CH_4 recovered. A default value (0) was used for Methane Recovery in the inventory period 1990 – 2022.

On the incineration and open burning of waste category; there is waste that is openly burned and those incinerated within medical facilities referred to as clinical waste. The emissions were calculated using the IPCC software using the available activity data to get resultant GHGs which are CH_4, N_2O and CO_2.

7.2.3. Description of any Flexibility applied

Flexibility was applied in different situations. Data collection stage called for adjustment in filling data sheets to ensure accommodation of county governments that had real-time weigh scales and those that relied on estimations to determine waste received at dumpsites. Equally, determination of the level of management of the dumpsites, and at times waste characterisation called for flexibility as was guided by expert judgement. It was necessary to apply flexibility when determining the magnitude of open waste burning, especially in situations where measurements were unavailable.

7.2.4. Uncertainty and consistency of the time series

Uncertainties in data can be attributed to data gaps in different years. In such circumstances, the data was calculated from existent population data, and the country's waste per capita. Such uncertainties are in the ranges of +/-30%, especially in areas where data on waste generation was collected on a regular basis. In addition to this, there were situations when estimations were done for waste generation by way of extrapolation based on population census using a constant. Uncertainties could also have resulted from characterisation of landfills; in the Kenyan situation, characterisation fell between unmanaged shallow and unmanaged deep dumpsites. Aspects of use of default values from the 2006 IPCC Guidelines, waste generation, composition, dominant climatic conditions, waste treatment type as well as waste management type adopted also contribute to uncertainties and overall, this category registers an uncertainty of +/- 30%.

The composition of waste segments has been demonstrated to change over time thereby influencing the amount of GHG emissions. The ever-changing composition over the years in the urban as well as rural settings contributes to the uncertainty aspect. The time that it takes for different components of municipal waste to degrade over time influences emissions in different parts of Kenya. They are affected by elements such as prevailing temperatures, content of moisture in the waste and the waste streams therein. These inconsistencies have been handled through application of studies that have explained waste composition for major cities of Kenya.

Consistency of time series has been addressed by way of ensuring that the same methodologies as well as emission factors for estimating emissions from this sector were applied throughout the inventory period uniformly. It is also necessary to indicate that checks for data quality were done for all the sets from the 22 sub-nationals that were used. The data was provided by competent offices authorised to process and handle the same.

7.2.5. QA/QC for Solid Waste Disposal

Quality assurance and quality control checks are inseparable. They play a pivotal role in ensuring good quality data that passes the test of time. In the inventory process, there were several stages at which quality was tested for purposes of ensuring consistency, accuracy and flow as was envisaged. At no time were there limitations to revision and checks on previously concluded work.

Verification was conducted on the statistics used and the sources of data. An international reviewer assessed the quality of the data and its sources and ensured that the correct format for the inventory process was being adhered to.

At the data collection stage, it was mandatory that data only emanated from authenticated sources at the county administrative levels. This data was then exposed, validated and compared with sources similar to what was provided. This was done for all data emanating from identified county governments.

Data cleaning was also done for purposes of ensuring that any outliers and anomalies were addressed appropriately. In regard to calculation procedures applied, careful choice and application of the right methodologies that align with the IPCC guidelines was done. This was subsequently followed by performance of independent checks to see to it that the corrections were done accurately.

7.2.6. Solid Waste - Specific Recalculations

The 2006 IPCC Guidelines were used in Kenya for estimation of emissions in the inventory period of 1990-2022. Emissions from the sub sector were not subjected to recalculations. However, there was a methodological refinement occasioned by the utilisation of data obtained from a wider geographical coverage. Emissions from Solid waste disposal have been estimated at tier 2 level in the inventory due to the availability of data sourced from 22 out of 47 counties from the year 2010 to 2022 and combined with data from Nairobi County which had been used for the years before; that is: 1990-2010 to calculate a national estimate. Hence, the two sets of data were combined using the splicing techniques with the most representative form to ensure there is time-series consistency as guided by the 2006 IPCC Guidelines.

The below activities were performed as part of the methodological refinement;

- Waste generation rates were adjusted using several scientific research data (JICA). Years with surveys on specific waste characterisation were also considered. Default values were applied in historical years with no surveys.
- The types of disposal sites utilised across the country were also adjusted with the availability of the counties' data.

Calculations were category specific as determined by existent situations. Existent IPCC guidelines and their subsequent revised versions dictated different parameters and limits within which categories fell. Equally, previous reports set pace on the manner in which calculations were done and presented.

7.2.7. Planned Improvements in SWD

There is need to improve on data management, especially at the county level since waste is a devolved function. It is imperative to note that not all counties have active databases on municipal solid waste management, yet they are the administrative units tasked with waste management. For accurate and efficient GHG estimation in the waste sector, the following measures will be required;

- establishment and operationalisation of the Waste management information system as envisioned in the Sustainable Waste Management Act, 2022,
- regular training of data providers on data generation and composition estimation techniques,
- capacity building on appropriate classification of disposal sites is important and data on quantities that are disposed of into them including their compositions,
- it is also critical that Kenya takes steps geared towards CH_4 recovery from the dumpsites and document the same,
- biological treatment of municipal solid waste would go a long way in ensuring little harm to the environment at relatively low costs. This would only be achieved if adequate and proper awareness creation is done and knowledge & skills impacted on the citizenry.

7.3. Biological Treatment of Solid Waste

This category comprises composting and the anaerobic digestion of organic waste. Biogas production is essential for energy use, and the use of organic waste as fertiliser helps in reduced volumes of waste material under this category. CH_4 and N_2O are the gases that are reported herein.

This category was not estimated for its GHGs in Kenya as activity data was scanty and insignificant. Biological treatment of solid waste is not a key category in Kenya at the moment.

7.4. Incineration and Open Burning of Waste

7.4.1. Description and Trend of GHGs

In this category, the estimation of emissions resulting from Solid Waste Disposal was calculated in terms of Waste Incineration (Clinical Waste) and Open Burning of Solid Waste, which are a common waste management practice in Kenya. Incineration is the combustion of solid and liquid waste in controlled incineration facilities. Open burning of waste is the combustion of unwanted combustible materials such as paper, wood, plastics, textiles, rubber, waste oils and other debris in open air or in open dumps, where smoke and other emissions are released directly into the air without passing through a chimney or a stack. The incineration of solid waste in Kenya is approved and licenced by the National Environment Management Authority (NEMA).

More emissions are recorded when large amounts of waste are incinerated or open-burned without energy recovery. Only CO_2 emissions resulting from the combustion of carbon in waste of fossil origin (e.g. plastics) are included in the national emissions estimates while CO_2 emissions from combustion of biomass materials (e.g. paper, food, wood) contained in the waste are biogenic emissions and should not be included. GHGs emitted from this category are CO_2, CH_4 and N_2O.

CH_4 emissions are a result of incomplete combustion, especially from open burning, where a large fraction of the carbon in the waste is not completely oxidised. N_2O results from the incomplete combustion of nitrogen-containing components. Fossil CO_2 is the main GHG that was estimated under the clinical waste incineration sub-category for the inventory year 1990-2022, while CO_2, CH_4 and N_2O were estimated from open burning.

Table 7-4 and Figure 7-5 provide emissions trends in incineration and open burning of waste for the period 1990 to 2022.

Emissions from incineration and open burning of waste rose from 151.9 Gg CO_{2eq} to 454.4 Gg CO_{2eq} in 2022. Emissions from waste incineration alone rose marginally from r from 0.0017 Gg CO_{2eq} in 1990 to 0.052 Gg CO_{2eq} in 2022 (Figure 7-4).

Table 7-4: Table 7- 4: Incineration and Open Burning trend in emissions

Category	Year				
	1990	2000	2010	2020	2022
4.C.1 - Waste Incineration (CO_2)	0.017	0.022	0.034	0.050	0.052
4.C.2 - Open Burning of Waste (CO_2)	105.8	125.1	241.0	279.7	321.5
4.C.2 - Open Burning of Waste (CH_4)	40.3	47.7	84.6	102.5	116.0
4.C.2 - Open Burning of Waste (N_2O)	5.8	6.8	12.5	14.9	17.0
Total: 4.C - Incineration and Open Burning of Waste	151.9	179.6	338.1	397.1	454.4

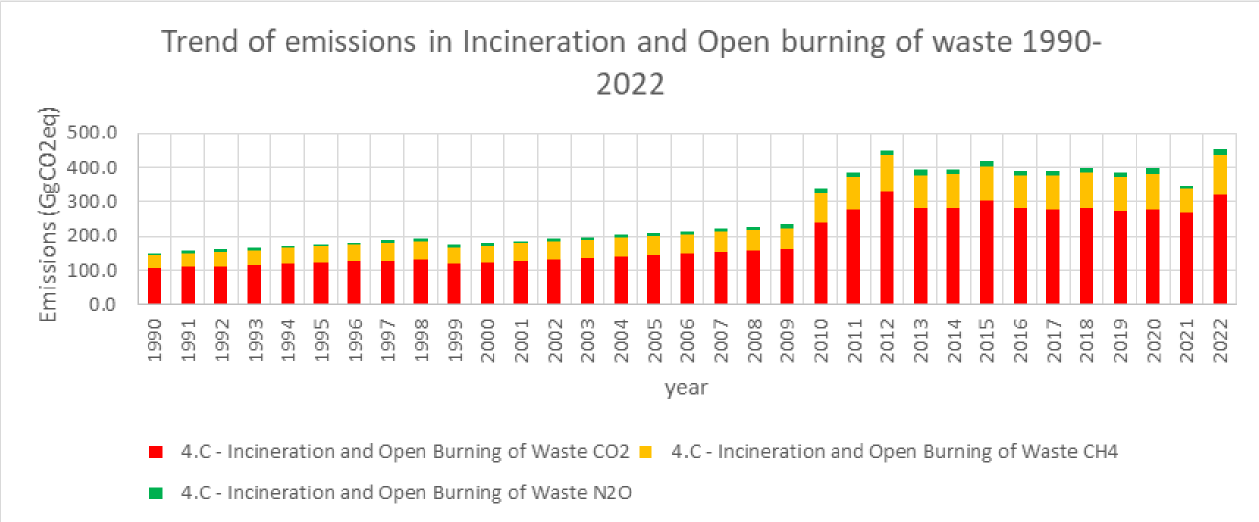


Figure 7-5: Trend of emissions in Incineration and Open Burning of waste 1990-2022

1. Waste Incineration

A rise in the amount of fossil CO_2 gas emanating from health facilities that practise clinical waste incineration has been noted. This is due to the fact that the number of those facilities has increased as the waste management policies emerge, human population increase, and the transformation of the economic profile of the country.

According to WHO, waste generated in Kenya is 0.5 kg/day per patient of which 20% is infectious; and thus, treated through incineration (burn), autoclaving (non-burn) and microwaves (non-burn). These technologies are used in the elimination of bio-hazardous, biomedical, infectious wastes, sharps/blades, body parts, contaminated animal carcasses and pathogens. Relevant to Kenya's GHG emissions is the use of incinerators in health facilities which contribute to some degree of emissions.

Incinerators are fitted in Level 6, 5 and in some cases Level 4 hospitals in the Counties of Nairobi, Mombasa, Nakuru, Kisumu, Nyeri, Nakuru and Uasin Gishu. Incinerator models and their performances are as follows; Today's Mathews - 75kg/hr, China Pad (50kg/hr) and Fine Pro (50kg/hr) these are fitted in hospitals such as Jaramogi Oginga Odinga Teaching and Referral Hospital (JOOTRH), Coast General Teaching and Referral Hospital (CGTRH), Moi Teaching and Referral Hospital (MTRH), Mama Lucy Kibaki Hospital, Mbagathi Hospital, Pumwani Maternity Hospital and Nyeri County Referral Hospital.

The Kenya National Guidelines on safe management of healthcare waste requires health facilities to dispose of ashes from incinerators in a lined ash pit which prevents uncontrolled disposal of the ash and its spread on the environment. For non-burn technologies, the guidelines require the shredded waste to be disposed of in a landfill. However, in Kenya, there are no landfills and hence disposal is done to the Municipal Solid Waste Disposal Sites.

The health sector has a strategic and legal framework that supports the realisation of sound management of healthcare waste (herein referred to as clinical waste). In the Healthcare Waste Management (HCWM) Strategic Plan 2015-2020, one of the 6 strategic priority investment areas is investing in Best Available Technologies (BAT) and Best Environmental Practices (BEP) in order to mitigate against adverse human and environmental risks and pollution. The implementation of this plan has been actualised by developing a sector HCWM implementation plan 2016-2021.

2. Open Burning of Waste

CO_2 emissions resulting from open burning in Kenya are mainly attributed to the burning of Municipal Solid Waste. The composition of this waste comprises food waste, garden and park, disposable nappies, paper and cardboard, textile, wood and inert, which includes plastics, glass, metal, rubber and leather, which all contribute differently to the emission of GHGs depending on their fraction of fossil carbon in total carbon (FCF). Burning of municipal waste is practised in the rural and urban settings alike. In some situations, waste burning takes place in uncategorized waste dumpsites and, on rare occasions, recorded in the categorised open dumps. Open burning of waste is against the existing national legal statutes in Kenya.

7.4.2. Methodological aspects of Incineration and Open Burning of Waste

Estimation of the amount of fossil carbon in the waste burned is the most important factor in determining CO_2 emissions. Activity data for both clinical waste incinerated and open burned waste were obtained as total amounts in wet weight for the estimation of GHGs in this category.

Activity data for waste incinerated mainly consisted of clinical waste that is treated through incineration. Activity data such as fraction of dry matter content (dm), fraction of carbon in dry matter (CF), fraction of fossil carbon in total carbon (FCF) and an oxidation factor (OF) were used as default 2006 IPCC values to estimate fossil CO_2 emissions from waste incineration of clinical waste under a Tier 2a Approach. Clinical waste data sources were from health institutions fitted with functional waste disposal infrastructure like incinerators of waste and Microwaves for non-burn technologies. These data were obtained from the Ministry of Health (MoH) online reporting system (DHIS2 MoH 2019) for waste generated by in-patient bed capacity. Per capita waste generation of 0.5 kg per day per patient was used for this analysis.

Estimation of CO_2 Emissions from Clinical Waste Incineration and Open Burning of Waste

For MSW, the calculation of CO2 emissions was done on the basis of waste types/material (such as paper, wood, and plastics) in the waste incinerated or open-burned, as shown in Equation 5.2.

EQUATION 5.2
CO_2 EMISSION ESTIMATE BASED ON THE MSW COMPOSITION

$$CO_2\ Emissions = MSW \bullet \sum_j \left(WF_j \bullet dm_j \bullet CF_j \bullet FCF_j \bullet OF_j\right) \bullet 44/12$$

Where:

CO_2 emissions = CO_2 emissions in inventory year, Gg/yr

MSW = total amount of municipal solid waste as wet weight incinerated or open-burned, Gg/yr

WF_j = fraction of waste type/material of component *j* in the MSW (as wet weight incinerated or open burned)

dm_j = dry matter content in the component *j* of the MSW incinerated or open-burned, (fraction)

CF_j = fraction of carbon in the dry matter (i.e., carbon content) of component *j*

FCF_j = fraction of fossil carbon in the total carbon of component $_j$

OF_j = oxidation factor, (fraction)

44/12 = conversion factor from C to CO_2

with: $\Sigma_j WF_j = 1$

j = component of the MSW incinerated/open-burned such as paper/cardboard, textiles, food waste, wood, garden (yard) and park waste, disposable nappies, rubber and leather, plastics, metal, glass, other inert waste.

Estimation of CH_4 emissions from Open Burning of Waste

CH_4 emissions from open burning occur where a large fraction of carbon in the waste is not oxidised. The calculation of CH_4 emissions was based on the amount of waste in wet weights open-burned and on the Methane Emission Factor (Kg CH_4/Gg) under a Tier 2 methodology as shown in Equation 5.4 below.

