REPUBLIC OF RWANDA

NATIONAL GREENHOUSE GAS INVENTORY

Report to the United Nation Framework Convention on Climate Change (UNFCCC)

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National greenhouse gas inventory (2006-2018)

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List of acronyms

AD	Activity Data
AfDB	African Development Bank
AFOLU	Agriculture, Forestry and Land Use
ANP	Akagera National Park
BAU	Business As Usual
BNR	National Bank of Rwanda
BOD	Biochemical Oxygen Demand
Btu	British Thermal Unit
BUR	Biennial Update Report
CH_4	Methane gas
CIP	Crop Intensification Program
CO_2	Carbon dioxide
CO_2eq	Carbon dioxide Equivalent
EDCL	Energy Development Corporation Limited
EF	Emission factor
EICV	Integrated Household Living Conditions Survey
EUCL	Energy Utility Corporation Limited
GDP	Gross Domestic Product
GEF	Global Environment Facility
Gg	Gigagram
GHG	Greenhouse gas
GIZ	Deutsche Gesellschaft für Internationale Zusammenarbeit
GoR	Government of Rwanda
GWP	Global warming potential
HFC	Hydrofluorocarbons
HFO	Heavy Fuels Oil
ICT	Information and Communication Technology
IEA	International Energy Agency
IPCC	Intergovernmental Panel on Climate Change
IPPU	Industrial Processes and Product Use
KCC	Kigali City Council
LD	Latest data
LIP	Livestock Intensification Program
MAC	Mobile air-conditioning
MCF	Methane Correction Factor
MINAGRI	Ministry of Agriculture and Animal Resources

MINICOM	Ministry of Trade and Industry
MININFRA	Ministry of Infrastructure
MSW	Municipal Solid Waste
N_2O	Nitrous Oxide
NAMA	Nationally Appropriate Mitigation Action(s)
NATCOM	National Communication Report
NISR	National Institute of Statistics of Rwanda
NST	National Strategy of Transformation
ODS	Ozone depleting substances
ODU	Oxidized During Use
PCA	Project Coordination Agreement
PD	Previous data
PSTA	Strategic Plan for Agriculture Transformation
QA/QC	Quality Assurance/Quality Control
RAB	Rwanda Agriculture and Animal Resources Development Board
RAC	Refrigeration and air-conditioning
RCMRD	Regional Centre for Mapping of Resources for Development
RDB	Rwanda Development Board
REMA	Rwanda Environment Management Authority
RFA	Rwanda Forest Authority
RoR	Republic of Rwanda
RRA	Rwanda Revenue Authority
RURA	Rwanda Utility Regulatory Agency
SAR	Second Assessment Report
SNC	Second National Communication to the UNFCCC
SWDS	Solid Waste Disposal Sites
TNC	Third National Communication to the UNFCCC
UNEP	United Nations Environment Programme
UNFCCC	United Nations Framework Convention on Climate Change
VNP	Volcano National Park
WAVES	Wealth Accounting and Valuation of Ecosystem Services

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Executive summary

ES 1 Basic information on the National GHG Inventory

As part of fulfilling the obligations of non-Annex I Parties to the UNFCCC, Rwanda has submitted its Initial, Second, and Third National Communication and is preparing its initial Biennial Update Report (BUR1). One of the major parts of the Biennial Update Report (BUR) is the updated greenhouse gas inventory, which reports on the updates in methodology and other improvements that happened after the last inventory. The inventory presented in the TNC covered a period from 2006 to 2015 and due to a lack of some activity data, some estimates were done based on interpolation and extrapolation of the available data. In addition, most source categories were not considered and/or reported elsewhere due to the lack of disaggregated data.

In this inventory, recalculations of the GHG emissions by sources and removals by the sink were conducted to update the Greenhouse Gas emissions inventory submitted in TNC and the period 2016 through 2018 was added to increase the coverage of the inventory, which is 2006-2018. The reported GHG emissions and removals estimates were calculated using the 2006 IPCC guidelines through the latest IPCC software (version 2.691). The sectoral activity data were gathered from various sector reports, the official national statistics from National Institute of Statistics of Rwanda and from recent surveys conducted by REMA to fill the data gaps reported in the previous national inventory. All the data appearing in these official documents were further crosschecked with relevant institutions working in their respective sectors. Specific and relevant data were also obtained from research work published locally and in international journals as well as annual and technical reports from the different research institutions. In this inventory, an effort was made to use Tier 2 in various categories of the Agriculture, Forest, and Land Use (AFOLU) and Waste sectors whereas a combination of the Tier 1 methodology with country-specific data was used in Energy and Industrial Process and Product Use (IPPU) sectors. Estimates of direct greenhouse gases, i.e., CO_2, CH_4, and N_2O were estimated in all four sectors (i.e., Energy, IPPU, AFOLU, and Waste) and reported.

ES 2 Summary of aggregated GHG emission and removals by sector

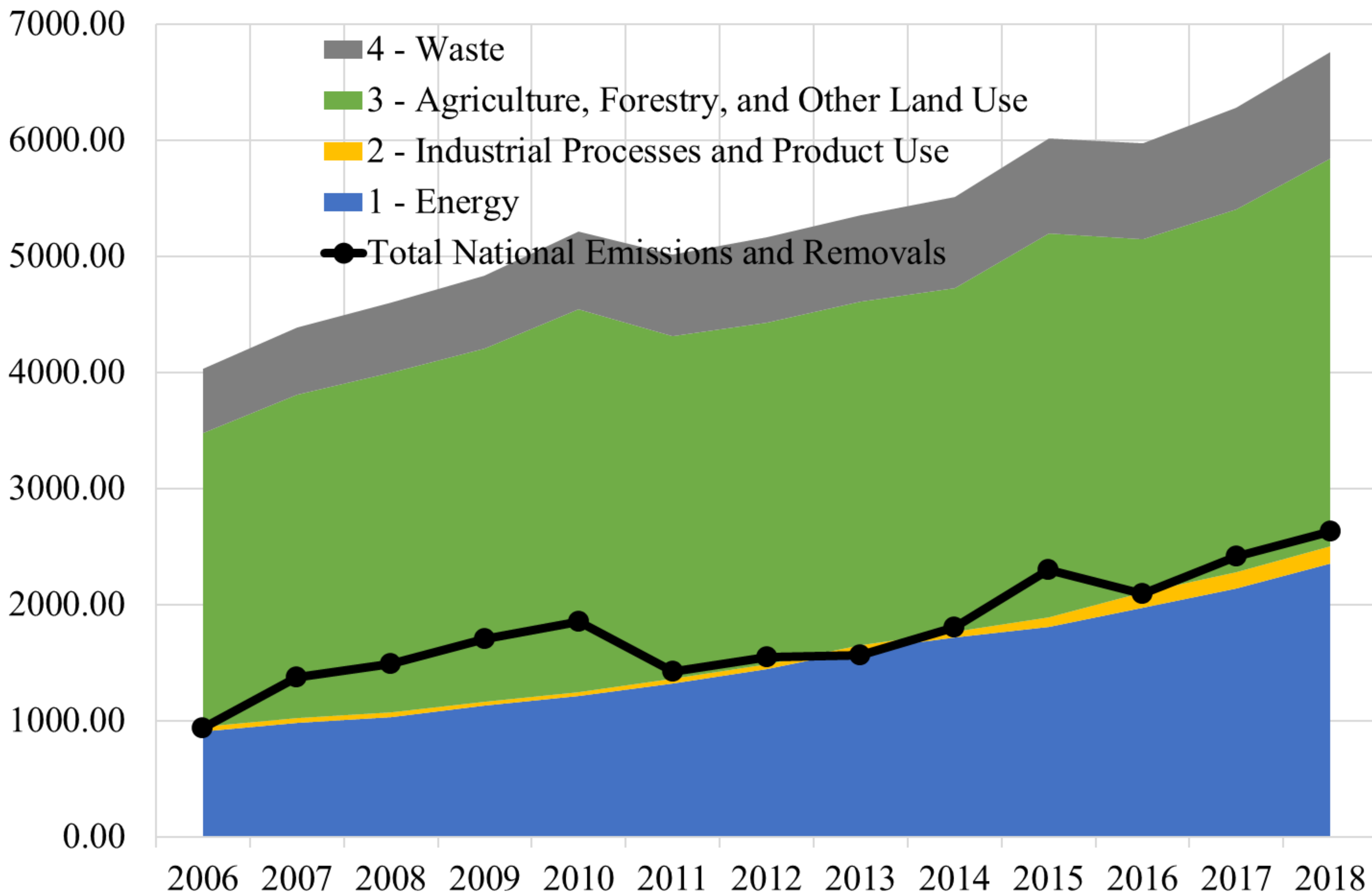
The aggregated GHG emission by sources and removals by the sink are summarized in **ES Table 1**. As evidenced in the table, GHG emissions by sources dominated over the removals by the sink, resulting in total net emissions in the whole period. It is interesting to note that in the previous inventory reported in the Third National Communication (TNC), GHG emissions from FOLU had a dominant contribution to net emissions, resulting in net carbon sequestration. This difference in GHG emissions and removals are the results of improvement in GHG emission calculation methodology and the discovery of new data sets, especially in Agriculture and Land use subcategories, which are the dominant contributor to total GHG emissions and removals.

The shares and trends in GHG emissions excluding Forests and Land Use (FOLU) are presented in **ES Figure 1**. Over the period 2006 through 2018, the GHG emissions excluding FOLU had a steady increase with peaks in 2010, 2015 and 2018. The latter peaks, which stem from the livestock category, are related to high populations of cattle in these years. It is clear from the figure that the livestock category was the main sources of the GHG emissions followed by the transportation category while the IPPU sector had the least contribution. **ES Figure 2** shows the shares and trends of GHG emissions and removals from FOLU. Clearly, the GHG removals from forests dominated over the GHG emissions from land use resulting into total net sink. However, as aforementioned, the removals were offsets by the total emissions. The GHG removals had a consistently increasing trend over the whole period 2006-2018, while the emissions from the land use activities showed a steady trend.

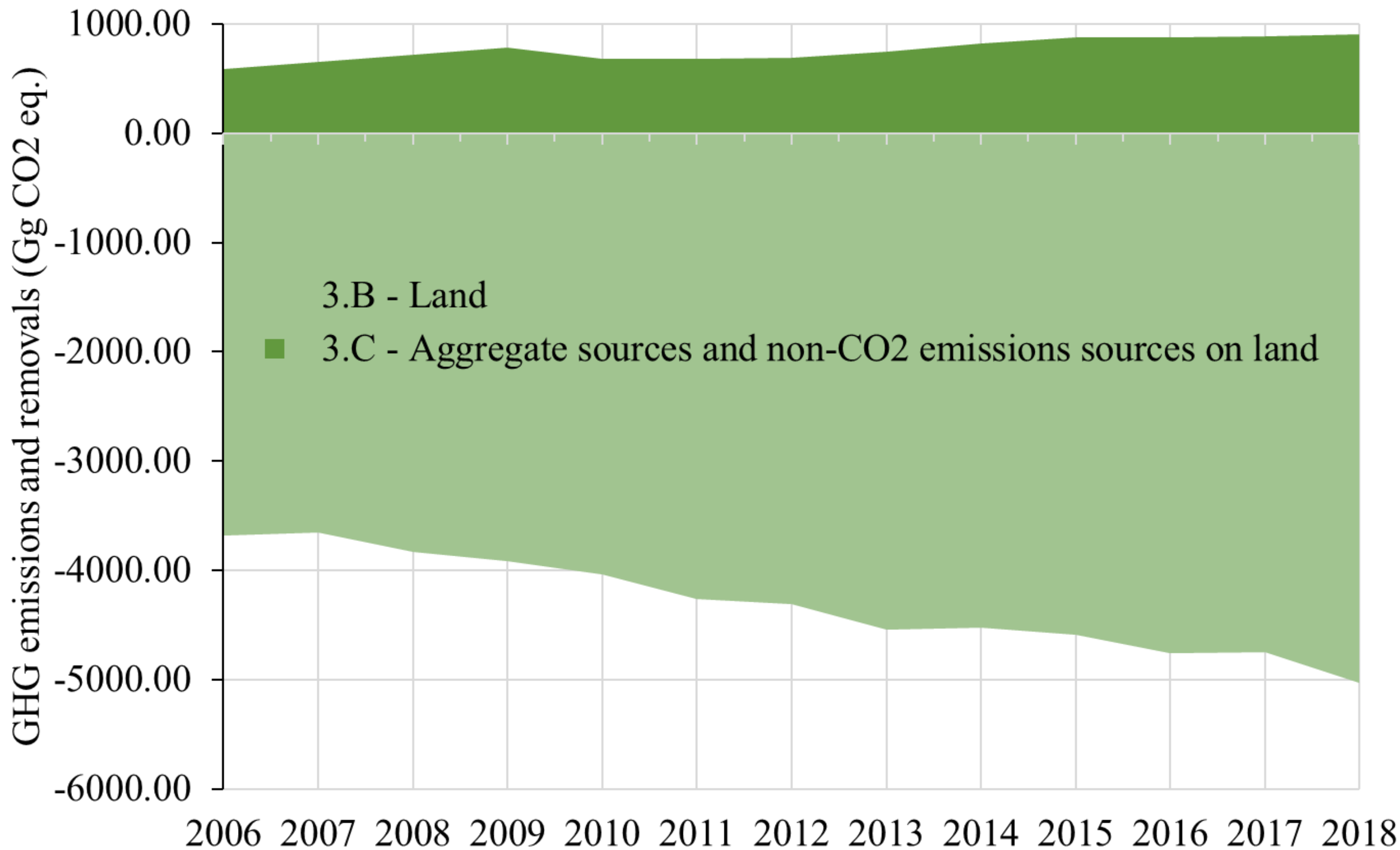
ES Table 1 GHG Emissions and Accompanying Variables (Gg CO_2 eq.)

Categories	2006	2015	2016	2017	2018
Total National Emissions and Removals	**981.71**	**1,820.75**	**1,532.64**	**2,278.77**	**2,630.11**
1 - Energy	909.21	1,808.31	1,977.31	2,136.51	2,354.85
1.A - Fuel Combustion Activities	909.21	1,808.31	1,977.31	2,136.51	2,354.85
1.B - Fugitive emissions from fuels	NO	NO	NO	NO	NO
1.C - Carbon dioxide Transport and Storage	NO	NO	NO	NO	NO
2 - Industrial Processes and Product Use	40.26	81.68	125.26	147.09	151.41
2.A - Mineral Industry	38.88	69.11	109.85	131.73	134.90
2.B - Chemical Industry	NO	NO	NO	NO	NO
2.C - Metal Industry	0.00	1.52	1.58	2.84	3.77
2.D - Non-Energy Products from Fuels and Solvent Use	0.96	3.88	5.67	3.40	3.17
2.E - Electronics Industry	NO	NO	NO	NO	NO
2.F - Product Uses as Substitutes for Ozone Depleting Substances	0.42	7.18	8.16	9.12	9.57
2.G - Other Product Manufacture and Use	NO	NO	NO	NO	NO
2.H - Other	NO	NO	NO	NO	NO
3 - Agriculture, Forestry, and Other Land Use	-522.92	-428.55	-849.58	-706.30	-793.30
3.A - Livestock	2,529.90	3,306.32	3,047.22	3,123.92	3,332.27
3.B - Land	-3,688.61	-4,665.20	-4,821.48	-4,779.09	-5,092.36
3.C - Aggregate sources and non-CO_2 emissions sources on land	635.78	934.26	928.69	952.99	966.79
3.D - Other	NE	NE	NE	NE	NE
4 - Waste	555.16	817.33	825.55	872.58	917.16
4.A - Solid Waste Disposal	175.36	351.18	376.58	413.02	446.39
4.B - Biological Treatment of Solid Waste	140.02	159.64	135.10	138.33	141.61
4.C - Incineration and Open Burning of Waste	15.31	19.08	19.73	20.20	20.69
4.D - Wastewater Treatment and Discharge	224.48	287.43	294.15	301.02	308.46
4.E - Other (please specify)	NO	NO	NO	NO	NO
5 - Other	NO	NO	NO	NO	NO

NO: Not Occurring, NE: Not Estimated



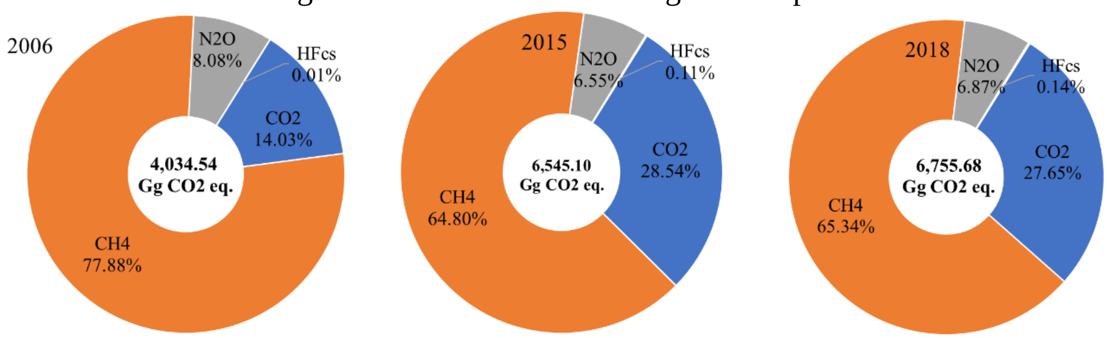
ES Figure 1 Shares and trends in GHG emissions excluding FOLU (2006-2018)



ES Figure 2 Shares and trends of GHG emissions and removals in FOLU (2006-2018)

ES 3 GHG emissions and removals per gas

The direct GHG (i.e., CO_2, CH_4, N_2O, and HFCs) were mainly considered in this inventory, and indirect gases such as carbon monoxide (CO) and Nitrogen oxide (NO_X) were estimated in AFOLU sector. **ES Figure 3** shows the shares of the direct GHG emissions excluding FOLU in 2006, 2015 and 2018 are presented in. It is clear from the figure that the CH_4 gas had the highest share in both years followed by the CO_2 and N_2O gases whereas The HFCs gases had a negligible share. Most of the CH_4 and N_2O were mainly generated from the AFOLU activities and to a lesser extent by the waste and energy sectors while most CO_2 emissions were generated by the energy sector. The GHG removal from forests contributed to the reduction of GHG emissions. However, the GHG emissions remained higher than the removals throughout the period 2006-2018.



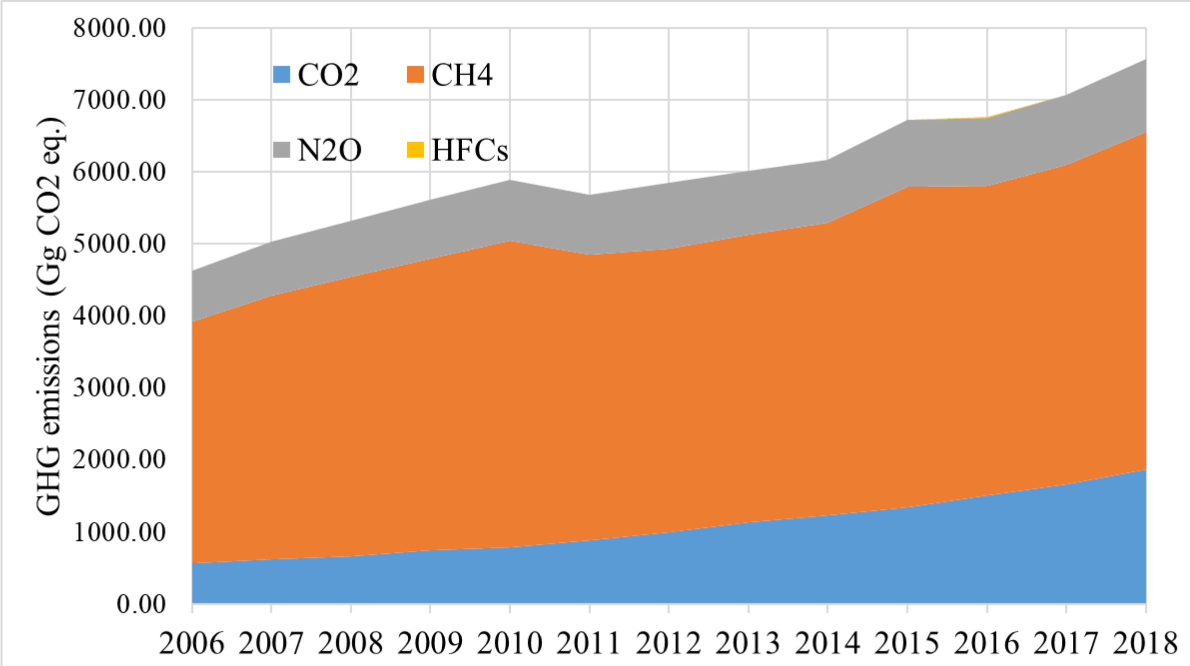
ES Figure 3 Shares of greenhouse gases to total GHG emissions excluding FOLU in 2006 and 2018

The summary of total GHG emissions and removals for the period 2006-2018 are shown in **ES Table 2**. As evidenced from the table, during the whole period, CH_4 emissions had a dominant contribution to total GHG emissions followed by the CO_2 removals, whereas the HFCs emissions had a negligible contribution. High CH_4 emissions were mainly generated by AFOLU and waste sectors while the nitrous oxides (N_2O) were mainly generated by biomass consumption in the energy sector. All the greenhouse gases showed a steadily increasing trend over the whole period 2006-2018.

ES Table 2 Summary of GHG emissions and removals by gas in 2018, Gg CO_2 eq.

	CO_2	CH_4	N_2O	HFcs	SF_6	Total
Total National Emissions and Removals	-3,146.89	4,726.60	1,046.12	9.57	NA	2,635.40
1 - Energy	1,722.94	455.00	176.90	NA	NA	2,354.85
1.A - Fuel Combustion Activities	1,722.94	455.00	176.90	NA	NA	2,354.85
1.B - Fugitive emissions from fuels	NO	NO	NO	NA	NA	NO
1.C - Carbon dioxide Transport and Storage	NO	NO	NO	NA	NA	NO
2 - Industrial Processes and Product Use	141.84	NA	NA	9.57	NA	151.41
2.A - Mineral Industry	134.90	NA	NA	NA	NA	134.90
2.B - Chemical Industry	NO	NO	NO	NA	NA	NO
2.C - Metal Industry	3.77	NA	NA	NA	NA	3.77
2.D - Non-Energy Products from Fuels and Solvent Use	3.17	NA	NA	NA	NA	3.17
2.E - Electronics Industry	NA	NA	NA	NO	NA	NO
2.F - Product Uses as Substitutes for Ozone Depleting Substances	NA	NA	NA	9.57	NA	9.57
2.G - Other Product Manufacture and Use	NA	NA	NA	NO	NA	NO
3 - Agriculture, Forestry, and Other Land Use	-5,014.72	3,590.11	636.60	NA	NA	-788.01
3.A - Livestock	NA	3,277.66	54.61	NA	NA	3,332.27
3.B - Land	-5,030.39	NA	0.18	NA	NA	-5,030.22
3.C - Aggregate sources and non-CO_2 emissions sources on land	15.68	312.44	581.82	NA	NA	909.94
3.D - Other	NE	NA	NA	NA	NA	NA
4 - Waste	3.04	681.49	232.62	NA	NA	917.16
4.A - Solid Waste Disposal	NA	446.39	NA	NA	NA	446.39
4.B - Biological Treatment of Solid Waste	0.00	75.10	66.52	NA	NA	141.61
4.C - Incineration and Open Burning of Waste	3.04	14.80	2.85	NA	NA	20.69
4.D - Wastewater Treatment and Discharge	NA	145.21	163.25	NA	NA	308.46
4.E - Other (please specify)	NO	NO	NO	NA	NA	NO
International Bunkers	131.89	0.02	1.14	NA	NA	133.06
1.A.5.c - Multilateral Operations	NO	NO	NO	NA	NA	NO

NO: Not occurring, NE: Not Estimated, NA: Not Applicable



ES Figure 4 Trends in GHG emissions by gas (2006-2018)

ES 4 Recalculations

Due to improvement in the methodology and data quality and the discovery of new datasets in various sectors, a recalculation of the latest GHG emissions and removals published in the Third National Communication (TNC) was conducted for the period 2006-2015. The recalculations were also motivated by the correction of the mistakes discovered in the previous inventory data for some categories.

ES Table 3 Results of the National Inventory recalculations

Period	Previous data	Latest data	Difference (%)
2006	-5,933.19	939.34	-115.83
2007	-5,556.22	1,378.95	-124.82
2008	-5,260.04	1,490.85	-128.34
2009	-4,957.49	1,705.90	-134.41
2010	-4,632.26	1,857.71	-140.10
2011	-4,460.63	1,426.20	-131.97
2012	-4,536.70	1,544.52	-134.04
2013	-4,357.87	1,561.51	-135.83
2014	-4,330.53	1,805.14	-141.68
2015	-3,769.09	2,299.73	-161.02

ES Table 3 shows the summary of the GHG emissions/Removals recalculation results. The recalculations were mainly conducted in Energy, AFOLU, and Waste, and no recalculations were conducted in IPPU. The latter led to higher GHG emissions in the AFOLU sector as compared to the previous inventory. GHG emissions and the socioeconomic development.

ES 5 GHG emissions and socioeconomic development

The dynamic of the GHG emissions is generally linked to the socioeconomic development and it is necessary to understand the linkage between these two variables at national level. ES Table 4 shows the summary of the Rwanda's GHG emissions and the socioeconomic parameters (i.e., population and GDP). The GHG intensity (i.e., the amount of GHG emitted per unit of GDP per capita) shows a relative stable level since 2006. The per capita GHG emissions intensity increased from 2.82 Gg CO2 eq. in 2006 to 3.34 Gg CO2 eq. 2018. This steady trend could be explained by the rapid increase in Rwanda economy. However, the increase in GHG emissions was more than double of the population growth, resulting in rapid increase in GHG emissions per capita. The per capita GHG emissions increased from 104.2 kg to 217.41 kg. The rapid increase in GHG emissions could be explained by the increase in livestock populations and the use of indigenous fuels (methane gas considered as natural gas in this inventory and the peat) in electricity generation mix and the use of coal in cement industries.

ES Table 4 GHG emissions and socioeconomic development

	2006	2009	2012	2015	2018
Total emissions (Gg CO_2 eq.)	938.87	1,734.04	1,538.56	2,291.99	2,628.38
Change with respect to 2006 (%)	0.00	45.86	38.98	59.04	64.28
GHG emissions excluding FOLU (Gg CO_2 eq.)	4,623.49	5,769.61	5,848.26	6,728.96	7,575.52
Change with respect to 2006 (%)	0.00	19.86	20.94	31.29	38.97
Total removal (Gg CO_2 eq.)	-5,413.16	-5,994.25	-6,280.84	-6,660.67	-7,089.67
Change with respect to 2006 (%)	0.00	9.69	13.81	18.73	23.65
Total fuel consumption (TJ)	85,610.52	96,177.77	115,017.28	136,404.69	172,952.51
Change with respect to 2006 (%)	0.00	10.99	25.57	37.24	50.50
GDP per capita (USD)	333.00	547.00	689.00	720.00	787.00
Change with respect to 2006 (%)	0.00	39.12	51.67	53.75	57.69
GHG emissions intensity per capita (Gg/USD/capita)	2.82	3.17	2.23	3.18	3.34
Change with respect to 2006 (%)	0.00	11.06	-26.26	11.43	15.58
Energy sector GHG emissions	909.21	1,129.35	1,448.62	1,808.31	2,354.85
Energy GHG Emission per fuel (Ton/TJ)	10.62	11.74	12.59	13.26	13.62
Change with respect to 2006 (%)	0.00	9.56	15.68	19.89	22.00
Population (Million)	9.01	9.73	10.48	11.26	12.09
Change with respect to 2006 (%)	0.00	7.41	14.07	19.76	19.76
GHG emissions per capita (kg per capita)	104.23	178.24	146.77	203.51	217.41
Change with respect to 2006 (%)	0.00	41.52	28.98	48.78	18.01

ES 6 Key category analysis

Key categories refer to sources/sinks that deserve special attention within the national inventory system because their estimated direct GHG emissions have a significant contribution to the country's total direct GHG emissions and/ removals, in terms of both absolute level and trends in GHG emissions. As described in the 2006 IPCC guidelines (IPCC 2006, 2006), it is good practice to identify key source categories and related gases as it could help the government to prioritize efforts in the improvement of the overall quality of national inventory. In this inventory, key categories and corresponding key gases were identified based on the Tier 1 methodology of the 2006 IPCC guidelines, and both level and trend analyses were conducted. The percentages of contributions to both levels and trends in GHG emissions were calculated and sorted in descending fashion using the 2006 IPCC software and a 95% cumulative contribution threshold has been applied as an upper boundary for key category identification. The results of the trend and level analyses are summarized in **ES Table 5.**

Sixteen key source/sink categories were identified for both trend and level analysis. As it could be seen from the table, identified key categories are mostly from Agriculture, Forestry, and Land Use (AFOLU) and Energy sectors, which are the main economic activities in Rwanda. According to the level assessment, half of the key categories are from the AFOLU sector while other sectors share the rest with the Energy sector having four categories. The dominance of the AFOLU sector was also confirmed by the results from the trend analysis, in which the AFOLU sector had 9 key categories, and others are shared by the energy and waste sectors. The IPPU does not appear on the list of trend key categories since the development of the industrial sector and thus the increase in its GHG emissions is very recent.

In addition to the key category analysis, the key gases and key fuels in the Energy sector were identified using the aforementioned methodology. As it can be seen from **Table 1.5**, CO_2 and CH_4 had significant shares to level GHG emissions whereas N_2O had a minute contribution. This observation is obvious since the CH_4 is mainly produced in various key categories of the AFOLU, energy, and waste sectors. The CO_2 is generally generated in liquid fuel combustion activities of the energy sector and the Land Use activities of the AFOLU sector. The N_2O emissions were generated by the Wastewater Treatment and Discharge category the Managed Soils key categories of the waste and AFOLU sectors, respectively. The same shares in key gases were also observed in the results of the trend analysis. According to the level analysis, four key fuels were identified in various key categories of the energy sector, viz., liquid fuels, biomass, solid fuels, and gaseous fuels. These fuels are generally used in various key categories of the energy sector including transportation, Other Sectors (i.e., residential and commercial buildings), manufacturing industries, and construction and energy industries. However, the gaseous fuels did on appear on the results of the key fuels according to trend analysis. This is because the increased use of gaseous fuels in electricity generation is relatively recent.

ES Table 5 Key categories

Sectors	IPCC Category	GHG	Level assessment	Trend assessment
AFOLU	Enteric Fermentation (3.A.1)	CH_4	X	X
Energy	Road Transportation (1.A.3.b)	CO_2	X	X
AFOLU	Land Converted to Cropland (3.B.2.b)	CO_2	X	X
AFOLU	Cropland Remaining Cropland (3.B.2.a)	CO_2	X	X
Waste	Solid Waste Disposal (4.A)	CH_4	X	
AFOLU	Direct N_2O Emissions from managed soils (3.C.4)	N_2O	X	X
Energy	Other Sectors - Biomass (1.A.4)	CH_4	X	X
AFOLU	Rice cultivation (3.C.7)	CH_4	X	X
AFOLU	Land Converted to Settlements (3.B.5.b)	CO_2	X	X
AFOLU	Land Converted to Grassland (3.B.3.b)	CO_2	X	X
Waste	Wastewater Treatment and Discharge (4.D)	N_2O	X	X
Waste	Wastewater Treatment and Discharge (4.D)	CH_4	X	X
IPPU	Cement production (2.A.1)	CO_2	X	
Energy	Manufacturing Industries and Construction - Solid Fuels (1.A.2)	CO_2	X	X
Energy	Energy Industries - Gaseous Fuels (1.A.1)	CO_2	X	
Energy	Energy Industries - Liquid Fuels (1.A.1)	CO_2	X	X
AFOLU	Manure Management (3.A.2)	CH_4	X	
AFOLU	Direct N_2O Emissions from managed soils (3.C.4)	N_2O		X
Waste	Biological Treatment of Solid Waste (4.B)	CH_4		X
AFOLU	Land Converted to Forest land (3.B.1.b)	CO_2		X
AFOLU	Forest land Remaining Forest land (3.B.1.a)	CO_2		X

ES 7 Uncertainty and times series consistence

Uncertainty and time-series assessments constitute important elements of a complete and transparent GHG emissions inventory. Uncertainty and time-series assessments were conducted using the Tier 1 methodology following the 2006 IPCC guidelines and good practices therein. Taking 2006 as the base year, the level and trend uncertainty were estimated using the 2006 IPCC software. The total uncertainty in total inventory and trend uncertainties were estimated at 9.97 % and 13.45 %, respectively. These uncertainties are relatively high due to various reasons including the data gaps and the use of default emission factors. The emissions evaluated in this inventory report represent the current best estimates in Rwanda's GHG inventory. However, it is worth mentioning that in some cases estimates were based on extrapolated data, assumptions, and approximation methodologies. These methodological issues also contributed significantly to higher and more fluctuating uncertainties. Rwanda's GHG inventory working group will continue to improve, revise, and recalculate its GHG emission estimates, as new sources of information are available. In addition, it should be recommended that, in future inventories, an effort should be made to develop country-specific emission factors to overcome high uncertainties in estimated GHG emissions and removals.

ES 8 Completeness assessment

The developed GHG emissions and removals inventory for the period 2006 through 2018 is mostly complete for direct gases including CO_2, CH_4, N_2O, and HFCs. In this inventory, an effort was made to estimate all the direct GHG emissions for all the source categories under Energy, Industrial Process and Product use (IPPU), Agriculture, Forestry, and Land Use (AFOLU), and Waste sectors. The indirect GHG emissions were estimated for some subcategories of the AFOLU sector. Despite the effort made, GHG emissions from some categories and subcategories were not included in this inventory chiefly due to lack of source data and/or disaggregated data. Details on various gaps in the inventory are discussed in the section on planned improvements.

Though reporting on precursors and indirect emissions is not mandatory for Non-Annex I countries, there is a need to consider these gases in future reports of national communication since they are linked with national air pollution management which is a priority for the GoR.

ES 9 Planned improvements

The emissions evaluated in this inventory report represent the current best estimates in Rwanda's GHG inventory. Despite the effort made to make Rwanda's GHG inventory as complete and comprehensive as possible, it is worth mentioning that in some cases estimates were based on extrapolated data, assumptions, and approximation methodologies. These methodological issues also contributed significantly to higher and more fluctuating uncertainties. Rwanda's GHG inventory working group will continue to improve, revise, and recalculate its GHG emission estimates, as new sources of information are available. As discussed in subsequent sections, planned improvements in various sectors will encompass improvement in methodology (including the disaggregation of the country-specific data, the emission factors and the uncertainty management), an improvement on capacity building and information sharing, and Strategies for long-term improvement.

Chapter 1. Introduction

1.1 Basic information on the National GHG Inventory

1.1.1 Process for Rwanda's GHG inventory preparation

Rwanda as a non-Annex I Party to the United Nations Framework Convention on Climate Change (UNFCCC) should submit National Communication Reports (NATCOMs) on climate change every four years, and their Biennial Update Reports (BURs) every two years. Biennial Update Reports provide an update of the information presented in National communications (NATCOMs), on national Greenhouse gases (GHG) inventories, mitigation actions, constraints, and gaps, including support needed and received. In this regard, Rwanda has already submitted its Initial, Second, and Third National Communications in 2005, 2012, and 2018, respectively. The most recent national communication was developed following the guidelines and Good Practices Guidance for the preparation of National Communications adopted in COP 17 under the United Nations Framework Convention on Climate Change (UNFCCC) from non-Annex I Parties contained in annex III of decision 2/CP.17.

The preparation of the first Biennial Update Report (BUR1) is in a bid to fulfil the obligation of the non-Annex I Party to submit the Biennial Update Report (BURs) to the UNFCCC every two years. One of the main chapters of the national communications and BURs is the national inventory of greenhouse gases in the main sectors of the country, i.e., Energy, Industrial Processes and Product Use (IPPU), Agriculture, Forestry, and Land Use (AFOLU), and Waste. This National Greenhouse gas inventory presents the updates of national GHG inventories according to paragraphs 8–24 in the "UNFCCC guidelines for the preparation of national communications from non-Annex I Parties as contained in the annex to decision 17/CP.8.

This national greenhouse gas inventory presents an update of Rwanda's GHG inventory from 2006 to 2018. Since the recent inventory published in the TNC reported estimates of GHG emissions up to 2015, activity data related to GHG emissions were collected for the 2016-2018 period and related GHG emissions were estimated. In addition, thanks to data collected in recent surveys for filling data gaps, appropriate recalculations were conducted for various subsectors. The recalculations were based on both the new dataset and the improvement in the methodology. The main improvement in the methodology was the disaggregation of source data and the inclusion of some categories, which were reported elsewhere and/or not reported due to a lack of activity data. Another improvement was done in transport, AFOLU, and waste where country-specific data were applied. Estimates of aggregated direct GHG emissions expressed in CO_2 equivalent were produced using the global warming potentials provided by IPCC in the Second Assessment Report based on the effects of GHGs over a 100-year time horizon and reported on the gas-by gas basis for direct gases (CO_2, CH_4, and N_2O) (IPCC, 2006a). In addition, key sources and gases were identified and uncertainty levels were provided.

1.1.2 Brief description of the GHG inventory steps

The national inventory of GHG emissions by sources and removals by sink involved the following steps, which were developed, based on the challenges encountered in the previous inventories and the 2006 IPCC guidelines:

- Identification of the data sources, surveys to fill the activity data gaps identified in the previous GHG inventory with emphasis on the key categories
- Activity data collection to complete the inventory timeline
- Selection of the applicable IPCC methodology Tiers and choice of emission factors based on the context of the country and the available data in each sector
- Estimation and recalculation of direct and some indirect greenhouse gases emissions/removals using the selected methodology and emission factors
- Development of individual sectors reports on the GHG emissions/removals including the summary of total GHG emissions/removal by subcategory and by gas, sectors key category analysis, uncertainty assessment, Sector quality assurance/Quality control, and completeness assessment
- Compilation of the individual sectors emissions/removals reports into the national inventory of GHG emissions by sources and removal by sink including the trend and level key category analysis
- Review of the final NIR based on the developed Quality Assurance/Quality control
- Data archiving and improved documentation

The figure depicts the followed steps and their sequence in the NIR preparation:

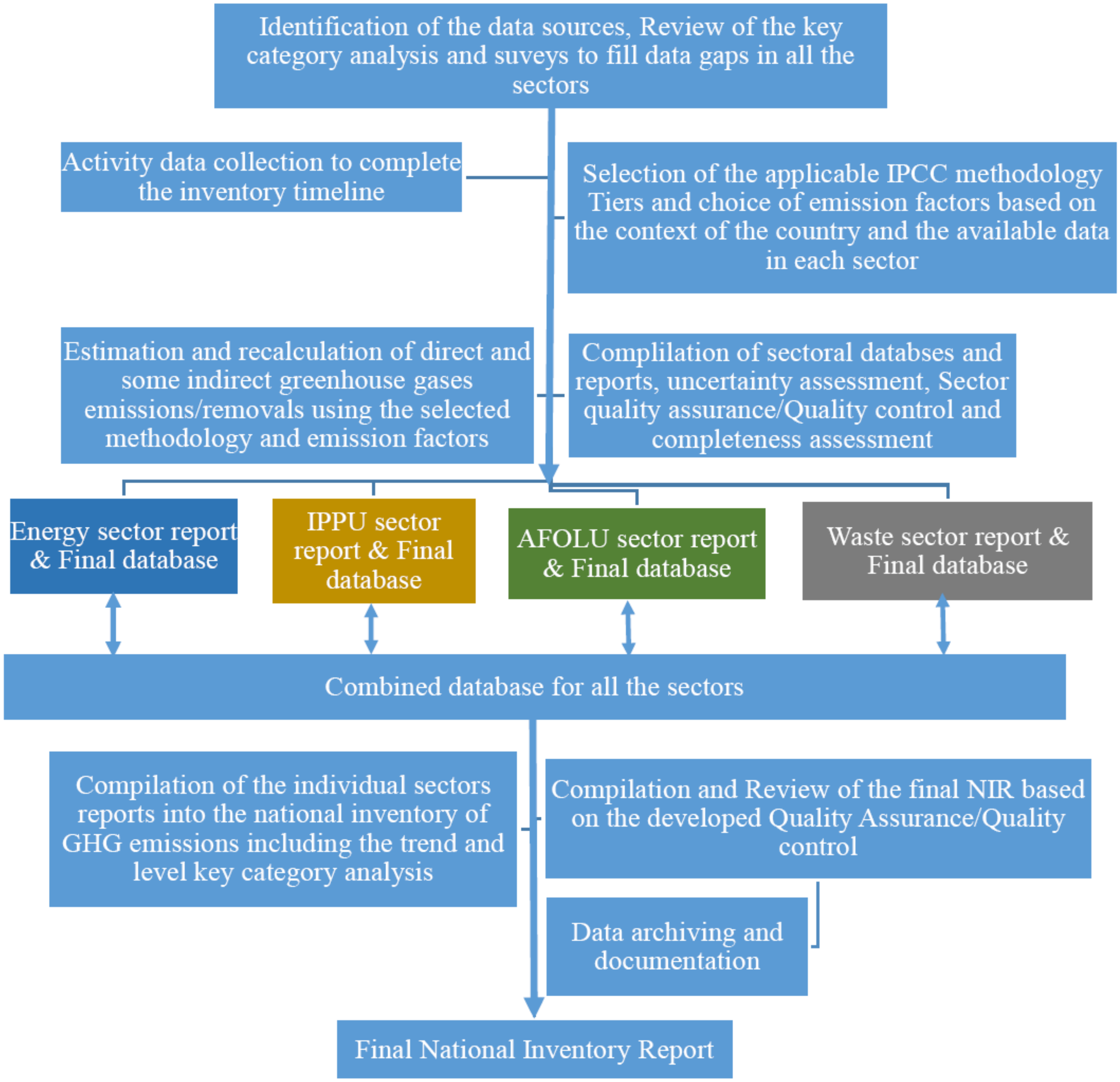


Figure 1.1 Steps in the development of the National Inventory

1.1.3 Brief description of the institutional arrangement

The institutional arrangement for GHG emissions inventory is presented in **Figure 1.2**. The GHG inventory for Rwanda was developed by the GHG working group, under the sole responsibility of the Rwanda Environmental Management Authority (REMA), through its Single Project Implementation Unit (SPIU). REMA's Technical staff have been involved in technical implementation by contributing as a member of the GHG working group.

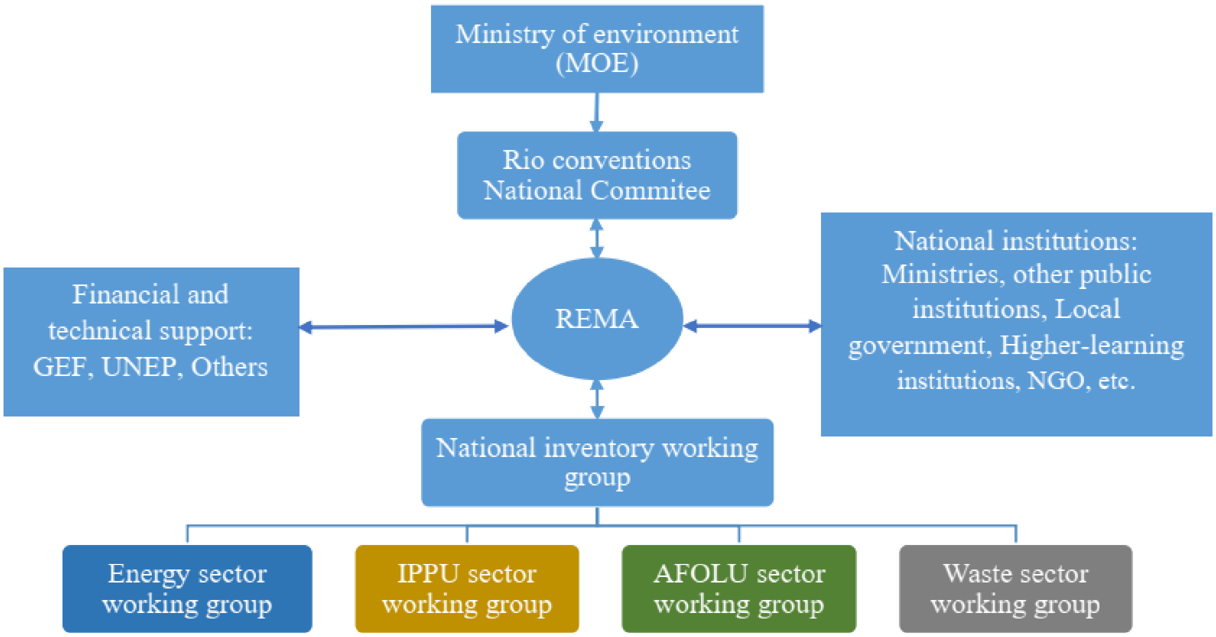


Figure 1.2 Institution arrangement for GHG inventory development

The National Climate Change Committee (NCCC), which comprises various stakeholders representing national institutions, was responsible for supervising the inventory report development including the evaluation of key outputs to ensure project activities are being carried out on time. The GHG working group is responsible for estimating GHG emissions and removals, key sources analysis, quality assurance and quality control activities, uncertainty assessment, documentation, and archiving of information related to the GHG inventory preparation process.

1.2 Brief description of the methodological issues and data collection

1.2.1 Guidelines

Rwanda's GHG inventory report was developed and structured according to the UNFCCC convention and in compliance with the 2006 IPCC guidelines. The latest IPCC 2006 Inventory Software version 2.691 (*released on 23 January 2020*), developed for these guidelines, was used for data entry, emission calculation, and analysis results. GHG emissions and their uncertainties were estimated for a period between 2006 and 2018 for the Energy, IPPU, AFOLU, and Waste sectors and their respective categories. In addition, the quality assurance, key category analysis, and completeness were assessed following the same guidelines.

1.2.2 Global warming potential

The global warming potential values (GWPs) used to convert the estimated CH_4, N_2O, HFCs emissions into CO_2 equivalent (CO_2eq.) are presented in **Table 1.1**. They consist of the Global

Warming Potentials (GWPs) values provided by the IPCC in its Second Assessment Report (SAR) based on the effects of greenhouse gases over a 100-year time horizon.

Table 1.1 Global warming potential values

GHG	CH_4	N_2O	HFC-32	HFC-125	HFC-134a	HFC-143a
GWP	21	310	650	2800	1300	3800

1.2.3 Methods

In general, Tier 1 and Tier 2 methodologies were applied to estimate emissions of direct greenhouse gases (CO_2, CH_4, N_2O, and HFCs) for all sectors, and country-specific data were considered where available and indirect gases from AFOLU. Activity data used for Rwanda's GHG inventory from 2006 through 2018 were mainly sourced from various stakeholders. Details of the specific methodologies to various sectors are described in subsequent sections.

Table 1.2 Summary of the methods used in GHG emissions and removal calculations

IPCC categories	CO_2	CH_4	N_2O	HFCs
1.A.1 - Energy Industries				
1.A.1.a.i - Electricity Generation	Tier 1&2	Tier 1	Tier 1	NA
1.A.1.c.ii - Other Energy Industries	Tier 1	Tier 1	Tier 1	NA
1.A.1 - Energy Industries				
1.A.2.e - Food Processing, Beverages and Tobacco	Tier 1	Tier 1	Tier 1	NA
1.A.2.f - Non-Metallic Minerals	Tier 1	Tier 1	Tier 1	NA
1.A.2.i - Mining (excluding fuels) and Quarrying	Tier 1	Tier 1	Tier 1	NA
1.A.2.k - Construction	Tier 1	Tier 1	Tier 1	NA
1.A.3 - Transport				
1.A.3.a.ii - Domestic Aviation	Tier 1	Tier 1	Tier 1	NA
1.A.3.b.i.1 - Passenger cars with 3-way catalysts	Tier 1&2	Tier 1	Tier 1	NA
1.A.3.b.ii.1 - Light-duty trucks with 3-way catalysts	Tier 1&2	Tier 1	Tier 1	NA
1.A.3.b.iii - Heavy-duty trucks and buses	Tier 1&2	Tier 1	Tier 1	NA
1.A.3.b.iv - Motorcycles	Tier 1&2	Tier 1	Tier 1	NA
1.A.3.d.ii - Domestic Water-borne Navigation	Tier 1	Tier 1	Tier 1	NA
1.A.3.e - Other Transportation	Tier 1	Tier 1	Tier 1	NA
1.A.3.e.ii - Off-road	Tier 1	Tier 1	Tier 1	NA
1.A.4 - Other Sectors				
1.A.4.a - Commercial/Institutional	Tier 1	Tier 1	Tier 1	NA
1.A.4.b - Residential	Tier 1	Tier 1	Tier 1	NA
1.A.4.c-Agriculture/Forestry/Fishing/Fish Farms	Tier 1	Tier 1	Tier 1	NA
2.A - Mineral Industry				
2A1: Cement Production	Tier 1	NA	NA	NA
2A2: Lime Production	Tier 1	NA	NA	NA
2.C - Metal Industry				

IPCC categories	CO_2	CH_4	N_2O	HFCs
2C1: Iron and Steel Production	Tier 1	Tier 1	NA	NA
2C2: Ferroalloys Production	Tier 1	NO	NA	NA
2.D - Non-Energy Products from Fuels and Solvent Use				
2D1: Lubricant Use	Tier 2	NA	NA	NA
2D2: Paraffin Wax Use	Tier 1	NA	NA	NA
2F Product Uses as Substitutes for Ozone Depleting Substances				
2F1a: Refrigeration and Stationary Air Conditioning	NA	NA	NA	Tier 2
2F1b: Mobile Air Conditioning	NA	NA	NA	Tier 2
3.A - Livestock				
3.A.1 Enteric Fermentation	NA	Tier 1&2	NA	NA
3.A.2 Manure Management	NA	Tier 1	Tier 1	NA
3.B - Land				
3.B.1 Forest Land	Tier 1	NE	NE	NA
3.B.2 Cropland	Tier 1	Tier 1	Tier 1	NA
3.B.3 – Grassland	Tier 1	NA	NA	NA
3.B.4 – Wetlands	Tier 1	NA	Tier 1	NA
3.B.5 - Settlements	Tier 1	NA	NA	NA
3.B.6 - Other Land	Tier 1	NA	NA	NA
3.C - Aggregate sources and non-CO_2 emissions sources on land				
3.C.1 - Emissions from biomass burning	Tier 1	Tier 1	Tier 1	NA
3.C.2 Liming	Tier 1	NA	NA	NA
3.C.3 Urea application	Tier 1	NA	NA	NA
3.C.4 Direct N_2O emissions from soils	NO	NA	Tier 1	NA
3.C.5 Indirect N_2O emissions from soils	NO	NO	Tier 1	NA
3.C.6 Indirect N_2O emissions from manure management	NO	NO	Tier 1	NA
3.C.7 Rice cultivation	NO	Tier 1	NO	NA
4A Solid waste disposal				
4A-Solid waste disposal	Tier 1	NO	NO	NA
4B-Biological Treatment of Solid waste				
4B-Biological Treatment of Solid waste	Tier 1	Tier 1	NO	NA
4C-Incineration and Open Burning				
4C1-Incineration	Tier 1	Tier 1	Tier 1	NA
4C2-Open Burning	Tier 1	Tier 1	Tier 1	NA
4D-Wastewater Treatment and discharge				
4D1-Domestic wastewater	Tier 1	Tier 1	NO	NA
4D1-Industrial wastewater	Tier 1	Tier 1	NA	NA

NA: Not Applicable, NO: Not Occurring

1.2.4 Activity data collection

The activity data were gathered from the official statistics published national documents including the national reports from various institutions, the national statistical yearbooks, the Seasonal

Agricultural Survey of NISR, and from recent surveys (REMA, 2019a, 2019b) conducted by REMA to fill the data gaps identified in the previous inventories. All the data appearing in these official documents were further crosschecked with relevant institutions working in their respective sectors. An indicative list of institutions that provided data and participated in data validation is provided in **Table 1.3.** Other sources of data include research work published locally and in international journals as well as annual and technical reports from the different research institutions. Specific data sources are detailed in subsequent sections.

Table 1.3 Institution participating in data provision and validation

Institutions	Responsibilities/data collected/Validated
CGIS-NUR/PAREF/RNRARNRA DFS/PAREF/RNRA RLMUA, MoE, RAB	Data on forestry for land-use and estimation of GHG emission/sequestration in forestry, other land use, and biomass
Rwanda Agricultural and Animal Resources Development Board (RAB)	• Data for livestock population, crop production data including fruits, flowers, fodder, and tea, national consumption of fertilizers, and soil fertility data. • Estimation of GHG emissions in agriculture.
NISR	• Most of the data were directly sourced from their published reports including the yearbooks and EICV reports • Data on Livestock number per type (Dairy cattle, Other cattle, Sheep, Goat, market swine, breeding swine), Manure production per livestock type (Dairy cattle, Other cattle, Sheep, Goat, market swine, breeding swine, chicken) • Number of imported vehicles
MINAGRI	Imports data on Mineral fertilizer applied to soils
MINAGRI, NISR, RAB	• Wetlands organic soil cultivated area • Area of annual crops; Area of perennial crops; area converted to cropland; N content in compost, mulch, and mineral fertilizers • Biomass quantity per crop; dead biomass applied to the soil • Harvested area: biomass applied; N fertilizers applied; water regime
Rwanda Civil Aviation, NISR	Data on domestic flights
CGIS-NUR/PAREF/RNRA, RNRA	• Land use/cover maps, Land use/cover change map, Land use change matrix

Institutions	Responsibilities/data collected/Validated
	• Biomass estimate for 5 IPCC pools (Above ground biomass, below-ground biomass, deadwood, herb, litter, and soil) • Land use/cover maps, Land use/cover change map, Land use change matrix • Biomass estimate for 5 IPCC pools (Above ground biomass, below-ground biomass, deadwood, herb, litter, and soil) • Land use/cover maps, Land use/cover change map, Land use change matrix
Rwanda Energy Group (EDCL and EUCL)	• Data on fuel consumption for electricity generation • Data on electricity generation and distribution and other energy data. • Data on installed biogas • Data on biomass consumption • Data on fuel consumption and fuels calorific values
Kigali city and COPED	Data on Wastewater Management and solid waste
Ministry of Trade and Industry (MINICOM) and Rwanda Revenue Authority (RRA)	• Data on the IPPU sector and estimation, Data on liquefied petroleum gas (LPG) • Data on ozone-depleting substances substitutes and estimation of GHG emission from products use as ozone-depleting substances • Data on fuels (diesel, residual fuel oil, kerosene, Jet kerosene, LPG, etc.) imports
National Bank of Rwanda (BNR)	Data on lime and cement production
University of Rwanda	Sectoral and final reports review and validation
Rwanda Environment Management Authority (REMA)	• Various data collected in to fill the data gaps for all the sectors were used for recalculation and GHG emissions estimation • Oversee the whole process of the National GHG Inventory • Validation of the data and methodology

1.3 Quality Assurance and Quality Control (QA/QC) procedures

The Quality Assurance (QA) and Quality Control (QC) constitute an important part of the inventory development cycle. The QC was conducted at all the steps of the inventory development through data validation and methodology checks from all the working groups. Activity data were collected from the national official documents and in the recent surveys conducted by REMA to fill the data gaps. All the data appearing in these official documents were further crosschecked with relevant institutions working in their respective sectors. Specific and relevant data were also from research work published locally and in international journals as well as annual and technical reports from the different research institutions.

The inventory team performed Quality Control procedures through the following activities:

- Routine and consistent checks to identify errors and omissions after introducing activity data and observing emission dynamics
- Use of approved standardized procedures for emissions calculations, measurements, and documentation as per IPCC guidelines
- Use of officially published data was given preference from the earlier used expert judgment;
- Presentation of inventory results to the stakeholders and its validation supervision by REMA.
- Any significant change in emission within a specific category was questioned and activity data was checked.

The overall report Quality Assurance was conducted and checked by an international consultant and validated *via* various stakeholders' meetings.

1.4 General uncertainty and time series assessment

Uncertainty and time-series assessments constitute important elements of a complete and transparent GHG emissions inventory. Uncertainty and time-series assessments were conducted using the Tier 1 methodology of the 2006 IPCC guidelines. Taking 2006 as the base year, the level and trend uncertainty were estimated using the 2006 IPCC software. **Table 1.4** summarizes the estimated national inventory quantitative uncertainties. It is evident from the table that for some years, uncertainties are relatively high. The main reason for high uncertainties could be the data gaps and the use of default emission factors. It is also worth mentioning that in some cases estimates were based on extrapolated data, assumptions, and approximation methodologies. These methodological issues also have led to significantly higher and more fluctuating uncertainties. Rwanda's GHG inventory working group will continue to improve, revise, and recalculate its GHG emission estimates, as new sources of information are available. In addition, it should be recommended that, in future inventories, an effort should be made to develop country-specific emission factors to overcome high uncertainties in estimated GHG emissions and removals.

Table 1.4 Estimated national inventory quantitative uncertainties

2006 IPCC Categories	Gas	Base Year emissions or removals (Gg CO_2 equivalent)	Year T emissions or removals (Gg CO_2 equivalent)	Contribution to Variance by Category in Year T	Inventory trend in national emissions for the year 2018 increase with respect to the 2006 year (% of the base year)	The uncertainty introduced into the trend in total national emissions (%)
1 - Energy						

2006 IPCC Categories	Gas	Base Year emissions or removals (Gg CO_2 equivalent)	Year T emissions or removals (Gg CO_2 equivalent)	Contribution to Variance by Category in Year T	Inventory trend in national emissions for the year 2018 increase with respect to the 2006 year (% of the base year)	The uncertainty introduced into the trend in total national emissions (%)
1.A.1 - Energy Industries - Liquid Fuels	CO_2	91.42	90.27	0.00	98.73	0.002
1.A.1 - Energy Industries - Liquid Fuels	CH_4	0.08	0.07	0.00	95.76	0.000
1.A.1 - Energy Industries - Liquid Fuels	N_2O	0.23	0.22	0.00	95.76	0.000
1.A.1 - Energy Industries - Gaseous Fuels	CO_2	0.00	101.61	0.00	0.00	0.007
1.A.1 - Energy Industries - Gaseous Fuels	CH_4	0.00	0.04	0.00	0.00	0.000
1.A.1 - Energy Industries - Gaseous Fuels	N_2O	0.00	0.06	0.00	0.00	0.000
1.A.1 - Energy Industries - Peat	CO_2	0.00	37.24	0.00	0.00	0.001
1.A.1 - Energy Industries - Peat	CH_4	0.00	0.01	0.00	0.00	0.000
1.A.1 - Energy Industries - Peat	N_2O	0.00	0.16	0.00	0.00	0.000
1.A.1 - Energy Industries - Biomass	CO_2	1432.65	2860.39	1.27	199.66	4.424
1.A.1 - Energy Industries - Biomass	CH_4	8.06	16.09	0.00	199.66	0.000
1.A.1 - Energy Industries - Biomass	N_2O	15.86	31.67	0.00	199.66	0.001
1.A.2 - Manufacturing Industries and Construction - Liquid Fuels	CO_2	35.14	14.60	0.00	41.54	0.001
1.A.2 - Manufacturing Industries and Construction - Liquid Fuels	CH_4	0.03	0.01	0.00	42.74	0.000
1.A.2 - Manufacturing Industries and Construction - Liquid Fuels	N_2O	0.08	0.04	0.00	42.73	0.000
1.A.2 - Manufacturing Industries and Construction - Biomass	CO_2	2408.37	4460.52	2.89	185.21	10.015
1.A.2 - Manufacturing Industries and Construction - Biomass	CH_4	13.55	25.09	0.00	185.20	0.000
1.A.2 - Manufacturing Industries and Construction - Biomass	N_2O	26.66	49.38	0.00	185.20	0.001
1.A.2 - Manufacturing Industries and Construction - Solid Fuels	CO_2	0.00	130.82	0.00	0.00	0.014
1.A.2 - Manufacturing Industries and Construction - Solid Fuels	CH_4	0.00	0.29	0.00	0.00	0.000
1.A.2 - Manufacturing Industries and Construction - Solid Fuels	N_2O	0.00	0.64	0.00	0.00	0.000
1.A.3.a - Civil Aviation - Liquid Fuels	CO_2	5.21	135.76	0.00	2606.41	0.012
1.A.3.a - Civil Aviation - Liquid Fuels	CH_4	0.00	0.02	0.00	2606.41	0.000
1.A.3.a - Civil Aviation - Liquid Fuels	N_2O	0.05	1.18	0.00	2606.41	0.000
1.A.3.b - Road Transportation - Liquid Fuels	CO_2	350.45	1286.77	0.04	367.18	0.110
1.A.3.b - Road Transportation - Liquid Fuels	CH_4	3.21	11.78	0.00	366.54	0.006
1.A.3.b - Road Transportation - Liquid Fuels	N_2O	5.29	19.78	0.00	373.73	0.010
1.A.3.b - Road Transportation	CO_2	0.00	0.00	0.00	100.00	0.000
1.A.3.d - Water-borne Navigation - Liquid Fuels	CO_2	0.00	1.43	0.00	0.00	0.000
1.A.3.d - Water-borne Navigation - Liquid Fuels	CH_4	0.00	0.00	0.00	0.00	0.000
1.A.3.d - Water-borne Navigation - Liquid Fuels	N_2O	0.00	0.01	0.00	0.00	0.000
1.A.3.e - Other Transportation - Liquid Fuels	CO_2	0.45	18.61	0.00	4171.43	0.000
1.A.3.e - Other Transportation - Liquid Fuels	CH_4	0.00	0.02	0.00	4171.43	0.000
1.A.3.e - Other Transportation - Liquid Fuels	N_2O	0.05	2.23	0.00	4171.43	0.000
1.A.4 - Other Sectors - Liquid Fuels	CO_2	46.42	37.72	0.00	81.26	0.001
1.A.4 - Other Sectors - Liquid Fuels	CH_4	0.14	0.09	0.00	64.34	0.000
1.A.4 - Other Sectors - Liquid Fuels	N_2O	0.12	0.06	0.00	50.11	0.000
1.A.4 - Other Sectors - Biomass	CO_2	4843.85	7835.42	45.50	161.76	35.242
1.A.4 - Other Sectors - Biomass	CH_4	261.95	401.51	16.83	153.28	8.672
1.A.4 - Other Sectors - Biomass	N_2O	49.95	72.62	0.90	145.39	0.746
1.B.1 - Solid Fuels	CO_2	0.00	0.00	0.00	100.00	0.000
1.B.1 - Solid Fuels	CH_4	0.00	0.00	0.00	100.00	0.000
1.C - Carbon dioxide Transport and Storage	CO_2	0.00	0.00	0.00	100.00	0.000
2 - Industrial Processes and Product Use						
2.A.1 - Cement production	CO_2	36.84	132.81	0.00	360.50	0.011
2.A.2 - Lime production	CO_2	0.00	0.00	0.00	100.00	0.000
2.C.1 - Iron and Steel Production	CO_2	0.00	3.65	0.00	472113.74	0.000
2.C.2 - Ferroalloys Production	CO_2	0.00	0.12	0.00	4448.12	0.000
2.F.1 - Refrigeration and Air Conditioning	CH2FCF3	0.00	2.83	0.00	0.00	0.000
3 - Agriculture, Forestry, and Other Land Use						
3.A.1 - Enteric Fermentation	CH_4	2450.56	3196.97	0.58	130.46	3.642

2006 IPCC Categories	Gas	Base Year emissions or removals (Gg CO_2 equivalent)	Year T emissions or removals (Gg CO_2 equivalent)	Contribution to Variance by Category in Year T	Inventory trend in national emissions for the year 2018 increase with respect to the 2006 year (% of the base year)	The uncertainty introduced into the trend in total national emissions (%)
3.A.2 - Manure Management	CH_4	40.97	80.69	0.00	196.97	0.003
3.A.2 - Manure Management	N_2O	38.38	54.61	0.00	142.29	0.003
3.B.1.a - Forest land Remaining Forest land	CO_2	-5299.67	-6975.03	30.31	0.00	114.088
3.B.1.b - Land Converted to Forest land	CO_2	-116.29	-115.72	0.01	0.00	0.028
3.B.2.a - Cropland Remaining Cropland	CO_2	671.04	671.04	0.28	100.00	1.331
3.B.2.b - Land Converted to Cropland	CO_2	624.98	938.53	0.49	150.17	1.744
3.B.3.a - Grassland Remaining Grassland	CO_2	0.00	0.00	0.00	100.00	0.000
3.B.3.b - Land Converted to Grassland	CO_2	197.19	170.98	0.02	86.71	0.103
3.B.4.a.i - Peatlands remaining peatlands	CO_2	0.00	11.48	0.00	0.00	0.001
3.B.4.a.i - Peatlands remaining peatlands	N_2O	0.00	0.18	0.00	0.00	0.000
3.B.5.b - Land Converted to Settlements	CO_2	235.91	266.27	0.04	112.87	0.180
3.B.6.b - Land Converted to Other Land	CO_2	2.05	2.06	0.00	100.90	0.000
3.C.1 - Emissions from biomass burning	CH_4	0.00	31.70	0.00	0.00	0.003
3.C.1 - Emissions from biomass burning	N_2O	0.00	42.73	0.00	0.00	0.004
3.C.2 - Liming	CO_2	0.00	8.66	0.00	0.00	0.000
3.C.3 - Urea application	CO_2	1.55	7.02	0.00	453.29	0.000
3.C.4 - Direct N_2O Emissions from managed soils	N_2O	293.85	405.92	0.10	138.14	0.377
3.C.5 - Indirect N_2O Emissions from managed soils	N_2O	33.61	64.38	0.00	191.55	0.009
3.C.6 - Indirect N_2O Emissions from manure management	N_2O	49.07	68.79	0.00	140.18	0.011
3.C.7 - Rice cultivation	CH_4	212.42	280.74	0.05	132.17	0.184
4 - Waste						
4.A - Solid Waste Disposal	CH_4	175.36	446.39	0.00	254.55	0.000
4.B - Biological Treatment of Solid Waste	CH_4	74.25	75.10	0.00	101.14	0.000
4.B - Biological Treatment of Solid Waste	N_2O	65.77	66.52	0.00	101.14	0.000
4.C - Incineration and Open Burning of Waste	CO_2	2.16	3.04	0.00	140.79	0.000
4.C - Incineration and Open Burning of Waste	CH_4	11.02	14.80	0.00	134.22	0.000
4.C - Incineration and Open Burning of Waste	N_2O	2.12	2.85	0.00	134.22	0.000
4.D - Wastewater Treatment and Discharge	CH_4	102.84	145.21	0.00	141.20	0.000
4.D - Wastewater Treatment and Discharge	N_2O	121.63	163.25	0.00	134.22	0.000
		9,626.91	**17,915.97**	**99.35**		**180.99**
		Uncertainty in total inventory: 9.97			**Trend uncertainty: 13.45**	

1.5 Key category analysis

Key categories refer to sources/sinks that deserve special attention within the national inventory system because their estimated direct GHG emissions have a significant contribution to the country's total direct GHG emissions and removals, in terms of both absolute level and trends in GHG emissions. The identification of the key source categories and related gases could help the government to prioritize efforts in the improvement of the overall quality of national inventory. In this inventory, key categories and corresponding key gases were identified based on the Tier 1 methodology of the 2006 IPCC guidelines, and both level and trend analyses were conducted. According to the IPCC guidelines, two approaches are generally used to identify the key categories, viz., approach 1 and approach 2. Whereas the approach 1 methodology is based on the assessment of the influence of various categories of sources and sinks on the *level* and the *trend* of the national greenhouse gas inventory, the approach 2 is based on the assessment of the results of the uncertainty analysis.

In this inventory, the approach 1 was used. The percentages of contributions to both levels and trends in GHG emissions were calculated and sorted in descending order using the 2006 IPCC software and a 95% cumulative contribution threshold has been applied as an upper boundary for key category identification.

1.5.1 Level assessment

The level assessment expresses the contribution of each source or sink category to the total national inventory level and is calculated using the equation 4.1 of the IPCC guidelines (IPCC 2006, 2006).

1.5.2 Trend assessment

As explained in the (IPCC, 2006a), the purpose of the trend assessment is to identify categories that may not be large enough to be identified by the level assessment, but whose trend is significantly different from the trend of the overall inventory, and should therefore receive particular attention. The trend assessment was conducted using equation 4.2 of the IPCC guidelines (IPCC 2006, 2006).

The results of the level and trend analyses are summarized in **Table 1.5** and **Table 1.6**, respectively**.** As evidenced by the tables, 16 key source/sink categories were identified for both trend and level analysis. As it could be seen from the table, identified key categories are mostly from Agriculture, Forestry, and Land Use (AFOLU) and Energy Sectors, which are the main economic activities in Rwanda. According to the level assessment, half of the key categories are from the AFOLU sector while the rest is shared by the energy, IPPU and waste sectors. The dominance of the AFOLU sector was also confirmed by the results from the trend analysis, in which the AFOLU sector had nine key categories, and others are shared by the energy and waste sectors. The IPPU does not appear on the list of trend key categories since the development of the industrial sector and thus the increase in its GHG emissions is very recent.

In addition to the key category analysis, the key gases and key fuels in the energy sector were identified using the aforementioned methodology. As it can be seen from **Table 1.5**, CO_2 and CH_4 had significant shares to level GHG emissions whereas N_2O had a minute contribution. This observation is obvious since the CH_4 is mainly produced in various key categories of the AFOLU, energy, and waste sectors. The CO_2 emissions are mainly generated in liquid fuel combustion activities of the energy sector and the Land Use activities of the AFOLU sector. N_2O appeared in the Wastewater Treatment and Discharge category of waste sector and Direct N_2O Emissions from managed soils key categories of the AFOLU sector. The same shares in key gases were also observed in the results of the trend analysis. According to the level analysis, four key fuels were identified in various key categories of the Energy sector, viz., liquid fuels, biomass, solid fuels, and gaseous fuels. These fuels are generally used in various key categories of the energy sector including transportation, Other Sectors (i.e., residential and commercial buildings), manufacturing industries, and construction and energy industries. However, the gaseous fuels did on appear on the results of the key fuels according to trend analysis. This is due to the increased use of gaseous fuels in electricity generation is relatively recent.

Table 1.5 Key categories from Level assessment in 2018

Sectors	IPCC Category	GHG	GHG emissions (Gg CO_2 eq.)	Contribution to level (%)	Cumulative contribution to level (%)
AFOLU	Enteric Fermentation (3.A.1)	CH_4	3,196.97	19.02	0.61
Energy	Road Transportation (1.A.3.b)	CO_2	1,286.77	7.66	0.68
AFOLU	Land Converted to Cropland (3.B.2.b)	CO_2	938.53	5.58	0.74
AFOLU	Cropland Remaining Cropland (3.B.2.a)	CO_2	671.04	3.99	0.78
Waste	Solid Waste Disposal (4.A)	CH_4	446.39	2.66	0.80
AFOLU	Direct N_2O Emissions from managed soils (3.C.4)	N_2O	405.92	2.42	0.83
Energy	Other Sectors - Biomass (1.A.4)	CH_4	401.51	2.39	0.85
AFOLU	Rice cultivation (3.C.7)	CH_4	280.74	1.67	0.87
AFOLU	Land Converted to Settlements (3.B.5.b)	CO_2	266.27	1.58	0.88
AFOLU	Land Converted to Grassland (3.B.3.b)	CO_2	170.98	1.02	0.89
Waste	Wastewater Treatment and Discharge (4.D)	N_2O	163.25	0.97	0.90
		CH_4	145.21	0.86	0.91
IPPU	Cement production (2.A.1)	CO_2	132.81	0.79	0.92
Energy	Manufacturing Industries and Construction - Solid Fuels (1.A.2)	CO_2	130.82	0.78	0.93
Energy	Energy Industries - Gaseous Fuels (1.A.1)	CO_2	101.61	0.60	0.94
Energy	Energy Industries - Liquid Fuels (1.A.1)	CO_2	90.27	0.54	0.95
AFOLU	Manure Management (3.A.2)	CH_4	80.69	0.48	0.95

Table 1.6 Key category from trend analysis (2006-2018)

Sectors	IPCC Category	GHG	2006 emissions /removals (Gg CO_2 eq.)	2018emissions /removals (Gg CO_2 eq.)	Trend	Contribution to Trend (%)	Cumulative Contribution to Trend (%)
AFOLU	Forest land Remaining Forest land (3.B.1.a)	CO_2	-5299.67	-6975.03	0.95	53.44	53.44
AFOLU	Enteric Fermentation (3.A.1)	CH_4	2450.56	3196.97	0.31	17.47	70.91
AFOLU	Cropland Remaining Cropland (3.B.2.a)	CO_2	671.04	671.04	0.10	5.76	76.67
AFOLU	Land Converted to Cropland (3.B.2.b)	CO_2	624.98	938.53	0.07	3.87	80.54
AFOLU	Direct N_2O Emissions from managed soils (3.C.4)	N_2O	293.85	405.92	0.04	1.99	82.52
AFOLU	Land Converted to Settlements (3.B.5.b)	CO_2	235.91	266.27	0.03	1.88	84.40
AFOLU	Land Converted to Grassland (3.B.3.b)	CO_2	197.19	170.98	0.03	1.82	86.22
Energy	Other Sectors - Biomass (1.A.4)	CH_4	261.95	401.51	0.03	1.58	87.80
AFOLU	Rice cultivation (3.C.7)	CH_4	212.42	280.74	0.03	1.50	89.30
Energy	Road Transportation (1.A.3.b)	CO_2	350.45	1286.77	0.03	1.45	90.75
AFOLU	Land Converted to Forest land (3.B.1.b)	CO_2	-116.29	-115.72	0.02	0.99	91.74
Waste	Wastewater Treatment and Discharge (4.D)	N_2O	121.63	163.25	0.02	0.85	92.59
Energy	Energy Industries - Liquid Fuels (1.A.1)	CO_2	91.42	90.27	0.01	0.79	93.38
Waste	Wastewater Treatment and Discharge (4.D)	CH_4	102.84	145.21	0.01	0.68	94.06
Waste	Biological Treatment of Solid Waste (4.B)	CH_4	74.25	75.10	0.01	0.63	94.69
Energy	Manufacturing Industries and Construction - Solid Fuels (1.A.2)	CO_2	0.00	130.82	0.01	0.62	95.32

1.6 Recalculations

Due to improvement in the methodology and data quality and the discovery of new datasets in Energy, AFOLU, and Waste sectors, a recalculation of the latest GHG emissions and removals published in the Third National Communication (TNC) was conducted for the period 2006-2015. **Table 1.7** shows the summary of recalculation results and the trends in recalculated GHG emissions/removals. Whereas the latest and previous data show the same trends, the latest data are far higher than the previous data over the whole period 2006-2015. The main reasons for the recalculations include the following:

- Data disaggregation
- Discovery of new datasets
- The addition of land use data derived from the Land Use class area per district by comparing the maps of 2000 and 2019;
- Inclusion of the newest study on forest cover, which updated the current forest area and uncovered deforestation extent;
- New, corrected calculation of emissions from urea application and its subsequent corrections for the TNC period (2006-2015, urea data in kg were counted in tons);
- Use of Tier 2 for dairy cattle using the recently measured data on mean live weight and adjustment of default value for local African cows from 275kg to locally measured values for Rwandan dairy cows, which are mostly cross-bred (60% of the female population) to 385.4 kg, which significantly increased emissions from enteric fermentation;
- Use of updated manure management systems from BUR surveys in AFOLU (REMA, 2019);
- Females, males, and heifers of Dairy cows were counted under the “Dairy cattle” category in one sheet in the new version of the software (IPCC, 2020), and not under the “other cattle” category as it was done in TNC;
- Inclusion of emissions from rabbits’ enteric fermentation with default emission factor available in the new version of the IPCC software (released in January 2020) and not included in the previous version of the IPCC software.
- Improvement of waste composition for the whole inventory period, due to survey results on waste composition in Rwanda conducted in 2019 by REMA and the EICV5 data on the main mode of waste management in Rwanda.
- In addition, the methodology used in the Waste sector was improved by considering the emissions from at least the last 50 years from the year 1965 while during the TNC the inventory started from 2004.

The main recalculations were conducted in the AFOLU sector and more GHG emissions were obtained in the Land use and enteric fermentation. The latter led to higher GHG emissions in the AFOLU sector compared to the previous inventory.

