Ghana's Fourth National Greenhouse Gas Inventory Report

National Greenhouse Gas Inventory to the United Nations Framework Convention on Climate Change

February 2019

Environmental Protection Agency (EPA)

With kind support from

The final electronic version of this report is available for download on the EPA website (www.epa.gov.gh).

For further information, please contact
Executive Director, Environmental Protection Agency
P.O. Box MB 326
Ministries - Accra
Telephone: +233- 302-664697/98
Email: info@epa.gov.gh

Foreword

The document is the fourth time Ghana has voluntarily prepared a standalone National Inventory Report (NIR). The NIR is to accompany the submission of the Second Biennial Update Report to the United Nations Framework Convention on Climate Change. The NIRs were produced during the preparation of the first, second and third national communications. The ability to efficiently generate credible national inventory estimates on time is the hallmark of any functional domestic monitoring, reporting, and verification (MRV) system. The GHG information does not only aid climate mitigation planning, but it is also to facilitate building the foundation for the regular tracking of impacts of mitigation actions; whether policy targets are being met, and even highlights which policies need further retooling. For instance, the NIR can be the critical source of data for monitoring the achievements of the nationally determined contributions.

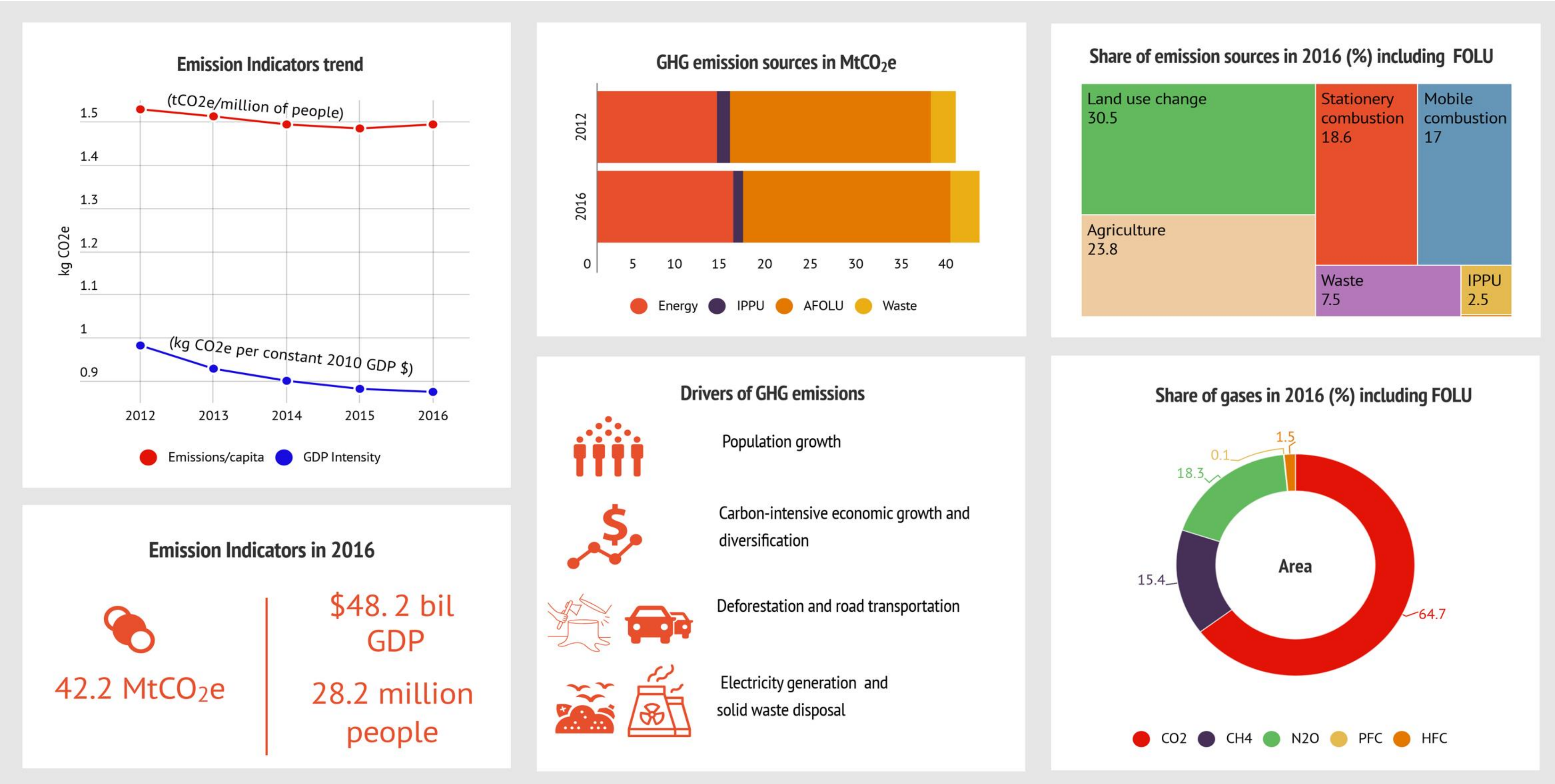
Ghana's national inventory system continues to improve. During this round of reporting, we have introduced a considerable number of reforms aimed at sharpening the functionality of the national system. Key among them is the entrenchment of the institutionalisation process for regular reporting and continuous training in new developments in the GHG inventories. Concerning the institutionalisation efforts: we have introduced several innovative measures including (a) the operationalisation of an online GHG database to host all the GHG inventory data and which are accessible to the general public, (b) the decentralisation of the inventory planning, preparation, and sector reporting to key Ministries, (c), as well as the adoption of a national GHG inventory manual and QA/QC, plan to guide future inventory work.

The NIR4 covers 26 years full time-series, from 1990 to 2016 for the four main IPCC sectors: Energy, Industrial Process and Product Use (IPPU), Agriculture, Forestry and Other Land Uses (AFOLU) and Waste. The inventory has been prepared using the 2006 IPCC Guidelines covering Greenhouse Gases (GHGs) (Carbon dioxide, Methane, Nitrous oxide, Hydrofluorocarbons, Perfluorocarbons), some Precursor gases (PGs) (Non-methane Volatile Organic Compound, Particulate Matter, Nitrogen Oxides) and Short-Lived Climate Pollutants (SLCPs) (Black carbon). For the 26 years, recalculations have been carried on the 1990-2012 estimates and new estimates for 2013 to 2016.

The national inventory report can be put to several uses. First, it is a good source of information for formulating national policies for reducing greenhouse gas emissions. Secondly, it can also serve as solid reference material for a range of users including those in the arena of international and national climate change policy, research and education, climate business development, students and the general public. For researchers, this report provides an in-depth understanding of GHG inventory for identifiable economic sectors, linkages between emissions, development indicators, and associated drivers. It also identifies several gaps where further research would be needed. For climate planning and policymaking, this report provides an outstanding basis for identifying, developing and prioritising climate mitigation actions and targets at sectors that have high emission reduction potential and benefits to the broader sustainable development goals. It is anticipated that the necessary resources would be found for some of the programmes in the specific sectors to improve on activity data collection and emission factors for future inventory preparation for the achievement of the ultimate objective of the Convention.

John A. Pwamang
(Ag. Executive Director, EPA)

Ghana's GHG emissions dashboard



List of contributors

Coordinating Authors

Mr John A. Pwamang, Ag. Executive Director, Environmental Protection Agency
Mr Ebenezer Appah-Sampong, Deputy Executive Director, Environmental Protection Agency
Mr K.Y. Oppong-Boadi (UNFCCC Focal Point, Environmental Protection Agency)

Energy sector

Mr Kennedy Amankwa (Energy Commission)
Mr Larry Kotoe (Environmental Protection Agency)
Mr Emmanuel Appoh (Environmental Protection Agency)
Mr Daniel Essel (Ministry of Transport)
Mr Ben Sackey (Volta River Authority)
Dr Daniel Tutu Benefoh (Environmental Protection Agency)
Mr Salifu Addo (Energy Commission)
Mr Mawunyo Dzobo (IRRP Project, ICF)

Industrial Processes and Products Use Sector

Mrs Selina Amoah (Environmental Protection Agency)
Mr Emmanuel Osae Quansah (Environmental Protection Agency)
Mr Joseph Baffoe (Environmental Protection Agency)
Mr Micheal Onwona Kwakye (Environmental Protection Agency)
Mrs Esi Nerquaye-Tetteh (Environmental Protection Agency)

Agriculture Forestry and Other Land-Use Sector

Dr Ernest Foli (Forestry Research Institute, CSIR)
Mr Kingsley Amoako (Ministry of Food and Agriculture)
Mr Christian Flafe (Ministry of Food and Agriculture)
Mr Jacob Amoako (Forestry Commission)
Mr Mohammed Yakubu (Forestry Commission)
Mr Kofi Affum Baffoe (Forestry Commission)
Dr Charles Domozoro (Animal Research Institute, CSIR)
Dr Winston A. Asante (Kwame Nkrumah University of Science and Technology)
Mr Kwabena Owusu Asubonteng (UNU - Institute for Natural Resources in Africa)
Mr Foster Mensah (CERSGIS, University of Ghana, Legon)
Mr Kwame Boakye Fredua (Environmental Protection Agency)
Dr Daniel Tutu Benefoh (Environmental Protection Agency)
Mr Reuben Ottou (SNV, Ghana)

Waste Sector

Mrs Juliana Bempah (Environmental Protection Agency)
Mr Joseph Baffoe (Environmental Protection Agency)
Dr George Rockson (Zoomlion Ghana Limited)
Mr Joy Hesse-Ankoma (Environmental Protection Agency)
Mr Daniel A. Lamptey (Environmental Protection Agency)

Reviewers

Institutional Reviewers
Mr Fredua Agyeman, Ministry of Environment, Science, Technology and Innovation
Ms Ruby Saakor Tetteh, Ministry of Trade and Industry
Mr Elliot Ansah, Ghana Statistical Service
Dr Solomon Gyan Ansah, Ministry of Food and Agriculture

International Reviewers
Dr Chris Malley, Stockholm Environment Institute, University of York
Mr Stanford Mwakasonda, Global Support Programme
Dr Ananth Chikkatur, ICF International
Mr Leslie Chinery, ICF International
Mr Andrews Sabrina, ICF International
Mr John Venezia, ICF International

Internal Reviewers at the Environmental Protection Agency
Mr Carl Fiati, Natural Resource Department, EPA
Mr Kwabena Badu-Yeboah, Environmental Assessment and Audit Department, EPA
Dr Sam Adu-Kumi, Chemicals Control and Management Centre, EPA
Dr Christine Asare, Strategic Environment Assessment Unit, EPA
Mrs Andriana Naa Kwakor Nelson, Environmental Assessment and Audit Department, EPA
Dr Antwi-Boasiako Amoah, Climate Change Unit, EPA
Dr Emmanuel Tachie-Obeng, Climate Change Unit, EPA
Mr Felix Addo-Okyireh, Regional Director, EPA, Eastern Region

National GHG Inventory Compiler
Dr Daniel Tutu Benefoh, Climate Change Unit, EPA

Acknowledgement

The Environmental Protection Agency (EPA) gratefully acknowledges individuals and organisations who contributed significantly to the successful completion of ofGhana's Fourth National Greenhouse Gas Inventory. Special thanks go to UNEP/GEF for funding the whole greenhouse gas inventory exercise. Mention specifically has to be made of institutions that provided various forms of support to the inventory process such as Volta River Authority, Petroleum Commission, Ghana Railways Company Limited, Ministry of Food and Agriculture, Energy Commission, Kwame Nkrumah University of Science and Technology, Forestry Commission, Tema Oil Refinery, Ghana Statistical Service, National Petroleum Authority, Forestry Research Institute, Soil Research Institute, Volta Aluminium Company (VALCO), Driver Vehicle and Licensing Authority(DVLA), Centre for Remote Sensing and Geographic Information Systems (CERSGIS) and FAO. These institutions provided most of the data, which was very crucial for the inventory.

It is also worthy of acknowledging the immense support the EPA received from the institutions that allowed its staff to be part of the inventory process from start to end. The Agency is pleased with the tireless efforts and wealth of knowledge they brought on board to enrich the quality of the report. Our utmost appreciation also goes to the various private data generators/owners, individuals and entities who provided the critical country-level activity data for the inventory. Furthermore, special gratitude goes to Ms Suzanne Lekoyiet of UN Environment for her support of this work from its commencement to completion. Finally, the EPA is immensely thankful to the various sector experts and the respective working groups for their hard work, which was demonstrated in the preparation and finalisation of this report. We also wish to express our profound gratitude to all the international partners who reviewed the inventory and made invaluable comments and suggestions, which added significant value to the entire report. We also appreciate the inputs from colleagues from the Ministry of Environment, Science, Technology, and Innovation for contextualising the NIR from the policy perspectives.

Ebenezer Appah-Sampong
Deputy Executive Director (Technical Services)

List of abbreviations and acronyms

AD	-	Activity Data
AFOLU	-	Agriculture, Forestry and Other Land Use
ATK	-	Aviation Turbine Kerosene
BC	-	Black Carbon
BDCs	-	Bulk Distribution Companies
BED	-	Built Environment Department
BOD	-	Biological Oxygen Demand
BOF	-	Basic Oxygen Furnace
BUR	-	Biennial Update Report
CC	-	Climate Change
CCAC	-	Coalition for Climate and Clean Air
CEL	-	Cenit Energy Limited
CERSGIS	-	Centre for Remote Sensing and Geographic Information System
CfRN	-	Coalition for Rainforest Nations
CH_4	-	Methane
CO_2	-	Carbon Dioxide
CO_2e	-	Carbon Dioxide Equivalent
COD	-	Chemical Oxygen Demand
CS	-	Country Specific
CSD	-	Crop Services Directorate
CWPB	-	Centre-worked Prebake
DFO	-	Distillate Fuel Oil
DOC	-	Degradable Organic Carbon
DVLA	-	Driver Vehicle Licensing Authority
EAF	-	Electric Arc Furnace
EC	-	Energy Commissions
EF	-	Emission Factors
EFDB	-	Emission Factor Database
EMP	-	Environmental Management Plan
EPA	-	Environmental Protection Agency
EQ	-	Environmental Quality
ETF	-	Enhanced Transparency Framework
FAO	-	Food and Agriculture Organisation
FAOSTAT	-	FAO Statistics
FOD	-	First Order Decay
FORIG	-	Forestry Research Institute of Ghana
FOLU	-	Forestry Other Land Use
FPP	-	Forest Preservation Programme
FPSO	-	Floating production storage and offloading
FREL	-	Forest Reference Emission Level
FRNR	-	Faculty of Renewable Natural Resource

FSD	-	Forest Services Division
GCARP	-	Ghana Climate Ambitious Reporting Programme
GDP	-	Gross Domestic Product
GEF	-	Global Environment Facility
Gg	-	Giga Gramme
GHG	-	Greenhouse Gas
GNGC	-	Ghana National Gas Company
GPG	-	Good Practice Guidance
GSP	-	Global Support Programme
GSS	-	Ghana Statistical Service
GWP	-	Global Warming Potential
HFC	-	Hydrofluorocarbons
HFO	-	Heavy Fuel Oil
IEA	-	International Energy Agency
IPCC	-	Intergovernmental Panel on Climate Change
IPPU	-	Industrial Processes and Product Use
KCA	-	Key Category Analysis
KNUST	-	Kwame Nkrumah University of Science and Technology
Ktoe	-	Kilo Tonne Oil Equivalent
LCO	-	Light Crude Oil
LPG	-	Liquified Petroleum Gas
MAC	-	Mobile Air Conditioning
MESTI	-	Ministry of Environment, Science, Technology, and Innovation
MICs	-	Multiple Cluster Indicator Survey
MID	-	Manufacturing Industry Department
MLGRD	-	Ministry of Local Government and Rural Development
MMDAs	-	Metropolitan, Municipal and District Assemblies
MODIS	-	Moderate Resolution Imaging Spectroradiometer
MOFA	-	Ministry of Food and Agriculture
MoU	-	Memorandum of Understanding
MRP	-	Mine Reverse Plant
MRV	-	Monitoring Reporting Verification
MSW	-	Municipal Solid Waste
Mtoe	-	Mega Tonne Oil Equivalent
Mt	-	Million Tonnes
MW	-	Megawatt
N_2O	-	Nitrous Oxide
NATCOMs	-	National Communications
NDC	-	Nationally Determined Contributions
NESSAP	-	National Environmental Sanitation Strategy and Action Plan
NFMS	-	National Forest Management System
NIR	-	National Inventory Report
NMVOCs	-	Non-methane Volatile Organic Compounds
NOx	-	Nitrogen Oxide

NPA	-	National Petroleum Authority
NPK	-	Nitrogen, Phosphorus, and Potassium
ODS	-	Ozone Depleting Substances
OMCs	-	Oil Marketing Companies
PA	-	Paris Agreement
PFC	-	Perfluorocarbons
PM	-	Particulate Matter
QA/QC	-	Quality Control/Quality Assurance
RA	-	Reference Approach
REDD+	-	Reducing Emission from Deforestation and Forest Degradation Plus
RFCC	-	Residue Fluid Catalytic Cracker
RFO	-	Residual Fuel Oil
RMSC	-	Resource Management and Support Centre
RRR+	-	Result-based REDD+
SA	-	Sectoral Approach
SAPP	-	Sunon Asogli Power Plant
SLCP	-	Short-Lived Climate Pollutant
SNEP	-	Strategic National Energy Plan
SOC	-	Soil Organic Carbon
SOPs	-	Standard Operating Procedures
SRID	-	Statistics, Research, and information Directorate
SWDS	-	Solid Waste Disposal Sites
TACCC	-	Transparency, Accuracy, Completeness, Consistency and Comparability
TAPCO	-	Takoradi Power Company
TEN	-	Tweneboa, Enyenra, Ntomme
TICO	-	Takoradi International Company
TT2PP	-	Tema Thermal 2 Power Plant
UN-INRA	-	United Nation University, Institute for Natural Resource in Africa
UNFCCC	-	United Nations Framework Convention on Climate Change
VALCO	-	Volta Aluminum Company
VRA	-	Volta River Authority
WRI	-	World Resources Institute

Table of Content

Chapter 4: Industrial Processes and Product Use Sector

Chapter 5: Agriculture, Forestry and Other Land-use Sector

Chapter 6: Waste sector

Annexes and References

List of Tables

General Section

Energy Sector

Industrial Processes and Product Use Sector

Agriculture, Forestry and Other Land-use Sector

Waste Sector

List of Figures

General Section

Energy Sector

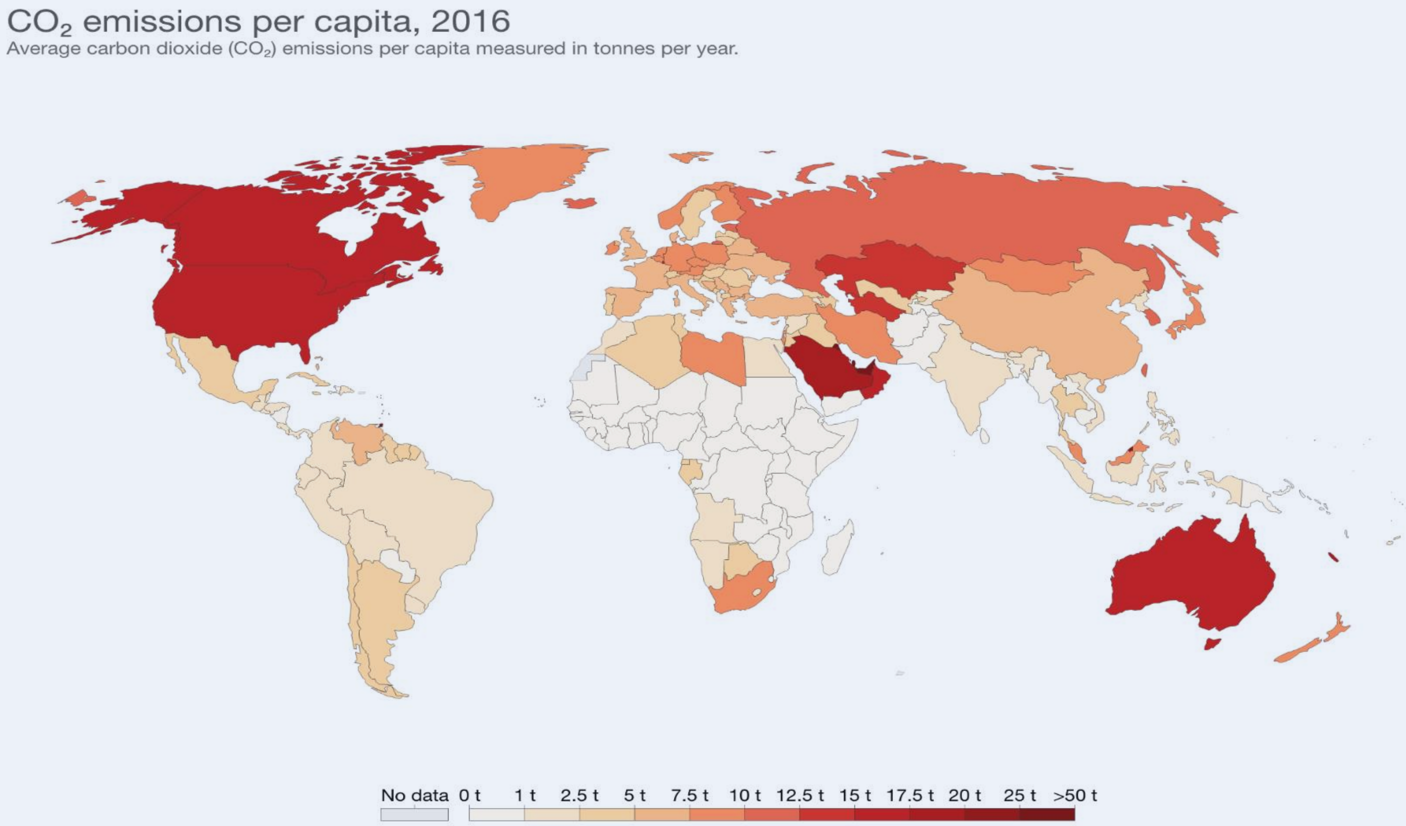
Industrial Processes and Products Use Sector

Agriculture, Forestry and Other Land-use Sector

Waste Sector

Executive summary

Source: https://ourworldindata.org/grapher/co-emissions-per-capita



ES. Executive Summary

ES 1. Background information on greenhouse gas inventories

Ghana's fourth National Inventory Report (NIR4) has been prepared to inform climate change policies in Ghana primarily. The NIR4 is part of the official submission to the United Nations Framework Convention on Climate Change (UNFCCC). It contains the national greenhouse gas emission inventory estimates for the period 1990-2016. The report and the associated tables are submitted to the UNFCCC to fulfil Ghana's obligations, in part, under the enhanced national communication reporting (Article 12, paragraph 1(a), of the Convention (Decisions 1/CP.16 para 60 (a-b)) and also in compliance with the reporting requirements for the preparation of its Second Biennial Update Report (BUR2) consistent with Decision 1/CP.16 para 60(c).

The NIR has been prepared in accordance with the UNFCCC Guidelines for the preparation of national communications from non-Annex I Parties (Decision 17/CP.8) and UNFCCC Biennial Update Report Guidelines for Parties not included in Annex I to Convention (Decision 2/CP. 17, paragraph 40 and Annex III of decision 2/CP.17). Where necessary, references have been made to the previous IPCC Guidelines/guidance documents of 1996, 2000 and 2003. The methodology used for the greenhouse gas inventory has improved over time and would continue to be refined as new data and information become available, and as international practices advance. The effects of the changes from the refinements to methodologies and the revisions of datasets have been reported in the recalculations section for each sector. The NIR and the preparation processes have not only helped Ghana to fulfil its international reporting obligations but have brought meaningful benefits to the efforts to raise the profile of climate issues among the line ministries as well as contributed immensely to:

- Capacity advancement for the participating institutions.
- Enhance the rigour of climate policy with reliable information in the evaluation of GHG mitigation options for increasing climate ambitions.
- Provide a meaningful basis for calibrating national emission reduction goals and feedback on the progress towards the realisation of mitigation goals in the long-run.
- Develop integrated strategies for reducing greenhouse gases and other atmospheric emissions, such as SLCPs, to simultaneously reduce air pollution while meeting climate change mitigation goals.

The inventory covers emissions from key economic sectors in Ghana. Generally, economic growth and GHG emissions are closely related. At any given period, the economic model Ghana pursues determines the consequent emission levels. The emissions volume, either at the economy level or sector-wide, would largely depend on the ambition of the sustainability-focus policy being implemented, the sectoral mitigation policy drive and the penetration of environmentally sound technologies in the economy. All the economic activities that have the potential to generate greenhouse emissions or take carbon dioxide from the atmosphere have been categorised into four broad sectors, according to the 2006 IPCC guidelines. The IPCC sectors are: (a) Energy, (b) Industrial Process and Product Use (IPPU), (c) Agriculture, Forestry, Other Land Use and (AFOLU) and (d) Waste. These emissions sources/removals have been further characterised into a cluster of activities according to the hierarchy below: (a) sector, (b) sub-sectors, (c) categories, (d) sub-categories, (f) activities and (g) technologies. The Environmental Protection Agency led the inventory processes. The Agency worked closely with a wide range of national stakeholders to undertake the following:

data management, a compilation of sectoral emissions estimates, quality control and assurance, preparation of the sector reports and submission of the NIR to UNFCCC on behalf of Ghana through the Ministry of Environment Science, Technology and Innovation (MESTI). The NIR is available on EPA's website: http://www.epa.gov.gh/epa/.

ES 2. National Greenhouse Gas Emissions and Removal Trends

ES 2.1 Greenhouse gas inventory results

In 2016, Ghana's total GHG emissions, including Forestry and Other Land Use (FOLU), was estimated to be 42.2 million tonnes (Mt) CO_2-equivalent (CO_2e). The 2016 level is 7.1% more than the 2012 total emissions and notably 66.4% above 1990 levels (Table ES.1). When the net emissions from FOLU are excluded from the national total, the emission estimates came down to 29.3 $MtCO_2e$ for 2016. In the same vein, the overall emissions increased by 10.9% over the 2012 amounts and by 158.7% relative to the 1990 estimates.

Table ES 1: Ghana's total greenhouse gas emissions for the period 1990 - 2016 categorised by sources

IPCC Sectors/Categories	Total Emissions ($MtCO_2e$)				Change		
	1990	2000	2012	2016	1990-2016	2000-2016	2012-2016
National Emissions with FOLU	25.34	27.26	39.35	42.15	66.3%	54.6%	7.1%
National Emissions without FOLU	11.32	14.53	26.39	29.28	158.7%	101.5%	10.9%
1 Energy	3.73	5.96	13.07	15.02	302.7%	152.0%	14.9%
2 Industrial Processes and Product Use	0.49	0.36	1.52	1.04	112.2%	188.9%	-31.3%
3 Agriculture, Forestry, and Other Land Use	20.10	19.47	22.05	22.92	14.0%	17.7%	4.0%
4 Waste	1.02	1.48	2.71	3.17	210.8%	114.2%	17.0%

The rising emissions trend correlates well with the continued implementation of economic transformation policies, as manifested by the impressive expansion of the national economy. The expansion in the economy, coupled with population pressures, has led to a notable emission increase from road transport, thermal electricity generation, biomass utilisation for cooking and deforestation.

ES 3 Changes in the inventory that necessitated recalculations

In line with the QA/QC procedures, Ghana has instituted a practice to systematically deal with technical review comments and the improvement list over a given period. In addressing the technical review comments that emerged from the ICA of BUR1, and the efforts to roll-out the prioritised improvement tasks, some methodological changes and revisions to datasets occurred. Consequently, recalculations were performed on the 1990-2012 estimates for most of the sectors to ensure time-series consistency. Some of the specific changes which justified the recalculations of the previous estimates are as follows:

- Changes in activity data due to the discovery and inclusion of new datasets, revision or updates of existing activity data and inclusions of new survey results.
- Filling of time-series data gaps with international data and trend interpolation or extrapolation.
- Changes in the inconsistent use of conversion fuel factors and appropriate emission factors due to shifting from the revised 1996 IPCC Guidelines to use of the 2006 IPCC Guidelines.
- Adoption of a new methodology for collecting new activity data and emission factors.
- Refinement in the use of expert judgment.
- Inclusion of additional pollutants for the full-time series.

In the relevant section of the report provides an elaborate explanation on the recalculations, its impacts on the previous estimates and the underlying reasons for recalculations. Section 2.6.1 of the NIR provides detailed information on the inventory-wide recalculations

ES 4 GHG Emissions and Development Indicators

Greenhouse gas emissions, population, economic and especially energy indicators are closely related quite well. The relationship depicts the extent to which economic growth, population pressures, and energy utilisation drive GHG emissions. Generally, the results shown in Table ES 2 suggest that total emissions went alongside the rising population, GDP, and energy consumption but at varying rates. Population, GDP, and energy consumption are rising at a faster rate than the emissions. The trend shows a positive sign of a possible medium-effects of some mitigation policies interventions on slowing down emission growth in the country.

Table ES 2: Macro-economy, energy and emission indicators

Indicators	1990	2000	2010	2012	2016	Change 1990-2016 (%)	Change 2012-2016 (%)
Population (million)	14.43	18.91	24.23	25.87	28.21	95.5	9
GDP (Constant 2010 USD billion) *	12.05	18.36	32.17	40.10	48.20	300	20.2
Total primary energy supply (Mtoe)**	5.29	6.88	9.84	8.36	9.67	82.8	15.7
Total final energy consumed (Mtoe)**	4.31	5.54	5.63	6.61	7.09	64.5	7.3
Total GHG emission ($MtCO_2e$)	25.34	27.54	35.24	39.35	42.15	66.3	7.1
Total CO_2 emission ($MtCO_2$)	16.84	17.86	22.71	25.71	27.29	62.1	6.1
Total electricity generated (GWh)**	5,721	7,223	10,167	12,024	13,022	127.6	8.3
of which is Hydroelectric (GWh)**	5,721	6,609	6,996	8,071	5,561	-2.8	-31.1
of which is Oil Products (GWh)**	-	614	3,171	3,953	7,435	-	88.1
of which is Renewable (GWh)**	-	-	-	-	26	-	-
Total Electricity Consumed*** (GWh)	4,462	6,067	8,317	9,258	11,418	155.9	23.3
Total energy consumed per capita (toe)	0.30	0.29	0.23	0.26	0.25	-16.7	-3.8
GHG emissions per capita (t CO_2 e)	1.73	1.45	1.44	1.53	1.49	-13.9	-2.6
CO_2 emission per capita (t CO_2)	1.15	0.94	0.93	1.00	0.97	-15.7	-3.0
GHG emissions per GDP unit (kg CO_2e / constant 2010 USD)	2.10	1.50	1.09	0.98	0.87	-58.6	-11.2
GHG emissions per GDP unit (kg CO_2 / constant 2010 USD)	1.39	0.97	0.71	0.64	0.57	-59.0	-10.9

* Source: World Bank, National Account (2018),

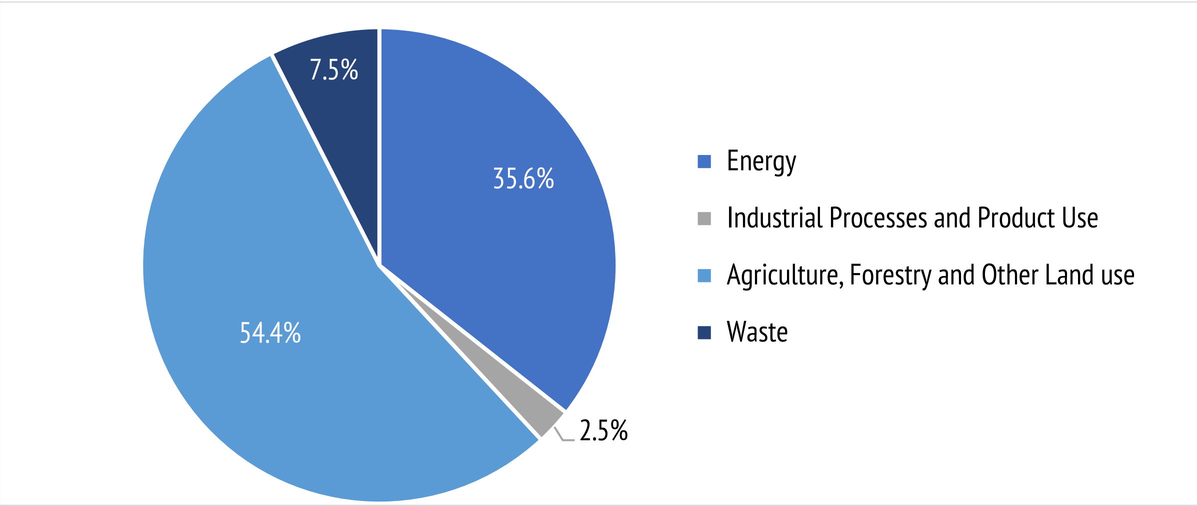
** Source: National Energy Statistics. The figure also considers electricity export to the neighbouring countries and total hours of electricity load.

It is also worthy to note that the observed consistent decline in GHG per capita and per GDP unit reflect the influence of the decarbonisation imperatives that underpin the country's economic transformation agenda.

ES 5. Overview of sources and sink category emission estimates and trends

ES 5.1 Greenhouse gas inventory by source/removal

The AFOLU sector is the largest source of GHG emissions in Ghana. It accounts for 54.4% of the overall national emissions of 42.2 $MtCO_2e$. With a total of 15.02 $MtCO_2e$, the energy sector is the next leading source contributing 35.6% of the national emissions and was followed by the Waste sector with 3.2 $MtCO_2e$ (7.5%) and then by the IPPU sector by 1.04 $MtCO_2e$ (2.5%). The total emissions recorded a growth of 7.1% between 2012 and 2016. All the sectors, except IPPU, experienced emission increases, with the Waste sector recording the highest growth in the same period. While emissions from the Waste and Energy sectors grew by 17% and 15% respectively, the AFOLU sector slightly rose by 4% over the period. In contrast, IPPU emissions saw a significant drop of 31.3% in the same period (ES Figure 1).



ES Figure 1: Total 2016 emissions by source/removal category

Below are the emission trends and the underlying drivers for sectors and categories:

For the AFOLU sector:

- The land category is the leading emissions source in the sector. Their emission levels amounted to 12.9 $MtCO_2e$ and were 30% of the total national emissions. It also constituted 46% of all AFOLU emissions in 2016, declining by 0.7% since 2012 due to the carbon stock enhancement interventions in degraded areas.
- Within the land category, cropland, grassland, and forestland are responsible for most of the emissions.
- The emissions from “aggregated sources and non-CO_2 emission on land” was the second-highest in the AFOLU sector. Its levels are 6.6 $MtCO_2e$ in 2016, making 16% of the national emissions and representing 3% increment compared to the 2012 levels.
- The “direct N_2O emissions from managed soils” formed a significant share to the tune of 63% of the total 3C emissions.
- Livestock emissions amounted to 3.03 $MtCO_2e$ and made up 8% of the total net emissions. The emissions increased by 18% between 2012 and 2016.
- More GHG emissions are associated with enteric fermentation than manure management.

Similarly, in the Energy sector:

- Stationary energy combustion operation is a point source of emissions in energy industries, manufacturing and construction industries, and residential/commercial.
- The emissions from stationary combustion are 7.83 $MtCO_2e$ with the energy industry being the largest source in 2016 and accounts for 52% of all the energy sector emissions. Between 2012 and 2016, stationary combustion emissions increased modestly by 19.8%.
- Mobile combustion emissions summed up to 7.2 $MtCO_2e$ in 2016 and are singularly responsible for 48% of the total energy emissions and 17% of the total national emissions.
- The 2016 transportation emissions increased by 7% relative to the levels reported in 2012.
- Within the transportation category, road transport was the most significant emission source due to growing vehicle ownership and the associated traffic congestion in the cities.

In the Waste sector,

- The 2016 total emissions of 3.2 $MtCO_2e$ represented 17% more than the 2012 figures, without emissions from FOLU, the waste sector emissions composed 17% of the national emissions. When net emissions from FOLU were added, the waste sector contributions came up to 8% of the total emissions.
- Wastewater treatment and discharge and solid waste disposal were the two dominant emission sources within the waste sector.
- Wastewater treatment and discharge contributed 58% to all waste sector emissions and followed by solid waste disposal, which was 36%.

Finally, for the IPPU sector

- The emissions were 1.04 $MtCO_2e$ for 2016, representing 3% of the total national emissions, and 5% without FOLU emissions.
- The 2016 emissions value is 31% less than the 2012 levels.
- HFC from product use as a substitute for ODS was the dominant emissions source and followed by emission from the mineral industry.

ES 5.2 Emission source and removal by sink according to gases

Carbon dioxide remained the dominant GHG in Ghana. The 2016 levels made up 66% of the total net emissions. When the FOLU emissions were removed from the national total, CO_2 was still the leading GHG with 14.4 $MtCO_2$. The AFOLU and the energy sectors were the two most significant sources of CO_2 emissions responsible for 99% of all the emissions. AFOLU was the leading source until 2015 onwards when the energy sector became a significant source. In 2016, the energy sector generated the most CO_2 emissions of 13.9 $MtCO_2$, followed by AFOLU as the second-rated source producing 12.9 $MtCO_2$. Across the time-series from 1990 to 2016, net CO_2 levels went up by 62%. Notably, in the last four years of the time-series (2012-2016), net CO_2 emissions marginally inched up by 6%. Forestland remaining forestland, conversion to cropland and grassland through deforestation, thermal electricity generation and road transport were responsible for the rising CO_2 emissions. The second leading GHG in the country was nitrous oxide totalling 7.7 $MtCO_2e$ in 2016. The latest emission levels were 18.3% of the total national emissions.

Similarly, the AFOLU sector, specifically, "direct N_2O emission from managed soil" under the "aggregate sources and non-CO_2 emission on land" category, was the principal source of N_2O releases into the atmosphere. Likewise, N_2O emissions exhibited an upward trend over the 26 years rising from 4.1 $MtCO_2e$ in 1990 to 6.9 $MtCO_2e$ in 2012 and further to 7.7 $MtCO_2e$ in 2016. The high levels of fertiliser use associated with the government fertiliser subsidy programme may account for the rising emissions. Apart from the AFOLU sector, insignificant amounts of N_2O came from the waste (0.6 $MtCO_2e$) and energy (0.4 $MtCO_2e$) sectors (Table ES 3).

Table ES 3: Contributions from different gases to the national emissions in 2016

Sectors & Sub-sectors	Mt	Emissions $MtCO_2e$					Share of Total	
	CO_2	CH_4	N_2O	PFC	HFC	Total	% with FOLU	% w/o FOLU
1. Energy	13.97	0.66	0.38	-	-	15.01	35.6	51.3
2. Industrial Process & Product Use	0.39	-	-	0.03	0.61	1.03	2.4	3.5
4. Waste	0.009	2.56	0.60	-	-	3.16	7.5	10.8
3. AFOLU	12.91	3.29	6.72	-	-	16.2	54.4	34.5
Total net emissions (including FOLU)	27.29	6.51	7.71	0.03	0.61	42.15	100	
Total emissions (excluding FOLU)	14.41	6.51	7.71	0.03	0.61	29.27		100

Concerning CH_4 emissions, a significant proportion came from the AFOLU and waste sectors. Almost half (50.6%) of the total methane gas was emitted from the AFOLU sector mostly from livestock rearing. Enteric fermentation and manure management contributed a whopping 77.3% of the total methane emissions produced within the AFOLU sector in 2016. The rest of the methane emissions came from the waste sector (39.3% of the total methane emissions) through the disposal of solid waste and wastewater treatment and discharge facilities. The energy sector emitted a relatively smaller percentage of 10.1% of the methane from the use of biomass for cooking and heating in the residential and commercial areas. In terms of trends, the overall methane levels also showed a rising pattern because of a variety of reasons.

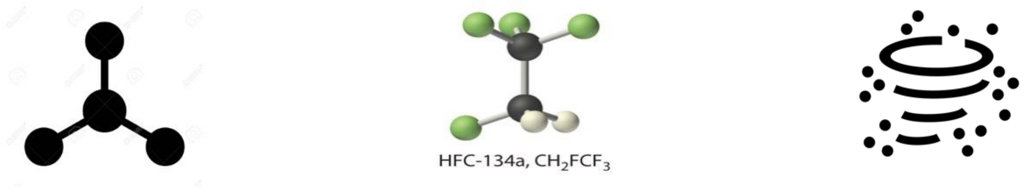
The rise in the nitrogen addition to managed soil, unmanaged waste disposal practices and the wastewater treatment technologies may have contributed to the upward trend in methane emissions. In all, the 2016 levels grew by 54.8% and 12.8% over 1990 and 2012 levels. For the 1990-2016 window, methane emissions from the waste sector recorded the highest (287.9%) growth at the fastest annual growth rate of 5.6% compared to the AFOLU that increased by 27.2% at a 1% rate per annum. Unlike the sectors above, methane emissions from the energy sector displayed a quantum decline of 31.1% at 1.5% drop every year.

PFC and HFC are key industrial gases that are emitted exclusively from the IPPU sector. PFC emissions are associated with the Aluminium production at VALCO in the metal industry category. The 2016 levels stood at 0.03 $MtCO_2e$, which represented an overall decline of 83.4% from 1990. But the recent efforts to renew the VALCO plant, though still operating at limited capacity, PFC emissions shot up by 101% from 2012 to 2016. The HFC emissions level of 0.61 $MtCO_2e$ in 2016 showed a strong response to policy interventions. As a result of a major policy push to phase out CFCs in the 2000s with HFC substitute in the RAC sector, there was a substantial increment in HFC consumption by 981.9% from 2005 to 2016 peaking in 2012 at 0.96 $MtCO_2e$ before declining in the subsequent year till 2016.

Between 2012 and 2016, HFC emissions showed a drop of 36% following the efforts to promote the adoption of low-GWP HFCs. Due to the lack of activity data, SF_6 emissions are not estimated. NF3 emissions do not occur in Ghana.

ES 5.3 Precursor gases and SLCPs emissions

Precursor gases themselves are not greenhouse gases at the point of release, but when they get into the atmosphere, they can contribute to global warming and local and regional air pollution with its attendant public health challenges. There are selected GHGs and air pollutants like methane, HFCs, black carbon and tropospheric ozone that are categorised as SLCPs because they have a relatively short life span in the atmosphere compared to carbon dioxide which can persist for an extended period in the atmosphere. Methane, HFCs and Black Carbon (BC) are the three main SLCPs in Ghana that are directly emitted, while tropospheric ozone is formed photochemically in the atmosphere from primary emissions of methane, nitrogen oxides, volatile organic compounds, and carbon monoxide. For these SLCPs, CH_4 was the foremost and accounted for 310 Gg in 2016. Black carbon emissions were 234.28 Gg, and HFC emissions were 0.29 Gg in the same year (ES Figure 2). The primary source of CH_4 is livestock rearing, solid waste disposal and biomass use in cooking. Black carbon emissions were mainly from transport, residential cooking, and manufacturing industry. HFC emissions were primarily from stationary and mobile air conditioners.



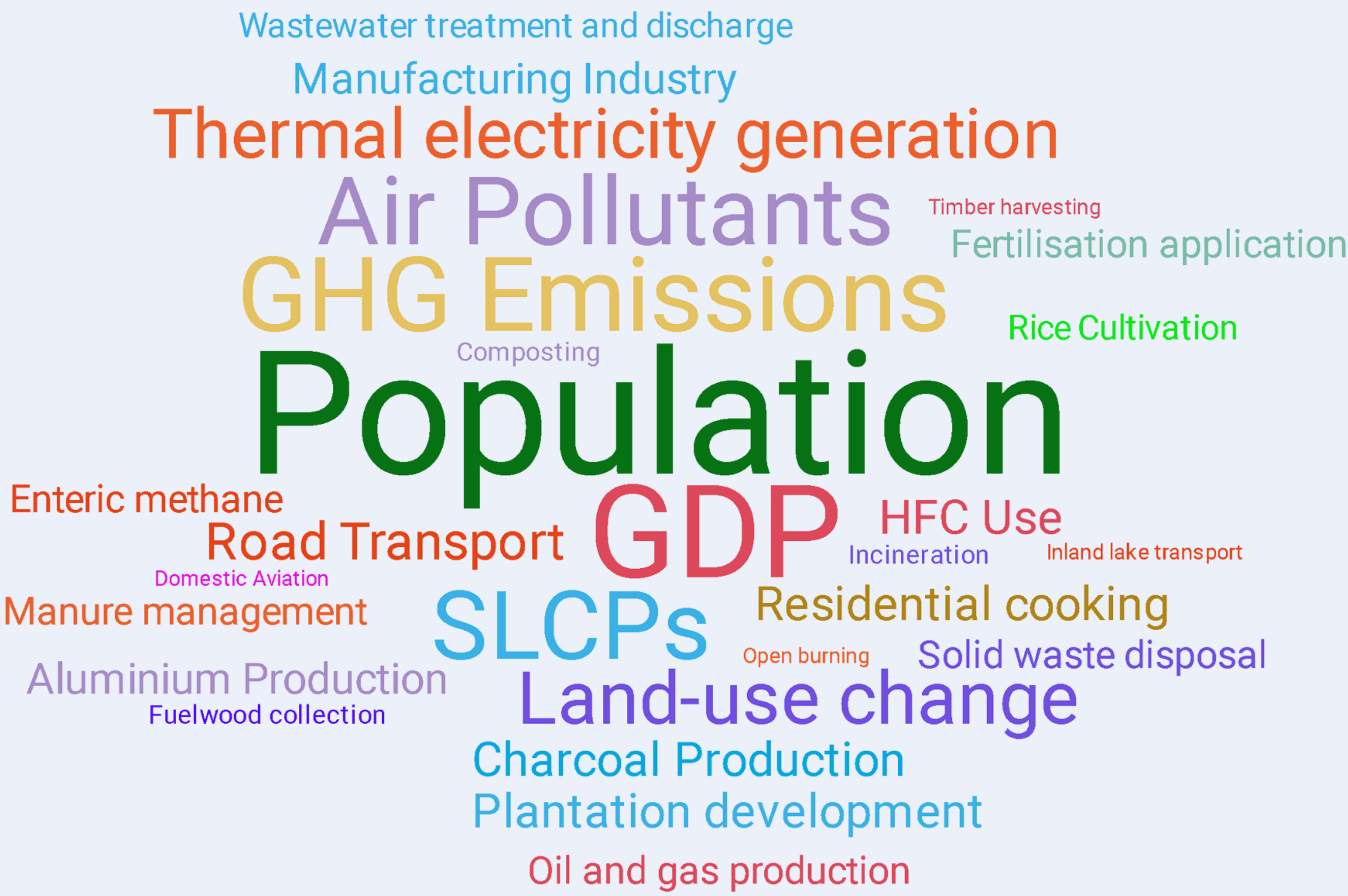
CH_4 310 Gg

0.2 Gg

ES Figure 2: Primary SLCPs reported in this inventory

In addition to the SLCPs, this NIR also reports on the estimates of precursor gases such as Nitrogen oxides (NOx), Carbon Monoxide (CO), Non-methane Volatile Organic Compounds (NMVOCs) and Particulate Matter ($PM_{2.5}$). The most predominant precursor gas was carbon monoxide recording 1,767.7 Gg in 2016. In the same year also, NOx, NMVOC and $PM_{2.5}$ levels were 122.4 Gg, 271.8 Gg, and 605.2 Gg respectively. These emissions were significant to quantify alongside emissions of GHGs and SLCPs for the development of integrated strategies to reduce air pollution and greenhouse gases. The NIR identified common sources of GHGs, SLCPs and air pollutants so that actions that can simultaneously reduce these substances can be developed.

General section



Chapter 1
Background to the national GHG inventory

1.1. Context of the national inventory report

Ghana has the obligation, under the Articles 12 and 4 of the United Nations Framework Convention on Climate Change (UNFCCC), to develop, publish and regularly update its national communications, including the national emission inventory. The adoption of Decision 1/CP.16 paragraphs 60 (a-c) in 2010 introduced an enhanced Monitoring Reporting and Verification (MRV) system which required Parties not included in Annex I to the Convention to submit national communication every four years and a biennial update report to the Conference of Parties. The Enhanced Transparency Framework (ETF) under Article 13 of the Paris Agreement (PA) would streamline and build on the existing global MRV architecture.

Ghana's Fourth National Inventory Report (NIR4) has been prepared in consultation with the key stakeholders based on Ghana's capabilities, best available data, and support received. Both the financial and technical support for preparing the NIR4 were part of the grant the enabling activities portfolio from the Global Environment Facility (GEF) through United National Environment Programme (UNEP) and the additional assistance from United Nations Development Programme (UNDP)[1]. The funding received from GEF was not adequate to cover the full cost of preparing a standalone national GHG inventory report. Therefore, the additional support from the UNDP's NDC Support Programme helped to fill the gap that the GEF funding did not cover.

The NIR4 contains updates of net GHG emission estimates from 1990 to2016 for four major economic sectors, namely Energy, IPPU, AFOLU, and Waste. The information contained in the NIR4 and the associated tables are submitted to the UNFCCC to fulfil Ghana's obligations partly under the enhanced National Communication reporting under Article 12, paragraph 1(a), of the Convention, Decisions 1/CP.16 paragraph 60(a-b) and consistent with Decision/CP.16 paragraph 60(c). The NIR4 has been prepared in accordance with the UNFCCC Guidelines for the preparation of National Communications from non-Annex I Parties (Decision 17/CP.8) and the UNFCCC Biennial Update Reporting Guidelines for Parties not included in Annex I to Convention (Decision 2/CP.17, and its annexe III). The submission of the NIR4 is not only meant to meet Ghana's international reporting obligation but also to provide necessary technical support and credible information, especially for the following purposes:

- Facilitate continuous technical capacity development for key stakeholders in line ministries, CSOs, data providers, industry and academia.
- Provide a basis for ex-ante mitigation policy planning and the evaluation of the effects of mitigation actions under implementation using the applicable accounting matrix.
- To inform the accounting and tracking of efforts toward achieving the emission reduction goals.

[1]http://www.ndcs.undp.org/content/ndc-support-programme/en/home/our-work/geographic/africa/ghana.html

- Ascertain the achieved emissions reductions, in which sector, and by which sets of policy such that at each point in time it would be possible to know the emission savings and the aggregate effects of individual policy initiatives.

The 2006 IPCC Guidelines for National Greenhouse Gas Inventories (IPCC, 2006)[2] and IPCC Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories (IPCC, 2000)[3] were used in preparing the GHG emission inventory report. Rarely, reference was made to the 2003 IPCC Good Practice for Land use, Land-use Change and Forestry (IPCC, 2003)[4] mainly for the AFOLU inventory. The use of these Guidelines made it possible to plan and undertake the estimates over a given period and ensured that the GHG emission estimates were Transparent, Complete, Consistent, Comparable and Accurate (TCCCA) through time and comparable with those inventories produced in other countries of similar national circumstances. Where Ghana has used country-specific methodology for the GHG estimation, explanations have been given at the relevant sections of the NIR.

1.2. Types of gases covered in the national inventory report

The national inventory covered direct GHGs, SLCPs and selected local air pollutants. The purpose of expanding the scope of the inventory to include non-GHGs was to improve completeness and coverage of gases from the selected economic activities. The widening of the variety of gases in the inventory was crucial because it helped to enhance the utility and relevance of the results beyond climate change to the impacts of SLCPs and air pollution on human lives, agricultural productivity, ecosystems, and sustainable development. The inventory covers direct GHGs emitted or removed through anthropogenic activities in energy production and utilisation, land clearing and waste disposal.

The essential emissions compounds included in this inventory are CO_2, CH_4, N_2O, HFCs and PFCs and their removals by sinks. Following the UNFCCC reporting guidelines, the inventory estimates for all the GHG emission/removals have been expressed in mass units. The levels of the individual emissions were also presented in Carbon Dioxide Equivalents (CO_2e) terms using the 100-year global warming potentials (GWPs) contained in the 1995 IPCC Second Assessment Report (IPCC 1996). Table 1 lists the specific GWPs values used in the conversion of non-CO_2 GHG in a common metric.

Table 1: Greenhouse gases and their corresponding global warming potentials

Gas	GWP
CO_2	1
CH_4	21
N_20	310
PFC_{14} or CF_4	6,500
PFC_{116} or C_2F_6	9, 200
$HFC_{32}(CH_2F_2)$,	650
HFC_{125} (CHF_2CF_3)	2,800
$HFC_{134a}(CH_2FCF_3)$	1,300
HFC_{143a} (CF_3CH_3)	3,800
SF_6	23,900

[2] https://www.ipcc-nggip.iges.or.jp/public/2006gl/
[3] http://agrienvarchive.ca/bioenergy/download/ipcc_ghg_inv.pdf
[4] https://www.ipcc-nggip.iges.or.jp/public/gpglulucf/gpglulucf_files/GPG_LULUCF_FULL.pdf

GWPs were not available for the precursor gases, so the results have been reported in mass units. The indirect GHGs have not been included in the summation of the total emissions expressed in the CO_2e either at the national, sector and category levels. In addition to the GHGs, this NIR4 also provides estimates for SLCPs and some selected relevant air pollutants. Both CH_4 and HFCs have been captured under GHGs and SLCPs in the inventory as well as Black Carbon (BC), which is also not captured in the CO_2e total even though it has a warming effect on the climate. The primary local air pollutants covered in this inventory include Nitrogen Oxides (NOx), Carbon Monoxide (CO), Non-Methane Volatile Organic Compounds (NMVOCs) and Particulate Matter 2.5 ($PM_{2.5}$).

1.3. Emissions/removal inventory sectors

This inventory exercise has been limited to the emissions from anthropogenic activities based on the good practice recommendations in the IPCC 2006 Guidelines. In this regard, the focus of the inventory had been on the critical productive sectors that drive Ghana's economy. This approach establishes relationships between the emissions and the economic development indicators in each sector and, on the economy-wide scale. For any given inventory period, the emissions/removals of a specific gas may be driven by the following factors: (a) ambition and level of achievement of emission reduction obligations, (b) penetration rate of climate-smart technologies and (c) the degree of adherence to sustainability practice or standards underpinning the overall productivity in each sector.

In this inventory, the economic activities that drive the emissions/removals have been categorised into four broad sectors consistent with the IPCC 2006 Guidelines. These sectors were: Energy, IPPU, AFOLU, and Waste. The IPCC guideline assigns unique numbering code for each sector (1 = Energy, 2 = IPPU, 3 = AFOLU, and 4 = Waste) to distinguish the categories under each of them quickly. Generally, the IPCC Guidelines characterise all the economic activities that have the potential to lead to emission/removals into standard classes in a systematically sequenced pattern as follows: Economy-wide → sectors → categories → sub-categories → activities/technologies. The inventory of each gas has been conducted for the activity/technology, where the available data permits before it is aggregated to the sub-category, category and sector levels for the year. Within a given year and across the entire inventory period, we have also identified the key category that consistently contributed most to the emission/removal levels and trend. Detailed information on the scope of the categories and methods used to assess them are in the sector-specific section of the NIR.

1.4. National inventory reporting years

The NIR4 publication year is 2019, which is different from the inventory years. The inventory reporting period covers 26 years spanning 1990 to 2016, with 2016 being the latest year. It is good practice that the latest inventory year is 2016 because it is consistent with the IPCC recommended 2-year lag of the year of publication of the recent inventory report. The year 2010 has been selected as the base year. Nevertheless, in the analysis of emission trends, attention is instead given to the changes that occurred after the last year of the previous NIR, which is the year 2012. The changes that happened between 2013 and 2016 can better depict current national circumstances than the previous base years. Besides, it is possible to do a trend analysis of the emissions beyond the selected years as far as it is within 1990-2016. In this inventory, recalculations have been done on the previous estimates for 1990-2012 while new estimates have been calculated for 2013-2016.

1.5. Outline of the national inventory report

The information in the NIR4 has been organised in a systematic format to be consistent with the critical aspects of the UNFCCC Guidelines for the preparation of National Communications from Parties not included in Annex 1 Parties to the Convention (Decision 17/CP.8), UNFCCC Biennial Update Reporting Guidelines for Parties not included in Annex I to the convention (Decision 2/CP.17, and its annexe III) and the user manual for the Guidelines on national communication from non-Annex I Parties. The report has also been concisely-structured to facilitate more clarity and comprehension of the information in the NIR and to stimulate its logical flow. As much as possible, real-life examples have been used to illustrate key concepts, major findings, and policy implications. The NIR4 has four chapters, and each addresses a specific GHG inventory topic. In each chapter, detailed information on the context, methodology used, key findings and the drivers are provided as below:

Chapter 1 introduces the NIR4 and further gives highlights on a wide range of cross-cutting inventory issues. The information provided on the cross-cutting issues seeks to establish the overall context of the NIR as the foundation for the ensuing chapters. Some of the general topics that the chapter 1 addresses are as follows: background information on the GHG inventory, updates in the national system, an overview of the inventory steps, methodologies, data sources and assumptions, key category analysis, quality control and quality assurance, assessment of completeness, uncertainty assessment and assessment of recalculations.

In chapter 2, the NIR presents the broad overview of the inventory results at the national levels by providing the aggregate national emissions for the latest the year 2016, as well as the analysis of the emissions trends for 1990-2016 time-series for each specific gas compound. The results have been divided according to the family of gases such as GHG, SLCPs and local air pollutants. Chapter 2 further explains emission trends and the underlying drivers.

Chapter 3 is dedicated to specific sectors. Here, the detail of information on sector-specific inventory has been reported. The information covers data acquisition and processing, methodological choices and assumptions, sector-relevant cross-cutting issues (such as recalculations, key category, QA/QC), yearly emission estimates and time-series trends.

Chapter 4 uses the central messages from the emission results to provide a brief discussion on the policy implications, mainly, drawing attention to areas where the results typically demonstrate the unintended trade-off between development imperatives and emissions. The chapter also provides additional information on planned improvements and conclusions.

The Annexes contain the list of mandatory reporting tables as well as extra information on the whole inventory.

1.6 National system for sustainable inventory preparation

Ghana adopted a Climate Ambitious Reporting Program (GCARP)[5] as its domestic MRV system in 2013. The operational aim of GCARP was to put in place a workable climate data management to support regular national and international reporting of information on GHG inventory, climate actions, and support. Although on paper, the GCARP system is well designed to suit the Ghanaian situation, implementation of the various components

[5] https://www.transparency-partnership.net/system/files/document/Good%20Practice-Ghana-Climate%20Ambitious%20Reporting%20Program.pdf

on the ground is at different levels. The GHG component of the G-CARP has seen some reforms over the years, all with the view to improving on the way it functions and eventually enables Ghana's capability to prepare and publish high-quality emission inventory on time continuously. The GHG component of the G-CARP was underpinned by four interwoven parts covering institutions, data handling, methods, tools and protocols and skills development (Figure 1).

The institution component deals with the governance aspects of the GHG inventory system. It involves the process of maintaining a functional team who regularly updates the national GHG inventories. Here, the inventory managers clarify the role and responsibilities of the team at each stage of the inventory. Making data choice and methodological choices are critical for the success of the national inventory. About data handling, this aspect guides the identification, collection, and storage of crucial data points for the inventory for all the sectors. Continuous skill development is another critical feature of the national arrangement because it can contribute to the long-term sustainability of the inventory.

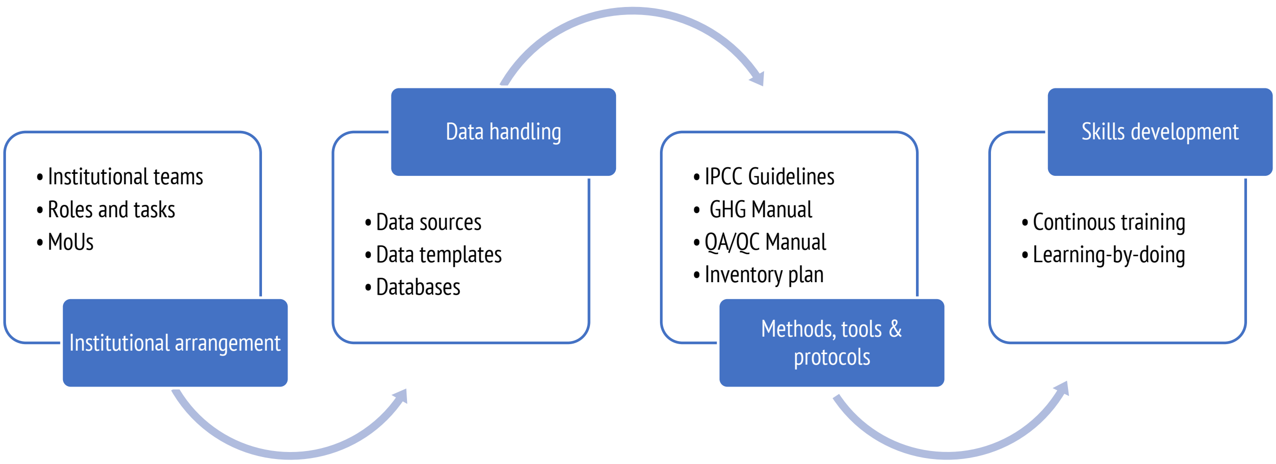


Figure 1: Overview of the relationships of the elements underpinning the national system for GHG inventory

1.6.1 Status of reforms in the GHG inventory system

Since the submission of the NIR3 to the UNFCCC in 2015, Ghana has carried out a series of reforms in the national system for the emission inventory. The changes aimed at expediting the institutionalisation process of the emissions inventory into the government structures. Instilling the culture of reporting greenhouse gas emission reporting inventory in the operations of line ministries is a way to demonstrate the importance of the results for policy-making. The reforms had focused more on sustaining gains in the past and initiated the implementation of the priority planned improvements. A summary of the updates in the national system are as follows:

1.6.1.1 Entrenching institutional roles

In the last two decades, the attention had been on transferring the core inventory tasks to the relevant line Ministries, Departments, and Agencies. And as a result, more than thirty national experts from twenty organisations have been involved in the preparation of this inventory. During this inventory cycle, we have ensured more and diverse institutional participation, revised the MoU that guides the working relationships between the EPA and the institutions involved and continued training of experienced experts on advanced topics and fresh entrants on the use of IPCC Guidelines. We have plans to continue the institutionalisation processes. The focus would be on exploring ways to weave the inventory tasks significantly into the work plans of, at least, the sector lead institutions. Three sectors are going to receive considerable attention. For those that regularly publish national data like Energy statistics, Agriculture Facts and Figures and the National Forest Monitoring System, we intend to synchronise the two publications to ensure that we get strong consistencies and synergies in the dataset and the timelines.

For instance, the Energy Commission, which publishes the yearly Energy Statistics would start to publish energy sector GHG emission figures in the Statistics beginning 2019. It is from the same source that much of the activity data for the energy sector inventory are obtained. At the ECOWAS sub-region, Ghana played a vital role in the establishment of the West African South-South Network on MRV to support technical and institutional capacities. Through the network, Ghana has collaborated with several countries in the sub-region (Sierra Leone, Côte d'Ivoire, Benin) on data exchanges, training and sharing of best practices for GHG inventory.

1.6.1.2 Strengthening data handling system

The timely generation and sharing of quality data from credible national and international sources are critical to the inventory. Thus, the strategy is to link the inventory data collection to the existing sector data platforms such as the Energy Statistics, Agriculture Facts, and Figures, National Forest Management System (NFMS), Annual Environmental Plans such that at any given time when the data provider initially publishes the data it is automatically transferred to inventory database hosted at the EPA. In situations where the data in the public domain are inadequate, a data template would be used to collect the data through official request. Besides, all the inventory data and reports are documented and published on the climate change data hub for easy retrieval from URL https://climatedatahubgh.com/. In the coming years, the focus would be on the integration of the functionality of the existing data generation platforms.

1.6.1.3 Revision of inventory cycle

The timelines and work schedules in the two-year inventory cycle have been revised to become more efficient. For example, more time has been allocated to the planning and preparation stage of the inventory to remove the bottlenecks in the system such as duplicate on or time overlaps, unrealistic timelines and less emphasis on the planning activities.

1.6.1.4 Specialised training

Two experts in Agriculture and LULUCF successfully participated in the UNFCCC Experts Review Training and passed the exam to qualify as review experts. They have since participated in several UNFCCC annual GHG inventory reviews for Annex 1 Party. Furthermore, many of the sectors' experienced experts and new entrants participated in several international and national training programmes on the various GHG inventory topics, including the use of 2006 Guidelines. Ghana was the first African country to undergo a voluntary in-country review of its GHG inventory system. Five international sector experts thoroughly reviewed Ghana's entire inventory system and together came up with a list of improvement activities. The in-country review also provided the platform for the national experts to learn about the best practices for the inventory practically.

1.6.1.5 Adoption of country-specific GHG manual and QA/QC Guidelines

As part of the continued efforts to make the national system more robust and credible, a country-specific protocol for the inventory has been adopted and is in use. The EPA, as the national coordinating entity of the inventory, led the preparation and training on the use of GHG inventory manual and QA/QC and Uncertainty Management to guide sector inventory as well as the task of the generalist. The Forestry Commission has started work to establish a forest monitoring system to improve forest monitoring capacities. As part of this initiative, the Forestry Commission has developed 12 standard operating procedures (SOPs) to guide the setting up of forest reference levels and LULUCF GHG inventory.

1.6.2 Information on the institutional arrangement

In Ghana, the EPA is designated as the national entity for the preparation of Ghana's national GHG inventory. The MESTI is responsible for the official approval and endorsement of NIR and onward submission to UNFCCC. The EPA functions as the "coordinating national entity" that works together with several public and private institutions to plan, implement and compile the inventory. There are nearly thirty national experts from twenty different public and private institutions. Each institution has been assigned a specific role at every stage of the inventory cycle with reporting lines. In each inventory, the EPA and the sector lead institution agree on the tasks and capture them in the memorandum of understanding (MoU). The EPA functions as the coordinating entity based on the legal mandate given to it by the (EPA) Act 490, 1994. As the "coordinating national entity" the EPA collaborates with the inventory institutions to undertake the management of activity data and emissions factors, the compilation of emission estimates from the sectors, quality control/quality assurance, improvement planning, and preparation of the reports. Within the EPA, the Climate Change unit is the national inventory entity and is directly responsible for the management of the entire inventory process. The Climate change unit ensures the prompt delivery of high-quality inventory estimates and reports that satisfy international standards (Figure 2).

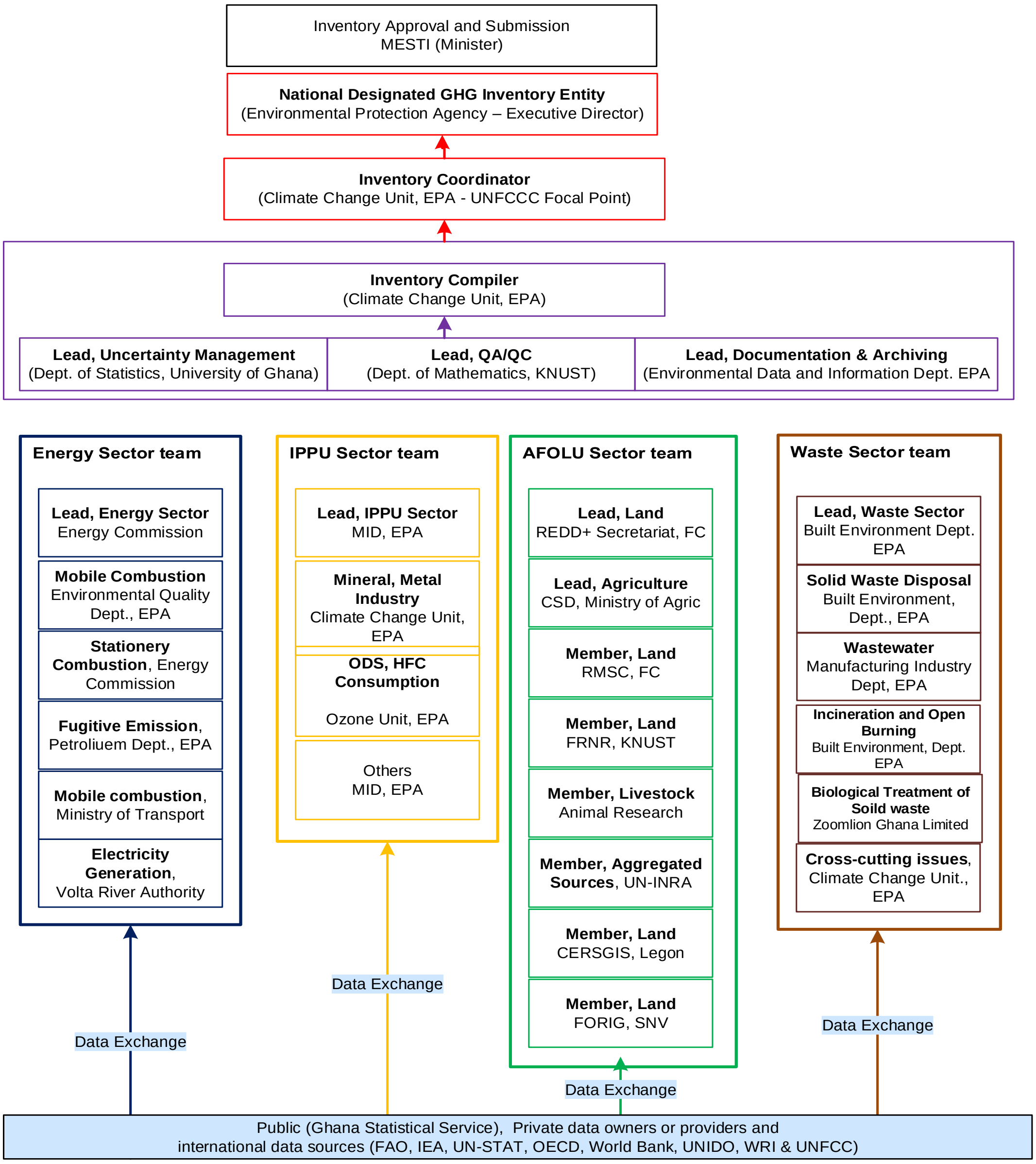


Figure 2: Institutional arrangements for preparation of national GHG inventory Source: GHG Inventory Manual

The inventory compiler also serves as the generalist and has the responsibility to ensure that the inventory issues that cut across the sectors are addressed sufficiently. Some of the issues the generalist deals with include, recalculations, ensuring the responsiveness of the national system, key category analysis, managing improvements list, addressing technical review comments and leads on QA/QC and uncertainty management. The generalist also works closely with the sector experts to plan and implement QA/QC and uncertainty management protocols. There are four sector teams, and each has been assigned to one IPCC inventory sector. Each team has a lead, and the members have a specific task in the sector inventory. The members of the sector teams are drawn from public, private organisations, and academia. Several institutions supply data to the inventory compilers. The inventory entities and their roles are in Table 2.

Table 2: Functional GHG inventory entities and their roles/responsibilities

Inventory task	Lead institution	Specific tasks
Approval and submission of the final inventory report	Ministry of Environment, Science, Technology, and Innovation.	• Reviews and approves of the national inventory report. • Uses of inventory estimate to inform policy. • Provides policy direction to the national inventory compilers.
National Entity	Environmental Protection Agency (Executive Director)	• Ensures overall technical oversight and coordinates timely deliverables. • Provides strategies to guide the long-term improvements in the inventory. • Facilitate dissemination and awareness of all the inventory products.
National Inventory Coordinator	UNFCCC Focal Point	• Acts as the inventory coordinator and responsible for the general planning and execution of the inventory on behalf of the EPA. • Plans the inventory and provides operational, management and technical oversight. • Reports directly to the Executive Director for onward transmission to its Board of Governors and Ministry of Environment, Science, Technology, and Innovation. • Manages all MOUs and facilitates the efficient delivery of all tasks.
Inventory Compiler	Climate Change Unit, EPA, (Inventory lead)	• Reports directly to the UNFCCC focal point and works closely with the GHG sector teams. • Creates a schedule using the inventory cycle timelines. The schedule covers timelines for the completion of assigned before, and after, the due dates. • Facilitates national and international technical reviews of the inventory • Responsible for data and document management, which is critical to the long-term improvement of the inventory. • Act as the receiver of inventory files from the sector teams – all worksheets and text and put together into one whole inventory document. • Doubles as the generalist for the inventory and ensures that recalculations, key category analysis, and filling data gaps are consistent with IPCC GPG. • Works closely with the sector leaders to ensure internal consistency across the inventory.
Lead, QA/QC	Mathematics Department, KNUST[6]	• Responsible for the planning and implementation of QA/QC. • Together with the inventory compiler, design and oversee the implementation of the QA/QC plan.
Lead, Uncertainty Management	Department of Statistics, University of Ghana, Legon[7]	• Designs and performs tier-1 uncertainty assessment for the entire inventory and at least for all the key categories. The methodology for the tier-1 uncertainty assessment would be entirely consistent with the 2006 IPCC. • Generates a simple-to-use worksheet for the sectors team to use. • Using 2006 IPCC, produce simple steps for the management of uncertainties in the sectors and at the inventory levels.
Documentation and Archive	Climate change Unit, EPA	• Designs and ensures complete references for all data in line with QA/QC protocols articulated in the QA/QC plan. • Documents all the responses to internal and external review comments and ensures that during the new inventory cycle, the sector team address outstanding comments and record them using the issue tracking template. • Ensures all information and data are collected consistently for purposes of later reference and archived with other inventory materials. • Designs data storage and documentation procedures for the inventory. • Ensures sector team leads complete the documentation-tracking log for onward transmission to the inventory compiler.

[6] Even though the Mathematics Department of KNUST was originally tasked to lead the QA/QC protocol there were still challenges that did not allow the full participation of the representative to function as expected. Therefore, under the new QA/QC plan, the QA/QC task has been frontloaded to the sector teams. The KNUST Mathematics still is expected to play the lead role in QA/QC in the next inventory. In this regard, the EPA will reengage KNUST to come up with a workable arrangement that will make them more active.

[7] Same comments on the QA/QC lead apply to the Uncertainty Management lead.

Sector Leads	Energy Commission, Forestry Commission, Crop Services Directorate, MOFA, MID, EPA Built Environment, Dept of EPA	• Undertake a detailed review of data needs per sector, identify the sources and access them with the support of the inventory coordinator/compiler using appropriate channels and document all the data and processes used. • Collect, collate, evaluate, and update all GHG and related data in each sector, and take final decisions on which data qualifies to be used in the inventory based on agreed conditions in the QA/QC plan. • Submit all processed data and any other data to the central database hosted at the Environmental Protection Agency and keep back-ups in the organisation that acts as sectors lead. • Liaise with the inventory compiler to undertake a review of options to inform methodological choices based on its applicability to the estimation of GHG emissions. • Estimate GHG emissions for all categories and gases under sectors using relevant factors/ GWPs and ensure that the processes/assumptions for the estimation, including the software used, are consistent with the IPCC Guidelines and thoroughly documented. • Conduct key category analysis and uncertainty assessment in collaboration with the generalist and the uncertainty management lead where applicable. • Compile all the sector estimates in the worksheets into "detailed" and "synthesis" reports, including clearly prioritised plans for improvements to be incorporated into the national inventory report. • Create and maintain hard and soft copies of all information, data, and estimates at the sector level and for onward transmission to the Environmental Protection Agency as the inventory documentation and archiving depository. • Consult with the inventory compiler to discuss and agree on the cost involved in activities that can be done within the quarter in the inventory year. The rate and mode for requesting funds would be discussed and agreed ahead of every inventory cycle.
Data providers	All data suppliers (Energy statistics, Agricultural Facts, and Figures, National Forest Monitoring System, Vehicle Statistics, Waste Statistics, Annual Environmental Reports)	• Publishes activity data on energy, transport, forestry, waste, industry production, agriculture) at a given period. • Provides additional clarifications on the data where necessary. • Jointly agrees with the inventory compiler and the sector lead on special treatment of confidential data.

1.6.2.1 Information on the inventory team

Many national experts contributed to the inventory. Each person had a specific role to play at each stage of the inventory. The list of personal contacts of the key individuals involved in the inventory and their roles are in Table 3.

Table 3: Contracts and roles of selected inventory team members

Name	Organisation	Contact Information	Role	Responsibility	Comments
Mr John A. Pwamang	Environmental Protection Agency	Ag. Executive Director Environmental Protection Agency P. O. Box. M326, Accra – Ghana. Tel: 0302 – 664697/98 Email: john.pwamang@epa.gov.gh	National Entity	Overall coordination	Regularly update EPA Management, Governing Board and MESTI
Mr Ebenezer Appah-Sampong	Environmental Protection Agency	Deputy Executive Director (Technical Services) Environmental Protection Agency, P. O. Box M326, Accra –Ghana.	National Entity	Functional coordination	Regularly updates the Executive Director.

		Tel: 0302 – 664697/98 Email: ebenezer.sampong@epa.gov.gh			Monitors key deliverables
Mr K.Y. Oppong-Boadi	Environmental Protection Agency	UNFCCC Focal Point, P. O. Box. M326, Accra – Ghana. Tel: 020-8186958 Email: koppongboadi@gmail.com	National Inventory Coordinator	Oversight over the implementation of activities	Fourth National Communication /Second Biennial Update Project Leader
Dr Daniel Tutu Benefoh	Environmental Protection Agency	Climate Change Unit P. O. Box. M326 Accra – Ghana. Tel: 0246-114652 Email: dbenefor2000@gmail.com	National Inventory Compiler & Generalist	Manages national inventory planning, implementation, and reporting	UNFCCC – Lead Reviewer. Energy Expert. Supports Energy AFOLU sector teams
Mr Joseph Amankwa Baffoe	Environmental Protection Agency	Climate Change Unit, P. O. Box. M326 Accra – Ghana. Tel: 026-2373698 Email: jabaffoe@gmail.com	Inventory Contributor	QA/QC and IPPU Sector	UNFCCC Reviewer – IP Expert. Supports Waste and IPPU sector teams
Mr Kennedy Amankwa	Energy Commission	Energy Efficiency and Climate Change Division, Energy Commission Tel: 0242-261212 Email: kenamankwah@yahoo.co.uk	Lead, Energy Sector	Manages Energy Sector Inventory	UNFCCC Reviewer – Energy Expert
Mr Salifu Addo	Energy Commission	Strategic Planning and Policy Division. Energy Commissions Tel: 0244667145 Email: salifuaddo@yahoo.com	Member, Energy Sector/ Energy Statistics	Stationery combustion	Joined the team at the beginning of this inventory cycle.
Mr Kingsley Amoako	Crop Services Directorate, Ministry of Food and Agriculture	Environment, Soil and Water Unit, Crop Services Directorate, Tel: 0207411864 Email: kingkwaw@yahoo.com	Lead, Agriculture sector	Manages Agriculture part of AFOLU sector	UNFCCC Reviewer – Agriculture Expert
Mrs Selina Amoah	Environmental Protection Agency	Manufacturing Industry Department, P. O. Box. M326, Accra – Ghana. Tel: 0265-086633 Email: selamoah@yahoo.co.uk	Lead, IPPU sector	Manages IPPU inventory	Works closely with the IPPU sector support expert.
Emmanuel Osae Quansah	Environmental Protection Agency	Climate Change and Ozone Department P. O. Box. M326, Accra Tel: 0244-633992 Email: eosaequansah@yahoo.com	Member, IPPU sector	Contributor, ODS/HFC Category	Joined the team at the beginning of the inventory cycle
Mrs Juliana Bempah	Environmental Protection Agency	Manufacturing Industry Department, Environmental Protection Agency, P. O. Box. M326, Accra Tel: 0262-886872 Email: Juliabb21@yahoo.com	Alternate Lead, Waste sector	Co-Manages Waste Sector Inventory	UNFCCC – Lead Reviewer and Waste Expert
Dr Ernest Foli	Forestry Research Institute of Ghana,	Forest and Climate Change Division P. O. Box UP 63 KNUST, Kumasi Tel: 0262-714148	Member, AFOLU Team	Contributor, Land category	Chairperson of the REDD+ MRV team and the inventory and Forest

					mensuration Expert
Mr Jacob Amoako	Forestry Commission	REDD+ Secretariat, Forestry Commission Tel: 0544-988606 Email: jacobamoako2012@gmail.com	Lead, Land category	Manages the Land part of AFOLU	GIS and MRV Expert
Mr Yakubu Mohammed	Forestry Commission	Manager, GIS Unit, RMSC, Forestry Commission Tel: 020-8112123 Email: myakubu89@yahoo.com	Member, AFOLU Team	Contributor, Land category	Land-use mapping and GIS Expert
Mr Affum Baffoe	Forestry Commission	Manager, Production Unit, RMSC, Forestry Commission Tel: 020-8138662 Email: Kofi1964ba@hotmail.com	Member, AFOLU Team	Contributor, Land category. Responsible for FRA reporting	Biomass Inventory and also responsible for FRA Reporting.
Dr Winston Asante	KNUST	Faculty of Renewable Natural Resource, Tel: 024-3143375 Email: winstonasante@gmail.com	Member, AFOLU Team	Contributor, Land category	Biomass Inventory
Mr Kwabena Asubonteng	United Nation University	UNU-INRA, University of Ghana Tel:0244-669048 Email: Kwabena.asubonteng@gmail.com	Member, AFOLU Team	Contributor, Land category	Land-use mapping and general section
Mr Reuben Ottou	SNV Netherland Development	Project Manager, REDD+ and Cocoa Programmes. No. 10 Maseru Street, East Legon Residential Area P.O. Box KIA 30284, Accra - Ghana Tel: 0244-893528 Email - rottou@snv.org	Member, AFOLU Team	Contributor, Land category	Land use mapping
Mr Foster Mensah	CERSGIS, University of Ghana, Legon	Executive Director Annie Jiagge Rd, Accra Tel: 0243-352468 Email – xtie67@yahoo.com	Member, AFOLU Team	Contributor, Land category	Land-use mapping and GIS Expert
Dr Charles Domozoro	CSIR – Animal Research Institute	Research Scientist CSIR - Animal Research Institute, P. O. Box AH 20 Greater Foster Home Down, Fafraha, Off Accra- Road, Dodowa Tel: 0278-622727 Email: fosu.way@gmail.com	Member, AFOLU Team	Contributor, Livestock category	Animal research scientist
Mr Christian Flafe	Ministry of Food and Agriculture	Statistics, Research and Information Directorate (SRID) Email: cris.flafe@gmail.com	Member, AFOLU Team	Contributor, Aggregated sources	Agriculture statistics.
Mr Larry Kotoe	Environmental Protection Agency	Oil & Gas Department, Environmental Protection Agency, P. O. Box. M326, Accra Tel: 0262-165575 Email: lkotoe@hotmail.com	Member, Energy Sector	Fugitive Emissions	UNFCCC Reviewer – Energy Expert
Mr Emmanuel Appoh	Environmental Protection Agency	Environmental Quality Department, P. O. Box. M326, Accra – Ghana. Tel: 0244-206475 Email: eeappoh@yahoo.com	Member, Energy Sector	Mobile Combustion	Air Quality Expert
Mr Daniel Essel	Ministry of Transport	Senior Planning Officer Policy Planning & Research Department Private Mail Bag Ministries Accra- Ghana Tel: 0207-581856 Email: desseldd@hotmail.com	Member, Energy Sector	Mobile Combustion	Transport Expert

Mr. Benjamin Arhin Sackey	Volta River Authority	Environmental Management Volta River Authority, P. O. Box MB 77. Accra, Ghana Tel: 020-7411123 Email: ben.sackey@vra.com	Member, Energy Sector	Electricity and heat generation	Joined the team at the beginning of the inventory cycle.
Mr Joy Ankoma Hesse	Environmental Protection Agency	Built Environment Department, P. O. Box. M326, Accra – Ghana. Tel: 0246-676414 Email: ankojoyhesse@yahoo.com	Member, Waste Sector	Solid waste disposal category	
Mr Daniel Lamptey	Environmental Protection Agency	Built Environment Department, P. O. Box. M326, Accra – Ghana. Tel: 0242-214111 Email: danlampteya@gmail.com	Member, Waste Sector	Incineration and open-burning category	
Mr Micheal Onwona Kwakye	Environmental Protection Agency	National Ozone Unit P. O. Box. M326, Accra – Ghana. Tel: 0247-600635 Email: mokatyk@gmail.com	Member, IPPU sector	Contributor, ODS/HFC Category	Joined the team at the beginning of the inventory cycle
Mr N.K. Frimpong	Kwame Nkrumah University of Science and Technology	Department of Mathematics, KNUST Tel: 0277-722137 Email: nkfrempong.cos@knust.edu.gh	QA/QC Lead		
Mr Richard Minkah	University of Ghana	Department of Statistics, Tel: 0245-032266 Email: rminkah@ug.edu.gh	Uncertainty Management		
Mr Sampson Botchwey	Environmental Protection Agency	Environmental Information and Data Management Department, P. O. Box. M326, Accra – Ghana. Tel: 024-3182362 Email: omarook@gmail.com	Online database archive	Manages climate change data hub	Uploads all the datasets on the database. Computer Expert
Mr Kwame Fredua	Environmental Protection Agency	Strategic Environment Assessment Unit. P. O. Box. M326, Accra – Ghana. Tel: 020-7311070 Email:	Attached AFOLU sector	All AFOLU activities	Joined the team at the beginning of the inventory cycle

1.6.3 Data handling measures

The EPA and the sector lead institutions are responsible for the identification and sourcing of all activity data and emission factors. In this regard, a data mapping matrix was completed for the entire inventory and was used by the sectors as a guide to prepare detailed sector-specific data needs, institutions to obtain the data from and how to access them. First, a data scan was done to collate all existing data that are publicly available into a single folder for each sector. For the dataset that was not readily available in the public domain, a direct request was made to the respective data providers. After initial contacts with the data owners/providers, the sector lead institution directly requests the data from the source with administrative support from the EPA. In the instances where the sector lead institutions asked the EPA to help in accessing the data, an official data request is made to the relevant institutions indicating the data format, the timeframe and the primary use of the data in the inventory via a formal letter. The EPA data request letters, especially those to industrial plants, usually refer to the relevant provisions to the EPA, Act 490[8], which permits EPA to access industry information

[8] http://extwprlegs1.fao.org/docs/pdf/gha13234.pdf

without hindrance. A confidential data request is treated separately according to the agreement between the data provider and the EPA. The collected data then goes through a series of screening and documentation procedures to ensure proper indexing and backup. Initial technical and quality evaluation of the data was done before transmission to the working teams. All the details on the acquired data were documented and stored in the online database for archiving and retrieval.

1.6.3.1 Information technology setup

An information technology setup that has been put in place to support the operations of the online database and data exchanges to and from the IPCC inventory software. It is critical for the smooth flow of data from the sector teams and the data providers to a central point where all datasets are archived for future use. The electronic archive aid in sharing of the inventory results with the public and served as a source of reference. Ghana has established a climate change data-hub which is an online database to hold all the inventory data and related information. The data hub is the storage unit of the inventory data and helps to streamline documentation and archiving protocols of the activity data and emission factors, reports and relevant publications. It has three sub-portals, of which one serves as the GHG inventory database.

The database hosts the following: (a) all inputs datasets from each sector; (b) datasheets for each sector; (c) emission estimates from the IPCC software for all sectors from 1990-2016, (d) IPCC 2006 software database, (f) completed QA/QC templates for sectors, and (g) all reports and documentation. The database is backed by IT infrastructure (cloud server running on Microsoft SharePoint) and is managed by a webmaster at EPA. Access to the database is differentiated from open access to restrict access. The public, institutional users and the inventory team have unlimited access to the front end of the database through this IP address http://climatedatahubgh.com/gh/. The users with unlimited access can only search for publicly available data and upload files through a trail filter run by the webmaster. There are two levels of restricted access. General access to the backend to the inventory data and institutional users who have the permission to (a) upload, (b) query, and (c) retrieve data from the database. Access to confidential data and publication of data on the database is restricted to the administrator. After the publication of the previous NIR in 2015, some changes have been made to the database to improve upon the overall performance, and these are as follows:

- Reduce downtime and ensure efficient online services, replace the standalone server to a cloud server.
- Migrated to SharePoint operating system to frontend interface.
- Reconfiguration of the backend data model to add extra functionality.
- Design of the landing page of the frontend and add two new sub-portals on NDCs and GCF pipeline.
- Train the webmaster and the IT team on the troubleshooting and quick fixes.

The IPCC software has a backend database file which has data inputs and emission results for the sectors. The software allows unlimited access levels to every user to the relevant sections of the database but not the entire database. Therefore, one "superuser login ID" was created for the inventory compiler to allow for access to the data for all the sectors. The team members of the sectors were given "log-in credentials" that only allowed them to access their relevant sections. When all the sector database files were completed, the sector lead institution submitted them to the inventory compilers who then created a "single inventory database file" containing all data for all the sectors for the completed time-series. The inventory data, individual results sheets and the database file were sent to the administrator of the online database for archiving and publication on the internet.

1.6.4 Summary of inventory steps and data flows

Generally, all the mapped-out inventory tasks were categorised into six steps. It started with the identification and sourcing of activity data and emission factors. The strategy was different for the variety of data sources be it public, private, academia and surveys. For much of the data obtained from the government sources, we focused on collecting data from public institutions that have the legal mandate to publish relevant statistics for the inventory regularly. The administrative data from the recognised public institution were the preferred source because they are considered the official government records. The EPA already collects data from industry required under the Environmental Impact Assessment (EIA) regulation as part of their Environmental Management Plans (EMPs). Industry-specific data on energy, waste, and production were obtained on the back of the existing Annual Environmental Report templates.

Data from published scientific literature or national reports were also used in the inventory. Going by the data documentation plan, anytime data from national reports or peer-reviewed literature were used, proper records of the source were referenced. The purpose was to ease retrieval of the data and to cite in the NIR correctly. The data acquired from international sources varied. The strategy was to rely on data from verifiable sources, mainly the reputable internationally-recognised organisation. The reason we limited the sourcing of international data to already known international bodies was to all third parties to authenticate data during the technical reviews.

Once all the data from the multiple sources are assembled in a single location, then we evaluate and process them in a usable format. The data processing usually involved the identification of outliers (inaccurate data, out-of-range data) time-series gaps, incompatible format, and indexing all selected data. The next step is on the selection of applicable methods. Except for a few cases where country-specific methodology methods or models were used, most of the methods used across the inventory were tier 1.

In the next step, recalculation of the previous years' emissions was carried out and new estimates calculated for the added years. After the recalculations and the new estimates, trend, key category analysis and uncertainty are performed. All the datasets (activity data, emission factors, sectoral datasheets, national totals, gas-by-gas, mandatory tables) were used to prepare the draft inventory report and third-party review.

Finally, both the datasheet and the report are uploaded to the climate change data hub for storage (Figure 3).

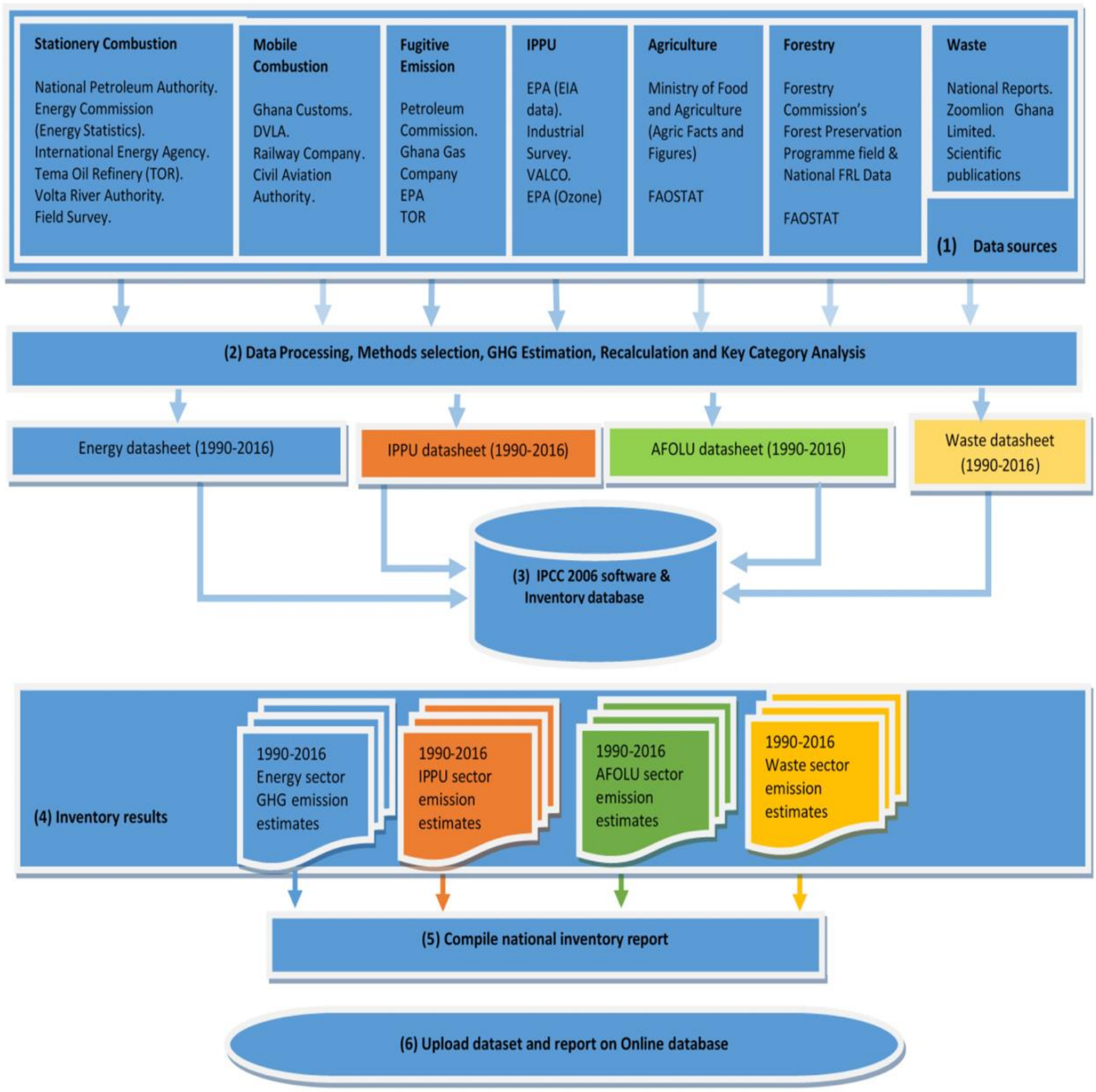


Figure 3: Summary of the inventory steps and data flows.

1.6.5 General description of the inventory preparation steps

The whole inventory process from start to end has been captured in three stages. These were the planning stage, the preparation stage, and the management stage. The selection of activities in each stage was informed by the guidance provided in the "UNFCCC Guidelines for the preparation of National Communications from non-Annex I Parties (Decision 17/CP.8) and UNFCCC Biennial Update Report Guidelines for Parties not included in Annex I to the convention (Decision 2/CP.17, paragraph 39-42 and Annex III)". The submission deadline determined the scope of work and the timelines for each activity to the UNFCCC and the number of resources allocated to each of them. The inventory activities have been summarised in the inventory cycle from the steps code 000-033 (Table 4). The inventory cycle starts with a review of previous emission estimation methods and estimates, team formation, allocation of tasks, and the data collection and evaluation for the compilation of the inventory. The cycle completes with an independent external review.

Table 4: List of inventory tasks, timelines and the responsible entities

ID	Description Inventory Tasks	Timelines	Responsible entity
000	Review of preview estimates, procedures and improvement tasks.	November	All
001	Review and update the GHG Inventory Manual.	November	Inventory coordinator
002	Validate and distribute instruction manuals to the inventory team.	December	EPA & all sectors
003	Identify and form a sector team for the inventory sectors.	October	EPA
004	Formulate and sign MoU among inventory institutions.	November	Inventory Compiler and FC, EC, MID, EQ, CSD, BED
005	Organise the first meeting of the sector team.	November	
006	Train inventory teams to ensure readiness and distribute overall and sector inventory instruction.	November	
007	Organise kick-off meeting.	January	
008	Identify and review data sources, select data, methodologies, and software.	February	Inventory compiler and FC, EC, MID, EQ, CSD, BED
009	Request data, conduct data evaluation and documentation.	April	
010	Set-up sector data documentation and archiving files and start using them.	February	All Entities
011	Update the inventory website.	February	Inventory Compiler
012	Establish a data storage server.	December	CC
013	Quarter review meeting.	March	Inventory Compiler
014	Estimate GHG using datasheet, worksheets, and synthesis sheets.	May	FC, EC, MID, EQ, CSD, BED
015	All sector sheets and documentation submitted the national inventory compiler.	July	
016	Compile a draft inventory and submit it to the inventory coordinator.	July	Inventory compiler
017	Distribute draft inventory for internal review and submit comments to the inventory compiler.	August	Inventory compiler and QA/QC coordinator
018	Distribute source files (worksheets) and internal review to lead institutions.	August	Inventory compiler
019	Incorporate internal comments, observations and corrections.	August	FC, EC, MID, EQ, CSD, BED
020	Conduct the uncertainty assessment.	September	DoS, QA/QC and Inventory compiler
021	Compile the second draft of inventory and revise worksheets.	September	Inventory compiler
022	Compile second order draft of composite inventory, source files and submit to inventory the compiler and external reviewers.	September	
023	Submit second draft inventory for external review.	November	External reviewers
024	Submit all review comments to the inventory compiler.	November	
025	Quarter review meeting.	June	Inventory coordinator
026	Incorporate external comments and revise worksheets for all sectors.	November	FC, EC, MID, EQ, CSD, BED & inventory compiler
Repeat the process of the inventory estimates, worksheets and reports every September.			
027	Draft improvement strategy for each sector.	January	FC, EC, MID, EQ, CSD, BED
028	Collect all pertinent paper and electronic source materials for archiving place in archives due to national archiving and documentation institutions.	December	CC & inventory compiler
029	Compile final Inventory and preparation of key category analysis.	December	Inventory compiler & FC, EC, MID, EQ, CSD, BED
030	Compile inventory improvement strategy due to inventory coordinator.	December	
031	Compilation of National Inventory Report (NIR).	December	Inventory Coordinator and FC, EC, MID, EQ, CSD, BED
032	NIR is ready for incorporation into National Communication and Biennial Update Report.	August	Inventory Compiler
033	Dissemination of NIR – Submission to UNFCCC. Make the inventory report to the public.	August	National Inventory Entity

Key: EC – Energy Commission; DoM – Dept. of Mathematics, KNUST; FC-Forestry Commission; BED – Built Environment Dept., EPA, MID – Manufacturing Industry Dept., EPA, CSD – Crop Service Directorate, MOFA; GSS – Ghana Statistical Service; CC –Climate change, EPA

1.7. Efforts to improve the national inventory system in the long-term

Since the launching of the GCARP, many reforms have been introduced into the national system for the inventory as indicated under section 1.6.1. Ghana plans to continue implementing new reforms that were particularly identified through the ICA process in future. The reforms are expected to lead to improving the efficiency of the functionality of the national system. Below are the activities and the focus areas:

a. Improvements in data handling

- Data exchange is key to having a functional national system for the inventory. Our strategy is to first, continue to support the system for generating and publishing sector-specific data regularly and later facilitate data sharing. In this regard, access credentials to the climate change data hub have been issued to the individuals involved in the energy statistics, agriculture facts and figures, national forest monitoring system, vehicles statistics, and the industrial environmental statistics. We intend to continue with the efforts of exchanging data through the existing data platforms and where possible, establish an online system for data sharing and archiving.

- Continue to work with the Energy Commission, Forestry Commission, Ministry of Food and Agriculture and the Environmental Sanitation Directorate of the Ministry of Local Government and Rural Development and Driver Vehicle and Licensing Authority to enhance the publication of primary activity data. The idea is to make sure that the timelines for the data publication are coordinated with the inventory cycle. Moreover, because none of the data providers publishes meta-data to the dataset, they make it available to the public when using them in the inventory, it is difficult to understand the circumstances under which they were produced. Therefore, one of the focus areas for improvement is about how to make the meta-data to the primary published data available to the inventory team. With the metadata availability, it would be possible to confidently estimate uncertainty levels in the inventory.

- Complete the process to incorporate GHG collection at the facility level using the corporate carbon accounting model and the Environmental Management Plan for manufacturing industries. The Volta River Authority (VRA)[9], a state-run power producer, has compiled the first-ever corporate accounting report for submission to the EPA. The plan is to rope in most of the independent power producers, oil and mining companies to join in the initiative.

b. The institutionalisation of the MRV functions

- The institutional arrangement for the inventory has seen some improvements, but a lot remains to be done. Apart from transferring the inventory task to the sector ministries and agreeing on an MoU, there is more work to be done to fully get the inventory activities embedded in the work programme of the ministries. In this respect, we would continue to work on the following areas with the line ministries:
    - recognition and inclusion of time spent on the inventory into the official performance appraisal.
    - inclusion of the inventory activities into the annual work plan and budget of the ministries.

[9]http://www.ndcs.undp.org/content/ndc-support-programme/en/home/impact-and-learning/ideas-and-insights/2017/ghana-pilots-corporate-carbon-footprint-reporting-for-electricit.html

- creation of a platform for the exchange of lessons from the inventory and policy implication.
- explore funding opportunities in both Ghana and international sources to complement the GEF funding, which is inadequate to cover the full cost of the inventory.

c. Regular capacity development

- Organise regular tailor-made training programs for national experts, public data providers, private data owners, potential users of the GHG results and new experts who join the inventory process.
- Conduct capacity needs assessment of industry or facility managers and uses the results to develop tailor-made training programmes for them.
- Nominate additional experts to the UNFCCC roster of experts to allow them to undertake training. The training would help to build capacity and awareness and also allow experts from Ghana to learn-on-the-job based on the experience from the review of GHG inventories from Annex I Parties.

1.8 Description of methodologies and data sources

Generally, the preparation of the inventory followed a series of iterative steps using data from multiple sources. The emissions/removal levels reported in this inventory were not directly measured. But they have been estimated using the internationally-recognised and scientifically acceptable methodologies. The processes for the estimation of emissions or removals are linked to the activity data on vital economic activities in the country and emission factors published from scientific studies. Therefore, the estimation of the emissions/removals for a specific gas for a given inventory year uses the following: (a) a country-specific or regional or IPCC accepted methodology, Activity Data (AD) from practices/technologies in a specific sector and the Emission Factor (EF).

The method used in the inventory is consistent with the 2006 IPCC Guidelines for National Greenhouse Gas Inventories and in line with international best practices. Broadly, the use of tier 1 IPCC methodology and default emission factors were dominant because, for most of the sectors, the existing dataset does not permit the use of higher-tier methodologies. It is also the case that a higher-tier or model-based method was not readily available in the country at the time of publishing this report. Furthermore, for most of the inventory categories, default emission factors were used due to the lack of country-specific emission factors. But where detailed datasets existed Land (3B), IPPU (2C) and solid waste disposal (4A) the higher inventory tier and country-factor factors were applied.

1.8.1 Overview of methods for the estimation of emissions/removals

The methodology and dataset used in the current inventory was an improvement of the previous inventories. Regarding the methodology used in this inventory, we have shifted from using the revised 1996 IPCC Guidelines to the 2006 Guidelines which required the addition of a new dataset consistent with the relevant decisions by the Conference of Parties to the UNFCCC. As a result, we have incorporated new country-specific activity data and emissions mostly for the new inventory years and the period recalculations were performed. In all, in the inventory, a two-tier approach was adopted. We have used the combination of tier 1 and 2 depending on the availability of adequate data to satisfy the level of depth of the inventory. A detailed elaboration of selected methods is provided under each sector of the NIR.

1.8.1.1 Selection of methods

The estimation of emissions/removals in the categories was based on the methods described in the 2006 IPCC Guidelines. The selection of the methods was guided by the decision-tree illustrated in Figure 4. Generally, tier 1 IPCC methodology was applied to most of the sectors, except in cases where available national data allowed us to adopt a higher tier. For example, the availability of facility-level data from Volta Aluminium Company (VALCO) enabled the use of tier 2 methodology for the estimation of emissions from aluminium production and solid waste disposal.

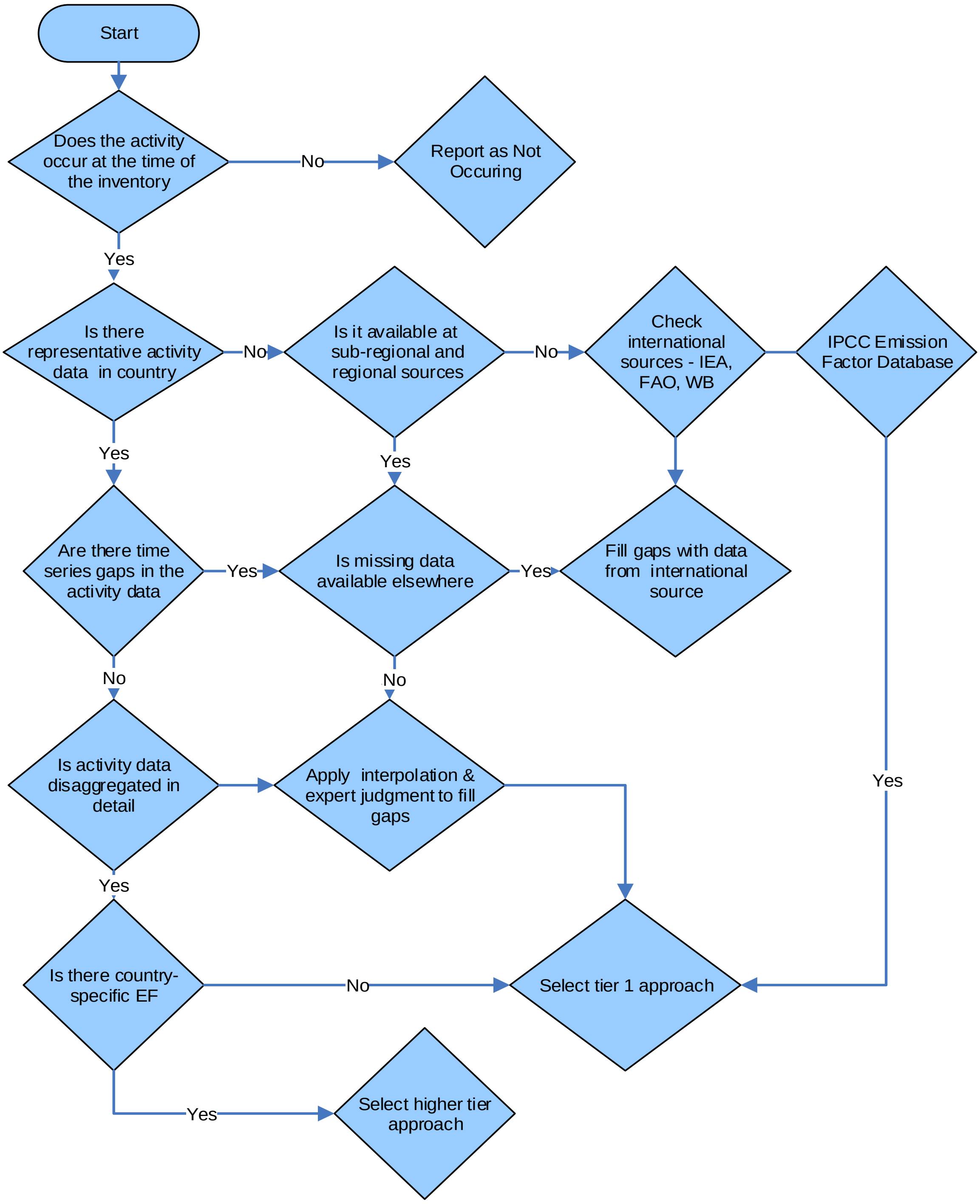


Figure 4: Snapshot of the steps followed for choosing methods for the inventory based on the modified IPCC decision tree for the selection of Methods

1.8.2 Description of inventory data sources

1.8.2.1 Selection of emission factors

The emission factors have been collected from country-specific and regional/international sources. The country-specific (CS) EFs were from stationary industrial plants (plant-specific such as VALCO) and land category (forestland, grassland, cropland). The default emissions factors were obtained mainly from the IPCC Emission Factor Database (EFDB)[10] and EMEP/EEA or EMEP/ CORINAIR[11] air pollutant emission inventory guidebook. We also relied on emission factors published in regional and international peer review studies. In the selection of the EFs, the following factors were considered: (a) representativeness of the EFs for a set of facility-level plants, ecological zone or the production system, and (b) applicability of the regional and international EFs to the unique country conditions.

Generally, in the inventory, the default emissions factors from the IPCC EFDB and EMEP/EEA were commonly used because of the non-existing country-specific emission factors. The use of the default EF per se does not render the calculated emissions/removals inaccurate but comes with high uncertainty. When country-specific or region-specific emission factors are available for the same activity, the country-specific factors were used instead of the IPCC default figures. The reason was that the country-specific factors tend to give a more accurate estimate of the emissions/removals associated with the activity than using the global factors. Table 5 shows the overview of methodological tiers and the type of emission factors used according to the category and gases. The list of specific EFs used has been provided under the section on the methodology for the categories below.

Table 5: List of emissions/removal categories, methodological tiers and emission factors on the gas-by-gas basis

Category		CO_2		CH_4		N_2O		PFCs		SF6		HFCs		Non-GHGs[12]	
		Meth	EF	Meth	EF	Meth	EF	Meth	EF	Meth	EF	Meth	EF	Meth	EF
1.A1	Energy Industries	T1	D	T1	D	T1	D							T1	D
1.A2	Manufacturing Industries and Construction	T1	D	T1	D	T1	D							T1	D
1.A3	Transport	T1	D	T1	D	T1	D							T1	D
1.A4	Other Sectors	T1	D	T1	D	T1	D							T1	D
1.B1	Solid Fuels			NO	NO									NO	NO
1.B2	Oil and Natural Gas			T1	D									NE	NE
2.A	Mineral Products	T1	D											NE	NE
2.B	Chemical Industry	NO	NO	NO	NO	NO	NO							NO	NO
2.C	Metal Production	T2	PS	NE	NE	NE	NE	T2	PS	NE	NE			NE	NE
2.D	Non-Energy Products from Fuels and Solvent Use	T1	D											NE	NE
2E	Electronics Industry							NO	NO	NO	NO	NO	NO	NO	NO
2.F	Product Uses as Substitutes for Ozone Depleting Substances											T1	D		
3.A	Livestock			T1	D										

[10] https://www.ipcc-nggip.iges.or.jp/EFDB/main.php

[11] https://www.eea.europa.eu/themes/air/emep-eea-air-pollutant-emission-inventory-guidebook/emep

[12] Applies to gases classified as non-GHG SLCP and indirect GHG such as Black Carbon (BC), Nitrogen Oxides (NOx), Particulate Matter (PM2.5), Carbon Monoxide (CO) and Non-methane volatile organic compounds (NMVOCs). SO_2 is not estimated due to the lack of appropriate factors.

3.B	Land	T2	CS											T1	D
3C	Aggregate sources and non-CO_2 emissions sources on land	T1	D	T1	D	TI	D							T1	D
4.A	Solid waste disposal			T2[13]	D	T1	D							T1	D
4.B	Biological Treatment of Solid Waste			TI	D	T1	D							NE	NE
4.C	Incineration and Open Burning of Waste	T1	D	TI	D	T1	D							T1	D
4.D	Wastewater Treatment and Discharge			T1	D	T1	D							NE	NE

Key: CS= Country-Specific, PS= Plant-Specific, NE = Not Estimated, NO=Not Occurring, D = Default IPCC methodology and emission factor, EF = Emission Factor, Meth=Methods, T1, T2 - Levels of Tiers. The ash-colour-fill cell indicates the gas emission/removal does not apply to the corresponding category.

1.8.2.2 Sources of activity data

Activity data is one of the primary data points for the inventory. They have been collected from several national and international institutions as well as from scientific literature. Majority of the AD were obtained from existing data platforms managed by government institutions such as Energy statistics (Energy Commission), Agriculture Facts and Figures (Ministry of Food and Agriculture), National Forest Management System, (Forestry Commission) Vehicle statistics, (Driver Vehicle and Licensing Authority - DVLA), Industry environmental statistics (EPA). The dataset format varies and is published at varying frequencies. For instance, the energy statistics are published every year online on URL address http://www.energycom.gov.gh/planning/data-center/energy-statistics. It contains data on energy balance, supply, and consumption for different fuels and demand sectors. The Energy Commission relies on data supplied to it by the oil refinery, electricity-producing companies, National Petroleum Authority (NPA), Petroleum Commission and the Ghana National Gas Company (GNGC). The Energy Commission also collects data from the Ghana Statistical Service (GSS) and uses survey data. The data from the energy statistics was the primary source of the AD for many of the sub-categories under the energy sector 1A1, 1A2, 1A3 and 1B. Data on vehicle population, car traffic, and circulation patterns were from the Ministry Transport and DVLA.

The AD sources for the IPPU sector categories came from a wide range of sources. Most of them were sourced from the facility statistics collected through official requests. Others are obtained from the Environmental Management Plans and Annual Environmental Reports companies submitted to the Environmental Protection Agency as part of the Environmental Permit Conditions. Some of the activity data were also retrieved from the Environmental Performance Rating and Public Disclosure Database hosted by the EPA and the Industry Survey published by the GSS and the EPA. The IPPU inventory team collected data on HFCs consumption refrigeration air-conditioners from the national survey on HFC conducted by the National Ozone Unit at the EPA. The Ministry of Food and Agriculture's Statistics Research and Information Directorate (SRID) publishes the Agric Facts and Figures at different times. Usually, whenever they put out figures, it covers several years other than the publication year. They make the dataset available to the public on the web address (http://mofa.gov.gh/site/wp-content/uploads/2011/04/mofa_facts_and_figures.pdf).

[13] This is because country-specific activity data and some default parameters used in the inventory as recommended under section 3.2.1 and figure 3.1 (Decision tree for CH_4 emissions from Solid Waste Disposal sites) of the 2006 IPCC Guidelines.

The current online version of the Facts and Figures was published covering data from 1999 to 2009. The SRID made the latest version of the facts and figures to the inventory team covering up to 2016 though they are not published online. The Facts and Figures is the primary activity data source for the 3A and selected categories under 3C. The primary source of the AD for Land category (3B) is the National Forest Management System (NFMS) hosted by the REDD+ Secretariat of the Forestry Commission. Though the full version of the NFMS has not been deployed, most of the requisite data have been pulled together at a central point at the Forest Commission during the preparation of the REDD+ National Forest Reference Level (FREL) to the UNFCCC. Having the dataset at Forest Commission made access to the land representations dataset far more accessible. The data on waste management was not well organised at a single location, and documentation is sparse. Mostly, the AD for the Waste sector was dispersed among several district assemblies. So, the waste inventory team had to consult a wide variety of data sources for government reports, scientific literature, data from environmental sanitation service companies and the GSS to be able to assemble all the necessary data. In the absence of national data, we used alternative reliable data from the international organisation's such as FAO, IEA and the World Bank. Table 6 provides an overview of the data used in the inventory.

Table 6: Sources of activity data, format and the principal data providers

Sector		Data Type	Data Sources	Principal Data Providers	Remarks
1. Energy Sector					
1.A1	Energy Industry	Fuel types, supply, and consumption: • Crude oil production, imports, exports and use for electricity generation and as refinery inputs. • Natural gas production, processed, imports and use as fuel for electricity generation. • Production, imports, export and petroleum products production. • Auto production of selected petroleum products in the refinery, the gas processing plants, and the oil fields.	National Energy Statistics. Tema oil refinery material balance. National Energy Plan. International Energy Agency Database. Oil and Gas Production Figures. Ghana National Gas Company Data.	Energy Commission. National Petroleum Authority. Tema Oil Refinery. Thermal Electricity Generation Utility Companies (VRA, Sunon Asogli, Takoradi International Company TICO and other independent power producers. Ghana National Gas Company Limited. National Petroleum Commission. International Energy Agency.	National Energy Statistics is published online in April every year. TOR material balance is updated every year but not published. TOR data is administrative data requests through the Energy Commission. Oil and Gas Production figures are published every month by the Petroleum Commission
1.A2	Manufacturing Industry and Construction	Industrial sectors and their fuel consumption: • Fuel types and consumption. • Quantity of fuel used as feedstock. • Quantity of fuels for non-energy use.	National Energy Statistics, 2018 Industry survey data, 2013 National Industry Census, 2003 IEA	Energy Commission. Manufacturing Industry Department of the Environmental Protection Agency. Ghana Statistical Service.	The share of fuel allocation per industry sector is based on the fuel shares in the Energy' Commission's SNEP dataset. There plans to survey to improve the existing data.