EQUATION 5.4
CH_4 EMISSION ESTIMATE BASED ON THE TOTAL AMOUNT OF WASTE COMBUSTED

$$CH_4\ Emissions = \sum_i (IW_i \bullet EF_i) \bullet 10^{-6}$$

Where:

CH_4 Emissions = CH_4 emissions in inventory year, Gg/yr

IW_i = amount of solid waste of type ***i*** incinerated or open-burned, Gg/yr

EF_i = aggregate CH_4 emission factor, kg CH_4/Gg of waste

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

i = category or type of waste incinerated/open-burned, specified as follows:

MSW: municipal solid waste, ISW: industrial solid waste, HW: hazardous waste,

CW: clinical waste, SS: sewage sludge, others (that must be specified)

Estimation of N_2O emissions from Open Burning of Waste

The calculation of N_2O emissions was based on the waste input to the incinerators or the amount of waste open-burned (dry weight) and a default emission factor (Nitrous Oxide Emission Factor (Kg N_2O /Gg Dry Waste)) and was calculated under Tier 2 methodology. This relationship is summarised in the following Equation 5.5:

EQUATION 5.5
N_2O EMISSION ESTIMATE BASED ON THE WASTE INPUT TO THE INCINERATORS

$$N_2O\ Emissions = \sum_i (IW_i \bullet EF_i) \bullet 10^{-6}$$

Where:

N_2O Emissions = N_2O emissions in inventory year, Gg/yr

IW_i = amount of waste incinerated/open-burned waste of type ***i***, Gg/yr

EF_i = N_2O emission factor (kg N_2O /Gg of waste) for waste of type ***i***

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

i = category or type of waste incinerated/open-burned, specified as follows:

MSW: municipal solid waste, ISW: industrial solid waste, HW: hazardous waste,

CW: clinical waste, SS: sewage sludge, others (that must be specified)

Composites of municipal solid waste that underwent open burning such as food, wood, plastics, paper were disaggregated in the IPCC Software and default values applied on averages calculated from the 22 counties activity data to generate fossil and biogenic emissions.

7.4.3. Description of any Flexibility applied

Flexibility was applied when determining the volume of openly burned waste. It was also applied to determine the apportioning of different waste streams, especially in counties that hadn't undertaken studies on waste characterisation before. Flexibility was necessary in determining the overall climatic zone under which to place Kenya considering the fact that counties experienced different climatic conditions throughout the year.

7.4.4. Uncertainty and consistency of the time series

The composition of waste segments has been demonstrated to change over time, and so are the volumes of waste that are burned in the open. The ever-changing composition over the years in the urban as well as rural settings contributes to the uncertainty aspect. In addition to this, the adoption and implementation of the use of plastic for packaging has, in a large way, influenced the volumes and, therefore, the level of GHGs from open burning.

Consistency of time series in the inventory period 1990-2022 has been addressed by way of ensuring that the same methodologies, as well as emission factors for estimating emissions from this sector, were applied throughout and uniformly. It is also necessary to indicate that checks for data quality were done for all the datasets from the 22 regions that were used. The data was provided by competent offices authorised to process and handle the same.

7.4.5. QA/QC for Incineration and Open Burning of Waste

At the data collection stage, it was mandatory that data only came from official sources at the county administrative levels. This data was then exposed to cross-check points and compared with sources similar to what was provided. This was done for all data emanating from identified county governments. Data validation checks were also done for the purpose of ensuring that any outliers and anomalies were addressed appropriately. In regard to calculation procedures applied, careful choice and application of the right methodologies that align to IPCC guidelines was done. This was subsequently followed by the performance of independent checks to see to it that the corrections were correct.

7.4.6. Incineration and Open Burning of Waste-Specific Recalculations

Calculations were category-specific as determined by existent situations. Existent IPCC guidelines and their subsequent revised versions dictated different parameters and limits within which categories fell. Equally, previous reports set the pace for the manner in which calculations were done and presented. Extrapolation of data acquired was used as the best technique to cover the data for years that were missing, which were 1990-1995 and 2015-2022.

7.4.7. Planned Improvements in Incineration and Open Burning of Waste

Adequate capacity-building sessions, especially among the administrative wing at the county government level, will be undertaken so as to address data gaps on matters of open waste burning.

The use of non-burn technologies will greatly reduce CO_2 emissions henceforth for clinical waste incineration.

7.5. Waste Water Treatment and Discharge

7.5.1. Description and Trend of GHGs

This category comprises Domestic and Industrial Wastewater Treatment and Discharge. Industrial sectors include paper and pulp, beer and malt, dairy products, and beverage processing and manufacturing. Kenya has no separate or dedicated treatment works for industrial wastewater; hence, most of it is discharged into domestic wastewater facilities post-treatment. Therefore, Industrial wastewater's emissions have not been estimated in this inventory.

CH_4 and N_2O are the main gases emitted from Domestic Wastewater Treatment and Discharge. CO_2 emissions from wastewater are of biogenic origin and are not included in national total emissions. Wastewater in Kenya emanates from domestic, commercial and industrial sources. This waste may be treated on site (uncollected), sewered to a centralised plant (collected) or disposed untreated to a nearby or via an outfall such as a river, lake or sea. Domestic wastewater in Kenya can be treated in centralized plants, pit latrines, septic systems or disposed of in unmanaged lagoons or waterways via open or closed sewers. Some industrial facilities have in-plant treatment systems before releasing the effluent into domestic wastewater systems or to nearby water ways.

Wastewater is a source of CH_4 when treated or disposed anaerobically. CH_4 generation depends primarily on the amount of degradable organic material in the wastewater, the surrounding temperature and the type of treatment system. Total Organically Degradable material in wastewater (TOW) is a function of human population and Biological Oxygen Demand (BOD) generation per person expressed as kg BOD/year. N_2O emissions are associated with the degradation of nitrogen components in the wastewater such as urea, nitrates and proteins. Activity data required is nitrogen content in the wastewater effluent, country population and average annual per capita protein consumption in kg/person/year. N_2O emissions occur as indirect emissions from wastewater after disposal of treated effluent into a receiving waterbody or waterways such as river, lake or ocean.

In the urban areas of Kenya, the sewerage systems consist of a closed underground network which conveys their sewage to a treatment plant. The sewers are however prone to blockage resulting in a high number of overflows into the environment. This has a direct impact on the rise in CH_4 emissions as the wastewater is subject to direct heating from the sun or the sewers may be stagnant allowing for anaerobic reactions to occur which becomes a perfect environment for the formation of the gas The blockages are mainly attributed to washed away sections of the sewers, accidental breakages or deliberate vandalism of manhole covers, blockages due to deliberate dumping of solid waste, accidental entry of stones and boulders into open manholes and blockages of sewer lines by urban farmers in order to trap sewage for irrigation and overflowing of sewers due to insufficient capacity.

When the overflow problem is adequately addressed, an optimally operating closed sewer would have minimal contribution of CH_4 emissions.

Industrial effluent is mostly pre-treated before being discharged into the domestic wastewater sewerage system. This makes it difficult to quantify volumes of industrial liquid waste since there doesn't exist a dedicated sewage treatment plant for industrial wastewater treatment in Kenya. Therefore, a professional judgement that industrial waste is equivalent to 10% of domestic wastewater was made.

At the national level, it is estimated that sewer coverage for the Kenyan populace stands at 16%. It therefore means that a substantive fraction of the country falls under the on-site sanitation treatment of wastewater which consists of latrines, septic tanks and open defecation which occurs in informal settlements in Kenya's urban areas.

Table 7-5 and Figure 7-6 show the trends for Methane and Nitrous Oxide emissions from Domestic Wastewater Treatment and Discharge. Methane Emission rose from 1552.1 Gg CO_{2eq} in 1990 to 3548.9 Gg-CO_{2eq} in 2022, while that of N2O more than doubled from 221.4 Gg CO_{2eq} to 506.2 Gg CO_{2eq}.

Table 7-5: Summary emissions trend of Waste Water Treatment and Discharge

Year	1990	2000	2010	2020	2022
4.D.1 - Domestic Wastewater Treatment and Discharge (CH4)	1552.1	2082.4	2770.4	3422.7	3549.0
4.D.1 - Domestic Wastewater Treatment and Discharge (N2O)	221.4	297.0	395.2	488.2	506.2
Year	**1990**	**2000**	**2010**	**2020**	**2022**
4.D - Wastewater Treatment and Discharge (total GgCO2eq)	1773.5	2379.4	3165.6	3910.9	4055.2

This trend could be associated with the steady rise in human population over the inventory period of 1990-2022, therefore an increase in volumes of wastewater generated. This in turn has led to an increase in CH_4 and N_2O emissions which are the main emissions from wastewater. Figure 7-6 below illustrate this phenomenon.

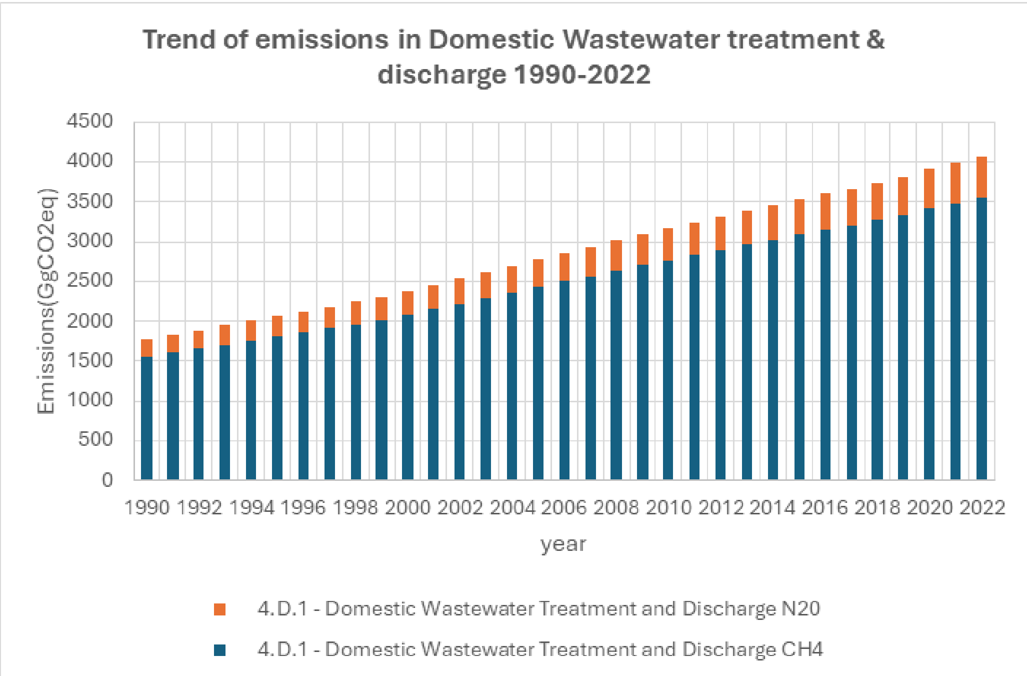


Figure 7-6: Domestic wastewater treatment emissions trends 1990-2022

7.5.2. Methodological aspects of the category

Tier 2 methodology and 2006 IPCC default emission factors were used to estimate both CH_4 and N_2O emissions from wastewater. Emissions are a function of the amount of organic waste generated and an emission factor (organically degradable material in wastewater in Kg BOD/yr.) that characterises the extent to which this waste generates CH_4 gas. Activity data applied here was country population, a weighted Emission Factor (Kg CH_4/Kg BOD) with total organic matter in the wastewater in kg BOD/year and country's BOD in g/person/day and the use of a correction factor (1.25 in this case) for additional industrial wastewater that is treated together with domestic wastewater. The weighted emission factor (Kg CH_4/Kg BOD) was calculated as a product of the fraction of population in income group (Rural, Urban high income, Urban low income), degree of utilization of a type of treatment and discharge pathway or system (e.g. septic system, latrine, open or closed flowing sewer, anaerobic deep lagoon and sea, river and lake discharge) and an emission factor (Maximum methane producing capacity (B_o)* Methane Conversion Factor (MCF)).

N_2O emissions are derived from urea and ammonia present in the wastewater which are as a result of protein intake by the populace. Protein intake is a function of population and protein generated. This multiplied by a default IPCC emission factor for N_2O gives the emissions from domestic wastewater nitrogen effluent.

The general equation to estimate CH_4 emissions from domestic wastewater is equation 6.1 below from IPCC guidelines.

EQUATION 6.1
TOTAL CH_4 EMISSIONS FROM DOMESTIC WASTEWATER

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

Where:

CH_4 Emissions = CH_4 emissions in inventory year, kg CH_4/yr

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

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

U_i = fraction of population in income group i in inventory year, See Table 6.5.

$T_{i,j}$ = degree of utilisation of treatment/discharge pathway or system, ***j***, for each income group fraction ***i*** in inventory year, See Table 6.5.

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

j = each treatment/discharge pathway or system

EF_j = emission factor, kg CH_4 / kg BOD

R = amount of CH_4 recovered in inventory year, kg CH_4/yr

The simplified general equation for estimating N_2O from domestic wastewater is equation 6.7

EQUATION 6.7
N_2O EMISSIONS FROM WASTEWATER EFFLUENT

$$N_2O\ Emissions = N_{EFFLUENT} \bullet EF_{EFFLUENT} \bullet 44/28$$

Where:

N_2O emissions = N_2O emissions in inventory year, kg N_2O /yr

$N_{EFFLUENT}$ = nitrogen in the effluent discharged to aquatic environments, kg N/yr

$EF_{EFFLUENT}$ = emission factor for N_2O emissions from discharge to wastewater, kg N_2O -N/kg N

The factor 44/28 is the conversion of kg N_2O -N into kg N_2O.

In this report, data from 12 utilities spread across Kenya was used most of which have similar characteristics of influent and effluent wastewater managed. This is majorly because they are regulated by the same government agencies that regularly check on their compliance. The main variable here is the country's population data.

The largest utility in terms of connectivity and handling of large volumes of wastewater from the population served is Nairobi City Water and Sewerage Company (NCWSC0) which treats 200,000m^3 received wastewater per day with a sewer network of approximately 2,000 km length and serves about 50% of the Nairobi population. The influent into this sewage treatment plant is 500 mg/l which forms the basis for CH_4 and N_2O emissions.

7.5.3. Description of any Flexibility applied

There was flexibility applied in data collection. It was assumed that all the wastewater treatment plants in Kenya recorded similar BOD's. It was also assumed that the calculation methods used to derive results in all the sampled wastewater treatment facilities were standardised.

7.5.4. Uncertainty and consistency of the time series

Wastewater data from the 12 utilities that were selected in Kenya has been collected over time and is regulated by various government agencies. The data came from the following water utilities: Bomet, Eldoret, Embu, Homa Bay, Isiolo, Kericho, Kakamega, Kisii, Kisumu, Mombasa, Nairobi and Trans-Nzoia. The volume of waste generated has steadily increased from 60,000 m^3/day in 2010 to 200,000 m^3/day in 2022.

While the data acquired is reliable, the number of utilities that provided the data were a small representation. Only 12 wastewater treatment facilities were selected. This can be considered as a small representation of the entire country with over 70 water utilities.

7.5.5. QA/QC

Data provided from the 12 wastewater treatment facilities is verifiable and corresponds to the population and number of sewer connections. The volume of industrial waste is presumed to be at 10% percent of the domestic waste and also correlates well with the volume of water consumed by the industrial facilities.

7.5.6. Category Specific recalculations

Wastewater emissions have been recalculated to a tier 2 level in the inventory due to the availability of data sourced from 12 utilities out of the many wastewater treatment plants available in Kenya from the year 2010 to 2022 and combined with surrogate data and 2006 IPCC default values which had been used for the years before that is 1990-2010 to calculate a national estimate. Hence, the two sets of data were combined using the splicing techniques with the most representative form to ensure there is time-series consistency as guided by the 2006 IPCC Guidelines.

Calculations were category specific as determined by existent situations. Existent IPCC guidelines and their subsequent revised versions dictated different parameters and limits within which categories fell. Equally, previous reports set pace on the manner in which calculations were done and presented.

7.5.7. Planned Improvements on Wastewater Treatment and Discharge

Provision or acquisition of specific, detailed and segregated data from the water utilities. Estimations for some of the emissions were based on default values due to lack of adequate data for some of the parameters or values required.

Increase the number of utilities that provide data as a representation of the country's situation.