Table 1.7 Results of the National Inventory recalculations

1-Energy										
1.A.1 - Energy Industries										
Peri	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
PD	91.73	95.94	58.03	104.9	105.6	130.3	143.7	179.5	176.8	144.9
LD	115.6	120.3	82.89	131.9	135.8	159.8	179.9	221.3	229.9	193.3
%-	26.08	25.40	42.84	25.70	28.57	22.64	25.16	23.29	30.03	33.33
1.A.2 - Manufacturing Industries and Construction										
PD	38.34	48.85	48.66	46.55	43.09	48.84	47.32	56.29	73.26	92.6
LD	75.46	84.62	82.74	82.03	81.46	85.52	84.15	91.1	113.6	134
%-	96.82	73.22	70.04	76.22	89.05	75.10	77.83	61.84	55.16	44.71
1.A.3 - Transport										
PD	301.9	369.4	432.8	394.1	355.5	393.5	458.2	468.5	489.5	547.3
LD	359.5	414.7	501.1	545.6	597.7	679.2	778.9	879.9	942.5	1,031.
%-	19.07	12.29	15.76	38.43	68.13	72.59	69.97	87.81	92.53	88.48
1.A.4 - Other Sectors										
PD	627.7	624.9	624.6	618.9	645.4	675.6	693.7	717.1	728.5	741.4
LD	358.5	362.5	366.4	369.7	395.9	397.9	405.5	417.8	433.0	449.3
%-	-42.88	-41.99	-41.33	-40.27	-38.65	-41.11	-41.54	-41.73	-40.56	-39.39
2-Industrial Process and Product Use (IPPU)										
No recalculations were conducted in IPPU										
3-Agriculture, Forestry and Land Use (AFOLU)										
3.A.1 - Enteric Fermentation										
Yea	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
PD	979.5	1116.	1181.	1213.	1303.	1207.	1173.	1174.	1147.	1283.
LD	2450.	2695.	2827.	2939.	3191.	2848.	2832.	2847.	2852.	3197.
%-	150.1	141.3	139.3	142.3	144.8	136.0	141.3	142.5	148.6	149.0
3.A.2 - Manure Management										
PD	488.5	524.0	613.3	653.2	690.6	692.4	702.4	698.5	676.5	672.9
LD	79.34	91.08	95.74	100.7	108.6	101.9	108.6	109.5	109.0	109.2
%-	-83.76	-82.62	-84.39	-84.58	-84.27	-85.27	-84.54	-84.32	-83.89	-83.77
3.B.1 - Forest land										
PD	-	-	-	-	-	-	-	-	-	-
LD	-	-	-	-	-	-	-	-	-	-
%-	-49.52	-48.43	-47.32	-46.48	-45.36	-44.69	-43.99	-42.69	-42.37	-41.34
3.C.3 - Urea application										
PD	3858.	4014.	4171.	4375.	5359.	6344.	5694.	6610.	7526.	8443.
LD	1.55	2.17	1.86	3.98	2.40	3.64	5.96	8.49	2.21	7.74
%-	-99.96	-99.95	-99.96	-99.91	-99.96	-99.94	-99.90	-99.87	-99.97	-99.91
3.C.4 - Direct N_2O Emissions from managed soils										
PD	381.1	403.3	511.3	594.8	629.1	662.2	565.7	522.1	478.6	551.1
LD	33.61	38.06	39.58	49.55	45.20	47.84	71.44	57.03	52.12	52.07

%-	-91.18	-90.56	-92.26	-91.67	-92.82	-92.78	-87.37	-89.08	-89.11	-90.55
3.C.5 - Indirect N_2O Emissions from managed soils										
PD	132.2	140.4	175.3	201.7	212.0	222.4	196.5	185.0	170.1	191.0
LD	49.07	54.35	56.99	59.71	64.96	58.97	60.96	61.38	61.68	65.84
%-	-62.90	-61.30	-67.49	-70.41	-69.37	-73.49	-68.99	-66.83	-63.74	-65.54
3.C.6 - Indirect N_2O Emissions from manure management										
PD	108.0	119.0	129.9	136.8	147.5	138.4	145.4	146.7	146.0	148.1
LD	49.07	54.35	56.99	59.71	64.96	58.97	60.96	61.38	61.68	65.84
%-	-54.57	-54.34	-56.16	-56.37	-55.98	-57.42	-58.09	-58.18	-57.78	-55.57
3.C.7 - Rice cultivation										
PD	118.5	181.4	166.6	177.6	117.2	130.8	103.1	100.1	90.98	98.33
LD	212.4	242.9	298.7	318.4	210.0	227.0	171.7	175.9	198.1	220.1
%-	79.19	33.91	79.24	79.23	79.24	73.48	66.56	75.61	117.8	123.8
4-Waste										
4.A - Solid Waste Disposal										
	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
PD	24.04	41.51	54.68	64.93	73.04	79.82	85.70	119.2	152.8	186.9
LD	175.3	189.7	204.0	219.9	235.6	257.1	278.2	300.0	326.4	351.1
%-	629.4	357.0	273.2	238.7	222.6	222.1	224.6	151.6	113.5	87.81
4.D - Wastewater Treatment and Discharge										
PD	231.6	237.1	243.9	250.1	256.9	263.5	269.9	276.4	282.8	289.6
LD	224.4	227.1	236.0	241.9	251.6	258.1	264.9	274.2	280.6	287.4
%-	-3.11	-4.20	-3.23	-3.25	-2.08	-2.06	-1.87	-0.80	-0.79	-0.76
4.B - Biological Treatment of Solid Waste										
PD	105.5	110.4	115.6	121.0	126.7	132.6	140.3	145.3	152.1	159.3
LD	140.0	143.6	147.3	151.2	163.4	167.6	172.1	152.5	156.0	159.6
%-	32.73	30.08	27.49	24.94	28.97	26.39	22.66	4.92	2.54	0.20
4.C - Incineration and Open Burning of Waste										
PD	1.06	1.08	1.12	1.14	1.17	1.20	1.23	1.26	1.29	1.32
LD	1.32	1.35	1.39	1.42	1.46	1.50	1.53	1.57	1.60	1.64
%-	24.50	24.50	24.50	24.50	24.50	24.50	24.50	24.50	24.50	24.50
4.D - Wastewater Treatment and Discharge										
PD	231.6	237.1	243.9	250.1	256.9	263.5	269.9	276.4	282.8	289.6
LD	224.4	227.1	236.0	241.9	251.6	258.1	264.9	274.2	280.6	287.4
%-	-3.11	-4.20	-3.23	-3.25	-2.08	-2.06	-1.87	-0.80	-0.79	-0.76

1.7 Assessment of completeness

The present national GHG inventory for the Republic of Rwanda for the period 2006-2018 is mostly complete for direct gases including CO_2, CH_4, N_2O, and HFCs. In this inventory, an effort was made to estimate all the direct GHG emissions for all the source categories under Energy, Industrial Process and Product use (IPPU), Agriculture, Forestry, and Land Use (AFOLU), and Waste sectors. Completeness tables of considered categories are provided in detail under respective sections of Rwanda's NIR. Despite the effort made, GHG emissions from some categories and subcategories were not included in this inventory chiefly due to lack of source data. Details on various gaps in the inventory and related data gaps are discussed in the section on planned improvements. Though reporting on precursors and indirect emissions is not mandatory for Non-Annex I countries, there is a need to consider these gases in future reports of national communication since they are linked with national air pollution management which is a priority for the GoR.

Table 1.8 General completeness assessment

Categories	CO_2	CH_4	N_2O	HFCs	PFCs	SF_6	NO_X	CO	NMVOCs	SO_2
1 - Energy										
1.A - Fuel Combustion Activities	X	X	X	NA	NA	NA	NE	NE	NA	NA
1.A.1 - Energy Industries	X	X	X	NA	NA	NA	NE	NE	NA	NA
1.A.1 - Energy Industries	X	X	X	NA	NA	NA	NE	NE	NA	NA
1.A.3 - Transport	X	X	X	NA	NA	NA	NE	NE	NA	NA
1.A.4 - Other Sectors	X	X	X	NA	NA	NA	NE	NE	NA	NA
1.A.5 - Non-Specified	NO	NO	NO	NA	NA	NA	NO	NO	NO	NO
1.B - Fugitive emissions from fuels										
1.B.1 - Solid Fuels	NO	NO	NO	NA	NA	NA	NO	NO	NO	NO
1.B.2 - Oil and Natural Gas	NO	NO	NO	NA	NA	NA	NO	NO	NO	NO
1.B.3 - Other emissions from Energy Production	NO	NO	NO	NA	NA	NA	NO	NO	NO	NO
1.C - Carbon dioxide Transport and Storage	NO	NO	NO	NA	NA	NA	NO	NO	NO	NO
1.C.1 - Transport of CO_2	NO	NO	NO	NA	NA	NA	NO	NO	NO	NO
1.C.2 - Injection and Storage	NO	NO	NO	NA	NA	NA	NO	NO	NO	NO
1.C.3 - Other	NO	NO	NO	NA	NA	NA	NO	NO	NO	NO
2 - Industrial Processes and Product Use										
2.A - Mineral Industry	X	NA	NA	NA	NA	NA	NA	NA	NA	NA
2.A.1 - Cement production	X	NA	NA	NA	NA	NA	NA	NA	NA	NA
2.A.2 - Lime production	X	NA	NA	NA	NA	NA	NA	NA	NA	NA
2.A.3 - Glass Production	NO	NA	NA	NA	NA	NA	NA	NA	NA	NA
2.A.4 - Other Process Uses of Carbonates	NO	NA	NA	NA	NA	NA	NA	NA	NA	NA
2.A.5 - Other (please specify)	NO	NO	NO	NA	NA	NA	NA	NA	NA	NA
2.B - Chemical Industry										
2.B.1 - Ammonia Production	NO	NA	NA	NA	NA	NA	NA	NA	NA	NA
2.B.2 - Nitric Acid Production	NA	NA	NO	NA	NA	NA	NA	NA	NA	NA
2.B.3 - Adipic Acid Production	NA	NA	NO	NA	NA	NA	NA	NA	NA	NA
2.B.4 - Caprolactam, Glyoxal, and Glyoxylic Acid Production	NA	NA	NO	NA	NA	NA	NA	NA	NA	NA

Categories	CO_2	CH_4	N_2O	HFCs	PFCs	SF_6	NO_x	CO	NMVOCs	SO_2
2.B.5 - Carbide Production	NO	NO	NA	NA	NA	NA	NA	NA	NA	NA
2.B.6 - Titanium Dioxide Production	NO	NA	NA	NA	NA	NA	NA	NA	NA	NA
2.B.7 - Soda Ash Production	NO	NA	NA	NA	NA	NA	NA	NA	NA	NA
2.B.8 - Petrochemical and Carbon Black Production	NO	NO	NA	NA	NA	NA	NA	NA	NA	NA
2.B.9 - Fluorochemical Production	NA	NA	NA	NO	NO	NO	NA	NA	NA	NA
2.B.10 - Other (Please specify)	NO	NO	NO	NO	NO	NO	NA	NA	NA	NA
2.C - Metal Industry										
2.C.1 - Iron and Steel Production	X	X	NA	NA	NA	NA	NA	NA	NA	NA
2.C.2 - Ferroalloys Production	X	NO	NA	NA	NA	NA	NA	NA	NA	NA
2.C.3 - Aluminium production	NO	NA	NA	NA	NO	NA	NA	NA	NA	NA
2.C.4 - Magnesium production	NO	NA	NA	NA	NA	NO	NA	NA	NA	NA
2.C.5 - Lead Production	NO	NA	NA	NA	NA	NA	NA	NA	NA	NA
2.C.6 - Zinc Production	NO	NA	NA	NA	NA	NA	NA	NA	NA	NA
2.C.7 - Other (please specify)	NO	NO	NO	NO	NO	NO	NA	NA	NA	NA
2.D - Non-Energy Products from Fuels and Solvent Use										
2.D.1 - Lubricant Use	X	NA	NA	NA	NA	NA	NE	NE	NE	NE
2.D.2 - Paraffin Wax Use	X	NA	NA	NA	NA	NA	NE	NE	NE	NE
2.D.3 - Solvent Use	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
2.D.4 - Other (please specify)	NO	NO	NO	NA	NA	NA	NA	NA	NA	NA
2.E - Electronics Industry										
2.E.1 - Integrated Circuit or Semiconductor	NA	NA	NA	NO	NO	NO	NA	NA	NA	NA
2.E.2 - TFT Flat Panel Display	NA	NA	NA	NA	NO	NO	NA	NA	NA	NA
2.E.3 - Photovoltaics	NA	NA	NA	NA	NO	NA	NA	NA	NA	NA
2.E.4 - Heat Transfer Fluid	NA	NA	NA	NA	NO	NA	NA	NA	NA	NA
2.E.5 - Other (please specify)	NO	NO	NO	NO	NO	NO	NA	NA	NA	NA
2.F - Product Uses as Substitutes for Ozone Depleting Substances										
2.F.1 - Refrigeration and Air Conditioning	NA	NA	NA	X	NA	NA	NA	NA	NA	NA
2.F.2 - Foam Blowing Agents	NA	NA	NA	NO	NA	NA	NA	NA	NA	NA
2.F.3 - Fire Protection	NA	NA	NA	NO	NO	NA	NA	NA	NA	NA

Categories	CO_2	CH_4	N_2O	HFCs	PFCs	SF_6	NO_x	CO	NMVOCs	SO_2
2.F.4 - Aerosols	NA	NA	NA	NO	NA	NA	NA	NA	NA	NA
2.F.5 - Solvents	NA	NA	NA	NO	NO	NA	NA	NA	NA	NA
2.F.6 - Other Applications (please specify)	NA	NA	NA	NO	NO	NA	NA	NA	NA	NA
2.G - Other Product Manufacture and Use										
2.G.1 - Electrical Equipment	NA	NA	NA	NA	NO	NO	NA	NA	NA	NA
2.G.2 - SF_6 and PFCs from Other Product Uses	NA	NA	NA	NA	NO	NO	NA	NA	NA	NA
2.G.3 - N_2O from Product Uses	NA	NA	NO	NA	NA	NA	NA	NA	NA	NA
2.G.4 - Other (Please specify)	NO	NO	NO	NO	NO	NO	NA	NA	NA	NA
2.H - Other										
2.H.1 - Pulp and Paper Industry	NO	NO	NA	NA	NA	NA	NA	NA	NA	NA
2.H.2 - Food and Beverages Industry	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
2.H.3 - Other (please specify)	NO	NO	NO	NA	NA	NA	NA	NA	NA	NA
3 - Agriculture, Forestry, and Other Land Use										
3.A - Livestock	NA	X	X	NA	NA	NA	NA	NA	NA	NA
3.A.1 - Enteric Fermentation	NA	X	NA	NA	NA	NA	NA	NA	NA	NA
3.A.2 - Manure Management	NA	X	X	NA	NA	NA	NA	NA	NA	NA
3.B - Land										
3.B.1 - Forest land	X	NA	NA	NA	NA	NA	NA	NA	NA	NA
3.B.2 - Cropland	X	NA	NA	NA	NA	NA	NA	NA	NA	NA
3.B.3 - Grassland	X	NA	NA	NA	NA	NA	NA	NA	NA	NA
3.B.4 - Wetlands	X	NA	X	NA	NA	NA	NA	NA	NA	NA
3.B.5 - Settlements	X	NA	NA	NA	NA	NA	NA	NA	NA	NA
3.B.6 - Other Land	X	NA	NA	NA	NA	NA	NA	NA	NA	NA
3.C - Aggregate sources and non-CO_2 emissions sources on land										
3.C.1 - Emissions from biomass burning	NA	X	X	NA	NA	NA	X	X	NA	NA
3.C.2 - Liming	X	NA	NA	NA	NA	NA	NA	NA	NA	NA
3.C.3 - Urea application	X	NA	NA	NA	NA	NA	NA	NA	NA	NA
3.C.4 - Direct N_2O Emissions from managed soils	NA	NA	X	NA	NA	NA	NA	NA	NA	NA
3.C.5 - Indirect N_2O Emissions from managed soils	NA	NA	X	NA	NA	NA	NA	NA	NA	NA

Categories	CO_2	CH_4	N_2O	HFCs	PFCs	SF_6	NO_X	CO	NMVOCs	SO_2
3.C.6 - Indirect N_2O Emissions from manure management	NA	NA	X	NA	NA	NA	NA	NA	NA	NA
3.C.7 - Rice cultivation	NA	X	NA	NA	NA	NA	NA	NA	NA	NA
3.C.8 - Other (please specify)	NA	NO	NO	NA	NA	NA	NO	NO	NO	NO
3.D - Other										
3.D.1 - Harvested Wood Products	X	NA	NA	NA	NA	NA	NA	NA	NA	NA
3.D.2 - Other (please specify)	NO	NO	NO	NA	NA	NA	NA	NA	NA	NA
4 - Waste										
4.A - Solid Waste Disposal	NA	X	NA	NA	NA	NA	NA	NA	NA	NA
4.B - Biological Treatment of Solid Waste	NA	X	X	NA	NA	NA	NA	NA	NA	NA
4.C - Incineration and Open Burning of Waste	X	X	X	NA	NA	NA	NA	NA	NA	NA
4.D - Wastewater Treatment and Discharge	NA	X	X	NA	NA	NA	NA	NA	NA	NA
4.E - Other (please specify)	NO	NO	NO	NA	NA	NA	NA	NA	NA	NA
5 - Other										
5.A - Indirect N_2O emissions from the atmospheric deposition of nitrogen in NO_X and NH_3	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
5.B - Other (please specify)	NO	NA	NA	NA	NA	NA	NA	NA	NA	NA
Memo Items (5)										
International Bunkers										
1.A.3.a.i - International Aviation (International Bunkers)	X	X	X	NA	NA	NA	NA	NA	NA	NA
1.A.3.d.i - International water-borne navigation (International bunkers)	NO	NO	NO	NA	NA	NA	NA	NA	NA	NA
1.A.5.c - Multilateral Operations	NO	NO	NO	NA	NA	NA	NA	NA	NA	NA

X: Estimated, NO: Not occurring, NA: Not Applicable, NE: Not Estimated

1.8 Planned improvements

The list of the identified future improvement areas are presented in **Table 1.9.** As discussed in subsequent sections, planned improvements in various sectors will encompass improvement in methodology (including QA/QC. uncertainty assessment and completeness at sectoral level), an improvement on capacity building and information sharing, and Strategies for long-term improvement.

Table 1.9 List of planned improvement activities

	Category	Sub-category	Challenge	Planned improvement
General	All	All	Insufficient capacity to conduct higher tier inventories and insufficient research on local emission factors to address the gaps mentioned below	Further capacity building to the inventory team.
	All	All	Lack of specific methodology for uncertainty management	Development of the uncertainty management system and training of the GHG inventory team on the uncertainty management
Energy sector	Energy industries	Other energy industries	Lack of the activity data	In the future, these gaps could be filled by improving the reporting system and encourage all the companies and cooperatives involved in charcoal production to keep records of their data activities.
		Electricity generation	Lack of country specific data	Conduct measurements of the physical characteristics of various fuels used in electricity generation
		Fugitive emissions	Lack of country specific data	In the future, this challenge could be handled through appropriate research and technical advisory for the companies involved in energy generation.

	Category	Sub-category	Challenge	Planned improvement
	Manufacturing industries and construction	All	Lack of country specific data	Future improvements should focus on the activity data recording and reporting as well as the development of country-specific emission factors.
	Transportation	All	Lack of country specific data	In the future, country-specific physical characteristics of fuels.
	Other sectors	All	Lack of updated activity data	• Conduct regular surveys on fuel consumption in building • Conduct research to develop the country-specific emission factors
IPPU sector	Mineral industries (2.A)	Cement production	Lack of accurate data on clinker fraction	There is a need to improve the data collection by collecting both cement and clinker quantities.
		Lime production	lack of country specific emission factor	Lime-producing industries in Rwanda should continue to record their production and provide the data to MINICOM to ease future inventories without conducting surveys.
	Metal industries (2.C)	All	Lack of disaggregated data	There is a need to develop methodologies for data collection for metal industries
	Non-Energy Products from Fuels and Solvent Use (2.D)	All		Further improvement can be made through surveys on the different uses of paraffin wax at the national level. In addition, a survey at Rwanda Energy Group is needed to provide detailed information on the consumption of Sulphur hexafluoride (SF_6) used in electrical equipment as gas-insulated switchgear

	Category	Sub-category	Challenge	Planned improvement
				and substations, and gas circuit breakers.
AFOLU sector	Livestock (3A)	3.A.1 Enteric fermentation	Lack of regular official data for livestock population structure and characteristics – mass, feeding habits, N excretion	A more complete database should be built for livestock populations by type and their characterizations, including mass, feeding habits and other factors related to GHG emissions such as N excretion and N fraction managed in different manure management systems.
	Land (3B)	3.A.2 Manure management systems (MMS)	Lack of information on N fraction in different MMS	Collect information on N fractions managed in different MMS.
		All	Lack of data on CH_4 emissions from different groups of swine, e.g., breeding swine and other	Conduct research to determine CH_4 emissions from swine
			Access to land use maps and staff time;	Plan for GIS staff at REMA and committee harmonizing various GIS data from different institutions
			Inconsistencies between land use classes reported by different public institutions, especially, for Agriculture – the harvested area from all crops exceeds the total area available for Agriculture due to intercropping;	

	Category	Sub-category	Challenge	Planned improvement
			Lack of "reference" office for merging all GIS data (ex. NISR oversees statistics but no detailed GIS data is available, which match the reported statistics (i.e., reported area of non-cultivated wetland does not match with the reported rice area and other cropland in wetlands, all together, they exceed the total area of wetlands from land use maps;	
	Land (3B)	All	Difficulty to differentiate maize area from grassland on land use maps;	Use crosscheck with data reported by Districts to MINAGRI to help disaggregation.
			Lack of local data on carbon stock and its change with land use for each AE Zone;	Conduct study on carbon stock and its change vs past soil surveys and published information analysis for an update of all available information
			Level of data disaggregation (having data at district level leaves to make assumptions/conclusion on Land Use Change extent which is less precise as if it would be if data were at the sector level);	Conduct GIS assessment with disaggregated data up to sector and cell levels. Land use and Land Use Change matrix going below the level of the district could facilitate the certainty of the Land Use Change detailed data.

	Category	Sub-category	Challenge	Planned improvement
		3.B.1 Forestland 3.B.2 Cropland	Lack of National statistics on harvested wood products.	Discuss with NISR to include data on wood harvest into Statistical Yearbook reports (annually)
			Lack of data on Agroforestry and carbon removal from agroforestry trees;	Conduct survey to assess wood harvest from agroforestry trees, and GIS analysis to document agroforestry cover via maps, otherwise, available forest survey data.
			Lack of data on soil C stock in different AE Zones and	Conduct an extensive study on C-stock in main cropland sub-categories and its change using available soil map data
	Agriculture (3C)	3.B.4 Wetlands	Lack of mapping of peatlands and their proportions used for peat extraction and agricultural use on annual basis;	Conduct surveys to assess the extent of peat extraction and GIS data analysis from available soil data to assess the proportion of peatland and other wetlands under cropland use.
		3.C.1 Biomass burning	Lack of National statistics on fire on land (cropland, forest, grassland)	Discuss with NISR to include data on fires in different Land Use classes into Statistical Yearbook reports (annually)
		3.C.2 Liming 3.C.4 Direct N_2O emission from managed soils	Lack of official statistics on lime production, origin, and types	Discuss with NISR to include data on agricultural and industrial lime production into Statistical Yearbook reports (annually)
			Lack of measured data on crop residues and manure applied over the whole season and the proportion of crop residues used for	Determine real quantities of crop residues and manure applied over the whole season, including not just crop biomass at harvest, but in addition weeds removed

	Category	Sub-category	Challenge	Planned improvement
			livestock feeding and other purposes.	
			Lack of local data on N content in crop residues	Determine N content in crop residues and weeds;
			Lack of local data on soil C and N and their dynamics in different Land Use Change patterns	Determine changes in soil N and C after Land Use Change and their dynamics (longer-term research on soil restoration.
Waste sector	Solid waste disposal (4A)			Future improvements should focus on developing methodologies for data collection in the waste sector through the partnership of NISR, which regularly collects national data
	Biological Treatment of Solid Waste (4B)	All		Planned improvement should focus on developing methodologies for data collection in the biological treatment of the solid waste sector through the partnership with the NISR, which regularly collects national data.
	Incineration and Open Burning of Waste (4C)	All	Due to lack of sufficient activity data, only clinical waste was considered for the estimation of emissions from incineration of solid waste.	Future improvement should consider the survey of other types of waste incinerated. In addition, there is a need to plan for the best way for the data collection on the quantity of waste incinerated at each hospital in Rwanda.
	Wastewater Treatment and Discharge (4 D)	All	Lack of activity data for some industries	Future improvements should focus on improving the methodology for data collection and consider other

	Category	Sub-category	Challenge	Planned improvement
				types of industrial wastewater such as vegetables, fruits, juices, soap, and detergents, etc. based on the available data.

Chapter 2. Trends in greenhouse gases emissions and removals

2.1 Trends in aggregated GHG emissions

The summary of total GHG emissions and removals was estimated for the period 2006-2018 (**Table 2.1**). As evidenced in the table, GHG emissions by sources dominated over the removals by the sink, resulting in total net emissions in the whole period. It is interesting to note that in the previous inventory reported in the Third National Communication (TNC), GHG emissions from FOLU had a dominant contribution to net emissions, resulting in net carbon sequestration. As it will be detailed in the subsequent sections, the difference in GHG emissions is the result of improvement in GHG emission calculation methodology and the discovery of new data sets, especially in agriculture and land use subcategories, which remained the dominant contributor to total GHG emissions and removals.

During the period 2006-2018, the dynamic of Rwanda's net GHG emissions had an increasing trend in total net emissions with some peaks in 2010, 2015, and 2018. The later peaks, which stem from Enteric the fermentation subcategory, were due to the higher dairy cow population numbers in these years as compared to other years.

Trends and shares in total GHG emissions and total GHG emissions and removals excluding FOLU are presented in **Figure 2.1.** It is evident from that the GHG emissions from the agriculture subsector had a dominant contribution to total GHG emissions excluding FOLU, followed by the Energy and Waste sectors, while IPPU had a minute contribution. The analysis of **Figure 2.2** shows that the GHG removals from Forestland dominate over the total GHG emissions from Land Use, resulting in net GHG sequestration in the FOLU subsector. In addition, it is important to note that the net GHG removals from FOLU are higher than the GHG emissions from the Agriculture subsector, making the AFOLU sector a net sink of GHG emissions (**Table 2.1**).

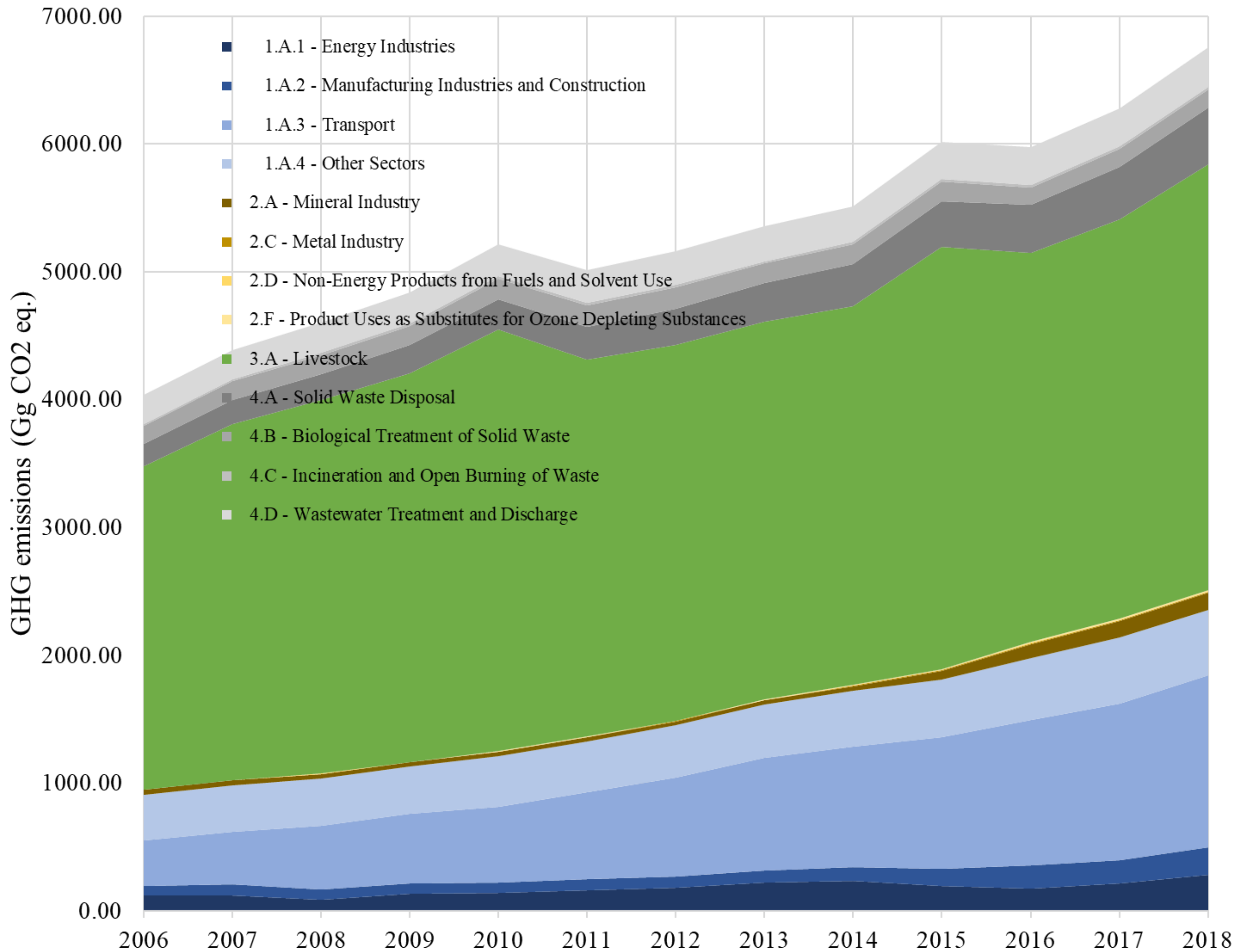


Figure 2.1 Trends in total GHG emissions and removals excluding Forestry and Other Land Use, Gg CO_2 eq. (2006-2018)

Table 2.1 Summary of GHG emissions and removals (Gg CO_2 eq.)

Categories	2006	2015	2016	2017	2018
Total National Emissions and Removals	**981.71**	**1,820.75**	**1,532.64**	**2,278.77**	**2,630.11**
1 - Energy	909.21	1,808.31	1,977.31	2,136.51	2,354.85
1.A - Fuel Combustion Activities	909.21	1,808.31	1,977.31	2,136.51	2,354.85
1.A.1 - Energy Industries	115.65	193.32	171.29	212.00	277.44
1.A.2 - Manufacturing Industries and Construction	75.46	134.00	183.03	184.75	220.87
1.A.3 - Transport	359.52	1,031.63	1,137.51	1,226.04	1,344.53
1.A.4 - Other Sectors	358.57	449.35	485.47	513.72	512.00
1.A.5 - Non-Specified	NO	NO	NO	NO	NO
1.B - Fugitive emissions from fuels	NO	NO	NO	NO	NO
1.B.1 - Solid Fuels	NO	NO	NO	NO	NO
1.B.2 - Oil and Natural Gas	NO	NO	NO	NO	NO
1.B.3 - Other emissions from Energy Production	NO	NO	NO	NO	NO
1.C - Carbon dioxide Transport and Storage	NO	NO	NO	NO	NO
1.C.1 - Transport of CO_2	NO	NO	NO	NO	NO
1.C.2 - Injection and Storage	NO	NO	NO	NO	NO
1.C.3 - Other	NO	NO	NO	NO	NO
2 - Industrial Processes and Product Use	40.26	81.68	125.26	147.09	151.41
2.A - Mineral Industry	38.88	69.11	109.85	131.73	134.90
2.A.1 - Cement production	38.10	65.44	106.68	129.15	132.81
2.A.2 - Lime production	0.79	3.67	3.17	2.58	2.09
2.A.3 - Glass Production	NO	NO	NO	NO	NO
2.A.4 - Other Process Uses of Carbonates	NO	NO	NO	NO	NO
2.A.5 - Other (please specify)	NO	NO	NO	NO	NO
2.B - Chemical Industry	NO	NO	NO	NO	NO
2.B.1 - Ammonia Production	NO	NO	NO	NO	NO
2.B.2 - Nitric Acid Production	NO	NO	NO	NO	NO

Categories	2006	2015	2016	2017	2018
Total National Emissions and Removals	**981.71**	**1,820.75**	**1,532.64**	**2,278.77**	**2,630.11**
2.B.3 - Adipic Acid Production	NO	NO	NO	NO	NO
2.B.4 - Caprolactam, Glyoxal and Glyoxylic Acid Production	NO	NO	NO	NO	NO
2.B.5 - Carbide Production	NO	NO	NO	NO	NO
2.B.6 - Titanium Dioxide Production	NO	NO	NO	NO	NO
2.B.7 - Soda Ash Production	NO	NO	NO	NO	NO
2.B.8 - Petrochemical and Carbon Black Production	NO	NO	NO	NO	NO
2.B.9 - Fluorochemical Production	NO	NO	NO	NO	NO
2.B.10 - Other (Please specify)	NO	NO	NO	NO	NO
2.C - Metal Industry	0.00	1.52	1.58	2.84	3.77
2.C.1 - Iron and Steel Production	0.00	1.41	1.43	2.71	3.65
2.C.2 - Ferroalloys Production	0.00	0.11	0.14	0.13	0.12
2.C.3 - Aluminium production	NO	NO	NO	NO	NO
2.C.4 - Magnesium production	NO	NO	NO	NO	NO
2.C.5 - Lead Production	NO	NO	NO	NO	NO
2.C.6 - Zinc Production	NO	NO	NO	NO	NO
2.C.7 - Other (please specify)	NO	NO	NO	NO	NO
2.D - Non-Energy Products from Fuels and Solvent Use	0.96	3.88	5.67	3.40	3.17
2.D.1 - Lubricant Use	0.78	2.47	4.46	2.05	2.03
2.D.2 - Paraffin Wax Use	0.18	1.40	1.21	1.35	1.14
2.D.3 - Solvent Use	NO	NO	NO	NO	NO
2.D.4 - Other (please specify)	NO	NO	NO	NO	NO
2.E - Electronics Industry	NO	NO	NO	NO	NO
2.E.1 - Integrated Circuit or Semiconductor	NO	NO	NO	NO	NO
2.E.2 - TFT Flat Panel Display	NO	NO	NO	NO	NO
2.E.3 - Photovoltaics	NO	NO	NO	NO	NO
2.E.4 - Heat Transfer Fluid	NO	NO	NO	NO	NO

Categories	2006	2015	2016	2017	2018
Total National Emissions and Removals	**981.71**	**1,820.75**	**1,532.64**	**2,278.77**	**2,630.11**
2.E.5 - Other (please specify)	NO	NO	NO	NO	NO
2.F - Product Uses as Substitutes for Ozone Depleting Substances	0.42	7.18	8.16	9.12	9.57
2.F.1 - Refrigeration and Air Conditioning	0.42	7.18	8.16	9.12	9.57
2.F.2 - Foam Blowing Agents	NO	NO	NO	NO	NO
2.F.3 - Fire Protection	NO	NO	NO	NO	NO
2.F.4 - Aerosols	NO	NO	NO	NO	NO
2.F.5 - Solvents	NO	NO	NO	NO	NO
2.F.6 - Other Applications (please specify)	NO	NO	NO	NO	NO
2.G - Other Product Manufacture and Use	NO	NO	NO	NO	NO
2.G.1 - Electrical Equipment	NO	NO	NO	NO	NO
2.G.2 - SF_6 and PFCs from Other Product Uses	NO	NO	NO	NO	NO
2.G.3 - N_2O from Product Uses	NO	NO	NO	NO	NO
2.G.4 - Other (Please specify)	NO	NO	NO	NO	NO
2.H - Other	NO	NO	NO	NO	NO
2.H.1 - Pulp and Paper Industry	NO	NO	NO	NO	NO
2.H.2 - Food and Beverages Industry	NO	NO	NO	NO	NO
2.H.3 - Other (please specify)	NO	NO	NO	NO	NO
3 - Agriculture, Forestry, and Other Land Use	-522.92	-428.55	-849.58	-706.30	-793.30
3.A - Livestock	2,529.90	3,306.32	3,047.22	3,123.92	3,332.27
3.A.1 - Enteric Fermentation	2,450.56	3,197.07	2,917.93	2,991.31	3,196.97
3.A.2 - Manure Management	79.34	109.25	129.29	132.61	135.30
3.B - Land	-3,688.61	-4,665.20	-4,821.48	-4,779.09	-5,092.36
3.B.1 - Forest land	-5,415.96	-6,663.47	-6,833.67	-6,895.67	-7,090.75
3.B.2 - Cropland	1,296.01	1,568.78	1,595.91	1,674.31	1,609.57
3.B.3 - Grassland	197.19	224.97	199.52	223.10	170.98

Categories	2006	2015	2016	2017	2018
Total National Emissions and Removals	**981.71**	**1,820.75**	**1,532.64**	**2,278.77**	**2,630.11**
3.B.4 - Wetlands	0.00	0.00	11.06	13.70	14.32
3.B.5 - Settlements	232.10	202.45	203.68	204.72	201.45
3.B.6 - Other Land	2.05	2.06	2.03	0.75	2.06
3.C - Aggregate sources and non-CO_2 emissions sources on land	635.78	934.26	928.69	952.99	966.79
3.C.1 - Emissions from biomass burning	NO	153.50	80.77	94.50	75.98
3.C.2 - Liming	NO	NO	8.37	10.72	8.66
3.C.3 - Urea application	1.55	7.74	4.75	2.78	7.02
3.C.4 - Direct N_2O Emissions from managed soils	293.85	377.33	377.27	378.59	405.92
3.C.5 - Indirect N_2O Emissions from managed soils	78.89	109.77	110.76	111.93	119.68
3.C.6 - Indirect N_2O Emissions from manure management	49.07	65.84	68.07	69.32	68.79
3.C.7 - Rice cultivation	212.42	220.10	278.70	285.15	280.74
3.C.8 - Other (please specify)	NO	NO	NO	NO	NO
3.D - Other	NE	NE	NE	NE	NE
3.D.1 - Harvested Wood Products	NE	NE	NE	NE	NE
3.D.2 - Other (please specify)	NO	NO	NO	NO	NO
4 - Waste	555.16	817.33	825.55	872.58	917.16
4.A - Solid Waste Disposal	175.36	351.18	376.58	413.02	446.39
4.B - Biological Treatment of Solid Waste	140.02	159.64	135.10	138.33	141.61
4.C - Incineration and Open Burning of Waste	15.31	19.08	19.73	20.20	20.69
4.D - Wastewater Treatment and Discharge	224.48	287.43	294.15	301.02	308.46
4.E - Other (please specify)	NO	NO	NO	NO	NO
5 - Other	NO	NO	NO	NO	NO
5.A - Indirect N_2O emissions from the atmospheric deposition of nitrogen in NO_X and NH_3	NO	NO	NO	NO	NO
5.B - Other (please specify)	NO	NO	NO	NO	NO
Memo Items (5)					
International Bunkers	5.19	60.04	4.67	60.04	133.06

Categories	2006	2015	2016	2017	2018
Total National Emissions and Removals	**981.71**	**1,820.75**	**1,532.64**	**2,278.77**	**2,630.11**
1.A.3.a.i - International Aviation (International Bunkers)	5.19	60.04	4.67	60.04	133.06
1.A.3.d.i - International water-borne navigation (International bunkers)	NO	NO	NO	NO	NO
1.A.5.c - Multilateral Operations	NO	NO	NO	NO	NO

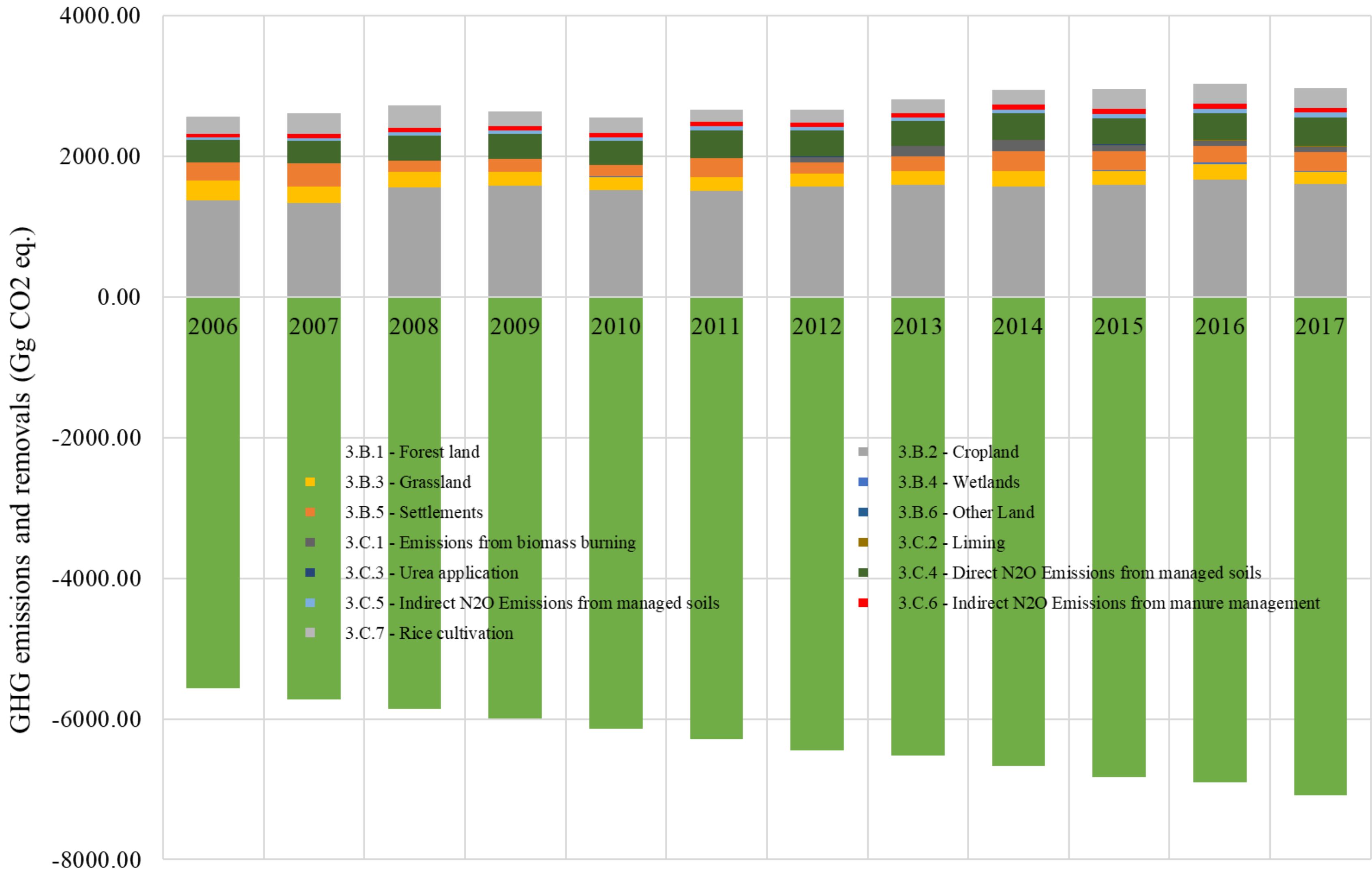


Figure 2.2 Trends and shares in total GHG emissions and removals from FOLU

2.2 Trends and shares in GHG emissions per category

The shares of various sectors to the total GHG emissions and removals for the period 2006-2018 were discussed in previous sections. In these sections, details regarding each sector and its categories are provided.

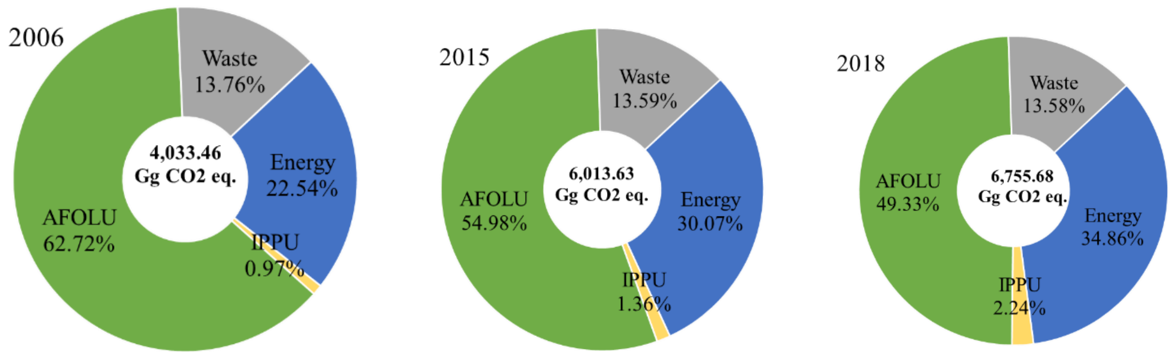


Figure 2.3 Shares of various sectors to total GHG emissions excluding FOLU in 2006, 2015 and 2018

The shares of various sectors to total GHG emissions are shown in **Figure 2.3.** From 2006 to 2018, the net GHG emissions were dominated by the Energy sector since the GHG emissions from Agriculture are partially offset by removals from FOLU. In addition, the share of the Energy sector to total GHG emissions kept increasing predominantly due to the increase in emission from transportation and industries (i.e., energy and manufacturing industries). It is clear from the figures that the share of AFOLU in 2018 has reduced to the half of the share in 2006. This could be justified by the rapid increase of the GHG emissions from Agriculture and Land Use subsectors over the removals from the Forests.

2.2.1 Trends and shares in GHG emissions from Energy Sector

According to the key category analysis, the energy sector is the second contributor to Rwanda's total GHG emissions excluding FOLU. However, considering the FOLU subsector, the Energy sector has become the main contributor to total GHG emissions and Removals since a part of the GHG emissions are offset by the GHG removals from Forests (**Figure 2.3**). The general key category analysis revealed in 2018, four categories from the Energy sector had a key contribution to total GHG emissions from the Energy sector, viz., Road Transportation (1.A.3.b), Other Sectors - Biomass (1.A.4), Energy Industries - Gaseous Fuels (1.A.1) and Energy Industries - Liquid Fuels (1.A.1). In addition, the results from the trend analysis showed that only three categories, i.e., Other Sectors - Biomass (1.A.4), Road Transportation (1.A.3.b), and Manufacturing Industries and Construction - Solid Fuels (1.A.2). A summary of total GHG emissions from the Energy sector is provided in **Table 2.2**. During the period 2006-2018, cumulative total GHG emissions enjoyed a continuously increasing trend.

Table 2.2 Summary of energy sector GHG emissions, Gg CO_2 eq. (2006-2018)

Period	Energy	Manufacturing	Transport	Other	Total	Change
2006	115.65	75.46	359.52	358.56	909.19	0.00%
2007	120.31	84.62	414.79	362.53	982.24	7.44%
2008	82.89	82.74	501.11	366.48	1,033.23	12.00%
2009	131.97	82.03	545.64	369.71	1,129.35	19.49%
2010	135.86	81.46	597.71	395.94	1,210.98	24.92%
2011	159.85	85.52	679.21	397.91	1,322.49	31.25%
2012	179.96	84.15	778.96	405.55	1,448.62	37.24%
2013	221.36	91.10	879.95	417.89	1,610.31	43.54%
2014	229.95	113.67	942.53	433.03	1,719.18	47.11%
2015	193.32	134.00	1,031.63	449.35	1,808.31	49.72%
2016	171.29	183.03	1,137.51	485.47	1,977.31	54.02%
2017	212.00	184.75	1,226.04	513.72	2,136.51	57.44%
2018	277.44	220.87	1,344.53	512.00	2,354.85	61.39%

As it could be seen from the table, transport remained the main source of GHG emissions for the whole period followed by other sectors, while Manufacturing Industries and Construction showed a modest increase contribution. It is noteworthy that the GHG emissions from other sectors are mainly generated by biomass combustion activities and following the IPCC guidelines, the CO_2 emissions generated by biomass are not added to the total GHG emissions. Following the IPCC guidelines, the CH_4 and N_2O emissions from biomass were added to the energy sector totals, whereas the CO_2 emissions were reported as information.

As can be seen from **Figure 2.4,** a sharp increase in GHG emissions from energy industries was observed from 2016, leading to a tremendous increase in total emissions from this year. This increase is attributable to the introduction of new peat to power, methane, and oil-powered power plants in the energy generation industries.

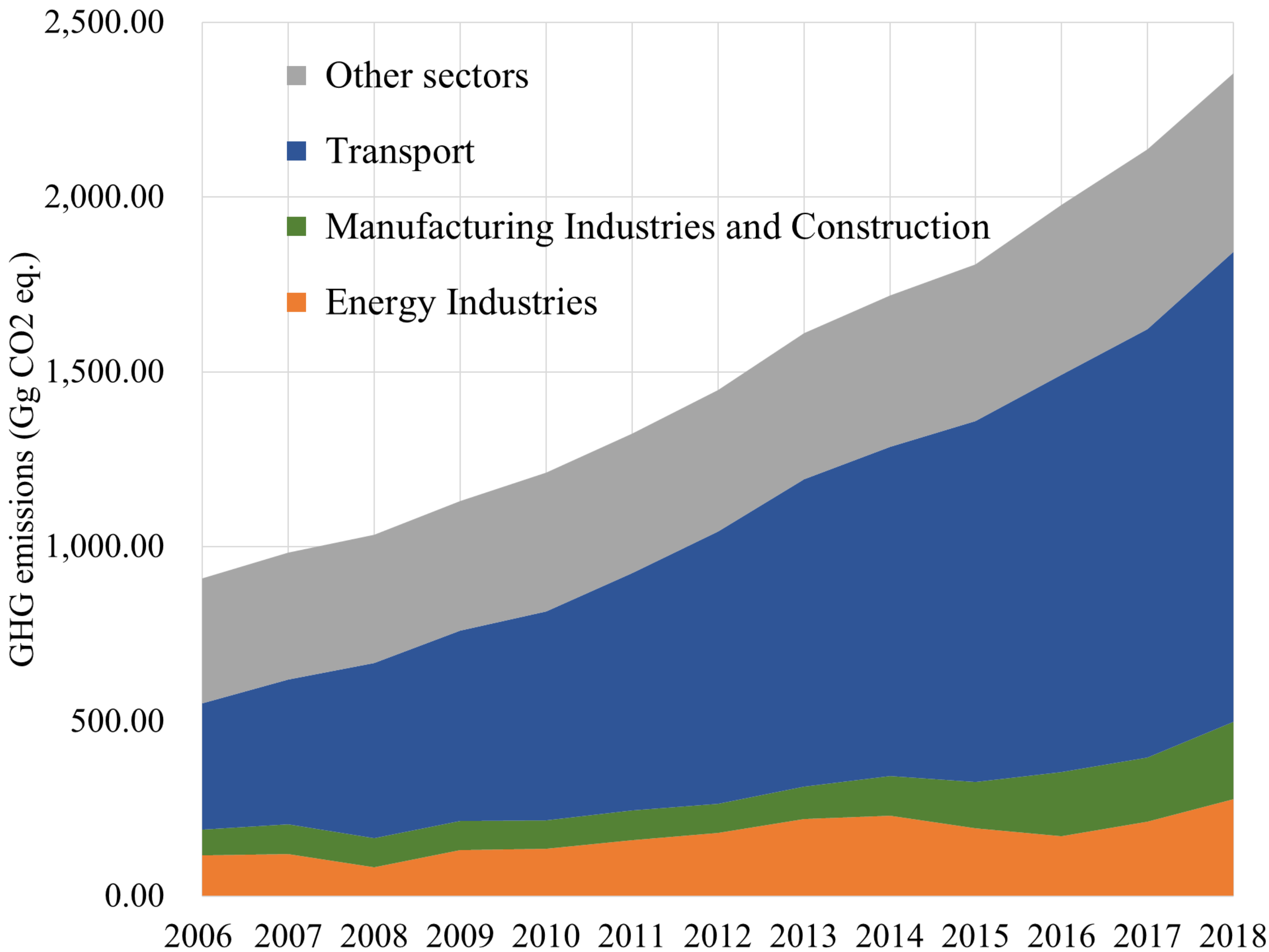


Figure 2.4 Trends in total GHG emissions from energy sector (2006-2018)

It is also important to mention that the results of recalculation brought a major difference between the emissions reported in the TNC and those obtained in the present inventory. The main reason for the difference could be attributed to the improved calculation methodology, the use of new datasets from the recent surveys, and the estimation of the GHG emissions from methane gas power plants, which were considered as natural gas in our analysis. For instance, GHG emissions from Other Sectors, which was the main source of GHG emissions in the previous inventory, present the smallest contribution to the total emissions chiefly due to the improvement in the methodology and the disaggregation of the source categories.

Shares of energy sector categories to total GHG emissions are shown in **Figure 2.5**. Clearly, all the energy subcategories showed an increasing trend. These trends could be explained by the economic growth and the lifestyle change observed over the period 2006-2018.

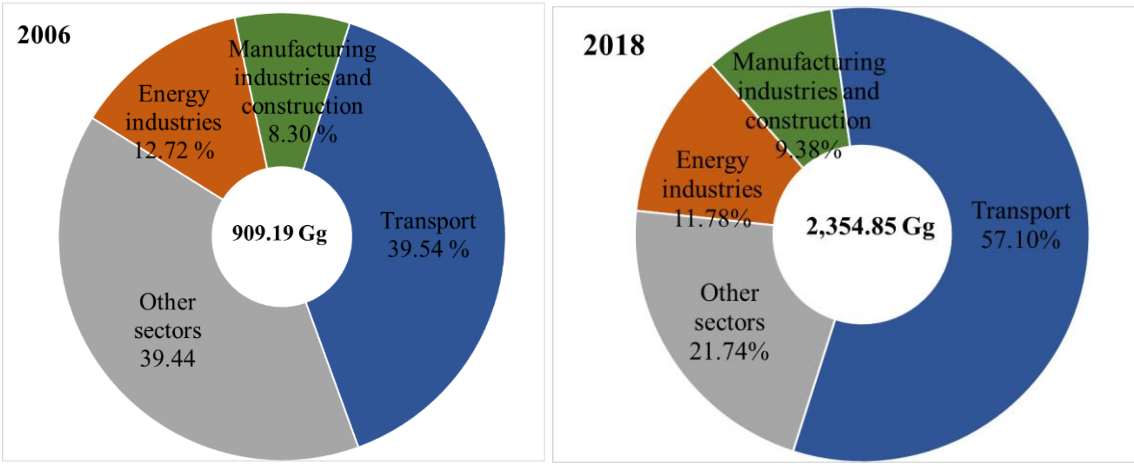


Figure 2.5 Shares of energy sector categories to total GHG emissions (2006-2018)

2.2.2 Trends and shares of GHG in IPPU

The GHG emissions from the IPPU sector in Rwanda include emissions generated from the mineral industry (A.2), metal industry (2.C), Non-Energy Products from Fuels and Solvent Use and (2D), and Product Use as Substitutes of ozone-depleting substances (2F). Nevertheless, considering the context of Rwanda and the activity data availability, only four categories were considered in this inventory. The considered categories and corresponding subcategories include the mineral industry (2A), metal industry (2.C) the Non-Energy Products from Fuels, and Solvent Use (2D and product use as substitutes of ozone-depleting substances (2F).

The results of the general key category analysis indicated that the IPPU sector has a minor contribution to the total GHG emissions with Cement production (2.A.1) as the only key category in 2018. **Figure 2.6** shows the trends and shares of GHG emissions from the IPPU sector. The total GHG emissions from the IPPU sector had a tremendous increase over the 2006-2018 period, which is mainly due to the mineral industries. It is estimated that the total GHG emissions tripled from 2006 to 2018, with an annual growth rate of 12.8%. This increase is mainly due to the use of cement for the construction sector in Rwanda, which is experiencing a huge boost from needed infrastructures, and it is a key driver of the national economy. In addition, the growth in IPPU emissions can be explained by the increasing consumption of lubricants at the national level, which shifted from 1.31 to 3.35 Gg respectively from 2006 through 2018.

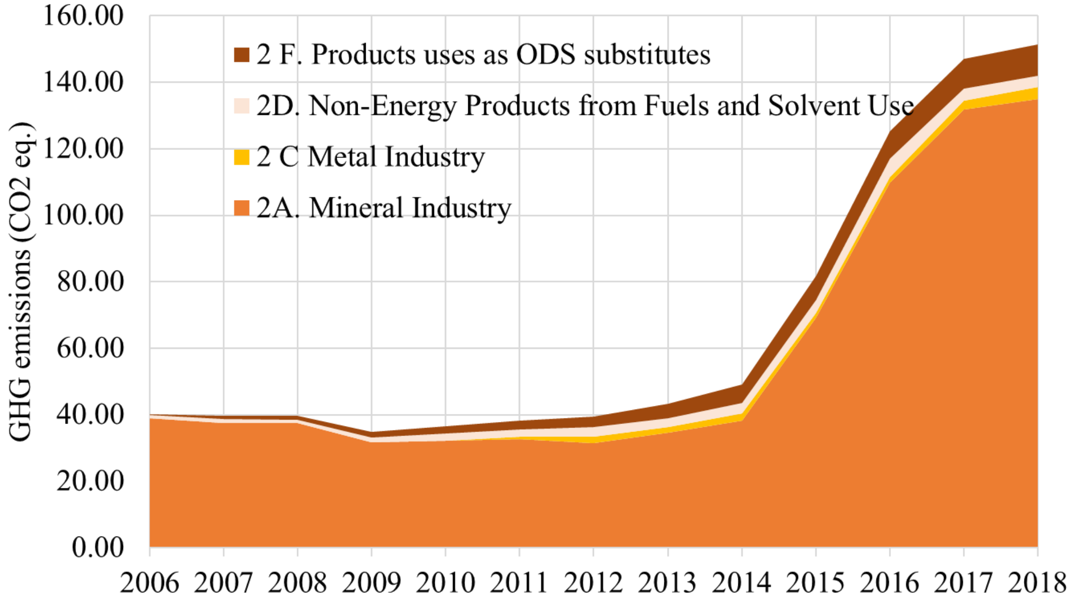


Figure 2.6 Trends and shares in GHG emissions from the IPPU sector

The consumption of lubricants is also linked to the increase in registered moto vehicles. It should be noted that Rwanda had 198,518 registered motor vehicles in 2017, which have increased from 47,631 vehicles in 2006 (REMA, 2019a). The huge import of lubricants in 2016 and the corresponding increase in 2D category emissions, compared to the previous and following years, can be explained by the decline in crude oil price experienced in 2016 as mentioned in historical annual data of oil prices[1]. Similarly, the rise in emissions from product uses as substitutes for ODS is due to the increase of imported quantities of HFCs for refrigeration and stationary air-conditioning.

2.2.3 Trends and shares of GHG emissions and removals in the AFOLU sector

The AFOLU sector, which is divided into Agriculture, Forest and Land Use subsectors, is the main source of GHG emissions and Removals throughout the period 2006-2018. The general key category analysis revealed that eight of the identified sixteen key categories in 2008 were from the AFOLU sector. They include the Enteric Fermentation (3.A.1), Land Converted to Cropland (3.B.2.b), Cropland Remaining Cropland (3.B.2.a), Direct N_2O Emissions from managed soils (3.C.4), Rice cultivation (3.C.7), Land Converted to Settlements (3.B.5.b), Land Converted to Grassland (3.B.3.b), Manure Management (3.A.2). In addition, according to the trend analysis, nine categories out of sixteen key categories were throughout the period 2006-2018. The identified key categories include the Forest land Remaining Forest land (3.B.1.a), Enteric Fermentation (3.A.1), Cropland Remaining Cropland (3.B.2.a), Land Converted to Cropland (3.B.2.b), Direct N_2O Emissions from managed soils (3.C.4), Land Converted to Settlements (3.B.5.b), Land

[1] https://www.macrotrends.net/1369/crude-oil-price-history-chart

Converted to Grassland (3.B.3.b), Rice cultivation (3.C.7), Land Converted to Forestland (3.B.1.b).

The main emission sources from 2006 through 2018 were from Enteric Fermentation, Land Use, and Direct N_2O emissions from managed soils. Change in land use consisted in conversion of forests and grasslands mostly to cropland and a lesser extent to new settlements **(Figure 2.7**). The shares and trends in AFOLU sector are presented on **Figure 2.7**. AFOLU sector was a net sink throughout the period 2006-2018 thanks to emission removals from Forests except for 2009 and 2010. The trend observed through the period 2006-2018 was different from the previous pushed data in AFOLU. The main reason for this difference is the improvement made in GHG emissions calculation, the use of more disaggregated/updated activity, especially disturbance and wood harvest in forests data, and correction of the mistakes in GHG estimate in the urea application category.

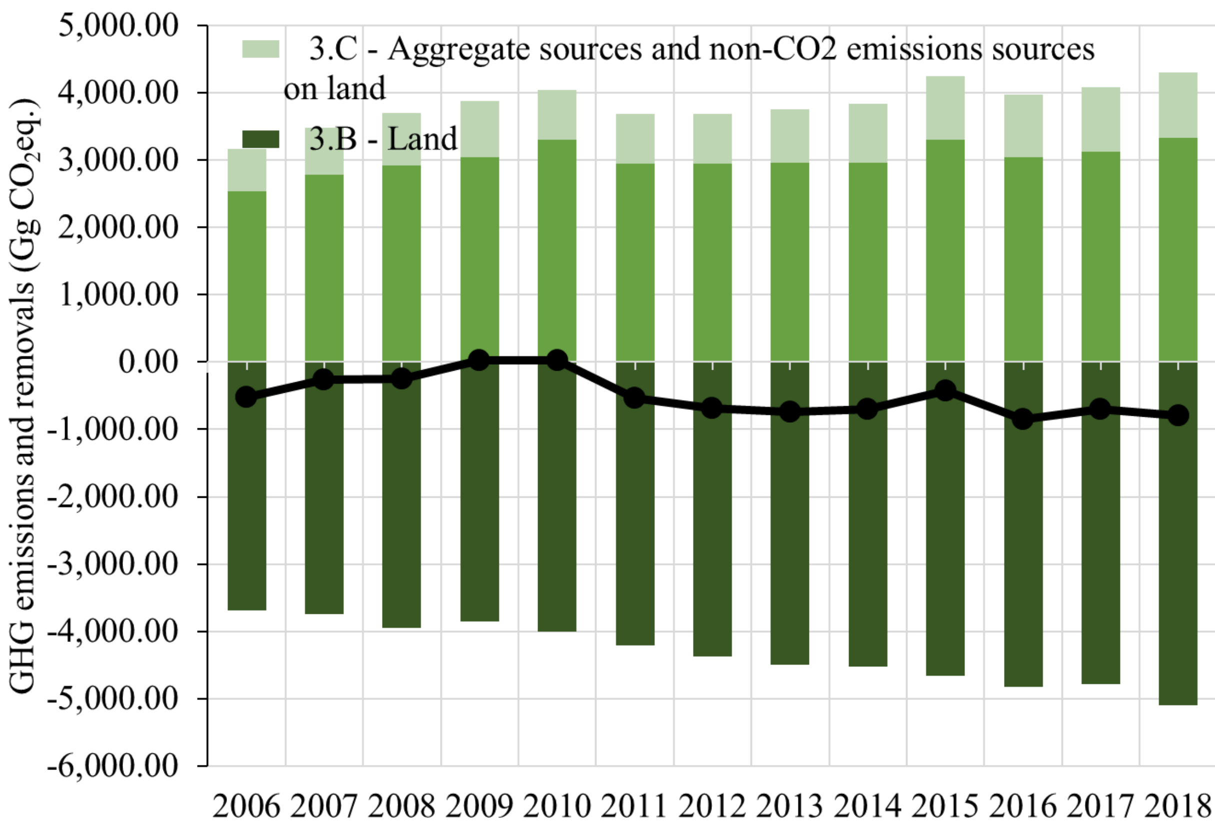


Figure 2.7 Summary and trend in GHG emissions from AFOLU sector

2.2.4 Trends and shares in GHG emissions from the Waste sector

The Waste sector ranks third in the GHG emissions contribution to national total GHG emissions. The results of the level key category analysis show that two categories from the Waste sector viz., Solid Waste Disposal (4.A), Wastewater Treatment, and Discharge (4.D) were key categories in 2018.

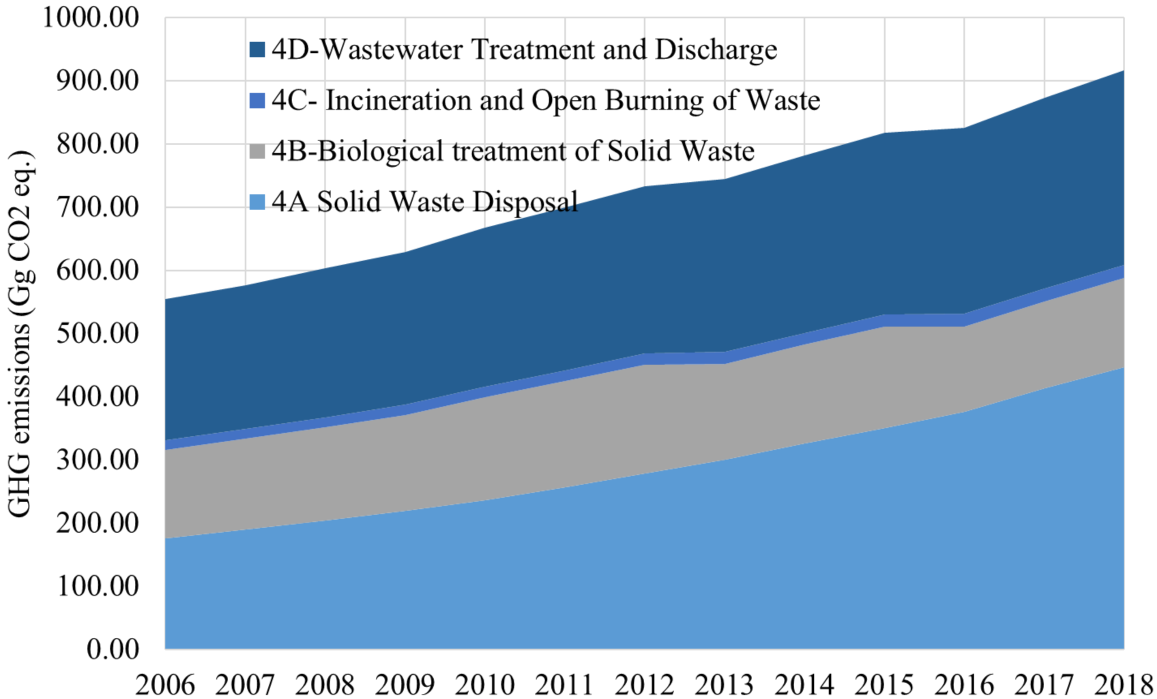


Figure 2.8 Shares and trends in GHG emissions from the waste sector

The current results show a slight growth of emissions in all subcategories mainly due to the increasing population in the same period and changes in the main mode of waste management. In general, the emissions in the Waste sector as shown in **Figure 2.8** were growing at an annual growth rate of 4% from 2006 to 2018. In terms of total emissions hierarchy, the Solid Waste Disposal has the highest emissions (48.67%) followed by Wastewater Treatment and Discharge (33.63%), Biological treatment of Solid Waste (15.44%), and the Incineration and Open Burning of Waste (2.26%). In particular, the increasing emissions from solid waste disposal sites is mainly explained by the involvement of private sector in solid waste collection which has increased the waste collection rate and hence, resulting in the increase of methane emissions from waste ending into dumpsite. On the other hand, the decreasing trend in 4B category is due to the reduction of households at national level with waste undergoing composting which decreased from 56.4% in 2003 to 42.5% in 2017 due to the increasing urbanization and increased involvement of private sector in waste collection services.

2.3 Trends in GHG emissions per gas

As aforementioned, direct GHG (i.e., CO_2, CH_4, N_2O, and HFCs) were mainly considered in this inventory and indirect gases such as carbon monoxide (CO) and Nitrogen oxide (NO_X) were estimated in AFOLU. The summary of total GHG emissions and removals for the period 2006-2018 are shown in **Table 2.3.** As evidenced from the table, during the whole period, CH_4 emissions had a dominant contribution to total GHG emissions followed by the CO_2 removals, whereas the HFCs emissions had a negligible contribution.

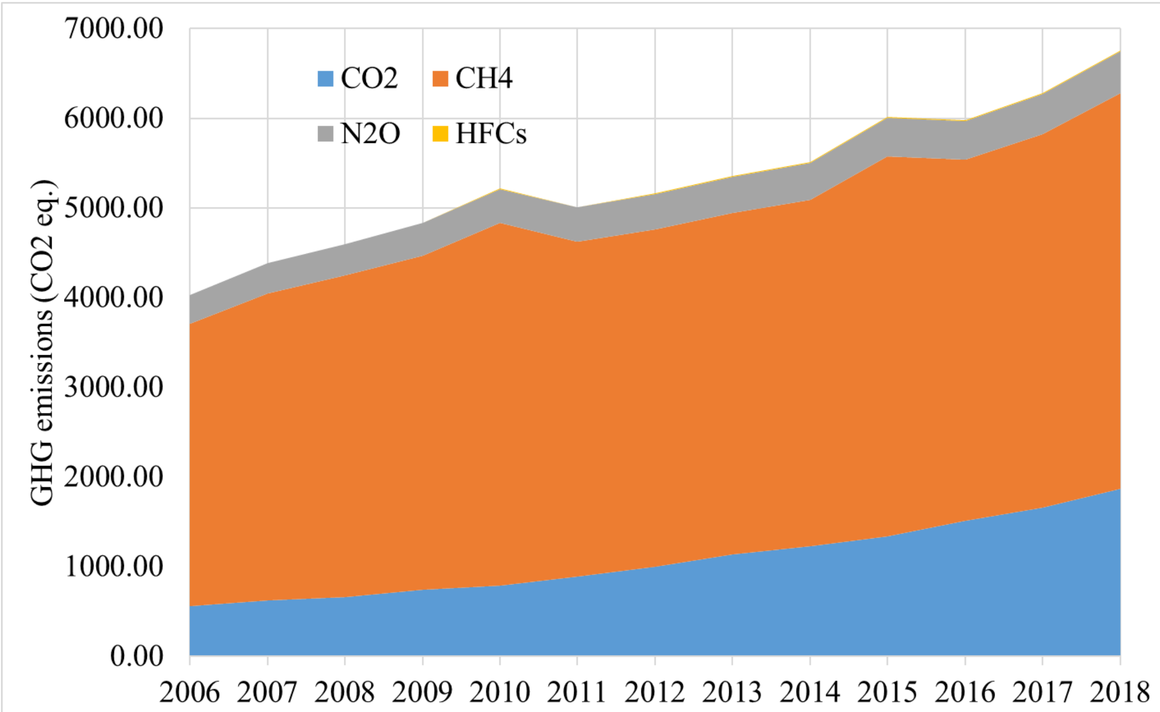


Figure 2.9 Trends in GHG emissions by gas (2006-2018)

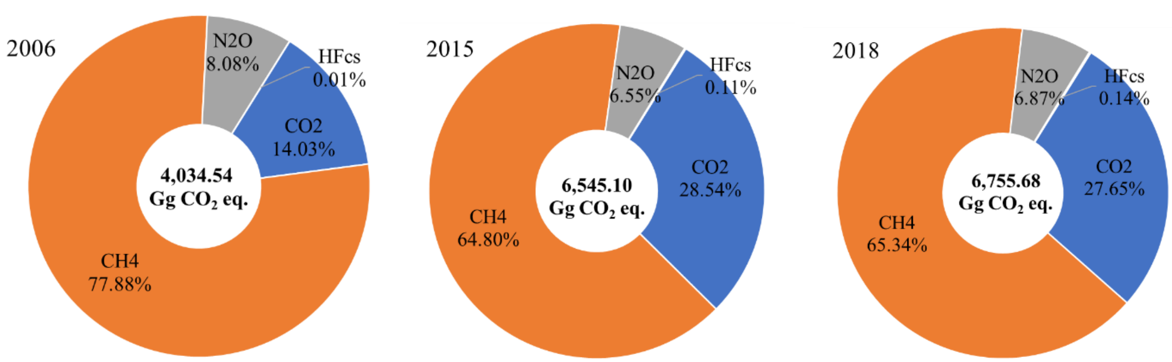


Figure 2.10 Shares of greenhouse gases to total GHG emissions excluding FOLU in 2006, 2015 and 2018

Table 2.3 Summary of GHG emissions and removals by gas in 2018, Gg CO_2 eq.

	CO_2	CH_4	N_2O	HFcs	SF_6	Total
Total National Emissions and Removals	**-3,209.21**	**4,727.26**	**1,102.49**	**9.57**	**NA**	**2,630.11**
Total National Emissions and Removals excluding FOLU	**1,867.83**	**4,414.16**	**464.12**	**9.57**	**NA**	**6,755.68**
1 - Energy	1,722.94	455.00	176.90	NA	NA	2,354.85
1.A - Fuel Combustion Activities	1,722.94	455.00	176.90	NA	NA	2,354.85
1.A.1 - Energy Industries	229.12	16.21	32.11	NA	NA	277.44
1.A.2 - Manufacturing Industries and Construction	145.42	25.39	50.06	NA	NA	220.87
1.A.3 - Transport	1,310.68	11.80	22.05	NA	NA	1,344.53
1.A.4 - Other Sectors	37.72	401.60	72.68	NA	NA	512.00
1.A.5 - Non-Specified	NO	NO	NO	NA	NA	NO
1.B - Fugitive emissions from fuels	NO	NO	NO	NA	NA	NO
1.B.1 - Solid Fuels	NO	NO	NO	NA	NA	NO
1.B.2 - Oil and Natural Gas	NO	NO	NO	NA	NA	NO
1.B.3 - Other emissions from Energy Production	NO	NO	NO	NA	NA	NO
1.C - Carbon dioxide Transport and Storage	NO	NO	NO	NA	NA	NO
1.C.1 - Transport of CO_2	NO	NO	NO	NA	NA	NO
1.C.2 - Injection and Storage	NO	NO	NO	NA	NA	NO
1.C.3 - Other	NO	NO	NO	NA	NA	NO
2 - Industrial Processes and Product Use	141.84	NA	NA	9.57	NA	151.41
2.A - Mineral Industry	134.90	NA	NA	NA	NA	134.90
2.A.1 - Cement production	132.81	NA	NA	NA	NA	132.81
2.A.2 - Lime production	2.09	NA	NA	NA	NA	2.09
2.A.3 - Glass Production	NO	NA	NA	NA	NA	NA
2.A.4 - Other Process Uses of Carbonates	NO	NA	NA	NA	NA	NA
2.B - Chemical Industry	NO	NO	NO	NA	NA	NA
2.B.1 - Ammonia Production	NO	NA	NA	NA	NA	NA
2.B.2 - Nitric Acid Production	NA	NA	NO	NA	NA	NA

	CO_2	CH_4	N_2O	HFcs	SF_6	Total
Total National Emissions and Removals	**-3,209.21**	**4,727.26**	**1,102.49**	**9.57**	**NA**	**2,630.11**
Total National Emissions and Removals excluding FOLU	**1,867.83**	**4,414.16**	**464.12**	**9.57**	**NA**	**6,755.68**
2.B.3 - Adipic Acid Production	NA	NA	NO	NA	NA	NA
2.B.4 - Caprolactam, Glyoxal and Glyoxylic Acid Production	NA	NA	NO	NA	NA	NA
2.B.5 - Carbide Production	NO	NO	NA	NA	NA	NA
2.B.6 - Titanium Dioxide Production	NO	NA	NA	NA	NA	NA
2.B.7 - Soda Ash Production	NO	NA	NA	NA	NA	NA
2.B.8 - Petrochemical and Carbon Black Production	NO	NO	NA	NA	NA	NA
2.B.9 - Fluorochemical Production	NA	NA	NA	NA	NA	NA
2.C - Metal Industry	3.77	0.00	NA	NA	NA	3.77
2.C.1 - Iron and Steel Production	3.65	0.00	NA	NA	NA	3.65
2.C.2 - Ferroalloys Production	0.12	0.00	NA	NA	NA	0.12
2.C.3 - Aluminium production	NO	NA	NA	NA	NA	NO
2.C.4 - Magnesium production	NO	NA	NA	NA	NA	NA
2.C.5 - Lead Production	NO	NA	NA	NA	NA	NA
2.C.6 - Zinc Production	NO	NA	NA	NA	NA	NA
2.D - Non-Energy Products from Fuels and Solvent Use	3.17	NA	NA	NA	NA	3.17
2.D.1 - Lubricant Use	2.03	NA	NA	NA	NA	2.03
2.D.2 - Paraffin Wax Use	1.14	NA	NA	NA	NA	1.14
2.D.3 - Solvent Use	NA	NA	NA	NA	NA	NA
2.E - Electronics Industry	NA	NA	NA	NO	NA	NO
2.E.1 - Integrated Circuit or Semiconductor	NA	NA	NA	NO	NA	NO
2.E.2 - TFT Flat Panel Display	NA	NA	NA	NA	NA	NO
2.E.3 - Photovoltaics	NA	NA	NA	NA	NA	NO
2.E.4 - Heat Transfer Fluid	NA	NA	NA	NA	NA	NO
2.F - Product Uses as Substitutes for Ozone Depleting Substances	NA	NA	NA	9.57	NA	9.57
2.F.1 - Refrigeration and Air Conditioning	NA	NA	NA	9.57	NA	9.57
2.F.2 - Foam Blowing Agents	NA	NA	NA	NE	NA	NE

	CO_2	CH_4	N_2O	HFcs	SF_6	Total
Total National Emissions and Removals	**-3,209.21**	**4,727.26**	**1,102.49**	**9.57**	**NA**	**2,630.11**
Total National Emissions and Removals excluding FOLU	**1,867.83**	**4,414.16**	**464.12**	**9.57**	**NA**	**6,755.68**
2.F.3 - Fire Protection	NA	NA	NA	NE	NA	NE
2.F.4 - Aerosols	NA	NA	NA	NE	NA	NE
2.F.5 - Solvents	NA	NA	NA	NE	NA	NE
2.F.6 - Other Applications (please specify)	NA	NA	NA	NE	NA	NE
2.G - Other Product Manufacture and Use	NA	NA	NA	NO	NA	NO
2.G.1 - Electrical Equipment	NA	NA	NA	NO	NO	NO
2.G.2 - SF_6 and PFCs from Other Product Uses	NA	NA	NA	NO	NE	NO
2.G.3 - N_2O from Product Uses	NA	NA	NE	NA	NA	NE
2.H - Other	NO	NO	NO	NA	NA	NO
2.H.1 - Pulp and Paper Industry	NA	NA	NA	NA	NA	NA
2.H.2 - Food and Beverages Industry	NA	NA	NA	NA	NA	NA
2.H.3 - Other (please specify)	NA	NA	NA	NA	NA	NA
3 - Agriculture, Forestry, and Other Land Use	-5,077.04	3,590.77	692.97	NA	NA	-788.01
3.A - Livestock	NA	3,277.66	54.61	NA	NA	3,332.27
3.A.1 - Enteric Fermentation	NA	3,196.97	NA	NA	NA	3,196.97
3.A.2 - Manure Management	NA	80.69	54.61	NA	NA	135.30
3.B - Land	-5,092.71	NA	0.35	NA	NA	-5,030.22
3.B.1 - Forest land	-7,090.75	NA	NA	NA	NA	-7,090.75
3.B.2 - Cropland	1,609.57	NA	NA	NA	NA	1,609.57
3.B.3 - Grassland	170.98	NA	NA	NA	NA	170.98
3.B.4 - Wetlands	13.97	NA	0.35	NA	NA	11.65
3.B.5 - Settlements	201.45	NA	NA	NA	NA	266.27
3.B.6 - Other Land	2.06	NA	NA	NA	NA	2.06
3.C - Aggregate sources and non-CO_2 emissions sources on land	15.68	313.11	638.01	NA	NA	909.94
3.C.1 - Emissions from biomass burning	0.00	32.36	43.62	NA	NA	74.43
3.C.2 - Liming	8.66	NA	NA	NA	NA	8.66

	CO_2	CH_4	N_2O	HFcs	SF_6	Total
Total National Emissions and Removals	**-3,209.21**	**4,727.26**	**1,102.49**	**9.57**	**NA**	**2,630.11**
Total National Emissions and Removals excluding FOLU	**1,867.83**	**4,414.16**	**464.12**	**9.57**	**NA**	**6,755.68**
3.C.3 - Urea application	7.02	NA	NA	NA	NA	7.02
3.C.4 - Direct N_2O Emissions from managed soils	NA	NA	405.92	NA	NA	405.92
3.C.5 - Indirect N_2O Emissions from managed soils	NA	NA	119.68	NA	NA	64.38
3.C.6 - Indirect N_2O Emissions from manure management	NA	NA	68.79	NA	NA	68.79
3.C.7 - Rice cultivation	NA	280.74	NA	NA	NA	280.74
3.D - Other	NA	NA	NA	NA	NA	NA
3.D.1 - Harvested Wood Products	NE	NA	NA	NA	NA	NA
4 - Waste	3.04	681.49	232.62	NA	NA	917.16
4.A - Solid Waste Disposal	NA	446.39	NA	NA	NA	446.39
4.B - Biological Treatment of Solid Waste	NA	75.10	66.52	NA	NA	141.61
4.C - Incineration and Open Burning of Waste	3.04	14.80	2.85	NA	NA	20.69
4.D - Wastewater Treatment and Discharge	NA	145.21	163.25	NA	NA	308.46
Memo Items (5)	NO	NO	NO	NA	NA	NO
International Bunkers	131.89	0.02	1.14	NA	NA	133.06
1.A.3.a.i - International Aviation (International Bunkers)	131.89	0.02	1.14	NA	NA	133.06
1.A.3.d.i - International water-borne navigation (International bunkers)	NO	NO	NO	NA	NA	NO
1.A.5.c - Multilateral Operations	NO	NO	NO	NA	NA	NO

NO: Not Occurring, NE: Not Estimated, NA: Not Applicable,

Figure 2.9 shows the national GHG emissions for the years 2006 through 2018 from each of the direct gases covered by the national inventory, excluding FOLU. The series shows that emissions increased significantly over the whole period with slight fluctuations in the methane emissions. As explained in the previous sections, the observed peaks in 2010, 2015 and 2018 are related to CH_4 emissions from the enteric fermentation.