1.A3	Transport	Fuel, vehicle and traffic information Fuel types and consumption by vehicles of different years of manufacture and technology class. International and domestic Aviation Rail and Navigation, Number of Registered Vehicles, Vehicle Types	Vehicle registration database. Transport sector study reports. Petroleum product sales data. Railway fuel consumption data. Water transport fuel consumption. Premix fuel consumption data.	Energy Commission. Environmental Protection Agency. Driver Vehicle Licensing Authority Oil Marketing Companies (particularly, Shell Ghana Limited, Total Ghana Limited). Ministry of Transport, Ghana Railway Company. Volta Lake Transport Company. Ghana Bunkering Services. Premix Committee at the Ministry of Fisheries and Aquaculture Development	Yearly vehicle population figures are sourced from the yearly release of administrative data on vehicle registration, roadworthy certification figures from DVLA and Vehicle import figures from the GcNET under Ghana Customs. There are plans to liaise with the newly established garages involved vehicle inspections in collecting additional vehicle odometer readings and measured emission figures.
1.A4	Other Sectors	Quantities of solid and liquid fuel consumption per category.	National Energy Statistics National Energy Plan, National Census Report, Ghana Living Standard Survey Report	Energy Commission Ghana Statistical Service	The share of fuel allocation per industry sector is based on the fuel shares in the Energy Commission's SNEP dataset. There plans to survey to improve the existing data.
1.B	Fugitive emissions from fuels	Quantities of wet production, quantities of reinjected, quantities of gas flared and gas consumed on site. Quantities of gas exported to Ghana National Gas Company.	Oil Exploration and Production. Gas transmission lines. Oil refinery data in the energy statistics.	Ghana National Petroleum Corporation. Petroleum Commission. Oil Production Companies. Environmental Protection Agency. Tema Oil Refinery.	Oil and Gas Production figures are published every month by the Petroleum Commission.
2. Industrial Process and Product Use Sector					
2.A	Mineral Industry	Industrial production and Plant-specific emission factors	Environmental Reports. Environmental Performance Rating and Public Disclosure Database. Industry Survey. Industrial data from facilities.	Volta Aluminum Company Limited Tema steelworks Aluworks Limited Environmental Protection Agency	No industry-specific data is published. Data are officially requested from industry and the Environmental Impact Statements.
2.C	Metal Industry				
2.D	Non-Energy Products from Fuels and Solvent Use	Amount of non-energy use of diesel and kerosene			
2F	Product Uses as Substitutes for Ozone	Quantities of different types of refrigerants imports and volumes sold per year to the	National survey on HFC consumption	National Ozone Office, Environmental Protection Agency	One-time national survey on HFCs by the Ghana EPA

	Depleting Substances	refrigeration and air conditioner.			
3. Agriculture, Forestry and Other Land use					
3.A1 and 3.A2	Enteric Fermentation & Manure Management	Animal population, Animal attribute (age, sex and weight classes). Fractions of manure management practices.	Agriculture Facts and Figures. FAOSTAT. Expert Judgment.	Ministry of Food and Agriculture – SRID. UN FAO. AFOLU Team	Agriculture Facts and Figures is published by the Ministry of Food and Agriculture online annually. The metadata for the Agriculture Facts and Figures are not available. The team consider the lack of metadata an area for improvement.
3.B1	Forest land	Land-use maps, land-use change map, land-use change matrix.	Forest Preservation Program, 2012, National Forest Reference Level, 2017.	Forestry Commission, Ghana	Land-use maps are not published at any scheduled time. They are generally produced as part of projects.
		Biomass estimates for 5 IPCC pools (AGB, BGB, deadwood, herb, litter and soil).			Biomass estimates across all the ecological zones were produced as part of the Forest Preservation Programme in 2014. There are scheduled updates.
		Climate zones, soil stratifications and ecological zone maps.	IPCC database	IPCC Forestry Commission	One-time GIS layers for climatic zones, soil classification and ecological zones exist.
		Industrial round wood.	RMSC, FAOSTAT	Forestry Commission FAO	Industrial round wood harvest figures are available in every quarter at RMSC but not published online. It is considered as an administrative request via official letter.
		Wood fuel production.	Energy Statistics	Energy Commission	Total wood fuel supply is published in the Energy Statistics every year.
		Areas affected by fires.	REDD+ National Forest Reference Level, 2017.	Forestry Commission	One-time GIS map produced by Forestry Commission when development the REDD+ FREL

3.B2	Cropland	Land-use maps, land-use change map, land-use change matrix.	Forest Preservation Program, 2012, National Forest Reference Level, 2017.	Forestry Commission	Land-use maps are not published at any scheduled time. They are typically produced as part of projects.
		Biomass estimate for 5 IPCC pools (AGB, BGB, deadwood, herb, litter and soil).			Biomass estimates across all the ecological zones were produced as part of the Forest Preservation Programme in 2014. There are scheduled o updates
		Climate zones, soil classification and ecological zone maps.	IPCC database	IPCC	One-time GIS layers for climatic zones, soil classification and ecological zones exist.
3.B3	Grassland	Land-use maps, Land-use change map, and change matrix.	Forest Preservation Program, 2012, National Forest Reference Level, 2017.	Forestry Commission	Ditto
		Biomass estimate for 5 IPCC pools (AGB, BGB, deadwood, herb, litter and soil)			Ditto
		Climate zones, soil classification and ecological zone maps	IPCC database	IPCC	Ditto
3.C1	Biomass burning	Areas affected by fire in cropland, forestland and grassland	National Forest Reference Level, 2017.	Forestry Commission	Ditto
		Mass of fuel available for burning.	Forest Preservation Program, 2012 National Forest Reference Level, 2017.	Forestry Commission	Derived from biomass figures for each land-cover type.
3.C3	Urea application	Annual Urea consumption figures	Agriculture Facts and Figures	Ministry of Food and Agriculture – SRID	Agriculture Facts and Figures is published by the Ministry of Food and Agriculture online annually.
3.C4	Direct N_2O emissions from managed soils	Annual generic NPK consumption	Agriculture Facts and Figures	Ministry of Food and Agriculture – SRID,	Ditto
3.C5	Indirect N_2O emissions from managed soils	Annual crop production in tonnes per annum	Agriculture Facts and Figures	Ministry of Food and Agriculture – SRID	Ditto
3.C6	Indirect N_2O emissions	Animal population (cattle, goats, sheep, swine, donkey, poultry, horse)	Agriculture Facts and Figures	Ministry of Food and Agriculture – SRID	Ditto

	from manure management	Fractions of manure management practices	Expert Judgment	AFOLU Team	Ditto
3.C7	Rice cultivation	Annual rice production areas	Agriculture Facts and Figures	Ministry of Food and Agriculture – SRID	Ditto
		Proportions of annual rice production area under rain-fed irrigated and upland systems	National Rice Development strategy	Ministry of Food and Agriculture - SRID	Ditto
4. Waste					
4A	Solid Waste Disposal	Waste Generation, Population Figures, Composition, amounts of waste deposited, means of disposals and their various percentages	Published national reports. Ghana Statistical Service. Sanitation Directorate of MLGRD. World Bank Country Database. Private Waste Management Companies and Civil Engineering Department KNUST. EPA	National Environmental Sanitation Strategy & Action Plan (NESSAP). Population Census Reports and Ghana Living Standards Survey 2008. Private Waste Management Companies (Zoomlion Ghana Limited, Waste care), and NGOs Academia (Civil Engineering Department, KNUST). Second National Communication Report.	Solid waste data is not at a single location. Documentation is poor. Relied on multiple reports, literature and scattered data at the assemblies. A major national survey is needed.
4B	Biological Treatment of Solid Waste	The fraction of waste composted, number of compost plants	Private Waste Management	Private Waste Management Companies (Zoomlion Ghana Limited) and NGOs. Expert judgment by the Waste Team	Ditto
4C	4C.1 Waste Incineration	Amount and types solid waste incinerated, type of incinerator including capacities and combustion efficiencies	Ghana Health Services. Ministry of Local Government and Rural Development.	National Environmental Sanitation Strategy Action Plan document. Ghana Health Service Facts and Figures. Expert Judgment by the Waste Team.	Data on incineration is scanty and scattered. Inventory team relied on different data sources. A major national survey is needed.
	4C.2 Open Burning of Solid Waste	Population, the proportion of population burning waste, duration of burning in the number of days per year, the fraction of waste burnt relative to the total amount treated.	Published national reports, Ghana Statistical Services, Sanitation Directorate of MLGRD,	National Environmental Sanitation Strategy & Action Plan (NESSAP), Population Census Reports and Ghana Living Standards Survey 2008, Expert Judgment by Waste Team	Data on open burning is not adequate. Inventory team relied on different data sources. A major national survey is needed.
4D	4D.1 Domestic wastewater treatment and discharge	Population, Wastewater Generated per year, Wastewater treated per year, Wastewater Treatment Systems and their various percentages, Protein Consumption, GDP/capita	Ghana Statistical Service. Sanitation Directorate of MLGRD. World Bank, Ghana Health Service. Ministry of Food and Agriculture	National Environmental Sanitation Strategy & Action Plan (NESSAP). Population Census Reports and Ghana Living Standards Survey 2008. Multiple Cluster Indicator Survey Data	Data on domestic wastewater are scattered. Inventory team relied on different data sources. A major national survey is needed.

				World Bank Country Database and FAO. Expert Judgment by Waste team.	
	4D.2 Industrial wastewater treatment and discharge	Industrial coverage, Total Industry Product Quantity of wastewater generated Type of Wastewater Treatment/discharge System	Industry survey	Industrial Outputs data collected during the national survey. Environmental Management Plans. Expert Judgment by Waste team.	The quality of the data from the survey and the Environmental Management Plans for Industries need to be improved.

1.9 Key categories analysis

Key Category Analysis (KCA) was performed to identify the main activities that contributed most to the emissions/removals for a given year or across the entire time series. The 2006 IPCC Guidelines provides guidance and a mathematical approach for the KCA. The Guidelines emphasises that the key category has a significant influence on a country's total inventory of greenhouse gases in terms of the absolute level of emissions or removals, the trend in emissions or removals, or both. In this inventory, the identification of key categories has been performed using the tier 1 level and trend assessments, as recommended in the 2006 IPCC Guidelines. This approach identifies sources/removals that makeup 95% of the total emissions or 95% of the trend of the inventory in absolute terms. The methods used for the identification of the key categories were the level assessment for 200 and 2016, and trend assessment for 2016, for 2000. The results of the key category analysis are presented as with and without the FOLU[14] category.

1.9.1 Key category analysis results

In 2016, twenty key categories were identified using the level assessment (L) with an aggregate emission of 40.1 $MtCO_2e$ (Table 7) amounting to 93% of the national totals. Out of the twenty identified key categories, nine of them were sources of CO_2 emissions and contributed most to the key category emissions and followed by CH_4 and N_2O with five each then by HFC. Without FOLU, the key categories analysis identified seventeen activities with emissions totalling 45.3 $MtCO_2e$. For the trend assessment (T) KCA, 20 categories were identified (Table 7). For both L and T assessments, the categories with CO_2 emissions dominated followed by CH_4 and then N_2O. Some of the categories that emerged from L and T assessments are as follows: (a) Electricity generation (1. A1ai), (b) land converted to cropland (3B2.b), (c) land converted to grassland (3B3.b), manufacturing industries and construction (1A2), road transportation (1A3b) wastewater treatment and discharge (4D).

Table 7: Level assessment key categories in 2016

IPCC Category	Gas	Emissions/Removals ($GgCO_2e$)	Contribution to level	Cumulative
3.B.2.b - Land Converted to Cropland	CO_2	8,837.88	16.59%	16.59%
3.B.3.b - Land Converted to Grassland	CO_2	8,804.18	16.53%	33.12%
1.A.3.b - Road Transportation	CO_2	5,918.52	11.11%	44.23%
1.A.1ai – Electricity generation	CO_2	5,038.47	9.46%	53.69%
3.C.4 - Direct N_2O Emissions from managed soils	N_2O	4,142.82	7.78%	61.46%

[14] FOLU – "Forestry and Other Land Use. Excludes emissions from Agriculture source categories (such as livestock), and includes emissions and removals from forest and other land use types."

3.B.1.a - Forest land Remaining Forest land (net sink)	CO_2	(3,562.51)	6.69%	68.15%
3.A.1 - Enteric Fermentation	CH_4	2,407.92	4.52%	72.67%
1.A.2 - Manufacturing Industries and Construction	CO_2	1,937.40	3.64%	76.31%
4.D - Wastewater Treatment and Discharge	CH_4	1,295.42	2.43%	78.74%
3.C.5 - Indirect N_2O Emissions from managed soils	N_2O	1,141.94	2.14%	80.89%
3.B.1.b - Land Converted to Forest land (net sink)	CO_2	(1,105.57)	2.08%	82.96%
1.A.3.c - Railways	CO_2	941.96	1.77%	84.73%
3.A.2 - Manure Management	N_2O	938.68	1.76%	86.49%
4.A.1 - Managed Waste Disposal Sites	CH_4	924.18	1.73%	88.23%
1.A.4.b - Residential	CH_4	848.09	1.59%	89.82%
2.F.1 - Refrigeration and Air Conditioning	HFC	613.00	1.15%	90.97%
4.D - Wastewater Treatment and Discharge	N_2O	541.12	1.02%	91.98%
3.C.1 - Emissions from biomass burning	CH_4	528.69	0.99%	92.98%
3.B.2.a - Cropland Remaining Cropland	CO_2	(506.42)	0.95%	93.93%
3.C.1 - Emissions from biomass burning	N_2O	440.71	0.83%	94.76%

Table 8: List of trends assessment key categories for the period 2000-2016

Category	Gas	Emissions/Removals ($GgCO_2e$)		Trend Assessment (Tx,t)	Contribution to trend (%)	Cumulative
1.A.1ai – Electricity generation	CO_2	548.79	5038.47	0.11	19.0%	19.0%
1.A.2 - Manufacturing Industries and Construction	CO_2	3735.88	1937.40	0.07	12.0%	31.1%
3.B.2.b - Land Converted to Cropland	CO_2	8837.88	8837.88	0.05	9.9%	40.9%
3.B.3.b - Land Converted to Grassland	CO_2	8804.18	8804.18	0.05	9.8%	50.7%
1.A.3.b - Road Transportation	CO_2	3038.71	5918.52	0.05	9.2%	59.9%
3.C.4 - Direct N_2O Emissions from managed soils	N_2O	2251.64	4142.82	0.03	5.8%	65.7%
3.B.1.a - Forest land Remaining Forest land	CO_2	3709.98	3562.51	0.03	4.8%	70.5%
1.A.3.c - Railways	CO_2	35.82	941.96	0.02	3.9%	74.4%
3.C.1 - Emissions from biomass burning	N_2O	933.89	440.71	0.02	3.2%	77.6%
4.D - Wastewater Treatment and Discharge	CH_4	464.63	1295.42	0.02	3.1%	80.7%
3.C.1 - Emissions from biomass burning	CH_4	987.00	528.69	0.02	3.1%	83.8%
3.A.1 - Enteric Fermentation	CH_4	1469.50	2407.92	0.01	2.5%	86.3%
3.C.5 - Indirect N_2O Emissions from managed soils	N_2O	608.04	1141.94	0.01	1.7%	88.0%
4.A.2 - Unmanaged Waste Disposal Sites	CH_4	479.11	231.04	0.01	1.6%	89.6%
3.B.1.b - Land Converted to Forest land	CO_2	1096.70	1105.57	0.01	1.2%	90.8%
2.A.4 - Other Process Uses of Carbonates	CO_2	44.29	312.23	0.01	1.1%	91.9%
2.C.3 - Aluminium production	CO_2	239.63	54.86	0.01	1.1%	93.0%
3.A.2 - Manure Management	N_2O	565.52	938.68	0.01	1.0%	94.0%
1.A.4.b - Residential	CO_2	193.18	28.52	0.01	0.9%	94.9%
3.B.2.a - Cropland Remaining Cropland	CO_2	506.42	506.42	0.00	0.6%	95.5%

Table 9: Status of level and trend key category assessment

Category	Level assessment (L)	Trend assessment (T)
Electricity generation	L	T
Manufacturing Industries and Construction	L	T
Land converted to cropland	L	T
Land converted to grassland	L	T
Road transportation	L	T
Direct N_2O emissions from managed soils	L	T
Forest land remaining forest land (net sink)	L	T
Railways	L	T
Emissions from biomass burning (CH_4)	L	T
Wastewater treatment and discharge	L	T
Emissions from biomass burning (N_2O)	L	T

Enteric fermentation	L	T
Indirect N_2O Emissions from managed soils	L	T
Unmanaged waste disposal sites		T
Managed waste disposal sites	L	
Land converted to Forest land (net sink)	L	T
Other process uses of carbonates		T
Aluminium production		T
Manure management	L	T
Residential	L	T
Cropland remaining cropland	L	T
Refrigeration and air conditioning	L	

Most of the key categories identified in the level and trend assessment are in the Energy and AFOLU sectors. It is also important to note that CO_2 emissions are the dominant pollutant for the categories under L and T assessments. Additional details on the key category analysis are provided in the chapters dedicated to the sectors (Tables 8 and 9).

1.10 Quality Assurance/Quality Control Procedures

Quality Assurance/Quality Control (QA/QC) procedures that pertain to a specific category have been comprehensively addressed under the relevant sector chapters. In this section, we have provided the broad outlook of the QA/QC procedures across the inventory relative to its current state, institutional roles, general and specific procedures, challenges and the strategies to continuously improve upon them. Also, the information on the status of addressing the technical comments during the informal third-party review and the ICA process have been reported. The QA/QC is an integral part of the national system, and the practices are broadly consistent with the good practices in the 2006 IPCC Guidelines.

The documentation and the implementation of the QA/QC procedures have been captured using the US template EPA QA/QC measures. The template helped the sector teams to document all the QA/QC activities (https://www.epa.gov/climatechange/Downloads/EPAactivities/Complete%20Template%20Workbook.doc).
The Forestry Commission has also prepared and adopted 12 Standard Operating Procedures (SOPs) to guide the inventory activities in the land category. The SOPs were useful in the planning and designing of the data collection techniques for activity data and emission factors (biomass inventory)[15]. Despite some progress in the improvements of the QA/QC, there were still challenges in the areas relating to:

- insufficient data handling protocols in the treatment of incompatible data formats,
- secondary data without metadata,
- detection of data errors and outliers, and
- data restriction and confidential data.
- non-standardised application of experts' judgement,
- the use of tier 1 or default emission factors for key categories and
- the application of generic approaches to address sector-specific problems.

[15] http://fcghana.org/userfiles/files/REDD%2B/Ghana%20MRV%20Final%20Report%20(ID%2067024).pdf.

To address the challenges, Ghana has also adopted a country-specific QA/QC plan and GHG inventory manual[16]. The GHG plan clearly articulates the inventory steps, institutional responsibilities and timelines. The plan would also be used to inform the training of existing experts. The QA/QC manual[17] seeks to streamline and formalise existing QA/QC procedures and communicate with a clear set of objectives to the inventory team in line with the 2006 IPCC Guidelines. These procedures are to ensure that the inventory system and estimates emerging from them are more transparent, credible and defensible.

1.10.1 QA/QC institutional roles and responsibilities

According to the QA/QC plan the EPA was tasked to play a facilitative role in implementing QA/QC measures and coordinates jointly with the QA/QC lead institution to ensure that the sector experts adhere to the plan. However, the Mathematics Department of KNUST could not be desirably engaged in the inventory process. Therefore, the EPA doubled as the QA/QC lead and performed the following broad functions:

- ensure that the sector teams follow QC checklist,
- collect and review completeness checklist submitted by the sector inventories;
- facilitate all technical reviews of the inventory both in-country and at the international level,
- organise training programmes on quality-related topics.

Nevertheless, the real QA/QC measures were implemented in the sector inventories, which is why the sector team leads had the responsibility to make sure that adequate QA/QC procedures were thoroughly implemented in the inventory backed by verifiable documentation.

1.10.1.1 Tier 1 QC protocols

In the inventory, Ghana implemented tier 1 QC procedures which covered checks, documentation and archiving practices the inventory compilers routinely used throughout the inventory cycle. The list of the QC procedure followed in the inventory is in Table 10.

Table 10: List of QC procedures followed in the inventory

QC Tasks	Details of QC Tasks	Responsibility
Internal consistency	Ensured that the total GHG emissions equal the sum of the individual emissions from the sectors and categories.	EPA
	Confirmed the total GHG emissions equal the sum of the emissions by gas.	EPA
	Ensured that parameters used in multiple categories (e.g., the population of livestock) are consistent across categories.	EPA
	Confirmed that the emissions data is reported in a manner consistent with the calculation tables in the Non-Annex 1 National Communications Reporting Guidelines.	EPA
	Confirmed that the selection and application of the estimation methods were consistent with IPCC Guidelines.	EPA
Documentation	Created back-ups of all documentation in hard and soft copies and uploaded files on to the central storage facility online.	All sectors Webmaster
	Moved all files and documentation to an "online climate change data hub".	Webmaster

[16] http://www.gh.undp.org/content/dam/ghana/docs/Doc/Susdev/LECBP_National%20GHG%20Inventory%20%20Manual_revised_v2.pdf.

[17] http://www.gh.undp.org/content/dam/ghana/docs/Doc/Susdev/LECBP_QAQC%20%20Plan_Ghana_final.pdf

Checks	Checked that assumptions and criteria for the selection of activity data and emission factors are documented	EPA
	Check that parameters and emission/removal units are correctly recorded, and that appropriate conversion factors are used.	EPA
	Checked for transcription errors in data input and reference.	EPA
	Checked methodological and data changes that led to recalculations.	EPA
	Checked that emissions/removals are calculated correctly.	EPA
	Compared current inventory estimates to previous estimates, if available. If there are significant changes or departures from expected trends, re-check estimates and explain any difference. Significant changes in emissions or removals from previous years may indicate possible input or calculation errors	EPA
	Checked that emissions/removals data are correctly aggregated from lower reporting levels to higher reporting levels when preparing summaries.	EPA
	Checked that data in tables are the same as the calculation in spreadsheets and the text.	EPA
	Check if there are any unusual or unexplained trends noticed for activity data or other parameters across the time series.	EPA

1.10.1.2 QA Procedures

Quality Assurance (QA) procedures are an essential part of the overall QA/QC procedures. Since QA allows the experts who have not been directly involved in the inventory to scrutinise the inventory system and the emissions to provide review comments. Ghana has undertaken extensive technical reviews of the inventory, and afterwards, the status of addressing the comments is documented with the issue-tracking template.

1.10.1.2.1 Third-party review of the inventory

After the inventory figures from sector teams were put together, a national inventory report was produced from the dataset. Then, the NIR, the datasheet and all related documentation were used in an extensive third-party review both in Ghana and at the international level. During this round of preparing the NIR, the first-ever voluntary in-country review was organised together with the UNFCCC. Besides, several international experts reviewed the draft NIR and the issues raised were addressed before the submission. Furthermore, a national review was also organised for stakeholders from line ministries.

1.10.1.2.2 Voluntary UNFCCC in-country review

Ghana was the first African country to undergo a voluntary in-country review of the National Greenhouse Gas Inventory Management System and National Greenhouse Gas Inventories of Ghana on 19-23 March 2018. The UNFCCC secretariat organised the review with support from the Global Support Programme, UNDP. Ghana responded positively to participate in a voluntary in-country review when it received an official invitation from the UNFCCC in November 2017. Afterwards, the Ghana team, UNFCCC, and the GSP started to work out the full details of the review modalities covering planning, selection of international review experts, review data exchanges, review week modalities and considerations of review outputs.

The pre-review communication was done through emails. In terms of coordination, the UNFCCC and GSP led in the planning hotel and DSA while the Ghana team focused on the selection and confirmation of participation of sector experts. The EPA came with the first list of participants who were drawn from the existing inventory sector teams. With a confirmed participant list, a joint programme for the review week was prepared by the UNDP and UNFCCC with input from the Ghanaian team. The review mainly focused on the review materials for

BUR1 and NIR3 since at the time the BUR2 and NIR4 were not ready. This approach allowed us to address the comments in the preparation of the BUR2 and the NIR4. On the first day, all the sector teams and generalists attended, and the review was focused on reviewing cross-cutting issues. Days 2 to 4 of the review week were dedicated to the review of sector inventories. During Day 5, all the sector teams attended, and the experts presented their initial findings for the Ghanaian team to provide their feedback. Then both the review experts and the sector teams jointly come up with a prioritised improvement list with implementation timelines and the capacity building needs.

The UNFCCC and GSP selected six international experts with diverse experiences, three of whom led in sector review and three from the UNFCCC Bonn and Lomé facilitated the review. The sector expert was; Sandro Federici (Italy and AFOLU), Stanford Mwakasonda (GSP, IPPU) and Romain BORT (Citepa, France Energy and Waste). Also, representatives from the UNFCCC, William Kojo Agyeman-Bonsu, Dominique Revet, and Saverio Ragazzi participated in the review. The review modalities were agreed upon by the Ghanaian team and the UNFCCC before starting the review. The agreed modalities clarified the format of the review, timelines and roles, legal nature of the review and its implications for any future ICA and remit of questions of clarification and responses. Before the review week, Ghana shared all the relevant data (sectoral and consolidated datasheet, NIR, and reports) with the UNFCCC through a secured FTP for onward transmission to the selected review experts. Two weeks after receiving the review materials, the review experts prepared and submitted their initial questions to Ghana via the UNFCCC.

During the review week, Ghana made a presentation on the broad overview of the GHG national system after which the individual experts took turns to raise additional questions for plenary discussions. Subsequently, each sector review experts engaged with the sector team to go over the prefilled templates containing the question of clarifications based on the UNFCCC reporting requirements. At the end of the week, each review expert finalised the draft review template and later consolidated into one for a joint discussion with the Ghanaian team. The review ended with a prioritised improvement list that would be implemented to enhance the functionality of the national system in the long run. Ghana completed a satisfaction survey questionnaire to provide feedback to the UNFCCC on the review. Table 13 contains the critical recommendations for implementation in the BUR2 and BUR3.

In addition to the formal review, the draft NIR4 was reviewed by international experts (Table 11). The review allowed the team to scrutinise and uncover technical issues to the application of methodologies, selection of activity data, development and selection of emission factors by the IPCC guidelines. The listed experts and their organisations indicated in Table 11, below were sent a draft copy of the inventory for review four weeks before publication. The review package that was sent to the third-party reviewers included (a) data inputs, (b) inventory datasheets and results and (c) inventory report.

Table 11: List of Experts for External Review of National Greenhouse Gas Inventory

Reviewer	Affiliation and organisation	Sector/Gas	Comments
Mr Stanford Mwakasonda	GSP	All sectors	Facilitated by Ms Suzanne Lekoyiet of UN Environment.
Dr Chris Malley	Stockholm Environment Institute, University of York.	SLCP sectors	under the CCAC SNAP Initiative
Dr Ananth Chikkatur	ICF	All sector	Collaboration under with IRRP Project
Leslie Chinery	ICF	All sector	Collaboration under with IRRP Project

Andrews Sabrina	ICF	All sector	Collaboration under with IRRP Project
John Venezia	ICF	All sector	Collaboration under with IRRP Project

All the sector inventory results were subjected to "internal disclosure and assessment" by the relevant Ministries, Department and Agencies (MDAs). The "internal disclosure assessment" was done through four "reality check" meetings that were held at the various MDAs to collect inputs on (a) policy implications of the sector estimates (b) practical steps that are needed to be taken to facilitate further mainstreaming of inventory in the sector and (c) how to strengthen the linkages with research.

1.10.1.2.3 Handling of technical review comments

As part of the QA/QC protocol, Ghana developed and adopted the review issues tracking template to document the efforts to address recommendations/findings/issues identified during the formal and informal review of the previous NIR (Table 12). Three technical reviews were performed on the NIR3. These were: (a) Technical Analysis of the BUR under the ICA consistent with Decisions/CP.17 and 20/CP/.19, (b) Informal review of the NIR3 before submission to the UNFCCC and (c) voluntary in-country review of the GHG Inventory. All the comments from the reviews were documented and guided subsequent NIRs. Table 13 presents the critical recommendations from the three reviews, but the emphasis would be given to the recommendations from the Technical Analysis since it was the official review.

Table 12: Sample of the template used for the documentation of the general QC procedures

QC Activity	Procedures	Task Completed		Corrective Measures Taken		
		Name/ Initials	Date	Supporting Documents (List Document Name)	Name/ Initials	Date
Data gathering, input, and handling checks						
Check that assumptions and criteria for the selection of activity data and emission factors are documented.	• Cross-check descriptions of activity data and emission factors with information on categories and ensure that these are recorded correctly and archived.					
Check for transcription errors in data input and reference.	• Check that all citations in spreadsheets and inventory are complete. • Confirm that bibliographical data references are cited correctly in all internal records. • Randomly check that the originals of citations contain the material & content referenced					
	• Cross-check a sample of input data from each category (either measurements or parameters used in calculations) for transcription errors. • Use electronic data where possible to minimise transcription errors. • Check that spreadsheet features are used to minimise user/entry error: (a) use cell protection so fixed data cannot accidentally be changed; (b) build in automated checks, such as computational checks for calculations, or range checks for input data.					
Check that emissions/removals are calculated correctly.	• Reproduce a representative sample of emissions/removals calculations. • If models are used, the test runs the model calculations at a minimal level to judge its relative accuracy.					
Check that parameters and emission/removal units are correctly recorded, and that appropriate conversion factors are used.	• Check that the units are labelled appropriately in calculation sheets. • Check that the units are carried correctly through from beginning to end of calculations. • Check that conversion factors are correct. • Check that temporal and spatial adjustment factors are used correctly.					
Check the integrity of database files.	• Confirm that the appropriate data processing steps are correctly represented in the database. • Confirm that data relationships are represented correctly in the database.					

	• Ensure that data fields are correctly labelled and have the correct design specifications. • Ensure that adequate documentation of database and model structure and operation are archived.					
Check for consistency in data between categories.	• Identify parameters (e.g., activity data, constants) that are common to multiple categories and confirm that there is consistency in the values used for these parameters in the emissions/removal calculation.					
Check that the movement of inventory data among processing steps is correct.	• Check that emissions/removals data are aggregated correctly from lower reporting levels to higher reporting levels when preparing summaries. • Check that emissions/removals data are transcribed correctly between different intermediate products.					
Data Documentation						
Review of internal documentation and archiving.	• Check that there is detailed internal documentation to support the estimates and enable duplication of calculations. • Check that every primary data element has a reference for the source of the data (via cell comments or another system of notation). • Check that inventory data, supporting data, and inventory records are archived and stored to facilitate a detailed review. • Check that the archive is closed and retained in a secure place (preferably on the online server) following completion of the inventory. • Check integrity of any data archiving arrangements of outside organisations involved in inventory preparation. • Check that archiving has been done at both the sector and inventory level.					
Calculation Checks						
Check methodological and data changes resulting in recalculations.	• Check for temporal consistency in time-series input data for each category. • Check for consistency in the method used for calculations throughout the time series. • Reproduce a representative sample of emission calculations to ensure mathematical correctness.					
Check time-series consistency	• Check for temporal consistency in time-series input data for each category. • Check for consistency in the method used for calculations throughout the time series. • Check methodological and data changes resulting in recalculations.					

	• Check that the effects of mitigation activities have been appropriately reflected in time series calculations.					
Check completeness	• Confirm that estimates are reported for all categories and all years from the appropriate base year throughout the current inventory. • For sub-categories, confirm that the entire category is being covered. • Prove a clear definition of 'Other' type categories. • Check that known data gaps that result in incomplete category emissions/removals estimates are documented, including qualitative evaluation of the importance of the estimate with total net emissions (e.g. subcategories classified as 'not estimated').					
Trend checks	• For each category, compare current inventory estimates to previous estimates, if available. If there are significant changes or departures from expected trends, re-check estimates and explain any difference. Significant changes in emissions or removals from previous years may indicate possible input or calculation errors. • Check the value of implied emission factors (aggregate emissions/removals divided by activity data) across time series. Are changes in emissions or removals being captured? • Check if there are any unusual or unexplained trends noticed for activity data or other parameters across the time series.					
Internal consistency checks	• Check that the total GHG emissions equalled the sum of the individual emission from the sectors and categories. • Check that the total GHG emissions equalled the sum of the emissions by gas. • Check that data in tables are the same as the calculation in spreadsheets and the text. • Check that parameters used in multiple categories (e.g., animal population) are consistent across categories.					
Source: This list has been adapted from IPCC Good Practice Guidance and the 2006 IPCC Guidelines for National GHG Inventories.						

Table 13: Review issues tracking template

Review	Sector	Main issues	Description of issue and critical recommendations	Timelines	Actions taken	Status
Technical Analysis	Cross-cutting	Use of notation keys	Include information on other areas such as the control of consistent values, the use of the notation key "NE" (not estimated) and the values of non-CO_2 gas emissions in units of Gg and CO_2 eq.	BUR2/NIR4	QA/QC has been improved to improve the checking of the use of notation keys.	Resolved
		Use of notation keys	The transparency of the information reported could be enhanced if, following decision 17/CP.8, annexe, paragraph 22, notation keys were used where numerical data are not provided.	BUR2/NIR4	All "0" was used to denote not applicable has been changed to dash.	Resolved
		Uncertainty analysis	Provides a category-specific uncertainty assessment	BUR2/NIR4	The uncertainty assessment for the Land representation system has been provided. Uncertainty in other sectors has not been done due to the lack of requisite meta-data. Due to the lack of requisite data, there was no clear basis to assign a default range of uncertainty in the IPCC software.	Unresolved
		Key category analysis (KCA	Make the threshold for KCA consistent with that of the 2006 IPCC Guidelines (95%).	BUR2/NIR4	The threshold for the KCA calculation has been changed to 95%.	Resolved
		Consistency with IPCC Guidelines	Report estimates of emissions/removals on a gas-by-gas basis and in units of mass, as suggested in the UNFCCC Guidelines for the preparation of national communications from non-Annex I Parties.	BUR2/NIR4	Emissions/removal has been reported on the gas-by-gas basis and in units of mass (Annex 1).	Resolved
	Energy	Reference Approach vs Sectoral Approach	Enhance the capacity of national experts in the use of the reference and sectoral approaches.	BUR2/NIR4	Improvements in the energy balance have significantly reduced the differences in reference and sectoral approaches (section 3.6.1.1)	Resolved
	Cross-cutting	Use of country-specific factors	Descriptions of country-or plant-specific factors are reported, where such information is not confidential	BUR2/NIR4	Detailed elaborations are provided at the relevant section of the NIR where the country or plant-specific factors have been used.	Resolved
		Completeness of source categories	Conduct regular surveys to determine the completeness of all source categories.	Long-term	Survey on missing categories has not been implemented due to lack of financial resources.	Unsolved
Voluntary In-country review	Cross-cutting	Quality Control/Quality Assurance	There is an increase between 2007 and 2008 for waste sector emissions (figure 45 of the NIR of NIR3). There is a possible inconsistency in the time series because industrial wastewater emissions are estimated from 2008. Need to	BUR2/NIR4	Emissions from industrial wastewater for the years before 2007 have not	Unresolved.

			estimate industrial wastewater for previous years to ensure the consistency (e.g. extrapolation with industrial production ratio).		been estimated due to lack of data. Deferred to NIR5	
	Waste		The specific country solid waste composition in 2012 (figure 43 of the NIR3) is very different compared with the 2006 IPCC Guidelines composition (Vol5_Ch2_table 2.3), particularly for food waste. During the review, Ghana explained that a study was carried out and explained this difference. The team review recommends specifying this study in the reference of the NIR.	BUR2/NIR4	Comparison of CH_4 emissions from the use of country-specific food waste fraction and the IPCC defaults has been performed and reported in Annex 4	Resolved.
	IPPU		Lack of transparency of QA/QC information including the use of the notation keys and QA/QC at IPPU sector and category level	BUR2/NIR4	QA/QC has been improved to improve the checking of the use of notation keys.	Resolved
	Waste		Ghana could compare the results from Solid Waste Disposal sector emissions (4A) estimated with Tier 2 methodology with the Tier 1 methodology.	BUR2/NIR4	Estimates of Tier 1 and Tier 2 of emissions of solid waste disposal has been provided under the waste sector	Resolved
	Cross-cutting	Uncertainty analysis	The uncertainty range reported in Table 11 of the NIR for all the sectors (but LULUCF to be addressed later) must be reviewed by applying the appropriate uncertainty threshold in the IPCC Guidelines.	BUR2/NIR4	The uncertainty assessment for the Land representation system has been provided. Uncertainty in other sectors has not been done due to the lack of requisite meta-data. Due to the lack of requisite data, there was no clear basis to assign a default range of uncertainty in the IPCC software.	Unsolved
			Lack of information on the level of uncertainty associated with inventory data and their underlying assumptions, and to describe the methodologies used, if any, for estimating these uncertainties, at sector and category level.	BUR2/NIR4		
			Methodology for the estimation of uncertainty was not documented. Information on the methodology and sources of uncertainties should be provided or explained in the next national inventory report.	BUR2/NIR4 to BUR3/NIR5		
		Key category analysis	The KCA only performed with the AFOLU sector, and the country should also perform KCA without the AFOLU	BUR2/NIR4	KCA results have been presented with and without FOLU under section 1.8.1.	Resolved
		TCCCA Principles	Fugitive emissions from natural gas and oil exploration and transport are not estimated. Need to estimate these sub-categories	BUR3/NIR5	Emissions from natural products have been estimated (section 3.7.1). Emissions from oil exploration and transport have not been estimated.	Resolving
	Energy	Choice and updates of factors	Need to replace the EF used for flaring in oil production (1.B.2.a.ii) and need to ensure the consistency between EF specified in IPCC Guidelines and activity data used	BUR2/NIR4	Appropriate emission factors for flaring (section 3.7.1) has been selected considering Ghana's unique industry practice and consistent with the IPCC Guidelines	Resolved
	Waste		Concerning Biological Treatment of solid waste (4B), the N_2O EF used corresponds to the old version of the 2006 IPCC Guidelines (volume 5, chapter 5, table 4.1)	BUR2/NIR4	Old emission factor has been changed to 0.2g/kg	Resolved

			(0.30 g/kg) but there was an update in July 2015 where this value had been corrected (0.26 g/kg).			
	IPPU	Surveys for missing source categories	Lack of regular surveys to determine the inclusion of missing category emissions reported as insignificant or non-existent; Chemical industry, Ceramics emissions (2.A.4a), Product uses as substitutes for ozone-depleting substances (2F), Other product use (2G) – SF6 electrical equipment; N_2O for medical applications.	Long-term	Survey on missing categories has not been done due to lack of financial resources. Emissions from 2F have been estimated from 2005 to 2016, but 2G has not been conducted due to the lack of data.	Resolving
	IPPU		Estimation of emission from specific categories due to lack of data, in cases where emission activities are known to take place; Ceramics emissions (2.A.4a), ODS substitutes (2F)-Refrigeration and air conditioning, aerosols, fire protection, Other product use (2G) – SF6 electrical equipment; N_2O for medical applications. Lack of justification for insignificant emissions based on IPCC reporting Guidelines (e.g. lime production emissions (2.A.2); Soda Ash Use (2.A.4b), NIR page 103).	BUR2/NIR4 to BUR3/NIR5		
	Agriculture	Identification of outliers of animal population	Animal populations data seems to contain inconsistencies, e.g. the year 1995 for cattle, which affects associated estimates of manure management and enteric fermentation. An error in the calculation seems to have been occurring in N_2O emissions from manure management for sheep population for the year 2000 and 2012. To avoid such errors in time series, it is recommended to strengthen the QC of time series, e.g. using an algorithm to identify outliers in activity data, emission factors and GHG estimates.	BUR2/NIR4	Trend analysis has been used to identify outliers in activity data, emission factors and the GHG estimates for livestock population (section 5.1.1).	Resolved
	Energy	Other sectors	Need to split off-road emissions (between 1.A.3.e.ii -Off-road vs 1.A.4.c.ii -Off-road Vehicles and Other Machinery, but there is no double-counting). The appropriate notation key for 1.A.4.c.ii -Off-road Vehicles and Other Machinery included elsewhere IE).	BUR2/NIR4	Off-road emission and other machinery have been separated and appropriate notation key used (section 3.6.5.4).	Resolved
	Energy	Other sectors	Need to split 1.A.4.c.i -Stationary emissions and use appropriate EF for each 1.A.4.c subcategories.	BUR2/NIR4	Split of emissions Stationary emission under 1.A.4.c is reported in Section 3.6.5.4.2	Resolved
	Energy	Other sectors	The appropriate notation key for 1.A.4.c.iii - Fishing (mobile combustion) should be included elsewhere IE.	BUR2/NIR4	See information reported in Section 3.6.5.4.2 of the NIR	Resolved
	Energy	1.B2a	Venting emissions are part of the emissions from flaring due to the technology used. So, the notation key for emission category would be IE. Need to specify more explanation/evidence in the NIR about this.	BUR2/NIR4	Explanation of the use of IE has been provided under section 3.8.2	Resolved
	AFOLU, Livestock	Manure Management	Data on manure distribution among different systems were revised in 2000. It is suggested that the difference with the previous distribution (i.e. the 1990s) is apportioned across the period to avoid inconsistencies in the time series	BUR2/NIR4	Share of manure among different are applied consistently across the time series	Resolved

		Manure Management	No removal of N excreted from total N; the 2006 EFs are applied. The calculation is performed with the 2006 IPCC software with default factors only. As a priority, the Ghanaian typical animal mass for each livestock category should be calculated and applied for calculating the Nex instead of the IPCC default.	BUR2/NIR4	Unable to access reliable data. Deferred to NIR5.	Unsolved
	AFOLU, Rice cultivation	Conditions of rice cultivation	IPCC default EFs are applied. No amendments are assumed to be applied. Check whether irrigated fields are used twice a year for rice cultivation and amend Sfp accordingly.	BUR2/NIR4	Irrigated field are used throughout the year. Harvesting occurs once a year.	Resolved
			Rice belowground residues should not be included (bias to be corrected).	BUR2	Belowground crop residues were excluded.	Resolved
	AFOLU, Fertiliser Application	Completeness	Organic fertiliser is missing and should be estimated (no statistics available, could use expert judgment).	BUR2/NIR4	Deferred to NIR5	Unsolved.
		Fertiliser consumption	Fertiliser consumption isn't estimated. The N import is used as activity data; however, N export isn't subtracted. Double-check export and so the net N balance. Then provide explanations for the large inter-annual variability.	NIR4	Confirmed. There are no official records of fertiliser exports. Explanations on the inter-annual variation are provided under section 3.5.2.2	Resolving
	AFOLU, biomass burning	Activity data	Possible double counting of emissions from crop residues since a fraction of them could have been grazed, collected or burnt.	BUR2/NIR4	The effects of grazing, the amount collected or burnt on crop residues have been considered to avoid double counting. See section 3.5.2.3	Resolved
	AFOLU, Land	Land representation system	Although the time series of raw data doesn't start in 1971, to reconstruct a consistent time series method are available from IPCC. The easiest is to assume that the same rate of change also applies to the past and for the future. Another viable option is to use the human population as a proxy for changes, so projecting land-use changes according to trends in the human population.	BUR2/NIR4	Historical land use rates were derived from 1970 onwards. The rate was determined based on general land use drivers like peculiar population factors like policies, (the structural economic programme), 1983 fires.	Resolved
	AFOLU, Land	Fire on Forest land	Fire emissions, although subsequent removals have not been estimated yet. It is recommended to estimate C stock gains associated with forest regrowth in all forests subject to harvesting, fires and any other disturbances.	BUR2/NIR4	Check section 5.9.1.2.3.1 for carbon removal associated with regrowth	Resolved
	AFOLU, Land	Cropland and Grassland	Different biomass stocks have been used for conversion to annual vs perennial. According to IPCC, also SOC should be different (potential overestimation of losses).	BUR2/NIR4	SOC generated from on-time field study is still in use.	Unsolved

	Waste	Solid waste disposal	Ghana does not estimate municipal solid waste generation before 1990. IPCC tool is used with first-order decay; this has the potential to underestimate the real methane emissions. Consequently, the team review strongly recommends estimating MSW generation before 1990	BUR2/NIR4	MSW generated has been derived from 1950 before the 1990 base year to be consistent with the IPCC tool. (Annexe 3)	Resolved
	Waste	Industrial wastewater	Industrial wastewater treatment: MCF used is high (0.9). Ghana needs to have more information about the type of treatment plant used to improve the accuracy of the methane emissions for industrial wastewater	BUR2/NIR4	Information on various treatment plants in Ghana has been provided in section 6.9.4.2	Resolved
	AFOLU, Livestock	Livestock characterisation	Enhance characterisation should be applied; it is recommended as a (second) priority to work on together with the Animal research institute.	BUR2/NIR4 to BUR3/NIR5	Studies on enhancing livestock characterisation not yet started	Unsolved

1.11 General Uncertainty Assessment

The emission inventory figures are best estimated using standard IPCC protocols. The method used to produce the underlying datasets introduced inherent uncertainties into the inventory. For instance, physical measurements or modelling to generate activity data and emission factors carry a wide range of errors that must be accounted for in the inventory. Additionally, when expert judgments are used to guide the filling in of time series gaps, select default activity data and emission factor, they add on to the uncertainty levels of the inventory. Having recognised the possible sources of uncertainties and the ways to manage them, the 2006 IPCC Guidelines provide precise methods on how to assess the overall uncertainties and report as well as the strategy to reduce their effects on the final emissions. The IPCC guidelines require that inventory estimates are reported with the uncertainty range at least using a tier 1 uncertainty analysis across the sectors. The detailed uncertainty assessment for the Land representation category has been reported under the AFOLU section of the NIR.

However, Ghana is unable to report on the uncertainty range for the other sectors because there is no credible basis to assign default range of uncertainty in the IPCC software due to the absence of requisite meta-data, particularly for the country-specific activity data. The reason is that most of the activity data were from secondary sources that hardly reported uncertainty ranges in their metadata, qualitative approaches backed by experts' judgment were used to assign the uncertainty ranges based on the sources of data consistently and transparently. Although the IPCC guideline provides the methodology for uncertainty assessment and even the inventory software has a sub-menu of uncertainty values to choose from, in the case where the supplier of the activity data does not publish enough background data to allow for the quantitative calculation of the uncertainty, the assignment of the error range becomes arbitrary. In this regard, Ghana plans to work closely with the Mathematics Department of KNUST and the Department of Statistics to come up with a practical approach to statistically quantify uncertainty levels associated with inventory and report on the progress in the next NIR.

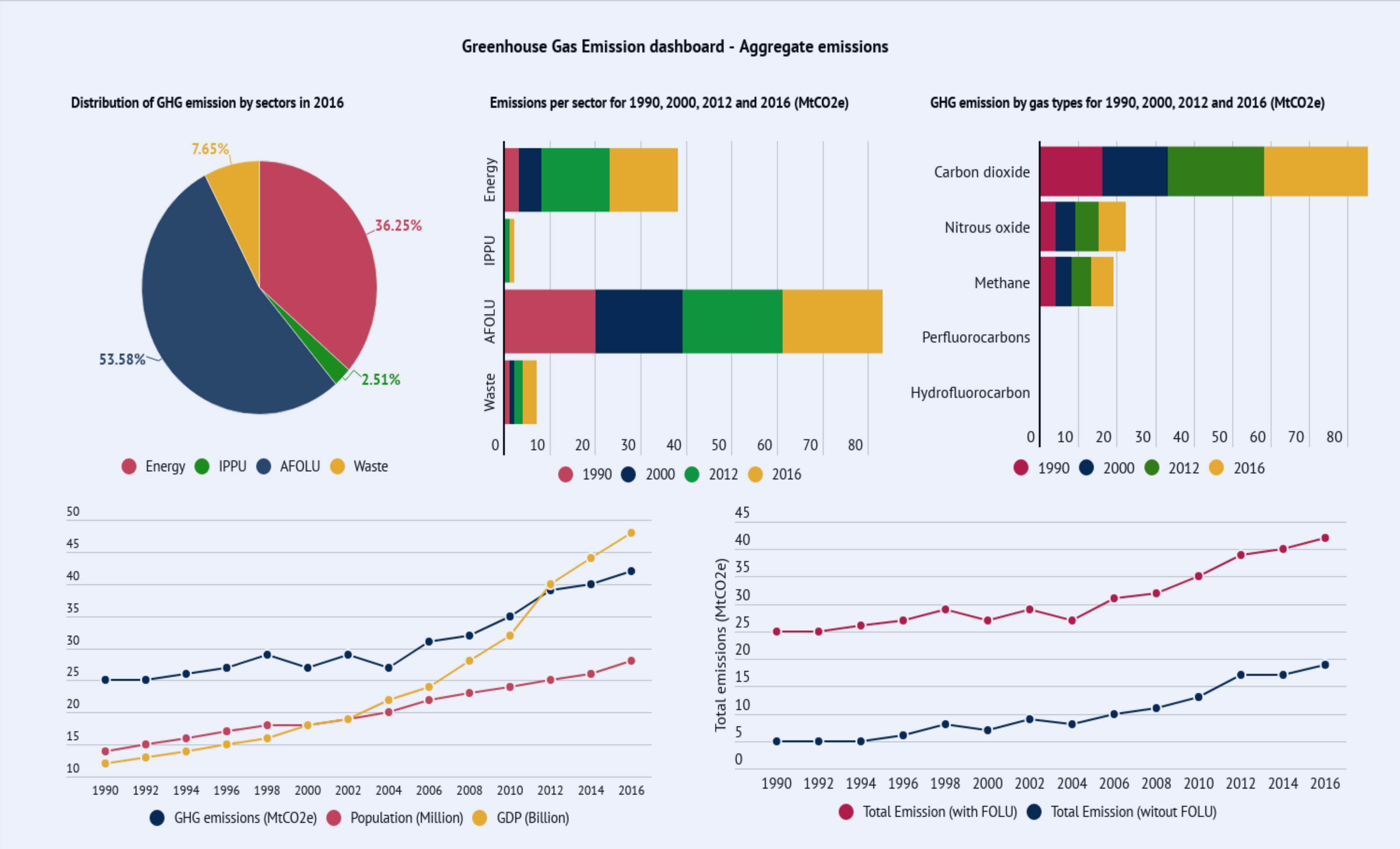
1.12 General assessment of the completeness

According to the IPCC Guidelines, it is good practice to assess the completeness of inventory in terms of its geographic coverage, scope (sectors and gases included, missing or non-applicable) and the time series. Therefore, the assessment of completeness for each sector has been reported in sections dedicated to the sectors. A list of completeness issues are in Table 14:

Table 14: Overview of the general assessment of completeness

Completeness parameter	Status	Comments
Geographic coverage	Nation-wide	The inventory covered the entire territorial boundary of the Republic of Ghana. Thus, none of the ten administrative regions in Ghana has been left uncovered by the inventory.
Sectors (Identified sources and sinks)	4 IPCC sectors	All sources or removals of direct GHG gases that are associated with activities occurring in Ghana, outlined in the 2006 IPCC Guidelines, were covered in the inventory except the following activities which were considered insignificant or where there is no data: • 1B.2a.iii.5 – Distribution of oil products • 3D.i – Harvested wood products • 2G – SF6 electrical equipment; N2O for medical applications. • 1B.2a.iii.5 - Distribution of oil products

		The emission inventory does not include activities that are not captured in the official records published by State institutions. For example, unreported fuel use, household animals that are not captured in the livestock census and unaccounted harvested wood.
Gas compounds	Direct and indirect GHGs	Direct GHG included CO_2, CH_4, N_2O and PFCs (CF_4 and C_2F_6) HFCs. SF_6 has not been considered in this inventory due to data unavailability. Also, SLCPs and local pollutants such as BC, CO, NMVOCs, NOx and $PM_{2.5}$ have been included.
Time series	26 years	Time series range – 1990 to 2016 Base year - 2010 Previous reporting year – 2012 Latest report year - 2016
Notation keys	-	Categories and gases where emissions are: • Not estimated (NE) • No occurring (NO) • Included Elsewhere (IE) • Confidential (C) • Not Applicable



Greenhouse Gas Emission dashboard - Aggregate emissions
Distribution of GHG emission by sectors in 2016
7.65%
36.25%
53.58%
2.51%
Energy
IPPU
AFOLU
Waste
Emissions per sector for 1990, 2000, 2012 and 2016 (MtCO2e)
Energy
IPPU
AFOLU
Waste
0 10 20 30 40 50 60 70 80
1990 2000 2012 2016
GHG emission by gas types for 1990, 2000, 2012 and 2016 (MtCO2e)
Carbon dioxide
Nitrous oxide
Methane
Perfluorocarbons
Hydrofluorocarbon
0 10 20 30 40 50 60 70 80
1990 2000 2012 2016
50 45 40 35 30 25 20 15 10
1990 1992 1994 1996 1998 2000 2002 2004 2006 2008 2010 2012 2014 2016
GHG emissions (MtCO2e)
Population (Million)
GDP (Billion)
Total emissions (MtCO2e)
45 40 35 30 25 20 15 10 5 0
1990 1992 1994 1996 1998 2000 2002 2004 2006 2008 2010 2012 2014 2016
Total Emission (with FOLU)
Total Emission (witout FOLU)

Chapter 2
Emissions inventory results

2.1 National greenhouse gas emissions profile and outlook

Ghana's recorded total national greenhouse gas emissions were 42.2 $MtCO_2e$ (million tonnes of carbon dioxide equivalent) in 2016. The 2016 emissions are 66.4%, 53% and 7.1% more than the previously reported net emission levels for 1990, 2000 and 2012, respectively (Figure 5). In all, the national emissions increased at a 2.1% annual growth rate between 1990-2016. When the emissions from the FOLU sector were excluded from the totals, Ghana's emissions stood at 29.3 $MtCO_2e$ in 2016. This represented a nominal increase of 17.9 $MtCO_2e$ (158.6%), 14.7 $MtCO_2e$ (101.5%) and 0.6 $MtCO_2e$ (2.1%) over the emissions estimate for 1990, 2000 and 2012 respectively. The noticeable drop in the emissions between 2004 and 2005 was because of the reductions in fuel consumption in the transport and electricity categories.

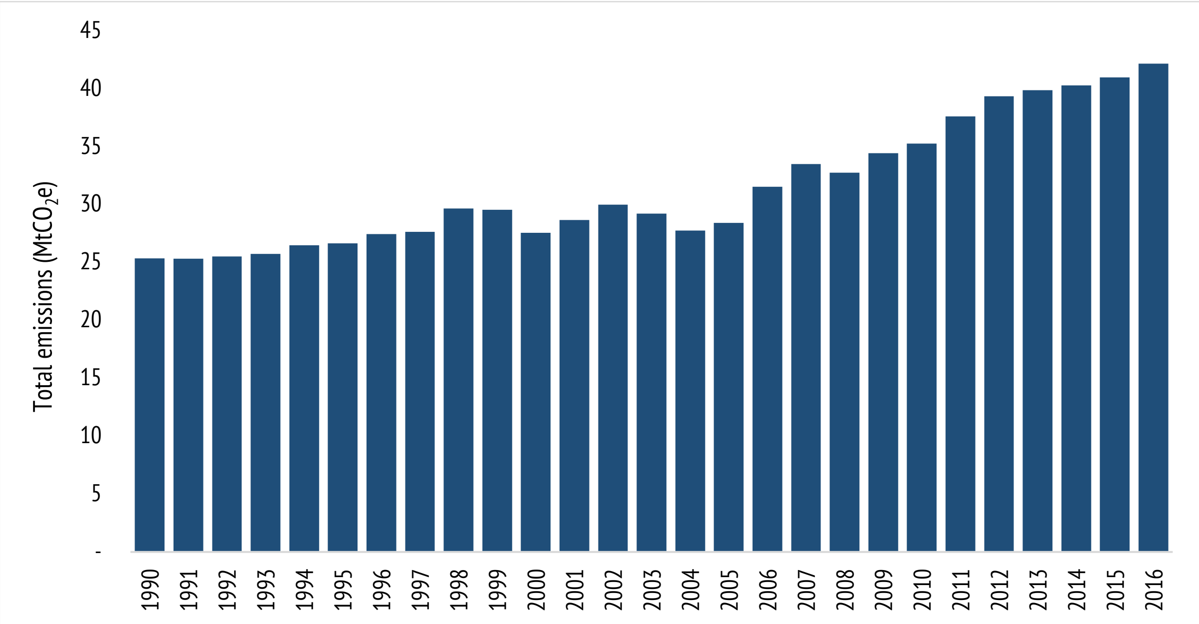


Figure 5: Trend of national aggregate net greenhouse gas emissions for the period 1990-2016

2.2 Trends in national GHG emissions, population and GDP

Ghana's GHG emissions expressed in per capita and gross domestic product (GDP) in dollars showed a declining trend over the 26 years (Figure 6). The emission per capita decreased from 1.7 tCO_2e per person in 1990 to 1.5 tCO_2e in 2016, representing a drop of 13.7% over the period. Similarly, the emissions intensity of GDP, the emission per unit GDP output (at constant 2010 US$) has dropped from 2.1 kg/ per GDP (constant 2010 US$) to 0.87 kg per GDP (constant 2010 US$) which is 59.3% reduction in the same period. The overall decreases in the emission per capita and GDP intensity suggest a positive effect of the growth-focus and economic diversification policies Ghana pursued in the last two decades. What it means is that the economy and population are expanding at a faster rate than the GHG emission growth rate.

The Ghanaian population has more than doubled from 14.6 million in 1990 to 28 million in 2016 at a 2.7% annual growth rate. In the same vein, the GDP recorded a consistent growth of 12 US billion to 48.2 billion US dollars for the same period with an annual growth rate of 5.7%. Within the same period, the GHG emissions grew from 25.3 $MtCO_2e$ to 42.2 $MtCO_2e$ at a 2.1% yearly rate. For the GHG emissions and GDP comparison, it is particularly important to highlight the kink from 2010 onwards when the proceeds from the commercial oil production were added to the GDP basket. Between 2011 and 2016, GDP increased by 31.4% with a corresponding GHG emissions rise of 11.7%.

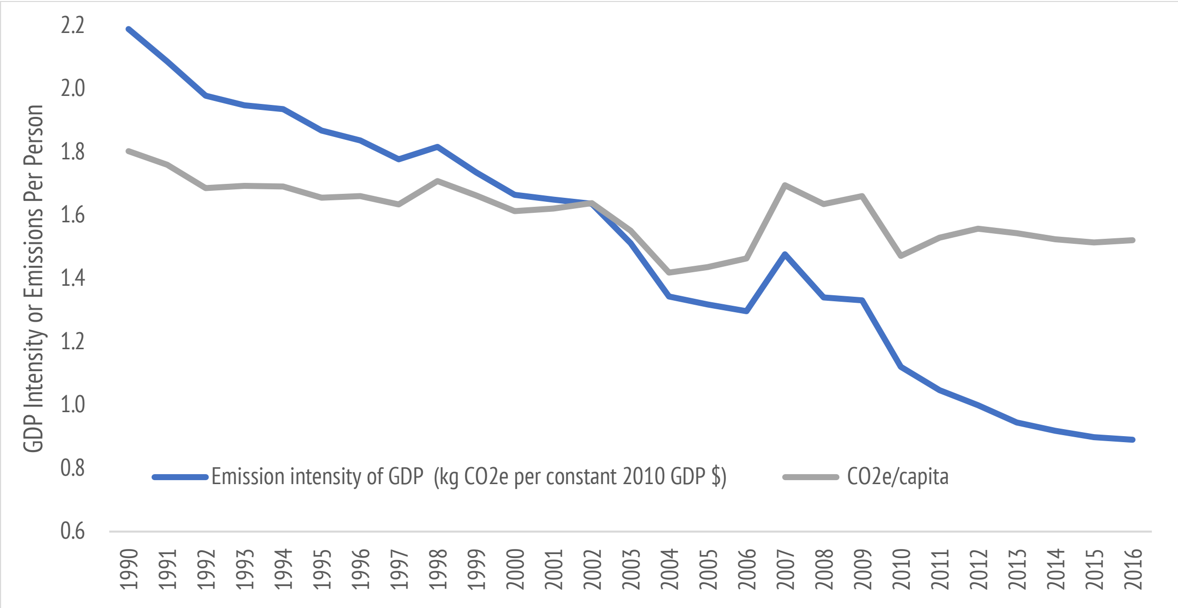


Figure 6: Trends of Emission intensity of GDP and emission per capita

2.3 Emissions projections

With a projected average population growth rate of 2.4% per annum and 7% average GDP growth rate in the period 2016-2030, Ghana's business as usual emissions are expected to increase from 42.2 $MtCO_2e$ in 2016 to 48 $MtCO_2e$ in 2020 to 59.1 $MtCO_2e$ in 2025 and further to 73.3 $MtCO_2e$ in 2030 (Figure 7).

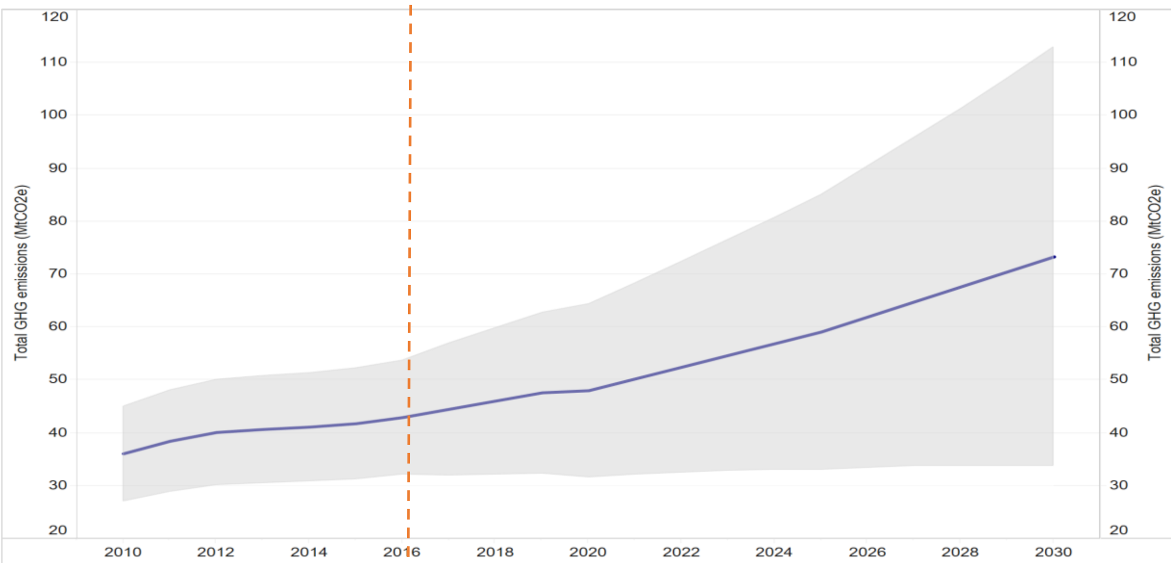


Figure 7: Projected Business-as-Usual emissions trajectory up to 2030 showing the uncertainty band

2.4 Emission trends by sectors

The AFOLU sector has consistently been the largest contributor to the national emissions between 1990 and 2016. In 2016, with the total emissions of 42.2 $MtCO_2e$, the AFOLU sector constituted 54.4% which followed by the Energy sector (35.6% from stationary, mobile and fugitive emission), Waste sector (7.5%) and IPPU (2.5%) (Figure 8). Without the FOLU emissions, the Energy sector emissions made up more than half (52.5%) of the total national emissions. The second-largest emission sources were livestock and aggregates sources and non-CO_2 emissions (3A and 3C) (33.4%) then by the Waste sector (10.5%) and IPPU (3.5%).

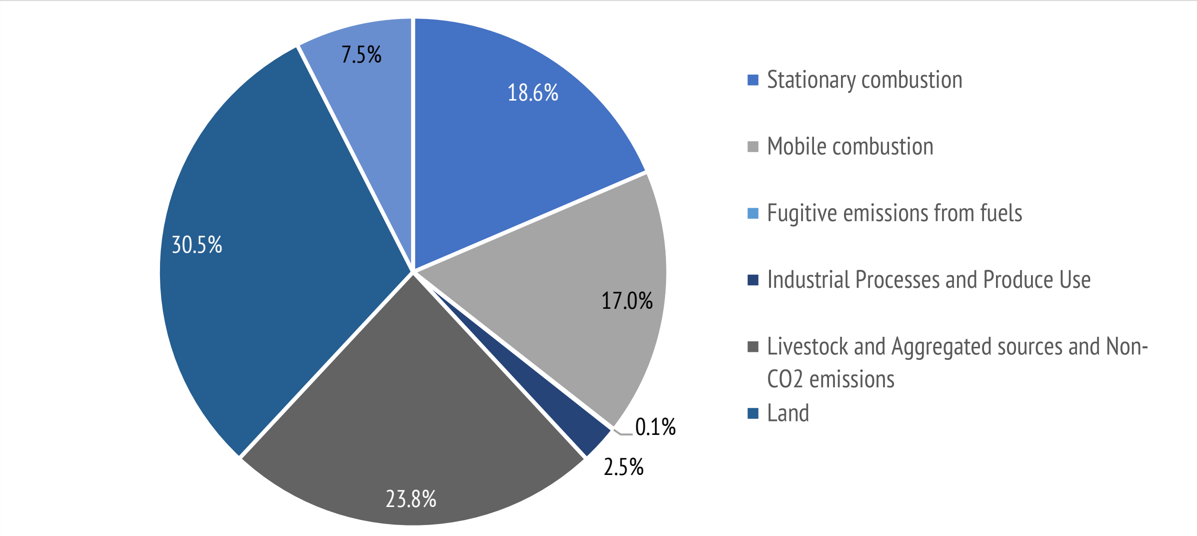


Figure 8: Share of total net emissions by sectors for 2016

All the sectors have recorded emission increases over the 26-year inventory period. But for the emissions that occurred between 2012 and 2016, the waste sector saw the highest increase of 17% followed by the energy sector (14.2%) and then by the AFOLU sector (4.0%). On the other hand, emissions from the IPPU sector notably decreased from 1.52 $MtCO_2e$ to 1.04 $MtCO_2e$ representing a 31.3% reduction (Table 15).

Table 15: Sector contributions to total emissions in 1990, 2000, 2012 and 2016 and percentage change from 2012 to 2016

Sector/Category	Total emissions ($MtCO_2e$)				Percentage change
	1990	2000	2012	2016	(2012-2016)
National Emissions with FOLU	25.34	27.26	41.62	42.15	1.3%
National Emissions without FOLU	11.32	14.53	28.66	29.28	2.2%
1 - Energy	3.73	5.96	15.35	15.02	-2.1%
Stationery combustion	2.31	2.77	8.65	7.83	-9.5%
Transport Mobile combustion	1.41	3.17	6.68	7.17	7.3%
Oil and Natural Gas (Fugitive emission)	0.016	0.023	0.012	0.024	100%
2. Industrial Processes and Product Use	0.49	0.36	1.52	1.04	-31.6%
Mineral Industry	0.01	0.04	0.48	0.33	-31.3%
Metal Industry	0.48	0.31	0.08	0.09	12.5%
Non-Energy Products from Fuels and Solvent Use	-	0.00	0.00	0.00	1.9%
Product Uses as Substitutes for ODS	-	-	0.96	0.61	-36.5%
3. Agriculture, Forestry, and Other Land Use	20.10	19.47	22.05	22.92	3.9%
Livestock	1.72	1.82	2.91	3.48	19.6%
Land	14.01	12.73	12.96	12.87	-0.7%
Aggregate sources and Non-CO_2 emissions sources on land	4.36	4.91	6.18	6.57	6.3%
4. Waste	1.02	1.48	2.71	3.17	17.0%
Solid Waste Disposal	0.26	0.48	0.99	1.16	17.2%

Biological Treatment of Solid Waste	0.09	0.06	0.06	0.10	66.7%
Incineration and Open Burning of Waste	0.03	0.03	0.07	0.08	14.3%
Wastewater Treatment and Discharge	0.64	0.90	1.58	1.84	16.5%

The AFOLU sector has consistently remained the dominant GHG emission source in the country. On average, the AFOLU sector emissions contribute to the national totals had declined from 79% in 1990 to 54% though it remains the leading source of national GHG emissions (Figure 9).

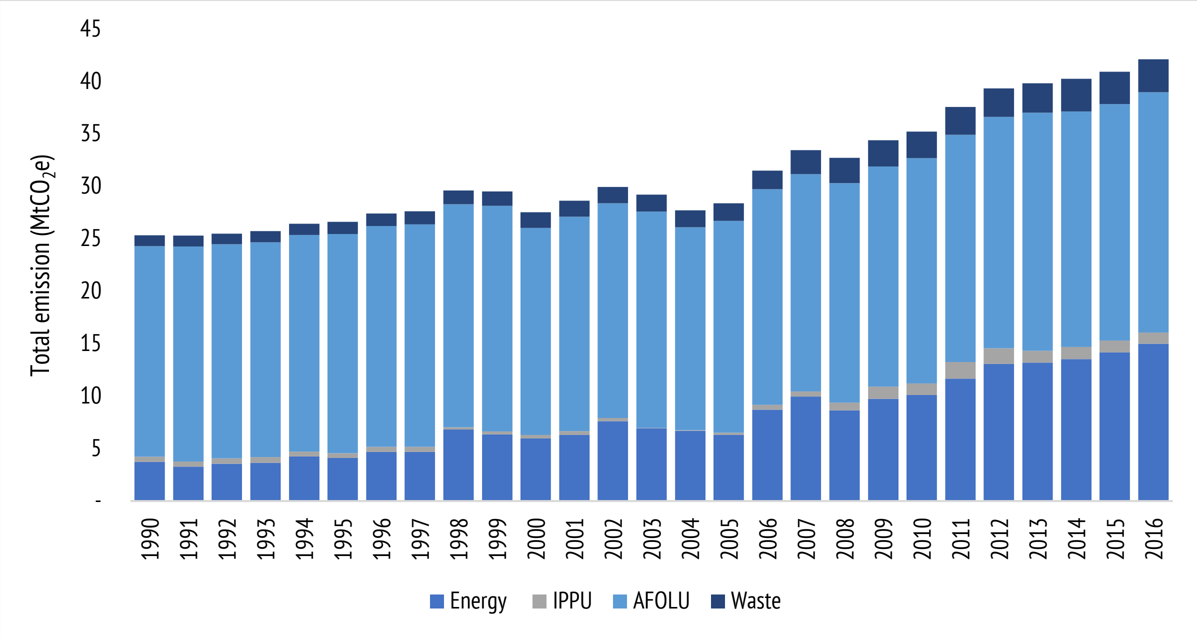


Figure 9: Trends of sector contributions to total national emissions from 1990 to 2016

The energy sector is the second-highest source of GHG emissions. The percentage share of emissions from the energy sector to the total emission increased from 15% in 1990 to 36% in 2016. Likewise, the proportion of emissions from the waste sector went up marginally relative to the national total. Its share of the national total doubled from 4% in 1990 to 8% in 2016. It was also realised that the contribution of emissions from the IPPU to the total emission was the least, and it recorded a marginal increase of only 0.6% rise. Its share of the national total rose from 1.9% in 1990 to 2.5% in 2016. The main sectors of the economy contribution towards the emissions are below:

Energy sector - Within the energy sector, even though the percentage of fugitive emissions from fuel was relatively small (average of 0.32%), it recorded the highest sectoral emissions rise of 101.3% (0.012 $MtCO_2e$ to 0.024 $MtCO_2e$) for the period 2012-2016. Stationary and mobile combustions were the primary sources of emissions, so in terms of the trends, they both recorded 22.7% and 7.2% increases respectively within the same timeframe. The fugitive emissions have also increased over the period 2012-2016 primarily due to the increased oil and gas production. It is during this period that Ghana started producing crude oil and natural gas in commercial quantities through the investment in oil production and the establishment of a natural gas processing plant. The 20.6% rise in stationary combustion emissions was the resultant effects of the capacity expansion of electricity power plants (i.e. 2,280 MW in 2012 to 3,795 MW) in 2016) as well as the increased fuel use in the manufacturing industry and changes in household energy consumption patterns. The main drivers for the increase in transport emissions were the continued growth in the number of vehicle population, along with a rise in fuel (diesel and petrol) consumption.

IPPU sector – The emission reduction since 2012 was mostly driven by the decreases in emissions associated with HFCs, and the metals industry, particularly Aluminium production by VALCO. The decline in HFC emissions corresponds to the influence for phase-down of high-GWP HFCs in the country.

AFOLU sector - The net emissions were primarily driven by the growth in the land category emissions, especially from land converted to cropland, grassland, and forestland (forest remaining forest and land converted to forest). The high emissions associated with land conversions to cropland and grassland showed the impacts of the drivers of deforestation on the growing emissions. Furthermore, the emission increases under the "direct N_2O emissions from managed soils" sub-category influenced the rising emission trends.

Waste sector – Emissions from unmanaged waste disposal sites and the domestic wastewater treatment and discharge determined the waste sector emission trends. The increases in the net emissions from waste were due to growing populations, operational and management challenges at most landfill sites and the poor state of domestic wastewater treatment facilities in the country.

2.5 GHG emissions by gases

2.5.1 Distribution of share of GHG emissions

Carbon dioxide continues as the most prevalent greenhouse gas in Ghana and accounts for 64.7% (27.3 $MtCO_2$) of the total emissions (including FOLU) in 2016 and is followed by nitrous oxide (18.3%) and methane (15.4%). The share of the fluorinated gases (different types of HFCs and PFCs) were 1.5% and 0.1% respectively in 2016 (Figure 10).

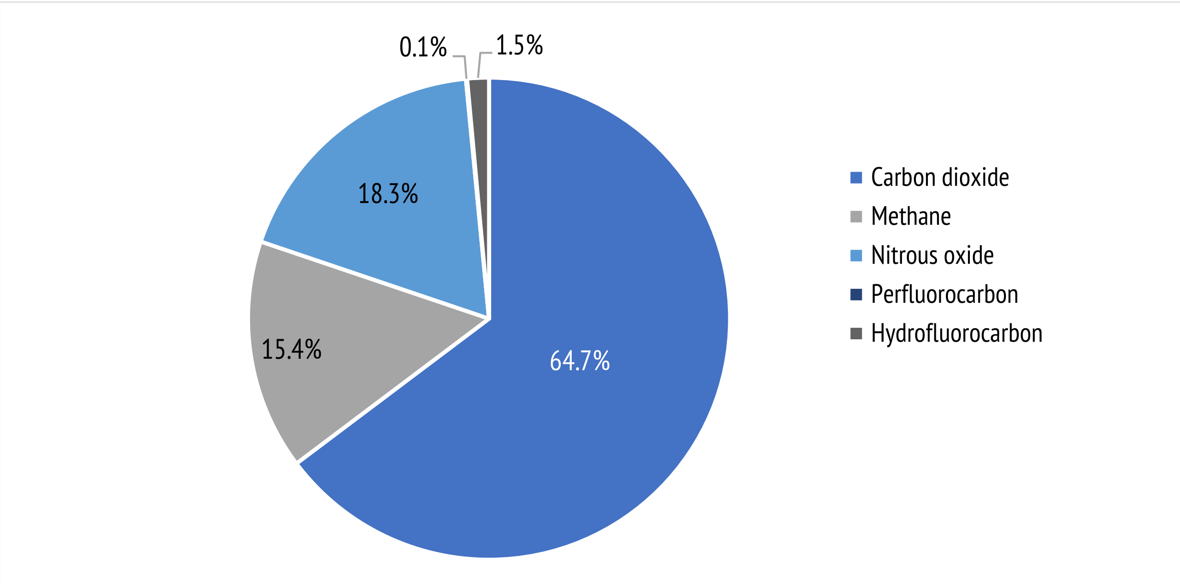


Figure 10: Distribution of emissions in 2016 by gases

When the emissions from FOLU were eliminated from the national totals, CO_2 still constituted almost half (49.2% - 14.41 Mt) of the total emissions in the same year. Nitrous oxide was the second-highest GHG emission compound representing 26.3% (7.71 $MtCO_2e$) of the total emissions. Methane levels made up 22.2% (6.51 $MtCO_2e$) of all the emissions (Table 16). The rest were HFCs emissions (2.1% - 0.61 $MtCO_2e$) and PFC (0.1% - 0.03 $MtCO_2e$).

Table 16: Distribution of emission contributions per sector and category on gas-by-gas basis in 2016

Sector and sub-sectors	CO_2 [Mt]	CO_2 [%]		CH_4[$MtCO_2e$]	CH_4 [%]		N_2O [$MtCO_2e$]	N_2O [%]		PFC [$MtCO_2e$]	PFC [%]		HFC [$MtCO_2e$]	HFC [%]	
		w/O FOLU	w/FOLU		w/O FOLU	w/FOLU		w/O FOLU	w/FOLU		w/O FOLU	w/FOLU		w/O FOLU	w/FOLU
1. All Energy (combustion & fugitive)	13.97	96.9%	51.2%	0.66	16.6%	10.1%	0.38	5.0%	2.62	-	-	-	-	-	-
Stationery energy combustion	7.05	50.4%	-	0.61	92.2%	-	0.17	44.8%	-	-	-	-	-	-	-
Transport	6.92	49.5%	-	0.04	5.4%	-	0.21	55.2%	-	-	-	-	-	-	-
Fugitive emission	0.01	0.1%	-	0.02	2.4%	-	-	-	-	-	-	-	-	-	-
2. Industrial Process & Product Use	0.39	2.7%	1.4%	-	-	-	-	-	-	0.03	100	100	0.61	100	
3. AFOLU	12.91	0.3%	47.3%	3.29	18.9%	50.6%	6.72	87.2%	92.7	-	-	-	-	-	-
Livestock	-	-	-	2.54	-	77.3%	0.94	14.0%	9.58	-	-	-	-	-	-
Land	12.87	-	99.7%	-	-	-	-	-	-	-	-	-	-	-	-
Aggregated and non-CO_2 emissions	0.04	-	0.3%	0.75	-	22.7%	5.78	86.0%	90.4	-	-	-	-	-	-
4. Waste	0.01	0.1%	0.03%	2.56	64.5%	39.3%	0.60	7.8%	4.72	-	-	-	-	-	-
Total net emissions (w/ FOLU)	27.29	-	100	6.51	-	100	7.71	-	100	0.03	-	100	0.61	-	100
Total emissions (w/o FOLU)	14.41	100	-	-	100	-	7.71	100	-	0.03	100	-	0.61	100	-

The carbon dioxide levels often make up the most considerable share (64.7%) of the total national emissions throughout the time series 1990-2016. Overall, the total CO_2 emissions showed an upward trend at a 1.9% annual growth rate in the same period. Particularly for the period 2012-2016, it was observed that CO_2 emission recorded an average 6.1% increase (Figure 11). The rising trends in CO_2 emissions over the period were because of the rising CO_2 emissions from energy industries, transport, and land-use change.

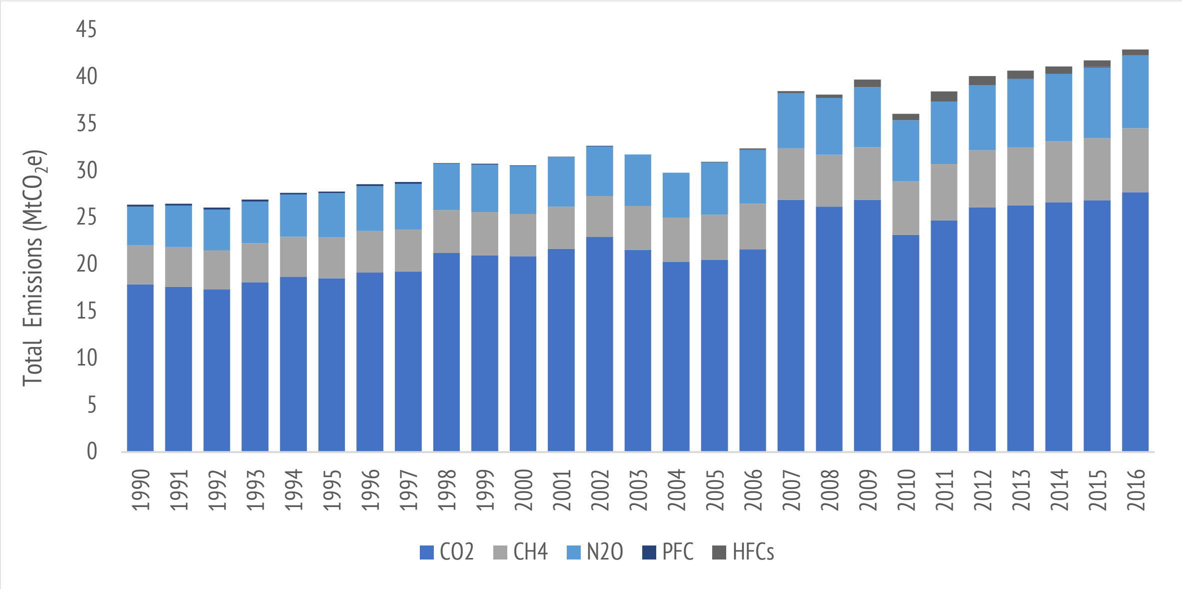


Figure 11: Trends of emissions by gases for the period 1990 to 2016

In the same vein, nitrous oxide emissions, being the second-largest GHG compound, exhibited a rising trend from 1990 to 2016 at a 2.6% growth rate per annum. Compared to 2012 levels, the nitrous oxide emissions went up by 11.8% in 2016. A critical driver of N_2O emissions relates to multiple sources of nitrogen accumulation in soils from the application of synthetic fertilisers, crop residues, organic fertiliser, and land-use change and management. Methane was the third commonest GHG in Ghana and recorded a growth rate of 1.8% per annum over the 26 years. Between 2012 and 2016, CH_4 levels grew by 12.8% from 5.57 $MtCO_2e$ in 2012 to 6.51 $MtCO_2e$ in 2016. Majority of the CH_4 emissions came from livestock rearing (enteric fermentation and manure management), solid waste disposal and water treatment and discharge.

Perfluorocarbons are another family of greenhouses in Ghana. It mainly comes from the industrial operation operations of VALCO. The level of PFC emission has steadily declined at an annual rate of 6.9% from 0.2 $MtCO_2e$ in 1990 to 0.03 $MtCO_2e$ in 2016. The downward trend of PFC has been determined by the operational capacity of the VALCO Aluminum Plant. The gases used in refrigerators and air-conditioners are the primary source of HFCs. The imports HFC are for use in stationary and mobile air-conditioning and refrigerating appliances. In the national inventory, Ghana has reported HFC emissions from 2005 to 2016. The results showed that HFCs emissions increased up to 1.05 $MtCO_2e$ in 2011 before it started reducing to 0.61 $MtCO_2e$ in 2016. The HFCs between 2012 and 2016 has seen a considerable decrease of 35.9%.

2.5.2 Analysis of emissions on the gas-by-gas basis

2.5.2.1 Carbon dioxide emissions

The total CO_2 emissions grew from 16.83 Mt in 1990 to 27.29 Mt in 2016 (Table 17). The Energy and AFOLU sectors were the principal sources of CO_2 emissions from fossil fuel combustion and land-use change. While CO_2 in the energy sector saw a four hundred-fold increment (from 2.52 Mt to 13.97 Mt) that of the AFOLU sector dropped by 7.9% from 14.02 Mt in 1990 to 12.91 Mt in 2016. Again, the energy sector CO_2 emissions increased by 15% for the period 2012-2016, and AFOLU CO_2 slightly declined by nearly 1% in the same period.

Table 17: Net carbon dioxide emissions per sector in Mt

Year	Energy	IPPU	AFOLU	Waste	Total
1990	2.52	0.29	14.02	0.003	16.839
1991	2.03	0.30	14.07	0.003	16.402
1992	2.29	0.30	14.13	0.003	16.730
1993	2.34	0.32	14.18	0.003	16.842
1994	2.89	0.30	14.24	0.003	17.427
1995	2.69	0.30	14.30	0.003	17.292
1996	3.21	0.29	14.36	0.003	17.859
1997	3.16	0.29	14.43	0.003	17.872
1998	5.33	0.13	14.43	0.003	19.889
1999	4.81	0.19	14.59	0.003	19.598
2000	4.83	0.29	12.74	0.003	17.865
2001	5.22	0.31	13.31	0.004	18.848
2002	6.60	0.24	13.53	0.004	20.370
2003	5.98	0.05	13.17	0.004	19.205
2004	5.76	0.05	12.63	0.004	18.450
2005	5.67	0.14	12.71	0.004	18.521
2006	7.82	0.30	12.89	0.004	21.019
2007	8.98	0.29	12.93	0.005	22.206
2008	7.94	0.40	12.97	0.006	21.309
2009	9.03	0.34	12.72	0.006	22.101
2010	9.29	0.40	13.02	0.007	22.713
2011	10.79	0.52	12.89	0.007	24.208
2012	12.15	0.54	13.01	0.007	25.710
2013	12.24	0.27	13.34	0.009	25.853
2014	12.54	0.38	13.20	0.008	26.128
2015	13.14	0.40	12.86	0.008	26.413
2016	13.97	0.39	12.91	0.009	27.285

2.5.2.2 Nitrous oxide emissions

Apart from the IPPU sector, nitrous oxide emissions occurred in AFOLU, waste, and the energy sectors. The N_2O emissions saw notable increment from 4.09 $MtCO_2e$ in 1990 to 7.1 $MtCO_2e$ in 2016 with the AFOLU sector being the dominant source. Within the AFOLU sector, direct and indirect N_2O emissions from managed soils (3.C4, 3.C5 and 3.C6) accounted for 86% of the N_2O emissions (Table 18) in 2016. The remaining 14% came from livestock rearing. Besides the AFOLU sector, relatively smaller quantities of N_2O emissions were from the waste and energy sectors. In the waste sector, open burning was a significant source of N_2O while for the Energy sector, "other sectors" and road transport accounted for most of the emissions.

Table 18: Nitrous oxide emissions per sector in $MtCO_2e$

Year	Energy	IPPU	AFOLU	Waste	Total
1990	0.25	NA	3.49	0.36	4.09
1991	0.26	NA	3.80	0.36	4.42
1992	0.26	NA	3.72	0.37	4.35
1993	0.28	NA	3.77	0.37	4.41
1994	0.29	NA	3.87	0.37	4.53
1995	0.30	NA	4.01	0.38	4.69
1996	0.31	NA	4.12	0.40	4.82
1997	0.32	NA	4.16	0.42	4.91
1998	0.33	NA	4.22	0.43	4.98
1999	0.33	NA	4.31	0.44	5.09
2000	0.26	NA	4.40	0.47	5.13
2001	0.25	NA	4.56	0.47	5.28
2002	0.24	NA	4.55	0.48	5.27
2003	0.23	NA	4.78	0.49	5.49
2004	0.22	NA	4.02	0.49	4.73
2005	0.18	NA	4.80	0.49	5.48
2006	0.23	NA	4.98	0.50	5.71
2007	0.29	NA	5.08	0.50	5.87
2008	0.25	NA	5.22	0.50	5.98
2009	0.27	NA	5.50	0.51	6.28
2010	0.23	NA	5.68	0.51	6.42
2011	0.27	NA	5.84	0.51	6.62
2012	0.30	NA	6.08	0.51	6.89
2013	0.33	NA	6.33	0.58	7.25
2014	0.36	NA	6.18	0.59	7.13
2015	0.38	NA	6.51	0.60	7.49
2016	0.38	NA	6.72	0.60	7.71

NA - Not Applicable

2.5.2.3 Methane emissions

From 1990 to 2016, methane emissions increased by 54.8%, with the majority coming from the AFOLU and Waste sectors (Table 19). Methane emissions for the periods 2012-2016 also went up by 9.5%. The AFOLU and Waste sectors were the two dominant sources of methane, and they both correspondingly account for 50.6% and 39.3% of the total methane emissions. In the AFOLU sector, the emissions from enteric fermentation and manure management were the primary sources of methane. For the waste sector, most of the methane emissions were from wastewater treatment and discharge and solid waste disposal.

Table 19: Methane emissions per sector expressed in $MtCO_2e$

Year	Energy	IPPU	AFOLU	Waste	Total
1990	0.96	NA	2.59	0.66	4.20
1991	0.99	NA	2.62	0.68	4.29
1992	1.01	NA	2.54	0.64	4.20
1993	1.04	NA	2.53	0.69	4.26
1994	1.08	NA	2.55	0.72	4.34
1995	1.12	NA	2.60	0.76	4.48
1996	1.17	NA	2.60	0.80	4.56
1997	1.20	NA	2.61	0.84	4.65
1998	1.18	NA	2.63	0.89	4.70
1999	1.21	NA	2.62	0.94	4.77

2000	0.87	NA	2.61	1.00	4.48
2001	0.82	NA	2.61	1.03	4.46
2002	0.78	NA	2.42	1.06	4.26
2003	0.73	NA	2.66	1.12	4.52
2004	0.72	NA	2.70	1.14	4.56
2005	0.46	NA	2.69	1.21	4.35
2006	0.67	NA	2.70	1.28	4.66
2007	0.69	NA	2.70	1.81	5.20
2008	0.45	NA	2.74	1.90	5.10
2009	0.45	NA	2.79	1.97	5.21
2010	0.59	NA	2.80	2.02	5.41
2011	0.62	NA	2.95	2.14	5.71
2012	0.62	NA	2.96	2.19	5.77
2013	0.63	NA	3.02	2.24	5.89
2014	0.65	NA	3.09	2.49	6.24
2015	0.65	NA	3.18	2.49	6.32
2016	0.66	NA	3.29	2.56	6.51

NA - Not Applicable

2.5.2.4 Perfluorocarbon emissions

Perfluorocarbons are industrial emissions from technology used in the primary aluminium production by VALCO during anode effects. Apart from the fact that PFCs emissions generally depict a declining trend (-83% between 1999-2016), there were years (2002, 2003, 2009, and 2010) that the emissions were completely missing because the aluminium plant (VALCO) was not operating at all (Table 20). Since VALCO's operations have been consistent, though, on a limited capacity (running a single pot), PFC emissions have increased a hundredfold between 2012 and 2016.

Table 20: Perfluorocarbon emissions per sector expressed in $MtCO_2e$

Year	Energy	IPPU	AFOLU	Waste	Total
1990	NA	0.20	NA	NA	0.20
1991	NA	0.21	NA	NA	0.21
1992	NA	0.22	NA	NA	0.22
1993	NA	0.22	NA	NA	0.22
1994	NA	0.16	NA	NA	0.16
1995	NA	0.17	NA	NA	0.17
1996	NA	0.19	NA	NA	0.19
1997	NA	0.21	NA	NA	0.21
1998	NA	0.07	NA	NA	0.07
1999	NA	0.08	NA	NA	0.08
2000	NA	0.07	NA	NA	0.07
2001	NA	0.05	NA	NA	0.05
2002	NA	0.06	NA	NA	0.06
2003	NA	NE	NA	NA	NE
2004	NA	NE	NA	NA	NE
2005	NA	0.01	NA	NA	0.01
2006	NA	0.02	NA	NA	0.02
2007	NA	NE	NA	NA	NE
2008	NA	NE	NA	NA	NE
2009	NA	NE	NA	NA	NE
2010	NA	NE	NA	NA	NE

2011	NA	0.01	NA	NA	0.01
2012	NA	0.02	NA	NA	0.02
2013	NA	0.02	NA	NA	0.02
2014	NA	0.03	NA	NA	0.03
2015	NA	0.05	NA	NA	0.05
2016	NA	0.03	NA	NA	0.03

NA - Not Applicable, NE – Not Estimated

2.5.2.5 Hydrofluorocarbons emissions

This is the first time Ghana is reporting on HFC emissions after EPA published a national survey report on HFC in 2017. With the available survey data, it was possible to estimate HFC emissions from stationary refrigeration and air-conditioning appliances. The HFC emissions increased from 2005 (0.1 $MtCO_2e$) until it peaked in 2011 (1.1 $MtCO_2e$) and started dipping afterwards to 0.6 $MtCO_2e$ in 2016 (Table 21).

Table 21: Hydrofluorocarbon emissions per sector expressed in $MtCO_2e$

Year	Energy	IPPU	AFOLU	Waste	Total
1990	NA	NE	NA	NA	NE
1991	NA	NE	NA	NA	NE
1992	NA	NE	NA	NA	NE
1993	NA	NE	NA	NA	NE
1994	NA	NE	NA	NA	NE
1995	NA	NE	NA	NA	NE
1996	NA	NE	NA	NA	NE
1997	NA	NE	NA	NA	NE
1998	NA	NE	NA	NA	NE
1999	NA	NE	NA	NA	NE
2000	NA	NE	NA	NA	NE
2001	NA	NE	NA	NA	NE
2002	NA	NE	NA	NA	NE
2003	NA	NE	NA	NA	NE
2004	NA	NE	NA	NA	NE
2005	NA	0.06	NA	NA	0.06
2006	NA	0.12	NA	NA	0.12
2007	NA	0.20	NA	NA	0.20
2008	NA	0.36	NA	NA	0.36
2009	NA	0.82	NA	NA	0.82
2010	NA	0.70	NA	NA	0.70
2011	NA	1.05	NA	NA	1.05
2012	NA	0.96	NA	NA	0.96
2013	NA	0.86	NA	NA	0.86
2014	NA	0.75	NA	NA	0.75
2015	NA	0.69	NA	NA	0.69
2016	NA	0.61	NA	NA	0.61

NA - Not Applicable, NE – Not Estimated

2.6 Precursors and indirect emissions

2.6.1 Short-lived climate pollutants

Short-Lived Climate Pollutants are powerful greenhouse gases and local air pollutants and are emitted through similar economic activities as the GHGs. Tackling SLCPs emission has a global climate and local air quality benefits. Therefore, Ghana has reported on an inventory of GHG and SLCPs covering CH_4, BC and HFC for the period 1990-2016. Figure 12 is a chart showing the trend in SLCP emissions for 1990-2016.

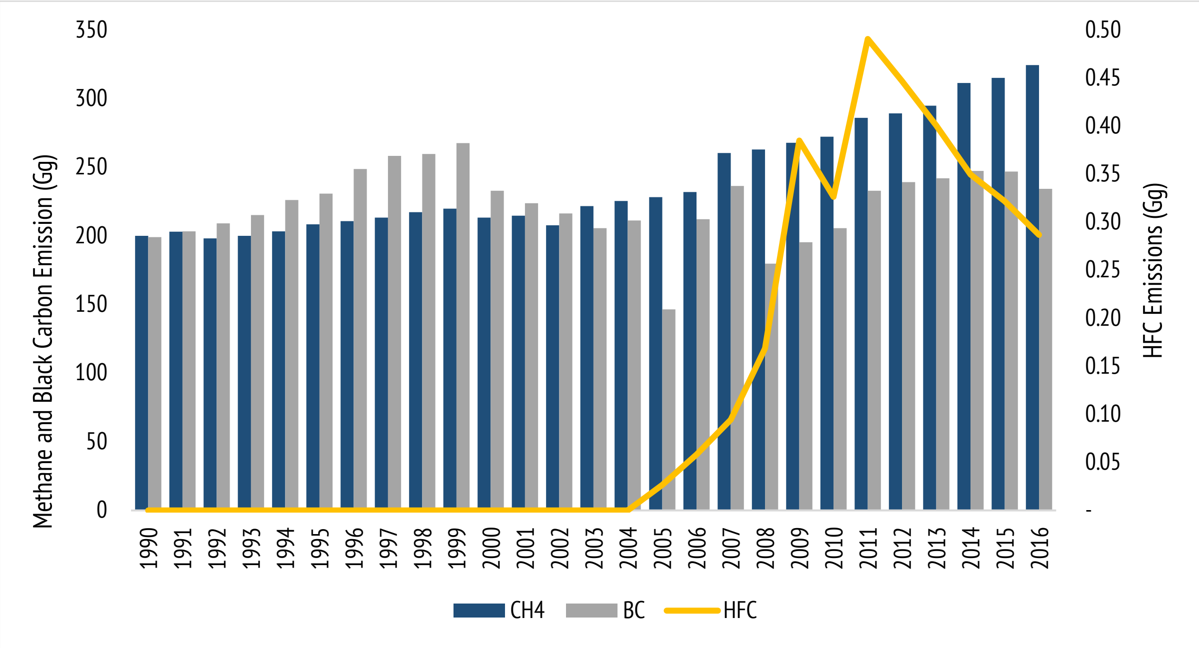


Figure 12: A chart showing SLCPs emission trends for the period 1990-2016

In 2016, the methane emissions level was 324.7 Gg and, the majority (48%) of which came from livestock enteric fermentation and manure management. The waste sector was the second-largest source of methane constituting 38% of the total national emissions. Within the waste sector, municipal solid waste disposal and domestic wastewater were the sources of methane, whereas, under the energy sector, residential cooking with solid biomass contributed most to methane emissions. Black carbon levels increased from 199.29 Gg in 1990 to 234.28 Gg in 2016, and almost all of BC emissions came from the Energy sector. Under the IPPU, Products Uses as Substitutes for ODS was the only source of HFC emissions.

2.6.2 Precursor and local air pollutants

Consistent with the IPCC guidelines, emissions of some precursor and local air pollutants have been estimated using national activity data and default emission factors from EMEP/EEA or EMEP/ CORINAIR air pollutant emission inventory guidebook. It is noteworthy that these estimates do not replace the measured local air pollutants that are usually published by the Environmental Quality Department of EPA for different locations at the city level but are an essential complement to them. The measurements of air pollution at monitoring sites provide an estimate of the concentration of air pollutants at specific locations resulting from all sources. At the same time, the Information In this report is estimates of the emissions of air pollutants from specific emission sources. Table 22 shows the trends of NOx, CO, BC, NMVOCs and $PM_{2.5}$ emissions for the period 1990-2016. Except for CO that saw a decline, the rest of the pollutants showed a rising pattern. Nitrogen oxides are a group of poisonous, highly reactive gases. NOx gases form when burned at high temperatures.

In 2016, most (80.4%) of the NOx emissions came from the energy sector through the burning of fossil fuels. The remaining 19.6% were from the burning activities in the AFOLU (18%) and waste (1.7%) sectors respectively. Between 1990 and 2016, NOx emission levels increased by 21.6%. Carbon monoxide (CO) is a common industrial hazard resulting from the incomplete burning of natural gas and any other material containing carbon such as gasoline, kerosene or wood.

Table 22: Trends of selected precursor and local air pollutants for the period 1990-2016

Year	Gg/Year				
	NOx	CO	BC	NMVOC	$PM_{2.5}$
1990	100.64	2,279.92	199.29	282.05	561.10
1991	97.54	2,281.99	203.43	291.18	576.20
1992	98.67	2,267.03	209.21	297.60	594.60
1993	97.24	2,291.83	215.24	310.25	608.57
1994	99.89	2,308.31	226.28	322.26	632.13
1995	97.50	2,310.02	230.89	332.81	652.13
1996	102.80	2,319.93	248.88	345.55	674.32
1997	101.57	2,334.33	258.41	359.58	701.82
1998	106.66	2,291.51	259.77	352.33	689.57
1999	106.76	2,278.42	267.66	357.98	698.62
2000	112.78	2,134.15	233.03	267.32	546.71
2001	111.64	2,070.30	223.94	253.37	526.07
2002	111.98	2,004.48	216.39	240.64	509.61
2003	104.36	1,903.41	205.64	223.73	499.30
2004	109.42	1.891.82	211.28	220.76	502.79
2005	96.87	1,730.13	146.64	172.58	367.50
2006	113.58	1,861.65	212.20	234.05	517.89
2007	121.23	1,973.53	236.60	248.32	517.74
2008	111.11	1,707.92	179.76	205.72	373.44
2009	119.37	1,734.54	195.38	219.73	401.44
2010	114.79	1,745.38	205.79	237.53	519.99
2011	127.09	1,816.14	233.10	250.94	561.45
2012	131.59	1,815.05	239.18	257.11	575.90
2013	128.51	1,827.43	242.05	265.92	582.34
2014	130.38	1,847.26	247.37	274.91	610.98
2015	127.83	1,804.80	246.90	274.63	625.47
2016	122.42	1,767.67	234.28	271.84	605.20

Most of the CO emissions were from the energy sector (69.2%) and followed by the AFOLU (29.9%) and waste (0.9%) sectors. The patterns of CO emissions indicated a steady decline of 22.5% between 1990 and 2016. Black carbon is a constituent of $PM_{2.5}$ and is produced from the incomplete burning of fossil fuels and biomass. The inventory estimates total black carbon emission in Ghana to be 234.3 Gg in 2016, mainly from road transport and residential cooking activities under the sector. The 2016 BC emission was 7.6% higher than the 1990 levels and increased at a 0.6% annual growth rate. $PM_{2.5}$ are tiny particles with an aerodynamic diameter of 2.5 microns in the air that reduce visibility and cause haziness. It is a mixture of solid particles and liquid droplets found in the air. Some particles, such as dust, dirt, soot, or smoke, are large or dark enough to be seen with the naked eye.

Typically, in Ghana, $PM_{2.5}$ concentrations are measured using a gravimetric method and high-volume samplers located in strategic locations along roadsides, residential, commercial and industrial areas. The $PM_{2.5}$ concentrations measured at these sites are the result of emissions of different pollutants, including primary $PM_{2.5}$ emissions, but also emissions of gaseous precursors, such as nitrogen oxides, sulphur dioxide and ammonia, which react in the atmosphere to form particles. The estimation of primary $PM_{2.5}$ emissions based on specific activity data and emission factors is in no way replacing the measured $PM_{2.5}$ concentration monitoring figures. It is to complement them by providing estimated primary $PM_{2.5}$ emissions from the technology and sectoral point of view. Transport and domestic cooking and open burning are the dominant sources of primary $PM_{2.5}$ emissions in Ghana. In 2016, a total of 605.2 Gg of $PM_{2.5}$ was recorded in Ghana and of which 99.3 were emitted from the Energy sector through activities like road transport and domestic cooking accounted for most of them. The remaining 0.7% was open burning in the Waste sectors.

2.7 Time-series consistency

According to the 2006 IPCC Guidelines, "time series is a central component of the greenhouse gas inventory because it provides information on historical emissions trends and tracks the effects of strategies to reduce emissions at the national level. As is the case with estimates for individual years, emission trends should be neither over nor underestimated as far as can be judged. All emissions estimates in a time series should be estimated consistently, which means that as far as possible, the time series should be calculated using the same method and data sources in all years. Using different methods and data in a time series could introduce bias because the estimated emission trend reflects not only real changes in emissions or removals but also the pattern of methodological refinements."

2.7.1 Description of recalculations

To ensure time-series consistency for the inventory period 1990-2016, recalculations have been performed on the 1990-2012 estimates. The reasons for the recalculations were mainly due to methodological changes and refinement and the addition of new categories in the inventory. The general reasons for the recalculations have been provided in Table 23. Detailed descriptions of the recalculation and the underlying explanations have been provided under each sector.

Table 23: Summary of the recalculations and the underlying reasons for each

Inventory sector	Category	Key reasons for the recalculations	Recalculation tasks
All sectors	All categories	Addition of new categories & methodological changes and refinement	Changes in methodology and the inclusion of extra data due to the use of the 2006 Guidelines
Energy	Manufacture of solid fuel (1A1c)	Addition of new categories	Inclusion of new activity data on the manufacture of charcoal.
	Other sectors (1A4)	Availability of new dataset	Revisions in solid biomass (firewood and charcoal) activity data for 2006-2012.
	Fuel combustion (1A)	Availability of new dataset	Changes in the activity data on fuel balance due to the revisions in the energy balance.
IPPU	Product Uses as substitutes for ODS (2F)	Addition of new categories	Inclusion of newly available HFC consumption figures from 2005 to 2012.
	Lubricant use (2D1)	Availability of new dataset	Changes in activity data on lubricant due to new dataset from companies.
AFOLU	Land (3B)	Methodological changes and refinement	Availability of new and more accurate land-use change matrix for the period 1990-2012

			Changes in timber harvesting figures due to the use of new bottom-up data collection methodology.
			Revision and changes of areas affected by fires due to the use of MODIS fire dataset.
		Addition of new categories	Inclusion of new plantation areas and further categorisation into the teak and non-teak species.
		Methodological changes and refinement., correction of errors.	Revision of fuelwood harvesting figures due to the changes in the energy statistics.
		Choice of emission factors	Changes in aboveground net biomass growth in natural forests from 4.7 tonnes d.m/ha/yr. to 1.6 tonnes d.m/ha/yr.
Waste	Solid waste disposal (4A)	Changes in the solid waste dataset	Revision of solid waste generation, collection and disposal dataset.

The recalculations led to an average 72% increase in the previous emissions trends for 1990-2012. The most significant difference between 159% was recorded in 1991 and the least increase of 19% in 2012(Figure 13).

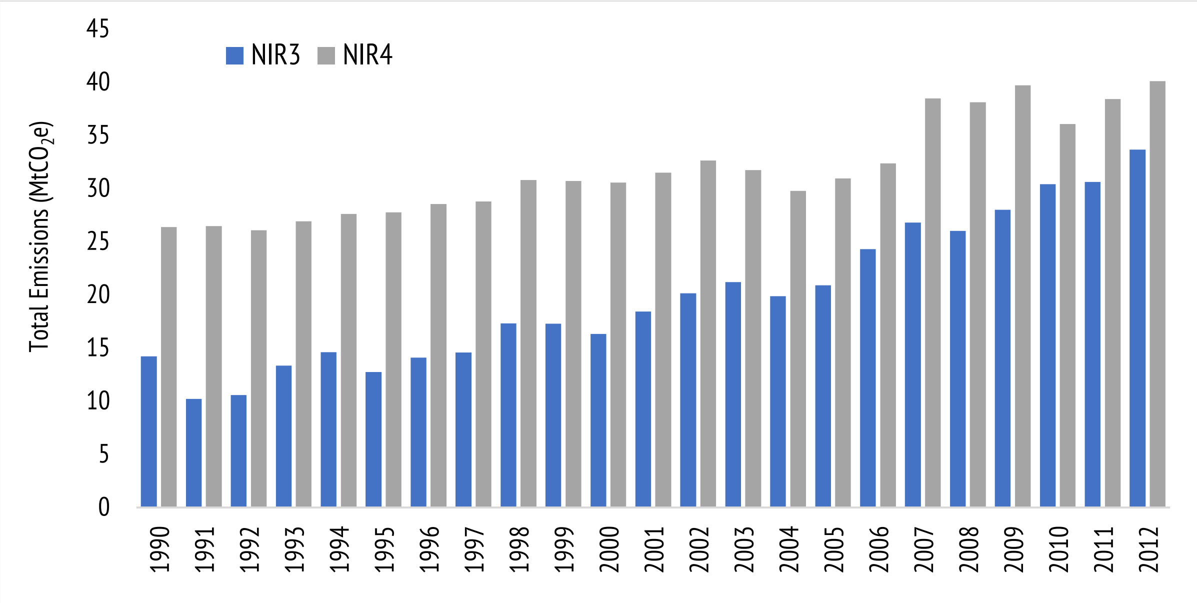


Figure 13: Comparison of total national emission trends in NIR3 and NIR4 as a result recalculation

2.7.2 Filling of time series gaps

In the inventory where we observed time series data gaps across the inventory years, interpolation and extrapolation techniques were used to resolve them. Table 24 contains the list of categories interpolation and extrapolation techniques that have been used to fill time series gaps.

Table 24: Techniques used to fill time series data gaps

Sector	Category	Activity data	Type of Technique used
AFOLU	Land – areas of land-use representations	Missing 2016 land category areas	Extrapolation
		Missing land use areas for the intervening years, 1991-1999, 2001-2011, 2013-2014	Interpolation
		20-year time points	Extrapolation
	Land – areas affected fire	1991-1999 missing, 2001-2009, 2011-2014	Interpolation
	Fertiliser application	Missing years – 1991 -1994	Interpolation
	Timber harvesting	Missing 2016 activity data	Extrapolation

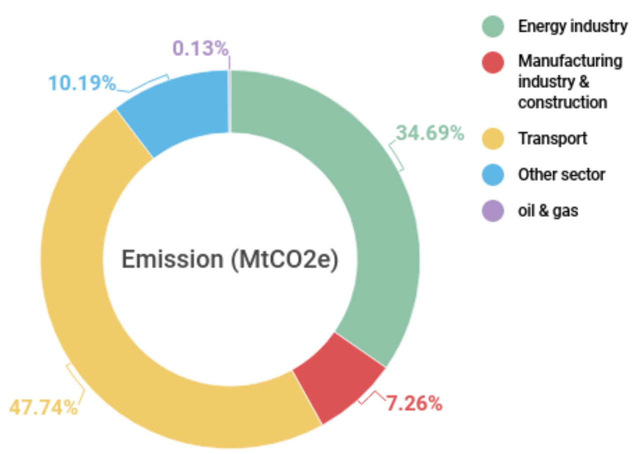
Waste	Solid Waste Disposal (4A)	Missing data of annual per capita solid waste generation 1950-1989, 1990-2004, 2006-2014, 2016	Trend extrapolation and interpolation
	Biological treatment of Solid waste (4B)	Missing data on amount composted from 1990-1993	Extrapolation
	Wastewater discharge and treatment (4D)	Missing data income class which was derived from urban and rural population classification for 1990-1995, 1997-2004, 2006-2009 and 2011-2016	Interpolation and extrapolation
		Distribution of the share of the population in different income classes using different waste treatment facilities for 1990-1995, 1997-2004, 2006-2009 and 2011-2016	Interpolation

Energy Sector

Energy sector GHG emissions Dashboard

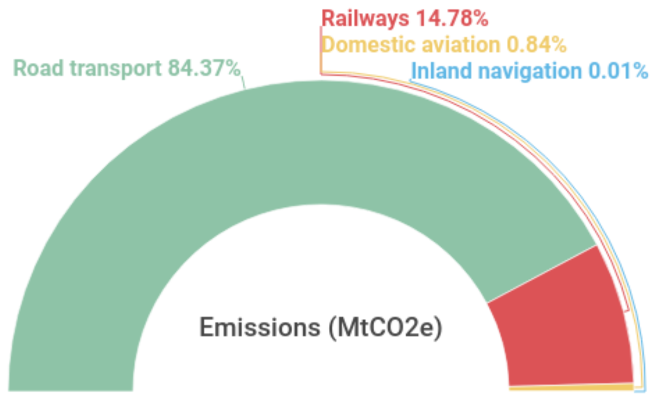
Total 2016 emissions	2016 fuel consumption	Emission trends	Major greenhouse gases
15.02 $MtCO_2e$	5.3 Mtoe	303% more than 1990 levels	CO_2 = 13.97 Mt (93.1% of all GHGs)

Emission by energy category in 2016



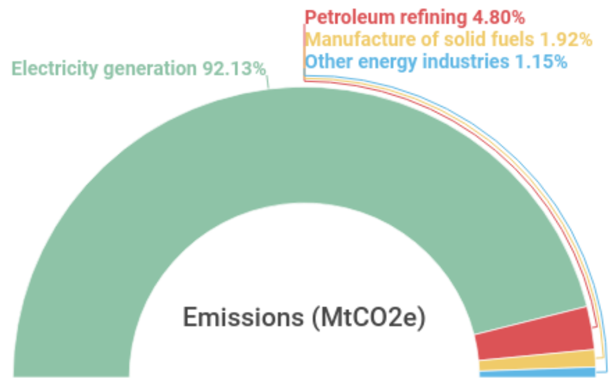
Transport emission in 2016

7.2 $MtCO_2e$



Energy industry emissions in 2016

5.2 $MtCO_2e$



Chapter 3
Energy sector

3.1 Summary of the energy sector emissions for 2016

In 2016, the total energy sector emissions summed up to 15.02 MtCO_2e. The emission levels made the energy sector the second-largest source of GHG emissions in the country. The 2016 emissions are 36% of the total national emissions, including FOLU and 79% when without the net emissions from FOLU. In terms of trends, both the total GHG emissions and final energy consumption recorded steady growth for the period 1990-2016. Whereas the absolute emissions increased by 303%, final energy consumption went up 64.5% over the same period. The rising emission trends for the energy sector correlates well with the increasing use of liquid fuels in electricity generation and transportation. Carbon dioxide alone constituted 93% of the total energy sector emission in 2016.

The rest of the emissions are methane of 4.4% and nitrous oxide of 2.6%. The transport category is the predominant source of greenhouse gas in the energy sector (Figure 14). It accounted for 48% of the entire energy sector emissions. The transport category expectedly trailed by the energy industry category whose emissions composed 35% of the overall energy emissions. For the rest of the emissions, 10.2% were from the other sectors, 7.2% from the manufacturing industry and construction and finally, 0.2% from oil and gas operations.

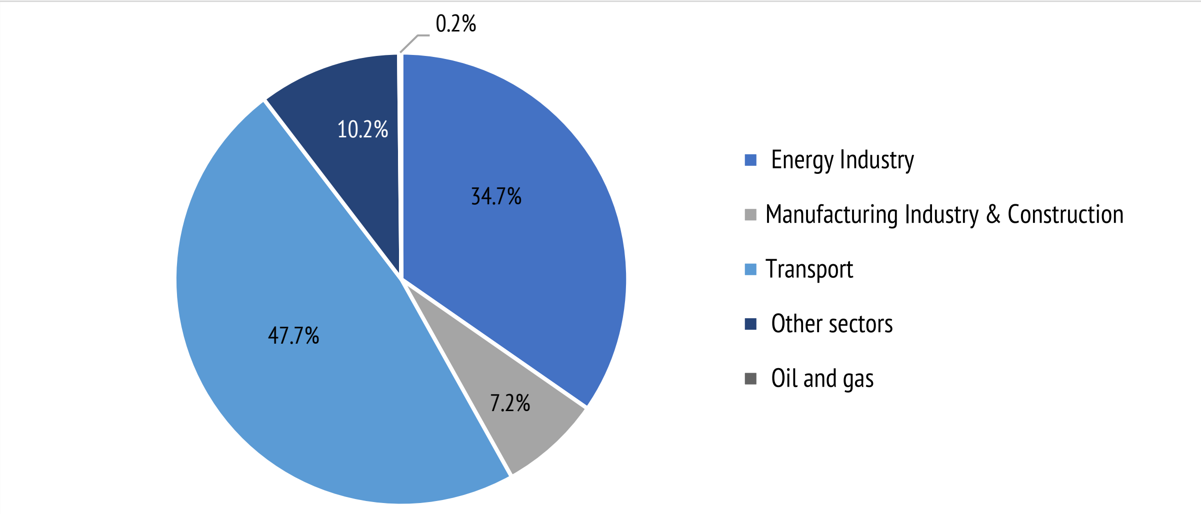


Figure 14: Energy sector emissions by category in 2016

Overall, the tier 1 method and the default emission factors from the IPCC 2006 Guidelines were used in estimating the emissions in the sector. An overview of the methods and emission factors used are in Table 25.

Table 25: Overview of methods and emission factors used in the energy sector

Category	Sub-category	CO_2		CH_4		N_2O	
		method	emission factor	method	emission factor	method	emission factor
Energy Industries	Electricity generation	T1	DF	T1	DF	T1	DF
	Petroleum Refining	T1	DF	T1	DF	T1	DF
	Manufacture of solid fuels	T1	DF	T1	DF	T1	DF
	Other energy industries	T1	DF	T1	DF	T1	DF
Manufacturing Industries and Construction	Iron and steel	T1	DF	T1	DF	T1	DF
	Chemicals	T1	DF	T1	DF	T1	DF
	Pulp, Paper and Print	T1	DF	T1	DF	T1	DF
	Food and Beverages	T1	DF	T1	DF	T1	DF
	Mining and Quarrying	T1	DF	T1	DF	T1	DF
	Construction	T1	DF	T1	DF	T1	DF
	Wood and Wood Products	T1	DF	T1	DF	T1	DF
	Leather and Textile	T1	DF	T1	DF	T1	DF
	Non-specified	T1	DF	T1	DF	T1	DF
Transportation	Domestic Aviation	T1	DF	T1	DF	T1	DF
	Cars	T1	DF	T1	DF	T1	DF
	Railways	T1	DF	T1	DF	T1	DF
	Inland navigation	T1	DF	T1	DF	T1	DF
Other sectors	Commercial/institutional	T1	DF	T1	DF	T1	DF
	Residential	T1	DF	T1	DF	T1	DF
	Agriculture/Forestry/ Fishing/Fish Farms	T1	DF	T1	DF	T1	DF
Oil and gas	Oil - flaring	T1	DF	T1	DF	T1	DF
	Natural gas	T1	DF	T1	DF	T1	DF

3.2. Overview of the energy sector

Greenhouse gas emissions are associated with all the stages of energy production to transformation and further to its final utilisation. The emissions from the energy sector are associated with the production and processing of primary energy, its transformation into secondary energy and the utilisation of the final energy (i.e. in the form of, e.g. oil products and biomass) for economic activities. For instance, the crude oil production from the Jubilee fields is considered as a source of emission of methane gas because of venting, flaring and leaks during the operation of the field equipment. Generally, the processes of production of electricity, process heat or steam from the combustion of petroleum products and biomass often lead to emissions of anthropogenic greenhouse gases. For example, the processes for producing heat/steam because of the transformation (e.g. thermal combustion or refining) of primary energy (e.g. crude oil) into secondary energy (e.g. electricity generation or diesel production) or conversion of woody biomass into charcoal.

When the Tema oil refinery produces petroleum products or the Oil Market Companies (OMCs) import finished petroleum products such as diesel, gasoline, LPG, they are typically used in stationary and mobile operations for economic activities that generate emissions. Apart from the combustion emissions, unintended emissions are also generated from upstream exploitation of oil and gas, their processing and the refining of crude oil. The degree to which the production, processing and utilisation of energy resources generate many operational factors that determine air emissions, the chief amongst them are:

- type, quality and quantity of fuels consumed or burnt at a given period
- installed capacity and operation hours

- technology vintage and
- environmental conditions.

3.3 Categorisation of energy sector activities

The 2006 IPCC Guideline broadly groups the core energy sector activities into the following categories:

- fuel combustion - 1A
- fugitive emissions from fuels – 1B
- carbon dioxide transport and storage – 1C

The classification is based on the type of activity in the energy supply chain and the operational flows through which the emissions are either released or removed from the atmosphere. The disaggregation of the energy activities into a similar emission by sources or removals by sink corresponds to the different IPCC activity codes.

