VASUDHA FOUNDATION
Green ways for a good earth!

DIRECTORATE OF ENVIRONMENT AND CLIMATE CHANGE
Department of Environment
Government of Kerala

SAPCC 2.0 IMPLEMENTATION

KERALA GHG INVENTORY REPORT

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Directorate of Environment & Climate Change
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The Directorate of Environment and Climate Change (DoECC) is a wing of the Department of Environment, Government of Kerala. DoECC is the nodal agency in the administrative structure of the Environment Department, for the planning, coordination and overseeing of the implementation of the Environment and Climate Change policies and programmes of the Central and State Governments.DoECC coordinates all the Climate Change Actions and programmes in the State.

Kerala GHG Inventory Report-State Policy Document

SAPCC 2.0 Implementation

Citation: DoECC, 2024. Kerala GHG Inventory Report, Directorate of Environment and Climate Change, Department of Environment, Government of Kerala.

Priority Intervention
Outcome 6: State-wide climate data collection and database systems established
Project/Objective-6-Climate Change Monitoring and Database Management
Planned Action--4-GHG Monitoring Mechanism

GOVERNMENT OF KERALA

Pinarayi Vijayan

Chief Minister

The world is currently facing an unprecedented threat in the form of climate change, which has profound impacts on nations, societies, and economies. The Government of Kerala remains dedicated to its commitment to address the challenges posed by climate change and associated extreme weather events.

Kerala has taken proactive steps and implemented various projects not just to mitigate greenhouse gas emissions, but also to build the climate resilience of vulnerable populations. The revised State Action Plan on Climate Change (SAPCC 2.0), formulated in 2022, provides crucial policy directives for Kerala in tackling climate change effectively.

The state government has set an ambitious target of achieving net-zero emissions by 2050 and I am pleased to note that the GHG Inventory of the state has been completed by the Department of Environment, Government of Kerala, as part of this initiative. This report will serve as a pivot for mitigation efforts, providing a baseline for developing a pathway towards achieving Kerala's goal of becoming carbon neutral by 2050.

Let me congratulate the Department of Environment, Government of Kerala, on the preparation of this crucial scientific report.

Pinarayi Vijayan

GOVERNMENT OF KERALA

Dr Venu V IAS

Chief Secretary

Global warming and climate change pose significant threats to humanity and are issues of utmost concern. The State has witnessed the effects of climate change as evidenced by the recent natural disasters and may continue to increase in severity and frequency. Nevertheless, Kerala stands out for its proactive approach in addressing these challenges. It is imperative to integrate climate policies and planning into all levels of governance to mitigate the release of harmful greenhouse gases. While nationally determined contributions (NDCs) at the country level offer crucial policy direction for reducing greenhouse gas emissions, Kerala is taking proactive steps to develop region-specific policies to safeguard its population.

Aligned with the national goal of achieving carbon neutrality by 2070, the Government of Kerala has declared its target of attaining carbon neutrality by 2050. I'm sure that this GHG Inventory Report will not just help to identify and track the greenhouse gas emissions across all sectors but also monitor the effectiveness of ongoing mitigation actions in the State. I congratulate the team behind this endeavour and I am confident that this document will serve as a crucial policy tool.

Dr. Venu V, IAS

GOVERNMENT OF KERALA

Dr. Rathan U. Kelkar IAS

Secretary, Environment Department

Climate change has introduced the State to new challenges that require immediate attention and action. Being the nodal agency for planning, coordination and monitoring climate change-related activities in the State, the Directorate of Environment and Climate Change (DoECC) has formulated SAPCC 2.0 which has devised the framework for climate change mitigation and adaptation actions up to 2030, to address climate change-related issues. Spearheading the carbon-neutral initiative of the Government of Kerala, the Department has given utmost priority to the development of a GHG emission monitoring mechanism, as planned in the priority interventions in SAPCC 2.0. To initiate this, the DoECC in partnership with the Vasudha Foundation has completed the GHG inventory of the State, producing a comprehensive report. This report sets the foundation for developing pathways for achieving carbon neutrality by 2050.

On behalf of the Department of Environment, Government of Kerala, I extend my gratitude to the Vasudha Foundation for technical assistance in preparing this report. I appreciate the support provided by Government departments, other stakeholders, research institutions, and organizations in the preparation of this inventory report successfully. I want to place on record a special word of appreciation for the team at DoECC who have put in their best effort to prepare this report.

Dr. Rathan U. Kelkar IAS

GOVERNMENT OF KERALA

Suneel Pamidi IFS

Director, Directorate of Environment and Climate Change

The State initiated its climate change planning back in 2014 with the inception of the State Action Plan on Climate Change (SAPCC) 1.0. This commitment was further strengthened in 2022 when Kerala revised its Action Plan to better tackle the evolving threats posed by climate change and related extremes.

The global drive towards achieving Net Zero Emissions has gained significant momentum, with numerous States and non-state entities setting ambitious targets in pursuit of this goal. The per capita emission of Kerala was significantly lower (0.41 tCO2e) than that of India's per capita emission (2.46 tCO2e) in 2019 making it the fifth least GHG-emitting State in India. Despite some localized assessments of greenhouse gas (GHG) emissions, there remains a notable gap in quantifying GHG emissions comprehensively at the state level in Kerala. Establishing a robust dataset on GHG emissions in Kerala, employing internationally recognized methodologies is very important. Such data would aid in pinpointing the primary sectors/sub-sectors responsible for GHG emissions, understanding their growth patterns over time, and identifying the underlying drivers of these emissions. This, in turn, would facilitate the development of effective solutions to reduce emissions from these sectors/sub-sectors. Furthermore, leveraging Kerala's natural advantages, it is essential to assess current sequestration levels and identify areas with untapped potential for further enhancing sequestration.

The Directorate, as the nodal department responsible for implementing SAPCC 2.0 and the Government's Carbon Neutral Initiative, has partnered with the Vasudha Foundation to undertake a comprehensive GHG inventory of the State. This inventory report would form a base to chart pathways toward achieving Net Zero emissions by 2050. I congratulate and thank all the authors and editors who contributed to this scientific document, which will be a vital resource for all stakeholders committed to addressing climate change.

Suneel Pamidi IFS

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Acronyms

IPCC AR2	Second Assessment Report of Intergovernmental Panel on Climate Change
IPCC AR6	Sixth Assessment Report of Intergovernmental Panel on Climate Change
ATF	Aviation Turbine Fuel
CAGR	Compounded Annual Growth Rate
CCC	Climate Change Cell
COP	Conference of the Parties
DoECC	Directorate of Environment and Climate Change
GHGs	Greenhouse gases
GTP	Global Temperature Potential
GWP	Global Warming Potential
HSD	High-Speed Diesel
IPCC	Intergovernmental Panel on Climate Change
IPPU	Industrial Processes and Product Use
LPG	Liquefied Petroleum Gas
LULC	Land Use Land Cover Change
LULUCF	Land Use, Land-Use Change and Forestry
MoEFCC	Ministry of Environment Forest and Climate Change
NAPCC	National Action Plan for Climate Change
NDCs	Nationally Determined Contributions
SAPCC	State Action Plan on Climate Change
UNFCCC	United Nations Framework Convention on Climate Change
WG	Working Group

1

Introduction

This report compiles an inventory of anthropogenic Greenhouse Gas (GHG) emissions in Kerala, estimated as a priority policy aid and a baseline for climate change mitigation actions. The report is part of the implementation blueprint for the State Action Plan on Climate Change (SAPCC 2.0), commissioned by the State in 2022. Even though the GHG emission from the State may not own a major share in the cumulative warming phenomena at the national or global levels, the identification of the various sources of GHG emission and their quantification would aid the State in engaging in the NDC[1] commitments at the national level and to device its emission pathways.

It has been unequivocally established that the earth is warming at an increased rate and that being caused by anthropogenic GHGs[2]. On the global scale, 2023 was the planet's warmest year on record[3]. On regional scales the Kerala SAPCC 2.0 projects a *warming scenario* in the State (RCP 4.5 and RCP 8.5) for the near term (2021-2050). GHGs absorb infrared radiation, trapping heat in the atmosphere and making the planet warmer. The most important greenhouse gases directly emitted by human activity include carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), and several fluorine-containing halogenated substances (e.g. HFCs, PFCs, SF6 and NF3). Although CO_2, CH_4, and N_2O occur naturally in the atmosphere, human activities have evidently changed their atmospheric concentrations. Global net anthropogenic GHG emissions have been estimated to be 59 ± 6.6 $GtCO_2e$ in 2019, about 12% (6.5 $GtCO_2e$) higher than in 2010 and 54% (21 $GtCO_2e$) higher than in 1990, with the largest share and growth in gross GHG emissions occurring in CO_2 from fossil fuels combustion and industrial processes followed by CH_4 (IPCC, 2023).

The assessments presented here have significant near-term and Long-term policy leads to highlight. Kerala has been a highly urbanized society with almost half of the population (48%) living in urban centres (GoK, 2021). The population density of Kerala is the highest in the nation (860/km^2) and is estimated to have reached 904.61/km^2 if the latest population projections are considered[4]. With these demographic features, urban planning and management have gained increased significance. This assessment identifies the Waste sector as the second largest emitter of GHG in the State. Domestic wastewater along with solid waste is identified to be the main source of emissions in the sector. Waste treatment essentially

1 NDCs are climate actions that each country had communicated to the United Nations Framework Convention on Climate Change (UNFCCC), that are aligned to achieve the Long-term goals of the Paris Agreement—i.e., limiting global average temperature well below 2 ^{0} C compared to the pre-industrial period. India also announced the following NDC targets: i) increasing the fossil free electric power installed-capacity share to 40%, ii) reducing the emissions intensity of GDP by 33%–35% (from 2005 levels), and iii) adding 2.5 to 3 billion tonnes of carbon sink by the year 20303

2 IPCC AR-6

3 State of Climate Report 2023, WMO

4 Based on Projected Mid-year Population in the state for the year 2021 as per Annual Vital Statistics Report 2021

demands innovative approaches to reduce emissions from these sources.

Agriculture has emerged to be the third largest emitting sector in the order of emissions, However, its contribution is at least ten times less than the lead emitting sector and is showing a decline at an average rate of 1.5%. This has to be seen consistent with the fact that, from 2002-03 levels, the net cropped area in Kerala has declined ~7% and this decline is steady across the long term. Moreover, the wetland paddy area alone has recorded a decline of 39.84% during the period (GoK, 2023a). Thus, emissions from the Agriculture sector are mainly associated with livestock emissions rather than the mainline agricultural practices.