Annex

Annex I. Improvement Plan

No.	Sector	Category	Key Category (Y/N)	Description of Improvement	Priority (High, Medium, Low)	Responsible Party [Individual, Organization]	Impact to GHGI compilation elements (National Inventory Document (NID), CRT, Calculation File / Model / Database)	Primary type of Improvement (TACCC, Inventory Arrangements, Other)	Source of Improvement (MoECCF identified, QA Finding, etc.)	Describe succinctly any resource requirements or dependencies (i.e. Coordination with data agency, etc., funds ($$), etc.)	Improve ability to track mitigation measures (Y/N)	Start Date	Timing (i.e., include submission date if known or indicate medium-term (BTR2), long-term (BTR3))	Status (pending, addressing, complete)	Notes
	Energy	Uncertainty analysis	n/a	Train experts on estimation of uncertainty	High	CCD	Completeness	Accuracy	Training of experts		Y	2025	BTR2	Pending	
	Energy	Country emission factors	n/a	To make arrangements for definition of country EF	Medium	Various	Completeness	Accuracy	Research		Y	2025		Pending	
	Energy	Data collection arrangements	n/a	Arrangements for data collection, sharing and archiving	High	CCD	Completeness	Transparency, Completeness	Finding	Data sharing contracts, engagement with KNBS for appropriate data classification and other synergies	Y	2025	BTR2	Pending	
	Energy	Fugitive emissions	Y	Quantification of fugitive emissions from fuel handling	High	MOEP / EPRA / KPC / NEMA	Completeness	Completeness	Emission modelling		Y		BTR2	Pending	
	Energy	Fugitive emissions	N	Quantification of fugitive emissions from petroleum exploration activities	Low	MoEP - SDP / NEMA	Completeness	Completeness	Data collection		Y	2025	BTR3	Pending	
	Energy	Pipeline Transport	N	Quantification of fugitive emissions from petroleum exploration activities	Low	KPC	TACCC	TACCC	Data collection		Y	2025	BTR3	Pending	
	Energy	Waterborne navigation	N	Arrangements for data collection, sharing and archiving in the Waterborne navigation (maritime) sector	Medium	KMA	TACCC	TACCC	Data collection		Y	2025	BTR3	Pending	

No.	Sector	Category	Key Category (Y/N)	Description of Improvement	Priority (High, Medium, Low)	Responsible Party [Individual, Organization]	Impact to GHGI compilation elements (National Inventory Document (NID), CRT, Calculation File / Model / Database)	Primary type of Improvement (TACCC, Inventory Arrangements, Other)	Source of Improvement (MoECCF identified, QA Finding, etc.)	Describe succinctly any resource requirements or dependencies (i.e. Coordination with data agency, etc., funds ($$), etc.)	Improve ability to track mitigation measures (Y/N)	Start Date	Timing (i.e., include submission date if known or indicate medium-term (BTR2), long-term (BTR3))	Status (pending, addressing, complete)	Notes
	Energy	Road Transport	Y	Disaggregation of the activity data to the various vehicle categories and technologies	High	MoRT / NTSA /	TACCC	TACCC	Data collection		Y	2025	BTR2	Pending	
	Energy	Biomass	Y		High	MoEP / EPRA / KNBS	CRT	Completeness	Data collection		Y	2025	BTR2	Pending	
	Energy	Fuel	N	Collection of waste lubricants (greases and oils) data and their disposal	Medium	NEMA		Completeness	Data collection		Y	2025		Pending	
	Agriculture (Crops)	Rice	Y	Establish country specific emission factor for intermittently grown rice Harmonization data collection on irrigated rice system Harmonized data collection of upland rice system Harmonization of data collection on intermittent irrigated rice system	High	MoALD, KALRO, KNBS, KRA	NID, Model, calculation file	Accuracy, completeness	Finding	Research, Funds ($1M)	Y	2025	BTR2	Pending	Essential for accurate estimation of GHG emission and transition to tier 2
	Agriculture (Crops)	Liming	Y	Enhance harmonization of liming data collection and information sharing	Medium	MoALD, Industries in lime production, KRA	NID, Model, calculation file	TACCC					BTR3		
	Agriculture (Crops)	Urea Application	Y	Enhance harmonization of Urea application data collection and information sharing	High	MoALD, KALRO, KNBS, KRA	NID, Model, calculation file	TACCC					BTR2		
	Agriculture (Crops)	Aggregate sources and non-CO2 emissions sources (Burning in crop land) & Direct N2O emissions from managed soils	Y	Implement real time monitoring, evaluation and reporting tool of mitigation and adaptation initiative	High	MoALD, KALRO	Database, Calculation file, Model	accuracy, consistency	QA/QC	Research, Funds ($1M)	Y	2025	BTR2	pending	Essential for accurate estimation of GHG emissions, consistency in reporting and transition to tier 2

No.	Sector	Category	Key Category (Y/N)	Description of Improvement	Priority (High, Medium, Low)	Responsible Party [Individual, Organization]	Impact to GHGI compilation elements (National Inventory Document (NID), CRT, Calculation File / Model / Database)	Primary type of Improvement (TACCC, Inventory Arrangements, Other)	Source of Improvement (MoECCF identified, QA Finding, etc.)	Describe succinctly any resource requirements or dependencies (i.e. Coordination with data agency, etc., funds ($$), etc.)	Improve ability to track mitigation measures (Y/N)	Start Date	Timing (i.e., include submission date if known or indicate medium-term (BTR2), long-term (BTR3))	Status (pending, addressing, complete)	Notes
	Agriculture (Crops)			Establish actual data collection and sharing tools and protocols	High	MoALD, KNBS	NID, Model, Database, Calculation file, CRT	TACCC	Finding	Research, funds, coordination with data agencies	Y	2025	BTR2	pending	Essential for accurate estimation of GHG emissions, consistency in reporting and transition to tier 2
	Agriculture (Crops)			Harmonize data collection and information sharing protocol in all mitigation initiatives such as Promotion of integrated Sustainable Land Management (SLM) practices	High	MoALD, KALRO, KNBS	NID, Model, Database, Calculation file, CRT	Accuracy	QA/QC	Coordination with data agencies, funds ($ 2M); research agencies, Funds ($1M)	Y	2025	BTR2	addressing	Essential for accurate estimation of GHG emissions, consistency in reporting and transition to tier 2
	Agriculture (Crops)			Efficient application of Integrated nutrient/fertilizer/ carbon, harmonize data collection and information sharing protocol	Medium	MoALD, KALRO, KNBS	Database, Calculation file	Transparency	QA/QC	Research, coordination with research agencies	Y	2025	BTR2	addressing	Essential for accurate estimation of GHG emissions, consistency in reporting and transition to tier 2
	Agriculture (Crops)			Ensure accurate tracking of fertilizers supply	High	MoALD, KALRO, KNBS, KRA	Database, Calculation file	Accuracy	QA/QC	Coordination with data agencies	Y	2025	BTR2	pending	Essential for accurate estimation of GHG emissions, consistency in reporting and transition to tier 2
	Agriculture (Livestock)	Enteric Fermentation	Y	Research to develop cost-effective methods for accurate representation of diet composition for different dairy cattle sub-categories and feeding systems	High	SDLD/ KALRO	Model/Database	TACCC, Tailored research	QA	Research, funds ($ 76000)	Y	2025	BTR2	Addressing	Facilitate Tier 2 and Inventory

No.	Sector	Category	Key Category (Y/N)	Description of Improvement	Priority (High, Medium, Low)	Responsible Party [Individual, Organization]	Impact to GHGI compilation elements (National Inventory Document (NID), CRT, Calculation File / Model / Database)	Primary type of Improvement (TACCC, Inventory Arrangements, Other)	Source of Improvement (MoECCF identified, QA Finding, etc.)	Describe succinctly any resource requirements or dependencies (i.e. Coordination with data agency, etc., funds ($$), etc.)	Improve ability to track mitigation measures (Y/N)	Start Date	Timing (i.e., include submission date if known or indicate medium-term (BTR2), long-term (BTR3))	Status (pending, addressing, complete)	Notes
	Agriculture (Livestock)	Enteric Fermentation	Y	Develop country-specific emission factors for non-dairy cattle livestock (non-dairy cattle, sheep, goats and camels)	High	SDLD/ KNBS	Database	Invetory Arrangements	QA and QC	Coordnation with data agency	Y	2025	BTR2	Addressing	To facilitate Tier 2 and 3 inventory
	Agriculture (Livestock)	Enteric Fermentation	Y	Harmonize livestock data collection protocols and methodologies, while incorporating parameters on herd structures for every livestock sub-category	High	SDLD/ KNBS/ MoT&NP	Database	TACCC, Inventory Arrangements	QA and QC	Coordination with data agency, Funds ($ 700,000)	Y	2026	BTR3	Pending	Consolidate and domecticate one livestock population data protocol and methodology
	Agriculture (Livestock)	Enteric fermentation	Y	Conduct regular livestock census; defining herd structures for all livestock sub-categories	High	SDLD/ KNBS/ MoT&NP	Database	TACCC, Inventory Arrangements	QA and QC	Coordination with data agency, Funds ($ 15,000,000)	Y	2026	BTR3	Pending	Well defined herd/flock structures to necessitate Tier 2&3 inventory
	Agriculture (Livestock)	Enteric fermentation	Y	Upscaled performance recording for parameters such as milk yields, lactation lengths, milk components, live body weights for various livestock age classes	High	SDLD (NLRC)	Database/ Calculations	Inventory arrangements	Finding	Coordination with data, Fund ($ 770,000)	Y	2025	BTR2	Pending	Consistency in data collection on milk yields and components, liveweights; feed efficiency; facilitate modelling
	Agriculture (Livestock)	Enteric fermentation	Y	Timely update of livestock feed inventory/basket; Regular (once in 5 years) nationally representative surveys of feed basket composition by SDL, KALRO and/or academia.	Medium	SDLD/ KNBS/ KEBS	Database/Model and Calculation	Inventory arrangements	Finding	Coordination with data, Fund ($ 770,000)	Y	2026	BTR3	Addressing	Quality supply of livestock feeds
	Agriculture (Livestock)	Enteric fermentation	Y	Characterization of livestock production environments and systems (Cross-check and validate or adjust allocation of counties to production systems)	Medium	SDLD/ NEMA/ KALRO	NID	Inventory arrangements	MoECCF identified	Funds ($ 850,000) and Research	N	2026	BTR2	Pending	Understanding dynamics in production environments with regards to inventory process

No.	Sector	Category	Key Category (Y/N)	Description of Improvement	Priority (High, Medium, Low)	Responsible Party [Individual, Organization]	Impact to GHGI compilation elements (National Inventory Document (NID), CRT, Calculation File / Model / Database)	Primary type of Improvement (TACCC, Inventory Arrangements, Other)	Source of Improvement (MoECCF identified, QA Finding, etc.)	Describe succinctly any resource requirements or dependencies (i.e. Coordination with data agency, etc., funds ($$), etc.)	Improve ability to track mitigation measures (Y/N)	Start Date	Timing (i.e., include submission date if known or indicate medium-term (BTR2), long-term (BTR3))	Status (pending, addressing, complete)	Notes
	Agriculture (Livestock)	Manure Management Systems	Y	Characterization and review of manure management systems in livestock production systems	High	SDLD/ NEMA/ SDECC	NID, Calculation, Model, Database	TACCC, Inventory Arrangements	Finding	Coordination with data, Fund ($ 500,000)	Y	2026	BTR2	Addressing	Customize MMS to the local livestock production systems
	Agriculture (Livestock)	Manure Management Systems	Y	Improve availability and quality of data on manure management in Livestock production systems	High	SDLD/ SDECC/ NEMA/ KALRO	Database, Calculation, Model	TACCC, Inventory Arrangements	QA and Finding	Coordination with data agency, Fund ($ 600,000)	Y	2026	BTR2	Pending	Inventory on quantities of manure nd managament dynamics
	Agriculture (Livestock)	Manure Management Systems	Y	Capacity building and institutional coordination	High	SDLD/ SDECC/ NEMA/ KALRO	NID, Database	Accuracy and Completeness	QA	Institutional coordination, Research, Funds ($ 300,000)	Y	2025	BTR2	Addressing	Enhance accuracy of MMS
	Lulucf	Forest Land	Y	Implementing an NFI to allow provision of site-specific (based on strata and substrata) emission factors and increasing the number of sample points for improved uncertainty	High	SDF/ KFS/ KEFRI	NID	TACCC, Inventory Arrangements	EF estimation	Funds (5,000,000 USD)	Y	Depends on availability of funds	Long-term	Pending	The NFI will avail data for estimating all carbon pools
	Lulucf		Y	Use of a systematic grid to enhance land cover mapping methodology and increase the number of samples that should be interpreted across the entire reporting period for Activity Data generation	High	SDF/ KFS/ DRSRS	NID	TACCC, Inventory Arrangements	AD generation	Funds (1,000,000 USD)	Y	Depends on availability of funds	Medium term	Pending	The mapping will improve accuracy of AD and availing time series data up to 1990
	Lulucf		Y	Performing recalculation backward for the entire country using the Sample Based Area Estimation methodology for the years 1990-2000	High	SDF/ KFS/ DRSRS	NID	TACCC, Inventory Arrangements	QA finding	Capacity building and funds	N	2025	Medium term	Pending	

No.	Sector	Category	Key Category (Y/N)	Description of Improvement	Priority (High, Medium, Low)	Responsible Party [Individual, Organization]	Impact to GHGI compilation elements (National Inventory Document (NID), CRT, Calculation File / Model / Database)	Primary type of Improvement (TACCC, Inventory Arrangements, Other)	Source of Improvement (MoECCF identified, QA Finding, etc.)	Describe succinctly any resource requirements or dependencies (i.e. Coordination with data agency, etc., funds ($$), etc.)	Improve ability to track mitigation measures (Y/N)	Start Date	Timing (i.e., include submission date if known or indicate medium-term (BTR2), long-term (BTR3))	Status (pending, addressing, complete)	Notes
	Lulucf		Y	Developing a system for data collection to allow for the estimation of the harvested wood products (post deforestation factors) because the use of instantaneous oxidation for all deforestation may exaggerate emissions.	High	SDF/KFS	NID, Database	TACCC, Inventory Arrangements	QC finding	Funds	Y	2025	Long-term	Pending	Will help better estimate emissions from HWPs
	Lulucf		Y	Developing a system for monitoring non-CO2 emissions e.g. CH4 from mangrove forests and biomass burning, and N2O from forest fires.	High	KEMFRI/ KFS/ SDF	NID, Database	TACCC, Inventory Arrangements	QAQC finding	Coordination with data agency and funding (800,000 USD)	Y	2025	Long-term	Pending	Having a system to track HWP will allow for estimation of HWP as a carbon pool
	Lulucf	Cropland	Y	Use of systematic grid to enhance land cover mapping methodology and increase the number of samples which should be interpreted across the entire reporting period for Activity Data generation and performing recalculation backwards for the entire country using the Sample Based Area Estimation methodology.	High	SDF/ KFS/ DRSRS	NID	TACCC, Inventory Arrangements	AD generation	Funds (1,000,000 USD)	Y	Depends on availability of funds	Medium term	Pending	
	Lulucf			Improving the emission factor for the different types of the perennial cropland category through collection of data on AGB, BGB and annual increment.	High		NID	TACCC, Inventory Arrangements	EF estimation	Funds (5,000,000 USD)	Y	Depends on availability of funds	Long-term	Pending	

No.	Sector	Category	Key Category (Y/N)	Description of Improvement	Priority (High, Medium, Low)	Responsible Party [Individual, Organization]	Impact to GHGI compilation elements (National Inventory Document (NID), CRT, Calculation File / Model / Database)	Primary type of Improvement (TACCC, Inventory Arrangements, Other)	Source of Improvement (MoECCF identified, QA Finding, etc.)	Describe succinctly any resource requirements or dependencies (i.e. Coordination with data agency, etc., funds ($$), etc.)	Improve ability to track mitigation measures (Y/N)	Start Date	Timing (i.e., include submission date if known or indicate medium-term (BTR2), long-term (BTR3))	Status (pending, addressing, complete)	Notes
	Lulucf	Grassland	Y	Use of systematic grid to enhance land cover mapping methodology and increase the number of samples which should be interpreted across the entire reporting period for Activity Data generation and performing recalculation backwards for the entire country using the Sample Based Area Estimation methodology.	High	SDF/ KFS / DRSRS	NID	TACCC, Inventory Arrangements	AD generation	Funds (1,000,000 USD)	Y	Depends on availability of funds	Medium term	Pending	
	Lulucf		Y	Improving country specific EF for Wooded grassland and open grassland through collection of data on AGB and BGB and annual increment.	High		NID	TACCC, Inventory Arrangements	EF estimation	Funds (5,000,000 USD)	Y	Depends on availability of funds	Long-term	Pending	
	Lulucf	Wetland	N	Use of systematic grid to enhance land cover mapping methodology and increase the number of samples which should be interpreted across the entire reporting period for Activity Data generation and performing recalculation backwards for the entire country using the Sample Based Area Estimation methodology.	High	SDF/ KFS/ DRSRS	NID	TACCC, Inventory Arrangements	EF estimation	Funds (1,000,000 USD)	Y	Depends on availability of funds	Medium term	Pending	