Figure 2.10 shows the shares of the direct GHG emissions excluding FOLU in 2006, 2015 and 2018. Methane (CH_4) emissions accounted for the largest share throughout the three years, followed by carbon dioxide (CO_2) emissions and the nitrous oxide (N_2O) emissions. Hydrofluorocarbon (HFCs) represented the lowest share to total GHG emissions excluding FOLU.

2.3.1 Carbon dioxide (CO_2) emissions and removals

During the period between from 2006 through 2018, gross CO_2 emissions (excluding FOLU) estimates showed an increasing trend throughout the whole period 2006-2018. The key sources of these emissions are the combustion activities in the Energy sector, IPPU, and Land Use.

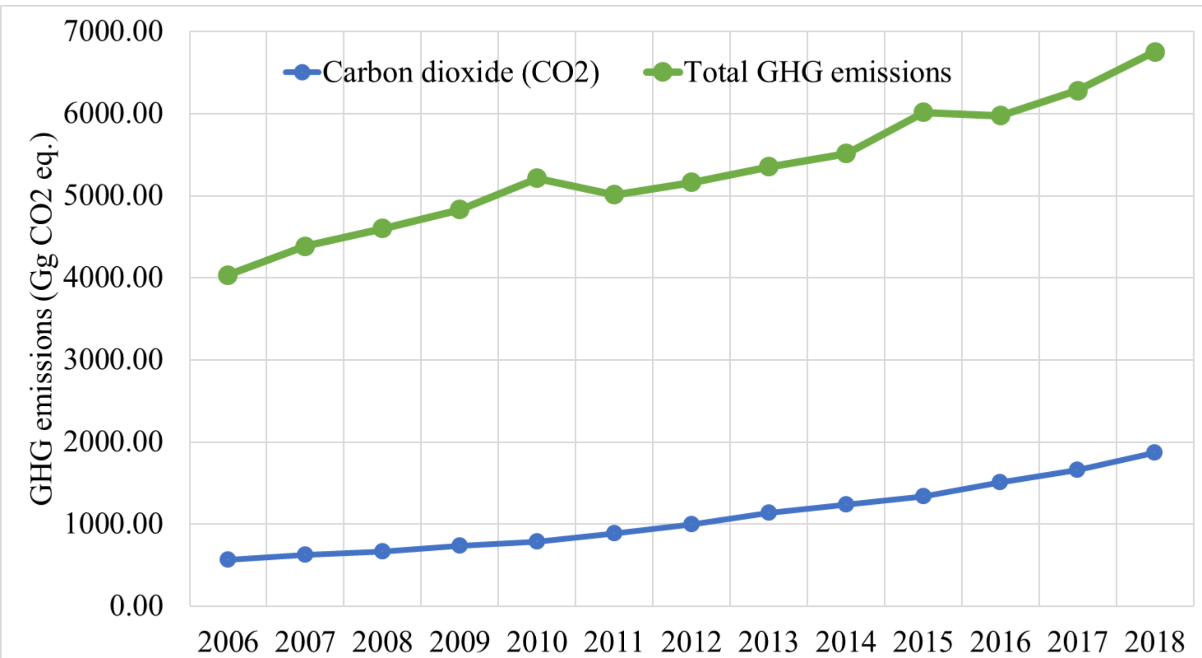


Figure 2.11 Trends in CO_2 emissions/Removals (2006-2018)

However, these emissions were offset by the removals from forests, which showed a steady increase over the inventory period. As it could be seen from **Figure 2.11**, the CO_2 removals remained higher than the CO_2 emissions. However, as will be discussed in subsequent sections, other greenhouse gases (i.e., CH_4 and N_2O) offset these removals and led to net GHG emissions over the inventory period.

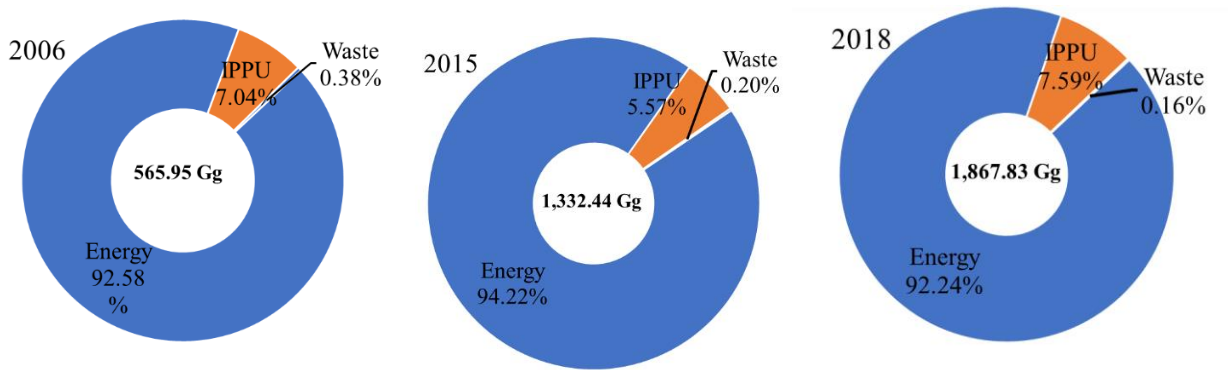


Figure 2.12 CO_2 emissions by sectors in 2006, 2015 and 2018 (excluding FOLU)

Figure 2.12 shows the Greenhouse gas emissions by gases and by sectors in 2006, 2015 and 2018 (excluding Forestry and Other Land Use). The energy sector remained the key source of CO_2 emissions thought the three years followed by IPPU, while the waste sector had the least contribution.

2.3.2 Methane (CH_4) emissions

The methane gas emissions are mainly generated from livestock category some subcategories of the Waste and energy sectors had a considerable contribution to the country's total emissions throughout the period 2006-2018. In 2018, the CH_4 gas emissions appeared in Enteric Fermentation (3.A.1), Solid Waste Disposal (4.A), Other Sectors - Biomass (1.A.4), Rice cultivation (3.C.7), Wastewater Treatment and Discharge (4.D), and Manure Management (3.A.2) key categories. **Figure 2.14** shows the trends in CH_4 gas emissions from 2006-2018. As it could be seen from the figure, the CH_4 gas emissions had an increasing trend with slight fluctuations in the period 2010-2015.

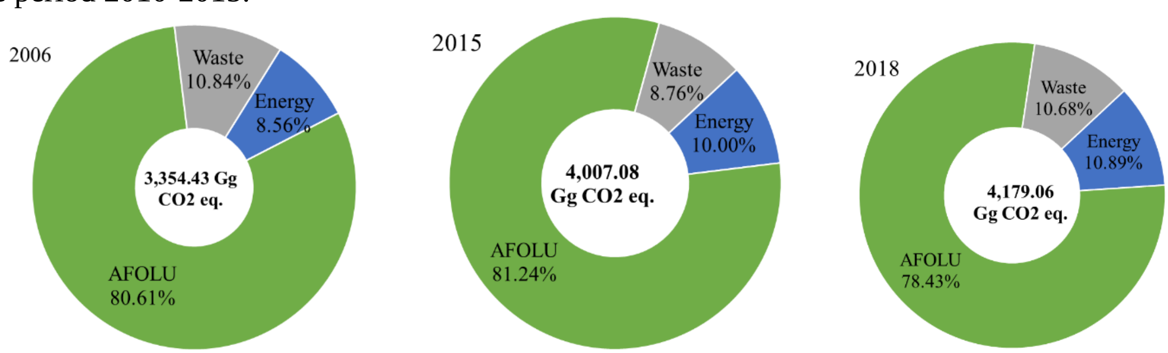


Figure 2.13 CH_4 emissions by sector in 2006, 2015 and 2018 (excluding FOLU)

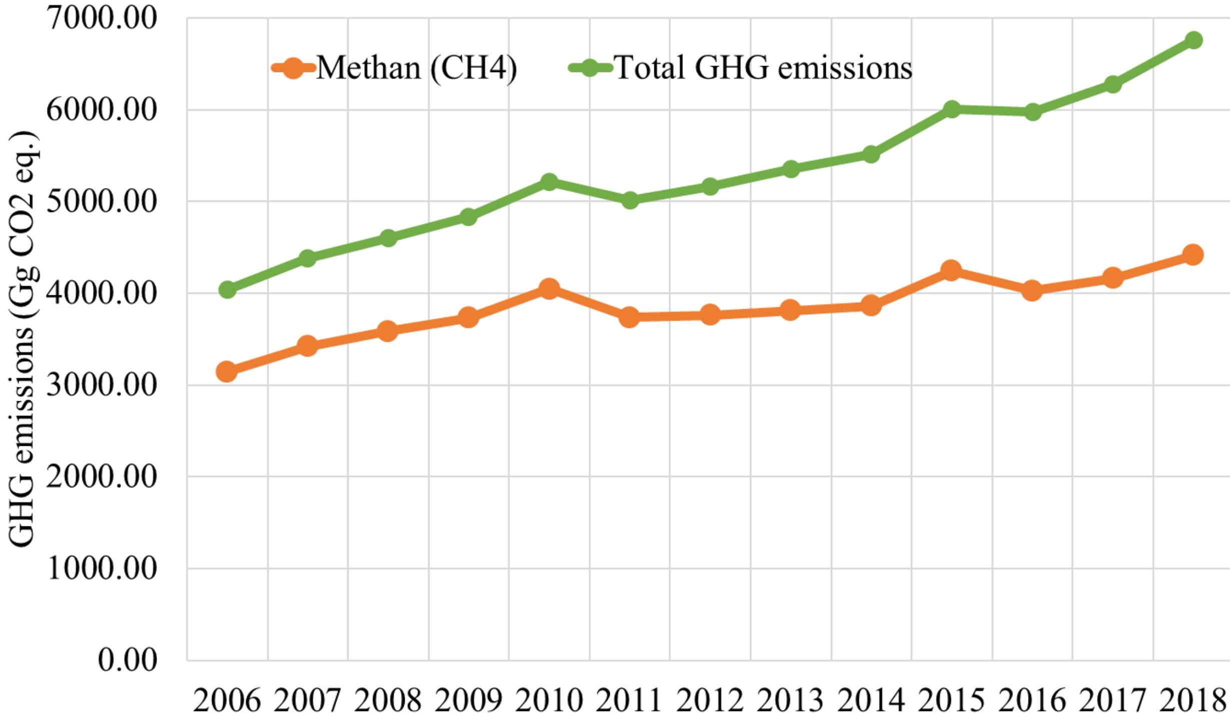


Figure 2.14 Trends in methane gas emissions (2006-2018)

It is interesting to note that the CH_4 gas emissions had the same trend as the total emissions, confirming their notable contribution to the country's total emissions. Most of the CH_4 and N_2O were mainly generated from the AFOLU activities and to a lesser extent by the Waste and Energy sectors while most CO_2 emissions were generated by the Energy sector.

2.3.3 Nitrous oxide (N_2O) emission

Nitrous oxide emissions are mainly generated by Livestock, enteric fermentation subcategories and the (direct and indirect) N_2O from managed soils of the AFOLU sector. There also generated by Biological Treatment of Solid Waste Wastewater Treatment and Discharge categories of the waste sector and to a lesser extent by biomass combustion activities. During the period 2006 through 2018, Rwanda's N_2O emissions showed an increasing trend throughout the whole period (**Figure 2.16**).

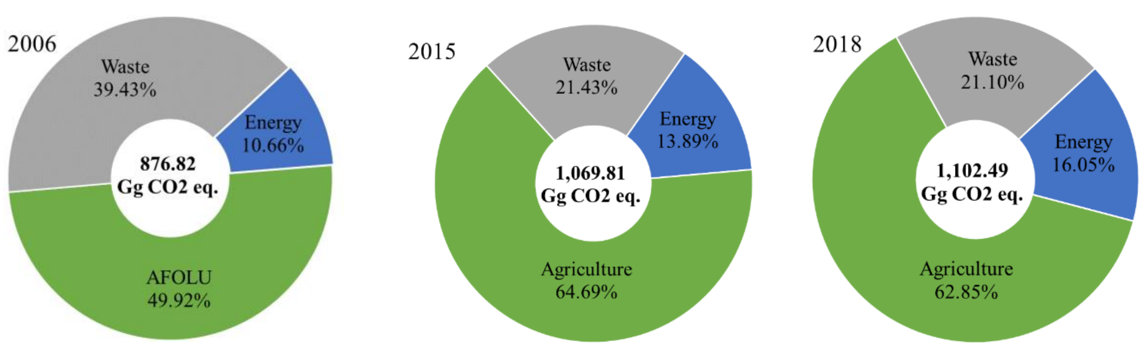


Figure 2.15 N_2O emissions by sector in 2006, 2015 and 2018 (excluding FOLU)

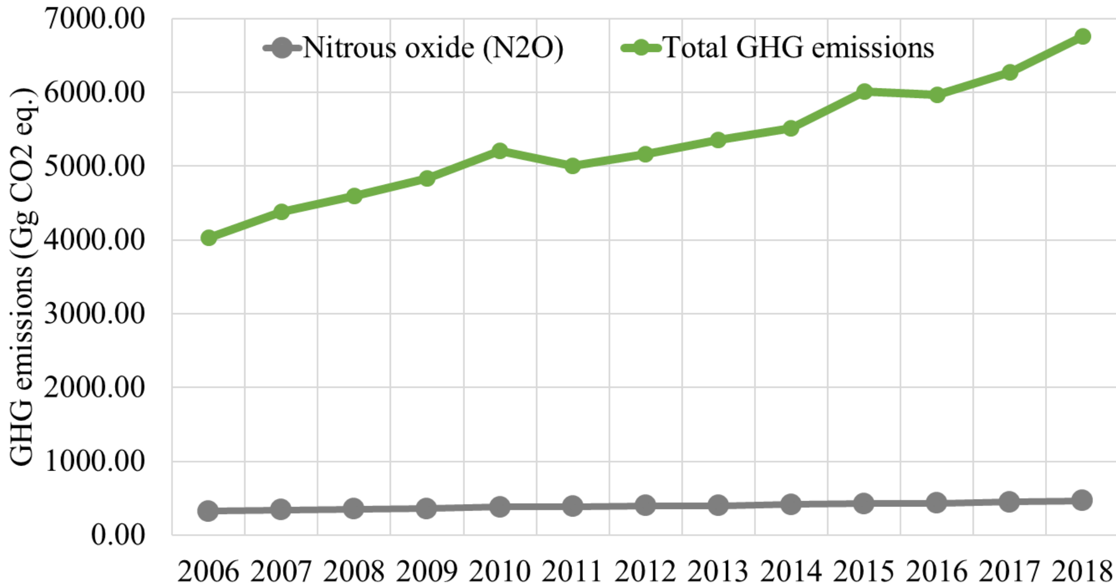


Figure 2.16 Nitrous oxide (N_2O) emission

As it could be seen from **Figure 2.16,** the N_2O emissions had a relatively lower contribution to the trend in total emissions.

2.3.4 Hydrofluorocarbons (HFCs) emissions

Hydrofluorocarbons (HFCs) and, to a very limited extent, perfluorocarbons (PFCs), have high global warming potentials and are being used as alternatives to different classes of ozone-depleting substances (ODS) that are being phased out under the Montreal Protocol. According to the IPCC 2006 guidelines, HFCs and PFCs are being used in a variety of applications that includes refrigeration and air conditioning, fire suppression and explosion protection, aerosols, solvent cleaning, foam blowing, and other applications such as equipment's sterilization.

Rwanda neither produces nor export substitutes for ozone-depleting substances but they are being imported mainly for refrigeration and stationary air conditioning and also the Mobile air conditioning. Other applications, such as aerosols, solvent cleaning, and foam blowing are also used in Rwanda, however, there is a lack of data to include these sources of emissions for inventory. At the end of 2016, Rwanda initiated a survey on the use of alternatives to ODS as an activity under the Montreal Protocol. The survey covered the period from 2012 to 2015 and the major aim was to determine the trend of consumption of ODS alternatives in Rwanda from the year 2012 and beyond. The results show that the most commonly used ODS alternative for that period was R134a while the least used was R290 (REMA, 2016). Among the ODS alternatives surveyed in Rwanda, the following HFCs were categorized as GHGs: HFC-134a which is known as 1,1,1,2-tetrafluoroethane, HFC-125 known as 1,1,1,2,2-pentafluoroethane, HFC-143a, known as 1,1,1-Trifluoroethane, and HFC-32 known as difluoromethane. In addition, another survey on ODS and its alternative was conducted by REMA in 2020 and covered the period from 2016 to 2019 and the results were used to complete this inventory. According to the above-mentioned inventories conducted by REMA in 2016 and 2020 (REMA, 2016, 2020), the blends imported in Rwanda do not contain PFCs.

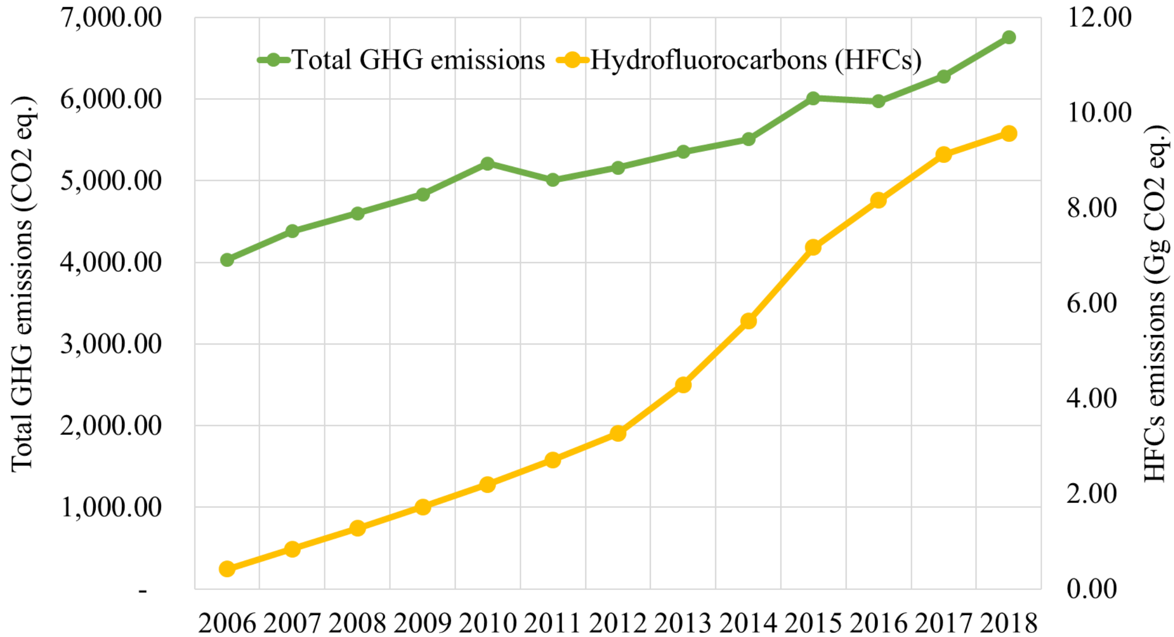


Figure 2.17 trends in hydrofluorocarbons (HFCs) emissions

The trends in hydrofluorocarbons (HFCs) emissions are shown in **Figure 2.17**. It is evident from the figure that HFCs had an increasing trend with a sharp increase from 2012 to 2018. Over the latter period, which was covered by the previous two surveys on the use of ODS alternatives (REMA, 2016, 2020), the emissions have increased at an annual growth rate of 24%. In general, from 2012, HFC-134a as the major imported chemical is the principal contributor of the total emissions with an average contribution of 44.90% followed by HFC-143a contributing 28.89% and HFC-125 with 24.67% and lastly HFC-32 with 1.54% of the total HFCs emissions. It should be noted that the HFCs emissions have an annual growth of 10% from 2015 to 2018.

Chapter 3. Energy sector (1.A)

3.1 Energy Sector Overview

3.1.1 Energy resources and energy production in Rwanda

Energy resources and energy production encompasses all the renewable and conventional (non-renewable) energy resources and technologies for both primary and secondary energy uses. In Rwanda, energy production is largely driven by the combustion of renewable resources such as biomass, biogas and conventional resources such as petroleum-based resources. In addition referred to as liquid fuels, gaseous fuels such as methane gas, solid fuels (coal), and peat (MININFRA, 2018). The combustion of carbon and hydrogen of the later fuels is converted mainly into carbon dioxide (CO_2) and water (H_2O) during combustion, releasing the chemical energy in the fuel as heat. This heat is generally either used directly or used (with some conversion losses) to produce mechanical energy, often to generate electricity or for transportation.

Direct GHGs (i.e., CO_2, CH_4, and N_2O) and indirect GHGs such as CO, NO_X, SO_X, and Non-Methane Volatile Organic Compounds (NMVOC) generated during the latter processes are the main contributors to energy GHG emissions. In this inventory, following the 2006 IPCC guidelines, only direct GHG emissions and their sources are considered. GHG emissions are estimated based on fuel consumption in different categories and subcategories. In this inventory, energy consumptions were estimated by collecting data on fuel consumption and the physical characteristics (including calorific values and densities for data collected in volume units).

As stipulated in the 2006 IPCC guidelines, fuel combustion activities refer to intentional oxidation of materials within an apparatus that is designed to provide heat or mechanical work to a process, or for use away from the apparatus. Fuel combustion activities are thus categorized into stationary and mobile combustion activities. Regarding source categories and subcategories provided in the 2006 IPCC guidelines and considering the context of Rwanda and the availability of activity data, the source categories, and subcategories considered in this inventory are summarized in **Table 3.1**.

Table 3.1 Overview of the energy sector categories and methods

2006 IPCC Categories	Greenhouse gas	2018 emissions (Gg CO_2 eq.)	Contribution to total energy emissions in 2018	Key categories	Uncertainty (%)	Methodology
1 - Energy			(%)		(%)	
1.A.1 - Energy Industries - Liquid Fuels	CO_2	90.27	3.833	□	0.002	Tier 1
1.A.1 - Energy Industries - Liquid Fuels	CH_4	0.07	0.003		0.000	Tier 1
1.A.1 - Energy Industries - Liquid Fuels	N_2O	0.22	0.009		0.000	Tier 1
1.A.1 - Energy Industries - Gaseous Fuels	CO_2	101.61	4.315	□	0.007	Tier 1
1.A.1 - Energy Industries - Gaseous Fuels	CH_4	0.04	0.002		0.000	Tier 1
1.A.1 - Energy Industries - Gaseous Fuels	N_2O	0.06	0.002		0.000	Tier 1
1.A.1 - Energy Industries - Peat	CO_2	37.24	1.582		0.001	Tier 1
1.A.1 - Energy Industries - Peat	CH_4	0.01	0.00031		0.000	Tier 1
1.A.1 - Energy Industries - Peat	N_2O	0.16	0.007		0.000	Tier 1
1.A.1 - Energy Industries - Biomass	CH_4	16.09	0.683		0.000	Tier 1
1.A.1 - Energy Industries - Biomass	N_2O	31.67	1.345		0.001	Tier 1
1.A.2 - Manufacturing Industries and Construction - Liquid Fuels	CO_2	14.60	0.620		0.001	Tier 1
1.A.2 - Manufacturing Industries and Construction - Liquid Fuels	CH_4	0.01	0.00052		0.000	Tier 1
1.A.2 - Manufacturing Industries and Construction - Liquid Fuels	N_2O	0.04	0.0015		0.000	Tier 1
1.A.2 - Manufacturing Industries and Construction - Biomass	CH_4	25.09	1.065		0.000	Tier 1
1.A.2 - Manufacturing Industries and Construction - Biomass	N_2O	49.38	2.097		0.001	Tier 1
1.A.2 - Manufacturing Industries and Construction - Solid Fuels	CO_2	130.82	5.556	□	0.014	Tier 1
1.A.2 - Manufacturing Industries and Construction - Solid Fuels	CH_4	0.29	0.012		0.000	Tier 1
1.A.2 - Manufacturing Industries and Construction - Solid Fuels	N_2O	0.64	0.027		0.000	Tier 1
1.A.3.a - Civil Aviation - Liquid Fuels	CO_2	135.76	5.765		0.012	Tier 1
1.A.3.a - Civil Aviation - Liquid Fuels	CH_4	0.02	0.00085		0.000	Tier 1
1.A.3.a - Civil Aviation - Liquid Fuels	N_2O	1.18	0.050		0.000	Tier 1

2006 IPCC Categories	Greenhouse gas	2018 emissions (Gg CO_2 eq.)	Contribution to total energy emissions in 2018	Key categories	Uncertainty (%)	Methodology
1.A.3.b - Road Transportation - Liquid Fuels	CO_2	1286.77	54.643	□	0.110	Tier 1&2
1.A.3.b - Road Transportation - Liquid Fuels	CH_4	11.78	0.500		0.006	Tier 1&2
1.A.3.b - Road Transportation - Liquid Fuels	N_2O	19.78	0.840		0.010	Tier 1&2
1.A.3.d - Water-borne Navigation - Liquid Fuels	CO_2	1.43	0.061		0.000	Tier 1&2
1.A.3.d - Water-borne Navigation - Liquid Fuels	CH_4	0.0028	0.000		0.000	Tier 1&2
1.A.3.d - Water-borne Navigation - Liquid Fuels	N_2O	0.01	0.001		0.000	Tier 1&2
1.A.3.e - Other Transportation - Liquid Fuels	CO_2	18.61	0.790		0.000	Tier 1&2
1.A.3.e - Other Transportation - Liquid Fuels	CH_4	0.02	0.001		0.000	Tier 1&2
1.A.3.e - Other Transportation - Liquid Fuels	N_2O	2.23	0.095		0.000	Tier 1&2
1.A.4 - Other Sectors - Liquid Fuels	CO_2	37.72	1.602		0.001	Tier 1
1.A.4 - Other Sectors - Liquid Fuels	CH_4	0.09	0.004		0.000	Tier 1
1.A.4 - Other Sectors - Liquid Fuels	N_2O	0.06	0.003		0.000	Tier 1
1.A.4 - Other Sectors - Biomass	CH_4	401.51	17.050	□	8.672	Tier 1
1.A.4 - Other Sectors - Biomass	N_2O	72.62	3.084		0.746	Tier 1

3.1.2 Primary fuel consumption

The primary fuel consumption for the period 2006-2018 is summarized in **Table 3.2** and the trend in various fuel consumption is depicted in **Figure 3.1.** As it can be seen from the figure, the primary energy consumption is dominated by biomass (wood, wood waste, and charcoal), which is relied on for cooking in urban and rural areas. It is also used in different industries including tea estates, brick-making industries, food industries, charcoal manufacturing, and in some commercial and institutions such as restaurants, hotels, prisons, and schools. Liquid fuels (diesel, gasoline, residual fuels, and LPG) are mainly consumed by power generation industries and transportation. It is also important to note the recent increase in indigenous fuels such as peat and methane gas in power generation industries and the use of coal in non-metallic industries, which had an impact on the GHG emissions from the Energy sector. While gas and peat have been introduced in the energy industries (electricity generation) in 2009 and 2016, respectively, peat consumption and solid fuels (coal) were introduced in 2010 and 2016, respectively.

Table 3.2 Primary energy consumption per fuel in energy sector, TJ (2006-2018)

Period	Biomass	Liquid fuels	Gas	Peat	Solid fuel	Total
2006	78,220.27	7,369.62	-	-	-	85,589.89
2007	81,042.16	8,209.59	-	-	-	89,251.76
2008	83,436.41	8,787.83	-	-	-	92,224.24
2009	86,029.12	9,905.54	27.50	-	-	95,962.16
2010	91,837.20	10,508.36	74.50	14.54	-	102,434.59
2011	93,545.23	11,886.30	50.74	50.94	-	105,533.20
2012	100,934.73	13,432.87	73.29	36.64	-	114,477.53
2013	106,634.75	15,397.76	82.52	51.68	-	122,166.71
2014	111,551.31	16,558.83	169.00	44.12	-	128,323.25
2015	117,375.76	17,615.54	167.03	50.57	-	135,208.90
2016	125,952.11	17,626.67	921.88	351.36	1,110.23	145,610.89
2017	132,508.17	18,477.41	1,676.72	351.36	979.10	153,992.77
2018	137,572.09	20,416.07	1,811.28	351.36	1,382.93	161,533.73

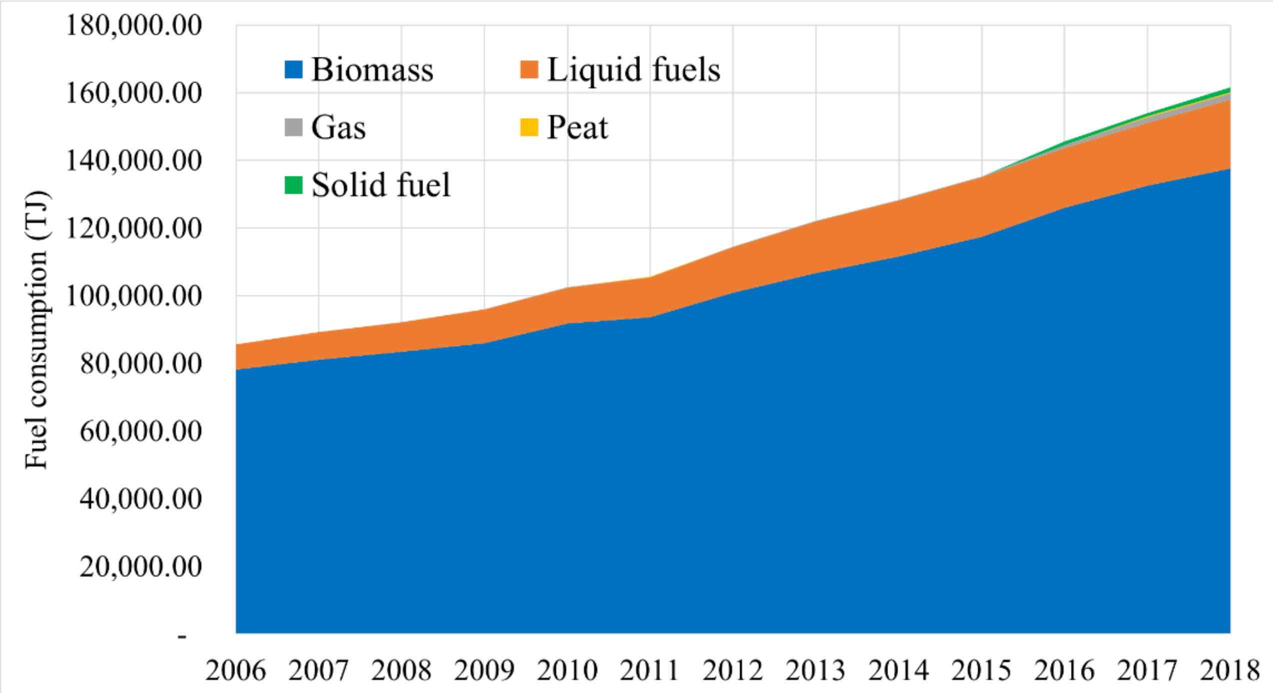


Figure 3.1 Estimated primary energy consumption per fuel type (2006- 2018)

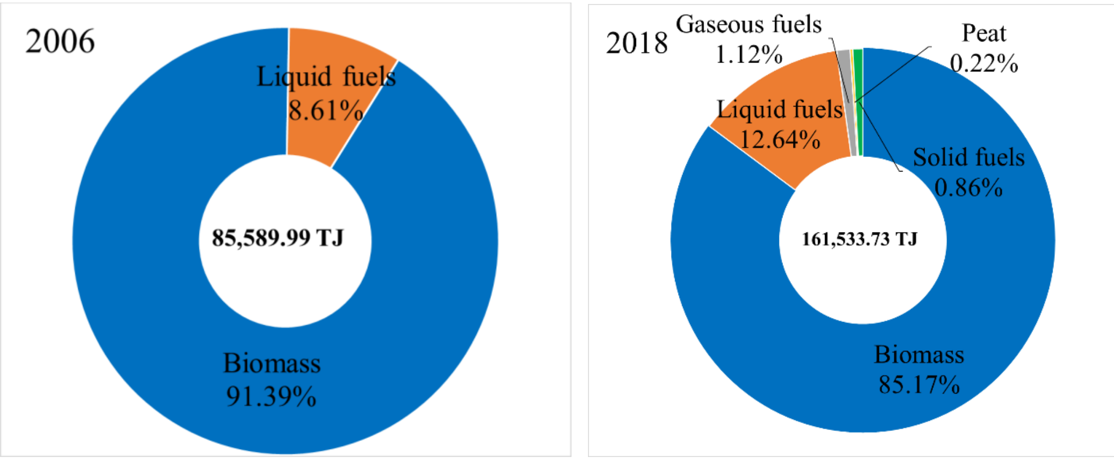


Figure 3.2 Total fuels consumption shares in 2006 and 2018

The total fuel consumption shares in 2006 and 2018 are presented in **Figure 3.2**. As seen from the figure, the period 2006-2018 was characterized by a tremendous change in fuel consumption diversification. Whereas sole biomass and liquid fuels were the only fuels consumed in 2006, various fuels (peat, coal, methane gas) were added to the list through the years. Biomass consumption remained the highest throughout the whole period followed by liquid fuels.

A breakdown of fuel consumption by categories is presented in **Table 3.3** and the trends in fuel consumption per category are presented in **Figure 3.3**. It is clear from the figure that "other sectors" (institutional, commercial, and residential) is the main consumer of primary energy followed by the manufacturing industries and construction, while transportation and energy industries were the least consumers. The contribution of various categories to total energy consumption is shown in **Figure 3.4**.

Table 3.3 Primary energy consumption in various energy activities, TJ (2006-2018)

Period	Energy Industries	Manufacturing Industries and Construction	Transport	Others	Total	Increase from 2006
2006	14,025.33	21,958.81	5,035.90	44,569.85	85,589.89	0.00%
2007	14,320.02	23,205.44	5,808.68	45,917.62	89,251.76	4.10%
2008	14,076.17	23,823.76	7,019.67	47,304.63	92,224.24	7.19%
2009	15,007.20	24,778.65	7,642.19	48,534.12	95,962.16	10.81%
2010	15,383.25	25,671.51	8,371.87	53,007.96	102,434.59	16.44%
2011	16,025.61	25,832.58	9,512.57	54,162.44	105,533.20	18.90%
2012	19,111.17	25,761.81	10,907.89	58,696.67	114,477.53	25.23%
2013	22,347.19	26,665.04	12,320.66	60,833.81	122,166.71	29.94%
2014	22,230.50	29,931.24	13,194.45	62,967.06	128,323.25	33.30%
2015	22,920.15	33,166.40	14,468.84	64,653.52	135,208.90	36.70%
2016	24,016.39	36,551.51	15,953.47	69,089.52	145,610.89	41.22%
2017	24,481.87	39,901.53	17,193.78	72,415.58	153,992.77	44.42%
2018	28,883.33	41,405.67	18,488.19	72,756.54	161,533.73	47.01%

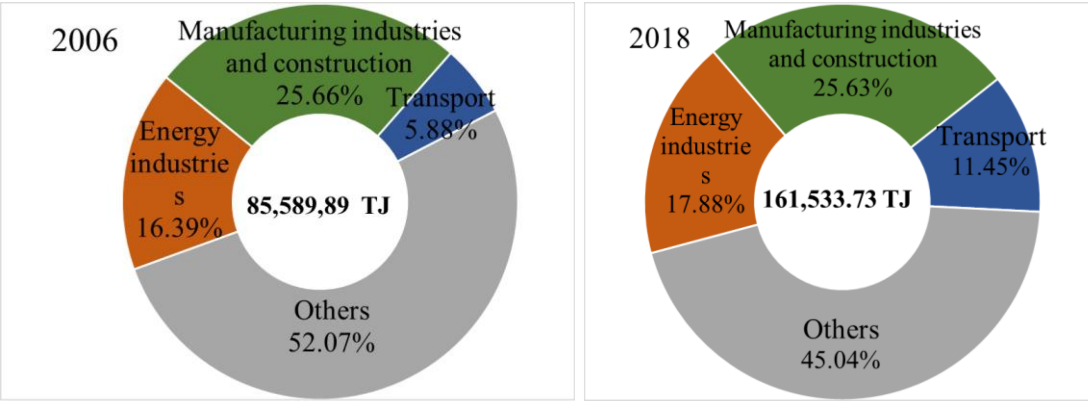


Figure 3.3 Estimated primary energy consumption by source category (2006-2018)

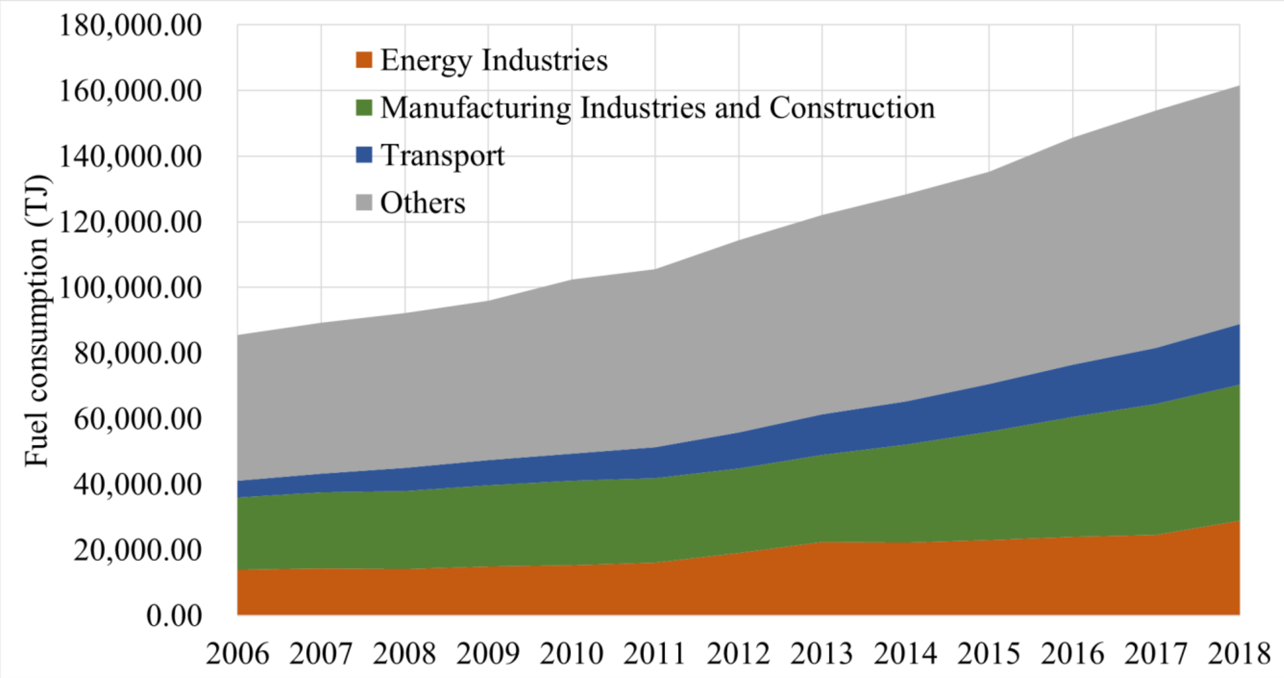


Figure 3.4 shares of various energy sector categories to total fuel consumption in 2006 and 2018

3.1.3 Feedstocks and non-energy use of fuels

During the inventory compilation, it was noted that some of the fuels imported are rather used as raw materials in the production process than for energy production purposes. This was the case for instance for paint, detergent industries, and road construction companies in which some petroleum products are used as raw materials. Data regarding the feedstock and non-energy use of fuels were collected mainly from the Ministry of Trade and Industry (MINICOM) and the Rwanda Revenue Authority (RRA). Sources considered included the use of solvents, lubricants, waxes, and bitumen in road construction and paint, detergent, and plastic industries. To comply with the 2006 IPCC guidelines and to avoid possible double counting, these fuels were not considered in estimating GHG emissions from the Energy sector and could be accounted for in the IPPU sector.

3.2 Comparison of reference and sectoral approaches

3.2.1 Methodological issues

In contrast to the sectoral approach, the Reference Approach is a relatively quick and first-order estimate of the CO_2 emissions based on the fossil fuels supplied to the country. In this inventory, reference and sectoral approaches were performed independently and the results from the reference approach were used as a verification crosscheck of those from the sectoral approach. According to the 2006 IPCC guidelines, the methodology for the reference approach was implemented *via* five steps as outlined below:

Step 1: Estimate Apparent Fuel Consumption in Original Units

Step 2: Convert to a Common Energy Unit

Step 3: Multiply by Carbon Content to Compute the Total Carbon
Step 4: Compute the Excluded Carbon
Step 5: Correct for Carbon Unoxidised and Convert to CO_2 Emissions

3.2.2 Data sources

To estimate the supply of fossil fuels to the country, the following information for each fuel and inventory year is needed:

- Amount of primary and secondary fuels imported
- Amount of primary and secondary fuels exported
- Amount of primary and secondary fuels used in international bunkers
- Net increase or decrease in stocks of primary and secondary fuels.

The data related to this information were collected from MINICOM and RRA.

3.2.3 GHG emissions

Using the algorithm described above, carbon dioxide (CO_2) emissions were estimated and compared with those obtained *via* the sectoral approach for a period of 13 years from 2006 to 2018. **Figure 3.5**shows the results of the comparison between sectoral and reference approaches results. Results from the two approaches were slightly different with differences ranging from -1.4% to 1.17%. The observed differences are plausibly the results of uncertainties in the used source data. However, it is important to mention that they are in the acceptable range of the 2006 IPCC guidelines and thus confirm the accuracy of the sectoral approach results.

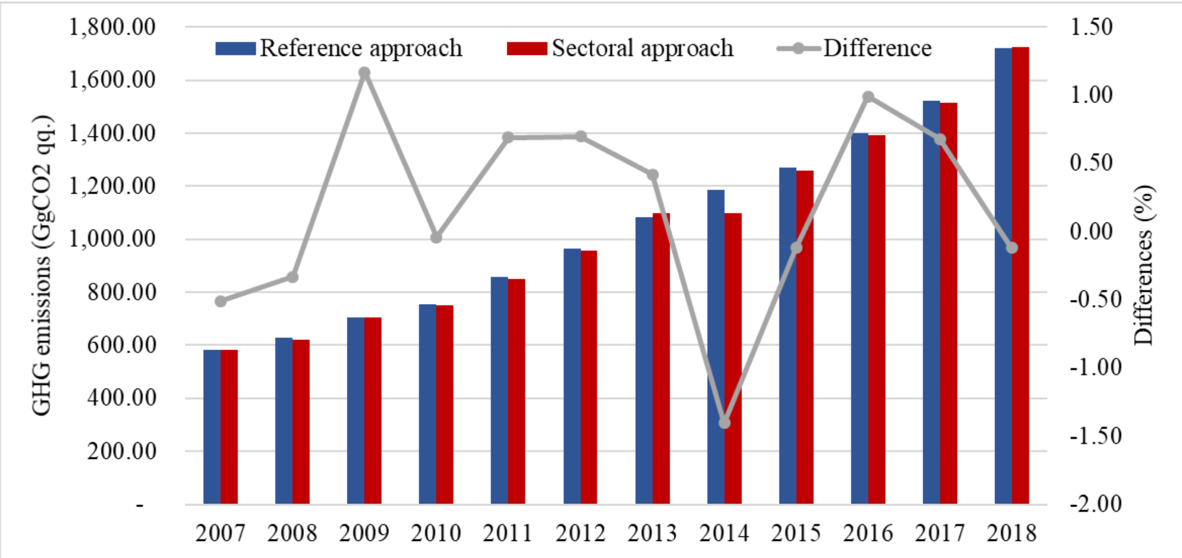


Figure 3.5 Comparison between sectoral and reference approaches results

3.3 Summary of emission trends in the Energy sector

3.3.1 General trends and shares in GHG emissions

During the period 2006-2018, cumulative total GHG emissions enjoyed a continuously increasing trend. The summary of total GHG emissions per source category is summarized in **Table 3.4**. As it could be seen from the table, transport remained the main source of GHG emissions for the whole period followed by other sectors, while Manufacturing Industries and Construction showed a modest increase contribution. It is noteworthy that the GHG emissions from other sectors are mainly generated by biomass combustion activities and following the IPCC guidelines, the CO_2 emissions generated by biomass are not added to the total GHG emissions. The emissions of CO_2 from biomass fuels are estimated and reported in the AFOLU sector as part of the AFOLU methodology. In the reporting tables, emissions from the combustion of biofuels are reported as information items but not included in the sectoral or national totals to avoid double counting. The emissions of CH_4 and N_2O, however, are estimated and included in the sector and national totals because their effect is in addition to the stock changes estimated in the AFOLU sector. Following this methodology, the CH_4 and N_2O emissions from biomass were estimated and added to the energy sector totals. This is the main reason why the transportation category, which was having a minute contribution to total energy consumption, became the main contributor to total GHG emissions. (IPCC 2006, 2006).

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Table 3.4 Summary of energy sector GHG emissions, Gg CO_2 eq. (2006-2018)

	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
	909.21	**982.24**	**1033.23**	**1129.35**	**1210.98**	**1322.49**	**1448.62**	**1610.31**	**1719.18**	**1808.31**	**1977.31**	**2136.51**	**2354.85**
1.A	**909.21**	**982.24**	**1033.23**	**1129.35**	**1210.98**	**1322.49**	**1448.62**	**1610.31**	**1719.18**	**1808.31**	**1977.31**	**2136.51**	**2354.85**
1.A.1	115.65	120.31	82.89	131.97	135.86	159.85	179.96	221.36	229.95	193.32	171.29	212.00	277.44
1.A.2	75.46	84.62	82.74	82.03	81.46	85.52	84.15	91.10	113.67	134.00	183.03	184.75	220.87
1.A.3	359.52	414.79	501.11	545.64	597.71	679.21	778.96	879.95	942.53	1031.63	1137.51	1226.04	1344.53
1.A.4	358.57	362.53	366.48	369.71	395.94	397.91	405.55	417.89	433.03	449.35	485.47	513.72	512.00
1.A.5	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
1.B	**NO**	**NO**	**NO**	**NO**	**NO**	**NO**	**NO**	**NO**	**NO**	**NO**	**NO**	**NO**	**NO**
1.B.1	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
1.B.2	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
1.B.3	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
1.C	**NO**	**NO**	**NO**	**NO**	**NO**	**NO**	**NO**	**NO**	**NO**	**NO**	**NO**	**NO**	**NO**
1.C.1	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
1.C.2	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
1.C.3	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO

1.A.1 - Energy Industries 1.A.2 - Manufacturing Industries and Construction 1.A.3 - Transport 1.A.4 - Other Sectors 1.A.5 - Non-Specified 1.B - Fugitive emissions from fuels 1.B.1 - Solid Fuels 1.B.2 - Oil and Natural Gas 1.B.3 - Other emissions from Energy Production 1.C - Carbon dioxide Transport and Storage 1.C.1 - Transport of CO_2 1.C.2 - Injection and Storage 1.C.3 - Other

3.3.1.1 Comparison of GHG emissions from stationary and mobile combustions

The GHG emissions generated by mobile and stationary and their contribution to the total energy sector GHG emissions are presented in **Table 3.5.** During the period 2006-2010, GHG emissions from stationary combustion dominated over the stationary emissions generated by stationary sources.

Table 3.5 Emissions from stationary and mobile combustions, Gg CO_2e (2006-2018)

Period	Mobile sources	Stationary sources	Total	Stationary
2006	359.52	549.67	909.19	60.46%
2007	414.79	567.45	982.24	57.77%
2008	501.11	532.11	1,033.23	51.50%
2009	545.64	583.71	1,129.35	51.69%
2010	597.71	613.27	1,210.98	50.64%
2011	679.21	643.27	1,322.49	48.64%
2012	778.96	669.66	1,448.62	46.23%
2013	879.95	730.35	1,610.31	45.36%
2014	942.53	776.64	1,719.18	45.18%
2015	1,031.63	776.67	1,808.31	42.95%
2016	1,137.51	839.79	1,977.31	42.47%
2017	1,226.04	910.47	2,136.51	42.61%
2018	1,344.53	1,010.31	2,354.85	42.90%

However, during the remaining period emissions from mobile sources increased due to the increase in the number of imported vehicles and surpassed the GHG emissions from stationary sources. These trends are also evidenced in **Figure 3.6.** A steady increase in GHG emissions from stationary combustion was observed from 2006 to 2015, followed by a sharp increase in the remaining period, while a continuous and steady increase in GHG emissions from mobile combustion was observed for the whole period. As will be discussed in subsequent sections, the sharp increase in stationary emissions was brought in by power generation emissions.

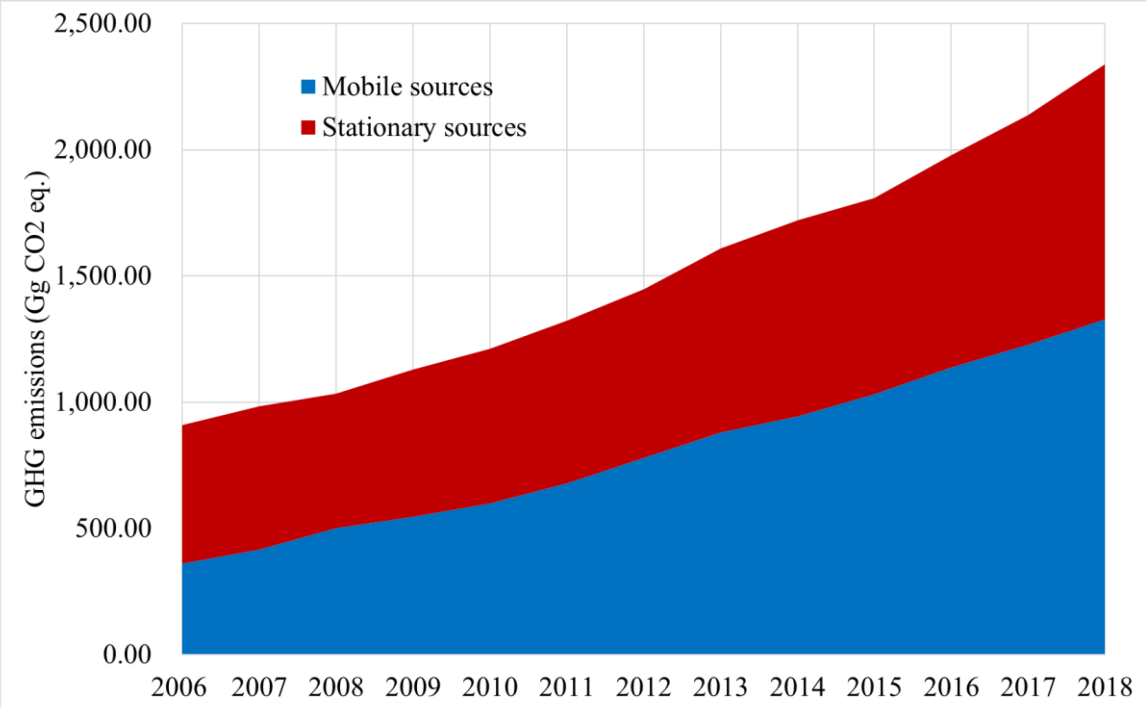


Figure 3.6 Comparison of GHG emissions from stationary and mobile sources (2006-2018)

3.3.1.2 Trends in GHG emissions per gas

As aforementioned, direct GHGs (CO_2, CH_4, and N_2O) were estimated in this inventory. **Table 3.6** summarizes the GHG emissions per gas and their contribution to total emissions. The trends in emissions are shown in **Figure 3.6**. Clearly, all the gases show an increasing trend during the whole period. CO_2 emission remained the most significant, while N_2O emissions had the lowest contribution. The trends in emissions could also be seen from GHG shares to total emissions as evidenced from **Table 3.6**. Clearly, CO_2 emissions show an increasing trend thanks to the increase in liquid fuel consumption, while a decreasing trend is observed in N_2O and CH_4. The slight decrease in the later gases could be attributed to the decrease in biomass consumption (REMA, 2019a).

Table 3.6 Shares GHG to total energy sector emissions, Gg CO_2 eq. (2006 -2018)

GHG	CO_2	CH_4	N_2O	Total	CO_2	CH_4	N_2O
2006	523.94	287.00	98.25	909.19	57.63%	31.57%	10.81%
2007	583.30	296.63	102.31	982.24	59.38%	30.20%	10.42%
2008	620.66	306.45	106.11	1,033.23	60.07%	29.66%	10.27%
2009	704.53	315.06	109.76	1,129.35	62.38%	27.90%	9.72%
2010	749.40	344.21	117.37	1,210.98	61.88%	28.42%	9.69%
2011	849.93	352.12	120.43	1,322.49	64.27%	26.63%	9.11%
2012	958.88	363.19	126.56	1,448.62	66.19%	25.07%	8.74%
2013	1,099.91	376.40	133.99	1,610.31	68.30%	23.37%	8.32%
2014	1,187.34	391.04	140.79	1,719.18	69.06%	22.75%	8.19%
2015	1,259.17	400.57	148.57	1,808.31	69.63%	22.15%	8.22%
2016	1,391.16	428.88	157.26	1,977.31	70.36%	21.69%	7.95%
2017	1,515.51	451.30	169.70	2,136.51	70.93%	21.12%	7.94%

GHG	CO_2	CH_4	N_2O	Total	CO_2	CH_4	N_2O
2018	1,722.94	455.00	176.90	2,354.85	73.17%	19.32%	7.51%

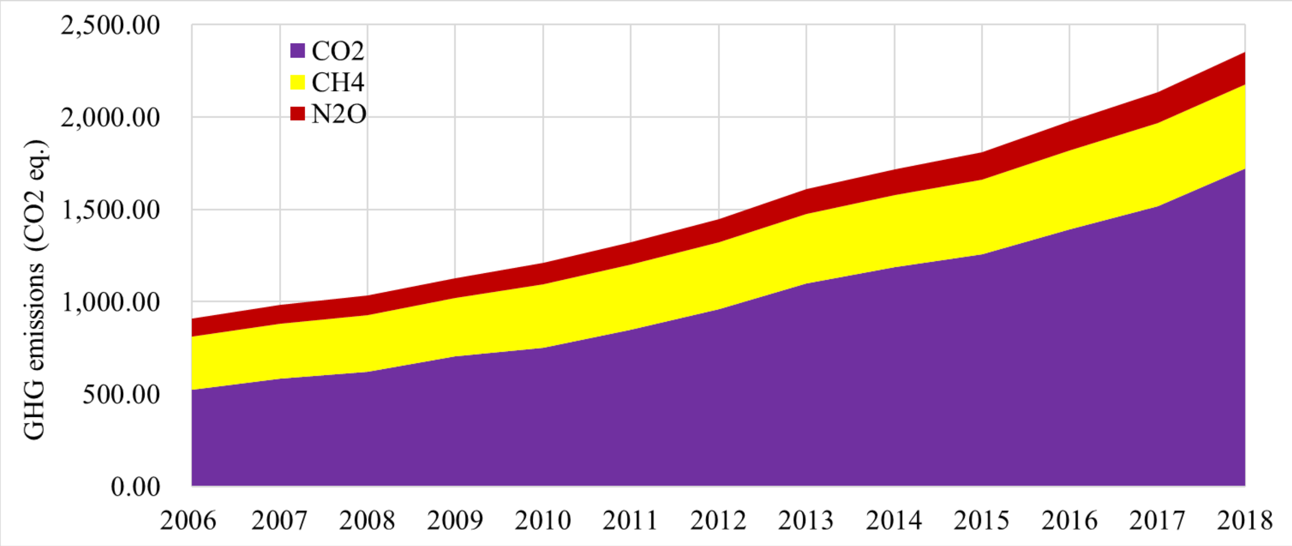


Figure 3.7 Trends in total energy sector GHG emissions per gas (2006-2018)

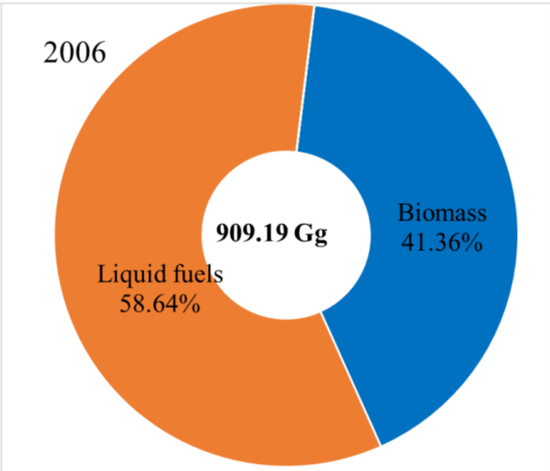
3.3.1.3 Energy sector GHG emissions per fuel

During the period 2006-2018, five categories of fuels contributed to total GHG emissions from the Energy sector, viz., liquid fuels (i.e., diesel liquid/gas oil, residual fuel, kerosene, and liquefied petroleum gas), biomass (wood/wood wastes, charcoal, and biogas), solid fuels (coal), gaseous fuels (methane gas), and peat (**Table 3.7**). The trends in GHG emissions per fuel consumption are depicted in **Figure 3.9**. Liquid fuels contributed the most of total GHG emissions with an average contribution followed by biomass, while peat, gas, and solid fuels have minor contributions. These observations are confirmed by the shares in GHG emissions per fuel shown in **Figure 3.8**. The gaseous fuels (methane gas), peat solid fuels (coal) appeared from 2009, 2010, and 2016, respectively. Methane power plants have been introduced into the electricity generation mix of Rwanda since 2009 as a pilot project with a minute contribution to total GHG emissions. However, from 2015 its contribution became significant thanks to the increase in the methane gas installed capacity (NISR, 2019). Peat has been consumed by the non-metallic mineral industries (cement industries) since 2010 as a supplement to liquid fuels, which were the main fuels in these industries. However, since 2015, liquid fuels are slowly replaced by solid fuels (coal). This is the main reason for the sharp rise recorded in solid fuel GHG emissions from 2015. In addition, a sharp rise in GHG emissions was observed in peat GHG emissions from 2016 chiefly due to the introduction of the peat-to-power thermal power plant in the electricity mix of the country.

Table 3.7 Trends in Energy sector GHG emissions per fuel, Gg CO_2 eq. (2006-2018)

Period	Biomass	Liquid fuels	Gaseous fuels	Peat	Solid fuels	Total
2006	376.01	533.18	-	-	-	909.19
2007	388.37	593.88	-	-	-	982.24
2008	400.08	633.14	-	-	-	1,033.23

Period	Biomass	Liquid fuels	Gaseous fuels	Peat	Solid fuels	Total
2009	411.15	716.66	1.54	-	-	1,129.35
2010	446.68	758.57	4.18	1.55	-	1,210.98
2011	455.59	858.62	2.85	5.43	-	1,322.49
2012	470.25	970.35	4.12	3.90	-	1,448.62
2013	488.20	1,111.97	4.63	5.50	-	1,610.31
2014	508.01	1,196.97	9.49	4.70	-	1,719.18
2015	524.87	1,268.67	9.38	5.39	-	1,808.31
2016	559.13	1,260.63	51.77	37.41	105.78	1,977.31
2017	591.94	1,319.71	94.15	37.41	93.28	2,136.51
2018	596.36	1,487.61	101.71	37.41	131.76	2,354.85



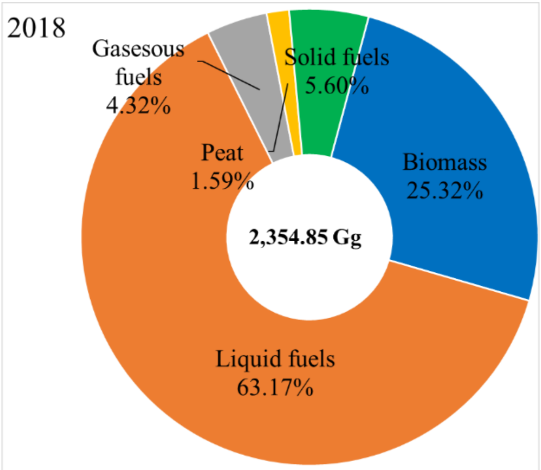


Figure 3.8 Shares of various fuels to total energy sector GHG emissions (2006-2018)

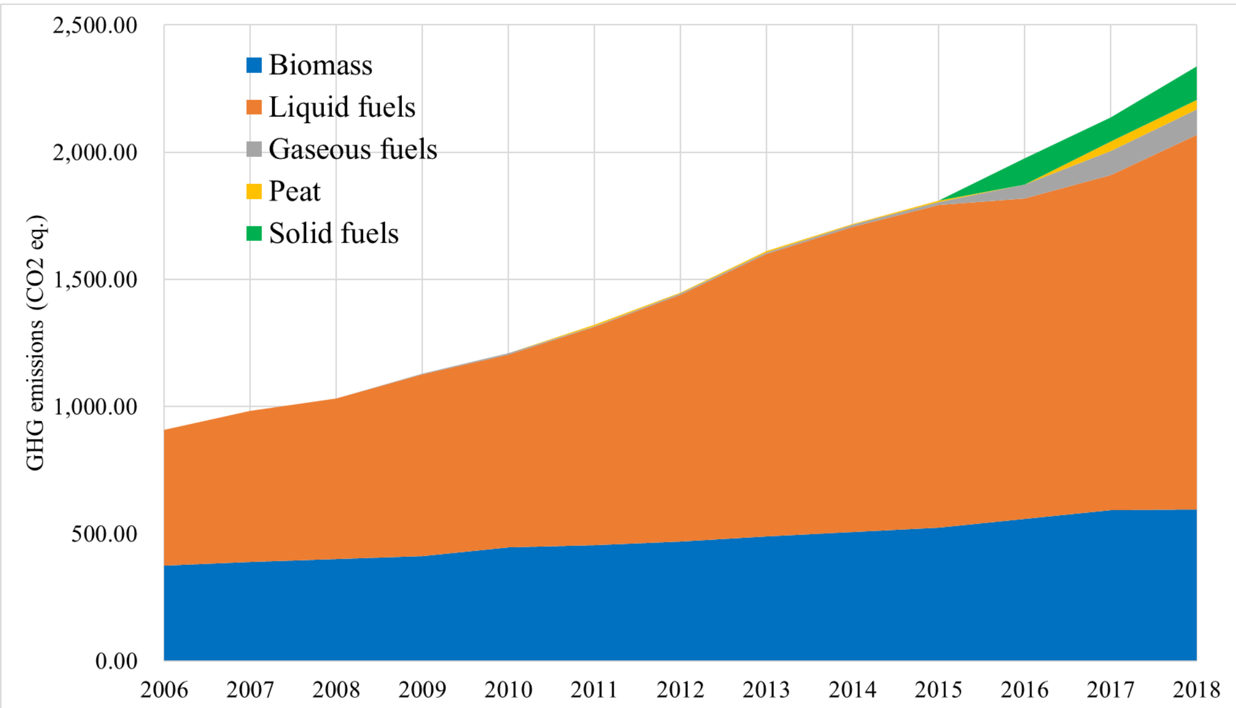


Figure 3.9 Trends in GHG emissions per fuel (2006-2018)

3.3.2 Memo items

Following the 2006 IPCC guidelines (IPCC, 2006a), GHG emissions resulting from the combustion of fuels used in international transport activities referred to as international bunkers, and CO_2 from biomass combustion for energy production should not be reported in national GHG emissions. They are reported under Memo and information Items, respectively. As stressed in the 2006 IPCC guidelines, all emissions from fuels used for international aviation (bunkers) and multilateral operations under the Charter of UN are to be excluded from national totals and reported separately as memo items (Waldron et al., 2006). In Rwanda, GHG emissions from the international aviation source category are mainly generated by jet kerosene combustion in aircraft that operate international flights whereas CO_2 from biomass combustions results from combustion activities in various categories including charcoal manufacturing, brick making, food industries, households, and public/commercial institutions (hotels, schools, restaurants, prisons, etc.).

Table 3.8 Memo items and information items, Gg CO_2 eq. (2006-2018)

Period	Information item	Memo item
2006	8,684.58	5.13
2007	9,000.55	4.98
2008	9,268.21	2.03
2009	9,557.99	0.54
2010	10,207.74	1.51
2011	10,398.41	4.47
2012	11,064.05	4.62
2013	11,698.72	2.34
2014	12,245.30	22.82
2015	12,896.16	59.31
2016	13,855.94	93.52
2017	14,589.70	111.89
2018	15,156.34	131.43

GHG emissions from information and memo items are summarized in **Table 3.8**. The trends in the emissions from information and memo items increased over the whole period, following the general trend of the reported emissions. Some fluctuations in GHG emissions were observed during the period 2006-2015 followed by a sharp increase in the remaining period. While the observed fluctuations could be attributed to the fluctuations in international flights, the plausible cause of the observed sharp increase after 2015 is the increase in international flights during this period. According to data published by the National Institute of Statistics of Rwanda (NISR), the number of international passengers from 2015-2018 increased from 520,863 to 679,948 and the total international cargo increased from 7,882.42 metric tonnes to 11,072.11 metric tonnes, respectively.

3.3.3 Energy sector emissions and socioeconomic development

Energy GHG emissions are related to the economic growth of any country as the main driver of the economy. During the period 2006-2018, the Rwandan economy enjoyed continuous growth justified by the increase in GDP and GDP per capita. This economic growth is the main reason for the increase in GHG emissions observed over the same period. The increase in the Energy sector's GHG emissions could also be related to population growth, especially those generated in the residential sector.

Table 3.9 GHG emissions and accompanying variables (2006-2018)

Period	Total fuel consumption (TJ)	GHG emissions (Gg CO_2 eq.)	GDP per capita (USD)	GHG emission intensity (tCO_2 eq.TJ^{-1})	GHG per GDP per capita
2006	85,589.89	909.19	333.00	10.62	2.73
2007	89,251.76	982.24	391.00	11.00	2.51
2008	92,224.24	1,033.23	480.00	11.20	2.15
2009	95,962.16	1,129.35	547.00	11.74	2.06
2010	102,434.59	1,210.98	572.00	11.76	2.12
2011	105,533.20	1,322.49	627.00	12.49	2.11
2012	114,477.53	1,448.62	689.00	12.59	2.10
2013	122,166.71	1,610.31	701.00	13.12	2.30
2014	128,323.25	1,719.18	719.00	13.27	2.39
2015	135,208.90	1,808.31	720.00	13.26	2.51
2016	145,610.89	1,977.31	729.00	13.04	2.71
2017	153,992.77	2,136.51	774.00	12.89	2.76
2018	161,533.73	2,354.85	787.00	13.52	2.97

Source for GDP: NISR (Statistical yearbooks 2009, 2013, 2015, 2019)

In addition, GHG emissions are related to population growth and lifestyle change. However, the adoption of energy efficiency measures and energy conservation policies could keep the latter increase in reasonable ranges. It is interesting to note that the slight drop in GHG emissions per fuel consumption (i.e., GHG emissions intensity) observed in 2008, 2010, and 2017 were related to the drop in both fuel consumption and the GHG emissions (**Figure 3.10**).

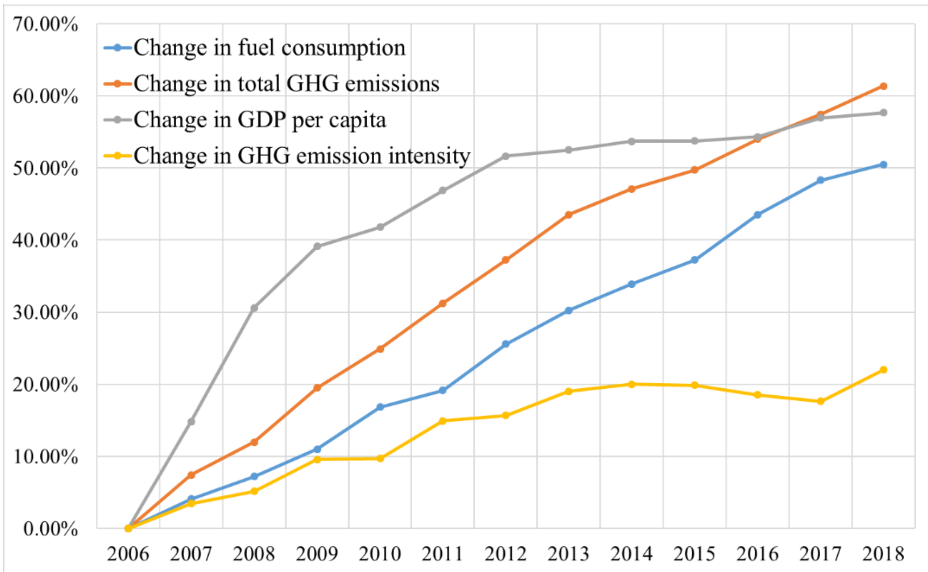


Figure 3.10 Changes in total GHG emissions and accompanying variables (2016-2018)

3.3.4 Methodological issues

In this inventory, we used both top-down (reference approach) and bottom-up (sectoral approach) methodologies with appropriate choices of tiers as detailed in the 2006 IPCC guidelines. While categories specific methodologies for the sectoral approach are well documented in appropriate subsections, in this section general methodologies are described. GHG emissions inventory was developed through different steps including the assessment of source categories to which filling data gaps were carried out, data collection, a compilation of the GHG inventory, uncertainty assessment, key category analysis, and reporting. The aggregated emissions in CO_2 eq. were estimated using the global warming potentials provided by SAR (IPCC, 2006a).

Energy GHG emissions were estimated for a period 2006- 2018 on a gas-by-gas basis considering direct GHGs i.e., CO_2, CH_4, and N_2O (**Table 3.10**). Estimates of the key sources, sensitivity analysis, and uncertainty level were provided. Estimates of aggregated GHG emissions expressed in CO_2 equivalent were also reported.

Due to the lack of country-specific emission factors, tier 1 methodologies were mainly used in the Energy sector. The 2006 IPCC inventory software was used for all categories. In general, default emission factors provided by IPCC 2006 Guidelines were used with country-specific physical characteristics (Net calorific values, densities) of fuels were available (**Table 3.10**). In addition, the approaches used during Rwanda Third National Communication (TNC) for data estimation were used.

Table 3.10 Summary of Methodologies used for Energy sector GHG emissions

Energy	CO_2			CH_4		N_2O	
	Method	NCV	EF	Method	EF	Method	EF
1.A.1.a.i - Electricity Generation	T1&T2	CS	D	T1	D	T1	D

1.A.1.c.ii - Other Energy Industries	T1	CS	D	T1	D	T1	D
1.A.2.e - Food Processing, Beverages and Tobacco	T1	CS	D	T1	D	T1	D
1.A.2.f - Non-Metallic Minerals	T1	CS	D	T1	D	T1	D
1.A.2.i - Mining (excluding fuels) and Quarrying	T1	CS	D	T1	D	T1	D
1.A.2.k - Construction	T1	CS	D	T1	D	T1	D
1.A.3.a.ii - Domestic Aviation	T1	CS	D	T1	D	T1	D
1.A.3.b.i.1 - Passenger cars with 3-way catalysts	T1&T2	CS	D	T1	D	T1	D
1.A.3.b.ii.1 - Light-duty trucks with 3-way catalysts	T1&T2	CS	D	T1	D	T1	D
1.A.3.b.iii - Heavy-duty trucks and buses	T1&T2	CS	D	T1	D	T1	D
1.A.3.b.iv - Motorcycles	T1&T2	CS	D	T1	D	T1	D
1.A.3.d.ii - Domestic Water-borne Navigation	T1	CS	D	T1	D	T1	D
1.A.3.e - Other Transportation	T1	CS	D	T1	D	T1	D
1.A.3.e.ii - Off-road	T1	CS	D	T1	D	T1	D
1.A.4.a - Commercial/Institutional	T1	CS	D	T1	D	T1	D
1.A.4.b - Residential	T1	CS	D	T1	D	T1	D
1.A.4.c-Agriculture/Forestry/Fishing/Fish Farms	T1	CS	D	T1	D	T1	D

T1: Tier 1; T2: Tier 2, D: Default values; CS: Country specific (for some fuels), NO: Not occurring; NE: Not Estimated

3.3.5 Assessment of Completeness

The assessment of completeness was conducted according to the IPCC 2006 methodologies and the results are summarized in **Table 3.11**. All the major contributors to total GHG emissions were considered according to the IPCC 2006 guidelines. All combustion activities were considered as recommended. However, due to the lack of appropriate data, fugitive emissions were not estimated in this inventory.

Table 3.11 Assessment of completeness for the Energy sector in Rwanda

Categories	CO	CH	N_2	HFC	PFC	SF	NO	CO	NMVOC	SO
1 - Energy										
1.A - Fuel Combustion Activities	X	X	X	NA	NA	N	NE	NE	NA	NA
1.A.1 - Energy Industries	X	X	X	NA	NA	N	NE	NE	NA	NA
1.A.2 - Manufacturing Industries and Construction	X	X	X	NA	NA	N	NE	NE	NA	NA
1.A.3 - Transport	X	X	X	NA	NA	N	NE	NE	NA	NA
1.A.4 - Other Sectors	X	X	X	NA	NA	N	NE	NE	NA	NA
1.A.5 - Non-Specified	NO	NO	NO	NA	NA	N	NO	N	NO	NO
1.B - Fugitive emissions from fuels										
1.B.1 - Solid Fuels	NO	NO	NO	NA	NA	N	NO	N	NO	NO
1.B.2 - Oil and Natural Gas	NO	NO	NO	NA	NA	N	NO	N	NO	NO
1.B.3 - Other emissions from Energy Production	NO	NO	NO	NA	NA	N	NO	N	NO	NO
1.C - Carbon dioxide Transport and Storage	NO	NO	NO	NA	NA	N	NO	N	NO	NO
1.C.1 - Transport of CO_2	NO	NO	NO	NA	NA	N	NO	N	NO	NO
1.C.2 - Injection and Storage	NO	NO	NO	NA	NA	N	NO	N	NO	NO
1.C.3 - Other	NO	NO	NO	NA	NA	N	NO	N	NO	NO
4.E - Other (please specify)	NO	NO	NO	NA	NA	N	NA	N	NA	NA
5 - Other										
5.A - Indirect N_2O emissions from the atmospheric deposition of nitrogen in NO_X and	NA	NA	0	NA	NA	N	NA	N	NA	NA
5.B - Other (please specify)	NO	NA	0	NA	NA	N	NA	N	NA	NA
Memo Items (5)										
International Bunkers										
1.A.3.a.i - International Aviation (International Bunkers)	X	X	X	NA	NA	N	NA	N	NA	NA
1.A.3.d.i - International water-borne navigation (International bunkers)	NO	NO	NO	NA	NA	N	NA	N	NA	NA
1.A.5.c - Multilateral Operations	NO	NO	NO	NA	NA	N	NA	N	NA	NA

3.3.6 Uncertainties Assessment and Time-Series Consistency

Uncertainties Assessment and Time-Series Consistency analysis were conducted using the 2006 IPCC guidelines and tier methodology was applied through the 2006 IPCC software. The time series was checked for a period between 2006 and 2018 (**Table 3.12**). Since the Tier 1 methodology was used with the default physical characteristics of fuels and emission factors, the time series was checked against the fuels. A clear time-series consistency was obtained for GHG emissions estimated between 2006 and 2018. The time-series consistency is also evidenced in **Figure 3.11**. A few sudden drops in the emissions were observed in GHG emissions from electricity generation mainly due to the sudden retirement of various thermal power plants under the purchase power agreement. However, these drops did not affect the general trends in the Energy sector's GHG emissions.

The uncertainty was also estimated using the IPCC 2006 software and Tier 1 methodology was used. Default values for emission factor uncertainties were used in combination with uncertainties of the collected data. Lower uncertainties were observed in the current GHG emissions compared to the previous inventory. This is chiefly due to an improvement in the quality of data and methodology.

Table 3.12 Summary of GHG emissions, Gg CO_2 eq. (2003-2018)

Period	GHG emissions	Change from 2003
2003	770.92	0.00%
2004	815.91	5.51%
2005	878.02	12.20%
2006	909.19	15.21%
2007	982.24	21.51%
2008	1,033.23	25.39%
2009	1,129.35	31.74%
2010	1,210.98	36.34%
2011	1,322.49	41.71%
2012	1,448.62	46.78%
2013	1,610.31	52.13%
2014	1,719.18	55.16%
2015	1,808.31	57.37%
2016	1,977.31	61.01%
2017	2,136.51	63.92%
2018	2,354.85	67.26%

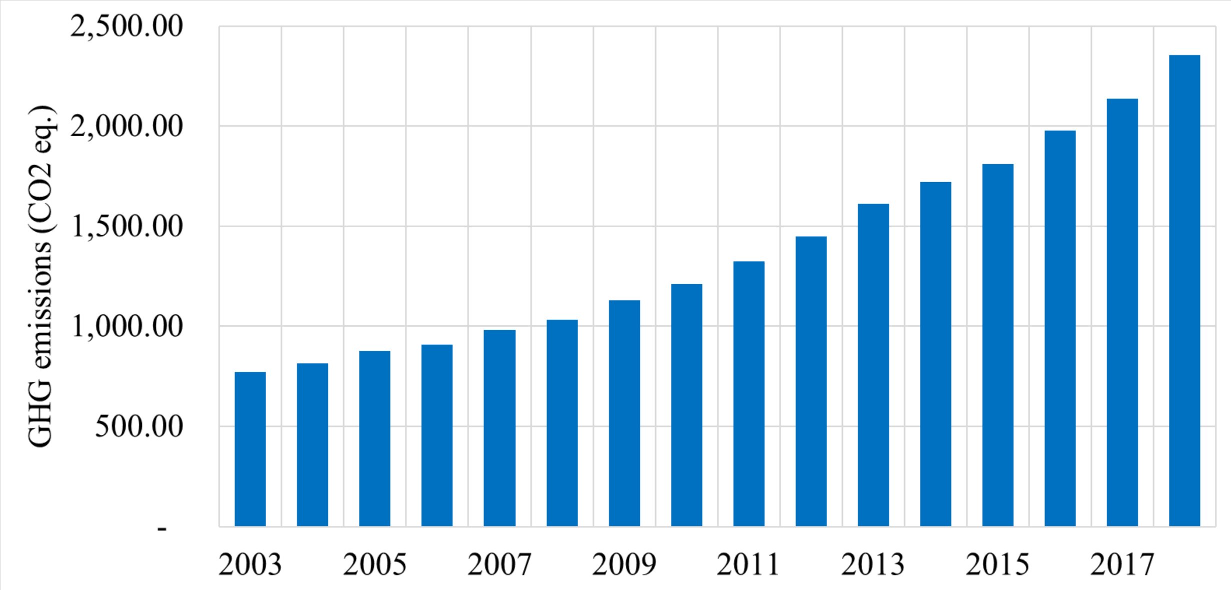


Figure 3.11 Trends in GHG emissions (2003-2018)

3.3.7 Quality assurance, quality control, and verification

According to the 2006 IPCC guidelines, Quality Assurance (QA) and Quality Control (QC) constitute an important part of the inventory development cycle. Thus, it should be conducted at different steps. The QA & QC was conducted at all steps of the inventory development through data validation and methodology checks from the team members and stakeholders. Details regarding the QA & QC are well documented in subsequent sections.