Kerala has a relatively developing industrial base, industrial emissions are the fourth largest contributor to GHG emissions in the State. This may have certain data limitations regarding the present assessment; however, the State needs modern approaches to bring in emission-containing industrial processes, especially in the chemical and mineral industries to decarbonize the sector. This can be a possible enhancement in the Kerala Industrial and Commercial Policy. Fostering measures to improve energy efficiency or to reduce emission intensity of industries at the State level has to be brought under proper policy and standards framework. In fact, SAPCC 2.0 envisages improving the energy efficiency of Non-PAT (Perform Achieve and Trade) industries and micro, small and medium enterprises as a major mitigation strategy for 2023-2030.

The most striking part of this inventory is the quintessential results from the LULUCF and the Energy Sectors. These outcomes have implications for specific policies and near-term strategies in climate change intervention and sustainable lifestyles in the State. Kerala is a State with 29.66%[5] of forest area and a forest cover of 54.68%[6], [7]. This essentially has resulted in a large carbon sink in the State. The legal forest area of Kerala has remained largely undisturbed for the last few decades and the forest cover which includes tree cover outside the legal forest area has increased as per the India State of Forest Report (ISFR, 2021). Even with the above sink, Kerala has emerged to be a net emitter mainly due to the contributions from the Energy sector. The Energy sector is identified as the lead emitting sector in the State.The Transport sub-sector primes the Energy Sector emissions with a sole contribution of 49% of total emissions from all sectors combined in the State, of which 91% was from road transport. The SAPCC 2.0 estimates Kerala to have ~2 Crore two-wheelers, ~6 Lakh rickshaws, ~1 Crore cars, and 1.5 Lakh buses by 2030[8]. With these growth projections, innovative transport solutions are inevitable to decarbonize the sector on a priority basis.

The Fourteenth Five Year Plan of the State envisages improving the efficiency of public transportation by modernizing the fleet with energy-efficient buses including e-buses and innovative mass rapid transit systems like the integrated transport system in Kochi which link the metro rail and water metro networks. A modest way forward for the State may be to explore and use its plentiful inland waterways more intensively and introduce more solar-powered vessels that could lessen the load from the emission-intensive road transport.

Based on the mitigation potential assessment of the State, the mitigation strategies envisaged in the SAPCC 2.0 aim at a reduction of ~57000 ktCO_2 in 2030. Moreover, there are various policy interventions existing in the State that can be aligned with such target strategies to leverage the collective momentum. The Carbon Neutral Kerala 2050 initiative envisages net zero emissions by 2050, the Eco Restoration Policy 2021 envisages the restoration of monoculture plantations inside forests. Mission LiFE envisages an environmentally conscious lifestyle at the national level. The Electric Vehicle

5 Administrative Report Kerala Forests & Wildlife Department 2022

6 ISFR 2021

7 The term 'Forest Area' (or recorded forest area) generally refers to all the geographic areas recorded as forests in government records. On the other hand, the term 'Forest Cover' refers to all lands more than one hectare in area, having a tree canopy density of more than 10%. (FSI, 2021)

8 Assessment Based on data available with VAHAN and existing vehicle growth trends (SAPCC 2.0),

Policy Kerala 2019 envisages electric mobility as a tool to promote shared mobility and clean transportation to ensure environment sustainability. The Energy Conservation (Building Code) Rules 2017 defines norms of energy performance for various building components and takes into consideration the climatic region. This report is expected to establish a fundamental link with all such endeavours in the State towards the 2050 target. Further to this assessment, the pathways for carbon neutrality shall be prepared to supplement the findings.

2

SAPCC 2.0 Implementation

SAPCC 2.0 is the master plan for climate change adaptation and mitigation actions in the State. The plan was approved by the State and the MoEFCC and lists the major adaptation and mitigation actions to be undertaken for the period 2023-2030. Specific outcomes, objectives, and actions for attaining climate resilience in the State have been listed in the plan. Under Priority Interventions envisaged, Outcome 6 proposes to establish a Statewide Climate Database System. The objective is to establish an effective climate change monitoring mechanism. Action-4 under this objective, proposes a GHG emission monitoring mechanism for the State. Concurrently, to achieve the State's carbon neutral target by 2050, the State government has constituted a Working Group as per G.O (Rt) No. 81/2021/Envt dated 10.11.2021, with the Additional Chief Secretary, Environment as the Chairperson and entrusted the Directorate of Environment and Climate Change (DoECC) to draw up an action plan. In this context, the DoECC has signed a Memorandum of Understanding with Vasudha Foundation, an independent not-for-profit policy research institution working in the areas of climate policy and clean energy, in developing a detailed greenhouse gas inventory of the State and formulate framework/pathways to achieve carbon neutrality by 2050, through active participation of all the stakeholders.

3

Approach and Methodology

An exhaustive approach involving multiple levels of stakeholder consultations, review of technical documents, data sets and guidelines have been followed to arrive at the estimates in this report. The inventory network comprises a technical core team of 15 sector-based experts and professionals from the Directorate of Environment and Climate Change and Vasudha Foundation and a statewide technical team of 109 technical officers and academics from 76 stakeholder departments, agencies, and universities, guiding the processes through two State-level core group deliberations and multiple consultation sessions across 24 months. Identification and consolidation of State-specific activities, activity data and elimination of anomalies have been ensured through the consultative process.

Box 1.1. Carbon Dioxide Equivalent (CO_2e)

A carbon dioxide equivalent or CO_2e, is a metric measure used to compare the emissions from various greenhouse gases based on their Global-Warming Potential (GWP), by converting amounts of other gases to the equivalent amount of carbon dioxide with the same Global Warming Potential.

The assessments for the inventory have rigorously followed the latest IPCC methodology and guidelines (IPCC, 2006; IPCC, 2019) covering four sectors, namely, Energy, IPPU (Industrial Processes and Product Use), AFOLU (Agriculture, Forestry & Other Land Use) and Waste. However, for reporting AFOLU has been bifurcated to the Agriculture and LULUCF sectors in alignment with the Government of India's GHG inventory reports. Moreover, this inventory covers all relevant sub-sectors and categories that contribute to the GHG emissions accounting for CO_2, CH_4 and N_2O emissions.

Box 1.2. Global Warming Potential (GWP)

The IPCC developed the Global Warming Potential (GWP) concept to compare the ability of a greenhouse gas to trap heat in the atmosphere relative to another gas. The GWP of a greenhouse gas is defined as the ratio of the accumulated radiative forcing within a specific time horizon caused by emitting 1 kilogram of the gas, relative to that of the reference gas CO_2 (IPCC 2013). CO_2-equivalent emissions are provided in million tonnes of CO_2 equivalent ($MtCO_2e$). 100-year GWP values from the IPCC Second Assessment Report (AR2) has been used in this report for calculating CO_2-equivalents to align with the National Communications of India to the UNFCCC. A comparison of emission values with the 100-year GWP values from the IPCC Sixth Assessment Report (AR6) (IPCC 2021) can be found in the Climate Change Portal of DoECC. The 100-year GWP values used in this report are listed in *Appendix-2*.

The estimations are largely based on IPCC's Tier 1 and Tier 2 methods of emissions estimation *(see Box 1.1)*. The emission factors assumed for various categories of emissions are by and large taken from the Government of India's inventory submissions to the United Nations Framework Convention on Climate Change (UNFCCC)[9]. The Tier 1 (T1) or IPCC-suggested standard approach (by using default emission factors) is followed in the absence of country-specific emission factors.

The assessment has pooled data from relevant stakeholder departments of the Government of Kerala as well as the data available in national-level portals. However, the best efforts were made to source both activity data and emission factors that are available at the State level, and wherever possible, a Tier 2 method was followed.

All computations in the report are based on the Global Warming Potentials (GWP) of greenhouse gases for a 100-year timeframe, as per IPCC AR2 (IPCC, 1995) (*see Box 1.2*). Although GWP AR2, GWP AR6 and GTP AR6-based emission values are estimated as part of the inventory, only the GWP AR2 values are presented in this report. This is following the practice followed by the Government of India in GHG inventory reporting. A detailed overview of the various sectors, sub-sectors, and categories for which emissions have occurred along with an analysis of emission trends has been provided.

Box 1.3. Tiers of GHG emission inventory

Based on the level of data requirements, degree of details incorporated and the usage of emission factors, IPCC suggests three tires. Tier 1 is the basic approach that derives data from already assessed baselines and from default emission factors identified by the IPCC. Tier 2 employ more specific and accurate activity data and more region-specific emission factors. Tier 3 has the highest level of precision, employing spatially disaggregated site-specific data collection and often include advanced modeling techniques.

In alignment with the base year followed in India's Nationally Determined Contribution Commitment under the Paris Agreement,[10] the report takes 2005 as the base year and the reference period is 2005 to 2021.

Detailed sector-based information on sources of activity data, emission factors, methodology and formulae are given in *Annexure-1*. The type of emission factors and level of methodological tier employed for GHG emission estimation are given in *Appendix 1A*. GWP for the gases is given in *Appendix 2*.

The sub-sectors and categories identified under each sector that are relevant for GHG emissions estimation in Kerala are listed in A*ppendix 1* [11].

9 India. Biennial Update Report (BUR). BUR3

10 India. Biennial Update Report (BUR). BUR1

11 This report considers Sector-Subsector-Category terminology for policy purposes. IPCC follows the Sector-Category-Sub Category terminology

4

Comparability of the Report

The 2006 IPCC Guidelines for National Greenhouse Gas Inventories took the transition to an integrated approach in GHG Reporting[12]. This approach integrates the previous (Revised 1996 IPCC Guidelines) separate guidance for Agriculture and Land Use, Land-Use Change and Forestry (LULUCF) to form the Agriculture, Forestry and Other Land Use (AFOLU) guidance. This integration recognizes that the processes underlying greenhouse gas emissions and removals, as well as the different forms of terrestrial carbon stocks, can occur across all types of land. It recognizes that land-use changes can involve all types of land. However, the transition to the 2006 reporting has happened at a slower pace and many nations including India currently follow the previous mode of reporting in GHG inventory. To ensure comparability with the national emissions and emission reporting, this report follows the current Indian national government reporting method in accordance with the UNFCCC/Paris Agreement tables and the NATCOM-3[13] of India. This report considers emissions from 2019 to 2021 as recent emissions and emissions from 2005 to 2021 as Long-term emissions.