No.	Sector	Category	Key Category (Y/N)	Description of Improvement	Priority (High, Medium, Low)	Responsible Party [Individual, Organization]	Impact to GHGI compilation elements (National Inventory Document (NID), CRT, Calculation File / Model / Database)	Primary type of Improvement (TACCC, Inventory Arrangements, Other)	Source of Improvement (MoECCF identified, QA Finding, etc.)	Describe succinctly any resource requirements or dependencies (i.e. Coordination with data agency, etc., funds ($$), etc.)	Improve ability to track mitigation measures (Y/N)	Start Date	Timing (i.e., include submission date if known or indicate medium-term (BTR2), long-term (BTR3))	Status (pending, addressing, complete)	Notes
	Lulucf	Settlement	N	Use of systematic grid to enhance land cover mapping methodology and increase the number of samples which should be interpreted across the entire reporting period for Activity Data generation and performing recalculation backwards for the entire country using the Sample Based Area Estimation methodology.	High	SDF/KFS/ DRSRS	NID	TACCC, Inventory Arrangements	EF estimation	Funds (1,000,000 USD)	Y	Depends on availability of funds	Medium term	Pending	
	Lulucf		N	Data collection for determining emission factors for treed settlements.	High	SDF/KFS/ KEFRI	NID	TACCC, Inventory Arrangements	EF estimation	Funds (5,000,000 USD)	Y	Depends on availability of funds	Long-term	Pending	
	Lulucf	Other Land	N	Use of systematic grid to enhance land cover mapping methodology and increase the number of samples which should be interpreted across the entire reporting period for Activity Data generation and performing recalculation backwards for the entire country using the Sample Based Area Estimation methodology.	High	SDF/KFS/ DRSRS	NID	TACCC, Inventory Arrangements	AD generation	Funds (1,000,000 USD)	Y	Depends on availability of funds	Medium term	Pending	
	Waste	SWDs (Data collection arrangements)	Y	Establishment of waste management information systems that capture data across all sub-categories. Sharing of data between the county governments and the national governments	High	NEMA	CRT, NID,	Completeness	MoECCF	Equipment, Software, Personnel, Office spaces in each county, Financial resources	Y	January, 2025	BTR2	Pending	Important for estimation of GHGs in ALL sub-categories for completeness

No.	Sector	Category	Key Category (Y/N)	Description of Improvement	Priority (High, Medium, Low)	Responsible Party [Individual, Organization]	Impact to GHGI compilation elements (National Inventory Document (NID), CRT, Calculation File / Model / Database)	Primary type of Improvement (TACCC, Inventory Arrangements, Other)	Source of Improvement (MoECCF identified, QA Finding, etc.)	Describe succinctly any resource requirements or dependencies (i.e. Coordination with data agency, etc., funds ($$), etc.)	Improve ability to track mitigation measures (Y/N)	Start Date	Timing (i.e., include submission date if known or indicate medium-term (BTR2), long-term (BTR3))	Status (pending, addressing, complete)	Notes
		Wastewater Treatment & Discharge (Country specific EF)	N	Develop country specific factors where possible. There is also need for estimation of Weighted Emission Factors in Waste water	Medium	KIRDI, MoECCF	NID, CRT, Model, Database	Accuracy	MoECCF	Financial resources for training personnel	Y	January, 2026	BTR3	Pending	Important for reliable data of good quality and improved tracking of mitigation actions
	Waste	SWDs, Wastewater Treatment &. Discharge, Incineration & Open Burning of Waste, Biological Treatment of Waste (Capacity Building)	Y	Experts training on Splicing Techniques, Uncertainty Analysis,	High	MoECCF	NID, CRT, Model, Database	TACCC	MoECCF	Financial resources for training personnel	Y	January, 2025	BTR2	Pending	Capacity building will improve the quality of reporting under ETF.
	Waste	SWDs (Categorization of SWDs)	Y	Conduct rapid surveys on modes of Solid Waste and wastewater management in the country.	High	MoECCF, MoWSI, NEMA	NID, CRT, Model, Database	TACCC	MoWSI, NEMA	Financial resources for training personnel	Y	January, 2025	BTR2	Pending	Improves Accuracy of GHG estimation
	Waste	Cover all waste subcategories	Y	Get activity data for biological waste treatment and industrial waste (solid and wastewater)	Medium	NEMA, MoWSI	NID, CRT	TACCC	MoECCF	Financial resources for training personnel	Y	January, 2026	BTR3	Pending	It will ensure complete reporting of emissions from all sub categories of waste

No.	Sector	Category	Key Category (Y/N)	Description of Improvement	Priority (High, Medium, Low)	Responsible Party [Individual, Organization]	Impact to GHGI compilation elements (National Inventory Document (NID), CRT, Calculation File / Model / Database)	Primary type of Improvement (TACCC, Inventory Arrangements, Other)	Source of Improvement (MoECCF identified, QA Finding, etc.)	Describe succinctly any resource requirements or dependencies (i.e. Coordination with data agency, etc., funds ($$), etc.)	Improve ability to track mitigation measures (Y/N)	Start Date	Timing (i.e., include submission date if known or indicate medium-term (BTR2), long-term (BTR3))	Status (pending, addressing, complete)	Notes
	Ippu	Mineral Industry - Cement, Lime and Glass Production	Y	Capacity building for inventory experts and enhance competency. Establishment of relations with industries for data collection and/or institutionalize data collection. Awareness creation to industry on the importance of the GHG inventory process. The inadequate detailed data limits movement of the sector reporting under tier 2 and also venturing into other IPPU categories	High	KNBS, KAM, MITI, MoECCF, KIRDI	NID	TACCC, Inventory arrangements	QA/QC	Financial resources for training personnel	Y	January ,2025	BTR2	Pending	This will enhance data completeness, QC and QA. Capacity building and awareness will strengthen data collection.
	Ippu	Chemical Industry - Soda Ash Production	Y	Capacity building for inventory experts and enhance competency. Establishment of relations with industries for data collection and/or institutionalize data collection.	High	KNBS, KAM, MITI, MoECCF, KIRDI	NID	TACCC, Inventory arrangements	QA/QC	Financial resources for training personnel	Y	January 2025	BTR2	Pending	This will enhance data completeness, QA/QC, Capacity building and awareness will strengthen data collection.

Annex II: Tier 2 Approach-Modelling of Dairy Cattle

Dairy Cattle (Tier 2)

Dairy Cattle Population

Official data are available at the State Department of Livestock (SDL) on the total population of dairy cattle for each year from 1990 to 2022. Since 2012, the national total has been derived from the sum of dairy cattle populations reported by each county to the Ministry of Agriculture, Livestock, Fisheries and Irrigation, and is available by county. Prior to 2012, the data was collected through the administrative statistics system of the ministry and is available by province and county.

Allocating each county to a production system results in proportions of the total dairy cattle population in each system as shown in Figure 5.11. The figure shows a decrease in livestock population in the semi-intensive system between the early 2000's and 2009, followed by an increase. The decrease may be due to successive and prolonged droughts during these years. In 2020 it will be possible to cross-check the 2019 reported population data against the results of the 2019 census, to verify the trend since 2010.

The official data do not distinguish different sub-categories of dairy cattle, and only give the total dairy cattle population. The structure of dairy herds (i.e., the proportion of each animal sub-category) in each production system was estimated using data from a large-scale repeat survey conducted by the Tegemeo Institute in 2000, 2004, 2007, 2010 and 2014, supplemented by literature reports. Applying the estimated herd structure to the official dairy cattle population statistics gives a population of each sub-category of dairy cattle in each production system in each inventory year as shown in Table 5.13:

Table 1: Time Series for Head of Dairy Cattle Sub-Category Populations, 1995 - 2023

	Intensive					Semi-intensive					Extensive				
Year	Cows	Heifers	Adult males	Growing males	Calves	Cows	Heifers	Adult males	Growing males	Calves	Cows	Heifers	Adult males	Growing males	Calves
1995	402,698	180,101	34,282	98,666	220,423	630,009	394,025	155,611	193,088	471,115	133,435	83,454	72,454	54,105	132,011
1996	457,326	204,532	38,933	112,050	250,325	637,148	398,490	157,375	195,276	476,454	119,915	74,998	65,113	48,623	118,636
1997	422,974	189,169	36,008	103,633	231,522	631,645	395,049	155,513	193,693	472,591	126,213	78,937	68,533	51,177	124,866
1998	464,521	207,750	39,545	113,813	254,263	675,451	422,446	165,760	207,237	505,636	108,335	67,756	58,825	43,928	107,180
1999	462,094	206,665	39,339	113,218	252,935	672,275	420,460	164,445	206,372	503,527	110,521	69,123	60,012	44,814	109,342
2000	406,805	181,937	34,632	99,672	222,671	656,001	410,281	159,942	201,484	491,600	137,872	86,229	70,918	51,128	124,748
2001	471,047	210,669	50,464	112,504	251,339	629,124	393,472	152,889	193,332	471,710	154,357	96,539	75,332	52,320	127,657
2002	469,959	210,182	60,705	109,338	244,266	658,973	412,140	159,618	202,612	494,353	167,736	104,907	77,782	51,917	126,673
2003	497,672	222,577	75,273	112,703	251,783	635,789	397,640	153,497	195,588	477,215	212,562	132,942	93,780	59,995	146,384
2004	457,439	204,583	79,305	100,753	225,086	658,567	411,886	158,472	202,703	494,574	208,958	130,688	87,817	53,686	130,988
2005	456,282	204,066	68,218	102,861	229,797	657,903	411,471	160,984	199,852	487,619	210,093	131,398	69,363	55,104	134,449
2006	515,064	230,355	64,793	118,765	265,326	591,457	369,914	147,111	177,304	432,604	260,371	162,843	63,621	69,621	169,869
2007	485,779	217,257	49,660	114,498	255,793	644,271	402,945	162,829	190,579	464,995	249,269	155,900	40,517	67,866	165,588
2008	451,557	201,952	45,046	105,891	236,566	581,861	363,912	140,564	168,039	409,998	253,257	158,394	55,457	67,110	163,743
2009	451,732	202,031	43,954	105,395	235,458	517,165	323,450	119,304	145,817	355,778	290,815	181,884	80,475	74,898	182,745
2010	400,426	179,085	37,983	92,951	207,657	568,992	355,864	125,211	156,629	382,159	308,233	192,777	103,515	77,036	187,961
2011	434,417	194,287	46,821	103,726	231,729	676,584	423,154	131,506	181,603	443,094	314,412	196,642	90,159	78,920	192,556
2012	461,012	206,181	55,826	113,231	252,963	820,421	513,114	139,117	214,777	524,033	313,983	196,374	75,115	79,139	193,093
2013	488,216	218,348	65,822	123,357	275,585	906,399	566,887	131,985	231,486	564,801	346,839	216,923	67,006	87,772	214,156
2014	508,029	227,209	75,686	132,060	295,027	817,760	511,450	100,146	203,791	497,231	357,933	223,862	53,175	90,931	221,862
2015	516,842	231,150	76,999	134,350	300,145	810,386	506,838	99,243	201,954	492,747	329,123	205,843	48,895	83,611	204,004
2016	498,897	223,124	74,326	129,686	289,724	893,111	558,577	109,374	222,569	543,047	363,800	227,531	54,046	92,421	225,499
2017	526,508	235,473	78,439	136,863	305,758	898,336	561,845	110,014	223,872	546,224	358,981	224,517	53,331	91,197	222,512
2018	572,790	256,172	85,334	148,894	332,635	1,023,748	640,280	125,372	255,125	622,479	412,045	257,705	61,214	104,678	255,403
2019	618322	276,535	92,118	160,730	359,077	825,793	516,474	101,130	205,793	502,115	331,761	207,493	49,287	84,282	205,640
2020	719955	321,989	107,259	187,149	418,099	968,976	606,024	118,664	241,475	589,175	314,808	196,890	46,768	79,975	195,132
2021	634221	283,646	94,486	164,863	368,311	969,835	606,562	118,770	241,689	589,698	357,233	223,424	53,071	90,753	221,429
2022	673365	301,153	100,318	175,038	391,043	978,235	611,816	119,798	243,783	594,806	343,327	214,727	51,005	87,220	212,809
2023	687,273	307,373	102,390	178,653	399,119	970,995	607,287	118,912	241,979	590,403	355,325	222,230	52,787	90,268	220,245

Enteric fermentation dairy cattle Tier 2

a. Methodological issues

This section summarizes the methods and data used in the Tier 2 inventory to estimate dairy cattle enteric fermentation emissions. Supporting data is presented in the annexes. For detailed description of data sources and methods used in data compilation, analysis and calculation of emissions, see SDL (2023).

The T2 method is applied by using mainly country-specific parameters. Necessary data for T2 calculations are mainly gathered from the Statistics Unit of the Directorate of Livestock Production (DLP), Ministry of Agriculture and Livestock Development, and academic publications

b. Emissions model and inventory structure

Enteric fermentation emissions have been estimated using the IPCC Tier 2 model (IPCC 2006, Vol 4, Ch 10, Equations 10.3-10.16). These equations were used to estimate emissions from 15 categories of dairy cattle.

In Kenya's national livestock population statistics, dairy cattle are distinguished from beef cattle. During census activities and administrative statistics reporting, dairy cattle in Kenya are defined as cattle with some percentage of genetics from exotic dairy breeds. Common dairy cattle breeds include Friesian, Ayrshire, Jersey and Guernsey. The national livestock population data for dairy cattle include all sub-categories of dairy cattle of these breeds. In this inventory, 5 sub-categories are identified:

- Dairy cows: Dairy cows that have calved at least once;
- Heifers: Female cattle > 1 year old that have not calved;
- Adult males: Bulls and oxen > 3 years old;
- Growing males: Males > 1 year old and <3 years old;
- Male and female calves: Calves <1 year old.

Separate calculations were made for each dairy cattle sub-category in each of three production systems: intensive, semi-intensive and extensive. These production systems are based on three common feeding systems for dairy cattle in Kenya: zero-grazing (i.e. stall feeding only), a mix of stall feeding and grazing (referred to as 'semi-zero grazing'), and grazing only. The definition of each production system is as follows:

- **Intensive:** The population of dairy cattle in a county is defined as being in the intensive production system if zero-grazing is the most common feeding system used at household level
- **Semi-intensive:** Semi-intensive is indicated if semi-zero grazing is the most common feeding system; and
- **Extensive:** extensive is indicated if grazing only feeding systems are the most common feeding system in the county.

Each of Kenya's 47 counties was allocated to one of these production systems based on the estimated prevalence of different feeding systems implemented at the farm level. The allocation of each county to one of the three production systems is shown in ***Table 3***. This allocation was made based on a prior classification using expert judgement,[4] and additional expert judgement by county livestock officers and State Livestock Department staff collected as part of county livestock statistics validation exercises in 2019. The allocation of counties has not been revised for this inventory update. Each production system has cattle raised in each of the three main feeding systems. Surveys conducted in counties mostly in the semi-intensive production system estimated 19% zero-grazing, 31% semi-zero grazing and 50% grazing in 1998, and 18%, 42% and 40% respectively in 2008 (EADD 2010), and 27.8%, 32.5% and 39.8% respectively in 2014 (Njarui et al. 2016). The proportions of cattle in each feeding system from 2018 and 2021 was estimated using linear extrapolation of the trend in these data sources. In 2021 it is estimated that in the intensive system, 28 % of cattle were raised in zero-grazing systems, 51% in semi-zero grazing and 20% in grazing systems.

Thus, in total, the inventory is based on 15 dairy cattle categories (i.e., 5 cattle sub-categories and 3 production systems).

c. Dairy cattle population

Official data are available at the State Department of Livestock Development (SDLD) on the total population of dairy cattle for each year from 1995 to 2023. Prior to 2012, the data was collected through the administrative statistics system of the ministry and is available by province and county. Since 2012, the national total has been derived from the sum of dairy cattle populations reported by each county to the Ministry of Agriculture and Livestock Development, and is available by county. Table 17 shows the total national dairy cattle population for the time series 1995-2023. For 2018 and 2019, herd structure was estimated using linear extrapolation of the trend from 2015-2017. ***Table 5*** shows the estimated herd structure for the period 1995-2022.

4 FAO (2017) Options for low-emission development in the Kenya Dairy Sector. FAO, Rome.

Table 1.1: Table 17. Total national dairy cattle population 1995-2023

Year	Population	Year	Population	Year	Population	Year	Population	Year	Population	Year	Population
1995	3,255,479	**2000**	3,335,920	**2005**	3,579,461	**2010**	3,376,479	**2015**	4,242,132	**2020**	5,112,340
1996	3,355,192	**2001**	3,442,754	**2006**	3,639,018	**2011**	3,739,610	**2016**	4,505,733	**2021**	5,017,991
1997	3,281,522	**2002**	3,551,160	**2007**	3,667,746	**2012**	4,158,378	**2017**	4,573,871	**2022**	5,098,443
1998	3,442,446	**2003**	3,665,398	**2008**	3,403,346	**2013**	4,505,582	**2018**	5,153,875	**2023**	5,145,240
1999	3,435,141	**2004**	3,605,506	**2009**	3,310,898	**2014**	4,316,153	**2019**	4,536,551		

Allocating each county to a production system results in proportions of the total dairy cattle population in each system as shown in *Figure 2*. Applying the estimated herd structure to the official dairy cattle population statistics gives a population of each sub-category of dairy cattle in each production system in each inventory year as shown in *Table 6*.