3.3.1. Fuel combustion activities (1.A)

3.3.1.1 Stationary combustion (1.A.1, 1.A.2 and A.1.4)

The variety of energy activities that fall in the stationary combustion category are a point source of emissions. Some examples of point sources are power plants, industrial boilers, and crude oil refineries (e.g. Tema Oil Refinery), stand-alone electric generators, household and commercial cooking devices, and gas processing plants (e.g. Atuabo Gas Processing Plant). The classification of the activities under the stationary combustion category was done by considering the types of operations. The classification led to four IPCC categories:

- energy industries (1.A.1)
- manufacturing industry and construction (1.A.2)
- other sectors (1.A.4).

It broadly captured most of the energy activities in Ghana that contribute to the national economy. In Ghana, emissions from energy activities in mining, oil, industry, ports are already included in the manufacturing and construction category. Therefore, having a separate emission inventory for the enclave industries like mining alone could be a potential for double counting. All the emissions are accounted for by the manufacturing and construction industry. Other sectors cover emissions associated with energy activities in the residential, commercial and forestry/fisheries/agriculture.

3.3.1.2 Mobile combustion (Transportation - 1. A3)

There is a wide range of mobile energy-combustion operations in Ghana, and most of them are covered under the mobile combustion category. These comprise on-road and off-road transport via air, road, rail, water and are categorised into:

- air transportation (1. A.3a),
- road transportation (1.A.3b),
- railway transportation (1.A.3c),
- marine transportation (1.A.3d)
- other transportation (1.A.3f)

The IPCC Guidelines recommend that vehicles used for airport operations should be treated separately. It was not possible to isolate them because of lack of data. Therefore, off-road transport emissions vehicles had been added to the general road transportation emissions.

3.3.2 Fugitive emission from fuels (1.B)

In 2010, Ghana started producing oil in commercial quantities from the offshore Jubilee field using floating production storage and offloading (FPSO Kwame Nkrumah). Since then, two more oil and natural gas fields at TEN and Sankofa respectively have been discovered, and production has already been on-going. The government has put in place "flaring restrictions" policy and has established the Ghana National Gas Company to process wet gas from the three oil and gas fields into lean gas, condensates, and LPG for the local market to add commercial value to the natural gas. The production of oil from the Jubilee and TEN and recently natural gas from the Sankofa fields, the processing, and distribution of natural gas is linked to fugitive emissions. The main sources of fugitive emissions fall in the following IPCC sub-categories:

- venting (1. B.2.a.i),
- flaring (1.B.2.a.ii),
- refining (1.B.2.a.iii.4)
- natural Gas processing (1.B.2.b.iii.3),
- natural Gas Distribution (1.B.2.b.iii.5).

3.3.3 Carbon dioxide transport and storage (1C)

This category is not applicable in Ghana and was excluded from the inventory.

3.4 Data and methodology used for the Energy sector inventory

3.4.1 Description of data requirements and data sources

The energy sector inventory was conducted using activity data and emission factors obtained from a variety of national and international sources. In selecting the type of data for the inventory, priority was given to using country-specific data. Where country-specific data were available, the team prioritised them over other data sources. The reason being that country-specific data tend to give better emissions estimates with lower uncertainties than default data. In this inventory, the country-specific activity data used were from:

- Energy Commissions' national energy statistics
- Energy Commissions' Strategic energy planning database,
- Ghana National Petroleum Authority's petroleum product consumption figures,
- Ghana Petroleum Commission's data on oil and gas production and export,
- Ghana National Gas Company's data on natural gas production and distribution and own-fuel consumption
- Tema Oil Refinery material balance,
- Driver and Vehicle Licensing Authority's vehicle registration and roadworthy figures,
- Ghana Customs vehicle imports data from GCNet,
- GSS's Ghana Living Standard Survey report

Peer-reviewed literature was another preferred source of data for the inventory, especially for those that the study was done in Ghana or the sub-region. In the absence of country-specific activity data and factors, data from databases of international organisations such as the IEA, FAO, UN-STAT and the World Bank were used. When there are disparities in the data from two credible sources, both were evaluated to detect patterns of inconsistencies and the reasons why there is a large difference. For example, the fuel consumption figures for selected energy demand categories in Ghana's energy statistics and the IEA were compared to assess the differences in them. Where there were notable differences, possible explanations were proffered to clarify possible contributing factors. The primary source of activity data for the inventory was the Energy Statistics published by the Energy Commission of Ghana. The statistics contain sectoral data on primary and secondary fuel supply and consumption for a given period. The energy statistic data used covered the multi-years below:

- 1995 Energy Statistics (1974-1994),
- 1998 Energy Statistics (1974 – 1997),
- 2001 Energy Statistics (2000-2008)
- 2012 Energy Statistics (2000-2011)
- 2017 Energy Statistics (2007-2016).

Whenever previous data are updated the new figures in the recent publication supersede the old dataset. The preparation cycle of the energy statistics typically ends in April after which data collection and processing start upon the completion of a previous report. The Energy Commission collects from original data owners or facility operators as stipulated by the Energy Commission Act 541. Energy statistics are the primary data source for the energy inventory because it is the credible official publication release every year. Another vital energy data source is the petroleum products consumption figures. The data is published by the National Petroleum Authority (NPA). The NPA regularly updates the data and release them online as open-source data[18].

The total fuel consumption figures in the energy statistics and energy inventory because they are sourced from the NPA database. Even though the energy statistics data was the primary data source for the energy inventory, in cases where the dataset does not match or is missing, the fall back is on the NPA primary data. The latest NPA figures covered the period 1996 to 2016 and have been reported monthly for each petroleum product like fuel oil, diesel (Open market, Mines and Rigs), gasoline, kerosene, LPG, premix fuel, ATK, industrial kerosene. The National Petroleum Commission and Petroleum Department of EPA have daily and monthly oil production figures from the Jubilee, TEN and Sankofa fields. Since the oil and gas production figures were not publicly available, a formal request was made to the institutions to access them. The obtained data were daily oil and gas production figures from 2010 to 2018. The Jubilee field data covered from November 2010 to April 2018, TEN field was from August 2016 to April 2018 and Sankofa field, May 2017 to April 2018.

Generally, the production data included raw and reconciled figures on the following variables: oil production, gas production, total water injection, gas injection, fuel gas usage, gas flared and gas exported. The Tema oil refinery has the refinery material balance that covered 1995-2016, and it was requested via official letter. The material balance usually is not published online, but it serves as the database for reporting to the primary regulators of the downstream petroleum market. Generally, the materials balance contains figures on individual crude import for each product grade, refinery input/intake, plant production, withdrawal for the internal market, transfers, imports of refined products and crude export to VRA.

[18] http://www.npa.gov.gh/images/npa/documents/statistics/National_Consumption_1999-2016.xlsx

The daily operational figures for natural gas processing was obtained from the Ghana National Gas Company (GNGC) covering August 2015 to July 2018. The figures included quantities of wet net gas imports from the oil fields, gas production at Atuabo, product (lean gas, condensate and LPG) amounts to consumers and fuel consumption at the plant.

Transport data were collected from multiple sources. For data on vehicle population, the DVLA has figures on vehicle registration and roadworthy certification per region between 1995 and 2016. Some of the vehicle data include make, model, year of manufacture, chassis, gross weight and fuel type. Data on annual vehicle imports came from Ghana Custom's GCNet database. It had more details on the vehicle reconciled with the DVLA data on annual vehicle registrations and roadworthy certification figures to validate vehicle population values. Ghana Bunkering Services (GBS) provided data on aviation and marine bunkers. The GBS data were used to cross-check the quantities of ATK and diesel fuel allocation for bunkering in the energy statistics. Inland water navigation relies on premix and diesel fuels. Consumption figures were collected from the Ministry of Fisheries and Aquaculture Development and the Volta Lake Transport Company. Table 26 below gives an overview of the main activity data datasets and their sources.

Table 26: Type of activity data, sources and the data providers

Category	Data Type	Data Source	Principal Data Providers
Energy Industry			
Electricity generation	The number and installed capacities of active thermal power plants commissioned and in operation each year. Quantities of electricity generated in a year. Type and quantities of light crude oil, heavy oil and natural gas consumption per plants and the corresponding electricity production	National Energy Statistics	Energy Commission Volta River Authority Independent Power Producers Ghana Gas Company
Petroleum Refinery	Quantities of Residual Fuel Oil (RFO), Petroleum Coke and Refinery consumption per year.	National Energy Statistics	Tema oil refinery material balance.
Manufacture of solid fuels	Quantities of wood fuel as input into charcoal production	National Energy Statistics. FAOSTAT. IEA Database.	National survey. FAOSTAT Ghana country data. IEA Ghana country data.
Other industries	Consumption of diesel to support the operation of Ghana National Gas Company (GNGC) and the oil fields.	Statistics on diesel consumption on-site at GNGC and on the oil rigs.	Ghana National Gas Company National Petroleum Commission
Manufacturing industry and construction			
Iron and steel	Quantities of RFO and Diesel consumption per year.	National Energy Statistics. National Industry Survey. Annual Environmental Report for Permitted Industries. IEA Database.	Energy Commission. Manufacturing Industry Department of EPA Ghana Statistical Service. IEA Ghana country data.
Chemicals	Quantities of RFO, diesel and wood fuel consumption per year.		
Pulp, paper and print	Quantities of diesel and LPG consumption per year.		
Food processing, Beverage and Tobacco	Quantities of RFO, diesel, LPG, Charcoal and Woodfuel consumption per year.		
Mining and Quarrying	Quantities of diesel and gasoline consumption per year		
Wood and wood products	Quantity of diesel consumption per year		
Construction	Quantity of diesel consumption per year		

Textile and Leather	Quantities of RFO and Diesel consumption per year.		
Non-specified	Quantities of RFO, diesel, LPG and Woodfuel consumption per year		
Transport			
International aviation bunkers	Quantity of total ATK transferred to international bunkers for the consumption of international airlines.	National Energy Statistics. National Survey	Energy Commission Ghana Bunkering Services. National Petroleum Authority. Oil marketing companies. Ghana EPA Ministry of Transport
Domestic Aviation	Quantity of total ATK consumption by domestic airlines per annum. Data on land and take-off per flight per day (not available).		
Cars, trucks, heavy-duty vehicles, buses and motorcycle	Quantity of gasoline, diesel and LPG consumption per vehicle classes and technology type. Distance and speed data on different road class (urban road, highways and feeder roads).		
Railways	Quantity of diesel consumption per year.	National Energy Statistics. Ghana Railways Diesel Consumption Figures	Energy Commission. Ghana Railway Development Authority.
International water-borne navigation	Quantity of total diesel transferred to international bunkers for the consumption of international ships.	National Energy Statistics.	Energy Commission
Domestic water-borne navigation	Quantity of diesel and premix consumption for inland navigation per annum.	National Energy Statistics. Volta River Lake Transport. Premix supply data	Energy Commission. Volta River Transport Company. National Petroleum Authority Ministry of Fisheries and Aquaculture Development.
Other sectors			
Commercial/Institutional and Residential	LPG, Kerosene, Charcoal and Woodfuel consumption per annum.	National Energy Statistics Strategic National Energy Plan National Census Report Ghana Living Standard Survey Report.	Energy Commission Ghana Statistical Service.
Fishing	Quantity of premix consumption for inland navigation.	Premix supply data	Ministry of Fisheries and Aquaculture Development.
Stationery	Quantity of diesel consumption per year	National Energy Statistics. Strategic National Energy Plan	Energy Commission
Off-road vehicle and other machines	Quantity of gasoline and diesel consumption per year	National Energy Statistics. Strategic National Energy Plan	Energy Commission
Fugitive emissions			
Oil production (flaring)	Quantity of gas production The fraction of gas production export to GNGC The fraction of gas production injected The fraction of gas production flared.	National Energy Statistics. Oil Production Figures	Energy Commission Petroleum Commission EPA
Gas Processing	Quantity of gas flared during the processing of natural gas at GNGC.	GNGC production figures	Ghana National Gas Company
Refining	Quantity of throughput refinery input.	TOR material balance	Tema Oil Refinery
Gas distribution	Quantity of lean gas export to Aboadze thermal plant per year.	GNGC production figures	Ghana National Gas Company

3.4.2 Overview of the data flow of the energy statistics

Accurate, timely and accessible energy statistics support a range of energy planning activities and are used by a wide range of stakeholders to understand the status of energy developments in a country. Good statistics are also essential for countries to develop energy policies and action plans, set targets, track progress towards goals and design finance mechanisms.

3.4.2.1 Legal framework backing the energy statistics

A legal framework is recognised as the most crucial aspect of establishing a credible and sound energy statistical system. The Energy Commission was established by an Act of Ghanaian Parliament, the Energy Commission Act, 1997 (Act 541) to among other functions to secure a comprehensive energy database for national decision making for the efficient development and utilisation of the energy resources available to the nation. The Act, therefore, mandates the Energy Commission to collect energy data, compile, analyse and make the information available to policymakers, researchers and planners. The Energy Commission has been executing this mandate in close collaboration with stakeholders such as the NPA, Petroleum Commission, Ghana National Petroleum Corporation, Ministry of Energy, Volta River Authority, Independent Power Producers and GSS, among others. These institutions serve as the primary sources of energy and allied data. The Energy Commission collects and compiles data and disseminates them for the use of the general public. All these institutions, as much as possible, recognise their roles in ensuring that they make data available timeously to ensure the establishment of a sound energy statistical system. Data collected are analysed and published by the Energy Commission.

3.4.2.2 Organisation of data collection and data flow in the Energy statistics

Two main types of data are collected for analysis and dissemination. These are primary and secondary data. Secondary energy data are collected from the utilities and other regulators; while primary data are collected periodically during the survey. Data on electricity generation, transmission, distribution, sales and losses are submitted to the Energy Commission by the utilities (generation, transmission and distribution utilities) as part of their licensing requirements. As a form of data validation, reconciliation of the monthly data submitted is done at the end of the year before data are processed for dissemination. Data on crude oil and petroleum products are collected from institutions and regulators of the sub-sector. The Energy Commission has an established system with the Petroleum Commission and Ghana National Petroleum Corporation where crude oil and natural gas production data from the production fields are collected daily. Monthly and annual reconciliation of daily data collected is done before data are made available to the public.

The National Petroleum Commission was the source of data on petroleum product import, export and distribution/sales. Data is collected monthly, and as a form of verification and validation, reconciliation of monthly data is done at the end of the year. The existence of an established system between the Energy Commission and Tema Oil Refinery enables the collection of data on activities of the refinery (production, sales, losses, crude oil intake) every quarter. Data on sectoral consumption of energy products is collected using sample surveys since the utilities do not keep data on that. These surveys are conducted periodically, when funds are available, in close collaboration with GSS. Demographic and macroeconomic data are collected periodically from GSS to compute energy indicators for the country. Table 27 shows the institutions involved in the supply of energy data to the Energy Commission and the frequency of supply of data.

Table 27: Energy data sources and frequency of data supply

Fuel	Type of data	Frequency	Aggregation/Disaggregation	Data Source
Electricity	Generation	Daily/monthly/ annually	National	GRIDCo, VRA, IPPs
	Import/export	Monthly/annually	National	GRIDCo
	Transmission/transmission losses	Monthly/annually	National	GRIDCo
	Fuel use for electricity generation	Monthly/ annually	National	GRIDCo, VRA, IPPs
	Distribution & sales	Monthly/ annually	National, Regional, Customer class	ECG, NEDCo, EPC
	Distribution losses	Monthly/ annually	National	ECG, NEDCo, EPC
	Prices	Periodic	National, Customer class	PURC
	Sectorial Consumption	Periodic	National, Rural/Urban, Sectorial - Residential, Service, industry, Agriculture	Sample Survey
Petroleum	Crude oil & natural gas production	Daily/monthly/ annually	National	GNPC, GNGC
	Refinery activity - refined products production	quarterly/annually	National	TOR
	Crude oil and products import & export	Monthly/annually	National	NPA
	Products distribution and sales	Monthly/annually	National/regional	NPA
	Prices	Bi-weekly	National	NPA, OMCs
	Sectorial Consumption	Periodic	National, Rural/Urban, Sectorial - Residential, Service, industry, Agriculture	Sample Survey
Biomass	Production	Periodic	National	Sample Survey
	Sales & Consumption	Periodic	National, Rural/Urban, Sectorial - Residential, Service, industry, Agriculture	Sample Survey
	Prices	Periodic	National, Regional	Sample Survey

The necessary quality control procedures are introduced in the verification and analysis of data. Where discrepancies are detected in the data submitted, a follow-up meeting and discussion with the entity involved is done before data are analysed for dissemination. Energy data collection and dissemination is, as much as possible, done according to the International Recommendation of Energy Statistics (IRES) and the Energy Statistics Compilers Manual (ESCM) of the United Nations Statistics Division (UNSD) and the Energy Statistics Manual of the International Energy Agency (IEA). The Energy Commission applies the principle of official statistics by compiling and making available on an impartial basis official statistics to citizens and users, following basic procedures in the dissemination of energy statistics, which include timeliness, confidentiality, and feedback. The flow of data is presented in Figure 15.

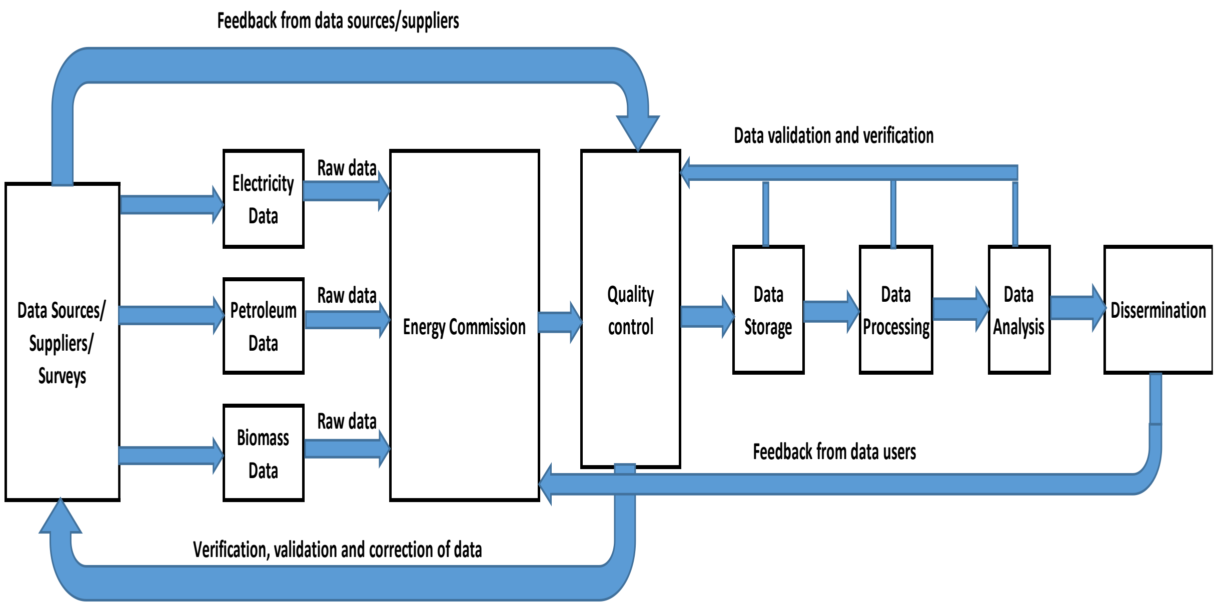


Figure 15: Overview of data flows in the energy statistics

3.4.2.3 Key challenges in the compilation of the Energy statistics

Some of the key challenges the Commission has encountered in the preparation of the national statistics are summarised below:

- **Inadequate financial resources**: Due to lack of financial resources, the Energy Commission has not been able to update the last survey conducted in 2010 to determine the pattern and quantity of energy consumed in the various sectors of the economy. This survey normally forms the basis for the preparation of energy plans. Ideally, surveys should be conducted every 3-5 years to update the patterns and quantities of energy use. Currently, we rely on projections based on the 2010 study to allocate fuel shares for the various sectors of the economy based on the projections developed in the Strategic National Energy Plan (SNEP). There is, therefore, the need to undertake the necessary study to update the shares of energy use in the economy.

- **Data quality:** secondary data are mainly collected from the institutions and entities in the sector. However, the Commission has minimal control over the compilation of these data hence cannot guarantee with certainty the quality of data being submitted by the entities involved, especially for those institutions that do not fall in the regulatory arm of the Energy Commission. Continuous work, however, is being done with these entities through the establishment of a technological mechanism where the commission can have a first-hand insight into the data being compiled or collected.

- **Inadequate capacity building process:** continuous capacity building in every data collection process is essential. Continuous capacity building on new techniques and methodology in the compilation, analysis and dissemination of energy statistics would go a long way to improve on the quality of data and statistics produced by the Energy Commission.

3.4.3 Energy sector methodology

3.4.3.1 General overview of methods and underlying assumptions

The energy sector inventory has been prepared according to volume 2 of the 2006 IPCC Guidelines. The Guidelines set out the broad systematic steps and the rationale for the identification of emission sources in the energy sector, selection of methodological approaches, activity data, factors and the formulation of underlying assumptions in a consistent manner. Furthermore, the IPCC Guidelines offer good practice advice on the calculations of the GHG emissions using AD and the EF and strategies for documentation, archiving and reporting. For the benefit of the readers who are not familiar with the use of the terms AD and EF, the general definition is provided here. Mostly, AD is a quantity that measures the level of intensity or frequency of a specific operation at a given rate that results in the generation of GHG emissions at different stages of production and utilisation cycle. An example of AD could be the quantity of natural gas produced at the oil field and the fraction used by a single or multiple thermal power plants to generate electricity for the national grid.

Almost all the activity data used in the energy sector inventory were obtained from primary and publicly available secondary country sources. As much as possible, the collected AD fell within the 1990-2016 time-series. In a few instances where there were gaps in the country-specific AD across, regional and international data were used to fill the gaps. In case there is no data at the regional and international levels to fill the gap, appropriate statistical methods (e.g. extrapolation, interpolation) consistent with the IPCC good practice was applied to generate the missing data. Expert judgment was seldom applied were very necessary, and the requisite underlying assumptions documented.

An emission factor is the other variable in the GHG emission calculation. The EF is defined as the measure of the rate at which the level, intensity, frequency of use or production would produce specific GHG emissions under a given condition. Majority of the EFs used in the energy sector inventory were obtained from the IPCC Emission Factor Database. It is important to state that the use of default emission factors per se in the inventory is not wrong. But because they are normally generated under different conditions other than what pertains in Ghana using them to calculate the emissions come with its high levels of uncertainties. The preference is to have country-specific or plant-specific factors that better represent the emissions where it was realised. Nevertheless, the EFs that have been used in this inventory is the best possible available data and efforts would be made to support work to develop country-specific factors in future.

The product of the AD and the EF is the total GHG emissions(E) of an activity [E=AD*EF]. This equation can be adapted to suit different levels of complexities of the methodology for the emission estimates. Generally, the Tier 1 methodology was adopted in the estimation of the Energy sector emissions. Detailed descriptions of the respective methodologies or tiers are given in the specific sections of the source categories.

3.4.3.2 Energy sector activity data and emissions factors applied

The AD used in the inventory, after the collection was processed to identify and exclude mistakes and outliers before using in the emission estimation with the EFs. The list of AD for 2016 and EFs are presented in Tables 28 and 29. Except stated, all the EFs were obtained from the IPCC Emission Factor Database.

Table 28: List of activity data used in the energy sector inventory for 2016

IPCC Codes	Sub-categories	Quantity of Fuel Types (TJ)													Liquid fuel (10^m^3)	Gaseous fuel ($10^6 m^3$)	Natural Gas(TJ)
		RFO	Crude oil	HFO	Diesel	Gasoline	LPG	DFO	Petroleum Coke	Charcoal	Woodfuel	Refinery gas	ATK	Kerosene			
1.A1ai	Electricity generation		25,635.2	14,949				2,356.4									28,072.17
1.A1b	Petroleum Refining	1,547.8							242.7			1,896.4					
1.A1ci	Manufacture of solid fuel (charcoal)										51,070.6						
1.A1cii	Other energy industries				469												442.3
1.A2a	Iron and steel	2.50			58.5												
1.A2c	Chemicals	11.5			78.2						634.8						
1.A2d	Pulp, Paper & Print				22.6		41.8										
1.A2e	Food Processing, Beverage & Tobacco	320.3			814.8		129.9			175.59	6,815.3						
1.A2i	Mining & Quarrying				9,375.5	0.22											
1.A2j	Wood & Wood Products				434.6												
1.A2k	Construction				2,204.4												
1.A2l	Textiles & Leather	81.8			19.8												
1.A2m	Non-specified	122.8			545.9		139.04				647.83						
1.A3ai	International Aviation Bunkers												4,742				
1.A3aii	Domestic Aviation												793.4				
1.A3bi	Passenger cars				17,225.9	18,756.86	4,248.9										
1.A3bii	Light-duty truck				8,71.9	7,421.78											
1.A3biii	Heavy-duty & buses				15,656.1	4,349.02											
1.A3biv	Motorcycle					13,223.84											
1.A3c	Railways				12,711.9												
1.A3di	International water-borne navigation				101.2												
1.A3dii	Domestic water-borne navigation				19.0												
1.A4a	Commercial/ Institutional						544.7			4,141.5	945.6			35.7			
1.A4b	Residential						6,629.8			46,510.6	5,4614			254.9			
1.A4ci	Stationery				5.8												
1.A4cii	Off-road vehicle and other machines				970.2	1,423.3											
1.A4ciii	Fishing				914.4	2,461.5											
1.B2aii	Oil - flaring														169.9		
1.B2biii.3	Gas Processing															0.6	
1.B2biii.4	Refining														34,536.3		
1.B2biii.5	Gas Distribution															1.1	

Table 29: List of energy sector emission factors per sub-category and fuel type from the 2006 IPCC Guidelines

IPCC Codes	Sub-categories	Gas		Quantity of Fuel Types (TJ)													Liquid fuel (10^m^3)	Gaseous fuel (10^6 m^3)	Natural Gas(TJ)
				RFO	Crude oil	HFO	Diesel	Gasoline	LPG	DFO	Petroleum Coke	Charcoal	Woodfuel	Refinery gas	ATK	Kerosene			
1.A1ai	Electricity generation	CO_2			73,300	77,400				74,100									56,100
		CH_4	Kg/TJ		3.00	3.00				3.00									1.00
		N_2O			0.6	0.6				0.6									0.1
1.A1b	Petroleum Refining	CO_2		77,400							97,500			57,600					
		CH_4	Kg/TJ	3.00							3.00			1.00					
		N_2O		0.6							0.6			0.1					
1.A1ci	Manufacture of solid fuel (charcoal)	CO_2											112,000*						
		CH_4	Kg/TJ										30						
		N_2O											4						
1.A1cii	Other energy industries	CO_2					74,100												56,100
		CH_4	Kg/TJ				3.00												1.00
		N_2O					0.6												0.1
1.A2a	Iron and steel	CO_2		77,400			74,100												
		CH_4	Kg/TJ	3.00			3.00												
		N_2O		0.6			0.6												
1.A2c	Chemicals	CO_2		77,400			74,100						112,000*						
		CH_4	Kg/TJ	3.00			3.00						30						
		N_2O		0.6			0.6						4						
1.A2d	Pulp, Paper & Print	CO_2					74,100		63,100										
		CH_4	Kg/TJ				3.00		1.00										
		N_2O					0.6		0.1										
1.A2e	Food Processing, Beverage & Tobacco	CO_2		77,400			74,100		63,100			95,000*	112,000*						
		CH_4	Kg/TJ	3.00			3.00		1.00			1.00	30						
		N_2O		0.6			0.6		0.1			0.1	4						
1.A2i	Mining & Quarrying	CO_2					74,100	69,300											
		CH_4	Kg/TJ				3.00	3.00											
		N_2O					0.6	0.6											
1.A2j	Wood & Wood Products	CO_2					74,100												
		CH_4	Kg/TJ				3.00												
		N_2O					0.6												
1.A2k	Construction	CO_2					74,100												
		CH_4	Kg/TJ				3.00												
		N_2O					0.6												
1.A2l	Textiles & Leather	CO_2		77,400			74,100												
		CH_4	Kg/TJ	3.00			3.00												
		N_2O		0.6			0.6												
1.A2m	Non-specified	CO_2	Kg	77,400			74,100		63,100				112,000*						

		CH_4		3.00			3.00		1.00				30						
		N_2O		0.6			0.6		0.1				4						
1.A3ai	International Aviation Bunkers	CO_2	Kg/TJ												71,500*				
		CH_4													0.5*				
		N_2O													2*				
1.A3aii	Domestic Aviation	CO_2	Kg/TJ												71,500				
		CH_4													0.5				
		N_2O													2				
1.A3bia	Passenger cars with 3-way catalyst	CO_2	Kg/TJ					69,300											
		CH_4						25											
		N_2O						8											
1.A3bib	Passenger cars without 3-way catalyst	CO_2	Kg/TJ				74,100	69,300	63,100										
		CH_4					3.9	33	62										
		N_2O					3.9	3.2	0.2										
1.A3biia	Light-duty truck with 3-way catalyst	CO_2	Kg/TJ					69,300											
		CH_4						33											
		N_2O						3.2											
1.A3biib	Light-duty truck without 3-way catalyst	CO_2	Kg/TJ				74,100	69,300											
		CH_4					3.9	33											
		N_2O					3.9	3.2											
1.A3biii	Heavy-duty & buses	CO_2	Kg/TJ				74,100	69,300											
		CH_4					3.9	25											
		N_2O					3.9	8											
1.A3biv	Motorcycle	CO_2	Kg/TJ					69,300											
		CH_4						25											
		N_2O						8											
1.A3c	Railways	CO_2	Kg/TJ				74,100												
		CH_4					4.15												
		N_2O					28.6												
1.A3di	International water-borne navigation	CO_2	Kg/TJ				74,100												
		CH_4					7												
		N_2O					2												
1.A3dii	Domestic water-borne navigation	CO_2	Kg/TJ				74,100												
		CH_4					7												
		N_2O					2												
1.A4a	Commercial/ Institutional	CO_2	Kg/TJ						63,100			112,000*	112,000*			71,900			
		CH_4							5			200	300			10			
		N_2O							0.1			1	4			0.6			
1.A4b	Residential	CO_2	Kg/TJ						63,100			112,000*	112,000*			71,900			
		CH_4							5			200	300			10			
		N_2O							0.1			1	4			0.6			
1.A4ci	Stationery	CO_2	Kg /TJ				74,100												
		CH_4					10												

		N_2O					0.6												
1.A4cii	Off-road vehicle and other machines	CO_2	Kg/TJ				74,100	6,300											
		CH_4					10	10											
		N_2O					0.6	0.6											
1.A4ciii	Fishing	CO_2	Kg/TJ				74,100	6,300											
		CH_4					10	10											
		N_2O					0.6	0.6											
1.B2aii	Oil - flaring	CO_2	10^3 m3														0.049		
		CH_4																	
		N_2O																	
1.B2biii.3	Gas Processing	CO_2	10^6 Sm3															0.0014	
		CH_4																0.0000024	
		N_2O																0.0000024	
1.B2biii.4	Refining	CO_2	10^3 m3																
		CH_4															0.0000218		
		N_2O																	
1.B2biii.5	Gas Distribution	CO_2	10^6 m3															0.000051	
		CH_4																0.0018	
		N_2O																	

* Memo item. Emission not included in the national totals

3.5 Analysis of fuel consumption pattern

3.5.1 Total primary fuel consumption

Ghana is endowed with fossil hydrocarbons and biomass. It produces offshore crude oil for exports and natural gas domestic primarily for domestic consumption. Additional natural gas imports from Nigeria via West Africa Gas Pipeline complements the domestic gas resources. Ghana is a net importer of refined petroleum products Commercial crude oil production started in 2010 on the Jubilee Field offshore in the Western Region of Ghana Since then, operations on two additional oil and fields (TEN and Sankofa fields) have started in 2016 and 2017 respectively. Almost all the crude oil produced from the oil fields are exported offshore. The crude oil input for the refinery and electricity is imported from the international market. The natural gas produced from two offshore fields is sent to GNGC for processing into lean gas, condensate, and LPG for the local market. Associated gas produced on the Jubilee and TEN oil fields as an undesirable by-product and fractions are either injected, flared, vented and the rest sent to GNPC. In 2017, the Sankofa field managed by ENI/Vitol started producing non-associated gas for GNGC.

Solid biomass is sourced from different parts of the country, particularly in the transition and savannah zones as wood fuel. Some of the wood fuels are directly used as firewood, and others are converted to charcoal using inefficient kilns. Secondary fuel is produced from the transformation of primary fuel (crude oil, natural gas, and wood fuel) through refinery (crude oil to gasoline, kerosene), gas processing (wet gas to lean gas) and charcoal making (charcoal). The secondary energy is in the liquid, solid and gaseous form. Liquid fuels include petroleum products such as diesel, gasoline, LPG, kerosene, refinery fuel oil, refinery gas, aviation kerosene, lubricants. They are usually used in stationary and mobile combustion operations and as feedstock/non-energy. The secondary fuels are produced from the state-owned Tema oil refinery. The government deregulation policy of the downstream petroleum market permits the private sector to also import refined products.

Firewood and charcoal are the main sources of solid fuels. They are typically used as fuels for cooking and heating in households, commerce and industry. Firewood is solid biomass materials gathered from vegetated areas and used as fuel. They are neither processed nor seasoned before use. On the other hand, charcoal is made from the pyrolysis of wood in a dominantly earth-mound kiln. Petroleum coke is another form of solid fuel mainly used in the oil refinery. Natural gas is the main gaseous fuel in the country. It is produced domestically by GNGC. Additional national gas is imported from Nigeria through the West Africa Gas Pipeline. Natural gas is mainly utilised in electricity generation. Table 30 shows the total fuel consumption from 1990 to 2016. Ghana consumes an average of 5.7 million tonnes of oil equivalent to primary fuels every year. It has increased from 4.8 Mtoe in 1990 to 5.4Mtoe in 2016. In 2016 alone, the total primary fuel consumption was estimated at 5.33 Mtoe representing 12.1% and 6.1% higher than the quantities of fuel consumption reported in 1990 and 2012, respectively.

Table 30: Trends of total primary fuel consumption shares between 1990 to 2016 in ktoe

Year	Crude oil	Natural gas	Solid Biomass	Total fuel
1990	801.72	-	3,961.00	4,762.72
1991	981.65	-	4,112.00	5,093.65
1992	959.78	-	4,269.00	5,228.78
1993	759.92	-	4,434.00	5,193.92
1994	1,075.78	-	4,606.00	5,681.78
1995	911.92	-	4,786.00	5,697.92
1996	989.50	-	4,974.00	5,963.50

1997	34.65	-	5,170.00	5,204.65
1998	1,221.61	-	5,083.88	6,305.49
1999	1,666.48	-	5,195.74	6,862.22
2000	1,310.60	-	4,672.50	5,983.10
2001	1,569.58	-	5,075.00	6,644.58
2002	1,816.60	4.37	5,267.50	7,088.47
2003	1,972.48	5.81	5,616.00	7,594.29
2004	2,016.44	15.76	5,547.50	7,579.70
2005	2,006.85	-	3,141.00	5,147.85
2006	1,747.06	-	3,067.70	4,814.76
2007	2,094.77	-	3,068.10	5,162.87
2008	2,015.32	-	3,070.40	5,085.72
2009	1,002.46	-	3,127.00	4,129.46
2010	1,694.83	393.50	3,207.00	5,295.33
2011	1,562.23	1,671.28	3,370.70	6,604.21
2012	1,233.69	389.30	3,409.20	5,032.19
2013	1,328.30	291.60	3,554.90	5,174.80
2014	706.30	619.40	3,629.00	4,954.70
2015	317.00	1,184.90	3,618.00	5,119.90
2016	1,047.97	688.20	3,602.40	5,338.57
% change 2012-2016	-15.1%	76.8%	5.7%	6.1%

Solid biomass had consistently remained the largest of primary fuel from 1990 to 2016. On the average, solid biomass made up 73.7% of the total primary energy consumption followed by crude oil (22.8%) and natural gas (3.5%). Even though the biomass is still the dominant primary energy, its share of the total primary fuels recorded a consistent decline (83% in 1990 to 67% in 2016) due to the in-roads of crude oil (17% in 1990 to 24% in 2016) and natural gas (0% in 1990 to 13% on 2016) (Figure 16). The persistent drops in biomass consumption are linked to the growing use of alternative fuels. The rapid shifting to oil reflects the national policy to diversify the reliance on biomass fuel. On a similar note, the continued implementation of the promotion of Liquified Petroleum Gas (LGP) as an alternative fuel for domestic and commercial cooking contributed significantly to reducing biomass consumption for cooking in Ghana.

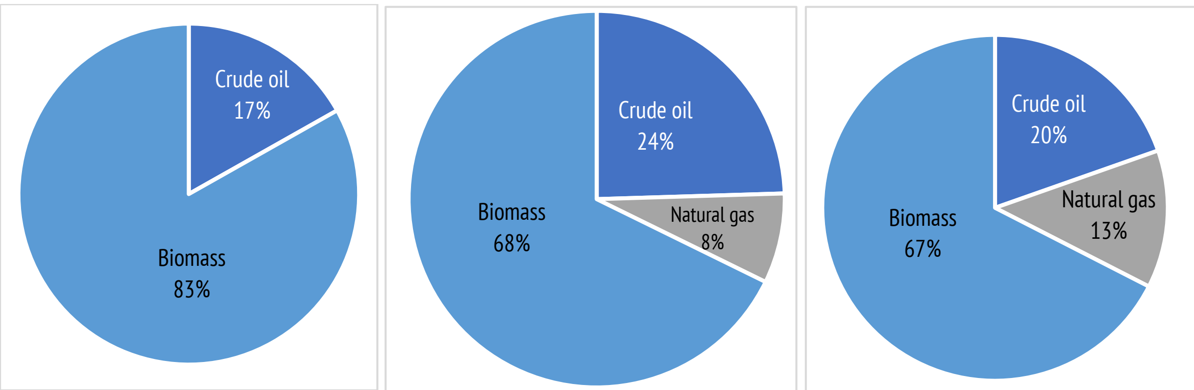


Figure 16: Percentage shares of fuel consumption for 1990, 2012 and 2016

Table 30 indicates a sharp increase in natural gas consumption of 75.8% between 2012 and 2016 in contrast to crude oil which declined by 15.1% and was mostly driven by the growing use of natural gas as a substitute fuel to crude oil in electricity generation. Figure 16 further revealed that solid biomass was still the dominant primary fuel as at 2016 trailed by crude oil (20%) and gaseous (13%). However, if the figures on imports of secondary fuels are added to the total primary oil fuel, oil products become the largest share (50.8%) of primary fuel consumption followed by solid biomass (41.3%) and by natural gas of 7.9%.

3.5.1.1 Secondary fuel consumptions by sources

Different forms of liquid, solid and gaseous fuels are used in activities in the energy industries, manufacturing and construction, transport and other sectors categories. For liquid fuels, the dominant ones are gasoline, diesel, LPG, refinery gas, refinery fuel oil, heavy fuel oil. Petroleum coke, charcoal, firewood, and natural gas are the main solid and gaseous fuels in the country. These fuels are predominantly used to fire vehicles, boilers, cooking stoves and power plants. The figures on total secondary fuel consumption showed an increase from 5.3 Mtoe in 1990, 7.8 Mtoe in 2012 to 8.7 Mtoe in 2016. This upward trend was instigated by the apparent persistent rise in energy demand due to the expanding economic activities and population pressures.

Furthermore, table 31 suggests that consumption trends for the various types of fuels varied. It confirms the earlier observations of a fasting growing liquid and natural gas consumption as against a decline in biomass over the 1990-2016 horizon. In the same vein, fuel consumption levels among energy categories widely differed over the time series. Fuel consumption in both energy industries and transport increased more than three hundred folds. In the energy industries category, total fuel use leapt from 0.73 Mtoe in 1990 to 3.0 Mtoe in 2016. Relatedly, the transportation category recorded the sharp rise of 390% between 1990-2016 compared to “other sectors”, which fuel consumption fell by 23% (Figure 17).

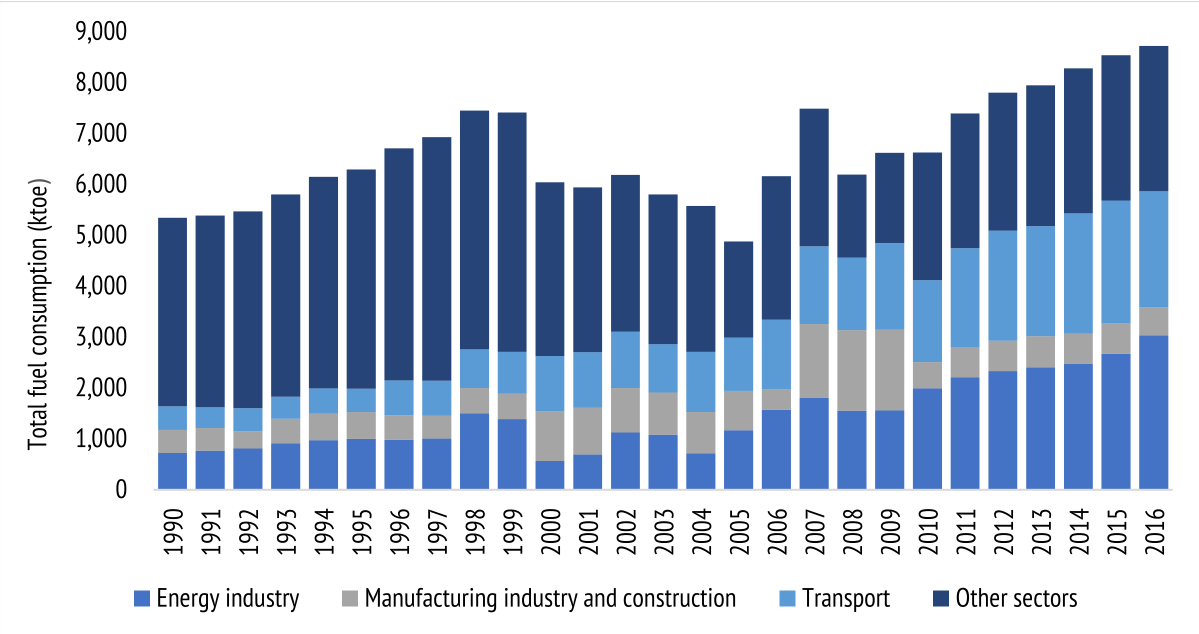


Figure 17: Trends of fuel consumption per energy category

The total secondary fuel consumption for 2016 was 8.72 Mtoe, of which 47% (4.07 Mtoe) constituted liquid fuels. The rests were solid biomass 45% (3.96 Mtoe) and gaseous fuels 8% (0.68 Mtoe) (Table 31). Among the fuels, gaseous fuel recorded the highest growth of 71.4% between 2012 and 2016 because of the increasing natural gas consumption mainly for thermal electricity generation. Likewise, the trend in the consumption of liquid and solid biomass fuels showed a 9% increase and 8% respectively for the same period.

Table 31: Fuel and consumption levels in 1990, 2000, 2012 and 2016 and percentage change between 2012-2016

Fuel Types	1990	2000	2012	2016	% change (2012-2016)
Liquid Fuel (Mtoe)	0.86	1.71	3.74	4.07	9.0%
Gaseous Fuel (Mtoe)	-	-	0.40	0.68	71.4%
Solid Biomass (Mtoe)	4.48	4.33	3.67	3.96	8.0%
Total Fuel (Mtoe)	5.34	6.04	7.80	8.72	11.7%

3.5.1.2 Trends in fuel consumptions by types

3.5.1.2.1 Liquid fuels

Different types of liquid fuels are used in various energy combustion operations. Some of them are the use of gasoline, diesel, kerosene, ATK, LPG, refinery gas, RFO, HFO, DFO in electricity generation, oil refinery, lighting and transport. For instance, in the transportation category, diesel, gasoline and LPG are commonly used in road transport, whereas ATK and diesel are used in domestic aeroplanes as well as inland-navigation by vessels and boats. In Tema oil refinery, the predominant liquid fuels in use are refinery gas and residual fuel oil. In the commercial and residential sectors, the commonly used liquid fuels are kerosene and diesel. Overall, the total liquid fuel consumption stood at 4.07 Mtoe in 2016, which was 8% more than the 2012 levels. As indicated in Table 32, in 2016, most of the fuels were consumed in transport (55.9%) and followed by energy industries (27.5%), manufacturing industry and construction (8.8%) and other sectors (7.8%).

Table 32: Changes in total liquid fuel consumption among source energy sub-categories in Mtoe

Sub-categories	1990	2000	2012	2016	2016 share (%)	% change (2012-2016)
Energy Industries	-	0.18	0.82	1.12	27.5	36.6
Manufacturing Industry and Construction	0.21	0.26	0.41	0.36	8.8	-12.2
Transport	0.46	1.09	2.16	2.28	55.9	5.6
Other sectors	0.19	0.18	0.34	0.32	7.8	-5.9
Total Liquid fuel	0.86	1.71	3.74	4.07	100	8.8

Table 32 further reveals that while liquid fuel consumption in energy industries and the transport was on the rise, that of the manufacturing industry and construction and other sectors dropped. Specifically, liquid fuel consumption in the energy industry recorded the highest rise of 36.9% from 0.82 Mtoe in 2012 to 27.5 Mtoe in 2016. Similarly, transport, which had the largest share, recorded 5.3% increment for the same period. Manufacturing industry and construction showed the highest decrease of 12.2%, with "other sectors" also showing a decrease in fuel consumption by 5.9% within the same period.

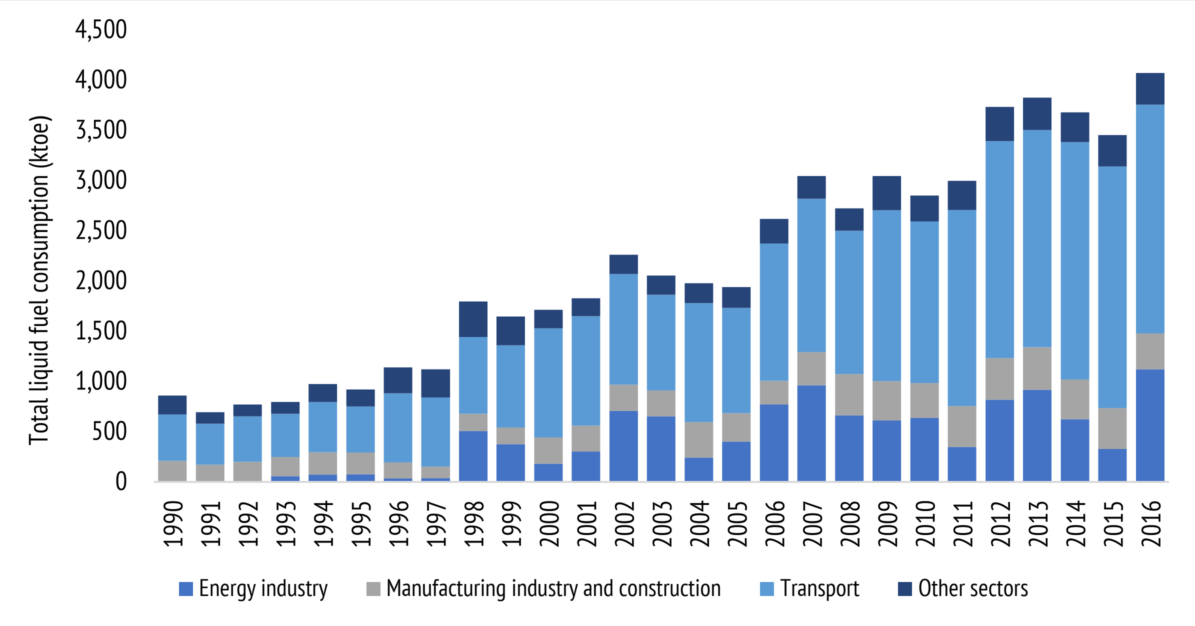


Figure 18: Liquid fuel consumption trends by the categories in the fuel combustion category

In terms of trends, the transportation category had been the dominant consumer of liquid fuel between 1990 and 2016 (Figure 18). Within the category, fuel consumption in road transport. Some of the underlying factors for the high fuel consumption in the road sub-category have been listed below:

- increase vehicle population and its associated traffic congestion in the major cities in the country
- unorganised high-occupancy bus-based transport
- heavy reliance on fossil-based liquid fuels
- inadequate non-motorised transport modes.
- non-existing fuel economy or maintenance standards.

It is also important to recognise the positive effects of the government deregulation policy on petroleum. The policy had contributed to open the downstream petroleum market to allow more private sector participation. Oil Marketing Companies (OMCs) are now more involved in the import and retailing of petroleum products. The deregulation policy had also led to the availability of a range of high-grade fuels in the market, which contributed to the quality of fuels. Railways are the second-largest consumer of liquid fuels. Though the railway system in the country had been operating at the desired level, its freight cargo along the Western corridor was still active. Fuel consumption in domestic aviation was rated as the third consumer of liquid fuels.

The domestic aviation industry in Ghana has seen tremendous growth not just in terms of the number of active airlines operating in the country but more importantly, in terms of passenger uplifts. As of 2012, there were four active airlines in the domestic aviation industry, but this declined to two in 2016. The rest of the liquid fuels were consumed in the inland water-navigation sub-category involving the use of boat and vessel on the inland marine waters and inland freshwater transport. Premix and diesel are the main liquid fuels. The energy industry sub-category includes activities like electricity generation, refining, manufacture of solid fuels (charcoal) and other sectors (diesel and natural gas consumption at oil fields and GNGC). For electricity generation, it involves the use of Light Crude Oil (LCO), diesel, Heavy Fuel Oil (HFO), Distillate Fuel Oil (DFO) in a thermal power plant to produce electricity for the national grid.

In the early 1990s, the majority of the stand-by thermal power plants mostly relied on diesel until 1998 when crude oil-fired plants started kicking-in during the power crises. Since then, crude oil has been the backbone fuel for the thermal power plants. Recently, natural gas, HFO, and DFO fired plants have come online, resulting from the capacity expansion to boost electricity generation. Tema oil refinery is the only oil refinery in the country and consumes refinery gas, petroleum and residual fuel oil in the refinery process.

Overall, energy industries contributed 27.5% to liquid fuel consumption in the energy sector. Liquid fuel consumption in electricity generation made up more than 90% of the energy industry in 2016. The rest was consumed in the oil refinery and other sectors. Liquid fuel consumption in energy industries showed notable increases, 518% between 2000 and 2016 (Figure 18). The sharp rise in the liquid fuel consumption pattern was due to the increasing electricity generation using oil-fired thermal plants. Activities that fall under the "other sector" category are commercial/institutional, residential and agriculture and forestry. It was the third important source of liquid fuel consumption amounting to 7.8% in 2016. The patterns of liquid fuel consumption in "other sectors" showed an increase from 1990 until 2012 when it peaked and started to decline later towards 2016. The increasing use of diesel-fired and gasoline-fired stand-by generators by commercial operators and in households because of the frequent erratic electricity supply from the national grid was the main factor driving fuel consumption in the other sectors.

3.5.1.2.2 Solid fuels

Firewood, charcoal and petroleum coke are main solid fuels. They are used in refining, manufacture of solid fuels, and manufacturing industry and construction and other sectors (commercial and residential). As a by-product of the crude oil refining process, petroleum coke is used to produce heat in multiple industrial operations. Charcoal-making is the only activity in the manufacture of solid fuel sub-category. A fraction of total wood fuel supply is used as raw material input in the charcoal production. Firewood and charcoal fuels are used in the manufacturing industry and construction and other sectors. The solid fuel consumption amounted to 3.96 Mtoe in 2016 with most consumed in the commercial, residential and the manufacture of solid fuels (Table 33).

Table 33: Share of total solid fuel consumption among the energy categories

Sub-categories	1990 [Mtoe]	2000 [Mtoe]	2012 [Mtoe]	2016 [Mtoe]	Share (%) in 2016	% change (2012-2016)
Energy Industries	0.73	0.38	1.12	1.23	30.9%	9.8
Manufacturing Industry and Construction	0.24	0.72	0.18	0.20	5.1%	11.1
Transport	-	-	-	-	0.0%	-
Other sectors	3.51	3.23	2.37	2.54	64.0%	7.2
Total solid biomass fuel	4.48	4.33	3.67	3.96	100.0%	7.9

The "other sector" category accounted for 64% of the total solid fuel consumption. Within the other sector category, firewood was the most common solid fuel in residential and commercial cooking and then by the manufacture and use of the charcoal, which saw marginal increases in the residential sub-category. The second largest consumption of solid biomass was the manufacture of solid fuel (30.9%) involving the transformation of wood fuel to charcoal through the pyrolysis process. The remaining 5.1% of the solid fuel consumption was in the manufacturing industry and construction category. Generally, figure 19 showed that while the solid fuel consumption trend under the energy industry category showed a considerable increase between 2000 and 2016, the "other sector" and manufacturing industry and construction categories showed a decline with the most drop in the latter as a result of the shift to the use of alternative fuels.

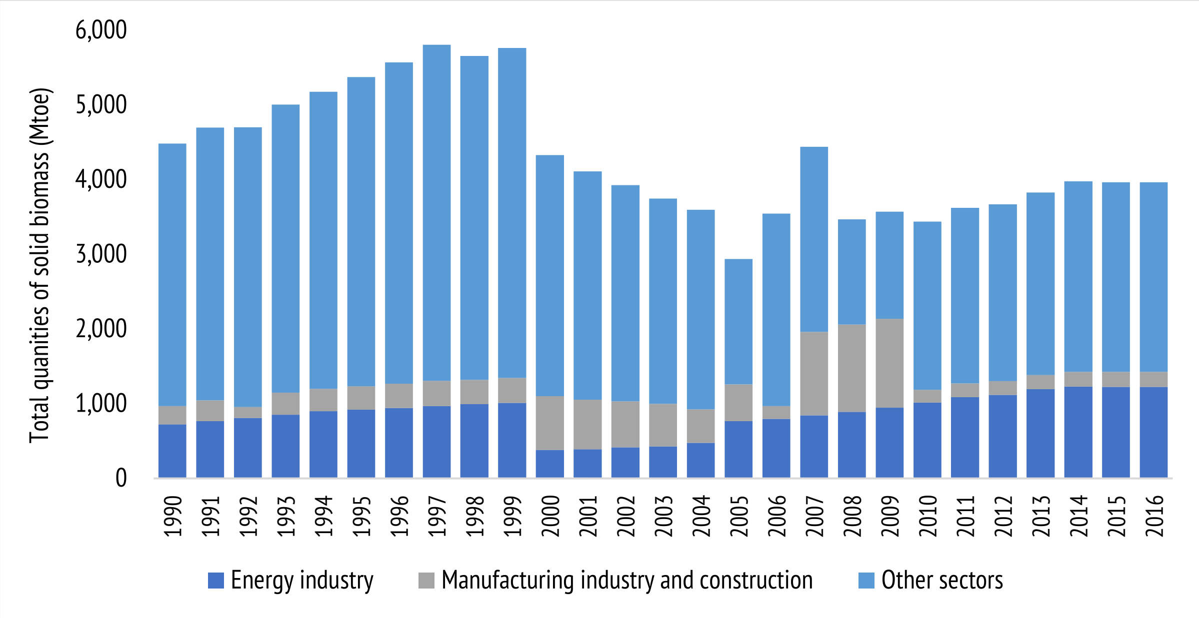


Figure 19: Trends of solid fuel consumption by the categories in the fuel combustion category

Figure 19 also displayed a declining trend of solid biomass consumption of 8.5% from 4.48 Mtoe in 1990 to 3.96 Mtoe in 2016 The reduction in solid biomass consumption was driven by a downward shift in the consumption of firewood in commercial and residential and the manufacturing industry and construction. The observed drop in solid fuels consumption could also be associated with the positive impacts of the increased LPG use through the government LPG promotion programme. Figure 18 also shows an inter-annual fluctuation in solid fuels between 2004 to 2007. The changes in the woodfuel consumption figures, especially in the firewood figures, explains the observed inter-annual variations. Another type of solid in the energy sector is petroleum coke in refining within the energy industry category. All the petroleum coke is consumed in Tema Oil Refinery (TOR) in the crude oil refinery process.

3.5.1.2.3 Gaseous fuels

Natural gas is the single gaseous fuel being used in the energy sector. It is used as fuel in a single-fuel or dual-fuel thermal electricity plant. Natural gas is mainly sourced from a state-run GNGC and Nigeria through the West Africa Gas Pipeline. The Nigeria imports started in 2010 till date as a joint sub-region project. The submarine pipeline crosses Benin, Togo before getting to Ghana. In Ghana, there is an on-shore/off-shore tie-in pipeline to carry the gas for distribution to the individual power plants. After 2012, GNGC commenced operations to produce domestic gas to complement the Nigeria gas imports. The GNGC wet gas is sourced from the Jubilee and Sankofa oil fields.

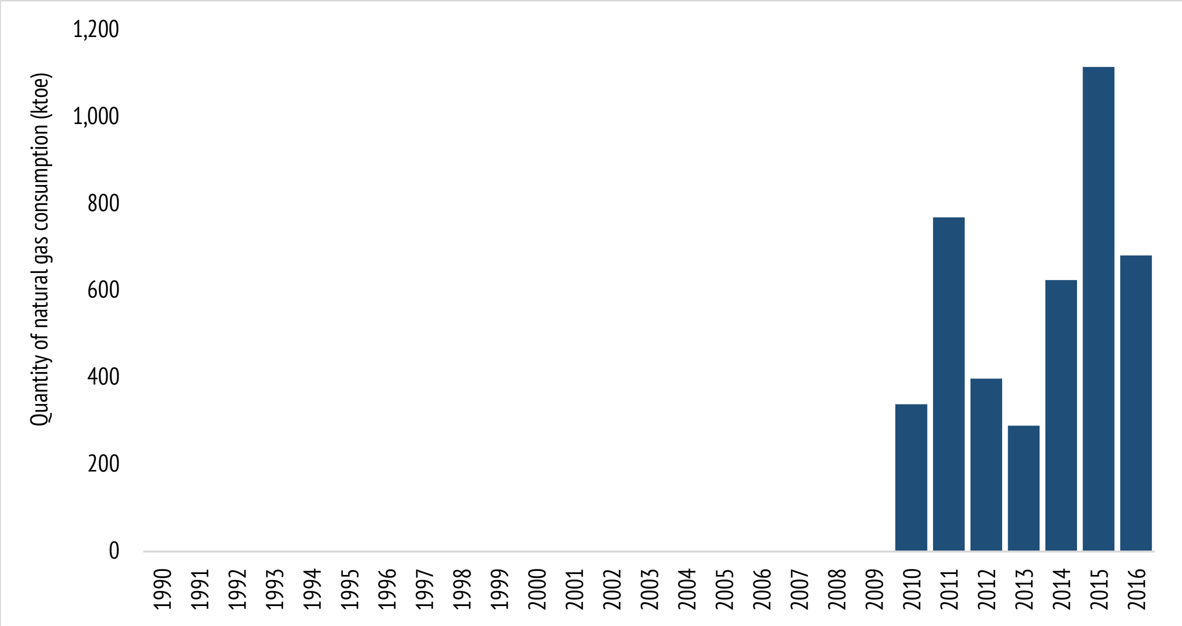


Figure 20: Natural gas consumption trend from 2010 to 2016

The trends of the natural gas consumption exhibited inter-annual variation due to the fluctuations in substituting of crude oil with natural gas for electricity production (Figure 20). The degree of switch depended on the supply of LCO at a competitive price relative to natural gas. In the first year of commercial production in 2010, natural gas consumption hovered around 0.33 Mtoe suggesting a majority coming from Nigeria imports. The reason was that, usually, the new plant had to undergo a test run at the early stage of the commissioning, so not much natural gas may be produced from the new plants. Even if after the test run the transportation pipeline is not ready gas may be not available at the processing plant. In this case, most of the low natural gas consumption in 2010 may be imported from Nigeria. The natural gas consumption peaked at 1.1 Mtoe in 2015 and declined to 0.68 Mtoe in 2016.

3.6 Analysis of energy sector emissions

3.6.1 Overall energy emission trends

The GHG emissions in the energy sector amounted to 15.02 $MtCO_2e$ in 2016, making up 35.6% of the national totals, including FOLU. When the FOLU emissions were excluded from the total national emissions, the emission constituted a lion share of 79% of Ghana's emissions. The energy emissions showed a generally rising trend with a notable peak between 2007 and 2009. The observed jumpy pattern relates to the high CO_2 emissions recorded in the manufacturing industry and construction and the transport sectors (Figure 21). Furthermore, the 2016 energy emissions of 15.02 $MtCO_2e$ is 302.7%, 151.9% and 14.9% higher than the levels reported in 1990, 2000 and 2012, respectively. It is important to note that, not only does the rise in the energy emissions strongly relate to final fuel consumption in the electricity and transport sectors, it also closely follows similar trends with population and GDP growth (ES Table 2). The rising trend among total energy emissions, population and GDP firmly suggest a statistical relationship like Kaya identity components described in Peter, 2017. Kaya identifies CO_2 as the product of population, GDP per capita, energy use per unit of GDP, and carbon emissions per unit of energy consumed. It is used as an indicator of the driving factors of CO2 emissions in the energy sector (https://sustainabilitydictionary.com/2011/03/13/the-kaya-identity access on 17th February 2019.)

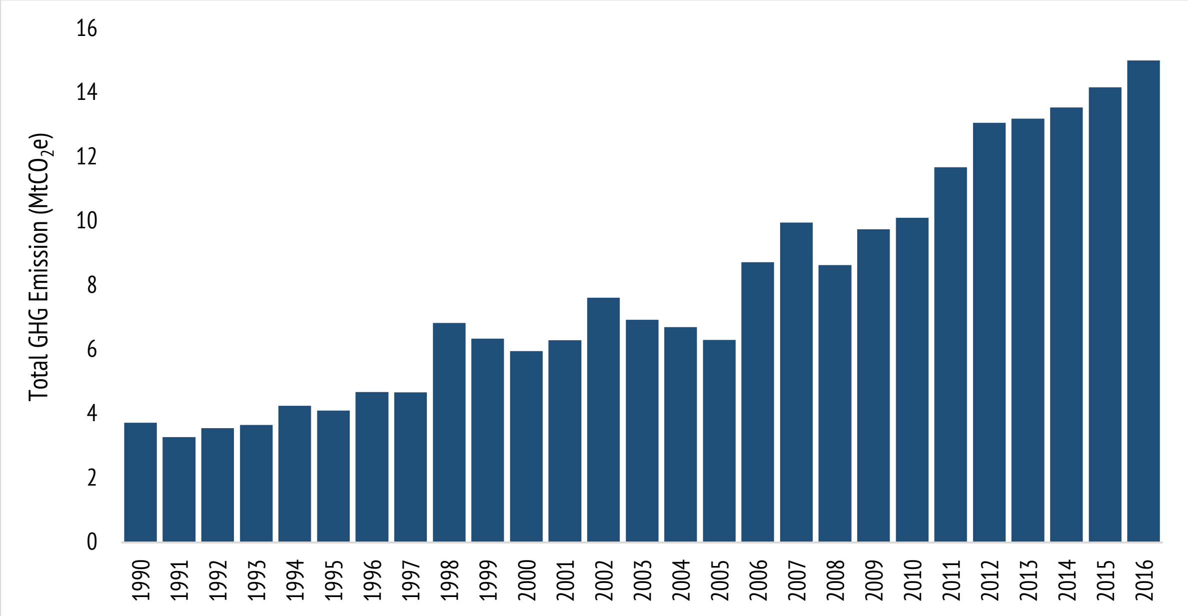


Figure 21: Trends of energy sector trends for 1990-2016

Figure 22 revealed that fuel combustion contributed 99.8% of the total energy emission compared to fugitive emission from fuels that made up the remaining 0.2%. For the fuel combustion emissions of 14.99 $MtCO_2e$, stationery combustion (1A.1, 1A.2 and 1A.3) contributed 52.2% (7.83 $MtCO_2e$) as against 47.8% (71.17 $MtCO_2e$) from the mobile combustion (1A.3). Virtually, all the fugitive emissions from fuels were from venting during oil production as well as through the processing, distribution of natural gas and oil refining even though the emissions were relatively smaller. Figure 22 further depicts the sharp inter-annual variations in the fugitive emission trends throughout the period 1990-2016 primarily due to the sinusoidal trend in the emissions from flaring at the oil refinery.

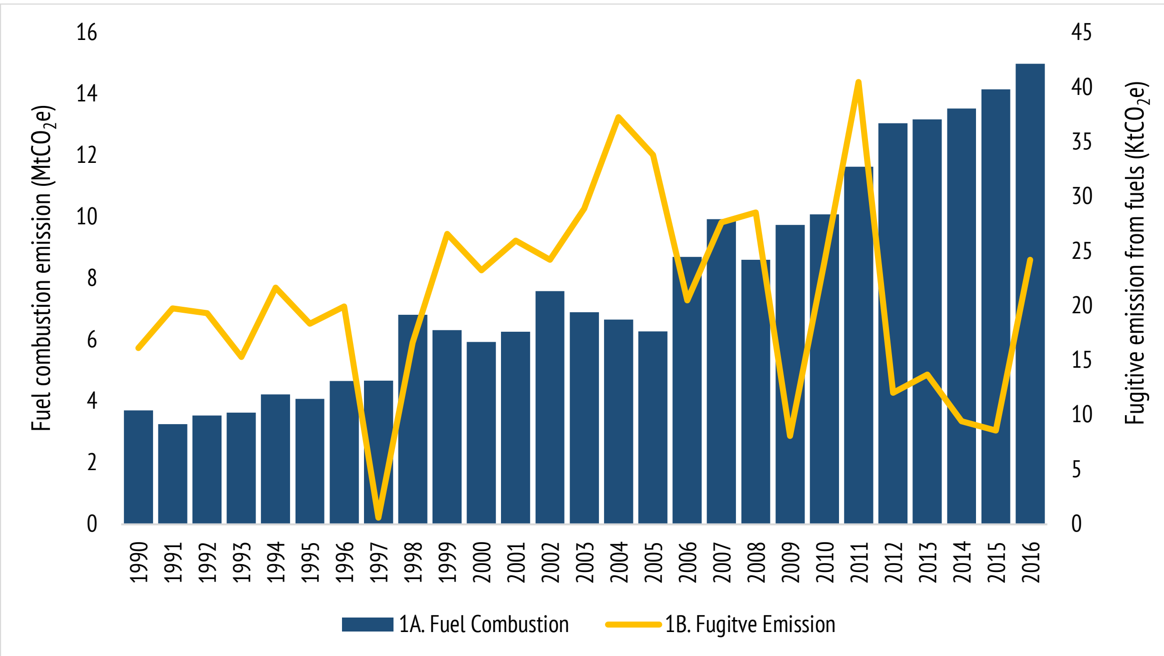


Figure 22: Trends of fuel combustion and fugitive emissions from fuels

Transportation was the largest source of GHG emissions in the energy sector and was trailed by energy industries, other sectors and manufacturing industries and construction and other sectors (Figure 23). The transport sector share of the total energy emissions saw a consistent rise at an average of 45.4% for 1990 and 2016. Likewise, the energy industry's contribution to the total emissions grew remarkably at an average of 18.1% in the same period.

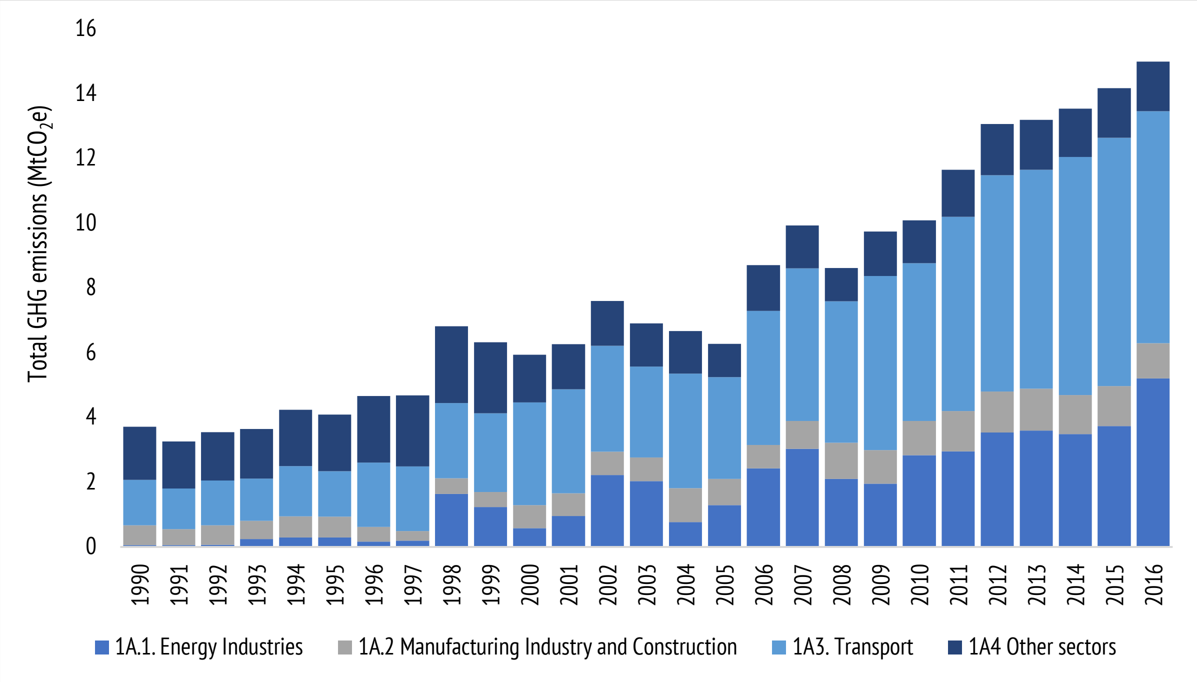


Figure 23: Contributions of fuel combustion activities to Energy Emissions

3.6.2 Energy sector emissions by gases

Carbon dioxide was by far the most dominant GHG in the energy sector. Of the total 2016 emissions of 15.02 $MtCO_2e$, 93.1% (13.97 Mt) was carbon dioxide. The CO_2 emissions composed of 51.2% of the total net CO_2 emissions with FOLU. The rest of the GHG emissions were CH_4 constituting 4.38% (0.66 $MtCO_2e$) and N_20 which made up of 2.56% (0.38 $MtCO_2e$). Both the CO_2 and N_2O gases exhibited upward trends over 1990-2016 (Table 34) with CO_2 recording the fastest growth, whereas CH_4 showed a declining trend. For instance, from 2012 to 2016, while the N_2O and CO_2 emissions grew by 26.5% and 15% respectively, CH_4 only saw a 6.5% rise in the same period.

Table 34: Dominant greenhouse gas emissions trend in the energy sector between 1990-2016

Year	CO_2[Mt]	CH_4 [$MtCO_2e$]	N_2O [$MtCO_2e$]	Total
1990	2.52	0.96	0.25	3.73
1991	2.03	0.99	0.26	3.28
1992	2.29	1.01	0.26	3.56
1993	2.34	1.04	0.28	3.66
1994	2.89	1.08	0.29	4.26
1995	2.69	1.12	0.30	4.10
1996	3.21	1.17	0.31	4.69
1997	3.16	1.20	0.32	4.68
1998	5.33	1.18	0.33	6.84

1999	4.81	1.21	0.33	6.35
2000	4.83	0.87	0.26	5.96
2001	5.22	0.82	0.25	6.29
2002	6.60	0.78	0.24	7.62
2003	5.98	0.73	0.23	6.94
2004	5.76	0.72	0.22	6.70
2005	5.67	0.46	0.18	6.31
2006	7.82	0.67	0.23	8.73
2007	8.98	0.69	0.29	9.96
2008	7.94	0.45	0.25	8.64
2009	9.03	0.45	0.27	9.75
2010	9.29	0.59	0.23	10.12
2011	10.79	0.62	0.27	11.69
2012	12.15	0.62	0.30	13.07
2013	12.24	0.63	0.33	13.20
2014	12.54	0.65	0.36	13.54
2015	13.14	0.65	0.38	14.17
2016	13.97	0.66	0.38	15.02
Change (2012-2016)	15.0%	6.5%	26.5%	14.9%

The increases in CO_2 emissions were driven by emissions associated with road transport and electricity generation, particularly with the growing traffic congestion in the major cities and the high carbon-intensive thermal electricity generation. LPG and kerosene use in the residential sub-categories also contributed to CO_2 emission in the energy sector. Within the energy sector, the dominant use of solid biomass for residential cooking constituted the main source of CH_4 emissions in 2016. The slow increase in the CH_4 emissions can be attributed to the positive influence of the gradual shift to efficient cooking stoves and penetration of LPG use.

3.6.3 Energy sector emission trends by categories

The GHG emissions for “fuel combustion” and “fugitive emissions from fuel” exhibited upward patterns between 1990 and 2016. Fuel combustion emissions generally showed steady growth over the 26-years at average at a rate of 4.9% per annum (Table 35). On the contrary, fugitive emissions from fuels displayed a sinusoidal trend with sharp inter-annual variations. The emissions trends of activities that make up fuel combustion categories showed different patterns because of the growing dependence on oil products in the country and the implementation of the fuel diversification policies. The policies have largely focused on shifting reliance on solid biomass and heavy fuels to relatively cleaner oil products. Although in recent times emissions from energy industries and transport form most of the energy emissions, it is worthy to note that before 1999, manufacturing industry and construction and other sectors dominated.

The thermal electricity diversification policy made energy industries record the fastest GHG emission growth followed by transport, manufacturing industry and construction as well as oil and gas between 1990 and 2016. In the same period emissions from other sectors saw a decline due to the fuel switch policy from solid biomass to LPG for cooking. Flaring and leakages in the upstream and downstream oil and gas operations were the main GHG emission source. Commercial oil production started in 2010 on the Jubilee fields.

Since then, two additional fields, TEN and Sankofa fields, started oil and gas operations in 2014 and 2016 respectively. The main emission sources in the oil and gas production stream are: (a) flaring from oil production at Jubilee and TEN fields, natural gas production at Sankofa fields; (b) natural gas transmission to the Atuabo Gas Processing Plant; (c) natural gas processing and (d) natural gas distribution from Atuabo and Aboadze Thermal Power Plants.

Table 35: Total energy sector emissions grouped into source-categories in $MtCO_2e$

Year	Energy	Fuel Combustion	Energy Industry	Manufacturing Industry & Construction	Transport	Other sectors	Fugitive emissions from fuels	Oil and gas
	1	1A	1A.1	1A.2	1A.3	1A.4	1B	1B.2
1990	3.73	3.71	0.06	0.61	1.41	1.64	0.02	0.02
1991	3.28	3.26	0.06	0.50	1.25	1.46	0.02	0.02
1992	3.56	3.54	0.06	0.61	1.38	1.49	0.02	0.02
1993	3.66	3.64	0.25	0.56	1.31	1.53	0.02	0.02
1994	4.26	4.23	0.30	0.65	1.55	1.74	0.02	0.02
1995	4.10	4.09	0.30	0.63	1.41	1.75	0.02	0.02
1996	4.69	4.67	0.17	0.45	1.99	2.06	0.02	0.02
1997	4.68	4.68	0.19	0.30	1.99	2.19	0.00	0.00
1998	6.84	6.82	1.64	0.49	2.32	2.37	0.02	0.02
1999	6.35	6.33	1.23	0.47	2.42	2.20	0.03	0.03
2000	5.96	5.94	0.58	0.71	3.17	1.47	0.02	0.02
2001	6.29	6.27	0.96	0.70	3.21	1.40	0.03	0.03
2002	7.62	7.60	2.22	0.72	3.27	1.38	0.02	0.02
2003	6.94	6.91	2.04	0.73	2.81	1.34	0.03	0.03
2004	6.70	6.67	0.77	1.05	3.53	1.32	0.04	0.04
2005	6.31	6.28	1.29	0.81	3.15	1.03	0.03	0.03
2006	8.73	8.71	2.43	0.72	4.15	1.41	0.02	0.02
2007	9.96	9.93	3.03	0.86	4.71	1.33	0.03	0.03
2008	8.64	8.61	2.11	1.11	4.37	1.03	0.03	0.03
2009	9.75	9.74	1.96	1.04	5.38	1.37	0.01	0.01
2010	10.12	10.09	2.83	1.06	4.88	1.33	0.02	0.02
2011	11.69	11.65	2.95	1.24	6.00	1.45	0.04	0.04
2012	13.07	13.06	3.54	1.26	6.68	1.58	0.01	0.01
2013	13.20	13.19	3.60	1.29	6.76	1.54	0.01	0.01
2014	13.54	13.53	3.49	1.20	7.36	1.49	0.01	0.01
2015	14.17	14.17	3.73	1.24	7.67	1.53	0.01	0.01
2016	15.02	14.99	5.21	1.09	7.17	1.53	0.02	0.02
Change 2012-2016	14.9%	14.8%	47.2%	-13.9%	7.2%	-3.1%	101.3%	101.3%

3.7 Fuel combustion activities (1.A)

The energy production and consumption operations that involved burning or heating are classified into the fuel combustion category. They have been clustered into the four IPCC sub-categories: (a) energy industries, (b) manufacturing industry, (c) transport and (d) other sectors. Under this section, the NIR reports information on the following areas: comparison of sectoral/reference approach, feedstock/non-energy use, emission trends, the methodology used, completeness, QA/QC and planned improvements.

3.7.1 Carbon dioxides emissions comparison using reference approach and sectoral approach

The Reference Approach (RA) is a top-down approach which uses Ghana's total energy supply data to calculate CO_2 emissions from combustion of mainly liquid and gaseous fuels. The RA does not distinguish between different source categories within the energy sector but only estimates total CO_2 emissions from the fuel combustion (1A) source category. On the other hand, the Sectoral Approach (SA) distinguishes different source categories within the energy sector and estimates the emissions for the respective sources.

The RA and SA often have different results because RA has no detailed information on how the individual fuels were used in each category. Therefore, it is good practice to apply both RA and SA to estimate Ghana's CO_2 emissions from fuel combustion and compare the results of these two independent estimates. Significant differences may indicate possible problems with the activity data, net calorific values, carbon content, excluded carbon calculation. Typically, the gap between the two approaches is relatively small (5% or less) when compared to the total carbon flows involved. Therefore, explanations should be provided when the difference is more than 5%.

3.7.1.1 Comparison of CO_2 emissions in the energy sector

The comparison and the reasons accounting for the differences between CO_2 emissions estimated using RA and SA have been provided below in Table 36. The differences in CO_2 emissions between RA and SA ranges from 0.4% to 4.6%. Generally, estimates for RA CO_2 emissions are higher than SA CO_2 emissions. The following reasons explain the inconsistencies in RA and SA CO_2 emissions: (a) statistical differences among petroleum products and biomass (b) observed variations associated with secondary data used to derive the stock change. Steps are underway to improve fuel allocation formulae in the energy balance and expected to correct some of the identified inconsistencies below.

Table 36: Differences in RA and SA estimates of carbon dioxide emissions

Year	Reference Approach ($MtCO_2$)			Sectoral Approach ($MtCO_2$)			Differences (%)			
	Liquid	Solid	Gaseous	Liquid	Solid	Gaseous	Liquid	Solid	Gaseous	Total
1990	2.61	-	-	2.52	-	-	3.62%	-	-	3.62%
1991	2.10	-	-	2.02	-	-	3.78%	-	-	3.78%
1992	2.38	-	-	2.28	-	-	4.37%	-	-	4.37%
1993	2.38	-	-	2.33	-	-	2.01%	-	-	2.01%
1994	2.88	-	-	2.86	-	-	0.87%	-	-	0.87%
1995	2.72	-	-	2.67	-	-	1.87%	-	-	1.87%
1996	3.40	-	-	3.30	-	-	2.89%	-	-	2.89%
1997	3.35	-	-	3.25	-	-	3.16%	-	-	3.16%
1998	5.51	-	-	5.32	-	-	3.63%	-	-	3.63%
1999	5.08	-	-	4.88	-	-	4.14%	-	-	4.14%
2000	5.10	-	-	4.99	-	-	2.19%	-	-	2.19%
2001	5.65	-	-	5.36	-	-	5.47%	-	-	5.47%
2002	7.01	0.02	-	6.69	0.02	-	4.74%	0.03%	-	4.78%
2003	6.09	0.03	-	6.07	0.03	-	0.40%	0.03%	-	0.44%
2004	6.02	0.03	-	5.81	0.03	-	3.53%	0.03%	-	3.56%
2005	5.72	0.03	-	5.69	0.03	-	0.47%	0.03%	-	0.51%
2006	8.20	0.01	-	7.87	0.01	-	4.22%	0.03%	-	4.25%
2007	9.10	0.04	-	8.92	0.04	-	2.03%	0.03%	-	2.06%
2008	8.10	0.03	-	7.93	0.03	-	2.14%	0.03%	-	2.18%
2009	8.89	0.01	-	8.85	0.01	-	0.49%	0.03%	-	0.52%
2010	8.55	0.02	0.82	8.45	0.02	0.80	1.21%	0.03%	3.56%	4.81%
2011	9.30	0.02	1.81	8.92	0.02	1.81	4.22%	0.03%	0.06%	4.32%
2012	11.36	0.01	0.94	11.16	0.01	0.93	1.77%	0.03%	0.72%	2.52%
2013	11.77	0.01	0.68	11.49	0.01	0.68	2.48%	0.03%	0.82%	3.34%
2014	11.20	0.002	1.49	11.00	0.002	1.47	1.82%	0.03%	1.88%	3.73%
2015	10.36	0.003	2.68	10.30	0.003	2.62	0.56%	0.03%	2.46%	3.06%
2016	12.16	0.02	1.62	12.06	0.02	1.60	0.81%	0.03%	1.04%	1.88%

Some specific explanations on the differences between CO_2 emissions for the major fuels are provided below:

- The national energy balance was based on mass-balanced and not carbon balanced. That approach introduced inherent consistencies in the fuel balance.
- Observed statistical differences in the supply and consumption figures in the energy balance contributed to some of the differences.
- Data on annual stock change for liquid fuels were hardly reported in the energy balance. Therefore, it was derived using production, imports, export, and consumption and ending stocks figures. Because most of the data on stock changes were not reported in the energy balance but calculated, there was a possibility of overestimations or underestimations.
- Kerosene – RA and SA excluded CO_2 emissions from non-energy use of kerosene in the industrial process.

3.7.2 International bunker fuels

The emissions associated with liquid fuels consumption in international bunkers were part of the original inventory estimates. However, the emission has been set aside as a memo item (information note) from the overall inventory results consistent with the IPCC guidelines. International bunkers consisted of the supply and use of jet kerosene and diesel fuels for international aviation and marine bunkers services. In 2016, with a total of 115.68 ktoe used (3.5% of the total liquid fuel consumption), a corresponding total emission of 0.35 $MtCO_2e$ was recorded in the international bunkers (Table 37).

Table 37: Trends of ATK and diesel Consumption and GHG emissions for international bunkers

Year	Total liquid fuel supply	Total Domestic Consumption	International Bunkers					
			Fuel consumption			GHG Emissions		
			Total	Marine Bunkers	Aviation Bunkers	Marine Bunkers	Aviation Bunkers	Total
1990	933.86	911.92	21.94	0.92	21.02	0.003	0.063	0.066
1991	728.87	719.42	9.45	1.06	8.39	0.003	0.025	0.029
1992	982.58	972.94	9.64	1.52	8.12	0.005	0.025	0.029
1993	1,023.23	1,014.47	8.75	0.98	7.77	0.003	0.023	0.027
1994	1,221.93	1,210.41	11.52	1.79	9.73	0.006	0.029	0.035
1995	1,233.23	1,132.53	100.70	1.70	99.00	0.005	0.299	0.304
1996	1,337.75	1,323.38	14.37	1.36	13.01	0.004	0.039	0.044
1997	1,290.43	1,274.53	15.89	0.45	15.44	0.001	0.047	0.048
1998	1,499.51	1,475.52	23.99	0.87	23.12	0.003	0.070	0.073
1999	1,465.03	1,397.82	67.21	49.64	17.57	0.156	0.053	0.209
2000	1,733.18	1,634.76	98.42	0.61	97.81	0.002	0.295	0.297
2001	1,636.95	1,558.99	77.96	1.00	76.96	0.003	0.232	0.235
2002	1,738.43	1,645.52	92.91	1.93	90.98	0.006	0.275	0.281
2003	1,789.01	1,699.27	89.73	3.53	86.20	0.011	0.260	0.271
2004	1,856.41	1,753.07	103.34	1.46	101.88	0.005	0.308	0.312
2005	1,832.44	1,718.06	114.38	1.33	113.05	0.004	0.341	0.345
2006	2,160.06	1,985.35	174.71	66.14	108.57	0.207	0.328	0.535
2007	2,283.37	2,123.02	160.35	45.50	114.85	0.143	0.347	0.489
2008	2,338.94	2,170.97	167.96	58.20	109.76	0.182	0.331	0.514
2009	2,596.08	2,442.44	153.64	39.20	114.44	0.123	0.346	0.468

2010	2,646.47	2,533.16	113.32	14.00	99.32	0.044	0.300	0.344
2011	3,052.97	2,928.97	124.00	-	124.00	0.000	0.374	0.374
2012	3,239.22	3,034.26	204.95	80.81	124.14	0.253	0.375	0.628
2013	4,881.65	4,714.76	166.90	51.75	115.14	0.162	0.348	0.510
2014	3,685.32	3,573.26	112.06	11.10	100.96	0.035	0.305	0.340
2015	3,604.87	3,506.73	98.14	10.30	87.83	0.032	0.265	0.297
2016	3,348.98	3,233.30	115.68	2.42	113.26	0.008	0.342	0.350

Of the total international bunker fuels of 115.68 ktoe, ATK fuel of 113.26 ktoe was allotted to the aviation bunkers whereas 2.42 ktoe of diesel fuel went to the marine bunkers.

3.7.2.1 Methodological issues in international civil aviation and marine transport

3.7.2.1.1 International civil aviation

Generally, GHG emissions from international aviation operations were divided into landing and take-off cycles (LTO) and air operations and cruising. The parts of civil aviation that fell into this class were those that took off from Ghana cruise across borders and landed in another country. So, when a plane fuels ATK in Ghana and takes off from the Kotoka International Airport, cruise for the near number of hours in the international space, and land in Addis Ababa. The flight falls in the category of international bunkers because the COP has not officially adopted the methodology for allocating the GHG emissions that occurred during the cruising phase.

Therefore, GHG emissions from international aviation and marine operations were estimated separately from the national totals consistent with the 2006 guidelines. Due to the lack of access to LTO and fuel use data, tier 1 approach was used. The tier 1 methodology required the total ATK fuel allocation to the international aviation bunkers to estimate the emissions. In this inventory, the GHG emission was estimated using the quantity of ATK sent to the Ghana bunkering services and sales to the airlines and applicable IPCC default emission factors. The Ghana Bunkering Services manage ATK for civil aviation. Total ATK consumption is frequently reported in the energy statistics, but the split between domestic and international aviation was not reported in the energy balance. ATK sale figures to the local airlines were collected from the OMCs. With the data from the OMCs, it was possible to use a bottom-up approach to split the share of international aviation from domestic aviation.

3.7.2.1.2 International marine bunkers

Diesel was the main international marine bunker fuel in the country. Data on diesel supply was obtained from Ghana bunkering services, and diesel export data reported in the national energy balance were used to derive the total diesel consumption for international marine navigation. It was assumed that most of the reported diesel exports sent to the international were meant for the international marine bunkers. The diesel allocated to the international marine bunkers and IPCC default emission factors were used for the emission calculations under this sub-category.

3.7.3 Feedstock and non-energy use of fuels

Fuels used as non-energy and feedstock are not reported in the national energy balance. In the absence of country-specific data on feedstock and non-energy use of fuels, the data was sourced from the International Energy Agency (IEA) and some of the private companies that produce them locally. Some of the feedstock and non-energy use fuels are bitumen, some kerosene, lubricants and other fuels such as tar and grease products that were used in transport, construction and industrial activities. On the average, the yearly consumption of lubricant, bitumen and kerosene is 26.83 ktoe, 5.24 ktoe and 4.22 Mtoe respectively per annum. The following assumptions were made:

- Emissions associated with the manufacture of lubricants, bitumen and kerosene emissions are included in category 1A1.b (petroleum refinery).
- Emissions from the use of motor oil are included in 2.2D (lubricant and solvent use).
- Emissions from the disposal of waste oil are not estimated due to lack of data. The waste oil disposal is considered non-combustible because they are mainly used for wood preservation.
- Emissions from the use of bitumen for road paving and roofing that was not reported because of lack of data.

3.7.4 Time-series consistency

It is good practice to ensure that the methodology used for the emission estimation and the underlying data are as far as possible consistent throughout the time series in all the inventory years. The coherent use of the methods and the data helped to reduce inconsistencies in the estimates as well as voiding overestimations or underestimations. If the method used in the inventory is not consistent throughout bias can be introduced into the emission trends. Therefore, when changes in methods and data or time-series gaps occurred, recalculation was done, and appropriate IPCC methods for resolving data gaps were applied.

3.7.4.1 Energy sector recalculations

In the energy sector, recalculation has been done for the previous estimates for the period 1990 and 2012. The recalculations were done largely because of the inclusion of new emission sources, updates of sector fuels allocation to be consistent with the energy statistics and inclusion of newly available activity data from different national and international sources. The changes that made the largest impact was the revision of fuel consumption share to ensure consistency with the Energy Statistic figures. Detailed descriptions of the reasons for and impacts of recalculations have been provided under each source-specific category. Table 38 shows the results of the impacts of recalculations on the previous estimates.

Table 38: Assessment of the overall impacts of recalculations in the energy sector

Year	CO_2 (Mt)			CH_4 ($MtCO_2e$)			N_2O ($MtCO_2e$)			Total Emissions ($MtCO_2e$)		
	PE	LE	Change	PE	LE	Change	PE	LE	Change	PE	LE	Change
1990	2.60	2.52	-3%	0.72	0.96	33%	0.18	0.25	40%	3.50	4.94	41%
1991	2.23	2.03	-9%	0.59	0.99	68%	0.15	0.26	72%	2.98	4.65	56%
1992	2.44	2.29	-6%	0.62	1.01	64%	0.18	0.26	45%	3.23	4.36	35%
1993	2.57	2.34	-9%	0.63	1.04	66%	0.18	0.28	53%	3.38	5.11	51%
1994	3.26	2.89	-11%	0.63	1.08	72%	0.19	0.29	52%	4.08	5.73	40%
1995	2.99	2.69	-10%	0.68	1.12	65%	0.19	0.30	55%	3.86	5.64	46%
1996	3.76	3.21	-15%	0.72	1.17	62%	0.21	0.31	48%	4.70	6.29	34%
1997	3.50	3.16	-10%	0.75	1.20	60%	0.20	0.32	62%	4.45	6.35	43%
1998	6.38	5.33	-16%	0.72	1.18	63%	0.21	0.33	56%	7.31	8.45	16%
1999	6.03	4.81	-20%	0.74	1.21	63%	0.21	0.33	58%	6.98	8.00	15%
2000	4.76	4.83	2%	0.59	0.87	47%	0.19	0.26	37%	5.54	9.20	66%
2001	5.22	5.22	0%	0.75	0.82	10%	0.23	0.25	9%	6.20	9.30	50%
2002	6.78	6.60	-3%	0.82	0.78	-5%	0.26	0.24	-6%	7.87	10.40	32%
2003	6.41	5.98	-7%	0.88	0.73	-17%	0.27	0.23	-17%	7.57	9.52	26%
2004	5.76	5.76	0%	0.74	0.72	-3%	0.24	0.22	-7%	6.75	8.77	30%

2005	5.77	5.67	-2%	0.88	0.46	-48%	0.28	0.18	-35%	6.93	8.50	23%
2006	7.70	7.82	2%	0.92	0.67	-27%	0.30	0.23	-23%	8.91	9.57	7%
2007	8.96	8.98	0%	1.25	0.69	-45%	0.37	0.29	-21%	10.59	14.90	41%
2008	8.08	7.94	-2%	0.98	0.45	-54%	0.32	0.25	-21%	9.39	13.75	46%
2009	8.94	9.03	1%	1.01	0.45	-56%	0.34	0.27	-19%	10.28	14.95	45%
2010	10.23	9.29	-9%	0.84	0.59	-29%	0.27	0.23	-15%	11.35	10.94	-4%
2011	11.06	10.79	-2%	0.48	0.62	29%	0.21	0.27	29%	11.75	12.54	7%
2012	12.51	12.15	-3%	0.64	0.62	-3%	0.27	0.30	12%	13.42	13.94	4%

NB: PE – Previous estimates, LE- Latest estimates

The recalculation impacts ranged from 66% to 4% compared to the previous estimates. Generally, the impacts on recent estimates were lower relative to the estimates from the past. The recalculations on CO_2 emission showed a similar impact on CO_2 and CH_4 emissions, unlike N_2O, which did not follow any particular pattern. The specific reasons for the recalculations are provided below:

- Inclusion of new activity data on the manufacture of charcoal reported under Manufacture of solid fuel (1A1c) and led to increases in non-CO_2 emissions.
- Revisions in solid biomass (firewood and charcoal) activity data for 2006-2012 under Other sectors (1A4) and resulted in increases in the previous non-CO_2 emissions
- Changes in the activity data on fuel balance due to the revisions in the energy balance. Changes in the total fuel such as diesel, LPG, charcoal, firewood, RFO, gasoline fuels in transport, manufacturing industry and construction, residential and commercial sector to be consistent with the figures reported in the energy statistics.
- Allocation of diesel, RFO, charcoal, firewood and gasoline to new industrial sectors such as iron and steel, mining and quarrying, chemicals, plastics, metal fabrication, cement, ceramic and lime under Manufacture of solid fuel (1A1c).
- Relocation and split of diesel and gasoline fuels 1. A4ciii Fishing, 1. A4cii Off-road vehicle and other machines and 1.A4ciii Fishing.

3.7.4.2 Filling of data gaps in the energy sector

Data gaps identified during the inventory were filled using approved approaches prescribed in the IPCC Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories (IPCC 2000) and fuel balance approaches which have been described in Table 39. The methodology used for each data gap identified depended on the types and nature of data.

Table 39: Overview of data gaps

Category	Gaps	Methodology used	Justification for the methodology used	Description of the approach of filling gaps
Electricity generation (1.A1a)	Lack of time series for diesel data inputs for electricity generation plant	overlap approach	Data gaps in the time series data and where consistent correlation or relationship existed between activity data being used	One category where this approach was used is the energy industries where a relationship was observed between the amounts of power consumed for thermal power generation and the quantum of electricity generated by a specific plant. A ratio was calculated between the amount of diesel consumed by the plant and the power generated for the years with complete data. The average of these calculated ratios was applied to the power generated in the years with the data gap to obtain the quantities of diesel consumption.

Stock changes	Missing stock change data	Fuel balance	Used in years where both National statistics and IEA do not report on the stock change	Stock change calculation involves using figures on balance between production, import against consumption, export, and ending stock.
Road Transport	Missing vehicle population data from1990 and 1995	Trend Extrapolation	The data gap occurred at the beginning of the time series.	Vehicle population between 1990-and 1994 was generated using annual growth of the five years of the period (1995-2000) data reported by DVLA.

3.7.5 Description of source-specific categories in the energy sector

3.7.5.1 Energy industries (1.A1)

Key category (level and trend): (1.A.1ai) Electricity generation CO_2 emissions (liquid fuel)

3.7.5.1.1 Overall emissions and fuel consumption trends in energy industries

In 2016, the total GHG emissions in energy industries were 5.21 $MtCO_2e$ which constituted 32.6% of the total energy sector emissions. Of the total, the proportion of CO_2 emissions was 97.8%, N_2O emission was 1.4% and then by CH_4 having 0.68%. All the individual gases recorded upward trends with CO_2 showing the fastest growth over the 26 years. The latest emission level made up 1.5%, 27.1% and 34.7% of the total fuel combustion emissions in 1990, 2012 and 2016, respectively. Over the 26 years, total GHG emissions considerably increased by 5.2 $MtCO_2e$ at an annual average growth rate of 19.6%. Particularly for 2012-2016, the emissions increased by 47.2% from 3.54 $MtCO_2e$ to 5.21 $MtCO_2e$ (Figure 24). The upward trend in the energy industries emissions was dictated by the increasing use of fossil fuel for thermal electricity generation. Light crude oil was the dominant fuel for electricity generation until 2010 when natural gas became part of the fossil fuels used for electricity generation primarily, due to its cost-effectiveness. More recently, some newly commissioned thermal plants run on heavy and distillate fuel oils.

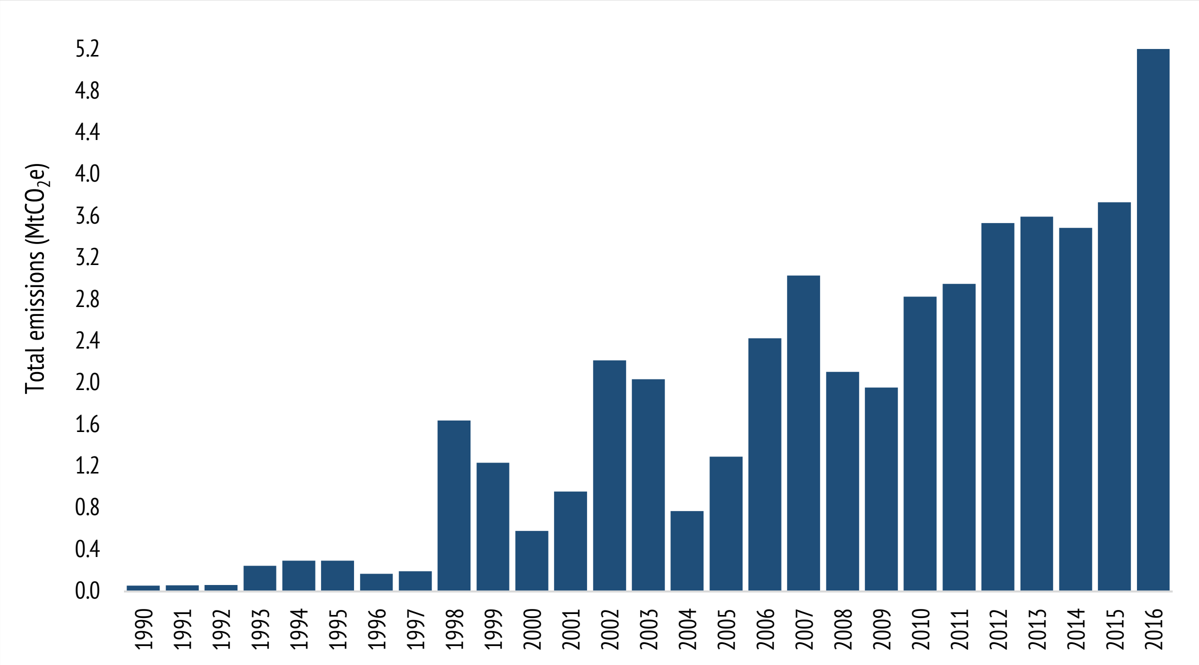


Figure 24: Trends of emissions from the energy industry

Energy industry emissions are primarily from three main sources, and these are: (a) electricity generation, (b) refinery, (c) manufacture of solid fuels (charcoal) and (d) other sectors. In the order of rank, electricity generation is the foremost source since it accounts for the largest share of 93.2% of the total energy industries emissions in 2016. The rest are spread among refineries (4.9%), manufacture of solid fuels (1.9%) and other energy industries (0.05%). Similarly, electricity generation is the largest source (94.9%) of the total CO_2 emissions from energy industries. The rest is shared among oil refining (5.02%) and other energy industries (0.004%) (Figure 25).

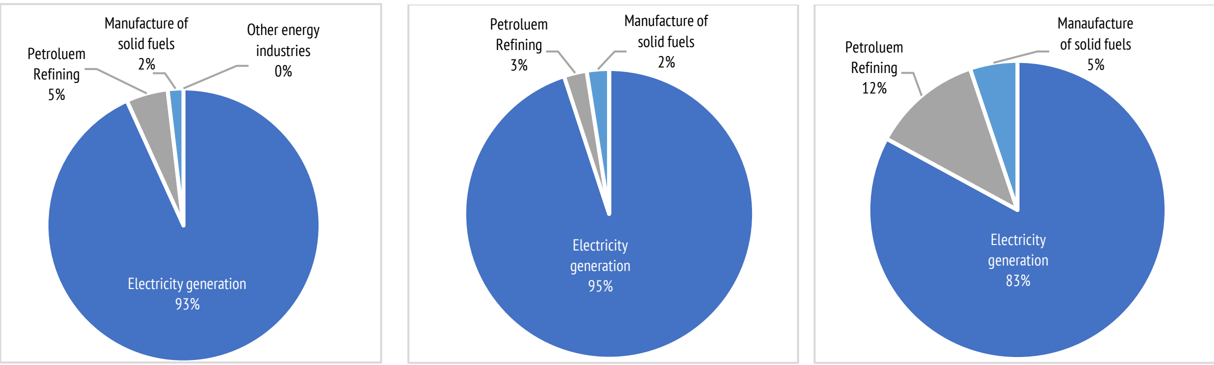


Figure 25: Total greenhouse gas emissions in the energy industry in 2016, 2012 and 2000

The main consuming liquid fuels under this category were light crude oil, heavy fuel oil, distillate fuel oil, refinery gas, residual fuel oil, and diesel. The solid and gaseous fuels included petroleum coke, wood fuel, and natural gas. The total fuel consumption in energy industries amounted to 3,027.17 ktoe in 2016, which is 35.5% of the total use in the energy sector. For 1990-2016, the total fuel consumption more than quadrupled from 726.01 ktoe to 3,027.17 ktoe at 5.9% an annual growth rate. Out of the total, solid fuel accounted for 40.6% then by liquid fuel (36.8%) and gaseous fuels (22.6%) in 2016. All the individual fuel types increased at different rates between 2010 and 2016 with gaseous fuel recording the fastest growth of 101% percentage change.

Overall, the share of solid fuels to the total fuel consumption, declined from 100% to 40.6% for the period 1990-2016, whereas the proportions of liquid and gaseous fuels somewhat increased from 0% in 1990 to 36.8% and 22.6% respectively. The solid fuel was made up of 99.5% (1,219 ktoe of wood fuel) in the manufacture of solid fuel and the remaining 0.5% (5.8k toe of petroleum coke) in a petroleum refinery. The share of the total liquid fuel consumption was 1,109.24 ktoe in the same year from which 55% was crude oil, 32% HFO, 5% DFO and 4% each for RFO and Refinery gas (Figure 26). They are mainly used in electricity generation and petroleum refineries.

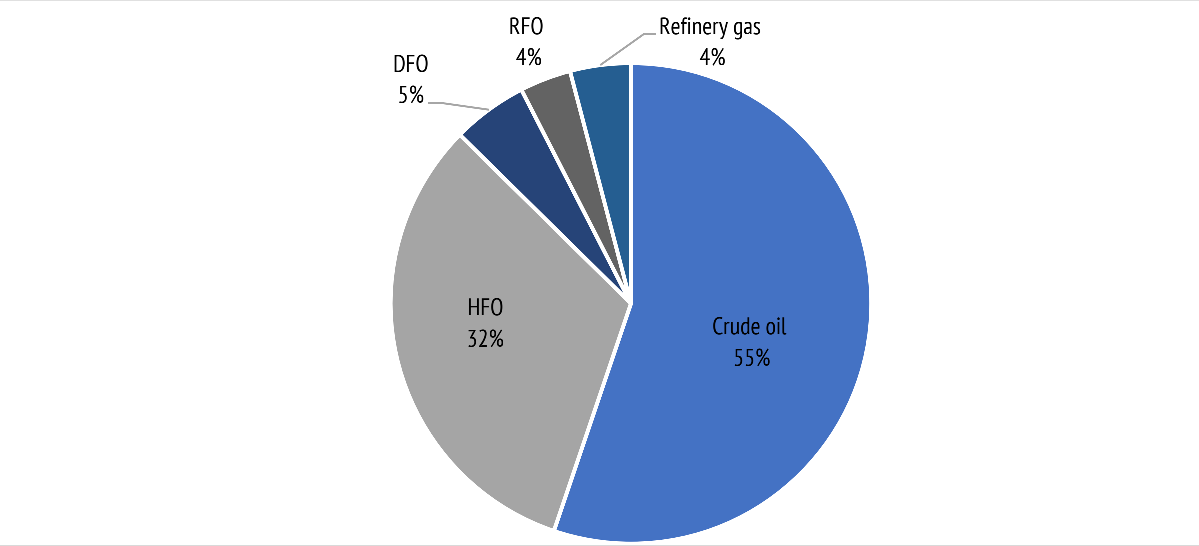


Figure 26: Breakdown of liquid fuels in energy industries for 2016

The gaseous fuel is mainly natural gas consumed in electricity generation and other energy industries. It increased by 71% from 397.36 ktoe in 2012 to 681.13 ktoe in 2016. Of the total 681.13 ktoe consumed in 2016, 98.4% was used in electricity generation and the outstanding 1.6% in other energy industries Table 40.

Table 40: Trends of fuel consumption in the energy industries for 1990-2016

Years	Electricity generation [TJ]						Petroleum Refining [TJ]				Manufacture of solid fuels [TJ]	Other energy industries [TJ_			Liquid fuel	Gaseous fuel	Solid fuel	Total
	Crude oil	HFO	Diesel	DFO	Natural Gas	Sub-total	RFO	Petroleum Coke	Refinery Gas	Sub-total	Wood	Diesel	Natural Gas	Sub-total	[TJ]	[TJ]	[TJ]	TJ
1990	-	-	-	-	-	-	-	-	-	-	30,396.67	-	-	-	-	-	30,396.67	30,396.67
1991	-	-	-	-	-	-	-	-	-	-	32,081.27	-	-	-	-	-	32,081.27	32,081.27
1992	-	-	-	-	-	-	-	-	-	-	33,855.80	-	-	-	-	-	33,855.80	33,855.80
1993	-	-	2,422.90	-	-	2,422.90	-	-	-	-	35,777.04	-	-	-	2,422.90	-	35,777.04	38,199.94
1994	-	-	3,042.97	-	-	3,042.97	-	-	-	-	37,699.29	-	-	-	3,042.97	-	37,699.29	40,742.25
1995	-	-	2,091.73	-	-	2,091.73	323.90	-	777.35	1,101.25	38,659.91	-	-	-	3,192.97	-	38,659.91	41,852.88
1996	-	-	219.81	-	-	219.81	238.42	-	1,041.58	1,280.00	39,547.17	-	-	-	1,499.81	-	39,547.17	41,046.98
1997	208.92	-	1,365.32	-	-	1,574.24	11.01	-	11.19	22.20	40,507.79	-	-	-	1,596.44	-	40,507.79	42,104.23
1998	16,598.65	-	4,040.26	-	-	20,638.91	322.10	-	296.46	618.55	41,542.77	-	-	-	21,257.47	-	41,542.77	62,800.24
1999	14,533.22	-	37.26	-	-	14,570.48	753.30	-	470.15	1,223.45	42,430.04	-	-	-	15,793.93	-	42,430.04	58,223.97
2000	6,529.78	-	15.49	-	-	6,545.27	543.60	-	493.37	1,036.97	15,976.83	-	-	-	7,582.24	-	15,976.83	23,559.07
2001	11,762.99	-	-	-	-	11,762.99	451.89	-	497.72	949.61	16,303.40	-	-	-	12,712.59	-	16,303.40	29,015.99
2002	25,707.35	-	2,512.08	-	-	28,219.43	570.66	189.54	834.77	1,594.96	17,182.63	-	-	-	29,624.86	-	17,372.17	46,997.02
2003	22,531.26	-	2,048.60	51.68	-	24,631.54	562.16	263.64	2,120.88	2,946.67	17,710.16	-	-	-	27,314.57	-	17,973.80	45,288.38
2004	6,978.14	-	-	43.59	-	7,021.73	650.40	312.55	2,426.44	3,389.39	19,644.47	-	-	-	10,098.57	-	19,957.02	30,055.59
2005	13,751.13	-	-	35.77	-	13,786.90	579.79	346.35	2,455.65	3,381.78	31,853.17	-	-	-	16,822.33	-	32,199.53	49,021.86
2006	30,694.69	-	-	33.49	-	30,728.18	343.54	135.98	1,194.24	1,673.76	33,290.08	-	-	-	32,265.96	-	33,426.06	65,692.02
2007	33,139.78	-	3,884.09	239.48	-	37,263.36	520.53	362.11	2,571.08	3,453.71	34,953.08	-	-	-	40,354.96	-	35,315.19	75,670.15
2008	22,358.35	-	2,627.22	51.50	-	25,037.06	601.10	278.26	2,114.79	2,994.15	37,015.50	-	-	-	27,752.96	-	37,293.75	65,046.71
2009	24,715.52	-	-	76.20	-	24,791.72	199.52	87.10	613.06	899.67	39,607.97	-	-	-	25,604.29	-	39,695.07	65,299.36
2010	23,901.60	-	-	665.28	14,186.97	38,753.86	647.84	166.96	1,416.05	2,230.85	42,381.30	-	-	-	26,630.77	14,186.97	42,548.26	83,366.01
2011	11,530.45	-	-	-	31,933.56	43,464.01	538.58	225.48	2,086.28	2,850.34	45,348.07	378.99	251.76	630.74	14,155.30	32,185.32	45,573.55	91,914.17

2012	32,933.79	-	-	-	16,304.24	49,238.02	309.74	89.66	1,003.46	1,402.87	46,707.10	31.00	332.39	363.39	34,247.00	16,636.63	46,796.76	97,680.39
2013	36,597.66	-	-	-	11,823.94	48,421.60	952.95	117.21	873.68	1,943.83	49,977.83	-	285.17	285.17	38,424.28	12,109.11	50,095.04	100,628.42
2014	25,470.82	-	-	64.90	25,820.83	51,356.54	468.80	21.09	174.24	664.14	51,472.52	-	333.96	333.96	26,178.76	26,154.79	51,493.61	103,827.16
2015	12,506.39	553.08	-	40.61	46,344.11	59,444.19	513.95	31.62	136.57	682.14	51,321.79	27.68	332.22	359.90	13,750.60	46,676.33	51,353.42	111,780.35
2016	25,635.16	14,949.04	-	2,356.44	28,072.17	71,012.80	1,604.51	242.68	1,896.44	3,743.63	51,070.59	469.04	445.32	914.36	46,441.58	28,517.49	51,313.26	126,272.34

3.7.5.1.1.1 Electricity generation (1. A1ai)

In Ghana, electricity is mainly produced from hydro and thermal sources to the national electricity grid. Emissions associated with off-grid electricity generation fall under the residential, commercial and manufacturing industry and construction categories. In 2016 a total of 13,022 GWh electricity was generated to the national grid. Out of that, 42.7% was hydro, 57.1% was thermal and the remaining 0.2% and other renewable (solar) sources respectively. In this inventory, the focus is on emissions from combustion of fossil fuel. Emissions from water and sun for the hydro-dam and solar are assumed to be zero. Thermal power plants run on fossil fuels to generate electricity and in the process, produce greenhouse gas emissions. In 2016, 11 publicly and privately-owned thermal plants generated electricity for the national grid using LCO, diesel and natural gas fuels. Out of the 11 power plants, four of them, i.e. (Takoradi Power Company (TAPCO), Takoradi International Company (TICO), Cenit Energy Limited (CEL), and Tema Thermal 1 Power Plant (TT1PP) relied on LCO and natural gas as input fuels. Four of them (i.e. Sunon Asogli Power - Ghana Limited (SAPP), Mines Reserve Plant (MRP), AMERI Plant and Tema Thermal 2 Power Plant (TT2PP) solely run on natural gas. The other two thermal plants, Karpower plant and Kpone Thermal Power Station run on HFO and DFO respectively.

For the period between 1990 and 2016, the share of thermal electricity grew because Ghana's large hydro-dams have been optimally developed and the electricity demand is on the rise which calls for electricity generation from diversified sources. The upturn in thermal electricity led to significant use of LCO, heavy fuel oils and natural gas as fuel for electricity generation. Before 1993, electricity generated into the national grid was 100% hydro. After 1993 diesel-powered generators started kicking in to complement hydro generation. Later, as the electricity demand kept going up and there was the need to find an alternative source to produce electricity, the use of LCO kicked in 1997 with 4.99 ktoe, peaked in 2013 and declined afterwards. The drop LCO due to its high cost and the availability of natural gas. In response to the government's fuel diversification agenda, other fuel alternatives such as natural gas featured from 2010 onwards when dual-fuel and single fuel thermal plants that use natural gas were commissioned (Table 41). At the initial stages, the quantity of natural gas of 338.85 ktoe was supplied from the West Africa Gas Pipeline. Then in 2014, GNGC started to produce domestic lean gas for the Volta River Authority (VRA) thermal plant in the Aboadze power enclave in the Western Region of Ghana.

Table 41: Trends in the fuel mix for the electricity sub-category

Years	Electricity generation					
	Crude oil[ktoe]	HFO [ktoe]	Diesel [ktoe]	DFO [ktoe]	Natural Gas [ktoe)	Total [ktoe]
1990	-	-	-	-	-	-
1991	-	-	-	-	-	-
1992	-	-	-	-	-	-
1993	-	-	57.87	-	-	57.87
1994	-	-	72.68	-	-	72.68
1995	-	-	49.96	-	-	49.96
1996	-	-	5.25	-	-	5.25
1997	4.99	-	32.61	-	-	37.60
1998	396.45	-	96.50	-	-	492.95
1999	347.12	-	0.89	-	-	348.01
2000	155.96	-	0.37	-	-	156.33
2001	280.95	-	-	-	-	280.95
2002	614.01	-	60.00	-	-	674.01
2003	538.15	-	48.93	1.23	-	588.31
2004	166.67	-	-	1.04	-	167.71

2005	328.44	-	-	0.85	-	329.29
2006	733.13	-	-	0.80	-	733.93
2007	791.53	-	92.77	5.72	-	890.02
2008	534.02	-	62.75	1.23	-	598.00
2009	590.32	-	-	1.82	-	592.14
2010	570.88	-	-	15.89	338.85	925.62
2011	275.40	-	-	-	762.72	1,038.12
2012	786.61	-	-	-	389.42	1,176.03
2013	874.12	-	-	-	282.41	1,156.53
2014	608.36	-	-	1.55	616.72	1,226.63
2015	298.71	13.21	-	0.97	1,106.91	1,419.80
2016	612.29	357.05	-	56.28	670.49	1,696.11

After the commissioning of Karpower plant and Kpone Thermal Power Stations in 2016, HFO and DFO were added to the fuel mix for electricity generation. Natural gas had the largest share of 40% (670.69ktoe) of the total electricity generation fuel mix in 2016 and is trailed closely by crude oil (612.29 ktoe), HFO (357.05 ktoe) and DFO (56.28) (Figure 27)

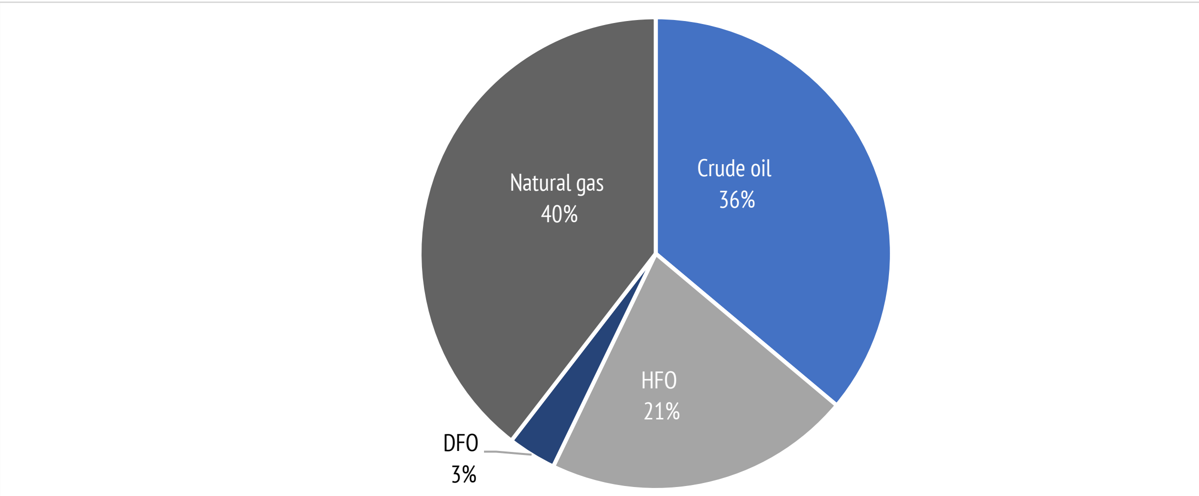


Figure 27: Liquid fuel mix in electricity generation in 2016

The total GHG emissions for the electricity generation was estimated at 4.8 $MtCO_2e$. The emission was 43.7% and 90% higher than the levels reported in 2012 and 2000 respectively. The 2016 emission levels translate into CO_2 intensity of 0.07 $ktCO_2e/GWh$ in 2000 to 0.37$ktCO_2e/GWh$ in the same year. Ever since 1993 thermal electricity kicked in the total emissions had gone up by nearly 500 hundred-fold, from a low of 0.18 $MtCO_2e$ to 4.8 $MtCO_2e$ at 16.1annual growth rate. The upward emission trends tie-in well with the quantities of fuel consumption and the inter-annual variations in the share of the input fuel mix for electricity generation (Table 41). Given the effort to get more natural-gas based fired thermal plants, several initiatives were emplaced to:

- expand indigenous natural gas supply base. So far, natural gas production-consumption has nearly doubled.
- invest in an additional thermal capacity that would have dual-fuel technology capability.
- ensure a reliable supply of natural gas from Nigeria through the West Gas Pipeline and Ghana National Gas Company.
- make improvements in the efficiency of thermal plants through the conversion of single cycles to combined cycles.