12 The UNFCCC reporting guidelines on annual inventories for Annex I Parties (decision 24/CP.19) require that Annex I Parties should use of the 2006 IPCC Guidelines for National Greenhouse Gas Inventories

13 The Ministry of Environment and Forests (MoEFCC), Government of India, has initiated a National Communication (NATCOM) project for communicating to the UNFCCC about anthropogenic emissions of GHGs from various sources and their removal by sinks not controlled by the Montreal Protocol. NATCOM is as per the commitment under UNFCCC.

5

Recent Trends in GHG Emissions from Kerala

In 2021, Kerala emitted 21.86 million tonnes of carbon dioxide equivalent ($MtCO_2e$), which is 6.8% less compared to the 2005 emissions of 23.46 $MtCO_2e$ (*see figure-ER-1*). Gross emissions[14] recorded a sharp fall of 12% in 2020 relative to the previous year and increased by 2% in 2021 (*see figure-ER-3*). Between 2020 and 2021, the increase in total greenhouse gas emissions was largely driven by an increase in CO_2 emissions from fossil fuel combustion across most end-use sectors. This was partly due to increased energy use from the continued rebound of economic activity after the COVID-19 pandemic-induced slump in 2020. The Energy sector dominated the emission spectrum in the state in 2021 with a total emission of 17.24 $MtCO_2e$, accounting for 79% of the State's gross emissions.

Even though energy emissions in 2021 were 4.9% less compared to the 2005 baseline, it may be seen that the emissions from the Energy sector were growing at an average rate of 0.8% until the COVID-19 outbreak in 2020.

Net emissions from the State, after accounting for the removals through sequestration, stood at 11.22 $MtCO_2e$ in 2020 and 11.60 $MtCO_2e$ in 2021, the difference being a 3% year-on-year rise. In per capita terms, a person in Kerala owned 0.33 tCO_2e in 2021[15]. Compared with the National per capita emission as per the latest available emission estimates, Kerala's per capita emissions were 0.41 tCO_2e and that of India were 2.46 tCO_2e in 2019 *(see figure ER-2)*.

14 Gross emission is emissions excluding LULUCF and Net Emission is emission inclusive of the LULUCF

*The LULUCF sector comprises biomass burning in forestland removals/emissions due to changes in the land-use pattern.

15 Based on Projected Mid-year Population in the state for the year 2021 as per Annual Vital Statistics Report 2021

6

Long-term GHG Emissions and Removals-Trends of Kerala

The Long-term gross emissions in the State have been growing at an average rate of 0.33%. The Long-term emissions profile across the reference period has been dominated by emissions from the Energy sector. Even though all sectors other than the Energy sector have recorded a declining trend in emissions in the long term (*see figure-ER-6*), this cannot be exclusively attributed to any concentrated effort of decarbonization but may be due to such factors that have determined the scale and size of various activities in the concerned sectors in the long term. The Long-term gross annual average emissions of Kerala across the 16-year reference period were estimated to be ~ 21.83 $MtCO_2e$ per year, which in absolute terms were the lowest in 2011 (*Figure-ER-1)*. From 2011 it grew at an average rate of 2% annually to reach peak emissions of 24.53 $MtCO_2e$ in 2019 (*Figure-ER-1*). The state's peak emissions in 2019 when compared with the national emissions for the same period would account for ~0.8% of the total national emissions[16].

16 India: Third National Communication to the UNFCCC, 2023. The latest national GHG Emission estimates available for India is for 2019

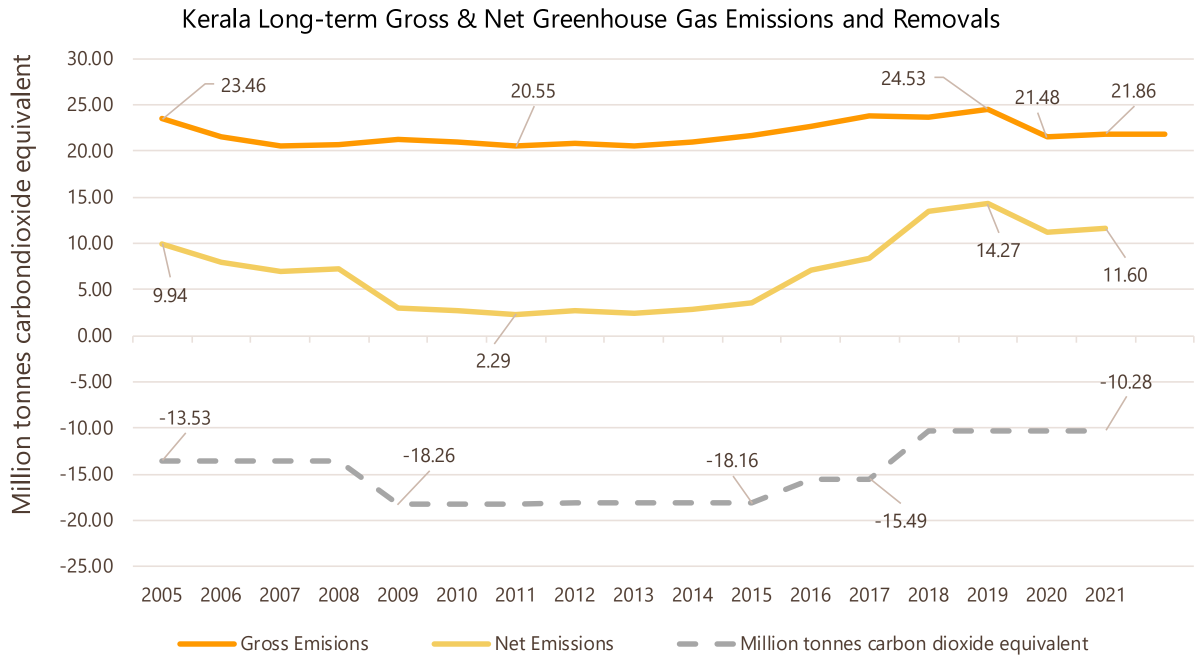


Figure-ER-1: *Kerala Long-term Gross & Net Greenhouse Gas Emissions and Removals - Shows the overall trends in Greenhouse Gas emissions from Kerala in the long term (2005-2021). The dotted line shows the total CO2 removals through carbon sequestration.*

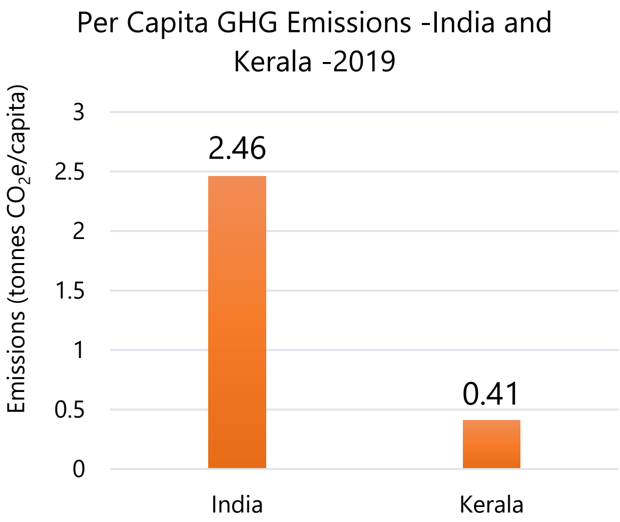


Figure-ER-2: *Per Capita GHG Emissions -India and Kerala -2019- Based on Projected Mid-year Population in the State for the year 2019 as per Annual Vital Statistics Report 2019. India's per capita emissions for 2019, as per the* ***latest estimates*** *available with India's Long-term Low-Carbon Development Strategy submission to UNFCCC.*

The annual average removal of CO_2 through carbon sequestration by the sinks in the state remained at 14.91 $MtCO_2e$ per year. The detailed profile of removals/ emissions from the LULUCF sector which accounts for the removals in the long term is given in *Section 8.4*. The removal by carbon sequestration offset 47% of gross CO_2e emissions in 2021. It may be seen that the average sequestration of the state has remained robustly above 60% across the long term in the reference period. This is primarily due to the recorded forest cover of 54.04% acting as a large source of carbon sink. However, the trend in removals shows a declining trend mainly due to changes in carbon stock density *(see figure ER-4)*.

Of the total gross emissions in 2021, ~79% of the emissions was from the Energy

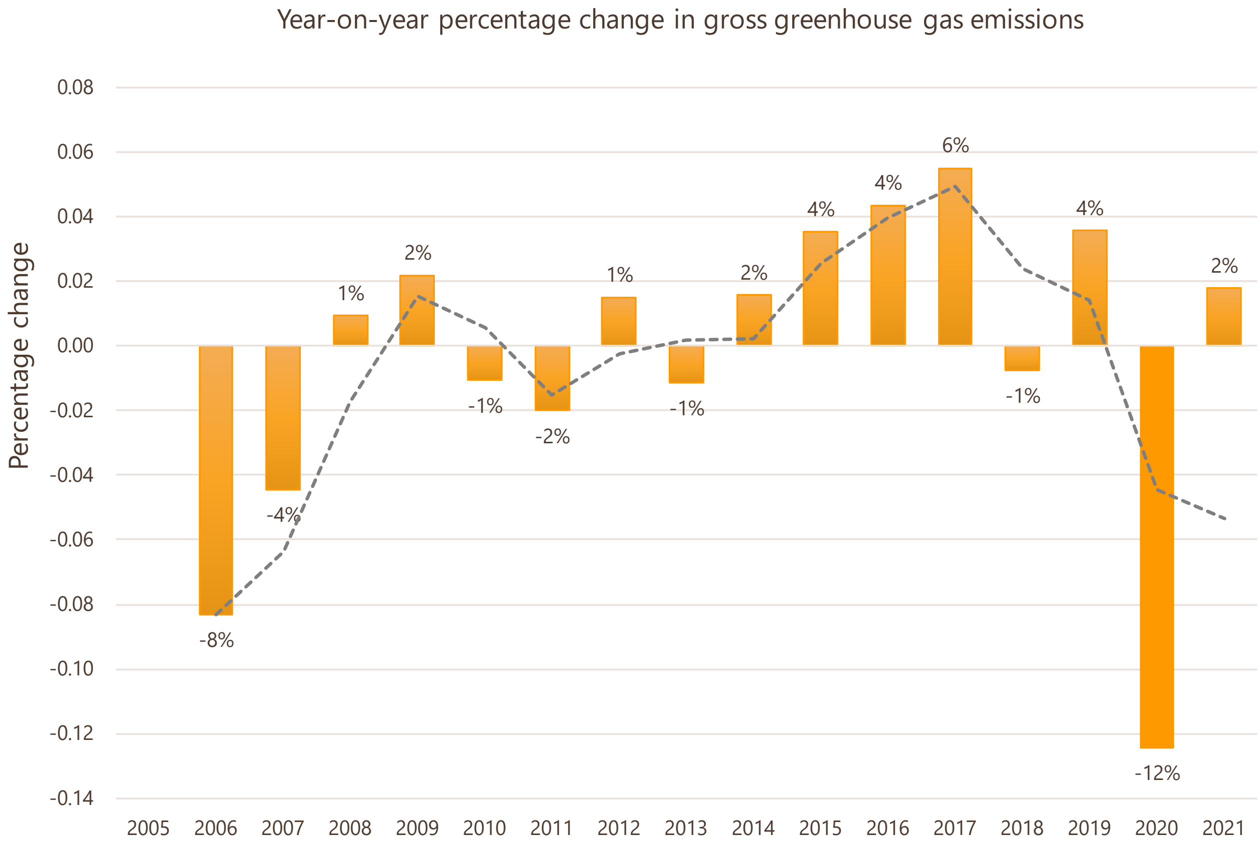


Figure-ER-3 : *Long-term percentage changes (Year-on-Year) in gross greenhouse gas emissions, Kerala. The dotted line shows the trend in the changes (two-period moving average).*