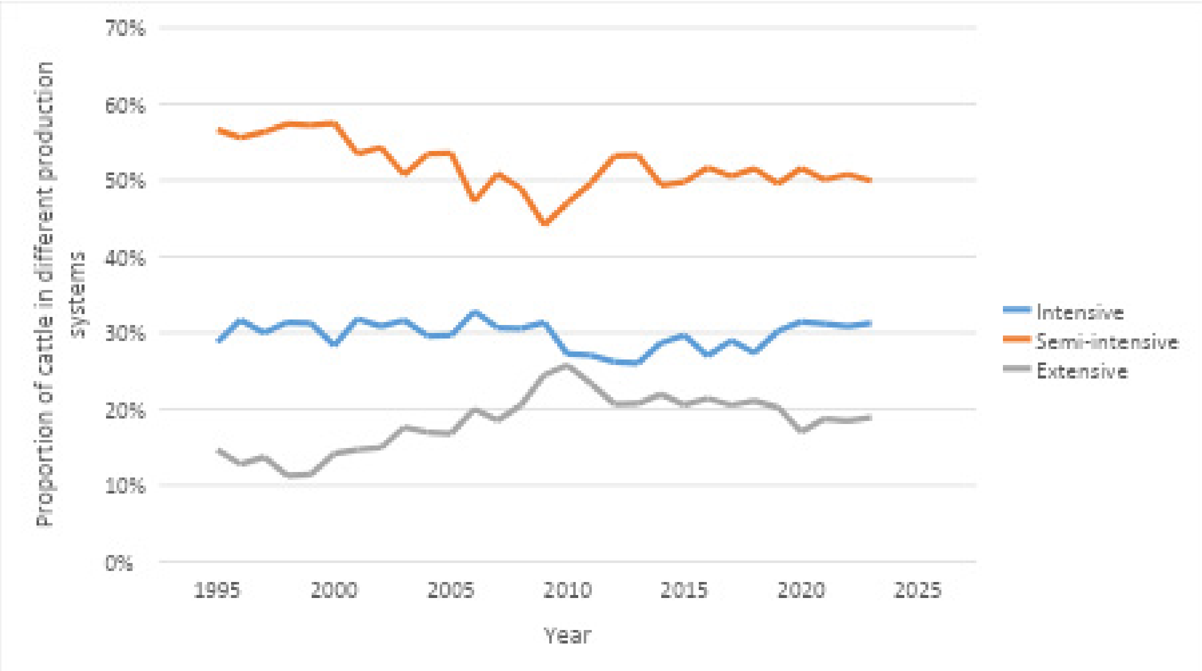


Table 2: Table 2. Time series for dairy cattle herd structure (% of total population in each production system)

	Intensive					Semi-intensive					Extensive				
	Cows	Heifers	Adult males	Growing males	Calves	Cows	Heifers	Adult males	Growing males	Calves	Cows	Heifers	Adult males	Growing males	Calves
1995	0.43	0.19	0.03	0.11	0.24	0.34	0.21	0.08	0.10	0.26	0.28	0.18	0.15	0.11	0.28
1996	0.43	0.19	0.03	0.11	0.24	0.34	0.21	0.08	0.10	0.26	0.28	0.18	0.15	0.11	0.28
1997	0.43	0.19	0.03	0.11	0.24	0.34	0.21	0.08	0.10	0.26	0.28	0.18	0.15	0.11	0.28
1998	0.43	0.19	0.03	0.11	0.24	0.34	0.21	0.08	0.10	0.26	0.28	0.18	0.15	0.11	0.28
1999	0.43	0.19	0.03	0.11	0.24	0.34	0.21	0.08	0.10	0.26	0.28	0.18	0.15	0.11	0.28
2000	0.43	0.19	0.04	0.11	0.24	0.34	0.21	0.08	0.10	0.26	0.29	0.18	0.15	0.11	0.26
2001	0.43	0.19	0.05	0.10	0.23	0.34	0.21	0.08	0.11	0.26	0.30	0.19	0.15	0.10	0.25
2002	0.43	0.19	0.06	0.10	0.22	0.34	0.21	0.08	0.11	0.26	0.32	0.20	0.15	0.10	0.24
2003	0.43	0.19	0.06	0.10	0.22	0.34	0.21	0.08	0.11	0.26	0.33	0.21	0.15	0.09	0.23
2004	0.43	0.19	0.07	0.09	0.21	0.34	0.21	0.08	0.11	0.26	0.34	0.21	0.14	0.09	0.21
2005	0.43	0.19	0.06	0.10	0.22	0.34	0.21	0.08	0.10	0.25	0.35	0.22	0.12	0.09	0.22
2006	0.43	0.19	0.05	0.10	0.22	0.34	0.22	0.09	0.10	0.25	0.36	0.22	0.09	0.10	0.23
2007	0.43	0.19	0.04	0.10	0.23	0.35	0.22	0.09	0.10	0.25	0.37	0.23	0.06	0.10	0.24
2008	0.43	0.19	0.04	0.10	0.23	0.35	0.22	0.08	0.10	0.25	0.36	0.23	0.08	0.10	0.23
2009	0.43	0.19	0.04	0.10	0.23	0.35	0.22	0.08	0.10	0.24	0.36	0.22	0.10	0.09	0.23
2010	0.44	0.20	0.04	0.10	0.23	0.36	0.22	0.08	0.10	0.24	0.35	0.22	0.12	0.09	0.22

	Intensive					Semi-intensive					Extensive				
	Cows	Heifers	Adult males	Growing males	Calves	Cows	Heifers	Adult males	Growing males	Calves	Cows	Heifers	Adult males	Growing males	Calves
2011	0.43	0.19	0.05	0.10	0.23	0.36	0.23	0.07	0.10	0.24	0.36	0.23	0.10	0.09	0.22
2012	0.42	0.19	0.05	0.10	0.23	0.37	0.23	0.06	0.10	0.24	0.37	0.23	0.09	0.09	0.23
2013	0.42	0.19	0.06	0.11	0.24	0.38	0.24	0.05	0.10	0.24	0.37	0.23	0.07	0.09	0.23
2014	0.41	0.18	0.06	0.11	0.24	0.38	0.24	0.05	0.10	0.23	0.38	0.24	0.06	0.10	0.23
2015	0.41	0.18	0.06	0.11	0.24	0.38	0.24	0.05	0.10	0.23	0.38	0.24	0.06	0.10	0.23
2016	0.41	0.18	0.06	0.11	0.24	0.38	0.24	0.05	0.10	0.23	0.38	0.24	0.06	0.10	0.23
2017	0.41	0.18	0.06	0.11	0.24	0.38	0.24	0.05	0.10	0.23	0.38	0.24	0.06	0.10	0.23
2018	0.41	0.18	0.06	0.11	0.24	0.38	0.24	0.05	0.10	0.23	0.38	0.24	0.06	0.10	0.23
2019	0.41	0.18	0.06	0.11	0.24	0.38	0.24	0.05	0.10	0.23	0.38	0.24	0.06	0.10	0.23
2020	0.41	0.18	0.06	0.11	0.24	0.38	0.24	0.05	0.10	0.23	0.38	0.24	0.06	0.10	0.23
2021	0.41	0.18	0.06	0.11	0.24	0.38	0.24	0.05	0.10	0.23	0.38	0.24	0.06	0.10	0.23
2022	0.41	0.18	0.06	0.11	0.24	0.38	0.24	0.05	0.10	0.23	0.38	0.24	0.06	0.10	0.23

d. Net energy for maintenance (NEm)

Net energy for maintenance (NE_m) was calculated following IPCC (2006) Equation 10.3:

$$NE_{m,j} = Cf_j * (Weight_j)^{0.75}$$

where:

$NE_{m,j}$ - is net energy for maintenance for dairy cattle of type ***j*** (MJ $head^{-1}$ day^{-1})

Cf_j - is coefficient for calculating NE_m for dairy cattle type ***j***

$Weight_j$ is the live weight of dairy cattle of type ***j*** (kg).

IPCC 2006 Table 10.4 gives default values for Cf_j for lactating cows (0.386), non-lactating cows (0.322) and bulls (0.37). IPCC 2006 Table 10.4 does not give specific guidance on choice of the coefficient for castrated males, so a Cf of 0.322 was used for oxen (i.e. adult castrated males) and heifers. For cows, the value of Cf was weighted by the proportion of lactating cows in the herd. Here, and elsewhere in the inventory, it was assumed that lactating cows lactate for 365 days.

For adult males, the value of Cf was weighted by the proportion of oxen and intact males in the population, and for calves the value of Cf was weighted by the proportion of female and male calves (see SDL 2019). ***Table 5*** shows the values of Cf used for different sub-categories.

Table 3: Coefficient for maintenance values for different cattle sub-categories, 2018 and 2019

	Cf	Notes
Cows	2018: XXXX 2019: XXXX	IPCC default (0.386 lactating, 0.322 dry), average weighted by proportion of lactating cows
Heifers	0.322	IPCC default value
Adult male - intensive system - semi-intensive and extensive	 0.368 0.346	IPCC default (0.37 bulls 0.322 oxen), average weighted by proportion of intact and castrated adult males (SDL 2019)
Growing male	0.370	IPCC default value
Calves - intensive system - semi-intensive and extensive	 0.340 0.344	IPCC default (0.37 intact males, 0.322 non-lactating females), average weighted by proportion of male and female calves (SDL 2019)

The 1995-2017 inventory report (SDL 2019) explains in detail the data sources and methods used. For 2018 and 2019, LW in each year was estimated using linear extrapolation of the trend. The time series for live weight of each sub-category of dairy cattle is shown in ***Table 6***. It should be noted that the average weights of cows in the intensive production system are significantly higher than the IPCC default weight for Africa (i.e. 275 kg), so we can expect that the resulting emission factors are higher than the Tier 1 IPCC default value for Africa. Also, the estimated live weights in the semi-intensive and extensive production systems are lower than those used in the IPCC default factor (see IPCC 2006 Table 10A.1), and therefore we can expect the resulting emission factors are lower than the Tier 1 IPCC default value for Africa.

Table 4: Live weight (kg) of dairy cattle sub-categories for 1995-2021

	Intensive system					Semi-intensive system					Extensive system				
	Cows	Heifers	Adult males	Growing males	Calves	Cows	Heifers	Adult males	Growing males	Calves	Cows	Heifers	Adult males	Growing males	Calves
1995	354.10	254.95	357.64	241.00	84.98	253.12	205.79	235.40	179.04	60.75	253.12	205.79	235.40	179.04	60.75
1996	354.95	255.56	357.64	241.00	85.19	253.39	206.01	235.65	179.22	60.81	253.39	206.01	235.65	179.22	60.81
1997	355.79	256.17	357.64	241.00	85.39	253.66	206.22	235.90	179.41	60.88	253.66	206.22	235.90	179.41	60.88
1998	356.63	256.78	357.64	241.00	85.59	253.92	206.44	236.15	179.60	60.94	253.92	206.44	236.15	179.60	60.94
1999	357.48	257.38	357.64	241.00	85.79	254.19	206.66	236.40	179.79	61.01	254.19	206.66	236.40	179.79	61.01
2000	358.32	257.99	357.64	241.00	86.00	254.46	206.88	236.65	179.98	61.07	254.46	206.88	236.65	179.98	61.07
2001	359.16	258.60	357.64	241.00	86.20	254.73	207.09	236.90	180.17	61.13	254.73	207.09	236.90	180.17	61.13
2002	360.01	259.21	357.64	241.00	86.40	255.00	207.31	237.15	180.36	61.20	255.00	207.31	237.15	180.36	61.20
2003	360.85	259.81	357.64	241.00	86.60	255.26	207.53	237.39	180.55	61.26	255.26	207.53	237.39	180.55	61.26
2004	361.70	260.42	357.64	241.00	86.81	255.53	207.75	237.64	180.74	61.33	255.53	207.75	237.64	180.74	61.33
2005	362.54	261.03	357.64	241.00	87.01	255.80	207.96	237.89	180.93	61.39	255.80	207.96	237.89	180.93	61.39
2006	363.38	261.64	357.64	241.00	87.21	256.07	208.18	238.14	181.12	61.46	256.07	208.18	238.14	181.12	61.46
2007	364.23	262.24	357.64	241.00	87.41	256.33	208.40	238.39	181.31	61.52	256.33	208.40	238.39	181.31	61.52
2008	365.07	262.85	357.64	241.00	87.62	256.60	208.62	238.64	181.50	61.58	256.60	208.62	238.64	181.50	61.58
2009	365.18	262.93	357.64	241.00	87.64	256.87	208.83	238.89	181.69	61.65	256.87	208.83	238.89	181.69	61.65
2010	365.28	263.00	357.64	241.00	87.67	257.14	209.05	239.14	181.88	61.71	257.14	209.05	239.14	181.88	61.71
2011	365.39	263.08	357.64	241.00	87.69	257.40	209.27	239.39	182.06	61.78	257.40	209.27	239.39	182.06	61.78
2012	365.49	263.15	357.64	241.00	87.72	257.67	209.49	239.63	182.25	61.84	257.67	209.49	239.63	182.25	61.84
2013	365.60	263.23	357.64	241.00	87.74	257.94	209.70	239.88	182.44	61.91	257.94	209.70	239.88	182.44	61.91
2014	365.70	263.31	357.64	241.00	87.77	258.21	209.92	240.13	182.63	61.97	258.21	209.92	240.13	182.63	61.97
2015	365.81	263.38	357.64	241.00	87.79	258.48	210.14	240.38	182.82	62.03	258.48	210.14	240.38	182.82	62.03
2016	365.91	263.46	357.64	241.00	87.82	258.74	210.36	240.63	183.01	62.10	258.74	210.36	240.63	183.01	62.10
2017	366.02	263.53	357.64	241.00	87.84	259.01	210.58	240.88	183.20	62.16	259.01	210.58	240.88	183.20	62.16
2018	366.12	263.61	357.64	241.00	87.87	259.28	210.79	241.13	183.39	62.23	259.28	210.79	241.13	183.39	62.23
2019	366.23	263.69	357.64	241.00	87.90	259.55	211.01	241.38	183.58	62.29	259.55	211.01	241.38	183.58	62.29
2020	366.34	263.76	357.64	241.00	87.92	259.81	211.23	241.63	183.77	62.36	259.81	211.23	241.63	183.77	62.36
2021	366.44	263.84	357.64	241.00	87.95	260.08	211.45	241.88	183.96	62.42	260.08	211.45	241.88	183.96	62.42
2022	366.48	263.91	357.64	241.00	87.96	260.90	211.62	241.74	184.88	62.52	260.56	211.72	241.84	183.98	6244

e. Net energy for activity (NEa)

NE_a was calculated using IPCC (2006) Equation 10.4:

$$NE_a = C_a \bullet NE_m$$

where

NE_a is net energy for animal activity, MJ day^{-1}

C_a is a coefficient corresponding to the animal's feeding situation MJ day^{-1} kg^{-1}

NE_m is net energy for maintenance for dairy cattle (MJ $head^{-1}$ day^{-1}) as determined above.

IPCC 2006 Table 10.5 gives default values for C_a for animals that are stall-fed (0.00), that graze pasture (0.17) and that graze large areas or hilly terrain (0.36). Dairy cattle in semi-zero and grazing only feeding systems in Kenya often do not travel long distances for grazing, as tethering in paddocks and by roadsides is common. To estimate appropriate values of C_a, the methods presented in NRC (2001) to estimate net energy for activity were used together with available data on grazing distances in Kenya (see SDL (2019) for detailed explanation and data used). The values for C_a used in this inventory are shown in ***Table 7***.

Table 5: Estimated coefficients for activity (Ca) used for 2018 and 2019

	Intensive			Semi-intensive and extensive		
	Distance grazed per day (km)	% of cattle grazing	C_a for each sub-category	Distance grazed per day (km)	% of cattle grazing	C_a for each sub-category
Cows	0.73	0.37	0.03	5.2	0.71	0.11
Heifers	0.71	0.42	0.03	5.2	0.71	0.12
Adult males	0.63	0.40	0.03	5.2	0.71	0.12
Growing males	0.86	0.43	0.03	5.2	0.71	0.10
Calves	0.76	0.36	0.02	0	0.00	0.00

f. Net energy for growth (NEg)

NE_g was calculated using IPCC (2006) Equation 10.6:

where

BW is average live weight (kg head^{-1});

C is a coefficient with a value of 0.8 for females, 1.0 for castrates and 1.2 for bulls;

MW is the mature live body weight of an adult animal in moderate body condition, kg

WG is the average daily weight gain of cattle in each sub-category, kg day^{-1}.