These government initiatives are on-going and have started showing positive impacts on GHG emission reduction in the electricity sub-sector.

3.7.5.1.1.2 Petroleum Refinery (1.A1b)

The Tema Oil Refinery operates the only petroleum refining plant in Ghana. The plant is among the first-generation technology refineries in the ECOWAS sub-region. In 2008, a refurbishment work was done through a government programme which added a Residue Fluid Catalytic Cracker (RFCC) to the plant. The installation of the RFCC enabled the refinery to efficiently refine residual fuel oil into products such as LPG, gasoline, light crude oil, heavy fuel oil. Recently, the operations of the refinery have declined mainly due to cash flow problems which have made it less competitive in the deregulated petroleum market as well as the involvement of Bulk Oil Distribution Companies (BDCs) in the imports of refined oil products. Residual fuel oil, petroleum coke and refinery gas are the main fuel sources the refinery derives energy from to support its operations and thus constitute the main source of GHG emissions in the refinery operations. Besides, the transformation process of the crude oil into the various grade petroleum products generate methane as fugitive emissions which have been incorporated under 1.B. The fuel consumption at the refinery has more than tripled from 26.3 ktoe in 1995 to 89.14 ktoe (Table 42).

Table 42: Fuel consumption at the Tema Oil Refinery and associated GHG emissions

Years	Fuel Types [ktoe]				GHG Emissions			
	RFO	Petroleum Coke	Refinery Gas	Total	CO_2 [Mt]	CH_4 [$MtCO_2e$]	N_2O [$MtCO_2e$]	Total [$MtCO_2e$]
1990	-	-	-	-	-	-	-	-
1991	-	-	-	-	-	-	-	-
1992	-	-	-	-	-	-	-	-
1993	-	-	-	-	-	-	-	-
1994	-	-	-	-	-	-	-	-
1995	7.736	-	18.567	26.303	0.07	0.00004	0.00008	0.06908
1996	5.695	-	24.878	30.572	0.08	0.00004	0.00008	0.07791
1997	0.263	-	0.267	0.530	0.00	0.00000	0.00000	0.00147
1998	7.693	-	7.081	14.774	0.04	0.00003	0.00007	0.04122
1999	17.992	-	11.229	29.222	0.08	0.00006	0.00015	0.08353
2000	12.984	-	11.784	24.768	0.07	0.00004	0.00011	0.06916
2001	10.793	-	11.888	22.681	0.06	0.00004	0.00010	0.06254
2002	13.630	4.527	19.938	38.095	0.11	0.00006	0.00016	0.10940
2003	13.427	6.297	50.656	70.380	0.19	0.00010	0.00022	0.19015
2004	15.534	7.465	57.955	80.954	0.22	0.00011	0.00025	0.21916
2005	13.848	8.272	58.652	80.773	0.22	0.00011	0.00024	0.21886
2006	8.205	3.248	28.524	39.977	0.11	0.00005	0.00012	0.10788
2007	12.433	8.649	61.409	82.491	0.22	0.00011	0.00024	0.22261
2008	14.357	6.646	50.511	71.514	0.19	0.00010	0.00023	0.19415
2009	4.765	2.080	14.643	21.488	0.06	0.00003	0.00007	0.05880
2010	15.473	3.988	33.822	53.283	0.15	0.00008	0.00019	0.14648
2011	12.864	5.386	49.830	68.079	0.18	0.00009	0.00020	0.18266

2012	7.398	2.141	23.967	33.507	0.09	0.00005	0.00010	0.08982
2013	22.761	2.799	20.867	46.428	0.13	0.00008	0.00022	0.13321
2014	11.197	0.504	4.162	15.863	0.05	0.00003	0.00009	0.04722
2015	12.276	0.755	3.262	16.293	0.05	0.00004	0.00010	0.04946
2016	38.323	5.796	45.296	89.415	0.25	0.00015	0.00039	0.25324

Total emissions from refinery operations were 0.25 $MtCO_2e$ in 2016 and represented 4.9% of the overall energy industry emissions. Carbon dioxide contributes 99.7% of the total emissions and then by methane (0.2%) and nitrous oxide (0.1%). As fuel consumption increased, the consequent GHG emissions showed a rising trend. For instance, between 2012 and 2016, the operations at the refinery were invigorated, resulting in the increases in fuel consumption by 167% and emissions by 182% (Table 42). Although total GHG emissions from the refinery showed an increasing trend except in cases where the refinery's operations declined, and the emissions reduced accordingly. The increases in emissions were because of the retrofitting of the refinery in 2008 to expand its capacity, which led to optimising refinery operations. However, after 2008, the decline in the emissions was mainly due to the decreases in the level of operations of the refinery. In 1997, the refinery shut down for scheduled maintenance, and that resulted in particularly low emissions and fuel consumption in the refinery. As a result, more secondary fuels were imported to make up for the deficit in the refinery supply.

3.7.5.1.1.3 Manufacture of solid fuels (1.A1ci)

The manufacture of solid fuels is a new addition under the energy industry category. The GHG estimates of charcoal production depend on carbonisation technology. In Ghana, the majority (99%) of the fraction of wood fuel converted to charcoal was considered as non-renewable. There were reasons for this assumption. Firstly, most of the wood used as feedstock were from unsustainable sources. Secondly, the efficiency of the carbonisation process (mainly earth moulds) hovers around 25% yield. The total GHG emissions associated with charcoal-making in 2016 stood at 0.1 $MtCO_2e$, which consisted of 1.9% of the energy industry emissions. The trend indicates an increase of 68% between 1990 and 2016 at a 2.1% rate per annum (Table 43). Notably, for 2012 and 2016, the emission grew marginally by 2.2%.

Table 43: Trend of wood fuel input for charcoal-making and related GHG emissions

Years	Fuel type [ktoe)	Total GHG emission ($MtCO_2e$]		
	Wood fuel	CH_4	N_2O	Total
1990	726.01	0.019	0.038	0.057
1991	766.25	0.020	0.040	0.060
1992	808.63	0.021	0.042	0.063
1993	854.52	0.023	0.044	0.067
1994	900.43	0.024	0.047	0.070
1995	923.38	0.024	0.048	0.072
1996	944.57	0.025	0.049	0.074
1997	967.51	0.026	0.050	0.076
1998	992.23	0.026	0.052	0.078
1999	1,013.42	0.027	0.053	0.079
2000	381.60	0.010	0.020	0.030
2001	389.40	0.010	0.020	0.030

2002	410.40	0.011	0.021	0.032
2003	423.00	0.011	0.022	0.033
2004	469.20	0.012	0.024	0.037
2005	760.80	0.020	0.039	0.060
2006	795.12	0.021	0.041	0.062
2007	834.84	0.022	0.043	0.065
2008	884.10	0.023	0.046	0.069
2009	946.02	0.025	0.049	0.074
2010	1,012.26	0.027	0.053	0.079
2011	1,083.12	0.029	0.056	0.085
2012	1,115.58	0.029	0.058	0.087
2013	1,193.70	0.031	0.062	0.093
2014	1,229.40	0.032	0.064	0.096
2015	1,225.80	0.032	0.064	0.096
2016	1,219.80	0.032	0.063	0.096

The slow growth in the emissions in recent times was a probable indication of the impacts of a possible decline in charcoal demand for household cooking because of numerous government programmes aimed at lowering the use of charcoal.

3.7.5.1.1.4 Other energy industries (1. A1cii)

Another new addition is the consumption of diesel and natural gas on the oil rigs and the GNGC's processing plant since 2011 when oil production started at a commercial scale. Total fuel used on the oil rigs and the gas processing plant was 21.84 ktoe, which are mainly diesel and natural gas (Table 44). The total fuel consumption had increased by 45% since 2011.

Table 44: Fuel consumption and GHG emissions under other energy industries

Years	Fuel Consumption (ktoe)			GHG Emissions			
	Diesel	Natural gas	Total	CO_2 [Gg]	CH_4 [$GgCO_2e$]	N_2O [$GgCO_2e$]	Total [$GgCO_2e$]
2011	9.05	6.01	15.07	42.21	0.03	0.08	42.32
2012	0.74	7.94	8.68	20.94	0.01	0.02	20.97
2013	NE	6.81	6.81	16.00	0.01	0.01	16.01
2014	NE	7.98	7.98	18.73	0.01	0.01	18.75
2015	0.66	7.93	8.60	20.69	0.01	0.02	20.71
2016	11.20	10.64	21.84	59.74	0.04	0.10	59.88

The total emissions have seen corresponding increases as fuel use goes up. It increased by 41.5% for the same period from 42.32 $GgCO_2e$ in 2011 to 59.88 $GgCO_2e$ in 2016. Carbon dioxide made up 99.8% of the total 2016 emissions and rest 0.2% were split among CH_4 (0.0031%) and N_2O (0.0005%).

3.7.5.1.2 Energy industries methodological issues

Generally, the emissions from the energy industries category were estimated using the Tier 1 approach and IPCC default emission factor. Table 45 shows the overview of methods and emission factors used in the GHG estimation.

Table 45: Overview of methods used for greenhouse gas estimation and emission factors

Categories	CO_2		CH_4		N_2O	
	Method Used	Emission Factor	Method Used	Emission Factor	Method Used	Emission Factor
1A1a Electricity generation	T1	DF	T1	DF	T1	DF
1A1b Petroleum Refining	T1	DF	T1	DF	T1	DF
Manufacture of solid fuels (1.A1ci)	T1	DF	T1	DF	T1	DF
Other energy industries (1.A1cii)	T1	DF	T1	DF	T1	DF

Note: T1 = Tier 1, DF = IPCC Default Factors

Methodology for estimating emissions from electricity generation

Electricity generation is electrical power generated by publicly-owned and Independent Power Producers (IPPs) and evacuated to the existing national grid. Fuel (diesel, LPG and gasoline, biofuel) used for off-grid electricity generating systems in homes, commercial and industrial sites and the associated emissions have been accounted for under categories 1.A.4 Other Sectors and 1.A.2 Manufacturing Industries and Construction. The main fuels in grid-connected thermal power stations were imported from the international markets until recently when GNGC started to produce domestic natural gas for the Aboadze thermal power plant managed by VRA. In essence, apart from the parts of the natural gas produced by Ghana Gas, all the rest of the fuels electricity generated are imported.

The quantity of LCO, natural gas, diesel, DFO, and HFO consumption figures and electricity production reported by the individual power plants in the national energy statistics were used. Since the inventory was not compiled at the individual thermal power station located mainly on the east and west coast of the country, fuel consumption and the corresponding electricity production has been aggregated. Therefore, the sum of LCO, natural gas, and diesel consumption in each power plant in a particular year was calculated to give the total consumption of each fuel type in the year. The diesel consumption in the power generation was excluded from the total diesel supply used in transportation, industry and other sectors to avoid double counting. The activity data for electricity generation were obtained from electricity generation companies (private and public) and the Energy Commission. The collected data were evaluated to ensure internal consistency. The emission factors used for each fuel and a specific compound was obtained from the IPCC EFDB. This approach was opted for because there was no country-specific emission factor for the power plant as desired.

The use of country-specific factors would be useful particularly for non-CO_2 GHG emissions since their levels are influenced by the type of technology in use and the operations of the plant, unlike CO_2 which is largely dependent on the carbon content of the fuel in use. Since the electricity generation contributed most to the energy total emissions, there are plans to carry out a study on the thermal power stations across the country to enhance the transparency of the estimation.

Methodology for estimating emissions from petroleum refining

Crude oil is used as feedstock or as refinery input and is transformed into petroleum products during the refinery process. The transformation of the crude oil was not considered in the combustion-related estimations of the refinery emissions because it does not lead to fuel combustion emissions. The portion of the crude oil lost through the transformation process as fugitive emissions were considered separately under fugitive emissions from fuels. In the refinery, fuel is burnt to generate heat/steam to support the running of the production process. The only refinery in Ghana, Tema Oil Refinery uses the following fuels in their operations: refinery gas, petroleum coke, and RFO. The estimation of the emissions from the refinery was based on the amounts of the fuels used in the refinery per year and the specific emission factor for each gas. The activity data were obtained from Tema Oil Refinery's energy balance and the national energy statistics, which covered the 1990-2016 time-series.

Methodology for estimating emissions from Manufacture of solid fuels

Combustion emissions from fuel use during the manufacture of secondary and tertiary products from solid fuels include the production of charcoal. In Ghana, the dominant charcoal production technologies are kiln and the earth mound. Majority of the informal charcoal producers use inefficient earth mounds to carbonise woodfuel into charcoal for consumption within Ghana. Formal charcoal producers mainly use wood off-cuts from sawmills as feedstock in kiln carbonisation for export to the offshore market. The emissions from the manufacture of charcoal are calculated using the fraction of total woodfuel supply published in the energy statistics by the Energy Commission. The fraction of woodfuel supply as input into charcoal production ranged from 30.5% in 1990 to 56.4%. Expert judgement was used to estimate the percentage of woodfuel supply as charcoal production feedstock. Then, the estimated percentage was then multiplied by the total woodfuel supply figures to derive the fraction of woodfuel as charcoal production feedstock. The dominant earth-mound charcoal production technology has estimated 25% efficiency. It was not possible to split woodfuel inputs as into those processed with earth mound and efficient kilns. So, all the woodfuel feedstock have been allocated to the earth mound technology. Besides, the IPCC EFDB do not provide specific factors applicable to the kind of kiln used in Ghana. Even if the type of carbonisation technology separated the activity, it would not be possible to get suitable IPCC methods to use.

Methodology for estimating emissions from Other energy industries

Under this category, emissions from own on-site fuel use have been estimated for the Jubilee and TEN oil fields and the Atuabo gas processing plant. The diesel and natural gas consumption on the oil rigs and the gas process plant were obtained from the Ghana Petroleum Commission and the Ghana National Gas Company. Both report monthly fuel consumption for the oil field and gas plant. After receiving the activity data, the monthly averages summed for each oil field before adding up to obtain the total fuel consumption per year.

3.7.5.1.3 Source-specific recalculations in Energy industries (1. A1)

Recalculations were done for the emission estimates from 1990 to 2012 due to the inclusion of new and revision of existing activity data and have led to changes in CO_2, CH_4 and N_2O emissions for the period the recalculation was applied. Specifically, the following revisions have been introduced: (a) changes in fuel consumption figures for selected thermal plants to be consistent with the energy statistics from 2010 to 2012, (b) subtracted fraction of total woodfuel supply from 1990-2012 included as activity data on manufacture of solid fuel, (c) inclusion of new figures on diesel and natural gas consumption from two oil rigs for 2011 and 2012. Table 46 presents the recalculation results and its impacts on the emissions.

Table 46: Energy industry recalculations and impacts on the previous emissions

Years	CO_2			CH_4			N_2O		
	PE (Gg)	LE(Gg)	% Change	PE (Gg)	LE(Gg)	% Change	PE (Gg)	LE(Gg)	% Change
1990	73.03	-	-100.00	0.002	0.912	45495.01	0.0002	0.1216	60693.34
1991	96.53	-	-100.00	0.002	0.962	48021.91	0.0004	0.1283	31981.27
1992	79.75	-	-100.00	0.002	1.016	50683.71	0.0003	0.1354	45041.07
1993	242.56	179.54	-25.98	0.009	1.081	11906.44	0.0017	0.1446	8403.64
1994	310.64	225.48	-27.41	0.011	1.140	10264.61	0.0021	0.1526	7167.76
1995	222.86	223.96	0.49	0.008	1.168	14497.34	0.0015	0.1562	10310.66
1996	92.54	94.08	1.67	0.002	1.189	59340.31	0.0004	0.1586	39540.68
1997	117.94	117.95	0.01	0.005	1.220	24299.99	0.001	0.1630	16198.32
1998	1556.85	1557.19	0.02	0.063	1.309	1978.46	0.0126	0.1788	1318.81
1999	1150.93	1151.37	0.04	0.046	1.319	2767.96	0.0092	0.1789	1845.06
2000	548.22	548.79	0.10	0.022	0.501	2177.31	0.0043	0.0682	1486.01
2001	924.03	924.64	0.07	0.037	0.526	1322.15	0.0074	0.0726	880.85
2002	2190.35	2179.66	-0.49	0.088	0.603	585.45	0.0175	0.0862	392.51
2003	2005.82	1997.01	-0.44	0.079	0.610	671.82	0.0155	0.0863	456.87
2004	729.24	733.53	0.59	0.026	0.616	2267.87	0.005	0.0836	1571.95
2005	1225.6	1229.11	0.29	0.046	1.002	2078.54	0.0091	0.1365	1399.71
2006	2456.64	2360.10	-3.93	0.099	1.093	1004.53	0.0196	0.1520	675.50
2007	3071.05	2956.97	-3.71	0.122	1.166	857.83	0.0241	0.1629	576.48
2008	2215.78	2031.18	-8.33	0.087	1.190	1261.77	0.0173	0.1638	848.23
2009	1775.09	1876.00	5.68	0.072	1.264	1662.86	0.0143	0.1735	1115.12
2010	3220.91	2743.39	-14.83	0.110	1.363	1135.05	0.0204	0.1863	811.07
2011	2991.82	2819.02	-5.78	0.073	1.431	1849.30	0.0109	0.1922	1656.76
2012	3264.20	3418.38	4.72	0.111	1.518	1271.14	0.0204	0.2086	922.13

Reasons for the recalculations

- **Natural Gas** - Revision of activity data to be consistent with national energy statistics - Inclusion of natural gas for electricity generation from 2010 onwards. Added 338.85 ktoe, 762.71 ktoe and 389.42 ktoe of natural gas to 2010, 2011 and 2012 figures respectively.
- **Crude Oil** - Revision of activity data to be consistent with national energy statistics – Revision of crude oil data for electricity generation in the inventory period, including 2010, 2011 and 2012.
- **Diesel** - Removed diesel consumption for electricity generation from 2009 to 2012. Changed diesel input for electricity generation to 92.77 ktoe and 62.75 ktoe in 2007 and 2008 respectively due to the availability of new data.
- **Refinery Fuel Oil** - Removal of RFO consumption data from the emission estimation from 1990-1994 due to the discovery of new RFO dataset from Tema Oil Refinery. Revision of RFO consumption data from 1995 – 2012. due to the availability of new dataset from Tema Oil Refinery.
- **Refinery Gas** - Removed RFO consumption data from 1990-1994 due to new RFO dataset from the refinery. Changed RFO data from 1995 – 2012 due to new dataset from the Oil Refinery.
- **Petroleum Coke** - Included data for Petroleum Coke data for 2002-2012 due to the discovery of new data from the refinery.
- **Woodfuel** - Inclusion of new dataset on the manufacture of charcoal.

3.7.5.2 Manufacturing industry and construction (1.A2)

Key category (level and trend) – CO_2 emissions

3.7.5.2.1 Emissions and fuel consumption patterns in manufacturing industries and construction

Combustion emissions from energy use in the manufacturing industry and construction were covered under this category. It included nine industrial sectors are:

- Iron and steel
- Chemicals
- Pulp, Paper and Print
- Food processing and Beverage
- Tobacco
- Mining and Quarrying
- Wood and Wood Products
- Construction, Textile and Leather
- Non-specified industries

The emissions are those from boilers and other heating operations. Emissions that are generated from electricity use from the national grid, standby generators and "industrial processes" are accounted for under 1.A1a (Electricity generation), 1.A4a (Commercial/Institutional) and specific categories under industrial process and solvent use respectively. The fuel types typically used in the manufacturing industry and constructions are diesel, RFO and some wood, charcoal, LPG and gasoline (Figure 28). The total fuel consumption in this category was 561.2 ktoe in 2016 and constituted 6.4% of the overall energy sector fuel consumption. Mining and quarrying and food and beverage consume 75% of the total fuel in this category. In 2015, the mining sector consumed most of the diesel fuel of 223.93 ktoe and some amounts of gasoline (0.01 ktoe). Food and beverage consume the most variety of fuels (diesel, RFO, LPG, wood and charcoal) because of the diverse nature of the operations.

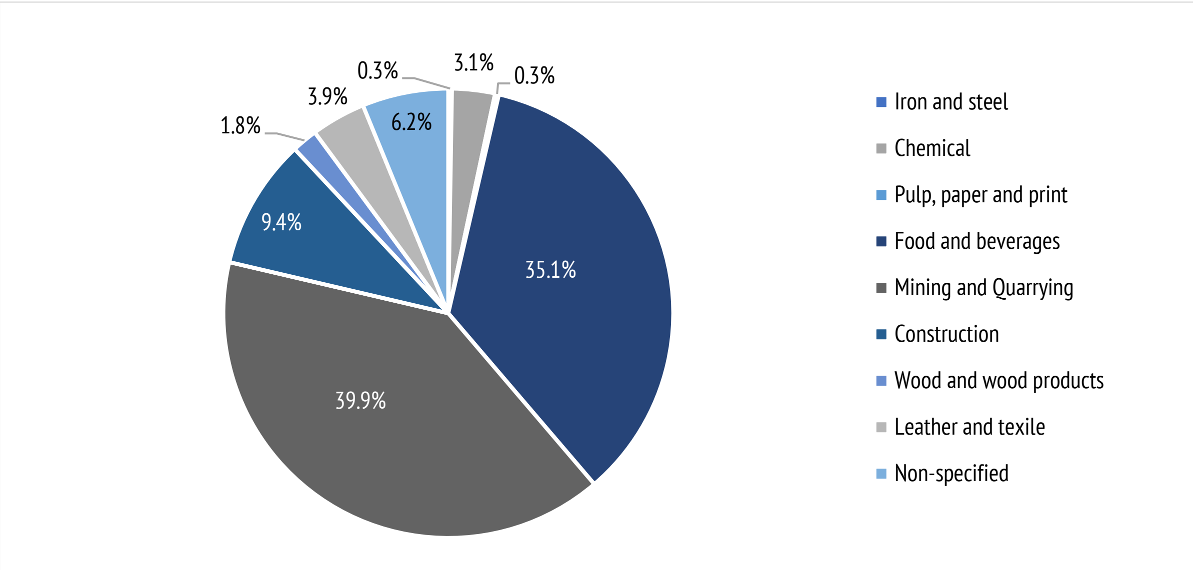


Figure 28: Share of fuel consumption among manufacturing sectors in 2016

Since 2010, the liquid fuel has consistently made up 65.1% of the total fuel consumption of which diesel fuels constitute 80% on an average followed by RFO consumption with a 19% share of the total liquid fuels and then by LPG and gasoline. The trend showed the importance of diesel and RFO in driving the manufacturing sector emissions, the reason being that diesel and RFO are two dominant primary fuels that most of the manufacturing industries use in their boiler and furnace operations. The remaining 34.9% of the total fuel consumption are solid fuels consisting of woodfuel and charcoal.

Most of the solid biomass is used in the food and beverage industries for heating and cooking. The 2016 total fuel consumption levels of 561.2 ktoe were 24.5% more than over the 1990 level and 5.8 decrease over the 2012 fuel consumption level. Although the total fuel consumption has risen, not all the individual fuels increased in tandem per sub-category. While there was an upward trend in total fuel consumptions between 1990 and 2016, iron and steel (101.6%), mining and quarrying (215.5%), construction (169.8%), wood and wood product (187.7%), some key manufacturing sectors recorded a decline by 19.6% (chemical), 52% (pulp, paper and print), 23.2% (food and beverages), 34% (leather and textile) and 15.5% (non-specified) in the same period (Table 47).

Table 47: Fuel consumption among sectors under the manufacturing industry and construction from 1990 to 2016

Year	Iron & Steel		Chemicals			Pulp, Paper & Print		Food & Beverages					Mining & Quarrying		Construction	Wood & Wood Products	Leather & Textile			Non-specified			
	Diesel	RFO	Diesel	RFO	Wood	Diesel	LPG	Diesel	LPG	RFO	Wood	Charcoal	Diesel	Gasoline	Diesel	Diesel	Diesel	RFO	Wood	Diesel	RFO	LPG	Wood
1990	0.41	0.32	0.55	1.47	19.51	0.16	3.05	5.73	9.68	41.08	197.55	2.87	70.99	-	19.51	3.61	0.15	11.28	21.88	3.68	8.76	9.66	18.95
1991	0.40	0.23	0.54	1.08	22.34	0.15	-	5.62	-	30.22	226.20	3.19	69.63	-	19.14	3.54	0.14	8.30	25.05	3.61	6.45	-	21.70
1992	0.51	0.28	0.69	1.32	11.51	0.20	-	7.23	-	36.74	116.54	2.66	89.48	-	24.60	4.55	0.18	10.09	12.91	4.64	7.84	-	11.18
1993	0.47	0.24	0.63	1.12	23.72	0.18	-	6.60	-	31.37	240.15	2.50	81.76	-	22.48	4.16	0.17	8.62	26.59	4.24	6.69	-	23.04
1994	0.58	0.25	0.79	1.15	24.05	0.23	-	8.23	-	32.07	243.53	2.34	101.87	-	28.00	5.18	0.21	8.81	26.97	5.28	6.84	-	23.37
1995	0.53	0.25	0.71	1.18	25.15	0.21	0.96	7.45	3.06	32.99	254.65	2.13	92.28	-	25.37	4.69	0.19	9.06	28.20	4.79	7.04	3.06	24.43
1996	0.31	0.24	0.42	1.13	26.20	0.12	0.78	4.36	2.47	31.56	265.28	1.94	53.96	-	14.83	2.74	0.11	8.67	29.38	2.80	6.73	2.47	25.45
1997	0.32	-	0.43	-	27.42	0.13	0.71	4.54	2.25	-	277.59	1.99	56.18	-	15.44	2.85	0.12	-	30.74	2.91	-	2.25	26.63
1998	0.43	0.16	0.58	0.74	26.44	0.17	0.48	6.05	1.53	20.65	267.67	1.61	74.95	-	20.60	3.81	0.15	5.67	29.64	3.89	4.41	1.52	25.68
1999	0.38	0.20	0.52	0.92	27.02	0.15	0.13	5.38	0.40	25.58	273.63	1.46	66.65	-	18.32	3.39	0.14	7.02	30.30	3.46	5.46	0.40	26.25
2000	0.58	0.29	0.78	1.34	58.08	0.22	0.00	8.16	0.00	37.28	588.09	6.36	100.99	-	27.76	5.13	0.21	10.24	65.12	5.24	7.96	0.00	56.43
2001	0.59	0.25	0.80	1.18	53.78	0.23	0.00	8.40	0.00	32.91	544.55	6.49	103.98	-	28.58	5.28	0.21	9.04	60.30	5.39	7.02	0.00	52.25
2002	0.62	0.26	0.84	1.21	49.78	0.24	-	8.79	-	33.89	504.02	5.40	108.88	-	29.93	5.53	0.22	9.31	55.81	5.65	7.23	-	48.36
2003	0.65	0.23	0.89	1.07	46.09	0.26	-	9.25	-	29.84	466.70	4.95	114.56	-	31.49	5.82	0.23	8.20	51.68	5.94	6.37	-	44.78
2004	1.01	0.30	1.36	1.41	36.32	0.39	-	14.25	-	39.22	367.71	4.87	176.40	-	48.49	8.96	0.36	10.77	40.72	9.15	8.37	-	35.28
2005	0.76	0.23	1.03	1.09	39.68	0.30	-	10.78	-	30.27	401.71	4.63	133.54	-	36.71	6.79	0.27	8.31	44.49	6.93	6.46	-	38.54
2006	0.65	0.28	0.88	1.29	13.45	0.25	-	9.20	-	35.97	136.14	4.47	113.92	-	31.32	5.79	0.23	9.88	15.08	5.91	7.68	-	13.06
2007	0.86	0.11	1.16	0.51	91.01	0.33	-	12.10	-	14.25	921.44	4.52	149.80	-	41.18	7.61	0.31	3.91	102.04	7.77	3.04	-	88.41
2008	0.95	0.38	1.28	1.75	95.14	0.37	-	13.38	-	48.73	963.33	3.58	165.65	-	45.54	8.42	0.34	13.39	106.68	8.59	10.40	-	92.43
2009	1.12	0.04	1.52	0.18	96.99	0.44	-	15.91	-	4.89	982.06	3.26	196.95	-	54.14	10.01	0.40	1.34	108.75	10.22	1.04	-	94.23
2010	1.03	0.16	1.42	0.78	14.50	0.41	0.63	14.76	2.90	21.38	138.01	2.90	198.04	0.00	63.38	11.16	0.40	6.40	13.70	8.76	1.06	1.83	13.39
2011	1.26	0.18	1.74	0.84	15.30	0.50	0.77	18.08	2.14	23.40	148.88	3.18	234.83	0.00	71.20	12.74	0.48	6.76	15.48	11.63	4.99	2.46	14.38
2012	1.35	0.17	1.84	0.78	14.87	0.53	0.90	19.17	2.58	21.80	147.76	3.33	241.87	0.01	69.72	12.69	0.49	6.10	15.97	12.45	4.45	2.86	14.22
2013	1.41	0.20	1.90	0.93	15.03	0.55	0.85	19.92	2.51	26.03	152.59	3.64	245.81	0.01	67.26	12.44	0.50	7.08	17.04	12.84	4.86	2.68	14.63
2014	1.39	0.13	1.87	0.62	15.19	0.53	0.82	19.58	2.49	17.33	157.35	4.05	237.30	0.01	61.69	11.60	0.49	4.59	18.06	12.63	3.98	2.61	15.04
2015	1.53	0.07	2.04	0.30	15.14	0.59	0.95	21.46	2.96	8.53	159.94	4.14	256.42	0.01	63.37	12.11	0.52	2.20	18.78	13.80	2.22	3.04	15.24
2016	1.40	0.06	1.87	0.27	15.16	0.54	1.00	19.46	3.10	7.65	162.78	4.19	223.93	0.01	52.65	10.38	0.47	1.95	19.55	13.04	2.93	3.32	15.47

The total emissions of 1.09 $MtCO_2e$ were recorded in 2016, making up 7.2% of the total energy sector emissions. Carbon dioxide emissions constituted 99% of the total manufacturing industry and construction emissions. The remaining 0.7% and 0.3% were from nitrous oxide and methane gas, respectively (Figure 29). In terms of trends, overall, the total emissions showed a considerable 77.6% increment from 0.61 $MtCO_2e$ in 1990 to 1.09 $MtCO_2e$ in 2016 at a growth rate of 2.3% per annum. Despite the generally recorded increases over the 26 years, the emissions trend between 2012 and 2016, showed a decline of 13.9%. The major emissions grew over the two decades were associated with the high fuel consumption in food processing and beverage, mining and quarrying, construction and leather and textile in order of rank.

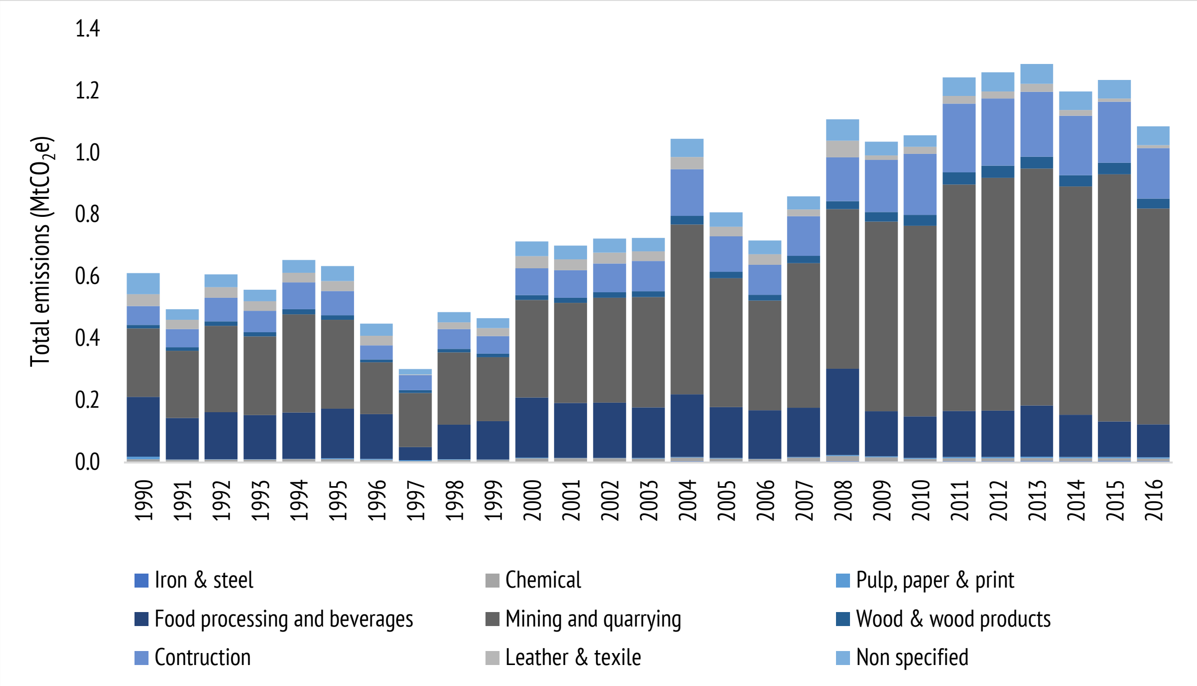


Figure 29: GHG emission trends in the manufacturing industry and construction category for 1990-2016

Within the Manufacturing Industries and Construction category, food processing was the dominant source of emissions followed by mining and quarrying, textile and leather, construction, non-specified industries, wood and wood products, pulp, paper and print, chemicals and iron/steel. The dominance emission from food, beverage and tobacco industries could be explained by the growing consumption of wood and liquid fuels in boilers and heating processes.

3.7.5.2.2 Methodological issues under Manufacturing industry and construction

Data on fuel consumption for the applicable nine sub-categories under Manufacturing and Construction (1.A.2) were obtained from the national energy statistics. There were two levels of analysis of the fuels. First, for each fuel, out of the total consumption each year, certain aggregate or share was allotted to the manufacturing industry and construction and further divided among the industry sectors. The sector fuel distribution was done consistently with shares reported in the energy statistics. The total quantity of various fuels consumed in manufacturing industries and construction sectors were disaggregated among the nine sub-categories mentioned above to arrive at the quantities of fuels consumed by each sub-category. The shares of the sub-categories were derived using the results of (a) industrial fuel consumption surveys, (b) the fuel combustion patterns of sub-categories and (c) expert judgment based on the sectoral shares in the energy statistics. The fuels considered in the estimation of the emissions in the manufacturing industries and construction were diesel, residual fuel oil, LPG, wood, and charcoal. The quantity of gasoline used in this category was mainly used for transportation in the industry and has therefore been included in category 1.A.3 (transportation). LPG consumption in the manufacturing industry and construction was assigned to the Food Processing industries because it is the only industry that uses LPG directly to fuel its operations. There was no consumption of LPG, wood, and charcoal in the construction industry; hence these fuels were not considered in the estimation of emissions from that sub-category. The estimation of the emissions from each sub-category of the Manufacturing Industries and Construction sector was done using the quantities of fuels consumed by each sub-category under consideration and the applicable emission factors. The IPCC Tier 1 approach was used to estimate the emissions from this sector using the default IPCC emission factors.

3.6.5.2.3 Source-specific recalculation in the manufacturing industry and construction (1.A2)

The availability of new dataset, exclusion of unreliable data, the addition of more sub-categories and revision of existing data were the main reasons why recalculation was done for emissions estimates from 1990 to 2012 for this category. The recalculation resulted in the revision of the activity data, which led to changes in the levels of CO_2, CH_4 and N_2O emissions. Table 48 presents the recalculation results and its impacts on the emissions.

Table 48: Results of recalculation and its impacts on emissions

Year	CO_2			CH_4			N_2O		
	PE (Gg)	LE(Gg)	% Change	PE (Gg)	LE(Gg)	% Change	PE (Gg)	LE(Gg)	% Change
1990	462.62	1628.44	252.01	0.378	0.42	10.24	0.052	0.048	-8.01
1991	476.57	1659.69	248.25	0.390	0.46	18.95	0.053	0.053	0.00
1992	527.49	1209.74	129.34	0.697	0.29	-58.23	0.124	0.030	-75.57
1993	546.88	1790.86	227.47	0.715	0.49	-30.91	0.127	0.057	-55.23
1994	632.10	1903.40	201.12	0.727	0.50	-30.65	0.129	0.058	-54.81
1995	606.43	1939.88	219.89	0.760	0.52	-30.97	0.135	0.060	-55.17
1996	420.01	1808.27	330.53	0.786	0.54	-31.54	0.139	0.061	-56.01
1997	272.08	1724.75	533.90	0.466	0.56	19.52	0.063	0.063	0.02
1998	455.54	1855.61	307.35	0.457	0.54	19.14	0.062	0.062	0.02
1999	441.24	1865.62	322.81	0.465	0.56	19.44	0.063	0.063	0.20
2000	647.50	3735.88	476.97	0.900	1.18	31.47	0.122	0.134	9.92
2001	644.66	3501.59	443.17	1.191	1.10	-7.88	0.160	0.124	-22.61
2002	666.77	3313.42	396.94	1.325	1.02	-23.14	0.178	0.116	-35.24
2003	672.77	3123.19	364.23	1.444	0.95	-34.54	0.194	0.107	-44.72
2004	731.72	2937.04	301.39	1.192	0.79	-34.13	0.161	0.088	-45.03
2005	761.77	2872.49	277.08	1.443	0.82	-43.12	0.194	0.094	-51.69
2006	827.29	1427.09	72.50	1.50	0.30	-80.28	0.202	0.035	-82.51
2007	867.43	5574.03	542.59	1.55	1.84	19.24	0.208	0.208	-0.43
2008	1000.45	6032.17	502.95	1.62	1.94	19.50	0.219	0.219	0.00
2009	889.08	6054.22	580.95	1.65	1.97	19.64	0.222	0.222	0.13
2010	1015.79	1762.34	73.49	2.84	0.27	-90.60	0.108	0.038	-64.38
2011	1309.80	2008.22	53.32	2.02	0.29	-85.53	0.108	0.042	-61.03
2012	1320.79	2022.93	53.16	2.44	0.29	-88.04	0.137	0.042	-69.12

Reasons for recalculations

- Revision of liquid fuel consumption data from 1990–2012 due to the availability of new data.
- Expansion of the manufacturing industry and construction sector to include iron & steel, chemicals, mining & quarrying and non-specified industries.
- Removal of woodfuel use from the fuels used in Pulp & Paper and Wood / Wood product industries.
- Revisions in solid biomass (firewood and charcoal) dataset for 2006-2012.

3.7.5.3 Transportation (1.A3)

Key category (level and trend) – (1A3.b) Road transport CO_2 emissions (liquid fuel)

3.7.5.3.1 Overview of fuel consumption and emissions in transport

The transportation category consists of civil aviation, road transport, railways, and inland waterborne navigation. International and marine navigation are reported as memo items, though their emissions were estimated but excluded from the overall analysis. Gasoline, diesel, LPG, and ATK were the fuels commonly used in transport. In 2016, the total fuel used to support transport services was 2.28 Mtoe representing a 390% increase during the 26 years (Table 49). For 2012-2016, fuel consumption grew by 5% principally driven by diesel and gasoline consumption. Since 1996, diesel had consistently been the dominant fuel in transport. In 2016, diesel alone constituted 55.7% of the total transport fuel consumption for the year and trailed by gasoline (39%), LPG (4.5%) and ATK (0.8%). Diesel was mostly used in road, railways and inland navigation operations in heavy engines.

Table 49: Fuel consumption among transport modes

Year	Fuel types [ktoe]				Fuel Consumption per transport category [ktoe]				Total [ktoe]
	Gasoline	Diesel	LPG	ATK	Domestic aviation	Road	Railways	Inland navigation	All fuels
1990	306.08	157.85	-	0.07	0.07	456.91	4.68	2.34	464.00
1991	263.71	143.80	-	0.04	0.04	400.67	4.56	2.28	407.56
1992	295.13	157.01	-	0.04	0.04	444.49	5.10	2.55	452.18
1993	277.51	151.30	-	0.04	0.04	420.88	5.29	2.64	428.85
1994	312.97	188.03	0.03	0.10	0.10	491.14	6.59	3.30	501.13
1995	297.30	160.79	0.09	0.07	0.07	449.28	5.94	2.97	458.25
1996	332.10	326.05	29.64	0.13	0.13	675.73	8.04	4.02	687.92
1997	332.10	326.39	29.64	0.24	0.24	675.73	8.26	4.13	688.36
1998	331.78	411.73	19.32	0.35	0.35	754.57	8.26	-	763.18
1999	330.22	469.24	18.46	0.27	0.27	804.88	8.26	4.78	818.19
2000	513.31	556.04	15.31	2.00	2.00	1,067.34	11.54	5.77	1,086.66
2001	510.63	564.75	13.68	1.73	1.73	1,071.38	11.79	5.89	1,090.79
2002	507.26	579.52	14.98	2.24	2.24	1,083.54	12.14	6.07	1,103.99
2003	361.94	567.82	15.62	6.29	6.29	926.51	12.58	6.29	951.67
2004	517.49	633.78	23.69	8.74	8.74	1,153.97	13.99	7.00	1,183.70
2005	496.75	521.31	22.75	9.83	9.83	1,019.33	14.33	7.17	1,050.65
2006	495.92	825.19	37.18	9.57	9.57	1,333.20	16.72	8.36	1,367.85
2007	488.00	988.54	37.20	11.64	11.64	1,483.76	19.98	9.99	1,525.37

2008	485.26	881.58	48.44	13.01	13.01	1,387.09	18.79	9.40	1,428.29
2009	584.24	1,009.45	93.97	14.00	14.00	1,655.36	21.53	10.77	1,701.65
2010	675.78	842.91	78.56	12.33	12.33	1,594.95	1.55	0.77	1,609.59
2011	743.78	1,113.59	78.56	16.18	16.18	1,880.56	54.47	0.89	1,952.11
2012	830.31	1,209.27	104.98	17.20	17.20	2,033.27	110.40	0.89	2,161.77
2013	903.02	1,245.39	96.00	16.79	16.79	1,980.56	167.18	0.66	2,261.20
2014	946.63	1,310.48	90.71	15.44	15.44	2,132.83	214.57	0.42	2,363.27
2015	927.80	1,361.23	102.69	14.07	14.07	2,101.69	289.58	0.45	2,405.79
2016	888.54	1,266.71	101.48	18.95	18.95	1,952.67	303.62	0.45	2,275.69

With regards to fuel consumption in the different transport modes, road transport was the biggest user of liquid fuels. In 2016, out of the total 2.28 Mtoe fuel consumed, road transport consumed the most by 85.8%, followed by railway (13.3%), aviation (0.83%) and inland navigation (0.02%) (Table 50).

Table 50: Fuel consumption trends per each transport category

Year	Domestic aviation	Passenger			Light duty		Heavy-duty & buses		Motor	Railway	Inland navigation
	ATK	Gasoline	Diesel	LPG	Gasoline	Diesel	Gasoline	Diesel	Gasoline	Diesel	Diesel
1990	0.07	216.61	7.09	-	8.48	47.01	26.03	96.72	54.96	4.68	2.34
1991	0.04	184.02	13.19	-	7.21	39.94	25.80	83.83	46.69	4.56	2.28
1992	0.04	205.91	21.13	-	8.06	44.69	28.90	83.54	52.25	5.10	2.55
1993	0.04	189.27	27.96	-	7.41	41.08	32.80	74.33	48.03	5.29	2.64
1994	0.10	216.24	41.77	0.03	8.47	46.93	33.40	89.43	54.87	6.59	3.30
1995	0.07	201.39	43.32	0.09	7.89	43.71	36.92	64.86	51.10	5.94	2.97
1996	0.13	223.66	65.00	29.64	0.18	105.00	65.20	144.00	43.06	8.04	4.02
1997	0.24	223.66	65.00	29.64	0.18	105.00	65.20	144.00	43.06	8.26	4.13
1998	0.35	222.80	130.52	19.32	4.87	35.00	59.00	237.95	45.11	8.26	-
1999	0.27	223.13	160.19	18.46	0.80	36.00	62.05	260.00	44.24	8.26	4.78
2000	2.00	350.55	202.74	15.31	1.90	38.00	91.79	297.99	69.07	11.54	5.77
2001	1.73	350.52	212.64	13.68	2.50	42.40	87.32	292.03	70.28	11.79	5.89
2002	2.24	349.72	227.79	14.98	3.24	50.50	82.98	283.02	71.32	12.14	6.07
2003	6.29	177.63	280.42	15.62	4.62	34.91	92.85	233.62	86.84	12.58	6.29
2004	8.74	330.65	314.30	23.69	5.14	44.33	88.60	254.16	93.11	13.99	7.00
2005	9.83	327.31	301.99	22.75	4.92	67.04	76.25	130.79	88.28	14.33	7.17
2006	9.57	303.74	414.75	37.18	6.13	77.57	82.17	307.78	103.89	16.72	8.36
2007	11.64	307.17	450.09	37.20	7.37	103.89	65.14	404.59	108.32	19.98	9.99
2008	13.01	284.76	438.47	48.44	7.66	107.88	78.46	307.04	114.37	18.79	9.40
2009	14.00	435.00	484.84	93.97	8.41	134.48	19.51	357.83	121.32	21.53	10.77
2010	12.33	361.00	428.11	78.56	13.13	130.49	109.13	282.00	192.52	1.55	0.77
2011	16.18	389.35	511.06	78.56	14.68	150.10	105.07	397.06	234.67	54.47	0.89
2012	17.20	469.05	516.06	104.98	15.08	168.79	97.74	413.13	248.45	110.40	0.89
2013	16.79	462.00	484.31	96.00	19.04	175.74	112.56	417.49	309.43	167.18	0.66
2014	15.44	493.00	454.77	90.71	19.97	177.03	116.43	463.69	317.24	214.57	0.42
2015	14.07	491.00	480.95	102.69	21.82	197.25	74.80	393.00	340.18	289.58	0.45
2016	18.95	448.00	411.44	101.48	20.82	177.27	103.87	373.94	315.85	303.62	0.45

Within the road transport category, fuel consumption for passenger vehicles (private and commercial) is the highest. Over the 26 years, fuel consumption in passenger vehicles constitutes an average 52% of all total fuel usage in road transport followed by heavy-duty and buses (28.6%), motorcycles (10%) and light-duty vehicles (8.8%). Most of the passenger cars use slightly more gasoline (46.6% of the total fuel consumption for passenger cars) than the diesel (42.8%) and greatly more than LPG (10.6%) (Table 50). From the results, it was evident that road transport was an important source of fuel consumption in the transport sector in which the passenger car contributes the most.

When it comes to the type of fuel, diesel was the leading fuel in all the transport mode except domestic aviation. The rising levels of fuel consumption have corresponding effects on GHG emissions in the transport sector. Generally, GHG emissions have steadily increased by 409.6% from 1.41 $MtCO_2e$ in 1990 to 7.17 $MtCO_2e$ in 2016 at a 6.7% annual growth rate. For the period 2012-2016, the emissions have increased by 34.4% from 6.68 $MtCO_2e$ in the previous inventory year to 7.17 $MtCO_2e$ in the latest inventory year. The 2016 emission levels amount to 47.7% of the total energy sector emissions and 17% of the national GHG emissions. With regards to the gas compounds, CO_2 was the largest emission source comprising 96.6% of the total transport GHG emissions, N_2O followed suit with 3% and then by CH_4 of 0.5%. Of the total transportation emissions, road transportation alone accounts for 84.5%, trailed by rail, domestic aviation and inland water-borne navigation in that order (Figure 30).

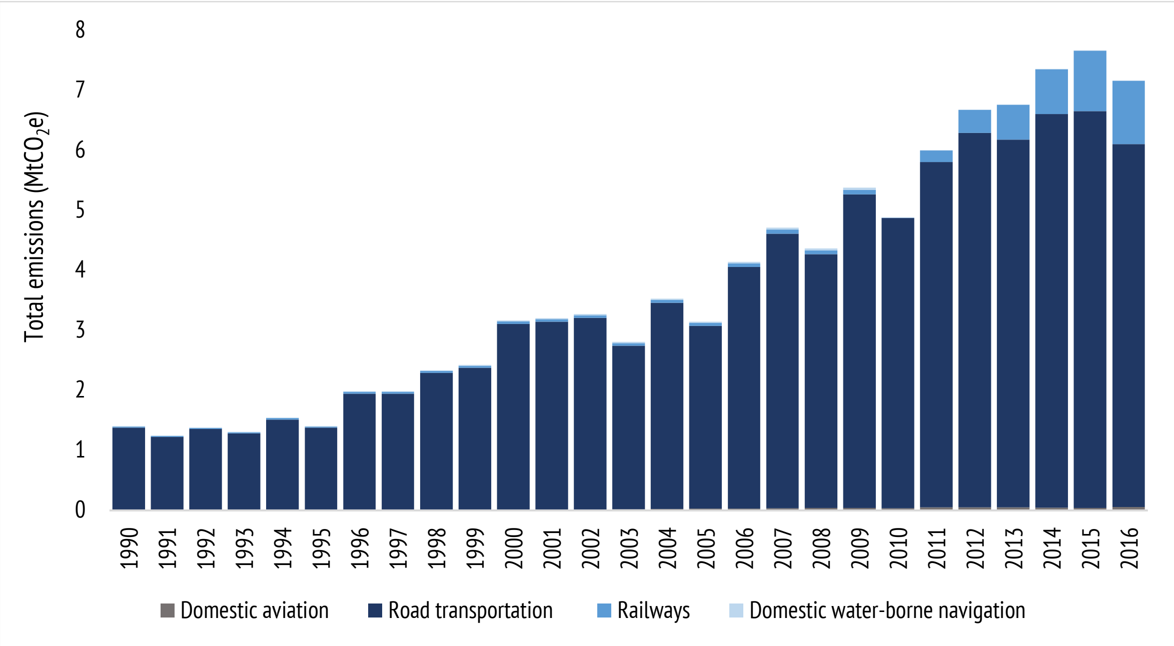


Figure 30: GHG emissions trends in the transportation sector

The road transportation category vehicular mobility on urban, highways and feeder roads include cars, trucks, buses, heavy-duty vehicles and motorcycles. The determinants of road transport emissions are mainly vehicle population and prevailing technology type and traffic situation (distance covered and speed), which can affect fuel consumption. In 2016, a total of 1.92 Mtoe of fuel was used in road transport which represents a 327% increase and a 4% decrease of the 1990 and 2012 fuel consumption respectively. The breakdown of the 2016 fuel consumption is as follows: (a) diesel – 49.3%, (b) gasoline – 45.5% and (c) LPG – 5.2%. In the same vein, the vehicle population has increased from 1,542,467 in 2012 to 2,077,330 in 2016 of which passenger (44%) cars were in the majority. The rest were motorcycles (25%), heavy-duty trucks and buses (18%) and light-duty vehicles (13%). The distribution of vehicle population share affected the total road transport fuel consumption.

The passenger cars accounted for 49.2% of the total road transport fuel followed by heavy-duty and buses (24.5%), motorcycle (16.2%) and light-duty (10.1%). The rise in vehicle population and fuel consumption had a corresponding GHG emission increment from 1.38 $MtCO_2e$ in 1990 to 6.05 $MtCO_2e$ in 2016. The 2016 emissions level represents an overall increase of about 337.7% and 16.8% of the 1990 and 2012 levels respectively. Cars were the most significant contributor to road transport emissions, accounting for about 48% of the total road transport emissions. The main contributory factor for this was the rapid increase in vehicle numbers and their associated traffic congestion. Between 1995 and 2016, the total number of registered vehicles increased by about nine folds from 220,806 in 1995 to 2,077,330 in 2016, representing an increase of over 800% over the period. The road sector emission variations had been influenced by the factors listed below:

- implementation of 10-year over-aged import duty policy.
- general importation of new vehicles.
- increased use of LPG in vehicles.
- deregulation of the downstream petroleum market
- fleet renewal

The railway was the next important source of GHG emissions within the transportation category because it was the third-largest consumer of diesel fuel beyond heavy-duty vehicles and buses and passenger cars. Diesel consumption in rail transport went up from 4.4 ktoe in 1990 to 110.4 ktoe in 2012 and further to 303.62 ktoe in 2016. The upward fuel consumption manifested in the increase in GHG emissions from 0.02 $MtCO_2e$ in 1990 to 1.01 $MtCO_2e$ in 2016. The increases in fuel consumption and emissions in rail transport may be due to the revamping of the hitherto collapsed rail infrastructure. The 1.01 $MtCO_2e$ is made of CO_2 (89.2%), N_2O (10.7%) and CH_4 (0.1%) in the order of importance. The domestic aviation industry has seen a gradual expansion since 2002. Indeed, the growth in the industry saw the addition of active airlines operating in the country. The expanding domestic aviation contributed to more internal flights and passenger uplift on the Accra to Kumasi, Tamale and Takoradi routes. The passenger uplift increased from 199,073 in 2011 to 421,986 in 2016. From 2002, the consumption of ATK increased from 2.24 ktoe to 17.2 ktoe in 2012 and 18.95 ktoe in 2016. Domestic aviation experienced a corresponding rise in emissions from 0.01 $MtCO_2e$ in 2002 to 0.06 $MtCO_2e$ in 2016.

3.6.5.3.2 Methodological issues in the transport sector

GHG emissions from transportation were estimated for the following four (4) transport modes (a) civil aviation (b) road transport, (c) railways and (d) inland water-borne navigation. Different methodological approaches were used for the different transport modes in the estimation. For civil aviation, railways and inland water-borne navigation, the tier-1 IPCC methodology was used in the estimation of the emissions. Default IPCC emission factors were used with country-specific activity data (i.e. Diesel and ATK consumption per year). For road transport, a mix of tier 1 and simplified tier 2 approaches was used in the estimation. Default IPCC emissions factors and a range of country-specific activity data were used. Details of the methodological approaches for the different transport modes are provided below:

Civil Aviation

Activity data, mainly Aviation Turbine Kerosene (ATK) consumption, were collected from three major OMCs that are responsible for the supply of the bulk of the ATK to the domestic airline companies. The data collected represented the bulk ATK supply from a specific OMC. The annual ATK supply to the airlines was derived from the sum of all the supply from the individual OMCs in a year. The shares of ATK consumption of international bunkers and the domestic airlines were estimated based on the aggregated annual sale figures of the OMCs. The LTO data on domestic aviation was not readily available; therefore, the IPCC Tier 1 approach was used to estimate GHG emissions using default emission factors. As part of the future improvements in the civil aviation emission estimations, efforts would be made to collect additional data to use a tier 2 approach in future.

Road Transportation

The emission estimates for road transportation has improved compared to the methodology used in the previous inventory, although a lot remains to be done to ensure greater transparency and robustness. In the previous inventory, transport emissions were estimated using tier 1 approach whereas, in the current inventory, accessibility to more data made it possible to move partially to a higher tier. Country-specific activity data on vehicle population (i.e. annual vehicle registration and roadworthy certification data) was collected from the DVLA for 1995-2016. The missing data from 1990 to 1994 was retrieved by trend extrapolation using the average annual growth rate of the five years (1995-2000) of the period DVLA provided the data. The original DVLA vehicle population data format was further categorised into vehicle classes (passenger, light-duty, heavy-duty and motorcycle) to conform to the IPCC vehicle population classifications. The categorisation of the DVLA data in the IPCC vehicle classes was based on the average gross weight. Based on the 2005 survey conducted as part of the DANIDA Vehicular Emission Project, the vehicle classes were further divided into technology classes based on the Euro standards. A further breakdown of the gasoline passenger and light-duty vehicles was based on the functionality of the catalytic device in the vehicles. Based on expert judgment and local industry knowledge in Ghana, 10% of the total gasoline passenger and light-duty vehicles were assumed to have functional embedded catalytic converters.

The total amounts of liquid fuels (diesel, gasoline, and LPG) allocated to transportation was derived from the national totals reported in the energy statistics. The allocations of fuel mix to transport and other sectors were based on the shares derived through surveys and expert judgments. Therefore, the annual fuel consumption for road transport was estimated out of the overall allocation of the transportation category. The remaining fuel was split among non-motorised transport modes, i.e. civil aviation, railways and inland water navigation. The share of fuel consumption of road transport was further allocated to the various vehicle classes. The quantity of fuel allocated to the vehicle classes was dependent on the number of vehicles in each technology class. Because of the outdated nature of the 2005 traffic circulation data (average speed, mileage, fuel economy), full tier 3 methodology was not possible to use. Instead, with the IPCC default emission factors, country-specific disaggregated vehicle classifications, and its fuel allocation, the GHG emissions for each vehicle class were estimated. Given the plan to improve the methodology for the estimation in the future, attention would be given to the collection of data to enable Ghana to implement a higher tier approach in the transport sector. The emission factors were obtained from the IPCC EFDB using selection criteria that aimed at selecting emission factors applied to the prevailing transport condition in Ghana.

Railways

Activity data (diesel consumption) was initially collected from the Ghana Railway Company for the inventory period. Inconsistencies were found during the preliminary assessment of the data from Ghana Railway Company; hence the annual fuel consumption data from the Energy Statistics disaggregated energy balance was used to ensure internal and time series consistency. However, efforts would be made to reconcile the two data sources and appropriately report the emissions in the next inventory. Default IPCC emission factors for CO_2, CH_4 and N_2O, were used together with the IEA activity data to determine the emissions. The fuel allocation to railways seems to be on the high side, considering the actual passenger and freight rail transport in the last two decades. Ghana intends to investigate the diesel consumption figures from the Energy Statistics and calibrate with the actual diesel consumption figures from the Ghana Railway Corporation and report the differences in the future inventory report.

Inland water-borne navigation

The main activity data (annual diesel consumption) was obtained from the Volta Lake Transport Company from 2006 to 2016 to estimate GHG emissions using the tier 1 approach. The missing data from 1990-2005 was obtained from the national energy balance for Ghana. IPCC default emission factors were used for CO_2, CH_4 and N_2O

3.6.5.3.3 Source-specific recalculations in the transport sector

The availability of new dataset, exclusion of unreliable data and revision of existing data were the main reasons why recalculation was done for emissions estimates from 1990 to 2012 for this category. The recalculation resulted in the revision of the activity data, which led to changes in the levels of CO_2, CH_4 and N_2O emissions. Table 51 presents the recalculation results and its impacts on the emissions.

Table 51: Results of recalculation and its impacts on emissions

Year	CO_2			CH_4			N_2O		
	PE (Gg)	LE(Gg)	% Change	PE (Gg)	LE(Gg)	% Change	PE (Gg)	LE(Gg)	% Change
1990	1432.39	1368.60	-4.45	0.46	0.47	2.01	0.09	0.09	1.56
1991	1281.64	1213.70	-5.30	0.40	0.41	2.66	0.08	0.08	0.21
1992	1437.06	1345.54	-6.37	0.44	0.45	1.84	0.09	0.09	-1.43
1993	1388.65	1276.00	-8.11	0.41	0.42	1.88	0.09	0.08	-3.82
1994	1654.97	1507.51	-8.91	0.47	0.48	0.93	0.11	0.10	-7.85
1995	1523.07	1370.74	-10.00	0.45	0.44	-0.36	0.09	0.09	-4.20
1996	2196.36	1942.84	-11.54	0.56	0.52	-6.87	0.14	0.11	-19.08
1997	2009.54	1944.20	-3.25	0.45	0.52	14.73	0.13	0.11	-13.18
1998	2899.77	2269.34	-21.74	0.71	0.54	-23.47	0.18	0.13	-26.35
1999	3156.92	2370.90	-24.90	0.91	0.52	-42.63	0.19	0.14	-27.16
2000	2743.51	3098.41	12.94	0.77	0.74	-3.72	0.16	0.18	8.81
2001	2810.90	3134.57	11.51	0.74	0.74	0.21	0.17	0.18	9.31
2002	3027.48	3199.21	5.67	0.82	0.75	-8.39	0.18	0.19	1.39
2003	2845.10	2747.11	-3.44	0.72	0.55	-23.41	0.17	0.16	-3.22
2004	3303.87	3451.82	4.48	0.85	0.80	-5.10	0.20	0.20	-0.46
2005	2806.29	3076.13	9.62	0.59	0.77	30.54	0.18	0.18	3.05
2006	3297.27	4054.66	22.97	0.78	0.85	9.78	0.20	0.23	15.05
2007	3798.47	4612.65	21.43	0.84	0.90	6.75	1.21	0.27	-77.85
2008	3699.07	4272.39	15.50	0.84	0.89	5.79	0.23	0.25	9.12
2009	4518.32	5261.78	16.45	1.08	1.25	15.05	0.28	0.30	6.72
2010	4715.07	4775.73	1.29	1.22	1.21	-0.74	0.30	0.26	-15.45
2011	5234.08	5859.24	11.94	1.37	1.36	-0.91	0.33	0.37	12.21
2012	6192.31	6507.22	5.09	1.58	1.57	-0.50	0.40	0.46	14.49

Reasons for recalculations

- Revision of the fuel consumption data (gasoline, diesel and LPG) for transportation due to the availability of new and updated data from the energy statistics.
- Inclusion of revised ATK consumption for domestic aviation from 1990 to 2012.

3.7.5.4 Other sectors (1.A4)

Key category (level and trend) – 1.A.4.b - Residential CH_4 emissions

3.7.5.4.1 Overview of fuel consumption and emissions in Other sectors

Energy-related activities other than those captured in 1.A1, 1.A2, 1.A3 are covered under the "other sectors" category. These are combustions activities in commercial, residential and Agriculture/Forestry/Fishing/Fish Farms. In 2016, the overall fuel consumption in the other sectors category was 2.9 Mtoe and contributed 32.7% of the total energy sector fuel consumption in the same year (Table 52). The major fuels used in the category include LPG, kerosene, firewood, charcoal, gasoline and diesel. LPG, Kerosene, firewood and charcoal are commonly used in commercial and residential sub-categories whereas diesel and gasoline are used in fishing, off-road vehicles and stationary operations.

Table 52: Fuel consumption trend in other sectors

Year	Fuel Consumption (ktoe)								
	LPG	Kerosene	Wood	Charcoal	Gasoline	Diesel	Liquid fuel	Solid fuel	Total
1990	4.23	139.35	3,209.48	304.11	33.19	11.98	188.76	3,513.59	3,702.35
1991	4.70	66.32	3,313.31	338.43	34.07	11.32	116.42	3,651.74	3,768.16
1992	6.82	64.06	3,392.66	354.56	35.14	12.22	118.25	3,747.22	3,865.47
1993	10.04	61.14	3,484.42	373.32	36.10	12.27	119.56	3,857.73	3,977.29
1994	13.54	112.24	3,585.27	391.95	37.09	14.81	177.69	3,977.21	4,154.90
1995	42.06	75.13	3,737.11	400.47	38.12	12.93	168.24	4,137.58	4,305.82
1996	50.68	149.43	3,893.50	408.18	39.19	17.47	256.76	4,301.68	4,558.44
1997	44.61	177.91	4,082.05	418.09	40.29	16.89	279.69	4,500.14	4,779.83
1998	29.16	265.81	3,911.23	425.67	41.43	16.89	353.29	4,336.90	4,690.19
1999	26.37	201.21	3,985.94	433.19	42.75	18.30	288.62	4,419.13	4,707.76
2000	31.20	62.46	2,549.87	680.36	52.28	37.45	183.39	3,230.22	3,413.61
2001	30.68	64.77	2,361.27	694.43	46.72	36.08	178.25	3,055.70	3,233.95
2002	37.52	68.34	2,168.55	726.92	48.88	35.06	189.80	2,895.47	3,085.26
2003	44.35	62.50	1,999.93	746.09	51.55	34.27	192.67	2,746.02	2,938.69
2004	44.47	66.20	1,846.14	824.40	50.47	35.95	197.09	2,670.54	2,867.63
2005	50.83	66.82	841.80	835.00	54.97	34.74	207.37	1,676.80	1,884.17
2006	61.15	86.90	1,685.99	889.53	57.91	38.23	244.20	2,575.52	2,819.72
2007	61.10	56.40	1,572.20	904.77	66.15	43.08	226.73	2,476.98	2,703.71
2008	75.21	30.70	990.83	417.11	77.04	38.23	221.18	1,407.94	1,629.12
2009	137.94	78.93	1,010.48	421.52	82.22	41.31	340.40	1,432.00	1,772.40
2010	109.21	43.43	1,310.55	941.06	68.95	36.06	257.65	2,251.61	2,509.26
2011	109.21	54.58	1,345.39	1,006.85	83.70	43.57	291.06	2,352.24	2,643.30
2012	156.10	41.49	1,331.19	1,038.65	97.69	45.81	341.08	2,369.84	2,710.92
2013	148.22	24.88	1,335.41	1,107.93	100.52	47.35	320.97	2,443.35	2,764.31
2014	143.92	8.50	1,344.35	1,207.95	97.21	46.44	296.07	2,552.30	2,848.37
2015	168.20	6.25	1,335.90	1,205.86	87.89	50.95	313.29	2,541.76	2,855.05
2016	171.36	6.94	1,327.02	1,209.81	92.79	45.15	316.24	2,536.82	2,853.06

Since 1990, the share of "other sectors" fuel consumption of the total for the energy sector dropped by more than double percentage points from 69.3% to 32.7% in the latest year. The fuel consumption level showed a downward trend by 22.9% for the 26 years. Throughout the inventory period, solid fuel continued to be dominant fuel. Solid fuels have consistently made up 92% of the total fuel consumption in "other fuels", and the remaining 8% is liquid fuels. For the solid fuels, the share of firewood averaged 73.4%, and the remaining 26.6% was charcoal. Kerosene had the largest share of averagely 36.1% of the total liquid fuel consumption followed by LPG (25.4%), gasoline (25.3%) and diesel (13.2%). The residential sub-category consumed most of the fuels in other sectors. It accounts for an average of 85.4% of the total fuel compared to 11.4% of commercial and 3.2% of agriculture (Table 53). Similarly, Table 53 further showed that for fuel consumption under agriculture/forestry/fishing, fuel consumption the share of both fishing and off-road vehicles dominated accounting for 99.9%.

Table 53: Fuel consumption per sub-categories in the "other sector" category

Years	Commercial/Institutional [ktoe]				Residential [ktoe]				Fishing (ktoe)		Stationery [ktoe]	Off-road vehicles and other machines (Ktoe)	
	LPG	Kerosene	Wood	Charcoal	LPG	Kerosene	Wood	Charcoal	Gasoline	Diesel	Diesel	Gasoline	Diesel
1990	0.37	5.39	739.33	28.69	3.86	133.97	2,470.15	275.42	20.02	5.11	0.10	0.0131	0.007
1991	0.40	2.65	761.88	31.93	4.31	63.67	2,551.43	306.50	20.79	4.82	0.11	0.0133	0.006
1992	0.55	2.65	785.09	33.69	6.28	61.41	2,607.57	320.86	21.60	5.21	0.10	0.0135	0.007
1993	0.75	2.62	808.88	35.61	9.29	58.52	2,675.53	337.71	22.44	5.23	0.10	0.0137	0.007
1994	0.93	4.98	836.21	37.52	12.61	107.26	2,749.06	354.43	23.31	6.33	0.10	0.0138	0.008
1995	2.96	3.45	874.38	38.47	39.10	71.68	2,862.73	362.00	24.21	5.52	0.10	0.0139	0.007
1996	3.56	7.12	916.02	39.36	47.11	142.31	2,977.48	368.82	25.15	7.47	0.10	0.014	0.010
1997	3.26	8.79	958.53	40.31	41.35	169.12	3,123.52	377.78	26.12	7.22	0.10	0.0142	0.010
1998	1.96	13.62	924.22	41.34	27.20	252.19	2,987.01	384.33	27.14	7.22	0.10	0.0143	0.010
1999	1.52	11.11	944.84	42.23	24.85	190.10	3,041.10	390.97	28.19	7.82	0.10	0.0146	0.010
2000	3.69	1.67	82.26	69.96	27.51	60.79	2,467.61	610.40	33.01	16.06	0.10	0.0193	0.021
2001	3.52	1.89	76.17	71.39	27.16	62.88	2,285.10	623.04	29.10	15.47	0.10	0.0176	0.021
2002	4.17	2.16	70.50	75.24	33.35	66.18	2,098.05	651.68	28.89	15.03	0.10	0.0199	0.020
2003	4.78	2.13	65.28	77.56	39.57	60.38	1,934.65	668.54	31.19	14.69	0.10	0.0204	0.019
2004	1.99	2.41	60.51	86.02	42.48	63.79	1,785.63	738.38	29.74	15.42	0.10	0.0207	0.020
2005	3.20	2.62	56.19	91.85	47.64	64.19	785.61	743.15	33.85	16.28	0.11	0.02112	0.018
2006	5.14	3.68	34.85	51.85	56.02	83.22	1,651.14	837.68	36.41	17.92	0.10	0.02151	0.020
2007	5.10	2.58	128.89	45.48	56.00	53.82	1,443.32	859.29	44.24	20.20	0.10	0.02191	0.023
2008	5.44	1.51	134.75	45.88	69.77	29.19	856.08	371.23	54.72	17.92	0.10	0.02231	0.020
2009	8.57	4.20	137.37	46.37	129.37	74.73	873.11	375.15	59.50	19.37	0.10	0.02272	0.022
2010	5.82	2.48	23.57	70.57	103.39	40.95	1,286.99	870.49	34.96	16.91	0.13	0.03399	0.019
2011	5.82	3.92	24.61	68.77	103.39	50.66	1,320.78	938.08	47.85	20.50	0.16	0.03585	0.023
2012	9.47	2.26	23.62	73.81	146.63	39.22	1,307.57	964.84	61.84	21.65	0.16	0.03585	0.024
2013	9.54	1.44	23.56	82.10	138.68	23.43	1,311.85	1,025.83	61.27	22.49	0.16	0.03926	0.025
2014	9.81	0.60	23.44	92.77	134.11	7.89	1,320.91	1,115.18	59.07	22.18	0.15	0.03814	0.024
2015	12.11	0.71	22.97	95.69	156.10	5.54	1,312.93	1,110.17	49.56	24.49	0.16	0.03833	0.026
2016	13.01	0.85	22.59	98.92	158.35	6.09	1,304.43	1,110.89	58.79	21.84	0.14	0.03399	0.023

In 2016, the total fuel consumption translated into total emissions of 1.53 $MtCO_2e$, amounting to about 10% of the total energy sector emissions. The emissions represented a decrease of about 9% of the 1990 emissions of 1.64 $MtCO_2e$ (Figure 31). However, there was a minimal percentage change in the emission levels from 1990 to 2000 was minimal.

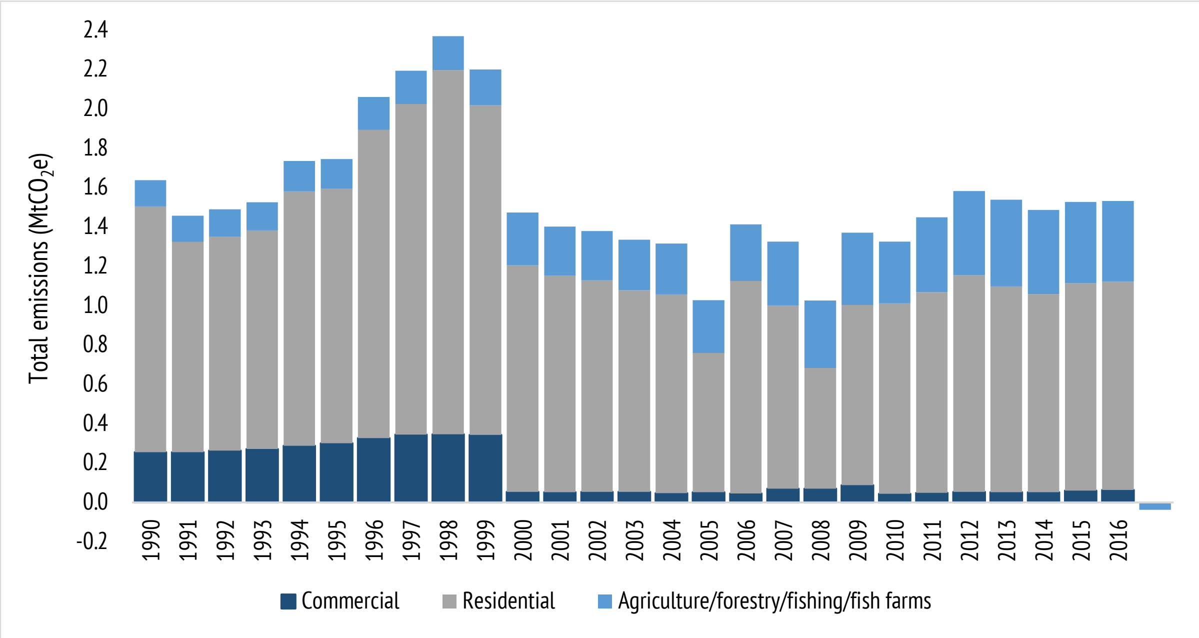


Figure 31: Total emissions trends in the other sector category

In 2016, the levels of 2016, CO_2, CH_4 and N_2O emissions under "other sectors" were 0.88Mt, 0.56 $MtCO_2e$, and 0.09 $MtCO_2e$ respectively. In terms of sub-categories, residential category (68.24%) was the largest source of GHG emissions followed by Agriculture/forestry/fishing/fish farms (27.55%) and commercial/institutional (4.21 %) in the same year. The total residential sector emissions of 1.02 $MtCO_2e$ were 15.1% and 3.9% lower than the 1990 and 2012 levels of 1.25 $MtCO_2e$ and 1.10 $MtCO_2e$ respectively. In terms of gases, CO_2 was the main contributor to the emission in other sectors followed by CH_4 and N_2O.

While the trends of total CO_2 emissions in the sector decreased from 0.56 Mt in 1990 to 0.47 Mt in 2016, CH_4 emission trends recorded a dramatic decrease from 0.9 $MtCO_2e$ in 1990 to 0.6 $MtCO_2e$ in 2016. The declining trends relate to the reduction in biomass use for particularly in residential and institutional cooking as well as the growing adoption of LPG fuel. The emission drop may be attributed to the LPG promotion programme that has been implemented for more than two decades. The policy is now giving special focus in the rural areas. Likewise, the N_2O emissions pattern showed a visible drop of 6.4% from 0.01 $MtCO_2e$ to 0.006 $MtCO_2e$ during the same period. The 2016 Agriculture, forestry and fisheries emissions of 0.41 $MtCO_2e$ is about 207% higher than the 1990 value of 0.13 $MtCO_2e$ and 3.8% lower than the 2012 levels. The changes in the emission trends were mainly attributable to the fluctuations in diesel consumption in stationary Agriculture, forestry and fisheries activities.

3.7.5.4.2 Methodological issues in Other sectors

GHG emissions from the other sectors were estimated for three main source activities: commercial/institutional, residential and agriculture/forestry/fisheries/fish farms. Activities under the commercial/institutional category comprise combustion activities in the commercial and public services such as (banks, schools and hospitals, and trade, retail and communication). Residential activities cover fuel consumption by household heating and cooking, and Agriculture/Forestry/Fisheries/Fish Farms comprise stationary combustion emissions from agriculture, cattle breeding, and forestry, and fuel combustion emissions from fisheries and off-road machinery used in agriculture (mainly tractors). The methodology for estimating emissions improved compared to the previous inventory. In the current inventory, although the IPCC tier-one approach was used, the activity data were updated to reflect the changes in the national energy statistics. The IPCC default emission factors were used for all the fuel under the activities. Carbon dioxide emission from biomass in residential and commercial/institutional use was excluded from the inventory emission and reported as a memo item. The main activity data are LPG, kerosene, diesel, gasoline, and biomass fuel (firewood and charcoal). The activity data were obtained from national energy statistics. Although in the energy statistics, data on total national fuel supply and consumption are provided for the period 1990-2016, where there were gaps, trend interpolation was used to ensure time-series consistency.

3.7.5.4.3 Source-specific recalculation in Other sectors

The availability of new dataset, exclusion of unreliable data and revision of existing data were the main reasons why recalculation was done for emissions estimates from 1990 to 2006 for this category. The recalculation resulted in the revision of the activity data, which led to changes in the levels of CO_2, CH_4 and N_2O emissions. Table 54 presents the recalculation results and its impacts on the previously reported emissions for the other sectors category.

Table 54: Results of recalculation and its impacts on emissions

Year	CO_2 Emissions			CH_4 Emissions			N_2O Emissions		
	PE (Gg)	LE (Gg)	% Change	PE (Gg)	LE (Gg)	% Change	PE (Gg)	LE (Gg)	% Change
1990	0.63	0.56	-10.92	0.033	0.043	28.38	0.00043	0.00055	29.06
1991	0.38	0.34	-9.22	0.027	0.044	58.56	0.00035	0.00056	61.36
1992	0.40	0.34	-13.09	0.028	0.044	56.00	0.00035	0.00056	58.78
1993	0.39	0.34	-13.88	0.029	0.044	53.66	0.00036	0.00057	56.46
1994	0.66	0.50	-24.06	0.030	0.045	50.74	0.00037	0.00057	53.17
1995	0.64	0.39	-38.04	0.031	0.045	45.49	0.00039	0.00058	47.68
1996	1.06	0.64	-39.61	0.033	0.046	39.91	0.00042	0.00059	41.38
1997	1.10	0.72	-34.41	0.035	0.047	33.85	0.00044	0.00060	35.02
1998	1.47	0.99	-32.75	0.033	0.046	40.15	0.00042	0.00059	41.44
1999	1.28	0.80	-37.66	0.034	0.047	38.14	0.00043	0.00060	39.38
2000	0.82	0.48	-42.32	0.026	0.038	44.50	0.00032	0.00046	42.02
2001	0.84	0.46	-45.01	0.034	0.038	12.25	0.00042	0.00046	8.30
2002	0.90	0.48	-46.91	0.037	0.038	3.55	0.00047	0.00046	-1.78
2003	0.88	0.47	-47.17	0.040	0.038	-4.24	0.00051	0.00046	-9.69
2004	0.99	0.47	-52.48	0.033	0.039	16.18	0.00042	0.00046	9.37
2005	0.98	0.49	-50.21	0.040	0.039	-2.55	0.00051	0.00046	-9.09
2006	1.11	0.57	-48.67	0.041	0.039	-5.56	0.00053	0.00046	-12.62
2007	1.22	0.52	-57.62	0.057	0.040	-29.30	0.00002	0.00048	2151.96
2008	1.17	0.46	-60.72	0.044	0.036	-17.93	0.00057	0.00046	-19.27
2009	1.75	0.64	-63.69	0.045	0.036	-19.39	0.00058	0.00046	-20.83
2010	1.28	0.47	-63.34	0.036	0.039	9.22	0.00044	0.00046	4.56
2011	1.50	0.57	-62.21	0.020	0.040	103.77	0.00024	0.00046	96.23
2012	1.73	0.59	-66.19	0.026	0.040	53.19	0.00032	0.00047	44.91

Reasons for recalculations

- Revision of gasoline consumption figures from 1990-2012 resulting in changes in activity data for gasoline due to the identification of new dataset from the national energy statistics.

- Removal of gasoline from the fuels consumed by commercial and residential category and the emission calculations for the period 1990-2016
- Redistribution of gasoline consumption for Agriculture/Forestry/Fisheries to fishing and off-road vehicles due to availability of new dataset from the national energy statistics and expert judgment on the allocation of fuels.
- Removal of diesel fuel from the types of liquid fuels consumed in the commercial/residential sectors and assigned to stationery.
- Redistribution of total diesel use in Agriculture /Forestry/ Fishing to stationary, off-road vehicles & other machinery and fishing.
- Revision of kerosene consumption figures in the residential and commercial sub-categories due to the availability of new kerosene consumption dataset for the period 1990-2012.
- Revision of LPG consumption figures due to the availability of new datasets from 1990 to 2012.
- Inclusion of new wood fuel dataset from the period of 1990-2012 for commercial/institutional and residential due to the discovery of data from the national energy statistics.

3.8 Fugitive emissions from fuels (1.B)

Fugitive emissions from fuels in Ghana mainly come from the offshore oil and gas production, gas processing distribution as well as petroleum refining. The estimation of fugitive emissions from oil production through flaring started in 2010 when Ghana started commercial production from the Jubilee field. Since then operations on two additional fields (TEN and Sankofa) have commenced in 2016 and 2017. Over 16 years, Ghana has produced a total of 202.01 million barrels of crude oil at an annual average of 28.86 million barrels. In the same period, a cumulative total of 266,936 MMscf of associated natural gas has been produced at an average of 38,134 MMscf every year. Since production commenced in 2010, oil produced has exponentially increased from 1.39 million barrels to 29.52 million barrels in 2012 and further by 12% to 32.94 million barrels in 2016 (Table 55).

Table 55: Oil and gas production statistics

Year	Crude oil production [barrels]	Natural gas statistics [MMscf]					
		Associated Gas Production	Own use	Injection	Export to Atuabo Plant	Gas Flared	Statistical Difference
2010	1,392,300	2,655.71	1,170.00	-	-	1,484.00	1.71
2011	24,310,300	30,620.35	2,386.19	14,741.29	-	13,493.87	(1.00)
2012	29,515,360	32,970.16	3,150.49	28,877.77	-	942.06	(0.16)
2013	37,595,600	47,430.22	2,702.85	41,203.27	-	3,524.08	0.02
2014	38,045,000	55,758.14	3,121.15	45,526.15	1,910.07	5,200.75	0.02
2015	38,207,400	52,549.19	2,975.85	20,553.04	24,236.01	4,784.27	0.02
2016	32,943,400	44,952.49	4,192.22	12,921.63	21,579.60	6,259.08	(0.04)

Production of associated gas went up at the same rate. It moved from 2,655.71 MMscf in 2010 to 32,970.16 in 2012 and up by 36% to 44,952.49 MMscf. The fraction of the flared gas had notably decreased from 55.9% in 2010 to 2.9% in 2012 and up to 14% in 2016. The substantial reduction in gas flaring was due to gas injection as a strategy to reduce environmental impacts and to store the gas for future use in anticipation of government policy to develop the natural gas downstream market. Fugitive emissions were also reported from the Atuabo gas processing and the Tema oil refinery. Since 2014, the Atuabo Gas Plant has processed an aggregate total of 77,036.98 MMBtu of lean gas on an annual average of 19,259.24 MMBtu. Conversely, fugitive emission estimates for oil refining spans 1990 to 2016 and depends on the operational capacity of the refinery at any given time. Generally, the crude oil refining operations slowed down in 2009 picked in 2010 and 2011 declined afterwards (Figure 32).

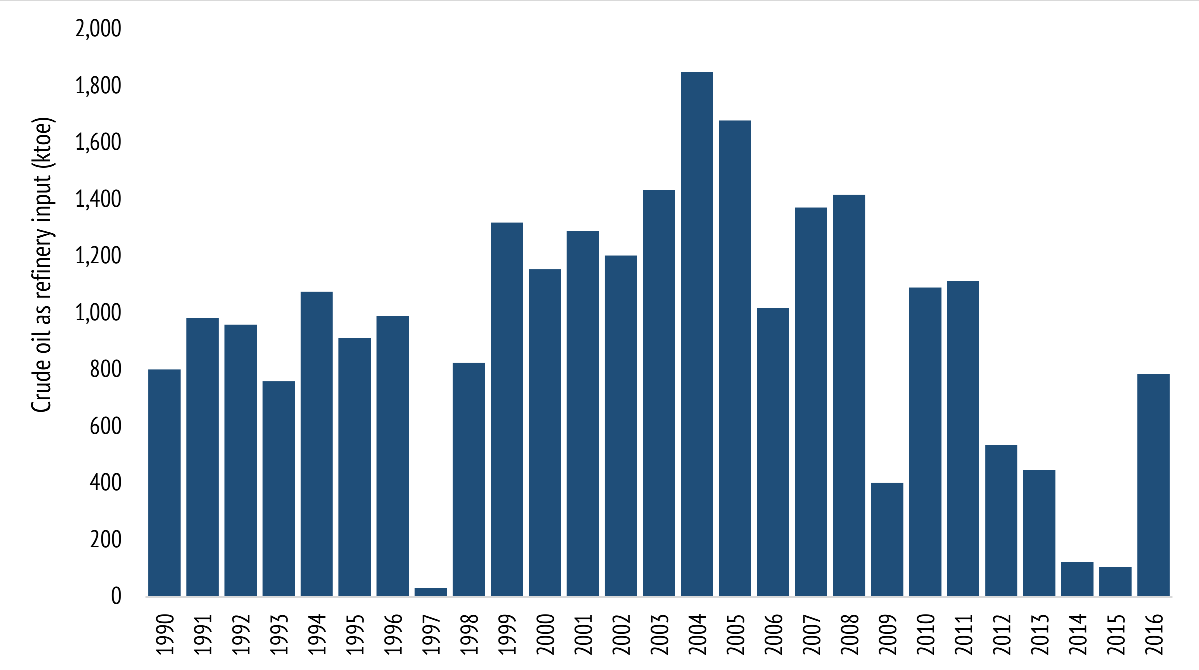


Figure 32: Crude oil inputs into refinery operations from 1999 to 2016

The emissions from the gas distribution from the oil field to Atuabo and the onward transmission to the Aboadze thermal plant enclave. There are two 12-inch-deep and shallow 14km and 45km lateral pipelines that connect the oil field to the Atuabo plant. Another 20-inch 111km pipeline links the Atuabo gas processing plant to the thermal electricity plant at Aboadze.

3.8.1 Description of source-specific activities

3.8.1.1 Emissions from Oil and Natural gas (1.B2)

The total emissions from the upstream and downstream oil and gas operations were estimated at 0.024 $MtCO_2e$ in 2016. This value represented 0.2% of the total energy sector emissions of 15.02 $MtCO_2e$ in the same year. Over the two and a half decades (1990-2016), the emissions increased by 50% from 0.016 $MtCO_2e$ in 1990 to 0.024 $MtCO_2e$ in 2016 (Table 56). Methane gas was the most dominant greenhouse emission from the oil and gas industry in Ghana. For 1990-009, CH_4 gas was the only reported GHG for the oil refinery until 2010 commercial oil and gas operations when instigated CO_2 and N_2O emissions.

Table 56: Greenhouse gas emissions trend in the Oil and Gas category

Year	Oil and Natural Gas Emissions (Gg)			
	CO_2	CH_4	N_2O	Total (Gg CO_2e)
1990	-	16.16	-	16.16
1991	-	19.79	-	19.79
1992	-	19.35	-	19.35

1993	-	15.32	-	15.32
1994	-	21.68	-	21.68
1995	-	18.38	-	18.38
1996	-	19.95	-	19.95
1997	-	0.61	-	0.61
1998	-	16.63	-	16.63
1999	-	26.59	-	26.59
2000	-	23.27	-	23.27
2001	-	25.97	-	25.97
2002	-	24.24	-	24.24
2003	-	28.91	-	28.91
2004	-	37.29	-	37.29
2005	-	33.83	-	33.83
2006	-	20.52	-	20.52
2007	-	27.65	-	27.65
2008	-	28.57	-	28.57
2009	-	8.10	-	8.10
2010	1.95	21.99	0.009	23.96
2011	17.76	22.66	0.086	40.51
2012	1.24	10.80	0.006	12.04
2013	4.64	9.06	0.023	13.72
2014	6.85	2.56	0.033	9.44
2015	6.30	2.26	0.031	8.59
2016	8.24	15.96	0.040	24.24

As of 2016, methane remained the dominant GHG in the oil and gas operations and contributed 65.8% of the total emissions followed by CO_2 emissions (34%) and N_2O (0.2%). Majority of the emissions came from the oil refining industry. It accounted for 90% of the share of overall emissions, although it showed wide inter-annual variations throughout the 26 years. The observed differences are due to the operational downturn at the Tema Oil Refinery in recent times (Table 57). The second-largest emissions source was flaring during oil production from 2010. Its levels peaked at 18.08 $GgCO_2e$ in 2011 a year after production commenced ahead of the coming on stream of the gas processing plant. Afterwards, the emissions have shown a consistent falling-off to 8.34 $GgCO_2e$ in 2016 (Table 57).

Table 57: Fugitive emissions from fuel among oil and operations

Years	GHG Emissions (Gg CO_2e)			
	Conventional oil production(flaring)	Refining	Gas Processing	Gas Distribution
1990	-	16.16	-	-
1991	-	19.79	-	-

1992	-	19.35	-	-
1993	-	15.32	-	-
1994	-	21.68	-	-
1995	-	18.38	-	-
1996	-	19.95	-	-
1997	-	0.61	-	-
1998	-	16.63	-	-
1999	-	26.59	-	-
2000	-	23.27	-	-
2001	-	25.97	-	-
2002	-	24.24	-	-
2003	-	28.91	-	-
2004	-	37.29	-	-
2005	-	33.83	-	-
2006	-	20.52	-	-
2007	-	27.65	-	-
2008	-	28.57	-	-
2009	-	8.10	-	-
2010	1.988	21.97	0.00003	-
2011	18.077	22.43	0.00028	-
2012	1.262	10.78	0.00002	-
2013	4.721	9.00	0.00007	-
2014	6.967	2.47	0.00167	0.004
2015	6.409	2.13	0.01993	0.046
2016	8.385	15.81	0.01779	0.043

The continued decreasing emission patterns strongly related to the effects of utilisation of wet associated gas sent to the gas processing plant and own use on the oil production platforms and the amount. Gas distribution produces the least of the total emissions. It only accounted for 0.18% of the overall emissions in 2016. This was expected because the pipelines are in good conditions because they were recently laid to connect the oil field to the gas processing plant and further to the thermal plant.

3.8.1.2 Methodological issues in the oil and gas category

Activity data were collected from the Tema Oil Refinery, which is the only refinery plant in the country. The data which covered 1990 to 2016 was from the TOR material balance. For the refinery, the fugitive emission was from the evaporations during the transformation of crude oil into secondary products. Since the inventory was carried out with refinery inputs data from one oil refinery, the associated emission seems to be higher than expected. In this respect, Ghana plans to undertake a study to assess the quantities of gas flaring at the refinery when funding is made available to the team. When the data on actual flaring at the refinery is obtained, it will improve the quality of the fugitive emission estimate from the refinery. Currently, the emissions are estimated based on the crude refinery input.

The rest of the activity data were from the Ghana Petroleum Commission, Environmental Protection Agency and the Ghana National Gas Company. The Petroleum Commission's figures on monthly oil and gas production for the three oil fields was reconciled with the figures in the energy balance. Generally, the figures neatly tallied except for the venting data. The venting on the rig and production platforms are currently not accurately monitored and reported. So, emissions from venting would have to be improved in the next inventory circle. The activity data on gas processed and gas distribution was collected from Ghana Gas. The monthly data on gas processing and distribution covered the period the plant has been in operations. Using the IPCC tier methodology, the activity data, oil refining, oil production, and gas processing and distribution and the IPCC default emission factors, the total fugitive emissions were estimated.

3.9 Cross-cutting issues in the Energy sector

3.9.1 Comparison of Activity data with international data sources

This section presents a comparison of activity data used in the inventory with the International Energy Agency (IEA) data for Ghana. The purpose of this comparison is to be able to assess the extent of consistency of the two data sources to understand the reasons behind the difference between the two data sources. The comparison, which is the measures of the percentage difference of the individual input fuels from the two data sources have been provided yearly (Table 58) between 1990 and 2016. The negative sign indicates that the country-specific data are lower than the IEA activity.

Table 58: Comparison of National Activity Data to International Energy Agency data from 1990-2016

Year	Data Source	Crude Oil [ktoe]	LPG [ktoe]	Gasoline [ktoe]	Diesel [ktoe]	Kerosene [ktoe]	RFO [ktoe]	Solid Biomass [ktoe]
1990	Ghana Data	801.72	6.57	349.55	291.33	153.58	40.3	2750.98
	IEA Data	801.17	6.78	344.55	301.99	128.68	40.33	2750.98
	Difference (%)	0.07	-3.20	1.43	-3.66	16.21	-0.07	0.00
1991	Ghana Data	981.65	7.31	296.96	285.78	75.89	46.28	2834.92
	IEA Data	979.32	10.17	316.73	285.44	80.55	40.33	2834.56
	Difference (%)	0.24	-39.12	-6.66	0.12	-6.14	12.86	0.01
1992	Ghana Data	959.78	10.65	332.29	321.51	73.49	48.59	2921.28
	IEA Data	924.35	15.82	372.37	349.56	86.83	42.25	2920.52
	Difference (%)	3.69	-48.54	-12.06	-8.72	-18.15	13.05	0.03
1993	Ghana Data	759.92	15.87	305.44	335.56	70.31	48.04	3009.8
	IEA Data	790.99	22.59	374.51	357.7	85.78	41.29	3008.88
	Difference (%)	-4.09	-42.34	-22.61	-6.60	-22.00	14.05	0.03
1994	Ghana Data	1075.78	21.92	372.09	421.23	119.55	49.12	3105.29
	IEA Data	1072.98	31.63	356.32	417.82	93.11	43.21	3102.01
	Difference (%)	0.26	-44.30	4.24	0.81	22.12	12.03	0.11
1995	Ghana Data	849.43	68.52	346.53	381.56	80.22	50.53	3247.04
	IEA Data	919.26	37.28	378.79	469.53	104.61	46.09	3187.98
	Difference (%)	-8.22	45.59	-9.31	-23.06	-30.40	8.79	1.82
1996	Ghana Data	1014	82.56	422.17	516.61	154.44	48.34	3399.72
	IEA Data	1013.94	45.19	408.75	519.17	118.21	48.01	3264.49
	Difference (%)	0.01	45.26	3.18	-0.50	23.46	0.68	3.98
1997	Ghana Data	181	75.25	330.48	537.86	184.27	35.6	3557.48
	IEA Data	181.21	40.67	429.08	536.75	127.63	52.81	3339.57
	Difference (%)	-0.12	45.95	-29.84	0.21	30.74	-48.34	6.13

1998	Ghana Data	1221.61	49.8	526.68	717.59	275.88	31.63	3430.16
	IEA Data	1221.61	41.8	475.09	692.92	142.28	48.97	3427.78
	Difference (%)	0.00	16.06	9.80	3.44	48.43	-54.82	0.07
1999	Ghana Data	1666.48	46.03	694.62	638.17	209.62	39.17	3506.7
	IEA Data	1666.48	47.45	514.68	791.17	139.14	55.69	3503.2
	Difference (%)	0.00	-3.08	25.90	-23.97	33.62	-42.18	0.10
2000	Ghana Data	1310.60	48.6	550.62	679.13	65.77	57.1	2485
	IEA Data	1308.14	47.45	582.1	726.01	69.05	54.73	3583.77
	Difference (%)	0.19	2.37	-5.72	-6.90	-4.99	4.15	-44.22
2001	Ghana Data	1569.58	45.9	561.855	699.38	68.39	52	3312.4
	IEA Data	1566.72	51.97	587.45	707.39	75.32	49.93	3659.01
	Difference (%)	0.18	-13.22	-4.56	-1.15	-10.13	3.98	-10.46
2002	Ghana Data	1816.6	54	598.71	732.17	74.8	51.9	3696.18
	IEA Data	1820.2	58.75	650.58	768.41	60.68	49.93	3735.83
	Difference (%)	-0.20	-8.80	-8.66	-4.95	18.88	3.80	-1.07
2003	Ghana Data	1972.48	55.00	503.79	770.42	66.74	45.70	4029.96
	IEA Data	1979.01	68.91	527.52	780.82	73.23	44.17	3734.40
	Difference (%)	-0.33	-25.29	-4.71	-1.35	-9.72	3.35	7.33
2004	Ghana Data	2016.44	63.73	604.38	865.90	71.00	43.84	3306.00
	IEA Data	2035.00	79.08	633.46	879.07	78.46	43.21	3772.68
	Difference (%)	-0.92	-24.09	-4.81	-1.52	-10.50	1.45	-14.12
2005	Ghana Data	2006.85	68.39	392.49	898.03	72.07	46.37	4016.60
	IEA Data	2003.44	86.99	591.73	911.13	80.55	46.09	3811.34
	Difference (%)	0.17	-27.21	-50.76	-1.46	-11.77	0.60	5.11
2006	Ghana Data	1747.06	95.04	537.49	952.70	74.21	55.10	4173.83
	IEA Data	1743.85	107.33	563.91	966.98	82.65	54.73	3850.39
	Difference (%)	0.18	-12.93	-4.92	-1.50	-11.37	0.67	7.75
2007	Ghana Data	2094.77	100.76	571.41	1169.97	63.24	21.83	4296.28
	IEA Data	2090.99	114.10	615.27	990.77	68.00	52.81	3889.84
	Difference (%)	0.18	-13.24	-7.68	15.32	-7.53	-141.91	9.46
2008	Ghana Data	2015.32	127.01	572.25	1113.98	33.56	74.64	4491.56
	IEA Data	2011.59	143.48	616.34	940.09	37.66	48.97	3929.69
	Difference (%)	0.19	-12.97	-7.70	15.61	-12.22	34.39	12.51
2009	Ghana Data	1002.50	238.25	736.47	1305.63	89.22	34.34	4578.92
	IEA Data	998.67	249.67	750.09	1322.75	92.06	38.41	3969.93
	Difference (%)	0.38	-4.79	-1.85	-1.31	-3.18	-11.85	13.30
2010	Ghana Data	1694.83	192.67	774.69	1297.37	50.78	29.97	2748.77
	IEA Data	1809.00	202.22	789.68	1317.57	51.26	29.76	3207.00
	Difference (%)	-6.74	-4.96	-1.93	-1.56	-0.95	0.70	-16.67
2011	Ghana Data	1231.00	192.67	586.20	1176.90	64.27	36.40	3370.70
	IEA Data	1069.00	201.00	545.00	1160.00	59.00	36.00	3370.00
	Difference (%)	13.16	-4.32	7.03	1.44	8.20	1.10	0.02
2012	Ghana Data	1233.69	268.49	957.08	1761.14	47.00	33.50	3409.20
	IEA Data	1163.00	273.00	957.00	1596.00	48.00	33.00	3408.00
	Difference (%)	5.73	-1.68	0.01	9.38	-2.13	1.49	0.04
2013	Ghana Data	1446.40	251.76	1030.40	1618.70	28.62	38.10	3554.90
	IEA Data	1653.00	230.00	1050.00	1629.00	29.00	37.00	3553.00
	Difference (%)	-14.28	8.64	-1.90	-0.64	-1.33	2.89	0.05

2014	Ghana Data	706.30	260.90	1306.30	1765.90	9.30	26.00	3629.00
	IEA Data	646.00	267.00	1331.00	1790.00	53.00	26.00	3628.00
	Difference (%)	8.54	-2.34	-1.89	-1.36	-469.89	0.00	0.03
2015	Ghana Data	441.40	218.30	1212.76	2045.00	34.90	13.00	3618.00
	IEA Data	461.00	224.00	1254.00	2225.00	49.00	12.00	3618.00
	Difference (%)	-4.44	-2.61	-3.40	-8.80	-40.40	7.69	0.00
2016	Ghana Data	1741.80	281.47	1127.97	1605.50	21.90	12.60	3602.40
	IEA Data	1820.00	173.00	1032.00	1603.00	32.00	12.00	3600.00
	Difference (%)	-4.49	38.54	8.51	0.16	-46.12	4.76	0.07

Generally, the two datasets were consistent except in a few cases where major differences were observed, such as RFO and Kerosene supply and consumption figures. Besides, the following are some examples of the cases where similarities and difference between the data set were observed:

- For crude oil, the difference between the two data sources was generally within the range of -14.22% in 2013 to 13.2% in 2011. The difference was less than plus or minus 10%, which is indicative of the appreciable level of consistency between the two sources.
- The difference between LPG was between -48.59% in 1992 and 45% in 1995, with large indicative variations.
- The difference between diesel data ranged between -23.9% in 1999 and 15.6% in 2008, indicating moderate variation.

These observations are expected because of the different statistical approaches used to compile the data.

3.9.2 Description of notation keys and completeness information

Information on completeness and use of notation keys in the energy sector are provided below. The information on completeness includes coverage of gases, categories and as well as time series completeness. Additional information is given on the status of emission estimates of all sub-categories. "E" indicates that emissions from this sub-category have been estimated. "NO" means "Not Occurring" thus indicates that Ghana's energy balance does report energy consumption for the relevant sector and fuel category. Emissions of all sources of category 1. A Fuel Combustion has been estimated; the status of emission estimates of this category is complete. Table 59 provides an overview of subcategories of Category 1.A Fuel Combustion and status of estimation.

Table 59: Overview of subcategories of Category 1.A Fuel Combustion and status of estimation

IPCC categories	Time series completeness										
	1990-2012 (recalculations)				2013-2016 (latest estimates)				Gases Covered		
	E	NE	NO	IE	E	NE	NO	IE	CO_2	CH_4	N_2O
1.A.1.a.i – Electricity Generation											
1.A.1.a Crude oil	x				x				x	x	x
1.A.1.a HFO					x				x	x	x
1.A.1.a Diesel	x								x	x	x
1.A.1.a DFO					x				x	x	x
1.A.1.a Natural gas	x				x				x	x	x
1.A.1.a Biomass			x				x		NO	NO	NO

1.A.1.a Solid			x				x		NO	NO	NO
1.A.1.b Petroleum refining											
1.A.1.b Refinery gas	x				x				x	x	x
1.A.1.b Residual fuel oil	x				x				x	x	x
1.A.1.b Gaseous Fuels			x				x		NO	NO	NO
1.A.1.b Biomass			x				x		NO	NO	NO
1.A.1.bPetroleum coke	x				x				x	x	x
1.A1ci, Manufacture of solid fuel											
1.A.1ci Liquid Fuels			x				x		NO	NO	NO
1.A.1ci Gaseous Fuels			x				x		NO	NO	NO
1.A.1ci Woodfuel	x				x				IE	x	x
1.A.1ci Solid			x				x		NO	NO	NO
1.A1cii. Other energy industries											
1.A.1cii Diesel	x				x				x	x	x
1.A.1cii Natural gas	x				x				x	x	x
	E	NE	NO	IE	E	NE	NO	IE	CO_2	CH_4	N_20
1.A.1cii Biomass			x				x		NO	NO	NO
1.A.1cii Solid			x				x		NO	NO	NO
1.A.2a Iron and steel											
1.A.2.a Diesel	x				x				x	x	x
1.A.2.a RFO	x				x				x	x	x
1.A.2.a Gaseous Fuels			x				x		NO	NO	NO
1.A.2.a Biomass			x				x		NO	NO	NO
1.A.2.a Solid			x				x		NO	NO	NO
1.A.2c Chemicals											
1.A.2.c Diesel	x				x				x	x	x
1.A.2.c RFO	x				x				x	x	x
1.A.2.c Gaseous Fuels			x				x		NO	NO	NO
1.A.2.c Biomass			x				x		NO	NO	NO
1.A.2.c Solid			x				x		NO	NO	NO
1.A.2.d Pulp, Paper and Print											
1.A.2.d LPG	x				x				x	x	x
1.A.2.e Diesel	x				x				x	x	x
1.A.2.d Gaseous Fuels			x				x		NO	NO	NO
1.A.2.d Biomass			x				x		NO	NO	NO
1.A.2.d Solid			x				x		NO	NO	NO
1.A.2.e Food Processing, Beverages and Tobacco											
1.A.2.e Diesel	x				x				x	x	x
1.A.2.e LPG	x				x				x	x	x
1.A.2.e RFO	x				x				x	x	x
1.A.2.e Gaseous Fuels			x		x				NO	NO	NO
1.A.2.e Woodfuel	x				x				IE	x	x
1.A.2.e Charcoal	x				x				IE	x	x
1.A2i. Mining & Quarrying											
1.A.2.e Gasoline	x				x				x	x	x

1.A.2.e Diesel	x				x				x	x	x
1.A.2.e Gaseous Fuels			x				x		NO	NO	NO
1.A.2.e Biomass			x				x		NO	NO	NO
1.A.2.e Solid			x				x		NO	NO	NO
1.A.2.j Wood and Wood Products											
1.A.2.j Diesel	x				x				x	x	x
1.A.2.j Gaseous Fuels			x				x		NO	NO	NO
1.A.2.j Biomass			x				x		NO	NO	NO
1.A.2.j Solid			x				x		NO	NO	NO
1.A.2.k Construction											
1.A.2.k Diesel	x				x				x	x	x
1.A.2.k Gaseous Fuels			x				x		NO	NO	NO
1.A.2.k Biomass			x				x		NO	NO	NO
1.A.2.k Solid			x				x		NO	NO	NO
1.A.2.l Textiles and Leather											
1.A.2.l Diesel	x								x	x	x
1.A.2.l RFO	x								x	x	x
1.A.2.l Gaseous Fuels			x		x		x		NO	NO	NO
1.A.2.l Woodfuel	x				x				IE	x	x
1.A.2.l Solid			x				x		NO	NO	NO
1.A.2.m Non-specified											
1.A.2.l Diesel	x								x	x	x
1.A.2.l RFO	x								x	x	x
1.A.2.l LPG	x								x	x	x
1.A.2.l Gaseous Fuels			x		x		x		NO	NO	NO
1.A.2.l Woodfuel	x				x				IE	x	x
1.A.2.l Solid			x				x		NO	NO	NO
1.A.3a Civil Aviation											
1.A.3a Jet Kerosene	x				x				x	x	x
1.A.3b Road Transportation											
1.A.3b Gasoline	x				x				x	x	x
1.A.3b Diesel	x				x				x	x	x
1.A.3b LPG	x				x				x	x	x
1.A.3b Natural Gas			x				x		NO	NO	NO
1.A.3b Biomass			x				x		NO	NO	NO
1.A.3c Railways											
1.A.3c Diesel	x				x				x	x	x
1.A.3d Water-borne Navigation											
1.A.3d Diesel	x				x				x	x	x
1.A.4a Commercial and Institutional											
1.A.4a Kerosene	x				x				x	x	x
1.A.4A LPG	x				x				x	x	x
1.A.4a Natural Gas			x				x		NO	NO	NO
1.A.4a Woodfuel	x				x				IE	x	x
1.A.4a Charcoal	x				x				IE	x	x
1.A.4b Residential											

1.A.4b Kerosene	x				x				x	x	x
1.A.4Blpg	x				x				x	x	x
1.A.4b Natural Gas			x				x		NO	NO	NO
1.A.4b Woodfuel	x				x				IE	x	x
1.A.4b Charcoal	x				x				IE	x	x
1.A.4c Agriculture, Forestry/Fishing and Fish Farms											
1.A.3c Gasoline	x				x				x	x	x
1.A.4c Diesel	x				x				x	x	x
1.A.4c LPG			x				x		NO	NO	NO
1.A.4c Natural Gas			x				x		NO	NO	NO
1.A.4c Biomass			x				x		NO	NO	NO
1.A.4c Other fuels			x				x		NO	NO	NO

3.9.3 Energy sector key categories

The key category sources were generated based on the steps contained in the IPCC 2006 Guidelines for both trends and levels. The IPCC 2006 software was used to generate the key category sources in the energy sector. Table 60 presents the key source categories of 1A Fuel combustion activity.

Table 60: Key category results for fuel combustion under Energy

IPCC Category code	IPCC Category	Greenhouse gas	Key Source Assessment (Level Assessment – LA - 2016)	Key Source Assessment Trend Assessment (TA) (2000-2016)
1.A.3.b	Road Transportation	CO_2	2000, 2016	LA, TA
1.A.1	Energy Industries – Liquid Fuels	CO_2	2016	LA, TA
1.A.2	Manufacturing Industries and Construction – Liquid Fuels	CO_2	2016	LA, TA
1.A.1	Energy Industries – Gaseous Fuels	CO_2		LA, TA
1.A.3.c	Railways	CO_2	2000, 2016	LA, TA
1.A.4.b	Residential	CH4	2016	LA, LA
1.A.4.c	Agriculture/Forestry/Fishing/Fish Farms	CO_2	2016	LA, LA

Note: LA – level assessment if not specified otherwise is for 2016 TA – trend assessment (2000 to 2016)

3.9.4 Quality Control/Quality Assurance Procedures in the Energy sector

Table 61 contains the information on the category-specific QA/QC procedures that were carried out during the inventory. The QA/QC procedures were given serious attention to ensure greater transparency, reliability and completeness as of the improvements in the inventory.

Table 61: QA/QC procedures implemented in the Energy sector

Data type	QA/QC procedure	Remarks/comments/examples
Activity data check	Check for transcription, typographical errors and error transposition.	Division of task among the inventory team to ensure that one or two members of the team always focus on double-checking and ensure that data errors associated with those described in the left column are avoided.
	Comparison with published data	Ghana's energy balance published by the International Energy Agency, Ghana National Energy Statistics,

		Strategic National Energy Plan for Ghana, Ghana Living Standard Survey reports.
	Consistency checks of categories and subcategories with totals	Ensuring that disaggregated figures at the category and subcategories levels add up to the overall totals.
	Identify and fix outliers in data inputs (including checking for dips and spikes in the trend)	Data that do not fall in the realistic range and are suspected as inaccurate are excluded and replaced with deemed appropriate from international sources or derived from expert judgment.
	Documentation of all data sources, data format and assumptions for easy reference	Keeping a record of data and assumption at the point used in the datasheet and helped in easy cross-referencing.
	Ensure reduction in data clumsiness or data redundancy	Logical sequence data flow according to the IPCC methodology for the GHG emission estimation was designed for: • easy understanding and further probing of the final IPCC software results. • easy cross-referencing and avoidance of mistakes. • easy transmission into the IPCC software. • aid in better interpretation of the implication of the use of the data.
Emission factors	Check of implied emission factors (time series)	Ensure the consistency check of the use of the emissions factors.
	Double Check with EFDB	To ensure that emission factors being used are the minimum range specified in the IPCC Guidelines.
Calculation by the approved 2006 IPCC software	Cross-checks all steps involved in the calculation.	Ensure that steps used for determining, estimating and deriving data are accurate, transparent and internally consistent.
	Documentation of sources and correct use of units.	Use of the documentation template records all data sources and assumptions.
	Check for transcription, typographical errors and error transposition.	Check mistake and blunders in data entry data into the software
	Checked completeness of data coverage	Ensuring all the relevant gases for the specific activity were covered.
Results (emissions)	Check of recalculation differences	To identify and pinpoint changes, revision and reallocation to improve accuracy and transparency of the estimates
	Identify and fix outliers in the results	checking for dips and spikes in trends and levels
	Check of implied emission factors	Ensure the consistency check of the use of the emissions factors.
Documentation	Assumptions, corrections, data and sources.	Ensure consistency, transparency, facilitate repeatability and easy retrieval
	Improvement list (internal and external findings)	Help prioritise areas that require actions.

3.9.5 Planned improvements in the Energy sector

During the inventory, certain areas were identified for future improvements to ensure building greater confidence in the inventory estimate by reducing uncertainties to the extent possible. Table 62 contains the list of identified planned improvement activities and the necessary next steps that must be taken.

Table 62: Planned improvement activities in the Energy sector

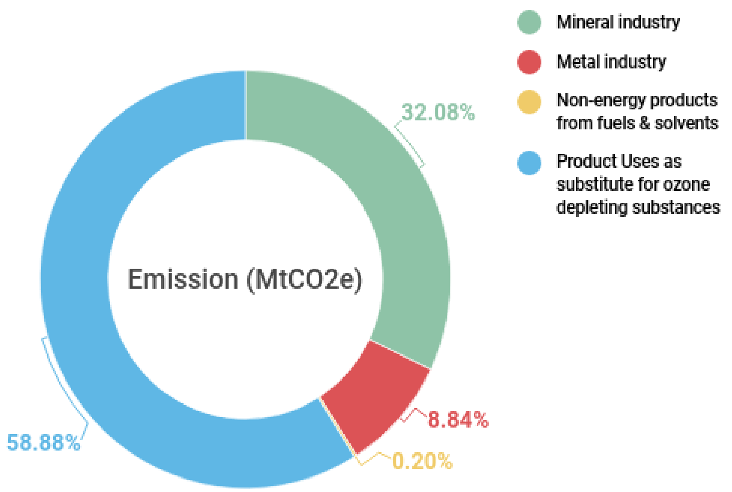
Category	Identification of planned improvement areas	Prioritisation of improvement activities	Responsibility and next steps	Expected time to resolve or comments
1.A1b – Electricity generation	Develop or request IPPs to report on their plant-specific emissions and emission factors or conduct a study.	KC	EPA and Energy Commission.	When funding is made available.
All Categories	Survey to update and review the existing pattern and share of fuel consumption in all sectors of the economy	-	Energy Statistic Team. Energy Commission.	Medium-long term improvement in the reporting in Energy Statistics
1.A3b – Road Transportation	Survey to update the existing 2005 data on fuels allocation to the various vehicle classes.	KC	DVLA, EPA and Energy Commission.	Medium to long term bearing in mind on-going project on roadmap emission and fuel economy standards by 2020.
	Survey to improve the technology-based classification of the vehicle on based EU standards (besides, focus on separating the functional catalytic device).			
	Survey to establish fuel economy baseline for different classes of vehicles		DVLA, EPA and Energy Commission, Private garages.	
	Separate portions of the total fleet are that use for freight transport from passenger transport		Energy Team	Next inventory
1.A3a – Civil aviation	Collect additional ATK consumption, LTO of domestic airlines data from OMCs, Civil Aviation Authority, and the Airlines	Non-KC	Energy Team	Next inventory
	Additional data collection to produce tier 2 estimates – data on domestic air traffic movement (LTO),	Non-KC	Energy Team	Next inventory
1.A3c Railways	Reconcile the Ghana Railway Company's and IEA diesel consumption for rail transport to ensure consistency and transparency.	Non-KC	Energy Team	Next inventory
	Collect additional data from Ghana Railway Company on the following: (a) number of trains in service, (b) annual distances or destinations covered and (c) technologies of the trains	Non-KC	Energy Team	Next inventory
1.B2a.iii.4	undertake a study to assess the quantities of gas flaring at the refinery when funding is made available to the team	Non-KC	Energy Team	When funds are available

Industrial Process and Product Use Sector

IPPU sector GHG emissions Dashboard

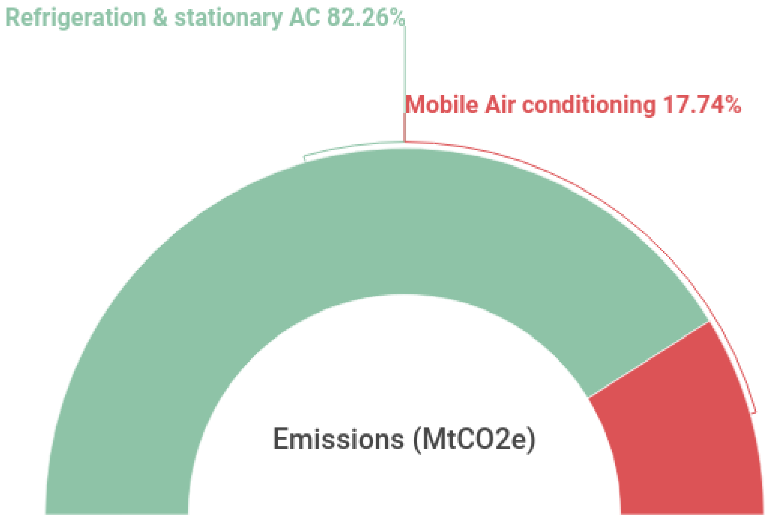
Total 2016 emissions	45.5% more	Emission trends	Major greenhouse gases
1.04 $MtCO_2e$	than 2012 levels	112% more than 1990 levels	HFC = 0.61 Mt (58.9% of all GHGs)

Emission by IPPU category in 2016



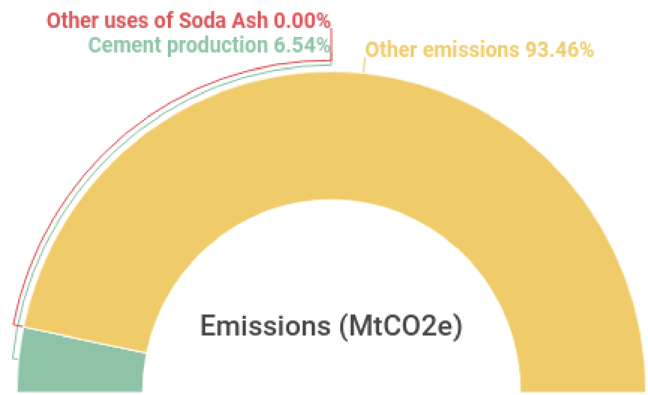
Product Uses as substitute for ODS emission in 2016

0.61 $MtCO_2e$



Mineral industry emissions in 2016

0.33 $MtCO_2e$



Chapter 4
Industrial Process and Product Use sector

4.1 IPPU Emission trends

The total GHG emissions for the IPPU sector were 1.04 $MtCO_2e$ in 2016 and 1.52 $MtCO_2e$ in 2012, representing a decrease of 45.5% on emissions recorded for the year. The emissions trend exhibited upwards from 1990 to 2016 by 111.2%. (Figure 33). HFC emissions from "Product use as a substitute of Ozone-depleting substances" category was the most important GHG in the IPPU inventory. Of the total emissions as at 2016, HFCs emissions was 0.613 $MtCO_2e$ followed by CO_2 0.395 $MtCO_2e$ and PFCs with 0.0033 $MtCO_2e$. The emission constituted a share of 58.9% of HFCs, 37.9% of CO_2 and 3.2% of PFC of the total emissions in 2016. There was a total emission decrease in the sector of 31.3% from 2012 to 2016. Of the individual greenhouse gases, emissions of CO_2 decreased by 27.31%, an increase of 101.5% for PFC and a decrease of 35.85% for HFCs between 2012 and 2016.