3.4 Energy industries (1.A.1)

3.4.1 Source category description

Generally, the energy industries source category encompasses three main activities, viz., electricity and heat production (1.A.1.a), petroleum refining (1.A.1.b), and Manufacture of Solid Fuels and Other Energy Industries (1.A.1.c). According to the 2006 IPCC guidelines, the fossil fuels considered in this category are both raw materials for the conversion processes, and sources of energy to run these processes. The energy industry comprises the following three main kinds of activities:

- Primary fuel production (including coal mining, oil, and gas extraction),
- Conversion to the secondary or tertiary fossil fuels (crude oil to petroleum products in refineries, coal to coke, and coke oven gas to coke ovens) and
- Conversion to non-fossil energy vectors (including the conversion of fuels to electricity and/heat).

Energy industries considered in this inventory consist of electricity generation industries (1.A1.a.i) and other energy industries (1.A1.c.ii) activities, which correspond to the main activities of electricity and heat source categories and manufacture of solid fuels and other energy industries of the 2006 IPCC guidelines, respectively. GHG emissions in electricity generation are generated by liquid fuels (diesel and residual fuels), gaseous fuels (methane gas), and peat, whereas the only fuel used in other industries (charcoal production) is firewood. **Table 3.13** shows the fuel consumption during the period 2006-2018.

Table 3.13 Fuels consumption by energy industries, TJ (2006-2018)

Period	Biomass	Liquid fuels	Gaseous fuels	Peat	Total
2006	12,791.53	1,233.80	-	-	14,025.33
2007	13,029.59	1,290.43	-	-	14,320.02
2008	13,295.72	780.45	-	-	14,076.17
2009	13,597.27	1,382.43	27.50	-	15,007.20
2010	13,908.34	1,400.41	74.50	-	15,383.25
2011	14,254.34	1,720.52	50.74	-	16,025.61
2012	17,146.43	1,891.45	73.29	-	19,111.17
2013	19,885.01	2,379.66	82.52	-	22,347.19
2014	19,631.51	2,429.99	169.00	-	22,230.50
2015	20,833.18	1,919.94	167.03	-	22,920.15
2016	22,061.52	1,032.99	921.88	-	24,016.39
2017	21,935.47	518.32	1,676.72	351.36	24,481.87
2018	25,539.23	1,181.46	1,811.28	351.36	28,883.33

Biomass consumption dominates over other fuels, followed by liquid fuels, while peat has a minute share of total fuel consumption.

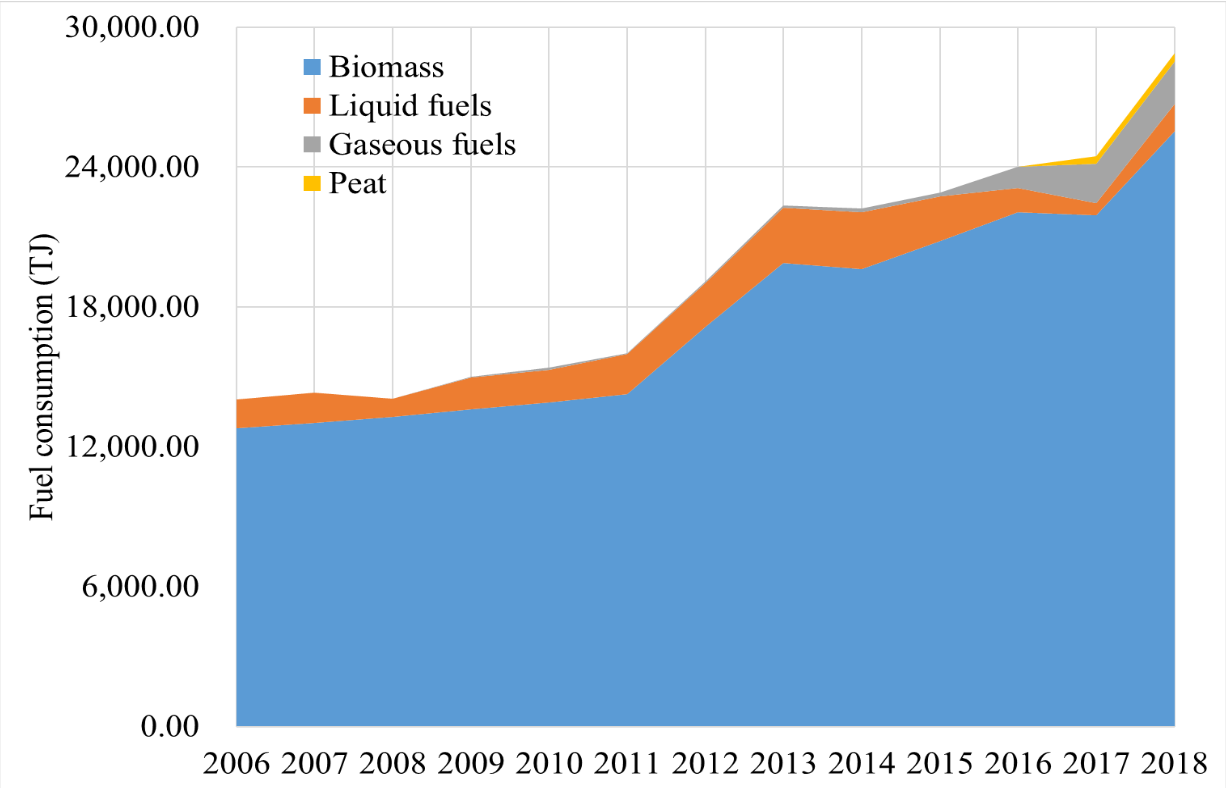


Figure 3.12 Trends in fuel consumption by energy industries (2006-2018)

GHG emissions from the energy industries category are estimated using the quantity of fuel combusted. The fuel used in this category includes biomass, liquid fuels (diesel and residual fuels) methane gas (considered as natural gas in this inventory), and peat. While biomass fuels such as firewood are generally used for charcoal production, liquid fuels, methane gas, and peat are used for electricity generation.

The quantity of fuel (expressed in energy units) consumed by energy industries during the period 2006-2018 is summarized in **Table 3.13**. The biomass consumption increased over the whole period while liquid fuel showed a fluctuating trend (**Figure 3.12**). The observed fluctuations could be attributed to the sudden retirement and installation of new thermal oil power plants. Gaseous fuels (methane gas) and peat consumption started in 2009 and 2017, respectively. As it can be seen from **Figure 3.12**, gaseous fuel consumption had a steady increase during the period 2009-2015 after which a sharp increase was observed due to the installation of the new methane power plant. Peat is a relatively new technology and had a minor contribution to the total fuel consumption (**Figure 3.13**).

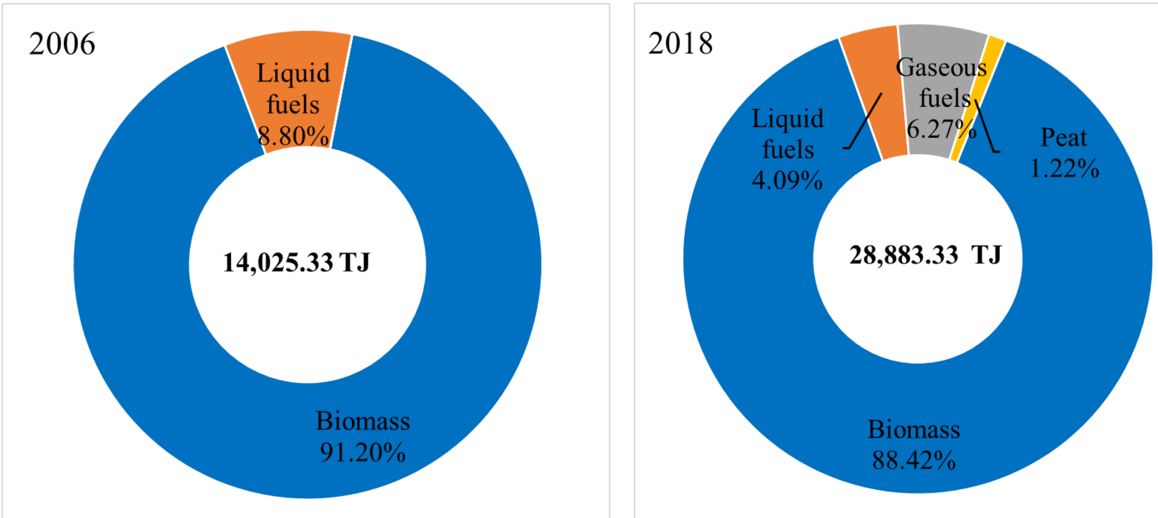


Figure 3.13 Shares of fuel consumption in energy industries

Shares of various fuels to total fuel consumption in energy industries in 2006 and 2018 are shown in **Figure 3.13**. As seen from the figure, biomass remained on top of fuel consumption in 2006 and 2018. In addition, a part of the liquid fuels and biomass were replaced by peat and gaseous fuels leading to the reduction in their respective contribution to total fuel consumption in 2018.

3.4.2 Electricity generation (1.A1.a.i)

GHG emissions by fuel combustion in electricity generation comprise emissions from electricity generation producers except those from heat and power plants. In Rwanda, electricity is generated via both renewable and conventional (non-renewable) energy sources. GHG emissions considered for electricity generation are combustion emissions for on-grid electricity generation including those from the private companies that feed in the grid under the Power Purchase Agreement scheme. In these industries, electricity is generated by liquid fuels (heavy fuel oil also referred to as residual fuels and diesel gas/oils) combustion in thermal generators. In this inventory, In addition to GHG emissions for liquid fuels, GHG emissions from methane gas and peat were considered and appropriate recalculations were conducted.

3.4.3 Other Energy Industries (1.A.1.c.ii)

According to the 2006 IPCC guidelines, GHG emissions from other energy industries consist of combustion emissions arising from energy-producing industries for own (on-site) energy use not mentioned in other subcategories or for which separate data are not available. This includes the emissions from own energy use for the production of charcoal, bagasse, sawdust, cotton stalks, and carbonizing of biofuels as well as fuel used for coal mining, oil and gas extraction, and the processing and upgrading of natural gas. It also includes emissions from pre-combustion processing for CO_2 capture and storage. Other energy industries are a subcategory of the Manufacture of Solid Fuels and Other Energy Industries (1.A.1.c) under IPCC guidelines. Considering the context of Rwanda, the only activities considered under this source category are charcoal production activities.

3.4.4 Energy industries emissions

3.4.4.1 Trends in energy industries GHG emissions

GHG emissions generated by energy industries in the period 2006-2018 summarized in **Table 3.14**. GHG emissions followed the trend of fuel consumption and electricity generation as discussed in section 3.1.1. The cumulative average increase in GHG emissions of 15.31 % was observed over the estimation period. This increase could be related to the growth of Rwanda's economy and the importance of electricity as a key driver of economic growth and development. As described in the Rwanda energy sector strategic plan (MININFRA, 2015a), petroleum consumption increased in absolute terms by over 16% between 2000 and 2012 while the oil import bill grew by more than 700% in the same period. As a share of GDP, oil imports increased from about 2.5% in 2000 to above 5.5% by 2012. The cost of procurement has an important macroeconomic impact. In 2013, oil products accounted for 25% of import costs and the proportion of export revenues spent on oil products was even higher at around 55%.

A sharp increase in GHG emissions observed from 2010 could be justified by the increase in the number of private companies under the so-called Power Purchase Agreement (PPA). A decline of about 36.74% was observed in 2008 plausibly due to a temporal closing of some thermal power plants (**Figure 3.15**). The same trend was also observed in electricity generation and fuel consumption in the same year. In addition, a remarkable decrease in emission was observed in the periods 2014-2016. The latter was mainly due to the implementation of the Rwandan policy to reduce the use of liquid fuels for electricity generation. However, a relatively sharp increase is observed in the period 2016-2018 chiefly due to the installation of new methane gas and peat-fired thermal power plants.

Table 3.14 GHG emissions from energy industries per category, Gg CO_2 eq. (2006-2018)

Period	Electricity Generation	Other Energy Industries	Energy Industries	Change
2006	91.73	23.92	115.65	0.00%
2007	95.94	24.37	120.31	3.87%
2008	58.03	24.86	82.89	-39.53%
2009	106.54	25.43	131.97	12.36%
2010	109.85	26.01	135.86	14.88%
2011	133.19	26.66	159.85	27.65%
2012	147.89	32.06	179.96	35.73%
2013	184.17	37.18	221.36	47.75%
2014	193.24	36.71	229.95	49.71%
2015	154.37	38.96	193.32	40.18%
2016	130.04	41.26	171.29	32.48%
2017	170.98	41.02	212.00	45.45%
2018	229.68	47.76	277.44	58.31%

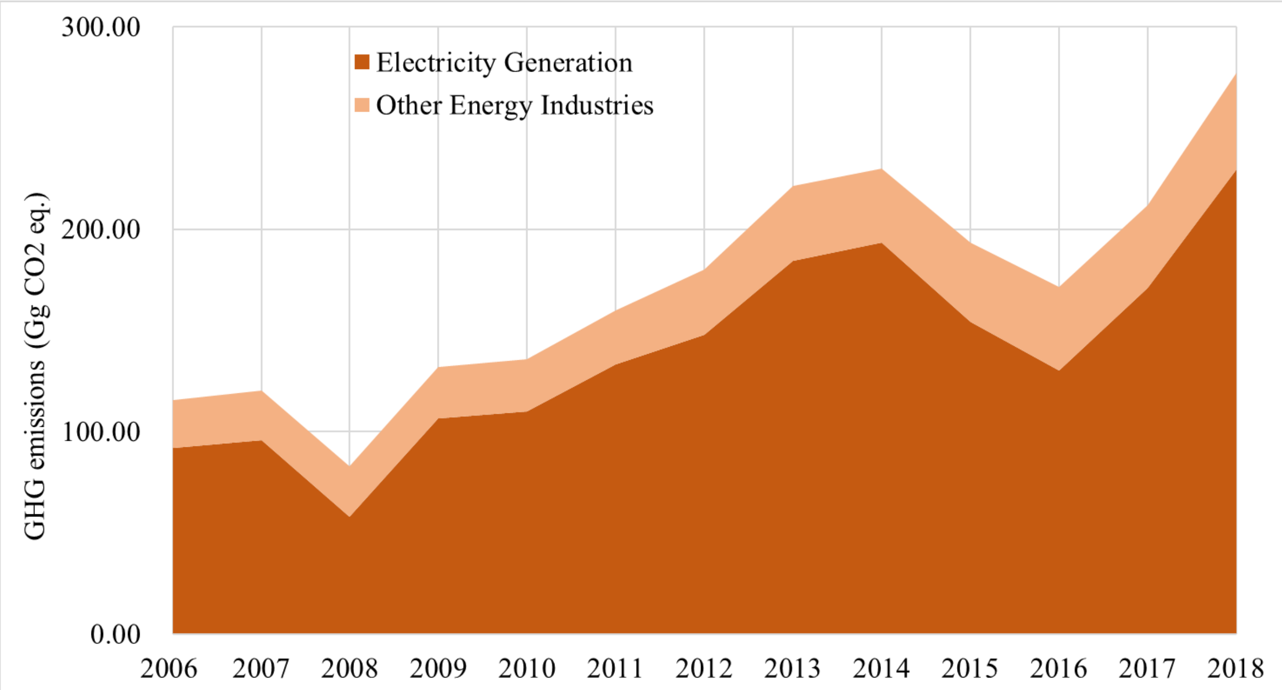


Figure 3.14 Energy industries GHG emissions (2006-2018)

3.4.4.2 Energy industries emissions by gas

Energy industry GHG emissions by gas are summarized in **Table 3.14**. CO_2 was the key gas for the energy industries category followed by CH_4 throughout the whole period. The dominance of CO_2 emissions is obvious since the latter is generated by carbon-intensive liquid fuels and gaseous fuels combusted for electricity generation.

Table 3.15 Summary of GHG emissions from energy industries by gas (2006-2018)

Period	CO_2	CH_4	N_2O	Total	CO_2 %	CH_4%	N_2O%
2006	91.42	8.14	16.09	115.65	79.05%	7.04%	13.91%
2007	95.62	8.29	16.40	120.31	79.48%	6.89%	13.63%
2008	57.83	8.43	16.63	82.89	69.77%	10.16%	20.07%
2009	106.19	8.65	17.12	131.97	80.47%	6.56%	12.97%
2010	109.50	8.85	17.51	135.86	80.60%	6.52%	12.89%
2011	132.76	9.09	18.00	159.85	83.05%	5.69%	11.26%
2012	147.42	10.92	21.62	179.96	81.92%	6.07%	12.01%
2013	183.58	12.68	25.10	221.36	82.93%	5.73%	11.34%
2014	192.62	12.52	24.80	229.95	83.77%	5.45%	10.79%
2015	153.88	13.25	26.20	193.32	79.60%	6.85%	13.55%
2016	129.73	13.98	27.58	171.29	75.74%	8.16%	16.10%
2017	170.59	13.89	27.51	212.00	80.47%	6.55%	12.98%
2018	229.12	16.21	32.11	277.44	82.58%	5.84%	11.57%

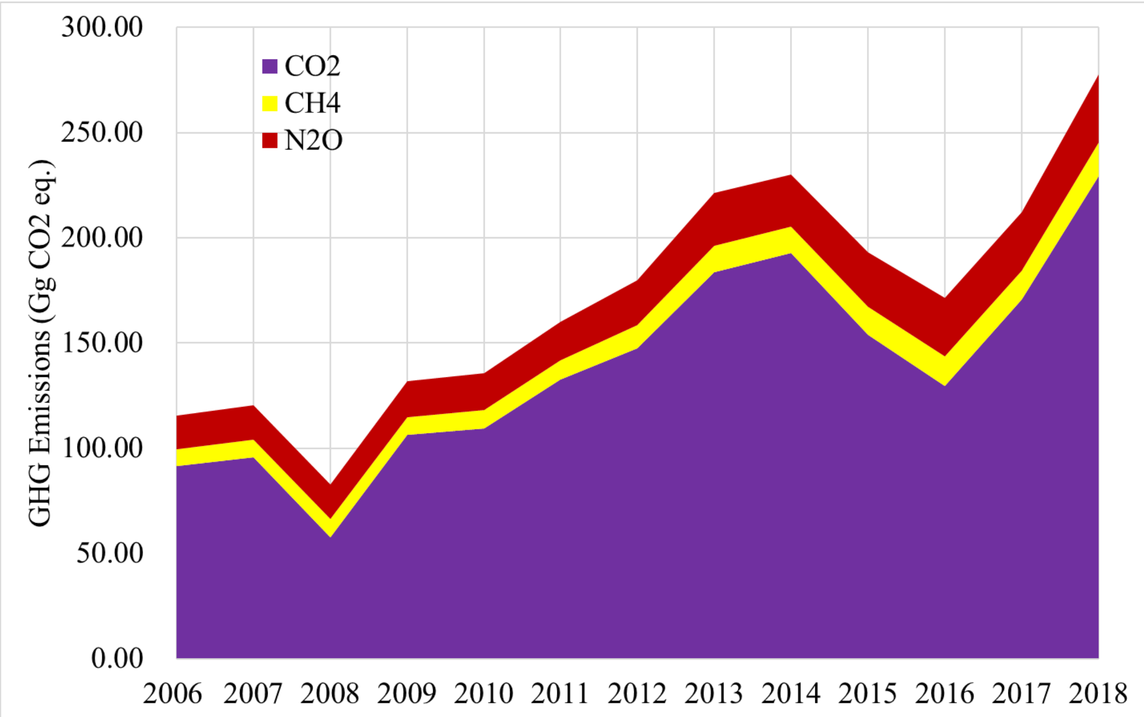


Figure 3.15 Trend in energy industries GHG emission per gas (2006-2018)

Trends in energy industries GHG emissions by gas are shown in **Figure 3.15**. The trends in emissions per gas are similar to the trends in emissions by fuels. CH_4 and N_2O had a steadily increasing trend while some drops in CO_2 emissions were recorded in 2008, 2015, and 2016. Since CO_2 is mainly generated by liquid fuels, the drops in CO_2 could be explained by the sudden retirement of some oil thermal power plants during these years. The analysis of the GHG emissions shares to energy industries shows that the CO_2 share in 2018 is far higher than that of 2006.

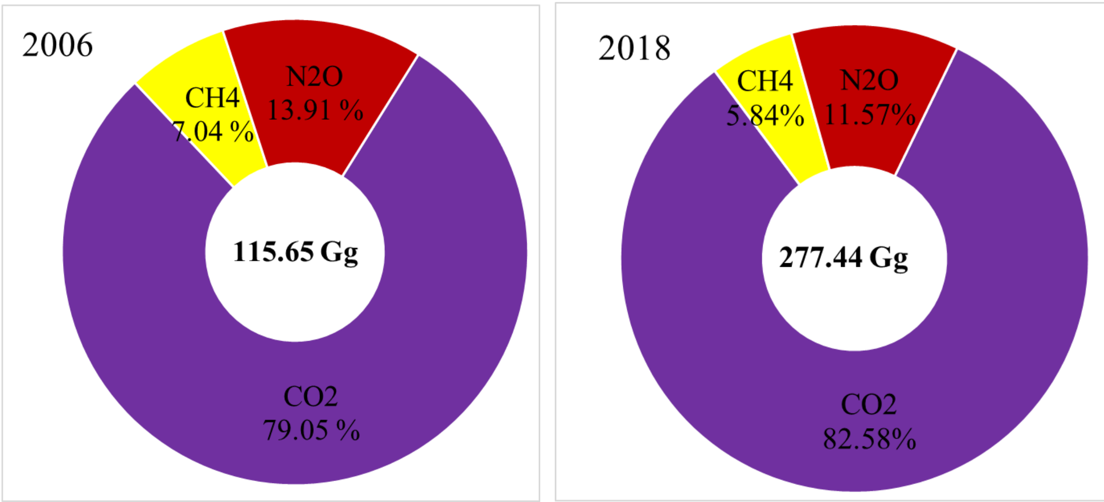


Figure 3.16 Contributions of various GHG to total emissions in 2006 and 2018

The plausible cause of this difference is the increase in carbon-intensive fuels (i.e., peat and methane gas), while biomass fuels, which are the main source of CH_4 and N_2O had a steady increase up to 2018.

3.4.4.3 Energy industries GHG emissions by fuels

As aforementioned, energy industries' GHG emissions are generated by various fuel combustion activities including biomass (firewood), liquid fuels (residual fuel oil and diesel), gaseous fuels (methane), and peat. Shares of GHG emissions generated by each fuel are summarized in **Table 3.16**. Liquid fuels for electricity generation were the main source of GHG emissions until 2015, followed by gaseous fuels. After this year, the commissioning of new methane gas power plants led to a sharp increase in related GHG emissions (**Figure 3.17**). Peat, which was recently introduced in the electricity generation mix, had the least contribution to the energy industries' GHG emissions.

Table 3.16 Energy industries GHG emissions by fuel, $GgCO_2eq$ (2006-2018)

Period	Biomass	Liquid fuels	Gaseous fuels	Peat	Total
2006	23.92	91.73	-	-	115.65
2007	24.37	95.94	-	-	120.31
2008	24.86	58.03	-	-	82.89
2009	25.43	104.99	1.54	-	131.97
2010	26.01	105.67	4.18	-	135.86
2011	26.66	130.34	2.85	-	159.85
2012	32.06	143.78	4.12	-	179.96
2013	37.18	179.54	4.63	-	221.36
2014	36.71	183.75	9.49	-	229.95
2015	38.96	144.99	9.38	-	193.32
2016	41.26	78.27	51.77	37.41	171.29
2017	41.02	39.41	94.15	37.41	212.00
2018	47.76	90.56	101.71	37.41	277.44

Trends in energy industries GHG emissions by fuel are displayed in **Figure 3.17.** Total, methane gas and biomass GHG emissions showed an increasing trend throughout the whole period, while liquid fuel emissions showed an increasing trend with drops in 2008, 2015, and 2016.

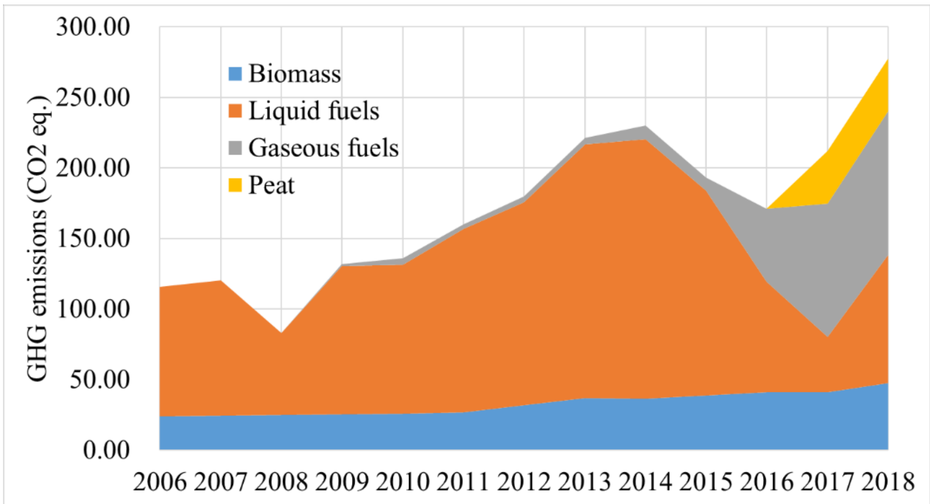


Figure 3.17 Trends in energy industries GHG emissions by fuel (2006-2018)

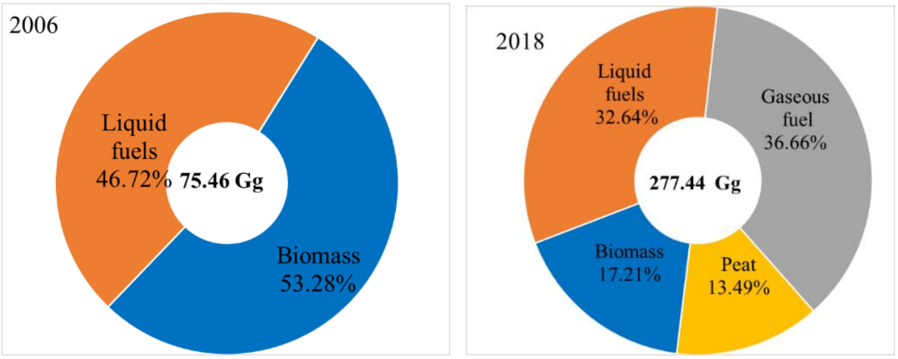


Figure 3.18 shares of various sources to energy industries GHG emissions in 2015 and 2018

Shares of various sources of energy industries' GHG emissions are presented in **Figure 3.18**. A clear difference in shares is seen from the figure chiefly due to the introduction of new methane gas power plants in the electricity generation mix in 2009 and the introduction of peat power plants in 2016.

3.4.5 Methodological issues

As described in the 2006 IPCC guidelines and good practices, GHG emissions from energy industries are generally calculated by multiplying the fuel combustion by its corresponding emission factors. In this inventory, data for liquid fuels (diesel and residual fuels) were collected in volume units and converted to energy content using the methodology described in the energy statistics manual (IEA, 2019). Due to the lack of sufficient country-specific data, a combination of Tier 1 and Tier 2 methodologies was mainly applied for all the fuels and gases following the methodologies and good practices detailed in volume two of the 2006 IPCC guidelines.

Emission factors and physical characteristics of different fuels considered in this inventory are summarized in **Table 3.17**. Country-specific values of net calorific values (NCV) and density were considered while for emission factors, default values as provided in the 2006 IPCC guidelines were used with their respective uncertainty ranges.

Table 3.17 Emission factors and physical characteristics of various fuels used in energy industry category

Fuels	Conversion factor/NCV	Density	Emission factor ($kgTJ^{-1}$)		
Unit/gases	**TJ/Gg**	**Kg/l**	**CO_2**	**CH_4**	**NO_2**
Residual Fuel oil	41	0.96	77,400	3	0.6
Gas/Diesel oil	43	0.84	74,100	3	0.6
Wood/wood wastes	15.6	NA	112,000	30	4
Peat	9.76	NA	106,000	1	1.5
Natural gas	48	NA	56,100	1	0.1

Source: Kobil, SP & IPCC

3.4.6 Data sources

According to the 2006 IPCC guidelines, data collection is a fundamental part of inventory preparation. The main activity data in the Energy sector are typically the amounts of combusted fuels, their characteristics, and the combustion technologies as well. In this inventory, an effort was made to collect data on all three parameters (i.e., amounts of fuels combusted and fuel characteristics and combustion technologies).

In Rwanda, electricity is generated from the combustion of various fossil fuels including diesel, residual fuels, methane gas from Kivu Lake, and recently, peat. Data on liquid fuel combustion for the whole period 2006-2018 were collected directly from the power plants (Jabana 1, Jabana 2, and SO Energy). Data on methane gas consumption were estimated based on electricity generated as reported in various statistical yearbooks for the period 2009-2018 (NISR, 2018b, 2019). The generated electricity was converted into fuel consumption units using the heat rate of a conventional gas-fired power plant, which was estimated at 7870 Btu/kWh (World Bank Group, 2020). It is noteworthy that due to the lack of IPCC guidance and emission factors/physical characteristics of methane gas, values for natural gas were used for the latter parameters. It is recommended to conduct appropriate research on the development of emission factors and physical characteristics of methane gas to improve the accuracy of GHG emissions from methane gas projects. In other Industries category, charcoal production was considered and the data on fuel consumption was estimated based on charcoal consumption in households and commercial/institutions subcategories and the kiln efficiencies. Data on charcoal consumption and kiln efficiencies were sourced in the recent energy survey (REMA, 2019a) and the feasibility study on the green Charcoal Value Chain in Rwanda (World Bank Group, 2012), respectively. It is interesting to note that in the previous inventory, the GHG emissions from charcoal production were reported in the Other Sector's subcategories due to a lack of data (Republic of Rwanda, 2018). In this inventory thanks to the data filling survey conducted before inventory development, a proper data disaggregation was conducted and the GHG emissions from charcoal production were reported under energy industries.

3.4.7 Uncertainty and time-series consistency

According to the 2006 IPCC guidelines, estimates of uncertainty are needed for all relevant source and sink categories, greenhouse gases, inventory totals as a whole, and their trends. In this inventory, uncertainties were estimated and analysed according to chapter 3 of volume 1 in combination with the methods provided in volume 2 (Energy sector) of 2006 IPCC guidelines and a mode v 2.17 IPCC software was used (IPCC, 2006b). Uncertainties for all three GHG gases, i.e., CO_2, CH_4, and N_2O were estimated and reported. Default uncertainties from source data activities were used in addition to information from the practices and measurements from oil companies, especially from Kobil, a company that has a long experience in petroleum products in Rwanda. A consistent time series was observed throughout the whole period of the analysis.

3.4.8 Source-specific QA/QC and verification

In this inventory, the Quality Assurance (QA) and Quality Control (QC) in both electricity generation and other energy industries activities were conducted through a comparison of collected data on fuel consumption with the data collected from different reports (MININFRA, 2015a, 2015b; NISR, 2018b; REMA, 2019a). Different interviews were conducted with concerned plant managers and charcoal production cooperatives to ensure the quality of the collected data. In addition, the Quality Assurance (QA) and Quality Control (QC) were implemented *via* a comparison of the estimates from the reference and sectoral approaches as aforementioned.

3.4.9 Source-specific recalculations

Considering the contribution of methane gas to electricity generation in Rwanda, a recalculation was conducted to include the GHG emissions generated by related power plants. In addition, an improvement in the methodology was done and GHG emissions from charcoal production were calculated for the whole period 2006-2018. The results of recalculation are summarized in **Table 3.18**. High differences between the latest data and previous data are observed. The main reason for these differences is the introduction of GHG emissions from a new source category (i.e., Other Energy Industries) and the GHG emissions related to methane gas-fired power plants. While the latter was not estimated on the previous inventory, the former were reported elsewhere (in Other Sectors).

Table 3.18 Results of recalculation in Energy Industries

Energy industries emissions (Gg)										
Period	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
Previous Data	91.73	95.94	58.03	104.99	105.67	130.34	143.78	179.54	176.84	144.99
Latest Data	115.65	120.31	82.89	131.97	135.86	159.85	179.96	221.36	229.95	193.32
Difference (%)	26.08	25.40	42.85	25.69	28.57	22.64	25.16	23.29	30.03	33.34

Energy industries emissions (Gg)
Documentation (reason for recalculation): • The recalculation for electricity generation was done in 2009. Methane gas, which was not considered in the previous inventory due to a lack of data, was considered in this inventory. • In the previous inventory, the emissions for charcoal production were included elsewhere (in other sectors). In this inventory, thanks to a recent survey to fill data gaps, emissions generated by charcoal production were estimated and reported in energy industries according to IPCC guidelines.)

The differences in previous and latest data are also evidenced by the trends in GHG emissions as depicted in **Figure 3.17**.

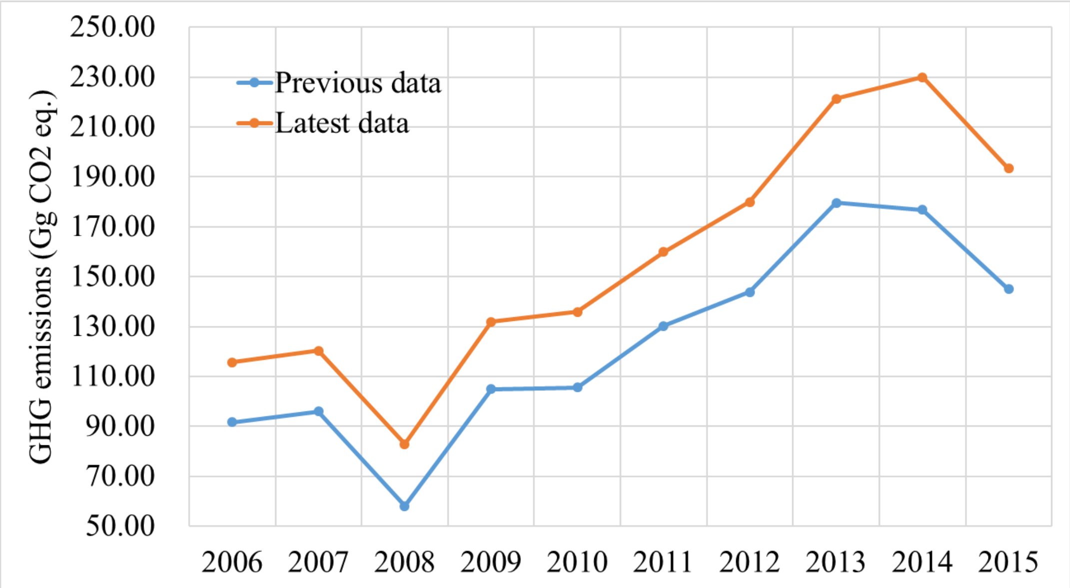


Table 3.19 Trend in recalculated GHG emissions from energy industries

3.4.10 Source-specific planned improvements and recommendations

Though a consistent time series was obtained, some improvements related to the filling of data gaps are needed. Due to lack of the activity data, the GHG emissions related to charcoal production were estimated using the assumptions reported in (World Bank Group, 2012). In the future, these gaps could be filled by improving the reporting system and encourage all the companies and cooperatives involved in charcoal production to keep records of their data activities. Another challenge faced was the possibility to use country-specific data, especially for calorific values, densities, emission factors, etc. In the future, this challenge could be handled through appropriate research and technical advisory for the companies involved in energy generation.

GHG emissions generated by methane gas combustion for electricity generation were considered as natural gas in this inventory chiefly due to the lack of necessary data to be included in the calculation methodologies. In future inventories, this issue should also be handled. The lacking data include the physical characteristics (net calorific value, density, etc.) and the emission factor related to the conversion technologies used at various power plants.

3.5 Manufacturing industries and construction

3.5.1 Source category description

According to the 2006 IPCC Guidelines, emissions from the industry sector were specified by sub-categories that correspond to the International Standard Industrial Classification (ISIC) of all Economic Activities. Considering the latter classification and the source activities available in Rwanda, the activities sources considered under this source category include Food processing, beverages and tobacco (1.A.2.e), Non-metallic minerals (1.A.2.f), Mining (excluding fuels), and Quarrying (1.A.2.i) and Construction (1.A.2.k).

Table 3.20 Manufacturing industries and construction fuel consumption, TJ (2006-2018)

Period	Biomass	Liquid fuels	Peat	Solid fuels	Total	Change
2006	21,503.34	455.47	-	-	21,958.81	0.00%
2007	22,659.97	545.47	-	-	23,205.44	5.37%
2008	23,318.20	505.56	-	-	23,823.76	7.83%
2009	24,306.11	472.55	-	-	24,778.65	11.38%
2010	25,233.31	423.66	14.54	-	25,671.51	14.46%
2011	25,358.48	423.16	50.94	-	25,832.58	15.00%
2012	25,298.36	426.81	36.64	-	25,761.81	14.76%
2013	26,137.39	475.98	51.68	-	26,665.04	17.65%
2014	29,181.65	705.48	44.12	-	29,931.24	26.64%
2015	32,231.08	884.75	50.57	-	33,166.40	33.79%
2016	35,291.75	149.52	-	1,110.23	36,551.51	39.92%
2017	38,668.64	253.79	-	979.10	39,901.53	44.97%
2018	39,828.08	194.66	-	1,382.93	41,405.67	46.97%

Table 3.20 shows the fuel consumption by the identified subcategories. Biomass fuels are mainly consumed in food processing, beverage, and tobacco industries including tea estates, sugar industries, and other food processing industries including biscuit manufacturers. Liquid fuels such as diesel, residual fuel oil, and kerosene are mainly consumed in non-metallic mineral industries (CIMERWA), various mining and quarrying companies, and some food processing industries.

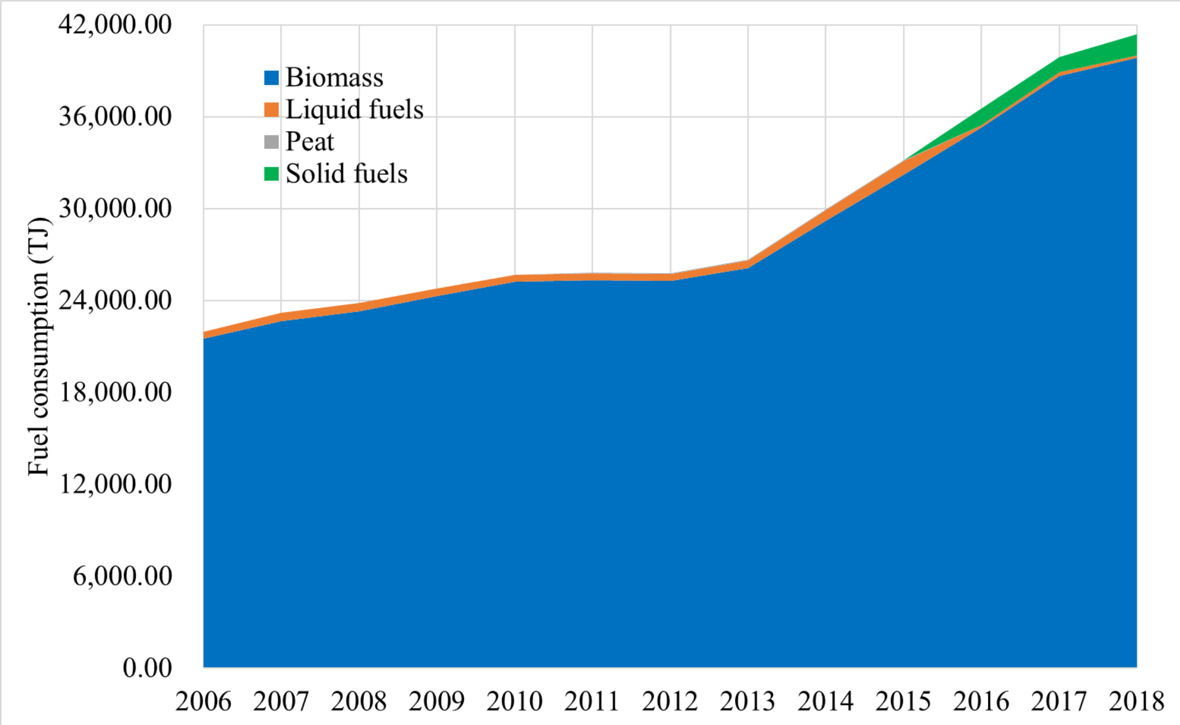


Figure 3.19 Trends in manufacturing industries and construction fuel consumption (2006-2018)

As it could be seen from **Table 3.21** and **Figure 3.19**, biomass is the main fuel consumed in the manufacturing and construction industries followed by liquid fuels. Peat was used in non-metallic industries in the period 2010-2015 and replaced by solid fuels (coal) from 2016 in non-metallic industries.

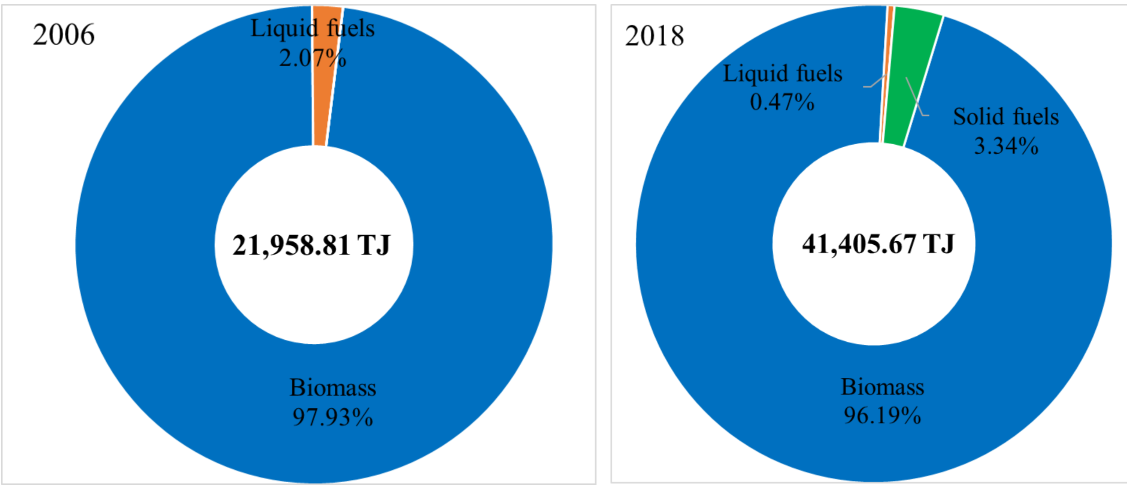


Figure 3.20 Shares of various fuels to total fuel consumption in manufacturing industries and construction category in 2006 and 2018

As it is indicated in **Figure 3.20**, solid fuel (coal) was adopted in 2016 as a replacement for peat and a part of liquid had a significant contribution to the total fuel consumption over the period 2016-2018. This contribution to fuel consumption was also reflected in the GHG emissions from non-metallic industries. It is noteworthy that despite the high share of biomass thorough the whole period 2006-2018, related emissions are surpassed by more carbon-intensive liquid and solid fuels.

3.5.2 Total manufacturing industries and construction emissions

As aforementioned, estimated GHG emissions were the lowest of the total emissions from manufacturing industries and the construction category. During the period 2006-2018, total GHG emissions from manufacturing industries and construction showed an increasing trend with an average increase of 22.80% (**Table 3.21**). Fast increases of 46.33% and 46.69% were observed for non-mineral industries and construction, respectively following the development of construction industries over the period 2006-2018.

Table 3.21 Manufacturing industries and construction emissions, Gg CO_2 eq. (2006-2018)

Period	Food Processing, Beverages and Tobacco	Non-Metallic Minerals	Mining and Quarrying	Construction	Total	Change
2006	2.17	32.95	2.29	38.05	75.46	0.00%
2007	2.75	39.92	2.31	39.64	84.62	10.81%
2008	2.33	36.80	2.32	41.29	82.74	8.80%
2009	2.46	34.23	2.33	43.01	82.03	8.00%
2010	2.40	30.84	3.42	44.80	81.46	7.36%
2011	2.27	34.30	3.74	45.20	85.52	11.75%
2012	2.40	32.78	3.74	45.23	84.15	10.32%
2013	2.69	37.60	3.88	46.93	91.10	17.16%
2014	3.43	51.40	6.59	52.25	113.67	33.61%
2015	3.20	67.38	5.63	57.79	134.00	43.68%
2016	7.11	107.08	5.28	63.56	183.03	58.77%
2017	11.38	97.77	6.03	69.57	184.75	59.15%
2018	12.53	132.52	3.88	71.93	220.87	65.83%

As it could be seen from the table, non-metallic industries were the main contributor to total GHG emissions followed by the construction industries while mining and food processing industries had modest contributions. The trend in emissions is similar to that of fuel consumption. It is also noteworthy the fluctuation trend observed in mining industries, which is linked to its production behaviour. Generally, the mining and quarrying companies do not follow a steady production pattern and thus the generated GHG emissions follow the same trend.

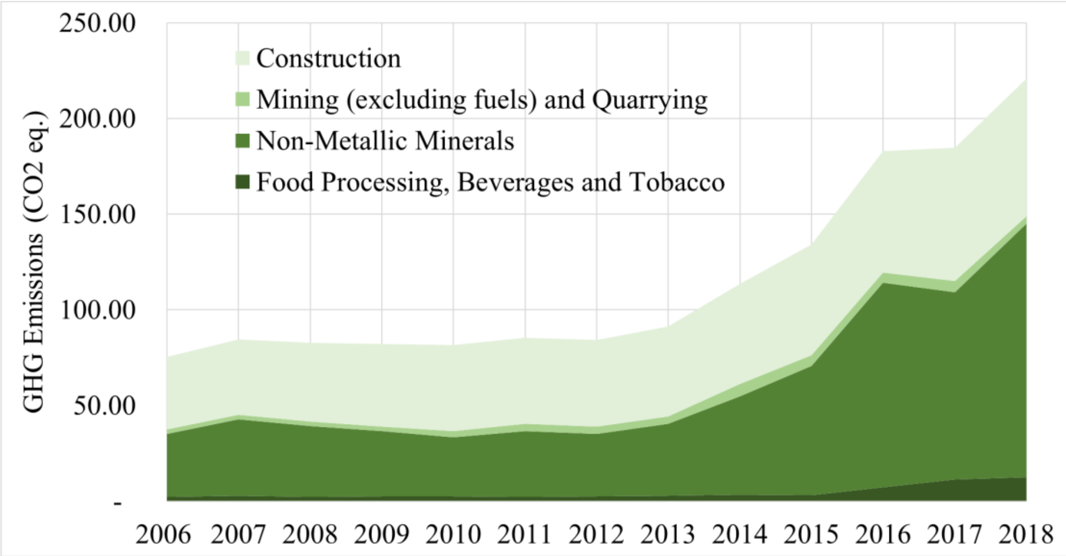


Figure 3.21 Trends in GHG emissions from manufacturing industries and construction

Figure 3.21 shows the trends in GHG emissions for various subcategories of the manufacturing and construction industries. The total emissions are characterized by a steady increase in GHG emissions from 2006 to 2015 followed by sharp increase thereafter. The plausible reason for the observed sharp increase in emissions is the use of highly carbon-intensive coal in non-metallic mineral industries and the increase in food processing industries, which rely on kerosene and other carbon-intensive liquid fuels. During this period, a considerable increase in industrial production for food processing and cement industries and construction was noted justifying the high GHG emissions.

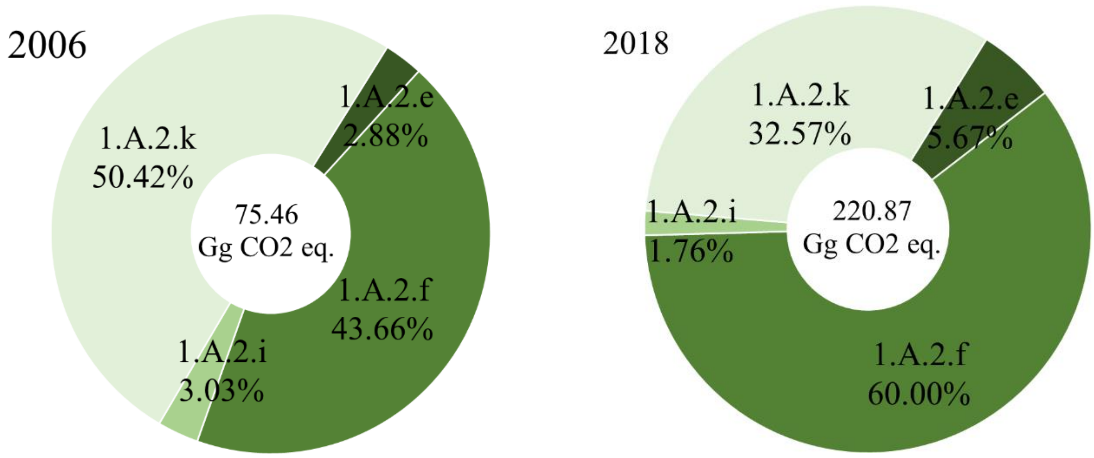


Figure 3.22 Shares of various subcategories to total emissions from manufacturing industries and construction

3.5.3 Manufacturing industries and construction emissions by gas

The manufacturing industries and construction emissions by gas and their trend during the period 2006-2018 are shown in **Table 3.22**. CO_2 remissions remained on the top for the whole period followed by N_2O, while CH_4 had a minor contribution. The high contribution of CO_2 is justified by the use of carbon-intensive fuels, especially in non-metallic minerals, which are the main source of GHG emissions in this category. The high share of N_2O emissions could be justified by the high biomass consumption, especially in food processing industries. It is also important to note that the high share of CO_2 in 2018 compared to 2015 was caused by coal consumption in the former year (**Figure 3.24**). The trend in emissions as displayed in **Figure 3.23** followed the same trend as the total emissions.

Table 3.22 Manufacturing industries and construction emissions by gas, Gg CO_2 eq. (2006-2018)

Period	CO_2	CH_4	N_2O	Total
2006	35.14	13.58	26.75	75.46
2007	42.11	14.31	28.20	84.62
2008	39.01	14.72	29.01	82.74
2009	36.46	15.34	30.23	82.03
2010	34.16	15.92	31.37	81.46
2011	37.97	16.00	31.55	85.52
2012	36.72	15.97	31.47	84.15
2013	42.08	16.50	32.52	91.10
2014	58.90	18.43	36.34	113.67
2015	73.49	20.36	40.15	134.00
2016	116.26	22.47	44.30	183.03
2017	111.73	24.58	48.45	184.75
2018	145.42	25.39	50.06	220.87

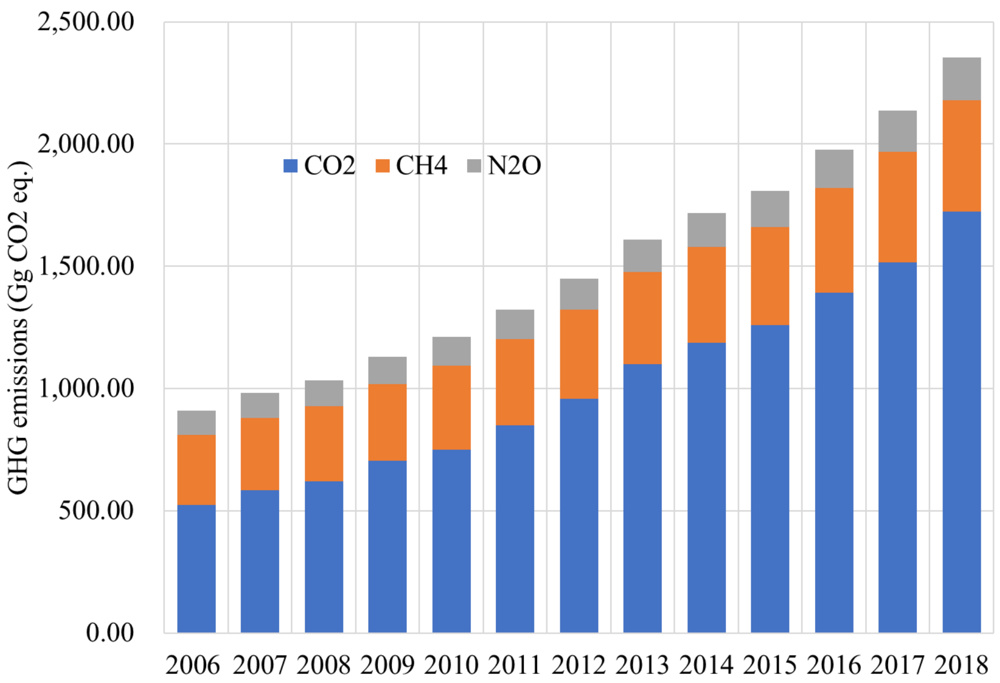


Figure 3.23 GHG emissions from manufacturing industries and construction

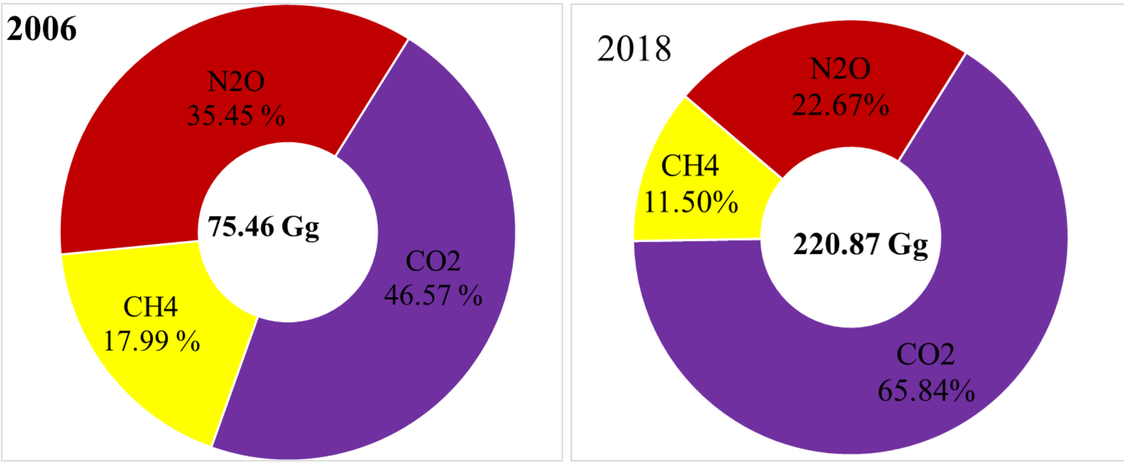


Figure 3.24 Shares of GHG to manufacturing industries and construction emissions in 2006 and 2018

3.5.4 Manufacturing industries and construction emissions by fuel

All the estimated GHG emissions from manufacturing industries and construction are generated by four main fuel combustion activities in these industries, viz., biomass, liquid fuels (diesel, residual fuel oil and kerosene), peat, and solid fuel (coal). While biomass and kerosene are solely consumed in food processing industries, peat, coal is consumed in non-metallic industries. Residual fuels also known as heavy fuel oils (HFO) are consumed by non-metallic mineral and beer industries and diesel also referred to as light fuel oil (LFO) is generally consumed in all the subcategories. The GHG emissions by fuel are summarized in Table 3.23. Biomass emissions are the major contributor to total GHG emissions in this category during 2006-2018. The latter emissions are generated by firewood and bagasse combustion in sugar industries, wood waste consumption in brick manufacturing, firewood consumption in tea factories, and biogas consumption in beer industries.

Table 3.23 Manufacturing industries and construction emission by fuel, $GgCO_2eq$ (2006-2018)

	Biomass	Liquid fuels	Peat	Solid fuels	Total
2006	40.21	35.25	-	-	75.46
2007	42.37	42.24	-	-	84.62
2008	43.61	39.14	-	-	82.74
2009	45.45	36.57	-	-	82.03
2010	47.19	32.73	1.55	-	81.46
2011	47.42	32.67	5.43	-	85.52
2012	47.31	32.94	3.90	-	84.15
2013	48.88	36.72	5.50	-	91.10
2014	54.57	54.40	4.70	-	113.67
2015	60.27	68.35	5.39	-	134.00
2016	65.99	11.27	-	105.78	183.03
2017	72.30	19.17	-	93.28	184.75
2018	74.47	14.64	-	131.76	220.87

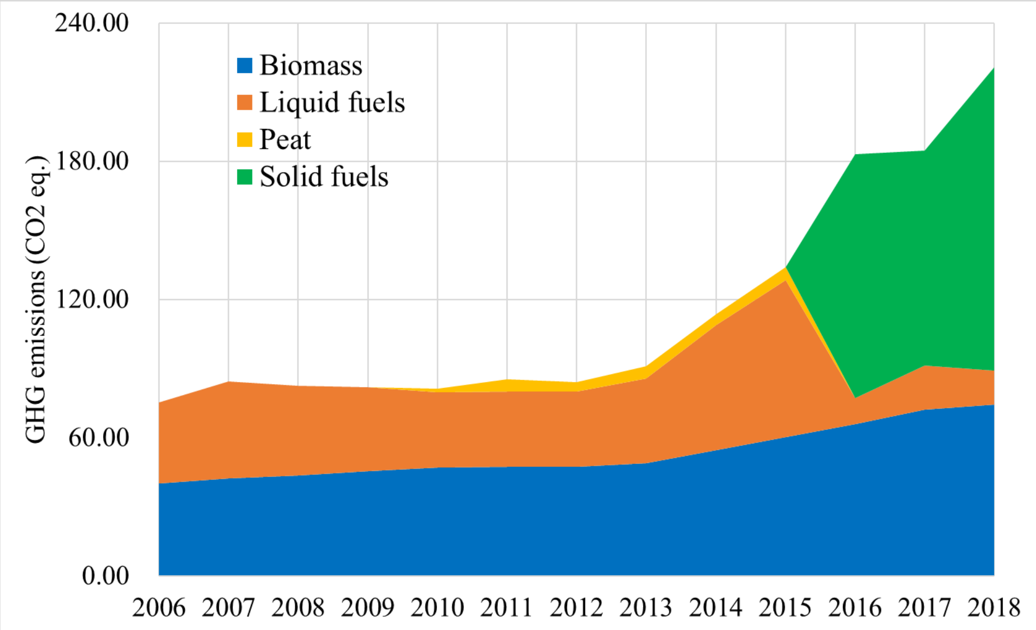


Figure 3.26

Trend in Manufacturing industries and construction emissions by fuel

The period 2015-2018 was characterized by a rapid increase in GHG emissions generated by the consumption of high carbon-intensive coal in nonmetallic industries (**Figure 3.26**), which resulted in a heavy reduction in liquid fuel emissions (**Figure 3.27**). Peat consumption in non-metallic minerals generated minute emissions during the period 2010-2015 and was replaced by coal in 2016.

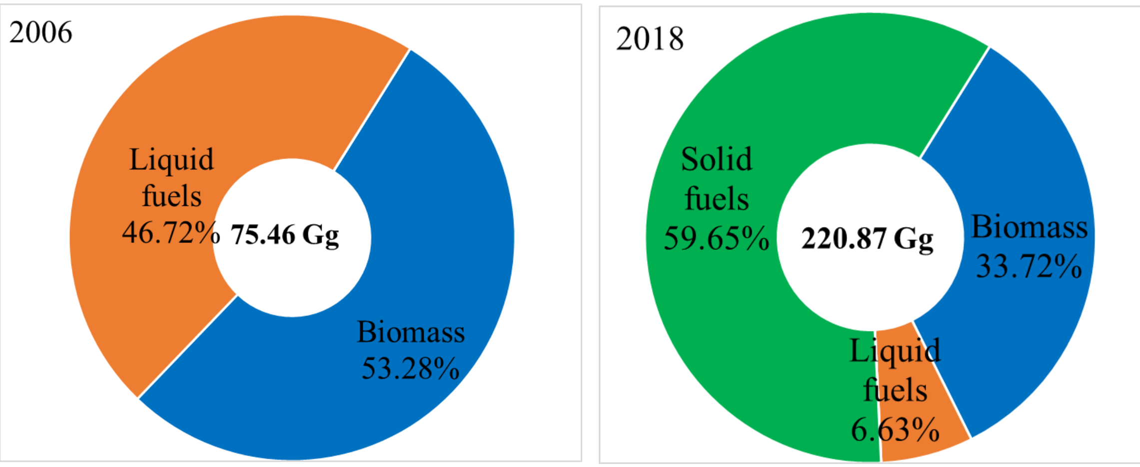


Figure 3.25 Shares of GHG emissions from various fuels to total emissions

Liquid fuel emissions showed a steady increasing trend up to 2013, followed by a sharp increase due to the use of residual fuels in beer industries and kerosene combustion in food processing industries up to 2015 and a substantive decline between 2015 and 2018.

3.5.5 Methodological issues

GHG emissions from manufacturing industries and construction source categories include emissions from combustion of fuels during manufacturing processes and fuel combustion for the generation of electricity and heat for own use in these industries. Due to the lack of country sufficient data, a combination of Tier 1 and Tier 2 methodologies was applied following the IPCC 2006 default emission factors. Physical characteristics (calorific values and densities) and emission factors of various fuels used in this category are summarized in **Table 3.24**. Country-specific convention factors/Net Calorific Values of liquid fuels and peat were considered.

Table 3.24: Physical characteristics and emission factors of fuels used in manufacturing industries and construction category

Fuels	Convention factor /NCV	Density	Emission factor ($kgTJ^{-1}$)		
Unit/gases	**TJ/Gg**	**Kg/l**	**CO_2**	**CH_4**	**NO_2**
Residual Fuel oil	41	0.96	77,400	3.0	0.6
Peat	9.76	NA	106,000	2.0	1.5
Biomass	15.6	NA	-	30.0	4.0
Gas/Diesel oil	43	0.84	74,100	3.9	3.9
Coal	28.2	NA	94600	10	1.5

Source: CIMERWA LTD. & IPCC guidelines

3.5.6 Data sources

Data from manufacturing industries and construction source categories were mainly collected from CIMERWA LTD, Rwanda Revenue Authority, Ministry of trade and industry (MINICOM), and relevant national and international reports (IPCC, 2006a).

Non-metallic minerals considered in this inventory include cement industries. In these industries, GHG emissions are generated by liquid fuel, peat, and coal combustion activities. The main liquid fuels consumed include heavy fuel oils used during cement manufacturing and light fuel oil used for electricity generation for own use. Data on both heavy and light fuel consumption and physical characteristics were collected from CIMERWA ltd. Peat is mainly used in clinker manufacturing in CIMERWA ltd. Data on peat consumption and its physical characteristics were collected from CIMERWA Ltd., which is the only industry in Rwanda that produces clinker cement.

GHG emissions from food processing, beverages, and tobacco industries were estimated for tea factories, which are considered as the big consumer of fuel under this category. The main fuels used in these industries are biomass (firewood, biogas, and bagasse) that are combusted in tea driers and sugar processing units, and cassava processing plants. Biomass consumption data were estimated based on historic specific energy consumption (quantity of fuel combusted for one ton of processed tea) and quantities of tea produced by different factories/industries. Data for estimation were mainly sourced from National Agricultural Export Development Board (NAEB) reports and some archives of the former OCIR THE, which are also kept by NAEB. The specific fuel consumption was estimated by dividing the average fuel consumption for the period 2006-2015 by the produced tea over the same period. The fuel consumptions were estimated simply by multiplication of the specific fuel consumptions by the produced tea for the whole period 2006-2018 and all the factories. Data on fuel consumption in breweries were sourced from BRALIRWA and SKOL breweries while the data from other food industries were collected from various biscuits manufacturing industries. It is important to note that most of the latter industries are relatively new and were not considered in the previous inventory. This could be the justification for the high difference between the previous and the current data as presented in the recalculation section.

Fuel consumption in mining industries was estimated based on the exported volume of minerals and the specific energy consumption (i.e., energy consumption per tonne of processed minerals). The data on mineral exports were sourced from National statistics reports and the data used in specific energy consumption were collected from various mineral companies including DUMAC, EUROTRADE, RUTOONGO MINING, NEW BUGARAMA MINES, and PILLEN. The fuel consumption differs from company to company based on their production. To avoid any bias, yearly average specific fuel consumption per mineral was estimated and applied to the annual production for the whole period 2006-2018.

3.5.7 Uncertainties and time-series consistency

Uncertainties in estimated GHG emissions from manufacturing industries and construction were calculated and analysed according to chapter 3 of volume 1 in combination with the methods provided in volume 2 (Energy sector) of the IPCC guidelines. Combined uncertainties for biomass combustion activities were 12.5% for all the greenhouse gases considered while those for liquid fuels were 13.1% for CO_2 and 11.00% for both CH_4 and N_2O. The calculated uncertainties were in the acceptable range of IPCC guidelines and the analysis of time series consistency indicated consistency in all estimated data.

3.5.8 Source-specific QA/QC and verification

To ensure the QA/QC of both the collected data and estimates of GHG emissions, a verification exercise was done along the whole process of GHG inventory compilation. Data were collected from individual industries and were compared with the reported data to MINEACOM to ensure completeness and comparability. In case of differences, a verification was done *via* interviews with the appropriate personnel at the industry level and a consensus was drawn. In addition, the data were validated in the group of contributors and the methodologies were well checked before the final compilation. The QA/QC was also confirmed by the comparison between the reference and sectoral approaches as aforementioned.

3.5.9 Source-specific recalculation

During the previous inventories, due to insufficient data sources, emissions were calculated based on estimated data sources. Thanks to recent data surveys, recalculations were conducted mainly in mining industries, construction, and some new subcategories such as sugar industries, and beer industries. These recalculations resulted in major differences between the current emissions and the previously reported emissions (**Table 3.25**). However, the two datasets showed similar trends as shown in **Figure 3.26**. The main reason for the observed differences in the use of new datasets, especially in the sugar, beer industries, and cassava processing industries.

Table 3.25 Results of recalculation in manufacturing industries and construction

Energy sector emissions (Gg)										
Energy industries	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
Previous Data	38.34	48.85	48.66	46.55	43.09	48.84	47.32	56.29	73.26	92.60
Latest Data	75.46	84.62	82.74	82.03	81.46	85.52	84.15	91.10	113.67	134.00
Difference	96.81%	73.22%	70.04%	76.20%	89.04%	75.08%	77.84%	61.85%	55.16%	44.71%

Documentation (reason for recalculation):

- The main reason for recalculation was the discovery of new data sets for sugar industries, breweries (BRALIRWA and SKOL), cassava processing industries, and biscuit manufacturing industries.
- In addition, recalculations were conducted in mining industries using newly collected data. In the previous inventory, fuel consumption in mining industries was estimated using industrial surveys conducted in 2012.

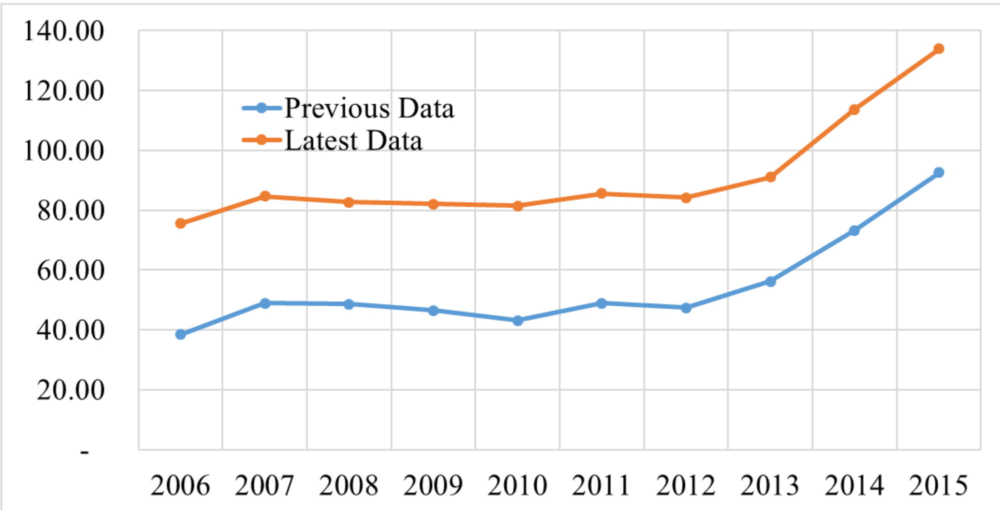


Figure 3.26 Trends in recalculated GHG emissions from manufacturing industries and construction

3.5.10 Source-specific planned improvement and recommendation

Despite the modest contribution of the manufacturing industries and construction category to total energy sector GHG emissions over the period 2006-2018, it is rapidly growing and according to the government plans, it will keep growing over the coming decades. Thus, it will need increasing attention in future inventories. As aforementioned, the GHG emissions in this category were estimated based on calculated activity data and using Tier 1 methodology with default emission factors. This could have led to higher uncertainties in the estimated GHG emissions. Future improvements should focus on the activity data recording and reporting as well as the development of country-specific emission factors. These improvements will reduce the uncertainties in the future inventories.

3.6 Transportation

3.6.1 Source category description

According to the 2006 IPCC guidelines, mobile combustion also to as transportation activities mainly produce direct GHG emissions of carbon dioxide (CO_2), methane (CH_4), nitrous oxide (NO_2) through the combustion of different types of fuels. In this inventory, the GHG emissions were estimated using the guidance provided in volume 2 of the 2006 IPCC guidelines, and major transport activities such as road, air navigation, waterborne navigation, and off-road transport were considered. Direct emissions estimated under this category are mainly from the combustion of liquid fuels (including gasoline, diesel, aviation gasoline, and jet fuel).

Rwanda is one of the least urbanized in the world with its population, vehicle fleet, economic and technical activities heavily concentrated in the capital city of Kigali, which serves as the financial and commercial hub of the country. Among others, the transport sector is expected to play a vital role in the improvement of this situation as a growth engine for stimulating economic growth in domestic goods, services, and industries and access to key international markets.

As described in the 2006 IPCC guidelines, civil aviation emissions are generally produced through the combustion of jet fuels (i.e., kerosene and jet gasoline) and aviation gasoline. Generally, aircraft engine emissions are roughly composed of about 70% of CO_2, a little less than 30 % H_2O, and less than 1% of indirect gases (i.e., CO, SO_X, NMVOC, and PM) and other trace components of pollutants including hazardous air pollutants.

Air transportation in Rwanda is still dominated by international aviation. Currently, Rwanda has two international and three domestic airports. Among others, Kigali International Airport is considered the main centre for both domestic and international air movements. During the period 2006-2018, aircraft movements of the country had a considerable increase mostly due to improvements in infrastructure and service delivery in the air transport sector. However, since these increases were dominated by international aviation, they had a minute influence on national GHG emissions.

Road transportation is well described in the 2006 IPCC guidelines. GHG emissions from road transportation encompass the emissions from all fossil fuel combustion and evaporative emissions from fuel use in road vehicles, including the use of agricultural vehicles on paved roads. Thus, the road transportation category includes all the type of light-duty vehicles such as automobiles, and heavy-duty vehicles such as tractor, trailers, and buses and on-road motorcycles (including mopeds, scooters, and three-wheelers). According to the 2006 IPCC guidelines, the later vehicles operate on various types of gaseous and liquid fuels.

Rwanda is a land-locked and mostly mountainous country; its transportation system is dominated by road transportation. Inspired by the nature of its environment, Rwanda has developed a relatively important and partly well-paved road network with good accessibility to most parts of the country and the neighbouring countries (MININFRA, 2015a, 2018). During the last decades, road transportation activities increased tremendously. The increase could be justified by the increase in both the number of registered vehicles and fuel consumption as discussed in subsequent sections. These increases have put the road transportation subcategory among the top contributors to energy GHG emissions.

In addition, the GHG emissions from off-road transport were estimated. These consist of emissions generated by various machinery in industries and agriculture and construction sites. It is important to note that the latter emissions, which were aggregated with the road transportation in previous inventories, were estimated separately using the recent energy surveys conducted to fill data gaps.

Table 3.26 Transportation Fuel consumption, TJ (2006-2018)

Period	Civil Aviation	Road Transportation	Water-borne Navigation	Other Transportation	Total
2006	0.91	5,028.97	-	6.02	5,035.90
2007	1.29	5,796.64	-	10.75	5,808.68
2008	0.63	7,004.42	-	14.62	7,019.67
2009	0.19	7,616.63	5.59	19.78	7,642.19
2010	0.49	8,342.14	3.44	25.80	8,371.87
2011	3.64	9,465.94	4.73	38.27	9,512.57
2012	4.08	10,841.03	3.01	59.77	10,907.89
2013	1.77	12,229.02	4.30	85.57	12,320.66
2014	12.41	13,078.84	4.30	98.90	13,194.45
2015	17.87	14,311.65	12.90	126.42	14,468.84
2016	43.41	15,727.73	15.91	166.41	15,953.47
2017	55.38	16,917.39	15.48	205.54	17,193.78
2018	54.05	18,163.67	19.35	251.12	18,488.19

Fuel consumption in the transportation category is summarized in **Table 3.26.** Fuel consumption in road transportation dominates over other subcategories followed by Other Transportation, while waterborne navigation has the least consumption. The high fuel consumption in road transportation could be justified by the high number of road vehicles as presented in **Table 3.27**. From 2006 to 2018, fuel consumption by road transportation increased tremendously. As can be seen from **Table 3.27**, the number of registered vehicles also followed the same trend. However, it is noteworthy that the vehicles registered under Unknown were reported in the Other Transportation subcategory. As it could be seen from **Table 3.27**, the cumulative numbers of registered vehicles are dominated by motorcycles and cars, which are mainly used in public transportation and personal use, respectively. It is also interesting to note a tremendous increase in the buses as a replacement for small minibuses over the studied period (i.e., 2006-2018). The relationships between these trends, fuel consumption, and the corresponding GHG emissions are discussed in subsequent sections.

Table 3.27 Cumulative number of registered vehicles by category (2006-2018)

Category	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
Bus	87	133	224	250	397	469	531	597	794	1,059	1,264	1,464	1,576
Car	11,198	13,003	14,925	16,292	17,220	19,177	22,772	25,471	27,312	30,238	33,238	35,062	36,951
Half trailer	89	101	124	162	178	186	189	188	196	218	232	278	316
Jeep	6,797	7,829	9,156	10,387	11,549	13,567	16,083	18,026	20,156	20,276	22,292	24,419	26,715
Microbus	61	74	89	115	130	144	150	155	161	254	545	1,016	1,466
Minibus	3,698	3,910	4,567	4,760	4,853	5,021	5,503	6,223	6,118	6,160	6,283	6,343	6,411
Motorcycle	15,224	20,598	28,416	33,121	38,521	49,349	60,624	68,779	75,017	85,072	93,866	101,694	112,404
Pick up	8,119	9,409	10,634	11,448	11,932	12,974	14,225	15,067	16,113	16,402	17,245	17,953	18,618
Special engine	96	179	241	327	423	548	645	757	854	1,187	1,726	2,256	2,856
Trailer	457	577	626	667	694	733	764	831	874	887	920	934	976
Tricycle	-	-	-	-	-	18	61	67	70	73	73	73	73
Truck	1,805	2,106	2,304	2,490	2,723	3,134	3,435	3,931	4,315	4,961	6,049	6,881	7,694
Unknown	-	-	-	-	1	4	17	17	25	26	28	31	34
Total	47,631	57,919	71,306	80,019	88,621	105,324	124,999	140,109	152,005	166,813	183,761	198,404	216,090

Source: National Institute of Statistics of Rwanda

3.6.2 Summary of GHG emissions from Transportation

3.6.2.1 Total transportation emissions and trends

GHG emissions from transportation showed an increasing trend over the whole period of 2006-2018 (**Table 3.28**). The road transportation emissions dominated over other subsectors followed by other transportation (i.e., off-road transportation), while civil aviation and water navigation showed modest shares.

Table 3.28 Summary of transportation GHG emissions, Gg CO_2eq (2006-2018)

Period	Civil Aviation	Road Transport	Water-borne Navigation	Other Transport	Total	Change
2006	0.07	358.95	-	0.50	359.52	0.00%
2007	0.09	413.81	-	0.89	414.79	13.33%
2008	0.05	499.85	-	1.21	501.11	28.26%
2009	0.01	543.57	0.42	1.64	545.64	34.11%
2010	0.04	595.28	0.26	2.14	597.71	39.85%
2011	0.26	675.42	0.35	3.18	679.21	47.07%
2012	0.29	773.48	0.23	4.96	778.96	53.85%
2013	0.13	872.40	0.32	7.11	879.95	59.14%
2014	0.89	933.10	0.32	8.21	942.53	61.86%
2015	1.29	1,018.88	0.97	10.50	1,031.63	65.15%
2016	3.13	1,119.37	1.19	13.82	1,137.51	68.39%
2017	3.99	1,203.81	1.16	17.07	1,226.04	70.68%
2018	3.90	1,318.33	1.45	20.86	1,344.53	73.26%

Transport GHG emissions are summarized in **Table 3.28**. As it could be seen from the table, all the subcategories showed an increasing trend with a sharp increase after 2013. The rapid increase recorded in the period after 2013 could be related to the country's development as justified by an increase in GDP per capita. The increase in GHG emissions in transportation is related to the increase in the vehicle fleet. Road transportation remained on top of emissions for the whole period, while civil aviation had a minute contribution to total emissions.

3.6.2.2 Trends in civil aviation, waterborne navigation, and other transportation

Trends in GHG emissions generated by civil aviation, waterborne navigation, and other transportation activities are depicted in **Figure 3.27**. As seen from the figure, the GHG emission from these three subcategories had an increasing trend for the whole of 2006-2018. However, other transport subcategories showed a sharp increase from 2013, which could be related to the modernization of the agriculture sector and the industrial development observed during this period.

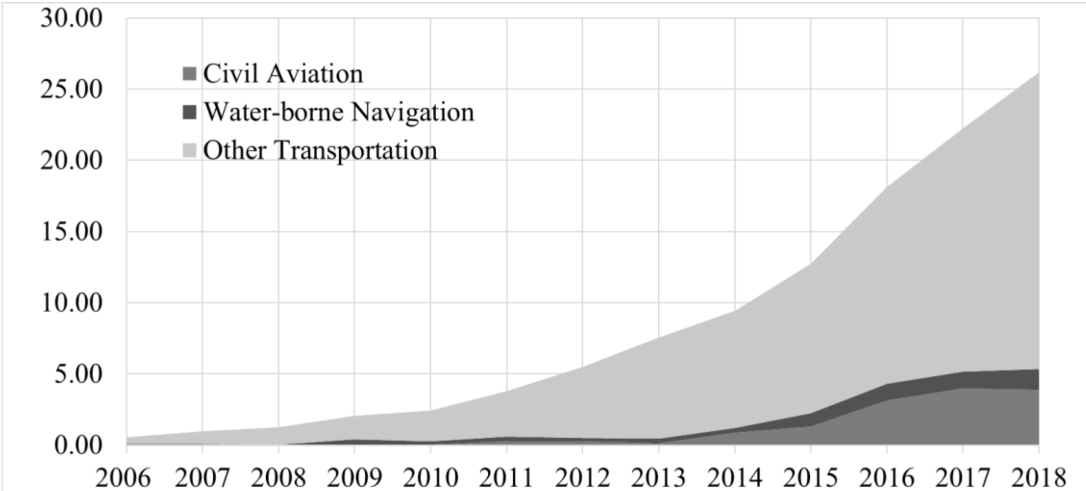


Figure 3.27 Trends in civil aviation, waterborne navigation and other transportation (2006-2018)

3.6.2.3 Shares and trends in GHG emissions from road transportation

During the period 2006- 2018, GHG emissions from road transportation were characterized by a steady increase (**Table 3.29**). The observed increase in GHG emissions could be attributed to the increase in the total number of vehicles and thus an increase in fuel consumption.