The inventory used the live weight values shown in Table 6 above. The data and methods used to estimate daily weight gain are explained in SDL (2019). The weight gain values used in 2018 and 2019 are shown in ***Table 8***.

Table 6: Average daily weight gain (kg) values used for different dairy cattle sub-categories

Animal categories	Intensive	Semi-intensive and extensive
Cows	0.017	0.03
Heifers	0.25	0.22
Adult males	0.14	0.03
Growing males	0.2	0.17
Calves	0.42	0.22

g. Net energy for lactation (NEl)

NE_l was calculated using IPCC (2006) Equation 10.8:

$$NE_l = Milk \times (1.47 + 0.40 \times Fat)$$

Where

NEl is net energy for lactation, MJ day^{-1}

Milk is amount of milk produced, kg of milk day^{-1}, and

Fat is the fat content of milk, % by weight.

In the IPCC model, milk yield is expressed in kg head^{-1} day^{-1} over 365 days. In the 1995-2017 inventory (SDL 2019), milk yield and its trend were estimated using literature reports on the average milk yields of Friesian, Ayrshire and other breeds and genotypes, and their proportions in the herd. To calculate net energy for lactation, the daily milk yields for lactating cows were multiplied by the proportion of cows lactating. For 2018 and 2019, milk yield was estimated using linear extrapolation of the trend in the 1995-2017 period. The resulting estimated average milk yields in each production system are shown in ***Table 9***. For milk fat content, a default value of 4% was used (IPCC 2006).

Table 7: Average milk yields for lactating cows in different production systems, 1995-2021 (kg head-1 day-1)

	Intensive	Semi-intensive	Extensive	Weighted average
1995	6.17	4.75	4.75	5.16
1996	6.21	4.76	4.76	5.22
1997	6.25	4.77	4.77	5.21
1998	6.29	4.78	4.78	5.25
1999	6.33	4.79	4.79	5.27
2000	6.37	4.80	4.80	5.25
2001	6.41	4.81	4.81	5.32
2002	6.45	4.82	4.82	5.32
2003	6.49	4.84	4.84	5.36
2004	6.53	4.85	4.85	5.34
2005	6.57	4.86	4.86	5.36
2006	6.60	4.87	4.87	5.44
2007	6.64	4.88	4.88	5.42
2008	6.68	4.89	4.89	5.44
2009	6.69	4.90	4.90	5.46
2010	6.69	4.91	4.91	5.40
2011	6.70	4.92	4.92	5.40
2012	6.70	4.94	4.94	5.40
2013	6.71	4.95	4.95	5.41
2014	6.71	4.96	4.96	5.46
2015	6.72	4.97	4.97	5.49
2016	6.72	4.98	4.98	5.45
2017	6.73	4.99	4.99	5.48
2018	6.73	5.00	5.00	5.49
2019	6.74	5.01	5.01	5.50
2020	6.74	5.02	5.02	5.51
2021	6.75	5.04	5.04	5.52
2022	6.80	5.08	5.08	5.62

h. Net energy for pregnancy (NEp)

NE_p was calculated using IPCC (2006) Equation 10.13:

$$NE_p = C_{pregnancy} \times NE_m$$

where

$C_{pregnancy}$ is a coefficient with a value of 0.1.

$C_{pregnancy}$ was applied to the proportion of cows giving birth in the year. The 1995-2017 inventory used various data sources and methods to estimate proportions of cows giving birth in the year (SDL 2019). For 2018 and 2019 the values were estimated using linear extrapolation of the trend in the previous years. The proportion of cows and heifers pregnant in the year are shown in ***Table 10***. For the semi-intensive and extensive systems, the estimated proportion of cows giving birth is lower than the IPCC default value of 67% for dairy cows in Africa (IPCC 2006, Table A10.1), but in the intensive system the estimated value is higher from 2003 onwards. For all other animal types, the coefficient was given a value of zero.

Table 8: Proportions of cows giving birth and heifers pregnant, 1995-2021

	Intensive system		Semi-intensive system		Extensive system	
	Cows	Heifers	Cows	Heifers	Cows	Heifers
1995	0.63	0.2	0.60	0.2	0.60	0.2
1996	0.64	0.2	0.60	0.2	0.60	0.2
1997	0.64	0.2	0.60	0.2	0.60	0.2
1998	0.65	0.2	0.60	0.2	0.60	0.2
1999	0.65	0.2	0.60	0.2	0.60	0.2
2000	0.66	0.2	0.60	0.2	0.60	0.2
2001	0.66	0.2	0.60	0.2	0.60	0.2
2002	0.67	0.2	0.60	0.2	0.60	0.2
2003	0.68	0.2	0.60	0.2	0.60	0.2
2004	0.68	0.2	0.61	0.2	0.61	0.2
2005	0.69	0.2	0.61	0.2	0.61	0.2
2006	0.69	0.2	0.61	0.2	0.61	0.2
2007	0.70	0.2	0.61	0.2	0.61	0.2
2008	0.70	0.2	0.61	0.2	0.61	0.2
2009	0.71	0.2	0.61	0.2	0.61	0.2
2010	0.71	0.2	0.61	0.2	0.61	0.2
2011	0.72	0.2	0.61	0.2	0.61	0.2
2012	0.73	0.2	0.61	0.2	0.61	0.2
2013	0.73	0.2	0.62	0.2	0.62	0.2
2014	0.74	0.2	0.62	0.2	0.62	0.2
2015	0.74	0.2	0.62	0.2	0.62	0.2
2016	0.75	0.2	0.62	0.2	0.62	0.2
2017	0.75	0.2	0.62	0.2	0.62	0.2
2018	0.76	0.2	0.62	0.2	0.62	0.2
2019	0.77	0.2	0.62	0.2	0.62	0.2
2020	0.77	0.2	0.62	0.2	0.62	0.2
2022	0.78	0.2	0.62	0.2	0.62	0.2

i. Net energy for work (NEwork)

NE_{work} was calculated using IPCC (2006) Equation 10.9:

$$NE_{work} = 0.10 \times NE_m \times Hours$$

where

NE_{work} is net energy for work, MJ day^{-1} and

Hours is the average number of hours of work per calendar day.

The source of data on hours is described in SDL (2019). It is assumed that only oxen do work. In the intensive system, a value of 0.003 hours is used and in the semi-intensive and extensive systems a value of 0.3 hours is used. This is lower than the IPCC default value for work hours for other cattle in Africa (IPCC 2006, Table 10A.2), reflecting that most work is done by non-dairy breeds in Kenya.

j. Digestible energy as a proportion of gross energy in feed

The 1995-2017 inventory estimated digestible energy of feed as a proportion of gross energy (DE%) using various data sources and methods (SDL 2019). For 2018 and 2019, the values of DE were estimated using linear extrapolation of the trend in previous years. The values for DE% used in the inventory are shown in *Table 11*. The estimated feed digestibility values for different dairy cattle sub-categories in different years range between 54.1% and 61.5%, whereas the IPCC default value for dairy cattle in Africa is 60% (IPCC 2006, Table 10A.1). The trend in estimated feed digestibility is mainly due to assumptions about the change in proportions of dairy cattle raised in different feeding systems (i.e. zero-grazing, semi-zero grazing and grazing only systems), whereby an increase in zero- or semi-zero grazing is associated with a decrease in average digestibility of the diet, which is partially offset by the increasing use of commercial concentrate over time. Details of the data, assumptions and methods used are given in SDL (2019).

Table 9: Time series for feed digestibility (%) for dairy cattle sub-categories in each production system (1995-2021)

	Intensive system					Semi-intensive system					Extensive system				
	Cows	Heifers	Adult males	Growing males	Calves	Cows	Heifers	Adult males	Growing males	Calves	Cows	Heifers	Adult males	Growing males	Calves
1995	59.52	57.48	57.96	54.12	57.88	60.85	60.21	60.21	60.21	60.21	60.85	60.21	60.21	60.21	60.21
1996	59.51	57.50	58.00	54.19	57.87	60.90	60.20	60.20	60.20	60.20	60.90	60.20	60.20	60.20	60.20
1997	59.51	57.52	58.03	54.26	57.86	60.95	60.20	60.20	60.20	60.20	60.95	60.20	60.20	60.20	60.20
1998	59.50	57.54	58.07	54.33	57.86	61.00	60.19	60.19	60.19	60.19	61.00	60.19	60.19	60.19	60.19
1999	59.50	57.56	58.11	54.40	57.85	61.06	60.18	60.18	60.18	60.18	61.06	60.18	60.18	60.18	60.18
2000	59.49	57.58	58.14	54.47	57.85	61.11	60.18	60.18	60.18	60.18	61.11	60.18	60.18	60.18	60.18
2001	59.49	57.60	58.18	54.54	57.84	61.16	60.17	60.17	60.17	60.17	61.16	60.17	60.17	60.17	60.17
2002	59.48	57.62	58.21	54.61	57.83	61.21	60.16	60.16	60.16	60.16	61.21	60.16	60.16	60.16	60.16
2003	59.47	57.64	58.25	54.67	57.83	61.27	60.15	60.15	60.15	60.15	61.27	60.15	60.15	60.15	60.15
2004	59.47	57.66	58.29	54.74	57.82	61.32	60.15	60.15	60.15	60.15	61.32	60.15	60.15	60.15	60.15
2005	59.46	57.69	58.32	54.81	57.82	61.37	60.14	60.14	60.14	60.14	61.37	60.14	60.14	60.14	60.14
2006	59.46	57.71	58.36	54.88	57.81	61.43	60.13	60.13	60.13	60.13	61.43	60.13	60.13	60.13	60.13
2007	59.45	57.73	58.39	54.95	57.81	61.48	60.13	60.13	60.13	60.13	61.48	60.13	60.13	60.13	60.13
2008	59.44	57.75	58.43	55.02	57.80	61.53	60.12	60.12	60.12	60.12	61.53	60.12	60.12	60.12	60.12
2009	59.44	57.77	58.46	55.09	57.79	61.53	60.07	60.07	60.07	60.07	61.53	60.07	60.07	60.07	60.07
2010	59.43	57.79	58.50	55.16	57.79	61.53	60.03	60.03	60.03	60.03	61.53	60.03	60.03	60.03	60.03
2011	59.43	57.81	58.54	55.23	57.78	61.52	59.98	59.98	59.98	59.98	61.52	59.98	59.98	59.98	59.98
2012	59.42	57.83	58.57	55.30	57.78	61.52	59.93	59.93	59.93	59.93	61.52	59.93	59.93	59.93	59.93
2013	59.42	57.85	58.61	55.37	57.77	61.52	59.89	59.89	59.89	59.89	61.52	59.89	59.89	59.89	59.89
2014	59.41	57.87	58.64	55.43	57.76	61.52	59.84	59.84	59.84	59.84	61.52	59.84	59.84	59.84	59.84
2015	59.40	57.90	58.68	55.50	57.76	61.51	59.79	59.79	59.79	59.79	61.51	59.79	59.79	59.79	59.79
2016	59.40	57.92	58.71	55.57	57.75	61.51	59.75	59.75	59.75	59.75	61.51	59.75	59.75	59.75	59.75
2017	59.39	57.94	58.75	55.64	57.75	61.51	59.70	59.70	59.70	59.70	61.51	59.70	59.70	59.70	59.70
2018	59.39	57.96	58.79	55.71	57.74	61.39	59.65	59.65	59.65	59.65	61.39	59.65	59.65	59.65	59.65
2019	59.38	57.93	58.80	55.66	57.71	61.36	59.61	59.61	59.61	59.61	61.36	59.61	59.61	59.61	59.61
2020	59.38	57.91	58.80	55.61	57.68	61.33	59.56	59.56	59.56	59.56	61.33	59.56	59.56	59.56	59.56
2021	59.37	57.89	58.81	55.56	57.65	61.30	59.51	59.51	59.51	59.51	61.30	59.51	59.51	59.51	59.51

Calculation of gross energy

Gross energy was calculated using IPCC (2006) equations 10.14-10.16. Gross energy for each sub-category is shown in ***Table 12***. The estimated gross energy was cross-checked against the implied dry matter intake (DMI) using IPCC equations 10.17 and 10.18. The estimated DMI was in the range of 2.3%-2.8% of body weight for most animal types and 3.1%-3.5% for calves. Except for calves, this is within the range of 2-3% of body weight recommended by the IPCC (2006). The higher ratio of estimated DMI to body weight for calves and other growing animals has been widely reported in the literature.

Calculation of emission factors

The emission factors were calculated using IPCC (2006) Equation 10.21. The value for the methane conversion factor used was the IPCC default value of 6.5%. The resulting emission factors and implied emission factors (i.e. population-weighted emission factors) for each year are shown in ***Table 13***. The implied emission factor increases over time, but is lower than the IPCC Tier 1 default value for dairy cattle in Africa (IPCC 2006, Table 10.11). This is because the Tier 1 default for dairy only includes the emission factor for lactating cows, while the implied emission factor includes all dairy cattle sub-categories. The emission factors range from 13.45 to 52.26 kg CH_4 head^{-1} year^{-1} dependant on sub-category, production system and year. The Tier 1 default for Other Cattle is 31 kg CH_4 head^{-1} year^{-1}, which is between the emission factors determined for the dairy cattle categories other than cows.

The IPCC Tier 1 default emission factor for cows (i.e. 46 kg CH_4 head^{-1} year^{-1}) was derived on the basis of assumed characteristics of a lactating dairy cow in Africa and the Middle East (annual milk yield 475 kg head^{-1} year^{-1}, see IPCC 2006, Table A10.1). The emission factors for dairy cows estimated in this inventory range between 51 and 74 kg CH_4 head^{-1} year^{-1}, which are all higher than the IPCC Tier 1 default emission factor. We have assumed an annual milk yield of between 1732 kg and 2458 kg head^{-1} year^{-1} dependant on the production system and year in the inventory. Further discussion on the differences between the defaults and calculated emission factors can be found in section 2.4.

Total emissions from dairy cattle from enteric fermentation in each year between 1990-2022 are given in Table 1.

Table 10: Time series for gross energy (MJ head-1 day-1) for dairy cattle sub-categories in each production system (1995-2021)

	Intensive system					Semi-intensive system					Extensive system				
	Cows	Heifers	Adult males	Growing males	Calves	Cows	Heifers	Adult males	Growing males	Calves	Cows	Heifers	Adult males	Growing males	Calves
1995	152.70	107.03	122.58	107.94	52.88	120.01	91.62	87.62	77.26	33.15	120.01	91.62	87.62	77.26	33.15
1996	153.72	107.09	122.46	107.68	52.97	120.06	91.69	87.70	77.32	33.18	120.06	91.69	87.70	77.32	33.18
1997	154.75	107.16	122.33	107.43	53.05	120.12	91.76	87.79	77.39	33.21	120.12	91.76	87.79	77.39	33.21
1998	155.78	107.22	122.20	107.17	53.14	120.17	91.83	87.87	77.46	33.23	120.22	91.83	87.87	77.46	33.23
1999	156.81	107.29	122.08	106.92	53.22	120.23	91.91	87.96	77.53	33.26	120.23	91.91	87.96	77.53	33.26
2000	157.86	107.35	121.95	106.67	53.31	120.28	91.98	88.04	77.60	33.29	120.28	91.98	88.04	77.60	33.29
2001	158.90	107.41	121.83	106.41	53.39	120.34	92.05	88.12	77.66	33.31	120.34	92.05	88.12	77.66	33.31
2002	159.96	107.48	121.70	106.16	53.48	120.39	92.12	88.21	77.73	33.34	120.39	92.12	88.21	77.73	33.34
2003	161.02	107.54	121.58	105.92	53.57	120.45	92.19	88.29	77.80	33.37	120.45	92.19	88.29	77.80	33.37
2004	162.08	107.61	121.46	105.67	53.65	120.50	92.27	88.37	77.87	33.39	120.50	92.27	88.37	77.87	33.39
2005	163.15	107.67	121.33	105.42	53.74	120.56	92.34	88.46	77.93	33.42	120.56	92.34	88.46	77.93	33.42
2006	164.23	107.73	121.21	105.18	53.82	120.61	92.41	88.54	78.00	33.45	120.61	92.41	88.54	78.00	33.45
2007	165.31	107.80	121.09	104.94	53.91	120.67	92.48	88.62	78.07	33.47	120.67	92.48	88.62	78.07	33.47
2008	166.40	107.86	120.96	104.69	53.99	120.72	92.55	88.71	78.14	33.50	120.72	92.55	88.71	78.14	33.50
2009	167.05	107.81	120.84	104.45	54.01	120.94	92.73	88.88	78.29	33.56	120.94	92.73	88.88	78.29	33.56
2010	167.71	107.75	120.72	104.21	54.03	121.16	92.92	89.06	78.44	33.63	121.16	92.92	89.06	78.44	33.63
2011	168.37	107.69	120.60	103.98	54.05	121.38	93.10	89.23	78.60	33.70	121.38	93.10	89.23	78.60	33.70
2012	169.03	107.64	120.48	103.74	54.07	121.60	93.28	89.41	78.75	33.76	121.60	93.28	89.41	78.75	33.76
2013	169.69	107.58	120.36	103.50	54.09	121.82	93.46	89.58	78.91	33.83	121.82	93.46	89.58	78.91	33.83
2014	170.35	107.53	120.23	103.27	54.11	122.04	93.65	89.76	79.06	33.89	122.04	93.65	89.76	79.06	33.89
2015	171.01	107.47	120.11	103.04	54.13	122.27	93.83	89.94	79.22	33.96	122.27	93.83	89.94	79.22	33.96
2016	171.68	107.41	119.99	102.80	54.15	122.49	94.01	90.11	79.37	34.03	122.49	94.01	90.11	79.37	34.03
2017	172.34	107.36	119.87	102.57	54.17	122.71	94.20	90.29	79.53	34.09	122.71	94.20	90.29	79.53	34.09
2018	173.01	107.30	119.75	102.34	54.19	123.28	94.38	90.47	79.69	34.16	123.28	94.38	90.47	79.69	34.16