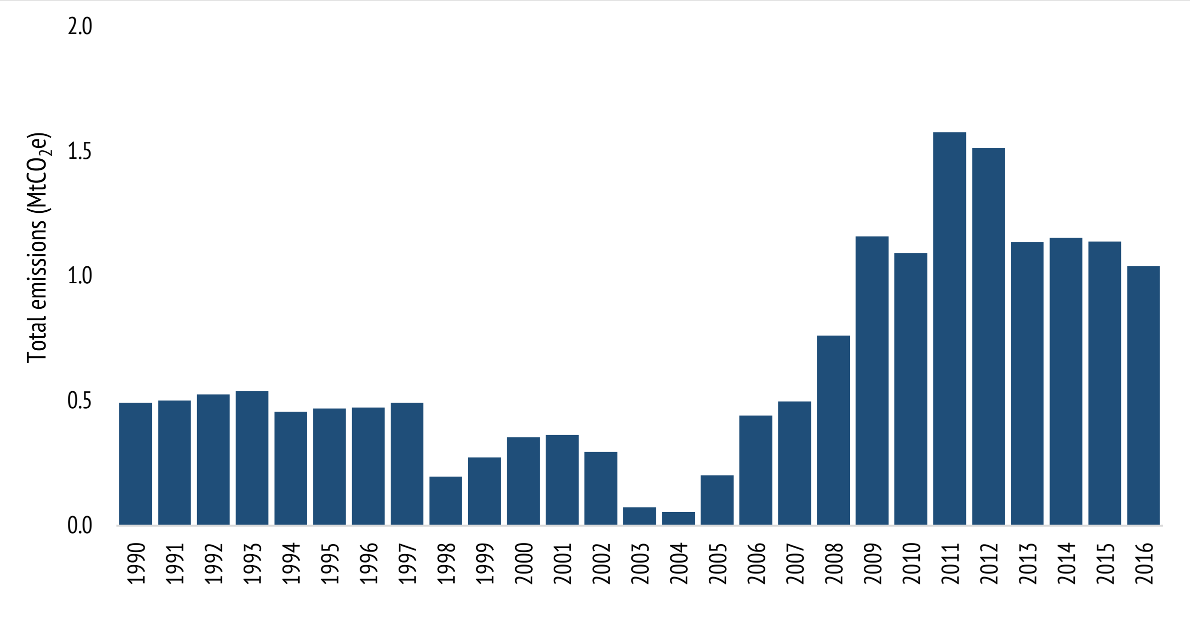


Figure 33: Emissions trends of the IPPU sector for the period 1990-2016

As of 2016, the Mineral product category was the major contributor of CO_2 with emissions mainly from limestone use followed by cement production. Carbon dioxide emissions from the metal industry subcategory mainly from aluminium production. Generally, CO_2 emissions increased largely from 2005 due to limestone used by the cement industry. For aluminium production, CO_2 emissions generally decreased due to the power availability challenges with the plant. Stationary air conditioners are the major source of HFC emissions followed by mobile air conditions, while PFCs emissions are mainly from Aluminium production. In terms of category, Product use as a substitute of Ozone-depleting substances category contributed 58.87%, with 32.09% from the mineral industry, 8.84% from the metal industry and 0.02% from non-energy products.

Compared to 1990 emissions, 64.74%, 27.23%, 7.88% and 0.15% were from Product use as a substitute of Ozone-depleting substances, mineral industry, metal industry and non-energy products categories respectively (Figure 33). There are no other gases from the emissions estimated.

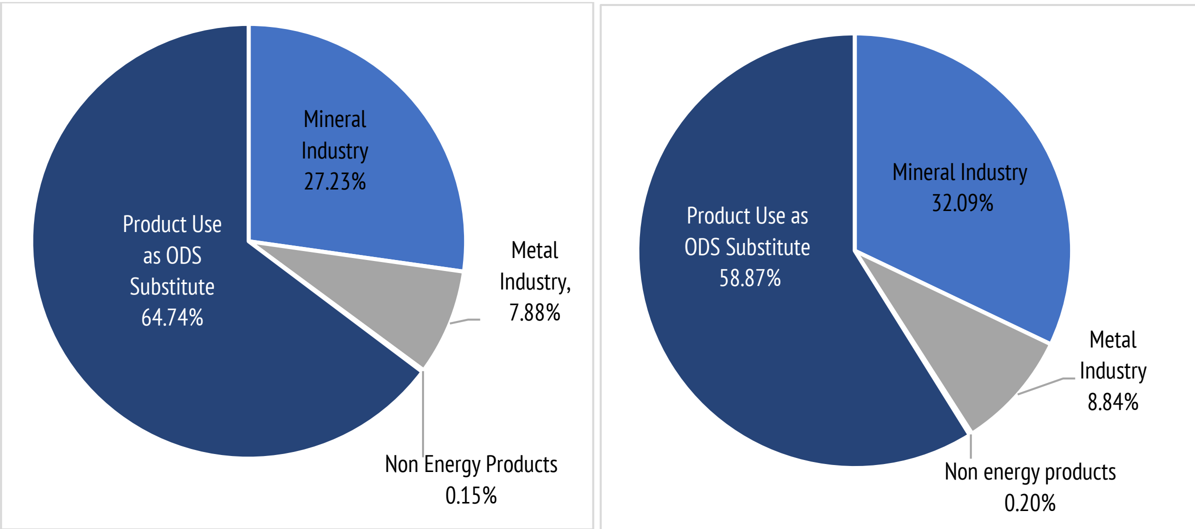


Figure 34: Share of emissions in the IPPU sector 1990 (Left), 2016 (Right)

Within the mineral industry, limestone use, soda ash use, and cement production were the main sources of emissions. Of the three sources, emissions from limestone use dominated throughout the time series. Emissions generally recorded increases from 1990 (14.72 GgCO_2e) to 2012 (476.11 GgCO_2e). Emissions dropped in 2013 rising again until 2016 (312.22 GgCO_2e). The high demand for limestone use in the cement industry contributed to the rise in CO_2 emissions. Limestone use has increased significantly since 1990 largely due to the production of cement for infrastructural activities and the setting up of additional cement plants in-country. Similar increases were recorded for Soda ash use even though emissions were minimal between 1999 and 2008 after which emissions decreased to 2016. Emissions from cement production increased from 2013 to 2016. Carbon dioxide is the main gas from this category. The mineral industry observed increases from 14.76 GgCO_2e in 1990 to 334.08 GgCO_2e in 2016.

Emissions from the metal production category were dominated by aluminium production followed by steel production from steel recycling plants. Emissions from aluminium production decreased from 1990 to 2003 rising slightly until 2016. The decreases in CO_2 emissions due to significant power cuts to the facility. The power cuts eventually resulted in low production activities in 2004, 2009 and 2010. Emissions from the facility started picking up in 2011 following the restoration of limited electricity which enabled the plant to be fully operational. In 1990, 478.12 Gg CO_2e emissions were from aluminium production whiles iron and steel contributed only 0.03 Gg CO_2e while in 2016, 88.18 Gg CO_2e and 3.89 Gg CO_2e were from aluminium and steel production respectively. Under non-energy products from fuels and solvent use, lubricant use was the main source of emissions. The emissions from lubricant use recorded increases from 1992 and peaked in 2004 (2.5 GgCO_2e) before declining to 2.08 GgCO_2e in 2016. HFC emissions from Product Uses as Substitutes for Ozone Depleting Substances dominated emission from 2005.

Emissions from refrigeration and AC subcategory dominated HFC emissions followed by Mobile AC. Emissions peaked at 2011 (1049.23 Gg CO_2e) and gradually decreased to 613 Gg CO_2e in 2016. HFC emissions were the largest source of greenhouse gases reported during the period 2005-2016 and followed by CO_2 emission from the mineral industry and PFC from aluminium production. For CO_2 emissions, the metal industry (aluminium production) consistently remained the dominant source until 2003, when CO_2 emissions from the mineral industry (Limestone use) rose to high levels (Table 63).

Table 63: Total emission trends according to different gases

Year	CO_2 [$MtCO_2e$]	PFCs [$MtCO_2e$]	HFC[$MtCO_2e$]	Total [$MtCO_2e$]
1990	0.29	0.20	-	0.49
1991	0.30	0.21	-	0.50
1992	0.30	0.22	-	0.53
1993	0.32	0.22	-	0.54
1994	0.30	0.16	-	0.46
1995	0.30	0.17	-	0.47
1996	0.29	0.19	-	0.47
1997	0.29	0.21	-	0.49
1998	0.13	0.07	-	0.20
1999	0.19	0.08	-	0.27
2000	0.29	0.07	-	0.36
2001	0.31	0.05	-	0.36
2002	0.24	0.06	-	0.30
2003	0.07	0.01	-	0.07
2004	0.05	-	-	0.05
2005	0.14	0.01	0.06	0.20
2006	0.30	0.02	0.12	0.44
2007	0.29	-	0.20	0.50
2008	0.40	-	0.36	0.76
2009	0.34	-	0.82	1.16
2010	0.40	-	0.70	1.09
2011	0.52	0.01	1.05	1.58
2012	0.54	0.02	0.96	1.52
2013	0.27	0.02	0.86	1.14
2014	0.38	0.03	0.75	1.16
2015	0.40	0.05	0.69	1.14
2016	0.39	0.03	0.61	1.04

4.2 Overview of the Industrial Process and Product Use Sector

Emissions from industrial processes are generated from several processes and a range of often diffuse sources. It is produced as the by-products of various non-energy-related industrial activities. These emissions are produced from industrial processes and are not directly by virtue of energy consumption in the process. For example, material transformation can result in the release of gases such as CO_2, CH_4, and N_2O. Majority of the

IPPU activities that were covered included those relating to the: (a) mineral industry, (b) metal industry, (c) Non-Energy Products from Fuels and Solvent Use and d) Product Uses as Substitute for Ozone Depleting Substances. The rest of the activities under IPPU have not been included in the inventory because those activities do not take place in Ghana (Table 64). Therefore, emissions from Electronics Industry and Other Product Manufacture and Use categories have not been accounted for as they are not occurring in the country (Table 64). The CO_2, PFCs (CF_4 and C_2F_6) and HFCs were the main direct greenhouse gases estimated and reported.

4.3. Summary of IPPU Sector Activities

The overview of IPPU sector activities and their emissions are in Table 64. Below is the additional information on the description of the IPPU activities occurring in Ghana.

Table 64: Overview of total emissions estimate for IPPU sector Activities

Greenhouse Gas Source and Sink Categories	2012						2016					
	$MtCO_2e$						$MtCO_2e$					
	CO_2	CH_4	N_2o	PFC	HFC	Total	CO_2	CH_4	N_2o	PFC	HFC	Total
2 Industrial Processes and Product Use	0.543	NO	NO	0.017	0.956	1.515	0.395	NO	NO	0.033	0.613	1.041
2.A - Mineral Industry	0.476	NA	NA	NA	NA	314.6	0.334	NA	NA	NA	NA	0.334
2.B - Chemical Industry	NO	NO	NO	NA	NA	NO	NO	NO	NO	NA	NA	NO
2.C - Metal Industry	0.065	NO	NO	0.017	NA	91	0.059	NO	NO	0.033	NA	0.092
2.D- Non-Energy Products from Fuels and Solvent	0.002	NA	NA	NA	NA	1.71	0.0021	NA	NA	NA	NA	0.0021
2.E – Electronics Industry	NA	NA	NA	NO	NA	NO	NA	NA	NA	NO	NA	NO
2.F – Product Uses as a Substitute for Ozone Depleting Substances	NA	NA	NA	NO	0.956	747.9	NA	NA	NA	NO	0.613	0.613
2.G - Other Product Manufacture and Use	NA	NA	NO	NO/ NE	NA	NO	NA	NA	NE	NE	NA	NE

4.4 Overview of Emissions for the IPPU sector

4.4.1 Aggregate IPPU sector emissions trend

The total greenhouse gas emissions for the IPPU sector were 1.04 $MtCO_2e$ in 2016 and 1.52 $MtCO_2e$ in 2012, representing a decrease of 45.54% on emissions recorded from 2012 to 2016. HFC was the most important GHG in the IPPU sector in 2016. HFCs emissions were 0.613 $MtCO_2e$ followed by CO_2 of 0.395 $MtCO_2e$ and PFCs with 0.033 $MtCO_2e$ (Table 64). The emissions constituted a share of 58.87% of HFCs, 37.93% of CO_2 and 3.2% of PFC of the total emissions. There was a total emission decrease of 31.3% from 2012 to 2016 in the sector. Carbon dioxide and HFC emissions decreased by 27.3% and 35.9% respectively, whereas PFC increased by 101.5% for the period 2012-2016.

4.4.2 Emission trends by sources and gases

Mineral product category was the major contributor to CO_2 in 2016. The emissions were mainly from "limestone use" and cement production. Carbon dioxide emissions from the metal industry sub-category were mainly from Aluminium production. Generally, CO_2 emissions increased largely from 2005 due to increased limestone use by the cement industry. The additional increase was seen with the emissions from cement production from 2004 with clinker production from one cement plant established to produce clinker. For Aluminium production, CO_2 emissions generally decreased across the time series due to the power availability challenges with the plant. Stationary air conditioners were the major source of HFC emissions followed by mobile air conditioners while PFCs emissions were mainly from Aluminium production.

The observed annual increases in the emissions for each category was driven by HFC use in the refrigeration and stationery air-conditioning sector after 2005. Before 2005, CO_2 from Aluminium production under the Metal Industry category drove emissions in the sector. Between 2005 and 2011, HFC emissions increased largely due to high imports of HFCs based refrigerants equipment's and gas due to the Hydrochlorofluorocarbon (HCFCs) phased out programme until 2011 and decreased after that towards 2016. The decrease was mainly due to the conversion of HFC based ACs to hydrocarbon-based air conditioners from 2012 which was necessitated by the phase-down schedules of HCFCs under the Montreal protocol and initiated by the national ozone office. Additionally, with the high imports of HFCs based refrigerants equipment's and gas, most of them were not completely utilised, and these served as stocks in subsequent years while imports and consumption reduced.

Limestone use in the cement industry gradually increased from 1990 as production went up through to 2004 where emissions went up till 2016. From 2013 to 2016 under mineral production emissions from cement production also contributed to increases in the subcategory. Changes from steel production and lubricant use and soda ash use are minor (Figure 35). HFC emissions were the largest source of greenhouse gases reported during the period 2005-2016. CO_2 emission from the mineral industry and PFC from aluminium production is the next highest. For CO_2 emissions, the metal industry (aluminium production) consistently remained the dominant source until 2003, when CO_2 emissions from the mineral industry (Limestone use) increased significantly (Figure 35).

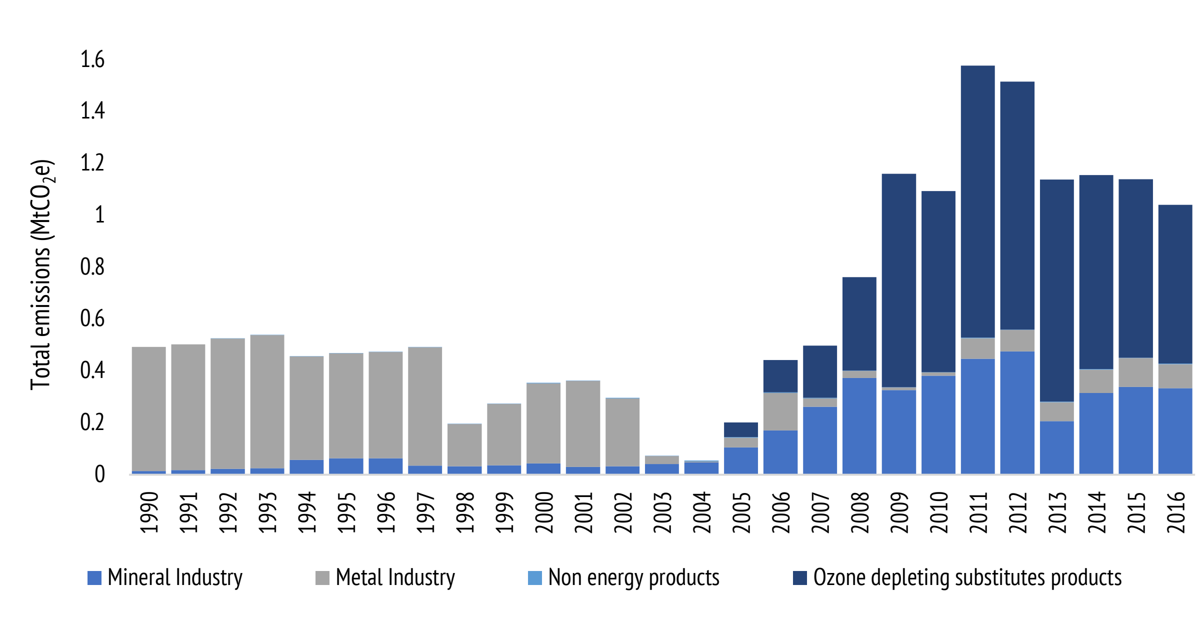


Figure 35: Share by sub-category of the total IPPU emissions

4.4.3 IPPU sector Data sources and Methodology

The description of data sources and methodology used in the inventory for the IPPU sector is below.

4.4.3.1 Data sources in IPPU

The data used in this inventory were obtained from different relevant national sources. Table 65 provides an overview of the data used in the inventory.

Table 65: Overview of the data used in the inventory

Categories	Subcategory		Data types	Data sources	Data providers
2A Mineral Industry	2A1 Cement Production		Mass of Clinker produced, Type of clinker.	Data collected from Plant	Savannah Diamond Cement
	2A4 Other Process Uses of Carbonates	2A4b Other Uses of Soda Ash	Amount of carbonate consumed	Soda ash use data from plants	Private Companies
		2A4d Other (Limestone Use in Cement Production)	Amount of carbonate consumed	Cement Plants	GHACEM, Savannah Diamond Cement plants
2C Metal Industry	2C1 Iron and Steel Production		Amount of steel produced	Steelmaking plants	
	2C3 Aluminium Production		Amount of Aluminium produced, plant EF CO_2, CF_4, $C2F_6$, Anode effect per cell-day.	Aluminum Plant	Volta Aluminium Company
2D Non-Energy Products from Fuels and Solvent Use	2D1 Lubricant Use		Lubricant consumption	Lubricant plant	Plant Data

2F Product Uses as Substitutes for Ozone Depleting Substances	2F1 Refrigeration and Air Conditioning	2F1a Refrigeration and Stationary Air Conditioning	F-gas imports	EPA	National Ozone Unit at EPA, Customs

4.4.4 Description of notation keys and completeness information in IPPU

Information on completeness and use of notation keys in the IPPU sector are provided below. Completeness includes coverage of gases, categories and as well as time series. Additional information is given on the status of emission estimates of all sub-categories. Table 66 contains information on the completeness status of the estimations under various sub-categories.

Table 66: Notation keys and status of emission estimations in IPPU categories

IPCC Category	Time series Completeness									Status of Gas				
	1990-2012 (recalculations)				2013-2016 (latest estimates)									
	IE	E	NE	NO	IE	E	NE	NO	IE	CO_2	CH_4	N_2O	PFC	HFC
Cement Production				X		X				X	NO	NO	NA	NA
Other Process Uses of Carbonates		X				X				NO	NO	NO	NA	NA
Iron and Steel Production		X				X				X	NO	NA	NA	NA
Aluminium Production		X				X				X	NA	NA	X	NA
Lubricant Use		X				X				X	NA	NA	NA	NA
Refrigeration and Air Conditioning		X				X				NA	NA	NA	NA	X

X – applicable to the notation key or gas stated in the header

4.4.5 Description of source-specific emission trends

4.4.5.1 Mineral Industry (2A)

Emissions from the mineral industry are mainly process-related carbon dioxide emissions resulting from the use of carbonate as raw materials in the production and use of a variety of mineral industry products. Two main pathways release CO_2 from carbonates: calcination and the acid-induced release of CO_2. In Ghana, the primary process resulting in the release of CO_2 is the calcination of carbonate compounds, during which, through heating, a metallic oxide is formed. Under mineral industry, the use of carbonates as basic raw materials having commercial applications in industries where carbonates are consumed in metallurgy is also key (e.g., iron and steel), agriculture, construction and environmental pollution control (e.g., flue gas desulphurisation.).

Four broad source categories are considered under carbonate use, and these include ceramics, other uses of soda ash, non-metallurgical magnesia production, and other uses of carbonates. Soda ash use in industry has been considered while the lack of data has not made it possible to estimate emissions under ceramics. Limestone use under cement production and reducing agents in the steel industry have been reported in their respective sources of use under other uses of carbonates.

From Figure 36, emissions from mineral production marginally increased from 1990 until 2005 when there were substantial increases until 2012 after which there was a sharp drop to 2013 and subsequent increase until 2016. The increase has mainly been due to an increase in limestone use in cement production. It also applies to the reduction from 2012 to 2013, where cement production decreased. Emissions from cement production with the production of clinker have been estimated from 2013 to 2016 from one cement producing plant.

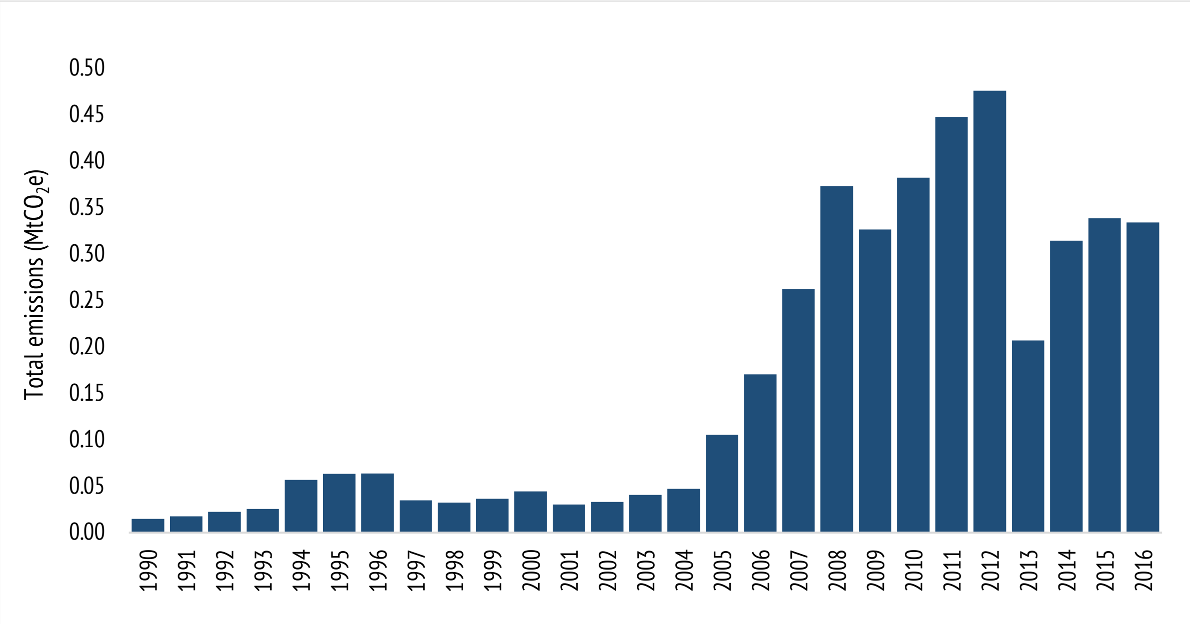


Figure 36: Mineral industry category emissions

In 1990, limestone use in the cement industry contributed 99.7% of emissions under the mineral industry, followed by Soda ash use with 0.3%. In 2016 Limestone use contributed 93.5% of emissions followed by cement production with 6.5% and lastly soda ash use with 0.005% (Figure 34).

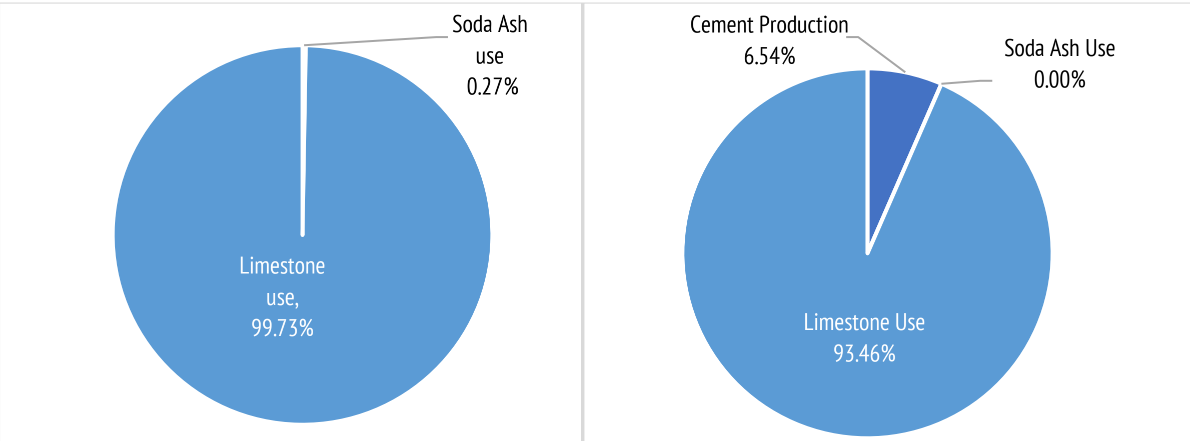


Figure 37: Share of emissions for the mineral industry in 1990 (left) and 2016 (right)

4.4.5.2 Cement Production (2.A.1)

Cement manufacture is an energy-intensive process where CO_2 is produced during the production of clinker, an intermediate product which is then finely ground, along with a small proportion of calcium sulphate (gypsum ($CaSO_2O$)) or anhydrite ($CaSO_4$), into Portland cement. During the cement production process, calcium carbonate ($CaCO_3$) is heated in a cement kiln at a temperature of about 1,450°C (2,400°F) to form lime (i.e., calcium oxide or CaO) and CO_2 in a process known as calcination or calcining. Portland cement was produced in Ghana from four cement producing plants. Two of the plants import clinkers where its manufacture generates significant amounts of CO_2 and is the primary step in cement production. These plants primarily mill the imported clinker with limestone, and therefore the actual CO_2 emissions are from the uses of limestone, which has been estimated under Other Process Uses of Carbonates (2A4). One plant only imports already produced cement for bagging. Beginning in 2013, one plant started the production of clinker for its use in the country. Emissions from cement production increased from 2013 to 2016. In 2016, 21.847 $GgCO_2e$ was emitted from the manufacture of cement (Figure 38)

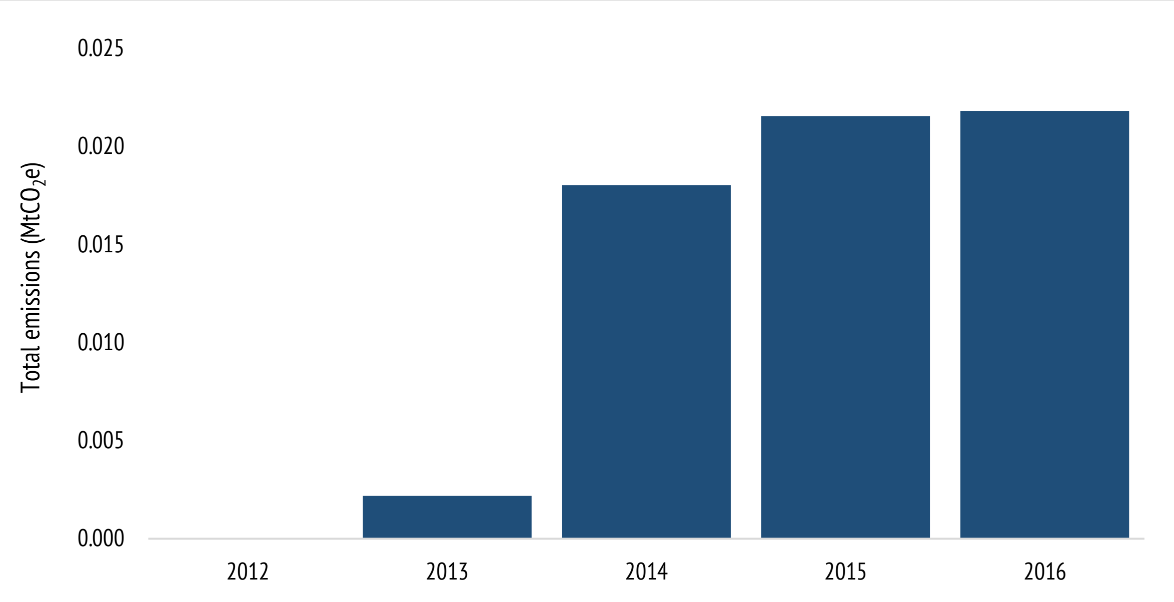


Figure 38: Cement production emissions between 2012 and 2016

4.4.5.3 Other Process Uses of Carbonates (2A4)

4.4.5.3.1 Ceramics (2. A4a)

Ceramics include the production of bricks and roof tiles, vitrified clay pipes, refractory products, expanded clay products, wall and floor tiles. Process-related emissions from ceramics result from the calcination of carbonates in the clay. Carbonates are heated to high temperatures in a kiln, producing oxides and CO_2. The ceramic industry is particularly for bricks and roof tiles which is quite common in Ghana. However, because of lack of data emissions have not been estimated from the subcategory. An initial survey conducted on the use of clay in the Ashanti Region revealed the clay type used as kaolin.

4.4.5.3.2 Other Uses of Soda Ash (2. A4b)

Soda ash is used in a variety of applications such as glass production, soaps and detergents, flue gas desulphurisation, chemicals, pulp and paper and other common consumer products. Soda ash production and consumption (including sodium carbonate, Na_2CO_3) results in the release of CO_2 emissions. Soda ash consumption has been reported for some industrial undertakings such as soap and detergents and the textile industry. In 2016, emissions from the sub-category were 0.015 $GgCO_2e$ which is below the 1990 level of 0.040 Gg CO_2e. Emissions from soda ash consumption increased gradually from 1990 to 2008 after which it decreased gradually until 2016. The observed increase was due to the increase in the productive use of soda ash. On the hand, the reduction in the emission between 2008 and 2016 was because some beverage industries that relied on Soda Ash stopped the use of the product (Figure 39). There has also been a decrease in use by the textile industry.

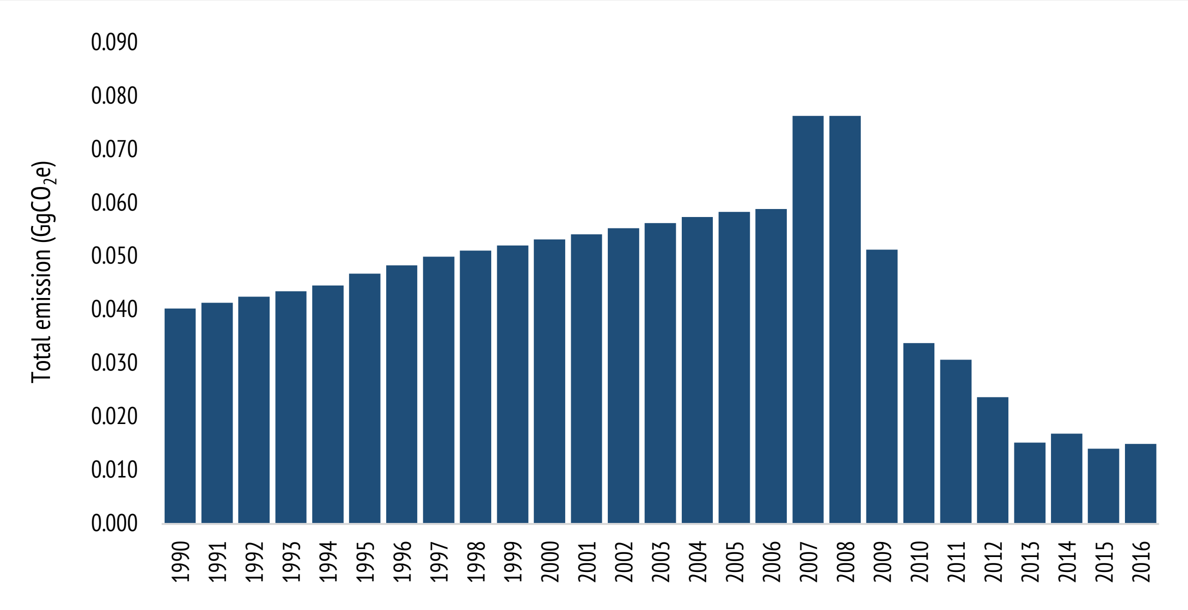


Figure 39: Soda Ash use emissions for the period 1990-2016

4.4.5.3.3 Other (Limestone and Dolomite use) (2A4d)

Emissions may result from many other source categories. According to the 2006 guideline, emissions from Limestone use are reported under the source from which they are used. Limestone use in the cement and steel making industry as a flux has been reported accordingly. Limestone ($CaCO_3$) and dolomite ($CaCO_3MgCO_3$) are basic raw materials used by a wide variety of industries, including construction, agriculture, chemical, metallurgy, glass production, and environmental pollution control. Deposits of limestone occur in some parts of Ghana, and significant quantities are extracted for cement industrial application. For this application, limestone is heated sufficiently enough to calcine the material and generate CO2 as a by-product. Other applications include limestone used as a flux in metallurgical furnaces for the iron and steel industrial plants. The total limestone consumption 1, 082,771 tonnes in 2012 to 710,056.91 tonnes in 2016 (Table 67). Carbon dioxide emissions from limestone use in the cement industry and steel industry have been slightly increasing from 1990 with 0.0015 $MtCO_2e$ to 1994 when it had remained stable until 2005 when emissions increased until 2012 (Figure 40).

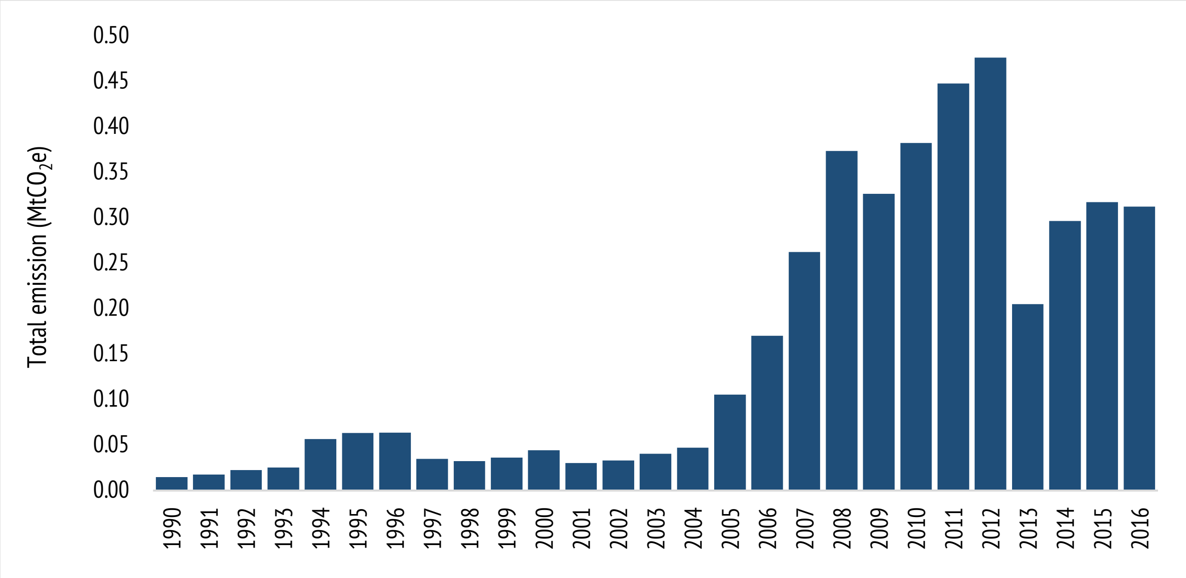


Figure 40: Limestone use emission trends for the period 1999-2016

From 2013, emissions dropped but started increasing 0.0312 $MtCO_2e$ in 2016. Data have been obtained from the cement making plants directly (Figure 40). Some cement industry has recently used small amounts of dolomite; however, data have not been available for the emission estimation.

Table 67: Annual limestone consumption in Ghana in Metric Tons

Year	Limestone Quantity (Mt)
1990	33,472.85
2005	239,616
2006	387,287
2007	596,512.81
2008	849,059.92
2009	742,304.11
2010	869,488.02
2011	1,018,102.32
2012	1, 082,771
2013	466,163.47
2014	674,449.86
2015	720,940.93
2016	710,056.91

4.4.5.4 Chemical Industry (2B)

Emissions from the chemical category are basically from the production of some chemicals with the resultant emissions of greenhouse gases. In Ghana, the production of chemicals by the chemical industry is non-existent and that GHG emissions are not occurring and hence not estimated.

4.4.5.5 Metal Industry (2C)

The metal industry covers emissions from iron and steel, and metallurgical coke production; ferroalloy production; aluminium production; magnesium production; lead production; and zinc production. Under this category, emissions have been reported for Aluminium production and iron and steel. Under the iron and steel, primary production of iron does not occur, and therefore emissions have only been reported for steel recycling.

Total emissions from metal production decreased from 1990 to 2003 rising slightly from 2011 until 2016. The decreases in CO_2 emissions from the metal industry were associated with the consistent decline in the only aluminium production plant due to significant power cuts to the facility over time resulting in no production activities in 2004, 2009 and 2010. Emissions from the facility started picking up in 2011 when production resumed following the restoration of limited electricity to the plant to be fully operational. Emissions decreased from 0.478 $MtCO_2e$ in 1990 to 0.092 $MtCO_2e$ in 2016 (Figure 41).

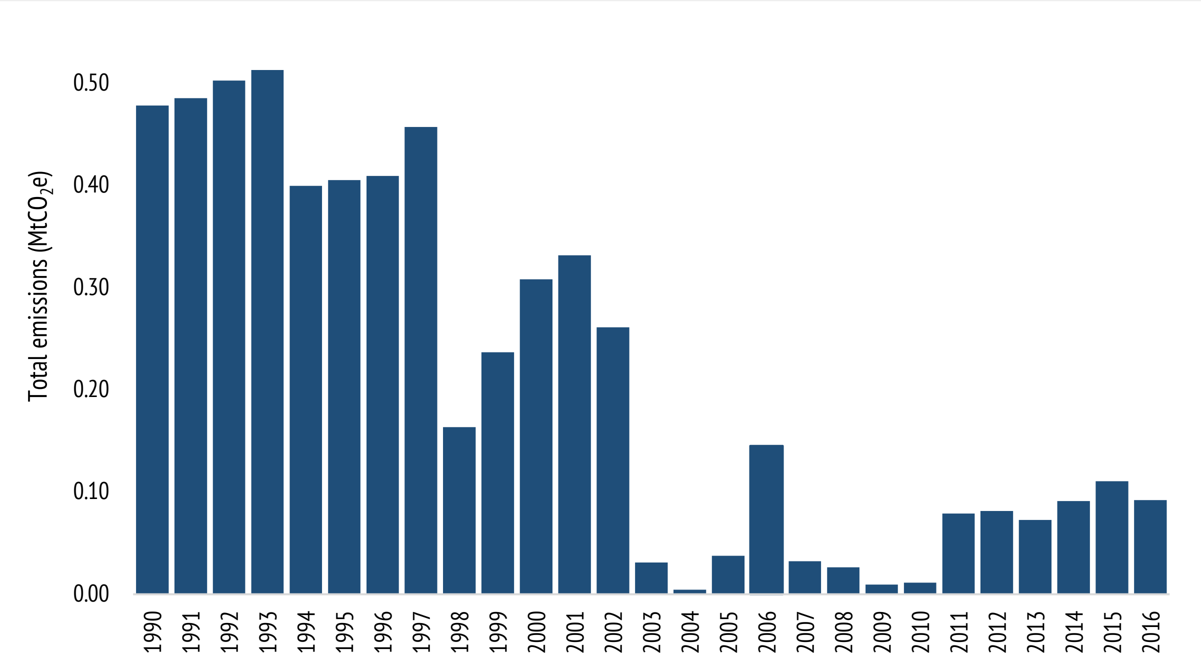


Figure 41: Trend of total emissions in the Metal Industry

Emissions from metal production were dominated by Aluminium production followed by steel production from steel recycling plants. Emissions from Aluminium are contributed by CO_2 and PFC. In 1990, 478.1 $GgCO_2e$ emissions were from Aluminium production whereas iron and steel contributed only 0.03 Gg CO_2e while in 2016, 88.2 $GgCO_2e$ and 3.89 $GgCO_2e$ were from Aluminium and steel production respectively (Figure 42).

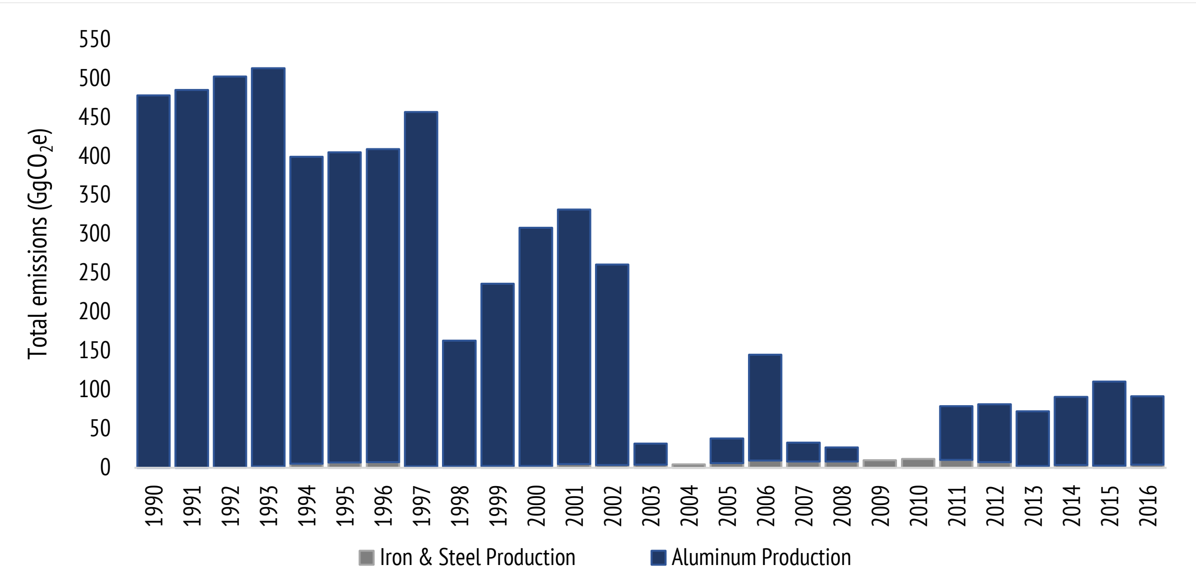


Figure 42: Metal industry emission trends by sub-category

In terms of gases, a share of 42.1% of emissions from PFC in aluminium production was emitted in 1990 while 57.95 came for the emission of carbon dioxide. In 2016, the share of PFC emissions reduced to 36.2% while the share of carbon dioxide emissions increased to 63.8% (Figure 43).

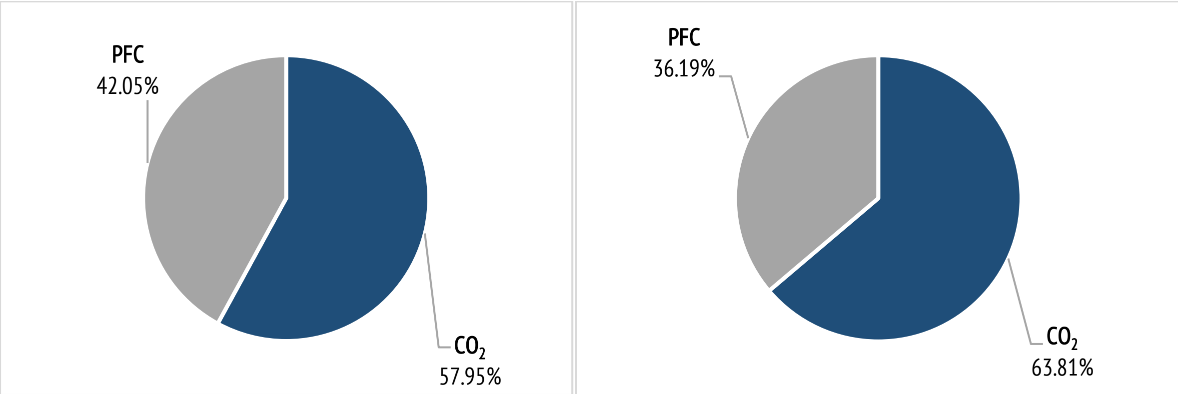


Figure 43: Share of emissions from the metal industry for 1990 (left) and 2016(right)

4.3.5.5.1 Iron and Steel Production (2C1)

The production of iron and steel is an energy-intensive activity that also generates process-related emissions of CO_2 and CH_4. Process emissions occur at each step of steel production from the production of raw materials to the refinement of iron to the making of crude steel. Primary production using a Basic Oxygen Furnace (BOF) with pig iron as the primary feedstock is usually the dominant method. But secondary production using scrap steel and Electric Arc Furnaces (EAFs) also occurs for steel recycling, which has been driven by the increased availability of scrap steel. Iron is produced by first reducing iron oxide (iron ore) with metallurgical coke in a blast furnace. Iron can be introduced into the blast furnace in the form of raw iron ore, briquettes, or sinter. Pig iron or crude iron is produced from this process. The pig iron production process in a blast furnace produces CO_2 emissions and fugitive CH_4 emissions.

Steel is produced from varying levels of pig iron and scrap steel in specialised BOF and EAF steel-making furnaces. Carbon inputs to BOF steel-making furnaces include pig iron and scrap steel as well as natural gas, fuel oil, and fluxes (e.g., limestone, dolomite). Carbon dioxide emissions occur in BOFs through a reduction process resulting primarily from the consumption of carbon electrodes and from the consumption of supplemental materials used to augment the melting process. Steel production in Ghana is mainly secondary steelmaking from scrap recycling using EAF. No primary activity with the production of pig iron occurs in the country. The ferrous metals are melted using heat produced from electricity through the graphite electrode of an EAF. To maintain the silicon and manganese levels, Ferro-silicon and ferromanganese are added. Metallurgical refining to remove impurities as slag is achieved with the aid of fluxes (oyster, limestone, activated carbon). The molten metal is converted into ingots or square billets which are reheated in the reheating furnace and rolled into iron rods. Data used in the calculations were obtained from four scrap recycling companies.

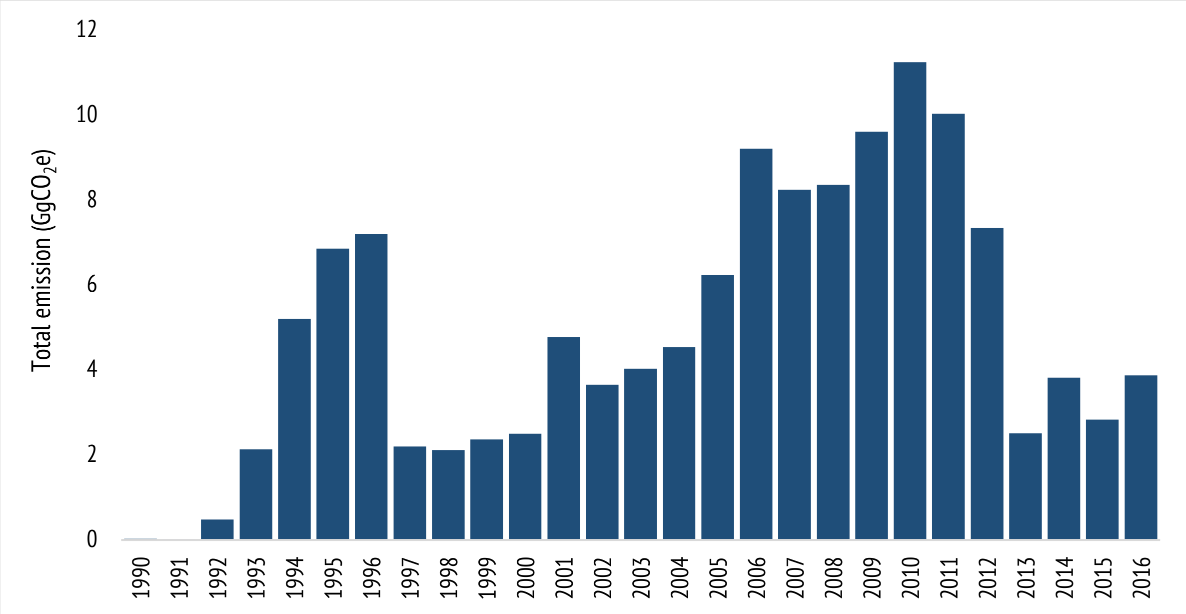


Figure 44: Total Emissions from Iron and steel industry

Figure 44 above shows a general increase in CO_2 emission from 1990 till 2010, after which there was a decreasing trend. The decrease could be due to the unavailability of scrap because of export to other countries. One industry was completely shut down in 2013, and that could account for the extremely low emission levels recorded. The low emission years could also be times that the export activity was high. Emissions as of 2016 were 3.87 $GgCO_2e$ while 0.03 $GgCO_2e$ was emitted in 1990.

4.3.5.5.2 Aluminium Production (2C3)

Aluminium is a light-weight, malleable, and corrosion-resistant metal that is used in many manufactured products, including aircraft, automobiles, bicycles, and kitchen utensils. The production of primary aluminium results in process-related emissions of CO_2 and two perfluorocarbons (PFCs): perfluoro methane (CF_4) and perfluoro ethane (C_2F_6). CO_2 is emitted during the aluminium smelting process when alumina (aluminium oxide, Al_2O_3) is reduced to aluminium using the Hall-Heroult reduction process. The reduction of the alumina occurs through electrolysis in a molten bath of natural or synthetic cryolite (Na3AlF6). During reduction, most of the carbon is oxidized and released to the atmosphere as CO_2. In Ghana, only the Centre-Worked Prebake (CWPB) alumina feed system is available at the only aluminium production plant. There was no production in 2004, 2009 and 2010 due to unavailability of electricity. Production of aluminium in the country involves anode production where petroleum coke, pitch and butts are used to produce anodes for the reduction cells. The molten aluminium produced is further processed and cast into a variety of products including sows, billets, ingots.

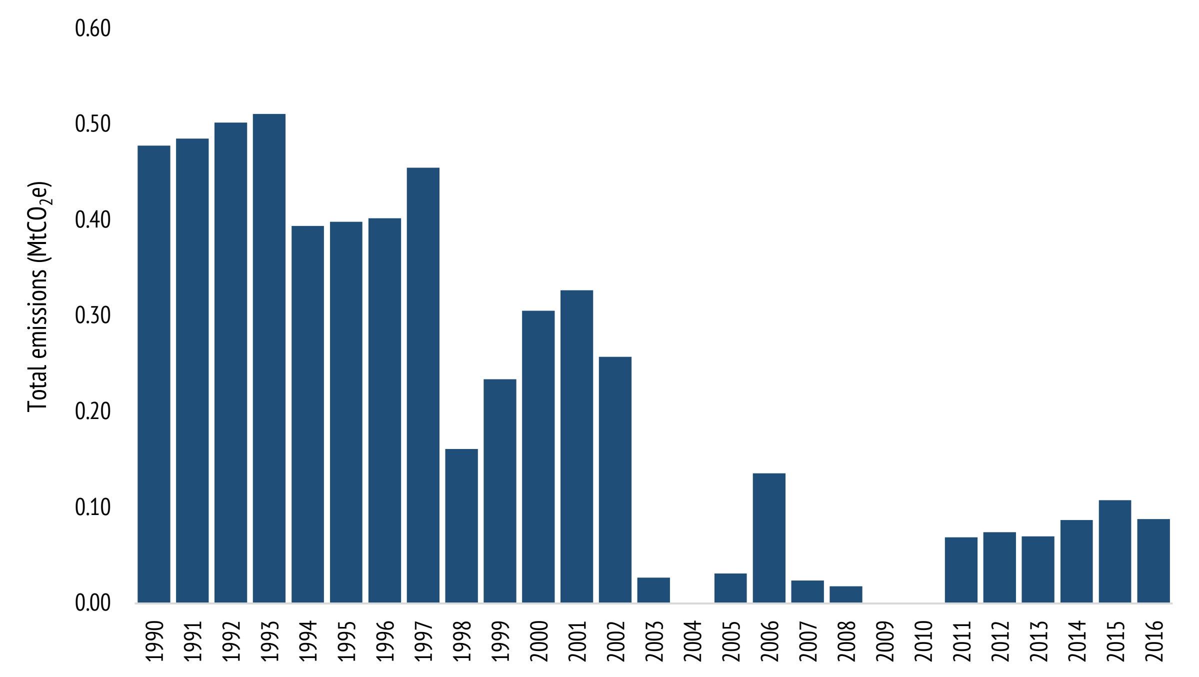


Figure 45: Trends in total emissions from Aluminum Production

Generally, emission from aluminium production shows a declining trend because production has not been stable due to unavailability of adequate electricity supply (Figure 46). Given the electricity-intensive nature of the operations, the industry is unable to operate when supply is not adequate and accounted for the no production in 2009 and 2010 when the nation was confronted with acute power supply. Total emissions as of 2016 were 0.009 $MtCO_2e$ while in 1990, the total emissions from aluminium production were 0.48 $MtCO_2e$ (Figure 46).

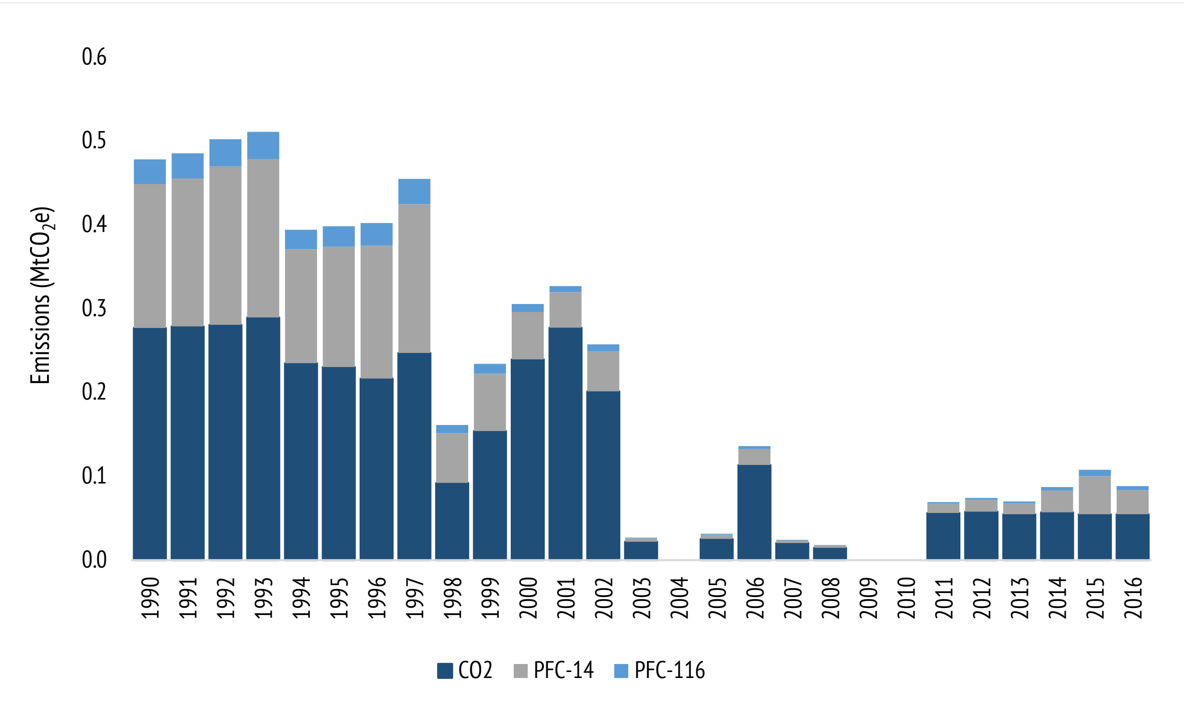


Figure 46: Emissions trends for the Aluminum Production by gases

Most of the emissions released during aluminium production occurred during the electrolysis reaction of the carbon anode. Figure 47 indicates that emissions from CO_2 contributed more to the total emissions followed by CF_4 while emission from C_2F_6 was the least contributor to the total emission from aluminium production. As of 2016, 62.2% of emissions were from CO_2 while 32.3% and 5.5% emissions were from CF_4 and C_2F_6 respectively. About 37.8% of emissions are from PFC (Figure 47).

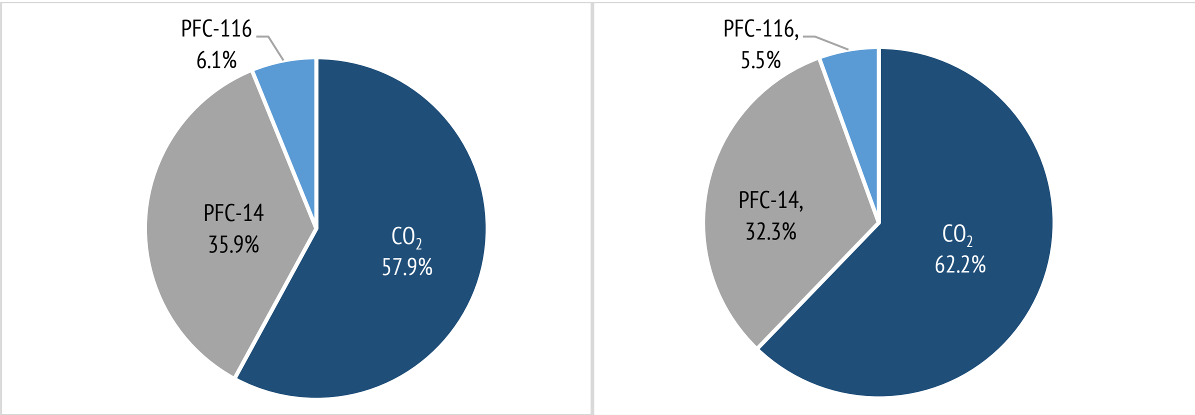


Figure 47: Emission by Gas from Aluminum production for 1990 (left) and 2016 (right)

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

4.3.5.6.1 Lubricant Use (2.D1)

Lubricants are mostly used in industrial and transport applications to reduce friction in machinery parts and also protect internal combustion engines in motor vehicles and powered equipment. Lubrication helps to reduce friction, surface fatigue, heat generation, noise and vibrations. Lubricants are produced either at refineries through separation from crude oil or at petrochemical facilities. Lubricants are subdivided into two: (a) motor oils and industrial oils, and (b) greases, which differ in terms of physical characteristics (e.g. viscosity), commercial applications, and environmental fate.

It is difficult to determine which fraction of the lubricant consumed in machinery and vehicles is actually combusted and thus directly results in CO_2 emissions, therefore, for calculating CO_2 emissions the total amount of lubricants lost during their use is assumed to be fully combusted, and these emissions are directly reported as CO_2 emissions. There is only one known industry in Ghana operating since 1992 to produce lubricants including engine oils, hydraulic oils, gear oils and industrial oil under franchise for distribution by the OMCs. The main raw materials (base oils and additives) are imported. Production activities are mainly blending of the materials to meet the required standard.

Production data was available from the company; however, in calculating emissions estimates, it was assumed that all motor oil produced by the company in a particular year was consumed in that same year. The trend depicted in figure 48 below shows a general increase in CO_2 emissions. The fluctuating levels recorded from 2004 was because of the reduction in orders received from the oil marketing companies (which could mean an increase in import quantities) and power outages. As of 2016, 2.08 $GgCO_2e$ was emitted while 1.06 $GgCO_2e$ was emitted in 1990.

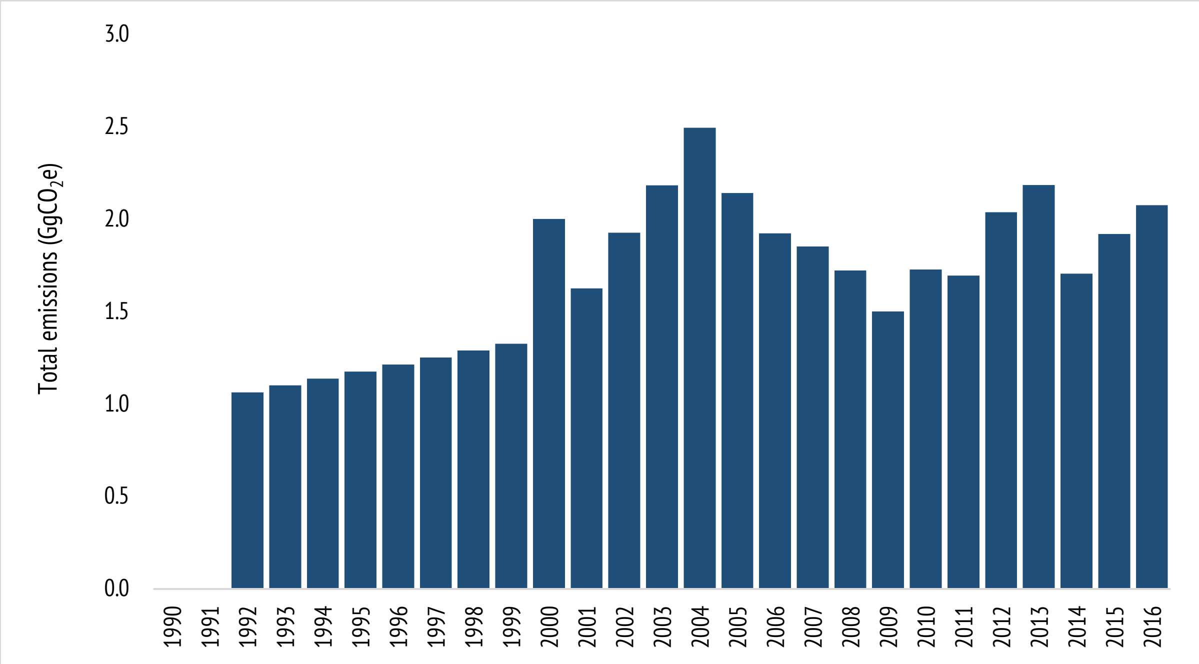


Figure 48 Total emissions from lubricant use from 1990 to 2016

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

Hydrofluorocarbons and perfluorocarbons serve as alternatives to ozone-depleting substances (ODS) being phased out under the Montreal Protocol. Until the inception of the Kigali Amendment to the Montreal Protocol, HFCs and PFCs were not controlled by the Montreal Protocol because they did not contribute to the depletion of the stratospheric ozone layer. However, HFCs and PFCs have high global warming potentials and are potent greenhouse gases; in the case of PFCs, they have long atmospheric residence time. Ozone-depleting substances—chlorofluorocarbons (CFCs), halons, carbon tetrachloride, methyl chloroform, and hydrochlorofluorocarbons (HCFCs)—are used in a variety of industrial applications including refrigeration and air conditioning equipment, solvent cleaning, foam production, sterilization, fire extinguishing, and aerosols.

Emissions have been estimated from imports of HFCs into the country for use in the refrigeration and mobile air-conditioning sectors. HFC-32, HFC-125, HFC-134a and HFC-143a are the gases in use for the refrigeration and stationary air conditioning subcategory while HFC-143a was used in mobile air-conditioning. Emissions have been estimated from 2005 to 2016. As of 2016, a total of 613 GgCO_2e was emitted from the Product Uses as Substitutes for Ozone Depleting Substances category. Of the total 2016 emissions, 82.46% came from the refrigeration and stationary air conditioning while 17.54 % was from mobile air-conditioning categories, respectively (Figures 49 and 50). The products that were used as substitutes for ozone-depleting substances emission grew from 0.057 MgCO_2e in 2005 to 0.61 MtCO_2e in 2016, representing 46.1% over the period (Figure 15).

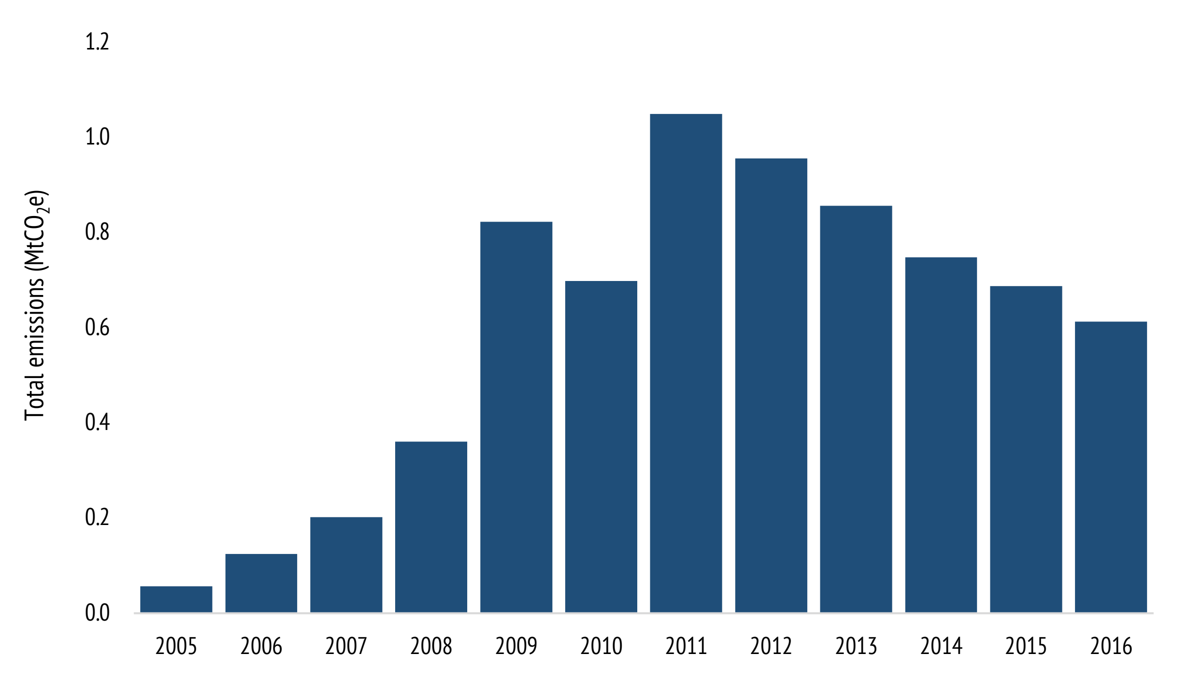


Figure 49: Total Emissions from product uses as a substitute for ODS from 2005 to 2016

Products used as substitutes for ozone-depleting substances consist of HFC-32, HFC-125, HFC-134a and HFC-143a gases which are all emitted under the refrigeration and stationary air condition subcategory. The MAC sector, however, only uses HFC-134a gas. The refrigeration and air conditioning GHG emissions share were 0.51 $MgCO_2e$ for 2016, representing 82.4%. Of the total emissions, the MAC sector accounted for 17.6% for 2016 (Figure 50).

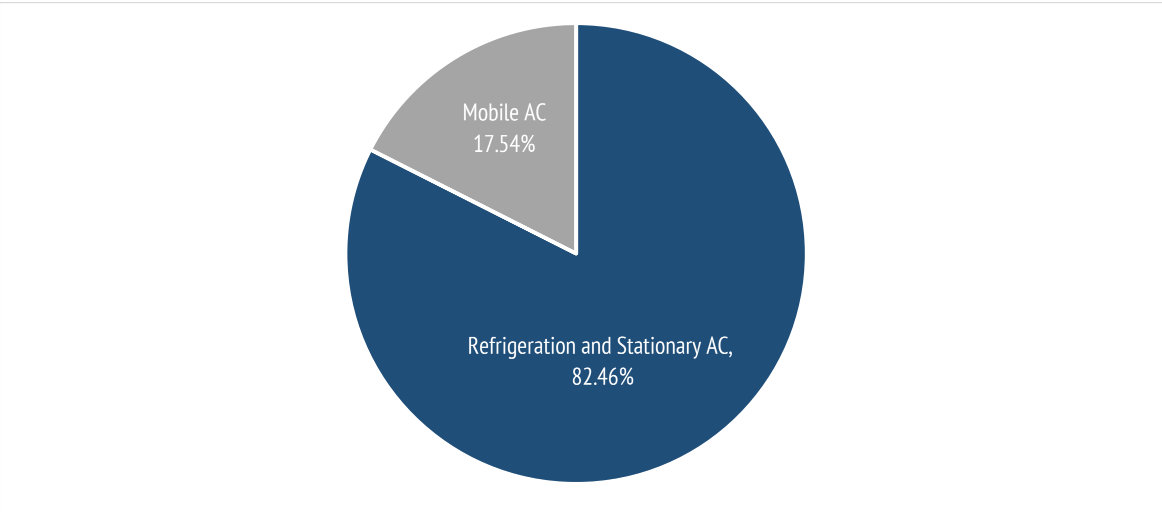


Figure 50: Share of Emissions by sub-category under ozone-depleting substances for 2016

4.3.5.7.1 Refrigeration and Air Conditioning (2F1)

The refrigeration and air-conditioning subcategory includes a wide variety of equipment types that have used CFCs or HCFCs. End-uses within this subcategory include motor vehicle air-conditioning, retail food refrigeration, refrigerated transport (e.g., ship holds, truck trailers, railway freight cars), household refrigeration, residential and small commercial air-conditioning and heat pumps, chillers (large comfort cooling), cold storage facilities, and industrial process refrigeration (e.g. systems used in food processing, chemical, petrochemical, pharmaceutical, oil and gas, and metallurgical industries). These HFCs are emitted to the atmosphere during equipment manufacture and operation (because of component failure, leaks, and purges), as well as servicing and disposal. Following the sustained rural electrification programme in Ghana, which has brought power to a large proportion of rural communities and resulted in increasing urbanisation and improved standard of living, the distribution of domestic refrigerators and freezers in the country is very high.

The increased electrification contributed to the fast growth of the domestic refrigeration sector containing HFC equipment. It was also attributable to the phase-down activities of the Montreal Protocol, which seeks to phase out hydrochlorofluorocarbons which is an ongoing activity. Comfort air conditioning of offices and other indoor workplaces, as well as residential homes, has become a standard feature of the modern lifestyle in the country. With increasing estate development, stationary air conditioning has become a fast-growing sub-sector. The sector is dominated by unitary air conditioners of which the single split has the largest market share and was presumably because of their ease of installation and relatively low cost. The multi-split system, variable refrigerant volume, VRV (aka variable refrigerant flow, VRF) has become popular for complex office applications, especially due to its higher energy efficiency. Refrigeration and air conditioning appliances are using HFCs (HFC-32, HFC-125, HFC-134a and HFC-143a) in Ghana. Emissions have been estimated for these gases from 2005 to 2016 (Figure 51).

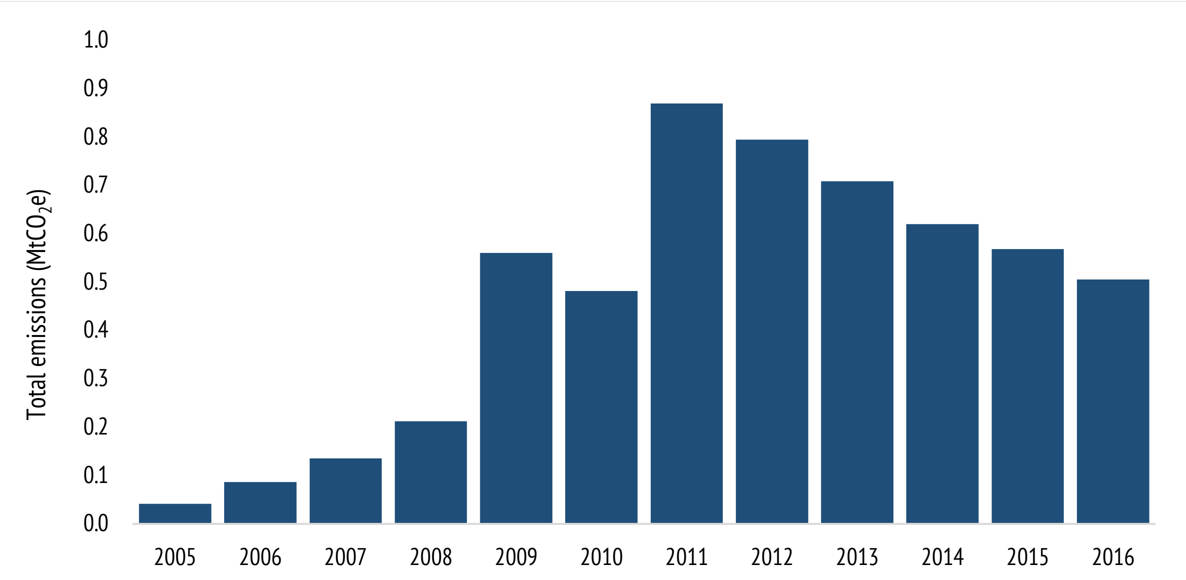


Figure 51: Total emissions for the refrigeration and air-condition subcategory from 2005 to 2016

Generally, emissions gradually increased for this subcategory from 2005 to 2011 and decreased after that for HFC-125, HFC-134a and HFC-143a until 2016. The increase has been due to increases in import of the HFC containing equipment and refrigerants for charging or recharging, increase in power availability and phase-down of HCFC containing equipment under the Montreal Protocol phase down activities. The decreases have been due to the conversion of HFC based ACs to hydrocarbon-based air conditioners from 2012 that has been necessitated by the phase-down schedules of HCFCs under the Montreal protocol, and the high imports of HFCs based refrigerants equipment's and gas stocks that were not completely utilised from 2012 and these served as stocks in subsequent years while imports and consumption reduced. In 2016, under the refrigeration and AC subcategory, 0.0075 $MtCO_2e$ of emissions was from HFC-32, 0.223 $MtCO_2e$ emissions from HFC-125, 0.127 Mt CO_2e emissions from HFC-134a and HFC-143a emitted 0.155 $MtCO_2e$ (Figure 52).

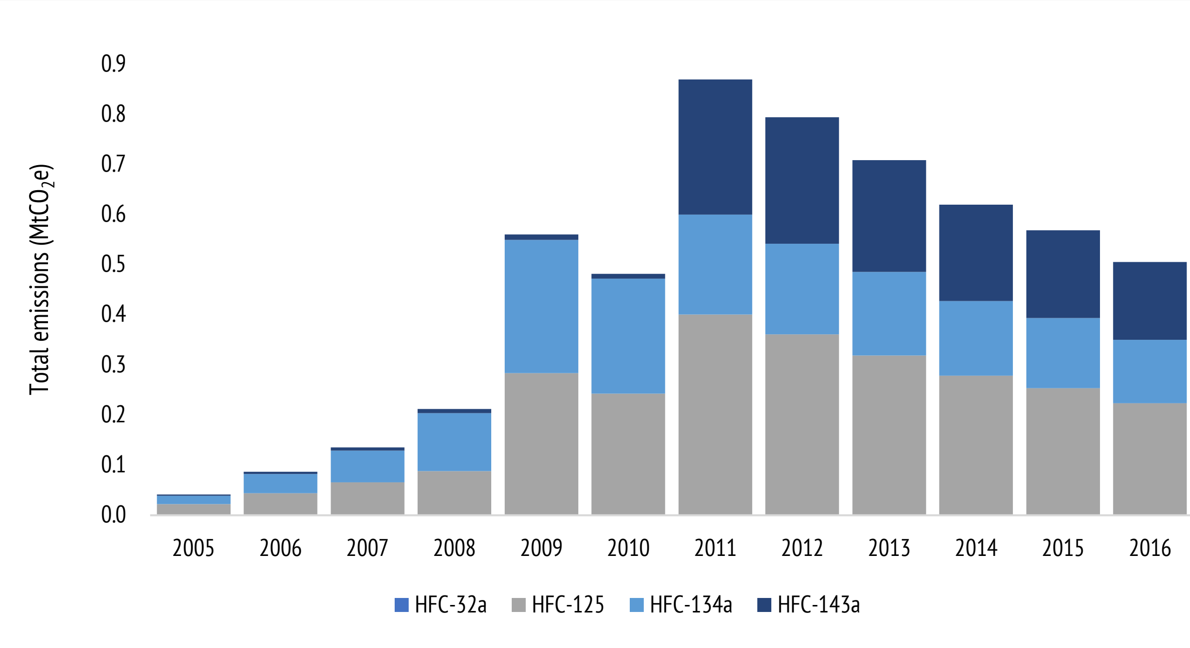


Figure 52: Trend by gases of emissions under refrigeration and stationery AC for the period 2005-2016

As of 2016, HFC-125 constituted about 44.05% of total emissions and the largest share of emissions and followed by HFC-143a, with 30.7% of the total share. HFC-134a and HFC-32 contributed 25.11% and 0.15% respectively (Figure 53).

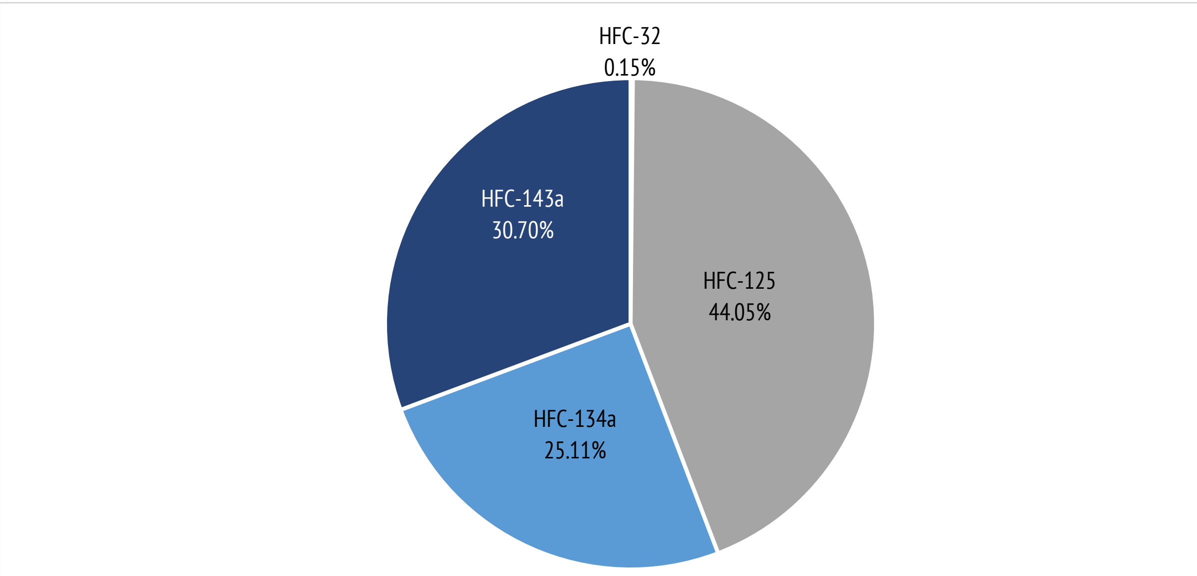


Figure 53: Share of Emissions by sub-category under refrigeration and stationery AC for 2016

4.3.5.7.2 Mobile Air Conditioning (2F2)

The mobile air-conditioning subcategory includes a wide variety of equipment types that have historically used CFCs, HCFCs or HFCs. End-uses within this category include motor vehicle air-conditioning, refrigerated transport (e.g., ship holds, truck trailers, railway freight cars). In Ghana, most of the emissions are from motor vehicles. Transport refrigeration is not actively used and very limited in operation. The MAC sector is rapidly expanding, driven by improving the standard of living and rapidly increasing vehicle population. The dominant refrigerant in the mobile air-conditioning sector is R134a. Servicing of MAC units was carried out by private workshops operated by refrigeration service technicians where R134a refrigerants are used for top-ups. Data were available for emission estimations for the period 2005-2016 (Figure 54). As of 2016, a total of 107.52 Gg CO_2e of HFC-134 was emitted from the mobile AC subcategory.

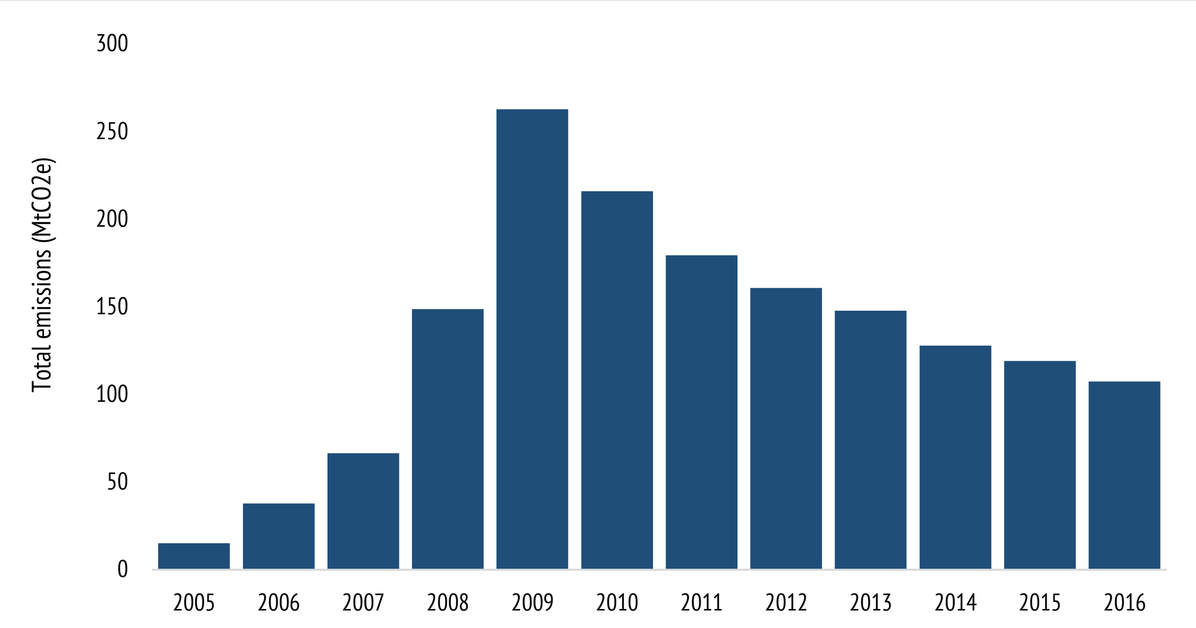


Figure 54: Total emissions from Mobile AC (134a) from 1990 to 2016

4.5 Key categories and recalculations in the IPPU sector

4.5.1 Key categories in IPPU sector

The methodology and results of the key category analysis in the IPPU sector are presented in Table 68 below.

Table 68: Result of the key category analysis of the IPPU sector

IPCC Category code	IPCC Category	Greenhouse gas	Key Source Assessment (Level Assessment – LA)	Key Source Assessment Trend Assessment (TA) (2000-2016)
2A4	Other Process Uses of Carbonates	CO_2	-	TA
2C3	Aluminium Production	CO_2	-	TA

Carbon dioxide emissions from Other process use of carbonate, which mainly consist of limestone use and Aluminium production were the key categories in terms of trends (2000 - 2016).

4.5.2 Description of recalculation in the IPPU sector

Recalculation was done for CO_2 emissions for both Lubricant use for 1992 – 2012 and limestone use for 2005-2012. The new set of datasets were received from one industry on steel production for the period 2010 to 2012. Generally, activity data for both subcategories were updated due to the availability of new datasets from companies.

4.6 Quality Control/Quality Assurance Protocols Observed in IPPU

The QA/QC procedures that were followed in the IPPU sector is detailed in Table 69.

Table 69: QA/QC procedures implemented in the IPPU Sector

Data Type	QA/QC procedure	Remarks/Comment/Examples
Activity data check	Check for transcription, typographical errors and error transposition.	Division of task among the inventory team to ensure that one or two members of the team always focus on double-checking and ensure that data errors associated with those described in the left column are avoided.
	Consistency checks of categories and subcategories with totals	Ensuring that disaggregated figures at the category and subcategories levels add up to the overall totals.
	Identify and fix outliers in data inputs (including checking for dips and spikes in the trend)	Data that deviate unrealistically from the trends and spikes beyond ranges are suspected as inaccurate and replaced
	Documentation of all data sources, data format and assumptions for easy reference	A record of all data, their sources and assumptions made in admitting the data used were kept and helped in easy cross-referencing.
	Ensure reduction in data clumsiness or data redundancy	Logical sequence data flow according to the IPCC methodology for the GHG emission estimation was designed for: (a) easy understanding and further probing of how the final results in the IPCC software would be like, (b) easy cross-referencing and avoidance of mistakes, (c) easy transmission into the IPCC software and (d) aid in better interpretation of the implication of the use of the data.
	Cross-checks all steps involved in the calculation.	Ensure that steps used for determining, estimating and deriving data are accurate, transparent and internally consistent.
Calculation by the approved 2006 IPCC software	Documentation of sources and correct use of units.	Use of the documentation template to record all data sources and assumptions.
	Check for transcription, typographical errors and error transposition.	Check mistakes and blunders in the data entered into the software.
	Checked completeness of data coverage	Ensuring all the relevant gases for the specific activity were covered.
	Check of recalculation differences	To identify and pinpoint changes, revision and reallocation to improve accuracy and transparency of the estimates
Results (emissions)	Identify and fix outliers in the results	checking for dips and spikes in trends and levels
	Assumptions, corrections, data and sources.	Ensure consistency, transparency, facilitate repeatability and easy retrieval
Documentation	Improvement list (internal and external findings)	Help prioritize areas that require actions.

4.7 IPPU planned improvements

Significant improvements in the IPPU sector is needed in short to medium-term. The improvements are in areas such as:

- Collection of additional data to improve completeness.
- Improvements in methodology for estimation.
- Processing of aggregated data.
- Collection of additional data on emission factors.

Details of the planned improvements are provided below:

(a) Data improvements

- Conduct industrial survey in-country to identify all possible sources according to the IPCC Guidelines for both formal and informal sources and ensure data is collected and sources maintained for future inventories.
- Identify, track and monitor any potential new sources that would be important for inclusion in inventories according to the IPCC Guidelines, e.g. SF6 use in electrical equipment.
- Collect data for the ceramics industry on carbonate used and estimate emissions for the sub-category.
- Update data on ODS substitute gas (HFCs) especially in the refrigeration and air-conditioning and mobile air-condition subcategories.
- Improve data completeness for lubricants use to cover imported quantities by oil marketing companies and individuals. Efforts would be made to identify the importers to collect data to improve upon future calculations.

(b) Methodological improvements

- Improvement in estimates on non-energy use and feedstock to ensure internal consistency.
- Collect data reported for dolomite use by the cement industry to improve the emission estimates for the Other Carbonate use source category. In implementing improvements and integration of data from the plant, the latest guidance from the IPCC on the use of facility-level data in national inventories would be used.
- Improvements on methodology to ensure the use of tier 2 method for all years to improve emission calculations particularly for Lubricant use, steel production, limestone use and refrigeration and AC including mobile AC sub-sectors.
- Future improvements to involve evaluating and analysing data reported under all source categories that would be useful to improve the emission estimates using a tier 2 option. Particular attention would be made to ensure time-series consistency for all inventory years as required for inventory.

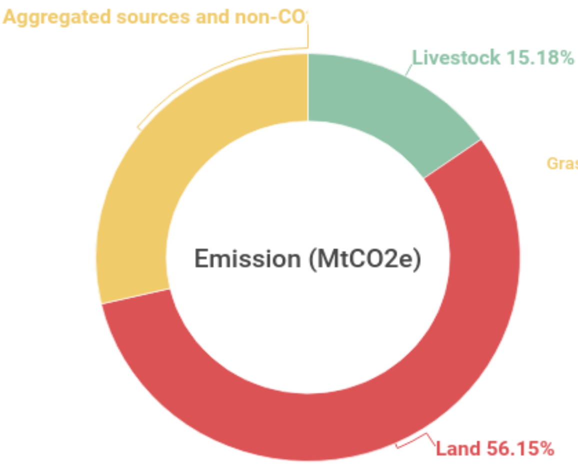
Agriculture, Forestry and Other Land-use Sector




AFOLU sector GHG emissions Dashboard

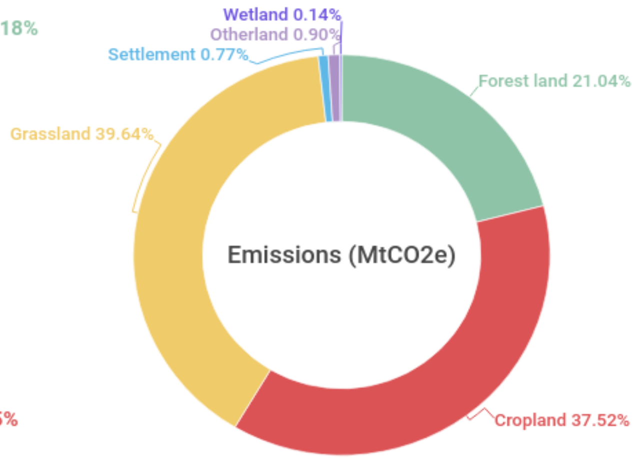
Total 2016 emissions	Drivers of the AFOLU emissions	Emission trends	Major greenhouse gases
22.9 $MtCO_2e$	86 million animals 293 kilo tonne of fertiliser use 236,000 ha rice under cultivation 11 million ha involved in land-use changes	14% more than 1990 levels	CO_2 = 56%, N_20 = 29% CH_4 = 14%

Emission by AFOLU category in 2016



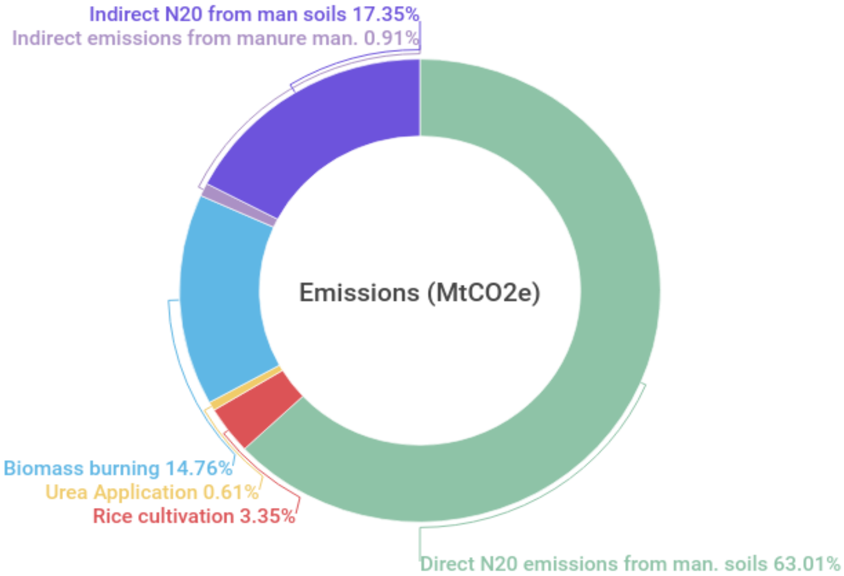
Land emissions in 2016

12.9 $MtCO_2e$



Aggregated sources and non-CO^2 emissions on land in 2016

6.57 $MtCO_2e$



Chapter 5
Agriculture, Forestry and Other Land Use sector

5.1 Summary of AFOLU sector net emissions in 2016

With the net emissions of 22.9 MtCO_2e, AFOLU sector is the leading source of GHG in the country. The 2016 AFOLU emissions constitute 54% of the total emissions. The current emissions also represented 14% and 4% more than the levels reported in 1990 and 2012. The relatively marginal emission increases relate to deforestation through forest conversions to cropland and grassland, biomass burning and nitrogen additions to soil. On a gas-by-gas basis, CO_2 had a greater share of the AFOLU accounting for 56% of the AFOLU sector emissions followed by N_20 (29%) and CH_4 (15%). Within the AFOLU sector, the land category was the main emission source consisting of 56% of the AFOLU emission. The rest was shared among "Aggregated sources and non-CO_2 emissions on land" (29%) and livestock (15%) in 2016 (Figure 55).

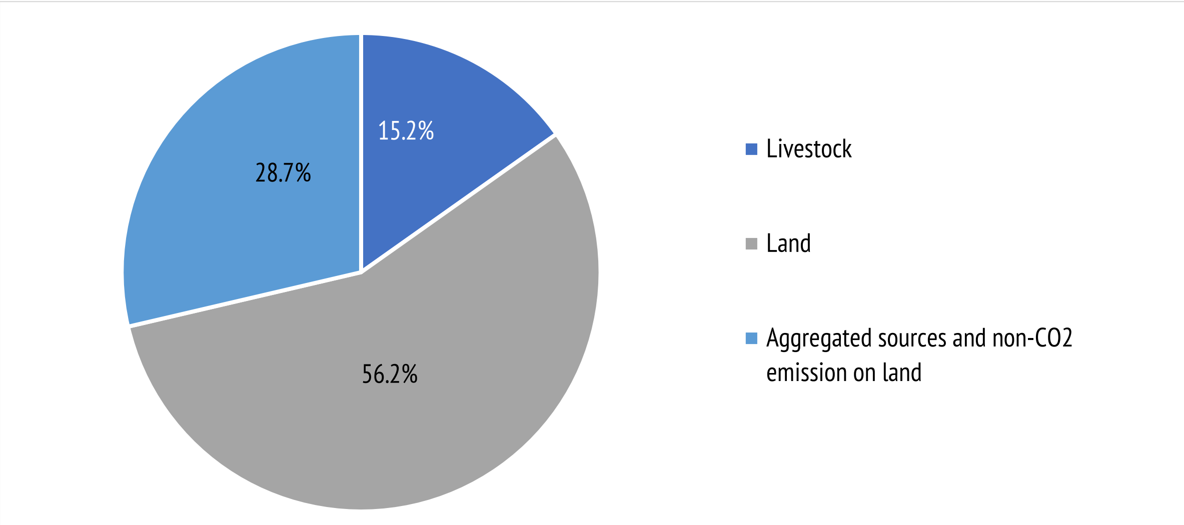


Figure 55: Overview of GHG net emissions in the AFOLU sector in 2016

Ghana adopted a mix of tier 1 and higher tier methodology for the AFOLU emissions inventory. While the methodology and factors for the land category were tier 3 and country-specific, the "livestock" and "aggregated sources and non-CO_2 emissions on land" categories relied on tier 1 and IPCC defaults factors. The snapshot of the methods and factors used are presented in Table 70

Table 70: Snapshot of methods and factors used in the AFOLU sector inventory

Category code	Source/removal	Emission reported	Status	Method	EF
3.A.1.a.i	Dairy Cows	CH_4	NO	NA	NA
3.A.1.a.ii	Other Cattle	CH_4	E	T1	D
3.A.1.b	Buffalo	CH_4	NO	NA	NA
3.A.1.c	Sheep	CH_4	E	T1	D
3.A.1.d	Goats	CH_4	E	T1	D
3.A.1.e	Camels	CH_4	NO	NA	NA
3.A.1.f	Horses	CH_4	E	T1	D

3.A.1.g	Mules and Asses	CH_4	E	T1	D
3.A.1.h	Swine	CH_4	E	T1	D
3.B.1	Forest land	CO_2	E	T3	CS
3.B.2	Cropland	CO_2	E	T3	CS
3.B.3	Grassland	CO_2	E	T3	CS
3.B.4	Wetlands	CO_2	E	T3	CS
3.B.5	Settlements	CO_2	E	T3	CS
3.B.6	Other Land	CO_2	E	T3	CS
3.C.1	Emissions from biomass burning	CH_4, N_20	E	T1	D
3.C.2	Liming	CO_2	NE	T1	D
3.C.3	Urea application	CO_2	E	T1	D
3.C.4	Direct N_20 Emissions from managed soils	N_20	E	T1	D
3.C.5	Indirect N_20 Emissions from managed soils	N_20	E	T1	D
3.C.6	Indirect N_20 Emissions from manure management	N_20	E	T1	D
3.C.6	Rice Cultivation	CH_4	E	T1	D

Notation keys: E – estimated, NE – Not Estimated, NA – Not Applicable, D – Defaults, T1 – Tier 1, CS – Country Specific, T3 – Tier 3

5.2 Overview of the Agriculture, Forestry and Other Use Sector

About 80% of the livelihoods in Ghana depend mainly on the AFOLU sector. The sector also contributes 17% of the national GDP through exports of major commodities including cocoa, oil palm, timber and non-traditional agricultural exports. The exploitation of land-based resources such as forest, agricultural lands and livestock coupled with inherent practices, can lead to the emissions or removals of greenhouse gases. For example, unsustainable timber extraction, expansion of agricultural lands into forest frontiers and the misapplication of fertilisers. The emissions from the AFOLU sector is influenced by the combination of the effects and implementation of national policies, available technologies and the management regimes. The aggregate effects of the policies, technologies and management regime largely determine land-use practices and the associated emissions or removal of GHG from the AFOLU sector. Some of the practices include (a) livestock rearing and dung management (b) land-use change via forest conversion, farming land preparation including slash and burn (c) conservation or sustainable forest management, (d) afforestation and reforestation, (e) woodfuel extraction, (f) wildfire disturbance (g) application of nitrogen-based fertilisers, (h) generation and disposal of crop residue and (i) rice cultivation in different ecosystems.

The AFOLU sector GHG emissions/removal was inventoried using a land-based approach. This approach focused on land-based activities that either contributes to the emission or removals depending on the intensities and "geographic coverage". The 2006 IPCC Guidelines was used for the estimation of emissions/removals of the AFOLU sector because it provides a more recent scientifically-robust methodology and approaches for undertaking the inventory of GHG emissions/removals at the national level. This inventory has been done to the extent possible using country-specific data to cover the categories of land-based activities occurring in Ghana as well as considering the need to ensure consistency with any accounting that takes place at the sub-national level and those that focus on a specific set of land-based activities such as REDD+.

5.3 Categorisation of AFOLU activities under IPCC 2006 Guidelines

The AFOLU sector inventory made use of both the 2003 good practice guidance and the IPCC 2006 guidelines. However, most of the approaches and factors used were drawn from the IPCC Guidelines. The Guidelines divide the AFOLU sector activities into three clusters of emission/removal categories. The criteria for the clustering are based on the activity being a land-based or non-land based.

Each category is further disaggregated into the activities that contribute to emissions/removals. The three clusters of emission/removal categories were: livestock, land and aggregated source and non-CO_2 emission sources from the land. The IPCC guidelines assign unique code for sectors, categories, sub-categories and activities. The code for the AFOLU sector is prefixed with figure 3 because it is the third in the sequence of sectors. The three categories under the AFOLU sector and their codes are as follows: Livestock (3A), Land (3B) and Aggregated and Non-CO_2 Emissions Sources (3C). The subcategories and the activities under them derive their unique codes from three main categories under the sector. For example, under the livestock category (IPCC code- 3A), the unique codes for Enteric Fermentation are 3.A1, and Manure management is 3.A2 sequentially related to the 3A. This way of categorising activities allows for easy aggregation from bottom-up.

5.3.1. Livestock (3A)

Livestock rearing is associated with the emissions of N_2O and CH_4. The type of animal husbandry system and the management practice influence the levels of emissions. The livestock emissions are mainly associated with Enteric fermentation (3. A1) and Manure management (3.A2). The factors that influence emissions associated with enteric fermentation include, but not limited to, animal feed (quantity and quality) and digestive processes (e.g. animal weight, excretion rate). Emissions from manure management estimates depend on the various livestock management systems (mainly pasture/range/paddock, dry lot, liquid/slurry) and the rate of utilisation. The main data inputs for estimating N_20 and CH_4 emissions are animal type, population (head), average weight, age and excretion rate and the type of management of the animal dung. The data on livestock population is mainly from the Agriculture Facts and Figures published by the Statistics Research and Information Directorate of the Ministry of Food and Agriculture.

5.3.2 Land (3B)

The land category (3B) deals with net CO_2 emissions from deforestation, forest degradation, afforestation/reforestation, and sustainable forest management/conservation. The land category (3B) is divided into six land representations, namely: -Forestland (3.B1), Cropland (3.B2), Grassland (3.B3), Wetland (3.B4)), Settlement (3.B5) and -Other Lands (3.B6). The drivers that influence the emissions/removals in each of the six land representations is unique. For example, in forest land, the timber harvest, fire, enhancement through natural regeneration, enrichment planting and plantations, woodfuel collection determines the levels of net CO_2 emissions. However, in the cropland class, the emission rate is dependent on the agricultural management practices such as the application of soil and water management technologies, fertiliser application.

Notwithstanding the internal factors that influence the emissions/removals within respective land representations, transitions between land representations can also lead to CO_2 emissions/removals. Within each land category, CO_2 emissions/removals were estimated for two main activities – (a) lands remaining same over a given period and (b) lands converted to another land category over a given timeframe. Depending on the direction and the extent of transitions in land classes, the effect could be CO_2 emissions or removal. When forestlands which have relatively high carbon stocks per unit area are converted to non-forestlands such as croplands or grasslands, they lead to emissions of greenhouse gases. On the other hand, when cropland is abandoned to fallow over a given period or non-forestlands are reforested, carbon dioxide is absorbed from the atmosphere. Again, standing forest estate can accumulate more carbon through its mean annual biomass increment. At any point in time, net emissions from forestland would depend on the balance of carbon stock removal and sources. The main data requirements for the category are:

- Areas of managed and unmanaged lands.
- Areas of the six land representations for each ecological zone.
- Transitions in land representations over a defined timeframe or temporal scale.
- Average carbon stocks for five biomass pools in each land representation per ecological zone.
- Quantity of round wood and woodfuel extraction per year.
- Size of areas and intensity of wildfire per annum.
- Soil classification and soil carbon stocks.

The country-specific dataset used for the Land category inventory was obtained from the studies conducted under Forest Preservation Project (FPP) in 2012 and during the preparation of the National Forest Reference Level (FREL) in 2017 by the Forestry Commission and where necessary, data from FAOSTAT by FAO. To a large extent, the FREL was the main data source for the Land category inventory, but there is some difference in them. The differences between the FREL and Land category inventory is the completeness level of activity data and the Emission Factors. The difference is in Table 71

Table 71: Relationship between Land GHG inventory and REDD+ FREL

Item	Land inventory	REDD+ FREL
Activity covered	Forestland, Cropland, Grassland, Wetland, Settlement and Other lands	Forestland
Land transition pathways	Loss, Gain and Persisted for all the 6 IPCC land representation classes	Forest loss
Carbon stock enhancement	Natural forest regeneration and tree plantation. Annual biomass increment	Carbon stock enhancement through Tree plantation

5.3.3 Aggregated Sources and Non-CO_2 Emission Sources from Land (3C)

The "Aggregated sources and Non-CO_2 emission sources from Land" (3C) category comprise activities that produce emissions which are not covered under 3A or 3B. The GHG emissions activities under 3C are subdivided into: (a) Biomass Burning (3C.1); (b) Liming (3C.2); (c) Urea application (3C.3), (d) Direct N_2O emissions from managed soil(3C.4); (e) Indirect N_2O emissions from managed soil (3C.5); (f) Indirect N_2O emissions from manure management(3C.6); and (g) Rice cultivations(3C.7). For example, for biomass burning occurring in forestland, the emissions emanating from the fires that lead to deforestation and forest degradation. Also, the fires used in land preparation under Cropland results in CH_4, N_2O, CO, and black carbon emissions are considered in the inventory. Rice cultivation, for instance, also emits CH_4 depending on where the rice cultivation occurs (ecosystem – upland rice, irrigated rice, and valley-bottom rice). Most of the CH_4 emissions are from valley-bottom and irrigated rice cultivation based on intermittent rice flooding regime. The applicable data for the 3C in Ghana's situation is as follows:

- Area cultivated and yield of major staple crops (plantain, cassava, maize, sorghum)
- Areas affected by fire in cropland, grassland, forestland
- Quantities of nitrogen fertiliser and urea consumption and mode of application
- Areas of rice cultivations and quantities produced per year.

The main data source for this category was the Agriculture Facts and Figures published by the Ministry of Food and Agriculture and the FAOSTAT (http://www.fao.org/faostat/en/#data accessed on 20th April 2018)

5.4 Data, sources and methodology

This section provides an overview of the data, data sources and the description of the methodology applied in the inventory.

5.4.1 Data and data sources

The data used in this inventory were obtained from diverse sources from relevant national and international institutions. The datasets were in different formats and had varying publishing periods. While some of the datasets were readily available online, those that were not readily available required special requests to the data providers. In cases, where the dataset was completely unavailable at the national, regional and international levels, expert judgement was used. In some cases, the data were available both nationally and internationally, but they were at variance. In such instances, the country-specific dataset was used instead of the one acquired from international sources. Table 72 provides an overview of the data, data source and data providers.

Table 72: Overview of the AFOLU categories, data and data sources in the inventory

Categories		Sub-categories	Data Type	Data Source	Principal Data Providers	Remarks
3.A Livestock	3.A1	Enteric Fermentation	Animal population (cattle, goats, sheep, swine, donkey, poultry, horse Fractions of manure management practices	Agriculture Facts and Figures FAOSTAT Expert Judgment	Ministry of Food and Agriculture – Statistics Research and Information Directorate, UN Food and Agriculture Organisation AFOLU Team	Expert judgement was used in the following: the splitting proportions of heads dairy and non-dairy cattle and Percentage allocation of the manure management practices.
	3.A2	Manure Management				
3.B. Land	3.B1	Forestland	Land representation maps (1990, 2000, 2010 and 2015), Land representation change maps (1990-2000, 2000-2010 and 2010-2015 and 1990-2015. Land representation matrix and change matrix Accuracy estimates	Forest Preservation Programme, 2012 and RMSC National Forest Reference Level, 2017	Forestry Commission of Ghana	Dataset (maps and tables, reports) are readily available at the Forestry Commission Office The land representation change maps were derived from the land representation maps for the years 1990, 2000, 2010 and 2015. Land representation map matrix and change matrix are in excel format and obtained from individual land maps. Accuracy assessment was derived from the individual and change matrix.

			Biomass estimates for Above-ground biomass, Below-ground biomass, Deadwood, Litter and Soil for forestland Average biomass estimates for teak plantations Annual Biomass Growth for Natural Forest	Forest Preservation Programme, 2012 Adu-Bredu et al. 2012 2006 and 2003 IPCC	CSIR-FORIG IPCC	Biomass estimates are for natural forest (closed and open forest) and non-teak plantation. Biomass estimates for teak plantation were applied to the plantation with dominant teak plantation in both on-reserve and off-reserve areas. The above-ground net biomass growth in natural forests was changed from 4.7 tonnes d.m/ha/yr. to 1.6 tonnes d.m/ha/yr. for the first time in the current inventory. The new figure was obtained from IPCC, 2003. Annex 3A_1_Data_Tables. Table 3A.1.5. Africa >20 years. Average of Moist with the short dry season and Moist Long Dry Season (2000 > R> 1000).
			Ecological zone map	Shapefile of ecological zones	Forestry Commission and Survey Department.	The GIS layer of the ecological zone map was used to delineate and calculate the areas of 9 forest ecological zones.
			The volume of industrial round-wood production per year (1990-2016)	Resource Management Support Centre FAOSTAT	Forestry Commission UN Food and Agriculture Organisation	Majority of the data on industrial timber production was obtained from the Forestry Commission. Where there were missing data in the time series, timber production data from the FAOSTAT was used.

			Wood-fuel supply data for 1990 to 2016	Energy Statistics	Energy Commission	Dataset on woodfuel supply for the time-series was obtained from the individual Energy Statistics published for the period 1990 to 2016.
			Areas affected by fires that led to deforestation and forest degradation	National Forest Reference Level, 2017	Forestry Commission	The methodology to estimate areas affected by fires and intensities were based on MODIS fire products.
	3.B2	Cropland	Land representations, change maps, area and change matrix and Accuracy Estimates Delineations of cropland areas and changes over a given period.	Forest Preservation Program, 2012 National Forest Reference Level, 2017 FAOSTATS Agric Facts and Figures	Forestry Commission, Ghana FAO Ministry of Food and Agriculture	Dataset (maps and tables, reports) are readily available at the Forestry Commission Office Data on cultivated areas for 1990-2016 were obtained from FAOSTAT and Agric and Fact Figures to complement the land representation maps. Cropland areas were divided into annual and perennial crops and further according to different management.
			Biomass estimates for Above-ground biomass, Below-ground biomass, Deadwood, Litter and Soils for the Cropland			Biomass estimates for specific tree crops such as cocoa, citrus, rubber, oil palm, cashew and mango were average and applied. The figures were from Kongsager et al. 2013, Noumi et al. 2017 and Tom-dery et al., 2015.
			Forest ecological zone maps	Ditto as described under Forestland	Ditto as described under Forestland	Ditto as described under Forestland

	3.B3	Grassland	Land representations, change maps, area and change matrix and Accuracy estimates	Forest Preservation Programme, 2012	Forestry Commission, Ghana	Dataset (maps and tables, reports) are readily available at the Forestry Commission Office
			Biomass estimates for Above-ground biomass, Below-ground biomass, Deadwood, Litter and Soils for the Grassland			
			Forest ecological zone maps	Ditto as described under Forestland	Ditto as described under Forestland	Ditto as described under Forestland
	3.B4	Wetland	Land representations, change maps, area and change matrix and Accuracy estimates	Forest Preservation Program, 2012	Forestry Commission, Ghana	Dataset (maps and tables, reports) are readily available at the Forestry Commission Office
			Forest ecological zone maps	Ditto as described under Forestland	Ditto as described under Forestland	Ditto as described under Forestland
	3.B5	Settlement	Land representations, change maps, area and change matrix and Accuracy estimates	Forest Preservation Program, 2012	Forestry Commission, Ghana	Dataset (maps and tables, reports) are readily available at the Forestry Commission Office
			Biomass estimates for Above-ground biomass, Below-ground biomass, Deadwood, Litter and Soils for the Settlement			
			Forest ecological zone maps	Ditto as described under Forestland	Ditto as described under Forestland	Ditto as described under Forestland
	3.B6	Other lands	Land use maps, Land use change map, Land use change matrix	Forest Preservation Program, 2012	Forestry Commission, Ghana	
			Forest ecological zone maps	Ditto as described under Forestland	Ditto as described under Forestland	Ditto as described under Forestland
3.C Aggregated and non-CO_2 emissions on land	3.C1	Biomass burning	Areas affected by fire in cropland, forestland and grassland	Forest Preservation Program, 2012, National Forest Reference Level, 2017	Forestry Commission	The methodology to estimate areas affected by fires and intensities were based on MODIS fire products.

			Mass fuel available for burning			Mass of fuel available was derived from the biomass estimates for each of the affected land representation (Forestland, cropland and grassland).
	3.C3	Urea application	Annual Urea consumption figures	Agric Facts and Figures	Ministry of Food and Agriculture – Statistics Research and Information Directorate	Data on Urea application from FAOSTAT were used to fill missing data for the time series.
	3.C4	Direct N_2O emissions from manage soils	Annual generic NPK consumption	Agriculture Facts and Figures	Ministry of Food and Agriculture – Statistics Research and Information Directorate,	Data on Nitrogen-based fertiliser application from FAOSTAT were used to fill missing data for the time series
	3.C5	Indirect N_2O emissions from manage soils	Annual crop production in tonnes per annum			Data on crop production from FAOSTAT were used to fill missing data for the time series
	3.C6	Indirect N_2O emissions from manure management	Animal population (cattle, goats, sheep, swine, donkey, poultry, horse	Agriculture Facts and Figures	Ministry of Food and Agriculture – Statistics Research and Information Directorate,	The splitting proportions for the heads of dairy and non-dairy cattle was based on expert judgement.
	3.C7	Rice cultivation	Annual rice production areas	Agriculture Facts and Figures	Ministry of Food and Agriculture – Statistics Research and Information Directorate	Data on rice production from FAOSTAT were used to fill missing data for the time series. Expert judgement was used to split the proportions of rice cultivation areas under different production systems (upland rice, valley-bottom rise and rice under irrigation.

5.4.1.1 Overview of AFOLU inventory methodology

The estimation of emissions from the AFOLU depends on the use of appropriate methods prescribed in the 2006 IPCC Guidelines. The methods used in the estimation are unique for each category under the AFOLU sector. This section sums up the processes for making methodological choices and description of the methods, as well as the assumptions behind the activity data and emission factors. The current inventory followed the 2006 IPCC Guidelines instead of the previous method, which was entirely based on the 2003 Good Practice Guidance (GPG). The inventory shifted from the use of the revised 1996 IPCC Guidelines to the 2006 IPCC Guidelines. However, there was one case under Forestland that factors from the 2003 GPG were used. Generally, the use of the 2006 IPCC guidelines combined activities under Agriculture and Forestry together as one sector. The adoption of the 2006 guidelines led to the addition of new datasets and changes in the methodology for estimating the emissions or removals.

The 2006 IPCC Guidelines offer step-by-step guidance on the following: (a) data identification of the type and the selection of methods, (b) application of selected methods and their underlying assumptions. The Guidelines also provide specific suggestions on ways to estimate GHG emissions/removals and other gases by using activity data and emission factors. Activity data refers to the degree or frequency of use or extent of an activity that can result in the emission of gases (GHG, SLCPs or local pollutants) or removal of carbon dioxide from the atmosphere. Examples of activity data under AFOLU sectors include the following: (a) land representation areas for different forest ecological zones and area change over time, (b) quantities of industrial wood extracted in a given period, (c) annual livestock population and (d) amount of fertiliser consumption per year. Emission or removal factors are needed to complete the emission/removals calculations. The factors quantify the degree to which a specific gas such as carbon dioxide or methane is released or removed from the use of or change of a technology or practice or the variation in the rate of use or the number of activities in each condition. Some examples of emission factors under the land category (3A) are biomass estimates for various pools in distinct land representations under a specific forest ecological zone and the rate of methane emission per head of livestock. So, the calculation of the emissions or removal of gases in the AFOLU sector depends on the products of activity data, emission/removal factors and the GWP and expressed in equation 1.

$$Etj = \sum_{i,j}^{i+1n,j+1y} ADij * EFi * GWPi \qquad \text{equation 1}$$

Where:

I = Type of greenhouse gas
J = inventory
I+1n = n^{th} greenhouse gas
J+1y =y^{th} inventory year
AD = Activity Data,
EF = Emission Factor and
GWP = Global Warming Potential of the gas in question.
Etj = Total emission in an inventory year

Overall, a combination of tiers one and higher tiers methodologies were applied in the emission/removal computation using available country-specific data and internationally reliable data sources. The availability of ample country-specific activity data and emission factors enabled the use of higher-tier methodologies. For instance, multi-temporal satellite images were used to generate time-series land-cover maps and burnt area estimations. Furthermore, field-based methods were used to produce specific biomass factors for the forest, cropland, grassland and settlement of land representations. The use of the higher-tier methods and the associated dataset improved the rigour, and the level of confidence in the estimates because the dataset tends to represent the reality on the ground rather than relying on global or regional default figures. A step-by-step explanation of the methods is provided under the dedicated sections to a specific category. In this inventory, where country-specific activity data and emission factors were available, it was the preference.

However, in the absence of the country-specific data, applicable regional or international data were used. Majority of the national datasets were sourced from publicly available secondary data and primary data published by the data providers. When similar datasets are to be used to report to multiple international organisations or different mechanisms, as much as possible, we strive for data consistency as much as possible. For example, Ghana supplies data on land representation to UNFCCC (via BUR and FREL) and FAO (via FRA and FAOSTAT) for different reporting needs. In that case, all efforts are made to ensure the data supplied are retrieved from the singular land cover map produced by the Forestry Commission. Data from 1990-2016 were used for the inventory in the AFOLU sector. However, in situations where missing data were encountered, we fell on reliable sub-regional and international sources to fill the gaps. In cases where there were time-series gaps, IPCC-recommended statistical methods (e.g. trends extrapolation, interpolation) were adopted to fill the data gaps. For instance, the land representation maps covered up to 2015, yet the reporting period was up 2016; hence the extrapolation method was used to generate the activity data for 2016.

In rare situations where data were completely unavailable both in-country and from international sources, expert judgement was used and the underlying assumptions documented. Even though the practice of using expert judgment in the inventory was not common, the resulting emissions/removals from is likely to have high uncertainty. Expert judgment has been used in the allocation of percentage share of manure management systems and the proportion of dairy and non-dairy cattle. One improvement has been in the use of expert judgment under the estimation of areas affected by fires. In the previous inventory, the areas regularly affected by fire in all the six IPCC land representations were missing; thus, we resorted to using expert judgement. Under the current inventory, the use of the new methodology based on satellite imagery to detect fire burns substantially improved the emission estimates associated with fire.

5.4.1.2 Overview of completeness of the AFOLU sector

This section highlights information on the completeness of the AFOLU sector inventory. The completeness information is presented using notation keys which are duly explained beneath Table 63. Completeness comprises coverage of gases, categories as well as time series. The table also indicates for all sub-categories whether emissions/removals were estimated. The AFOLU sector estimates are deemed complete because emissions/removals of all subcategories - 3A (Livestock), 3B (Land) and 3C (Aggregated and Non-CO_2 emission source on land) have been appropriately estimated. The overview of the completeness status of the estimations under various subcategories of the AFOLU sector is indicated in Table 73.