Table 3.29 Road transportation GHG emission, Gg CO_2eq (2006-2018)

Period	Cars	Light-duty trucks	Heavy-duty trucks and buses	Motorcycles	Total
2006	219.75	16.67	64.68	57.86	358.95
2007	236.84	19.34	79.37	78.27	413.81
2008	276.14	21.85	93.88	107.99	499.85
2009	292.23	23.52	101.94	125.88	543.57
2010	302.49	24.48	121.92	146.38	595.28
2011	321.27	26.67	139.87	187.61	675.42
2012	359.77	29.21	153.87	230.63	773.48
2013	405.72	30.95	174.09	261.63	872.40
2014	411.83	33.11	202.82	285.34	933.10
2015	419.76	33.68	241.86	323.58	1,018.88
2016	438.42	35.42	288.55	356.98	1,119.37
2017	452.30	36.87	327.92	386.73	1,203.81
2018	467.22	38.25	385.41	427.45	1,318.33

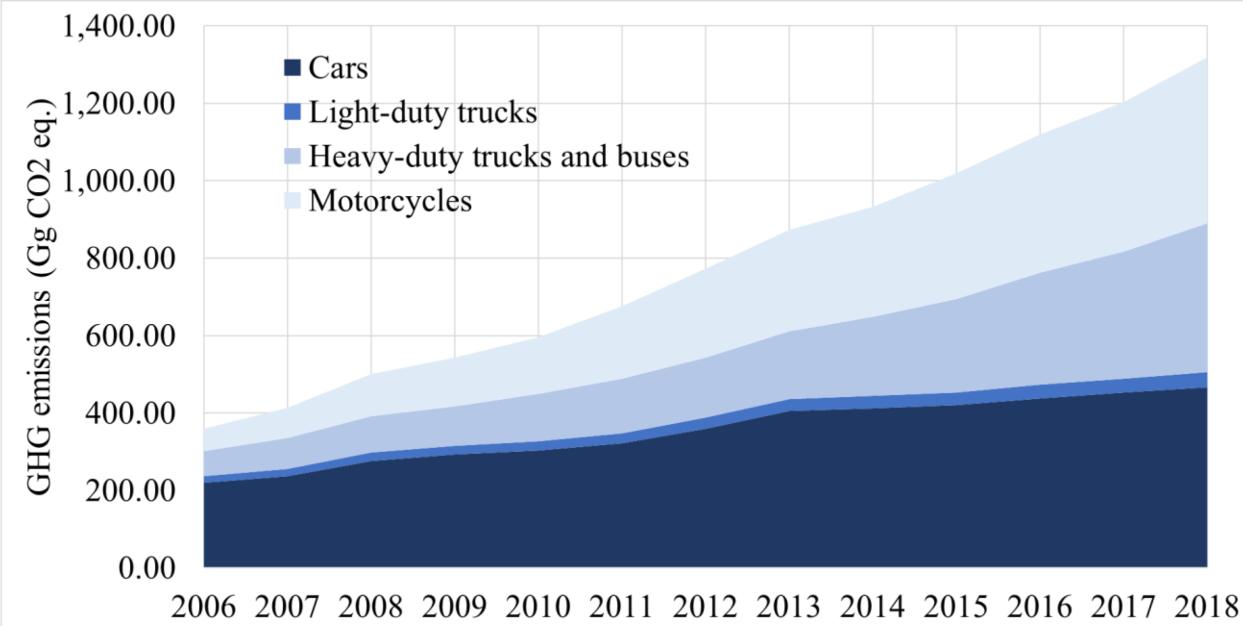
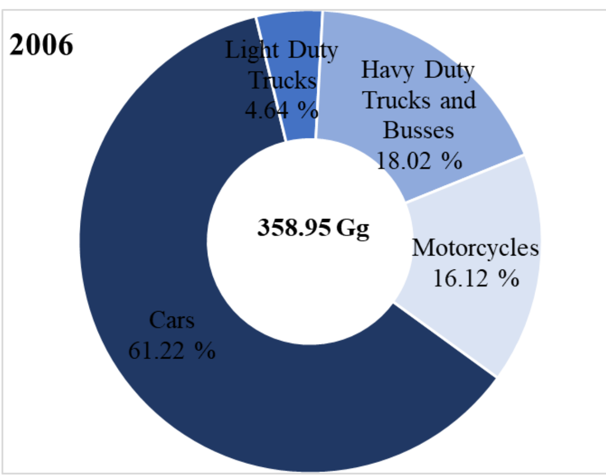


Figure 3.28 Trends shares in road transportation GHG emissions (2006- 2018)

The GHG emissions generated by the cars and motorcycles are on top of the emissions followed by the heavy-duty trucks and buses emissions, while light-duty trucks had the least share in emissions.



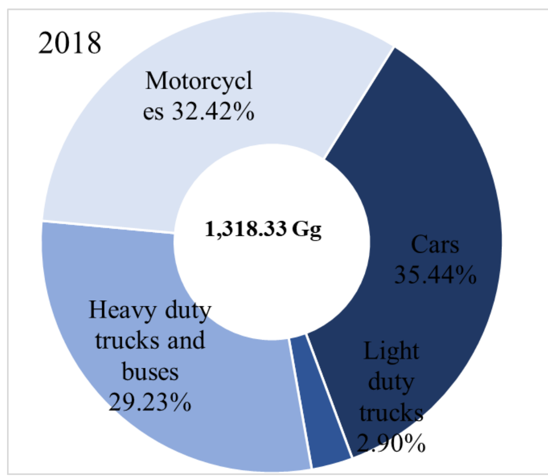


Figure 3.29 Shares of various subcategories to total road transport GHG emissions in 2006 and 2018

Shares of various subcategories to total road transport GHG emissions are presented in **Figure 3.29**. As evidenced from the figure, the road transport GHG emissions are dominated by cars and motorcycle subcategories while light-duty trucks have the least contribution.

3.6.2.4 Transportation emissions by gas

Trends in transport GHG emissions per gas are presented in **Table 3.30**. CO_2 has a dominant contribution for the whole period 2006-2018. While N_2O and CH_4 have a minor contribution. These trends are obvious since only liquids fuels are consumed in the transport source category. It is also important to mention a tremendous increase in total emissions is depicted in **Table 3.30.**

Table 3.30 Summary of transport GHG emissions per gas (Gg CO_2 eq.)

Period	CO_2	CH_4	N_2O	Total	CO_2	CH_4	N_2O
2006	350.96	3.21	5.35	359.52	97.62%	0.89%	1.49%
2007	404.89	3.70	6.20	414.79	97.61%	0.89%	1.50%
2008	489.14	4.49	7.48	501.11	97.61%	0.90%	1.49%
2009	532.59	4.88	8.17	545.64	97.61%	0.89%	1.50%
2010	583.39	5.36	8.96	597.71	97.60%	0.90%	1.50%
2011	662.89	6.09	10.24	679.21	97.60%	0.90%	1.51%
2012	760.14	6.98	11.85	778.96	97.58%	0.90%	1.52%
2013	858.57	7.89	13.49	879.95	97.57%	0.90%	1.53%
2014	919.60	8.43	14.50	942.53	97.57%	0.89%	1.54%
2015	1,008.20	7.45	15.99	1,031.63	97.73%	0.72%	1.55%
2016	1,111.72	7.99	17.81	1,137.51	97.73%	0.70%	1.57%
2017	1,198.23	8.43	19.38	1,226.04	97.73%	0.69%	1.58%
2018	1,298.19	9.00	21.19	1,328.38	97.73%	0.68%	1.60%

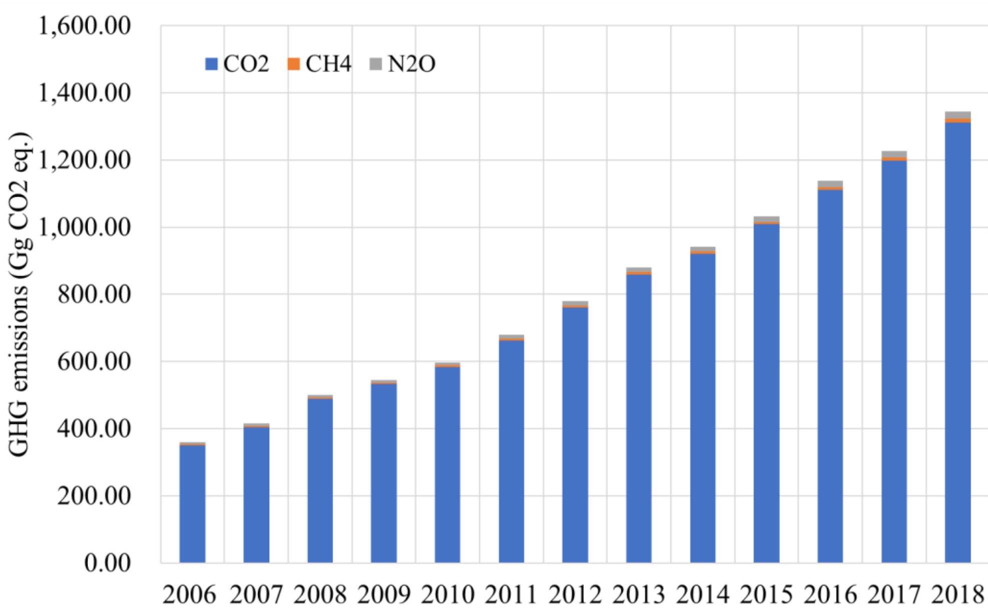


Figure 3.30 Trends in transportation GHG emissions by gas (2006-2018)

3.6.3 Methodological issues

3.6.3.1 Civil aviation (1.A.3.a)

According to the 2006 IPCC guidelines, GHG emissions from civil aviation encompass all emissions from all civil commercial use of airplanes, civil commercial use of airplanes, including, scheduled and charter traffic for passengers and freight, air taxiing, and general aviation. In addition, the fuel consumption during including take-offs and landings is considered under this category. The civil aviation source category is generally subdivided into international aviation and domestic aviation.

As recommended in the 2006 IPCC guidelines, GHG emissions from international aviation (1.A.3.a) and domestic aviation (1.A.3.b) subcategories were considered separately based on the departure and landing locations for each flight stage. The Tier 1 methodology was used as provided in the 2006 IPCC guidelines.

3.6.3.2 Road transport (1.A.3.b)

As stipulated in the 2006 IPCC guidelines, the estimation of GHG emissions is based on both fuel consumption (fuel sold) and vehicle kilometres. While the fuel consumption data are sufficient for CO_2 emissions estimation, the estimation of CH_4 and N_2O emissions relies on the distance travelled by vehicle type and road type. In this inventory, a combination of Tier 1 and Tier 2 methodologies was used to estimate CO_2 emissions. Total emissions were calculated through a multiplication of the fuel sold by default emission factors from the 2006 IPCC guidelines. Emission factors and Net Calorific Values used under this source category are those provided in the 2006 IPCC guidelines. However, country-specific data were used for the conversion of collected data from volume to mass units. Details of the emission factors, Net Calorific Values (NCV), and densities used are given in **Table 3.31**.

Table 3.31 Emission factors and physical characteristics of used fuels in road transport category

Fuels	NCV	Density	Emission factor ($kgTJ^{-1}$)		
Unit/gases	**TJ/Gg**	**Kg/l**	**CO_2**	**CH_4**	**NO_2**
Motor gasoline	44.3	0.74	69,300	33	3.2
Gas/Diesel oil	43	0.84	74,100	3.9	3.9

SOURCE: KOBIL, SP & IPCC GUIDELINES

In the same way, due to the unavailability of data on Vehicle travelled kilometres (VTK) methodologies based on fuel sold were used to estimate CH_4 and N_2O emissions were used. Again, a combination of Tier 1 and Tier 2 was used.

3.6.3.3 Domestic water-borne navigation (1.A.3.d.ii)

According to the 2006 IPCC guidelines, the water-borne navigation source category covers all water-borne transport from recreational craft to large ocean-going cargo ships that are driven primarily by large, slow, and medium-speed diesel engines and occasionally by steam or gas turbines. Water-borne navigation causes emissions of carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O), as well as carbon monoxide (CO), non-methane volatile organic compounds (NMVOCs), Sulphur dioxide (SO_2), particulate matter (PM) and oxides of nitrogen (NO_X). In this inventory, only the direct gases (i.e., CO_2, CH_4, and N_2O) were considered. They were estimated using Tier 1 of the 2006 IPCC methodology and the default emission factors were used. Since diesel and gasoline are the only fuels consumed in this subcategory, the physical characteristics and emission factors used in road transportation were adopted in this subcategory.

3.6.3.4 Off-road transportation (1.A.3.e.ii)

The off-road category includes vehicles and mobile machinery used within the agriculture, forestry, industry (including construction and maintenance), residential, and sectors, such as airport ground support equipment, agricultural tractors, chain saws, forklifts, snowmobiles. Considering the situation of Rwanda and the IPCC guidelines, the existing activity data were disaggregated from other transportation activity data and the related GHG emission were estimated using the Tier 1 and the 2006 IPCC default emission factors. It is important to note that this subcategory was aggregated in with the road transportation in the previous inventory and the disaggregation was an improvement in the methodology.

3.6.4 Activity data sources

3.6.4.1 Civil aviation (1.A.3.a)

Activity data on aviation fuels such as jet kerosene and aviation gasoline for the whole period were sourced from Rwanda revenue authority (RRA) and different national reports including the National yearbooks (NISR, 2015b, 2018b, 2019; “Statistical Yearbook: Introduction,” 2016). As stipulated in the IPCC 2006 guidelines, fuels for domestic aviation (i.e., freight that is planned and deplaned in Rwanda) and international aviation were disaggregated and corresponding GHG emissions were reported separately.

3.6.4.2 Road transport (1.A.3.b)

As suggested in the 2006 IPCC guidelines, GHG emissions from road transportation were attributed to the fuel consumption that is sold within Rwanda. In this inventory, data on fuel consumption were collected from Rwanda Revenue Authority (RRA), Rwanda Utility Regulation Authority (RURA), and different national and international reports. To avoid double-counting, data on fuel consumption in other sectors and subcategories such as on-grid and off-grid electricity generation were subtracted from the solid fuels. Activity data on fleet populations for the whole period 2006-2018 were sourced from Rwanda National statistical yearbooks and classified according to the subcategories provided by the 2006 IPCC guidelines.

(a) Fleet classification in the 2006 IPCC guidelines categories

Table 3.32 shows the categories reported in the statistical yearbooks and the corresponding classification in the 2006 IPCC Guidelines done based on the assumptions previously used in a recent TNC and based on the IPCC guidelines.

Table 3.32: Classification of fleet populations in the IPCC categories

NISR categories	IPCC 2006 categories
Jeep, car, Minibus	Car
Pick up	Light Duty Truck
Tricycle, Motorcycle	Motorcycle
Truck, Bus, Microbus, Half trailer Unknown, Trailer, Special engine, caterpillar	Heavy-duty truck and buses

(b) Fuel consumption estimations

The fuel consumption was estimated based on the recent fuel economy data and the assumptions used in the recent NDC report as shown in **Table 3.33**. These assumptions were developed based on the survey conducted in 2019 (REMA, 2019a).

Table 3.33 Fleet classification by fuel

Category	Gasoline	Diesel	Total	Category	Gasoline	Diesel	Total
Motorcycles	100%	0%	100%	Minibus	100%	0%	100%
Passenger cars	90%	10%	100%	Trailers	0%	100%	100%
LDV	70%	30%	100%	Half trailers	0%	100%	100%
Buses	0%	100%	100%	Truck	0%	100%	100%
Microbuses	30%	70%	100%	Other vehicles	0%	100%	100%

3.6.4.3 Domestic water-borne navigation (1.A.3.d.ii)

Rwanda is gifted with lakes and rivers with considerable potential for inland water navigation. However, water navigation activities are still limited to some lakes including Kivu, Muhazi, etc. In this inventory, an effort was made to collect data on registered boats and report GHG emissions under this category. The water fuels were categorized in boats and ships and the fuel consumption was collected from the vessel owners. Data on fuel consumption per water vessel per year was estimated from the collected data on fuel consumption and the annual fuel consumption was estimated by multiplying the number of the vessel by the fuel consumption per vessel per year.

Table 3.34 Cumulative number of registered water vessels (2006-2018)

Period	Number of boats	Number of ships	Total number of water vessels
2006	0	0	0

2007	0	0	0
2008	0	0	0
2009	76	20	96
2010	49	12	61
2011	65	16	81
2012	39	10	49
2013	61	15	76
2014	59	15	74
2015	179	46	225
2016	221	57	278
2017	216	55	271
2018	264	67	331

Source: RURA & NISR

Due to limited activity data, the GHG emissions from waterborne navigation were estimated for the period 2009-2018 (**Table 3.34**). This could be the plausible reason for the sharp increase observed in the energy GHG emissions during this period.

3.6.4.4 Off-road transport

Data on numbers of off-road vehicles and machinery were collected from various statistical yearbooks (**Table 3.27**) and the data on fuel economies were sourced from the previous NAMA report. The vehicles considered for off-road transportation correspond to the unknown and special engine categories of the National Institute of Statistics (**Table 3.27**).

3.6.5 Uncertainty and time-series consistency

Uncertainty and time-series consistency were assessed based on the 2006 IPCC methodologies. Since default emission factors were used in GHG emission estimation, default uncertainties were used. A consistent time series was observed, and uncertainties ranged between 4.29% and 7.07%. Uncertainties on source data were estimated from the information collected from different companies dealing with liquid fuels such as Kobil and Societe Petroliere (SP). An uncertainty of ± 3% was obtained for both gasoline and diesel gas/oil in agreement with TNC data.

3.6.6 Source-specific QA/QC and verification

Since default emission factors were used, the QA/QC and verification were conducted on source data. This was conducted via different interviews and visits to different petrol stations to ensure the accuracy of the collected data. In addition, before the data entry exercise, the collected data were validated by the group members.

3.6.7 Source-specific recalculations

From the estimated GHG emissions from civil aviation, both domestic and international emissions showed consistency in time series. However, some recalculations were conducted due to new data on vehicle fuel economies, especially in road transportation. The results of these recalculations are presented in **Table 3.35**. The use of the new fuel economies led to an improvement in GHG emissions methodology and thus to more country representative GHG emissions.

Table 3.35 Results of recalculations in the transportation source category

Energy sector emissions (Gg)										
Period	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
Previous Data	301.94	369.40	432.87	394.17	355.50	393.54	458.29	468.53	489.56	547.35
Latest Data	359.52	414.79	501.11	545.64	597.71	679.21	778.96	879.95	942.53	1,031.63
Difference (%)	19.07	12.29	15.76	38.43	68.13	72.59	69.97	87.81	92.53	88.48
Documentation (reason for recalculation): The recalculation in the transport source category was based on the survey conducted in the energy sector, which led to new datasets in water-borne navigation fuel consumption, fuel consumption by off-road machinery operated in agricultural mechanization, industries, and construction and fuel economics in road transportation.										

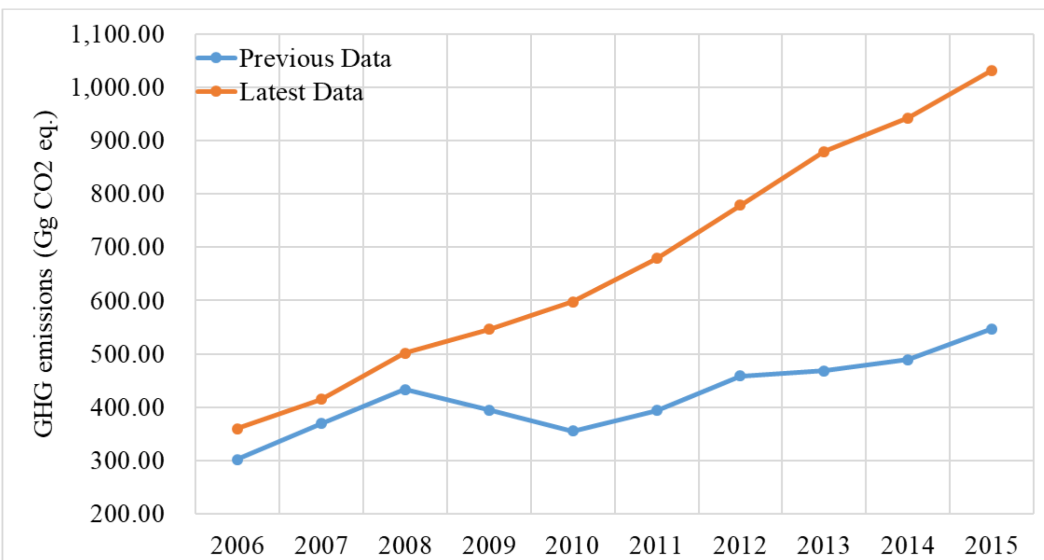


Figure 3.31 Trends in recalculated GHG emission in the transportation source category

Trends in GHG emissions recalculation in transport are displayed in **Figure 3.33**. A clear difference in estimated emissions between the previous and current data is observed due to the inclusion of new subcategories in the transport sector. In previous inventory, due to the lack of activity data, waterborne navigation and part of off-road transportation were considered. However, in this inventory, thanks to new datasets these subcategories were considered and included in the transport category following the IPCC guidelines. In addition, the differences could have resulted from the new fuel economies.

3.6.8 Source-specific planned improvements and recommendations

As aforementioned, the estimates of GHG emissions were improved through the addition of new subcategories and the use of country-specific economies. However, the default emissions factors were used with the Tier 1 methodology. In the future, country-specific emissions factors could be estimated, which could lead to an improvement in the methodology and accuracy of the transportation category GHG emissions.

3.7 Other sectors

3.7.1 Source category description

As described in the 2006 IPCC guidelines, GHG emissions for Other Sectors' source activities consist of emissions produced from combustion activities in commercial and institutional buildings, households, and agriculture/forestry/fishing/fishing/farms. These also include GHG emissions produced in combustion for the generation of electricity and heat for their use in these sectors. GHG emissions from commercial/institutions encompass emissions from all combustion in commercial and institutional buildings. Considering activities included in ISIC divisions and the context of Rwanda, GHG emissions reported under this subcategory were estimated from fuel combustion activities in schools, hospitals, and health centers, and prisons. The main fuels combusted in this subcategory are biomass, which is mainly used for cooking activities.

In Rwanda, most activities under the residential subcategory use three main fuels, viz., biomass (including biogas), kerosene for lighting and cooking activities, and Liquefied Petroleum Gases (LPG). GHG emissions reported under this source category are generated by biomass, kerosene, and LPG combustion activities. For biomass, only CH_4 and N_2O emissions were reported according to good practices proposed in the 2006 IPCC guidelines while CO_2 emissions were reported as a memo. The GHG emissions estimated for agriculture/forestry/fishing/fishing/farm considered in this inventory are those from irrigation pumps. Fuel consumption in other sectors category is summarized in **Table 3.36**. Biomass fuels (firewood, charcoal, and biogas) consumption in households and institutions/commercial had a dominant contribution to total consumption. All the fuels showed a steady increase during the whole period.

Table 3.36 Fuel consumption in other sectors, TJ (2006-2018)

Period	Biomass	Liquid fuels	Totals
2006	43,925.40	644.45	44,569.85
2007	45,352.61	565.01	45,917.62
2008	46,822.48	482.15	47,304.63

2009	48,125.74	408.37	48,534.12
2010	52,695.55	312.41	53,007.96
2011	53,932.40	230.04	54,162.44
2012	58,489.94	206.72	58,696.67
2013	60,612.35	221.47	60,833.81
2014	62,738.15	228.91	62,967.06
2015	64,311.50	342.01	64,653.52
2016	68,598.83	490.69	69,089.52
2017	71,904.05	511.53	72,415.58
2018	72,204.78	551.76	72,756.54

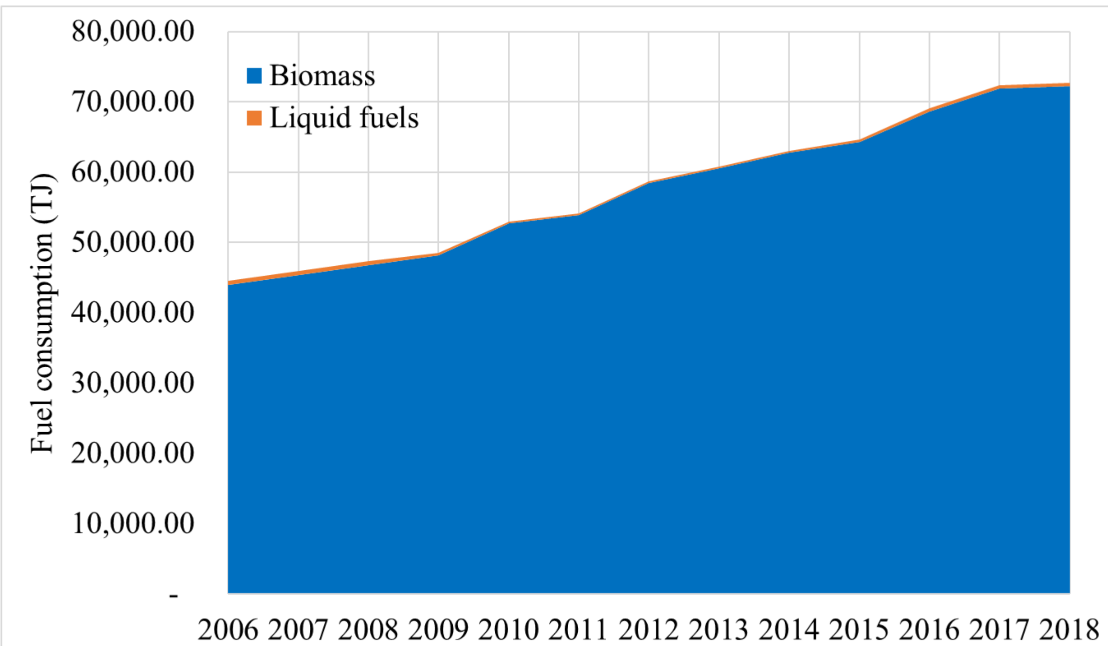


Figure 3.32 Trends in fuel consumption by other sectors (2006-2018)

3.7.2 Summary of GHG emissions from other sectors

3.7.2.1 Trends in aggregated emissions

Total GHG emissions from Other Sectors' activities are presented in **Table 3.37**. During the period 2006-2018, GHG emissions from other sectors showed a steady increase with an average increase of 14.59 %. The residential emissions generated by various fuels including biomass (firewood, charcoal, and biogas), liquid fuels (kerosene and LPG) are the main sources of residential GHG emissions followed by the institution/commercial subcategory. The agriculture/forestry/fishing/fishing/farms subcategory represents the least share of the emissions.

Table 3.37 Summary of GHG emissions from other sectors in $GgCO_2eq$ (2006-2018)

Period	Commercial/ Institutional	Residential	Agriculture/Forestry /Fishing/Fish Farms	Total
2006	29.35	329.21	-	358.56
2007	31.23	331.30	-	362.53
2008	33.31	333.17	-	366.48
2009	34.84	334.88	-	369.71
2010	59.63	336.32	-	395.94
2011	60.41	337.50	-	397.91
2012	57.22	348.34	-	405.55
2013	61.24	356.65	-	417.89
2014	62.49	370.54	-	433.03
2015	64.09	385.26	-	449.35
2016	86.65	398.07	0.74	485.47
2017	95.73	416.26	1.73	513.72
2018	111.27	399.24	1.49	512.00

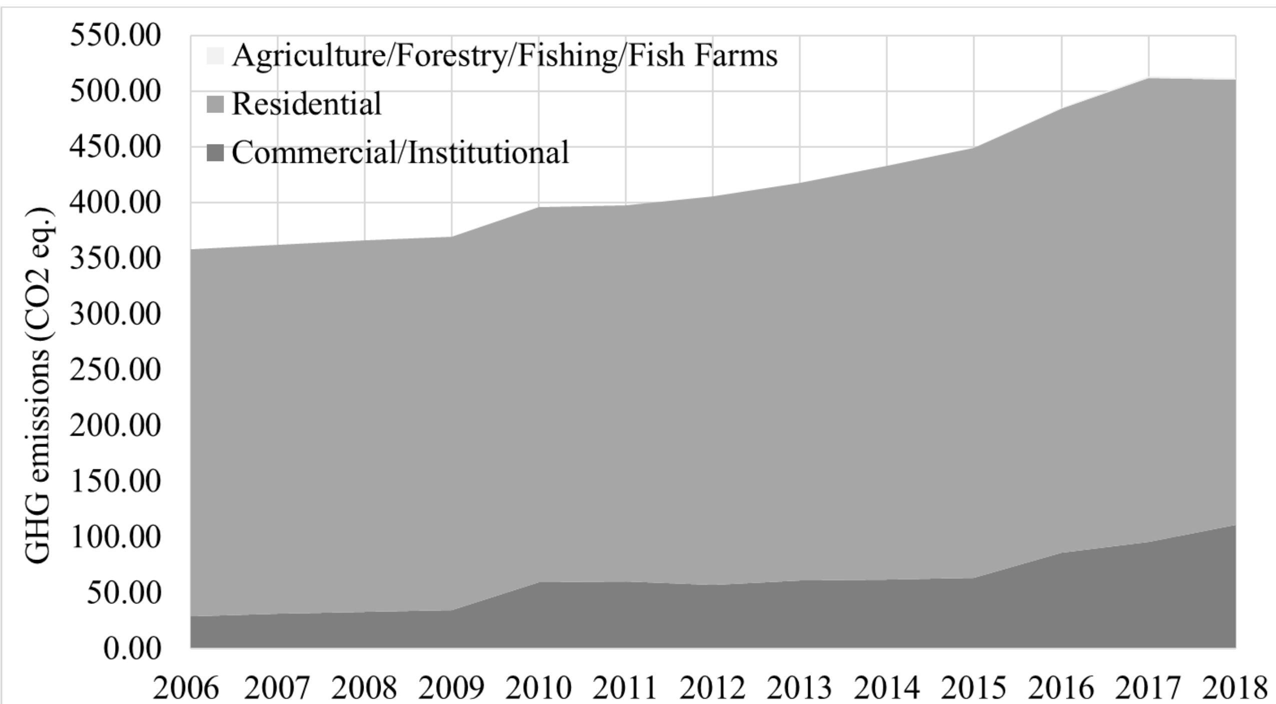


Figure 3.33 Summary of GHG emissions from other sectors (2006-2018)

Trends in GHG emissions for the three subcategories are shown in **Figure 3.33**. Clearly, all the subcategories showed a steady increase during the whole period. The slight sharp increases observed from 2013 could be explained by the slight replacement of biomass by LPG in some hotels and households. The increase in institutional/commercial emissions could also be attributed to an increase in biomass consumption in the school-feeding program.

3.7.2.2 Other sectors emissions by gas

Analysis of GHG emissions gas per gas showed that CH_4 is the main contributor to the total emissions over the whole period followed by N_2O. The high share of CH_4 and N_2O is due to biomass consumption, which is the main fuel consumed in Other Sector's subcategories. Emissions from residential activities are the highest. As aforementioned, residential activities are the main consumers of biomass, which is the main source of GHG emissions under this category.

Table 3.38 GHG emissions from other sectors, Gg CO_2 eq. (2006-2018)

Period	CO_2	CH_4	N_2O	Total	CO_2	CH_4	N_2O
2006	46.42	262.07	50.07	358.56	12.95%	73.09%	13.96%
2007	40.68	270.34	51.51	362.53	11.22%	74.57%	14.21%
2008	34.68	278.81	52.99	366.48	9.46%	76.08%	14.46%
2009	29.29	286.18	54.24	369.71	7.92%	77.41%	14.67%
2010	22.34	314.08	59.52	395.94	5.64%	79.32%	15.03%
2011	16.32	320.94	60.65	397.91	4.10%	80.66%	15.24%
2012	14.60	329.32	61.63	405.55	3.60%	81.20%	15.20%
2013	15.68	339.34	62.88	417.89	3.75%	81.20%	15.05%
2014	16.22	351.66	65.15	433.03	3.74%	81.21%	15.05%
2015	23.61	359.51	66.23	449.35	5.25%	80.01%	14.74%
2016	33.45	384.44	67.58	485.47	6.89%	79.19%	13.92%
2017	34.97	404.39	74.37	513.72	6.81%	78.72%	14.48%
2018	37.72	401.60	72.68	512.00	7.37%	78.44%	14.19%

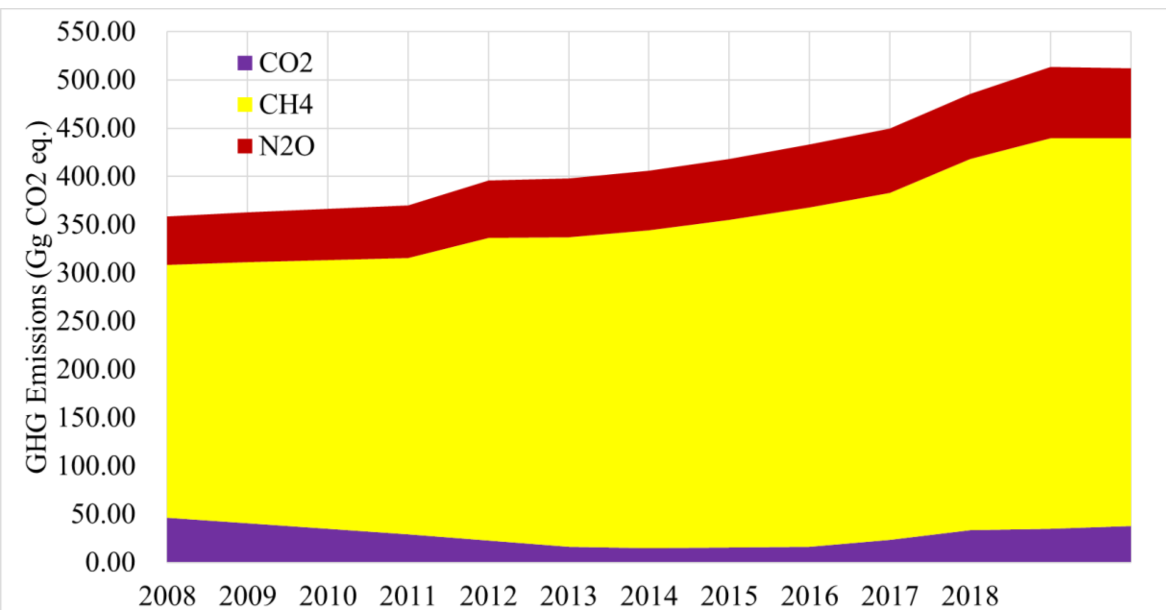


Figure 3.34 Trends in Other Sector's total GHG emissions per gas (2006-2018)

3.7.2.3 Other sectors emissions by fuels

As indicated in the 2006 IPCC guidelines, it is important to conduct a thorough analysis of the contributions of various fuels to the total GHG emissions. GHG emissions generated by various fuels are presented in **Table 3.39**. Emissions generated by biomass fuels showed a dominant share of the total emissions for the whole period of 2006-2018.

Table 3.39 Summary of GHG emissions by fuels, Gg CO_2 eq. (2006-2018)

Period	Biomass	Liquid fuels	Total
2006	311.88	46.57	358.45
2007	321.63	40.81	362.43
2008	331.62	34.79	366.40
2009	340.27	29.38	369.65
2010	373.49	22.41	395.90
2011	381.51	16.37	397.88
2012	390.88	14.64	405.52
2013	402.14	15.73	417.86
2014	416.73	16.26	433.00
2015	425.64	23.67	449.31
2016	451.89	33.53	485.42
2017	478.62	35.05	513.67
2018	474.13	37.82	511.94

The trends in GHG emissions by fuels as presented in **Figure 3.35** show that biomass emissions increased steadily throughout the period 2006-2018 whereas liquid fuel had a decreasing trend from 2006 to 2012. After this period, they increased slowly up to 2015 and a sharp increase is observed in the remaining period. The decreasing trend observed during the first period is related to the reduction in kerosene consumption for lighting in households. As it was revealed in various surveys, many households have adopted the use of torches and cell phones as replacements for kerosene lamps for lighting. From 2012, some households and commercial institutions changed from biomass for cooking to LPG, which is also classified as a liquid fuel. However, the penetration of LPG use was slow at the beginning and as a result, the GHG emissions from the liquid fuels increased slowly.

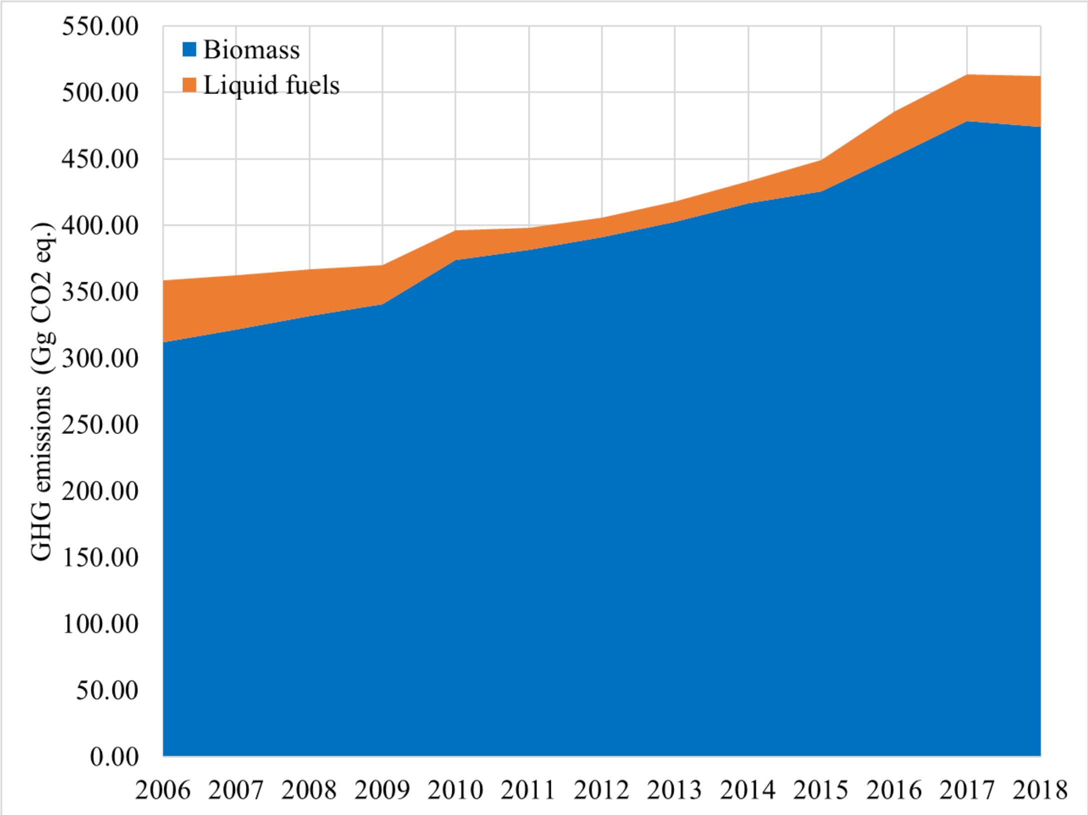


Figure 3.35 Trends in other sectors GHG emissions by fuel

3.7.3 Methodological issues

GHG emissions under the other sector source category were estimated according to the methodologies provided in the 2006 IPCC guidelines. Due to the lack of country-specific data, emissions were estimated using a Tier 1 methodology.

3.7.4 Activity data sources

3.7.4.1 Commercial/institution

Data on fuel consumption from commercial and institutional activities consisted of liquid fuels combusted in thermal generators for electricity generation for own use in hospitals, schools, hotels, and restaurants and biomass combustion activities in the same Commercial/institution. Data on liquid fuel consumption were estimated based on the technologies, hourly fuel consumption, types of generators, and the estimated time of use in different institutions. Data related to hourly fuel consumption types of generators were collected from Generator dealers.

Statistics regarding generators for the whole period 2006-2018 were sourced from MINEDUC statistical yearbooks and MINISANTE reports for schools and hospitals and health centres, respectively. The statistics for the hotels and restaurants were sourced from the National statistics yearbooks 2009, 2012, 2013, 2018, and 2019. Liquid fuels for electricity generation were estimated based on the following assumptions:

- The average full load hourly consumptions of technical schools and other schools are 16.1 litters and 6.4 litters, respectively. This assumption was made based on data collected from the generator dealers.
- The estimated time for generator use was assumed 3 and 2 hours for technical schools and other schools, respectively.
- The average full-load fuel consumption for generators used in health centres was assumed 2.6 litters/hour for 5 hours per day and 8.4 litters/hour for 1 hour per day.

Total fuel consumptions were converted into weight units using a density of 0.84 kg/l as sourced from Kobil.

3.7.4.2 Residential

Data for Liquefied Petroleum Gas (LPG) were sourced from Rwanda Revenue Authority and MINICOM. Data for firewood, charcoal, and kerosene were estimated based on the fuel consumption per household estimated in the recent surveys in combination with the data collected from the various EICVs and the population/households data reported in the statistical yearbooks (NISR, 2019, 2018c). The same methodology was used for liquid fuel (kerosene and LPG) consumption in households and commercial/institutions. Estimates of the fuel consumption were calculated as a simple multiplication of the fuel consumption per capita/household and the population size/number of households. Data for installed biogas plants were collected from REG and biogas consumptions for the period 2006-2015 were estimated based on the number of installed biogas plants, the percentage of methane content in biogas, and its density. The following assumptions were made in estimations:

- The average capacity of a biogas plant was assumed to be 4 m^3
- The methane content in biogas is 60 %.
- The density of methane is 0.67 kgm^{-3}.

Due to a lack of activity data for the period 2015-2018, a linear extrapolation was used to fill the gap. In addition, a 25% factor was used to account for the effect of closed biogas plants. The estimates of the closed biogas plants were chosen based on the data collected from REG on the status of the installed biogas plants.

3.7.5 Uncertainty and time-series consistency

Uncertainties and time series consistence were analysed according to the 2006 IPCC guidelines. Combined uncertainties for liquid fuels were 9.40, 7.94, and 7.94% for CO_2, CH_4, and N_2O, respectively while those for biomass were 20.60, 10, and 10 for CO_2, CH_4, and N_2O, respectively. According to the 2006 IPCC guidelines, these uncertainties are in acceptable ranges.

3.7.6 Source-specific QA/QC and verification

The QA/QC and verification were conducted according to the 2006 IPCC guidelines. Since default emission factors were used for this subcategory, the QA/QC was applied only for data sources and methodologies used for data estimations. Assumptions and collected data were validated via short interviews and discussions with stakeholders. In addition, data validation exercises were conducted among the team members for verification.

3.7.7 Source-specific recalculations

Recalculations in Other sectors were in both residential and commercial/institution subcategories. The results of recalculations are presented in **Table 3.40**. As can be seen from the table, the latest GHG emissions are far less than those reported in the TNC (Republic of Rwanda, 2018). The main reason for this difference is the assumptions made about LPG and kerosene consumption in the previous inventory. In addition, the biomass used in charcoal production was accounted for in other sectors due to a lack of disaggregated data.

Table 3.40 Results of recalculation in other sectors

Other sectors GHG emissions										
Period	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
Previous Data	627.77	624.92	624.62	618.94	645.43	675.68	693.78	717.10	728.56	741.44
Latest Data	358.56	362.53	366.48	369.71	395.94	397.91	405.55	417.89	433.03	449.35
Difference (%)	-42.88	-41.99	-41.33	-40.27	-38.65	-41.11	-41.54	-41.72	-40.56	-39.40

Documentation (reason for recalculation):
The main reason for recalculation was the availability of new data on kerosene and LPG use in households and charcoal production. In the previous inventory, due to the lack of disaggregated data, it was assumed that all the imported kerosene and LPG fuels are used in the households. In this inventory, the data disaggregation was done based on recent energy surveys and only GHG emissions generated from kerosene and LPG combustion in households were reported under other sectors (residential and commercial/institutional categories). In addition, in the previous inventory, the GHG generated by firewood combustion in charcoal production was reported in other sectors due to the lack of data. After filling the data gaps and following the IPCC guidelines, the GHG emissions generated in the latter activities were reported in energy industries.

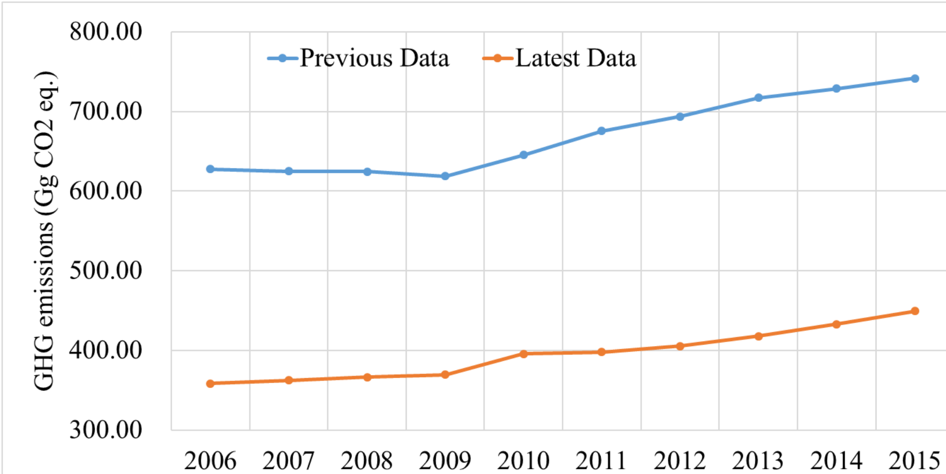


Figure 3.36 Trends in recalculated GHG emissions from other sectors

Figure 3.368 shows the trends in recalculated GHG emissions from other sectors. The recalculated GHG emissions showed the same trend as those from the previous inventory.

3.7.8 Source specific planned improvement

The GHG emissions from other sectors were estimated using the Tier 1 methodology of the 2006 IPCC guidelines and the default emission factors. The activity data were estimated based on the existing surveys data published by the NISR and REMA. The estimated data and the use of the default emission factors are generally the key sources on the uncertainties. To reduce the uncertainties in future inventories regular surveys on fuel consumption in households and institutions/commercial buildings should be conducted. In addition, the development of the country-specific emission factors should be considered.

Chapter 4. Industrial Process and Products Use (IPPU)

4.1 IPPU Sector Overview

The GHG emissions from the IPPU sector in Rwanda include emissions generated from 2A-mineral industry, 2.C-metal industry, 2D-Non-Energy Products from Fuels and Solvent Use, and 2F-Product Use as Substitutes of Ozone-depleting substances. Considering the data availability and the context of the country the subcategories considered in this inventory and the corresponding methodologies are summarized in **Table 4.1.**

Table 4.1 Overview of the IPPU sector categories and methods

2006 IPCC Categories	Greenhouse gas	2018 emissions	Contribution to total IPPU emissions in 2018	Key categories	Uncertainty	Methodology
2 - Industrial Processes and Product Use		(Gg CO_2 eq.)	(%)		(%)	
2.A.1 - Cement production	CO_2	132.81	87.72	□	0.011	Tier 1
2.A.2 - Lime production	CO_2	2.09	1.38		0.000	Tier 1
2.C.1 - Iron and Steel Production	CO_2	3.65	2.41		2.15E-05	Tier 1
2.C.1 - Iron and Steel Production	CH_4	2.40E-04	1.59E-04		2.15E-05	Tier 1
2.C.2 - Ferroalloys Production	CO_2	0.12	0.08		2.36E-08	Tier 1
2.F.1 - Refrigeration and Air Conditioning	HFCs	9.57	6.32		0.00005	Tier 1
2.D.1 - Lubricant Use	CO_2	2.03	1.34		5.61E-06	Tier 2
2.D.2 - Paraffin Wax Use	CO_2	1.14	0.75		3.16E-05	Tier 1

It is clear that considering the 2006 IPCC guidelines, some categories/subcategories were omitted chiefly because they are not occurring, or the activity data are missing. A detailed overview of the missing categories/subcategories is provided in the completeness assessment section.

4.2 Trends and shares of GHG emissions per category

The summary of GHG emissions from IPPU sector and their trends are presented in **Table 4.2** and **Figure 4.1,** respectively. Total emissions in the IPPU sector have more than tripled over the 2006-2018 period, with an annual growth rate of 12.8%.

Table 4.2 Summary of GHG emissions from IPPU sector

	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
Total	39.18	39.60	39.76	34.94	36.54	38.29	39.47	43.32	49.15	81.68	125.26	147.09	151.41
2.A	37.44	37.44	37.49	31.70	32.21	32.79	31.51	34.63	38.13	69.11	109.85	131.73	134.90
2.A.1	36.84	36.84	36.84	30.88	31.38	31.47	29.63	31.39	35.97	65.44	106.68	129.15	132.81
2.A.2	0.596	0.596	0.648	0.814	0.834	1.323	1.878	3.237	2.156	3.667	3.168	2.582	2.085
2.A.3	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
2.A.4	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
2.A.5	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
2.B	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
2.C	0.004	0.004	0.009	0.048	0.071	0.700	1.878	1.594	2.196	1.517	1.578	2.845	3.773
2.C.1	0.001	0.001	0.002	0.011	0.016	0.622	1.761	1.474	2.050	1.407	1.434	2.713	3.649
2.C.2	0.003	0.003	0.007	0.037	0.055	0.077	0.117	0.120	0.146	0.110	0.144	0.132	0.124
2.C.3	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
2.C.4	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
2.C.5	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
2.C.6	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
2.C.7	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
2.D	1.32	1.32	0.99	1.47	2.06	2.09	2.81	2.81	3.20	3.88	5.67	3.40	3.17
2.D.1	1.28	1.28	0.99	1.11	1.42	1.52	1.98	1.93	2.05	2.47	4.46	2.05	2.03
2.D.2	0.04	0.04	0.00	0.36	0.64	0.57	0.84	0.88	1.15	1.40	1.21	1.35	1.14
2.D.3	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
2.D.4	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
2.E	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
2.F	0.42	0.84	1.27	1.72	2.20	2.71	3.26	4.29	5.63	7.18	8.16	9.12	9.57
2.F.1	0.42	0.84	1.27	1.72	2.20	2.71	3.26	4.29	5.63	7.18	8.16	9.12	9.57
2.F.2	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
2.F.3	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO

	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
2.F.4	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
2.F.5	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
2.F.6	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
2.G	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
2.H	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO

2 - Industrial Processes and Product Use 2.A - Mineral Industry 2.A.1 - Cement production 2.A.2 - Lime production 2.A.3 - Glass Production 2.A.4 - Other Process Uses of Carbonates 2.A.5 - Other (please specify) 2.B - Chemical Industry 2.C - Metal Industry 2.C.1 - Iron and Steel Production 2.C.2 - Ferroalloys Production 2.C.3 - Aluminium production 2.C.4 - Magnesium production 2.C.5 - Lead Production 2.C.6 - Zinc Production 2.C.7 - Other (please specify) 2.D - Non-Energy Products from Fuels and Solvent Use 2.D.1 - Lubricant Use 2.D.2 - Paraffin Wax 2.D.3 - Solvent Use 2.D.4 - Other (please specify) 2.E - Electronics Industry 2.F - Product Uses as Substitutes for Ozone Depleting Substances 2.F.1 - Refrigeration and Air Conditioning 2.F.2 - Foam Blowing Agents 2.F.3 - Fire Protection 2.F.4 - Aerosols 2.F.5 - Solvents 2.F.6 - Other Applications (please specify) 2.G - Other Product Manufacture and Use 2.H – Other, NO: Not Occurring, NA: Not Applicable,

As seen from the figure, the cement industries and the Product Use as the ODS substitutes are the main contributors to total emissions from IPPU throughout the period 2006-2018, followed by Non-energy Products from the Fuel and Solvent Use category while the metal industries had the least contribution. The analysis of the GHG emissions trends shows that the GHG emissions from IPPU had a steady increase in the period 2006-2014, followed by a tremendous increase, especially in the cement industries. This increase is mainly due to the use of cement for the construction sector in Rwanda, which is experiencing a huge boost from needed infrastructures, and it is a key driver of the national economy.

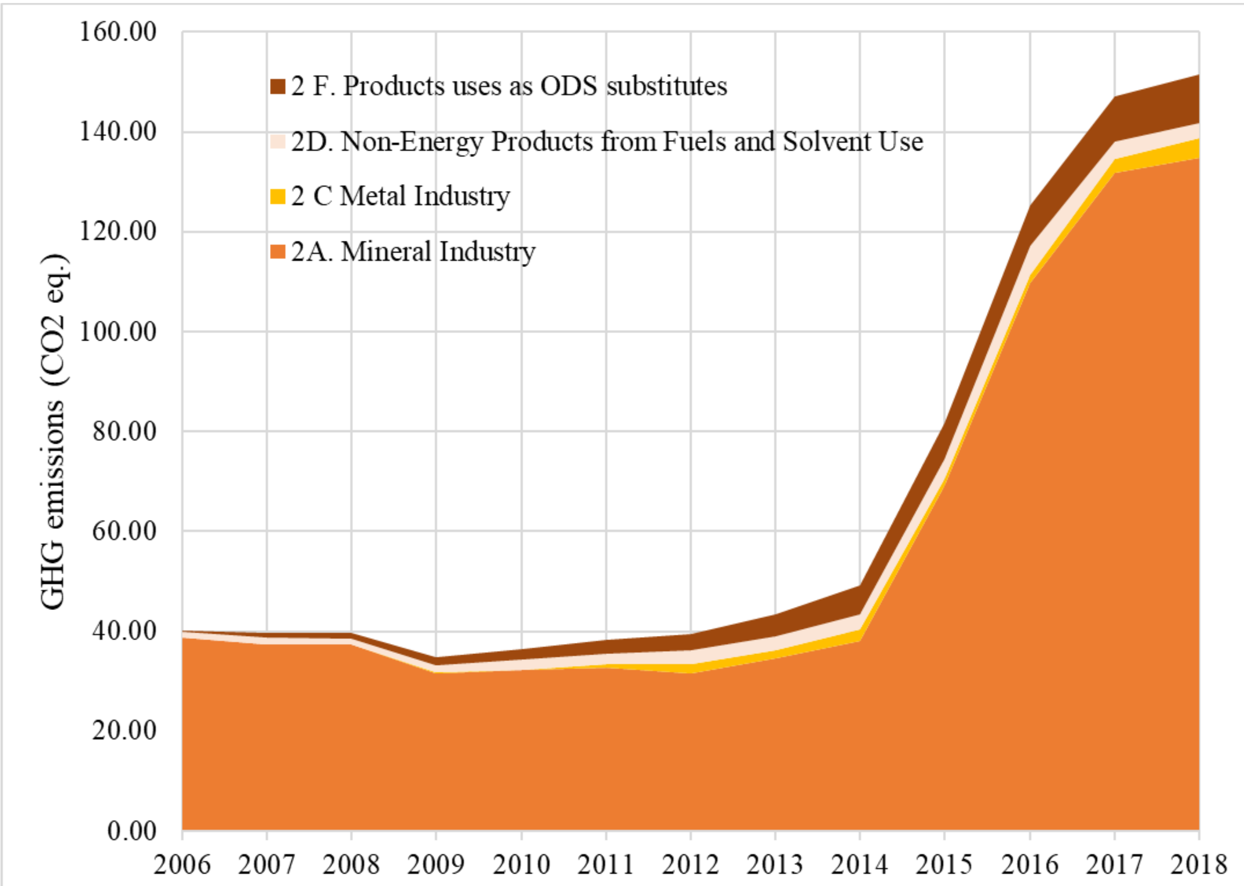


Figure 4.1Trends in IPPU emissions (2006-2018)

In addition, the growth in IPPU emissions can be explained by the increasing consumption of lubricants at the national level. The consumption of lubricants is also linked to the increase in registered moto vehicles. It should be noted that Rwanda had 198,518 registered motor vehicles in 2017, which have increased from 47,631 vehicles in 2006 (REMA, 2019). The huge import of lubricants in 2016 and the corresponding increase in 2D category emissions, compared to the previous and following years, can be explained by the decline in crude oil price experienced in 2016 as mentioned in historical annual data of oil prices. Similarly, the rise in emissions from product uses as substitutes for ODS is due to the increase of imported quantities of HFCs for refrigeration and stationary air-conditioning.

4.3 Trends of GHG emissions from per gas

The trends of GHG emissions per gas show that CO_2 is the main GHG gas followed by HFCs and the methane emissions have a minute contribution (**Figure 4.2**). The CO_2 emissions are mainly generated by the mineral industries and to a lesser extent by the metal industries.

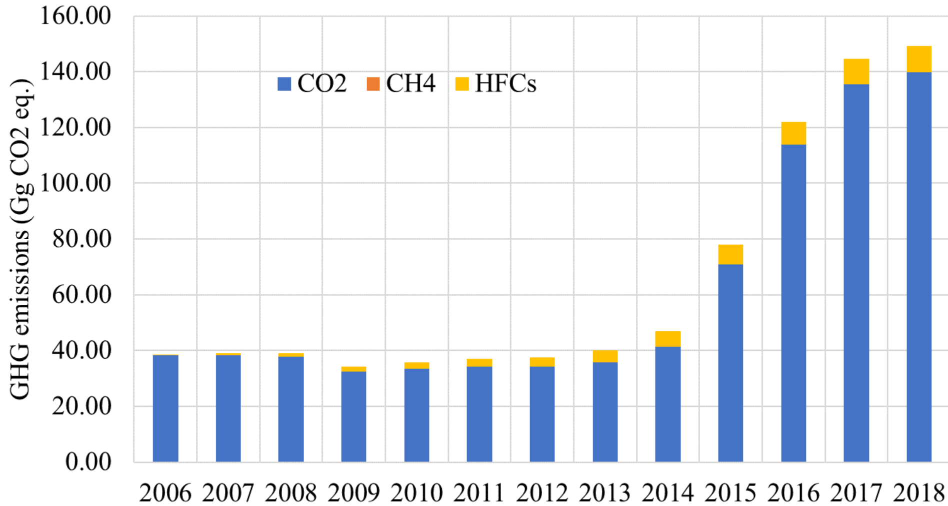


Figure 4.2 Trends of GHG emissions from IPPU per gas

4.4 Mineral industries (2.A)

4.4.1 Source category description

According to the 2006 IPCC guidelines, the GHGs emissions under the mineral industry source category encompass five sub-categories, viz., cement production (1.A.1); lime production (1.A.2); glass production (1.A.3); other process uses of carbonates (1.A.4) and other mineral product process (1.A.5). In general, IPPU concerns the process-related emissions from mineral products following the use of carbonate-containing materials. The GHGs emissions resulting from calcination of carbonate materials, mainly from Cement Production, Lime Production, and Glass Production, have been recorded as sources that relatively contribute significantly to the global emissions (IPCC 2006, 2006). Since there is no glass production industry in Rwanda, the GHG inventory in this source category considered the GHG emissions generated in the cement and lime production industries.

4.4.2 Overview of shares and trends in emissions from mineral industries

The mineral industry has one of the total IPPU largest shares of emissions estimated at 90%. As shown in **Figure 4.3**, the GHG emissions from mineral industries had an increasing trend with slight fluctuations in the period 2006-2015.

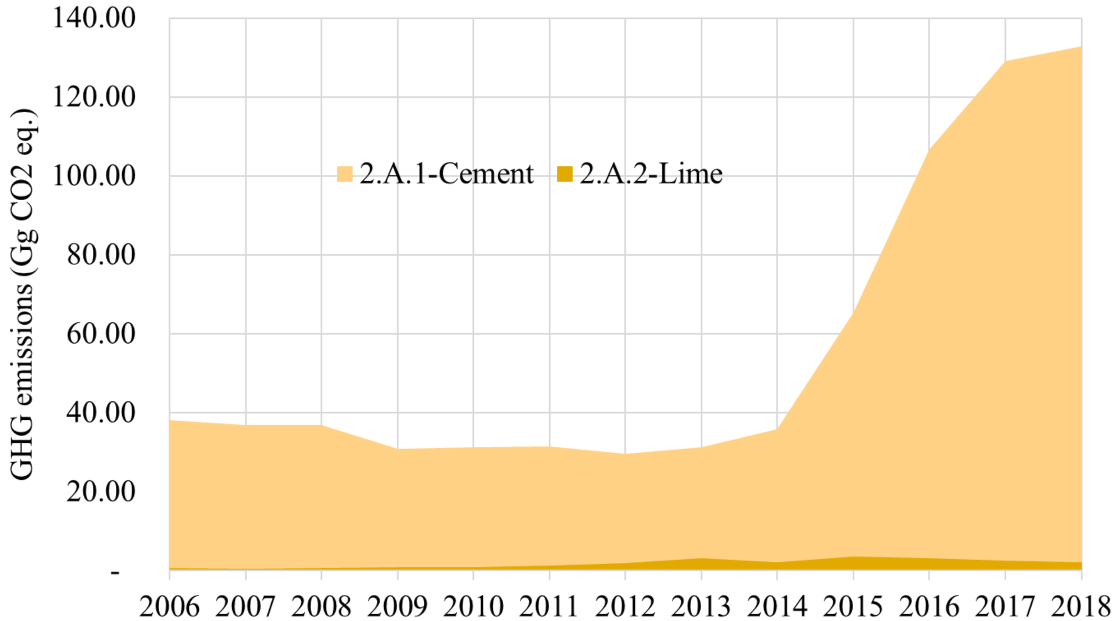


Figure 4.3 Trends and shares in GHG emissions from mineral industries

The observed fluctuations could be explained by the decrease in cement production during the period 2008-2014, for instance from 101,216 tons (2008) to 84,844 tons (2009) due to CIMERWA plant renovation from the end of the year 2009 until July 2015. The GHG emissions from cement industries contributed more than 96% of the total emission from the mineral industry throughout the period 2006-2018. This is due to high cement production as described in section **4.4.3.2**. The impact of this renovation is also explained by the increase in production after renovation from 86,237 tons in 2013 to 106,097 tons in 2014, 179,782 tons in 2015, and 364,863 tons in 2018.

4.4.3 Cement production industries (2.A.1)

4.4.3.1 Methodological issues

In Rwanda, there are currently three plants that produce cement namely CIMERWA Ltd (since 1982), Kigali Cement Company (since 1999), and Prime Cement Ltd (since 2020), but only the CIMERWA plant produces clinker by limestone calcination. As explained in 2006 IPCC Guidelines (IPCC 2006, 2006), during the production of cement, CO_2 is produced in the course of the production of clinker. During this process, limestone is heated to produce lime (CaO) and CO_2 as a by-product, which is the case for CIMERWA. Cement may also be made entirely from the imported clinker. In this case, the cement production process may be considered as CO_2 emissions-free process, which is the case for Kigali cement and Prime Cement Ltd.

The cement kiln dust (CKD) may be generated during the manufacture of clinker. The estimation of emissions considers the emissions linked to CKD. In contrast, the production of masonry cement for the case of Kigali Cement Company and Prime Cement Ltd is considered as an emission-free process because of the addition of ground limestone to Portland cement or its clinker to produce masonry cement does not lead to additional emissions.

Tier 1 methodology was used for estimating the emission from cement production. This is because the emissions were based directly on a known quantity of cement production (Tier 1), and a default emission factor of 0.52 for clinker fraction was applied using Equation 2.1 (IPCC 2006, 2006). To use Tier 2 for future estimates, there is a need to know, the exact quantity of clinker produced, the calcium oxide (CaO) content of the clinker, and other inputs of non-carbonate sources that are required for Tier 2 methodology. It should be highlighted that for Tier 2 and 3; the emission factor of cement production should be calculated. Generally, the value of the emissions factor varies with the clinker content in $CaCO_3$ and/or MgO. The default clinker emission factor (EFclc) is corrected for CKD.

4.4.3.2 Data sources

The following input activity data and emission factors were used to compute CO_2 emissions from cement production: the types and quantity of cement produced and the clinker fraction of the cement to estimate clinker production. For the case of Rwanda, the Portland cement type is produced as reported in **Table 4.3**. Data on cement production were collected from BNR (National Bank of Rwanda). The data collected in BNR were sent to CIMERWA for their validation at the plant level and it was reported that the clinker fraction used was 70% and a default emission factor of 0.52 was used.

Table 4.3 Cement and clinker production, tons (2006-2018)

Period	Cement production	Clinker component
2006	104,663.0	73,264.1
2007	101,210.0	70,847.0
2008	101,216.0	70,851.2
2009	84,844.0	59,390.8
2010	86,200.0	60,340.0
2011	86,450.0	60,515.0
2012	81,412.0	56,988.4
2013	86,237.0	60,365.9
2014	106,097.0	74,267.9
2015	179,782.0	125,842.4
2016	293,090.5	205,163.4
2017	354,801.4	248,361.0
2018	364,863.5	255,404.5

Source: Adapted from BNR, 2016 & MINICOM, 2020

4.4.3.3 Uncertainty and time-series consistency

Uncertainty estimates for cement production are mainly a result of uncertainties linked to input activity data, and a lesser extent a result of uncertainty related to the emission factor for clinker. This is also the case for cement production in Rwanda as the clinker fraction of 70% was used and crosschecking data from MINICOM with the data from CIMERWA were conducted. For this, the following uncertainty ranges were considered by this study:

- Activity data uncertainties: ±5% (Raw data were sent to CIMERWA for verification)
- Emission factor uncertainties: ±5% (For composition: 2% Assumption that 100% CaO is from $CaCO_3$. For production: 2% Uncertainty of plant-level weighing of raw materials, For CKD: 1% Assumption that all carbonate (calcined or remaining) in CKD is $CaCO_3$.

4.4.3.4 Quality assurance and Quality control

Quality Control (QC) was made by comparing emissions estimates using different approaches, reviewing emission factors, and by site-specific activity data crosschecking with CIMERWA. In addition, data on cement production from BNR have been sent to REMA for verification during the validation workshop for quality assurance. Quality assurance was conducted with the support of an international consultant.

4.4.4 Lime production (2.A.2)

4.4.4.1 Source category description

The limestone or travertine from Rusizi and Musanze is mainly characterized by a high content of calcium. In Rwanda, there are relatively good sources of limestone/travertine mainly in the Western (Karongi and Rusizi districts) and the Northern (Musanze district) provinces and other small deposits in Gakenke and Rulindo districts (Nduwumuremyi, Mugwe, Rusanganwa, & Mupenzi, 2013). Agricultural deposits are mined only in Musanze while the Mashyuza limestone deposit is mainly used for construction purposes. Mashyuza deposits in the Rusizi region had 50% ±3.4 of CaO and moderate MgO of 3% ±0.6 (Nduwumuremyi et al., 2013). However, few studies characterize the type of lime throughout Rwanda. Thus, based on the Nduwumuremyi results, the lime composition fraction used in the SNC was maintained as 85/15, respectively, for high calcium lime/dolomitic lime.

Limestone and dolomite are basic raw materials used by a wide variety of industries, including construction, agriculture, chemical, metallurgy, glass production, and environmental pollution control. The inventoried lime in this report is in the form of burned lime (REMA, 2019b), mainly used for construction while the major quantity of limestone used for the agricultural purpose in Rwanda is not calcinated, thus was not considered in the IPPU sector but it is considered in AFOLU sector.

4.4.4.2 Overview of shares and trends in emissions from lime production

As detailed above in Table 2.1, lime annual production has recorded fluctuation for the last ten years, from 1,046.00 tonnes of lime (2006) to 4,869.21 tons of lime (2015) and 2,769.37 tonnes (2018). This explains the considerable increase in the use of non-calcinated lime in agriculture activities. On the other hand, **Figure 4.4** shows that in general CO_2 emissions from lime production have recorded a peak during the year 2015 followed by a decline.

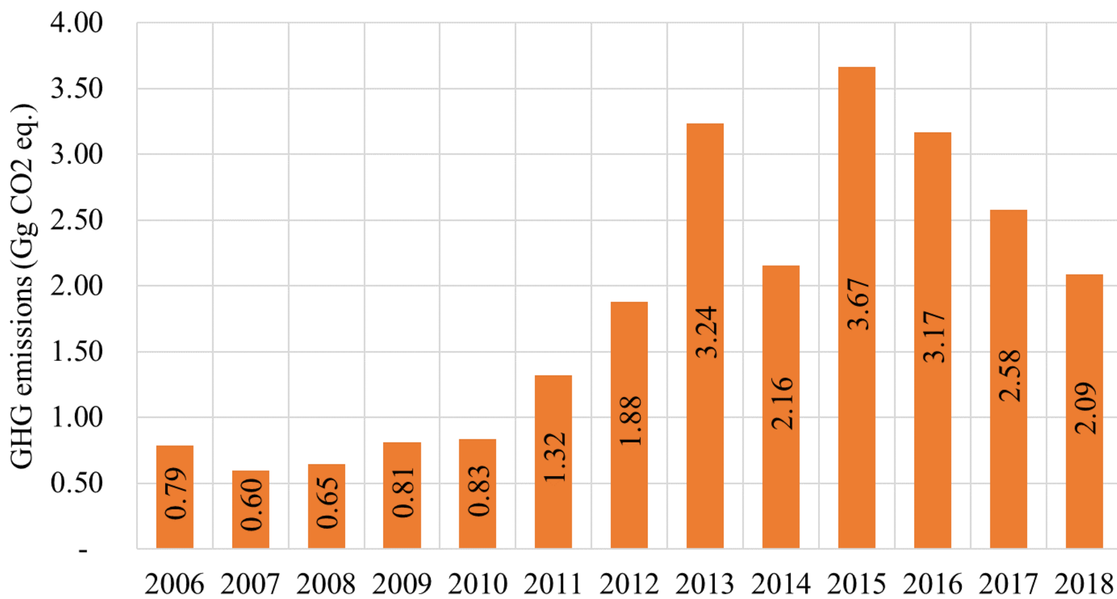


Figure 4.4 Total emissions of carbon dioxide from lime production, 2006-2015

This decline may be partly explained by the reduction of demand for calcinated lime that was previously used in the agriculture sector. The latter has been replaced by non-calcinated lime.

4.4.4.3 Methodology, choice of activity data, and emission factors

Based on the circumstances of the country, Tier 1 method was used and the IPCC default fraction of 85/15, respectively. For high calcium lime/dolomitic lime was applied. As discussed in section **4.4.4.1**, Mashyuza deposit in the Rusizi region had 50% ±3.4 of CaO and moderate MgO of 3% ±0.6. (Nduwamungu et al., 2013), from this paper, we consider it as moderate dolomitic but further studies are needed for lime characterization in Rwanda. Therefore, to estimate emissions from lime production the equation 2.6 of the 2006 IPCC guidelines reported in the volume 3, chapter 2 (IPCC 2006, 2006) was used based on national lime production data by type.

To calculate the emissions from lime production, the emission factor for lime production was used viz., 0.75 for high-calcium lime and 0.77 for dolomitic lime. Other input activity data were considered such as the type of lime produced, the mass of lime produced (tons). Two types of lime are produced in Rwanda, namely, high-calcium lime and dolomitic lime. The quantity (mass) of lime produced in Rwanda was collected from BNR, which regularly collects the data of calcinated lime in Rwanda. Depending on the national circumstances, the assumption of a default breakdown of limestone versus dolomite of 85%/15 % was used as reported in **Table 4.4**.

Table 4.4 Mineral Industries (2.A.2): Lime production

Year	Total (tonnes)	High-calcium lime (tonnes)	Dolomitic lime (tonnes)
2006	1,046.0	889.1	156.9
2007	792.0	673.2	118.8
2008	860.0	731.0	129.0
2009	1,080.4	918.3	162.1
2010	1,107.0	941.0	166.1
2011	1,756.7	1,493.2	263.5
2012	2,493.9	2,119.8	374.1
2013	4,299.4	3,654.5	644.9
2014	2,862.6	2,433.2	429.4
2015	4,869.2	4,138.8	730.4
2016	4,206.8	3,575.8	631.0
2017	3,428.5	2,914.2	514.3
2018	2,769.4	2,354.0	415.4

Source: Adapted from BNR, 2016 & MINICOM, 2020

4.4.4.4 Uncertainty and time-series consistency

Uncertainty estimates for lime production are also dominated by uncertainties linked to activity data and slightly to uncertainty related to the emission factor. Time series has been consistent as the same method for every year in the model has been used to calculate emissions from lime production (IPCC 2006, 2006). For this, the following uncertainty ranges were considered for lime production:

- Activity data uncertainties: ±10% (It is assumed that data from non-calcinated lime are not always well reported by the producers to reduce their taxes)
- Emission factor uncertainties: ±10% (Uncertainty is assumed to be high based on (i) default value for the High Calcium lime and Dolomitic lime, (ii) Uncertainty of plant-level lime production data, and (iii) the Uncertainty of plant-level weighing of raw materials.

4.4.4.5 Quality assurance and Quality control

The quality control was made by comparing the emissions estimates using different approaches, reviewing emission factors, and using the activity data collected during the 2019 survey on lime production as well as crosscheck with the data available at MINICOM. In addition, quality assurance was conducted with the support of an international consultant.

4.4.4.6 Mineral industry emissions recalculations

There was no emissions recalculation for the mineral industry subcategory.

4.4.5 Source Specific planned improvements

Although the quantity of cement produced is regularly reported, the clinker has considered a fraction of 70%, and this fraction was approved by CIMERWA. However, there is a need to improve the data collection by collecting both cement and clinker quantities. This will help to improve the reporting from Tier 1 to Tier 2. In addition, considering the higher emissions from cement production, the national clinker emission factor should be calculated to replace the current default value is 0.52 tonne CO_2/tonne Clinker.

Lime-producing industries in Rwanda should continue to record their production and provide the data to MINICOM to ease future inventories without conducting surveys. This should be supported by the existing inventory through the records of the National Bank of Rwanda (BNR), the Ministry of Agriculture records, and with the support of the National Institute of Statistics in Rwanda.

4.5 Metal Industry (2.C)

The metal industry source category consists of iron and steel production (2.C.1); ferroalloys production (2.C.2); aluminium production (2.C.3); magnesium production (2.C.4); lead production (2.C.5); zinc production (2.C.6) and any other metal (2.C.7) based on the circumstances of the country. Currently, the Iron and Steel Production (2.C.1) and Ferroalloys Production (2.C.2) are the only subcategories relevant for Rwanda. In general, metal production in Rwanda is still at the infant level with ferroalloys production, which started in 2007, and steel production, which started in 2011.

4.5.1 Overview of shares and trends in emissions from the metal industry

The trend in emissions from the metal industry sector is shown in Figure 6 and it could be noticed that from the year 2007 to 2010 the total emissions were still lower compared to the following years. These lower emissions could be explained by the starting period of the ferroalloys and iron production in Rwanda initiated by Chillington Rwanda Ltd. Since 2011, the steel production by mainly using the recycled materials initiated by SteellRwa Industries and later on by Imana steel Rwanda has considerably increased with an annual growth rate of 32% from 2011 to 2018. This shows that in the future, the growth of the metal production sector may result in higher emissions.

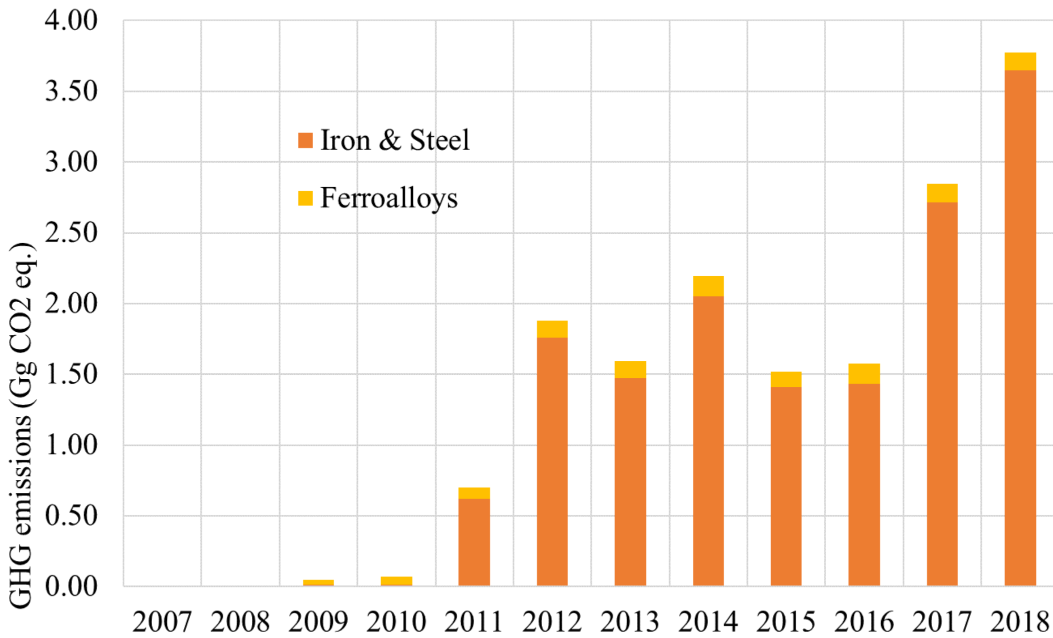


Figure 4.5 Trend in GHG emissions from the metal industry

4.5.2 Iron and steel production (2.C.1)

4.5.2.1 Source category description

In Rwanda, the current steel production is the secondary steel making mainly from recycled steel scrap, and the data on production are regularly collected by MINICOM. SteellRwa Industries and Imana steel Rwanda are the only secondary facilities for steel production, located respectively in Rwamagana and Bugesera Districts in the Eastern Province. Electric induction furnace or electric arc furnaces (EAFs) is the method used for Secondary steelmaking in Rwanda. In addition, the quantity of cast iron production since 2007 was considered in this section by using the data collected from Chillington Rwanda Ltd.

4.5.2.2 Overview of shares and trends in emissions

Figure 4.6 shows that the emissions from Iron and steel production were estimated from 2007, the time of initiation of cast iron production in Rwanda. In general, the iron and steel emissions were increasing mainly starting from 2011 when the steel production was making the first move. For several years, Rwanda has been depending on metal import but since 2007, there has been a slow increase in CO_2 emissions of this sector. The trend in emissions, although in general increases, records fluctuations for the period 2013-2016, and this may be partly explained by the fact that GDP was In addition fluctuating in the same period[2].

[2] https://data.worldbank.org/indicator/NY.GDP.PCAP.CD?locations=RW.

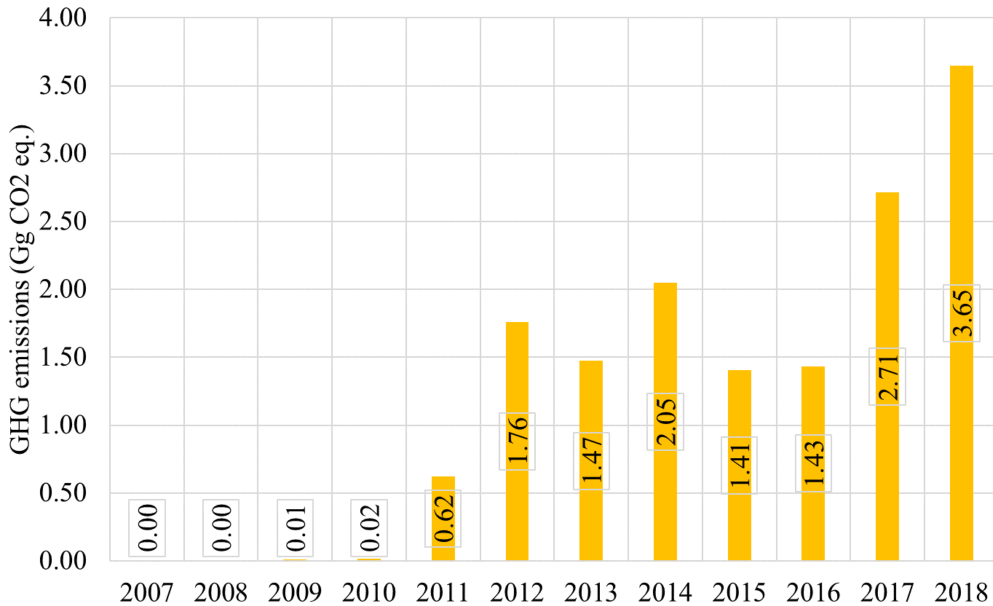


Figure 4.6 Total emissions of CO_2eq from iron and steel production

4.5.2.3 Methodology, choice of activity data, and emission factors

To compute the emissions from Iron and steel production, the following input activity data and emission factor were required: type of steelmaking method, amount of steel and iron production (tons), and emission factor. In the case of Rwanda, Electric Arc Furnace (EAF) is used as a type of steelmaking method while the Direct Reduced Iron production method is used for cast iron production.