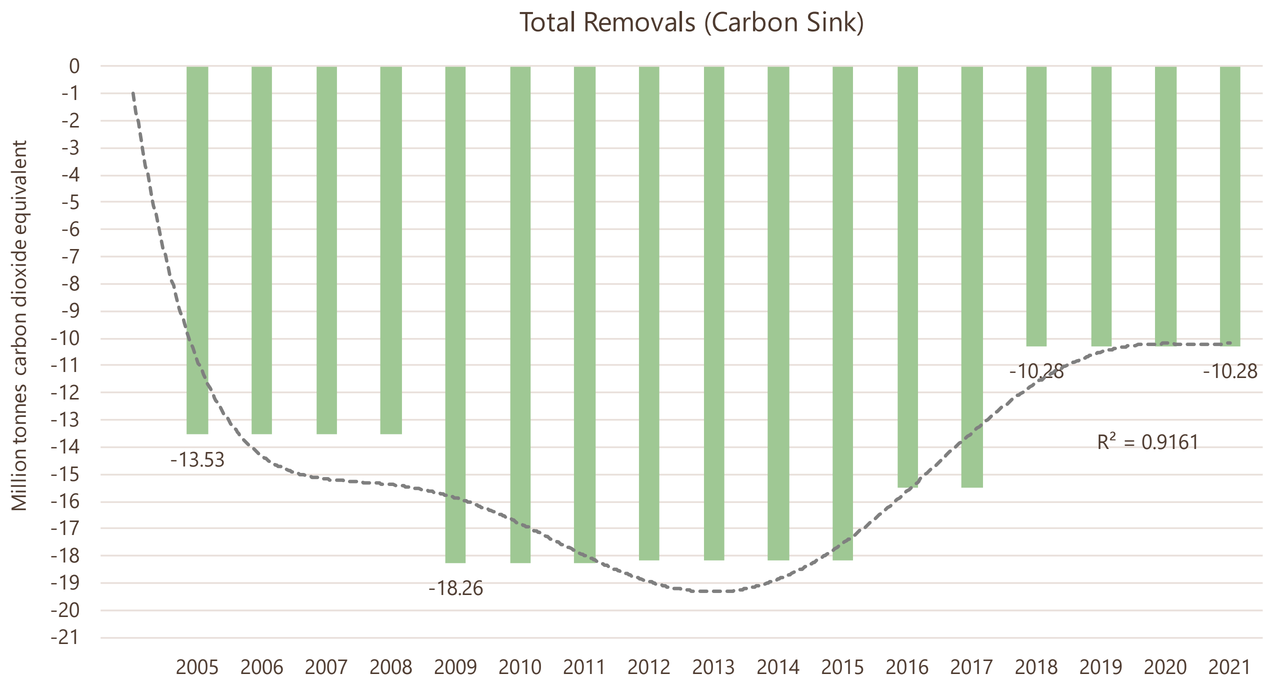
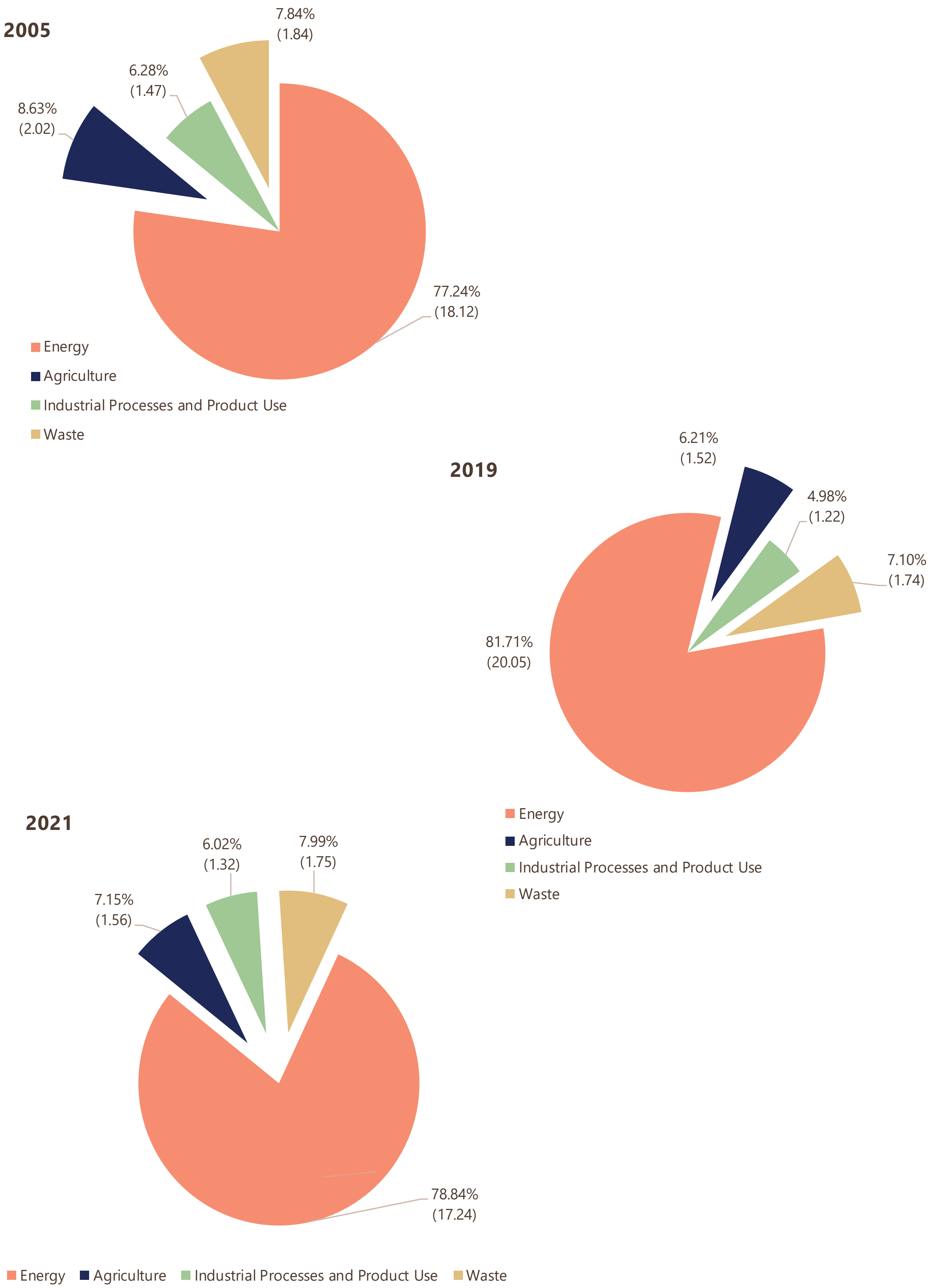


Figure ER-4: *Total Removals in the Long term from sink categories in the state. The figure shows the quantity of atmospheric CO2 sequestered as carbon in vegetation and soils in terrestrial ecosystems. The dotted line shows the best-fit trendline.*

sector (*see figure ER-5*). It amounts to ~17.24 $MtCO_2e$. The significant emissions from the Energy sector over the long term, surpass those of the Industrial Processes and Product Use (IPPU) sector by more than tenfold. Similarly, when comparing the cumulative emissions of both Agriculture and Waste sectors, they amount to only around one-tenth of the Energy sector's accumulated emissions over the same period.

The Waste sector was the second largest emitter with total emissions of 1.75 $MtCO_2e$ in 2021, accounting for ~8% of the Gross GHG emissions of the State (*Figure ER-5*). Whereas the Agriculture sector, which was the third largest emitter, contributed 1.56 $MtCO_2e$ in 2021, accounting for ~7% of the state's Gross emissions. The contribution of the IPPU sector was the least in 2021, with a total GHG emissions of 1.32 $MtCO_2e$ and accounting for ~6% of the Gross emissions. At the national level also, the Energy sector leads the emission trends. Nationally, the Energy sector accounted for 75.81% of the total emissions in 2019.

Figure ER-5 shows the absolute share of each sector in 2005, 2019 and 2021. However, it has to be noted that other than the Energy sector all other sectors have recorded lower emissions in 2019 and 2021 relative to 2005. (*See figure-ER-6*) This is examined in the subsequent sections. Eventhough the emissions from the waste sector has shown a decrease in 2019 compared to the baseline this may be partially due to limited data avilability with regard to the method of treatments adopted. However the State has attained significant progress in solid waste mangemnet in recent years (see section 8.5). The increase in total greenhouse gas emissions was driven largely by an increase in CO_2 emissions from fossil fuel combustion across most end-use sub-sectors.