Table 73: Overview of sub-categories in the AFOLU sector and status of estimations

IPCC Category	Time series Completeness								Explanation of status of use notation key per gas						
	1990-2012 (recalculations)				2013-2016 (new estimates)										
	Notation keys				Notation keys										
	E	NE	NO	IE	E	NE	NO	IE	CO_2	CH_4	N_2O	CO	PM	BC	NMVOC
3.A.1.ai Dairy Cows							√[19]		NA	NA	NA	NA	NA	NA	NA
3.A.1.aii Other Cattle					√				NA	√	NA	NA	NA	NA	NA
3.A.1b Buffalo							√		NA	NA	NA	NA	NA	NA	NA
3.A.1c Sheep					√				NA	√	NA	NA	NA	NA	NA
3.A.1d Goat					√				NA	√	NA	NA	NA	NA	NA
3.A.1e Camel							√		NA	NA	NA	NA	NA	NA	NA
1.A.1.f horses					√				NA	√	NA	NA	NA	NA	NA
1.A.1.g donkey					√				NA	√	NA	NA	NA	NA	NA
1.A.1.h swine					√				NA	√	NA	NA	NA	NA	NA
3.A.2.ai Dairy Cows							√		NA	NA	NA	NA	NA	NA	NA
3.A.2.aii Other Cattle					√				NA	√	NA	NA	NA	NA	NA
3.A.2b Buffalo							√		NA	NA	NA	NA	NA	NA	NA
3.A.2c Sheep					√				NA	√	NA	NA	NA	NA	NA
3.A.2d Goat					√				NA	√	NA	NA	NA	NA	NA
3.A.2e Camel							√		NA	NA	NA	NA	NA	NA	NA
3.A.2f horses					√				NA	√	NA	NA	NA	NA	NA
3.A.2.g donkey					√				NA	√	NA	NA	NA	NA	NA
3.A.2.h swine					√				NA	√	NA	NA	NA	NA	NA
3.A.2i Poultry					√				NA	√	NO	NA	NA	NA	NA
3.B.1a Forest land remains forest land	√				√				√	NA	NA	NA	NA	NA	NA
3.B.1b All other lands converted to forest land	√				√				√	NA	NA	NA	NA	NA	NA
3.B.2a Cropland remaining cropland	√				√				√	NA	NA	NA	NA	NA	NA
3.b.2b All other lands converted to Cropland	√				√				√	NA	NA	NA	NA	NA	NA
3.B.3a Grassland remaining grassland	√				√				√	NA	NA	NA	NA	NA	NA
3.b.3b All other lands converted to grassland	√				√				√	NA	NA	NA	NA	NA	NA
3.B.4a Wetland remaining wetlands		√					√		√	NA	NA	NA	NA	NA	NA
3.b.4b Other land converted to wetlands	√				√				√	NA	NA	NA	NA	NA	NA
3.C.1a biomass burning in Forestland	√				√				√	√	√	√	√	√	√
3.C.1b biomass burning in cropland	√				√				√	√	√	√	√	√	√
3.C.1c biomass burning in grassland	√				√				√	√	√	√	√	√	√
3.C.1d biomass burning in other lands			√				√		NA	NA	NA	NA	NA	NA	NA

[19] In Ghana there are no typical dairy cows. This is because the milk produced in the country is from beef cattle.

3.C.2 Liming		√[20]					√[1]		NA	NA	NA	NA	NA	NA	NA
3.C.3 Urea application					√				√	√	NA	NA	NA	NA	NA
3.C.4 Direct N_2O Emissions from Managed Soils					√				NA	NA	√	NA	NA	NA	NA
3.C.5 Indirect N_2O Emissions from Managed Soils					√				NA	NA	√	NA	NA	NA	NA
3.C.6 Indirect N_2O Emissions from Manure Management and Managed Soils					√				NA	NA	√	NA	NA	NA	NA
3.C. Rice cultivations					√				NA	√	NO	NA	NA	NA	NA
3D1. Harvested Wood Products						√			NA	NA	NA	NA	NA	NA	NA

E" indicates that emissions/removals from this sub-category have been estimated, "NO" means "Not Occurring" "NE" means "Not Estimated", "IE" means "included elsewhere."

5.5 Category-specific activity and emission factors

Data for the AFOLU sector inventory are from diverse sources. This section summarily describes the datasets that were applied in the computations and their respective sources.

5.5.1 Description of data generation platform -system backing the Agriculture Fact and Figures

The estimation of emissions of CH_4 and N_2O from enteric fermentation and manure management considered the heads of different livestock and weight per year. These livestock datasets were gathered from Agriculture Facts and Figures published by MOFA in Ghana and FAOSTAT. The two datasets agreed, however where differences occurred in the livestock data, the country-specific data from MOFA were used. The IPCC default emission factors were used under this category.

5.5.1.1 Livestock (3A)

5.4.1.1.1 Description of Livestock activity data

Animal population (3. A1 and 3.A2)

The national animal population was 85,687,752 in 2016 of which 83.6% totalling 71,594,000 were poultry. The remaining 16.4% (14,093,752) was made of livestock such as cattle, sheep, goats, horses, donkeys and pigs. Among the livestock population, goats were the majority with a population 6,740,000. This was followed by sheep (4,744,000), Cattle (1,815,000), Pigs (777,000), Donkeys (14,820) and Horses (2,932). The 2016 total animal population is 23.3% higher than the reported 2012 population of 69,501,050. The annual growth rate over the period was 4%. However, the annual growth rate is 3.9% when poultry are excluded from the total national animal population (Figure 56).

[20] Liming application is very limited. It is usually used in research or rarely in correcting poor soil. Emissions are considered to be negligible.

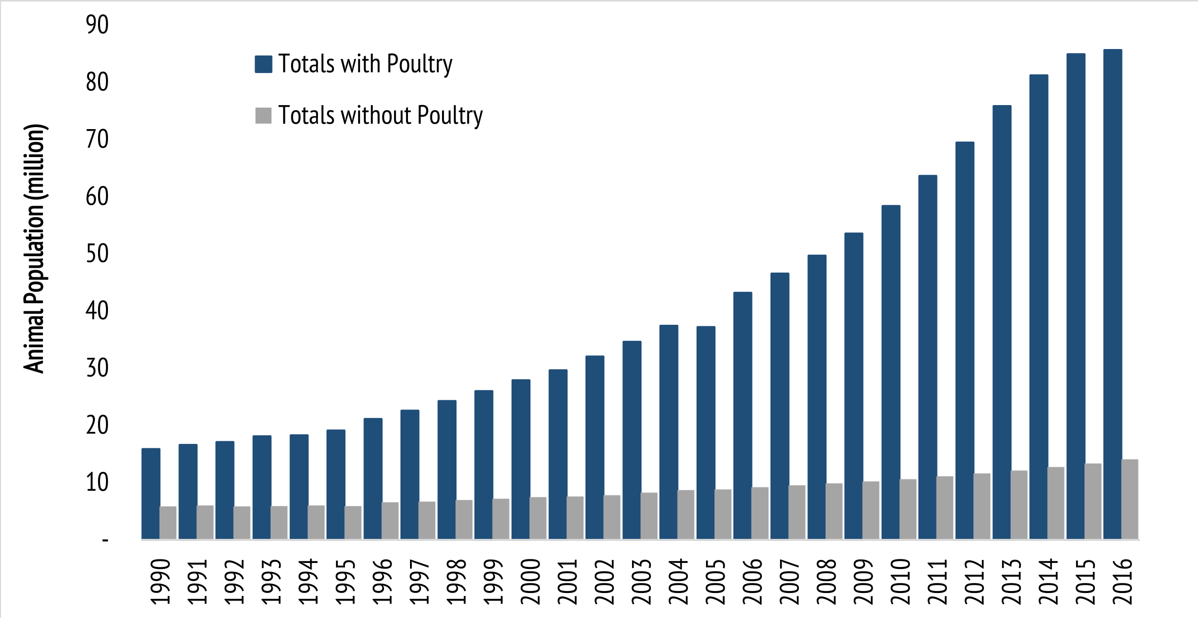


Figure 56:Trends of the animal population with and without poultry

The goat population has consistently been the largest proportion of the total livestock population except for 1990. The nominal percentage of the goat of the total livestock population recorded increased from 41% in 2000 to 47% in 2012 and further to 48% in 2016. On the other hand, the sheep proportion of the livestock population generally declined in the same period by 4% percentage points. Similarly, the share of cattle of the total livestock population also reduced by 7% between 1990 and 2016. For the pigs, the proportion of the total livestock population saw a decrease from 8% in 1990 to 4% in 2000 and remained relatively stable in subsequent years (Figure 57). The variations in the proportions of the individual animal populations could be attributed to the following factors:

- high market demand for meat products, i.e. goats
- import substitution effects on local production of livestock, i.e. beef
- incidence of diseases in pigs, i.e. swine flu.

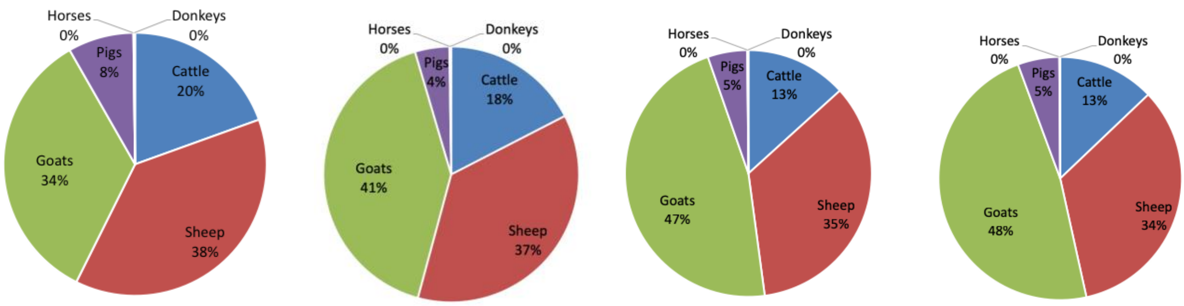


Figure 57: Percentages of livestock population in Ghana for 1990, 2000, 2012 and 2016

The overall cattle population increased at 1.9% per annum from 1,144,787 in 1990 to 1,815,000 in 2016. The 2016 cattle population was 17.6% higher than the 2012 population of 1,543,000. The growth in the cattle population over the period could be because of the various public and private interventions to improve animal husbandry practices in the country. For example, under the “Heifer International Project” calves of improved breeds were distributed to farmers. It is also important to note that in Ghana, many of the cattle are found in

Northern Ghana where cattle have cultural significance and are preserved as social capital. At a rate of 3.1% annually, the population of sheep reached 4,744,000 in 2016 and constituted an 18% change in the sheep population between 2012 and 2016. Similarly, the goat population also saw a gradual increase at a rate of 4.9% per annum, with an increase from 2,018,027 in 1990 to 6,740,000 in 2016. The goat population in 2016 constituted 24% change in the population recorded in 2012 (Table 74).

Table 74: Categorisation of the animal population for 1990-2016 in Ghana

Year	Cattle	Sheep	Goats	Pigs	Horses	Donkeys	Poultry	Totals with Poultry	Totals without Poultry
1990	1,144,787	2,223,599	2,018,027	473,946	1,366	10,398	9,989,889	15,862 012	5,872,123
1991	1,194,633	2,162,340	2,194,372	453,877	1,302	12,042	10,572,472	16,591,038	6,018,566
1992	1,159,431	2,125,522	2,157,278	413,243	1,648	13,048	11,231,574	17,101,744	5,870,170
1993	1,168,640	2,224,974	2,124,529	408,134	1,622	11,829	12,169,523	18,109,251	5,939,728
1994	1,216,677	2,215,964	2,204,150	351,875	1,912	11,511	12,289,376	18,291,465	6,002,089
1995	1,344,106	2,010,147	2,155,938	365,339	2,200	12,000	13,247,312	19,137,042	5,889,730
1996	1,247,861	2,418,738	2,532,710	354,678	2,768	13,215	14,589,303	21,159,273	6,569,970
1997	1,261,552	2,496,111	2,580,458	365,318	2,800	13,500	15,888,000	22,607,739	6,719,739
1998	1,273,000	2,576,000	2,792,000	339,000	2,900	14,000	17,302,000	24,298,900	6,996,900
1999	1,288,000	2,658,000	2,931,000	332,000	3,000	14,300	18,810,000	26,036,300	7,226,300
2000	1,302,000	2,743,000	3,077,000	324,000	2,800	14,000	20,472,000	27,934,800	7,462,800
2001	1,315,000	2,771,000	3,199,000	312,000	2,700	13,500	22,032,000	29,645,200	7,613,200
2002	1,330,000	2,922,000	3,230,000	310,000	2,700	13,100	24,251,000	30,058,800	5,807,800
2003	1,344,000	3,015,000	3,560,000	303,000	3,000	13,500	26,395,000	34,633,500	8,238,500
2004	1,359,000	3,112,000	3,925,000	297,000	3,000	13,700	28,727,000	37,436,700	8,709,700
2005	1,373,000	3,211,000	3,923,000	290,000	3,000	13,700	28,386,000	37,199,700	8,813,700
2006	1,392,000	3,314,000	3,997,000	477,000	3,000	14,000	34,030,000	43,227,000	9,197,000
2007	1,407,000	3,420,000	4,196,000	491,000	3,050	14,100	37,038,000	46,569,150	9,531,150
2008	1,422,000	3,529,000	4,405,000	506,000	2,598	14,150	39,816,000	49,694,748	9,878,748
2009	1,438,000	3,642,000	4,625,000	521,000	2,625	14,200	43,320,000	53,562,825	10,242,825
2010	1,454,000	3,759,000	4,855,000	536,000	2,653	14,250	47,752,000	58,372,903	10,620,903
2011	1,498,000	3,887,000	5,137,000	568,000	2,680	14,300	52,575,000	63,681,980	11,106,980
2012	1,543,000	4,019,000	5,435,000	602,000	2,700	14,350	57,885,000	69,501,050	11,616,050
2013	1,590,000	4,156,000	5,751,000	638,000	2,900	14,350	63,732,000	75,884,250	12,152,250
2014	1,657,000	4,335,000	6,044,000	682,000	3,000	14,400	68,511,000	81,246,400	12,735,400
2015	1,734,000	4,522,000	6,352,000	730,000	3,043	14,482	71,594,000	84,949,525	13,355,525
2016	1,815,000	4,744,000	6,740,000	777,000	2,932	14,820	71,594,000	85,687,752	14,093,752

Source: Ministry of Food and Agriculture, Facts and Figures, 2016

The pig population declined steadily from 1990 to 2006, after which it increased to 777,000 in 2016 with an average growth rate of 2%. However, the pig population increased by 29.1% from the last reporting year to 2016. In recent times, the piggery business has seen growth because it is profitable and requires low capital investment. Generally, the populations of horses and donkeys are low compared to other livestock populations even though they have seen an increase from 1990 to 2016.

The annual growth rate for Horses and Donkeys were 3.1% and 1.4% respectively. In Ghana, horses are mainly used for sports, cultural and special state ceremonial events. Majority of the horses in Ghana are housed and fed in stables.

On the other hand, Donkeys are mainly used for transport or farm labour and kept on free-range. Generally, livestock production in Ghana is done on a small-medium scale for subsistent, cultural and commercial purposes. They are mainly managed on a free-range basis; therefore, the feed and manure of the animals are not properly managed, unlike cattle that are typically herded. However, for pigs, many of them are housed and fed proper ration and on agricultural cum household waste. There are two main categories of poultry management with the majority being kept under a deep litter system and the rest falling under the free-range and semi-intensive systems. Usually, for those under the deep-litter system, the manure is managed and applied as manure in agricultural fields. The poultry population has since 1990 increased at a rate of 8.2% annually to peak at 71,594,000. This rate could have been higher but for the influence of increased importation, relatively cheaper cost of imported chicken and the outbreak of Avian Influenza.

5.4.1.2 Land category (3B)

5.4.1.2.1 Description of data generation platform (National Forest Management System)

The National Forest Monitoring System (NFMS) is anticipated to be the main source of data for the Land category. However, the NFMS has not been completely integrated as a functional unit, although almost all the components exist in isolation. The processes leading to the development of the national FREL brought together the publicly available data relevant for the land category inventory from different institutions and literature sources (Table 75). The ready availability of the FREL datasets at the Forestry Commission aided in the acquisition of the activity data and emission factors.

Table 75 Existing data for the NFMS relevant for the inventory

Existing NFMS system	Institutional owners	Data Supply /Data system	Remarks/Status	Link to a specific component of NFMS
National Forestry Inventory System	Forestry Commission (Production Unit of the RMSC)	• Permanent Sampling Plots (PSPs) • Biomass and Biomass Growth Dataset	• Spatial coverage of PSPs limited to Forest Reserves. • Regular monitoring of biomass has ceased and no longer useful due to the poor state of the PSPs • Data storage and format need to be clarified. • PSPs dataset does not cover all the carbon pools. • There are plans to revive and expand PSPs.	NFMS Component: GHG Inventory. Indicator: Emission/Removal Factors.
	Forest Services Division, FC	• Forestry plantation areas, average heights, DBH, survival survey, stocking.	• Focused on on-reserve areas with planted forest across the country • Annual Published of National Forest Plantation Development Programme.	
Land use/cover mapping	Forestry Commission (GIS/Remote Sensing Unit of the RMSC)	• GIS layers of all forest/wildlife reserve boundaries.	• GIS layers are used to produce timber yield maps and for regular updates. • GIS layers are also used to inform the development of forest management plans	NFMS Component: GHG Inventory Indicator: Activity Data

		• Land cover maps (1990, 2000, 2010, 2012, 2015).	• The land cover map was produced in a one-off exercise during FPP and the preparation of the FRL. • In the current land cover map, tree crops (cocoa, rubbers, citrus.) are not spatially isolated. It has been bunched into the forest category. • Land-cover maps are not produced at regular intervals. Funding for most of them is from Projects. • Plans to prepare a new Land cover map for 2017.	
	CERSGIS	• National land-cover map (2000). • Land cover maps prepared specifically for selected areas in the country. • Forest degradation maps for selected Forest Reserve (2018)	• Most land-use maps are produced on demand. • Limited in scale and focus on specific areas of interest. • Forest degradation maps show the extent of degradation but do not show the type of activity responsible for degradation.	NFMS Component: GHG Inventory Indicator: Activity Data
Other GIS Layers	Forestry Commission (GIS/Remote Sensing Unit of the RMSC)	• Fires Affected Areas	Fire affected areas are the non-spatial format. The affected areas are reported in the Annual Report on Monitoring and Evaluation of Wildfire Incidents across the country.	NFMS Component: GHG Inventory Indicator: Activity Data
	Lands Commission (Survey Department)	• National boundary Map • District Boundary Map • River Map • Road Map • Settlement Map • Forest Reserve • Ecological Layers • Land-cover classification scheme	• All the maps are produced once but are seldom updated. • District boundary maps are updated when new Administrative areas are delineated. • There is no standard land-cover classification code.	NFMS Component: GHG Inventory, Social and Environmental Safeguards Indicator: Activity Data, Biodiversity, Water Quality
	Soil Research Institute, CSIR	• National soil map	• An existing national soil map is at “association classification” scale. • There are plans to update the National Soil Maps	NFMS Component: Social and Environmental Safeguards. Indicator: Soil Quality
	Ghana COCOBOD	• Maps of cocoa-growing areas. • Shapefile of individual cocoa farms.	• Maps of cocoa-growing areas are available but regularly not updates. • Compilation of shapefile of individual farms is still on-going.	NFMS Component: GHG Inventory Indicator: Activity Data
Data Management & Registry	The University of Energy and Natural Resource	• Ground station for Level TERRA, AQUA, NPP, FY3, METOP. NOAA POES, FY1, FY3, DMSP • Ground station for COSMIC-2 Programme • Weather Forecasting for West Africa GEONET Cast	• Real-time active wildfires over Ghana, and parts of West Africa • Real-time vegetative indices across Africa • Land mapping services • Carbon fluxes over Bia Tano Forest Reserve	NFMS Component: GHG Inventory Indicator: Activity Data

		• Receiving Station – real-time vegetative and atmospheric indexes ZY-3 Cloud Platform – High-resolution satellite land mapping services • Carbon Flux Tower –Bia-Tano Forest Reserve (to be operational in January 2019)		
	Forestry Commission, ICT (SIS Data)	• Depository of all REDD+ safeguard data • Interface for communicating feedback	Safeguard Information System (URL – www.reddsis.fcghana.org) is still under development. Hope to be completed when fully populated with requisite safeguard data. Principles Criteria and indicators are being defined.	NFMS Component: Social and Environmental Safeguards Indicators: Resource use right, Participation and Cultural Heritage
	Forestry Commission, ICT and Climate Change Unit (Registry)	• Database of Emission transactions and cash flows. • Data on emission reduction at the jurisdictional scale.	Information /database system developed and shall be upgraded a REDD+ registry (https://www.ghanaredddatahub.org	NFMS Component: Registry Indicator: ERs, Non-ERs and Transactions
	Forestry Commission, Timber Validation Department	Wood tracking system which is a repository of data on (Tree information Form, Log Information, yield allocation, TUCs).	The wood tracking system is operational and would be used to issue the FLEGT license to check the chain of custody of wood products.	NFMS Component: Registry Indicator: Non-ERs
	Environmental Protection Agency	• Provide data on economy-wide national GHG inventory, NDC, PAMs, Project Registry and GCF.	Fully deployed on the URL: http://climatedatahubgh.com/gh/ Plan to upgrade to include tracking of actions in the Nationally Determined Contribution.	NFMS Component: Registry Indicator: ERs and Non-ERs
	Olam farmer information system	• Enable better understanding of farmers and community to invest appropriately and measure improvements. • Promote traceability and transparency	Fully deployed on the web address: http://olamgroup.com/sustainability/ofis/	NFMS Component: Registry Indicator: ERs and Non-ERs
	CERGIS/Parliament	E-mapping and monitoring system for development activities	http://ghemms.cersgis.org/map/	NFMS Component: Registry Indicator: Non-ERs
Manuals	FC, Climate Change	Using twelve Standard Operating Procedures to LULUCF Carbon Accounting	SOPs are adopted but not in operations	NFMS Component: GHG Inventory Indicator: Activity Data
		Ghana Forest Reference Level Guidance Document and Recommendation	Ghana Forest Reference Level Guidance Document and Recommendation in use.	NFMS Component: GHG Inventory Indicator: Activity Data
	FC, FSD	Manual of Procedures (MOP)	MOP for Forest Resource Management	NFMS Component: Social and

				Environmental Safeguards. Indicator: Biodiversity,

Once the NFMS is fully deployed, it would become the main source of data for the land category. The NFMS has been designed to have three main components, namely; GHG Inventory (for the REDD+ accounting and the AFOLU inventory), environment and social safeguards and the registry sub-system (Figure 58). There would be a central data storage system and a web portal to house all the data collected from the components. The centralised storage would be updated as and when new data becomes available. The web portal would provide information on REDD+ and related activities to the public online, while key stakeholders would have access to more detailed information and data per their access rights. Depending on the specific needs, reports and regular publications shall also be generated from the centralised database system. The publications could be synced with the reporting periods of the FC, as well as that of the BURs and NATCOMs.

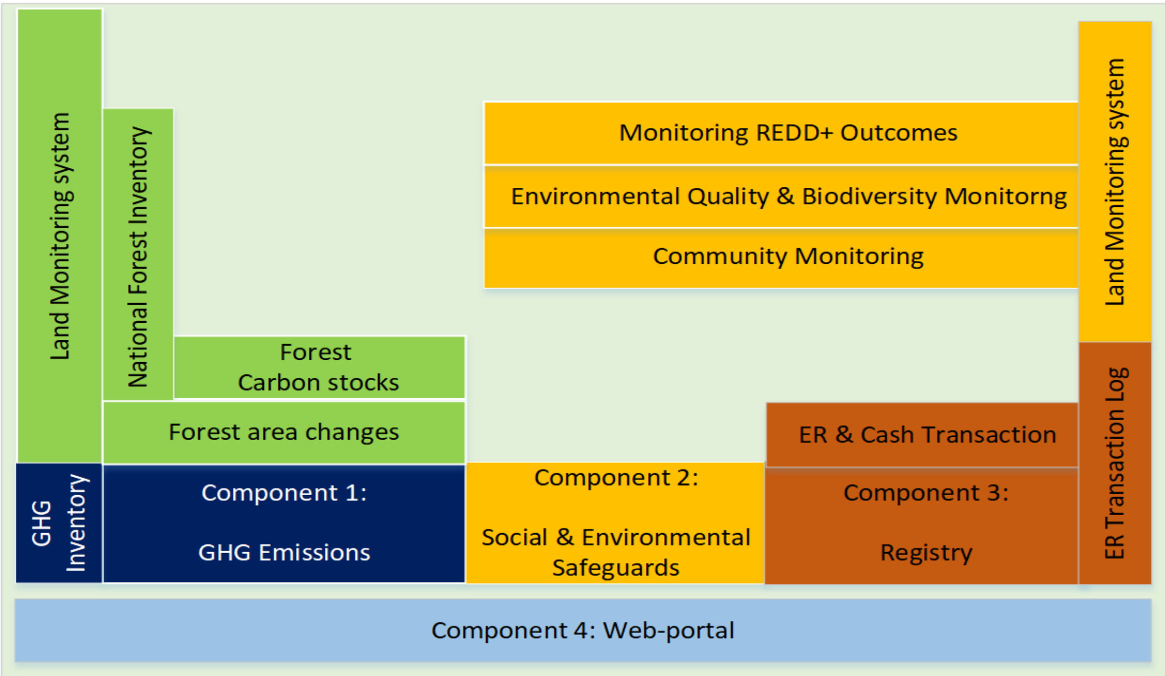


Figure 58: Elements of the proposed NFMS

5.4.1.2.2 Description of activity data in the Land category

5.4.1.2.2.1 Representations of land categories

Land use transitions resulting from land-based human activities determine the levels of terrestrial carbon emissions. The scope and intensities of the land dynamics at any given period underpin the rate of deforestation and forest degradation and its associated emissions. On the other hand, the management efforts towards restoring degraded areas, sustainable timber extraction and forest conservation, as well as other areas that are abandoned, contribute to sink capacity of the Ghanaian landscape. The changes that occur in the landscape determine whether it is a net sink or source. The landscape may be deemed as a net of the source of emissions when the underlying activities lead to greater loss of carbon stocks than the accumulation of carbon stocks.

It is considered a net sink when the carbon stocks accrual is more than the reduction in stocks. The main data types for the inventory include: (a) the six identified IPCC land categories or subcategories per ecological zone, (b) the areas of each identified land category or subcategory and (c) the transfer in the land categories or subcategories over the inventory period. The main dataset for the land categories was derived from the processing of satellite imageries for the years 1990, 2000, 2010, and 2015. The datasets were sourced from previous work done by the Forestry Commission under the Forest Preservation Programme in 2012 and also during the Forest Reference Level estimations in 2016. The land representations matrix obtained from land-use maps for periods 1990-2000, 2000-2010 and 2010-2015 (Table 76).

The pre-land use refers to the state of the land category in the initial year under consideration while the post-land-use refers to the state of the land category in the final year under consideration. The annual area changes have been estimated by dividing the total change area per time by the number of intervening years. The changes in the land categories over the period followed five main transition pathways, namely: persisted forests, persisted non-forest, forest loss, forest gain and non-forest change.

Table 76: Land representations matrix for the periods 1990-2000, 2000-2010 and 2010-2015 and the annual area change

		Post-land-use (ha)			Annual area change (ha yr-1)		
Pre-land-use	Post-land-use	1990-2000	2000-2010	2010-2015	1990-2000	2000-2010	2010-2015
Closed forest	Closed forest	1,665,727.77	1,281,136.48	984,426.97	166,572.78	128,113.65	196,885.39
Closed forest	Open forest	545,419.31	400,468.28	182,231.17	54,541.93	40,046.83	36,446.23
Closed forest	Water	1,190.20	465.29	903.90	119.02	46.53	180.78
Closed forest	Grassland	79,135.33	63,587.45	25,546.56	7,913.53	6,358.74	5,109.31
Closed forest	Settlement	249.52	0.09	576.73	24.95	0.01	115.35
Closed forest	Cropland	15,908.41	31,242.69	22,622.05	1,590.84	3,124.27	4,524.41
Closed forest	Wetland	1,270.41	61.56	65.92	127.04	6.16	13.18
Closed forest	Otherland	1,114.12	3,648.58	374.28	111.41	364.86	74.86
Open forest	Closed forest	885,091.36	741,461.90	631,729.04	88,509.14	74,146.19	126,345.81
Open forest	Open forest	2,460,110.42	3,844,110.63	3,775,933.10	246,011.04	384,411.06	755,186.62
Open forest	Water	1,588.91	2,454.17	45,370.27	158.89	245.42	9,074.05
Open forest	Grassland	1,961,381.63	1,588,833.13	2,265,476.87	196,138.16	158,883.31	453,095.37
Open forest	Settlement	1,757.14	3.50	38,191.02	175.71	0.35	7,638.20
Open forest	Cropland	367,194.49	779,408.94	1,702,355.06	36,719.45	77,940.89	340,471.01
Open forest	oil palm	30,000	207,100.00	68,500.00	3,000.00	20,710.00	13,700.00
Open forest	cocoa	806,751	100,200.00	117,240.00	80,675.10	10,020.00	23,448.00
Open forest	rubber	780	12,720.00	2,300.00	78.00	1,272.00	460.00
Open forest	citrus	32,000	26,000.00	1,690.00	3,200.00	2,600.00	338.00
Open forest	mango	81	6,481.00	800.00	8.10	648.10	160.00
Open forest	cashew	16,066	59,934.00	15,600.00	1,606.60	5,993.40	3,120.00
Open forest	Wetland	1,300.41	1,808.77	3,171.99	130.04	180.88	634.40
Open forest	Otherland	7,889.22	17,280.56	30,266.72	788.92	1,728.06	6,053.34
Cropland	Closed forest	106,278.20	198,363.90	91,617.16	10,627.82	19,836.39	18,323.43
Cropland	Open forest	445,227.29	1,030,471.35	1,218,604.46	44,522.73	103,047.13	243,720.89
Cropland	Water	1,628.16	1,240.36	78,846.89	162.82	124.04	15,769.38
Cropland	Grassland	1,685,045.37	2,168,437.52	1,476,597.90	168,504.54	216,843.75	295,319.58
Cropland	Settlement	4,125.51	0.45	82,501.14	412.55	0.04	16,500.23
Cropland	Cropland	1,641,755.89	1,786,748.52	1,660,833.29	164,175.59	178,674.85	332,166.66

Cropland	Wetland	3,486.26	2,535.38	8,891.96	348.63	253.54	1,778.39
Cropland	Otherland	6,220.10	18,472.64	31,644.68	622.01	1,847.26	6,328.94
Grassland	Closed forest	106,562.12	78,857.33	59,040.57	10,656.21	7,885.73	11,808.11
Grassland	Open forest	819,510.53	845,675.44	1,829,247.01	81,951.05	84,567.54	365,849.40
Grassland	Water	3,861.62	2,445.28	91,157.51	386.16	244.53	18,231.50
Grassland	Grassland	7,863,596.72	5,891,025.36	4,141,178.62	786,359.67	589,102.54	828,235.72
Grassland	Settlement	4,568.14	1.44	46,261.39	456.81	0.14	9,252.28
Grassland	Cropland	1,096,083.29	1,205,801.29	1,650,801.75	109,608.33	120,580.13	330,160.35
Grassland	Wetland	7,418.74	20,485.12	5,708.80	741.87	2,048.51	1,141.76
Grassland	Otherland	28,245.41	105,351.87	32,217.18	2,824.54	10,535.19	6,443.44
Settlement	Closed forest	2,518.45	2,435.23	13,243.06	251.85	243.52	2,648.61
Settlement	Open forest	13,740.25	18,198.14	170,164.79	1,374.03	1,819.81	34,032.96
Settlement	Water	65.21	279.00	50,921.12	6.52	27.90	10,184.22
Settlement	Grassland	64,284.37	72,642.50	199,091.47	6,428.44	7,264.25	39,818.29
Settlement	Settlement	90,462.31	203,248.00	171,816.80	9,046.23	20,324.80	34,363.36
Settlement	Cropland	29,351.09	44,047.27	152,638.98	2,935.11	4,404.73	30,527.80
Settlement	Wetland	228.68	1,883.34	3,209.90	22.87	188.33	641.98
Settlement	Otherland	2,654.71	1,311.80	10,205.89	265.47	131.18	2,041.18
Wetland	Closed forest	5,499.03	203.53	515.85	549.90	20.35	103.17
Wetland	Open forest	4,954.27	1,022.48	1,482.61	495.43	102.25	296.52
Wetland	Water	332.87	574.15	5,003.93	33.29	57.41	1,000.79
Wetland	Grassland	16,599.75	12,825.41	20,430.87	1,659.97	1,282.54	4,086.17
Wetland	Settlement	354.61	-	1,048.80	35.46	-	209.76
Wetland	Cropland	2,241.90	3,629.92	4,758.88	224.19	362.99	951.78
Wetland	Wetland	13,381.51	5,560.82	1,811.86	1,338.15	556.08	362.37
Wetland	Other land	263.89	298.20	203.53	26.39	29.82	40.71
Otherland	Closed forest	6,912.97	4,673.13	68.44	691.30	467.31	13.69
Otherland	Open forest	18,417.88	12,435.76	45.66	1,841.79	1,243.58	9.13
Otherland	Water	1,032.39	498.86	-	103.24	49.89	-
Otherland	Grassland	119,291.81	68,891.88	33.50	11,929.18	6,889.19	6.70
Otherland	Settlement	141.38	-	147.33	14.14	-	29.47
Otherland	Cropland	8,470.62	18,595.50	165.52	847.06	1,859.55	33.10
Otherland	Wetland	1,006.52	253.69	-	100.65	25.37	-
Otherland	Otherland	1,071.10	4,056.35	3,753.67	107.11	405.64	750.73
Water	Closed forest	4,158.38	3,298.42	2,105.08	415.84	329.84	421.02
Water	Open forest	4,027.51	7,463.45	10,699.31	402.75	746.35	2,139.86
Water	Water	714,256.54	738,802.06	579,979.04	71,425.65	73,880.21	115,995.81
Water	Grassland	13,609.92	61,449.70	20,489.05	1,360.99	6,144.97	4,097.81
Water	Settlement	89.91	-	1,107.79	8.99	-	221.56
Water	Cropland	3,256.32	24,266.96	6,642.61	325.63	2,426.70	1,328.52
Water	Wetland	4,747.51	11,026.69	1,188.03	474.75	1,102.67	237.61
Water	Otherland	956.31	5,807.51	504.68	95.63	580.75	100.94
Total		23,854,000	23,854,000	23,854,000	2,385,400	2,385,400	4,770,800

Key: Persisted forest | Forest loss | Non-forest change | Forest gain | Persisted non forest

Table 77 presents land transitions among the six IPCC land categories over the four-time periods. Persisted lands represent areas that remained unchanged over a given period. This category includes: persisted forest and persisted non-forest. Aside from the persisted areas, the remaining lands were involved in transitions. For example, 11,720,306.46 ha representing 49% of the landscape changed between 2010-2015 out of which 3,396,834.01 was forest gain, and 4,341,051.37 was forest loss.

Table 77: Summaries of areas associated with the different transition pathways for the three-time periods

Transition pathways	1990-2000	2000-2010	2010-2015	Remarks
Persisted Forest	5,556,348.87	6,267,177.29	5,574,320.28	Forestland remaining forestland
Forest Loss	3,325,657.80	2,901,229.73	4,341,051.37	Forestland to other lands
Forest gain	1,537,806.90	2,203,098.16	3,396,834.01	Other lands to Forest
Non-forest change	3,109,662.35	3,853,053.71	3,982,421.08	Change among non-forestland
Persisted Non-forest	10,324,524.08	8,629,441.11	6,559,373.27	Non-forest remaining non-forest

5.4.1.2.2.2 Industrial round wood supply and fuelwood production

Biomass harvesting is the main source of industrial round wood supply and fuelwood. The extraction of biomass has a significant impact on forest land carbon stocks and represents the key dataset for assessing the variation of carbon stocks in forestland remaining forest land. The Resource Management and Support Centre of the Forestry Commission, and the Energy Commission were the primary sources of data on industrial round wood and fuelwood harvesting. The industrial round wood data were segregated into "planned logging" and "unplanned logging". The planned logging refers to permitted systematic and supervised extraction of timber. Unplanned logging is unsupervised removal of timber and unaccounted for in official records. However, this is relevant because the resulting impact on the forest stocks is severe. The total harvested forest biomass for the year 2016 was 2,035,624.71 m^3/yr and consisted of 1,483,431 m^3/yr industrial round wood and 552,193.51 m^3/yr fuelwood extracted (Table 78).

Table 78 Quantities of wood harvesting grouped according to types between 1990 and 2016

Years	Harvesting (m^3/yr.)						
	Logging			Fuelwood (FW)			
	Planned logging	Unplanned logging	Total logging production	Total FW	Fraction as whole	Fraction as part	Total harvested
1990	1,328,677	1,131,836	2,460,512	607,173.73	364,304.24	242,869.49	3,067,686.06
1991	1,337,488	1,139,341	2,476,829	630,298.29	378,178.98	252,119.32	3,107,127.23
1992	1,346,357	1,146,897	2,493,254	654,449.86	392,669.92	261,779.94	3,147,703.61
1993	1,355,285	1,154,502	2,509,787	679,677.49	407,806.49	271,871.00	3,189,464.97
1994	1,364,273	1,162,158	2,526,431	706,034.83	423,620.90	282,413.93	3,232,465.68
1995	1,373,320	1,169,865	2,543,185	733,580.12	440,148.07	293,432.05	3,276,764.71
1996	1,382,427	1,177,623	2,560,049	762,373.16	457,423.89	304,949.26	3,322,422.59
1997	1,391,594	1,185,432	2,577,026	792,478.31	475,486.99	316,991.32	3,369,504.42
1998	1,400,822	1,193,293	2,594,115	779,282.01	467,569.21	311,712.81	3,373,397.38
1999	1,469,853	1,252,097	2,721,950	796,428.46	477,857.08	318,571.38	3,518,378.28
2000	982,955	837,332	1,820,287	204,635.34	122,781.20	81,854.13	2,024,922.74
2001	1,245,526	1,061,004	2,306,530	222,263.10	133,357.86	88,905.24	2,528,792.91
2002	1,364,392	1,162,260	2,526,651	230,693.77	138,416.26	92,277.51	2,757,344.88

2003	1,177,482	1,003,040	2,180,523	239,124.44	143,474.66	95,649.77	2,419,647.03
2004	902,232	768,568	1,670,800	242,956.56	145,773.94	97,182.62	1,913,756.74
2005	934,886	796,384	1,731,270	248,321.53	148,992.92	99,328.61	1,979,591.72
2006	858,861	731,623	1,590,484	470,232.07	282,139.24	188,092.83	2,060,715.96
2007	878,498	748,350	1,626,848	465,250.31	279,150.19	186,100.13	2,092,098.46
2008	898,161	765,100	1,663,261	465,848.13	279,508.88	186,339.25	2,129,109.61
2009	760,953	648,219	1,409,172	474,662.01	284,797.20	189,864.80	1,883,833.86
2010	901,154	767,650	1,668,804	487,016.77	292,210.06	194,806.71	2,155,821.03
2011	816,421	695,469	1,511,890	511,971.55	307,182.93	204,788.62	2,023,861.55
2012	864,413	736,352	1,600,765	517,919.00	310,751.40	207,167.60	2,118,684.00
2013	1,012,557	862,549	1,875,106	540,206.63	324,123.98	216,082.65	2,415,312.74
2014	957,272	815,454	1,772,726	551,672.34	331,003.40	220,668.94	2,324,398.26
2015	778,226	662,933	1,441,159	549,986.20	329,991.72	219,994.48	1,991,145.46
2016	801,053	682,378	1,483,431	552,193.51	331,316.10	220,877.40	2,035,624.71

Since 2012, the trends in biomass removal from forest lands have decreased by 1.3% per annum. Round wood extraction declined by 2.5% between 2012 and 2016, while fuelwood extraction increased by 2.1% over the same period.

5.4.1.2.2.3 Disturbances (areas affected by fire)

Forest land, cropland and grassland biomass consumption by fires is an important source of emissions in the land category. The areas affected by fire in the different ecological zones were estimated from Moderate Resolution Imaging Spectroradiometer (MODIS) satellite data. Emissions from burnt areas are a function of the area burnt, frequency of fire events, the type and amount of fuel load available. The prevailing weather conditions at the time of burning are also important in determining the amount of emissions. Table 79 shows the respective fractions of areas of land categories affected by annual fires in Ghana from 1990 to 2016.

Table 79: Areas of forest land, cropland, and grassland burnt per annum (ha)

Year	Forest land	Cropland	Grassland	Total burn per annum.
1990	184867.74	264753.68	1042938.92	1,492,560.34
1991	221341.69	259525.56	1000515.32	1,481,382.58
1992	257815.64	254297.44	958091.73	1470204.81
1993	294289.59	249069.32	915668.13	1459027.04
1994	330763.54	243841.19	873244.54	1447849.27
1995	367237.50	238613.07	830820.94	1436671.51
1996	403711.45	233384.95	788397.34	1425493.74
1997	440185.40	228156.82	745973.75	1414315.97
1998	476659.35	222928.70	703550.15	1403138.20
1999	513133.30	217700.58	661126.55	1391960.43
2000	549607.25	212472.45	618702.96	1380782.67
2001	560163.71	205807.05	586492.76	1352463.51
2002	570720.16	199141.64	554282.55	1324144.36
2003	581276.62	192476.24	522072.35	1295825.21
2004	591833.07	185810.83	489862.15	1267506.05

2005	602389.53	179145.42	457651.94	1239186.90
2006	612945.98	172480.02	425441.74	1210867.74
2007	623502.44	165814.61	393231.54	1182548.59
2008	634058.89	159149.21	361021.34	1154229.43
2009	644615.35	152483.80	328811.13	1125910.28
2010	655171.80	145818.40	296600.93	1097591.13
2011	564360.72	145802.60	296366.48	1006529.80
2012	473549.64	145786.80	296132.03	915468.46
2013	382738.55	145771.00	295897.58	824407.13
2014	291927.47	145755.20	295663.13	733345.80
2015	201116.39	145739.40	295428.68	642284.47
2016	149831.71	145719.01	295136.20	590686.91

The total area affected by fire declined by 35.5% from 915468.46 ha in 2012 to 590686.91 ha in 2016. The reduction in the area burnt was common in forestland, cropland and grassland. However, the decline rates differed. For the same period, the forest area declined by 68.36% while cropland and grassland areas decreased by 0.05% and 0.34% respectively.

5.4.1.2.3 Description of emission factors in the land category

5.4.1.2.3.1 Emission factors for land representations

Land category emission factors were generated from biomass stocks in different land-use types, annual biomass growth and reference soil organic carbon stocks. Biomass stock data were sourced from the FPP forest inventory report and reported in the Forest Reference Level. The data included carbon stocks for the five main biomass pools (above-ground biomass, dead wood, litter, herbs and soil) in the ten different ecological zones of Ghana. The carbon stocks for the individual pools were averaged for each ecological zone to represent forest land, cropland and grassland. Biomass data for wetland, settlement and other lands were not available from the FPP study. Country specific teak plantation and natural forest emission factors were obtained from a study by Adu-Bredu et al. 2008 and IPCC 2003 guidelines, respectively (Table 80).

Table 80 List of emission factors used in the inventory[21]

Type of land representations	Area fraction	AGB	AGB	Herb AGB	Herb AGB	Deadwood	Litter
		tC/ha	t dm/ha	tC/ha	t d.m/ha	tC/ha	tC/ha
Closed Forest							
Wet evergreen	2.56%	124.00	263.83	NA	NA	28.00	2.80
Moist evergreen	6.32%	139.00	295.74	0.50	1.06	79.50	2.60
Moist semi-deciduous (SE type)	5.95%	124.00	263.83	0.20	0.43	56.00	2.40
Moist semi-deciduous (NW type)	5.37%	40.00	85.11	0.70	1.49	10.90	2.20
Dry semi-deciduous (inner zone)	3.17%	23.00	48.94	2.10	4.47	6.00	1.30
Dry semi-deciduous (fire zone)	4.68%	15.00	31.91	0.90	1.91	NA	NA
Savannah	53.24%	18.00	38.30	0.60	1.28	NA	NA

[21] Unless otherwise stated, emission factors were obtained from the FPP studies.

Upland evergreen	0.22%	73.00	155.32	0.90	1.91	25.00	1.40
Coastal savannah	0.91%	11.00	23.40	0.90	1.91	2.00	2.20
Mangrove	0.00%	0.00	0.00	NA	NA	0.00	NA
Open Forest							
Wet evergreen	0.55%	30.00	63.83	NA	NA	NA	NA
Moist evergreen	1.35%	40.00	85.11	0.50	1.06	10.90	2.60
Moist semi-deciduous (SE type)	1.27%	35.00	74.47	1.20	2.55	56.00	2.20
Moist semi-deciduous (NW type)	1.15%	17.00	36.17	1.10	2.34	13.00	2.10
Dry semi-deciduous (inner zone)	0.68%	14.00	29.79	2.30	4.89	8.00	1.90
Dry semi-deciduous (fire zone)	1.00%	12.00	25.53	NA	NA	3.00	1.60
Savannah	11.37%	13.00	27.66	NA	NA	38.00	1.70
Upland evergreen	0.05%	26.00	55.32	0.40	0.85	15.00	1.10
Coastal savannah	0.19%	8.00	17.02	0.50	1.06	0.60	0.60
Mangrove	0.00%	0.00	0.00	NA	NA	NA	0.60
Average forest land		35.8	76.19	0.57	1.21	15.34	0.87
Wet evergreen	3.10%	21.00	44.68	NA	NA	6.00	3.80
Moist evergreen	7.67%	34.00	72.34	0.30	0.64	21.00	3.50
Moist semi-deciduous (SE type)	7.22%	19.00	40.43	1.60	3.40	9.00	3.60
Moist semi-deciduous (NW type)	6.52%	19.00	40.43	0.40	0.85	28.00	2.60
Dry semi-deciduous (inner zone)	3.85%	6.00	12.77	0.50	1.06	119.00	1.80
Dry semi-deciduous (fire zone)	5.68%	3.00	6.38	0.70	1.49	3.00	0.90
Savannah	64.61%	10.00	21.28	0.60	1.28	0.60	1.40
Upland evergreen	0.26%	6.00	12.77	0.30	0.64	8.00	2.00
Coastal savannah	1.10%	8.00	17.02	1.60	3.40	0.00	0.60
Mangrove	0.00%	0.00	0.00	NA	NA	NA	NA
Average cropland	-	12.83	27.31	0.63	1.34	9.43	1.85
Wet evergreen	3.10%	NA	NA	NA	NA	8.00	3.80
Moist evergreen	7.67%	0.00	0.00	1.90	4.04	31.00	3.50
Moist semi-deciduous (SE type)	7.22%	NA	NA	NA	NA	15.00	3.60
Moist semi-deciduous (NW type)	6.52%	1.00	2.13	NA	NA	43.00	2.60
Dry semi-deciduous (inner zone)	3.85%	NA	NA	NA	NA	178.00	1.80
Dry semi-deciduous (fire zone)	5.68%	1.00	2.13	1.00	2.13	4.00	0.90
Savannah	64.61%	9.00	19.15	1.30	2.77	1.00	1.40
Upland evergreen	0.26%	NA	NA	NA	NA	9.00	2.00
Coastal savannah	1.10%	1.00	2.13	0.40	0.85	0.00	0.60
Mangrove	0.00%	NA	NA	NA	NA	NA	NA
Average grassland		5.948	12.654	1.047	2.227	14.252	1.852
Average Annual aboveground biomass growth for Teak plantation	8.31 t.d.m/ha/yr.[22]						
Average annual aboveground biomass growth for natural forest	1.6 t.d.m/ha/yr.[23]						

[22] Adu-Bredu et. al 2008
[23] IPCC, 2003. Annex 3A_1_Data_Tables. Table 3A.1.5

The ratio of below-ground to aboveground for natural forest	0.37 t BG d.m/t ABG d.m[24]
Carbon fraction	0.47[25]
Basic wood density	0.51 t/m^3[26]
BCEF	1.67 tonnes per biomass removal (m^3 of removals per year)[27]
Mass of fuel forestland	132.25 t.d.m[28]
Mass of fuel cropland	56.44 t.d.m
Mass of fuel grassland	17.33 t.d.m
The fraction of biomass lost in disturbances	0.002 t.d.m[29]

5.4.1.3 Aggregated sources and Non-CO_2 emission sources on land (3C)

5.4.1.3.1 Nitrogen-based fertiliser and Urea application

Direct and indirect N_2O emissions are estimated from the application of nitrogen-based artificial fertilisers in cultivated lands. The emission estimation uses data on quantities of nitrogen-based fertilisers and urea in the country over a defined period. In the estimation, the assumption is that all fertiliser imports are utilised in the year they were imported. The actual consumption per the imported year may be less or more than what was imported due to surpluses or deficit from the previous year stock. Besides, the emissions would be influenced by the mode of the fertiliser application (broadcasting, ring or dip). The emissions calculation is based on the data on the total N-based fertiliser and urea application in the agricultural fields in a particular year.

The Nitrogen-based fertilisers include NPK, Sulphate of Ammonia and the Nitrate fertilisers (calcium and potassium nitrates). The direct N_2O emissions from fertilisers applied to soils are derived from the calculated nitrogen fraction of the N-based fertilisers. Generally, the quantities of nitrogen-based fertilisers and urea increased from 1990 to 2016. However, between 2012 and 2016, the trends in total fertiliser quantities declined by 15.6% from 346,780 t/year in 2012 to 292,511 t/year in 2016 (Table 81). The trends in the quantities of individual fertiliser types applied vary from year to year. While NPK and Calcium Nitrate recorded an increasing trend for the period 2012-2016, the quantities of Sulphate of Ammonia and Urea dropped for the same period.

Table 81: Quantities of nitrogen-based fertiliser, urea and the nitrogen fraction for the period 1990-2016

Year	Nitrogen-based Fertilisers(t/yr.)				Urea (t/yr.) (E)	Total F=(D+E)	N Fraction of N-based fertilisers G= N_{frac} *F
	NPK (A)	Sulphate of Ammonia (B)	Calcium Nitrate (C)	Total N-based D= (A+B+C)			
1990	21,250	2,500	-	23,750	20,100	43,850	12,745
1991	19,375	7000	-	26,375	10,050	36,425	9,431.9
1992	17,500	11,500	-	29,000	-	29,000	17,240.2

[24] IPCC 2006 (Mokany et al. 2006 R of BGB to AGB for tropical moist deciduous forest >125 t dry matter per ha

[25] IPCC 2006 Guidelines Volume 4 Table 4.3

[26] Based on field research conducted by Dr. Stephen Adu-Bredu of the Forestry Research Institute. The study covered nearly 100 different tree species in nine forest reserves in the nine ecological zones across the country

[27] IPCC 2006 Guidelines Volume 4 Table 4.5

28 Derived by the AFOLU inventory team based on the total carbon stocks for each land use category.

29 Weight average of areas of land use categories affected by fires in all the ecological zones

1993	10,000	7,600	-	17,600	-	17,600	5,874.9
1994	13,040	8,500	-	21,540	-	21,540	5,341.6
1995	9.3	9,000	-	9,009	4,250	13,259	5,152.5
1996	8,700	5,320	-	14,020	950	14,970	2,823.1
1997	37,080	10,700	-	47,780	1,850	49,630	8,588
1998	21,858	13,265	-	35,123	500	35,623	6,223
1999	3,602	4,800	-	8,402	-	8,402	1,524.3
2000	14,902	23,165	-	38,067	141	38,208	7,047.6
2001	49,287	22,628	-	71,915	2,500	74,415	13,156.8
2002	800	20,047	-	20,847	-	20,847	4,229.6
2003	18,890	25,715	7.35	44,612	500	45,112	8,331.2
2004	18,223	7,688	95,312	121,223	250	121,473	19,195.4
2005	38,978	15,000	157	54,135	4,540	58,675	10,989
2006	84,907	19,090	52,601	156,598	9,072	165,670	28,885.1
2007	87,388	17,458	52,823	157,669	4,962	162,631	27,107.6
2008	18,873	4,172	64,085	87,130	13,773	100,903	19,817.2
2009	197,631	4,616	110	202,357	25,028	227,385	41,870.6
2010	30,560	12,077	236,547	279,184	11,521	290,705	48,909
2011	139,128	46,222	75,292	260,642	12,363	273,005	47,578.3
2012	230,723	83,840	267	314,830	31,950	346,780	66,214.5
2013	227,571	68,979	407	296,957	51,044	348,001	71,309.2
2014	89,332	7,551	49,319	146,202	3,864	150,066	24,331
2015	121,510	59,676	49,492	230,678	23,594	254,272	48,748.73
2016	258,290	14,417	3,450	276,158	16,353	292,511	49,592.87
Change (2012-2016)	11.9%	-82.8%	1192.1%	-12.3%	-48.8%	-15.6%	-25.1%

Source: Ministry of Food and Agriculture, Facts and Figures (2016). The calculation of nitrogen fraction of n-based fertilisers are from the total N-based fertilisers

The government policy on fertiliser and the market demand for different fertiliser products largely determined the import volumes at any given period. The government introduced a national fertiliser subsidy programme (covering all compounds and urea) in 2008 to boost fertiliser application rates in Ghana since it was among the lowest in the world. The Government's fertiliser subsidy programme has contributed to the increased amounts of fertiliser imports and application on agricultural fields. The overall average fertiliser quantities and the corresponding nitrogen content tripled after the introduction of the fertiliser subsidy programme (Figure 3). The factors used in the calculation of CO_2 and N_20 are emission factor (tonnes of C / tonne of urea) = 0.2 and emission factor for N_2O emissions from N inputs (kg N_20-N/kg N input = 0.01 respectively were sourced from the IPCC guidelines.

5.4.1.3.2 Nitrogen-content of crop residues (crop production)

Crop residues are a major source of direct N_2O emissions from managed soils. The amount of crop residues each year depends on the type of crop, quantities harvested, and the harvesting method used. The nitrogen content of crop residue is, therefore, dependent on the available residue per crop type. The nitrogen content of the crop residue is a fraction of the total crop residue produced (above-/belowground residue: yield ratios, renewal time and residue nitrogen contents) in a year. Table 82 presents the quantities of crop production per year.

Table 82: Quantities of crop production in t/year between 1990 and 2016

Year	Maize	Millet	Sorghum	Cassava	Cocoyam	Yam	Plantain	Total
1990	553,000	75,000	136,000	2,717,000	815,000	877,000	799,000	6,053,000
1991	931,500	112,400	241,400	5,701,500	1,296,800	2,631,900	1,178,300	12,244,700
1992	730,600	133,300	258,800	5,662,000	1,202,200	2,331,400	1,082,000	11,531,800
1993	960,900	198,100	328,300	5,972,600	1,235,500	2,720,300	1,321,500	12,894,600
1994	939,900	167,800	323,900	6,025,000	1,147,700	1,700,100	1,474,700	11,941,400
1995	1,034,200	290,000	360,100	6,611,400	1,383,200	2,125,700	1,637,500	13,663,400
1996	1,007,600	193,300	353,400	7,111,200	1,551,800	2,274,800	1,823,400	14,531,200
1997	996,000	143,500	332,600	6,999,500	1,529,800	2,407,900	1,818,400	14,424,800
1998	1,015,000	162,300	355,400	7,171,500	1,576,700	2,702,900	1,912,600	15,177,500
1999	1,014,500	159,800	302,000	7,845,400	1,707,400	3,249,000	2,046,200	16,534,100
2000	1,012,700	169,400	279,800	8,106,800	1,625,100	3,362,900	1,932,500	16,703,800
2001	938,000	134,400	279,700	8,965,800	1,687,500	3,546,700	2,073,800	17,879,100
2002	1,400,000	159,120	316,100	9,731,000	1,860,000	3,900,000	2,278,800	19,925,020
2003	1,289,000	176,000	337,700	10,239,300	1,804,700	3,812,800	2,328,600	20,227,100
2004	1,157,600	143,800	287,400	9,738,200	1,715,900	3,892,300	2,380,800	19,557,800
2005	1,171,400	154,600	299,000	9,567,200	1,685,800	3,922,800	2,791,600	19,828,900
2006	1,188,800	165,000	315,000	9,638,000	1,660,000	4,288,000	2,900,000	20,404,800
2007	1,219,600	113,000	154,800	10,217,900	1,690,100	4,376,000	3,233,700	21,190,400
2008	1,470,100	193,800	331,000	11,351,100	1,688,300	4,894,900	3,337,700	23,568,800
2009	1,619,600	245,500	350,600	12,230,600	1,504,000	5,777,900	3,562,500	25,682,100
2010	1,871,700	219,000	353,000	13,504,100	1,354,800	5,860,500	3,537,700	27,192,400
2011	1,683,000	183,000	287,000	14,240,000	1,299,000	5,855,000	3,619,000	27,629,000
2012	1,950,000	180,000	280,000	14,547,000	1,270,000	6,639,000	3,556,000	28,903,000
2013	1,764,000	155,000	257,000	15,990,000	1,261,000	7,075,000	3,675,000	30,747,000
2014	1,769,000	155,000	259,000	16,524,000	1,299,000	7,119,000	3,828,000	31,557,000
2015	1,692,000	157,000	263,000	17,213,000	1,301,000	7,296,000	3,952,000	32,515,000
2016	1,722,000	159,000	230,000	17,798,000	1,344,000	7,440,000	4,000,000	33,381,000
Change (2012-2016)	-11.7%	-11.7%	-17.9%	22.3%	5.8%	12.1%	12.5%	15.5%

Source: MOFA, 2017

Total crop production statistics showed a steady rise from 6,053,000 tonnes in 1990 to 33,381,000 in 2016. The production trend among the individual staple crops generally differed. Among the cereals, except rice which increased 43% between 2012-2016, all the rest (Maize, Millet and Sorghum) showed a downward trend in the same period. On the hand, the root and tubers recorded an upward with cassava being the highest with 22.3% over the same period. It can be inferred that the increase in total crop production resulted in commensurate apparent above and below ground residue. However, the expected available residues, as a potential source of soil nitrogen, are computed after considering the effects of the quantity of residues burnt, collected or grazed.

5.4.1.3.3 Rice cultivation

Rice production in different ecosystems can produce methane emissions at varying levels depending on flooded soil environment and agricultural practices. Those cultivated in bottom-lands (low-land) have the higher potential to produce methane because of the aerobic condition created by intermittent inundation of the rice field. The determining factors of methane emission in upland rice systems or under irrigation are the slope and the dwell time of available water to the rice. Therefore, the potential of methane emissions from rice cultivation is influenced by the fraction of the total rice cultivation areas under rainfed, irrigation and upland and the prevailing management practices. Data on annual rice cultivation areas and percentage areas under different systems were obtained from the MOFA's Agric Fact and Figures and using expert judgement, respectively. Generally, there was an increase in areas of cultivation of rice from 88,300 ha in 1990 to 236,000 in 2016 (Table 83). For the years, rice cultivated under low land areas formed the majority and followed by rice grown under irrigation and upland rice.

Table 83: Rice Cultivation areas (Ha) from 1990 to 2016

Year	Rice upland	Rice lowland	Rice irrigated	Total
1990	5,298	68,874	14,128	88,300
1991	5,694	74,022	15,184	94,900
1992	4,782	62,166	12,752	79,700
1993	4,632	60,216	12,352	77,200
1994	4854	63102	12944	80,900
1995	5994	77922	15984	99,900
1996	6318	82134	16848	10,5300
1997	7062	91806	18832	11,7700
1998	7824	101712	20864	13,0400
1999	6318	82134	16848	10,5300
2000	5616	73008	14976	93,600
2001	5280	68640	14080	88,000
2002	7368	95784	19648	122,800
2003	7074	91962	18864	117,900
2004	7164	93132	19104	119,400
2005	7200	93600	19200	120,000
2006	7500	97500	20000	125,000
2007	6534	84942	17424	108,900
2008	7968	103584	21248	132,800
2009	9744	126672	25984	162,400
2010	10860	141180	28960	181,000
2011	11976	155688	31936	199,600
2012	13092	170196	34912	218,200
2013	12960	168480	34560	216,000
2014	13440	174720	35840	224,000
2015	13980	181740	37280	233,000
2016	14160	184080	37760	236,000

The total area under rice cultivation expanded from 218, 200 ha in 2012 to 236,000 ha in 2016. The IPCC 2006 Guidelines factors used in the calculation of the rice emissions are as below:

- Cultivation period = 120 days
- Baseline emission factor for continuously flooded fields without organic amendments = 1.3 (kg CH_4/ (ha day))
- Scaling factor to account for the differences in water regime during cultivation period = (Irrigated = 0.6, Rain-fed = 2.8)

- Scaling factor to account for the differences in water regime in the pre-season before the cultivation period = (Irrigated = 0.68, Rain-fed = 1)
- Scaling factor for both types and amount of organic amendment applied = (Irrigated = 1, Rainfed = 1, Upland =1)
- Scaling factor for soil type, rice cultivar etc, if available = (Irrigated = 1, Rain-fed = 1)
- Adjusted daily emission factor for each harvested area (kg CH_4/ (ha Day)) = (Irrigated = 0.53, Rain-fed = 0.36) from 2006 IPCC Guidelines.

5.6 Identification of AFOLU key categories

The KCA identified significant sources of emissions from the AFOLU sector using both the level and trend approach. Eleven key categories were identified for level and trend approach with net total GHG emissions of 22.1 $MtCO_2e$. Out of the 11, 5 were in the land category, two under livestock and the remaining four fell within the aggregate source and non-CO_2 emissions category. In terms of the gases, key categories were dominated by CO_2 emission, followed by N_2O and CH_4 in order of frequencies. The methodology and results of the key category analysis in the AFOLU sector are in Table 84.

Table 84: Results and methods of AFOLU key category analysis

IPCC Category	Gas	Level Assessment (2016)	Trend Assessment (2000-2016)
3.B.2.b - Land converted to cropland	CO_2	√	√
3.B.3.b - Land Converted to Grassland	CO_2	√	√
3.C.4 - Direct N_2O Emissions from managed soils	N_2O	√	√
3.B.1.a - Forest land Remaining Forest land (net sink)	CO_2	√	√
3.A.1 - Enteric Fermentation	CH_4	√	√
3.C.5 - Indirect N_2O Emissions from managed soils	N_2O	√	√
3.B.1.b - Land Converted to Forest land (net sink)	CO_2	√	√
3.A.2 - Manure Management	N_2O	√	√
3.C.1 - Emissions from biomass burning	CH_4	√	√
3.B.2.a - Cropland Remaining Cropland	CO_2	√	√
3.C.1 - Emissions from biomass burning	N_2O	√	√

Under the land category, the 2000 and 2016 level assessment produced the following key categories for CO_2: 'land converted to cropland', 'land converted to grassland", 'forest land remaining forest land', 'land converted to the forest' and "cropland remaining cropland". Land conversions to cropland and grassland were the major contributors under the land category, which are the key drivers of deforestation in Ghana. On the other hand, the consistent implementation of the government strategy on forest and national park management have contributed to the preservation of the forest lands over the period. In addition, traditional practices, including sacred groove protection, have been instrumental in maintaining forest patches outside reserved areas. These initiatives helped to boost the forest sink capacity. The continuous implementation of the National Forest Plantation development has aided the reforestation of degraded forest to improve total carbon sinks. The key categories for CH_4 emissions were 'emissions from biomass burning' and 'enteric fermentation' for both levels (2016) and trends (2000 to 2016) analysis. Forest and grassland forest are frequent mainly in the transition and savannah regions of the country. Besides, CH_4 emissions from enteric fermentation related to the rising livestock population observed in the same period. For N_2O emissions, biomass burning, direct and indirect N_2O emissions from managed soils and manure management constitute the key category for 2016 as well as in the trend analysis.

5.7 Time series consistency in the AFOLU Sector

5.7.1 AFOLU sector recalculations

The AFOLU section recalculations were done covering the period 1990-2012 due to the inclusion of new activity and emission factors and the adoption of new methods. The changes in both activity data and emission factors were as a result of (a) adoption of a new methodology for generating activity data and emission factors, (b) revisions of published data from the agricultural facts and figures, (c) new field data on legal logging, (d) changes in the use of emission factors and methodologies as a result of the shift from using the revised 1996 to 2006 IPCC Guidelines, (e) revision of the land representation areas and the changes in them. Additional information on the reasons for and impacts of the recalculations has been provided under each sub-category. Table 85 shows the results of the assessment of recalculations and its impacts on the emissions.

Table 85: Impacts of recalculations on the previous GHG estimates

Year	Net CO_2			CH_4			N_2O		
	PE	LE	Change	PE	LE	Change	PE	LE	Change
1990	-3.01	14.02	566%	19.95	2.589	-87%	27.23	3.49	-87%
1991	-6.59	14.07	314%	19.67	2.616	-87%	27.18	3.80	-86%
1992	-6.42	14.13	320%	19.3	2.544	-87%	16.36	3.72	-77%
1993	-3.83	14.18	470%	18.98	2.529	-87%	26.32	3.77	-86%
1994	-3.22	14.24	542%	18.69	2.545	-86%	25.92	3.87	-85%
1995	-5.04	14.30	384%	18.44	2.597	-86%	14.2	4.01	-72%
1996	-4.66	14.36	408%	18.14	2.599	-86%	25.29	4.12	-84%
1997	-4.08	14.43	454%	17.84	2.609	-85%	24.91	4.16	-83%
1998	-3.87	14.43	473%	17.56	2.635	-85%	24.53	4.22	-83%
1999	-3.9	14.59	474%	17.25	2.621	-85%	24.19	4.31	-82%
2000	-4.00	12.74	418%	16.94	2.612	-85%	24.04	4.40	-82%
2001	-2.64	13.31	604%	16.68	2.610	-84%	23.65	4.56	-81%
2002	-2.62	13.53	616%	16.48	2.424	-85%	23.39	4.55	-81%
2003	-0.99	13.17	1430%	16.25	2.664	-84%	23.16	4.78	-79%
2004	-0.76	12.63	1762%	16.05	2.697	-83%	22.03	4.02	-82%
2005	-0.92	12.71	1481%	15.8	2.687	-83%	22.48	4.80	-79%
2006	-0.06	12.89	21591%	15.58	2.704	-83%	22.29	4.98	-78%
2007	0.38	12.93	3301%	15.35	2.704	-82%	22.03	5.08	-77%
2008	0.81	12.97	1501%	15.13	2.743	-82%	21.82	5.22	-76%
2009	1.21	12.72	952%	14.93	2.789	-81%	21.74	5.50	-75%
2010	1.86	13.02	600%	14.75	2.797	-81%	21.54	5.68	-74%
2011	1.32	12.89	877%	14.76	2.945	-80%	21.54	5.84	-73%
2012	1.86	13.01	599%	14.74	2.962	-80%	21.98	6.08	-72%

The impacts of the recalculation are more profound in CO_2 emissions than CH_4 and N_2O. Generally, while the impacts of the recalculation on CO_2 emission were positive that of CH_4 and N_2O were rather negative was attributed to the excessive increase in the CO_2 emission in the latest estimates. On the other hand, the reductions in the CH_4 and N_2O emission in the latest estimates led to the negative impacts on the recalculations on the previous estimates.

Reasons for recalculations in the AFOLU sector

The recalculations resulted in the revisions of the previous activity data and emission factors between 1990 and 2012 due to the inclusion of new dataset, application of new methodologies and correction of errors.

These revisions and adoption of new methods led to changes in the levels of emissions/removals (Table 86). Table 83 summaries the main reasons for the recalculations.

Table 86: Description of reasons for recalculations

Gas	Data in category	Reasons
CH_4 and N_2O	Changes in the grasslands area affected by fires.	• The annual average of -82% decrease in the grassland areas affected by fire between 1990-2012. • The use of satellite-based technique and MODIS to derive grassland areas affected by fire for the same period instead of the expert judgement used for the previous estimates.
	Changes in the cropland affected by fires.	• The annual average of -69% decrease in the grassland areas affected by fire between 1990-2012 • The use of satellite-based technique and MODIS to derive croplands affected fire for the same period instead of the expert judgement used for the previous estimates
	Changes in the forestland affected by fires.	• The annual average of -80% decrease in the grassland areas affected by fire between 1990-2012 • The use of satellite-based technique and MODIS to derive croplands affected fire for the same period instead of the expert judgement used for the previous estimates
Carbon Dioxide	Land representations	• Changes and updates in the method for the derivation of activity data using remote sensing and field-based approach. • Revisions resulted in changes to the land-use change matrix for the period 1990-2000, 2000-2010. • Inclusion of new plantation areas and further categorisation into the teak and non-teak species. • Revision of industrial round wood and fuelwood harvest data in forest lands.
	Biomass	• Changes in above ground net biomass growth in the natural forest from 4.7 t.dm/ha/yr to 1.6 t.dm/ha/yr. • Inclusion of new emission factor of 8.31 t.d.m/ha/yr for teak plantation.

5.7.2 Filling of data gaps in the AFOLU sector

In the AFOLU inventory, where gaps existed in the time series, the applicable IPCC splicing methodology for filling gaps was used. The IPCC splicing methodology that was used for filling a specific gap depended on the type of gaps and the proven relationship with other proxy datasets. Generally, extrapolation and interpolation techniques were used in the filling of the data gaps to ensure time-series consistency. Table 84 presents the categories that had data gaps, and the methodology applied.

Table 87: Data gaps and the method used to fill them

Category	Data Gap	Method applied	Justification for the methodology used	Description of approach for filling of gaps
Land (3B.1-3B. 6)	Absence of data on annual areas and changes in land representations for the years 1991-1999,	Interpolation and extrapolation	Inter-decadal data for 1990, 2000 and 2010 and half decade were available. Annual data on areas and changes in different land representations are required for the intervening years in each decade and half-decade.	We assumed that for each year, there was an equal interval for each decade and a half-decade. The annual land areas figures were derived by dividing the matrix per decade by the number of years.

	2001- 2009, 2011- 2014 and 2016		The interpolation technique allowed us to calculate the annual land representation matrix. Extrapolation was then used to generate data for 2016.	Meaning that the first two decades were divided by ten years, while the last half-decade was divided by five years. The 2016 matrix was extrapolated by the trend of the previous years.
Emissions from biomass burning (3 C1)	Missing interannual data on areas affected fires.	Interpolation and extrapolation	Inter-decadal data on areas affected by fire existed for 1990, 2000, 2010 and 2015. The annual data of areas affected by fires needed to be generated for each decade with interpolation. The team used the extrapolation approach to generate data for 2016.	Trend interpolation factor was derived by dividing the difference between the starting and end of each decade. The difference was divided by 10 to generate an interpolation factor. The interpolation factor was then added from the starting year to ending year. The 2016 data was extrapolated based on the trends of the previous

5.8 Quality Control/Quality Assurance

The QA/QC procedures followed in the AFOLU sector are detailed out in Table 88.

Table 88: QA/QC procedures implemented in the AFOLU sector

Data Type	QA/QC procedure	Remarks
Activity data check	Check for transcription, typographical errors and error transposition.	Division of task among the inventory team to ensure that one or two members of the team always focus on double-checking and ensure that data errors associated with those described in the left column are avoided.
	Comparison with published data	Data on areas cultivated, animal heads and land cover areas and round wood data were compared to those published by International agencies such as FAO and FRL and Ghana Statistical services.
	Consistency checks of categories and subcategories with totals	Ensuring that disaggregated figures at the category and subcategories levels add up to the overall totals.
	Identify and fix outliers in data inputs (including checking for dips and spikes in the trend)	Data that deviate unrealistically from the trends and spikes beyond ranges are suspected as inaccurate and replaced with deemed appropriate values from international sources or derived from expert judgment.
	Documentation of all data sources, data format and assumptions for easy reference	A record of all data, their sources and assumptions made in admitting the data used were kept and helped in easy cross-referencing.
	Ensure reduction in data clumsiness or data redundancy	Logical sequence data flow according to the IPCC methodology for the GHG emission estimation was designed for: (a) easy understanding and further probing of how the final results in the IPCC software would be like, (b) easy cross-referencing and avoidance of mistakes, (c) easy transmission into the IPCC software and (d) aid in better interpretation of the implication of the use of the data.
	Improvement in accuracy of land use mapping	One thousand two hundred ground validation points for different land representations in wall-to-wall were obtained from the field and compared with remotely sensed imageries.

		Generation of confusion matrix as a measure of potential errors of commission or omission.
Emission factors	Ensure representativeness of field biomass sampling in the various land cover representations.	Make sure the sampling design adequately covered representative land classes in each ecological zone. Samples were taken at optimal intensity covering five biomass consistent with the IPCC Guidelines.
	Reduce potential errors resulting from sampling biomass and integrity of the analysis.	Adherence to sampling protocols from the design, field, lab analysis, data analysis, and report writing.
Calculation by the approved 2006 IPCC software	Cross-checks all steps involved in the calculation.	Ensure that steps used for determining, estimating and deriving data are accurate, transparent and internally consistent.
	Documentation of sources and correct use of units.	Use of the documentation template to record all data sources and assumptions.
	Check for transcription, typographical errors and error transposition.	Check mistake and blunders in the data entered into the software
	Checked completeness of data coverage	Ensuring all the relevant gases for the specific activity were covered.
Emissions Results	Check of recalculation differences	To identify and pinpoint changes, revisions and reallocations to improve accuracy and transparency of the estimates
	Identify and fix outliers in the results	Check for dips and spikes in trends and levels
Documentation	Assumptions, corrections, data and sources.	Ensure consistency, transparency, facilitate repeatability and easy retrieval
	Improvement list (internal and external findings)	Help prioritise areas that require actions.

5.9 AFOLU sector emission trend analysis

The total GHG emissions for the AFOLU sector was 22.9 MtCO_2e in 2016. This amount accounts for 54.4% of the national total GHG emissions. The sector had since 1990 contributed a greater share of the total national emissions. On average, the sector contribution since 1990 was 64.5% of the national total. Even though the share of the AFOLU emissions to the national total has decreased gradually over the year by 23%, the nominal emission levels had rather shown a general increasing trend from 20.1 MtCO_2e in 1990 to 22.9 MtCO_2e in 2016.

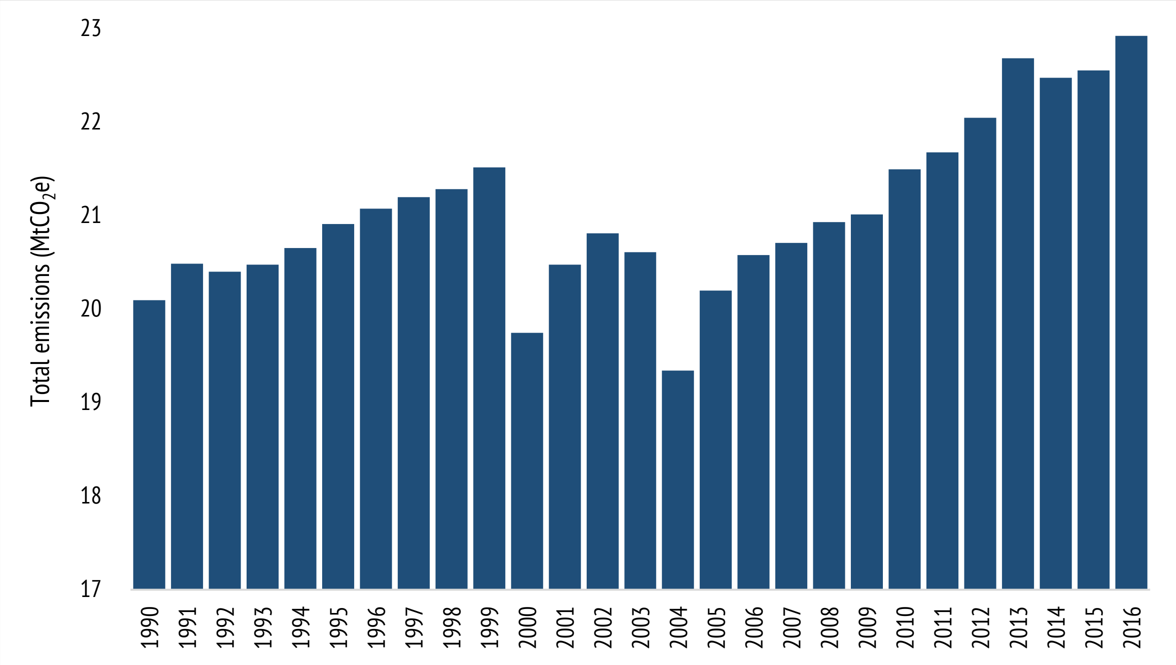


Figure 59: Trends of total net emissions for the AFOLU sector

The emission patterns exhibited two crests with one trough separating them. The first crest was between 1997 to 1999, and the second crest was between 2013 and 2016. A trough separates the two crests which lapsed from between 2000 up to 2009. The uneven emission trends correspond to the changes in net CO_2 emission from the land category, particularly from "forest remaining forest land" as well as "other lands converted to forestland" (Figure 59).

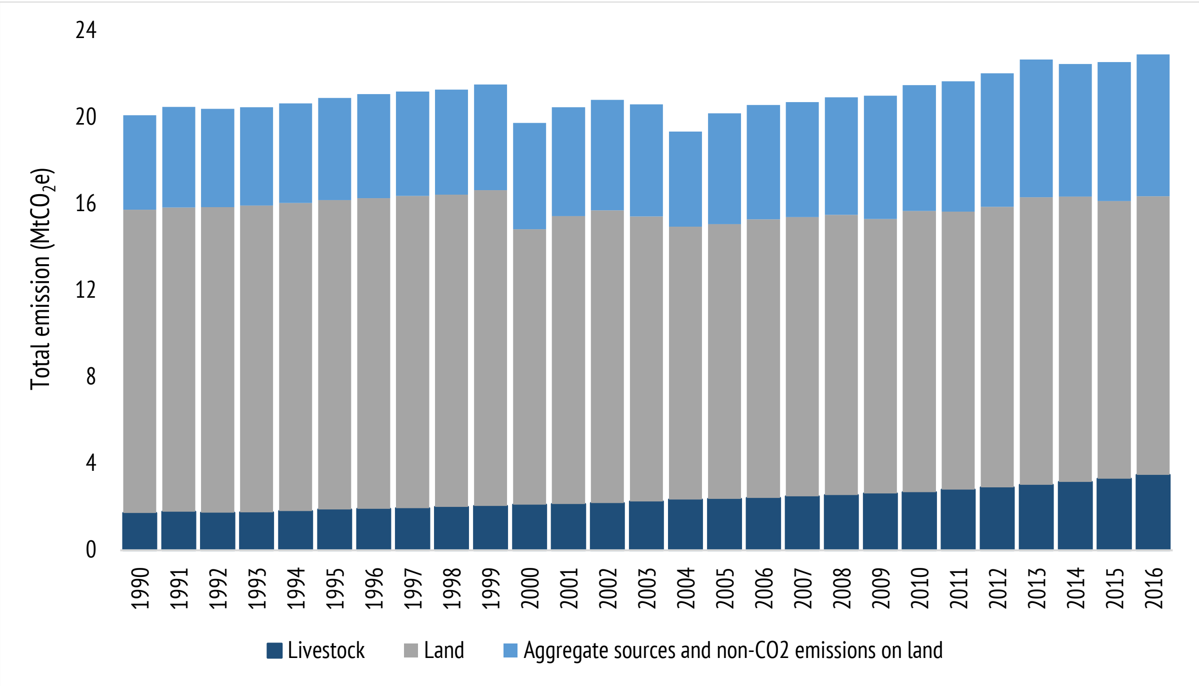


Figure 60: Total emissions trend according to sub-categories in AFOLU

The total AFOLU sector emissions for 2016 consisted of contributions from Land (3B.), Aggregated sources and non-CO_2 emission on land (3C.) and Agriculture (3A.) at 56%, 29% and 15% respectively. In terms of trends, the total emissions of 3B decreased from 12.95 in 2012 to 12.87 $MtCO_2e$ in 2016. However, the amount in 2016 represents a 1% increase in the emissions recorded in 2010. In 2016 the emissions of 6.57 $MtCO_2e$ from 3C represented an increase of 6% and 25% of 2012 and 2000 emission levels respectively. The increase in the emissions is attributed to the spike in N_2O emissions, mostly from direct N_2O Emissions from managed soils and biomass burning. Emissions from agriculture, 3A also increased from 2.9 $MtCO_2e$ to 3.5 $MtCO_2e$ between 2012 and 2016, representing a 16% increase. The trend of increase in emissions was also observed for the period 2000 and 2016 with a 40% increase in the emissions (Figure 60). Gas by gas contributions to annual emissions differed for the years 2000, 2012 and 2016. Carbon dioxide contributed most to the AFOLU emissions in 2016 with 56%, followed by nitrous oxide 29% and methane with 15%.

The trend was similar in both 2000 and 2012 for the contributions of the gases. In 2000, CO_2, N_2O and CH_4 proportions of emission were 65%, 22% and 13% respectively. Meanwhile, emissions in 2012 were composed of 61% for CO_2, 26% for N_2O and 13% for CH_4. All three gases exhibited increasing trends in emissions. N_2O, $CH_4$and CO_2 grew by 23%, 7% and 2% respectively between 2000 and 2012. However, the patterns for the different gases in the period 2012- 2016 were similar. While N_2O and CH_4 emissions inched up by 15%, CO_2 emissions showed a negligible downward trend by 1% in the same period (Table 89).

Table 89: AFOLU sector Emissions segregated into Gases

Year	Net CO_2 [Mt]	CH_4 [$MtCO_2e$]	N_2O [$MtCO_2e$]	Total [$MtCO_2e$]
1990	14.02	2.59	3.49	20.10
1991	14.07	2.62	3.80	20.49
1992	14.13	2.54	3.72	20.40
1993	14.18	2.53	3.77	20.48
1994	14.24	2.55	3.87	20.65
1995	14.30	2.60	4.01	20.91
1996	14.36	2.60	4.12	21.07
1997	14.43	2.61	4.16	21.20
1998	14.43	2.63	4.22	21.29
1999	14.59	2.62	4.31	21.52
2000	12.74	2.61	4.40	19.75
2001	13.31	2.61	4.56	20.48
2002	13.53	2.64	4.65	20.81
2003	13.17	2.66	4.78	20.61
2004	12.63	2.70	4.02	19.34
2005	12.71	2.69	4.80	20.20
2006	12.89	2.70	4.98	20.58
2007	12.93	2.70	5.08	20.71
2008	12.97	2.74	5.22	20.93
2009	12.72	2.79	5.50	21.01
2010	13.02	2.80	5.68	21.50
2011	12.89	2.95	5.84	21.68

2012	13.01	2.96	6.08	22.05
2013	13.34	3.02	6.33	22.69
2014	13.20	3.09	6.18	22.48
2015	12.86	3.18	6.51	22.56
2016	12.91	3.29	6.72	22.92

In 2016, almost all (99.7%) of the net CO_2 emissions originated from the Land (3B.) category, particularly from grassland and cropland; with an insignificant amount (0.3%) coming from the Aggregate sources and Non-CO_2 emission on land (3C.). The rather small amount of CO_2 in Aggregate sources and Non-CO_2 emission on land (3C.) is from Urea application. Methane emissions were predominantly from the Agriculture (3A.) category; specifically, the livestock subcategory contributed 77%. The remaining 23% of CH_4 emissions emanated from the biomass burning and rice cultivation. Nitrous Oxide emissions in the sector come from the Aggregate sources and Non-CO_2 emission on land (3C.) specifically from activities such as biomass burning, urea and generic NPK fertiliser applied to soils and Agriculture (3A.), i.e. livestock. In 2016, 86% of N_2O was from "Aggregate sources and Non-CO_2 emission on land" which is shared by "Direct N_2O Emissions from Managed Soils" (72%) and "Indirect N_2O emission from managed soils" (20%) and with the remaining being emitted from biomass burning and manure management.

5.10 Description of source/removal categories

5.10.1 Summary of source-specific emission trends

5.10.1.1 Livestock (3A)

Key category (2016): CH_4 emissions - Enteric fermentation and N_2O - Manure Management

Enteric fermentation and manure management from domestic animals such as cattle, sheep, goats, swine, horses, and donkeys (mules and asses) are the sources of emissions in livestock. Overall emissions from the livestock were 3.48 $MtCO_2e$ which constitutes 15% of the total AFOLU emissions in 2016. Generally, Livestock emissions increased from 1990 to 2016 even though the trend dipped slightly in 2002. Specifically, total livestock emissions showed an increasing trend from 2.1 $MtCO_2e$ in 2000 to 2.9 $MtCO_2e$ in 2012 and further increased by 0.57 $MtCO_2e$ in 2016 (Figure 61). The observed upward trends in emissions are attributable to rising animal populations and the associated management regimes. The annual total emissions from enteric fermentation and manure management have since 1990 been on an increasing pathway. However, the annual emissions from enteric fermentation were higher than manure management.

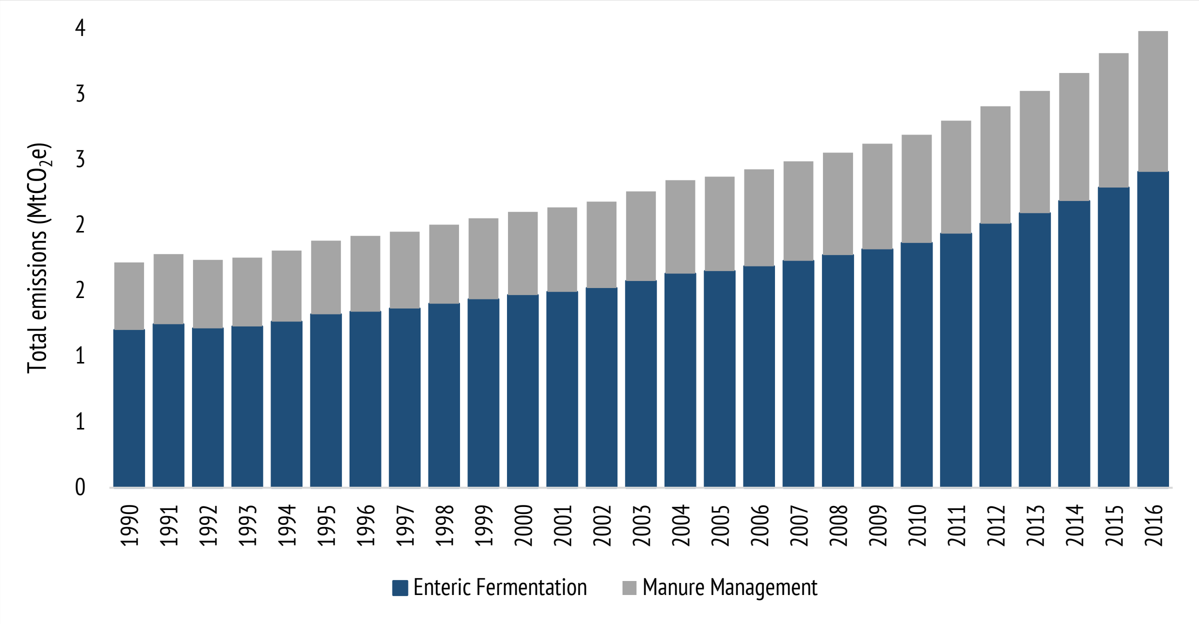


Figure 61: Greenhouse gas emission trends in livestock rearing

5.10.1.1.1 Enteric Fermentation (3.A1)

5.10.1.1.1.1 Source category description and results

Enteric fermentation produces methane as part of the digestion process in the alimentary canal of herbivores. Microbes in the animal's digestive system ferment feed ingested by the livestock which generates methane. Methane production is dependent on animal population, weight and age of the animals as well as the quantity and quality of feed. The type and efficiency of the animals' digestive system also influence methane production. The amount of methane production in ruminant livestock is more than that produced by non-ruminant livestock. The total emission generated from enteric fermentation in 2016 was 2.41 $MtCO_2e$.

The figure represents 69.1% of the overall emissions from Livestock. Enteric fermentation in 2016 shows an increasing trend with a 64% increase from 2000 and 20% from the last reporting period of 2012 (Figure 62).

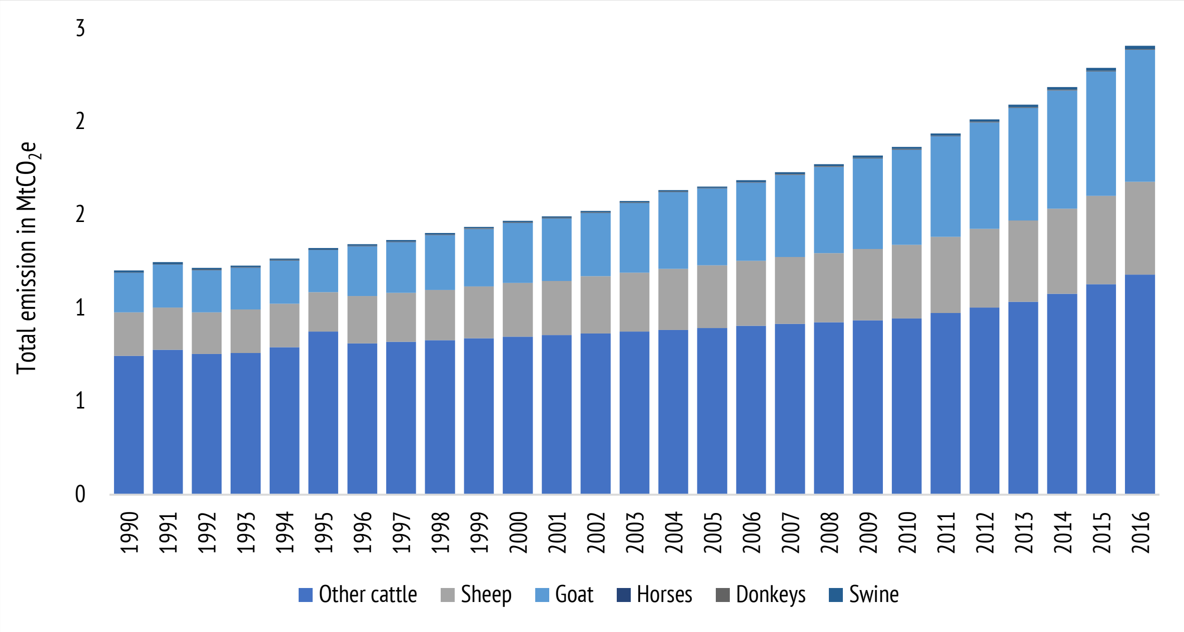


Figure 62: Total emission trends from Enteric fermentation of livestock

With 49.07% contribution, emissions from other cattle formed most emissions from enteric fermentation in 2016. This was followed by goats (29.39%), sheep (20.69%), swine (0.68%), donkey (0.13%) and horses (0.05%) in a declining order. Since 1990, cattle have been the main source of emissions through enteric fermentation and followed by goats, sheep, swine, donkey and horses within the same period.

5.10.1.1.1.2 Methodological issues for estimating emission from enteric fermentation in livestock

IPCC Tier 1 and default emission factors were used for the estimations from enteric fermentation. The emissions were estimated by multiplying the individual animal populations with emission factors for the respective animals (see IPCC default emission factors in tables 10.10 and 10.11 and annexe 10. A1 in Vol. 4 Chapter. 10). Overview of the methodologies and emission factors applied is shown in Table 90.

Table 90 methodologies, reported emissions and emission factors applied in 3.A1

Sector code	Source	Emissions reported	Method	EF
3.A.1.a.i	Dairy Cows	NO		
3.A.1.a.ii	Other Cattle	CH_4	T1	D
3.A.1.b	Buffalo	NO		
3.A.1.c	Sheep	CH_4	T1	D
3.A.1.d	Goats	CH_4	T1	D
3.A.1.e	Camels	NO		
3.A.1.f	Horses	CH_4	T1	D
3.A.1.g	Mules and Asses	CH_4	T1	D
3.A.1.h	Swine	CH_4	T1	D

NO= Not Occurring; T1= Tier 1; D= Default

The livestock population data for cattle, sheep, goats, swine and poultry were obtained from Agriculture Facts and Figures, which is produced annually by the Statistics, Research and Information Directorate (SRID) of MOFA[30]. The data presents animal population figures for every year.

[30] Data is accessible from www.mofa.gov.gh

The MOFA data was supplemented with data on horses and donkeys from FAOSTAT[31]. All the cattle population is assumed to be other cattle because many cattle are not reared for milk production in Ghana. There is also no data on the population of cattle that breastfeed at a point in time. The IPCC tier 1 and default emission factors were used because there were no country-specific data on the age and weight classes of the animals.

5.10.1.1.2 Manure management (3.A2)

Emissions in the manure management category are mainly methane and nitrous oxide from the management of livestock. Manure management systems included in this inventory were: paddock and pasture, slurry dry lot and poultry with or without litter. Ghana accounts for both CH_4 and N_2O emissions from manure management for cattle, sheep and goats and CH_4 emissions for horses, donkeys, swine and poultry. Manure management accounts for 30.9% of the aggregate livestock emissions.

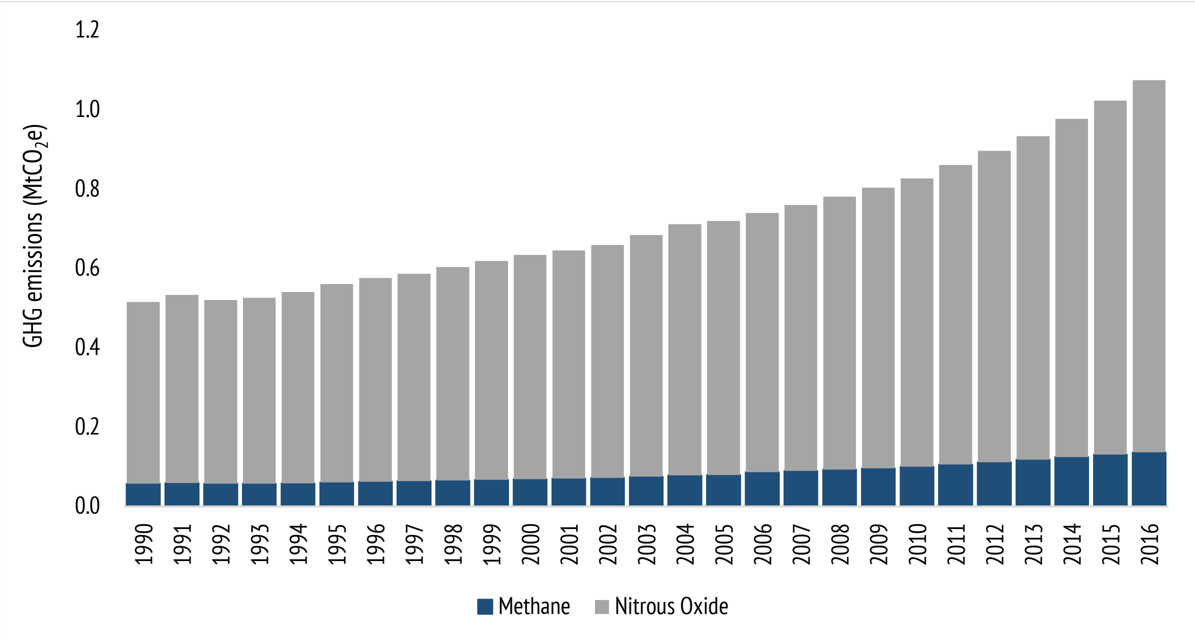


Figure 63: Methane and nitrous oxide emissions from manure management

Total emissions from manure management increased from 0.52 $MtCO_2e$ in 1990 to 0.90 $MtCO_2e$ in 2012 and further to 1.01 $MtCO_2e$ in 2016 (Figure 63). The nitrous oxide was the largest source of manure management emissions. It formed 88.5% on the average of the total manure management GHG emissions. The remainder 11.5% was methane emissions. Overall, GHG emissions associated with manure management more than doubled from 1990-2016 at 3% annual growth rate. When the emissions were considered within the 2012-2016 window, the results indicated a 19.9% rise relative to the 2012 levels. Both gases equally recorded upward trends over the 26 years with methane showing the highest growth at 3.5% per annum. While methane grew by 138% in the 1990-2016 period, and nitrous oxide did the same at 104.8%. The increases in the emissions were because of growing livestock populations reported from 1990 to 2016. The feeding regimes and animal waste management technologies have not seen any major changes.

[31] http://www.fao.org/faostat/en/#data

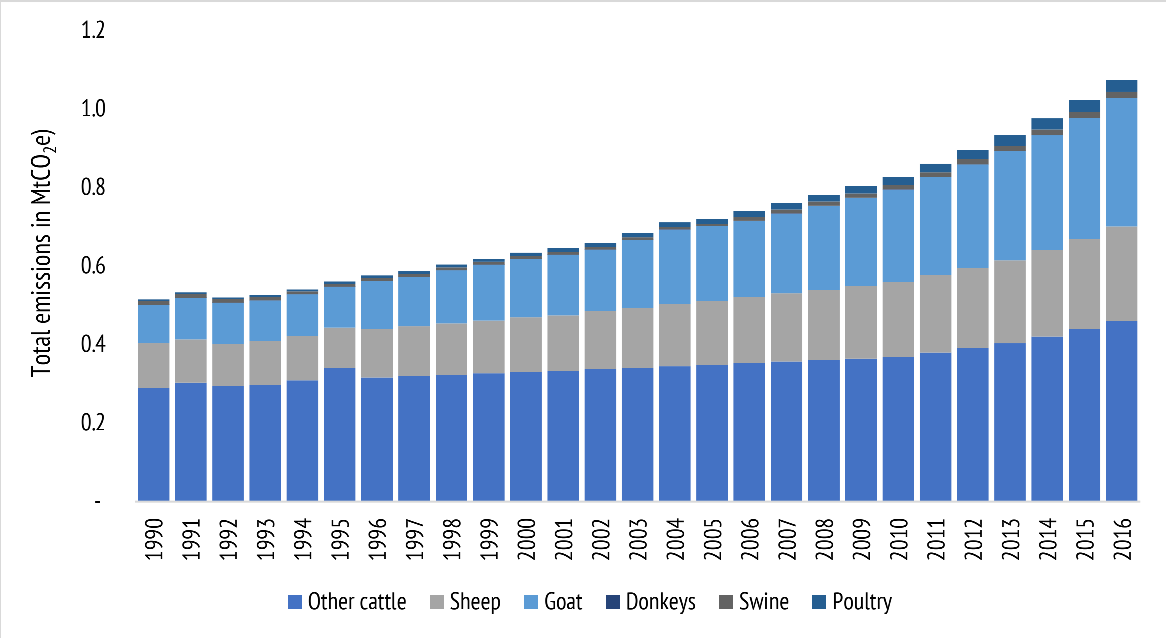


Figure 64: Greenhouse gas emissions trend for manure management for 1990-2016

Emissions from other cattle, sheep, goat and poultry composed 98% of the total manure management emissions. The rest is shared among donkeys, swine and horses. Cattle, sheep and goats were the largest sources throughout 1990-2016 (Figure 64). For instance, the average proportion of emissions from cattle amounts to 50% of the all manure management emission then followed suit by a goat (25%), sheep (22%) and poultry (2%). The remainder was distributed accordingly to donkeys, swine and horses. It is also important to highlight that emissions from all the animals grew in the same period; poultry recorded the highest and fastest growth of 617% at 8% annual rate.

5.10.1.1.2.1 Methodological issues for estimating emission from manure management in livestock

The IPCC default emission factors and the methodology were used in the calculation of emissions from manure management. The share of the individual animal waste management systems common in Ghana was estimated by expert judgment and categorised by animal type (Table 91). Data on animal population for the period 1990-2016 were obtained from the Agriculture Facts and Figures produced by MOFA.

Table 91: Share of Animal waste management system applied

Livestock	Manure Management systems (1990-1999)					Manure Management systems (2000-2016)				
	Pasture	Dry lot	Slurs	Poultry w/litter	Poultry w/o litter	Pasture	Dry lot	slurry	Poultry w/litter	Poultry w/o litter
Asses	100%	0%	0%	0%	0%	100%	0%	0%	0%	0%
Cattle	40%	60%	0%	0%	0%	40%	60%	0%	0%	0%
Poultry	0%	0%	0%	65%	35%	0%	0%	0%	50%	50%
Goats	70%	30%	0%	0%	0%	70%	30%	0%	0%	0%
Horses	100%	0%	0%	0%	0%	100%	0%	0%	0%	0%
Swine	50%	0%	50%	0%	0%	50%	0%	50%	0%	0%
Sheep	60%	40%	0%	0%	0%	60%	40%	0%	0%	0%

5.10.1.2 Land (3B)

Land-use and associated land-cover change resulting from anthropogenic activities can produce and absorb carbon dioxide emissions. The push or pull factors that drive the land-use change relates to the formulation and implementation of the following policy initiatives:

- Unintended Policy conflicts - Policies on food crop production, tree crop expansion, mineral resource extraction and conservation, forest restoration and diversification of energy from fossil to bioenergy sources
- Landscape technology adoption - Surface mining, forest fire-prevention techniques, afforestation and reforestation and chemical inputs.
- Forest governance - Forest management programmes such as REDD+, Forest Investment Programme and community awareness and involvement, i.e. Community Resource Management Areas

At any given time, the type of human activities, the direction of change and intensity (quantum of change) determines whether the land category is a net sink or net source of CO_2 emission. The land-use change is because of transitions of land categories among the following IPCC classes: forestland; cropland; grassland; wetlands; settlements and other lands. Forestland, cropland and grassland are the dominant subcategories which together constituted 94% of the land area of the country in 2016. The remaining 6% was shared by settlement, water and wetland and other lands. In 2016, Forestland accounted for 41.6%, grassland 32.9% and cropland 19.5% of the land area. By extension, the transitions among these classes constituted most of the net CO_2 emissions.

5.10.1.2.1 Emission trends and methodological issues from the Land category

The land emissions were 12.87 $MtCO_2$ in 2016 and constituted 30% of the total national emissions. The land emissions contributed 46% of the total CO_2 emissions in the country; it also amounted to 56% of the AFOLU emissions in 2016. The trend of emission from land generally decreased from 14.01 $MtCO_2$ in 1990 to 12.87 $MtCO_2$ in 2016 at an annual average rate of 8.51% (Figure 65).

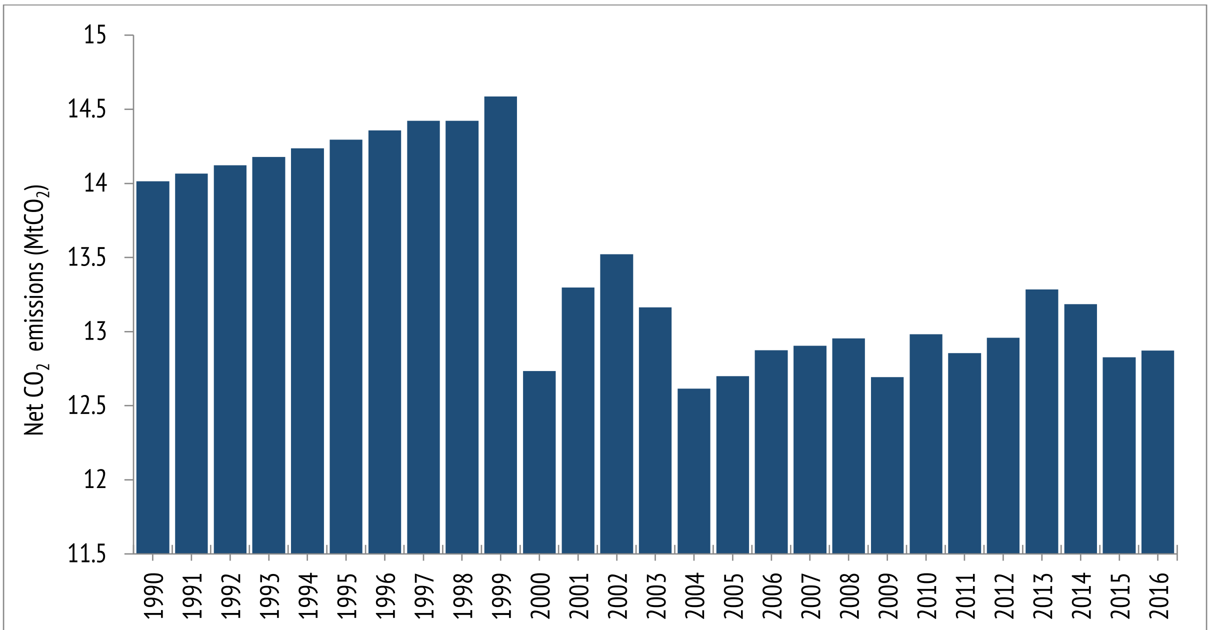


Figure 65: Net CO_2 emissions trend in the land category from 1990 to 2016

Even though the net CO_2 emission pattern showed a downtrend trend, it also displayed different degrees of inter-annual variations. The emissions between 1990 and 1999 exhibited increasing trends with relatively high levels after which it declined in 2000 with a sinusoidal pattern through to 2016. On the face of the data, the observed emission patterns tend to be driven by the net changes in the land-use transitions, particularly among forestland, grassland and cropland. Among the three land categories, the forest remained a sink whereas grassland, and cropland were sources of emissions. The general increase in net CO_2 emissions from land could be attributed to deforestation from the following: (a) expansion of areas under cropland as part of the food security interventions, (b) forest to grassland due to fires and through cropland. On the other, the rising levels of net CO_2 removals observed in forestland were owing to (a) the implementation of aggressive forest plantation development program targeted at degraded forest lands, (b) implementation of the Forest and Wildlife Policy which facilitated private sector participation in sustainable forest management.

5.10.1.2.1.1 Methodological issues for the land category

Land-use mapping

Land-use maps are the main source of activity data for land category inventory. With them, it is possible to detect and calculate areas of the six IPCC classes and additional sub-classes and transition among them over a given period. The land-use map data was obtained from the study conducted by the Forest Preservation Project (FPP) and recently during the preparation of the National Forest Reference Level (FREL) for REDD+ led by Winrock International. The Forestry Commission implemented the FPP with funding from the Japanese Government[32]. The study was undertaken by a multi-institutional team comprising the Forestry Commission, CSIR-Forestry Research Institute of Ghana, CSIR-Soil Research Institute of Ghana and PASCO Corporation of Japan as well as its local counterpart, RUDAN Engineering Limited. The FPP studies produced land-use maps for 1990, 2000 and 2012 whereas during the preparation of the FREL Winrock International facilitated the refinement of the 2000, 2010 maps and produced new 2012 and 2015 maps.

The land-use maps for 1990, 2000, 2010, 2012 and 2015 were produced from wall-to-wall remote sensing and ground-truthing techniques (Figure 66). For decades consistency, 1990, 2000, 2010 and 2015 were used in the inventory. The reasons were that persistent and distinguishable land-use change might take a half-decade or full-decade to crystallise in the Ghanaian landscape. The choice of the ten and 5-year interval also coincided with the epoch where good quality remote sensing imageries with less cloud effect were available for the entire country. The definitions adopted for various land categories used in the study are provided in Table 92.

Table 92: Land-use definitions

Category	Definition
Forestland	Includes all land with woody vegetation consistent with thresholds used to define Forest Land in the national greenhouse gas inventory. It also includes systems with a vegetation structure that currently fall below, but in situ and could potentially reach the proposed national values used to define the forest land category in Ghana as follows: • Minimum Mapping Unit (MMU) is 1.0 ha • The minimum crown cover is 15 % • Potential to reach a minimum height at maturity (in situ) as 5 m

[32] Refer to www.fcghana.org for details of the methodology

Cropland	Includes currently cropped or in fallow, including rice fields, and some agroforestry systems where the vegetation structure falls below the thresholds used for the forestland category. Includes land where over 50% of any defined area is used for agriculture.
Grassland	Includes rangelands and pasture lands that are not considered Cropland. It also includes herbs and brushes that fall below the threshold values used in the Forest Land category such as the other wooded land following the FAO definition in Ghana: • CC < 15 % and > 10%, height > 5 m, MMU > 0.5 ha • CC 5 % - 10 %, height > 5 m, MMU > 0.5 ha • Shrubs, bushes and trees CC > 10%, Height < 5 m, MMU > 0.5 ha
Wetland	These include land that is covered or saturated by water for all or part of the year (e.g., peatlands) and that does not fall into the forest land, cropland, and grassland or settlements categories. It also includes reservoirs as a managed sub-division and natural rivers and lakes as unmanaged sub-divisions.
Settlement	These include all developed land, including transport infrastructure and human settlements of any size, unless they are already included under other categories.
Other lands	This category includes bare soil, rock and all land areas that do not fall into any of the other five categories.
Water	Natural rivers and lakes as unmanaged sub-divisions of wetland.

Archives of Landsat and ALOS data were obtained from the USGS database and the propriety owners of DMC. The data covered Landsat TM for 1990, Landsat ETM+ for 2000, ALOS AVNIR – 2, DMC for 2010 and Landsat 8 for 2015. For 2010, the DMC satellite data was used to fill up gaps in the ALOS AVNIR data, mainly resulting from cloud cover. The imageries were pre-processed to evaluate and correct for haze effects using geometrical and radiometric methods in ENVI Software environment. After the pre-processing on the individual bands, the stacked satellite photos were ready for further processing.

A supervised classification method performed on the individual composite image for each year to delineate and estimate the areas of the six land-use variants using 1,100 field data. The ground data was collected through an extensive field campaign nation-wide. The field-data represents the different types of land-use classes on the ground. The individual land-use maps were validated using a mix of on-screen digitising on google earth, ground-truth and the key-informant approach. The 2000 land-use was 500 data points generated from google earth while for the 2010 map, 2,213 field points were utilised. For the 2015 map, 1000 data points were applied in the validation of the land-use map. The previous 1990 land-use map was validated using existing land use map for 1990 developed by RSMC, data from the permanent sampling plots, areas with relatively similar signatures and interviews with key informants.

The forestland category was further stratified into open and closed-forests based on the following factors:

- canopy cover (CC) – closed forests (CC > 60%); open forest (15% < CC < 60%).
- ecological zones.
- primary designated use.
- legal management scheme.

After the analysis, it was observed that cropland areas might have been underestimated because of the way tree crop areas were poorly segregated from other vegetation. For most of them, the typical tree crop was misclassified as open-forest. To compensate for the misclassification, the reported areas of oil palm, cocoa, rubber, citrus, mango and cashew in the FAOSTAT for 1990, 2000, 2010 and 2015 were used to adjust open-forest by subtracting the areas from them and adding them to cropland.

Afterwards, both closed-forest and the rest of the open-forest areas were summed up to form forestland for the four selected years. Using the four land-use maps, we conducted change detection to produce land-use change maps and the associated matrices. The analysis of the land-use areas was originally done for ten years and five years' intervals, i.e. 1990 – 2000; 2000 –2010, 2010-2015 in line with the IPCC guidelines, 20-year intervals and single year land-use matrix. To calculate the areas of the land-use areas for the intervening years, for example, 1990–1991 or 2011-2012, the overall land-use transition areas for each land-use class for a given period was divided by the number of years in each epoch. For example, if for the entire 2010-2015 period, the area of cropland was 10,000ha, to get the areas for the intervening areas, the 10,000ha was divided equally to 2,000ha per annum by dividing by five years. The land-use areas for 2016 was a repetition of the 2015 areas. The 20 years land-use figures were interpolated which followed the general steps: (a) generated individual 20-year epochs land-use matrix for the period (e.g. 2015-1995, 2010-1990, 2000-1980 and 1990-1970) are assumed that land-use changes in the previous epoch were generally slower than the present; calculated annual land-use change matrix for the individual years in each 20-year epoch. The analysis recognised the following assumptions, considering the principle of conservativeness:

- Annual area changes were assumed to be insignificantly different from the previous years. Thus, it was assumed that area change within a year would be spatially difficult to notice.
- Annual gain/loss among forest and non-forest classes would follow a similar pattern in the intervening years. Hence for 1990, 2000 and 2010, the difference in changes between the 20-year periods was determined and the annual rate of change applied to the base year to retrieve the data for the intervening years.
- The rate of change in the various land-use classes was slower in the 1980s than the 1990s and 2000s. Same applies to the 1990s and 2000s because: (a) the implementation of the policies such as the Economic Recovery Program which focused on the extractive sector, e.g. surface mining, and timber harvesting influenced the changes in the landscape in 1990s. Thus land-based economic activities in the 1990s were more intense than in the 1980s, (b) population growth rate was higher beyond the 1980s. Population growth and urbanisation and its associated high consumptive lifestyle influenced landscape dynamics.
- The effects of wildfires that happened in 1983 were episodic, and a result of wildfires that led deforestation may be exceptionally high in the early 1980s.
- The impacts of cocoa/tree crops expansion into forest areas catalysed the modification of the landscape in the 1980s at the time of the establishment of the crop. The subsequent expansion of cocoa or tree crops may be localised and largely target fallow and croplands.

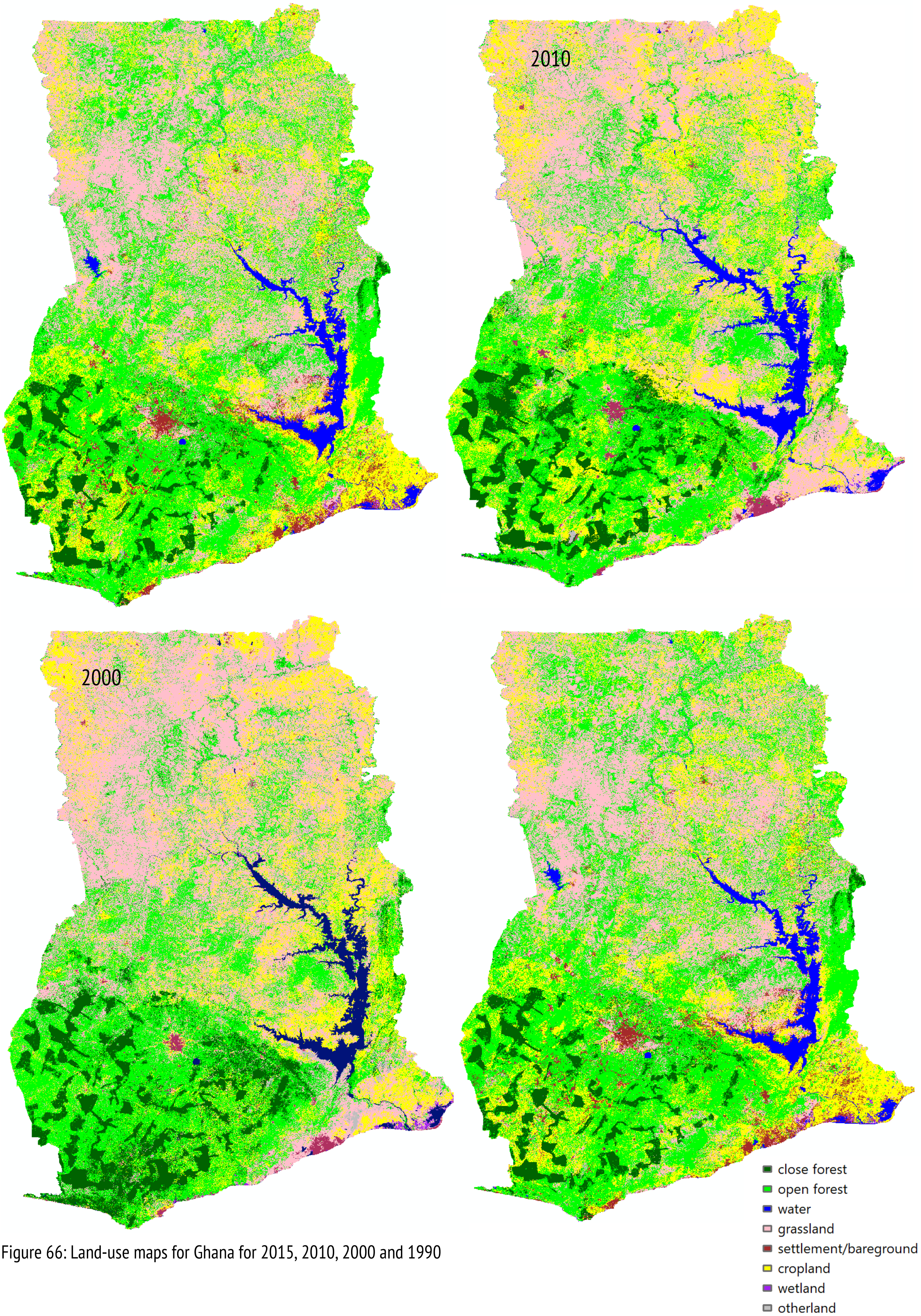


Figure 66: Land-use maps for Ghana for 2015, 2010, 2000 and 1990

5.10.1.2.1.2 Accuracy assessment of land-use maps

Two strings of assessments were done. One on the individual 2000, 2010, 2015 maps and the others on the change maps for 2000-2010 and 2012-2015. The purpose of adopting the two approaches was to complement each other. Even though the primary focus was to conduct the accuracy assessment of the individual maps evaluating the assessment was an added advantage. The results of the accuracy assessment are provided in Tables 93, 94 and 95.

Table 93: Accuracy assessment for 2000 land-use map

Class name	Reference total	Classified total	Number correct	Producer's Accuracy [%]	Users Accuracy [%]	Kappa
Closed forest	40	43	33	81.25	75.58	0.7346
Open forest	163	152	136	81.87	88.85	0.8334
Water body	11	15	11	100.00	70.00	0.6936
Grassland	100	104	82	82.00	78.85	0.7356
Settlement/Bare ground	45	49	37	82.22	76.29	0.7394
Cropland	125	129	103	82.00	79.77	0.7302
Wetland	11	5	5	52.63	100	1
Other land	5	3	4	77.78	100	1
Total	500	500	407			
Overall classification accuracy				81.70%		
Overall kappa statistics				0.7664		

For the 2000 map - 500 data points generated from Google Earth were used to assess the accuracy of this map. The assessment yielded an overall accuracy of 81.7%.