Based on limited national process, materials data availability, and the fact that the metal industry is not among key categories, the Tier1 method has been used to calculate CO_2 emissions using default emission factors and national production data. The used Emission Factor for Direct Reduced Iron production is 0.7 tonnes CO_2/ tonne produced while 0.08 tonne CO_2/ tonne produced was used for Electric Arc Furnace (EAF).

The estimate of the national production was taken from the data survey provided by MINICOM and the cast iron data collected from Chillington Rwanda Ltd as discussed in previous sections. The used production data are detailed in **Table 4.5**. The computation of emissions from iron and steel production has been a result of the sum of Equations 4.4 to 4.8 (IPCC, 2006; Vol.3_4_CH_4; pp 4.21). In addition , a Tier 1 default method for CH_4 from iron production similar to the below approaches described for estimating CO_2 emissions was used with Equations 4.12 to 4.13 of the volume 4 of the 2006 IPCC guidelines (IPCC 2006, 2006). The used production data are provided in **Table 4.5.** However, the data on cast iron production was not displayed due to the confidentiality agreement.

Table 4.5 Activity data used in the calculation of emissions form Iron and steel production, tonnes

Year	2011	2012	2013	2014	2015	2016	2017	2018
Total iron & steel production*	7,500	21,600	18,000	25,200	17,280	17,328	33,788	45,506

***** Production at SteellRwa Industries and Imana steel. **Source:** *MINICOM, 2020*

4.5.2.4 Uncertainty and time-series consistency

In Rwanda, cast iron and steel production were initiated respectively in 2007 and 2011. The 2006 IPCC guidelines as documented in its volume 3 suggests that emissions from coke production and iron and steel production should be computed using the same method for every year in the time series. The data used in this sub-category were directly corrected from the production facility (IPCC 2006, 2006). The estimated uncertainties are the following:

- Activity data uncertainties: ±5% (Data collected at the plant level were used)
- Emission factor uncertainties: ±10% (Due to the use of Material-Specific Default Carbon Contents)

4.5.2.5 Quality assurance and Quality control

Quality control has been done by running activity data check and it was complimented by involving various expert reviews from the metal industry and REMA as advised through the 2006 IPCC guidelines (IPCC 2006, 2006). In addition to the validation workshop, the quality assurance of the inventory was conducted with the support of an international consultant.

4.5.3 Ferroalloys Production (2.C.2)

4.5.3.1 Source category description

Ferroalloys are made of concentrated alloys of iron and one or more metals such as silicon, manganese, chromium, molybdenum, vanadium, and tungsten. Silicon metal production is usually included in the ferroalloy group because the silicon metal production process is quite similar to the ferrosilicon process. Ferroalloy production involves a metallurgical reduction process that results in significant carbon dioxide emissions (IPCC 2006, 2006). In Rwanda, ferroalloys productions are still at the starting level at Chillington Rwanda Ltd, which manufactures the casted spares, steel casting, and steel fabricated goods with a production capacity of 4 tons per day. Currently, the main products at this plant are stone crusher parts and wheelbarrows. The types of locally produced ferroalloys are ferrochromium and ferromanganese.

4.5.3.2 Overview of shares and trends in emissions

The growing trend of the emissions from ferroalloys production in Rwanda computed from 2007 to 2018 is presented in Figure 8, considering two types of ferroalloys, i.e., ferrochromium and ferromanganese manufacturing. In most cases, throughout the reporting period, the ferroalloys emissions were increasing from 2007 to 2018 with an annual growth rate of 46%. According to Chillington Rwanda Ltd, there is competition at the local market of ferroalloys imported from other countries, mainly China and Kenya, which explains the fluctuation of emissions recorded for the period from 2014 to 2018.

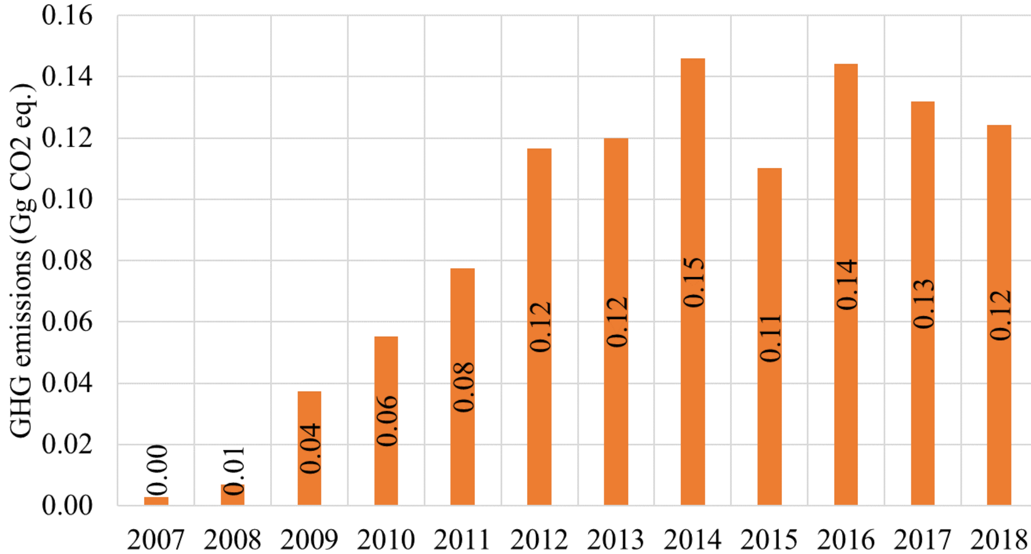


Figure 4.7 Total emissions of CO_2e from ferroalloys production

4.5.3.3 Methodology, choice of activity data, and emission factors

To calculate the emissions from ferroalloys productions, the following input activity data and emission factors were required: the amount of ferroalloys productions (tons) and the default emission factor. Thus, Tier 1 approach was used to determine the GHG emissions from ferroalloys production. The emission factor used are 1.3 tones CO_2/ton product for Ferromanganese (7% C) and 1.3 tones CO_2/ton product for ferrochromium (IPCC 2006, 2006). Due to the confidentiality agreement, for both ferrochromium and ferromanganese, their production quantities are not included in this report. The computation of emissions from ferroalloys productions has been a result of the equation 4.15 of the 2006IPCC guidelines (IPCC 2006, 2006).

4.5.3.4 Uncertainty and time-series consistency

The activity data for the production quantity was corrected directly by the manufacturer, which reduced the sources of error. Uncertainties for ferroalloy production result predominantly from uncertainties associated with activity data and to a lesser extent from uncertainty related to the emission factor (IPCC 2006, 2006). Thus, the following uncertainties were used for the activity data and emission factor:

- Activity data uncertainties: ±5% (Data collected at the plant level were used)
- Emission factor uncertainties: ±10% (Due to the use of default emission factor)

4.5.3.5 Quality assurance and Quality control

Quality control has been done by running activity data check and it was complimented by involving various expert reviews from the metal industry, REMA, and with the involvement of reviewers during the validation workshop. In addition to the validation workshop, quality assurance of the inventory was conducted with the support of an international consultant.

4.5.4 Metal industry emissions recalculations

There was no emissions recalculation for the metal industry subcategories.

4.5.5 Specific planned improvements and recommendations in the metal industry

There is a need to develop methodologies for data collection for metal industries because the data are currently not desegregated according to the type of metals produced. To obtain the disaggregated data, during the inventory we had to go to the manufacturing industries. This can be improved by the appropriate methodology and tools to collect data as well as to provide capacity building to companies/ industries on how to keep the records of activity data.

4.6 Non-Energy Products from Fuels and Solvent Use (2.D)

Emissions from Non-Energy Products from Fuels and Solvent Use (2.D) are generally generated from Lubricant use (2.D.1), Paraffin Wax use (2.D.2), Solvent Use (2.D.3), and other types of activities (2.D.4). This study has covered the emissions from lubricant and paraffin use source categories based on the circumstances of the country and the availability of data. For the 2.D.3 category, the emissions were not estimated because the inventory software used, IPCC 2006 version 2020, does not allow the input of solvent use data. In addition, data on Solvent Use should be collected to allow the estimate of emissions from various non-methane volatile organic compounds (NMVOC).

Lubricants are typically used in industrial and transportation applications and they can be divided into (i) motor oils and industrial oils, and (ii) greases. Paraffin Wax use comprises products such as petroleum jelly, paraffin waxes, and other waxes, including ozokerites, which are mixtures of saturated hydrocarbons, solid at ambient temperature (IPCC, 2006; Vol.3_4_Ch5; pp 5.11).

4.6.1 Overview of shares and trends in emissions

Emissions from Non-Energy Products from Fuels and Solvent Use for the period 2006-2018 are shown in **Figure 4.8**. The total GHG emissions from Non-Energy Products from Fuels and Solvent Use had an increasing trend with a peak in 2016. The total emission has more than tripled in the same period with an annual growth rate of 11%. The observed peak in the emissions corresponds to a peak observed in the Non-Energy Products from Fuels and Solvent Use consumption (**Table 4.6**). The huge consumption of Non-Energy Products from Fuels and Solvent Use in 2016 could be attributed to the decline in crude oil prices experienced in 2016 as mentioned in historical annual data of oil prices[3]. The emissions from lubricant use have the highest share of more than 70% compared to paraffin wax use.

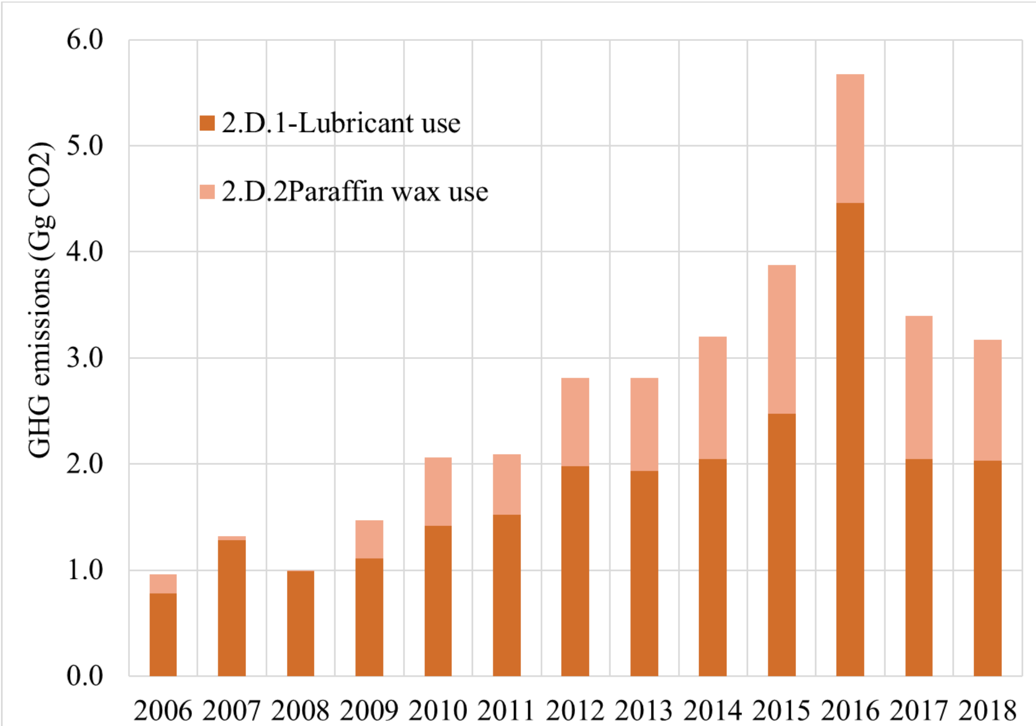


Figure 4.8 Trend in GHG emissions from Lubricant use and Paraffin wax use

Table 4.6 Non-Energy Products from Fuels and Solvent Use consumption, TJ (2006-2018)

Year	2 D.1 Lubricant use	2 D.2 Paraffin wax use
2006	54.742	12.087
2007	89.526	2.581
2008	70.423	0.101
2009	77.576	24.607
2010	100.669	43.788
2011	108.084	38.986
2012	140.493	57.028
2013	137.921	59.888
2014	145.380	78.643
2015	174.506	95.748
2016	316.021	82.417
2017	149.287	91.898
2018	149.694	77.793

[3] https://www.macrotrends.net/1369/crude-oil-price-history-chart

4.6.2 Lubricant use (2.D.1)

4.6.2.1 Source category description

Lubricants are usually used in industrial and transportation applications and they can be divided into (i) motor oils and industrial oils, and (ii) greases. The data for lubricant import in Rwanda were collected from the Rwanda Revenue Authority (RRA, 2020) and they are subdivided into (a) motor oils and industrial oils, and (b) greases. Various types of lubricants are imported from different countries and recorded without specifying the origin, which makes it difficult to have the import from each country. It should be noted that Rwanda does not produce lubricants and neither export the recorded lubricants for national use. However, it is always good to check the records at RRA to avoid the mixture of lubricants for use in Rwanda and the one in transit to neighbouring countries.

4.6.2.2 Overview of shares and trends in emissions from lubricant use

The trend in emissions from lubricant use is shown in **Figure 4.9** with emissions more than doubling during the period 2006-2018 and an annual growth rate of 9%. The peak of emissions is observed in 2016 due to the decline in crude oil price experienced in that year as explained in paragraph 3.4.1. Thus, the decreasing emissions from 2017 to 2018 could be attributed to the high import of lubricant for the year 2016, i.e., reduced import in the following year.

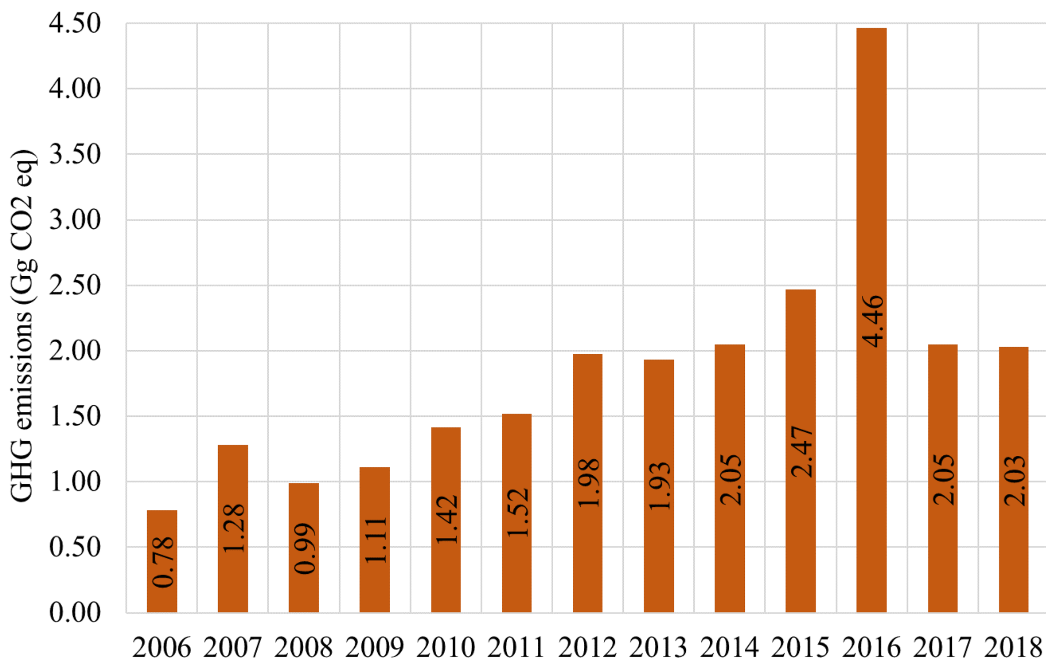


Figure 4.9 Total emissions of CO_2 from lubricant use, 2006-2018

4.6.2.3 Methodology, choice of activity data, and emission factors

To compute emissions from lubricant use, the following input activity data and factors were used: the amount of lubricant consumed or imported per type, lubricant carbon content, and Fraction Oxidized During Use (ODU factor). Based on the country's circumstances, the Tier 2 method was used. As recommended by the 206 IPCC guidelines (IPCC 2006, 2006), for Tier 2 method about the calculation of emissions from lubricant use, the equation 5.2 of the 2006 IPCC guidelines has been used (IPCC 2006, 2006).

The data for lubricant use in Rwanda were collected from the Rwanda Revenue Authority (RRA, 2020) and they are subdivided into (a) motor oils and industrial oils, and (b) greases. The lubricants are imported from different countries. Thus, it was not feasible to have the import from each country and it was therefore preferred to use a default factor of Oxidized During Use (ODU) as follows: 0.2 for lubricant oils and 0.05 for grease. For lubricants, the default carbon contents factor used is 20.0 kg C/GJ (kg C/GJ) on a Lower Heating Value basis (IPCC 2006, volume 3, chapter 5). To convert consumption data in physical units, tonnes into common energy units TJ, the calorific values of 40.2 TJ/Gg was used (IPCC 2006, volume 2, Chapter 1) as shown in **Table 4.7**. Lubricant is imported in Rwanda from several countries namely Qatar, Oman, Kuwait, Saudi Arabia, Nigeria, Germany, etc.

Table 4.7 Imported lubricant and greases (2006-2020)

Period	Description of goods	Net weight (Gg)	Energy content (TJ)
2006	Lubricant oils	1.31431	52.835
	Greases	0.04745	1.907
2007	Lubricant oils	2.16036	86.846
	Greases	0.06668	2.680
2008	Lubricant oils	1.64996	66.328
	Greases	0.10186	4.095
2009	Lubricant oils	1.86316	74.899
	Greases	0.06659	2.677
2010	Lubricant oils	2.36796	95.192
	Greases	0.13625	5.477
2011	Lubricant oils	2.54436	102.283
	Greases	0.14430	5.801
2012	Lubricant oils	3.30503	132.862
	Greases	0.18982	7.631
2013	Lubricant oils	3.22808	129.769
	Greases	0.20279	8.152
2014	Lubricant oils	3.42068	137.511
	Greases	0.19574	7.869
2015	Lubricant oils	4.14180	166.500
	Greases	0.19916	8.006

2016	Lubricant oils	7.47224	300.384
	Greases	0.38897	15.636
2017	Lubricant oils	3.39312	136.403
	Greases	0.32050	12.884
2018	Lubricant oils	3.35611	134.916
	Greases	0.36761	14.778

Source: RRA, 2020

4.6.2.4 Uncertainty and time-series consistency

Imported data were regularly corrected at the national level, which may reduce to some extent the uncertainties for the activity data. In contrast, the developed default ODU factors are very uncertain, as they are based on limited knowledge of typical lubricant oxidation rates. In addition, the carbon content varies depending on the origin of the lubricant. The same method has been used to estimate emissions from lubricant use every year. For this, the following uncertainty ranges were considered during this study:

- Activity data uncertainties: ±5%
- Emission factor uncertainties: ±50% (this is also proposed by IPCC 2006).

4.6.2.5 Quality assurance and Quality control

Quality control has been done by checking the consistency of the total annual consumption figure with the production, import, and export data. In addition, the data used were verified at REMA and during the validation workshop. In addition to validation workshops, quality assurance of the inventory was conducted with the support of an international consultant.

4.6.3 Paraffin Wax use

4.6.3.1 Source category description

This category includes products such as petroleum jelly, paraffin waxes, and other waxes, including ozokerite (mixtures of saturated hydrocarbons, solid at ambient temperature) (IPCC, 2006, V3, CH5). The main applications for paraffin wax in Rwanda include candle production and a smaller fraction is used as lubricant mainly in the textile manufacturing process. The data on imported paraffin waxes, other waxes, and petroleum jelly were regularly recorded at Rwanda Revenue Authority and the data were used to estimate the CO_2 emissions from the paraffin wax use category. However, there are no country-specific statistics available on the fates of waxes, which resulted in estimating CO_2 emissions using the IPCC default factor of 0.2 for oxidized fractions during use.

4.6.3.2 Trends of GHG emissions from paraffin wax use

The trends and the summary of GHG emissions from paraffin wax use are depicted in **Figure 4.10** and **Table 4.8**, respectively. As illustrated in the figure, the GHG emission from this category shows an increasing trend with some fluctuations throughout the period 2006-2018.

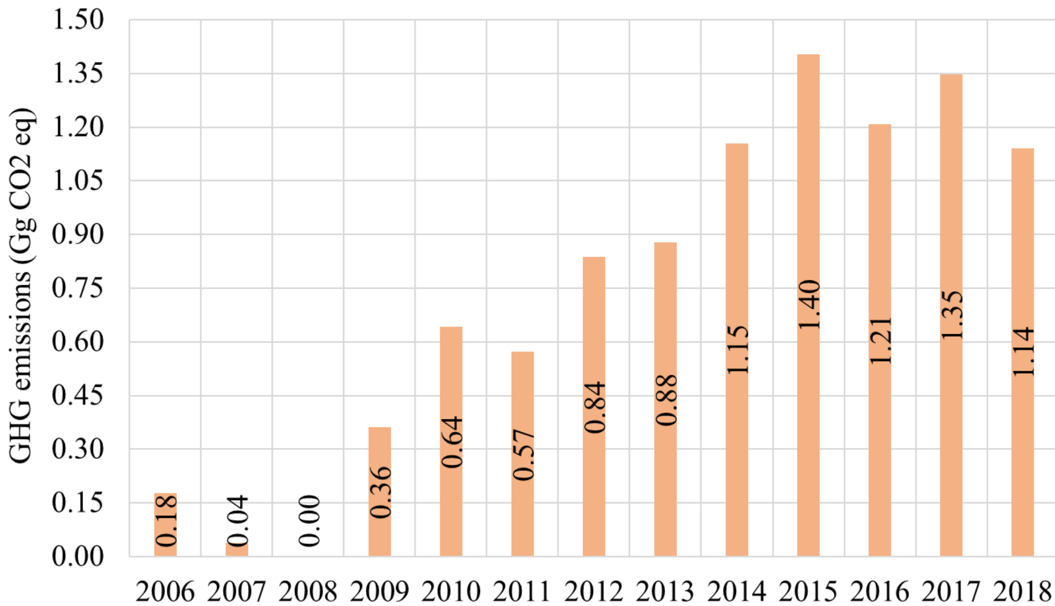


Figure 4.10 Total emissions of CO_2eq. from Paraffin Wax use, 2006-2018

The main applications for paraffin wax in Rwanda include candle production and a smaller fraction is used as lubricant mainly in the textile manufacturing process as explained in the above section. Comparing the emissions from Non-Energy Products from Fuels and Solvent Use source category, the contribution of the accumulated emissions from paraffin is lower (28%) than that from lubricant use (72%).

4.6.3.3 Methodology, choice of activity data, and emission factors

To estimate emissions from paraffin wax use, the following input activity data and factors were used: the quantity of paraffin waxes imported and paraffin waxes carbon content as input activity data, and the fraction of oxidized during use (ODU factor). The data for paraffin waxes used in Rwanda were collected from Rwanda Revenue Authority (RRA, 2012) and they include products such as paraffin waxes and petroleum jelly. It should be noted that Rwanda does not produce paraffin waxes and neither exports them, except products, which are in transit to neighbouring counties. Such products in transit were not part of this inventory. The Tier 1 method was used to estimate emissions from paraffin wax use due to the lack of specific statistics on the fates of waxes and the country-specific ODU factor. As recommended for the Tier 1 method, the computation of CO_2 emissions was done using Equation 5.4 of the 2006 IPCC guidelines with aggregated default data for the limited parameters available (IPCC 2006, 2006). The default carbon content coefficient of 20.0 kg C/GJ (kg C/GJ) was used, and it is considered to have an uncertainty range of ±5 percent (U.S.EPA, 2004).

Table 4.8 Activity data for the imported paraffin wax in Rwanda from 2006 to 2018

Year	Amount of paraffin wax (Gg)	Energy content (TJ)
2006	0.30068	12.087
2007	0.06420	2.581
2008	0.00252	0.101
2009	0.61212	24.607
2010	1.08926	43.788
2011	0.96981	38.986
2012	1.41860	57.028
2013	1.48976	59.888
2014	1.95629	78.643
2015	2.38178	95.748
2016	2.05017	82.417
2017	2.28603	91.898
2018	1.93515	77.793

Source: Adapted from RRA, 2020

As discussed above, in Rwanda there are no country-specific statistics available on the fates of waxes. Thus, it was preferred to use a default value of 0.2 Oxidized During Use (ODU) for the emission factor calculation (IPCC 2006, volume 3, chapter 5). To convert consumption data in physical units, tonnes into common energy units TJ, the calorific values of 40.2 TJ/Gg was used (IPCC 2006, volume 2, Chapter 1) as detailed in **Table 4.8**.

4.6.3.4 Uncertainty and time-series consistency

IPCC (2006) presumes that the default emission factors are highly uncertain, as there is limited knowledge about paraffin wax fates at the national level. Similarly, it is complex to determine the quantity of non-energy products used and discarded in the country, which is the case for Rwanda. The same method has been used to estimate emissions from Paraffin Wax Use every year. For this, the following uncertainty ranges were considered during this study:

- Activity data uncertainties: ±5% (Data were regularly recorded at the national level)
- Emission factor uncertainties: ±50% (The use and fate of wax are very uncertain, and the default value was used for the fraction oxidized during use, ODU)

4.6.3.5 Quality assurance and Quality control

Quality control has been done by checking the consistency of the total annual consumption figure with the production, import, and export data. REMA has also checked on the activity data and validation workshops were conducted. Quality assurance of the inventory was conducted with the support of an international consultant.

4.6.3.6 Non-Energy Products from Fuels and Solvent Use emissions recalculations

There was no emissions recalculation from the Non-Energy Products from Fuels and Solvent Use subcategories.

4.6.4 Specific planned improvements and recommendations

The current record of lubricants imports by Rwanda Revenue Authority (RRA) has significant effect on the GHG inventory. Thus, they should be reported to REMA each year with the information on the type of lubricants imported, the origin of lubricants, and the quantity of lubricants. To ensure the continuity and integrity of the inventory, the formal involvement of RRA as the institution that provided diverse data during the inventory should be initiated. Furthermore, the emission from the Non-Methane Volatile Organic Carbons (NMVOC) could be considered in the next inventory, as their data exist in Rwanda for the main emitting sectors such as thinner solvents and bitumen. However, it should be noted that Non-Annex I countries are not obliged to report on the NMVOC gases, and the 2006 IPCC methodology does not cover these gases.

4.6.5 Product Uses as Substitutes for Ozone Depleting Substances (2.F)

Hydrofluorocarbons (HFCs) and, to a very limited extent, perfluorocarbons (PFCs), have high global warming potentials and are being used as alternatives to different classes of ozone-depleting substances (ODS) that are being phased out under the Montreal Protocol. According to the IPCC 2006 guidelines, HFCs and PFCs are being used in a variety of applications that includes refrigeration and air conditioning, fire suppression and explosion protection, aerosols, solvent cleaning, foam blowing, and other applications such as equipment's sterilization. Rwanda neither produces nor export substitutes for ozone-depleting substances but they are being imported mainly for refrigeration and stationary air conditioning and also the Mobile air conditioning. Other applications, such as aerosols, solvent cleaning, and foam blowing exist in Rwanda; however, there is a lack of inventory data to estimate these sources of emissions.

At the end of 2016, Rwanda initiated a survey on the use of alternatives to ODS as an activity under the Montreal Protocol. The survey covered the period from 2012 to 2015 and the major aim was to determine the trend of consumption of ODS alternatives in Rwanda from the year 2012 and beyond. The results show that the most commonly used ODS alternative for that period was R134a while the least used was R290 (REMA, 2016). Among the ODS alternatives surveyed in Rwanda, the following HFCs were categorized as GHGs: HFC-134a which is known as 1,1,1,2-tetrafluoroethane, HFC-125 known as 1,1,1,2,2-pentafluoroethane, HFC-143a, which is known as 1,1,1-Trifluoroethane, and HFC-32 known as difluoromethane. In addition, another survey on ODS and its alternative was conducted by REMA in 2020 and covered the period from 2016 to 2019 and the results were used to complete this inventory. According to the above-mentioned inventories conducted by REMA in 2016 and 2020, the blends imported in Rwanda do not contain PFCs.

4.6.6 Overview of shares and trends in emissions

The trends and shares of GHG emissions from Product Use as Substitutes for Ozone Depleting Substances are shown in **Figure 4.11.** Over the whole period 2006-2018, the total GHG emission shows an increasing trend. Considering the period from 2012 to 2018, which was covered by the previous two surveys on the use of ODS alternatives, the emissions have increased at an annual growth rate of 24% in the same period. In general, from 2012, HFC-134a as the major imported chemical is the principal contributor of the total emissions with an average contribution of 44.90% followed by HFC-143a contributing 28.89% and HFC-125 with 24.67% and lastly HFC-32 with 1.54% of the total HFCs emissions. It should be noted that the HFCs emissions have an annual growth of 10% from 2015 to 2018.

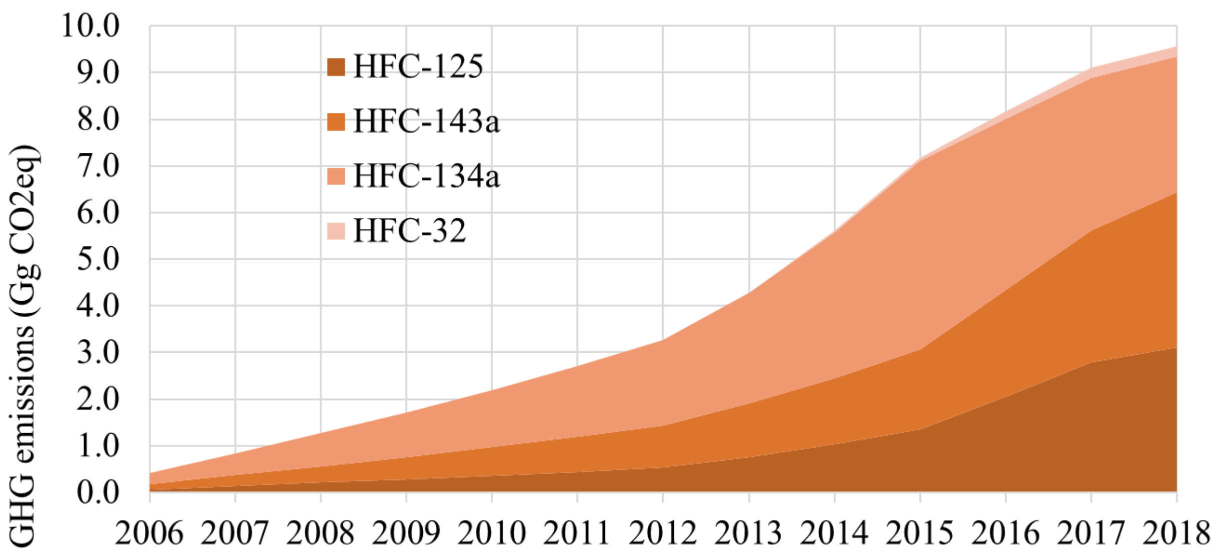


Figure 4.11 Trend and emission levels of HFC's in Rwanda, 2006-2018

4.6.7 Refrigeration and stationary air conditioning (2.F.1a)

4.6.7.1 Source category description

According to IPCC 2006, refrigeration and air-conditioning (RAC) systems can be categorized into up to six sub-application domains even though fewer sub-applications are typically used at a single country level. The following categories correspond to the sub-applications that can differ in different countries: (i) Domestic refrigeration, (ii) Commercial refrigeration including different types of equipment, from vending machines to centralized refrigeration systems in supermarkets, (iii) Industrial processes including chillers, cold storage, and industrial heat pumps used in the food, petrochemical, and other industries, (iv) Transport refrigeration including equipment and systems used in refrigerated trucks, containers, reefers, and wagons, (v) Stationary air conditioning including air-to-air systems, heat pumps, and chillers for building and residential applications, and (vi) Mobile air-conditioning systems.

In Rwanda, the domestic refrigeration sub-sector is governed by R-134a refrigerant, which is used in servicing mainly stand-alone units such as freezers and fridges. Currently, the used freezers and fridges in Rwanda are not destroyed at the end of life but most of them are being recycled or set aside in buildings. In general, the following HFCs and HFC blends were commonly imported in Rwanda as ODS substitutes for the survey period 2012-2015: R134a, R404a, R 410a, R407c, and R507a (REMA, 2016).

4.6.7.2 Overview of shares and trends in emissions

The emissions from refrigeration and stationary air conditioning were constantly increasing from 2006 to 2018 as detailed in **Table 4.8**. The hierarchy of HFCs emissions in the year 2015 was respectively for HFC-134a, HFC-143a, HFC-125, and HFC-32. It should be noted that in 2015 HFC 134a was ranked with the highest emissions in F-gases contributing about 56% while in 2018 HFC-143a were the highest with 35% of the total emissions in refrigeration and stationary air conditioning. For the total 9.319 Gg CO_2eq in 2018, HFC-143a contributed the average higher emissions, for the Refrigeration and stationary Air conditioning, estimated at 35.2% followed by HFC-125 with 33.1% and HFC-134a with 29.2% and HFC-32 with 2.5%.

Table 4.9 Summary of GHG emissions from refrigeration and stationary air-conditioning, Gg CO_2 eq. (2006-2018)

Year	2 F.1a Refrigeration and stationary Air conditioning				Total/year (Gg CO_2 eq.)
	HFC-125	HFC-143a	HFC-134a	HFC-32	HFCs
2006	0.063	0.103	0.213	0.001	0.379
2007	0.125	0.207	0.428	0.002	0.762
2008	0.190	0.313	0.653	0.003	1.158
2009	0.258	0.425	0.888	0.003	1.575
2010	0.333	0.544	1.139	0.004	2.020
2011	0.413	0.673	1.409	0.004	2.499
2012	0.502	0.812	1.701	0.004	3.019
2013	0.721	1.078	2.210	0.015	4.024
2014	0.987	1.332	2.969	0.039	5.327
2015	1.309	1.639	3.847	0.069	6.865
2016	2.020	2.220	3.477	0.142	7.859
2017	2.767	2.759	3.080	0.232	8.838
2018	3.087	3.280	2.725	0.226	9.319

4.6.7.3 Methodology, choice of activity data, and emission factors

The calculation of emissions from refrigeration and stationary air conditioning was done by considering the imported HFCs and HFC blends data for the period 2012-2015 (REMA, 2016) and the period 2016-2019 (REMA, 2020). The later surveys were conducted according to the UNEP format for preparation of the Surveys of ODS alternatives and presentation of the resulting data (Decision 74/53(g)) of November 2015. In addition, the constituents of the HFC blends summarized in **Table 4.10** were used for the estimation of HFCs imported as detailed in the 2006 guidelines (IPCC 2006, 2006).

Table 4.10 Blend, constituents and composition of imported HFCs

Blend	Constituents	Composition (%)
R-404A	HFC-125/HFC-143a/HFC-134a	(44.0/52.0/4.0)
R-407C	HFC-32/HFC-125/HFC-134a	(23.0/25.0/52.0)
R-410A	HFC-32/HFC-125	(50.0/50.0)
R-507A	HFC-125/HFC-143a	(50.0/50.0)

The activity data for ODS substitute consists of the net amount of each chemical consumed annually in a country in an application, sub-application, or more detailed equipment/product type. Thus, HFCs import data were collected considering the use of ODS alternatives per sector and therefore Tier 2a approaches were used by considering the annual chemical consumption data. The imported quantities of different HFCs in kilograms are summarized in **Table 4.10** below. A default emissions factor of 15 % was used by referring to the global sub-application experience. In addition, the growth rate of 8% in new equipment sales was used considering the annual economic growth rate of Rwanda of more than 8% since 2012.

Table 4.11 Imported amount of ODS alternatives for refrigeration and stationary air-conditioning

Year	2012	2013	2014	2015	2016	2017	2018
HFC-125	364.76	700.01	894.27	1121.05	2157.17	2496.58	1747.32
HFC-143a	419.1	681.46	733.24	893.7	1453.36	1525.64	1640.56
HFC-134a	2576.33	3924.84	5588.82	6793.73	1062.32	643.4	548.84
HFC-32	8.97	118.87	266.65	356.74	858.35	1138.38	296.48

Source: Adapted from REMA (2016) and REMA (2020)

Considering that Halon 1301 production was banned in January 1994, it was assumed that its alternatives HFC-125, HFC 143a, and HFC 32 were introduced in the following year 1995; a similar approach was used by (Olivier & Bakker, 2000). In Rwanda, old refrigeration and stationary air-conditioning are not destroyed but useful materials are being recycled while the rest is stored or landfilled. Thus, the percentage of destroyed HCFs for RAC was kept at zero. In addition, 15 years for the lifetime years of the RAC equipment were considered based on the local experience and the IPCC default value. In addition, **Table 4.12** provides the used global warming potential (GWP) of the second assessment report.

Table 4.12 Category and GWP conversion factor used

Categories	HFC-32	HFC-125	HFC-134a	HFC-143a
GWPs	650	2800	1300	3800

Source: SAR, (IPCC 2006, 2006)

4.6.7.4 Uncertainty and time series consistency

The uncertainty from refrigeration and air-conditioning (RAC) may arise from the completeness of the chemical import where for instance interpolations from the existing data were used for the period 2006-2011 and 2016-2018. In addition, it was, however, tricky to distinguish the application at each sub-application level (e.g., type of refrigerator and the HFC consumed), thus there is the uncertainty arising from the use of composite emission factors. In addition, a similar methodology has been used to estimate emissions from the different HFCs by considering the import data and the general RAC application level. Therefore, the following uncertainty ranges were considered during this study:

- Activity data uncertainties: ±10%
- Emission factor uncertainties: ±20%

4.6.7.5 Quality assurance and Quality control

A discussion was conducted, in September 2020 during the validation workshop of the study on Ozone Depleting Substances alternative survey report in Rwanda, with the consultant conducting the later study to check the consistency of the total HFCs annual consumption figures. The survey data were later validated and used for GHG inventory.

4.6.8 Mobile air conditioning (2.F.1b)

4.6.8.1 Source category description

The mobile air conditioning (MAC) sub-category includes MAC systems used to cool land transport systems (e.g., vehicles, vans/trucks, lorries such as 18-wheel trucks, buses, agricultural vehicles, and trains). The phase-out of ODS to HFCs in MACs happened earlier and more quickly than other Sub-Applications, such as residential (stationary) air conditioning and commercial refrigeration (supermarkets), which still rely substantially on ODSs. According to IPCC 2006 guidelines, the MACs produced since the mid- to late-1990s use HFC-134a as the refrigerant. However, CFC-12 is still used in some operating systems. Furthermore, for the future other refrigerants such as HFC-152a and R-744 (carbon dioxide) is being considered. In Rwanda, the survey for the MAC sector has recorded the uses of HFC134a and R-404a and it concerns mainly cars, small vans, and large vehicles (REMA, 2016). It should be noted that the HFC blend R-404a is constituted by a mixture of three chemicals HFC-125, HFC-143a, and HFC-134a with the respective percentage of 44.0%, 52.0%, and 4.0%.

4.6.8.2 Overview of shares and trends in emissions

Table 4.13 shows a continuous increase in GHG emissions from mobile air conditioning for the period 2006-2018. It should be noted that the HFCs emissions for the period 2012 to 2016 were increasing at an annual growth rate of 9%. The growing HFCs emission in mobile air conditioning can also be linked to the growing number of imported cars and small vans. The declining total HFCs' total emissions from 2016 to 2018 are due to the interpolated data, which should be revised upon the acquisition of the real data. The 2020 survey of ODS and its alternative did not consider the MAC data.

Table 4.13 Subcategories emission contribution from Mobile Air Conditioning, CO_2 eq.

	HFC-125	HFC-143a	HFC-134a	Total
2006	0.008	0.017	0.016	0.041
2007	0.016	0.032	0.031	0.078
2008	0.022	0.044	0.048	0.113
2009	0.027	0.054	0.066	0.147
2010	0.031	0.063	0.085	0.180
2011	0.035	0.071	0.106	0.211
2012	0.038	0.077	0.129	0.244
2013	0.041	0.077	0.148	0.266
2014	0.043	0.083	0.173	0.299
2015	0.041	0.082	0.188	0.310
2016	0.035	0.075	0.191	0.301
2017	0.030	0.064	0.184	0.277
2018	0.025	0.054	0.168	0.247

Source: Adapted from REMA (2016), Interpolation Gamlen model/IPCC 2006

4.6.8.3 Methodology, choice of activity data, and emission factors

The computation of emissions from MAC was based on the imported quantities of HFC-134a and R-404a for the period 2012-2015. Similar to the RAC, the methodology used for the MAC survey has followed the UNEP format for preparation of the Surveys of ODS alternatives and presentation of the resulting data (DECISION 74/53(g)) of November 2015 (REMA, 2016). It should be noted that the ODS supply chain in Rwanda for MAC refers to the imported vehicles and imported HFCs and HFCs blends for servicing. Hence, the Tier 2a methodology was used by considering the typical refrigerant charged and the 15 years' equipment lifetime per MAC. In addition, the emission factor of 15% for a refrigerant was set as representing the emissions at the operation, during servicing, and at the end of life. On the other hand, for the period 2006-2011 and 2016 to 2018, the interpolation and extrapolation method by Gamlen model / IPCC 2006 of the imported HFCs was used due to the lack of data in that period. It is not clear from the 2020 survey in REMA on the ODS alternative if the MAC data were included in the Refrigeration and Stationary Air Conditioning. However, according to the discussion held with the inventory team, MAC was not considered in that survey. **Table 4.14** shows the imported quantities of different HFCs used for MAC in kilograms.

Table 4.14 Imported amount of ODS alternatives for mobile air-conditioning

Period Year	HFCs quantity in MAC (Kg)		
	HFC-125	HFC-143a	HFC-134a
2012	22.0	26.0	202.0

Period Year	HFCs quantity in MAC (Kg)		
	HFC-125	HFC-143a	HFC-134a
2013	17.6	20.8	201.6
2014	24.2	28.6	242.2
2015	13.2	15.6	206.2
2016	9.0	10.0	160.0
2017	4.0	5.0	110.0
2018	2.0	2.0	60.0

Source: Adapted from REMA (2016), Interpolation Gamlen model / IPCC 2006

4.6.8.4 Uncertainty and time-series consistency

Uncertainties in mobile air conditioning (MAC) could be linked to the emission factor used where the factor applies to different operating conditions of the MAC. In addition, the interpolations used from the existing data for the period 2016-2018 could be a source of high uncertainties for that phase. It should be noted that the same method was kept to assess the emissions from the different HFCs by considering the chemical import data. For those reasons, the following uncertainty ranges were considered during this study:

- Activity data uncertainties: ±10%
- Emission factor uncertainties: ±20%

4.6.8.5 Quality assurance and Quality control

A discussion was conducted, in September 2020 during the validation workshop of the study on Ozone Depleting Substances alternative survey report in Rwanda, with the consultant conducting the later study to check the consistency of the total HFCs annual consumption figures. The survey data were later validated and used for GHG inventory. With the support of an international consultant, further QA was conducted.

4.6.9 Product Uses as Substitutes for ODS emissions recalculations

There was no emissions recalculation from the Product Uses as Substitutes for Ozone Depleting Substances subcategories.

4.6.10 Source specific planned improvements

The undergoing improvement in this sector is related to the ongoing survey that the government through REMA has initiated to record of import and use of ODS alternatives from 2016 to date, which will mainly benefit the accuracy in data correction for F-gases. Further improvement can be made through surveys on the different uses of paraffin wax at the national level. In addition, a survey at Rwanda Energy Group is needed to provide detailed information on the consumption of Sulphur hexafluoride (SF_6) used in electrical equipment as gas-insulated switchgear and substations, and gas circuit breakers. Several data from the imported materials or products such as the use of soda ash, type of imported circuit breakers can be easily retrieved at RRA if previously included in the list of data that should be regularly shared for GHGs inventory.

Chapter 5. Agriculture, Forestry and Other Land Use

5.1 Overview of Agriculture, Forestry and Other Land Use

The emissions from different source categories and sub-categories of the AFOLU sector were estimated for 2016-2018 and revised for the period 2006-2015 using the 2006 IPCC guidelines with the IPCC Inventory software version 2.691 (released on 23 January 2020). The categories/subcategories considered in the AFOLU sector and the corresponding methods are summarized in **Table 5.1**.

Table 5.1 Overview of the categories and methods applied in the AFOLU sector

2006 IPCC Categories	Gas	2018 emissions/removals (Gg CO_2 eq.)	Contribution to total AFOLU	Key categories	Uncertainty (%)	Methods
3 - AFOLU						
3.A.1 - Enteric Fermentation	CH_4	3196.97	-405.70	□	22.91	Tier 1 & 2
3.A.2 - Manure Management	CH_4	80.69	-10.24	□	26.46	Tier 1
3.A.2 - Manure Management	N_2O	54.61	-6.93		33.17	Tier 1
3.B.1.a - Forest land Remaining Forest land	CO_2	-6975.03	885.14		14.14	Tier 1
3.B.1.b - Land Converted to Forest land	CO_2	-115.72	14.69		20.00	Tier 1
3.B.2.a - Cropland Remaining Cropland	CO_2	671.04	-85.16	□	14.14	Tier 1
3.B.2.b - Land Converted to Cropland	CO_2	938.53	-119.10	□	20.00	Tier 1
3.B.3.b - Land Converted to Grassland	CO_2	170.98	-21.70	□	20.00	Tier 1
3.B.4.a.i - Peatlands remaining peatlands	CO_2	11.48	-1.46		22.36	Tier 1
3.B.4.a.i - Peatlands remaining peatlands	N_2O	0.18	-0.02		20.00	Tier 1
3.B.5.b - Land Converted to Settlements	CO_2	266.27	-33.79	□	24.49	Tier 1
3.B.6.b - Land Converted to Other land	CO_2	2.06	-0.26		24.49	Tier 1
3.C.1 - Emissions from biomass burning	CH_4	31.70	-4.02		14.14	Tier 1
3.C.1 - Emissions from biomass burning	N_2O	42.73	-5.42		10.00	Tier 1
3.C.2 - Liming	CO_2	8.66	-1.10		18.03	Tier 1
3.C.3 - Urea application	CO_2	7.02	-0.89		14.14	Tier 1
3.C.4 - Direct N_2O Emissions from managed soils	N_2O	405.92	-51.51	□	14.14	Tier 1
3.C.5 - Indirect N_2O Emissions from managed soils	N_2O	64.38	-8.17		14.14	Tier 1
3.C.6 - Indirect N_2O Emissions from manure management	N_2O	68.79	-8.73		14.14	Tier 1
3.C.7 - Rice cultivation	CH_4	280.74	-35.63	□	14.14	Tier 1

The categories and the methods were chosen based on the context of the country, the availability of data, and their disaggregation level. It should be noted that, in general, the whole AFOLU sector needs improvement from activity data to emission factors. Land use and disaggregated Land Use change data remain the greatest challenge in adequately estimating trends in GHG emissions and removals. A more complete database should be built for livestock populations by type and their characterizations, including mass (live weight), feeding habits, and other factors related to GHG emissions such as N excretion and N fraction managed in different manure management systems. The same applies to the forestry sector where the data on all carbon pools, such as expansion factors and emission factors (EFs), have to be validated to reflect national values. Land use and Land Use change matrix going below the level of the district could facilitate the certainty of the Land Use Change detailed data. More detailed statistics on peatlands area (i.e., cultivated peatlands and peatland used for peat extraction), area of wetland crops on mineral soil, and lime application are needed to improve the agriculture subsector methodology. Fertilizer quantities used by the crop and burning on agricultural land data are also needed to complete the minimum activity data collection set.

5.2 Trends of GHG emissions and removals from the AFOLU sector

5.2.1 Trends and shares of GHG emissions and removals per category

The summary of GHG emissions and removals per category is presented in **Table 5.2**. As it could be seen from the table, the total removals remained on top for the whole period 2006-2018. The highest GHG emissions were recorded in agriculture and enteric fermentation while the other land subsector had a minute contribution to the total GHG emissions and removals. However, these GHG emissions were offset by the removals from forestry and the AFOLU sector was a net sink throughout the whole period 2006-2018. As seen from **Figure 5.1**, the total GHG emissions were characterized by fluctuations due to the changes in the agriculture subcategory whereas the removals from forestry and other woody biomass stocks showed an increasing trend over the period 2006-2018.

Table 5.2 Summary of direct GHG emissions and removals from AFOLU sector, $GgCO_2$eq. (2006-2018)

Period	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
Total	**-564.21**	**-219.12**	**-185.82**	**-88.05**	**-57.51**	**-634.90**	**-676.79**	**-837.15**	**-744.93**	**-407.58**	**-834.38**	**-743.42**	**-788.01**
3.A	**2529.90**	**2786.44**	**2923.47**	**3040.66**	**3299.91**	**2950.86**	**2941.34**	**2957.38**	**2961.94**	**3306.32**	**3047.22**	**3123.92**	**3332.27**
3.A.1	2450.56	2695.37	2827.73	2939.95	3191.28	2848.87	2832.72	2847.82	2852.91	3197.07	2917.93	2991.31	3196.97
3.A.2	79.34	91.08	95.74	100.71	108.63	101.98	108.62	109.56	109.02	109.25	129.29	132.61	135.30
3.B	**-3684.62**	**-3657.06**	**-3829.44**	**-3916.39**	**-4035.57**	**-4265.41**	**-4309.70**	**-4542.12**	**-4525.32**	**-4590.47**	**-4761.15**	**-4752.40**	**-5030.22**
3.B.1	-5415.96	-5569.15	-5725.90	-5854.29	-5994.21	-6139.53	-6283.44	-6451.03	-6522.10	-6663.47	-6833.67	-6895.67	-7090.75
3.B.2	1296.01	1367.32	1339.39	1552.00	1575.43	1520.35	1508.10	1567.08	1596.54	1568.78	1595.91	1670.92	1609.57
3.B.3	197.19	283.79	224.12	228.97	199.61	189.99	200.34	182.14	197.14	224.97	199.52	223.10	170.98
3.B.4	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18	11.06	13.55	11.65
3.B.5	235.91	258.75	331.94	154.69	182.45	161.53	264.29	157.45	200.86	277.02	264.00	234.95	266.27
3.B.6	2.05	2.05	0.84	2.06	0.97	2.06	0.84	2.06	2.06	2.06	2.03	0.75	2.06
3.C	**590.50**	**651.50**	**720.14**	**787.68**	**678.16**	**679.66**	**691.57**	**747.59**	**818.45**	**876.57**	**879.55**	**885.07**	**909.94**
3.C.1	NO	NO	NO	NO	NO	NO	NO	76.41	150.06	153.50	80.77	76.41	74.43
3.C.2	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	8.37	10.72	8.66
3.C.3	1.55	2.17	1.86	3.98	2.40	3.64	5.96	8.49	2.21	7.74	4.75	2.78	7.02
3.C.4	293.85	314.00	322.94	356.02	355.54	342.14	381.47	368.36	354.23	377.33	377.27	378.59	405.92
3.C.5	33.61	38.06	39.58	49.55	45.20	47.84	71.44	57.03	52.12	52.07	61.62	62.09	64.38
3.C.6	49.07	54.35	56.99	59.71	64.96	58.97	60.96	61.38	61.68	65.84	68.07	69.32	68.79
3.C.7	212.42	242.92	298.77	318.42	210.07	227.07	171.74	175.91	198.16	220.10	278.70	285.15	280.74
3.C.8	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
3.D	**NE**	**NE**	**NE**	**NE**	**NE**	**NE**	**NE**	**NE**	**NE**	**NE**	**NE**	**NE**	**NE**
3.D.1	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE
3.D.2	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO

3.A - Livestock 3.A.1 - Enteric Fermentation 3.A.2 - Manure Management 3.B - Land 3.B.1 - Forest land 3.B.2 - Cropland 3.B.3 - Grassland 3.B.4 - Wetlands 3.B.5 - Settlements 3.B.6 - Other Land3.C - Aggregate sources and non-CO_2 emissions sources on land 3.C.1 - Emissions from biomass burning 3.C.2 – Liming 3.C.3 - Urea application 3.C.4 - Direct N_2O Emissions from managed soils 3.C.5 - Indirect N_2O Emissions from managed soils 3.C.6 - Indirect N_2O Emissions from manure management 3.C.7 - Rice cultivation 3.C.8 - Other (please specify) 3.D - Other 3.D.1 - Harvested Wood Products 3.D.2 - Other (please specify), NE: Not Estimated, NO: Not Occurring,

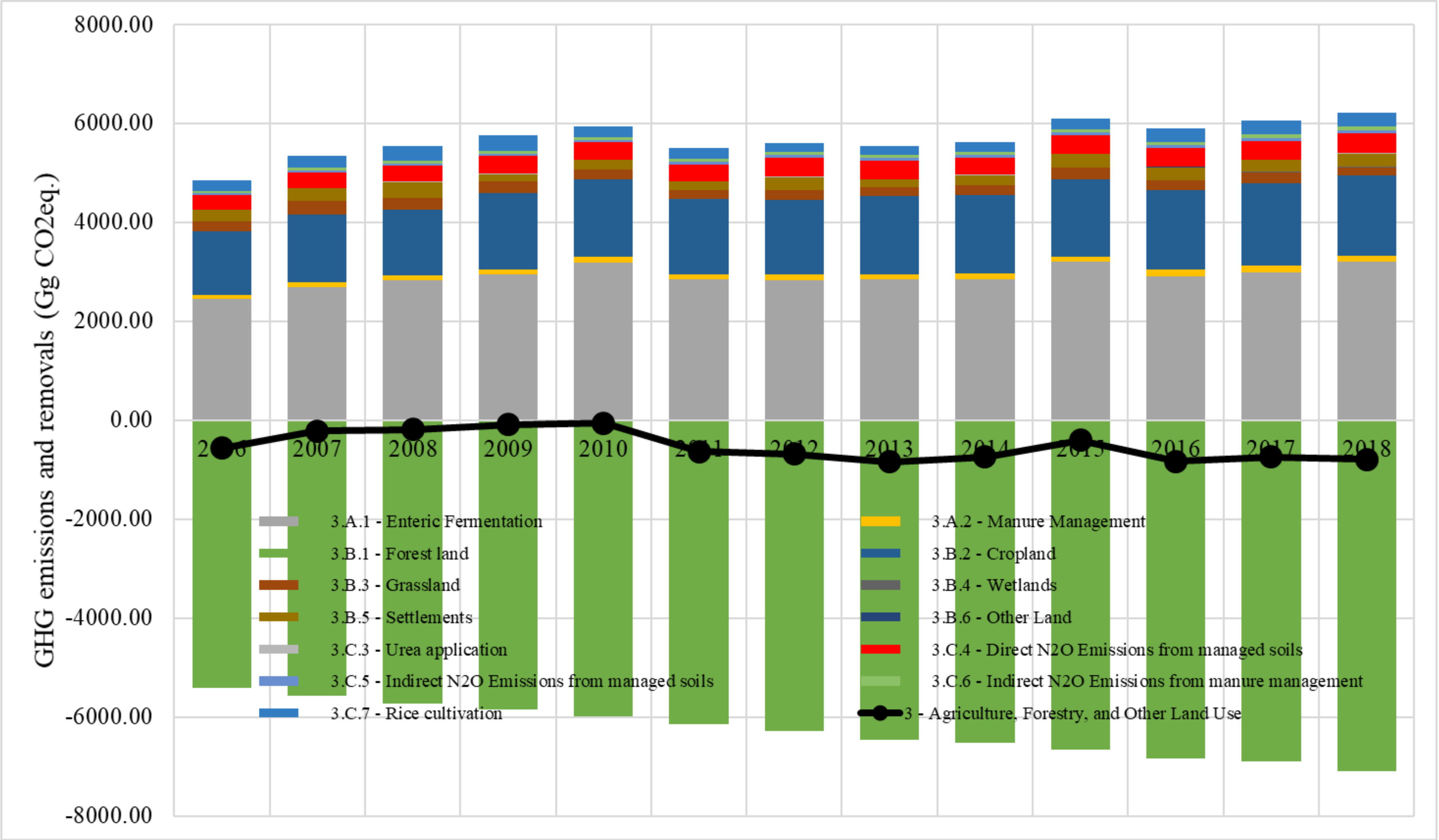


Figure 5.1 Trend in direct GHG emissions from AFOLU

5.2.2 Trends of GHG emissions and removals per gas

The trends and shares in GHG emissions and removals from AFOLU were analysed on a per-gas basis. **Figure 5.2** shows the shares and trends in GHG emissions from AFOLU per gas. While the CO_2 emissions removal was characterized by a steadily increasing trend, the CH and N_2O show slight fluctuations.

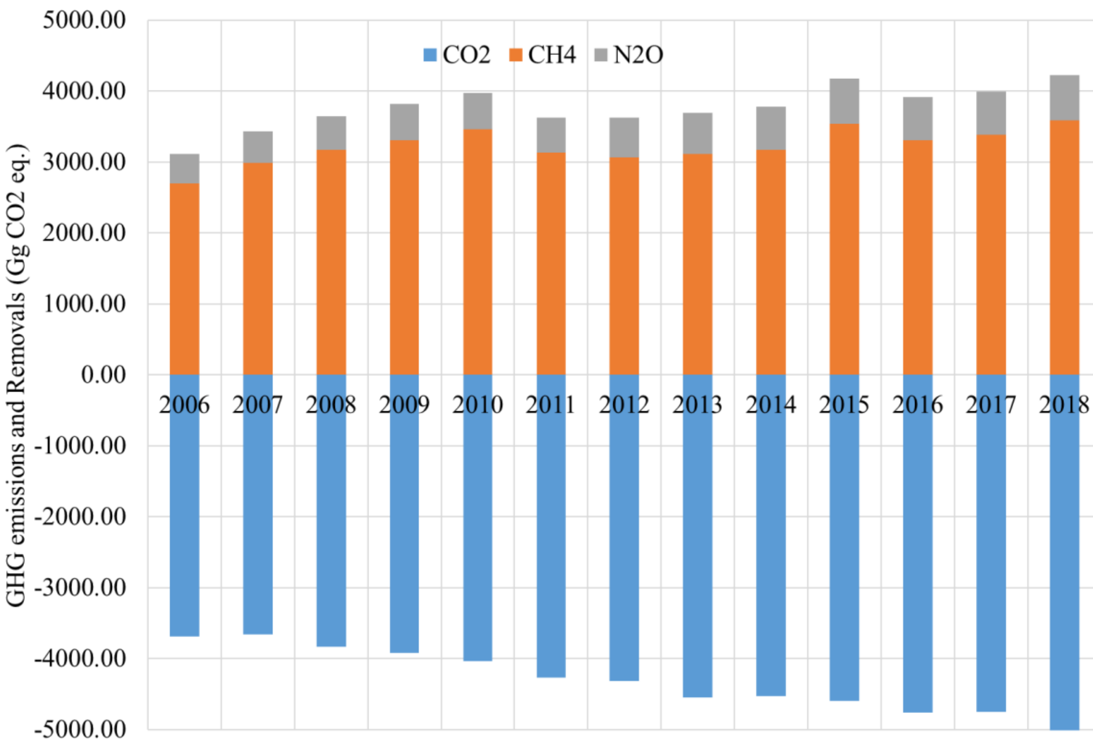


Figure 5.2 Shares and trends in GHG emissions and removals from AFOLU per gas

The analysis of GHG emissions and removals shares shows that the CO_2 removals were higher than the CO_2, CH_4, and N_2O emissions, which resulted in overall sequestration from the AFOLU sector. In addition, it is clear from the figure that CH_4 emissions were higher than N_2O emissions throughout the whole period. This share in CH_4 and N_2O emissions is obvious since only two key categories emitting N_2O appeared among the nine key categories identified in the AFOLU sector (**Table 5.1**).

5.3 Uncertainties

Uncertainty analysis identified uncertainty related to Activity data and Emission factors. The uncertainty for activity data was estimated at 10% for Enteric Fermentation from Livestock (3.A.1); Manure Management (3.A.2), and Agriculture emissions (biomass burning (3.C.1), Urea Application (3.C.3), direct N_2O emissions from Managed Soil (3.C.4), indirect N_2O emissions from Managed Soil (3.C.5), indirect N_2O emissions from Manure Management (3.C.6) and Rice

Cultivation (3.C.7). Activity data from Land Use and Land Use Change (3B sub-categories) and Liming (3.C.2) had higher uncertainty of 30%, while peatlands remaining peatlands and peatlands converted for peat extraction had the highest uncertainty of 50%, respectively. The uncertainty related to Emission factors was estimated at 10% for all sub-categories. All uncertainty values are based on expert judgment.

5.4 Quality assurance, quality control, and verification

The activity data were gathered from the official agriculture statistics via published national documents such as the Seasonal Agricultural Survey of NISR, and from recent surveys. All the data appearing in these official documents were further crosschecked with relevant institutions working in their respective sectors. Specific and relevant data were also obtained from research work published locally and in international journals as well as annual and technical reports from the different research institutions.

All the data used were reviewed during peer review meetings with stakeholders and research staff. The inventory team performed Quality Control procedures. Any significant change in emission within a specific category was questioned and activity data was checked. All calculations made during the exercise used approved procedures for emissions calculations, measurements, and documentations as per IPCC guidelines. Furthermore, the inventory process was carried out under close supervision of REMA to ensure compliance with IPCC guidelines.

5.5 GHG emissions and removals recalculations

The results of the recalculations conducted in the AFOLU sector are presented in **Table 5.3**. As it could be seen from the table, the recalculations resulted in higher emissions/removals compared to the previous inventory. The major improvements in the reported emissions in this inventory include the following:

(i) The addition of land use data derived from the Land Use class area per district by comparing the maps of 2000 and 2019.

(ii) Inclusion of the newest study on forest cover, which updated the current forest area and uncovered deforestation extent.

(iii) New, corrected calculation of emissions from urea application and its subsequent corrections for the TNC period (2006-2015, urea data in kg were counted in tonnes).

(iv) Use of Tier 2 for dairy cattle using the recently measured data on mean live weight and adjustment of default value for local African cows from 275kg to locally measured values for Rwandan dairy cows, which are mostly cross bred (60% of the female population) to 385.4 kg, which significantly increased emissions from enteric fermentation;

(v) Use of updated manure management systems from BUR surveys in AFOLU (REMA, 2019).

(vi) Females, males, and heifers of Dairy cows were counted under the “Dairy cattle” category in one sheet in the new version of the software (IPCC, 2020), and not under the “other cattle” category as it was done in TNC.

(vii) Inclusion of emissions from rabbits’ enteric fermentation with default emission factor available in the new version of the IPCC software (released in January 2020) and not included in the previous version of the IPCC software.

Table 5.3 Results of GHG emissions and removals recalculations

Year	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
	Enteric fermentation (3.A.1)									
Previous data (PD)	979.55	1,116.74	1,181.37	1,213.23	1,303.64	1,207.01	1,173.80	1,174.16	1,147.18	1,283.75
Latest Data (LD)	2,450.56	2,695.37	2,827.73	2,939.95	3,191.28	2,848.87	2,832.72	2,847.82	2,852.91	3,197.07
% change	150	141	139	142	145	136	141	143	149	149
	Manure management systems (3.A.2)									
PD	488.53	524.05	613.31	653.29	690.66	692.42	702.49	698.53	676.56	672.99
LD	79.35	91.07	95.75	100.71	108.62	101.98	108.62	109.57	109.03	109.25
% change	84	83	84	85	84	85	85	84	84	84
	Forestland (3.B.1)									
PD	-10,728.64	-10,798.32	-10,868.49	-10,938.82	-10,969.46	-11,101.13	-11,219.13	-11,255.49	-11,317.96	-11,359.85
LD	-5,415.96	-5,569.50	-5,725.90	-5,854.29	-5,994.21	-6,139.53	-6,283.44	-6,451.03	-6,522.10	-6,663.47
% change	53.10	52.30	51.40	50.80	49.80	49.60	49.40	48.00	47.80	47.00
	Urea (3.C.3)									
PD	3,858.88	4,014.94	4,171.01	4,375.39	5,359.86	6,344.32	5,694.18	6,610.53	7,526.87	8,443.21
LD	1.55	2.17	1.86	3.98	2.40	3.64	5.96	8.49	2.21	7.74
% change	-99.96	-99.95	-99.96	-99.91	-99.96	-99.94	-99.90	-99.87	-99.97	-99.91
	Direct emissions from managed soils (3.C.4)									
PD	381.15	403.39	511.36	594.85	629.14	662.27	565.77	522.11	478.64	551.15
LD	293.85	314.00	322.94	356.02	355.54	342.15	381.47	368.36	354.23	377.33
% change	-22.9	-22.2	-36.8	-40.1	-43.5	-48.3	-32.6	-29.4	-26	-31.5
	Indirect emissions from managed soils (3.C.5)									
PD	132.28	140.43	175.31	201.78	212.08	222.46	196.57	185.07	170.12	191.03
LD	78.89	87.09	90.65	101.64	102.25	96.71	119.97	105.42	101.02	109.77
% change	-40.4	-38	-48.3	-49.6	-51.8	-56.5	-39	-43	-40.6	-42.5
	Indirect emissions from manure management (3.C.6)									
PD	108.02	119.03	129.99	136.87	147.58	138.49	145.47	146.77	146.08	148.18
LD	49.07	54.35	56.99	59.71	64.96	58.97	60.96	61.38	61.68	65.84
% change	-54.6	-54.3	-56.2	-56.4	-56	-57.4	-58.1	-58.2	-57.8	-55.6

	Rice cultivation (3.C.7)									
PD	118.54	181.40	166.69	177.66	117.20	130.89	103.11	100.17	90.98	98.33
LD	212.42	242.92	298.77	318.42	210.07	227.07	171.74	175.91	198.16	220.10
% change	79.2	33.9	79.2	79.2	79.2	73.5	66.6	75.6	117.8	123.8

5.6 Source-specific planned improvements

Among the challenges encountered during the GHG inventory, the major ones were summarized in **Table 5.4**. Specific planned improvements for each sub-sector in AFOLU have been proposed in corresponding sections. In general, the whole AFOLU sector needs improvement in the collection of activity data, especially those mentioned under challenges and emission factors. The activity data requiring improvement concern: Land Use and Land Use Change, and their disaggregation up to sector level, while the use of remote-sensing and regular data collection with assistance from REMA and partners such as RAB, RLMUA, NISR, and RFA. Other improvements should address the challenges mentioned above to improve activity data collection and make them more relevant for the inventory of GHG emissions.

Research institutions should be encouraged/facilitated to research the existing gaps to develop local emission factors to enable Tier 2 computation of GHG inventory in the future. Future GHG emissions inventories can also be improved by providing further capacity building to the inventory team. All source categories and their sub-categories will need to be documented and integrated into the inventory in the AFOLU sector.

Table 5.4 Challenges and planned improvements

Category	Sub-category	Challenge	Planned improvement
General		Insufficient capacity to conduct higher tier inventories and insufficient research on local emission factors to address the gaps mentioned below	Further capacity building to the inventory team.
Livestock (3A)	3.A.1 Enteric fermentation	Lack of regular official data for livestock population structure and characteristics – mass, feeding habits, N excretion	A more complete database should be built for livestock populations by type and their characterizations, including mass, feeding habits and other factors related to GHG emissions such as N excretion and N fraction managed in different manure management systems.
	3.A.2 Manure management systems (MMS)	Lack of information on N fraction in different MMS	Collect information on N fractions managed in different MMS.
		Lack of data on CH_4 emissions from different groups of swine, e.g., breeding swine and other	Conduct research to determine CH_4 emissions from swine
Land (3B)	All	Access to land use maps and staff time;	Plan for GIS staff at REMA and committee harmonizing various GIS data from different institutions
		Inconsistencies between land use classes reported by different public institutions, especially, for Agriculture – the harvested area from all crops exceeds the total area available for Agriculture due to intercropping;	
		Lack of "reference" office for merging all GIS data (ex. NISR oversees statistics but no detailed GIS data is available, which match the reported statistics (i.e., reported area of non-cultivated wetland does not match with the reported rice area and other cropland in wetlands, all together, they exceed the total area of wetlands from land use maps;	
		Difficulty to differentiate maize area from grassland on land use maps;	Use crosscheck with data reported by Districts to MINAGRI to help disaggregation.
Land (3B)	All	Lack of local data on carbon stock and its change with land use for each AE Zone;	Conduct study on carbon stock and its change vs past soil surveys and published information

			analysis for an update of all available information
		Level of data disaggregation (having data at district level leaves to make assumptions/conclusion on Land Use Change extent which is less precise as if it would be if data were at the sector level);	Conduct GIS assessment with disaggregated data up to sector and cell levels. Land use and Land Use Change matrix going below the level of the district could facilitate the certainty of the Land Use Change detailed data.
	3.B.1 Forestland	Lack of National statistics on harvested wood products.	Discuss with NISR to include data on wood harvest into Statistical Yearbook reports (annually)
	3.B.2 Cropland	Lack of data on Agroforestry and carbon removal from agroforestry trees;	Conduct survey to assess wood harvest from agroforestry trees, and GIS analysis to document agroforestry cover via maps, otherwise, available forest survey data.
		Lack of data on soil C stock in different AE Zones and	Conduct an extensive study on C-stock in main cropland sub-categories and its change using available soil map data
	3.B.4 Wetlands	Lack of mapping of peatlands and their proportions used for peat extraction and agricultural use on annual basis;	Conduct surveys to assess the extent of peat extraction and GIS data analysis from available soil data to assess the proportion of peatland and other wetlands under cropland use.
Agriculture (3C)	3.C.1 Biomass burning	Lack of National statistics on fire on land (cropland, forest, grassland)	Discuss with NISR to include data on fires in different Land Use classes into Statistical Yearbook reports (annually)
	3.C.2 Liming	Lack of official statistics on lime production, origin, and types	Discuss with NISR to include data on agricultural and industrial lime production into Statistical Yearbook reports (annually)
	3.C.4 Direct N_2O emission	Lack of measured data on crop residues and manure applied over the whole season and the proportion of crop residues used for livestock feeding and other purposes.	Determine real quantities of crop residues and manure applied over the whole season,

	from managed soils		including not just crop biomass at harvest, but in addition weeds removed
		Lack of local data on N content in crop residues	Determine N content in crop residues and weeds;
		Lack of local data on soil C and N and their dynamics in different Land Use Change patterns	Determine changes in soil N and C after Land Use Change and their dynamics (longer-term research on soil restoration.

5.7 Livestock (3A)

5.7.1 Source category description

Rwanda has important livestock resources represented by dairy cattle, goats, sheep, swine, poultry, and rabbits. Although cattle keeping is a preferred choice for a traditional Rwandan household, small livestock constitutes a more economic and land-size-friendly option for many resource-poor farmers. Livestock keeping in Rwanda today is almost entirely zero-grazing system due to very limited land for grazing and is practiced extensively.

Table 5.5 Livestock population per species in Rwanda, 2006-2018

Year	Dairy cattle	Goats	Sheep	Pigs	Poultry	Rabbits
2006	1,059,000	1,659,000	584,000	427,000	1,913,000	469,000
2007	1,147,000	2,238,000	704,000	571,000	1,868,000	423,000
2008	1,194,895	2,519,803	718,178	586,620	2,217,724	451,396
2009	1,218,518	2,620,595	754,086	639,416	3,272,965	744,972
2010	1,334,820	2,688,273	769,937	684,708	3,537,608	792,895
2011	1,143,231	2,970,780	828,836	706,472	4,420,764	828,836
2012	1,135,141	2,672,751	807,392	989,316	4,687,984	993,685
2013	1,132,000	2,702,000	798,000	1,011,000	4,803,000	1,106,000
2014	1,144,000	2,532,000	631,000	1,015,000	4,917,000	1,203,000
2015	1,349,792	2,532,277	630,860	716,629	3,890,274	828,802
2016	1,149,749	2,605,780	637,068	1,684,709	5,238,497	1,387,669
2017	1,165,835	2,923,706	664,703	1,716,438	5,272,725	1,347,860
2018	1,293,768	2,731,795	601,836	1,330,461	5,442,152	1,264,734

Source: RAB (unpublished, for 2006-2015 data); RAB Annual report 2018-2019 (for 2016-2018 data).

The current policy aims to encourage and diversify the development of small stock, which could fit into the existing niches supplementing the production of meat, eggs, and milk and thus contributing to the reduction of protein deficit in diets. Although milk production is the main goal for cattle production in Rwanda as a source of important nutrients for the human being, farmyard was given much importance especially for poor soils, which need organic manure. In that regard, the government of Rwanda (GoR) has promoted a Livestock Intensification Program (LIP), which includes the Girinka program (one cow per poor household), and promotion of poultry and other small stock animals. Among major types of livestock, poultry, goats and dairy cattle are the most abundant (**Table 5.5**).

The main sources of GHG emissions in livestock are enteric fermentation and manure management. Different livestock species have different types of the digestive system: ruminant and monogastric. Ruminant livestock (Cattle, Sheep, Goat) generate significant quantities of methane in their digestive system, while monogastric livestock species (Poultry - Chickens, Ducks

& Turkeys - and swine) generate much less of this gas. Another source of GHG emissions is nitrous oxide (N_2O), which is generated in variable quantities from manure, depending on livestock species, feeding regimes, and the existing manure management systems. The emissions of N_2O are reported under the Livestock section for manure remaining on-farm before reaching the field or used for other purposes. Therefore, the assessment of GHG emissions focused on determining the quantities of methane from enteric fermentation and methane and nitrous oxide from manure stored in a kraal.

5.7.1.1 Enteric fermentation (3.A.1)

Methane is released in the process of enteric fermentation during digestion, by which carbohydrates are broken down by microorganisms into simple molecules for absorption into the bloodstream (IPCC 2006, 2006). The amount of methane released depends on the type, weight, and age of the animal, as well as the quality and quantity of the feed consumed. Ruminant livestock (e.g., cattle, sheep) release more methane than non-ruminant livestock (e.g., pigs).

The type of digestive system has a significant influence on the rate of methane emission. Ruminant livestock has an expansive chamber, the rumen, at the forepart of their digestive tract that supports intensive microbial fermentation of their diet, which yields several nutritional advantages including the capacity to digest cellulose in their diet. In Rwanda, the main ruminant livestock is cattle, goats, and sheep. Mono-gastric livestock (swine) have relatively lower methane emissions because much less methane-producing fermentation takes place in their digestive systems.

5.7.1.2 Manure management (Section 3.A.2)

The more livestock is shifted to a zero-grazing system, the more manure is managed in kraals generating various rates of methane and nitrous oxide emissions. A Zero-grazing system was the only way for livestock expansion to meet from one side, human nutrition requirements and increase lipid and protein intake, and on the other side, to increase the availability of livestock manure to maintain soil fertility and address plant nutrition needs under conditions of intensified agricultural production. Keeping cattle in kraal in the main part of the country helps more than 90% of cattle farmers to get manure. Most livestock farmers (59%) keep the manure collected in underground pits, while others (40%) leave the collected manure in upper ground heaps. Most of the farmers keep manure in heaps or pits for one to two months (30%) and 3 to 4 months (32%) before application in cropping fields (Kim et al., 2012). IPCC Guidelines (2006) state that confined animal management operations where manure is handled in liquid-based systems can generate substantial GHG emissions. These gases are methane from anaerobic and nitrous oxide from the open storage of manure on the farm. Manure management systems generate methane from manure storage; therefore, to estimate emissions, total manure quantities were calculated from the number of livestock per category. N excretion rate per head per year used was sourced from the FAO report (FAO, 2018)

5.7.2 Overview of shares and trends in Emissions

5.7.2.1 Trends of GHG emissions from enteric fermentation (3.A.1)

The emissions from enteric fermentation are shown in **Table 5.6**. Dairy cattle were the main contributors to the GHG emissions followed by goats and rabbits. There were no other types of cattle in the country. The peaks of emissions in 2010, 2015, and 2018 coincided with the higher dairy cow population numbers in these years as compared to other years (**Table 5.6**).

Table 5.6 Summary of the CH_4 emissions from enteric fermentation, 2006-2018

Year	Dairy cattle	Sheep	Goats	Swine	Rabbits	CH_4 (Gg CO_2eq.)	Change (%)
2006	2,127.29	61.32	174.20	8.97	78.79	2,450.56	
2007	2,303.40	73.92	234.99	11.99	71.06	2,695.37	10.00
2008	2,399.59	75.41	264.58	12.32	75.84	2,827.73	4.90
2009	2,447.03	79.18	275.16	13.43	125.16	2,939.95	3.90
2010	2,680.58	80.84	282.27	14.38	133.21	3,191.28	8.50
2011	2,295.83	87.03	311.93	14.84	139.24	2,848.87	11.00
2012	2,279.59	84.78	280.64	20.78	166.94	2,832.72	-11.00
2013	2,273.28	83.79	283.71	21.23	185.81	2,847.82	-0.50
2014	2,297.38	66.26	265.86	21.32	202.10	2,852.91	0.50
2015	2,710.65	66.24	265.89	15.05	139.24	3,197.07	0.20
2016	2,308.92	66.89	273.61	35.38	223.13	2,917.93	12.00
2017	2,341.23	69.79	306.99	46.86	226.44	2,991.31	-8.70
2018	2,598.14	63.19	286.84	36.32	212.48	3,196.97	6.90

5.7.2.2 GHG emissions from Manure Management Systems (MMS)

Manure management systems generated methane (CH_4) and nitrous oxide (N_20) (**Table 5.7**). In terms of CO_2eq, methane emissions were higher as compared to N_2O emissions (**Table 5.7**). Recalculations for 2006-2015 resulted in higher emissions than reported for Previous data (Third National Communication, TNC) (**Table 5.7**). This was caused by different proportions of various manure management systems that were reported by BUR 1 surveys report in AFOLU (REMA, 2019a) as compared to expert judgment assessment used for TNC. The peaks of emissions from manure management systems in 2010, 2015, and 2018 were closely related to the increase in the number of dairy cattle for these years (**Table 5.5**).