Emissions in $MtCO_2e$

Figure ER-5: *Kerala-IPCC Sector based emissions and percentage shares in the Long-term*

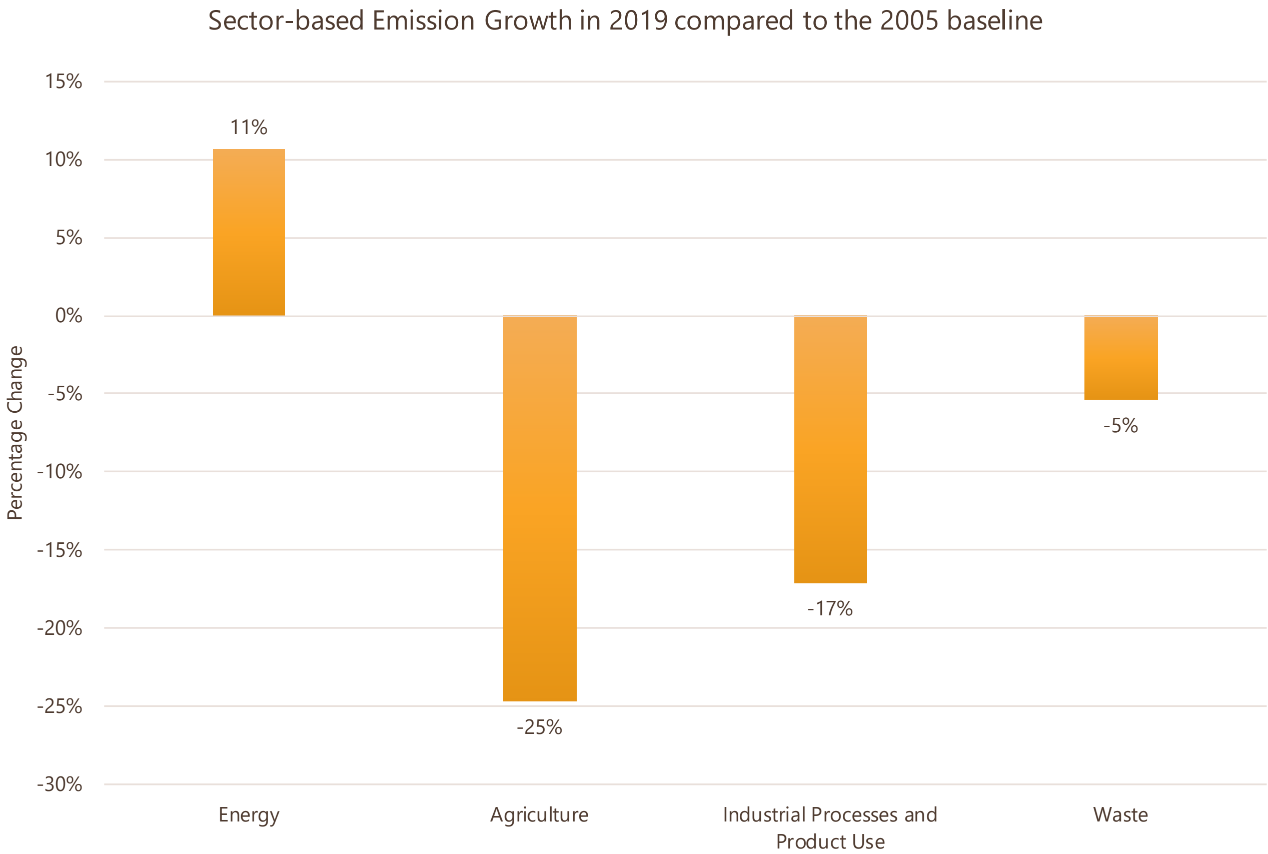


Figure ER-6: *Changes in sector-based emissions in 2019 compared to 2005 baseline-As 2019 is the peak emission year in the reference period considered, the graph shows the percentage change in emissions in each sector in 2019 from the baseline year ie, 2005.*

Table 1: Sector-based GHG emission in $MtCO_2e$ for 2005-2021

Sectors	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
Energy	18.12	16.19	15.33	15.58	16.09	15.95	15.63	16.10	15.90	16.31	17.04	18.04	19.16	19.14	20.05	16.96	17.24
Agriculture	2.02	1.98	1.92	1.89	1.84	1.77	1.74	1.64	1.67	1.61	1.60	1.52	1.64	1.55	1.52	1.56	1.56
Land Use, Land-Use Change and Forestry (LULUCF)	-13.53	-13.53	-13.53	-13.53	-18.26	-18.26	-18.26	-18.15	-18.15	-18.15	-18.15	-15.47	-15.48	-10.26	-10.26	-10.26	-10.26
Industrial Processes and Product Use (IPPU)	1.47	1.47	1.40	1.39	1.45	1.45	1.44	1.38	1.33	1.31	1.34	1.35	1.33	1.27	1.22	1.22	1.32
Waste	1.84	1.87	1.90	1.88	1.82	1.81	1.75	1.73	1.72	1.71	1.69	1.72	1.73	1.73	1.74	1.74	1.75
Net Emissions (including LULUCF)	9.94	7.98	7.03	7.22	2.94	2.71	2.29	2.71	2.47	2.79	3.53	7.15	8.40	13.43	14.27	11.22	11.60
Gross Emissions (excluding LULUCF)	23.46	21.51	20.55	20.75	21.20	20.97	20.55	20.86	20.62	20.94	21.68	22.62	23.87	23.69	24.53	21.48	21.86

7

Emissions by Greenhouse Gases

The primary greenhouse gas emitted by human activities in Kerala is carbon dioxide (CO_2), representing 69% of total greenhouse gas emissions[17].

The largest source of CO_2 and overall greenhouse gas emissions is fossil fuel combustion, primarily from transportation and residential emissions. Methane (CH_4) is significantly more effective than CO_2 at trapping heat in the atmosphere: by a factor of *21* over a 100-year time frame (IPCC 1996). Methane emissions in Kerala in 2021 were 0.12 million tonnes. The major sources of methane emissions in the State include enteric fermentation in domestic livestock, rice cultivation and waste management. Nitrous oxide (N_2O) is produced by biological processes that occur in soil and water and by various anthropogenic activities in the agricultural, energy, industrial, and waste management fields. Even though total N_2O emissions are much lower than CO_2 emissions, as per IPCC AR2, N_2O is *310 times* more powerful than CO_2 at trapping heat in the atmosphere over a 100-year time frame (IPCC 1996). Nitrous oxide (N_2O) emissions in Kerala in 2021 were 3270.78 tonnes. The major sources of N_2O emissions in the State are agricultural soil management, wastewater treatment, and fuel combustion in motor vehicles. Figures ER-7(a), (b) and (c) illustrate the trends and yearly contributions of the major greenhouse gases in more detail. Sector-based emission of these gases in 2021 is given in *Table 2*.

17 The total greenhouse gas emissions due to anthropogenic activities include sum of emissions of carbon-dioxide (CO_2), methane (CH_4) and nitrous oxide (NO2) and minor trace gases such as hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), and sulphur hexafluoride (SF6) emissions. Notably, emissions of trace gases primarily stem from industrial processes, such as aluminium and magnesium production, that are not encompassed within the scope of this inventory and hence not reflected herein.
Furthermore, it may be noted that the choice of data source for industrial energy fuel consumption, namely Pillai N, V., Am, N. (2019), was determined after extensive consultations and discussions with relevant stakeholders. Consequently, certain additional fuels not present in the selected data source or considered irrelevant have been kept outside the purview of this inventory.

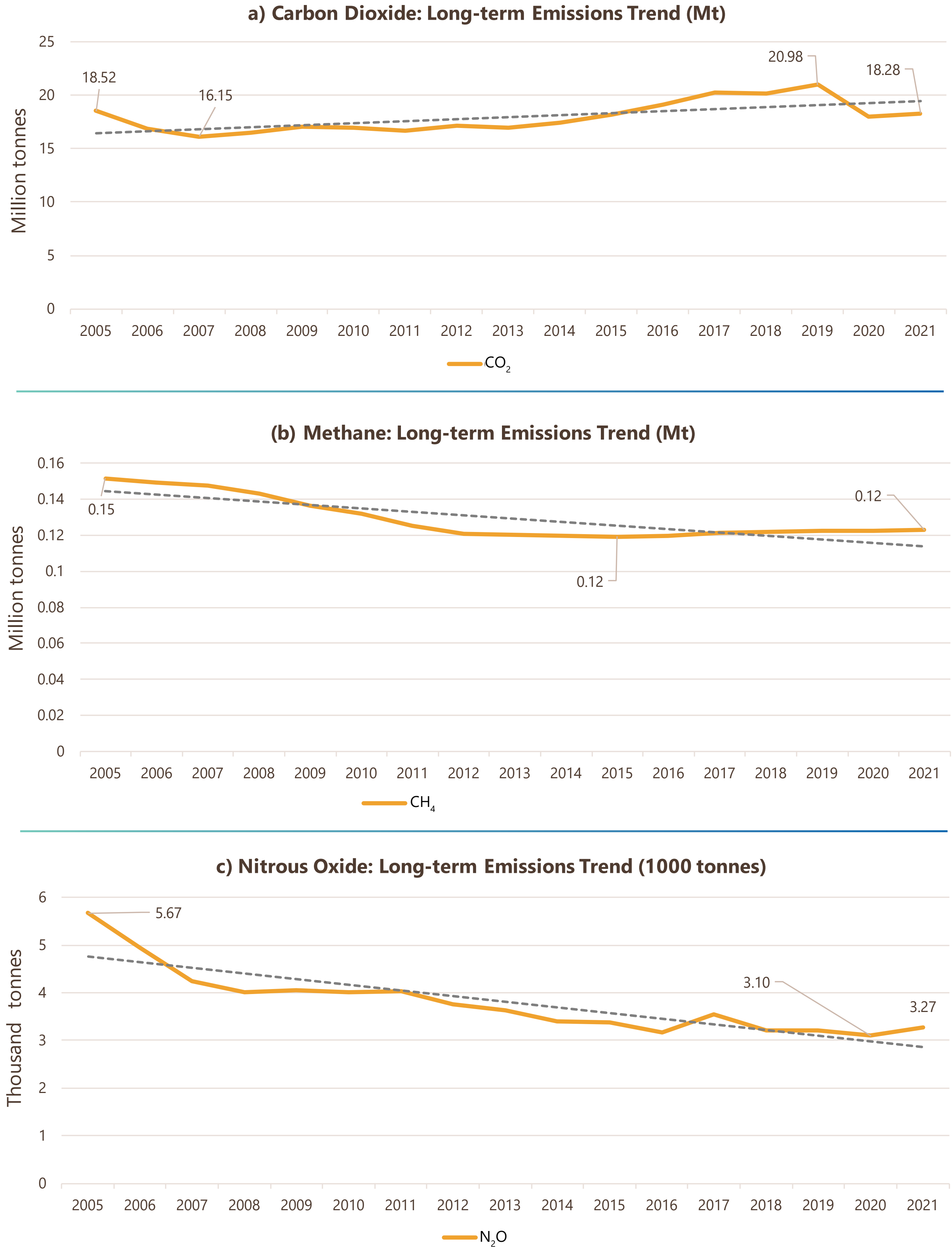


Figure-ER-7: *Long-term emissions trend of various Greenhouse Gases. Panel (a) shows the Long-term emission trend of Carbon dioxide which shows an increasing trend, panel (b) shows the Long-term emission trend of Methane in (Million tonnes) and panel (c) shows the Long-term emission trend of Nitrous Oxide. Both methane and Nitrous Oxide show a declining trend in emissions. The dotted lines show the linear trend.*