	Intensive system					Semi-intensive system					Extensive system				
	Cows	Heifers	Adult males	Growing males	Calves	Cows	Heifers	Adult males	Growing males	Calves	Cows	Heifers	Adult males	Growing males	Calves
2019	173.67	107.40	119.72	102.51	54.26	123.60	94.57	90.65	79.84	34.23	123.60	94.57	90.65	79.84	34.23
2020	174.34	107.51	119.69	102.67	54.33	123.91	94.76	90.83	80.00	34.30	123.91	94.76	90.83	80.00	34.30
2021	175.01	107.61	119.66	102.84	54.40	124.22	94.94	91.01	80.16	34.36	124.22	94.94	91.01	80.16	34.36

Table 1.2: Time series for emission factors (kg CH4 head-1 year-1) for dairy cattle sub-categories in each production system (1995-2021)

	Intensive system					Semi-intensive system					Extensive system					Implied emission factor
	Cows	Heifers	Adult males	Growing males	Calves	Cows	Heifers	Adult males	Growing males	Calves	Cows	Heifers	Adult males	Growing males	Calves	
1995	65.10	45.63	52.26	46.02	22.54	51.16	39.06	37.35	32.94	14.13	51.16	39.06	37.35	32.94	14.13	39.51
1996	65.54	45.66	52.21	45.91	22.58	51.19	39.09	37.39	32.97	14.15	51.19	39.09	37.39	32.97	14.15	39.99
1997	65.97	45.68	52.15	45.80	22.62	51.21	39.12	37.43	32.99	14.16	51.21	39.12	37.43	32.99	14.16	39.82
1998	66.41	45.71	52.10	45.69	22.65	51.23	39.15	37.46	33.02	14.17	51.25	39.15	37.46	33.02	14.17	40.12
1999	66.85	45.74	52.05	45.58	22.69	51.26	39.18	37.50	33.05	14.18	51.26	39.18	37.50	33.05	14.18	40.18
2000	67.30	45.77	51.99	45.47	22.73	51.28	39.21	37.53	33.08	14.19	51.28	39.21	37.53	33.08	14.19	39.88
2001	67.74	45.79	51.94	45.37	22.76	51.30	39.24	37.57	33.11	14.20	51.30	39.24	37.57	33.11	14.20	40.56
2002	68.19	45.82	51.89	45.26	22.80	51.33	39.27	37.60	33.14	14.21	51.33	39.27	37.60	33.14	14.21	40.63
2003	68.65	45.85	51.83	45.15	22.84	51.35	39.30	37.64	33.17	14.22	51.35	39.30	37.64	33.17	14.22	40.97
2004	69.10	45.88	51.78	45.05	22.87	51.37	39.34	37.68	33.20	14.24	51.37	39.34	37.68	33.20	14.24	40.88
2005	69.56	45.90	51.73	44.94	22.91	51.40	39.37	37.71	33.23	14.25	51.40	39.37	37.71	33.23	14.25	40.93
2006	70.01	45.93	51.67	44.84	22.95	51.42	39.40	37.75	33.25	14.26	51.42	39.40	37.75	33.25	14.26	41.48
2007	70.48	45.96	51.62	44.74	22.98	51.44	39.43	37.78	33.28	14.27	51.44	39.43	37.78	33.28	14.27	41.19
2008	70.94	45.98	51.57	44.63	23.02	51.47	39.46	37.82	33.31	14.28	51.47	39.46	37.82	33.31	14.28	41.38
2009	71.22	45.96	51.52	44.53	23.03	51.56	39.54	37.89	33.38	14.31	51.56	39.54	37.89	33.38	14.31	41.72
2010	71.50	45.94	51.47	44.43	23.04	51.65	39.61	37.97	33.44	14.34	51.65	39.61	37.97	33.44	14.34	41.30
2011	71.78	45.91	51.41	44.33	23.04	51.75	39.69	38.04	33.51	14.37	51.75	39.69	38.04	33.51	14.37	41.35
2012	72.06	45.89	51.36	44.23	23.05	51.84	39.77	38.12	33.57	14.39	51.84	39.77	38.12	33.57	14.39	41.31
2013	72.34	45.86	51.31	44.13	23.06	51.94	39.85	38.19	33.64	14.42	51.94	39.85	38.19	33.64	14.42	41.37
2014	72.62	45.84	51.26	44.03	23.07	52.03	39.92	38.27	33.71	14.45	52.03	39.92	38.27	33.71	14.45	41.83
2015	72.91	45.82	51.21	43.93	23.08	52.13	40.00	38.34	33.77	14.48	52.13	40.00	38.34	33.77	14.48	42.05
2016	73.19	45.79	51.16	43.83	23.09	52.22	40.08	38.42	33.84	14.51	52.22	40.08	38.42	33.84	14.51	41.75
2017	73.47	45.77	51.10	43.73	23.10	52.31	40.16	38.49	33.91	14.54	52.31	40.16	38.49	33.91	14.54	41.98
2018	73.76	45.75	51.05	43.63	23.10	52.56	40.24	38.57	33.97	14.56	52.56	40.24	38.57	33.97	14.56	41.97
2019	74.04	45.79	51.04	43.70	23.13	52.69	40.32	38.65	34.04	14.59	52.69	40.32	38.65	34.04	14.59	42.91
2020	74.33	45.83	51.03	43.77	23.16	52.82	40.40	38.72	34.11	14.62	52.82	40.40	38.72	34.11	14.62	43.17
2021	74.61	45.88	51.01	43.84	23.19	52.96	40.48	38.80	34.17	14.65	52.96	40.48	38.80	34.17	14.65	42.79

k. Uncertainties and time-series consistency

The 1995-2017 inventory estimated that the uncertainty of 2017 total enteric fermentation emissions was (+14.68%, -12.92%) (SDL 2022). Uncertainty analysis was not repeated for this updated inventory, and the same uncertainty range is assumed.

Within each production system, consistent methods have been used to estimate the time series for enteric fermentation emissions.

l. Source-specific QA/QC and verification

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

- Checking that the equations programmed in the spreadsheet were correctly input
- Checking those inputs to summed totals were obtained from the correct fields
- Checking that all data sources were fully documented
- Checking that the figures in the inventory spreadsheet were correctly transcribed from prior worksheets
- Checking that the figures in the inventory report were correctly transcribed
- Reconstructing a number of the calculations to cross-check the intermediate calculations and results in the inventory spreadsheet.

Verification of the estimated emission factors was described in the 1995-2017 inventory (SDL 2022).

m. Source-specific recalculations of Enteric fermentation

Disaggregated dairy cattle population numbers along with the updated methane emission factors and live weights for each subcategory were incorporated into this inventory. Therefore, the recalculations for all the years were completed using the same methodology with Tier II approach. Similar for other livestock, recalculations were done in light of applications of the IPCC 2006 guidelines and emissions factors using the same methodology as compared to the previous inventory.

Table 11: Enteric fermentation CH4 Emissions

Year	Enteric Fermentation CH_4 Emissions		
	Population	EF (kg CH_4 hd^{-1} yr^{-1})	Gg CH_4 CO2 Equivalent
1995	3,255,468	39.51	3601.67
1996	3,355,181	39.99	3756.91
1997	3,281,542	39.82	3659.09
1998	3,442,423	40.12	3866.98
1999	3,435,120	40.18	3864.2
2000	3,335,902	39.88	3725.23
2001	3,442,732	40.56	3910.15
2002	3,551,137	40.63	4039.66
2003	3,665,375	40.97	4205.03
2004	3,605,486	40.88	4127
2005	3,579,440	40.93	4102.65
2006	3,638,996	41.48	4226.59
2007	3,667,724	41.19	4229.91
2008	3,403,321	41.38	3943.66
2009	3,310,877	41.72	3867.31
2010	3,386,594	41.3	3904.39
2011	3,739,604	41.35	4329.45
2012	4,158,353	41.31	4809.54
2013	4,505,582	41.37	5219.27
2014	4,316,152	41.83	5054.87
2015	4,242,108	42.05	4994.1
2016	4,505,731	41.75	5267.8
2017	4,573,848	41.98	5376.45
2018	5,153,875	41.97	6056.58
2019	4,536,551	42.91	5450.84
2020	5,112,340	43.17	6179.77

Year	Enteric Fermentation CH_4 Emissions Population	EF (kg CH_4 hd^{-1} yr^{-1})	Gg CH_4 CO2 Equivalent
2021	5,017,991	42.79	6011.82
2022	5,145,240	43.28	5920.26

Of 2.6 Source-specific improvements

For enteric fermentation emissions, priorities for improvements include:

- Cross-check and validate or adjust allocation of counties to production systems;
- Conduct representative sample surveys in extensive and semi-intensive production systems to collect more accurate estimates of activity data used in the Tier 2 enteric fermentation model; and
- Research to develop cost-effective methods for accurate representation of diet composition for different dairy cattle sub-categories and feeding systems.

In the longer-term, improving the accuracy of dairy cattle population and milk yield estimates collected by local governments is a priority. The State Department of Livestock plans to work with development partners to improve the administrative data collection system to achieve this longer-term objective.

Manure management, dairy cattle

The Tier2 approach provides a more detailed method for estimating methane emissions from manure management systems. There is detailed information on animal characteristics and the manner in which manure is managed. Using the additional information, emission factors specific to the conditions of the country are estimated and the default emission factors from Tier 1 were not used.

Table 12: Source category description

Emissions sources	Sources included	Method	Emission factors
	Dairy cattle manure management	T2	CS
Gases reported	CH_4, N_2O		
Completeness	All dairy cattle accounted for. No known omissions		
Improvements since last submission	This is the second inventory for dairy cattle that uses a Tier 2 approach. The focus has been on strengthening capacities for regular inventory compilation. No methodological improvements have been made.		

This category reports emissions of CH_4 and direct N_2O emissions from management of manure from dairy cattle. The literature for Kenya identifies and main types of manure management system (not including deposit of dung and urine on pasture, which is reported under managed soils):

- **Daily spread**: Manure is removed daily from where animals are kept and applied to fodder or food crops. This system is common for households with zero-grazing units.
- **Dry lot:** Dung is deposited on the hard surface where animals are kept and removed periodically.
- **Solid storage:** Manure is stored in heaps in the farmyard.
- **Deep bedding**: Manure is mixed with other organic material and left as bedding. The bedding is mostly removed only after several months. This is common in households with open boma (kraals)
- **Compost:** Manure and other organic material in bedding is composted.
- **Liquid slurry:** Some zero-grazing units have drainage systems feeding into slurry pits. In some households, manure is stored in pits, which often gets inundated with rainwater.

These manure management systems may be associated with different housing types (e.g. traditional or improved bomas and zero-grazing units), but this association is currently not well documented. Specific manure management practices have also not been documented in detail.

Methodological issues

a. Methane emissions from manure management

Methane is produced by the decomposition of manure under anaerobic conditions. When stored in liquid or slurry form, anaerobic decomposition is greater and more methane is released, and when stored as a solid less methane is stored. Therefore, the manure management system used affects methane emission rates. The emission factors for manure management are calculated using the IPCC Tier 2 methodology using IPCC (2006) Equation 10.23:

Where:

- EF_T is the emission factor for a specific cattle sub-category, T, kg CH_4 head^{-1} year^{-1}
- VS_T is daily volatile solids excreted by cattle sub-category, T, kg dry matter head^{-1} year^{-1}
- $B_{o,T}$ is the maximum methane producing capacity for manure produced by sub-category T, m^3 CH_4 per kg VS excreted
- 0.67 is the conversion factor of m^3 CH_4 to kg CH_4
- $MCF_{S,k}$ is the methane conversion factors for each manure management system, ***S***, by climate region, ***k***, %
- $MS_{T,S,k}$ is the fraction of manure from livestock sub-category T handled using manure management system ***S*** in climate region ***k***, dimensionless

The value of VS is estimated using IPCC (2006) Equation 10.24:

Where:

- GE is gross energy intake, MJ day^{-1}, as calculated in the enteric fermentation equations above
- DE% is digestibility of feed as used in the enteric fermentation equations above
- UE X GE is urinary energy expressed as a fraction of GE, assumed to be 0.04GE (IPCC 2006)
- ASH is the ash content of manure, assumed to be 0.08 (IPCC 2006)
- 18.45 is the conversion factor for dietary GE per kg dry matter (MJ kg^{-1}).

No country specific data were identified for B_o or MCF, so the IPCC default values for Africa (IPCC 2006, Table 10A-4) were used.[5] Country specific manure management system activity data ($MS_{T,S,k}$) were estimated using data and methods described in SDL (2019). For 2018 and 2019, values were estimated using linear extrapolation of the trend in previous years (see ***Table 17*** and ***Table 18***). The methane emission factors thus derived are shown in ***Table 19***. These were multiplied by population numbers of the relevant category in each year and the resulting time series for methane emissions from manure management is shown in ***Table 19***.

Table 13: Table 13. Weighted average MMS fractions in the intensive production system

Year	Pasture	daily spread	drylot	solid storage	composted	liquid slurry	biogas	Deep bedding
1995	24.46%	10.98%	4.27%	37.19%	9.04%	14.55%	0.00%	0.00%
1996	24.05%	11.04%	4.29%	37.37%	9.09%	14.63%	0.00%	0.00%
1997	23.65%	11.10%	4.32%	37.54%	9.13%	14.70%	0.00%	0.00%
1998	23.24%	11.16%	4.34%	37.72%	9.18%	14.78%	0.00%	0.00%
1999	22.83%	11.22%	4.36%	37.90%	9.23%	14.86%	0.00%	0.00%
2000	22.43%	11.28%	4.38%	38.07%	9.28%	14.94%	0.00%	0.00%
2001	22.04%	11.33%	4.41%	38.24%	9.33%	15.01%	0.00%	0.00%
2002	21.66%	11.39%	4.43%	38.41%	9.37%	15.09%	0.00%	0.00%
2003	21.27%	11.44%	4.45%	38.57%	9.42%	15.16%	0.00%	0.00%
2004	20.89%	11.50%	4.47%	38.74%	9.46%	15.24%	0.00%	0.00%
2005	20.45%	11.56%	4.50%	38.93%	9.52%	15.32%	0.00%	0.00%
2006	20.02%	11.63%	4.52%	39.12%	9.57%	15.40%	0.00%	0.00%
2007	19.59%	11.69%	4.54%	39.31%	9.62%	15.48%	0.00%	0.00%
2008	19.18%	11.75%	4.57%	39.49%	9.67%	15.56%	0.00%	0.00%
2009	18.77%	11.81%	4.59%	39.24%	9.72%	15.64%	0.42%	0.00%
2010	18.36%	11.87%	4.61%	39.00%	9.77%	15.72%	0.85%	0.00%
2011	17.98%	11.92%	4.64%	38.74%	9.81%	15.80%	1.27%	0.00%
2012	17.60%	11.98%	4.66%	38.48%	9.86%	15.87%	1.69%	0.00%

5 Note, however, that the IPCC default values are based on Safley (1992), which used limited data to estimate Bo values for developing countries. Further examination should consider whether the Bo values for Africa are the most applicable to Kenyan dairy production systems.