Table 94: Accuracy assessment for 2010 land-use map

Class name	Forestland	Cropland	Grassland	Settlement	Wetland	Other lands	Classified total	User's Accuracy [%]
Forestland	520	48	39	0	0	0	607	85.67
Cropland	57	493	48	1	0	2	601	82.03
Grassland	55	44	384	0	0	9	492	78.05
Settlement	17	13	12	283	1	5	331	85.50
Wetland	0	0	1	0	152	0	153	99.35
Other land	2	0	3	0	0	24	29	82.76
Reference total	651	598	487	284	153	40	2213	-
Producer Accuracy [%]	79.88	82.44	78.85	99.35	99.35	60.00	-	83.87

For the 2010 map - 2,213 field points were used for the accuracy assessment of the 2010 map. The overall accuracy for this map is 83.9%.

Table 95: Accuracy assessment for 2015 land-use map

Class name	Reference total	Classified total	Number correct	Producer's Accuracy	User's Accuracy	Kappa
Closed forest	80	87	76	0.95	0.8735	0.7346
Open forest	331	263	255	0.7703	0.9696	0.8334
Water body	21	25	21	1	0.84	0.6936
Grassland	200	186	154	0.77	0.8279	0.7356

Settlement/Bare ground	90	142	84	0.933	0.5915	0.7394
Cropland	250	275	189	0.756	0.6872	0.7302
Wetland	19	15	15	0.7894	1	1
Other land	9	7	7	0.7778	1	1
Total	1000	1000	801			
Overall classification accuracy				80.1%		
Overall kappa statistics				0.7664		

For the 2015 map, an accuracy assessment with 1,000 field data points producing an overall accuracy is 80.1%. The accuracy assessment of selected change map areas and with a special focus on the high forest zone. The following steps were followed:

- Step 1: Comprehensive review of the existing accuracy/uncertainty worksheet as well as the accuracy assessment report - This step involved the careful review of map sources, extents and map years and their metadata. The associated spreadsheets generated from the maps were reviewed for accuracy. The team further went through the methodological flows in a step-by-step manner to link them to the results. These included checking the validation sample size, source of the data and the approach for the sampling. The values in the accuracy/uncertainty worksheets were cross-referenced with the map areas in the attribute tables of the maps. The equations in the accuracy/uncertainty worksheets were also checked for consistency by comparing with the equations provided in Olofson et al. 2014. All data gaps and inconsistencies were discussed and noted.

- Step 2: Review, discuss and agree on the steps to implement Olofson et al., 2014 – After reviewing the Olofson, 2014 paper, the team discussed the general import of the paper and its implication for the accuracy assessment; the sequence of steps and the data required to inform the workflow of the accuracy/uncertainty analysis.

Step 3: The implementation of the accuracy assessment following the Olofsson's approach was done at this stage and was included in the creation of new change maps from the four individual maps, generation of the validation points and visual interpretation in Google Earth after which the validated points were used for the accuracy assessment and uncertainty analysis. The three steps are further elaborated below:

Map processing (generation of change maps)

The team downloaded all the maps as used by Winrock from FC's website publicly available on http://www.fcghana.org/nrs/index.php/category/9-spatial-data. Each map was clipped to fit the extent of the high forest zone, which represents the boundary of the Ghana Cocoa Forest REDD+ area. Maps were reclassified to forest non-forest. In ArcGIS, we used the combined function to detect changes in the maps to represent each period (2000 and 2010, 2010 and 2012, 2012 and 2015) and further identified the areas of change (forest to other lands, (DF), forest remaining forest, (FL), other lands to the forest (RG), other land remaining other lands, (OL).

Framing the Response design

Using the change maps in each period (period 1 – 2000/2010 and period 2- 2010/2012 stratified random points were generated using create accuracy assessment points tools (spatial analyst tool). This sampling approach considered the relative area proportions of the four change classes (FL, DF, RG and OL) to ensure representativeness of the sample. We generated 4,000 points based on stratified random sampling on each of the three change maps using the accuracy assessment points functionality in the Spatial Analyst package in ARCGIS, 4000 points. Every 4,000 points were converted to KMZ and exported to Google Earth Pro (Figure 67) in tabular format with three columns labelled as FID, classified, and ground-truth. Then, visual validation of each point followed. In the validation of the change sample points for the three periods (e.g. 2000/2010 - P1 and 2010/2012 -P2) was used two-time reference change images.

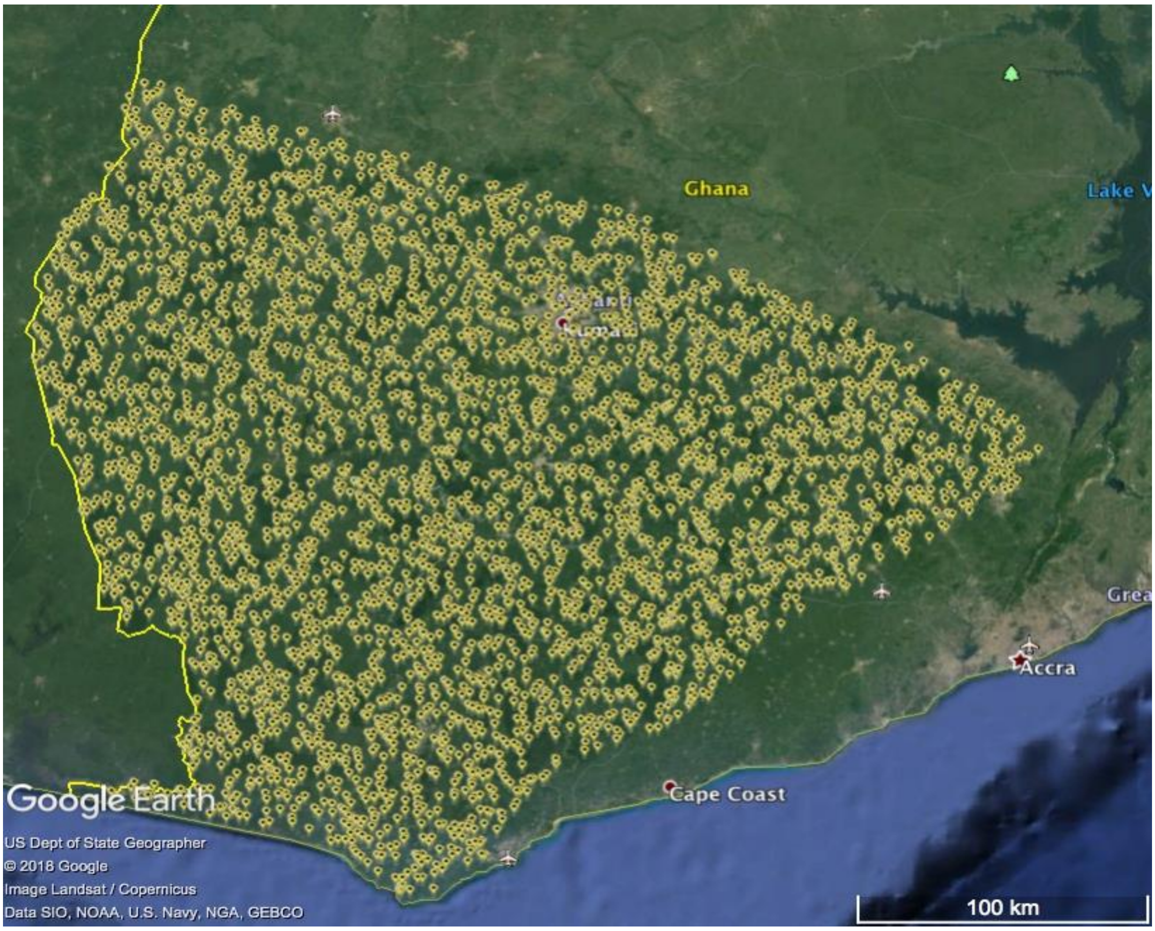


Figure 67: Spatial distribution of the 4000-validation point displayed in Google Earth Pro

The FID column contains the unique identifier of each of the 4000 validation points in each period. In the table, the "classified column" represented change classes (0 for OL-OL, 1 for OL to FL, 2, FL-OL and three and FL-FL is assigned) during the change detection process. The "Ground truth column" is for the visually validated code for the change (Figure 68).

FID	Classified	GrndTruth
0	3	
1	2	
2	0	
3	2	
4	1	
5	1	
6	3	
7	0	
8	3	
9	2	
10	3	

Figure 68: Extract of the table accompanying the validation samples used in Google Earth

The visual interpretation of the validation images followed the following steps

- Individual interpreters who are familiar with the landscape and are experienced in visual interpretation and landscape mapping were assigned the specific number of samples to validate. The validation was based on the visual interpretation element colour, texture, tone, pattern, and shape that together define the conspicuous nature of the feature of interest.
- Where there were discrepancies or challenges in the visual interpretation of the features in the validation maps, the whole team discussed and agreed on the type of change to be assigned to the sampling points. This approach ensures quality checks on the visual interpretation and the labelling of the assigned points.
- In all cases, the individual interpreters ensured that the determination of the change class assigned to each point is based on the interpretation of the minimum of two maps (previous and current years)[33]. In case the previous validation image does not exist or are of poor quality, the team excluded the reference points.

The first 2,000 points that were accurately validated and labelled using available High-Resolution Imagery in Google Earth of the corresponding years. Points that fell in clouds or haze and areas without high-resolution imagery were excluded from the additional analysis (Figure 69).

[33] For example, when validating the points for P1 (2000/2010) in google earth pro, we used the historical imagery button, to slide back to 2000 and forth to 2010 in order to visually determine the change (OL-FL, OL-OL, FL-FL, FL-OL). Once the change class is determined, an appropriate label (0 for OL-OL, 1 for OL to FL, 2, FL-OL and 3 and FL-FL is assigned)

Figure 69: Validation point located in a cloud cover

Accuracy/Uncertainty analysis stage

The individual validated points from the six interpreters were collated and populated into a single table. In the table, every referenced point under the column "classified" has a corresponding validated point under the "GrndTruth" column (Figure 70).

FID	Classified	GrndTruth
1682	0	0
1693	0	0
1695	2	2
1699	3	0
1701	3	0
1704	0	0
325	0	0
327	1	0
333	2	3
342	2	2
345	3	0
346	1	1
349	0	0
351	0	0
352	0	0
358	0	0
363	3	0
369	3	3
370	3	3

Figure 70: Extract of the validation points showing the classified and corresponding ground truth points

Then the table containing all the 2,000 validated samples, were sorted into four classes and permuted based on OL, RG, DF and FL. The resulting total counts were used to generate a matrix of classified and ground truth for the Olofsson's approach.

Accuracy assessment and uncertainty of change areas

The overall accuracies were 74% and 74% for period 1, period 2, respectively. For period 1, OL and FL recorded the highest user's accuracy, followed by DF and RG having the least user's accuracy. Similar accuracy levels were obtained for periods 2 (Tables 96 and 97). For example, in period 2, the user's accuracy for DF increased to 56% while that one for RG declined to 18%.

Table 96: Period 1 (2000-2010) accuracy assessment information

Unbiased change area matrix								
Land-use classes	Lower limit	Upper limit	Error-adjusted area estimates (000, ha)	Map areas (000, ha)	SE of adjusted area estimates	User's Accuracy	Producer's Accuracy	Overall accuracy
OL	284.63	540.43	1,159	354	65.26	0.86	0.31	0.74
RG	940.93	1,123.63	341	286	46.61	0.28	0.84	
DF	504.85	655.13	390	272	38.34	0.47	0.70	
FL	3,756.75	4,024.14	4,026	3,476	68.21	0.89	0.86	

Table 97: Period 2 (2010-2012) accuracy assessment information

Unbiased change area matrix								
Land-use classes	Lower limit	Upper limit	Error-adjusted area estimates (000, ha)	Map areas (000, ha)	SE of adjusted area estimates	User's Accuracy	Producer's Accuracy	Overall accuracy
OL	1,000.05	1,197.40	1,838	924	50.35	0.84	0.50	0.74
RG	446.17	514.25	108	87	17.37	0.18	0.81	
DF	286.26	406.74	439	194	30.73	0.56	0.44	
FL	3,885.79	4,093.81	3,530	3,161	53.07	0.79	0.90	

5.10.1.2.2 Biomass estimation

Biomass estimation was done using ground inventory. A pilot area within each of the nine forest ecological zones of Ghana was selected after a scoping exercise. A nested plot design in a rectangular shape, grouped in clusters was laid to delineate sampling areas for data collection. A cluster comprising three rectangular plots was systematically placed 500m apart. A main plot of 20m by 20m was laid to measure trees with a diameter above 10cm and their corresponding heights. A sub-plot of 10m by 10m was laid within the main plot to measure the diameter and height of juveniles with diameter below 10cm in addition to deadwood encountered. Another sub-plot of 5m by 5m was laid within the 10m sub-plot to collect litter and soil samples. Destructive sampling of 10 trees per ecological zones was done, and samples from the roots and stem were taken for analysis. The destructive sample results were used to develop allometric equations for the estimation of below and above-ground biomass.

5.10.1.2.3 Recalculation in the land category

The availability of new activity data from the FREL work justified the need for the recalculation in the land category. All the land-use areas and the accompanying change matrix were affected by the inclusion of the new dataset. The recalculation led to the changes in the activity data for the various land categories. The variations between previous CO_2 emission estimates and the latest figures are in Table 98.

Table 98: Results from recalculations and impacts on the previous emissions for the Land category

Year	PE [$MtCO_2e$]	LE [$MtCO_2e$]	Change [%]
1990	-3.02	14.01	564
1991	-6.60	14.07	313
1992	-6.44	14.12	319
1993	-3.84	14.18	469
1994	-3.23	14.24	541
1995	-5.05	14.30	383
1996	-4.67	14.36	407
1997	-4.09	14.42	453
1998	-3.87	14.42	473
1999	-3.90	14.59	474
2000	-4.00	12.73	418
2001	-2.65	13.30	602
2002	-2.62	13.52	616

2003	-0.99	13.16	1430
2004	-0.76	12.62	1760
2005	-0.93	12.70	1466
2006	-0.06	12.87	21555
2007	0.38	12.91	3296
2008	0.80	12.95	1519
2009	1.20	12.69	958
2010	1.85	12.98	602
2011	1.31	12.86	881
2012	1.84	12.96	604

Reasons for recalculations

- Changes to the land area (in hectares) based on 2006 IPCC classifications.
- Changes in new land-use change matrix based on the 6 IPCC classes.
- Changes in methodologies for the collection of activity data using remote sensing and field data collection.
- Revision of industrial round wood and fuelwood harvest data in forest lands
- Inclusion of teak specific emission factors.

5.10.1.2.4 Source-specific emissions for the land category

5.10.1.2.4.1 Emissions from forest lands

Forestland has been grouped into open and closed forests. The closed forests are the gazetted government reserves and national parks whereas open forests are generally forestlands outside the gazetted forests, which constitute the off-reserve forests. Besides, some gazetted forest reserves which have been degraded and are being rehabilitated were classified as open forests. Forestland continued to remain as a net carbon sink throughout 1990-2016. Figure 71 indicates that the sink capacity of the country in the forest has expanded 32.4% in the same period at a 1.1% annual accumulation rate. The carbon removal had increased from -3.5 $MtCO_2$ in 1990 to -4.58 $MtCO_2$ in 2012 and further to 4.67 $MtCO_2$ in 2016.

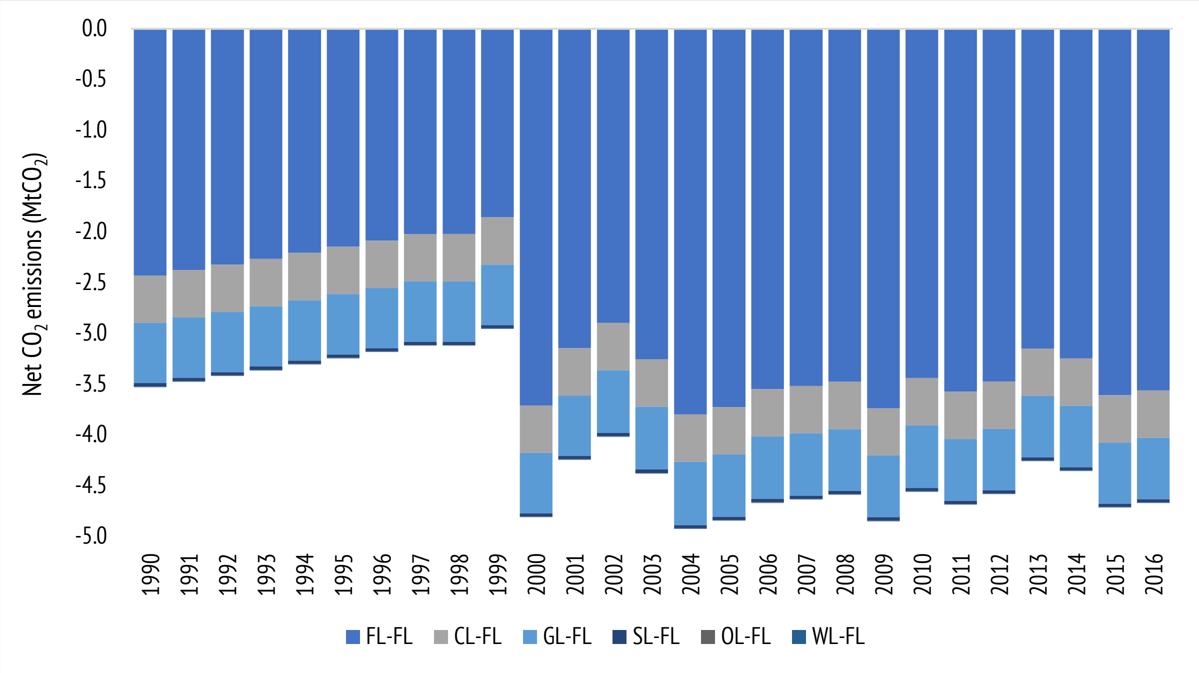


Figure 71: Net CO_2 emissions trend for forestland between 1990 and 2016

On the average, CO_2 removals from forestland remaining forestland (FL-FL) form 72.2% of the total CO_2 removals within the forest and the rest 27.8% were from other lands (all the rest of the conversion to forestland put together) to forestland. Grassland-forestland conversion is the largest CO_2 removals. It has consistently contributed to 54.6% of CO_2 removals in the forestland. The second-largest removals are from cropland-forestland conversion making up 42.1% of the total removals. The rest of the 3.3% CO_2 removals were shared among settlement-forest, other land-forest and wetland-forest conversions. The following factors could explain the general increasing removals by forestland: (a) the impacts of the ban on the export of round logs as part of government's policy to facilitate the enhancement of downstream timber processing and (b) implementation of aggressive forest plantation development program targeted at degraded forest lands and the establishment of plantation development fund to encourage private sector plantation development.

5.10.1.2.4.2 Emissions from cropland

Cropland refers mainly to crop fields on which annual staple food and perennial crops are cultivated. The land preparation methods in cropland are (a) slash and burn, (b) mechanisation (c) application of weedicides and (d) a combination of the former. GHG Emissions associated farmland management practices such as fertiliser application, handling of crop residues, burning are reported under 3C. The emissions reported under this category are related to land-use changes involving cropland. The conversion of forestland to cropland constitutes the sources of CO_2 emissions in cropland. Cropland was the second-largest source of net CO_2 emission in the land category. In 2016 alone, cropland contributed net 8.8 $MtCO_2$ to the total land emission of net 12.87 $MtCO_2$. Out of that figure, forest-cropland conversion through deforestation was the biggest contributor (Figure 72). Deforestation through cropland expansion has been identified as one of the key categories in the entire emission inventory. It occurred across the country with varying degrees of intensity. The drivers of the forest-cropland conversion are localised, but factors such as type of crop, agronomic and management practices and the land tenure can also influence the emission levels.

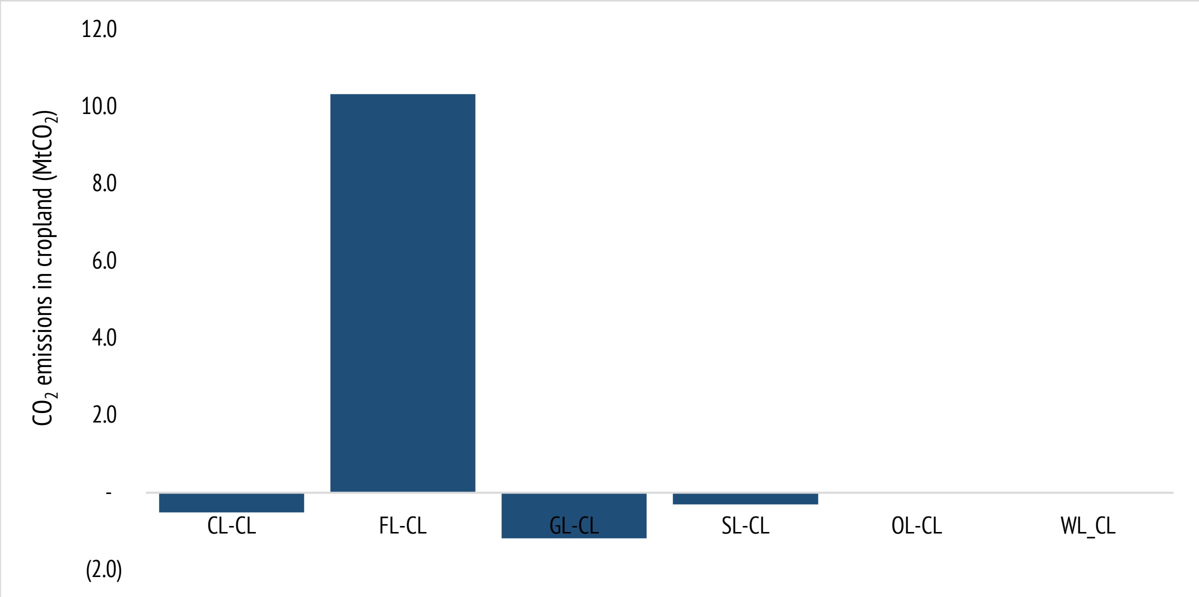


Figure 72: Net CO_2 emissions for cropland in 2016

5.10.1.2.4.3 Emissions from grassland

Grasslands exist mainly in the savannah and transition zones of Ghana as massive patches. There is grassland also in coastal savannah. Grass also occurred as shrubs that emerge during fallow or as transition vegetation after a major forest or agricultural activity. Not much woody vegetation was found in grassland. Typically, grassland was dominated by herbaceous plants which make it suitable for animal grazing and makes it sensitive to the seasonal changes. Burning is also a common practice in the grassland. To facilitate animal grazing, in some parts of the country, especially in the dryland, the grass is burnt to allow for fresh grass for animal grazing. The emissions from grassland largely follow the forest-to-cropland and cropland to grassland trajectory. Emissions from grassland account for 68% of all emissions in the land category. In 2016, the net CO_2 emissions from grassland were 8.8 $MtCO_2$ with most of it coming from forest-grassland conversion through deforestation (Figure 73).

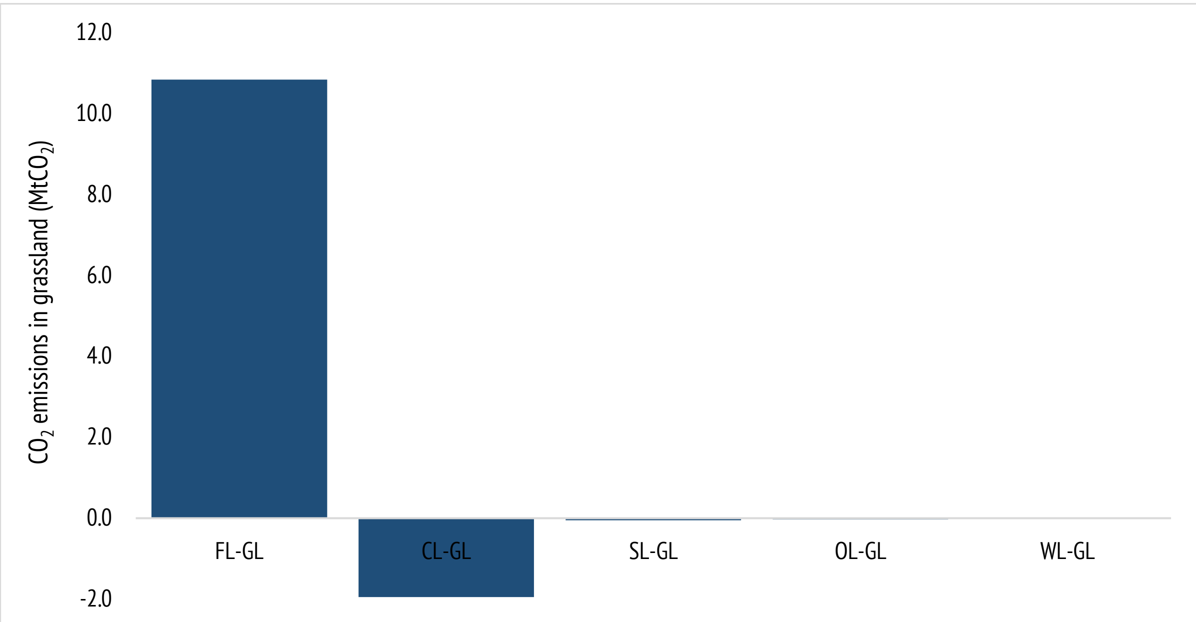


Figure 73: Net CO_2 emissions for grassland in 2016

5.10.1.3 Aggregated sources and non-CO_2 emission sources on land (3C)

GHG emissions related to activities other than livestock and land fall into this category. They include CH_4 and N_2O from biomass burning, CO_2 from Urea application, direct and indirect N_2O from managed soils and indirect N_2O from manure management as well as CH_4 emissions from rice cultivation. Total GHG emissions of 6.57 $MtCO_2e$ was recorded for 2016. The nitrous oxide formed 88.1% of the 2016 total emissions and trailed by methane (11.4%) and carbon dioxide (0.6%). The 2016 figure represents 50.5% and 6.3% greater than the 1990 and 2012 emission levels, respectively. It also accounted for 28.7% of the total AFOLU emission in 2016. The GHG emissions for the 3C category in the 1990-2016 window displayed upward trends growing at an annual average of 1.6%.

This emission trend was associated with agricultural activities that led to nitrogen fixation in the soil like fertiliser application, handling of crop residues, and the impacts of land management practice due to land-use conversions. The pattern explains why nitrous oxide emission has a major influence on the overall 3C emissions. But not all the gases experienced a rising trend. While N_2O and CO_2 increased CH_4 declined (Figure 72). In terms of the sub-categories, direct N_2O emissions from managed soils were the predominant source in 2016. It contributed 63.1% of the total 3C emissions of 6.57 $MtCO_2e$ in the latest year and followed by indirect N_2O emissions from managed soils making up 17.4% of the 2016 total emissions. The visible drop in emission in 2004, particularly in "Direct N_20" emissions. Managed soils" relate to the sharp decrease in crop production in the year in question. The rest were from emissions from biomass burning (14.8%), rice cultivation (3.3%) then by indirect emissions from manure management (0.9%) and finally urea application (0.6%) (Figure 74)

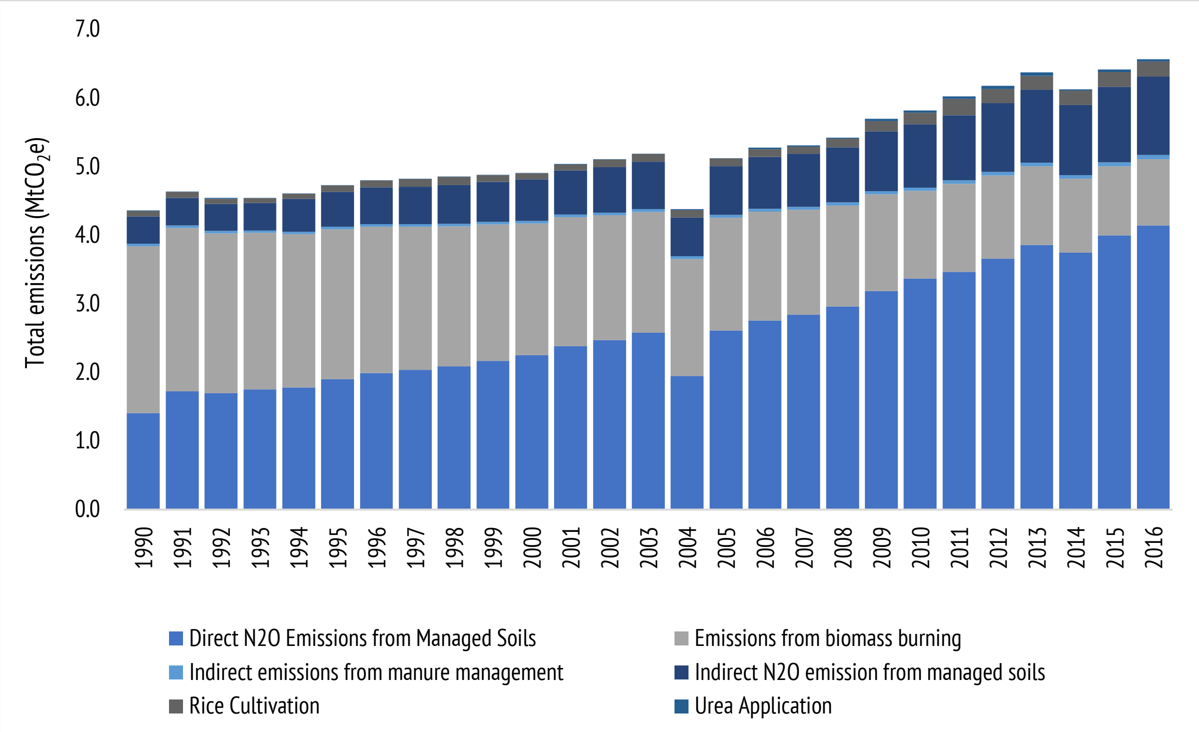


Figure 74: Total 3C emissions according to the subcategories

5.10.1.3.1 Description of emissions trends from biomass burning (3.C1)

The 3.C1 sub-category comprises biomass burning in forestland, cropland and grassland. The emissions estimated were CH_4 and N_2O. The total emissions decreased from 2.43 $MtCO_2e$ in 1990 to 1.22 $MtCO_2e$ in 2012 and further to 0.97 $MtCO_2e$ in 2016 (Figure 75). The reasons for the decline in the emissions were attributed to the sustained public awareness of fire management in the country. In 2016, emissions from biomass burning from grassland and cropland accounted for 44.3% and 44% each of the total emissions, whereas emission from biomass burning from the forest was 11.7% each. Generally, there was a steady decline in the emission levels of the three activities.

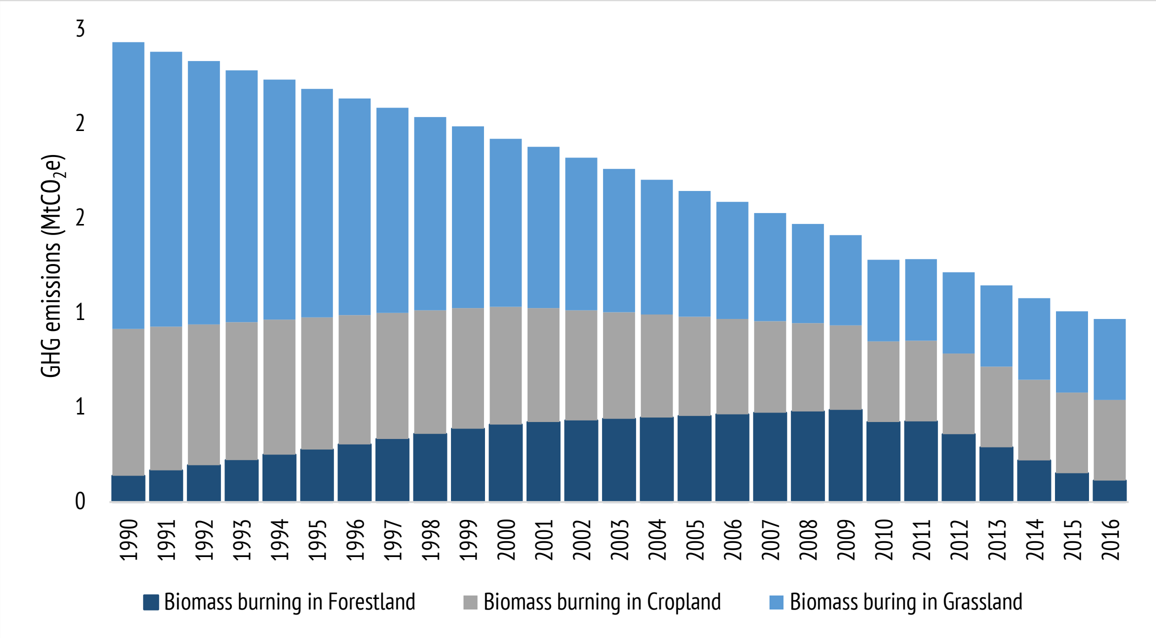


Figure 75: GHG emissions associated with biomass burning in different land-use types from 1990-2016

5.10.1.3.1.1 Methodological issues for biomass burning

The method of estimating emissions in the IPCC 2006 Guidelines and the revised 1996 IPCC Guidelines differ in the way the accounting of emissions from burning are disaggregated while the 1996 Guidelines considered burning as part of forestland to grassland conversion, the 2006 Guidelines classifies biomass burning separately under 3C. The methodology for estimating emissions from fire got better with the adoption of remote sensing approach. With the MODIS fire product, it was possible to delineate the fire spots and burnt areas for each land-use type and ecological zones. Expert judgment was used to determine fractions of the various areas affected by fire based on available biomass load. The actual areas affected by fire were derived from the sum of the individual areas affected by fires under each zone into the following land categories; biomass burning in forestland, cropland and grasslands. The total areas affected by burning in forestland, cropland and grassland included all forms of conversions between and within the three land categories that were due to burning.

Country-specific data on the mass of fuel from the FPP field survey were used to estimate total emissions from biomass burning for 1990, 2000 and 2010. To derive the inter-annual biomass burning estimates within each decade, trend interpolation for 1991 to 1999 and 2001 to 2014 was done. In 2015, areas affected by fire were obtained using a trend extrapolation approach based on the data generated for the immediate past five years. The measurement approach for fire uses spatial data to capture areas burned annually and IPCC factors to derive emission factors. The biomass values input incorporates live biomass (above and belowground) as well as down dead wood and litter as stocks impacted by degradation caused by forest fires. These stocks are derived from the FPP. The MODIS burned area product was used to identify areas that experienced emissions due to forest fire between 2001-2015 (Figure 76). Only forest areas that remained forested and where forest fires occurred but caused no change in land-use were counted as forest degradation. Any areas that burned and were identified as deforestation were removed from degradation forest fire accounting. Subsequently, the areas affected by the fire that led to forest degradation and deforestation were added as one for further analysis.

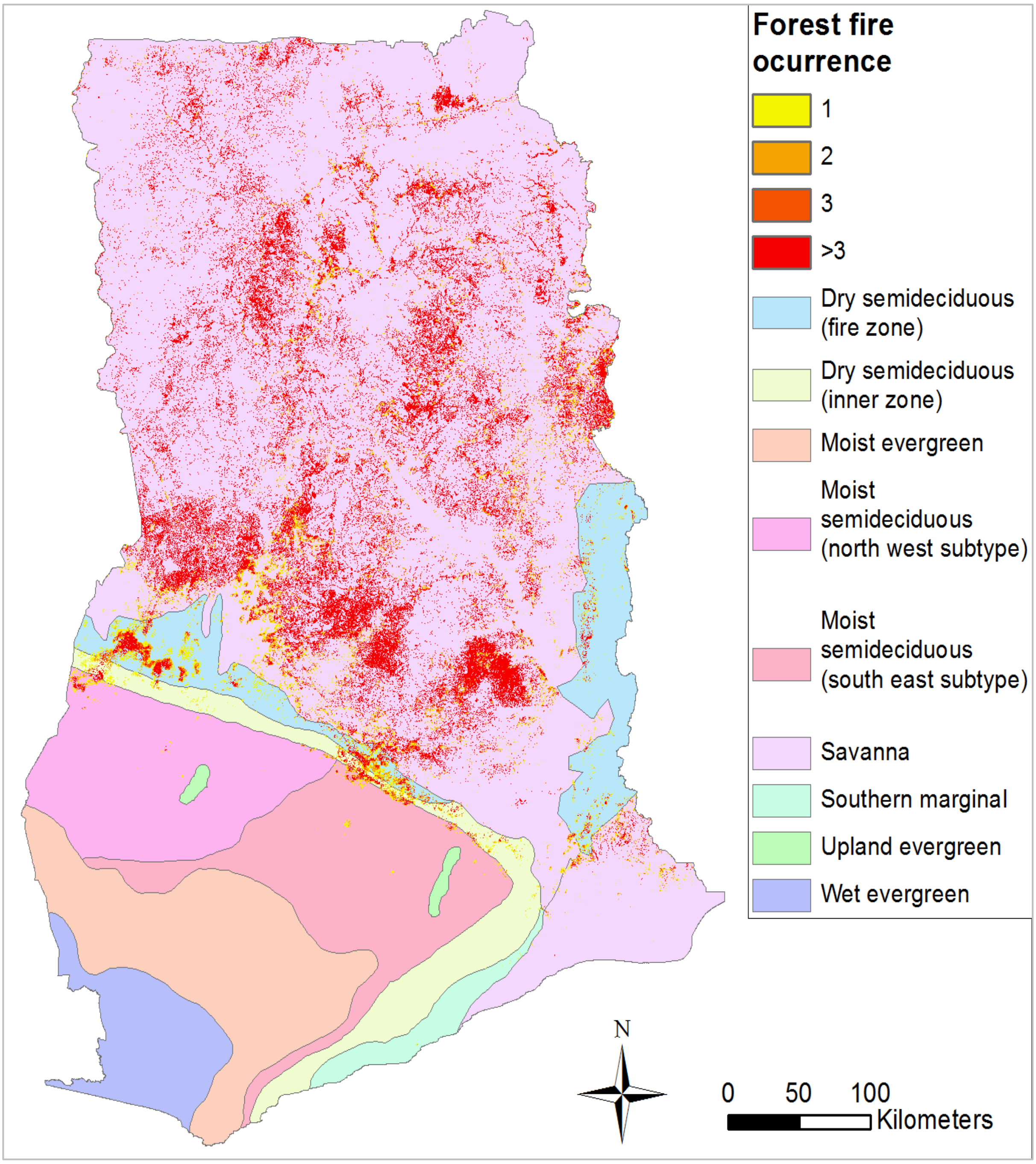


Figure 76: Forest fire occurrence in Ghana from 2001 - 2015

5.10.1.3.1.2 Recalculations of 3C.1 emission

Once a new remote sensing-based methodology was applied to estimate the fire spots and the fire-affected areas, it was good practice to perform recalculation on the previously reported emissions (1990-2012). The impact of the recalculation is in Table 99.

Table 99: Recalculations in biomass burning under 3C1

Year	PE [$MtCO_2e$]	LE [$MtCO_2e$]	Change
1990	8.12	2.43	-70.1%
1991	7.86	2.38	-69.7%
1992	7.32	2.33	-68.1%
1993	7.32	7.59	3.6%
1994	7.06	2.23	-68.3%
1995	6.79	2.19	-67.8%
1996	6.52	2.14	-67.3%
1997	6.26	2.09	-66.7%
1998	5.99	2.04	-66.0%
1999	5.72	1.99	-65.3%
2000	5.46	1.92	-64.8%
2001	5.25	1.88	-64.2%
2002	5.04	1.82	-63.9%
2003	4.83	1.76	-63.5%
2004	4.62	1.70	-63.1%
2005	4.41	1.65	-62.7%
2006	4.21	1.59	-62.3%
2007	4.00	1.53	-61.7%
2008	2.99	1.47	-50.8%
2009	3.58	1.41	-60.5%
2010	3.37	1.28	-62.0%
2011	3.27	1.29	-60.7%
2012	3.21	1.22	-62.2%

Reasons for the recalculations

- Adoption of a remote sensing technique for the estimation of areas affected by fires.
- Revisions in the fire burnt areas for the three land-use types.
- Separation of forest degradation and deforestation fires

5.11.1.3.2 Description of emissions trends from urea application (3.C3)

This sub-category covers CO_2 emissions from urea-based fertiliser application to agricultural soils in Ghana. The emission estimates focus on the fraction of cropland artificial fertiliser was applied to boost crop yields. In 2016, the CO_2 emissions from urea application to agricultural soil amounted to 0.04 $MtCO_2$, which was 0.6% of the total 3C emissions. The current value was an increase of 289% over the 1990 figure of 0.01 $MtCO_2$ (Figure 77). The variations in the emission trends reflect the effect of the factors that drove demand patterns of agricultural inputs in Ghana, especially the government fertiliser subsidy programme.

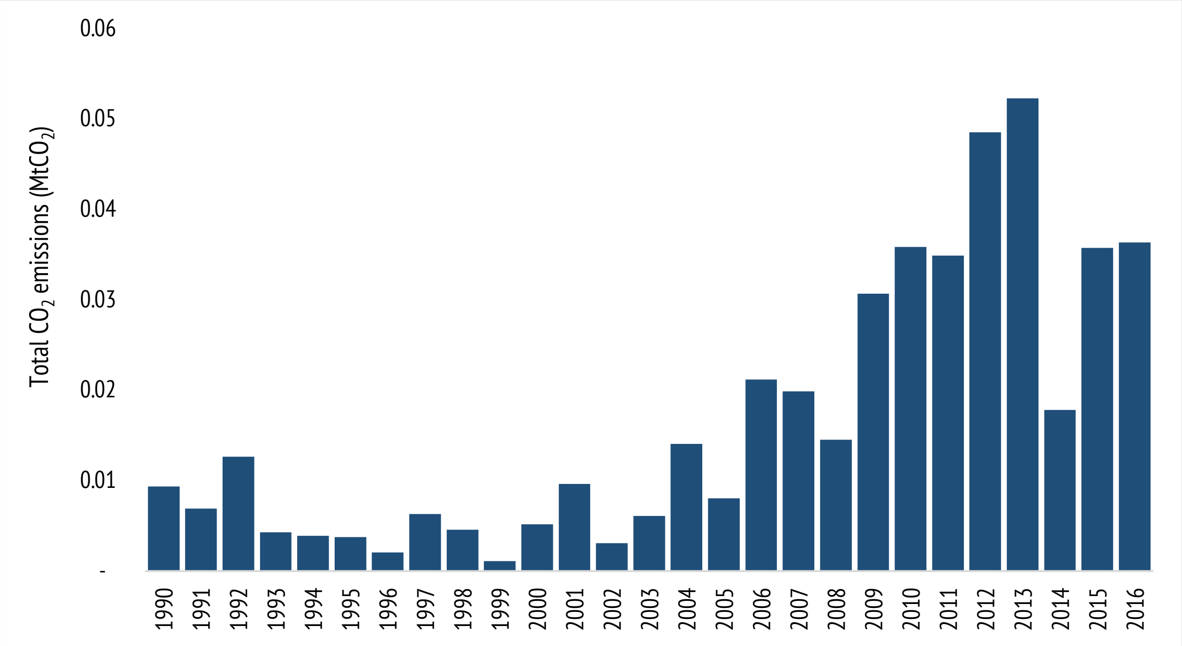


Figure 77: Carbon dioxide emissions from urea application to soils between 1990 to 2016

The fertiliser subsidy programme regulates the amount of urea imports in the country each year. It depends on how much money the government votes to subsidise fertiliser imports. It is most likely that the inter-annual variation in the CO_2 emissions associated with urea application is influenced by the quantities of urea imports and the use on the agricultural fields.

5.10.1.3.2.1 Methodological issues for urea application

The IPCC Tier 1 method and default emission factors were used in the calculation of the emissions from urea application. The activity data were obtained from the Agricultural Facts and Figures published by the Ministry of Food and Agriculture. Activity data were mainly annual urea imports into the country. Total annual imports of urea fertiliser were assumed as annual consumption because there was no data on annual stock balances or stock changes for fertilisers.

5.10.1.3.3 Description of emission trends from direct and indirect N_2O Emissions from Managed Soils (3.C4 and 3.C5)

Direct and indirect N_2O emissions from managed soil comprise nitrogen inputs from crop residues, application of synthetic nitrogen fertilisers and land-use practices associated with land-use change. Both sources produce the largest emissions under 3C. In 2016, 3C.4 and 3C.5 contributed 80.5% of the overall 3C emissions. Their actual emissions amounted to 5.28 $MtCO_2e$. Direct N_2O emissions from managed soil alone constituted 63.1% of the 2016 3C emissions. The emission levels went up from 1.41 $MtCO_2e$ in 1990 to 3.66 $MtCO_2e$ in 2012 and subsequently to 4.14 $MtCO_2e$ in 2016.

On the other hand, indirect N_2O emissions from managed soil made up 17.4% of the total 3C emissions in 2016. Similarly, the emission saw an upward trend from 0.4 $MtCO_2e$ in 1990 to 1.01 $MtCO_2e$ in 2012, then to 1.14 $MtCO_2e$ in 2016 (Figure 78). The observed increasing trends of both direct and indirect N_2O emissions from managed soils could also be linked to the Government of Ghana's fertiliser subsidy programme and the prevailing crop residue practice. The common farm practice is that for most staple crops, the leftover after harvesting is usually allowed to decompose. Only a limited fraction is burnt in-situ or grazed.

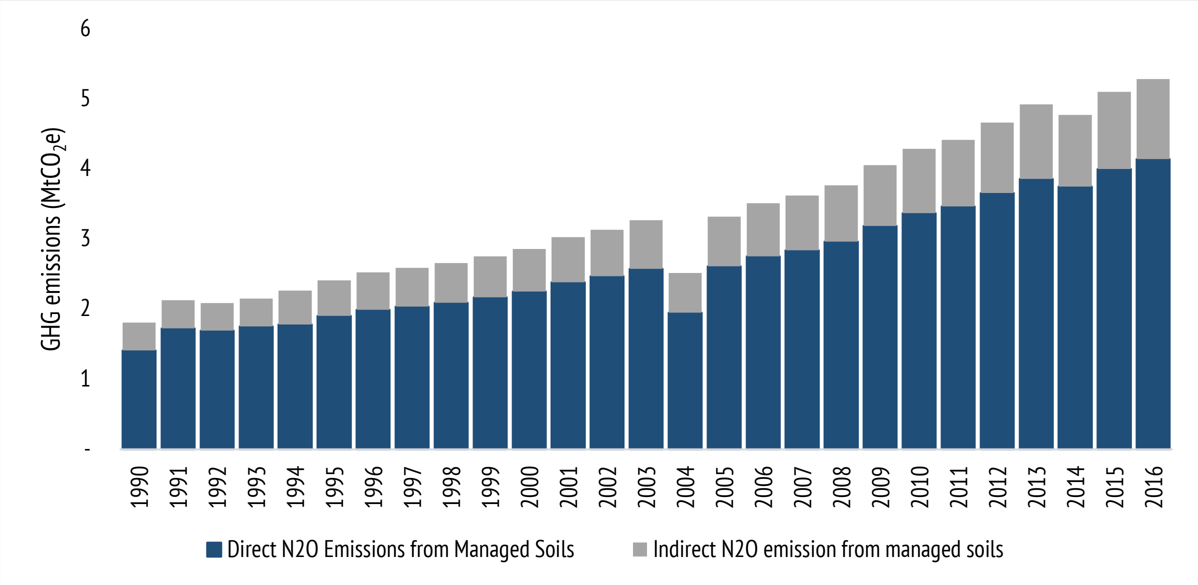


Figure 78: Trends in direct and indirect N_2O Emissions from Managed Soils

5.10.1.3.3.1 Methodological issues in 3.C4 and 3.C5

Direct and indirect N_2O emissions were estimated using the IPCC tier 1 and default emission factors. Country-specific activity data on annual crop production of key staples crops such as maize, yam, cassava, cocoyam, sorghum, and millet were obtained from the Agriculture Facts and Figures. Subsequently, appropriate default residue slope, residue intercept and dry matter fraction corresponding to the respective staple crops were used to estimate the above-ground biomass residue. The annual nitrogen fraction of the crop residue was obtained by applying the appropriate root-to-shoot ratio of the various crops. The individual crop residues were aggregated to form the total nitrogen fraction from the crop residue. Data on nitrogen-based fertilisers were obtained from the Agriculture Facts and Figures 1990-2016 and were subsequently summed up based on the fraction of nitrogen content for different fertilisers published in the FAOSTAT. The percentage of nitrogen content in fertilisers was derived by multiplying total volume consumed yearly by its corresponding nitrogen fraction.

The nitrogen content of the individual fertiliser types was summed to generate the annual total nitrogen input from synthetic fertilisers. Total annual N mineralisation in soils was calculated based on annual soil organic matter loss and the carbon-nitrogen ratio of the soil. For the annual soil organic matter, carbon stock change in mineral soils of individual land-use conversion was obtained from the land-use matrices and subsequently summed up to generate the annual total loss of soil organic matter per land category. The total annual nitrogen mineralisation in managed soils was derived by multiplying the annual loss of soil organic matter to the carbon-nitrogen ratio. The total annual N - synthetic fertilisers, N - crop residues and N – mineralisation was input for the calculation of the direct and indirect N_2O emissions from managed soils.

5.10.1.3.4 Description of emission trends from indirect N_2O Emissions from manure management (3.C5)

The quantity and the way animal manure is managed can lead to N_2O emissions. It is the second least emission source under 3C. It is the level of 0.06 $MtCO_2e$ accounts for only 0.9% of the total 3C emissions. The emissions grew by 73% over the 1990 figure of 0.03 $MtCO_2e$ and 19% of the 2012 value of 0.05 $MtCO_2e$. The increases in the N_2O emissions were because of reported rising livestock populations for the period 1990 to 2016 (Figure 79).

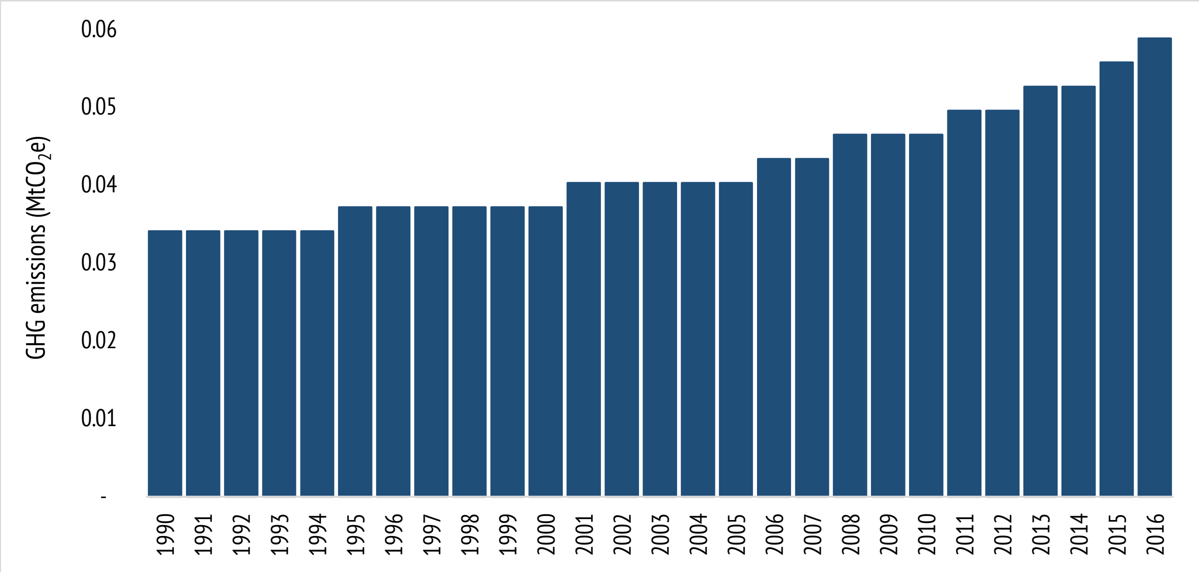


Figure 79: Emission trends of indirect N_2O Emissions from Manure Management

5.10.1.3.4.1 Indirect N_2O Emissions from Manure Management Methodological issues

The IPCC default emission factors were used in the calculation of emissions from manure management. Proportions of animal waste management systems were estimated by expert judgment and categorized according to animal type.

5.10.1.3.5 Description of emission trends from rice cultivations (3.C7)

The management practices on the farm largely determine methane emissions from rice cultivation. Bottomland rice or irrigated rice farms create suitable biological conditions for methane production. The duration of water inundation is a principal contributing factor to the emission levels. Overall, methane emission associated with rice cultivation increased by 167% over 1990-2016 (Figure 80).

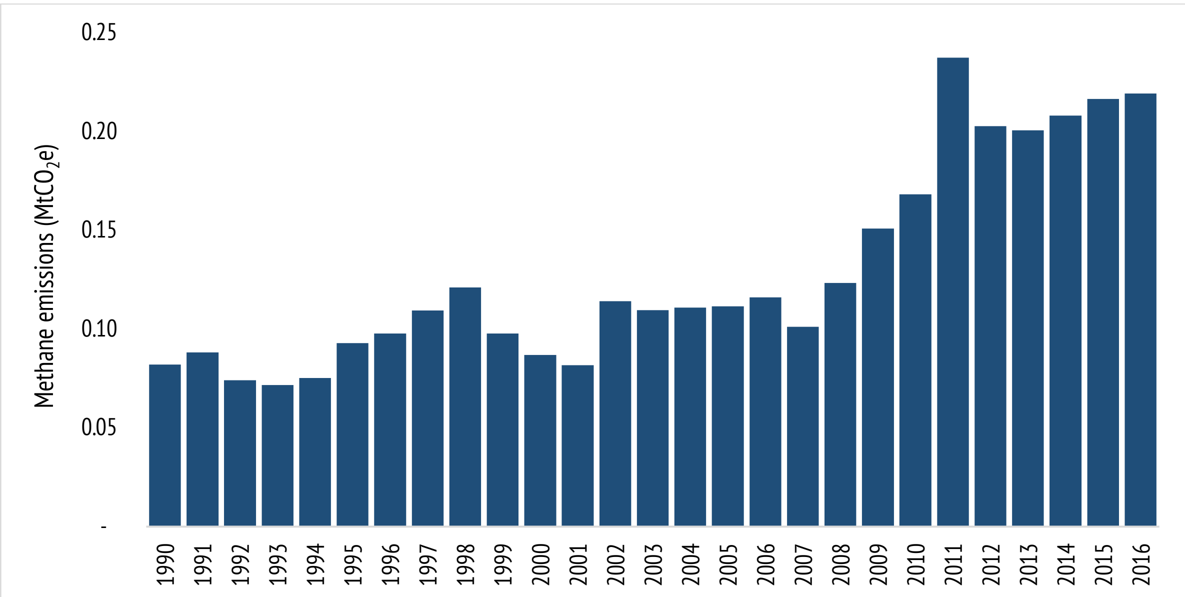


Figure 80: Methane emission trend from rice cultivation

5.10.1.3.5.1 Methodological issues in rice cultivation

The IPCC tier 1 methodology and default emission factors for rice cultivation were used. The data on percentages of the different rice cultivation systems from the National Rice Development Strategy (MOFA, 2009) were used to derive the breakdowns of the total annual rice cultivation areas into rain-fed, upland, and irrigated systems.

5.11 AFOLU planned improvements

Table 100 provides an overview of the key activities that have been planned for improving future inventories in addition to the ones identified during the in-country voluntary review. These include efforts to generate data in categories where they are lacking and reduce the reliance on expert knowledge and associated uncertainties as much as possible.

Table 100: List of activities for future improvements in accounting for the AFOLU sector

Improvement tasks	Responsibility & Collaborators	Priority	Next Step	Target	Assumptions
Develop all-embracing new land representations schemes with definitions (include the possibility of delineating tree crops from annual crop areas)	FC, EPA, UNU-INRA, Rudan, CERSGIS, Geomatics-KNUST, FAO, NATU-KNUST, Cocoa Board Survey department, RMSC, FC	High	Explore the possibility of linking with the FPP process as a follow-up. EPA can facilitate this assignment.	Next Inventory	Funding secured on time
Reprocess land-use maps and LUC matrices	FC, AFOLU Team, CERSGIS, RMSC	High	AFOLU technical team from the collaborating institutions would proceed with these activities following the initial action.		
Overlay land cover maps with map of ecozones, climate, soil and recalculate land-use change maps		High			
Integrate maps on perennial crops (mainly cocoa and rubber) in land-use maps and recalculate		High			
Reconsider the dealing with wetlands and eliminate some ways of change between categories.		High			
Reconsider factors that express the speed of land-use change in the 1970ies and 1980ies		High			
Cross-check area estimates from LUC matrices with data available at the plantation unit.		High			
Fire monitoring					
Include the annual fire hotspots and overlay on the land-use maps to assign disturbances to land-use subcategories	FC, Ghana National Fire Service, NADMO, District Assemblies	High	Link with AGRHYMET	Next Inventory	FC to initial contact with AGRHYMET supported by EPA
Work on biomass inventory	FC and FORIG	High			
Include the biomass density estimates for plantations	FC and FORIG	High	EPA to follow-up with FC and FORIG	Next Inventory	Contact FORIG

Remove outliers from biomass plot estimation (deadwood estimates)	FC and FORIG	High			Contact FC for updates
Quality check deadwood calculations in inventory data	FC and FORIG	High			Contact FC
Explore the possibility of including trees in annual croplands	FC and MOFA	Medium	Include in the discussions of the AFOLU team.	Next Inventory	part of the activity 1
Explore the possibility of reducing the uncertainty associated with time-series data (infilling of data gaps)	AFOLU Team	Medium	EPA to coordinate the revision of existing estimates.	Next Inventory	Funding is secured on time
a. biomass changes in different land representations, including different pools.					
b. Fuel production/supply					
d. Pools					
Other issues					
Account for the burning of crop residues beyond the burning of fields	MOFA	Low	MOFA to lead AFOLU team in the identification, collection and inclusion of data into the inventory	Next Inventory	Funding for BUR3 would cover this activity
Account for multiple cropping rice	MOFA and AFOLU Team	Low			
Include harvested wood products	FC	Low			
Include crop residues from plantain	MOFA and EPA	Low			
Clarify the fertiliser use in rice	MOFA and EPA	Low			

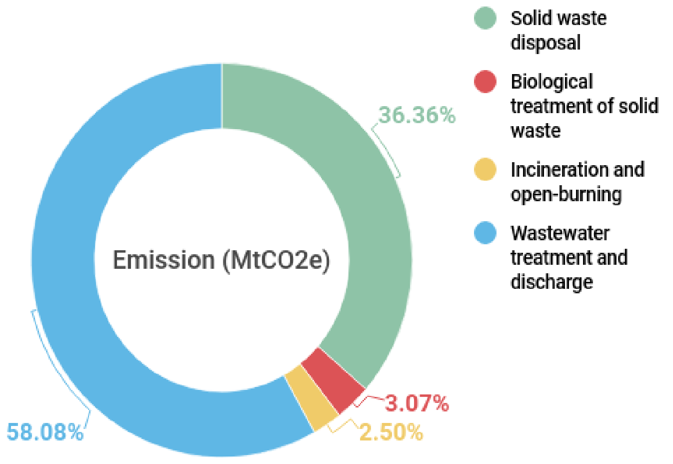
Waste Sector



Waste sector GHG emissions Dashboard

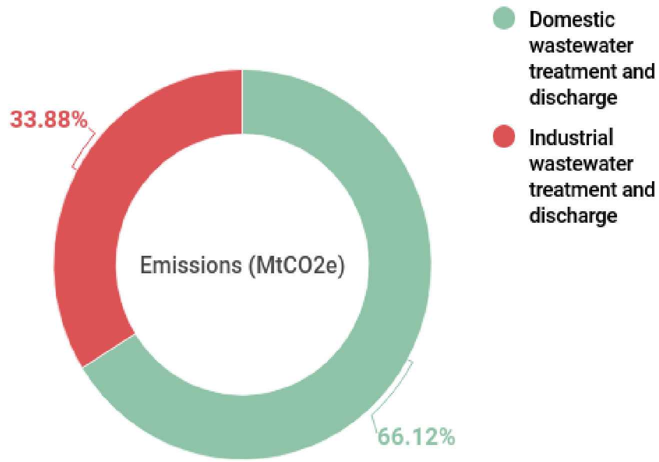
Total 2016 emissions	Drivers of waste sector emissions	Emission trends	Major greenhouse gases
3.17 $MtCO_2e$	Solid waste disposal Incineration & open-burning Wastewater discharge and treatment	14.6% more than 1990 levels	CO_2 = 0.3%, CH_4 = 80.8%, N_20 = 18.9%

Emissions in waste sector category in 2016



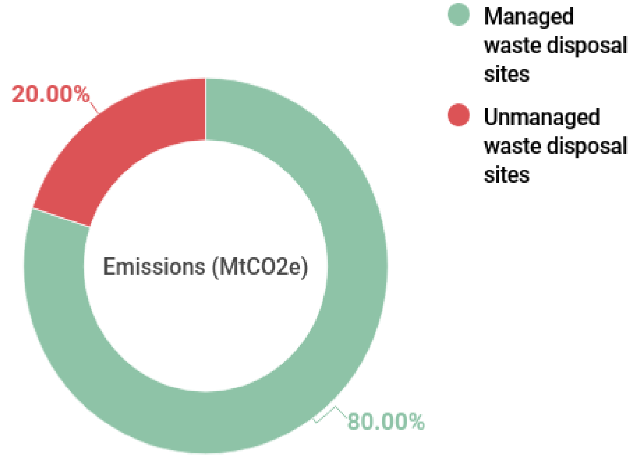
Wastewater treatment & discharge emission in 2016

1.84 $MtCO_2e$



Solid wast disposal emissions in 2016

1.16 $MtCO_2e$



Chapter 6
Waste sector

6.1 Summary of waste sector emissions in 2016

The waste sector is the third leading source of greenhouse gas in the country. In 2016, the Waste sector recorded a total of 3.2 $MtCO_2e$ of greenhouse gases, making 8% of the overall national emissions. The 2016 emissions are 211% and 17% higher than the 1990 and 2012 levels respectively. The upward emission trend is driven by the emissions associated with wastewater treatment and discharge as well as solid Waste disposal (Figure 81). Methane emission is the dominant GHG in the waste sector. It made up a large chunk (80.8%) of all the Waste sector emissions in 2016. The next important GHG in the sector was nitrous oxide and constituted 18.9%. The least was carbon dioxide accounting for merely 0.3% of the total waste emissions.

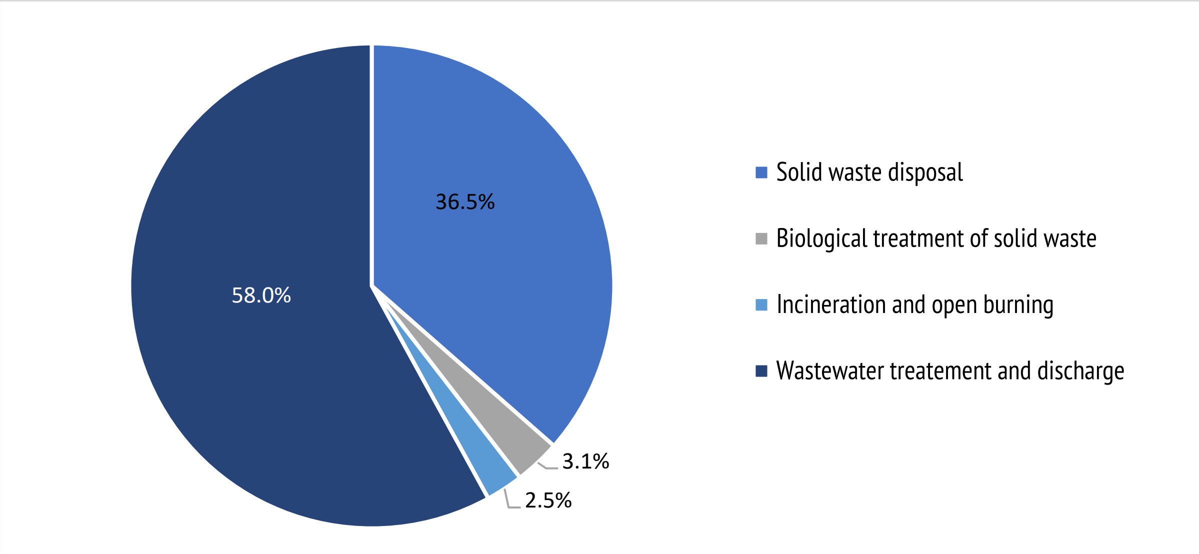


Figure 81: Overview of GHG emissions in the waste sector category

The tier 1 methodology described in the IPCC 2006 Guidelines was mainly used except for the estimation of CH_4 associated solid waste disposal tier 2 and country-specific factors were applied. Table 101 presents an overview of the methods and factors used in the waste sector.

Table 101: Methodology and factors used in the Waste sector

Category code	Emission Sources	Gas reported	Status	Method	EF
4.A	Solid waste disposal	CH_4	E	T2	D
4.B	Biological treatment of solid waste	CH_4, N_20	E	T1	D
4.C	Incineration and open burning of waste	CO_2, CH_4, N_20	E	T1	D
4. D	Wastewater treatment and discharge	CH_4, N_20	E	T1	D

6.2 Waste sector overview

The greenhouse gas emissions from the waste sector are from treatment and disposal of liquid waste (domestic and industrial) and municipal solid waste such as landfilling, composting, incineration, opening burning. Greenhouse gas emissions from waste are predominantly CH_4 and CO_2 from solid waste disposal incineration of solvents), nitrous oxide and methane from biological treatment of solid waste, wastewater treatment and discharge and decomposition of human waste. Carbon dioxide emissions from the breakdown of organic material were not reported because the carbon dioxide emitted is assumed to be reabsorbed by growth in vegetation and other organic matter in the following year. The key factors that affect emission generation in the waste sector are (a) population, (b) technology and (c) extent of emission (methane) recovery and management practices.

6.3 Classification of waste activities under IPCC 2006 Guidelines

According to the 2006 IPCC guidelines, the following source categories in the country are covered in the waste sector: solid waste disposal (4A), biological treatment of solid waste (4B), incineration and open burning (4C) and Wastewater treatment and discharge (4D). Each of the source categories is divided into subcategories taking recognisance of the prevailing waste attributes and management practices in the country.

6.3.1 Solid waste disposal (4A)

The quantity and type of solid waste generated in each period are closely linked to population growth, urbanisation and lifestyles. Methane and non-fossil CO_2 are the main greenhouse gases that are associated with solid waste disposal through biological decomposition. Depending on the common management practice at the solid waste disposal site, the solid waste emission sources are additionally grouped into (a)managed waste disposal sites (4. A1), (b) unmanaged waste disposal sites (4. A2) and (c) the uncategorised waste disposal sites (4. A3). With the lack of credible data on the different classes of solid waste management practices, Ghana was unable to report the methane emissions from solid waste disposal in a disaggregation of managed, unmanaged and uncategorised as expected. Instead, most of the final disposal sites were considered unmanaged. The estimation of methane associated with the various disposal methods relies on the following data inputs: population, waste generation per capita, solid waste streams, annual total waste generation, and fractions of waste disposed-off by different means. The emerging methane emissions from the decomposition of the solid waste deposited in different sites were incorporated into the inventory. The data were obtained from Ghana Statistical Service, published statistics in national reports, literature and personal communication with national waste experts at various Waste Management Departments of the MMDAs.

6.3.2 Biological treatment of solid waste (4B)

Methane and nitrous oxide are the key emission sources from the biological treatment of solid waste through composting. The main data inputs were the quantities of waste composted, the type of waste and the treatment system used. The data was collected from Zoomlion Ghana Limited, which is currently the only operator of a major Compost plant in Ghana. Additional data were sourced from Ghana Statistical Service, other literature for household composting and the decommissioned Teshie-Nungua treatment plant.

6.3.3 Incineration and open burning of solid waste (4C)

Disposal of solid waste through incineration and open burning produces CO_2, CH_4 and N_2O emissions. The emission from this sub-category is divided into incineration (4C.1) and open burning (4.C2). Under incineration, emissions from municipal solid waste and clinical waste were the main sources considered using the aggregate approach. Emissions from open burning were from municipal solid waste. Data on the incineration of municipal solid waste and clinical waste were obtained from the National Environmental Sanitation Strategy Action Plan document, and the Ghana Health Service Facts and Figures and Environmental Management Plans from the Manufacturing and Industry and Built Environment Departments within the EPA.

6.3.4 Wastewater treatment and discharge (4D)

Methane and Nitrous Oxides are the main gases from wastewater treatment and discharge, which is divided into two sub-categories: domestic (4D.1) and industrial (4D.2) wastewater treatment and discharge. Emissions from domestic wastewater treatment and discharge are owing to the disposal and treatment of sewage. Emissions from industrial wastewater treatment and discharge were mainly from seven industrial sectors namely: Beer and Malt, Dairy Products, Fish Processing, Meat and Poultry, Organic Chemicals, soap and detergents and fruit and juices. The activity data were obtained from (a) Ghana Living Standard Survey, (b) Ministry of Agriculture Facts and Figures, (c) Multiple Cluster Indicator Survey data, (d) National Environmental Sanitation Strategy Action Plan document and (e) the industry level environmental reports by the EPA.

6.4 Waste sector data sources and methodology

The description of data sources and methodology used in the inventory for the waste sector is provided below.

6.4.1 Data sources in the waste sector

The data used in this inventory were obtained from different relevant national and international sources. Table 102 provides an overview of the data used in the inventory.

Table 102: Overview of data and the sources in the waste sector

Categories		Subcategories	Data type	Data source	Principal data providers
4A. Solid Waste Disposal	4A	Solid Waste Disposal	Population Figures (1950- 2016). Waste Generation Rate per Capita (1950-2016). Amounts or % of Waste to Solid Waste. Disposal Sites, Composition/Streams of the Waste to SWDS, i.e. Food, Garden, Paper, Wood, Textiles, Nappies, Plastics, Others inert. Methods of Disposals and their various percentages, SWDS Type/Practice, i.e. Managed (≥ 5m) (Shallow and Deep),	Population Census Reports and Ghana Living, Standards Survey Reports. Published Waste National Reports, Publication from Academia. World Bank Country Database/Reports, National Environmental Sanitation Strategy & Action Plan (NESSAP). State of the Environment Reports. Various Reports by the Private Waste Management Companies and NGOs (Zoomlion, Waste care, Jekora Ventures)	Ghana Statistical Service (GSS). Academia; Civil Engineering Department, KNUST, UCC, UDS, Legon World Bank Country Database Sanitation Directorate of MLGRD. Private Waste Management Companies and NGOs (such as Zoomlion, Waste care, Jekora Ventures). Environmental Protection Agency. Sanitation Directorate of MLGRD, Ministry Sanitation and Water Resources (MSWR)

			unmanaged (≤ 5m), uncategorised. Management Practices at the various SWDS. Amount of Methane Recovered from SWDS	Third National Communication Data from the various SWDS sites or Waste Landfill sites	
4B. Biological Treatment of Solid Waste	4B	Biological Treatment of Solid Waste	The fraction of waste composted. The number of compost plants and operational capacities.	Population Census Reports. Ghana Living, Standards Survey Reports. Published national reports Private waste management companies. Waste sector team	Ghana Statistical Service Academia. Private waste management companies (Zoomlion) and NGOs Expert judgment by Waste Team
4C. Incineration and open burning	4C	4C.1 Solid waste incineration	Types and amount of waste incinerated. Incinerator type including capacities and combustion efficiencies	Ghana Health Service Facts and Figures. National Environmental Sanitation Strategy Action Plan document. Environmental Management Plans from EPA. Waste sector team.	Ghana Health Service. Ministry of Local Government and Rural Development. Expert Judgment by Waste Team. Private operators (Zeal and Zoil Companies).
		4C.2 Open Burning of Solid Waste	Population figures The fraction of the population burning solid waste. Duration of burning in the number of days per year. The fraction of waste burnt relative to the total amount treated.	Published national reports. Ghana Statistical Service. Sanitation Directorate of MLGRD.	National Environmental Sanitation Strategy and Action Plan (NESSAP). Population Census Reports. Ghana Living Standards Survey 6.
4D Wastewater treatment and discharge	4D	4D.1 Domestic wastewater treatment and discharge	National Population. Wastewater Generated per year. Wastewater treated per year.	Multiple Cluster Indicator Survey reports World Bank Country Database. Agriculture Facts and Figures Population Census Reports	Sanitation Directorate of MLGRD. World Bank. Ghana Health Service, Ministry of Food and Agriculture

			Wastewater Treatment Systems and their various percentages. Protein Consumption, GDP/capita (income classes).	Ghana Living Standards Survey reports National Environmental Sanitation Strategy & Action Plan (NESSAP)	Ghana Statistical Services. Expert Judgment by Waste Team
		4D.2 Industrial wastewater treatment and discharge	The number of industries whose data on wastewater are included in the inventory. Total Industry Product Quantity of wastewater generated. Type of Wastewater Treatment/discharge System.	Industry-level Environmental Management Report submitted to EPA.	Manufacturing Industry Department of EPA, Expert Judgment by Waste Team.

6.4.2 Description of waste sector methodology

6.4.2.1 Description of methods and assumption for the estimation of emissions

The description of methodological choices and assumptions behind the activity data and emission factors used in the Waste sector are provided. The inventory adopted the 2006 IPCC Guidelines and GPG, which guided data collection, methodological choices and the use of assumptions consistently and transparently. The Guidelines further guide how emissions are estimated using AD and EF. The product of the activity data and the emission factor and its GWP gives the total GHG emissions of an activity [E=AD*EF * GWP]. The inventory adopted a Tier 1 and Tier 2 methodologies in the estimation of the emission based on the available country-specific data and data from reliable international sources. The higher tier methodology was used when country-specific data was available. Example, the availability of national data on solid waste quantities, composition, properties and disposal practices in the period 1990-2016 were used in the estimation of the emissions.

The purpose of striving to use country-specific data and the higher tier was meant to help improve the robustness and quality of the estimates as much as possible. Also, the use of the country-specific data helped in making the results more representative of the national situation. Available country-specific activity data for all the categories were used. Where country-specific data did not exist, data from reliable international data sources were used. Most of these national data were either obtained from primary or publicly available secondary sources which covered the 1990-2016 time-series. However, where there were gaps, data from credible sub-regional and international sources were used. In the absence of data to fill the gaps, appropriate statistical methods (e.g. trends extrapolation, interpolation) were applied in-line with the IPCC Good Practice Guidance, 2000. In situations, where there was a complete absence of data for activities that occur in the country, expert judgment was used and the assumptions documented. Detailed descriptions of the respective methodologies are given in the specific sections of the various sub-categories.

6.5 Category-specific activity data inputs

The 2006 IPCC accounting rules require a variety of activity data into the various categories to estimate the GHG emissions from a particular activity. Description of the key dataset has been provided below:

6.5.1 Solid waste disposal (4A)

Emissions from municipal solid waste disposal were composed mainly of domestic, institutional and commercial sources. The emissions were estimated considering population, per capita waste generation rate, and quantity collected and deposited in different forms of waste disposal sites. At the various disposal sites, the management style, the depth of placement and the depth of the water table were considered. The relevant waste generation and disposal data were collected from different national sources such as Sanitation Directorate of the Ministry of Local Government Rural Development, scientific literature, and national reports.

6.5.1.1 Total solid waste generated and deposited

The total amount of MSW generated has increased steadily from 2.09 million tonnes in 1990, 2.76 Mt in 2000 to 4.91 Mt in 2016. In 2016, the MSW generated was 13%, 44% and 57% higher than 2012, 2000 and 1990 levels respectively (Table 103). The observed increases in the annual solid waste generation were due to growing population and change in lifestyles, particularly in the urban areas. The growing urbanisation has increased the average generation rate per capita. Of the 4,91 Mt generated, 3,92 Mt (80%) was deposited at the solid waste disposal sites in 2016 which represented an increase from 3.4 Mt (80%) in 2012, 1.7 Mt (60%) in 2000 and 0.75 Mt (36%) in 1990. A total of 3,92 Mt (in 2016) was sent to SWDs with the following compositions: (a) food (47%), (b) Paper (9%), (c) Textiles (8%) and (d) Plastics and other inert (36%). Figure 82 below shows the various solid waste compositions in 2016, 2000, and 1990. In 2016, about 80% of the waste disposal sites were classified as managed-semi aerobic (i.e. following the 2006 IPCC guidelines) and about 20% unmanaged shallow with depths less than 5 meters. The figure was an improvement from 2012 when it was 43% managed-semi aerobic and about 56% unmanaged sites.

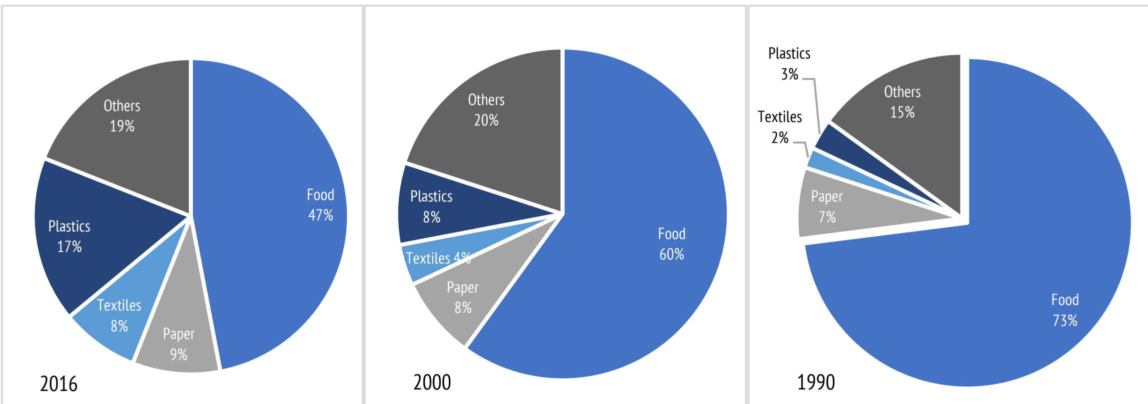


Figure 82: Solid waste composition 2016[34], 2000 and 1990

[34] Note that the solid waste composition for the period 2011-2016 are assumed to the same

Table 103: Solid waste and compositions from 1990 to 2016

Year	Total MSW Generated [Mt]	% of MSW to SWDS	Amount of MSW to SWMS [Mt]	Composition of the Amount of Waste to SWDS [Mt]			
				Food	Paper	Textile	Plastic and Other Inert
1990	2.094	36	0.754	0.550	0.053	0.015	0.136
1991	2.149	38	0.816	0.596	0.057	0.016	0.147
1992	2.204	40	0.882	0.644	0.062	0.018	0.159
1993	2.262	42	0.950	0.693	0.067	0.019	0.171
1994	2.321	44	1.021	0.745	0.071	0.020	0.184
1995	2.381	46	1.095	0.800	0.077	0.022	0.197
1996	2.443	49	1.192	0.870	0.083	0.024	0.215
1997	2.506	52	1.293	0.944	0.091	0.026	0.233
1998	2.571	54	1.399	1.021	0.098	0.028	0.252
1999	2.638	57	1.509	1.102	0.106	0.030	0.272
2000	2.761	60	1.657	0.994	0.133	0.066	0.464
2001	2.836	61	1.725	1.035	0.138	0.069	0.483
2002	2.912	62	1.796	1.077	0.144	0.072	0.503
2003	2.991	62	1.869	1.122	0.150	0.075	0.523
2004	3.072	63	1.945	1.167	0.156	0.078	0.545
2005	3.549	64	2.277	1.366	0.182	0.091	0.638
2006	3.645	65	2.369	1.421	0.190	0.095	0.663
2007	3.743	69	2.573	1.544	0.206	0.103	0.721
2008	3.844	73	2.787	1.672	0.223	0.111	0.780
2009	3.948	76	3.010	1.806	0.241	0.120	0.843
2010	4.050	80	3.240	1.944	0.259	0.130	0.907
2011	4.151	80	3.321	1.561	0.299	0.266	1.196
2012	4.255	80	3.404	1.600	0.306	0.272	1.226
2013	4.362	80	3.489	1.640	0.314	0.279	1.256
2014	4.471	80	3.577	1.681	0.322	0.286	1.288
2015	4.786	80	3.829	1.800	0.345	0.306	1.378
2016	4.906	80	3.925	1.845	0.353	0.314	1.413

6.5.2 Biological treatment of solid waste (4B)

The total amount of solid waste composted, apart from the general household composting by individuals has been random depending on when a private or commercial composting plant is functioning. The total amount of solid waste composted in 2016 was 167.09Gg, which is less than 1% of the total national solid waste generated. From Figure 83, the amount of solid waste composted was high from 1990 until 1994, where it reduced and remained steady until 2012. The amount of solid waste composted arose again from 2012 to 2016.

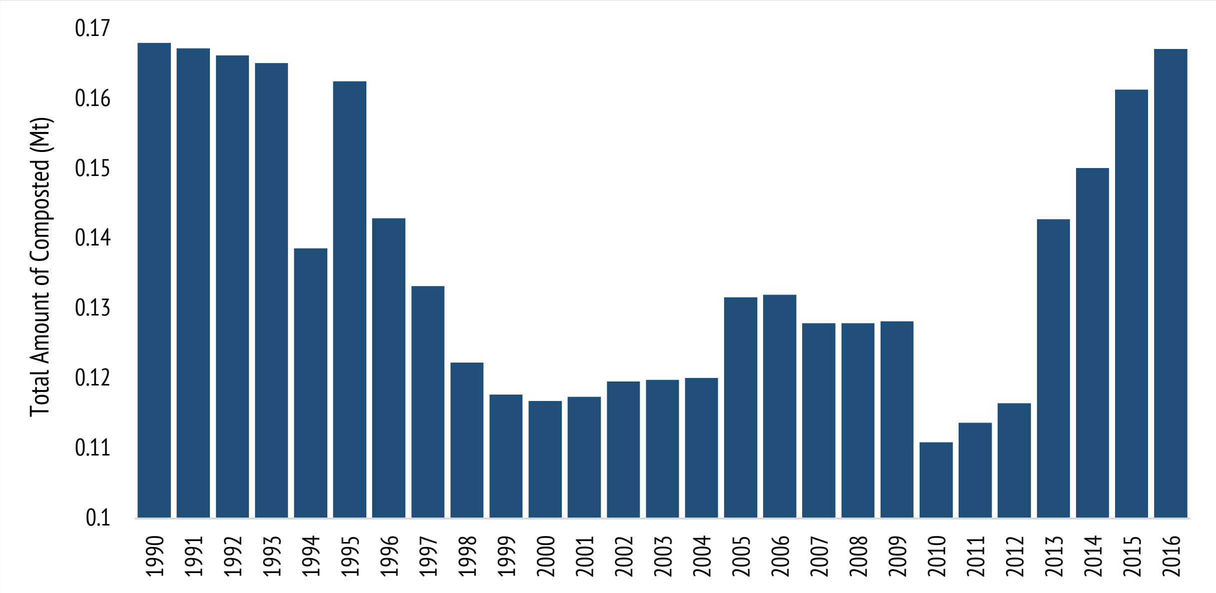


Figure 83: Trends of the amounts of solid waste composted for the period 1990-2016

6.5.3 Incineration and open burning (4C)

The disposal of municipal and clinical waste through incineration and open burning generates carbon dioxide, methane and nitrous oxide emissions. The emissions generated would depend on the amount and type of waste as well as the types of incineration and open burning taking place. In all, a total of 0.432 Mt of waste (MSW, waste oil, industrial hazardous and clinical Wastes) was disposed-off through incineration and open burning in 2016. Of the total 0.432 Mt solid waste, 0.088 Mt were incinerated, whereas the remaining 0.35 Mt were openly burnt (Table 104). Out of the 0.088 Mt waste incinerated, 0.083 Mt was a municipal solid waste, 0.00008 Mt was industrial waste, 0.00039 Mt was a hazardous waste, 0.00007 Mt was waste oil and the other 0.004 Mt was clinical waste in 2016. As at 2016, the total amount of 0.083 Mt of municipal solid waste incinerated was 13% higher than the 2012 levels of 0.072 Mt. The observed increase in the total amount of incinerated waste could be the result of large-scale hazardous incineration plants (Zeal Environmental Technologies Limited and Zoil Services Limited) set up from 2010.

Table 104: Solid Waste disposal by incineration and open burning

Quantities of Waste Incineration [Mt]							Open Burning [Mt]	Total [Mt]
Year	MSW	Industrial	Hazardous	Waste Oil	Clinical Waste	Total	MSW	
1990	0.053	-	-	-	0.003	0.056	0.225	0.281
1991	0.053	-	-	-	0.003	0.056	0.223	0.279
1992	0.053	-	-	-	0.003	0.055	0.222	0.277
1993	0.052	-	-	-	0.003	0.055	0.220	0.275
1994	0.052	-	-	-	0.003	0.054	0.218	0.272
1995	0.051	-	-	-	0.003	0.054	0.216	0.269
1996	0.050	-	-	-	0.003	0.052	0.210	0.262
1997	0.048	-	-	-	0.003	0.051	0.203	0.254
1998	0.047	-	-	-	0.002	0.049	0.197	0.246
1999	0.045	-	-	-	0.002	0.047	0.189	0.237
2000	0.044	-	-	-	0.002	0.046	0.185	0.231
2001	0.044	-	-	-	0.002	0.047	0.186	0.233

2002	0.044	-	-	-	0.002	0.047	0.187	0.234
2003	0.045	-	-	-	0.002	0.047	0.188	0.235
2004	0.045	-	-	-	0.002	0.047	0.189	0.236
2005	0.051	-	-	-	0.003	0.053	0.213	0.266
2006	0.051	-	-	-	0.003	0.053	0.214	0.267
2007	0.056	-	-	-	0.003	0.059	0.235	0.293
2008	0.063	-	-	-	0.003	0.066	0.264	0.330
2009	0.071	-	-	-	0.004	0.074	0.297	0.372
2010	0.068	0.00002	0.00008	0.00009	0.004	0.072	0.288	0.360
2011	0.070	0.00004	0.00008	0.00008	0.004	0.074	0.295	0.369
2012	0.072	0.00006	0.00008	0.00006	0.004	0.076	0.302	0.378
2013	0.074	0.00022	0.00131	0.00007	0.004	0.079	0.310	0.389
2014	0.075	0.00008	0.00039	0.00007	0.004	0.080	0.318	0.398
2015	0.081	0.00008	0.00039	0.00007	0.004	0.086	0.340	0.426
2016	0.083	0.00008	0.00039	0.00007	0.004	0.088	0.348	0.436
change (2012-2016)	15.3%	33.3%	387.5%	16.7%	15.3%	15.7%	15.3%	15.4%

6.5.4 Wastewater treatment and discharge (4D)

Domestic and industrial water treatment and discharge are sources of methane and nitrous oxide. For domestic wastewater, total population, biological oxygen demand (BOD), type of treatment systems and the amount of protein intake per person per year were the main input data for the estimation of the emissions. IPCC BOD default value of 13.505 kg BOD/person/year was used across the time series. Table 105 illustrates the rising trend of the national population and BOD per person and a decline in the protein intake per person.

Table 105: Trend of population, BOD per/capita and protein intake/capita

Year	Population (million)	Protein intake (kg/person/year)
1990	14.34	31.60
1991	14.71	31.38
1992	15.09	31.16
1993	15.49	30.94
1994	15.89	30.72
1995	16.30	30.50
1996	16.73	31.14
1997	17.16	31.78
1998	17.61	32.42
1999	18.07	33.06
2000	18.91	33.70
2001	19.42	33.10
2002	19.94	32.50
2003	20.48	31.90
2004	21.03	31.30
2005	21.60	30.70
2006	22.19	30.10
2007	22.78	29.50
2008	23.40	28.90

2009	24.03	28.30
2010	24.65	27.70
2011	25.27	27.10
2012	25.90	26.50
2013	26.55	29.30
2014	27.21	29.15
2015	27.89	29.01
2016	28.59	28.87

Centralised, aerobic, septic systems, latrines, sea, river and lake discharge and stagnant sewers were the main domestic treatment and discharge facilities in the country. In 2016, among the five treatment and discharge systems, latrine facility was the commonest among the populace, followed by sea, river and lake discharge, septic systems, centralised aerobic and stagnant sewer facilities (Table 106). For latrine facilities, the fraction of the rural population generally declined from 36.52% in 1990 to 29.34% in 2016 followed by sea, river and lake discharge thus 20.79% in 1990 to 16.44 % in 2016. Dependence by the high urban communities largely was between 7.53% for the septic system, 6.40% for stagnant sewer and 5.75% for centralised aerobic treatment plant with the other systems being the least for 1990 while there was a significant increase for latrine (15.65%) and septic system (9.08%) for 2016. The use of septic systems increased among urban low-income communities (7.04%), stagnant sewer (5.89%) and centralised aerobic system (4.54%) for 1990. There was an increase in the use of latrine (11.48%), septic system (8.24%) and sea, river and lake discharge (3.48%) for 2016. In the rural areas of the country, a significant fraction of the population depends on latrines and sea, river and lake discharge (Table 106).

Table 106: Type of wastewater treatment and discharge facilities

Year	Rural					Urban High					Urban Low				
	Sea, river and lake discharge	Stagnant sewer	Latrine	Septic system	A centralised, aerobic treatment plant	Sea, river and lake discharge	Stagnant sewer	Latrine	Septic system	A centralised, aerobic treatment plant	Sea, river and lake discharge	Stagnant sewer	Latrine	Septic system	A centralised, aerobic treatment plant
1990	20.79	0.71	36.52	2.41	1.56	0.11	6.40	0.53	7.53	5.75	0.06	5.89	0.16	7.04	4.54
1991	20.71	0.69	36.40	2.35	1.48	0.19	6.31	1.02	7.40	5.49	0.23	5.84	0.62	6.79	4.48
1992	20.63	0.67	36.21	2.22	1.38	0.38	6.22	1.98	7.11	5.31	0.51	5.53	1.01	6.54	4.29
1993	20.52	0.65	36.11	2.10	1.30	0.57	5.87	2.34	6.91	5.20	0.62	5.25	2.05	6.29	4.22
1994	20.45	0.63	35.95	1.98	1.25	0.82	5.37	2.73	6.73	5.15	0.73	4.79	3.19	6.04	4.18
1995	20.26	0.61	35.65	1.86	1.21	0.94	5.19	3.69	6.45	4.72	0.84	4.59	4.07	5.79	4.13
1996	20.09	0.59	35.47	1.77	1.18	1.07	4.71	4.93	6.22	4.50	0.97	4.28	4.48	5.65	4.09
1997	19.90	0.52	35.15	1.63	1.09	1.10	4.20	6.52	5.90	4.06	1.03	3.82	6.03	5.36	3.69
1998	19.73	0.48	34.73	1.49	0.98	1.19	3.87	8.10	5.59	3.61	1.12	3.36	7.40	5.08	3.28
1999	19.57	0.45	34.31	1.34	0.86	1.33	3.30	9.88	5.38	3.27	1.22	2.97	8.27	4.87	2.98
2000	19.40	0.41	34.08	1.27	0.75	1.47	3.01	11.19	5.06	2.83	1.35	2.54	9.49	4.58	2.58
2001	19.24	0.34	33.93	1.13	0.69	1.61	2.47	12.77	4.75	2.38	1.48	2.41	10.35	4.30	2.17
2002	19.07	0.28	33.83	0.99	0.63	1.74	1.93	13.98	4.43	2.28	1.60	2.05	11.41	4.01	1.77
2003	18.90	0.22	33.53	0.92	0.57	1.88	1.40	15.26	4.32	1.83	1.73	1.49	12.36	3.93	1.67
2004	18.87	0.16	33.20	0.77	0.44	2.02	0.86	16.47	4.01	1.39	1.85	0.94	14.11	3.65	1.26
2005	18.76	0.11	32.88	0.63	0.32	2.18	0.42	17.55	3.69	0.94	1.98	0.38	15.94	3.36	0.86
2006	18.48	0.13	32.50	0.63	0.29	2.28	0.36	17.36	4.18	0.94	2.07	0.33	15.79	3.80	0.86
2007	18.13	0.15	32.13	0.63	0.25	2.38	0.30	17.24	4.67	0.95	2.16	0.28	15.63	4.25	0.86
2008	17.77	0.16	31.81	0.64	0.22	2.48	0.25	17.05	5.16	0.95	2.26	0.22	15.47	4.69	0.87
2009	17.42	0.18	31.46	0.64	0.18	2.58	0.19	16.86	5.65	0.96	2.35	0.17	15.35	5.14	0.87
2010	17.35	0.20	31.00	0.64	0.15	2.68	0.13	16.61	6.14	0.96	2.44	0.12	15.13	5.58	0.87
2011	17.40	0.22	30.84	0.65	0.13	2.92	0.12	16.56	6.63	0.97	2.62	0.11	13.91	6.02	0.88
2012	17.21	0.24	30.54	0.65	0.12	3.05	0.11	16.38	7.12	0.97	2.73	0.11	13.44	6.47	0.88
2013	17.01	0.25	30.24	0.65	0.10	3.17	0.10	16.20	7.61	0.98	2.84	0.10	12.95	6.91	0.88
2014	16.82	0.27	29.94	0.66	0.08	3.29	0.09	16.02	8.10	0.98	2.95	0.09	12.45	7.36	0.89
2015	16.63	0.29	29.64	0.66	0.07	3.42	0.08	15.84	8.59	0.99	3.07	0.09	11.96	7.80	0.89
2016	16.44	0.31	29.34	0.66	0.05	3.54	0.07	15.65	9.08	0.99	3.18	0.08	11.48	8.24	0.89

Datasets on total industry products, COD and BOD levels, wastewater generated, and the fraction treated for seven main industrial sectors were obtained from the Environmental Management Plans (EMPs) and Environmental performance assessment disclosure reports submitted to the EPA. The Manufacturing Industry Department, EPA collected the reports. In 2016, industry products from Organic chemical industry constituted 58.4% of the industries followed by beer and malt (25%), dairy product (8.2%), meat and poultry (3.4%), Fruit Juice (2.4%), fish processing (2.1%) and Soap and Detergents (0.5%) (Table 107). The decreased percentage change from 2012 and 2016 can be attributed to a decrease in numbers of industries that reported wastewater output for the fish processing and the fruit and juice industries.

Table 107: Total Industry products per manufacturing sectors

Years	Total Industry Output (t/yr)						
	Beer and Malt	Dairy Products	Fish Processing	Meat and Poultry	Organic Chemicals	Soap & Detergent	Fruit & Juice
1990						5,760	
1991						5,721	
1992						3,940	
1993						4,007	
1994						4,041	
1995						3,020	
1996						3,241	
1997						5,000	15,089
1998					15	4,248	15,733
1999					18	4,240	16,865
2000				3,146	22	4,671	15,560
2001		10,882		5,692	21	6,070	19,602
2002		14,128		5,557	173	7,000	22,225
2003		16,465		7,736	174	6,811	22,421
2004		24,002		9,137	3,778	6,746	22,994
2005	93,965	23,973		10,587	3,093	6,080	23,696
2006	106,265	22,045	36,174	12,104	2,425	6,840	25,022
2007	118,565	27,001	31,979	13,644	541,480	4,831	23,948
2008	134,465	28,275	46,677	11,215	539,530	3,020	72,547
2009	146,585	39,701	37,494	11,752	525,181	5,080	52,503
2010	158,765	41,514	42,367	14,772	468,741	6,041	63,088
2011	171,366	35,552	43,542	27,692	501,895	6,000	75,517
2012	194,732	44,613	46,317	20,285	531,457	6,040	86,469
2013	215,699	59,807	33,116	30,724	537,788	6,080	90,752
2014	248,993	75,000	19,915	41,164	704,121	6,120	93,783
2015	291,779	75,000	22,942	41,164	708,151	6,160	29,411
2016	304,721	100,000	25,809	41,164	712,181	6,200	29,782
Change from 2012 -2016	56.5%	124.1%	-44.3%	102.9%	34.0%	2.6%	-65.6%

6.6 Description of notation key and completeness information

Information on completeness and use of notation keys in the waste sector are provided below. Completeness includes gases, categories as well as time series covered in the inventory. Additional information is given on the status of emission estimates of all sub-categories. Emissions of all subcategories of category 4.A (Solid Waste Disposal), 4B (Biological Treatment of Solid Waste), 4C (Incineration and Opening Burning of Solid Waste) and 4D (Wastewater treatment and discharge). Table 108 contains information on the completeness status of the estimations under various sub-categories.

Table 108: Overview of sub-categories of Waste and status of estimations

IPCC Category	Time series completeness								GHG covered		
	1990-2012 (recalculations)				2013-2016 (latest estimates)						
	E	NE	NO	IE	E	NE	NO	IE	CO_2	CH_4	N_20
4.A. - Solid Waste Disposal	x				x				NO	x	NO
4.B– Biological Treatment of Solid Waste	x				x				NO	x	x
4.C1 Incineration	x				x				x	x	x
4.C2 Open Burning	x				x				x	x	x
4.D1 Domestic wastewater treatment and discharge	x				x				NO	x	x
4.D2 Industrial wastewater treatment and discharge	x				x				NO	x	x

E" indicates that emissions from this sub-category have been estimated. "NO" means "Not Occurring."

6.7 Identification of key categories in the waste sector

The methodology and results of the key category analysis in the waste sector are presented in Table 109 below. Methane emissions from solid waste disposal, biological treatment of solid waste and wastewater treatment and discharge were the key categories in terms of trends (1990-2012) while solid waste disposal and wastewater treatment and discharge were key categories in terms of levels (2016) for the waste sector.

Table 109: Results of the key category analyses of the Waste sector

IPCC Category code	IPCC Category	Greenhouse gas	Key Source Assessment (Level Assessment – LA - 2016)	Key Source Assessment Trend Assessment (TA)(1990-2016)
4.A	Solid Waste Disposal	CH_4	2016	TA
4.B	Biological Treatment of Solid Waste	CH_4	-	TA
4.D	Wastewater Treatment and Discharge	CH_4	2016	TA

The levels of methane emissions from solid waste disposal and wastewater treatment and discharge were as a result of the following: rising population especially in the major cities, increase in efficiency of waste collection, disposal and treatment, no methane recovery in the landfills, poor state of existing treatment systems and discharge pathways.

6.8 Efforts to ensure time-series consistency in the waste sector

6.8.1 Recalculations in the waste sector

Recalculations have been done for the waste sector mainly due to changes in some activity data as a result of (a) methodological approach for solid waste disposal (4A) subsection due to the use of the first-order decay method (i.e. recalculation was done from 1950 instead of 1990) (b) identification and use of new datasets (c) filling of time series data gaps with national and international data sources (d) refinement in the use of expert judgments and (e) comments from the IPCC expert review of previous inventory. Detailed information on the descriptions of the reasons for and impacts of the recalculations have been provided under each category. The result of the assessment of recalculation and its impacts are in Table 110.

Table 110: Assessment of the impacts of recalculation on the previous estimates in $MtCO_2e$

Year	CO_2			CH_4			N_2O		
	PE	LE	% Change	PE	LE	% Change	PE	LE	% Change
1990	5.09	2.97	-41.65	969.91	659.95	-31.96	330.24	355.05	7.51
1991	5.12	3.03	-40.89	1022.22	677.85	-33.69	336.48	360.75	7.21
1992	5.13	3.07	-40.17	1136.69	643.29	-43.41	342.78	366.50	6.92
1993	5.14	3.12	-39.33	1194.95	686.36	-42.56	349.19	372.32	6.62
1994	5.14	3.17	-38.39	1300.25	715.47	-44.97	355.68	373.54	5.02
1995	5.14	3.22	-37.42	1367.01	764.47	-44.08	362.20	384.36	6.12
1996	5.05	3.25	-35.59	1469.89	795.91	-45.85	378.54	396.55	4.76
1997	4.95	3.29	-33.56	1548.40	842.32	-45.60	403.02	418.71	3.89
1998	4.83	3.32	-31.17	1650.77	889.66	-46.11	412.94	426.27	3.23
1999	4.70	3.36	-28.51	1735.72	940.99	-45.79	428.49	443.18	3.43
2000	4.57	3.46	-24.23	1837.94	1001.82	-45.49	449.35	470.23	4.65
2001	4.63	3.54	-23.45	1993.14	1031.68	-48.24	452.37	474.32	4.85
2002	4.72	3.62	-23.32	2081.10	1064.99	-48.83	463.67	478.59	3.22
2003	4.77	3.70	-22.44	2209.81	1100.81	-50.19	458.37	482.36	5.23
2004	4.87	3.78	-22.35	2323.25	1141.75	-50.86	461.10	485.97	5.39
2005	4.86	3.35	-31.10	2474.16	1205.30	-51.28	463.53	493.40	6.44
2006	4.96	4.44	-10.39	2595.65	1280.66	-50.66	466.05	496.80	6.60
2007	4.64	4.98	7.22	3171.12	1811.07	-42.89	467.08	499.56	6.95
2008	4.28	5.50	28.59	3331.27	1904.30	-42.84	467.69	503.16	7.58
2009	3.87	6.13	58.32	3481.34	1973.12	-43.32	468.17	506.83	8.26
2010	3.48	7.20	106.77	3755.19	2015.97	-46.32	479.96	505.07	5.23
2011	3.57	7.34	105.51	3955.98	2138.53	-45.94	486.66	507.31	4.24
2012	3.96	7.18	81.28	4021.87	2190.70	-45.53	489.82	509.40	4.00

Reasons for recalculations

Recalculations led to the revision of the previous activity data and emission factors, the addition of new datasets and application of new methodologies and explains the changes in the emissions illustrated in Table 111.

Table 111: Reasons for recalculations according to gases

Gases	Data in category	Reasons behind recalculations
Carbon Dioxide	Incineration (total solid waste incinerated)	• Introduction of a new dataset on a fraction of total solid waste, waste oil, clinical and hazardous waste incinerated from 2010-2016 due to discovery of new data from the Private Sector

	Open burning (total solid waste burnt)	• Introduction of new dataset due to the change in per capita waste generation rate from 1990-2016.
Methane	Solid waste disposal	• Methodological approach for solid waste disposal (4A) subsection due to the use of the first-order decay method (i.e. recalculation was done from 1950 instead of 1990). • Changes activity data (total municipal solid waste generation) due to the revision of per capita waste generation. Use of national representative generation rates instead of urban generation rates forms the country.
	Domestic and Industrial wastewater treatment and discharge	• New data set on the classification of systems for domestic liquid waste • Addition of new data from 1990-2016 due to revision of industrial output and the increase of sectors from 5 to 7.
	Biological treatment of solid waste (total solid waste composted)	• Introduction of a new dataset on the fraction of total solid waste composted from 1990-2016 due to discovery of new data based on data from the abandoned Teshie Nungua Compost Plant, Accra Compost and Recycling Treatment Plant and expert judgment of estimation of household composting.
	Incineration (total solid waste incinerated)	• Introduction of a new dataset on a fraction of total solid waste, waste oil, clinical and hazardous waste incinerated from 2010-2016 due to discovery of new data from the Private Sector
	Open burning (total solid waste burnt)	• Introduction of new dataset due to the change in per capita waste generation rate from 1990-2016.
Nitrous Oxide	Biological treatment of solid waste (total solid waste composted)	• Introduction of a new dataset on the fraction of total solid waste composted from 1990-2016 due to discovery of new data based on data from the abandoned Teshie Nungua Compost Plant, Zoomlion ACAP Treatment Plant and expert judgment of estimation of household composting.
	Incineration (total solid waste incinerated)	• Introduction of a new dataset on a fraction of total solid waste, waste oil, clinical and hazardous waste incinerated from 2010-2016 due to discovery of new data from the Private Sector
	Open burning (total solid waste burnt)	• Introduction of new dataset due to the change in per capita waste generation rate from 1990-2016.
	Domestic and Industrial wastewater treatment and discharge	• New data set on the classification of systems for domestic liquid waste • Addition of new data from 1990-2016 due to revision of industrial output and the increase of sectors from 5 to 7.

6.8.2 Filling of data gaps

The data gaps that were identified in the inventory were filled by adopting the appropriate IPCC methodology for filling such gaps. The specific methods used in filling the gaps were selected based on the type of the data and nature of the gaps. Table 112 presents the data gaps and how they were filled.

Table 112: Data gaps and the methods

Category	Data Gap	Method applied	Justification for the methodology used	Description of approach for filling of gaps
Solid Waste Disposal (4A)	Missing data of annual per capita solid waste generation 1950-1989, 1990-2004, 2006-2014, 2016	Trend extrapolation and interpolation	National sources, literature or study reports.	The annual per capita solid waste generation was derived from the difference between two known and divided by the number of interval years. The annual average difference was

				applied to the preceding known figure to generate the missing annual data.
Biological treatment of Solid waste (4B)	Missing data on amount composted from 1990-1993	extrapolation	literature or study reports	Based on the available 1990 and 1993 of plant data
Wastewater discharge and treatment (4D)	Missing data income class which was derived from urban and rural population classification for 1990-1995, 1997-2004, 2006-2009 and 2011-2016 Missing data on industry wastewater output on beer and malt, dairy, fish meat and poultry and organic chemicals	Interpolation and extrapolation	Urban and rural population share was obtained from the Ghana Statistical Service for 1990, and 2010 and classification of systems was obtained from MICs 1996, 2005 and 2010 EPRD reports	Based on the available 1990 and 2010 urban, rural population share, the interpolation factor was derived by finding the difference between the share for 1990 and 2010 and dividing by the difference between 1990 and 2010.
	Distribution of the share of the population in different income classes using different waste treatment facilities for 1990-1995, 1997-2004, 2006-2009 and 2011-2016	Interpolation	Data on the population using different treatment systems classification were obtained from MICs 1996, 2005 and 2010	The fraction of the population using a different treatment system was derived given year in the time series. For each given in the year, interpolation was made using average interpolation factor. The factor derived from the difference between the two known years and divided by the difference in the intervening years.

6.9 Quality Control/Quality Assurance in the Waste sector

The QA/QC procedures that were followed in the Waste sector are detailed out in Table 113.

Table 113: QA/QC procedures implemented in the Waste Sector

Data Type	QA/QC procedure	Remarks/Comment/Examples
Activity data check	Check for transcription, typographical errors and error transposition.	Division of task among the inventory team to ensure that one or two members of the team always focus on double-checking and ensure that data errors associated with those described in the left column are avoided.
	Comparison with published data/literature	Data on per capita solid waste generation, the fraction of waste composited and incinerated were cross-checked with published figures from the Ghana Statistical Services, different local governments and industry.
	Consistency checks of categories and subcategories with the totals.	Ensuring that disaggregated figures at the category and subcategories levels add up to the overall totals.
	Identify and fix outliers in data inputs (including checking for dips and spikes in the trend).	Data that deviate unrealistically from the trends and spikes beyond ranges are suspected as inaccurate and replaced with a figure using expert judgment.

	Documentation of all data sources, data format and assumptions for easy reference	A record of all data, their sources and assumptions made in admitting the data used were kept and helped in easy cross-referencing.
	Ensure reduction in data clumsiness or data redundancy.	Logical sequence data flow according to the IPCC methodology for the GHG emission estimation was designed for: • easy understanding and further probing of the results in the IPCC software. • easy cross-referencing and avoidance of mistakes, • easy transmission into the IPCC software. • aid in better interpretation of the implication of the use of the data.
Calculation by the approved 2006 IPCC software	Cross-check all steps involved in the calculation.	Ensure that steps used for determining, estimating and deriving data are accurate, transparent and internally consistent.
	Documentation of sources and correct use of units.	Use of the documentation template records for all data sources and assumptions.
	Check for transcription, typographical errors and error transposition.	Check mistakes and blunders in the data entered into the software.
	Checked completeness of data coverage.	Ensuring all the relevant gases for the specific activity were covered.
Results (emissions)	Check for recalculation differences.	To identify and pinpoint changes, revision and reallocation to improve the accuracy and transparency of the estimates.
	Identify and fix outliers in the results.	Check for dips and spikes in trends and levels.
Documentation	Assumptions, corrections, data and sources.	Ensure consistency, transparency, facilitate repeatability and easy retrieval.
	Improvement list (internal and external findings).	Help prioritise areas that require actions.

6.10 Waste sector emission trends

In 2016, total emissions from the waste sector were 3.17 $MtCO_2e$ which represents an increase of 14.6% from the 1990 levels. The total emissions from the sector recorded a consistent rise from 1.02 $MtCO_2e$ in 1990 to 1.48 $MtCO_2e$ in 2000 and further to 3.17 $MtCO_2e$ in 2016 (Figure 84). The observed changes in the emission trend corresponded to the rising emissions from wastewater treatment and discharge as well as solid waste disposal. In the waste sector, wastewater treatment and discharge (4D) contributed the most significant emissions making up 57.98% of the total emissions in 2016. The observed spike in 2007 and the sustained increasing rate onwards is driven by the changes emissions associated with wastewater discharge and followed by solid waste disposal (36.47%), biological treatment of solid waste (3.06%) and incineration and open burning of waste (2.49%) (Figure 84).

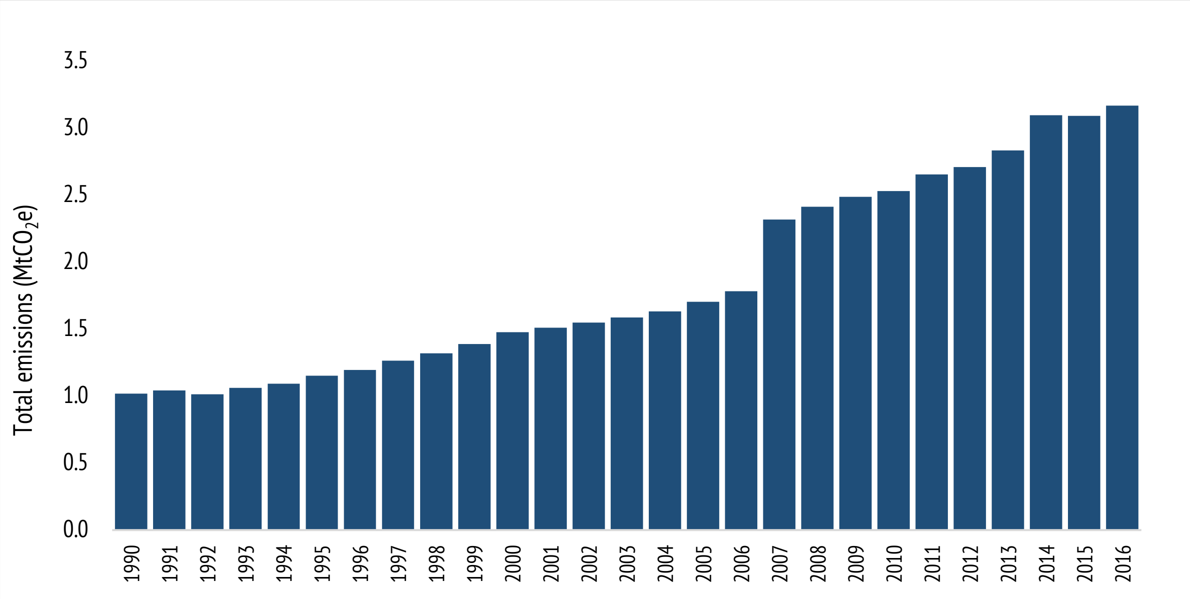


Figure 84: Total emission trends in the waste sector

In 2016, the total emissions of 3.17 $MtCO_2e$ represented an increase of 211.17% and 114.68% above the 1990 and 2000 levels. The trend is attributed to the following factors:

- rising domestic and industrial wastewater generation because of increasing population and expansion of industrial production.
    - inadequate wastewater treatment facilities
- a significant amount of untreated wastewater, particularly from households.

Emissions from solid waste disposal recorded similar trends rising steadily from 0.26 $MtCO_2e$ in 1990 to 0.48 $MtCO_2e$ in 2000 and 1.16 $MtCO_2e$ in 2016 (Figure 85). The observed emissions trends can be attributed to the growing population, changing lifestyles due to improving socio-economic conditions in the country particularly in the large cities, increased fraction of solid waste deposited on solid waste disposal sites and non-existing landfill management programmes in the country. Particularly, the increase in slum conditions in the major cities also accounts for the indiscriminate disposal of solid waste. The rest of the waste sector emissions came from biological treatment of solid waste (composting) and incineration and open burning. The emissions from biological treatment of solid waste, incineration and opening burning all recorded increases.

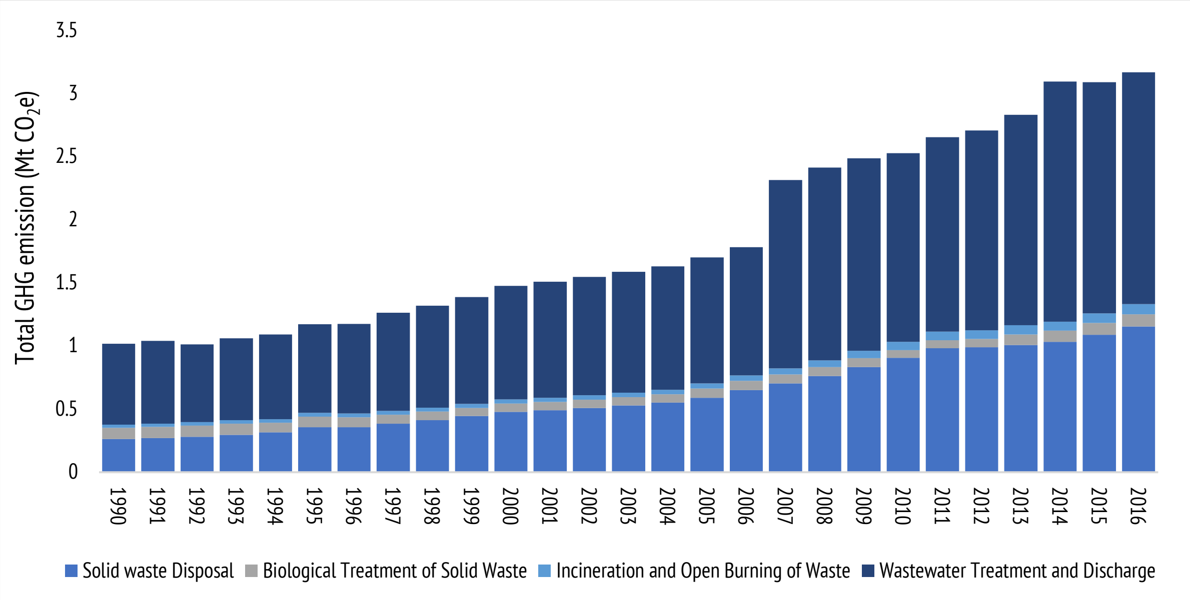


Figure 85: Total emissions trend according to sub-categories in the Waste sector

Methane was the most important gas in the waste sector. It constituted 80.81% of the total emissions from the waste sector in 2016 (Table 114). Within the waste sector, solid waste disposal was the dominant source of methane (59.64%), followed by wastewater treatment and discharge (4D) (34.73%). 2.98% was emitted from incineration and opening (4C) and 2.65% from biological treatment of solid waste (4B) in 2016. Nitrous oxide emission was the next important greenhouse gas making up 18.92% of the total emissions from the waste sector. Wastewater treatment and discharge (4D) accounted for the most nitrous oxide emissions making up 90.33% of the total nitrous oxide emission in the waste sector in 2016 (Table 114). The rest of the waste sector emission was carbon dioxide accounting for 0.27% of the total waste sector emissions.

Table 114: Waste sector emission according to gases

Year	CO_2	CH_4 ($GgCO_2e$)					N_2O ($GgCO_2e$)			
	4C	4A	4B	4C	4D	Total	4B	4C	4D	Total
1990	2.97	263.65	46.93	18.24	331.09	659.91	41.57	4.37	309.12	355.05
1991	3.03	270.40	46.68	18.71	342.02	677.82	41.35	4.46	314.95	360.75
1992	3.07	282.04	46.40	19.19	295.64	643.26	41.09	4.54	320.87	366.50
1993	3.12	297.28	46.07	19.68	323.32	686.34	40.80	4.63	326.89	372.32
1994	3.17	315.30	40.44	20.18	339.53	715.45	35.82	4.72	333.00	373.54
1995	3.22	355.58	45.58	20.70	362.58	784.45	40.37	4.77	339.21	384.36
1996	3.25	357.85	41.01	21.23	375.81	795.89	36.32	4.89	335.34	376.55
1997	3.29	383.88	38.59	21.77	395.68	839.91	34.18	4.97	379.56	418.71
1998	3.32	413.07	35.88	22.32	415.86	887.14	31.78	5.06	389.43	426.27
1999	3.36	444.88	34.55	22.89	435.98	938.29	30.60	5.14	407.44	443.18
2000	3.46	479.11	34.14	23.94	461.87	999.06	30.24	5.33	434.66	470.23
2001	3.54	491.99	34.34	24.58	476.83	1027.73	30.41	5.46	438.45	474.32
2002	3.62	508.80	34.86	25.24	491.51	1060.41	30.88	5.59	442.13	478.59
2003	3.70	528.79	34.94	25.92	506.31	1095.97	30.95	5.72	445.68	482.36
2004	3.78	550.86	35.00	26.61	520.96	1133.43	31.00	5.86	449.11	485.97
2005	3.35	589.12	38.68	30.74	536.09	1194.63	34.26	6.75	452.39	493.40
2006	4.44	650.17	38.80	31.57	551.19	1271.72	34.36	6.91	455.53	496.80
2007	4.98	703.00	37.60	35.50	566.81	1342.91	33.30	7.75	458.50	499.56
2008	5.50	761.73	37.59	39.11	582.82	1421.24	33.29	8.56	461.30	503.16

2009	6.13	832.76	37.69	43.42	599.00	1512.87	33.38	9.52	463.92	506.83
2010	7.20	906.97	32.61	47.85	613.33	1600.76	28.88	10.35	465.84	505.07
2011	7.34	983.70	33.43	48.82	627.04	1692.98	29.61	10.57	467.14	507.31
2012	7.18	990.57	34.26	50.04	642.17	1717.04	30.34	10.83	468.22	509.40
2013	9.11	1008.74	44.23	51.29	657.18	1761.44	39.17	11.14	530.64	580.95
2014	7.97	1034.40	46.01	52.57	672.76	1805.74	40.75	11.39	541.12	593.25
2015	8.48	1088.89	49.50	56.28	672.76	1867.43	43.84	12.19	541.12	597.15
2016	8.68	1155.21	51.37	57.70	672.76	1937.04	45.57	12.37	541.12	599.06

6.11 Summary description of source-specific categories emission trends

6.11.1 Solid waste disposal (4A)

Key category: CH_4 emissions (TA, 2016)

Methane emission from solid waste disposal is estimated based on the amounts and compositions of the waste disposed into SWDS and the waste management practices at the disposal sites. The nature of the management practice at the final solid waste disposal site determines aerobic conditions which produce methane. Solid waste is disposed-off and treated by unmanaged sites (dump sites) and few managed sites (landfills). Over the years, it has been observed that the amount of waste deposited keeps increasing due to the increase in waste generated, which is influenced by population increase. The fraction of solid waste collected for deposition at solid waste disposal sites has also increased. As of 2016, there were five operational engineered sanitary landfills as well as 172 official dumpsites in the country. Most of the disposal sites in the country are unmanaged with and well-engineered landfills are normally overloaded and not properly managed. Currently, most of the disposal sites are unmanaged dumpsites and only four well-engineered landfills, but these are not properly managed sites.