Table 2: Sector-based and Gas-based GHG Emissions (2021)

GHG Sources and Removals	Emissions			CO_2 Removals	CO_2 equivalent
	CH_4	N_2O	CO_2		
	Million tonnes (Mt)				Mt CO_2e
Energy	3.14×10^{-3}	5.66×10^{-4}	17.00	NA	17.24
IPPU	$4.66 X 10^{-6}$	1.41×10^{-4}	1.27	NA	1.32
Agriculture	6.09×10^{-2}	9.20×10^{-4}	NO	NO	1.56
LULUCF	7.37×10^{-6}	9.0×10^{-8}	NA	10.26	-10.26
Waste	58.87×10^{-3}	1.64×10^{-3}	NA	NA	1.75
Net Emissions (with LULUCF)	12.2927×10^{-2}	3.2708×10^{-3}	-	10.26	11.60
Gross Emissions (without LULUCF)	12.2920×10^{-2}	3.2707×10^{-3}	18.27	-	21.86

**NO – Not Occurring; NA – Not Applicable*

8

Overview of Sectoral Emissions and Trends in Kerala: 2005 to 2019-2021

8.1 Energy Sector

The Energy sector contains emissions of all greenhouse gases resulting from stationary and mobile energy activities including fuel combustion and fugitive fuel emissions, and the use of fossil fuels for non-energy purposes. The Energy sector accounted for 17.24 $MtCO_2e$ emissions of Kerala in 2021, which is 79% of the state's gross emissions. During the reference period, Kerala's Energy sector saw its highest recorded emissions of 20.05 $MtCO_2e$ in 2019, marking a 31% increase from its lowest emissions level of 15.33 $MtCO_2e$ in 2007. When compared with the baseline emissions (2005 levels) the energy use emissions stood ~11% higher in 2019 (*see figure-ER-8*).

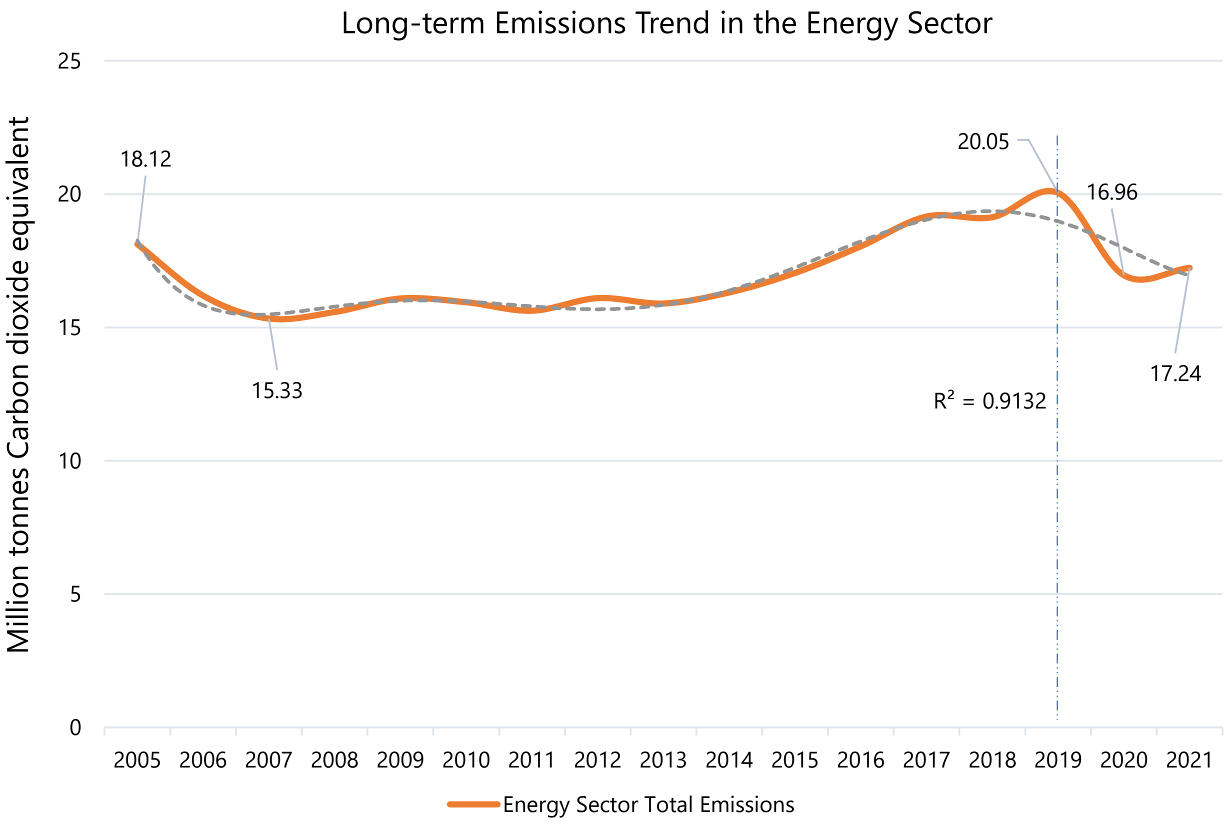


Figure-ER-8: *Long-term emissions trend in the Energy sector. The best-fit trend line shows a gradual decline in emissions until 2011 from the base year and gradual increase until 2019 and a steep decline in 2020.*

The Energy sector emissions comprise emissions from two sub-sectors; fuel combustion and fugitive emissions. Fuel combustion emission arises out of sources like Transport, Public Electricity Generation, Captive Power Plants, Industries, Commercial, Residential, Fisheries and Agriculture categories. Fugitive emissions are accounted for emissions occurring during fuel production. *Figure ER-9* shows the emission trend from various source categories during the reference period.

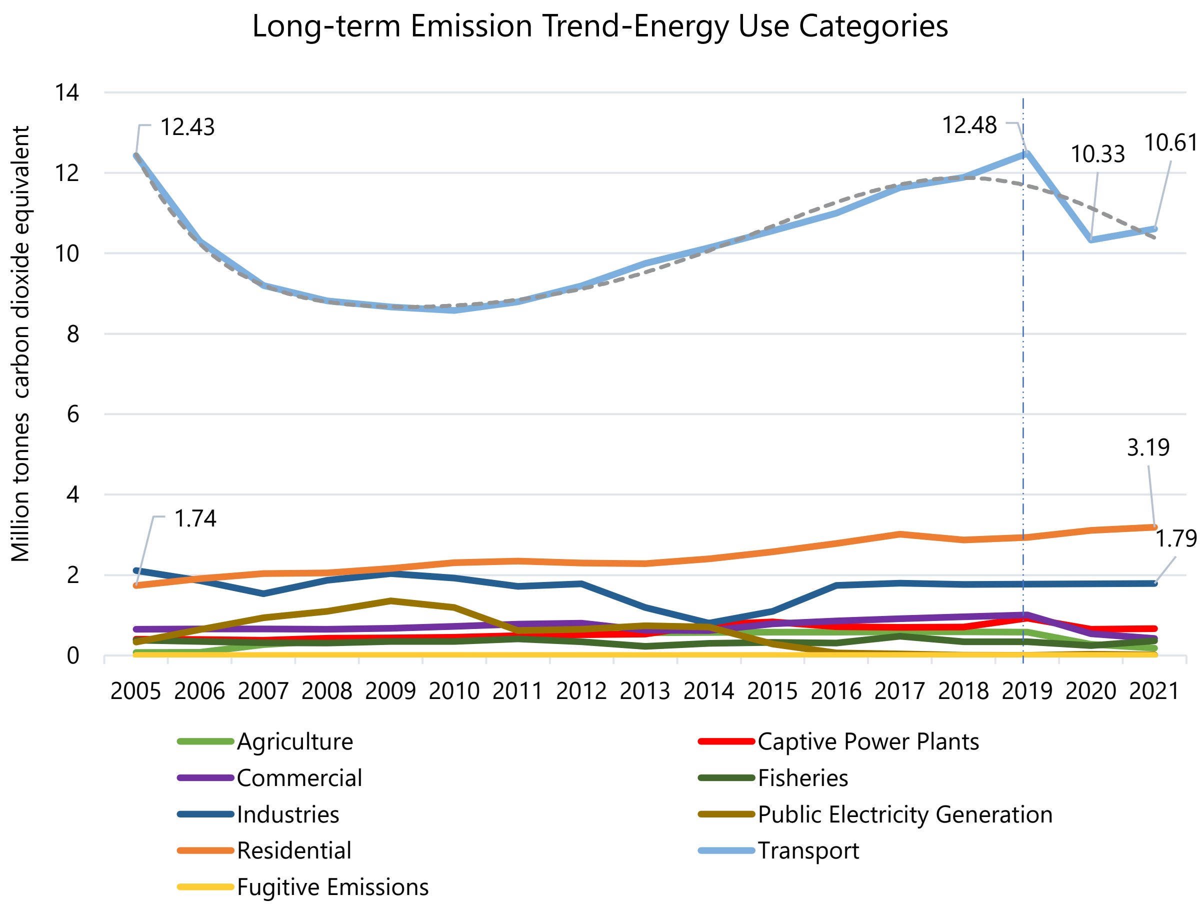


Figure-ER-9: *Long-term Emission trend-Energy use categories - Shows the Long-term trend in emissions from the various emission sources in the Energy sector contributing to the overall sector emission. Transport emissions are the cumulated emissions from various sources like road transport, railways, aviation and navigation. The dotted lines show the Long-term trend of the lead emitter.*

Energy emissions fell by 15% from 20.05 MtCO_2e in 2019 to 16.96 MtCO_2e in 2020. This fall in emissions in 2020 was due to a significant reduction in fuel combustion emissions from transportation activities, primarily due to the COVID-19-related mobility restrictions in the State. The recent Energy sector emissions trend shows a gradual rebound to the pre-covid peak emissions in 2019. From the 2020 levels, the emissions increased by ~2% to reach 17.24 MtCO_2e in 2021.