Year	Pasture	daily spread	drylot	solid storage	composted	liquid slurry	biogas	Deep bedding
2013	17.22%	12.03%	4.68%	38.22%	9.90%	15.94%	2.11%	0.00%
2014	16.84%	12.09%	4.70%	37.96%	9.95%	16.02%	2.54%	0.00%
2015	16.43%	12.15%	4.72%	37.72%	10.00%	16.09%	2.96%	0.00%
2016	16.02%	12.21%	4.75%	37.47%	10.05%	16.17%	3.38%	0.00%
2017	15.61%	12.27%	4.77%	37.22%	10.10%	16.25%	3.80%	0.00%
2018	15.20%	12.33%	4.79%	36.98%	10.14%	16.33%	4.23%	0.00%
2019	14.80%	12.39%	4.82%	37.15%	10.19%	16.41%	4.25%	0.00%
2020	14.39%	12.44%	4.84%	37.33%	10.24%	16.49%	4.27%	0.00%
2021	13.98%	12.50%	4.86%	37.51%	10.29%	16.57%	4.29%	0.00%

Table 14: Weighted average MMS fractions in the semi-intensive and extensive production systems

Year	Pasture	daily spread	drylot	solid storage	composted	liquid slurry	biogas	Deep bedding
1995	56.04%	2.30%	0.69%	21.75%	3.24%	8.34%	0.00%	7.64%
1996	55.91%	2.28%	0.68%	21.95%	3.26%	8.42%	0.00%	7.50%
1997	55.78%	2.27%	0.68%	22.14%	3.28%	8.50%	0.00%	7.35%
1998	55.64%	2.26%	0.68%	22.34%	3.30%	8.57%	0.00%	7.21%
1999	55.51%	2.25%	0.67%	22.53%	3.32%	8.65%	0.00%	7.06%
2000	55.37%	2.24%	0.67%	22.73%	3.35%	8.73%	0.00%	6.92%
2001	55.24%	2.22%	0.66%	22.92%	3.37%	8.80%	0.00%	6.78%
2002	55.11%	2.21%	0.66%	23.12%	3.39%	8.88%	0.00%	6.63%
2003	54.97%	2.20%	0.66%	23.32%	3.41%	8.96%	0.00%	6.49%
2004	54.84%	2.19%	0.65%	23.51%	3.43%	9.03%	0.00%	6.34%
2005	54.70%	2.18%	0.65%	23.71%	3.45%	9.11%	0.00%	6.20%
2006	54.57%	2.17%	0.65%	23.91%	3.47%	9.19%	0.00%	6.06%
2007	54.43%	2.15%	0.64%	24.10%	3.49%	9.27%	0.00%	5.91%
2008	54.28%	2.14%	0.64%	24.31%	3.51%	9.35%	0.00%	5.77%
2009	53.33%	2.34%	0.70%	24.51%	3.67%	9.49%	0.20%	5.77%
2010	52.38%	2.53%	0.76%	24.71%	3.82%	9.64%	0.39%	5.77%
2011	51.43%	2.72%	0.81%	24.92%	3.98%	9.79%	0.58%	5.77%
2012	50.47%	2.92%	0.87%	25.12%	4.14%	9.94%	0.78%	5.76%
2013	49.52%	3.11%	0.93%	25.33%	4.29%	10.09%	0.97%	5.76%
2014	48.57%	3.30%	0.99%	25.54%	4.45%	10.24%	1.16%	5.76%
2015	47.64%	3.50%	1.05%	25.73%	4.60%	10.38%	1.35%	5.76%
2016	46.71%	3.69%	1.10%	25.93%	4.76%	10.53%	1.54%	5.75%
2017	45.77%	3.88%	1.16%	26.12%	4.91%	10.67%	1.73%	5.74%
2018	44.84%	4.08%	1.22%	26.31%	5.07%	10.82%	1.93%	5.74%
2019	43.91%	4.27%	1.28%	26.20%	5.22%	10.96%	2.42%	5.73%
2020	42.98%	4.47%	1.33%	26.48%	5.38%	11.10%	2.53%	5.73%
2021	42.05%	4.66%	1.39%	26.75%	5.53%	11.25%	2.64%	5.72%

Table 1.3: Manure management methane emission factors (kg CH4 head-1 year-1) and Methane Emissions (Gg CH4) for dairy cattle sub-categories in each production system (1995-2021)

	Intensive system					Semi-intensive system					Extensive system					Implied EF	Methane Emissions
	Cows	Heifers	Adult males	Growing males	Calves	Cows	Heifers	Adult males	Growing males	Calves	Cows	Heifers	Adult males	Growing males	Calves		Gg CH4
1995	6.76	5.02	5.35	4.85	2.45	3.31	2.45	2.35	2.07	0.89	3.88	2.87	2.74	2.42	1.04	3.16	10.29
1996	6.84	5.04	5.37	4.86	2.47	3.33	2.47	2.36	2.08	0.89	3.91	2.89	2.76	2.44	1.05	3.26	10.95
1997	6.91	5.06	5.38	4.87	2.48	3.35	2.49	2.38	2.10	0.90	3.94	2.91	2.79	2.46	1.05	3.24	10.63
1998	6.98	5.08	5.40	4.88	2.49	3.37	2.51	2.40	2.11	0.91	3.96	2.93	2.81	2.47	1.06	3.30	11.35
1999	7.06	5.10	5.42	4.88	2.51	3.39	2.53	2.42	2.13	0.91	3.99	2.96	2.83	2.49	1.07	4.12	11.40
2000	7.13	5.11	5.43	4.89	2.52	3.41	2.54	2.43	2.15	0.92	4.01	2.98	2.85	2.51	1.08	4.06	10.90
2001	7.20	5.13	5.45	4.90	2.53	3.44	2.56	2.45	2.16	0.93	4.04	3.00	2.87	2.53	1.09	4.22	11.74
2002	7.28	5.15	5.46	4.91	2.55	3.46	2.58	2.47	2.18	0.93	4.07	3.02	2.89	2.55	1.09	4.22	12.13
2003	7.36	5.17	5.48	4.92	2.56	3.48	2.60	2.49	2.19	0.94	4.09	3.04	2.91	2.57	1.10	4.29	12.79
2004	7.43	5.19	5.50	4.93	2.57	3.50	2.61	2.50	2.21	0.95	4.12	3.07	2.94	2.59	1.11	4.25	12.47
2005	7.51	5.21	5.51	4.94	2.59	3.52	2.63	2.52	2.22	0.95	4.14	3.09	2.96	2.61	1.12	4.28	12.46
2006	7.59	5.23	5.53	4.94	2.60	3.54	2.65	2.54	2.24	0.96	4.17	3.11	2.98	2.63	1.13	4.45	13.16
2007	7.67	5.25	5.54	4.95	2.61	3.56	2.67	2.56	2.25	0.97	4.20	3.13	3.00	2.64	1.13	4.39	13.06
2008	7.75	5.26	5.56	4.96	2.63	3.58	2.69	2.58	2.27	0.97	4.22	3.15	3.02	2.66	1.14	4.43	12.26
2009	7.79	5.26	5.56	4.95	2.63	3.61	2.72	2.61	2.29	0.98	4.26	3.19	3.06	2.70	1.16	4.50	12.19
2010	7.83	5.26	5.56	4.95	2.64	3.65	2.75	2.63	2.32	1.00	4.31	3.24	3.10	2.73	1.17	4.38	12.12
2011	7.87	5.26	5.56	4.94	2.64	3.68	2.78	2.66	2.35	1.01	4.35	3.28	3.14	2.77	1.19	4.39	13.45
2012	7.91	5.26	5.56	4.94	2.64	3.71	2.81	2.69	2.37	1.02	4.39	3.32	3.18	2.80	1.20	4.38	14.89
2013	7.95	5.26	5.56	4.94	2.65	3.74	2.84	2.73	2.40	1.03	4.43	3.36	3.22	2.83	1.22	4.40	16.22
2014	7.99	5.26	5.57	4.93	2.65	3.78	2.87	2.76	2.43	1.04	4.48	3.40	3.26	2.87	1.23	4.54	16.02
2015	8.03	5.26	5.57	4.93	2.65	3.81	2.91	2.79	2.45	1.05	4.52	3.44	3.30	2.90	1.25	4.60	15.96
2016	8.07	5.26	5.57	4.92	2.66	3.84	2.94	2.82	2.48	1.06	4.56	3.48	3.34	2.94	1.26	4.54	16.72
2017	8.11	5.26	5.57	4.92	2.66	3.88	2.97	2.85	2.51	1.08	4.61	3.52	3.38	2.98	1.28	4.60	17.22
2018	8.15	5.25	5.57	4.91	2.66	3.90	3.00	2.88	2.54	1.09	4.64	3.57	3.42	3.01	1.29		
2019	8.21	5.28	5.59	4.95	2.68	3.94	3.04	2.91	2.57	1.10	4.69	3.61	3.46	3.05	1.31		
2020	8.27	5.31	5.61	4.99	2.69	3.98	3.08	2.95	2.60	1.11	4.74	3.66	3.51	3.09	1.32		
2021	8.33	5.33	5.64	5.03	2.71	4.02	3.11	2.98	2.63	1.13	4.79	3.70	3.55	3.13	1.34		

b. Direct N_2O emissions from manure management

Manure also releases nitrous oxide with different rates for different manure management systems. This section only covers the nitrous oxide released during the storage and treatment of manure before it is applied to the land or used elsewhere. Therefore, this section does not include the nitrous emissions from manure deposited directly to pasture. Instead, this is accounted for in Section 5. Emission factors for direct N_2O emissions were calculated using the IPCC Tier 2 approach by applying IPCC (2006) Equation 10.25:

Where:

- $N_2O_{D(mm)}$ is direct N_2O emissions from manure management, kg N_2O year^{-1}
- N_T is number of head of cattle sub-category T
- Nex_T is average nitrogen excretion per head of sub-category T, kg N head^{-1} year^{-1}
- $MS_{T,S}$ is fraction of total annual nitrogen excretion for sub-category T that is managed in manure management system ***S***, dimensionless
- EF_{3S} is emission factor for direct N_2O emissions from manure management system ***S***, kg N_2O-N/kg N
- 44/28 is the conversion of N_2O-N emissions to N_2O emissions.

N excretion was estimated as the balance of N intake and N retention calculated using IPCC (2006) Equations 10.31-10.33. The data sources and values used for crude protein content of the diet (CP%) are described in SDL (2019). For 2018 and 2019, the values were estimated using linear extrapolation of the trend in previous years (see *Table 20* and *Table 21*). Default values for milk protein content (milk PR%) were used (3.5% taken from IPCC 2006, page 10.60). Other values used in these calculations (i.e., GE, milk, WG, NEg) were the values used in the calculation of methane emissions from enteric fermentation.

Table 1.4: Time series for feed crude protein content for dairy cattle sub-categories in the intensive system (1995-2021)

	Cow	Heifer	Adult male	Growing male	Calf
1995	11.16	10.51	10.57	10.51	10.48
1996	11.15	10.52	10.58	10.51	10.49
1997	11.15	10.53	10.59	10.51	10.49
1998	11.15	10.53	10.60	10.51	10.50
1999	11.15	10.54	10.61	10.52	10.50
2000	11.15	10.55	10.62	10.52	10.51
2001	11.15	10.56	10.63	10.52	10.51
2002	11.15	10.57	10.64	10.52	10.51
2003	11.15	10.58	10.65	10.52	10.52
2004	11.15	10.59	10.65	10.52	10.52
2005	11.15	10.60	10.66	10.52	10.53
2006	11.15	10.61	10.67	10.52	10.53
2007	11.15	10.61	10.68	10.52	10.54
2008	11.15	10.62	10.69	10.52	10.54
2009	11.15	10.63	10.70	10.52	10.55
2010	11.15	10.64	10.71	10.52	10.55
2011	11.15	10.65	10.72	10.52	10.56
2012	11.15	10.66	10.73	10.53	10.56
2013	11.15	10.67	10.73	10.53	10.57
2014	11.15	10.68	10.74	10.53	10.57
2015	11.15	10.69	10.75	10.53	10.58
2016	11.15	10.69	10.76	10.53	10.58
2017	11.15	10.70	10.77	10.53	10.59
2018	11.15	10.71	10.78	10.53	10.59
2019	11.15	10.71	10.78	10.52	10.59
2020	11.15	10.70	10.78	10.52	10.58
2021	11.15	10.70	10.78	10.51	10.58
2021	11.15	10.70	10.78	10.51	11.58

Table 15: Time series for feed crude protein content for dairy cattle sub-categories in the semi-intensive and extensive systems (1995-2021)

	Cow	Heifer	Adult male	Growing male	Calf
1995	11.75	11.59	11.59	11.59	11.59
1996	11.77	11.59	11.59	11.59	11.59
1997	11.79	11.59	11.59	11.59	11.59
1998	11.80	11.59	11.59	11.59	11.59
1999	11.82	11.59	11.59	11.59	11.59
2000	11.84	11.59	11.59	11.59	11.59
2001	11.86	11.58	11.58	11.58	11.58
2002	11.87	11.58	11.58	11.58	11.58
2003	11.89	11.58	11.58	11.58	11.58
2004	11.91	11.58	11.58	11.58	11.58
2005	11.92	11.58	11.58	11.58	11.58
2006	11.94	11.58	11.58	11.58	11.58
2007	11.96	11.58	11.58	11.58	11.58
2008	11.98	11.58	11.58	11.58	11.58
2009	11.97	11.56	11.56	11.56	11.56
2010	11.97	11.55	11.55	11.55	11.55
2011	11.96	11.53	11.53	11.53	11.53
2012	11.96	11.51	11.51	11.51	11.51
2013	11.96	11.50	11.50	11.50	11.50
2014	11.95	11.48	11.48	11.48	11.48
2015	11.95	11.47	11.47	11.47	11.47
2016	11.95	11.45	11.45	11.45	11.45
2017	11.94	11.43	11.43	11.43	11.43
2018	11.94	11.42	11.42	11.42	11.42
2019	11.93	11.40	11.40	11.40	11.40
2020	11.93	11.38	11.38	11.38	11.38
2021	11.93	11.37	11.37	11.37	11.37
2022	11.93	11.38	11.40	11.39	11.40
2023	11.93	11.40	11.42	11.41	11.39

Manure management system activity data are the same as those used to estimate methane manure management emissions. The emission factors, EF_3, used were the IPCC default emission factors from 10.21 (***Table 22***). The resulting time series for direct N_2O emissions is shown in ***Table 23***.

Table 16: Emission factors (EF3) used in estimating direct N2O emissions from manure management

Manure management system	EF_3 [kg N_2O-N (kg Nitrogen excreted)-1]	Source
Daily spread	0	IPCC 2006 Table 10.21
Solid storage (e.g. heap)	0.005	IPCC 2006 Table 10.21
Dry lot (e.g. periodic removal from confinement area)	0.02	IPCC 2006 Table 10.21
Composted (static pile)	0.006	IPCC 2006 Table 10.21
Liquid (e.g. pit)	0.005	IPCC 2006 Table 10.21
Biogas	0	IPCC 2006 Table 10.21
Deep bedding	0.01	IPCC 2006 Table 10.21

Table 17: Direct N2O emissions from manure management from dairy cattle, Gg N20 (CO2 Equivalent), 1995-2022

Year	Gg N_20 -CO_2Eq	Year	Gg N_20 -CO_2Eq	Year	Gg N_20 -CO_2Eq	Year	Gg N_20 -CO_2Eq	Year	Gg N_20 -CO_2Eq
1995	114.92	2001	129.08	2007	141.84	2013	172.51	2019	206.22
1996	121.8	2002	133.15	2008	132.6	2014	170.06	2020	232.78
1997	118.02	2003	140.21	2009	131.8	2015	169.57	2021	227.9
1998	125.62	2004	136.44	2010	130.77	2016	177.61	2022	218.37
1999	125.85	2005	135.94	2011	144.5	2017	198.59		
2000	120.11	2006	143.4	2012	159.13	2018	223.33		

Uncertainties and time-series consistency

SDL (2019) estimated that the uncertainty of 2017 total methane emissions from manure management was (+24.39%, -20.65%), and for direct nitrous oxide emissions it was (+27.78% -23.48%).

Uncertainty analysis was not repeated for this updated inventory and the same uncertainty values are assumed.

Source-specific QA/QC and verification

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

- Checking that the equations programmed in the spreadsheet were correctly input
- Checking that inputs to summed totals were obtained from the correct fields
- Checking that all data sources were fully documented
- Checking that the figures in the inventory report were correctly transcribed
- Reconstructing a number of the calculations to cross-check the intermediate calculations and results in the inventory spreadsheet.

For verification, the estimated emission factors were compared with IPCC default values and emission factors used in other countries' national GHG inventories.

Source-specific recalculations

No recalculation was done.

Source-specific improvements

For manure management, the priority is to improve the availability of representative data on manure management systems that are collected using classifications and methods in line with the IPCC categories.

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