The total of 4.91Mt of MSW generated in 2016 represented 57%, 44% and 13% higher than the 1990 (base year), 2000 and 2012 MSW respectively. Similarly, the fraction of MSW collected and deposited for the period 1990-2016 increased from 36% in 1990, to 60% in 2000 and 80% in 2012 to 2016. From figure 86, the amount deposited at the SWDS increased from 0.75 Mt in 1990 to 1.66 Mt in 2000, 3.4 Mt in 2012 to 3.93 Mt in 2016. The increasing trend in waste collection and disposal in Ghana is due to a policy shift in public-private partnership arrangements (private sector collects about 80% of municipal solid waste generated in the urban suburbs. For instance, for a typical local government authority that manages a metropolis, it may decide to award franchises to different Environmental Sanitation Service Providers to collect waste from households and maybe market and transport them to a designated dumpsite. In the past, most of the dumpsites were managed by local assemblies, but in recent times, there is a shift to allow private companies to either manage the dump sites on behalf of the assemblies or even private companies are permitted to construct and manage their dump sites). Notwithstanding the increase in the waste collection, there has not been any policy introduced to ensure the collection of methane from the final disposal sites.

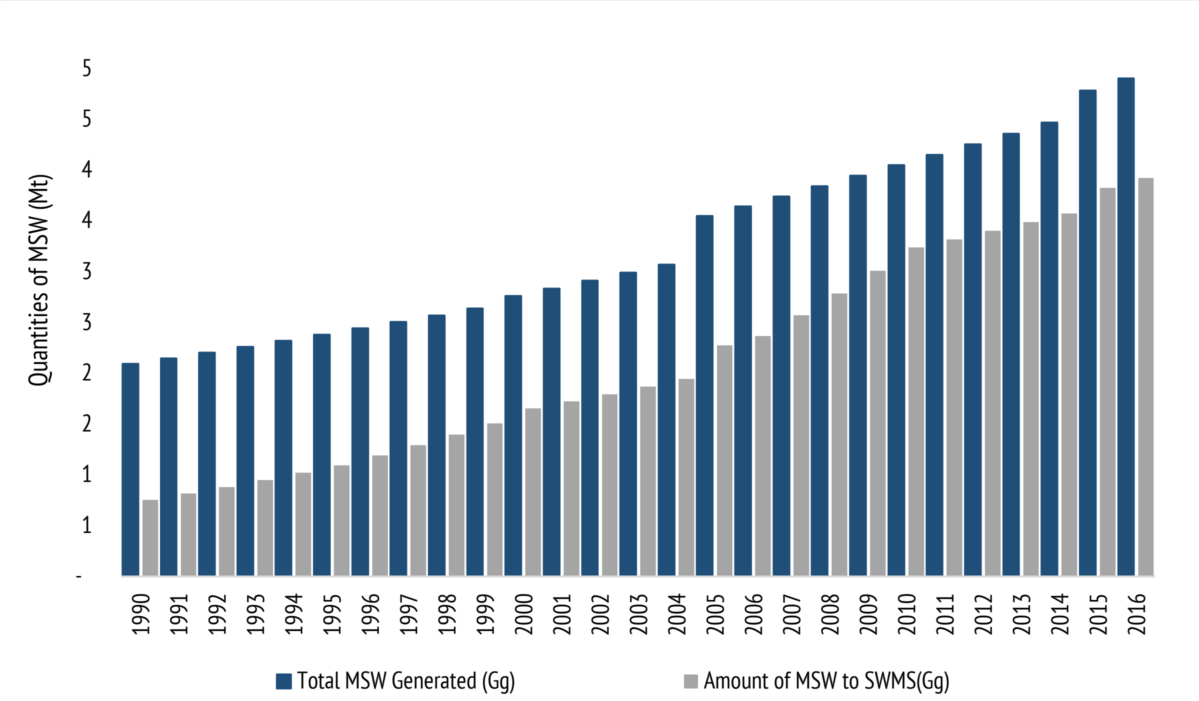


Figure 86: Comparison of the trend of total MSW generation and fraction of deposited

Between 1990 and 2016, the country had three distinctive waste streams, and these can be grouped under 1990-1999, 2000-2010 and 2011-2016. Food waste dominated the waste stream in the country constituting about 73% in 1990-1999, reduced to 60% in 2000 to 2010 and finally to 47% in 2011-2016. The fraction of paper also increased from 7%, 8% to 9% in 1990-1999, 2000 to 2010 and 2011-2016 respectively. The trends for the different streams of MSW sent to SWDS are shown in figure 87. The increasing MSW generation and fractions deposited at SWDS translated to similar patterns of CH_4 emissions for the solid waste disposal category (4A). Figure 82 below shows the CH_4 emissions trend for the period 1990-2016.

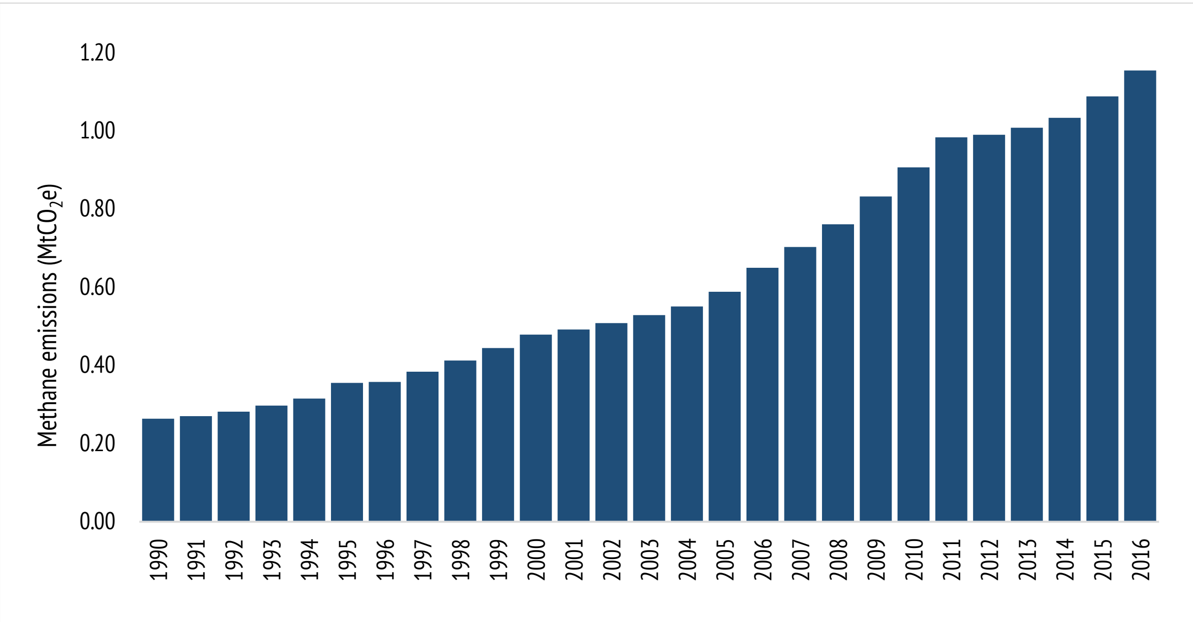


Figure 87: Total emission trends from solid waste disposal

It was observed that CH_4 emissions increased with the amount of waste collected and disposed throughout for the period 1990-2016. The increasing trend in the amount of waste disposed at SWDS reiterates the afore-mentioned policy shift, over the years, in solid waste service provision from central government to sole provision by local governments and now the involvement of the private sector in the country. Historically, in the early 1990s, there was a policy shift towards private sector-led development; this led to contracting out and franchising the solid waste collection services to the private sector in Accra and Tema. In 1995 Private sector involvement in solid waste services in four of the selected cities (Tema, Takoradi, Kumasi, Tamale) was supported as a component of Urban Environmental Sanitation Project (UESP-World Bank funded), the private sector was to collect 40% of waste, and in 1999 a policy change in public-private partnerships arrangements where the private sector was to collect 80% of waste. The shift helped to increase the amount of waste collected and deposited for treatment on landfill sites. Although the policy that allowed private sector participation yielded some level of efficiency in waste collection and disposal, not much has been done to improve management of waste disposal sites. Also, the existing policy does not offer clarity on landfill gas management.

6.11.1.1 Methodological issues in the solid waste disposal

The key parameters used in calculating the emission were (a) the amount of MSW generated (b) fraction of MSW deposited according to streams at the various sites and the amount of methane recovered at these sites over the years. The total amount of MSW generated was obtained from the products of the annual national population trend and per capita solid waste generation. The national population data were obtained from the national population census for 1984, 2000 and 2010. The population for the intervening years were derived from using the inter-census population growth rate published by the Ghana Statistical Service. From various studies and consultation with the waste management departments of some major MMDAs various solid waste generation rates for some specific years were obtained. The waste generation rates for other years were interpolated or were based on expert judgments (Table 115). After the estimation of the amount of waste generated, the waste deposited was calculated with the various percentage estimates from each year. The fraction of MSW collected and deposited were obtained from national experts from Accra and Tema Metropolitan Assemblies, Zoomlion Ghana Limited and the data published in the Ghana Living Standard Survey (2008).

Table 115: Overview of the amount of waste collected and deposited

Year	Population (Mil)	Waste per Capita (kg/cap/year)	Total MSW Generated (Gg)	% of MSW to SWDS	Amount of MSW to SWMS(Gg)
1990	14.34	146.00	2,094.13	36.0%	753.89
1991	14.72	146.00	2,148.58	38.0%	816.46
1992	15.10	146.00	2,204.44	40.0%	81.78
1993	15.49	146.00	2,261.76	42.0%	949.94
1994	15.89	146.00	2,320.56	44.0%	1,021.05
1995	16.31	146.00	2,380.90	46.0%	1,095.21
1996	16.73	146.00	2,442.80	48.8%	1,192.09
1997	17.17	146.00	2,506.31	51.6%	1,293.26
1998	17.61	146.00	2,571.48	54.4%	1,398.88
1999	18.07	146.00	2,638.34	57.2%	1,509.13
2000	18.91	146.00	2,761.16	60.0%	1,656.70

2001	19.42	146.00	2,835.71	60.8%	1,724.97
2002	19.95	146.00	2,912.28	61.7%	1,795.71
2003	20.49	146.00	2,990.91	62.5%	1,869.29
2004	21.04	146.00	3,071.67	63.3%	1,945.29
2005	21.61	164.25	3,548.93	64.2%	2,277.20
2006	22.19	164.25	3,644.75	65.0%	2,369.09
2007	22.79	164.25	3,743.15	68.8%	2,573.42
2008	23.40	164.25	3,844.22	72.5%	2,787.06
2009	24.04	164.25	3,948.01	76.3%	3,010.36
2010	24.66	164.25	4,050.21	80.0%	3,240.17
2011	25.28	164.25	4,151.47	80.0%	3,321.17
2012	25.91	164.25	4,255.25	80.0%	3,404.20
2013	26.55	164.25	4,361.63	80.0%	3,489.31
2014	27.22	164.25	4,470.68	80.0%	3,576.54
2015	27.90	171.55	4,786.11	80.0%	3,828.89
2016	28.60	171.55	4,905.76	80.0%	3,924.61

Methane recovery does not occur at any of the landfill sites in Ghana. Methane recovery was therefore assumed to be zero throughout the time series. The composition of waste available for Ghana was normally for the total municipal waste. The general composition of municipal waste in the country is shown in Table 116. The composition of waste in Ghana was predominantly made of biodegradable materials and a high percentage of inert materials as well. The inert material was mostly made of wood ash, sand and charcoal. The food waste ranges from 73-47%, paper from 7-9%, textile 2-8%, plastics 3-17% and others 15-20% for the various waste streams. Most of the garden and wood waste were combined with food waste, and nappies are included in other waste. It should be noted that the composition of waste streams of what was generated is similar if different from what was deposited.

Table 116: Waste composition deposited at SWD Sites

Food	Garden	Paper	Wood	Textile	Nappies	Plastics	Others	Total
(73%,60%,47%)	IE	(7%,8%,9%)	IE	(2%, 4%,8%)	IE	(3%,8%, 17%)	(19%, 20%,15%)	Waste (Gg)
550.337	IE	52.772	IE	15.078	IE	22.617	113.083	753.887
596.015	IE	57.152	IE	16.329	IE	24.494	122.469	816.460
643.697	IE	61.724	IE	17.636	IE	26.453	132.266	881.776
693.454	IE	66.496	IE	18.999	IE	28.498	142.491	949.938
745.365	IE	71.473	IE	20.421	IE	30.631	153.157	1021.047
799.505	IE	76.665	IE	21.904	IE	32.856	164.282	1095.212
870.223	IE	83.446	IE	23.842	IE	35.763	178.813	1192.086
944.078	IE	90.528	IE	25.865	IE	38.798	193.989	1293.257
1021.185	IE	97.922	IE	27.978	IE	41.967	209.833	1398.883
1101.663	IE	105.639	IE	30.183	IE	45.274	226.369	1509.128
994.019	IE	132.536	IE	66.268	IE	132.536	331.340	1656.698
1034.979	IE	137.997	IE	68.999	IE	137.997	344.993	1724.965
1077.427	IE	143.657	IE	71.828	IE	143.657	359.142	1795.711

1121.574	IE	149.543	IE	74.772	IE	149.543	373.858	1869.289
1167.171	IE	155.623	IE	77.811	IE	155.623	389.057	1945.286
1366.322	IE	182.176	IE	91.088	IE	182.176	455.441	2277.203
1421.451	IE	189.527	IE	94.763	IE	189.527	473.817	2369.085
1544.051	IE	205.873	IE	102.937	IE	205.873	514.684	2573.419
1672.236	IE	222.965	IE	111.482	IE	222.965	557.412	2787.059
1806.216	IE	240.829	IE	120.414	IE	240.829	602.072	3010.360
1944.102	IE	259.214	IE	129.607	IE	259.214	648.034	3240.169
1560.952	IE	298.906	IE	265.694	IE	564.600	631.023	3321.174
1599.975	IE	306.378	IE	272.336	IE	578.714	646.799	3404.203
1639.975	IE	314.038	IE	279.145	IE	593.182	662.969	3489.308
1680.974	IE	321.889	IE	286.123	IE	608.012	679.543	3576.541
1799.576	IE	344.600	IE	306.311	IE	650.911	727.488	3828.886
1844.566	IE	353.215	IE	313.969	IE	667.183	745.675	3924.608

In estimating the methane emissions from the various disposal sites, the “tier 2” methodology based on national data on waste quantities, composition, properties and disposal practices was used. The first-order decay (FOD) methodology for calculating the methane generation was used. This method assumes that the degradable organic component (degradable organic carbon, DOC) in waste decays slowly throughout a few decades, during which CH_4 and CO_2 are formed. Due to the use of the FOD methodology for calculating the methane generation waste deposited at the SWDS was estimated from 1950 to 1990. Only the methane remaining after subtraction of methane recovered is available for oxidation. In Ghana’s case, there was no methane recovery.

In the generation of the methane by the guidelines, the FOD model is built on an exponential factor that describes the fraction of degradable material which each year is degraded into CH_4 and CO_2. One key input in the model is the amount of degradable organic matter (DOCm) in waste disposed into SWDS. The estimation is based on information on disposal of different waste categories (MSW, industrial and other waste) and the different waste types/material (food, paper, wood, textiles) included in these categories, or as mean DOC in bulk waste disposed of in various treatment facilities. Information is also needed on the types of SWDS in the country and the parameters. With “tiers 2” some country-specific activity data and country-specific parameters were used. The CH_4 potential that is generated throughout the years was estimated based on the amounts and composition of the waste disposed into SWDS and the waste management practices at the disposal sites. The simple FOD spreadsheet model was used in the estimation of the methane.

6.11.1.2 Choice of emission factors and parameters

Degradable Organic Carbon (DOC) is the organic carbon in waste that is available for biochemical decomposition and is expressed as Gg C per Gg waste. The DOC in bulk waste is estimated using the waste compositions. It is calculated from a weighted average of the degradable carbon content of various components (waste types/material) of the waste stream. The DOC default values in the IPCC 2006 guidelines were used in this inventory due to the lack of country-specific data. Despite the lack of country-specific DOC factor, Ghana is allowed to use the IPCC default figures even though it is not the most desired option. The strategy is to encourage the research community to start considering undertaking relevant studies in this area.

The fraction of degradable organic carbon which decomposes (DOCf) is an estimate of the fraction of carbon that is ultimately degraded and released from SWDS and reflects the fact that some degradable organic carbon does not degrade, or degrades very slowly, under anaerobic conditions in the SWDS. The recommended IPCC default value for West Africa by weight fraction on a wet basis, which is dissimilated 0.5 (DOCf of 0.5) was used. The methane generation rate constant (k) for the Moist and Wet Tropical region (regions with temperatures greater than 20°C) for the IPCC default range was used. Also, the IPCC default values for the MSW were used as the Methane Correction Factors (MCF). Other IPCC default values that were used for the estimation includes; (a) 6 months delay time; that is the average time before anaerobic decay begins, (b) fraction of Methane (F) in developed gas as 0.5, (c) convection factor C to CH_4 of 1.33 and (d) oxidation Factor (ox) of zero (0).

6.11.2 Biological treatment of solid waste (4B)

Key category: CH_4 emissions (TA, 2016)

Composting is the major biological treatment of solid waste in Ghana. Methane and Nitrous oxide is the key emission sources from the biological treatment of solid waste through composting. In the past, composting was mostly practised in the form of back-yard farming in urban households. However, in recent times treatment of solid waste through composting has declined for the following reasons: a) space; b) market for the product c) lack of policy direction on composting. The historical trend on PPPs has resulted in the participation of the private sector in the compost market. For example, the establishment of the Accra Compost and Recycling Plant (ACARP) by Zoomlion Ghana Limited in 2012 and the partnership venture between CHF International and Jekora Ventures has increased composting in Ghana. From Figure 88, the trends for solid waste composted was high from 1900 to 1994 when the Teshie-Nungua composting plant was operational and started dropping when the plant broke down. The amount of solid waste composted rose again in 2012-2013 when the ACARP was commissioned and started operations. In 2016, the total amount of solid waste composted amounted to 0.17 Mt, representing an increase of 30% above both 2012 and 2000, respectively (Figure 88).

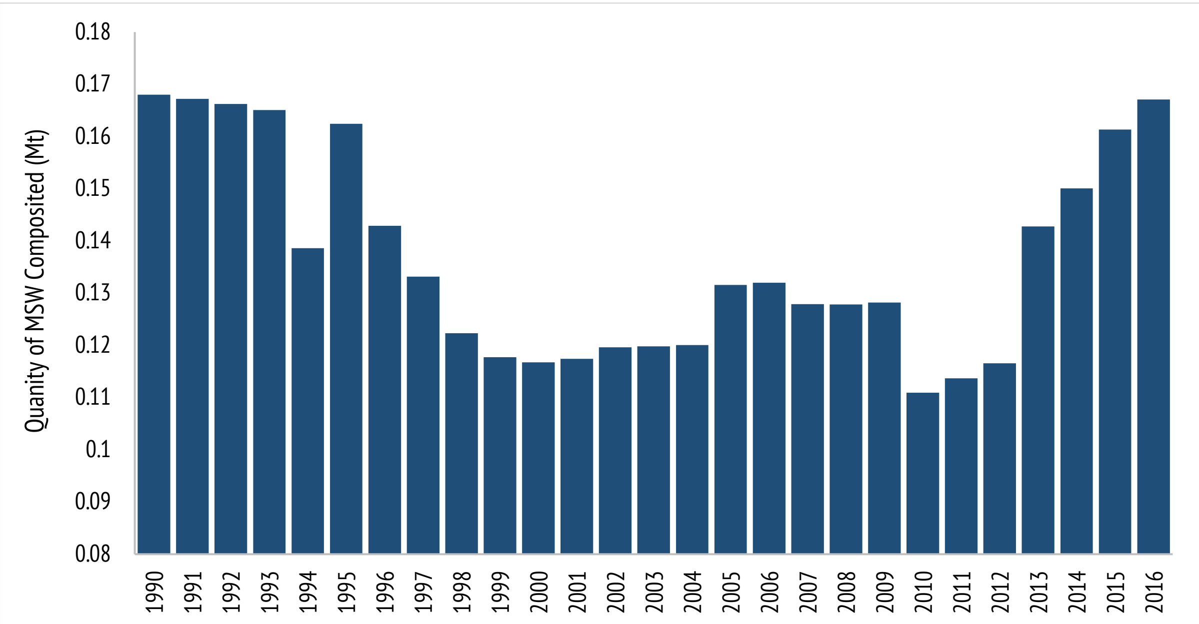


Figure 88: Trend of the fraction of MSW composted

The figure translates into total GHG emissions of 0.097 $MtCO_2e$ in 2016. This is 0.032 $MtCO_2e$ higher than 2012 levels and 0.033 $MtCO_2e$ above 2000 emissions (Figure 89). The observed increases in emissions from composting could be explained by the introduction of the ACAP commercial composting facility from the private sector.

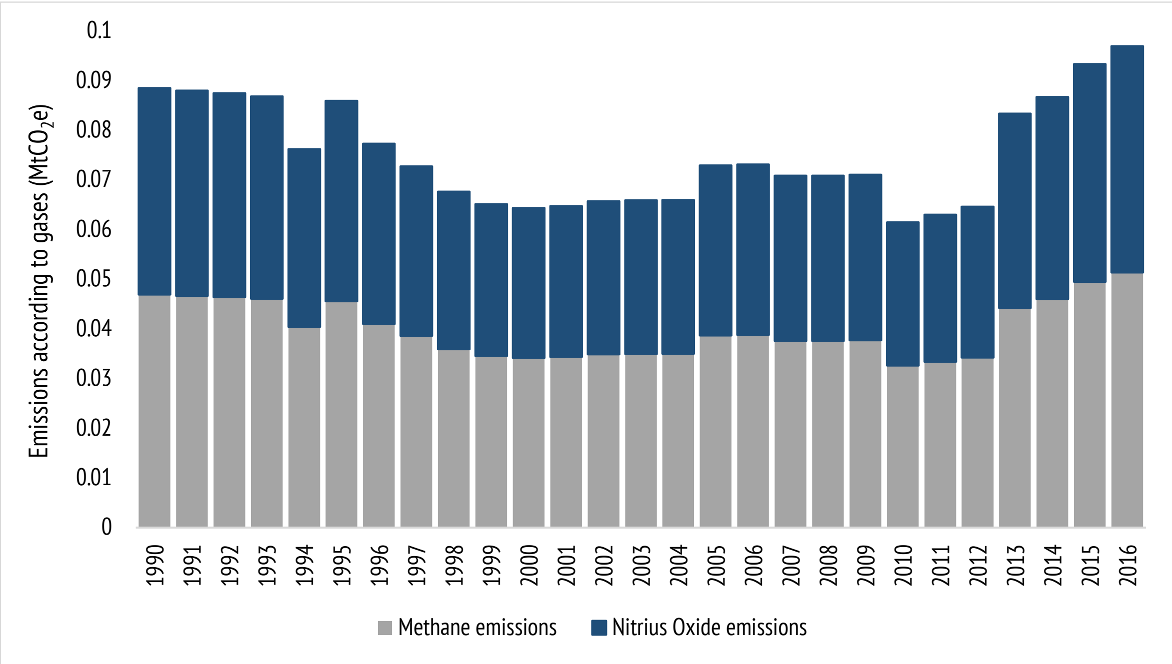


Figure 89: Trend of emissions from biological treatment of waste

6.11.2.1 Methodological choices in biological treatment of solid waste

The main data input is the amount of waste composted in Ghana and technology. The input data were derived from the fraction of solid waste treated. Although the amount of solid waste treated through composting although was derived as a fraction of solid waste treated and the data was compared with the actual existing operating composting capacity in the country provided by Zoomlion Ghana Limited. Extra data were sourced from Ghana Statistical Service and other literature for household composting and the decommissioned Teshie-Nungua compost plant.

6.11.3 Incineration and open burning (4C)

In Ghana, a fraction of MSW, industrial waste, hazardous waste, waste oil and clinical waste accounts for the proportions of wastes that are treated and disposed of through incineration. It consists of a mix of combustible and non-combustible materials, such as paper, plastics, food waste, glass, wood and other hazardous materials. Wastes from healthcare or medical facilities are also incinerated. Most senior high schools have installed incinerators to treat (controlled burning) and reduce volumes of municipal waste generated in these institutions. Furthermore, a large portion of the incinerators has been installed across the country in almost all District, and Regional as well as Teaching Hospitals. Few manufacturing companies incinerate their waste generated onsite to meet regulatory standards but hardly keep records on the volumes incinerated. It is also important to state that these incinerator plants are of small capacities hence supplied in batches in small quantities and accounted for increases in the frequency of start-up of these incinerators.

These incinerators are operated with the sole aim of converting waste materials into ash. Also, it is important to add that from 2010, large scale incineration plants were set up to treat industrial waste, hazardous waste and waste oil. These incineration facilities, Zeal Environmental Technologies Limited and Zoil Services Limited, were established in 2010 and 2012 respectively. Open burning of waste is a way by which communities treat and reduce their waste. Open burning covers the open burning of residential, municipal solid wastes and yard waste. In the early 1980s, almost every household had an area designated for this purpose. This practice was predominant in low income and rural areas. Open burning of waste resulted in public health and environmental issues; hence, stricter measures and strategies were developed to stop or abate this practice forcing Metropolitan, Municipal and District authorities to develop bye-laws to criminalise open burning of waste (NESSAP, 2010).

With the advent of these strategies and actions, some households moved towards operating 'backyard' dumps or composts. Even though open burning of waste has been criminalised in the assembly by-laws, open burning is still ongoing due to various reasons such as high solid waste collection fees (polluter pays principle). Open burning practices have worsened considerably and would continue to be worse due to lack of enforcement of regulations that criminalises open burning, lack of education of the public and conscious effort to reduce the volumes of waste at various dumpsites. Table 117 shows that the total amount of solid waste that is openly burnt is on the rise, confirming lack of enforcement to reduce open burning and incineration. Generally, there was a rise in the trends for both incineration and open burning of waste from 1990 to 2016.

Table 117: Solid waste disposal by incineration and open burning

Incineration [Gg]							Open Burning	Total [Gg]
Year	MSW [	Industrial	Hazardous	Waste Oil	Clinical Waste	Total	MSW [Gg]	
1990	53.36				2.81	56.17	224.68	280.85
1991	53.04				2.79	55.83	223.32	279.14
1992	52.66				2.77	55.43	221.73	277.16
1993	52.23				2.75	54.98	219.91	274.89
1994	51.74				2.72	54.46	217.85	272.31
1995	51.19				2.69	53.88	215.53	269.41
1996	49.80				2.62	52.42	209.67	262.09
1997	48.30				2.54	50.84	203.36	254.19
1998	46.69				2.46	49.14	196.57	245.72
1999	44.96				2.37	47.32	189.30	236.62
2000	43.97				2.31	46.29	185.15	231.44
2001	44.22				2.33	46.55	186.21	232.76
2002	44.46				2.34	46.80	187.18	233.98
2003	44.66				2.35	47.01	188.03	235.03
2004	44.85				2.36	47.21	188.83	236.03
2005	50.63				2.66	53.30	213.19	266.49
2006	50.79				2.67	53.46	213.85	267.31
2007	55.72				2.93	58.66	234.63	293.29
2008	62.75				3.30	66.06	264.23	330.29
2009	70.60				3.72	74.32	297.27	371.59
2010	68.33	0.02	0.08	0.09	3.60	72.12	287.72	359.84
2011	70.04	0.04	0.08	0.08	3.69	73.92	294.91	368.83

2012	71.79	0.06	0.08	0.06	3.78	75.77	302.28	378.05
2013	73.59	0.22	1.31	0.07	3.87	79.06	309.84	388.90
2014	75.43	0.08	0.39	0.07	3.97	79.94	317.58	397.53
2015	80.75	0.08	0.39	0.07	4.25	85.55	339.99	425.54
2016	82.77	0.08	0.39	0.07	4.36	87.67	348.49	436.16
Change (2012-2016)	15.3%	33.3%	387.5%	16.7%	15.3%	15.7%	15.3%	15.3%

In 2016, out of the 87.67Gg waste incinerated, 82.77Gg was a municipal solid waste, 0.08Gg was industrial waste, 0.39Gg was hazardous wastes, 0.07Gg was waste oil and the other 4.36Gg was clinical wastes. In 2016, the total amount of 71.79Gg municipal solid waste incinerated was 13% higher than the 2012 levels. The observed increase in the total amount of incinerated waste could be the result of large-scale hazardous incineration plants (Zeal Environmental Technologies Limited and Zoil Services Limited) set up in 2010 and 2012, respectively. On the other hand, the 6.65Gg clinical waste incinerated was an increase of 30.3% of the 2000 levels. The disposal of municipal and clinical waste through incineration and open burning generates Carbon dioxide, methane and nitrous oxide emissions. The observed reduction in the total amount of incinerated MSW could be the result of the declining incineration capacity at the local government level. The amount of emissions that would be generated depends on the amount and type of waste, the capacity and the combustion efficiency of the incinerators and open burning taking place. Emissions from municipal solid waste and clinical waste were the main sources considered using the aggregate approach. Emissions from open burning were from municipal solid waste. In Ghana, solid waste from industries is collected as part of the MSW, which may sometimes be incinerated as part of MSW.

Few industries separately treat their waste through on-site incineration generated, but records are not kept on amounts incinerated. Data on the incineration of municipal solid waste and clinical waste were obtained from the National Environmental Sanitation Strategy Action Plan document and the Ghana Health Service Facts and Figures. In all, a total of 436.05Gg of waste was disposed-off through incineration and open burning in 2016. Of the total 436.05Gg waste, 87.7Gg were incinerated whereas the remaining 348.49Gg were openly burnt. The total amount of waste disposed-off through incineration and open burning resulted in a total emission of 0.08 $MtCO_2e$ in 2016, which represented 2% of the total waste sector emissions. Of the total emission, 97% came from open burning and the rest from incineration. The 2016 emission of 0.08 $MtCO_2e$ represented 12% and 58% higher than emissions in 2012 and 2000, respectively (Figure 90).

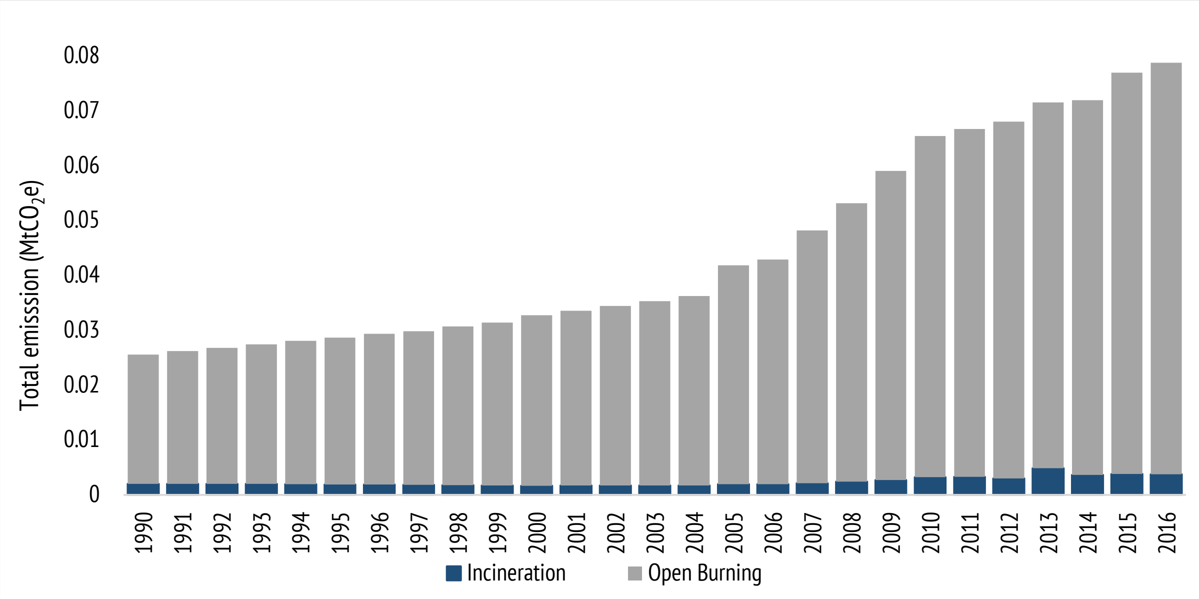


Figure 90: Emissions trend from waste Incineration and open burning

6.11.3.1 Methodological issues for incineration and open burning

The total amount of MSW open-burned and the amount of MSW and clinical waste incinerated was an important activity data required to undertake the emission calculations. The amount of MSW openly-burnt was obtained using the equation below;

$$MSW = P \times P_{frac} \times MSW_P \times B_{frac} \times 365 \times 10^{-6} \qquad \text{equation 2}$$

Where:

MSW = Total amount of municipal solid waste open-burned, Gg/yr
P = population (capita)
Pfrac = fraction of population burning waste, (fraction)
MSWP = per capita waste generation, kg waste/capita/day
Bfrac = fraction of the waste amount that is burned relative to the total amount of waste treated,
10-6 = conversion factor from kilogram to gigagram

Based on our national circumstances, a plant by plant basis as well as various waste categories could not be obtained. The tier 1 Approach was used for estimation because of reasons earlier stated. For incineration, the subcategories where estimation was conducted were from MSW and clinical waste. Hazardous and industrial waste has been estimated from 2010 to 2016 with data from Zeal Ghana limited. The methods for estimating CO_2, CH_4 and N_2O emissions from incineration and open burning of waste vary because of the different factors that influence emission levels. This tier 1 approach requires the use of activity data and default emission factors from IPCC 2006 guidelines for MSW and clinical waste. The calculation of CH_4 and N_2O emissions was based on the amount of waste incinerated or open-burned and on the related emission factor. The amount of waste used is consistent with the activity data used for CO_2 calculation and default CH_4 emission factors (IPCC, 2006 Guidelines). To determine the amount of waste that is incinerated and openly burnt, the percentage of MSW not collected was distributed among the various other means of disposal (recycle, reuse and recover). The percentage distribution among the various means of disposal was based on expert judgment. Table 118 below shows the amount of waste openly burnt, the fraction of population burning waste and fraction of MSW treated (Table 118).

Table 118: Trend of the amount of waste openly burnt

Year	Amount of waste open burnt (Gg)	Fractions of population Burning	fractions of total MSW treated
1990	224.68	0.0632	0.377
1991	223.32	0.0632	0.377
1992	221.73	0.0632	0.377
1993	219.91	0.0632	0.377
1994	217.85	0.0632	0.377
1995	215.53	0.0632	0.377
1996	209.67	0.0632	0.377
1997	203.36	0.0632	0.377
1998	196.57	0.0632	0.377
1999	189.30	0.0632	0.377
2000	185.15	0.0632	0.377
2001	186.21	0.0632	0.377
2002	187.18	0.0632	0.377
2003	188.03	0.0632	0.377
2004	188.83	0.0632	0.377
2005	213.19	0.0632	0.377
2006	213.85	0.0632	0.377
2007	234.63	0.0688	0.343
2008	264.23	0.0744	0.298
2009	297.27	0.08	0.252
2010	287.72	0.0856	0.241
2011	294.91	0.0856	0.241
2012	302.28	0.0856	0.241
2013	309.84	0.0856	0.241
2014	317.58	0.0856	0.241
2015	339.99	0.0856	0.241
2016	348.49	0.0856	0.241

Emphasis is placed on the fact that heat is not recovered from any of the incineration processes reported under the waste sector because in Ghana, as of 2016, there was no energy recovery from the incineration of waste.

6.11.4 Wastewater Treatment and Discharge (4D)

Key category: CH_4 Emissions (LA, 2016)

Wastewater originates from domestic, commercial and industrial sources. In Ghana, these may either be treated on-site (uncollected), channelled to a centralised point or disposed of in a near-by water body, (National Environmental Sanitation Strategy Action Plan, 2010). Domestic wastewater is mainly water from household water use, while industrial wastewater is from industrial process water only. The kind of wastewater treatment method used also differs for people living in the rural and urban areas and for those in urban high income and urban low-income areas.

Taking this into consideration, the type of treatment and discharge pathway or system was categorised into untreated system equivalent to unimproved facilities (i.e. sea, river and lake discharge and stagnant water) and treated system also equivalent to improved facilities (i.e. centralised, aerobic treatment plant, septic system and latrine), (MICs, 2011).

It is important to note that treatment systems are not final disposal points or sites. They are usually considered as intermediary treatment facilities since they ultimately end up in the sea or river but not in its raw state. Domestic wastewater includes human sewage mixed with other household water. In Ghana, after this effluent is processed, it is directly discharged into water bodies generating N_2O during both Nitrification and denitrification of the nitrogen present. Industrial wastewater treatment and discharge sources by estimates are noted to be the major contributor to Wastewater treatment and discharge emissions while domestic and commercial wastewater treatment and discharge is a minor contributor to wastewater treatment and discharge. This is rather the reverse in Ghana since wastewater coming from most industries end up in commercial wastewater streams.

Industrial wastewater may be treated on-site or released directly into the sewer system. Usually, most industries treat processed water to meet regulatory standards before discharge. The historical trend indicates that the provision of public toilet facility was free for users before 1982. The service providers and their supervisors were poorly motivated, and this led to the poor management and deterioration of sanitary conditions within the major cities. The situation improved due to the formation of the Committees for the Defense of the Revolution (CDRs) who charged minimal fees to manage the facilities. In 1989, following the implementation of the National Decentralisation Programme, the management of the public toilets was reverted to the Municipal Government now termed Metropolitan Assemblies. The sanitary facilities (public toilets) were managed under the franchise agreement with the payment of not less than 20% of gross revenue to the Assembly (Ayee and Crook, 2003).

In the 1990s and after that came into being the PPPs through franchising and contracting out and encouraging more community-based participation in the provision of local cleaning and sanitation services. The period of 2000 to date manifest that most environmental sanitation services are provided by the private sector including NGOs and community-based organisations and supervised by public agencies (especially the MMDAs) with the appointment of MMDA Chief Executives. Over the years, it has been observed that the amount of domestic wastewater generated keeps increasing due to increase in population and access to improved treatment systems such as flush to piped sewer systems and flush to septic tanks as shown in the table below (MICS, 2006 and 2011) (Table 119). For industrial wastewater, it has been observed over the period that industrial wastewater output keeps increasing due to the increasing number of industries in the country. A survey conducted by the Manufacturing Industries Department of the EPA as well as EMP reports submitted to the Department revealed that industrial outputs in terms of products output have been increasing over the years. The data that was obtained from the survey and EMPs were from the year 1990 basically for soap and detergents while data for the other sectors were from 1997 to 2016. There are, however, gaps for some industry categories for some years.

Table 119: Distribution of population and the dominant treatment system

Classification of the wastewater treatment system to IPCC classification			1996		2005		2010	
	IPCC classification	MICs Survey, 1996, 2006, 2011	Rural	Urban	Rural	Urban	Rural	Urban
1	Sea, river, and lake discharge	No facilities, or bush or field. Missing, other, Flush to somewhere else, No facilities.	20.09	2.05	18.76	4.16	17.35	5.12
2	Stagnant sewer	Bucket, Pan/Bucket	0.59	9.00	0.11	0.80	0.20	0.25
3	Centralised aerobic treatment plant	Flush to piped sewer system, Flash toilet (water closet)	1.18	8.59	0.32	1.80	0.15	1.83
4	Septic system	Flush to septic tank, Flush don't know where, Septic tank	1.77	11.86	0.63	7.05	0.64	11.71
5	Latrine	Flush to pit (latrine), Ventilated Improved Pit latrine (VIP), pit latrine with Slab, Pit Latrine without slab/open pit, VIP, KVIP	35.46	9.41	32.88	33.50	31.00	31.80

For industrial wastewater, it has been observed over the period that the wastewater output keeps increasing due to new datasets from industries in the country. The Environmental Performance Rating and Disclosure programme and the introduction of new data-intensive EMP format by the Manufacturing Industries Department of the EPA revealed that industrial outputs in terms of data output have increased over the years. The data that was obtained from the survey were from the year 2000 to 2012, but there are still gaps for some industry categories for some years.

6.11.4.1 Emissions trends wastewater treatment and discharge

The trends of emissions from wastewater treatment and discharge show a steady increase from 1990 to 2016. It was observed that emissions from 1990 amounted to 0.64 $MtCO_2e$, 0.89 $MtCO_2e$ in 2000 and 1.84 $MtCO_2e$ in 2016. Within the sub-category, 66.09% of the emissions were from Domestic wastewater treatment and discharge (4.D.1) while 33.90% of the emissions were from Industrial wastewater treatment and discharge (4.D.2) for 2016. The massive contribution of industrial wastewater treatment and discharge to the total wastewater treatment and discharge started in 2007 due to the unavailability of data in the previous years, as shown in Figure 91 below.

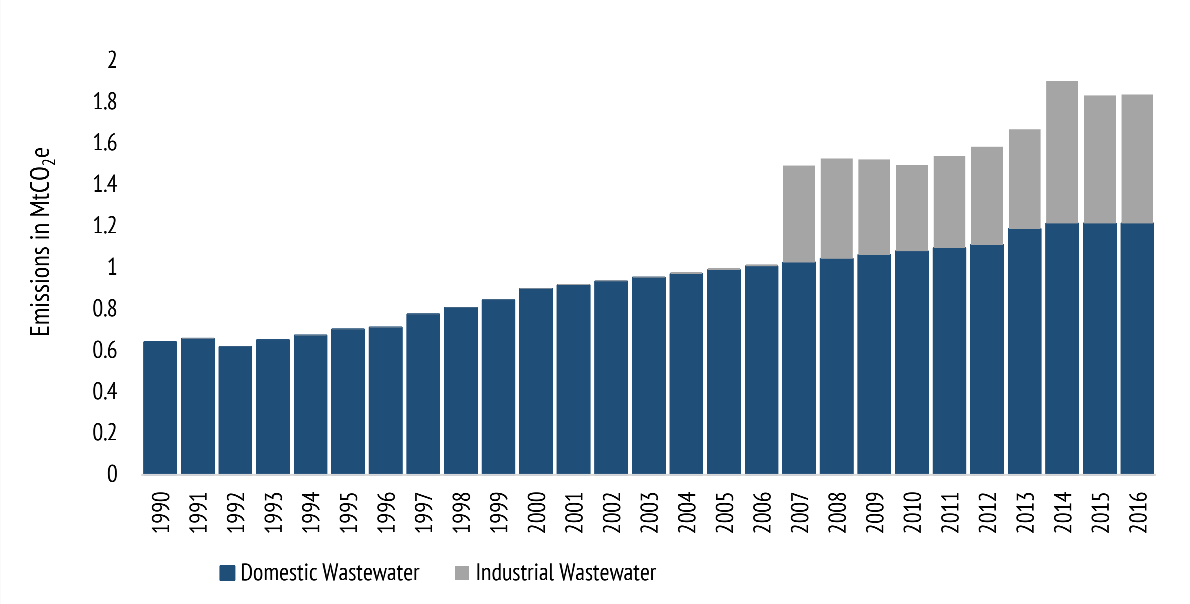


Figure 91: Trends of emission from wastewater treatment and discharge

Emissions of CH_4 and N_2O from wastewater have increased steadily during the period 1990-2016 inventory estimates. The emission trend for this period is shown in figure 91 above. The increase in emissions from domestic wastewater treatment and discharge is mainly due to the kind of treatment systems and discharge pathways being used in Ghana.

6.11.4.2 Methodological issues in wastewater treatment and discharge category

The methodology used to estimate emissions from wastewater treatment and discharge management activities require country-specific knowledge on wastewater generation, country-specific BOD, per capita protein intake and management practice/ discharge pathway. Waste management activities in Ghana are generally inadequately organized, and this results in the lack and inconsistency of data. Therefore, efforts were made to evaluate and compile data coming from different sources and adjust or classify them to recommended IPCC, 2006 Guidelines, which was used for GHGs emissions estimation. Estimation of emissions for the wastewater treatment and discharge was commenced from 1990-2016. The method used to calculate methane CH_4 and nitrous oxide N_2O emissions from wastewater water treatment and discharge was adopted from the 2006 IPCC Guidelines. The guideline informed how to use activity data and emission factors to attain an estimate of emissions. According to the analysis of emission estimates, CH_4 from wastewater handling was a key category in level and trend in 1990–2016.

6.11.4.2.1 Methane Emissions from Domestic/Commercial Wastewater Treatment

Generally, in estimating CH_4 emissions from wastewater treatment and discharge, for this sub-category, the total population (24,915,550) of the country (GSS, 2010) was considered. The household size of four and the number of households (5,599.00) were also used for the estimation (World Bank Country Data). As per the 2006 IPCC Guideline, the population in the urban, rural and different income classes (urban high, urban low and rural) were also taken into consideration. These income classes are equivalent to metro-urban, peri-urban and rural in Ghana. For the urban population, data on the sum of improved facilities (treated system) and unimproved facilities (untreated) as well as the rural population for 2010 were obtained for 1996, 2005 and 2010 survey data from the MICS. The fraction of the urban population was divided into metro-urban (52.4%) and peri-urban (47.6%) using the population share of 1996, 2005 and 2010, respectively (Table 120).

The IPCC methodology for estimation of methane emissions from domestic/commercial wastewater treatment and discharge is given by standard IPCC Equations below:

CH_4 Emissions = $\{\sum_{i,j} (Ui^* Ti.j * EFj)\}$ (TOW-S)-R equation 3

Where:

CH_4 emissions=	CH_4 emissions in inventory year, kg CH4/yr
TOW	= Total organics in wastewater in inventory year, kg BOD/year
S	= organic component removed as sludge in inventory year, kg BOD/year
U_i	= Fraction of population in income group I in inventory year
$T_{i,j}$	= degree of utilisation of treatment/discharge pathway or system, j, for each income group fraction I in inventory
i	= income group: rural, urban high income and low urban income
j	= each treatment/discharge pathway or system
EF_j	= emission factor, kg CH_4/kg BOD
R	= amount of CH_4 recovered in inventory year, kgCH_4/yr

The emission factor used for the estimation of emissions was based on the equation below:

EF_j= Bo * MCF_j equation 4

Where:

EFj	= emission factor, kg CH_4/kg BOD
j	= each treatment/discharge pathway or system
Bo	= Maximum CH_4 producing capacity, kg CH_4/kg BOD (Default value was used For estimation)
MCFj	= Methane correction factor (Default value was used for estimation)

The activity data for this source category is the total amount of organically degradable material in the wastewater. The parameters in the equation below were used for estimation.

TOW = P* BOD* 0.001 * I *365 equation 5

Where:

TOW	= total organics in wastewater in inventory year, kg BOD/yr
P	= country population in inventory year
BOD	= country-specific per capita BOD in inventory year, g/person/day
0.01	= conversion from grams BOD to kg BOD
I	= correction factor for additional industrial BOD discharged into sewers

Table 120: Treatment systems and population use distribution

Years	Rural					Urban H					Urban L				
	Sea, river and lake discharge	Stagnant sewer	Latrine	Septic system	Centralised, aerobic treatment plant	Sea, river and lake discharge	Stagnant sewer	Latrine	Septic system	Centralised, aerobic treatment plant	Sea, river and lake discharge	Stagnant sewer	Latrine	Septic system	Centralised, aerobic treatment plant
1990	0.208	0.007	0.365	0.024	0.016	0.001	0.064	0.005	0.075	0.058	0.001	0.059	0.002	0.070	0.045
1991	0.207	0.007	0.364	0.023	0.015	0.002	0.063	0.010	0.074	0.055	0.002	0.058	0.006	0.068	0.045
1992	0.206	0.007	0.362	0.022	0.014	0.004	0.062	0.020	0.071	0.053	0.005	0.055	0.010	0.065	0.043
1993	0.205	0.007	0.361	0.021	0.013	0.006	0.059	0.023	0.069	0.052	0.006	0.053	0.021	0.063	0.042
1994	0.205	0.006	0.360	0.020	0.013	0.008	0.054	0.027	0.067	0.052	0.007	0.048	0.032	0.060	0.042
1995	0.203	0.006	0.357	0.019	0.012	0.009	0.052	0.037	0.065	0.047	0.008	0.046	0.041	0.058	0.041
1996	0.201	0.006	0.355	0.018	0.012	0.011	0.047	0.049	0.062	0.045	0.010	0.043	0.045	0.057	0.041
1997	0.199	0.005	0.352	0.016	0.011	0.011	0.042	0.065	0.059	0.041	0.010	0.038	0.060	0.054	0.037
1998	0.197	0.005	0.347	0.015	0.010	0.012	0.039	0.081	0.056	0.036	0.011	0.034	0.074	0.051	0.033
1999	0.196	0.005	0.343	0.013	0.009	0.013	0.033	0.099	0.054	0.033	0.012	0.030	0.083	0.049	0.030
2000	0.194	0.004	0.341	0.013	0.008	0.015	0.030	0.112	0.051	0.028	0.013	0.025	0.095	0.046	0.026
2001	0.192	0.003	0.339	0.011	0.007	0.016	0.025	0.128	0.047	0.024	0.015	0.024	0.104	0.043	0.022
2002	0.191	0.003	0.338	0.010	0.006	0.017	0.019	0.140	0.044	0.023	0.016	0.021	0.114	0.040	0.018
2003	0.189	0.002	0.335	0.009	0.006	0.019	0.014	0.153	0.043	0.018	0.017	0.015	0.124	0.039	0.017
2004	0.189	0.002	0.332	0.008	0.004	0.020	0.009	0.165	0.040	0.014	0.019	0.009	0.141	0.036	0.013
2005	0.188	0.001	0.329	0.006	0.003	0.022	0.004	0.176	0.037	0.009	0.020	0.004	0.159	0.034	0.009
2006	0.185	0.001	0.325	0.006	0.003	0.023	0.004	0.174	0.042	0.009	0.021	0.003	0.158	0.038	0.009
2007	0.181	0.001	0.321	0.006	0.003	0.024	0.003	0.172	0.047	0.010	0.022	0.003	0.156	0.042	0.009
2008	0.178	0.002	0.318	0.006	0.002	0.025	0.002	0.171	0.052	0.010	0.023	0.002	0.155	0.047	0.009
2009	0.174	0.002	0.315	0.006	0.002	0.026	0.002	0.169	0.057	0.010	0.023	0.002	0.154	0.051	0.009
2010	0.174	0.002	0.310	0.006	0.002	0.027	0.001	0.166	0.061	0.010	0.024	0.001	0.151	0.056	0.009
2011	0.174	0.002	0.308	0.007	0.001	0.029	0.001	0.166	0.066	0.010	0.026	0.001	0.139	0.060	0.009
2012	0.172	0.002	0.305	0.007	0.001	0.030	0.001	0.164	0.071	0.010	0.027	0.001	0.134	0.065	0.009
2013	0.170	0.003	0.302	0.007	0.001	0.032	0.001	0.162	0.076	0.010	0.028	0.001	0.130	0.069	0.009
2014	0.168	0.003	0.299	0.007	0.001	0.033	0.001	0.160	0.081	0.010	0.030	0.001	0.125	0.074	0.009
2015	0.166	0.003	0.296	0.007	0.001	0.034	0.001	0.158	0.086	0.010	0.031	0.001	0.120	0.078	0.009
2016	0.164	0.003	0.293	0.007	0.001	0.035	0.001	0.157	0.091	0.010	0.032	0.001	0.115	0.082	0.009

6.11.4.2.2 Industrial wastewater treatment and discharge
In the estimation of emissions from industrial wastewater handling, oxygen-deficient water bodies are considered (anaerobic wastewater handling system). IPCC default values of 0.1 and 0.9 were used as emission factors for a fraction of wastewater treated by the handling system and methane conversion factor, respectively.

6.11.4.2.3 Indirect Nitrous Oxide Emissions from Human Sewage Estimation
The estimation of nitrous oxide emissions from human sewage was mainly based on the per capita protein consumption from FAO statistics, and population of the country. The emission factors were obtained from the IPCC 2006 Guidelines.

6.11.4.2.4 Per capita protein consumption
The per capita protein consumption (protein in kg/person/yr) was obtained from the FAO Statistics, 1995. Table 121 below shows the range of years and their respective per capita protein consumption values.

Table 121: Trend of per capita protein consumption

Year	BOD (kg/person/year)	Protein intake (kg/person/year)
1990	11.33	31.6
1991	11.56	31.38
1992	11.79	31.16
1993	12.02	30.94
1994	12.26	30.72
1995	12.49	30.5
1996	12.72	31.14
1997	12.95	31.78
1998	13.18	32.42
1999	13.41	33.06
2000	13.66	33.7
2001	13.87	33.1
2002	14.11	32.5
2003	14.34	31.9
2004	14.57	31.3
2005	14.80	30.7
2006	15.04	30.1
2007	15.27	29.5
2008	15.49	28.9
2009	15.73	28.3
2010	15.96	27.7
2011	16.19	27.1
2012	16.42	26.5
2013	16.65	29.30
2014	16.88	29.15
2015	17.11	29.01
2016	17.34	28.87

Sludge Handling System

There was no estimation of sludge handling system since there was no sludge removal data for the entire time series

6.12 Planned Improvements in the waste sector

Table 122 highlights key activities that have been planned for improving future inventories. These include efforts to generate data in categories where they are lacking and reduce the reliance on expert knowledge and associated uncertainties to an extent possible.

Table 122: List of activities for future improvements in the inventory for the Waste sector

Improvements	Responsibility & Collaborators	Priority	Next Step	Target	Assumption
Solid waste disposal					
Collect additional data on solid waste generation rate and waste classification at the landfill/disposal site	Built Environment Department, EPA, Civil Engineering Department, KNUST, MLGRD, AMA, KMA, STMA, TMA	high	Contact relevant institutions to include data need into surveys and research	next inventory	Funding is available
Support the establishment of proper waste data management system in selected assemblies	EPA Built Environment Department	high	Built Environment to prepare a project proposal to seek funding	medium to long term	Funding is available
Revise solid waste generation rates and waste stream fractions with new datasets	Waste inventory team	high	EPA to coordinate revision of existing estimates	next inventory	
Separate solid disposal further to managed, unmanaged and uncategorised	Waste inventory team	medium	EPA to coordinate	next inventory	Availability of new solid waste dataset
Revise fraction of solid waste biologically treated through composting	Built Environment Department, EPA and Zoomlion Ghana Limited	medium	EPA and Zoomlion to take the lead	next inventory	
Revision of the fraction of solid waste incinerated and openly burnt	Built Environment Department, EPA, statistical service, MID, private partners	high	EPA carry out a survey on incinerators for the Ghana Health Service and Ghana Education Service and private companies to include in their survey	next inventory	
Wastewater and treatment					
Update existing survey data on industrial and domestic waste	Manufacturing Industry Department, EPA, built environment	high	EPA to initiate a survey to review industrial and domestic WWTP for applicable sectors	next inventory	Funding is made available
Uncertainty management	Waste team	high	EPA to work closely with the University of Ghana's Statistic Department to start work on waste sector-specific uncertainty management	next inventory	Funding is made available

Chapter 7
Concluding remarks

The preparation of the NIR4 has been another opportunity to strengthen the credibility of the results and the rigour of the national system used to produce the inventory estimates. All aspects of the inventory system saw some improvements with the view to further enhance the transparency of the inventory processes. In the area of inventory governance, more institutions and experts have joined the team, received additional training both in the country and abroad on the inventory. There are serious efforts toward deepening institutionalisation of the inventory. Despite taking commendable steps to involve more institutions and particularly devolving the inventory tasks to the relevant key line ministries, there is more to be done in this regard. It is time the line ministries begin to incorporate inventory tasks into their annual work plans and consider staff time on the inventory in the official performance appraisal. This step would be a feather in the cap in the continued efforts to mainstream the inventory process.

Another important area of concern is about policy uptake of the inventory results and the visibility of the inventory at the high-level. This issue is at the core of the discussions on coming up with long-term sustainability strategies of the inventory process. There are two sides to this issue the inventory team considered during the discussions on the way forward. Firstly, the inventory system and the results must be of high-quality and reliable before policy-makers can confidently use them to inform policy. Secondly, the inventory results should be well packaged for widespread dissemination. When the stakeholders become aware of the central message of the inventory results, the more likely, they are to factor them into future climate policy planning. In this regard, the team plans to vigorously pursue the idea of engaging the potential users of the inventory on how best to package the inventory results for their future use, prepare infographics for dissemination and the where resources permit organise policy engagement meetings with the key stakeholders.

High integrity data and adequate financing are the lifelines of a robust inventory system. Although some improvements have been made on the activity data, emission factors and methodology, many efforts remain to be done in the coming years. More attention would be given to improving the methodology and the emission factors for key categories. On the data side, it would be a priority to develop country-specific emission factors and higher tier methodology for emission estimation for the electricity, transport, waste disposal and livestock category. The GEF enabling fund is the main funding source for the preparation of the national communication/biennial update report of which a fraction is dedicated to the GHG inventory.

Presently, Ghana does not provide direct funding to support the inventory but covers some of the operational cost through in-kind contributions. The current level of funding arrangement is not enough to cover the full cost of running an efficient national inventory system that can produce inventories on time and of high quality. In the coming years, Ghana would consider applying for a medium-size project fund window from GEF or develop a specific project proposal to seek funding from other donors to complement the GEF funding. Another option Ghana is seriously considering is the possibility to raise funding from the national budget.

Annexes

Annexe 1: Summary Table

Full list of tables submitted electronically together with this report

Annexe 1.1 Table A - Summary Table (2016)

Categories	Emissions (Gg)			Emissions CO2 Equivalents (Gg)			Emissions (Gg)				
	Net CO_2	CH_4	N_2O	HFCs	PFCs	SF_6	NOx	CO	NMVOCs	BC	PM2.5
Total National Emissions and Removals	27,285.46	309.99	24.86	613.00	33.32	-	121.26	1,751.42	270.49	234.80	598.86
1 - Energy	13,973.47	31.34	1.24	-	-	-	97.21	1,207.71	261.00	234.53	594.74
1.A - Fuel Combustion Activities	13,965.23	30.58	1.24	-	-	-	97.21	1,207.71	261.00	234.53	594.74
1.A.1 - Energy Industries	5,098.01	1.70	0.23				9.16	320.71	108.18	1.29	8.88
1.A.2 - Manufacturing Industries and Construction	1,065.70	0.31	0.04				7.73	37.35	5.36	23.85	1.66
1.A.3 - Transport	6,918.61	1.68	0.68				66.52	270.64	37.41	87.76	236.00
1.A.4 - Other Sectors	882.90	26.89	0.28				13.80	579.01	110.05	121.63	348.20
1.A.5 - Non-Specified	-	-	-				-	-	-	-	
1.B - Fugitive emissions from fuels	8.24	0.76	0.0001	-	-	-	-	-	-	-	
1.B.1 - Solid Fuels	-	-	-				-	-	-	-	
1.B.2 - Oil and Natural Gas	8.24	0.76	0.0001				-	-	-	-	
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	-						-	-	-	-	
2 - Industrial Processes and Product Use	394.89	-	-	613.00	33.32	-	-	-	-	-	
2.A - Mineral Industry	334.08	-	-	-	-	-	-	-	-	-	
2.A.1 - Cement production	21.85						-	-	-	-	
2.A.2 - Lime production	-						-	-	-	-	
2.A.3 - Glass Production	-						-	-	-	-	
2.A.4 - Other Process Uses of Carbonates	312.23						-	-	-	-	
2.A.5 - Other (please specify)	-	-	-				-	-	-	-	
2.B - Chemical Industry	-	-	-	-	-	-	-	-	-	-	
2.B.1 - Ammonia Production	-						-	-	-	-	
2.B.2 - Nitric Acid Production			-				-	-	-	-	
2.B.3 - Adipic Acid Production			-				-	-	-	-	
2.B.4 - Caprolactam, Glyoxal and Glyoxylic Acid Production			-				-	-	-	-	
2.B.5 - Carbide Production	-	-					-	-	-	-	
2.B.6 - Titanium Dioxide Production	-						-	-	-	-	
2.B.7 - Soda Ash Production	-						-	-	-	-	
2.B.8 - Petrochemical and Carbon Black Production	-	-					-	-	-	-	
2.B.9 - Fluorochemical Production				-	-	-	-	-	-	-	
2.B.10 - Other (Please specify)	-	-	-	-	-	-	-	-	-	-	
2.C - Metal Industry	58.74	-	-	-	33.32	-	-	-	-	-	
2.C.1 - Iron and Steel Production	3.87	-					-	-	-	-	

2.C.2 - Ferroalloys Production	-	-					-	-	-	-	
2.C.3 - Aluminium production	54.86				33.32		-	-	-	-	
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	2.08	-	-	-	-	-	-	-	-	-	
2.D.1 - Lubricant Use	2.08						-	-	-	-	
2.D.2 - Paraffin Wax Use	-						-	-	-	-	
2.D.3 - Solvent Use							-	-	-	-	
2.D.4 - Other (please specify)	-	-	-				-	-	-	-	
2.E - Electronics Industry	-	-	-	-	-	-	-	-	-	-	
2.E.1 - Integrated Circuit or Semiconductor				-	-	-	-	-	-	-	
2.E.2 - TFT Flat Panel Display					-	-	-	-	-	-	
2.E.3 - Photovoltaics					-		-	-	-	-	
2.E.4 - Heat Transfer Fluid					-		-	-	-	-	
2.E.5 - Other (please specify)	-	-	-	-	-	-	-	-	-	-	
2.F - Product Uses as Substitutes for Ozone Depleting Substances	-	-	-	613.00	-	-	-	-	-	-	
2.F.1 - Refrigeration and Air Conditioning				613.00			-	-	-	-	
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.G.1 - Electrical Equipment					-	-	-	-	-	-	
2.G.2 - SF6 and PFCs from Other Product Uses					-	-	-	-	-	-	
2.G.3 - N_2O from Product Uses			-				-	-	-	-	
2.G.4 - Other (Please specify)	-	-	-	-	-	-	-	-	-	-	
2.H - Other	-	-	-	-	-	-	-	-	-	-	
2.H.1 - Pulp and Paper Industry	-	-					-	-	-	-	
2.H.2 - Food and Beverages Industry	-	-					-	-	-	-	
2.H.3 - Other (please specify)	-	-	-				-	-	-	-	
3 - Agriculture, Forestry, and Other Land Use	12,908.42	156.76	21.69	-	-	-	22.00	527.75	-	-	
3.A - Livestock	-	121.14	3.03	-	-	-	-	-	-	-	
3.A.1 - Enteric Fermentation		114.66					-	-	-	-	
3.A.2 - Manure Management		6.48	3.03				-	-	-	-	
3.B - Land	12,872.05	-	-	-	-	-	-	-	-	-	
3.B.1 - Forest land	(4,668.07)						-	-	-	-	
3.B.2 - Cropland	8,331.46						-	-	-	-	
3.B.3 - Grassland	8,804.18						-	-	-	-	
3.B.4 - Wetlands	30.48		-				-	-	-	-	
3.B.5 - Settlements	173.75						-	-	-	-	
3.B.6 - Other Land	200.25						-	-	-	-	
3.C - Aggregate sources and non-CO_2 emissions sources on land	36.37	35.62	18.66	-	-	-	22.00	527.75	-	-	
3.C.1 - Emissions from biomass burning		25.18	1.42				22.00	527.75	-	-	
3.C.2 - Liming	-						-	-	-	-	
3.C.3 - Urea application	36.37						-	-	-	-	
3.C.4 - Direct N_2O Emissions from managed soils			13.36				-	-	-	-	

3.C.5 - Indirect N_2O Emissions from managed soils			3.68				-	-	-	-	
3.C.6 - Indirect N_2O Emissions from manure management			0.19				-	-	-	-	
3.C.7 - Rice cultivations		10.44					-	-	-	-	
3.C.8 - Other (please specify)		-	-				-	-	-	-	
3.D - Other	-	-	-	-	-	-	-	-	-	-	
3.D.1 - Harvested Wood Products	-						-	-	-	-	
3.D.2 - Other (please specify)	-	-	-				-	-	-	-	
4 - Waste	8.68	121.89	1.93	-	-	-	-	-	-	-	
4.A - Solid Waste Disposal	-	55.01	-	-	-	-	2.06	15.96	9.49	0.27	4.12
4.B - Biological Treatment of Solid Waste	-	2.45	0.15	-	-	-	-	-	-	-	
4.C - Incineration and Open Burning of Waste	8.68	2.75	0.04	-	-	-	2.06	15.96	9.49	0.27	4.12
4.D - Wastewater Treatment and Discharge	-	61.69	1.75	-	-	-	-	-	-	-	
4.E - Other (please specify)	-	-	-	-	-	-	-	-	-	-	
5 - Other	-	-	-	-	-	-	-	-	-	-	
5.A - Indirect N_2O emissions from the atmospheric deposition of nitrogen in NOx and NH3	-	-	-	-	-	-	-	-	-	-	
5.B - Other (please specify)	-	-	-	-	-	-	-	-	-	-	
Memo Items (5)											
International Bunkers	346.56	0.0031	0.01	-	-	-	-	-	-	-	
1.A.3.a.i - International Aviation (International Bunkers)	339.06	0.002	0.01				-	-	-	-	
1.A.3.d.i - International water-borne navigation (International bunkers)	7.50	0.001	0.0002				-	-	-	-	
1.A.5.c - Multilateral Operations	-	-	-	-	-	-	-	-	-	-	

Annexe 1.2 Table A – Summary Table (2016)

Categories	Emissions (Gg)			Emissions CO_2 Equivalents (Gg)			Emissions (Gg)			
	Net CO_2	CH_4	N_2O	HFCs	PFCs	SF_6	NOx	CO	NMVOCs	BC
Total National Emissions and Removals	27,285.46	309.99	24.86	613.00	33.32	-	117.68	1,116.04	92.56	6.10
1 - Energy	13,973.47	31.34	1.24	-	-	-	95.68	588.29	92.56	6.10
1.A - Fuel Combustion Activities	13,965.23	30.58	1.24	-	-	-	95.68	588.29	92.56	6.10
1.B - Fugitive emissions from fuels	8.24	0.76	0.0001	-	-	-	-	-	-	-
1.C - Carbon dioxide Transport and Storage	-	-	-	-	-	-	-	-	-	-
2 - Industrial Processes and Product Use	394.89	-	-	613.00	33.32	-	-	-	-	-
2.A - Mineral Industry	334.08	-	-	-	-	-	-	-	-	-
2.B - Chemical Industry	-	-	-	-	-	-	-	-	-	-
2.C - Metal Industry	58.74	-	-	-	33.32	-	-	-	-	-
2.D - Non-Energy Products from Fuels and Solvent Use	2.08	-	-	-	-	-	-	-	-	-
2.E - Electronics Industry	-	-	-	-	-	-	-	-	-	-
2.F - Product Uses as Substitutes for Ozone Depleting Substances	-	-	-	613.00	-	-	-	-	-	-
2.G - Other Product Manufacture and Use	-	-	-	-	-	-	-	-	-	-
2.H - Other	-	-	-	-	-	-	-	-	-	-
3 - Agriculture, Forestry, and Other Land Use	12,908.42	156.76	21.69	-	-	-	22.00	527.75	-	-
3.A - Livestock	-	121.14	3.03	-	-	-	-	-	-	-
3.B - Land	12,872.05	-	-	-	-	-	-	-	-	-
3.C - Aggregate sources and non-CO_2 emissions sources on land	36.37	35.62	18.66	-	-	-	22.00	527.75	-	-
3.D - Other	-	-	-	-	-	-	-	-	-	-
4 - Waste	8.68	121.89	1.93	-	-	-	-	-	-	-
4.A - Solid Waste Disposal	-	55.01	-	-	-	-	-	-	-	-
4.B - Biological Treatment of Solid Waste	-	2.45	0.15	-	-	-	-	-	-	-
4.C - Incineration and Open Burning of Waste	8.68	2.75	0.04	-	-	-	-	-	-	-
4.D - Wastewater Treatment and Discharge	-	61.69	1.75	-	-	-	-	-	-	-
4.E - Other (please specify)	-	-	-	-	-	-	-	-	-	-
5 - Other	-	-	-	-	-	-	-	-	-	-
5.A - Indirect N_2O emissions from the atmospheric deposition of nitrogen in NOx and NH3	-	-	-	-	-	-	-	-	-	-
5.B - Other (please specify)	-	-	-	-	-	-	-	-	-	-
Memo Items (5)										
International Bunkers	346.56	0.0031	0.01	-	-	-	-	-	-	-
1.A.3.a.i - International Aviation (International Bunkers)	339.06	0.0024	0.01				-	-	-	-
1.A.3.d.i - International water-borne navigation (International bunkers)	7.50	0.0007	0.00				-	-	-	-

Annexe 1.3 Energy sectoral table – 2016

	Emissions (Gg)							
Categories	CO_2	CH_4	N_2O	CO	BC	NOx	NMVOC	$PM_{2.5}$
1 - Energy	13,973.47	31.34	1.24	912.21	116.25	109.16	202.37	300.92
1.A - Fuel Combustion Activities	13,965.23	30.58	1.24	912.21	116.25	109.16	202.37	300.92
1.A.1 - Energy Industries	5,098.01	1.698	0.23	320.80	1.29	9.13	108.18	8.88
1.A.1.a - Main Activity Electricity and Heat Production	4,785.57	0.16	0.03	1.75	0.67	8.41	0.12	0.32
1.A.1.a.i - Electricity Generation	4,785.57	0.16	0.03	1.75	0.67	8.41	0.12	0.32
1.A.1.a.ii - Combined Heat and Power Generation (CHP)				-	-	-	-	-
1.A.1.a.iii - Heat Plants				-	-	-	-	-
1.A.1.b - Petroleum Refining	252.70	0.007	0.0013	0.12	0.0018	0.12	0.00004	-
1.A.1.c - Manufacture of Solid Fuels and Other Energy Industries	59.74	1.53	0.20	318.94	0.63	0.59	108.07	8.56
1.A.1.c.i - Manufacture of Solid Fuels		1.53	0.20	318.94	0.63	0.59	108.07	8.56
1.A.1.c.ii - Other Energy Industries	59.74	0.0018524	0.000326	0	-	-	-	-
1.A.2 - Manufacturing Industries and Construction	1,065.70	0.31	0.04	40.0616	25.3341	7.82469	6.083	
1.A.2.a - Iron and Steel	4.53	0.00018	0.00002	0.00402	0.118525	0.03128	0.0015	0.027389
1.A.2.b - Non-Ferrous Metals				-	-	-	-	-
1.A.2.c - Chemicals	6.68	0.0193	0.0026	2.71035	1.486875	0.09233	0.3831	-
1.A.2.d - Pulp, Paper and Print	4.31	0.0001	0.00002	0.0027	0.000262	0.01	0.0006	0.010619
1.A.2.e - Food Processing, Beverages and Tobacco	93.38	0.2079	0.0280	30.2611	0.281384	1.10261	4.1623	0.381761
1.A.2.f - Non-Metallic Minerals				-	-	-	-	-
1.A.2.g - Transport Equipment				-	-	-	-	-
1.A.2.h - Machinery				-	-	-	-	-
1.A.2.i - Mining (excluding fuels) and Quarrying	694.74	0.02813	0.00563	0.61878	19.3852	4.8096	0.2344	-
1.A.2.j - Wood and wood products	32.20	0.00130	0.00026	0.02868	0.004986	0.22294	0.0109	0.203526
1.A.2.k - Construction	163.35	0.00661	0.00132	0.14549	0.025293	1.13086	0.0551	1.0323811
1.A.2.l - Textile and Leather	7.80	0.0249	0.0033	3.49442	1.698952	0.11188	0.4937	0.0092812
1.A.2.m - Non-specified Industry	58.73	0.0214	0.0030	2.79609	2.332629	0.3085	0.7414	-
1.A.3 - Transport	6,918.61	1.6800	0.6837	272.929	87.3847	83.1755	40.1217	292.0438
1.A.3.a - Civil Aviation	56.72	0.0004	0.0016	0.0357	0.1728	1.2511	1.4405	3.1024
1.A.3.a.i - International Aviation (International Bunkers) (1)								
1.A.3.a.ii - Domestic Aviation	56.72	0.00040	0.0016	0.0357	0.172769	1.25108	1.4405	3.102408
1.A.3.b - Road Transportation	5,918.52	1.63	0.32	269.75	87.02	66.52	37.32	239.16
1.A.3.b.i - Cars	2,844.40	0.935	0.137	126.932	37.732	30.819	17.986	123.231
1.A.3.b.i.1 - Passenger cars with 3-way catalysts	129.99	0.047	0.02	11.28	0.42	1.25	1.44	7.33
1.A.3.b.i.2 - Passenger cars without 3-way catalysts	2,714.42	0.89	0.12	115.65	37.31	29.57	16.55	115.90
1.A.3.b.ii - Light-duty trucks	922.07	0.167	0.069	33.848	15.646	10.142	4.675	41.054
1.A.3.b.ii.1 - Light-duty trucks with 3-way catalysts	37.21	0.02	0.00	3.23	0.12	0.36	0.41	2.10
1.A.3.b.ii.2 - Light-duty trucks without 3-way catalysts	884.86	0.15	0.07	30.62	15.52	9.78	4.26	38.95
1.A.3.b.iii - Heavy-duty trucks and buses	1,235.64	0.09	0.07	29.42	30.67	16.74	4.50	23.16
1.A.3.b.iv - Motorcycles	916.41	0.44	0.04	79.55	2.97	8.82	10.16	51.71
1.A.3.b.v - Evaporative emissions from vehicles				-	-	-	-	-
1.A.3.b.vi - Urea-based catalysts				-	-	-	-	-
1.A.3.c - Railways	941.96	0.05	0.36	3.14	0.15	15.37	1.36	49.71
1.A.3.d - Water-borne Navigation	1.41	0.0001	0.00004	0.0032	0.0369	0.0344	0.0012	0.0743
1.A.3.d.i - International water-borne navigation (International bunkers) (1)								

1.A.3.d.ii - Domestic Water-borne Navigation	1.41	0.00013	0.00004	0.00325	0.03693	0.03443	0.0012	0.074306
1.A.3.e - Other Transportation				-	-	-	-	-
1.A.3.e.i - Pipeline Transport				-	-	-	-	-
1.A.3.e.ii - Off-road				-	-	-	-	-
1.A.4 - Other Sectors	882.90	26.89	0.28	278.41	2.24	9.03	47.98	-
1.A.4.a - Commercial/Institutional	36.94	1.12	0.01	19.06	0.13	0.40	1.26	-
1.A.4.b - Residential	436.67	25.72	0.27	259.35	2.11	8.64	46.72	-
1.A.4.c - Agriculture/Forestry/Fishing/Fish Farms	409.29	0.0577515	0.003465	-	-	-	-	-
1.A.4.c.i - Stationary	0.43	0.0001	0.000003	-	-	-	-	-
1.A.4.c.ii - Off-road Vehicles and Other Machinery	170.53	0.0239	0.0014	-	-	-	-	-
1.A.4.c.iii - Fishing (mobile combustion)	238.34	0.0338	0.0020	-	-	-	-	-
1.A.5 - Non-Specified				-	-	-	-	
1.A.5.a - Stationary				-	-	-	-	-
1.A.5.b - Mobile				-	-	-	-	
1.A.5.b.i - Mobile (aviation component)				-	-	-	-	-
1.A.5.b.ii - Mobile (water-borne component)				-	-	-	-	-
1.A.5.b.iii - Mobile (Other)				-	-	-	-	-
1.A.5.c - Multilateral Operations (1)(2)								
1.B - Fugitive emissions from fuels	8.24	0.76	0.0001	-	-	-	-	
1.B.1 - Solid Fuels	-	-		-	-	-	-	
1.B.1.a - Coal mining and handling	-	-		-	-	-	-	
1.B.1.a.i - Underground mines	-	-		-	-	-	-	
1.B.1.a.i.1 - Mining	-	-		-	-	-	-	
1.B.1.a.i.2 - Post-mining seam gas emissions	-	-		-	-	-	-	
1.B.1.a.i.3 - Abandoned underground mines	-	-		-	-	-	-	
1.B.1.a.i.4 - Flaring of drained methane or conversion of methane to CO2	-	-		-	-	-	-	
1.B.1.a.ii - Surface mines	-	-		-	-	-	-	
1.B.1.a.ii.1 - Mining	-	-		-	-	-	-	
1.B.1.a.ii.2 - Post-mining seam gas emissions	-	-		-	-	-	-	
1.B.1.b - Uncontrolled combustion and burning coal dumps				-	-	-	-	
1.B.1.c - Solid fuel transformation				-	-	-	-	
1.B.2 - Oil and Natural Gas	8.24	0.7599	0.0001	-	-	-	-	
1.B.2.a - Oil	8.24	0.76	0.00013	-	-	-	-	
1.B.2.a.i - Venting				-	-	-	-	
1.B.2.a.ii - Flaring	8.24	0.01	0.0001	-	-	-	-	
1.B.2.a.iii - All Other		0.75		-	-	-	-	
1.B.2.a.iii.1 - Exploration				-	-	-	-	
1.B.2.a.iii.2 - Production and Upgrading				-	-	-	-	
1.B.2.a.iii.3 - Transport				-	-	-	-	
1.B.2.a.iii.4 - Refining		0.75		-	-	-	-	
1.B.2.a.iii.5 - Distribution of oil products				-	-	-	-	
1.B.2.a.iii.6 - Other				-	-	-	-	
1.B.2.b - Natural Gas	0.00	0.0020	-	-	-	-	-	
1.B.2.b.i - Venting				-	-	-	-	
1.B.2.b.ii - Flaring				-	-	-	-	
1.B.2.b.iii - All Other	0.00	0.0020	-	-	-	-	-	
1.B.2.b.iii.1 - Exploration				-	-	-	-	

1.B.2.b.iii.2 - Production				-	-	-	-	
1.B.2.b.iii.3 - Processing	0.000820	1.406E-06	-	-	-	-	-	
1.B.2.b.iii.4 - Transmission and Storage				-	-	-	-	
1.B.2.b.iii.5 - Distribution	0.00006	0.00204	-	-	-	-	-	
1.B.2.b.iii.6 - Other				-	-	-	-	
1.B.3 - Other emissions from Energy Production				-	-	-	-	
1.C - Carbon dioxide Transport and Storage	-			-	-	-	-	
1.C.1 - Transport of CO2	-			-	-	-	-	
1.C.1.a - Pipelines	-			-	-	-	-	
1.C.1.b - Ships	-			-	-	-	-	
1.C.1.c - Other (please specify)	-			-	-	-	-	
1.C.2 - Injection and Storage	-			-	-	-	-	
1.C.2.a - Injection	-			-	-	-	-	
1.C.2.b - Storage	-			-	-	-	-	
1.C.3 - Other	-			-	-	-	-	

Annexe 1.4 IPPU sectoral table – 2016

Categories	(Gg)			CO_2 Equivalents (Gg)			
	CO_2	CH_4	N_2O	HFCs	PFCs	SF_6	Other halogenated gases with CO_2 equivalent conversion factors
2 - Industrial Processes and Product Use	394.81	-	-	613.00	33.319	-	-
2.A - Mineral Industry	334.08	-	-	-	-	-	-
2.A.1 - Cement production	21.85						
2.A.2 - Lime production	-						
2.A.3 - Glass Production	-						
2.A.4 - Other Process Uses of Carbonates	312.23	-	-	-	-	-	-
2.A.4.a - Ceramics	-						
2.A.4.b - Other Uses of Soda Ash	0.02						
2.A.4.c - Non-Metallurgical Magnesia Production	-						
2.A.4.d - Other (please specify)	312.22						
2.A.5 - Other (please specify)							
2.B - Chemical Industry	-	-	-	-	-	-	-
2.B.1 - Ammonia Production	-						
2.B.2 - Nitric Acid Production			-				
2.B.3 - Adipic Acid Production			-				
2.B.4 - Caprolactam, Glyoxal and Glyoxylic Acid Production			-				
2.B.5 - Carbide Production	-	-					
2.B.6 - Titanium Dioxide Production	-						
2.B.7 - Soda Ash Production	-						
2.B.8 - Petrochemical and Carbon Black Production	-	-	-	-	-	-	-
2.B.8.a - Methanol	-	-					
2.B.8.b - Ethylene	-	-					
2.B.8.c - Ethylene Dichloride and Vinyl Chloride Monomer	-	-					
2.B.8.d - Ethylene Oxide	-	-					
2.B.8.e - Acrylonitrile	-	-					
2.B.8.f - Carbon Black	-	-					
2.B.9 - Fluorochemical Production	-	-	-	-	-	-	-
2.B.9.a - By-product emissions				-			
2.B.9.b - Fugitive Emissions							
2.B.10 - Other (Please specify)							
2.C - Metal Industry	58.65	-	-	-	33.32	-	-
2.C.1 - Iron and Steel Production	3.79	-					
2.C.2 - Ferroalloys Production	-	-					
2.C.3 - Aluminium production	54.86				33.32		
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	2.08	-	-	-	-	-	-
2.D.1 - Lubricant Use	2.08						
2.D.2 - Paraffin Wax Use	-						
2.D.3 - Solvent Use							
2.D.4 - Other (please specify)							
2.E - Electronics Industry	-	-	-	-	-	-	-
2.E.1 - Integrated Circuit or Semiconductor				-	-	-	
2.E.2 - TFT Flat Panel Display					-	-	

2.E.3 - Photovoltaics					-		
2.E.4 - Heat Transfer Fluid					-		
2.E.5 - Other (please specify)							
2.F - Product Uses as Substitutes for Ozone Depleting Substances	-	-	-	613.00	-	-	-
2.F.1 - Refrigeration and Air Conditioning	-	-	-	613.00	-	-	-
2.F.1.a - Refrigeration and Stationary Air Conditioning				613.00			
2.F.1.b - Mobile 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.G.1 - Electrical Equipment	-	-	-	-	-	-	-
2.G.1.a - Manufacture of Electrical Equipment					-	-	
2.G.1.b - Use of Electrical Equipment					-	-	
2.G.1.c - Disposal of Electrical Equipment					-	-	
2.G.2 - SF6 and PFCs from Other Product Uses	-	-	-	-	-	-	-
2.G.2.a - Military Applications					-	-	
2.G.2.b - Accelerators					-	-	
2.G.2.c - Other (please specify)					-	-	
2.G.3 - N2O from Product Uses	-	-	-	-	-	-	-
2.G.3.a - Medical Applications			-				
2.G.3.b - Propellant for pressure and aerosol products			-				
2.G.3.c - Other (Please specify)			-				
2.G.4 - Other (Please specify)							
2.H - Other	-	-	-	-	-	-	-
2.H.1 - Pulp and Paper Industry							
2.H.2 - Food and Beverages Industry							
2.H.3 - Other (please specify)							

Annexe 1.5 AFOLU sectoral table – 2016

Categories	(Gg)					
	Net CO_2 emissions / removals	Emissions				
		CH_4	N_2O	NOx	CO	NMVOCs
3 - Agriculture, Forestry, and Other Land Use	12,908.42	156.76	21.73	0	0	0
3.A - Livestock	-	121.14	3.07	0	0	0
3.A.1 - Enteric Fermentation	-	114.66	-	-	-	-
3.A.1.a - Cattle	-	56.27	-	-	-	-
3.A.1.a.i - Dairy Cows		-		-	-	-
3.A.1.a.ii - Other Cattle		56.27		-	-	-
3.A.1.b - Buffalo		-		-	-	-
3.A.1.c - Sheep		23.72		-	-	-
3.A.1.d - Goats		33.70		-	-	-
3.A.1.e - Camels		-		-	-	-
3.A.1.f - Horses		0.05		-	-	-
3.A.1.g - Mules and Asses		0.15		-	-	-
3.A.1.h - Swine		0.78		-	-	-

3.A.1.j - Other (please specify)		-		-	-	-
3.A.2 - Manure Management (1)	-	6.48	3.07	-	-	-
3.A.2.a - Cattle	-	1.82	1.36	-	-	-
3.A.2.a.i - Dairy cows		-	-	-	-	-
3.A.2.a.ii - Other cattle		1.82	1.36	-	-	-
3.A.2.b - Buffalo		-	-	-	-	-
3.A.2.c - Sheep		0.95	0.71	-	-	-
3.A.2.d - Goats		1.48	0.95	-	-	-
3.A.2.e - Camels		-	-	-	-	-
3.A.2.f - Horses		0.01	0.00	-	-	-
3.A.2.g - Mules and Asses		0.02	0.00	-	-	-
3.A.2.h - Swine		0.78	0.02	-	-	-
3.A.2.i - Poultry		1.43	0.03	-	-	-
3.A.2.j - Other (please specify)		-	-	-	-	-
3.B - Land	12,872.05	-	-	-	-	-
3.B.1 - Forest land	(4,668.07)	-	-	-	-	-
3.B.1.a - Forest land Remaining Forest land	(3,562.51)			-	-	-
3.B.1.b - Land Converted to Forest land	(1,105.57)	-	-	-	-	-
3.B.1.b.i - Cropland converted to Forest Land	(465.91)			-	-	-
3.B.1.b.ii - Grassland converted to Forest Land	(603.22)			-	-	-
3.B.1.b.iii - Wetlands converted to Forest Land	(1.24)			-	-	-
3.B.1.b.iv - Settlements converted to Forest Land	(31.84)			-	-	-
3.B.1.b.v - Other Land converted to Forest Land	(3.37)			-	-	-
3.B.2 - Cropland	8,331.46	-	-	-	-	-
3.B.2.a - Cropland Remaining Cropland	(506.42)			-	-	-
3.B.2.b - Land Converted to Cropland	8,837.88	-	-	-	-	-
3.B.2.b.i - Forest Land converted to Cropland	10,334.45			-	-	-
3.B.2.b.ii - Grassland converted to Cropland	(1,182.72)			-	-	-
3.B.2.b.iii - Wetlands converted to Cropland	2.17			-	-	-
3.B.2.b.iv - Settlements converted to Cropland	(302.83)			-	-	-
3.B.2.b.v - Other Land converted to Cropland	(13.19)			-	-	-
3.B.3 - Grassland	8,804.18	-	-	-	-	-
3.B.3.a - Grassland Remaining Grassland	0			-	-	-
3.B.3.b - Land Converted to Grassland	8,804.18	-	-	-	-	-
3.B.3.b.i - Forest Land converted to Grassland	10,847.35			-	-	-
3.B.3.b.ii - Cropland converted to Grassland	(1,951.47)			-	-	-
3.B.3.b.iii - Wetlands converted to Grassland	(8.59)			-	-	-
3.B.3.b.iv - Settlements converted to Grassland	(52.51)			-	-	-
3.B.3.b.v - Other Land converted to Grassland	(30.59)			-	-	-
3.B.4 - Wetlands	30.48	-	-	-	-	-
3.B.4.a - Wetlands Remaining Wetlands	-	-	-	-	-	-
3.B.4.a.i - Peatlands remaining peatlands	-		-	-	-	-
3.B.4.a.ii - Flooded land remaining flooded land				-	-	-
3.B.4.b - Land Converted to Wetlands	30.48	-	-	-	-	-
3.B.4.b.i - Land converted for peat extraction			-	-	-	-
3.B.4.b.ii - Land converted to flooded land	-			-	-	-
3.B.4.b.iii - Land converted to other wetlands	30.48			-	-	-
3.B.5 - Settlements	173.75	-	-	-	-	-
3.B.5.a - Settlements Remaining Settlements	-			-	-	-
3.B.5.b - Land Converted to Settlements	173.75	-	-	-	-	-
3.B.5.b.i - Forest Land converted to Settlements	88.98			-	-	-

3.B.5.b.ii - Cropland converted to Settlements	71.54			-	-	-
3.B.5.b.iii - Grassland converted to Settlements	13.23			-	-	-
3.B.5.b.iv - Wetlands converted to Settlements	-			-	-	-
3.B.5.b.v - Other Land converted to Settlements	-			-	-	-
3.B.6 - Other Land	200.25	-	-	-	-	-
3.B.6.a - Other land Remaining Other lands				-	-	-
3.B.6.b - Land Converted to Other land	200.25	-	-	-	-	-
3.B.6.b.i - Forest Land converted to Other Land	136.04			-	-	-
3.B.6.b.ii - Cropland converted to Other Land	37.22			-	-	-
3.B.6.b.iii - Grassland converted to Other Land	26.99			-	-	-
3.B.6.b.iv - Wetlands converted to Other Land	-			-	-	-
3.B.6.b.v - Settlements converted to Other Land	-			-	-	-
3.C - Aggregate sources and non-CO2 emissions sources on land (2)	36.37	35.62	18.65	-	-	-
3.C.1 - Emissions from biomass burning	-	25.18	1.42	-	-	-
3.C.1.a - Biomass burning in forest lands		2.30	0.21	-	-	-
3.C.1.b - Biomass burning in croplands		14.17	0.42	-	-	-
3.C.1.c - Biomass burning in grasslands		8.71	0.79	-	-	-
3.C.1.d - Biomass burning in all other lands		-	-	-	-	-
3.C.2 - Liming	-			-	-	-
3.C.3 - Urea application	36.37			-	-	-
3.C.4 - Direct N2O Emissions from managed soils (3)			13.36	-	-	-
3.C.5 - Indirect N2O Emissions from managed soils			3.68	-	-	-
3.C.6 - Indirect N2O Emissions from manure management			0.19	-	-	-
3.C.7 - Rice cultivations		10.44		-	-	-
3.C.8 - Other (please specify)				-	-	-
3.D - Other	-	-	-	-	-	-
3.D.1 - Harvested Wood Products	-			-	-	-
3.D.2 - Other (please specify)				-	-	-

Annexe 1.6 Waste sectoral table – 2016

Categories	Emissions [Gg]						
	CO_2	CH_4	N_2O	NOx	CO	NMVOCs	SO2
4 - Waste	8.68	121.89	1.93	-	-	-	-
4.A - Solid Waste Disposal	-	55.01	-	-	-	-	-
4.A.1 - Managed Waste Disposal Sites				-	-	-	-
4.A.2 - Unmanaged Waste Disposal Sites				-	-	-	-
4.A.3 - Uncategorised Waste Disposal Sites				-	-	-	-
4.B - Biological Treatment of Solid Waste		2.45	0.15	-	-	-	-
4.C - Incineration and Open Burning of Waste	8.68	2.75	0.04	-	-	-	-
4.C.1 - Waste Incineration	2.16	0.02	0.00	-	-	-	-
4.C.2 - Open Burning of Waste	6.52	2.73	0.04	-	-	-	-
4.D - Wastewater Treatment and Discharge	-	61.69	1.75	-	-	-	-
4.D.1 - Domestic Wastewater Treatment and Discharge		32.04	1.75	-	-	-	-
4.D.2 - Industrial Wastewater Treatment and Discharge		29.65		-	-	-	-
4.E - Other (please specify)				-	-	-	-

Annexe 2:

Annexe 2.1 Sample Copy of MOU

Work-Package Memorandum of Understand (WP-MoU) Between Environmental Protection Agency and National Greenhouse Gas Inventory Entities in Ghana

What does the WP-MoU seek to do?

i. The vision of the new greenhouse gas inventory in Ghana is to, first, become more relevant to government policies and national planning and secondly, be able to meet present and future international reporting requirements. The GHG inventory system must be integrated to the extent that it would become responsive to any future international mechanism intended to subject the inventories to either "facilitative" or "technical" reviews, which may be required of the country. To ensure that Ghana's ability is strengthened to undertake the GHG inventory regularly and to make it relevant to decision-making, and improved National System for GHG Inventory is to be implemented under the Third National Communication (TNC).

ii. The National System for GHG inventory is mainly defined by a framework, which contains a set of institutions, their roles and responsibilities and above all, the collaborative mechanisms, which underpin them. As part of the efforts to establish a national system under the NC3, a new institutional arrangement has been put in place. The institutions have been identified; their roles and responsibilities defined and reporting channels have been delineated. The various organisations (GHG inventory entities) were selected based on their competence and relevance to the GHG inventory sectors.

iii. Considering the national circumstances of Ghana, the "state of progress of Ghana's inventory system and what the inventory system is envisaged to be in the coming years, the Environmental Protection Agency has in consultation with the key stakeholders, adopted the "Work-Package MoU" option. This is considered to be practical and suitable as the practical working guidance document between the Environmental Protection Agency and all the inventory entities.

iv. This WP-MoU, therefore, seeks to establish a set of common understanding GHG inventory tasks, which would be undertaken by the inventory entities during the latest inventory cycle. The list of activities that would be undertaken by the inventory entities would be designed to become consistent with the timeframe of the inventory and the available budget for the sector, bearing in mind that, the administrative and technical bottlenecks that are likely to hamper the smooth delivery of the activities within a reasonable time-frame would be progressively managed.

v. As much as possible, the activities that are to be undertaken by the inventory entities would be dependent on the overall satisfaction of all condition precedent on the part of the Environmental Protection Agency and the said entity. Because the Agency intends to ensure that the efficiency of the National System is progressively improved and become more integrated, the WP-MoU would be reviewed at the beginning and end of every inventory and reporting cycle. The purpose of the review is to help improve upon the overall efficiency of the national system and to make it more responsive to the lessons learnt in the previous inventory cycle.

Preamble

The Environmental Protection Agency is the Designated National GHG inventory Entity and in collaboration with "National Entity A"; recognises that:

i. There is an urgent need to have the national GHG inventories processes mainstreamed into the activities of the various inventory entities and making it relevant for national development and international reporting;

ii. Strengthening the capacities of GHG inventories entities is fundamental to the ability of Ghana to meet the increasing demand for reporting on GHG emissions regularly;

iii. Making GHG inventories relevant to sector planning and development, would facilitate the assessment of impacts of Ghana's policies and measures and support it received on GHG mitigation and development in general;

iv. A fully-fledged GHG national system in Ghana that is operational would help prepare Ghana for any potential review of our national GHG inventory system in the country or by any international body;

Responsibilities of Entity A

The Entity would be responsible for undertaking the following GHG inventories activities in the Energy sector with support from the Environmental Protection Agency.

i. Conduct a comprehensive assessment of GHG data requirements of the Energy sector, identify the sources and access them with the support of the inventory coordinator using appropriate channels and document all the data and processes involved.

ii. Collect, collate, process and update all GHG and related data in the Energy sector, and take final decisions on which processed data qualifies to be used in the inventory based on agreed conditions in the QA/QC plan.

iii. Submit all processed data and any other data to the central database hosted at the Environmental Protection Agency and keep back-up in your organisation.

iv. Liaise with the inventory coordinator at EPA to undertake a comprehensive review of available methodological choices and make sound methodological choices based on its applicability to the estimation of GHG emissions.

v. Estimate GHG emissions for all categories and gases under your sector using appropriate factors/ Global Warming Potentials (GWPs) that are occurring in Ghana and ensure that the processes/assumptions for the estimation including the software used are consistent with the Intergovernmental Panel on Climate Change (IPCC) Guidelines and fully documented.

vi. Conduct key categories analysis for the energy sector and uncertainty assessment, where appropriate and to the extent possible, in collaboration with the generalist and the uncertainty management lead.

vii. Compile all the Energy sector estimates in the worksheets into "detail", and "synthesis" reports including clear, prioritised plans for improvements to be incorporated into the national inventory report.

i. Create and maintain hard and soft back-up copies of all information, data, and estimates at the sector level and for subsequent onward transmission to the Environmental Protection Agency and Ghana Statistical Services as the inventory documentation and archiving depository.

ii. Consult with the inventory coordinator to discuss and agree on the cost involved in activities that can be done within the quarter in the inventory year. The rate and mode for requesting funds would be discussed and agreed ahead of every inventory cycle.

Timelines

iii. The activities listed above must be prioritised and implemented Not only based on the sequence of activities but in a manner that is realistic and achievable within the overall timeframe of the inventory cycle.

This WP-MoU has been done between the Environmental Protection Agency and the GHG Inventory Entity on

……..date…….

For: Environmental Protection Agency
(National Inventory Entity)
Executive Director

For: Entity A
(Energy Sector, Lead)
Executive Secretary

Annexe 3: Fractions of solid waste streams

Year	Population	Population (Million)	Waste per Capita (kg/cap/year)	Waste per Capita (kg/cap/day)	Total MSW Generation (tonnes)	Total MSW Generation (Gg)	% Waste deposited at SWDS	Waste collection/Deposited (Gg)	Waste Composition Deposited at SWD Sites								
									Food (73%,60%,47%)	Garden IE	Paper (7%,8%,9%)	Wood IE	Textile (2%, 4%,8%)	Nappies IE	Plastics (3%,8%, 17%)	Others (15%,20%,19%)	Total
1950	4,980,878	4.981	146.00	0.4	727,208	727.21	0.36	261.795	191.110	IE	18.326	IE	5.236	IE	7.854	39.269	261.795
1951	5,068,433	5.068	146.00	0.4	739,991	739.99	0.36	266.397	194.470	IE	18.648	IE	5.328	IE	7.992	39.960	266.397
1952	5,191,221	5.191	146.00	0.4	757,918	757.92	0.36	272.851	199.181	IE	19.100	IE	5.457	IE	8.186	40.928	272.851
1953	5,339,178	5.339	146.00	0.4	779,520	779.52	0.36	280.627	204.858	IE	19.644	IE	5.613	IE	8.419	42.094	280.627
1954	5,504,255	5.504	146.00	0.4	803,621	803.62	0.36	289.304	211.192	IE	20.251	IE	5.786	IE	8.679	43.396	289.304
1955	5,680,410	5.680	146.00	0.4	829,340	829.34	0.36	298.562	217.951	IE	20.899	IE	5.971	IE	8.957	44.784	298.562
1956	5,831,509	5.832	146.00	0.4	851,400	851.40	0.36	306.504	223.748	IE	21.455	IE	6.130	IE	9.195	45.976	306.504
1957	5,986,627	5.987	146.00	0.4	874,048	874.05	0.36	314.657	229.700	IE	22.026	IE	6.293	IE	9.440	47.199	314.657
1958	6,145,871	6.146	146.00	0.4	897,297	897.30	0.36	323.027	235.810	IE	22.612	IE	6.461	IE	9.691	48.454	323.027
1959	6,309,351	6.309	146.00	0.4	921,165	921.17	0.36	331.620	242.082	IE	23.213	IE	6.632	IE	9.949	49.743	331.620
1960	6,726,815	6.727	146.00	0.4	982,115	982.11	0.36	353.561	258.100	IE	24.749	IE	7.071	IE	10.607	53.034	353.561
1961	6,942,746	6.943	146.00	0.4	1,013,641	1013.64	0.36	364.911	266.385	IE	25.544	IE	7.298	IE	10.947	54.737	364.911
1962	7,165,608	7.166	146.00	0.4	1,046,179	1046.18	0.36	376.624	274.936	IE	26.364	IE	7.532	IE	11.299	56.494	376.624
1963	7,395,624	7.396	146.00	0.4	1,079,761	1079.76	0.36	388.714	283.761	IE	27.210	IE	7.774	IE	11.661	58.307	388.714
1964	7,633,023	7.633	146.00	0.4	1,114,421	1114.42	0.36	401.192	292.870	IE	28.083	IE	8.024	IE	12.036	60.179	401.192
1965	7,710,549	7.711	146.00	0.4	1,125,740	1125.74	0.36	405.266	295.845	IE	28.369	IE	8.105	IE	12.158	60.790	405.266
1966	7,941,865	7.942	146.00	0.4	1,159,512	1159.51	0.36	417.424	304.720	IE	29.220	IE	8.348	IE	12.523	62.614	417.424
1967	8,180,121	8.180	146.00	0.4	1,194,298	1194.30	0.36	429.947	313.861	IE	30.096	IE	8.599	IE	12.898	64.492	429.947
1968	8,425,525	8.426	146.00	0.4	1,230,127	1230.13	0.36	442.846	323.277	IE	30.999	IE	8.857	IE	13.285	66.427	442.846
1969	8,678,291	8.678	146.00	0.4	1,267,030	1267.03	0.36	456.131	332.976	IE	31.929	IE	9.123	IE	13.684	68.420	456.131
1970	8,559,313	8.559	146.00	0.4	1,249,660	1249.66	0.36	449.877	328.411	IE	31.491	IE	8.998	IE	13.496	67.482	449.877
1971	8,747,618	8.748	146.00	0.4	1,277,152	1277.15	0.36	459.775	335.636	IE	32.184	IE	9.195	IE	13.793	68.966	459.775
1972	8,940,065	8.940	146.00	0.4	1,305,250	1305.25	0.36	469.890	343.020	IE	32.892	IE	9.398	IE	14.097	70.483	469.890

1973	9,136,747	9.137	146.00	0.4	1,333,965	1333.97	0.36	480.227	350.566	IE	33.616	IE	9.605	IE	14.407	72.034	480.227
1974	9,337,755	9.338	146.00	0.4	1,363,312	1363.31	0.36	490.792	358.278	IE	34.355	IE	9.816	IE	14.724	73.619	490.792
1975	9,831,407	9.831	146.00	0.4	1,435,385	1435.39	0.36	516.739	377.219	IE	36.172	IE	10.335	IE	15.502	77.511	516.739
1976	10,054,580	10.055	146.00	0.4	1,467,969	1467.97	0.36	528.469	385.782	IE	36.993	IE	10.569	IE	15.854	79.270	528.469
1977	10,282,819	10.283	146.00	0.4	1,501,292	1501.29	0.36	540.465	394.539	IE	37.833	IE	10.809	IE	16.214	81.070	540.465
1978	10,516,239	10.516	146.00	0.4	1,535,371	1535.37	0.36	552.734	403.495	IE	38.691	IE	11.055	IE	16.582	82.910	552.734
1979	10,754,958	10.755	146.00	0.4	1,570,224	1570.22	0.36	565.281	412.655	IE	39.570	IE	11.306	IE	16.958	84.792	565.281
1980	10,802,028	10.802	146.00	0.4	1,577,096	1577.10	0.36	567.755	414.461	IE	39.743	IE	11.355	IE	17.033	85.163	567.755
1981	11,160,655	11.161	146.00	0.4	1,629,456	1629.46	0.36	586.604	428.221	IE	41.062	IE	11.732	IE	17.598	87.991	586.604
1982	11,531,189	11.531	146.00	0.4	1,683,554	1683.55	0.36	606.079	442.438	IE	42.426	IE	12.122	IE	18.182	90.912	606.079
1983	11,914,025	11.914	146.00	0.4	1,739,448	1739.45	0.36	626.201	457.127	IE	43.834	IE	12.524	IE	18.786	93.930	626.201
1984	12,296,081	12.296	146.00	0.4	1,795,228	1795.23	0.36	646.282	471.786	IE	45.240	IE	12.926	IE	19.388	96.942	646.282
1985	12,628,075	12.628	146.00	0.4	1,843,699	1843.70	0.36	663.732	484.524	IE	46.461	IE	13.275	IE	19.912	99.560	663.732
1986	12,969,033	12.969	146.00	0.4	1,893,479	1893.48	0.36	681.652	497.606	IE	47.716	IE	13.633	IE	20.450	102.248	681.652
1987	13,319,197	13.319	146.00	0.4	1,944,603	1944.60	0.36	700.057	511.042	IE	49.004	IE	14.001	IE	21.002	105.009	700.057
1988	13,678,815	13.679	146.00	0.4	1,997,107	1997.11	0.36	718.959	524.840	IE	50.327	IE	14.379	IE	21.569	107.844	718.959
1989	14,048,143	14.048	146.00	0.4	2,051,029	2051.03	0.36	738.370	539.010	IE	51.686	IE	14.767	IE	22.151	110.756	738.370
1990	14,343,359	14.343	146.00	0.4	2,094,130	2094.13	0.36	753.887	550.337	IE	52.772	IE	15.078	IE	22.617	113.083	753.887
1991	14,716,287	14.716	146.00	0.4	2,148,578	2148.58	0.38	816.460	596.015	IE	57.152	IE	16.329	IE	24.494	122.469	816.460
1992	15,098,910	15.099	146.00	0.4	2,204,441	2204.44	0.40	881.776	643.697	IE	61.724	IE	17.636	IE	26.453	132.266	881.776
1993	15,491,482	15.491	146.00	0.4	2,261,756	2261.76	0.42	949.938	693.454	IE	66.496	IE	18.999	IE	28.498	142.491	949.938
1994	15,894,260	15.894	146.00	0.4	2,320,562	2320.56	0.44	1021.047	745.365	IE	71.473	IE	20.421	IE	30.631	153.157	1021.047
1995	16,307,511	16.308	146.00	0.4	2,380,897	2380.90	0.46	1095.212	799.505	IE	76.665	IE	21.904	IE	32.856	164.282	1095.212
1996	16,731,506	16.732	146.00	0.4	2,442,800	2442.80	0.49	1192.086	870.223	IE	83.446	IE	23.842	IE	35.763	178.813	1192.086
1997	17,166,526	17.167	146.00	0.4	2,506,313	2506.31	0.52	1293.257	944.078	IE	90.528	IE	25.865	IE	38.798	193.989	1293.257
1998	17,612,855	17.613	146.00	0.4	2,571,477	2571.48	0.54	1398.883	1021.185	IE	97.922	IE	27.978	IE	41.967	209.833	1398.883
1999	18,070,790	18.071	146.00	0.4	2,638,335	2638.34	0.57	1509.128	1101.663	IE	105.639	IE	30.183	IE	45.274	226.369	1509.128
2000	18,912,079	18.912	146.00	0.4	2,761,164	2761.16	0.60	1656.698	994.019	IE	132.536	IE	66.268	IE	132.536	331.340	1656.698

2001	19,422,705	19.423	146.00	0.4	2,835,715	2835.71	0.61	1724.965	1034.979	IE	137.997	IE	68.999	IE	137.997	344.993	1724.965
2002	19,947,118	19.947	146.00	0.4	2,912,279	2912.28	0.62	1795.711	1077.427	IE	143.657	IE	71.828	IE	143.657	359.142	1795.711
2003	20,485,690	20.486	146.00	0.4	2,990,911	2990.91	0.62	1869.289	1121.574	IE	149.543	IE	74.772	IE	149.543	373.858	1869.289
2004	21,038,804	21.039	146.00	0.4	3,071,665	3071.67	0.63	1945.286	1167.171	IE	155.623	IE	77.811	IE	155.623	389.057	1945.286
2005	21,606,852	21.607	164.25	0.45	3,548,925	3548.93	0.64	2277.203	1366.322	IE	182.176	IE	91.088	IE	182.176	455.441	2277.203
2006	22,190,237	22.190	164.25	0.45	3,644,746	3644.75	0.65	2369.085	1421.451	IE	189.527	IE	94.763	IE	189.527	473.817	2369.085
2007	22,789,373	22.789	164.25	0.45	3,743,155	3743.15	0.69	2573.419	1544.051	IE	205.873	IE	102.937	IE	205.873	514.684	2573.419
2008	23,404,686	23.405	164.25	0.45	3,844,220	3844.22	0.73	2787.059	1672.236	IE	222.965	IE	111.482	IE	222.965	557.412	2787.059
2009	24,036,613	24.037	164.25	0.45	3,948,014	3948.01	0.76	3010.360	1806.216	IE	240.829	IE	120.414	IE	240.829	602.072	3010.360
2010	24,658,823	24.659	164.25	0.45	4,050,212	4050.21	0.80	3240.169	1944.102	IE	259.214	IE	129.607	IE	259.214	648.034	3240.169
2011	25,275,294	25.275	164.25	0.45	4,151,467	4151.47	0.80	3321.174	1560.952	IE	298.906	IE	265.694	IE	564.600	631.023	3321.174
2012	25,907,176	25.907	164.25	0.45	4,255,254	4255.25	0.80	3404.203	1599.975	IE	306.378	IE	272.336	IE	578.714	646.799	3404.203
2013	26,554,855	26.555	164.25	0.45	4,361,635	4361.63	0.80	3489.308	1639.975	IE	314.038	IE	279.145	IE	593.182	662.969	3489.308
2014	27,218,727	27.219	164.25	0.45	4,470,676	4470.68	0.80	3576.541	1680.974	IE	321.889	IE	286.123	IE	608.012	679.543	3576.541
2015	27,899,195	27.899	171.55	0.47	4,786,107	4786.11	0.80	3828.886	1799.576	IE	344.600	IE	306.311	IE	650.911	727.488	3828.886
2016	28,596,675	28.597	171.55	0.47	4,905,760	4905.76	0.80	3924.608	1844.566	IE	353.215	IE	313.969	IE	667.183	745.675	3924.608

Annexe 4: Food Waste Proportion Variation and its Effects on Emission from IPCC Default

Year	Food (%)		Paper (%)		Wood (%)		Textiles (%)		Plastics		Others*	
	CS	GL	CS	GL	CS	GL	CS	GL	CS	GL	CS	GL
2013	47	40.4	9	9.8	0	4.4	8	1	17	3	19	44.4
2014	47	40.4	9	9.8	0	4.4	8	1	17	3	19	44.4
2015	47	40.4	9	9.8	0	4.4	8	1	17	3	19	44.4
2016	47	40.4	9	9.8	0	4.4	8	1	17	3	19	44.4

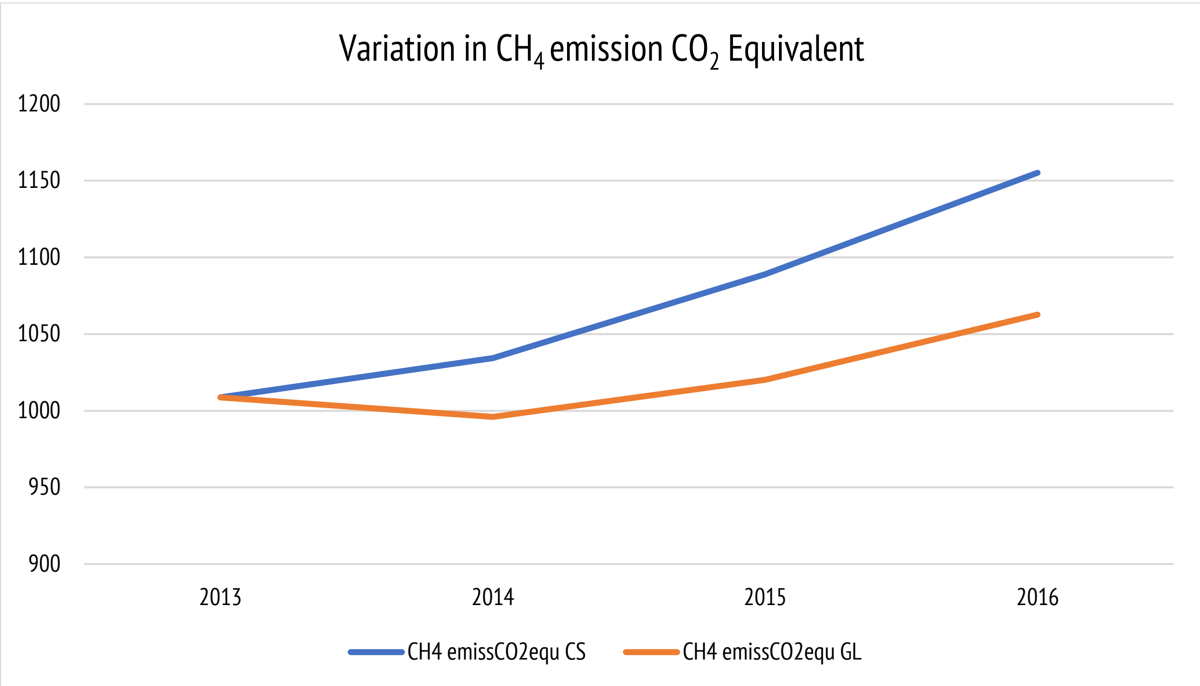
Key: CS: Country specific,

GL:- IPCC Default Value (IPCC 2006 Guidelines Chapter 2, Waste Generation, Composition and Management Data, Page 12, 2.12, Table 2.3)

* Plastics – 3%, and other (41.4%)

Year	CH_4 Generated		% Variation	Methane Emissions		% Variation
	CS	GL		CS	GL	
2013	8.788	8.788	0.000	48.035	48.035	0.000
2014	9.454	9.566	1.184	49.257	47.429	-3.712
2015	10.208	10.436	2.236	51.852	48.579	-6.313
2016	11.009	11.355	3.137	55.010	50.603	-8.011

Year	CH_4 emission CO_2equivalent		% Variation
	CS	GL	
2013	1008.740	1008.741	0.000
2014	1034.404	996.004	-3.712
2015	1088.888	1020.151	-6.313
2016	1155.219	1062.671	-8.011



References

1. EPA, 1994. Environmental Protection Agency Act, 1994.
2. EPA, 2016. Ghana Climate Ambitious Reporting Programme.
3. European Environment Agency, 2016. EMEP/EEA air pollutant emission inventory guidebook 2016. Technical guidance to prepare national emission inventories.
4. UNFCCC. Decision 1/CP 16. Report of the Conference of the Parties on its sixteenth session, held in Cancun from 29 November to 10 December 2010. GE.11-60550.
5. UNFCCC. Decision 17/CP 8. Guidelines for the preparation of national communications from Parties not included in Annex I to the Convention. November 2002.
6. UNFCCC. Decision 2/CP 1.7. Report of the Conference of the Parties on its seventeenth session, held in Durban from 28 November to 11 December 2011. GE.12-60548.
7. Intergovernmental Panel on Climate Change (IPCC), 2003. Good Practice Guidance for Land Use, Land-Use Change and Forestry. Published by the Institute for Global Environmental Strategies (IGES) for the IPCC.
8. Intergovernmental Panel on Climate Change (IPCC), 2000.Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories.
9. EPA, 2017. National Greenhouse Gas Inventory Manual of Procedures.
10. United Nations, 2015. Paris Agreement.
11. Intergovernmental Panel on Climate Change (IPCC), 2006. 2006 IPCC Guidelines for National Greenhouse Gas Inventories.
12. Ministry of Food and Agriculture. 2016. Agriculture Facts and Figures. http://mofa.gov.gh/site/wp-content/uploads/2011/04/mofa_facts_and_figures.pdf accessed in April 2018
13. Energy Commission, 2018. Energy Statistics. http://www.energycom.gov.gh/planning/data-center/energy-statistics accessed in February 2018.
14. National Petroleum Authority, 2018. National Fuel Consumption. http://www.npa.gov.gh/downloads accessed in November 2017.
15. Forestry Commission, 2017. Ghana's National Forest Reference Level. https://redd.unfccc.int/files/ghana__modified_frl_november_10_2017_clean.pdf accessed in June 2018.
16. FAO, 2018. FAOSTAT http://www.fao.org/ghana/en/ accessed in February 2018.
17. World Bank Group, 2018. https://data.worldbank.org/country/ghana accessed in March 2018.
18. EPA, 2015. Ghana's First Biennial Update Report to the UNFCCC. https://unfccc.int/files/national_reports/non-annex_i_parties/biennial_update_reports/application/pdf/ghnbur1.pdf accessed in July 2018.
19. EPA, 2015. Ghana's Greenhouse Gas Inventory Report. https://unfccc.int/sites/default/files/resource/NIR1%20to%20BUR1_Ghana.pdf accessed in July 2016
20. Glen P. Peters, Robbie M. Andrew, Josep G. Canadell, Sabine Fuss, Robert B. Jackson, Jan Ivar Korsbakken, Corinne Le Quéré and Nebojsa Nakicenovic, 2017. Key indicators to track current progress and future ambition of the Paris Agreement. Nature Climate Change. 30 January 2017.
21. Ministry of Local Government and Rural Development, 2010. National Environmental Sanitation Strategy and Action Plan NESSAP: materials in transition MINT.
22. Ghana Statistical Service. 2015. Ghana Living Standard Survey 6.
23. Ghana Statistical Service, 2011. Multiple Indicator Cluster Survey with an Enhanced Malaria Module and Biomarker.