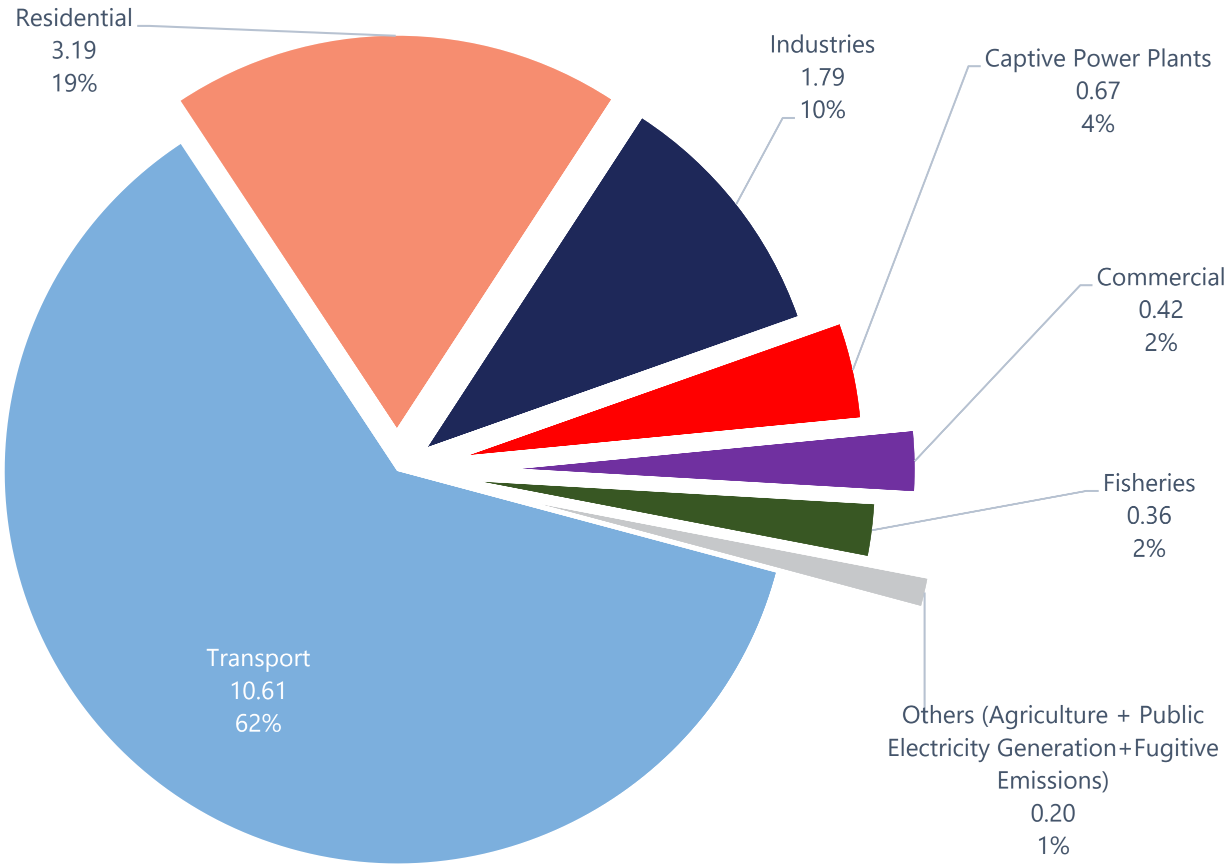
The key sub-sector contributing to Kerala's Energy sector emissions was the transport sub-sector. The fossil fuel combustion emission associated with transportation activities alone accounted for 10.61 MtCO_2e in 2021, constituting ~62% of the total Energy sector emissions, and ~49% of the gross emissions of Kerala. However, it has to be noted that the transport-related emission leading the emission trend in the Energy sector was at its peak of 12.48 MtCO_2e in 2019 which was 15%

higher than the 2021 levels (*see figure ER-9*). The second highest contributor to the Energy sector emissions was the residential category emissions emerging from consumption of LPG and kerosene, with total emissions of 3.19 $MtCO_2e$ in 2021, constituting 19% of the State's total Energy sector emissions, and ~15% of the gross emissions. These sub-sectors are followed by Industrial Energy emissions, with 1.79 $MtCO_2e$ in 2021, constituting 10% of the total Energy sector emissions of the State, and 8% of the gross emissions. Industrial energy emissions emerge from the industrial consumption of fuels including Naphtha, HSD, LDO, FO/LSHS and Natural Gas.

Of the various source categories in the Transport sub-sector, Road Transport was the major contributor with a share of 91% in 2021, followed by the Aviation category, with a share of ~8% in 2021.

Emissions share of Railways and Water-borne Navigation categories were 0.37% and 0.38% respectively, in 2021. Between 2005 and 2021, the emissions from the Road Transport category increased from 4.01 $MtCO_2e$ to 9.66 $MtCO_2e$ whereas the emissions from the Aviation category increased from 0.41 $MtCO_2e$ in 2005 to 0.86 $MtCO_2e$ in 2021.

Category-based Emissions and Percentage Share in Total Energy Sector Emissions



** Emissions in $MtCO_2e$. 2021*

Figure ER-10: *Category-based Emissions and Percentage Share in Total Energy sector Emissions (2021) - The figure shows the Category-based Emissions in MtCO2e and percentage share in total Energy sector Emissions in 2021. Transport and residential categories emit the maximum greenhouse gases in the State in 2021.*

Among the Fuel Combustion sources, emissions from Liquid Petroleum Fuels[18] remained the highest, with an average share of ~82% between 2005 and 2021 due to its usage in transport, agriculture, commercial, fisheries, residential, captive power plants and industries. This was followed by combustion involving Gaseous Petroleum Fuels[19], with an average share of ~16%. Coal used in captive power plants contributed ~2% of the overall fuel combustion emissions, throughout the reference period.

The emissions from Gaseous Petroleum Fuels increased between 2015 and 2021 due to the increased share of Gas use by Captive Power Plants and LPG use in the Residential category. Whereas the emissions from Liquid Petroleum Fuels declined between 2015 and 2021 due to a reduction in Naphtha and High-Speed Diesel (HSD) consumption for Public Electricity Generation. Moreover, the consumption of kerosene in the Residential category also decreased after 2010. Among the major gaseous fuels, emissions from LPG recorded an average growth of 6% per year. The emissions from Diesel have recorded a 46% decline from its emission levels in the baseline year. A gradual transition to the use of cleaner fuels is evident across the long term.

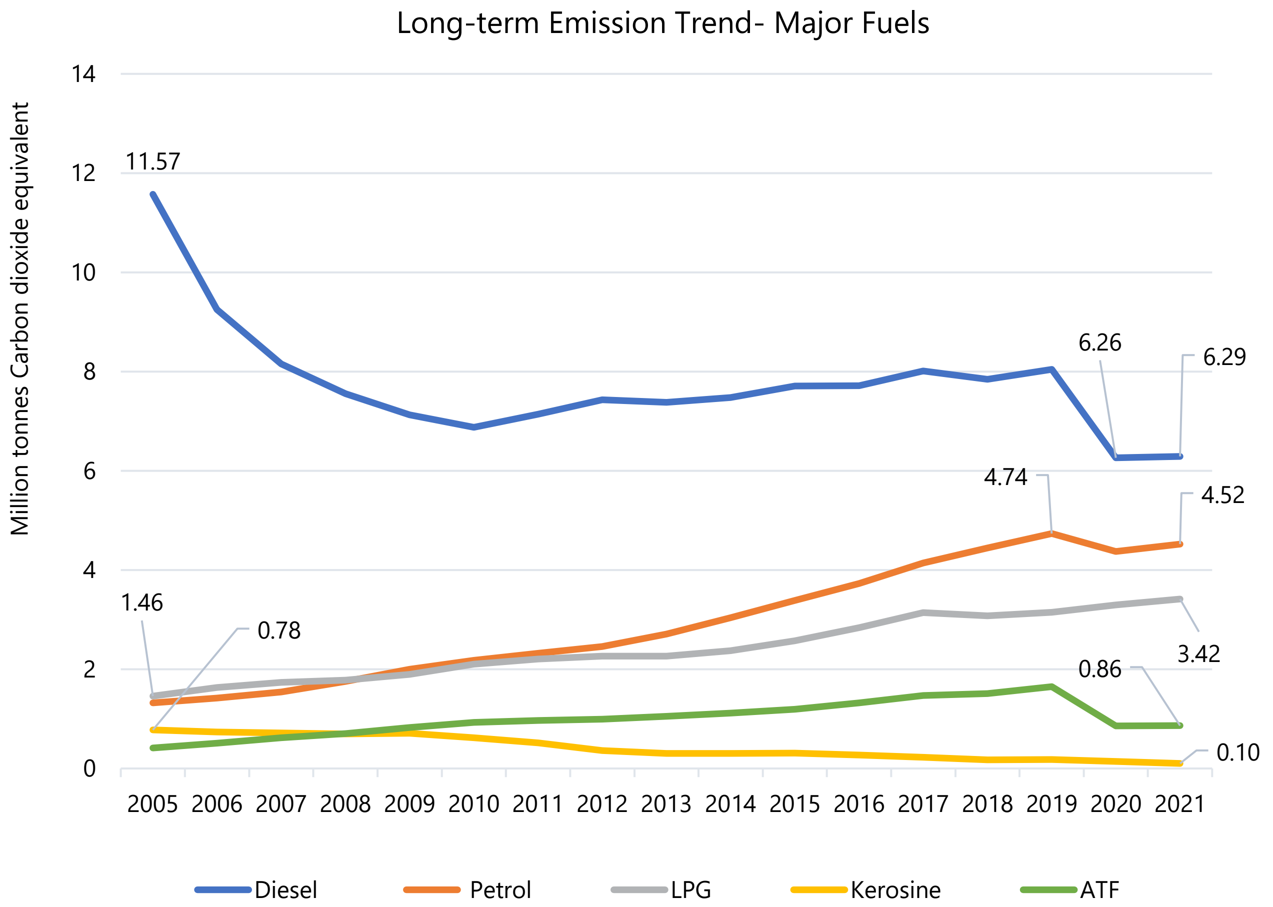


Figure-ER-11: *Long-term Emissions Trend – Major Fuel Categories – The figure shows the Long-term trend of liquid/ gaseous fuels that have the highest contribution to the total emission in the Energy Sector. There are combustion emissions from other fuels accounted for in the emission inventory including Naphtha and natural gas which are not represented in the graph. [LPG- Liquefied Petroleum Gas, ATF- Aviation Turbine Fuel]*

18 Liquid Petroleum Fuels include Aviation Turbine Fuel, Diesel, Kerosene, Motor spirit(petrol) and other liquid fuels

19 Gaseous Petroleum Fuels include Natural Gas, LPG and other gaseous fuels

Kerala has all four modes of transport. Road transport leads the emission trend in the Transport subsector. It may be noted that from 4.01 $MtCO_2e$ in 2005, the emission from this category has recorded a steady growth to 10.43 $MtCO_2e$ in 2019 which is a 160% growth (see *figure-ER-12 (a)*). 2019 was the peak of emissions from road transport and it fell ~10% in 2020 to 9.40 $MtCO_2e$ due to the pandemic-related restrictions and marginally rebounded to reach a high of 9.66 $MtCO_2e$ in 2021. The State had announced its Electric Vehicle (EV) Policy in 2019 and aimed to introduce one million EVs by 2022 which was however missed.