Table 5.7 GHG emissions from manure management system (2016-2018)

Categories	Dairy cattle	Sheep	Goats	Swine	Rabbits	Poultry	Total (CO_2 eq.)	Change (%)
Period	Emissions of CH_4 (Gg)							
2006	1.059	0.088	0.282	0.427	0.038	0.057	40.971	
2007	1.147	0.106	0.38	0.571	0.034	0.056	48.174	14.95
2008	1.195	0.108	0.428	0.587	0.036	0.067	50.841	19.41
2009	1.219	0.113	0.446	0.639	0.06	0.098	54.075	24.23
2010	1.335	0.115	0.457	0.685	0.063	0.106	57.981	29.34
2011	1.143	0.124	0.505	0.706	0.066	0.133	56.217	27.12
2012	1.135	0.121	0.454	0.989	0.079	0.141	61.299	33.16
2013	1.132	0.12	0.459	1.011	0.088	0.148	62.118	34.04
2014	1.144	0.095	0.43	1.015	0.096	0.117	60.837	32.65
2015	1.35	0.095	0.43	0.717	0.066	0.157	59.115	30.69
2016	1.15	0.096	0.443	1.685	0.111	0.157	76.482	46.43
2017	1.166	0.1	0.497	1.716	0.108	0.158	78.645	47.90
2018	1.294	0.09	0.464	1.73	0.101	0.163	80.682	49.22
Emissions of N_2O (Gg)							Total (CO_2 eq.)	Change (%)
2006	0.102	0.003	0.007	0.01	0.001	0.001	38.44	
2007	0.11	0.003	0.01	0.013	0.001	0.001	42.78	10.14
2008	0.115	0.004	0.011	0.014	0.001	0.001	45.26	15.07
2009	0.117	0.004	0.011	0.015	0.002	0.002	46.81	17.88
2010	0.128	0.004	0.011	0.016	0.003	0.002	50.84	24.39
2011	0.11	0.004	0.013	0.016	0.003	0.002	45.88	16.22
2012	0.109	0.004	0.011	0.023	0.003	0.003	47.43	18.95
2013	0.108	0.004	0.012	0.023	0.004	0.003	47.74	19.48
2014	0.11	0.003	0.011	0.023	0.004	0.003	47.74	19.48
2015	0.129	0.003	0.012	0.016	0.003	0.002	51.15	24.85
2016	0.11	0.003	0.011	0.039	0.004	0.003	52.7	27.06
2017	0.112	0.003	0.012	0.04	0.004	0.003	53.94	28.74
2018	0.124	0.003	0.012	0.031	0.004	0.003	54.87	29.94

5.7.3 Methodological issues

The IPCC methodology (IPCC Guidelines, 2006) was used to estimate GHG emissions resulting from livestock. The main categories for GHG emissions in livestock were CH_4 emissions from livestock, CH_4 and N_2O emissions from manure management. The GHG emissions for enteric fermentation were estimated for 2016-2018 using IPCC Inventory software version 2.691 (*released on 23 January 2020*). Tier 2 was used for dairy cattle and Tier 1 for other categories of livestock. Availability of local data from the BUR survey on agriculture, livestock, and forestry (REMA, 2019) on live weight, daily feed intake, the proportion of lactating cows and mean milk production per cow per day allowed the use of Tier 2 for dairy cattle. However, due to the lack of these data for other livestock types, Tier 1 was used. The CH_4 emissions per livestock category were calculated using the equation 10.19 of the 2006 IPCC guidelines (IPCC 2006, 2006).

Table 5.8 shows the values used to derive emissions from enteric fermentation. No emission factors were used for poultry because fermentation does not occur in their digestive process that could generate CH_4.

Table 5.8 Values used to assess emissions from enteric fermentation

	Default body weight, kg	Local body weight, kg	Local dairy cows milk yield per day, liters	Default CH_4 emission (kg/head per year)	CH_4 emitted /head per year (current inventory)
Dairy cows	275	385.4	4.75	46	95.6
Goats	30	33.3	NE	5	NE
Sheep	28	NA	NE	5	NE
Breeding swine	28	65	NE	1.5	NE
Growing swine	NA	25	NE	1	NE
Mature swine	28	60	NE	1	NE

Bold – used in the current inventory; Default values are from IPCC 2006. Local values are from REMA, 2019a; NA – not available; NE – not estimated.

5.7.3.1 Activity data sources and emission factors

The sources of GHG gases, the kind of data collected, and their sources are summarized in **Table 5.9**. Published data on livestock types and numbers were collected from Rwanda Agriculture and Animal Resource Development Board (RAB). The lactating cow population was considered at 30% of the total cattle population (REMA, 2019). The swine population was subdivided into breeding swine (60%) and growing swine (30%) and adult non-breeding swine (10%) (Manzi, Mutabazi, Hirwa, & Kugonza, 2013).

Table 5.9 Activity data for assessment of the GHG emissions from livestock

Sub-category	Kind of data	Gas	Methodology	Source of data
Enteric fermentation	Annual livestock population per species (Dairy cattle, Other cattle, Sheep, Goat, Swine, Rabbits);	CH_4	Tier 2 /IPCC 2006 for Dairy cattle. Tier 1 for other species	IPCC 2006 guidelines, NISR, FAOSTAT
	The proportion of milking cows per year			REMA, 2019a
	The proportion of young, manure, and breeding swine			RAB swine scientist
	Live weight of cows			REMA
	Live weight of goats			(Manzi et al., 2013)
	Live weight (other livestock)			IPCC
	daily feed intake			REMA surveys
	The proportion of milking cows.			REMA surveys
Manure management	Manure production per livestock species;	CH_4, N_2O	Tier 1/IPCC 2006	REMA surveys
	N excretion rate of manure per livestock species;	N_2O		(FAO, 2018)
	types and proportions of manure management systems per species	CH_4, N_2O		REMA

5.7.3.2 Emission factors

Availability of the recently collected local data on cow live weight, milk yield, and the proportion of cows giving birth each year allowed the use of Tier 2 for dairy cows. This led to higher quantities of methane emitted per year per cow: 95.6 kg CH_4 as compared to the earlier used default factor of 46kg CH_4 per cow (IPCC 2006, 2006). After using the mean weight and milk yield data, the emission factor for dairy cattle was adjusted to 95.6kg of methane per head per year. For other livestock, the default emission factors used were 5 for goats, 5 for sheep, and 1 for swine (IPCC 2006, 2006).

5.7.3.3 Quality assurance and Quality control

The data on livestock populations were taken from RAB annual reports and were crosschecked with districts before publishing. Specific and relevant data were also obtained from research work published locally and in international journals as well as annual and technical reports from the different research institutions. All the data used were further reviewed during peer review meetings with stakeholders.

In case of missing data, expert judgment with research staff working in the respective area was used. The routine quality control procedures included a check for omissions and errors, crosschecking the activity data and obtained emissions check for inconsistencies and their explanation, supervision from REMA, and validation by the stakeholders.

5.7.3.4 Time series

The emission of GHG from enteric fermentation reflected variations in livestock population per species. For instance, the peak of emissions from enteric fermentation was in 2010 when the dairy cattle population reached 1,334,820 cows (with emissions of 3,191.286Gg CO_2e). This number was 116,302 heads higher compared to 2009 statistics and 191,589 heads higher compared to the 2011 cow population (Refer to **Table 5.5** for cow population and **Table 5.6** for emissions from enteric fermentation). However, in general, the emissions from livestock did not vary much between 2016 and 2018.

5.7.4 Recalculations

5.7.4.1 Enteric fermentation

The results of the GHG emission recalculation in enteric fermentation are shown in Recalculations for 2006-2015 showed higher emissions from enteric fermentation than those reported in TNC (**Table 5.10**).

Table 5.10 Enteric fermentation recalculation of emissions for 2006-2015

Gas: CH_4	Emissions and Removals (in Gg CO_2e)									
Year	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**
PD	979.55	1,116.74	1,181.37	1,213.23	1,303.64	1,207.01	1,173.80	1,174.16	1,147.18	1,283.75
LD	2,450.56	2,695.37	2,827.73	2,939.95	3,191.28	2,848.87	2,832.72	2,847.82	2,852.91	3,197.07
Difference	150	141	139	142	145	136	141	143	149	149
Reasons for recalculation	Use of Tier 2 with the local weight of cows (385.4kg) instead of the default (275kg) as used in TNC, modified proportions of milking cows (60% LD instead of 13% of PD), use of milk daily yield data (REMA BUR surveys in AFOLU, 2019a)									

PD: Previous data LD: Latest data

This was because of using updated data on cow weight of 385.4kg instead of the default weight of 275kg, and the use of Tier 2, which included data on milk production and feed ratio as well as the updated proportion of milking cows' value of 60% instead of 13% used in the previous GHG inventory.

5.7.4.2 Manure management

The recalculations for 2006-2015 showed a 79 to 109% decrease in manure management emissions (**Table 5.7**). This was related to the use of default N excretion rates in the previous inventory. In the current inventory, thanks to the availability of a new dataset from FAO (FAO, 2018) recalculations were conducted.

Figure 5.3 Manure management recalculation of emissions for 2006-2015

Emissions and Removals (in Gg CO_2e)										
Year	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**
PD	488.5	524.05	613.31	653.29	690.66	692.42	702.49	698.53	676.56	672.99
LD	79.35	91.07	95.75	100.71	108.62	101.98	108.62	109.57	109.03	109.25
Difference (%)	84	83	84	85	84	85	85	84	84	84
Reasons for re-calculation: New data on N excretion rate per livestock species have become available (FAO, 2018) and they are much lower than the default values used in TNC. This led to much lower values in Manure management emissions after recalculation.										

5.7.5 Source-specific planned improvement

Due to the lack of all data needed and the availability of published information, some expert judgment was used. For improvement of future inventories, improve quality control, and reduce uncertainty, the following information should be searched for Rwandan conditions (**Table 5.11**):

Table 5.11 Planned improvement for GHG emission assessment in livestock

Sub-category	Planned improvement	Priority	Suggested responsible entity	Funding
3.A.1 Enteric fermentation	Introduce reporting on population structure per livestock species and proportions, particularly, proportions of lactating females and young animals per year	High	Districts, RAB	GoR/RAB budget
	Daily feed intake for all livestock,	High	RAB	REMA
	Ash content of manure for swine and goats	High	RAB/REMA	REMA
	Live weight for all livestock species and population sub-categories	High	RAB/REMA	REMA
3.A.2 Manure management	N excretion content in manure for all livestock categories	High	RAB/REMA	REMA
	Fraction of Nitrogen loss in different manure management systems and	Medium	RAB	REMA

	Proportions of different manure management systems for non-cattle livestock categories, including estimates of population share for commercial and traditional chicken keeping	Medium	REMA	REMA

5.8 Land (3B)

5.8.1 Source category description

Following the IPCC methodology, the major land use classes used in this GHG inventory report are Forestland, Cropland, Grassland, Wetland, Settlements, and Other Land (Table 5.12). Cropland, Grassland, Wetland, Settlement, and Other Land are considered as non-forest land because of the absence of trees or their presence in much lower densities than in forests or woodlots: with canopy cover less than 10% and patches of less than 0.25 ha. Water bodies occupy 152,304.8 ha and were excluded in this inventory, while natural forests and Eastern Savannah which are under National parks were considered under respective Land Use class (Forestland or Grassland). The territories of the National Parks of Akagera, Nyungwe Forest, and Volcano are largely unmanaged. However, in Akagera National park, some areas of Savannah undergo planned burning on areas between 25 and 40% since 2013, when Park management was given to a private conservation company.

Table 5.12 Change in land use classes in Rwanda, 2006-2018

	Forestland	Cropland	Grassland	Other Land	Settlement	Wetland	Total
Year	Area (ha)						
2006	664,217.25	1,246,525.35	344,479.60	2,867.20	27,334.50	138,535.60	2,423,959.5
2007	668,867.00	1,248,665.40	335,603.40	2,687.40	29,600.70	138,535.60	2,423,959.5
2008	673,516.75	1,250,805.45	326,727.20	2,507.60	31,866.90	138,535.60	2,423,959.5
2009	678,166.50	1,252,945.50	317,851.00	2,327.80	34,133.10	138,535.60	2,423,959.5
2010	682,816.25	1,255,085.25	308,974.80	2,148.30	36,399.30	138,535.60	2,423,959.5
2011	687,466.00	1,257,235.30	300,098.60	1,968.50	38,655.50	138,535.60	2,423,959.5
2012	692,115.75	1,259,365.35	291,222.40	1,788.70	40,931.70	138,535.60	2,423,959.5
2013	696,765.50	1,261,505.40	282,346.20	1,608.90	43,197.90	138,535.60	2,423,959.5
2014	701,415.25	1,264,546.05	273,470.00	1,429.10	45,464.10	138,535.60	2,423,959.5
2015	706,065.00	1,265,685.50	264,593.80	1,249.30	47,830.30	138,535.60	2,423,959.5
2016	710,714.75	1,267,825.55	255,717.60	1,069.50	50,096.50	138,535.60	2,423,959.5
2017	715,364.50	1,269,965.60	246,841.40	889.70	52,362.70	138,535.60	2,423,959.5
2018	720,014.25	1,272,105.65	237,965.20	709.90	54,628.90	138,535.60	2,423,959.5
2019	724,664.00	1,274,245.75	229,089.00	530.10	56,895.10	138,535.60	2,423,959.5

Source: Land use map 2000; 2007 (CGIS-NUR/PAREF/RNRA, 2012); 2019 (RAB, RLMUA data, 2020)

5.8.1.1 Forestland

Because of several direct and indirect drivers of deforestation such as population pressure, agriculture and livestock, poverty, infrastructure, and others, the forest resources in Rwanda have been declining over the years. Natural forest areas declined by 65% during the period from 1960 to 2007 (ROR, 2010). In a bid to restrict anthropogenic activities responsible for deforestation, most of the remaining natural forests in the country are now protected either as national parks or as forest reserves. Major natural forests include Nyungwe National Park, Gishwati-Mukura National Park, Volcanoes National Park, and Akagera National Park. Other remnant natural forests include gallery forests in the Eastern province and several tiny forest reserves such as Busaga in Muhanga district, Kibirizi in Nyanza district, and Sanza in Ngororero district.

The first forest cover map in Rwanda was prepared in 2007 using medium-resolution images (Aster, Landsat, and Spot images). Forests were defined as patches of 0.5 ha with a tree canopy cover of 10% or more. The trees were defined as woody plants of 5 m. The second forest cover mapping was carried out in 2012 using very high-resolution orthophotos (25 cm) taken in 2008 and 2009 (99% of the country) and QuickBird images covering part in the southwest of Rwanda (1%). This forest mapping exercise used similar definitions with the mapping of 2007; however, the minimum area mapped was increased to 0.25 ha. The third forest cover map was produced in 2019 using the World View Satellite images of 30cm resolution, with similar quality at the orthophotos used in 2012. The World View Images were made available by the National Institute of Statistics of Rwanda (NISR) through its memorandum of agreement with Digital Globe, USA.

Table 5.13 Size of different types of forests in Rwanda

Forest Cover Type	Province					Total (ha)
	Kigali City	East (ha)	North	South (ha)	West	ha
Forest plantations	12,379	64,649	73,791	132,683	103,924	387,425
Natural forest	-	7,085	11,740	43,014	69,012	130,850
Shrub Total	129	40,930	14	1,768	1,122	43,963
Wooded savannah	-	161,832		10	1	161,843
Bamboo	133	135	144	62	141	613
Total	12,641	274,630	85,688	177,537	174,199	724,695*

* The area includes the deforested area within the period of 2008-2019. Source: MoE (2019).

On-screen digitization techniques were used to map all forest patches down to 5m by 5m and the canopy density of less than 10% was considered to capture harvested forestlands. According to the 2019 forest cover mapping, the forests of Rwanda occupy about 724,695 ha which is about 30.4%of the total country land (MoE, 2019). Forest plantations cover 387,425 ha (53.5%), natural mountain rainforests 130,850 ha (18.1%), wooded savannah, 161,843 ha (22.3%) and shrubs, 43, 963 ha (6.1%). Bamboo plantations occupy about 613 ha (Table 3.9). The change in forest area for natural forests and forest plantations is shown in Table 3.10. Due to restraints in the processing of the available land use data, for calculating emissions and removals from Forestland, subcategories have been based on ecological zones rather than forest type (see **Section 5.8.3**)

Table 5.14 Change in natural forest and forest plantation area (2008- 2019)

Year	Natural forest (Ha)	Forest plantation (Ha)	Total forest area (Ha)
2008	380,688.70	292,828.06	673,516.75
2009	376,741.60	301,424.90	678,166.50
2010	372,794.54	310,021.71	682,816.25
2011	368,847.48	318,618.52	687,466.00
2012	364,900.42	327,215.33	692,115.75
2013	360,953.36	335,812.14	696,765.50
2014	357,006.30	344,408.95	701,415.25
2015	353,059.24	353,005.76	706,065.00
2016	349,112.18	361,602.57	710,714.75
2017	345,165.12	370,199.38	715,364.50
2018	341,218.06	378,796.19	720,014.25
2019	337,271.00	387,393.00	724,664.00
% change 2008 - 19	-11.41%	+32.29%	+7.59%

Source: MoE, 2019: Forest Cover 2019; CGIS-NUR/PAREF/RNRA, 2012

In terms of distribution of forest resources, the Southern and Western Provinces hold half of the total forest area in the country (50%) and the Eastern province takes up to 38% of the total forestland (**Table 5.15**).

Table 5.15 Distribution of forests by Province

Province Name	Province land (water bodies excluded) (ha)	Total Forest cover (ha)	Forestland (%)	Non-forest land (%)
Kigali City	72,829	12,641	17.4%	82.6%
Eastern Province	910,555	274,630	30.2%	69.8%
Northern Province	319,318	85,688	26.8%	73.2%
Southern Province	596,355	177,537	29.8%	70.2%
Western Province	486,773	174,199	35.8%	64.2%
Total	**2,385,830**	**724,695**	**30.4%**	**69.6%**

Source: MoE (2019)

A comparison of the 2019 forest cover statistics with the 2012 mapping enabled us to assess change detection and the resulting deforestation and afforestation. This assessment revealed that about 105,713 ha have been deforested (15.7% decrease), but at the same time, a new 139,674 ha were afforested (20.7% increase) from 2009 to 2019 (**Table 5.16**).

Table 5.16 Total deforested and afforested areas between (2009- 2018)

Province	FC 2019*	FC 2009	Deforested area (ha)	Afforested area (ha)	No change (ha)	Deforestation rate (%)	Afforestation rate (%)
Kigali	11,783	11,400	2,626	3,009	8,774	23.0	26.4
East	271,156	296,234	65,807	40,729	230,427	22.2	13.7
North	81,691	66,529	5,518	20,679	61,011	8.3	31.1
South	173,471	153,196	17,205	37,480	135,991	11.2	24.5
West	169,364	146,145	14,557	37,777	131,588	10.0	25.8
Total	707,465	673,504	105,713	139,674	567,791	15.7	20.7

* Plots of less than 0.25ha were excluded in the 2019 forest statistics in order to be comparable with the forest statistics of 2009. **Source:** MoE (2019).

5.8.1.2 Cropland

The cropland class is the biggest in Rwanda and occupies more than 1.2 million hectares of land. Agricultural activities are practiced on hill slopes, plateau as well as in valleys and wetlands, on a great variety of soils.

Under the cropland subcategory, the cultivated lands were disaggregated in sub-categories according to management practices as the following: Annual crops on wetland organic soil; Annual crops on wetland mineral soil, Rice on wetland mineral soil; Annual crops on hills; Banana, Fruit trees, Coffee, Tea and Fallow. Banana, fruit trees, coffee, and tea sub-categories represent perennial crops with higher biomass retention and soil cover as compared to annual crop sub-categories. The main criteria used to distinguish these sub-categories are summarized in **Table 5.17** and the area is shown in **Table 5.18**, these criteria for crop sub-categories are based on the differences in agronomic practices resulting in different N and C input and resulting in different C-stock in soil. The cropland area for each sub-category was sourced from NISR and NAEB. Activity data on crop production are shown in **Table 5.18**.

Table 5.17 Summary description of Cropland sub-categories used for GHG emission assessment

Cropland remaining cropland	Description	Reference
Annual crops on wetland organic soil	Organic soil rich in C, losing soil C intensely due to cultivation, partly flooded, high water table creating anaerobic conditions	IPCC 2006
Annual crops on wetland mineral soil	Partly flooded, with medium to low soil C, mineral fertilizer applied	Scientific papers, various
Rice on wetland mineral soil	Intermittently flooded, non-stop cultivation of rice with limited or no rotation, crop biomass 6t/ha	IPCC 2006
Annual crops on hills	Medium to poor soil fertility, depleted soil C-stock, crop biomass 5t/ha	IPCC 2006

Banana	Permanent biomass growth and returning to soil (full or partial), biomass growth 3.8995 tons C/ha per year, organic N-input	BUR study (REMA, 2019a)
Fruit trees	Perennial woody biomass growth, some C removal with harvest, variable with tree species	IPCC 2006
Coffee	Perennial woody biomass growth of 2.13 tons DM/ha per year; 15% DM in green bean, mean yield 660kg/ha; C removed with harvest 43.56kg/ha per year	Van Asten 2015; NAEB Annual reports on production and yield
Tea	Yearly woody biomass growth, C removed with harvest – 0.78783 t/ha dry tea yield; mean yield is 6.316 t/ha fresh leaf; C content in tea leaves 0.3821 t C/ha per year	NAEB annual reports, own calculation, info on dry matter from the internet
Fallow	Short term restoration of soil C	NISR reports

Table 5.18 Area of Cropland sub-categories used for the GHG inventory in 2006-2018

	Annual wetland organic soil	Annual wetland mineral soil	Rice	Annual on hills	Banana	Fruits	Tea	Coffee	Fallow	Total (Ha)
2006	9,151.0	107,729.8	6,560.5	543,101.3	183,198.0	16,821	11,670	22,510.0	345,783.8	1,246,525.4
2007	9,151.0	106,787.8	7,502.5	574,755.4	174,358.0	17,463	11,900	23,294.2	323,453.5	1,248,665.4
2008	9,151.0	105,062.8	9,227.5	597,523.5	173,358.0	8,778	12,500	24,078.4	311,126.3	1,250,805.5
2009	9,151.0	104,455.8	9,834.5	621,260.6	172,707.0	19,301	12,580	24,862.6	278,793.0	1,252,945.5
2010	9,151.0	107,802.3	6,488.0	648,393.4	167,333.0	20,258	13,550	25,646.8	256,462.8	1,255,085.3
2011	9,151.0	106,165.3	8,125.0	672,305.5	167,714.0	17,831	15,380	26,431.0	234,132.5	1,257,235.3
2012	9,151.0	106,484.3	7,806.0	695,981.8	167,714.0	17,831	15,380	27,215.2	211,802.1	1,259,365.4
2013	9,151.0	105,639.0	8,651.0	669,001.7	227,697.0	8,278	15,616	27,999.4	189,472.3	1,261,505.4
2014	9,151.0	102,405.3	11,885.0	613,542.4	296,214.0	11,380	24,043	28,783.6	167,141.8	1,264,546.1
2015	9,151.0	101,489.3	13,201.0	636,361.9	314,242.0	10,125	28,763	29,567.8	122,784.5	1,265,685.5
2016	9,151.0	97,574.3	16,839.0	603,836.4	229,633.0	8,569	33,333	30,351.9	238,538.0	1,267,825.6
2017	9,151.0	97,187.8	17,102.5	612,896.0	232,098.0	6,552	34,263	30,514.8	230,200.5	1,269,965.6
2018	9,151.0	97,451.3	16,839.0	756,910.1	229,633.0	6,326	34,423	30,751.0	90,621.5	1,272,105.7

Source: NAEB annual reports 2015/16; 2016/17; 2017-18; NISR SAS reports 2015/16; 2016-17; 2017-18.

The differences in C stock, biomass, and management practices between cropland sub-categories are reflected in **Table 5.17**. A distinction of cropland categories is important, as fertilizers and organic amendments are not distributed equally or proportionally. For example, the banana sub-category receives mostly organic manure, compost, or other amendments, while mineral fertilizers are extensively applied on Irish potato, maize, rice, some vegetables, tea, and coffee, i.e., the most commercialized commodity crops. The expansion in cultivated areas has continued for annual crops on hills, tea and coffee, and area reduction for banana and fruit trees.

5.8.1.3 Grassland

This land-use class defines an area that is free from trees (tree density is lower than 10% canopy and which may have scattered trees or trees planted at the borderline of different pasture plots (case of Easter Rwanda, where significant grazing space is available for open grazing). However, the area of National Parks was excluded from this sub-category and was considered under the Eastern Savannah Forestland sub-category. In other parts of the country, grassland patches occur in very limited areas.

Table 5.19 Crop production (tonnes/year) in Rwanda in 2006-2018.

Year	Beans	Soybean	Peas	Ground nut	Maize	Rice	Sorghum	Wheat	Banana	Irish potato	Sweet potato	Taro & Yam	Cassava
2006	296,724	26,409	11,882	17,151	96,662	60,446	187,380	18,978	2,658,232	1,275,586	775,640	129,275	765,199
2007	331,107	39,868	19,656	9,899	102,447	61,701	166,769	24,633	2,698,176	967,283	845,155	137,000	776,944
2008	308,563	50,931	21,689	11,122	166,853	82,024	144,418	67,868	2,603,949	1,161,943	826,440	144,919	1,681,823
2009	327,729	52,204	33,855	15,354	286,948	95,105	174,554	72,478	2,993,482	1,289,622	803,229	152,369	2,019,739
2010	325,165	56,573	37,092	14,052	440,951	66,624	162,577	87,496	2,779,662	1,794,042	831,899	168,815	2,292,533
2011	332,892	37,478	38,196	14,904	508,123	82,466	181,534	85,812	3,057,895	1,965,299	853,071	186,168	2,616,424
2012	378,816	15,127	18,257	15,042	466,510	88,702	215,271	72,822	2,842,298	1,458,033	1,009,743	102,354	1,439,398
2013	357,153	16,527	10,841	18,184	282,211	74,208	234,763	53,966	2,218,573	478,625	1,082,511	87,421	656,924
2014	412,682	17,119	19,994	10,182	357,083	72,723	140,578	11,617	1,804,649	603,165	940,787	121,597	900,227
2015	431,813	21,250	16,536	11,148	370,140	97,435	133,295	10,535	1,862,841	662,025	919,402	149,522	924,651
2016	497,889	24,669	23,346	12,107	12,107	98,861	95,044	8,730	2,011,868	739,382	1,007,521	164,488	811,921
2017	367,466	21,373	13,535	23,746	23,747	110,434	83,324	7,302	1,970,969	757,811	1,149,000	259,259	902,725
2018	502,378	24,311	18,002	25,091	25,092	115,869	73,162	11,900	1,905,368	879,023	1,323,166	141,305	972,881

Source: MINAGRI Crop Assessment survey, 2006-2012 (for 2006-2012A); NISR Seasonal Agriculture Survey 2012-2016 (for 2012B to 2015).

5.8.1.4 Wetland

This Land Use sub-category is defined by the flat landscape at hill feet, with specific soil type, which may be organic (peatland) or mineral by its origin and composition. Mineral soils in wetlands are formed by colluvium and have a hydromorphic origin. Part of Rwandan wetlands was cultivated until recently by annual crops – sweet potato, sorghum, beans, maize, and vegetables. The recent construction of drainage systems for the expansion of rice has increased rice crop, which is grown exclusively in wetlands. The wetland area was reported as constant in recent NISR reports, while detailed studies on earlier changes in wetlands are lacking.

5.8.1.5 Settlement

In the past 26 years, there have been significant shifts in settlement policy and patterns in Rwanda. Before the 1994 genocide, nearly all rural settlements were scattered on hills and wetlands borders with nearly no facilities as water supply and electricity. Urban settlements had few planning patterns with limited water, electricity, and waste removal systems. Between 1995 and 2000, there was a settlement policy introduced, and effort made to shift from scattered to organized planned settlements, which have grown to design of residential, industrial, and commercial areas with set standards for each in both, rural and urban areas. This made it possible to expand water and electricity supply and facilitate well-designed industrial area development as well as internet and mobile phone connection in almost all the country. Therefore, the Settlement land use sub-category has appeared with constant growth in recent years.

5.8.1.6 Other Land

This Land Use subcategory includes the areas, which may not be considered as any of the described above land use classes. This subcategory occupies the smallest area among all land use classes.

5.8.2 Trends of GHG emissions/removal from land use

The introduction of areas for each Land Use class for 2016, 2017, and 2018 and the areas of estimated Land Use class changes into IPCC software enabled the derivation of corresponding changes in carbon stock in soil, biomass, deadwood, and litter, which were translated into CO_2eq. units. The summary of GHG emissions/removals from land use and Land Use changes per category is provided in **Table 5.20**. The TNC report did not include emissions from Land and Land Use Change, and they are reported here for the first time.

Table 5.20 Emissions from land use and land use changes, Gg CO_2 eq. (2006-2018)

Period	3.B - Land	3.B.1 - Forest land	3.B.2 - Cropland	3.B.3 - Grassland	3.B.4 - Wetlands	3.B.5 - Settlements	3.B.6 - Other Land
2006	-3684.62	-5415.96	1296.01	197.19	0.18	235.91	2.05
2007	-3657.06	-5569.15	1367.32	283.79	0.18	258.75	2.05
2008	-3829.44	-5725.90	1339.39	224.12	0.18	331.94	0.84
2009	-3916.39	-5854.29	1552.00	228.97	0.18	154.69	2.06
2010	-4035.57	-5994.21	1575.43	199.61	0.18	182.45	0.97
2011	-4265.41	-6139.53	1520.35	189.99	0.18	161.53	2.06
2012	-4309.70	-6283.44	1508.10	200.34	0.18	264.29	0.84
2013	-4542.12	-6451.03	1567.08	182.14	0.18	157.45	2.06
2014	-4525.32	-6522.10	1596.54	197.14	0.18	200.86	2.06
2015	-4590.47	-6663.47	1568.78	224.97	0.18	277.02	2.06
2016	-4761.15	-6833.67	1595.91	199.52	11.06	264.00	2.03
2017	-4752.40	-6895.67	1670.92	223.10	13.55	234.95	0.75
2018	-5030.22	-7090.75	1609.57	170.98	11.65	266.27	2.06

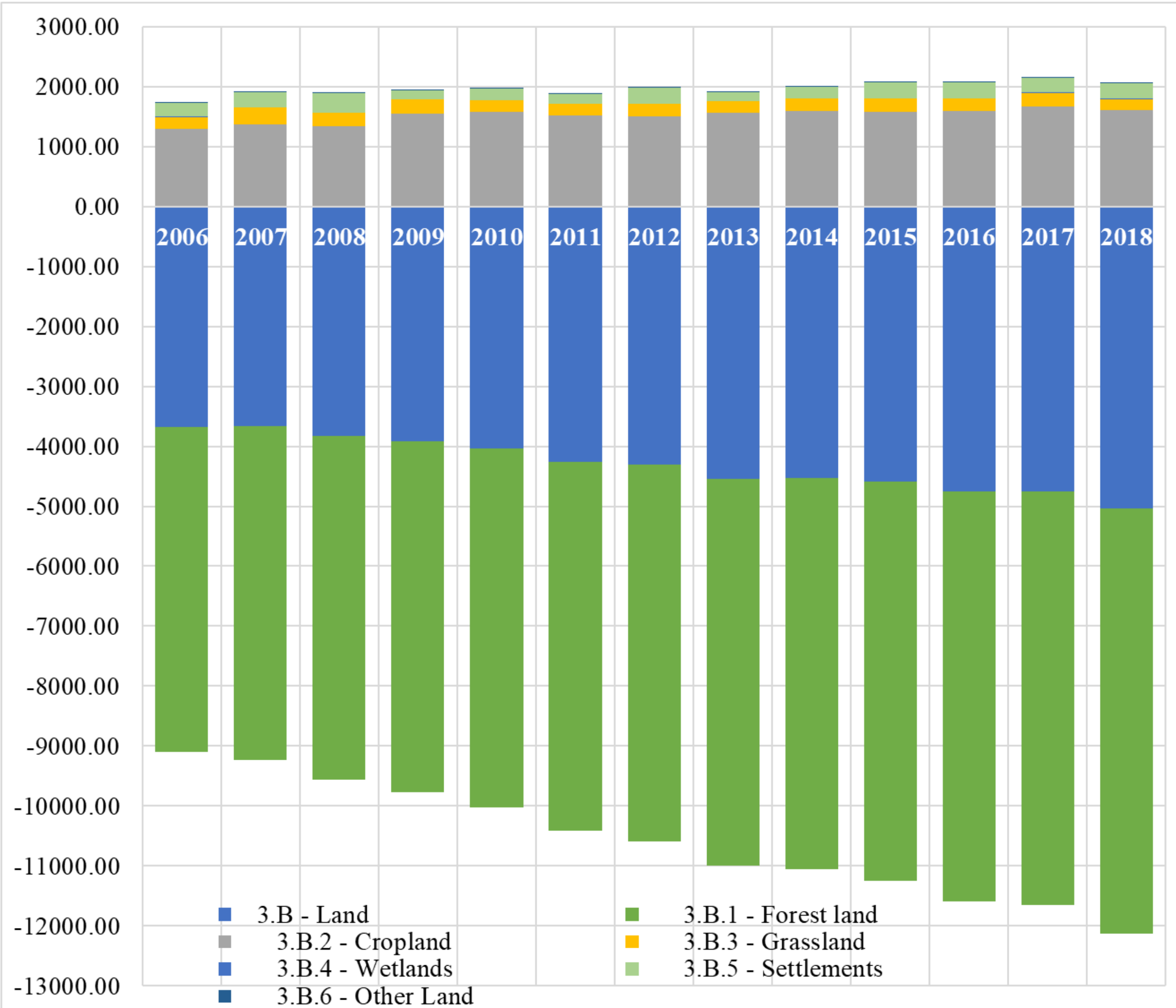


Figure 5.4 Trends of GHG emissions from Land Use and Land use

5.8.3 Methodological issues and activity data

Land Use assessment included a comparison of the Land Use class data disaggregated per district for 2000 and 2019. Based on soil type, rainfall, and altitude distribution, the country has been divided into six ecological zones (**Figure 5.5**; **Table 5.21**).

Table 5.21 Major AEZ characteristics

AE Zone	Altitude, m asl	Rainfall	Soil type
Volcanic	1500-2800	1500	Volcanic Andosols
Kivu lake border	1100-1700	1200	Clay loam soils
Central plateau	1400-1800	1100-1200	Weathered sandy loam soil on granite
Congo-Nile Divide	1800-2700	1600	Humic acid soils
Ndiza and Buberuka Highlands	2000-2800	1200	Oxisols on high altitude
Eastern Savannah	1200-1700	800-1000	Oxisols with high Ferrum oxide; clayey soil derived from shale; old infertile soils with variable texture

Source: Adapted from Clay, 1987.

The same subdivision of Agroecological zones was adopted during the GHG inventory for the TNC and the Rwanda Readiness Preparation Proposal for REDD document. First, the patterns of Land Use Change were determined per district, then per Ecological Zone using the grid point method to determine the proportions of each Ecological Zone for each district. The proportions of district area for each Ecological Zone are shown in **Table 5.22**.

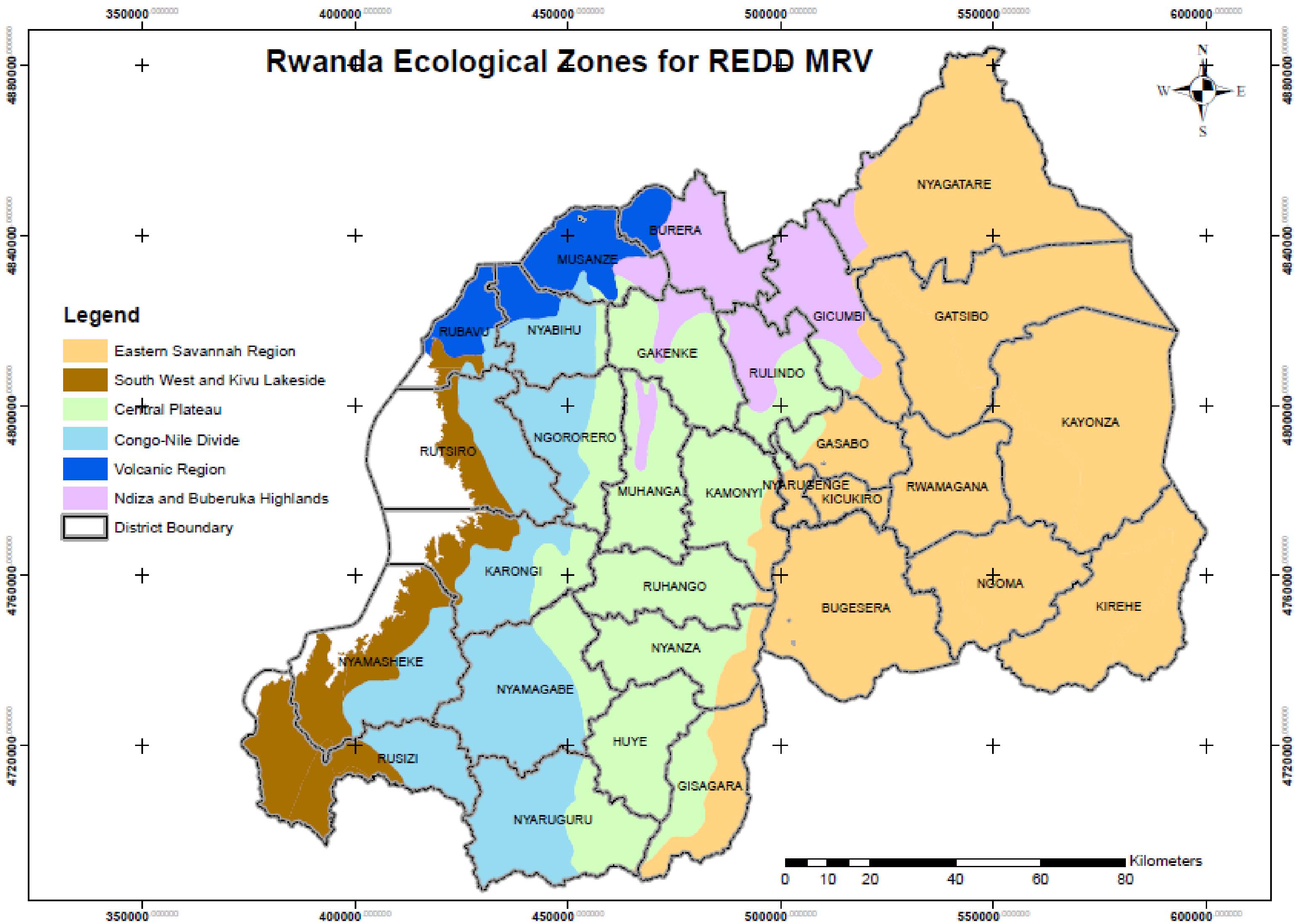


Figure 5.5 Ecological zones of Rwanda (Source: RNRA, 2014)

Table 5.22 Proportions of district area in Ecological Zone in Rwanda

1. Volcanic Zone		2. Kivu lake border		3. Central Plateau	
District	**Area (%)**	**District**	**Area (%)**	**District**	**Area (%)**
Burera	23.4	Rubavu	17.4	Gicumbi	12.2
Musanze	71.9	Rutsiro	29.3	Gasabo	18.5
Rubavu	65.2	Karongi	23.1	Nyarugenge	20.0
Nyabihu	34.1	Nyamasheke	53.3	Kamonyi	83.7
4. Congo-Nile Crest		Rusizi	60.8	Ruhango	97.4
				Nyanza	81.2
District	**Area (%)**			Gisagara	41.7
Musanze	3.1	**5. Ndiza-Buberuka**		Gakenke	81.8
Nyabihu	56.1			Rulindo	47.2
Rubavu	17.4	**District**	**Area (%)**	Muhanga	86.0
Ngororero	52.4	Nyagatare	4.9	Karongi	25.0
Nyamagabe	66.1	Gicumbi	68.9	Nyaruguru	37.8
Nyaruguru	66.2	Gakenke	18.2	Nyamagabe	33.9
Karongi	51.9	Burera	76.6	Ngororero	47.6
Nyamasheke	46.7	Rulindo	52.8	Nyabihu	9.6
Rutsiro	70.7	Muhanga	14.0	Musanze	3.1
Rusizi	39.2	Musanze	21.9	Huye	100
6. Eastern Savannah					
District	**Area (%)**	**District**	**Area (%)**	**District**	**Area (%)**
Nyagatare	95.1	Gasabo	81.5	Kamonyi	16.3
Gicumbi	18.9	Nyarugenge	80.0	Ruhango	2.6
Gatsibo	100	Gisagara	58.3	Nyanza	18.8
Kayonza	100	Rwamagana	100	Ngoma	100
Kicukiro	100	Bugesera	100	Kirehe	100

Source: Own estimates using grid and AE Zone map with district borders.

The land use data of each Land Use class were disaggregated by district, but they had to be assessed at agro-ecological (AE) Zone level. To determine the area of each AE Zone at each district, a grid was used to estimate which percentage area belongs to a specific AE zone at each district. For districts with no large areas of forest, an assumption was made that each Land Use class was equally present across the whole area of this district. Therefore, the area of each Land Use class was divided according to the proportions obtained from the grid to belong to a specific AE Zone. For example, if one district is located with 30% area in AE Zone 1, and 70% area in AE Zone 2, an assumption was made that 30% of the cropland in this district is in the AE Zone 1, and 70% in AE Zone 2. Thus, the areas of respective land use classes were assumed equal to the proportion of the area within each agro-ecological zone, except for big forest blocks like Nyungwe and Volcano National Parks where forest borders were confined to a district Ecological Zone. After calculating the proportions of each district area in the Ecological Zones, forest areas were disaggregated into Forest Plantations and Natural Forests sub-categories for differentiation of forest productivity parameters, which affect the sink potential. As both, afforestation and deforestation activities happened within the inventory period, it was clear that both, afforested and deforested areas do not have the same productivity and sink as the forests where no change happened. For this reason, deforested areas were excluded from the Forestland class and were accounted as Forest changed to Grassland or Forest changed to Cropland or Forest changed to Settlement (depending on specific district and proximity to urban areas). Afforested land is a forest plantation or forest with no change. All land except natural forests (National Parks and Forest reserves) are considered as managed land. Only conservation activities take place in natural forests.

Table 5.23 Land use (LU) change in Rwanda between, 2000- 2019

LU in 2000	Forestland	Cropland	Grassland	Other Land	Settlement	Wetland
LU in 2019	Area (ha)					
Forestland	750,457.1	12,044.4	97,853.8	3,004.1	0.0	0.0
Cropland	87,627.7	1,122,446.6	86,817.0	860.8	0.0	0.0
Grassland	21,403.8	3,532.1	397,737.3	4.0	0.0	0.0
Other land	122.8	152.9	177.4	3,945.9	0.0	0.0
Settlement	29,541.1	4,729.8	8,740.0	47.2	13,837.0	0.0
Wetland	0.0	0.0	0.0	0.0	0.0	138,535.6

Source: Land use maps 2000 and 2019 (RAB, RLMUA, MoE)

Table 5.24 Land use change in Rwanda in 2018

LU in 2017	Area (ha)					
	Forestland	Cropland	Grassland	Other Land	Settlement	Wetland
LU in 2018						
Forestland	715,364.5	633.9	5,150.2	158.1	0.0	0.0
Cropland	4,612	1,269,965.6	4,569.3	45.3	0.0	0.0
Grassland	1,126.5	185.9	246,841.4	0.2	0.0	0.0
Other land	6.5	8.0	9.3	889.7	0.0	0.0
Settlement	1,554.8	248.9	460.0	2.5	52,362.7	0.0
Wetland	0.0	0.0	0.0	0.0	0.0	138,535.6

Source: Land use maps 2000 and 2019 (RAB, RLMUA, MoE)

After making the difference between each Land Use class in 2000 and 2019 at each district level, and with field knowledge of the happening changes, Land Use change patterns were derived, and annual change was calculated by diving the total change by the number of years. The verification of errors was done by summing all land use classes for each year to get the same total land area. The general trend in Land Use change was the increase of Cropland, reduction of Grassland, and regional increase or decrease of Forestland depending on the specific district, as well as the change from Cropland, Grassland, or Forestland to Settlement.

Table 5.25 Land use change in Rwanda in 2017

LU change 2017	Areas (ha)					
	Forestland	Cropland	Grassland	Other land	Settlement	Wetland
Forestland	710,714.8	633.9	5,150.2	158.1	0.0	0.0
Cropland	4,612	1,267,825.6	4,569.3	45.3	0.0	0.0
Grassland	1,126.5	185.9	255,717.6	0.2	0.0	0.0

Other land	6.5	8.0	9.3	1,069.5	0.0	0.0
Settlement	1,554.8	248.9	460.0	2.5	50,096.5	0.0
Wetland	0.0	0.0	0.0	0.0	0.0	138,535.6
Source: Land use maps 2000 and 2019 (RAB, RLMUA, MoE)						

Table 5.26 Land use change in Rwanda in 2016

LU change 2016	Areas (ha)					
	Forestland	Cropland	Grassland	Other land	Settlement	Wetland
Forestland	706,714.8	633.9	5,150.2	158.1	0.0	0.0
Cropland	7,797.9	1,265,685.5	4,569.3	45.3	0.0	0.0
Grassland	1,126.5	185.9	264,593.8	0.2	0.0	0.0
Other land	6.5	8.0	9.3	1,249.3	0.0	0.0
Settlement	1,554.8	248.9	460.0	2.5	47,830.3	0.0
Wetland	0.0	0.0	0.0	0.0	0.0	138,535.6

Source: Land use maps 2000 and 2019 (RAB, RLMUA, MoE)

The summary of the Land Use change per year is shown in **Table 5.23**, **Table 5.24**, **Table 5.25**, and **Table 5.26**. Because of comparing the land use data in 2000 and 2019, the annual changes for the same Land Use class had similar values since it was assumed that these changes happened gradually and equally distributed in a year. The above data were obtained from various sources and methods that are provided in **Table 5.27**.

Table 5.27 Data source for forestry and land use category, 2016-2018

Category	Sub-category	Kind of data	Gas	Methods	Data source
3.B. Land	3.B.1 Forest land *	Land use/cover changes, Land use change matrix	CO_2	Tier 1/IPCC 2006	CGIS-NUR/PAREF/RNRA (2012); RNRA (2015) DFS/PAREF/RNRA (2016)
		Biomass estimate for 5 IPCC pools (Above & below-ground biomass, deadwood, herb, litter, and soil)	CO_2	Tier 1/IPCC 2006	
		Deforestation and wood removal	CO_2	Tier 1/IPCC 2006	IPCC (2006); MoE (2019)
	3.B.2 Cropland *	Land use/cover changes, Land use change matrix	CO_2	Tier 1/IPCC 2006	CGIS-NUR/PAREF/RNRA (2012); RNRA (2015), IPCC 2006; IPCC software, version 2.691; Map of built-up area from RLMUA (2019); MoE (2019); Water bodies map (RLMUA, 2019);
		Biomass estimate for 5 IPCC pools (Above & below-ground biomass, deadwood, herb, litter, and soil)	CO_2	Tier 1/IPCC 2006	
		Crop management practices	CO_2	Tier 1/IPCC 2006	
	3.B.3 Grassland*	Land use/cover changes, Land use change matrix	CO_2	Tier 1/IPCC 2006	

Category	Sub-category	Kind of data	Gas	Methods	Data source
		Biomass estimate for 5 IPCC pools (Above & below-ground biomass, deadwood, herb, litter, and soil)	CO_2	Tier 1/IPCC 2006	Other Land (RLMUA, 2019); Grazing land and agriculture map from RAB GIS unit, 2020; Own calculation; RAB reports
	3.B.4Wetland *	Land use/cover changes, Land use change matrix	CO_2, N_2O	Tier 1/IPCC 2006	
	3.B.5. Settlement	Land use/cover changes, Land use change matrix	CO_2	Tier 1/IPCC 2006	
	3.B.6. Other lands	Land use/cover changes, Land use change matrix	CO_2	Tier 1/IPCC 2006	

* Land use sub-category includes land remaining in the sub-category and land converted to another sub-category.

5.8.4 Emission factors and carbon stock in land use classes

Forestland has been divided into 12 sub-categories based on the 6 ecological zones, divided into "natural" and "plantations" (**Table 5.28**). These subcategories and their associated carbon stock characteristics are presented in the table below. As well as from biomass, carbon stock changes also occur from soil organic matter mineralization during practices such as ploughing and tillage. Land use class changes from Forest to Cropland and Grassland, from Grassland to Cropland, from both, Forest and Grassland to Settlement or Other land cause losses in carbon stock in soil, as well as crop biomass aboveground, deadwood and litter produced earlier by forest. The process of decreasing C in the soil goes together with N mineralization that accelerates N_2O emissions from the soil with the change of land use.

Default carbon stock change factors from the IPCC Guidelines 2006 have also been applied to the other land use categories. The development of local emission factors should be done for carbon pools, including all land use classes. The EFs must be validated to reflect national values.

Table 5.28 Carbon stock characteristics for Forestland sub-categories in Rwanda

Land use subcategory	C in above-ground biomass tC/tDM	Ratio below-ground to aboveground biomass, tDM root/tDMshoot	Aboveground biomass tDM/ha	Aboveground biomass growth tDM/ha per year	Reference soil organic C	Litter C stock, tC/ha
Volcanic plantation	0.47	0.27	150	10	80	2.1
Volcanic natural	0.47	0.27	150	1.3	80	2.1
Kivu Border natural	0.47	0.24	150	4	47	2.1
Kivu Border plantation	0.47	0.24	150	10	47	2.1
Central Plateau plantation	0.47	0.24	60	9	47	3.6
Central Plateau natural	0.47	0.24	150	1.3	47	2.1
Congo-Nile natural	0.47	0.27	100	1.3	63	2.1
Congo-Nile plantation	0.47	0.27	100	10	63	2.1
Ndiza -Buberuka highlands	0.47	0.27	50	1.3	63	2.1
Ndiza- Buberuka highland	0.47	0.27	50	10	63	2.1
Eastern Savannah natural	0.47	0.2	40	1.3	47	2.1
Eastern Savannah plantation	0.47	0.2	40	9	47	2.1

Source: IPCC Guidelines 2006, default values for all. Data on biomass growth were crosschecked and adapted from default values for forest sub-category

5.8.5 Specific QA/QC

The quality assurance/quality control was carried out throughout the inventory preparation process for all activity data collections and choice of carbon and biomass stocks and annual growth rates for Forestland subcategories. The values were crosschecked with available published papers, national statistics on forestry, agriculture, and the environment (NISR reports), and IPCC 2006 guidelines. Key forestry and land experts from the Ministry of Environment and its agencies including the Rwanda Forestry Authority and Rwanda Land Management and Use Authority were also consulted to crosscheck statistics on forests and Land Use changes.

5.8.6 Time series consistence

According to IPCC methodology, the assessment of Land Use Change should be done by comparing the current land cover maps (2019) with the maps of 2000, twenty years back from the assessment year. Therefore, for Land Use Change in 2006, a map of 1986 would be used. However, the earliest year available for land use maps was 2000.

Considering the lack of land use maps and data per year, an assumption of equal Land Use Change per year was made using this approach assuring gradual change in emissions from Land Use Change. However, considering that the change is happening in the various Ecological Zones each year, differences in GHG emissions per year can take place.

5.8.7 Recalculations

Because there was no assessment of GHG emissions from land, except Forestland (sink only) in the TNC, there were no recalculations for other land use classes. For Forestland, the recalculations of GHG emissions were based on the recently updated areas for forestland per agro-ecological zone by comparing the data on forest cover from the Forest survey 2007 (CGIS-NUR/PAREF/RNRA, 2012) and recent Forest cover study 2019 (Ministry of Environment, 2019). These included the annual increase of forest biomass (sinks) as well as deforestation and disturbance including wood harvest and firewood removal.

The recalculation of the emissions and removals from Forestland for the period of 2006-2015 showed almost a double decrease in sinks (**Table 5.29**). This was related to the following reasons: 1) In Previous data (PD), the total area of forest was overestimated due to the lack of appropriate reference. With the Latest Data (LD), we used updated forest area from the recently completed Forest Cover study (MoE, 2019) and Forest inventory of 2009 (CGIS-NUR/PAREF/RNRA, 2012); 2) In the PD, annual biomass growth was considered, but no removals due to the lack of data on disturbance, wood, and fuelwood removal. In the LD, the data on deforestation (MoE, 2019) were considered along with wood and fuelwood removal.

Table 5.29 Recalculation of the emissions and removals from Forestland, Gg CO_2 eq. (2006-2015)

	Forestland (3.B.1) emissions and removals. Gg CO_2e									
Year	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**
Forest area (PD), ha	1,100,357.7	1,094,986.9	1,089,639.1	1,084,297.4	1,077,096.7	1,074.601.0	1,071,404.2	1,064,542.7	1,058,843.5	1,052,207.7
Forest area (LD), ha	664,217.25	668,867.00	673,515.75	678,166.50	682,816.25	687,466.00	692,115.75	696,765.50	701,415.25	706,065.00
Net emissions (PD)	-10,728.64	-10,798.32	-10,868.49	-10,938.82	-10,969.46	-11,101.13	-11,219.13	-11,255.49	-11,317.96	-11,359.85
Recalculation	-5,415.96	-5,569.50	-5,725.90	-5,854.29	-5,994.21	-6,139.53	-6,283.44	-6,451.03	-6,522.10	-6,663.47
% change	53.10	52.30	51.40	50.80	49.80	49.60	49.40	48.00	47.80	47.00
Reason for recalculations	Earlier overestimated forest area due to inclusion of agroforestry equivalent estimates (latest forest area ignores agroforestry cover), the addition of the data on disturbance and wood removal from Forest Cover mapping of 2019 (afforestation and deforestation estimates) (MoE, 2019).									

5.8.8 Planned Improvements

Considering that there were some inconsistencies in the total areas of the districts as well as land use classes change, land cover/use mapping in the future could be a task assigned to a GIS specialist familiar with IPCC methodology and who would spend sufficient time to generate Land Use Change of smaller areas and in more details (for example, per district) on annual basis. The next work on inventorying Land Use Changes would consider using Land Use change data/areas per sector and separate maps of the districts. This would help to escape the assumption of the homogenous distribution of land use classes within the smallest available area unit and take a more precise decision on which side of the district Land Use Change happens more than in another side of the same district.

The activity data need to be fine-tuned so that accurate areas under the different crops can be assessed through extensive surveys and the use of accurate tools such as GIS, especially for the Land Use Change on annual basis. Other planned improvements for the Land sector include reviewing the available data on harvested wood products and collecting activity data on disturbances.

5.9 Aggregate sources and non-CO_2 emission sources on land (3C)

5.9.1 Source category description

Rwanda has about 2,173,167ha of arable land, of which 91% are cultivated during 2 (seasons A and B) or 3 growing seasons (A, B, and C seasons). The agriculture sector contributes about 30% of GDP and provides 35.5% of export revenues. Agriculture is the main source of revenue for most of the population. Due to high population density (482 persons/km^2 in 2016), poor development of the industrial sector, and limited options for further agricultural land expansion, the majority population lives in rural areas and relies partly or entirely on income from agricultural activities. This has led to increased pressure on land, decreasing farm size, reducing fallow area and duration, and intensification of multi-cropping systems. Limited land resources, livestock availability, and inadequate knowledge on available options for the crop, soil, and water management have resulted in limited use of organic and inorganic inputs to maintain soil fertility and crop yields.

Significant growth of urban population has substantially increased marketing of agriculture products from farms to cities thus accelerating several times nutrient mining and depletion from soils, and this has in addition led to Land Use Change through agricultural land converted to settlements. The Hilly/mountainous natural landscape, coupled with the increase in rainfall intensity, has maintained high run-off and soil erosion, thus challenging the existing soil protection structures.

To respond to these challenges, the Government has developed and promoted the following policies and programs:

(i) Crop Intensification Program (CIP) through land use consolidation for 8 strategic food crops – maize, rice, wheat, beans, soybean, Irish potato, cassava, and banana.
(ii) Livestock Intensification Program (LIP).
(iii) Development of new markets through diversification of horticulture and essential oil crops export in addition to the traditional coffee, tea, and pyrethrum;
(iv) Development of proximity extension services through '*Twigiremuhinzi*' program for both, crops and livestock; and further strengthening of industrial and service sectors for alternative job creation.

The National Strategy of Transformation (NST-1) and the fourth Strategic Plan for Agricultural Transformation (PSTA-4) target increased growth of the agriculture sector, with intensified production technologies, expansion of export commodities, increased production volume and quality, and reduction of post-harvest losses.

In Rwanda, crops are cultivated on a great variety of soils and landscapes including fertile volcanic soils in the North, which don't absorb water well and are prone to soil loss due to runoff during heavy rains; peatland and alluvial soils in valley bottoms all over the country along river plains; deep clay Nitisols in the Eastern plateau; medium-fertility Oxisols in Bugesera and Mayaga regions; highly acidic humic soils on steep slopes of Congo-Nile divide; tiny porous and always water-deficient FerrIn addition ls in West and Central parts of the country; highly weathered old sandy Acrisols of Central Plateau; and young clay loam soils along Kivu lake shore.

Nitrous oxide (N_2O) is produced naturally in soils through the microbial processes of nitrification and denitrification. Some agricultural activities add nitrogen (N) to soils, increasing the amount of nitrogen available for nitrification and denitrification, and ultimately the amount of N_2O emitted. The emissions of N_2O that result from anthropogenic N inputs occur through both a direct pathway (i.e., directly from the soils to which the N is added), and through two indirect pathways (i.e., through volatilization as NH_3 and NO_X and subsequent re-deposition, and through leaching and runoff).
Cultivation of agricultural soil (tillage), use of N-containing mineral and organic amendments including livestock manure, crop biomass, or compost, are the main sources of N_2O emissions from agriculture, and to a much lesser extent, inorganic fertilizers. The use of tillage increases mineralization processes, which leads to the depletion of natural C and N stocks in the soil. The cultivation of organic wetlands for rice production results in methane release from flooded fields. The use of limestone for soil acidity correction and urea leads to the release of CO_2 gas. For the inventory purpose, the emissions of GHG from the Agriculture sector are called "*Aggregate sources and non-CO_2 emission sources on land (3C)*", and this category combines sub-categories 3.C.1, 3.C 2, 3.C 3, 3.C 4, 3.C 5, 3 C. 6 and 3.C.7, which relate almost entirely to Agriculture.

5.9.2 Trends in GHG emissions

The summary and trends in the GHG emissions from Aggregate sources and non-CO_2 emission sources on land, Gg CO_2 eq. for the period 2006-2018 are presented in **Table 5.30,** and **Figure 5.6,** respectively.

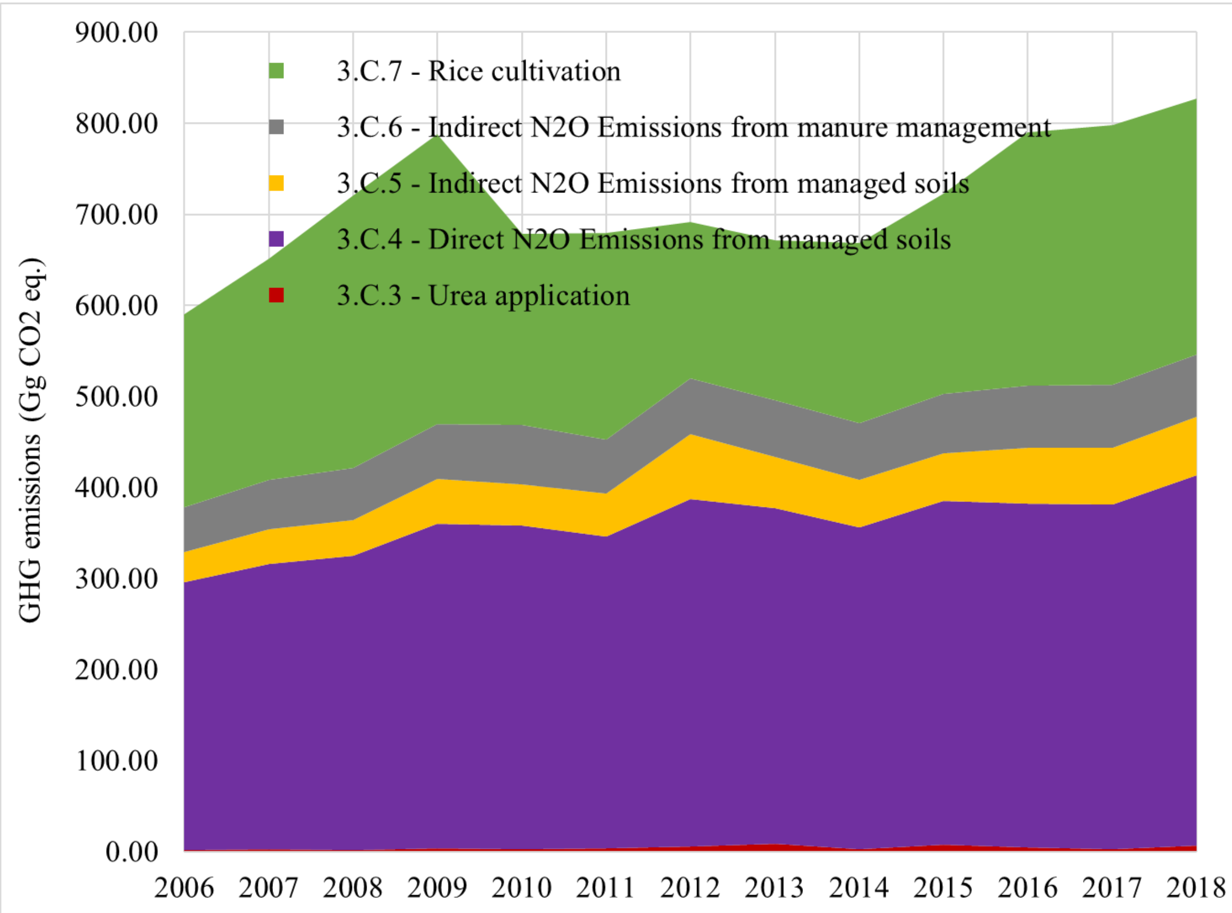


Figure 5.6 Trends in GHG emissions from Aggregate sources and non-CO_2 emission sources on land, Gg CO_2 eq. (2006-2018)

The GHG emissions from this category are dominated by the emissions from the Direct N_2O Emissions from managed soil (3.C.4) followed by the emissions from Rice cultivation (3.C.7), while the urea application has the least contribution. A detailed description of the various subcategories is provided in the subsequent sections.

Table 5.30 Summary of GHG emissions from Aggregate sources and non-CO_2 emission sources on land, Gg CO_2 eq. (2006-2018)

	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
3.C	590.50	651.50	720.14	787.68	678.16	679.66	691.57	747.59	818.45	876.57	879.55	885.07	909.94
3.C.1	NO	NO	NO	NO	NO	NO	NO	76.41	150.06	153.50	80.77	76.41	74.43
3.C.2	NO	NO	NO	NO	NO	NO	NO	NO	NE	NE	8.37	10.72	8.66
3.C.3	1.55	2.17	1.86	3.98	2.40	3.64	5.96	8.49	2.21	7.74	4.75	2.78	7.02
3.C.4	293.85	314.00	322.94	356.02	355.54	342.14	381.47	368.36	354.23	377.33	377.27	378.59	405.92
3.C.5	33.61	38.06	39.58	49.55	45.20	47.84	71.44	57.03	52.12	52.07	61.62	62.09	64.38
3.C.6	49.07	54.35	56.99	59.71	64.96	58.97	60.96	61.38	61.68	65.84	68.07	69.32	68.79
3.C.7	212.42	242.92	298.77	318.42	210.07	227.07	171.74	175.91	198.16	220.10	278.70	285.15	280.74

3.C.1 - Emissions from biomass burning 3.C.2 – Liming 3.C.3 - Urea application 3.C.4 - Direct N_2O Emissions from managed soil 3.C.5 - Indirect N_2O Emissions from managed soils 3.C.6 - Indirect N_2O Emissions from manure management 3.C.7 - Rice cultivation 3.C.8 - Other (please specify)

5.9.2.1 Emissions from biomass burning (3.C.1)

Biomass burning is legally prohibited in Rwanda. However, a planned Savannah burning is annually applied within different sides of the Akagera Park as part of the savannah management strategy. The assumption applied for biomass burning in Grassland is that the same proportion of the Park is burnt on yearly basis (maintaining the area size given in TNC) (**Table 5.31**).

Table 5.31 Emissions from Savannah burning (Forestland of Eastern Savannah)

Period	Area burnt (ha)	CH_4 (Gg)	N_2O (Gg)	CH_4 (Gg CO_2eq.)	N_2O (Gg CO_2eq.)	Total (Gg CO_2eq.)	NO_X (Gg)	CO (Gg)
		Direct gases					Indirect gases	
2013	29,045	1.55	0.142	32.55	44.02	76.57	2.628	43.8
2014	57,037	3.043	0.278	63.903	86.18	150.083	5.161	86.012
2015	58,344	3.113	0.284	65.373	88.04	153.413	5.279	87.983
2016	30,700	1.638	0.15	34.398	46.5	80.898	2.778	46.298
2017	35,920	1.917	0.175	40.257	54.25	94.507	3.25	54.168
2018	28,880	1.541	0.141	32.361	43.71	76.071	2.613	43,552

Emissions from biomass burning were estimated for Forestland, Eastern Savannah sub-category, precisely, Akagera National Park where planned burning is permitted and done annually for Savannah landscape management since 2013. The emissions of CO_2 were accounted for under 3B. Emissions from wildfires have not been included. The following gases were accounted for Biomass burning: CH_4, N_2O, NO_X, and CO (**Table 5.31**). Savannah burning, the main gas emitted was carbon monoxide followed by NO_X in case of grassland burning).

5.9.2.2 Emissions from liming (3.C.2)

Lime applied in Rwanda for agricultural purposes is non-calcinated limestone, which is produced mainly in Musanze. MINAGRI provides subsidies and markets for the whole limestone produced, while the districts report back to MINAGRI through MIS on the quantities of lime applied since 2019. The production of lime exceeds the range of 19,000 to 24,000 tons. However, due to the limited access to lime production data, the emissions from liming were estimated based on the available information about lime production (**Table 5.312**).

Table 5.32 Emissions from liming in Rwanda, CO_2 eq. (2006-2018)

Year	Lime produced	Emissions
2006	0	NO
2007	0	NO
2008	0	NO
2009	0	NO
2010	0	NO

Year	Lime produced	Emissions
2011	No disaggregated data	NE
2012	No disaggregated data	NE
2013	4,299.40	1.8917
2014	18,000.00	7.9200
2015	41,157.00	18.1091
2016	19,012.00	8.3650
2017	24,362.60	10.7200
2018	19,673.00	8.6560

Source: REMA report on burnt and non-calcined lime (REMA, 2019b). Note that lime mining began in 2011 – 12.

5.9.2.3 Emissions from urea application (3.C.3)

The emissions from urea were 4.7, 2.8, and 7.0 Gg CO_2 per year for 2016, 2017, and 2018, respectively (**Table 5.33**). The recalculations for 2006-2015 have adjusted values for urea emissions and some errors in the calculation were corrected from those reported in TNC.

Table 5.33 Emissions from urea application in Rwanda, 2006-2018

Year	Urea applied (tons)	Emissions from Urea, Gg CO_2 eq.
2006	2,111.646	1.548
2007	2,955.700	2.168
2008	2,537.150	1.861
2009	5,427.400	3.980
2010	3,266.290	2.395
2011	4,958.555	2.636
2012	8,121.968	5.956
2013	11,583.500	8.495
2014	3,017.560	2.213
2015	10,552.189	7.738
2016	6,483.997	4.755
2017	3,787.936	2.778
2018	9,571.926	7.019

Source: RAB Fertilizer Program, 2020.

5.9.2.4 N_2O emissions from managed soils (3.C.4)

Direct emissions from managed soils were1.217, 1.221, and 1.309Gg N_2O for 2016, 2017, and 2018, respectively (**Table 5.34**). Direct N_2O emissions from managed soils increased gradually from 293.88 Gg CO_2eq. in 2006 to 405.79 Gg CO_2eq. in 2018 (**Table 5.34**).

Table 5.34 Emissions from managed soil and manure, 2006-2018

Period	Direct emissions from land	Indirect emissions from land	Indirect emissions from manure	Direct emissions from land	Indirect emissions from land	Indirect emissions from manure
	Gg			Gg CO_2 eq.		
2006	0.948	0.254	0.158	293.88	78.74	48.98
2007	1.013	0.281	0.175	314.03	87.11	54.25
2008	1.042	0.292	0.184	323.02	90.52	57.04
2009	1.148	0.328	0.193	355.88	101.68	59.83
2010	1.147	0.33	0.21	355.57	102.3	65.1
2011	1.104	0.312	0.19	342.24	96.72	58.9
2012	1.321	0.387	0.197	409.51	119.97	61.07
2013	1.188	0.34	0.198	368.28	105.4	61.38
2014	1.143	0.326	0.199	354.33	101.06	61.69
2015	1.217	0.354	0.212	377.27	109.74	65.72
2016	1.217	0.357	0.22	377.27	110.67	68.2
2017	1.221	0.361	0.224	378.51	111.91	69.44
2018	1.309	0.386	0.222	405.79	119.66	68.82

5.9.2.5 Indirect emissions from managed soils (3.C.5)

Indirect emissions from managed soils were 0.357, 0.361, and 0.386 Gg N_2O for 2016, 2017, and 2018, respectively (**Table 5.34**).

5.9.2.6 Indirect emissions from manure management (3.C.6)

Indirect emissions from manure management were 0.22, 0.224, and 0.222 Gg N_2O for 2016, 2017, and 2018, respectively (**Table 5.34**).

5.9.2.7 Assessment of emissions from Rice cultivation (3.C.7)

Rice fields generated methane emissions of 13.271, 13.578, and 13.369 Gg methane in 2016, 2017, and 2018, respectively (**Table 5.34**).

Table 5.35 Emissions from rice cultivation, 2006-2018

Year	Annual area	Harvested area	Emissions,	Emissions
	(ha)	(ha)	Gg CH_4	Gg CO_2eq.
2006	6,560.50	13,121.00	10.115	212.415

Year	Annual area	Harvested area	Emissions,	Emissions
2007	7,502.50	15,005.00	11.567	242.907
2008	9,227.50	18,455.00	14.227	298.767
2009	9,834.50	19,669.00	15.163	318.423
2010	6,488.00	12,976.00	10.003	210.063
2011	8,125.00	16,250.00	10.813	227.073
2012	7,806.00	15,612.00	8.178	171.738
2013	8,651.00	17,302.00	8.377	175.917
2014	11,885.00	23,770.00	9.436	198.156
2015	13,201.00	26,402.00	10.481	220.101
2016	16,716.00	33,432.00	13.271	278.691
2017	17,102.50	34,205.00	13.578	285.138
2018	16,839.00	33,678.00	13.369	280.749

Source: NISR SAS annual reports 2013-2018; Crop assessment 2006-2012 (MINAGRI, unpublished)

5.9.3 Methodological issues and data collection

In Rwanda, the contribution of agriculture to GHG emissions occurs from Burning (3.C.1), Liming (3.C.2), Urea application (3.C.3); Direct N_2O emissions from managed soils (3.C.4) including the application of crop residues back to the soil, and organic amendments such as compost and animal manure during crop production, Indirect N_2O emissions from managed soils (3.C.6) including N losses from all amendments, Indirect emissions from manure management (3.C.6) after it left kraal, and flooded Rice cultivation (3.C.7).

5.9.3.1 Burning (3.C.1)

The burning process releases a high amount of GHG emissions, irrespective of burning type – wildfire, planned savannah burning, or burning of agricultural crop residues. In Rwanda, any type of burning is legally prohibited, however, planned burning of savannah is applied as part of management in the Akagera National Park (ANP), and a limited burning of agricultural residues still happens after crop harvest, illegal, and unreported. The activity data on burning are collected by Akagera National Park management for monitoring and rotation of areas burnt to maintain and restore Savannah ecosystems and grazing resources for protected animals living in the Park. This burning practice started to be applied in 2013 when the Akagera National Park was given to a private conservation company for management. No activity data on wildfires is currently available. Given the high level of resources required to assess wildfire activity, and its expected relatively low impact on overall emissions removals, this has not been included in the improvement plan.

5.9.3.2 Liming (3.C.2)

The information on lime production is not collected by NISR statistics. Therefore, production data from the lime mining industries are missing. However, we were able to collect some of the lime production data for 2016-2018 from the recent survey report done for REMA (REMA, 2019b).

5.9.3.3 Urea application (3.C.3)

The information on the quantities of fertilizers imported and distributed to agro-dealers on a seasonal basis was collected from the RAB Fertilizer program. The remaining stock at agro-dealer stores was deducted from the distributed quantities to obtain the quantity of fertilizer used. The fertilizer data were disaggregated by type of fertilizer, where the major types were NPK, urea, and DAP. For tea and coffee fertilizers, NAEB provided the data. NPK 22-6-12 was used for coffee and NPK 25-5-5 for tea. Therefore, NAEB fertilizer data were not considered for the assessment of emissions from urea applications.

5.9.3.4 Direct N_2O emissions from managed soil (3.C.4)

Assessment of direct N_2O emissions from managed soils considered various organic amendments, crop residues /biomass application, and mineral fertilization, where N_2O is generated after manure/biomass/compost, urine or dung, or mineral fertilizer were applied on soil within a specific cropping system. The main sources of nitrogen are shown in **Table 5.36**.

Table 5.36 Sources of nitrogen from compost, biomass, and crop residues applied on crops

Year	Crop area (ha)	Crop biomass, tons	Compost quantity (estimated), tons	N from compost (kg N)	N from crop biomass (kg N)
2006	834,029.1	8,340,291	526,512	4,212.096	8,115,103
2007	855,901.2	8,559,012	554,223	4,433.784	8,327,919
2008	875,944.3	8,759,443	583,393	4,667.144	8,522,938
2009	898,423.4	8,984,234	614,098	4,912.784	8,741,660
2010	923,528.7	9,235,287	646,419	5,171.352	8,985,934
2011	946,184.8	9,461,848	680,441	5,443.528	9,206,378
2012	970,180.1	9,701,801	716,254	5,730.032	9,439,852
2013	1,002,338.0	10,023,380	753,952	6,031.616	9,752,749
2014	1,012,161.7	10,121,617	793,634	6,349.072	9,848,333
2015	1,052,093.2	10,520,932	835,404	6,683.232	10,236,867
2016	931,043.7	9,310,437	879,373	7,034.984	9,059,055
2017	932,181.8	9,321,818	925,656	7,405.248	9,070,129

Source: Author’s calculation using default values from IPCC 2006.

5.9.3.5 Indirect N_2O emission from managed soils (3.C.5)

The indirect emission of Nitrous Oxide arises mainly from leaching and surface runoff of applied N applied to soil and later mineralized into the ground and surface water; N_2O volatilization from manure management; and atmospheric N deposition.

Table 5.37 Mineral fertilizers (in kg of N) used on main crops in Rwanda, 2006-2018

Crop	Annual	Tea	Coffee	Rice	Total N
	DAP, urea, NPK17-17-17	NPKS25-5-5-4S	NPK22-6-6	NPK17-17-17	
2006	4,517,210.0	583,500	462,050.0	0	5,562,760
2007	4,400,752.7	595,000	511,692.5	92,430.8	5,599,876
2008	3,852,224.4	621,179	561,335.0	227,365.6	5,262,104
2009	7,935,789.4	920,011	610,977.5	363,483.1	9,830,261
2010	4,308,591.4	677,500	660,620.0	319,728.6	5,966,440
2011	4,164,219.5	755,000	710,262.5	500,500	6,129,982
2012	8,336,535.5	769,000	759,905.0	577,019.5	10,442,460
2013	7,906,314.3	780,800	809,547.5	746,062.2	10,242,724
2014	4,532,070.4	1,202,150	859,190.0	1,171,385.6	7,764,796
2015	6,280,450.5	1,438,750	908,832.5	1,478,512	10,106,545
2016	4891,444.0	1,707,500	958,475.0	2,005,920	9,563,339
2017	3,577,479.0	1,996,260	1,081,162.0	2,189,120	8,844,021
2018	5,855,696.0	2,199,415	1,057,760.0	2,290,104	11,402,975

Source: MINAGRI MIS (2018); NAEB Annual reports 2011-12; 2012-13; 2013-14; 2014-15; 2015-16; 2016-17; 2017-18; RAB unpublished; RAB Annual report 2018-19.

For the estimation of direct and indirect N_2O emissions from managed soils, the following data were used:

1) Application rates of N-containing fertilizers per crop;
2) Quantity of fertilizers distributed to agro-dealers and quantities remaining in stock at the end of each season (RAB Fertilizer program, **Table 5.37**);
3) Quantities remaining at farmer stock after it was purchased from the agro-dealers (REMA, 2019a);
4) Crop residues returned to soil (IPCC software, new version released in Jan. 2020) as based on biomass production and dry matter of different crops data for each cropland sub-category (IPCC 2006; BUR study – REMA, 2019a);
5) Animal manure (IPCC software, new version released in Jan.2020) as based on livestock number and proportions applied to soil derived from crop management practices;
6) Compost quantity applied as reported by districts to MINAGRI MIS.
7) Management practices for major crop categories and rates of mineral fertilizer application.

5.9.3.6 Indirect N_2O emission from manure management (3.C.6)

The indirect N_2O emissions from manure management arise from N volatilization after manure has left the kraal, atmospheric deposition of nitrogen on soil and water surface, and the associated amount of manure that is lost from manure management systems.

5.9.3.7 Rice cultivation (3.C.7)

Methane emissions from rice cultivation are generated with anaerobic conditions in the soil following the flooding. The water regime and the quantity of crop residues applied back to the soil can affect emissions. In Rwanda, rice is grown with intermitted flooding and non-stop two seasons per year. Data for the rice area were sourced from the NISR SAS reports, and information on management practices and fertilizer rates applied was obtained from RAB.

In the IPCC Guidelines, direct and indirect emissions of N_2O from agricultural soils are estimated separately. The IPCC Guidelines method for estimating direct N_2O emissions from agricultural soils has two parts: (i) estimation of direct N_2O emissions due to N-inputs to soils (excluding N-inputs from animals on pasture, range, and paddock); and (ii) estimation of direct N_2O emissions from unmanaged animal manure (i.e., manure deposited by animals on pasture, range, and paddock).

The IPCC 2006 Guidelines divide the Agricultural Soil Management source category into five components: (1) direct emissions due to N additions to cropland and grassland mineral soils, including synthetic fertilizers, mulch, and crop residues applications, organic amendments, and biological N fixation associated with the planting of legumes on croplands; (2) direct emissions from soil organic matter mineralization due to land use and management change, (3) direct emissions from the drainage of organic soils in croplands and grasslands; (4) direct emissions from soils due to the deposition of manure by livestock on grasslands; and (5) indirect emissions from soils and water due to N additions and manure deposition to soils that lead to volatilization, leaching, or runoff of N and subsequent conversion to N_2O.

Direct N_2O emission was estimated from synthetic N fertilizers and manure/compost application; indirect N_2O emission from leaching and runoff, indirect N_2O emission from atmospheric N deposition, and direct N_2O from crop residues. A Tier 1 approach was applied.

5.9.4 Emission factors

5.9.4.1 Emissions from liming (3.C.1)

In Rwanda, the only limestone is applied for agricultural purposes, and therefore its default emission factor, which 0.12 according to the Tier 1 of the 2006 IPCC guidelines was used.

5.9.4.2 Urea application (3.C.2)

The default emission factor for urea was used which is 0.2 tonnes C per tonne of urea (IPCC 2006, Vol. 4, Ch. 11), and Tier 1 was used.

5.9.4.3 Biomass burning (3.C.3)

Tier 1 was used with default values on non-CO_2 emissions from biomass burning with biomass of 46.5t/ha combustion factor of 0.5 and an emission factor of 2.3g GHG/1dm of biomass burnt (IPCC 2006, 2006). The GHG emissions from biomass burning were estimated using the equation 2.27 of the 2006 IPCC guidelines of the IPCC guidelines (IPCC 2006, 2006).

5.9.4.4 Emissions from managed soil (3.C.4 and 3.C.5)

The GHG emissions from managed soil were calculated using a Tier 1 method according to the IPCC GHG Inventory Software, which is based on the 2006 IPCC guidelines. The equation for estimating direct N_2O emissions was, however, adapted to local conditions, and certain activities were excluded from it because of their limited extent in the local context. The equation 11.1 of the IPCC guidelines was used to estimate the direct N_2O from managed soils (IPCC 2006, 2006). The choice of emission factors for direct and indirect N_2O emissions used are shown in **Table 5.38.**

Table 5.38 Emission factors used to calculate direct and indirect N_2O emissions from managed soil

Source	Parameter	Unit	EF	Source
Direct N_2O emission from managed soil	N in synthetic fertilizer	Kg N_2O-N/kg N input	0.01	IPCC 2006, Vol.4, Chap.
	N in animal manure, compost, mulch, and other	Kg N_2O-N/kg N input	0.01	IPCC 2006 tool
	N in mineralized soil that is mineralized in association with loss of soil C from soil organic matter as a result of changes to land use or management	Kg N_2O-N/kg N input	0.01	IPCC 2006 tool
	N in crop residues	Kg N_2O-N/kg N input	0.01	IPCC 2006 tool
Indirect N_2O emission from managed soils	Fraction of synthetic fertilizers that volatilizes (GASF)	Kg NH_3-N + NO_X-N	0.1	IPCC 2006 tool
	Fraction of applied organic N fertilizer, urine, and dung N deposited by grazing animal that volatilizes	Kg NH_3-N + NO_X-N	0.2	IPCC 2006 tool
	Fraction of all N addition that is loss through leaching &run-off	Kg N/kg N additions	0.3	IPCC 2006 tool

Source	Parameter	Unit	EF	Source
	N_2O from N leaching/ run-off	Kg N_2O-N/kg N leaching/run-off	0.0075	As per IPCC 2006 tool

Source: IPCC Guidelines 2006, Vol.4 (AFOLU), Ch.11, Table 11.1 and 11.3.

5.9.4.5 Emissions from Rice cultivation (3.C.7)

The emissions for rice considered the following management practices: continuous rice cultivation on the same area (therefore with flooding of more than 30 days in preceding season); growing of 2 crops per year non-stop; intermittent flooding; rice straw incorporated back to soil shortly before sowing the next crop, no organic fertilizer applied (**Table 5.39**).

Table 5.39 Emission factors used for different rice management practices

Management practice	Emission factor	Reference
Continuous rice cultivation on the same area with flooding of more than 30 days in the preceding season	1.3 kg CH_4/ha per day	IPCC 2006, Ch.5, Table 5.11
Water regime intermitted flooding with multiple aerations	0.52	IPCC 2006, Ch.5, Table 5.12
Differences in water regime in pre-season	1.9	IPCC 2006, Ch.5, Table 5.13
The application rate of the organic amendment (fresh rice straw)	1.5	Local data, Rice expert at RAB consultation
The conversion factor for organic amendment	1	
Scaling factor for soil type and rice cultivar	1	

The emissions from rice are estimated using the equation 5.1 of the 2006 IPCC guidelines (IPCC 2006, 2006).

5.9.5 3.3.3 QA/QC (specific to this sector)

The activity data were gathered mainly from the official agriculture statistics published in national documents such as Seasonal Agricultural Surveys of NISR. All the data appearing in these official documents were further crosschecked with relevant institutions working in their respective sectors. Specific and relevant data were also obtained from research work published locally and in international journals as well as annual and technical reports from the different research institutions.

All the data used were reviewed during peer review meetings with stakeholders and research staff. Moreover, the inventory team performed Quality Control procedures using routine and consistent checks to identify errors and omissions. All calculations made during the exercise used approved standardized procedures for emissions calculations, measurements, and documentation as per IPCC guidelines. Furthermore, the inventory process was carried out under close supervision of REMA to ensure compliance with IPCC guidelines.

5.9.6 Time series

There have been minor fluctuations in emissions for most of the sub-categories between the years. The exception was urea, as in 2017; there was a significant decrease in the quantity of urea distributed to agro-dealers. This caused significant annual fluctuation in the quantity of mineral N fertilizer applied to soil, where mineral N fertilizer was the major contributor to GHG emissions. This decrease in urea in 2017 may be linked to the reduced imports of urea from outside of the country or delays in the purchase of urea from the farmers' side. The main trend was a gradual slight increase in the emissions following the trend of a slow increase in cropland.

5.9.7 3.3.5 Recalculations

5.9.7.1 Biomass burning (3.C.1)

There were no recalculations since this sub-category was not reported in the previous inventories.

5.9.7.2 Liming (3.C.2)

No recalculations were conducted on liming since, due to the lack of activity data on lime production, this sub-category was not reported in the previous inventories.

5.9.7.3 Urea (3.C.3)

The emissions from urea were reported as very high in the previous inventory reported in the TNC. This happened because of a mistake in the unit reading of the reported data. The results of the recalculations conducted in the urea application are summarized in **Table 5.40.**

Table 5.40 Results of recalculations from urea 2006-2015.

	Urea (3.C.3)									
Year	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**
PD	3,858.88	4,014.94	4,171.01	4,375.39	5,359.86	6,344.32	5,694.18	6,610.53	7,526.87	8,443.21
LD	1.55	2.17	1.86	3.98	2.40	3.64	5.96	8.49	2.21	7.74
% change	-99.96	-99.95	-99.96	-99.91	-99.96	-99.94	-99.90	-99.87	-99.97	-99.91

5.9.7.4 Direct N_2O emissions from managed soils (3.C.4)

The recalculations of the direct emissions from managed soil showed a 22.9 to 43.5% decrease as compared with previous data (TNC), which was caused using the new version of IPCC software, proportions of biomass and compost use as well as updated data on fertilizer applications per crop (**Table 5.41**).

Table 5.41 Recalculations of Direct N_2O emissions from managed soils for 2006-2015.

	Direct N_2O emissions from managed soils									
Year	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
PD	381.15	403.39	511.36	594.85	629.14	662.27	565.77	522.11	478.64	551.15
LD	293.85	314.00	322.94	356.02	355.54	342.15	381.47	368.36	354.23	377.33
% change	-22.9	-22.2	-36.8	-40.1	-43.5	-48.3	-32.6	-29.4	-26.0	-31.5
Reason for recalculations	Updated data on compost, proportions of fertilizers on crops.									

5.9.7.5 Indirect N_2O emissions from managed soils (3.C.5)

Recalculations were done for 2006-2015 to adjust the values reported in TNC, and they were slightly decreased by 38 to 56.5% as compared to the TNC values (**Table 5.42**).

Table 5.42 Recalculations of Indirect N_2O emissions from managed soils for 2006-2015

	Indirect N_2O emissions from managed soils									
Year	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**
PD	132.28	140.43	175.31	201.78	212.08	222.46	196.57	185.07	170.12	191.03
LD	78.89	87.09	90.65	101.64	102.25	96.71	119.97	105.42	101.02	109.77
% change	-40.4	-38	-48.3	-49.6	-51.8	-56.5	-39	-43	-40.6	-42.5
Reason for recalculations	Updated data on compost, proportions of fertilizers on crops.									

The recalculation of the Indirect N_2O emissions from manure showed a 54.6-58.2 % decrease as compared to the previous data (TNC) (**Table 5.43**). The changes were due to the discovery of a new dataset on manure quantities.

Table 5.43 Recalculations of Indirect N_2O emissions from manure for 2006-2015.

	Indirect N_2O emissions from manure									
	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
PD	108.02	119.03	129.99	136.87	147.58	138.49	145.47	146.77	146.08	148.18
LD	49.07	54.35	56.99	59.71	64.96	58.97	60.96	61.38	61.68	65.84
% change	-54.6	-54.3	-56.2	-56.4	-56	-57.4	-58.1	-58.2	-57.8	-55.6
Reason for recalculations	New data on manure management after recalculations.									

The recalculations of GHG emissions for the TNC period (2006-2015) for rice resulted in a 33.9-123.8% change (**Table 5.44**).

Table 5.44 Recalculation of rice emissions (2006-2015)

Rice cultivation emissions (Gg CO_2 eq.)										
Year	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
PD	118.54	181.40	166.69	177.66	117.20	130.89	103.11	100.17	90.98	98.33
LD	212.42	242.92	298.77	318.42	210.07	227.07	171.74	175.91	198.16	220.10
% change	79.2	33.9	79.2	79.2	79.2	73.5	66.6	75.6	117.8	123.8
Reason for recalculation			Updates in the IPCC methodology/software							

This is caused by updated data on management practices and sometimes rice areas. **Table 5.444** shows the parameters used for rice in TNC and the current inventory. The main differences in emission factors applied were in EF for the pre-season. The TNC considered non-flooded pre-season with EF=1, while the current inventory accounted for continuous cultivation of rice on the same area, which happens, and the shift of rice growing from one field to another does not happen because of lack of area to switch to for rotation. Thus, the EF for preseason flooded for more than 30 days is equal to 1.9 (**Table 3.45**). The current inventory has updated data for rice biomass applied to the field and judged some over-estimation for rice biomass, especially between 2006 and 2011. However, since due to the lack of locally measured data on rice biomass applied back to the rice field, an expert judgment of rice scientists at RAB was used.

Table 5.45 Parameters and emission factors used to determine CH_4 emissions from rice in TNC and current inventory (recalculations)

	Previous inventory (TNC)								Current inventory							
	Cult. period	Baseline EF for flooded field+ no organic	Scaling factor for water regime, current season	Scaling factor for water regime, the previous season	Biomass applied	The conversion factor for applied biomass	Rice area, ha		Cult. period	Baseline EF for flooded field+ no organic	Scaling factor for water regime, current season	Scaling factor for water regime, the previous season	Biomass applied	The conversion factor for applied biomass	Rice area, ha
2006	180	0.52	1.3	1	7.5	1	13,124	180	1.3	0.52	1.9	6.7	1	13,121
2007	180	0.52	1.3	1	7.5	1	20,084	180	1.3	0.52	1.9	6.7	1	15,005
2008	180	0.52	1.3	1	7.5	1	18,455	180	1.3	0.52	1.9	6.7	1	18,455
2009	180	0.52	1.3	1	7.5	1	19,669	180	1.3	0.52	1.9	6.7	1	19,669
2010	180	0.52	1.3	1	7.5	1	12,976	180	1.3	0.52	1.9	6.7	1	12,976
2011	180	0.52	1.3	1	6.0	1	16,250	180	1.3	0.52	1.9	5.0	1	16,250
2012	180	0.52	1.3	1	4	1	15,612	180	1.3	0.52	1.9	3.0	1	15,612
2013	180	0.52	1.3	1	3	1	17,302	180	1.3	0.52	1.9	2.5	1	17,302
2014	180	0.52	1.3	1	2	1	18,621	180	1.3	0.52	1.9	1.5	1	23,770
2015	180	0.52	1.3	1	2	1	20,125	180	1.3	0.52	1.9	1.5	1	26,402

5.9.8 Planned Improvements

To improve the quality of the GHG emission assessment in agriculture, more research is required: research surveys should be done soon to assess:

i. the area of cultivated organic soils (which is currently not disaggregated in agriculture statistics);
ii. the volume of peat produced (in air-dried weight) as well as the inventory of the existing peat-producing enterprises;
iii. the extent and volume of seasonal burning of agricultural residues;
iv. regular data on savannah burning (frequency and extent in Akagera National Park);
v. crop biomass seasonal production volumes for different crops including perennial banana plants;
vi. the proportion of fertilizer type and quantity used per crop vs annual rates and proportion of farmers using fertilizer on each crop;
vii. determine real quantities of crop residues and manure applied over the whole season, including not just crop biomass at harvest, but In addition weeds removed;
viii. N content in crop residues and weeds;
ix. Changes in soil N and C after Land Use change and their dynamics (longer-term research on soil restoration.

Chapter 6. Waste sector

6.1 Sector overview

The inventory was performed at the level of IPCC categories and subcategories, from which the IPCC methods and decision trees are generally provided in the sectoral volumes. For that purpose, we adapted the recommended categories to the national circumstances. Based on the country context and the data availability, the categories considered for wastes sector estimations and the corresponding methods are summarized in **Table 6.1.** The results have been computed using either available data from various literature or by using default values provided in the IPCC 2006 guidelines. The current results show a slight growth of emissions in all subcategories mainly due to the increasing population in the same period and changes in the main mode of waste management.

Table 6.1 Overview of waste sector categories and methods

2006 IPCC Categories	Gas	2018 emissions	Contribution to total waste emissions (%)	Key categories	Uncertainty (%)	Methods
4.A - Solid Waste Disposal	CH_4	446.39	48.67	☐	15.81	Tier 1
4.B - Biological Treatment of Solid Waste	CH_4	75.10	8.19		7.07	Tier 1
4.B - Biological Treatment of Solid Waste	N_2O	66.52	7.25		7.07	Tier 1
4.C - Incineration and Open Burning of Waste	CO_2	3.04	0.33		15.81	Tier 1
4.C - Incineration and Open Burning of Waste	CH_4	14.80	1.61		15.81	Tier 1
4.C - Incineration and Open Burning of Waste	N_2O	2.85	0.31		15.81	Tier 1
4.D - Wastewater Treatment and Discharge	CH_4	145.21	15.83	☐	33.54	Tier 1
4.D - Wastewater Treatment and Discharge	N_2O	163.25	17.80		30.41	Tier 1

6.2 Summary and trends in waste sector GHG emissions

Trends and shares of the waste sector's GHG emissions are depicted in **Figure 6.1.** In general, the GHG emissions in the waste sector had a steady growth at an annual growth rate of 4% from 2006 to 2018.

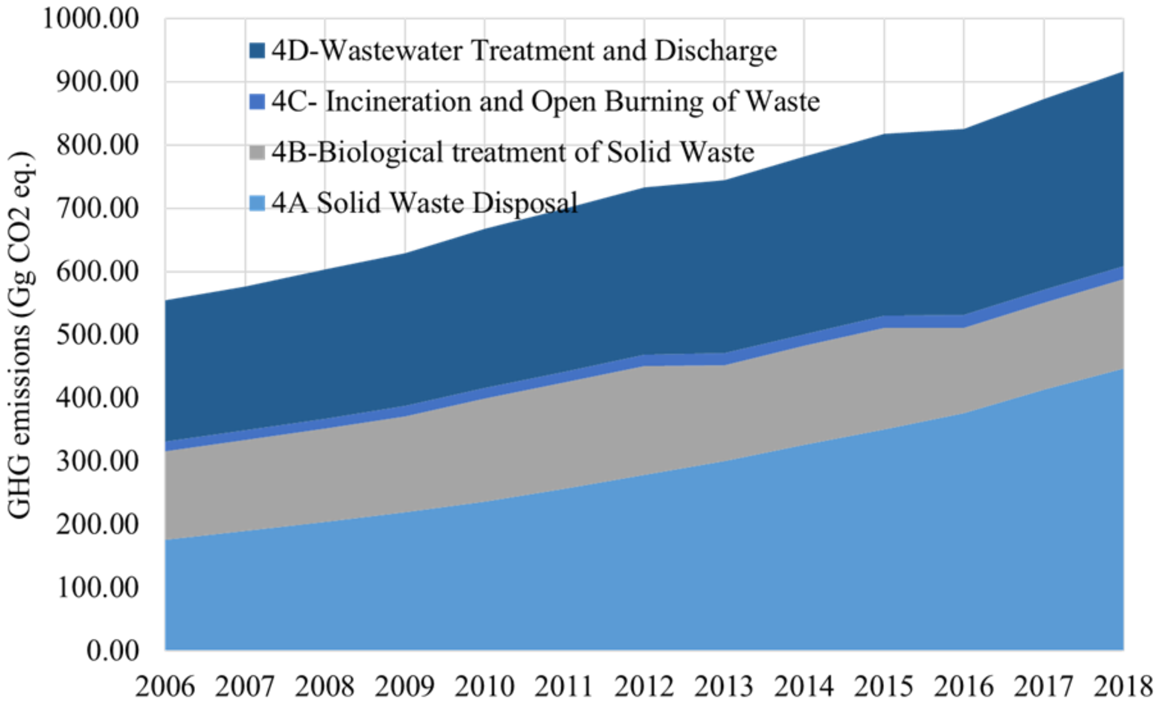


Figure 6.1 Trends and shares of GHG emissions from the waste sector

Table 6.2 Summary of GHG emissions from waste, Gg CO_2 eq. (2006-2018)

	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
4	555.16	576.23	603.69	629.66	667.70	700.31	733.22	745.03	781.74	817.33	825.55	872.58	917.16
4.A	175.36	189.71	204.09	219.92	235.69	257.13	278.25	300.02	326.41	351.18	376.58	413.02	446.39
4.B	140.02	143.66	147.39	151.23	163.41	167.66	172.16	152.54	156.06	159.64	135.10	138.33	141.61
4.C	15.31	15.70	16.12	16.53	16.96	17.40	17.86	18.23	18.65	19.08	19.73	20.20	20.69
4.D	224.48	227.16	236.09	241.98	251.64	258.12	264.94	274.25	280.63	287.43	294.15	301.02	308.46
4.E	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
5	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
5.A	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
5.B	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO

4 - Waste 4.A - Solid Waste Disposal 4.B - Biological Treatment of Solid Waste 4.C - Incineration and Open Burning of Waste 4.D - Wastewater Treatment and Discharge 4.E - Other (please specify) 5 - Other 5.A - Indirect N_2O emissions from the atmospheric deposition of nitrogen in NO_X and NH_3 5.B - Other (please specify), NO: Not occurring

Recalculations were conducted in solid waste disposal subcategories based on the improvement of waste composition for the whole inventory period, due to survey results on waste composition in Rwanda conducted in 2019 by REMA and the EICV5 data on the main mode of waste management in Rwanda. In addition, recalculations were conducted in the biological treatment of solid waste subcategories based on improved data for composting on own property in Rwanda as reported in EICVs. For incineration and open burning, the improvement was made by estimating the open burning subcategory, which was not considered in TNC due to the lack of data. In addition, there was a correction of errors in the incineration results of TNC where the GWP, i.e., N_2O and CH_4 were exchanged during the data processing. Finally, the methodology used during the TNC for estimating the emissions from wastewater treatment and discharge was improved by considering the fraction of wastewater treatment type per household approach as reported by NISR through the EICV main indicators reports.

6.3 Solid waste disposal (4A)

6.3.1 Source category description

Rwanda is recording a rapid population growth associated with the rapid urbanization process. The total population has increased from 8.12 to 12.08 million from 2002 to 2018, respectively (NSC, 2002, NISR, 2018). The change in population from the recent GHG in 2015 to 2018 is estimated to 864,530. The increase in population growth is resulting in high demand for public services including solid waste management services. This high demand for waste service has overshot the capacity of the public sector to provide the service alone, which has opened door to the involvement of the private sector in waste collection for Kigali and other cities as well.

6.3.2 Overview of shares and trends in emissions from Solid waste disposal

Figure 6.2 provides the trend in CH_4 emissions from solid waste ending into disposal sites at the national level considering the period from 2006 to 2018. The emissions from SWDS increases from 176.36 Gg CO_2eq to 446.39 Gg CO_2eq. from 2006 to 2018, respectively. The increasing methane emissions from the solid waste sector are mainly explained by the involvement of the private sector in the solid waste collection which has increased waste collection rate and hence, increasing waste ending into a dumpsite. The emissions from SWDS reported in TNC have been recalculated to account for the survey data on the waste composition, the wasted collection rate as proposed in EICV reports, and the accumulated waste over a period of 50 years. However, the introduction of these new data has significantly changed the previous emissions from SWDS reported to range from 24.04 Gg CO_2eq to 186.99 Gg CO_2eq from 2006 to 2015 respectively (GoR, 2018).

The IPCC 2006 approach 1 for key categories analysis was considered by using a pre-determined cumulative emissions threshold where key categories are those that, when summed together in descending order of magnitude, add up to 95 percent of the total level. Therefore, three waste categories have been identified to be the key categories in Rwanda: Solid waste disposal (4A) with 49.6%, Wastewater treatment and discharge (4D) with 34.34%, and

Biological treatment of solid waste (4B) with the contribution of 15.7%.

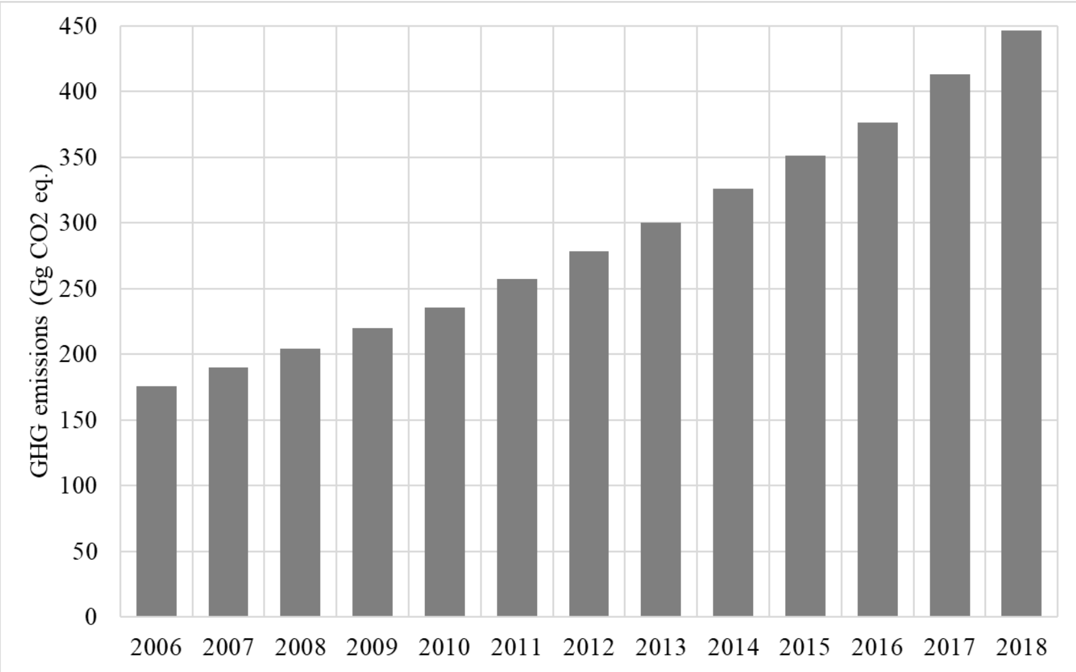


Figure 6.2 Trend in CH_4 emissions from Solid waste disposal sites (2006-2018)

6.3.3 Methodology, choice of activity data, and emission factors

Following the IPCC 2006 guidelines, all disposal sites in Rwanda fall in the subcategory of unmanaged waste disposal sites (4.A.2) as waste is disposed of on top of hills. From the expert judgment, unmanaged waste disposal sites in Rwanda were categorized into deep for Kigali where waste is dumped into a whole of >5m deep and shallow for other cities where a big fraction of disposed of waste is dumped on the surface and a small fraction dumped into a whole of <5m deep. From this observation, the expert has assumed that 60% of waste disposal sites are unmanaged deep and 40% are unmanaged shallow considering that the fraction of solid waste to SWDS is higher in Kigali than in other cities. The population data used to estimate the total solid waste ending in landfill sites is given in Appendix 1.

Based on the limited availability of country-specific data, Tier 1 model has mainly been used combined with some country-specific data available to estimate emissions from waste disposal sites. The percentage of the households that receive the waste collection services was used to account for the quantity of waste ending in SWDS. It should be noted that the TNC emissions from SWDS were based only on cities assuming that only urban areas in Rwanda receive the waste collection services.

6.3.3.1 Emissions calculation

CH_4 emissions normally result from the degradation of organic material under anaerobic conditions. The computation of CH_4 emissions from solid waste disposal has been made using the equation 6.1 of the IPCC guidelines (IPCC 2006, 2006). For the case of Rwanda there is no CH_4 recovery, i.e., almost all generated CH_4 emissions are emitted. This is the main reason of the highest contribution of solid waste disposal to CH_4 emissions from the waste sector.

The amount of CH_4 formed from degradable organic material was computed by multiplying the fraction of CH_4 emissions in the total generated landfill gas and the CH_4 /C molecular weight ratio according to the equation 6.2 of the 2006 IPCC guidelines.

6.3.3.2 Choice of activity data and methane correction factors

The following input activity data have been used: urban population, waste generation, and disposal rates and methane correction factor (MCF), and other factors provided in IPPC 2006 Guidelines, Vol.5, and Ch. 3 such as Degradable Carbon Fraction (DCF).

The population was estimated based on the third population census data published in 2002 (NSC, 2002) and Rwanda 4th Population and Housing Census, 2012 (NISR, 2014). The population from 1965 to 2001 has been referred to in the record from the World Population Prospects (United Nations, 2015). The distribution of solid waste (%) of households by the main mode of waste management was informed by the EICV reports as detailed in **Table 6.3**.

Due to limited country-specific data, the following assumptions have been made to estimate emissions from solid waste disposal:

- Waste Generation rate is considered constant for both time series and an African region default value of 0.29 tonnes/cap/year has been used to estimate total municipal waste taken from (IPCC 2006, 2006);
- The coverage rates at the Household level in waste collection services was based on the changes that happened in the waste collection from 2000 until 2017 as detailed in table 13 below with reference from EICV 2 to EICV 5;
- It is In addition assumed that all collected wastes end into SWDS;
- Background quantity of waste and emissions were estimated starting from the year 1965;
- Waste generation rate in industries was assumed constant: 0.1 Gg/$m GDP/year because industries in Rwanda are still at the low development stage (expert judgment).

Table 6.3 Distribution of households by the main mode of waste management in Rwanda (%)

Period	2016-2017	2013-2014	2010-2011	2005	2000	Source
Waste collection service (% HH)	8.3	6.2	5	3.9	3.2	EICV 5 (NISR, 2018)
Burnt (% HH)	0.1	0.1	0	0.1	1.2	EICV 4 (NISR, 2015)
Compost on own property (% HH)	42.5	51.6	59.4	56.4	-	EICV 3 (NISR, 2012)
Other management (% HH)	57.4	42.1	35.6	39.6	95.6	EICV 2 (NISR, 2005)

It is important to note that for this report, the category of other management has combined the categories in EICVs reported as waste thrown in household fields/bushes, waste in the publicly managed refuse area, waste dumped in rivers, waste in lakes and ditches, and other ways of rubbish disposal.

The choice of correction factors has based on the following assumptions:

- While Rwanda is classified among countries with a mixture of tropical wet and dry climates, the conditions of tropical wet climate have been used since the large percentage of disposed waste (70%) is organic waste.
- The default value of 0.4 and 0.8 for MCF has been used considering that the disposal sites fall in the category of unmanaged shallow and unmanaged deep categories, respectively (IPCC 2006, 2006).
- Considering the landfills classification and the municipal wastes quantities collected, it was assumed that types of unmanaged shallow and unmanaged deep landfills are respectively 40% and 60% (GoR, 2018).
- The percentage of industrial waste that goes to the unmanaged shallow and unmanaged deep landfills was estimated at 20% and 80%, respectively, based on the expert judgment, considering that the fraction of solid waste to SWDS is higher in Kigali and secondary cities where unmanaged deep landfills are mainly located.
- The percentage of industrial wastes that end in SWDS was estimated at 60% based on expert judgment.

6.3.4 Uncertainty and time-series consistency

The key uncertainties are that industrial waste is collected mixed with municipal solid waste by private companies. In addition, it is assumed that all collected waste as detailed in EICV reports ends in the dumpsites. The following uncertainty ranges were therefore used for this source category:

- Activity data uncertainties: ±15%
- Emission factor uncertainties: ±5%

6.3.5 Quality assurance and Quality control

This report was produced by making a continuous crosscheck of user activity data, emission factors, and inventory results with default values provided in IPCC 2006 Guidelines and following the instructions provided on QA/QC (IPCC, 2006, Vol. 5_3_ch3, pp 3.28). In addition, the data used were verified during the workshop session. With the support of an international consultant, further QA was conducted.

6.3.6 Solid waste disposal recalculations

Recalculations were conducted in solid waste disposal subcategories based on the improvement of waste composition for the whole inventory period, due to survey results on waste composition in Rwanda conducted in 2019 by REMA and the EICV5 data on the main mode of waste management in Rwanda. In addition, the change in methodology was made by considering the emissions from at least the last 50 years from the year 1965 while during the TNC the inventory started from 2004. The comparison of the data collected during the 2019 survey on waste composition in Rwanda and the assumption used during the GHG inventory for the Rwanda TNC shows that there is a significant difference in the proportion of textiles. Whereas it was previously assumed that 18% of wastes is textile, the recent survey data shows 5% throughout the whole country (**Figure 6.3**).

6.3.7 Specific planned improvements and recommendations

The percent composition in different waste categories in Rwanda has shown significant changes compared to the previous expert judgment composition used in the third national communication, and this will benefit the improvement for the estimate of GHG in the waste sector. Other improvements should focus on developing methodologies for data collection in the waste sector through the partnership of NISR, which regularly collects national data. To move to country-specific statistics, the data collected by NISR should be aligned with the needed data for the inventory, which is not always the case.

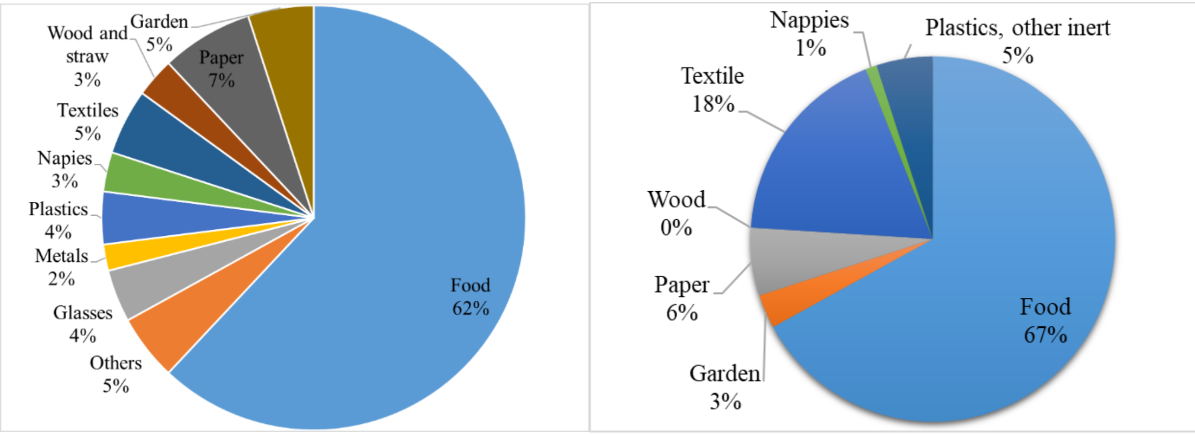


Figure 6.3 Percent composition of solid waste in Rwanda. Survey data (left) and assumption data (right)

Source: (REMA, 2019b)

This implies significant changes when recalculating the previous emissions by using recent data. It should also be reminded that the waste composition changes with the population affluence throughout the time, however, this improvement was not included in the calculations due to the lack of baseline data in the past 50 years. The results of recalculation in the solid waste disposal sector are presented in **Figure 6.4**.

Table 6.4 Results of recalculations conducted in Solid Waste Disposal Sites

	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
PD (Gg CO_2 eq.)	24.04	41.51	54.68	64.93	73.04	79.82	85.7	119.22	152.82	186.99
LD (Gg CO_2 eq.)	175.36	189.71	204.09	219.92	235.69	257.13	278.25	300.02	326.41	351.18
Difference (%)	629.46	357.07	273.25	238.68	222.69	222.13	224.69	151.64	113.6	87.8

6.4 Biological Treatment of Solid Waste (4B)

6.4.1 Biological Treatment of Solid Waste category description

It is estimated that more than 80% of the Rwandan population lives on agriculture activities and the main source of soil amendment is the use of household-made compost. The composted waste includes mainly food, park, and wet garden waste. On one hand, **Table 6.4** shows the increasing percentage of household solid waste collection at the national level from 3.2% in 2000 to 8.3% in 2017. This contributes to the increasing CH_4 emissions from the solid waste disposal source category, which also the case for many cities in Rwanda. On the other hand, the percentage of households at the national level with waste undergoing composting decreases from 56.4% in 2003 to 42.5% in 2017. This could be explained by the increasing urbanization and increased involvement of the private sector in waste collection services.

In general, households in rural areas are deprived of solid waste collection services. Each household digs an open shallow disposal site where organic and non-biodegradable components are disposed of. Following natural decomposition, both components are separated after decomposition and organic matter used as compost in farms and non-biodegradable exposed to open burning although this study has remained inconclusive to open burning status due to data limitation. This has contributed to the increasing amount of solid waste treated by biological facilities associated with population growth.

6.4.2 Overview of shares and trends in emissions

Figure 16 shows that methane emissions have slightly increased from 2006 to 2012 followed by a modest decrease in the following years. In addition, **Figure 6.4** shows a similar trend in N_2O emissions. The noticeable slow change is due to the mentioned reduction in households at the national level with waste treated by composting.

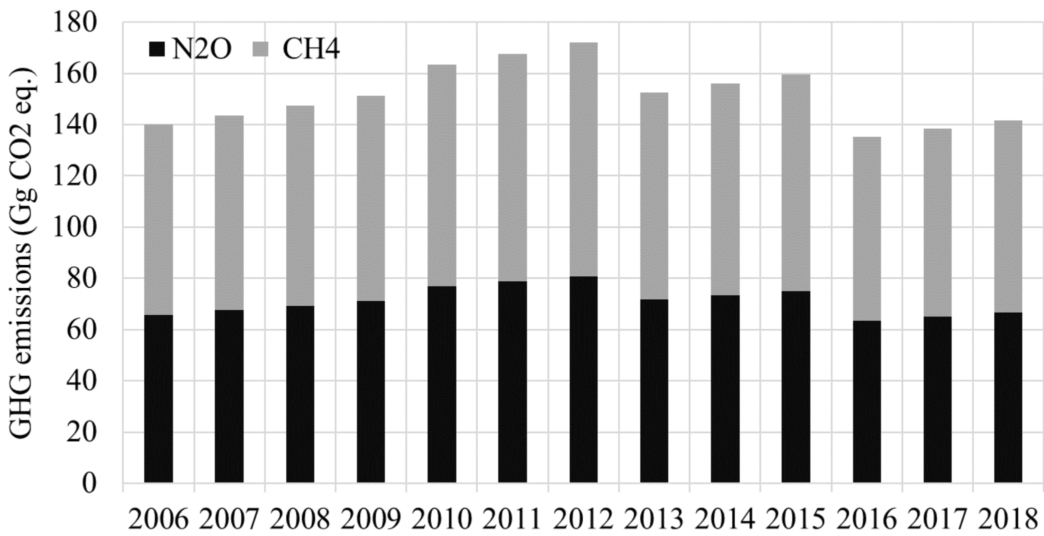


Figure 6.4 Trend of GHG emissions from Biological Treatment of Solid waste

The estimated CH_4 emissions from Biological treatment of solid waste ranges from < 1% to a few percent of the initial content in carbon in the compostable material (IPCC 2006, 2006). Likewise, Petersen et al. (1998); Hellebrand (Hellebrand, 1998), Vesterinen (Vesterinen, 1996), Beck-Friis (Beck-Friis, 2001); and Detzel et al. (Detzel, Vogt, Fehrenbach, Knappe, & Gromke, 2003) argue that biological treatment can produce N_2O emissions ranging from < 0.5% to 5% of the initial nitrogen content. On the other hand, Vesterinen (Vesterinen, 1996) argues that poorly managed composting processes can produce both CH_4 and N_2O. In this inventory, shares of N_2O and CH_4 emissions are 9% and 4%, respectively, which are higher than the above-mentioned range values. This is explained by the fact that compost is made in anaerobic conditions where it is made in dug completely allowing aeration only at surface level (0.5 m) and the rest is strictly anaerobic as discussed in the above section.

6.4.3 Methodology, choice of activity data, and emission factors

Biological treatment of solid waste has considered the household percentage using composting, which was assumed to be in the range of the same population fraction as discussed above. The following input activity data has been considered to compute emissions from this source category:

- Population making compost at household level;
- The percentage of HH using compost has referred to EICV data as detailed in table 13;
- The quantity of waste composted based on the total population with biological treatment method for waste, assuming 0.29 ton/cap/year (IPCC 2006, 2006);
- The fraction of waste composted was assumed to be 60% considering that more than 62% of biodegradable waste is food waste from kitchen waste (REMA, 2019b);
- There is no methane recovery, i.e., the total generated methane is released to the environment;
- The total annual amount of waste treated by biological treatment facility, and
- Biological treatment emission factor (EF).

6.4.3.1 Emissions calculation

The estimation of CH_4 and N_2O emissions from biological treatment of solid waste has been computed using 4.1 and 4.2 of the 2006 IPCC guidelines (IPCC 2006, 2006) and default emission factors as discussed above.

6.4.3.2 Choice of Activity data and emission factor

The total population making compost has been computed using the values on the number of households making the compost as detailed in table 13, and the corresponding national population from 2005 until 2018 taken from Rwanda 4th Population and Housing Census (NISR, 2014). For the EF of the Biological treatment, default values of 4 g/CH_4/ kg for methane emission, and 0.24 g/N_2O/kg for N_2O emissions were taken from (IPCC 2006, 2006). The latter values were chosen under the assumption that the moisture content of compostable material is greater than 60% as food waste composted is treated in open areas (no cover), commonly known as “Ingarani” or “ikimoteri” for most households. However, it should be noted that the previous assumption of 2 g/CH_4/ kg for methane emission and 0.3 g/N_2O/kg for N_2O emissions used in TNC were changed to account for the wet climatic condition of Rwanda. From the above, user activity data and emission factors are summarized in **Table 6.5**.

Table 6.5 Activity data and emission factors for biological treatment of solid waste

Year	Total annual amount treated by biological treatment facilities [Gg]	CH_4 Emission factor [g CH_4/kg waste treated]	N_2O Emission factor [g N_2O/kg waste treated]	Recovered methane per year [Gg]
2006	883.96	4	0.24	0
2007	906.94	4	0.24	0
2008	930.52	4	0.24	0
2009	954.71	4	0.24	0
2010	1,031.64	4	0.24	0
2011	1,058.46	4	0.24	0
2012	1,086.89	4	0.24	0
2013	962.98	4	0.24	0
2014	985.22	4	0.24	0
2015	1,007.84	4	0.24	0
2016	852.90	4	0.24	0
2017	873.30	4	0.24	0
2018	894.03	4	0.24	0

Source: The total annual amount of compost was adapted from the average household size in the rural area and the population that compost their waste: (NISR, 2005, 2012, 2015a, 2018a)

6.4.4 Uncertainty and time-series consistency

The uncertainties are derived mainly from the composted amount based on EICV reports. Based on the IPCC 2006 Guidelines on uncertainty assessment for biological treatment (Vol.5_4_CH_4_Bio_Treat, pp 4.7), the uncertainty range of ±5 was used for both activity data and emission factors and for both CH_4 and N_2O, based on the availability of data on population using compost in Rwanda as detailed in EICV reports.

6.4.5 Quality assurance and Quality control

The GHG estimation was produced by making a continuous cross-check of user activity data, emission factors, and inventory results with default values provided in IPCC 2006 Guidelines and following the instructions provided on QA/QC (IPCC, 2006, Vol. 5_3_ch3, pp 3.28) and as proposed in IPCC (2006, Vol.5_4_CH_4_Bio_Treat, pp 4.7). Quality assurance was conducted with the support of an international consultant.

6.4.6 Biological Treatment of Solid Waste recalculations

Recalculations were conducted in the biological treatment of solid waste subcategories based on improved data for composting on own property in Rwanda from NISR (2012), NISR (2014), NISR (2015), and NISR (2018) as detailed in **Table 6.6.** There has been a huge improvement to make easy the future inventory by only considering the EICV data and reducing the assumption that was used during the TNC to compute the emissions in 4.B category considering only rural population while 4.A-category has considered only urban population. The current inventory has resulted in an improved estimate of emissions, especially in the period before the 2012 Population and Housing Census in Rwanda. The previous assumptions were based only on the population using compost taken from Rwanda's 4th Population and Housing Census in 2012 (NISR, 2014), which was mainly in rural areas, and the fact that composting in urban areas was at the infant level where few companies are still exploring composting opportunities.

Table 6.6 Results of recalculations conducted in Biological Treatment of Solid Waste

Year	N_2O	N_2O	CH_4	CH_4	Total annual emissions (Gg CO_2 eq.)	Total annual emissions (Gg CO_2 eq.)	Difference
	TNC	BUR 1	TNC	BUR 1	TNC	BUR 1	%
2006	72.67	65.77	32.82	74.25	105.50	140.02	32.73
2007	76.08	67.48	34.36	76.18	110.44	143.66	30.08
2008	79.65	69.23	35.97	78.16	115.62	147.39	27.49
2009	83.38	71.03	37.66	80.20	121.04	151.23	24.94
2010	87.29	76.75	39.42	86.66	126.71	163.41	28.97
2011	91.38	78.75	41.27	88.91	132.65	167.66	26.39
2012	96.69	80.86	43.67	91.30	140.36	172.16	22.66
2013	100.15	71.65	45.23	80.89	145.38	152.54	4.92
2014	104.84	73.30	47.35	82.76	152.19	156.06	2.54
2015	109.76	74.98	49.57	84.66	159.33	159.64	0.20

6.4.7 Specific planned improvements and recommendations

Planned improvement should focus on developing methodologies for data collection in the biological treatment of the solid waste sector through the partnership with the NISR, which regularly collects national data.

6.5 Incineration and Open Burning of Waste (4C)

Based on the prohibition for open burning, from the Organic Law of the environment N° 04/2005 of April 2005, which has recently been amended, by the law n°48/2018 of August 2018 on the environment, the public sector ought to prohibit burning except for incineration. With this approach, the open burning restriction is becoming a custom, and only illegal practices exist out of the sight of the municipalities. This is the main reason data on open burning were not considered in TNC. However, after a complaint from REMA and other local administrative authorities that open burning is still practiced, a review of the available data and expert judgment has allowed estimating the quantity of waste openly burned.

6.5.1 Incineration and Open Burning of Waste category description

In Rwanda, incineration is generally applied in clinical wastes where each health facility is supposed to have an incinerator. Even though clinical waste is mainly incinerated in Rwanda, there is a need to consider other types of solid waste undergoing incineration such as industrial waste, expired goods such as drugs, and other hazardous waste to estimate the accurate contribution of incineration emissions. However, there is no consolidated data at the ministerial level to have the amount of incinerated waste at the country level. The estimation of emissions from incineration has then covered clinical waste incineration where one-year data (2014) was provided by REMA (REMA, 2016). Emissions from solid waste incineration are negligible compared to other emissions from the waste sector as discussed in the previous sections.

6.5.2 Overview of shares and trends in emissions

Figure 6.5 shows the trend of emissions from solid waste incineration and open burning for the total of CO_2, CH_4, and N_2O increasing from 2006 to 2018 with the open burning contribution of more than 90% of the total subcategory the emissions.

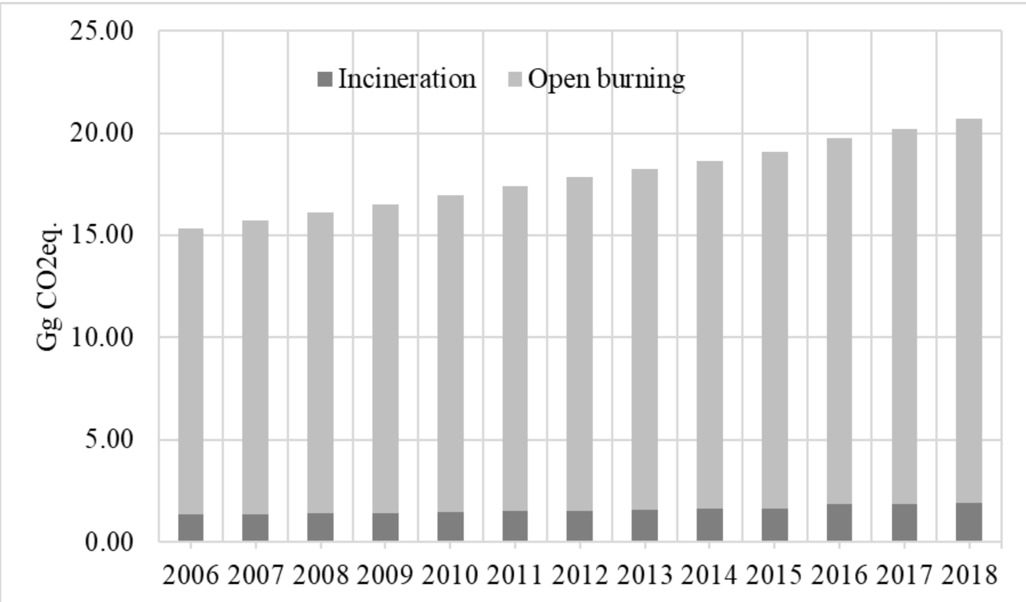


Figure 6.5 Trend of emissions from incineration and open burning of solid waste in Rwanda

As shown in **Table 6.7,** CH_4 is the main GHG emitted from the incineration and opening burning followed by CO_2 and N_20. It should be noted that waste incineration is the only source of CO_2 emissions from the waste sector.

Table 6.7 GHG emissions from incineration and open burning of solid waste by gas

	Incineration (Gg CO_2eq)	Open burning (Gg CO_2eq)	

Year	CO_2	N_2O	CH_4	CO_2	CH_4	N_20	Total (Gg
2006	0.9464	0.0445	0.3262	1.2159	10.6968	2.0771	15.3069
2007	0.9702	0.0456	0.3344	1.2475	10.9749	2.1311	15.7037
2008	0.9979	0.0469	0.3440	1.2800	11.2603	2.1865	16.1155
2009	1.0217	0.0480	0.3522	1.3133	11.5531	2.2433	16.5315
2010	1.0494	0.0493	0.3617	1.3474	11.8534	2.3016	16.9629
2011	1.0771	0.0506	0.3713	1.3824	12.1616	2.3615	17.4045
2012	1.1009	0.0517	0.3795	1.4196	12.4882	2.4249	17.8648
2013	1.1286	0.0530	0.3890	1.4478	12.7371	2.4732	18.2288
2014	1.1524	0.0541	0.3972	1.4813	13.0313	2.5304	18.6466
2015	1.1801	0.0554	0.4068	1.5153	13.3305	2.5885	19.0765
2016	1.3464	0.0569	0.4177	1.5569	13.6965	2.6595	19.7340
2017	1.3772	0.0582	0.4272	1.5941	14.0241	2.7231	20.2041
2018	1.4124	0.0597	0.4382	1.6320	14.3571	2.7878	20.6872

6.5.3 Methodology, choice of activity data, and emission factors

For the incineration of waste, only clinical waste has been covered during the estimation of emissions from incineration. The tier 1 equations used for estimating the emissions are based on the total amount of waste combusted. Equations 5.1, 5.4, and 5.5 of the 2006 IPCC guidelines (IPCC 2006, 2006)were used respectively for CO_2, CH_4, and N_2O emissions (IPCC, 2006). The estimate of CO_2 emissions was computed based on the total amount of waste incinerated.

Following the basic approach provided by IPCC 2006 Guidelines for CO_2 emissions from solid waste incineration and open burning, the following input activity data and factors have been used after the identification of the types of incinerated wastes (clinical) as summarized in **Table 6.8.** For the compilation of data on the amount of incinerated waste, only data from the 2014 period survey were available in REMA. For this, extrapolation and interpolation from the population were used to obtain estimates for the other years. The 2014 survey was covering all hospitals in all districts of Rwanda.

Table 6.8 Activity data and emissions factors for incineration of solid waste

Year	Total amount of waste incinerated [Gg waste]	Dry matter content -dm [Fraction]	Fraction of Carbon in Dry matter-CF [Fraction]	Fraction of Fossil Carbon in Total Carbon-FCF [Fraction]	Oxidation Factor-OF [Fraction]
2006	2.39	0.5	0.6	0.4	0.9
2007	2.45	0.5	0.6	0.4	0.9
2008	2.52	0.5	0.6	0.4	0.9
2009	2.58	0.5	0.6	0.4	0.9
2010	2.65	0.5	0.6	0.4	0.9
2011	2.72	0.5	0.6	0.4	0.9
2012	2.78	0.5	0.6	0.4	0.9
2013	2.85	0.5	0.6	0.4	0.9
2014	2.91	0.5	0.6	0.4	0.9

2015	2.98	0.5	0.6	0.4	0.9
2016	3.06	0.5	0.6	0.4	1
2017	3.13	0.5	0.6	0.4	1
2018	3.21	0.5	0.6	0.4	1

Source: The estimate for clinical waste incineration was adapted from REMA, 2016

Default values provided on dry matter content, total carbon content, fossil carbon fraction, and oxidation factor have been used:

- For CO_2 emissions, an Oxidation factor of 90% instead of 100 % was used based on the expert judgment referring to the fact that most local incinerators for clinical wastes are made in bricks, except for reference hospitals and 2 more incinerators starting from 2012 when the private sector set off to incinerate the hospital waste.
- From 2016-2018, an Oxidation factor of 100 % for CO_2 emissions was used, considering the improvement in hospitals for waste incineration
- For CH_4 emissions, the IPCC default value of 6,500 Kg CH_4/Gg wet waste was used as an Emission factor for incineration.
- For N_2O emissions, the IPCC default value of 60 Kg N_2O/Gg wet weight waste was used as an Emission factor for incineration.

Open burning:

Default values provided on dry matter content, total carbon content, fossil carbon fraction, and oxidation factor have been used:

- For CO_2 emissions, the IPCC 2006 default value of 0.57 dry matter content, 0.32 fraction of carbon in dry matter content, 0.04 fraction of fossil carbon in total carbon, 0.58 of oxidation fraction were used.
- For CH_4 emissions, the IPCC 2006 default value of 6,500 Kg CH_4/Gg wet waste was used as an Emission factor for open burning.
- For N_2O emissions, the IPCC default value of 150 Kg N_2O/Gg dry weight waste was used as an Emission factor for open burning.

The other Tier 1 activity data for population, the fraction of population burning waste, Per capita waste generation, and Fraction of waste amount open-burned are summarized in **Table 6.9**:

Table 6.9 Activity data and emissions factors for open burning of solid waste

Year	Population	Fraction of population burning waste	Per capita waste generation (kg waste/capita/day)	Fraction of waste amount open-burned	Days/ year
2006	9,007,467	0.1	0.794520548	0.3	365
2007	9,241,661	0.1	0.794520548	0.3	365
2008	9,481,944	0.1	0.794520548	0.3	365
2009	9,728,475	0.1	0.794520548	0.3	365

Year	Population	Fraction of population burning waste	Per capita waste generation (kg waste/capita/day)	Fraction of waste amount open-burned	Days/ year
2010	9,981,415	0.1	0.794520548	0.3	365
2011	10,240,932	0.1	0.794520548	0.3	365
2012	10,515,973	0.1	0.794520548	0.3	365
2013	10,725,541	0.1	0.794520548	0.3	365
2014	10,973,254	0.1	0.794520548	0.3	365
2015	11,225,190	0.1	0.794520548	0.3	365
2016	11,533,446	0.1	0.794520548	0.3	365
2017	11,809,295	0.1	0.794520548	0.3	365
2018	12,089,720	0.1	0.794520548	0.3	365

Source: EICV 2, EICV 3, EICV 4, EICV 5, IPCC 2006

It is interesting to note that for the fraction of waste amount, the open-burned IPCC 2006 default value is 0.6 for the burning of open dumps. However, this is not practiced in Rwanda. Waste is burned at the household level. For Rwanda 0.3 value was used because, the fraction of the population burning waste is suspected to include agriculture waste. In that case, agricultural waste was not considered in this report. In addition, the fraction of the population burning waste for the period 2010-2011 was kept at 0.1 although according to EICV 3 (NISR, 2012) this fraction was 0.0 as indicated in **Table 6.3.** This is because it was not clear how the fraction suddenly changed while it was the same for the previous and following years. Thus, we assume that open burning was practiced during that period as well.

6.5.4 Uncertainty and time-series consistency

Incineration activity data are based on only 2014 data from the survey conducted by REMA. Extrapolation from longer time series and trends were used to achieve time-series consistency as proposed in Chapter 5 of Volume 1 of IPCC 2006 Guidelines. The open burning activity data are based on regular EICV surveys conducted by the NISR. It is assumed that the interpolation and extrapolation resulted in high uncertainty for activity data compared to emission factors uncertainties. For this reason, the following uncertainty ranges were used:

- Activity data uncertainties:±15%
- Emission factor uncertainties: ±5%

6.5.5 Quality assurance and Quality control

Quality control was made through a continuous cross-check of user activity data, emission factors, and inventory results with default values provided in IPCC 2006 Guideline and following the instructions provided on QA/QC (IPCC, 2006, Vol. 5_3_ch3, pp 3.28) and as proposed in IPCC (2006, Vol.5_4_CH_4_Bio_Treat, pp 4.7). Quality assurance was conducted through a validation workshop and with the support of an international consultant.

6.5.6 Incineration and open burning recalculations

Recalculation in this subcategory was made for N_2O and CH_4 because there was a constant error of conversion in GWP, i.e., N_2O and CH_4 GWP were exchanged during the data processing in TNC as shown in **Table 6.10.** In addition, open burning was not reported during the TNC due to the lack of data and the concern that open burning was strictly prohibited. In the current inventory as indicated in **Table 6.10,** after a complaint from REMA and other local administrative authorities that open burning is still practiced, a review of the available data and expert judgment has allowed estimating open burning emissions. The methodology used is detailed in section 4.4.3 since this was the first time for the calculation.

Table 6.10 Results of recalculations conducted in the incineration of Solid Waste

Year	CO_2	CO_2	N_2O	N_2O	CH_4	CH_4	Total	Total (Gg CO_2 Eq.)	Difference
	Gg CO_2 eq.	Gg CO_2 eq.	Gg CO_2 eq.	Gg CO_2 eq.	Gg CO_2 eq.	Gg CO_2 Eq.	Gg CO_2 eq.	Gg CO_2 eq.	%
	TNC	BUR 1	TNC	BUR 1	TNC	BUR 1	TNC	BUR 1	
2006	0.9464	0.9464	0.1111	0.0445	0.0003	0.3262	1.0579	1.3171	24.50
2007	0.9702	0.9702	0.1139	0.0456	0.0003	0.3344	1.0845	1.3502	24.50
2008	0.9979	0.9979	0.1172	0.0469	0.0003	0.3440	1.1154	1.3888	24.50
2009	1.0217	1.0217	0.1200	0.0480	0.0004	0.3522	1.1420	1.4218	24.50
2010	1.0494	1.0494	0.1232	0.0493	0.0004	0.3617	1.1730	1.4604	24.50
2011	1.0771	1.0771	0.1265	0.0506	0.0004	0.3713	1.2040	1.4990	24.50
2012	1.1009	1.1009	0.1293	0.0517	0.0004	0.3795	1.2305	1.5321	24.50
2013	1.1286	1.1286	0.1325	0.0530	0.0004	0.3890	1.2615	1.5706	24.50
2014	1.1524	1.1524	0.1353	0.0541	0.0004	0.3972	1.2881	1.6037	24.50
2015	1.1801	1.1801	0.1386	0.0554	0.0004	0.4068	1.3191	1.6423	24.50

Table 6.11 Results of recalculations from open burning

Year	CO_2	CH_4	CO_2	Total annual emissions
	Gg CO_2 eq.	Gg CO_2 eq.	Gg CO_2 eq.	Gg CO_2 eq.
2006	1.2159	10.6968	2.0771	13.9898
2007	1.2475	10.9749	2.1311	14.3535
2008	1.2800	11.2603	2.1865	14.7267
2009	1.3133	11.5531	2.2433	15.1096
2010	1.3474	11.8534	2.3016	15.5025
2011	1.3824	12.1616	2.3615	15.9055
2012	1.4196	12.4882	2.4249	16.3327
2013	1.4478	12.7371	2.4732	16.6582
2014	1.4813	13.0313	2.5304	17.0429
2015	1.5153	13.3305	2.5885	17.4342
2016	1.5569	13.6965	2.6595	17.9130
2017	1.5941	14.0241	2.7231	18.3414
2018	1.6320	14.3571	2.7878	18.7770

6.5.7 Source specific planned improvements

Only clinical waste was considered for the estimation of emissions from incineration of solid waste as discussed in the report. It should be noted that the incineration in Rwanda is at the infant level and mainly clinical wastes are incinerated. However, future improvement should consider the survey of other types of waste incinerated. In addition, there is a need to plan for the best way for the data collection on the quantity of waste incinerated at each hospital in Rwanda. It is assumed that these data are regularly collected and reported at hospital levels, but they should be collected and centralized at the ministry of the health level and specifically at the health and sanitation department.

6.6 Wastewater Treatment and Discharge (4 D)

6.6.1 Wastewater Treatment and Discharge category description

Wastewater is derived from a variety of domestic, commercial, and industrial sources and may be treated on-site (uncollected), sewed to a centralized plant (collected), or disposed of untreated nearby or via an outfall. Domestic wastewater is defined as wastewater from household water use, while industrial wastewater is from industrial practices only (IPCC, 2006). Considering that, the methodology is on a per person basis, emissions from commercial wastewater are estimated as part of domestic wastewater. To avoid misunderstanding, the term municipal wastewater was not used in this report. Municipal wastewater is a mixture of household, commercial and non-hazardous industrial wastewater, treated at wastewater treatment plants (IPCC, 2006).

Water and sanitation services in Rwanda are ruled by the National Policy for Water and Sanitation of the Ministry of Infrastructure (2010) which has been revised in 2015. As far as urban sanitation was concerned, the latter policy aimed to:

- Raise the fraction of Household having access to sanitation up to 65% by 2012 and 100% by 2020;
- Improve the status of sanitation for all public institutions and locations such as schools, health facilities, etc.;
- Develop safe, well-regulated, and affordable off-site sanitation services for densely populated areas (sewerage and sludge collection, treatment, and reuse/disposal); and
- Enhance storm water management to mitigate impacts on properties, infrastructure, human health, and the environment.

The commitment of the government is also evidenced by the plan to develop a centralized wastewater treatment plant for Kigali, for which the study has been completed, and the sensitization of big institutions to build their wastewater treatment facilities. Due to this sensitization and enforcement, different public and private institutions have constructed wastewater treatment plants. However, although the government's commitment is a guarantee, the main waste disposal systems in Kigali, like in other cities, are dominated by septic tanks, soak ways, and direct discharge in public open watercourses and hence contributing to the increasing emissions. To compute emissions from the wastewater sector, two subcategories have been considered, namely domestic wastewater (4.D.1) and industrial wastewater (4.D.2) with domestic wastewater emissions being the main contributor to emissions from the wastewater source category.

6.6.2 Overview of shares and trends in emissions

The total emissions from wastewater treatment and discharge recorded a slight increase throughout the inventory period as shown in **Figure 6.6.** Although both CH_4 and N_2O emissions from wastewater treatment and discharge have recorded a slight increase, N_2O emissions are higher than CH_4 emissions for all years. In total, N_2O contributed 53.4% of the wastewater emissions while CH_4 contributed 46.6% of the emissions. The slight increase in emissions could be linked to the modest increase in the fraction of the population utilizing each treatment and discharge system in the urban and rural areas of Rwanda.

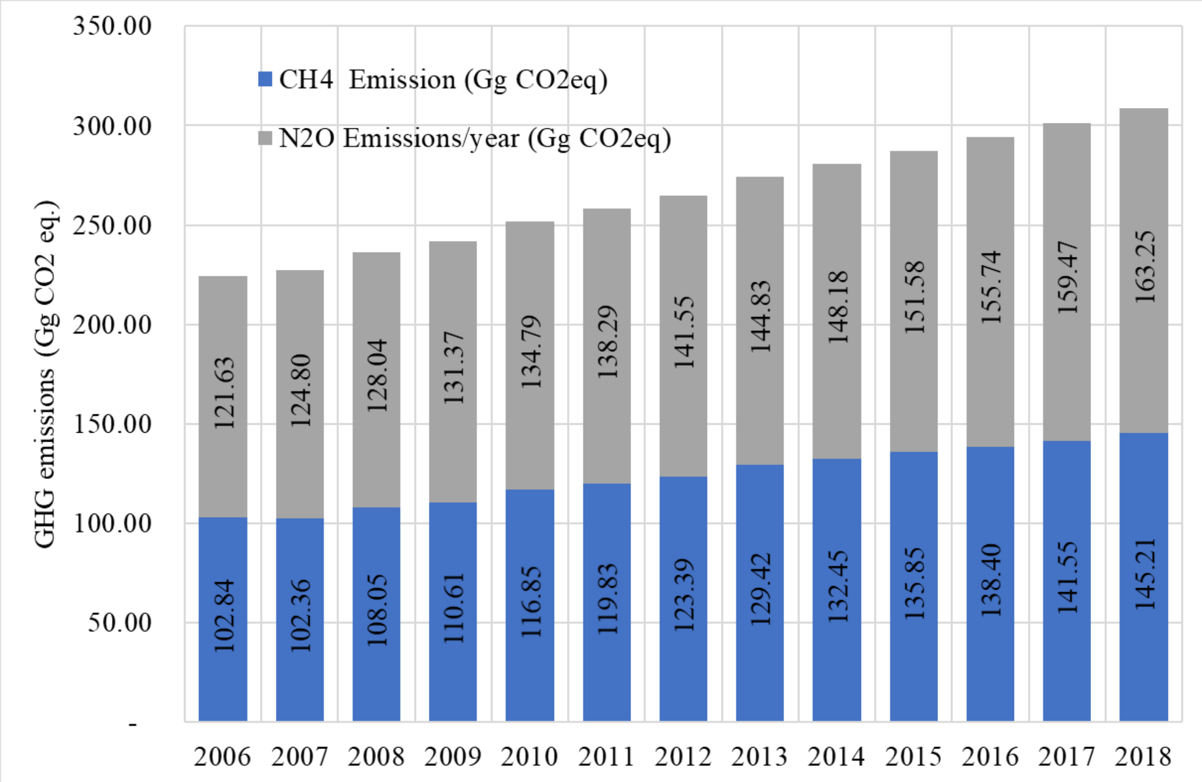


Figure 6.6 Trend of GHG emissions from wastewater treatment and discharge (2006-2018)

6.6.3 Methodology, choice of activity data, and emission factors

As discussed above, there are two distinct emissions from wastewater in Rwanda, namely domestic wastewater and industrial wastewater.

6.6.3.1 Domestic water

To compute the CH_4 emissions from wastewater treatment and discharge, two general equations (6.1 and 6.2) of the 2006 IPCC guidelines (IPCC 2006, 2006) were used. Due to limited data on the income level of the population, the fraction of population income group and degree of utilization for each treatment and discharge system, urban and rural shares have been considered in place of income group.

6.6.3.2 Choice of emission factors

To determine CH_4 emission factors for each treatment type, Equation 6.2 of the 2006 IPCC guidelines was used. Based on limited country-specific data for producing capacity, a default maximum value of 0.6kg CH_4/kg BOD for CH_4 producing capacity (Bo) of domestic wastewater was used. The following assumptions were made to choose MCF values for each treatment type:

- For Septic tanks, although the MCF values range is 0.4-0.8 (IPCC 2006, 2006), the expert prefers to take 0.5 because half of BOD settles in the anaerobic tank.
- For latrines, a default value of 0.7 is based on IPCC 2006 values.

From these assumptions, the following Bo and MCF values were used to determine emission factors as summarized in Table 6.12.

Table 6.12 Bo and MCF values used for domestic wastewater in Rwanda

Treatment type		MCF value	BO values
NISR, 2014a	IPCC 2006		
Flush toilet/ Water closet	Septic system	0.5	0.6
Pit latrine-shared	shared Latrine for communal use	0.7	0.6
Pit latrine- not shared	No shared latrine for a small family	0.1	0.6
Bush	Bush	0	0.6
Other	discharge in rivers and lakes and streets	0.1	0.6

Source: NISR, 2014 and IPCC, 2006

6.6.3.3 Activity data

Normally, the activity data for domestic wastewater is the total amount of organically degradable material in the wastewater (TOW). TOW is then a function of the human population and BOD generation per person, which is expressed in terms of BOD (kg BOD/year). To compute TOW, Equation 6.3 of the 2006 IPCC guidelines was used (IPCC 2006, 2006). A summary of key activity data and correction factors used to compute TOW is provided in Table 6.13. For BOD value, a default value of 37 BOD_5 g/person/day for domestic wastewater for Africa has been used assuming that domestic wastewater is not collected as septic tanks are used, which defines the use of 1.00 as the correction factor.

Table 6.13 Key activity data and correction factors used to compute TOW

Treatment type	Population - P [Capita/ 2018]	Degradable Organic component -BOD [kg BOD/cap/Year]	Correction Factor for industrial BOD discharged in sewers [I]
Flush toilet/ Water closet (WC)	229,705	13.505	1
Pit latrine-shared	1,184,793	13.505	1
Pit latrine- not shared	10,191,634	13.505	1
Other	24,179	13.505	0

Source: The fraction of treatment type per household was adapted from NISR (2012), NISR (2014), NISR (2015), and NISR (2018).

6.6.3.4 Industrial wastewater

Typically, the industrial wastewater can be treated in two ways: on-site or discharged into domestic sewer systems, which is the case for Rwanda. The emissions from the fraction that is released into domestic wastewater systems, mainly in the open warm system, are covered in the above domestic wastewater emissions. Although limited data were found about the on-site treatment of industrial wastewater, this report has covered the following industries based on data availability and based on country sector priorities: Coffee, Dairy products, Beer and Malt, Meat and Poultry, and Sugar refining. To compute CH_4 and N_2O emissions, equations 6.4 and 6.5 of the IPCC guidelines were used, respectively (IPCC 2006, 2006).

Choice of input activity data and emission factors

Generally, in Rwanda, there is no specific data on industrial wastewater treatment and discharge. The computation of emissions has been mainly used as activity data, the default values for emission factors, and the total production for the different industries, e.g., Coffee, Dairy products, meat and poultry, and sugar refining.

The following assumptions summarize the expert judgment on activity and emission factors choice per each category of the industry:

(a) Coffee

- In Rwanda, the coffee processing used Wet processing;
- Coffee processing using up to 15m^3 of water per ton of coffee (Eakin et al., 2011). According to the local practices and the literature review, we assume that 75% (i.e., 11 m^3) of the used water containing beans husks is released as wastewater while 25% of the water is reused (Delza G. Riley and Johan Verink, 1995);
- Coffee factories release the wastewater with husks into soak pit for composting and later used as fertilizers.

(b) Dairy products

- According to the 2009 milk master plan, 2% of the dairy farmers go directly to factories for processing and 18% of the dairy farmer goes to dairy farmer group, from which 8% goes to the processing factories;
- Data on dairy products was obtained from the Ministry of Trade and Industry (MINICOM, 2020);
- Among the milk processing factories, two factories were identified to have operating aerobic wastewater treatment plants namely: Inyange Industries operating since 1999 and Eastern Province Quality Dairy Plant operating since 2010;
- According to the MINAGRI (2009), the wastewater treatment plant at Inyange industries was removing 66% of the BOD in 2009 and therefore it was classified as aerobic treatment, not well managed during the reporting period.

(c) Meat & Poultry

- Following the IPCC 2006 Guidelines on wastewater generation rate for meat and Poultry, the lowest default value of 8 m^3/ton was considered due to local conditions (mainly low production);
- The data on meat production in tonnes/year were taken from the NISR in the statistical yearbook 2012 and the statistical yearbook 2015. The meat production for the period 2016-2018 was obtained through data extrapolation.

(d) Sugar refining

- The quantity of sugar produced in tonnes per year was collected at Kabuye Sugar Works factory, the sole sugar plant in Rwanda;
- For wastewater generation rate of sugar production, the IPCC (2006) average value of 9 m^3/ton was used;
- The wastewater generated from the sugar production activities is directly discharged into the Nyabugogo River without any treatment process.

(e) Beer production

- The data from beer production were collected at the Ministry of Trade and Industry (MINICOM, 2020)
- The average density of beer used is 1010 kg/m^3;
- The wastewater treatment method for both BRALIRWA and BMC, the main beer producers at the industrial scale, is aerobic;
- The sludge loading in the treatment plant was calculated based on the calculation that a brewery that produces 10^6 hl of beer per year has an average discharge of 3000 kg BOD per day (Klijnhout & Van, 1986). Thus, a factor of 1.05 kg COD/ hl was obtained;
- From the field discussion had at BRALIRWA, it was assumed that 70% of the produced sludge is removed each year (REMA, 2017)

Based on the above assumptions, the following product quantities per industry category have been used as summarized in **Table 6.14** and **Table 6.15** summarizes other key activity data used to calculate emissions from industrial wastewater.

Table 6.14 Production quantity per industry category (Tones/year), 2006-2018

Year of production	Coffee	Processed milk prod	Meat & poultry	Sugar	Beer
2006	26,151.00	2,145.17	52,226.00	11,432.00	71,053.50
2007	14,670.00	2,756.97	54,780.00	10,905.00	75,861.10
2008	21,283.00	3,098.89	69,637.00	14,613.00	88,021.50
2009	15,941.00	3,504.11	65,863.00	11,703.00	85,759.10
2010	19,319.00	3,831.70	79,035.00	12,235.00	104,514.80
2011	16,372.00	6,265.25	73,633.00	11,108.00	122,300.90
2012	19,955.00	10,314.89	74,519.00	8,352.00	129,482.00
2013	18,346.00	14,716.03	81,087.00	7,907.00	134,835.00
2014	16,379.00	19,507.59	86,348.00	7,298.00	141,137.40
2015	19,519.00	23,135.67	91,609.00	9,872.00	151,621.20
2016	21,720.34	23,689.14	94,648.33	8,328.75	155,280.80
2017	19,189.48	26,487.89	97,852.13	8,867.25	145,837.76
2018	20,314.06	30,857.26	100,190.36	11,055.81	172,723.04
Total	249,158.88	170,310.58	1,021,427.83	133,676.81	1,578,428.09

Source: Adapted from NISR (2012a), NISR (2015a), Kabuye Sugar Works factory, BRALIRWA, NAEB newsletter Issue No9_March 2016, Hope Magazine of 18th February 2015 and MINICOM, 2020

Table 6.15 Activity data for estimation of emissions from industrial wastewater

Industry sectors	Wastewater generated - Wi [m^3/t]	Chemical Oxygen Demand - CODi [kg COD/m^3]
Coffee	11	9
Dairy products	7	2.7
Meat and Poultry	8	4.1
Sugar	9	3.2
Beer	6.3	2.9

Source: IPCC (2006)

6.6.4 Uncertainty and time-series consistency

Large uncertainties for domestic wastewater are associated with the IPCC default emission factors for N_2O from effluent linked to a lack of country-specific values, which is also the case for Rwanda. There is insufficient field data to improve this factor. For the case of Rwanda, the following uncertainty ranges were used based on the context of the country.

Domestic wastewater:

- Activity data uncertainties:±5%
- Emission factor uncertainty:±30%

Industrial wastewater:

- Activity data uncertainties:±10%
- Emission factor uncertainty:±10%

6.6.5 Quality assurance and Quality control

IPCC 2006 Guidelines (IPCC 2006, 2006) presumes that a limited number of countries collect data on wastewater sludge handling. This is the case for Rwanda since the dominant wastewater treatment system is the septic system. This system does not allow the removal of the sludge. As also presumed by IPCC 2006 Guidelines, with this system, the methodology to estimate emissions from the effluent is based on population and on the assumption that all nitrogen is associated with consumption and domestic use, as well as nitrogen from co-discharged industrial wastewater, will eventually enter a waterway. Although conservative, this methodology has been used in the case of Rwanda to comply with IPCC directions for countries with limited country-specific data. Quality assurance was also conducted through the validation workshop and with the support of an international consultant.

6.6.6 Wastewater Treatment and Discharge recalculations

During the TNC, the population fraction for each treatment type has been determined using the data from Rwanda 4th Population and Housing Census of 2012 (NISR, 2014a) and taking 2012 as the baseline year and from which linear interpolation and extrapolation was calculated based on the population. In this inventory, the improvement was made by considering the new activity data by using the fraction of wastewater treatment type per household approach from NISR (2012), NISR (2014), NISR (2015), and NISR (2018) as indicated in **Table 6.16**.

Table 6.16 Types of domestic wastewater treatment and discharge systems

Period /source	Flush toilet Water closet (WC) (%)	Pit latrine with solid slab (%)	Pit latrine without slab (%)	No toilet whatsoever (%)	Other (%)
2006-2009 (assumption)	1.5	66.8	22.8	8.6	0.3
2010-2011 & 2012 / (EICV 3)	1.7	72.8	19.4	6.0	0.1
2013-2014 & 2015 / (EICV 4)	1.8	81.6	13.5	3.0	0.1
2016-2017 & 2018 / (EICV 5)	1.9	84.3	9.8	3.8	0.2

The types of domestic wastewater treatment and discharge systems as defined by Rwanda 4th Population and Housing Census of 2012 (NISR, 2014a) have been adopted and adapted to the classifications provided in IPCC 2006 Guidelines as well as EICV 3 to EICV 5. It was assumed that the percentage of pit latrine with solid slab and pit latrine without slab equals, respectively, the percentage of pit latrine not shared, and pit latrine shared, given the correlation in their numbers in EICV reports and the data from Rwanda 4th Population and Housing Census. The recalculated emissions from solid waste and discharge are reported in **Table 6.17**.

Table 6.17 Results of recalculations conducted in Wastewater treatment and discharge

Year	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
PD (Gg CO_2eq)	231.7	237.1	244	250.1	257	263.5	270	276.5	282.9	289.6
LD (Gg CO_2eq)	224.5	227.2	236.1	242	251.6	258.1	264.9	274.3	280.6	287.4
Difference (%)	-3.11	-4.2	-3.23	-3.25	-2.08	-2.06	-1.87	-0.8	-0.79	-0.76

6.6.7 Source specific planned improvements and recommendations

This report has covered the following industries based on data availability and based on country sector priorities: Coffee, Dairy products, Beer and Malt, Meat and Poultry, and Sugar refining. Future improvements should focus on improving the methodology for data collection and consider other types of industrial wastewater such as vegetables, fruits, juices, soap, and detergents, etc. based on the available data.

Chapter 7. Conclusion

In this inventory, the GHG emissions reported in the TNC were updated to the period 2006-2018 using the 2006 IPCC guidelines. Estimates of the key sources, sensitivity analysis, and uncertainty level were provided. Estimates of aggregated GHG emissions expressed in CO_2 equivalent were also estimated using the Second Assessment Report global warming potentials and reported. In addition, thanks to the availability of new datasets in various sectors and the improvement in methodology, recalculations were conducted for the period 2006-2015. In general, default emission factors provided by the 2006 IPCC Guidelines were used with country-specific data where available. In addition, the approach used during the recent NDC report for identification of appropriate emission factors were considered, especially in transportation GHG emissions estimations.

The results showed that, during the period 2006-2018, total GHG emissions increased steadily with peaks in 2010, 2015 and 2018. The latter peaks, which stem from the livestock category, are related to high populations of cattle in these years. During the whole period, the GHG emissions by sources dominated over the removals by the sink, resulting in total net emissions. The analysis of the shares of various sectors to total GHG emissions excluding Forests and Land Use (FOLU) revealed that the livestock category was the main sources of the GHG emissions followed by the transportation category while the IPPU sector had the least contribution. The total GHG emissions from Land Use category were dominated by the removals from forests resulting into total net sink. However, these removals were offsets by the total emissions from other categories. The GHG removals had a consistently increasing trend over the whole period 2006-2018, while the emissions from the land use activities showed a steady trend.

Estimates on GHG were produced on a gas-by-gas basis considering the direct GHG (i.e., CO_2, CH_4, N_2O, and HFCs) emissions from all the sectors and indirect gases emissions such as carbon monoxide (CO) and Nitrogen oxide (NO_X) from AFOLU sector. Over the period 200-2018, methane gas (CH_4) emissions had a dominant contribution to total GHG emissions followed by the CO_2 removals, whereas the HFCs emissions had a negligible contribution. High CH_4 emissions were mainly generated by AFOLU and waste sectors while the nitrous oxides (N_2O) were mainly generated by biomass consumption in the energy sector. All the greenhouse gases showed a steadily increasing trend over the whole period 2006-2018. The GHG removal from forests contributed to the reduction of GHG emissions. However, the GHG emissions remained higher than the removals throughout the period 2006-2018.

Due to some improvement in the methodology, data quality, the discovery of new datasets in various sectors, and the correction of the mistakes discovered in the previous inventory data for some categories, recalculations of the latest GHG emissions and removals published in the Third National Communication (TNC) were conducted for the period 2006-2015. The results of the recalculations, which were conducted in Energy, AFOLU and waste sectors, showed higher values the GHG emissions than those published in the TNC. The key reasons for this difference was the correction of some mistakes made in the TNC, the improvement in GHG emission calculation methodology and the discovery of new data sets, especially in Agriculture and Land use subcategories, which are the dominant contributor to total GHG emissions and removals.

The key category analysis was conducted for both sources and GHG gases according to the 2006 IPCC guidelines in terms of both absolute level and trends in GHG emissions. Sixteen key source/sink categories were identified for both trend and level analysis. Identified key categories are mostly from Agriculture, Forestry, and Land Use (AFOLU) and Energy sectors, which are the main economic activities in Rwanda. According to the level assessment, half of the key categories are from the AFOLU sector while other sectors share the rest with the Energy sector having four categories. The dominance of the AFOLU sector was also confirmed by the results from the trend analysis, in which the AFOLU sector had 9 key categories, and others are shared by the energy and waste sectors. The IPPU does not appear on the list of trend key categories since the development of the industrial sector and thus the increase in its GHG emissions is very recent.

The key gases analysis revealed that the CO_2 and CH_4 had significant shares to level GHG emissions whereas N_2O had a minute contribution. This observation is obvious since the CH_4 is mainly produced in various key categories of the AFOLU, energy, and waste sectors. The CO_2 is generally generated in liquid fuel combustion activities of the energy sector and the Land Use activities of the AFOLU sector. The N_2O emissions were generated by the Wastewater Treatment and Discharge category the Managed Soils key categories of the waste and AFOLU sectors, respectively. The same shares in key gases were also observed in the results of the trend analysis. According to the level analysis, four key fuels were identified in various key categories of the energy sector, viz., liquid fuels, biomass, solid fuels, and gaseous fuels. These fuels are generally used in various key categories of the energy sector including transportation, Other Sectors (i.e., residential and commercial buildings), manufacturing industries, and construction and energy industries. However, the gaseous fuels did on appear on the results of the key fuels according to trend analysis. This is because the increased use of gaseous fuels in electricity generation is relatively recent.

Uncertainty and time-series assessments constitute important elements of a complete and transparent GHG emissions inventory. Uncertainty and time-series assessments were conducted using the Tier 1 methodology following the 2006 IPCC guidelines and good practices therein. Taking 2006 as the base year, the level and trend uncertainty were estimated using the 2006 IPCC software. The total uncertainty in total inventory and trend uncertainties were estimated at 9.97 % and 13.45 %, respectively. These uncertainties are relatively high due to various reasons including the data gaps and the use of default emission factors. The emissions evaluated in this inventory report represent the current best estimates in Rwanda's GHG inventory. However, it is worth mentioning that in some cases estimates were based on extrapolated data, assumptions, and approximation methodologies. These methodological issues also contributed significantly to higher and more fluctuating uncertainties. Rwanda's GHG inventory working group will continue to improve, revise, and recalculate its GHG emission estimates, as new sources of information are available. In addition, it should be recommended that, in future inventories, an effort should be made to develop country-specific emission factors to overcome high uncertainties in estimated GHG emissions and removals.

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