In contrast, the emissions from the railways have come down drastically due to the electrification of the lines see *figure-ER-12 (b)*. In 2005 the

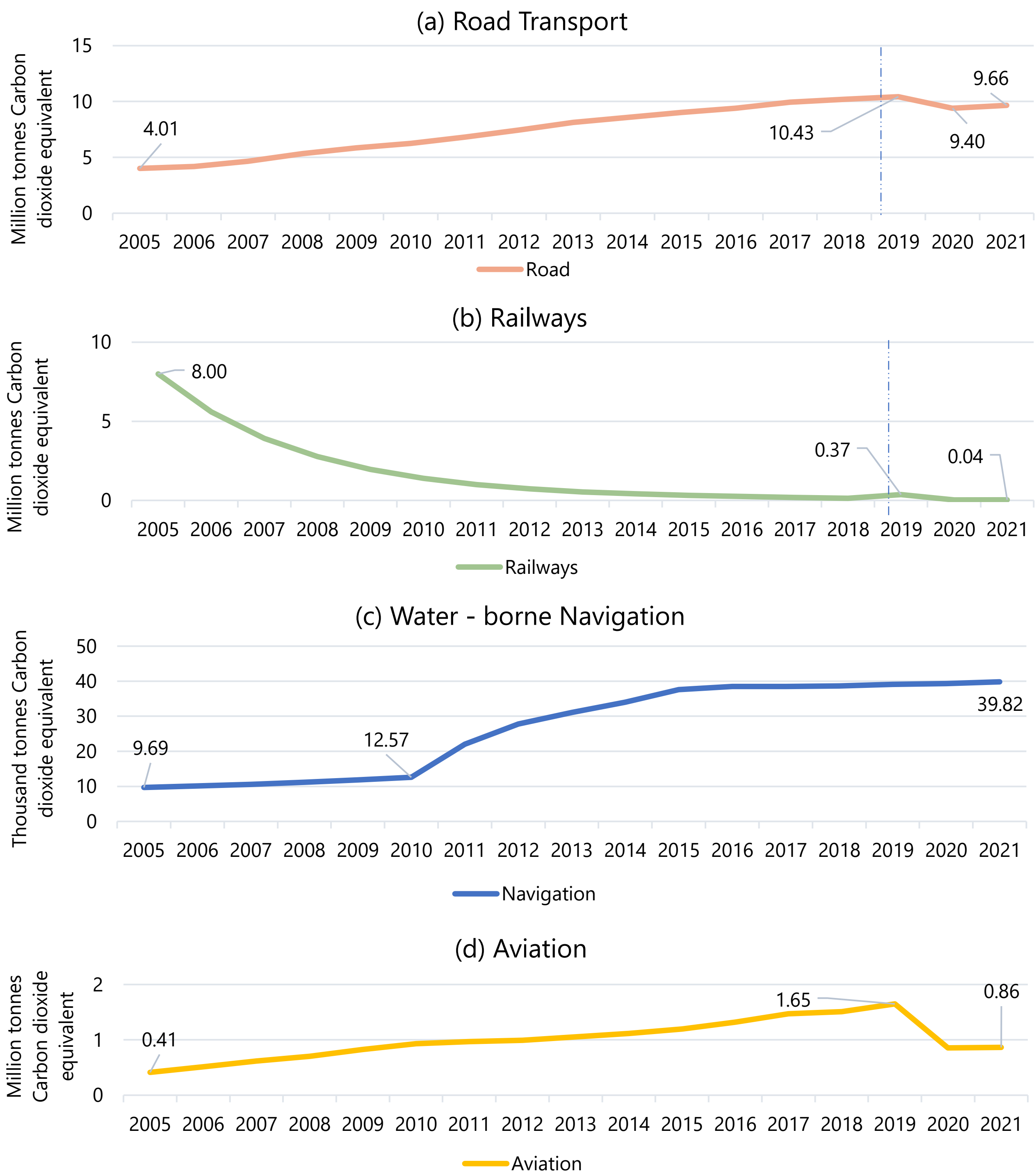


Figure-ER-12: *(a), (b), (c) &(d)| Long-term Emission Trends Various Transport Categories.*

railways emitted 8 $MtCO_2e$ which came down 99.5% to reach 0.04 $MtCO_2e$ in 2021. However, this cannot be said as a reduction in the carbon footprint of the railways due to decarbonization, as a significant share of its power requirement is still met from power generated from non-renewable sources. For the present assessments as per the IPCC methodology, only emissions occurring within the regional boundary of Kerala have been taken into consideration[20] and hence this is not accounted for. The railways have however planned to gradually reduce their carbon footprint and become a net zero carbon emitter by 2030 primarily through sourcing its energy requirements from renewable energy sources[21].

Water transport is a significant mode of transport in Kerala. 53.98% of the total available 2988.61km river/canal stretch in Kerala is Navigable (GoI 2021). The West Coast Canal from Kottapuram to Kollam (168 km) together with Champakara Canal (14 km) and Udyogmandal Canal (23 km) was declared as National Waterways-3. 16.95 lakh tonnes of cargo were handled by the NW-3 alone in 2021[22]. Parallelly The Kerala State Water Transport Department transports about 150 lakh passengers per annum[23].

8.2 Industrial Processes and Product Use (IPPU) sector

The IPPU sector accounted for 1.32 $MtCO_2e$ emissions of Kerala in 2021, which is 6% of the State's gross emissions. Emissions from the

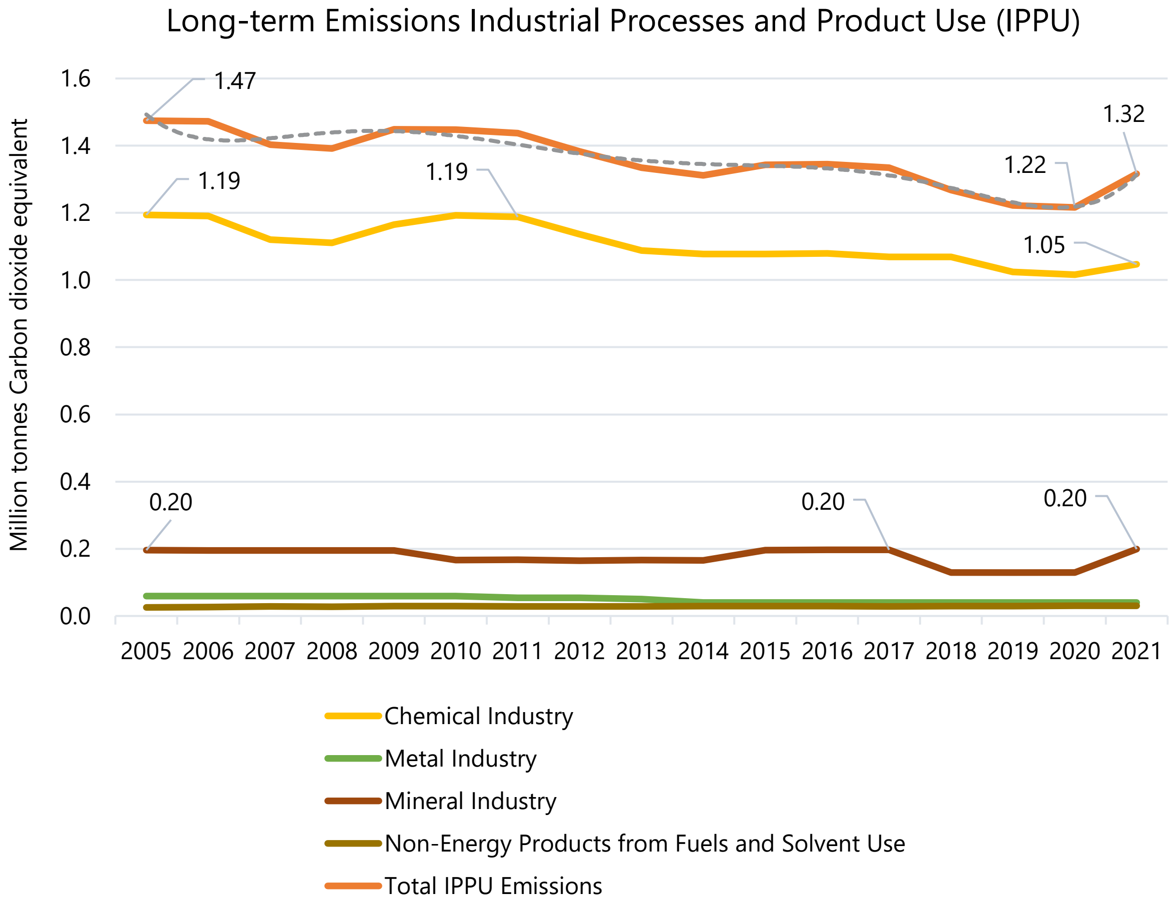


Figure-ER-13: *Long-term Emissions Industrial Processes and Product Use (IPPU). The emissions trend is led by the Chemical Industry.*

20 2006 IPCC Guidelines for National Greenhouse Gas Inventories, Volume 1: General Guidance and Reporting

21 https://pib.gov.in/PressReleasePage.aspx?PRID=1865754

22 Statistics of Inland Water Transport 2021-22, Ministry of Ports, Shipping and Waterways.

23 https://www.swtd.kerala.gov.in/pages-en-IN/aboutdept. php

IPPU sector are largely driven by the Chemical, Metal, Mineral Industries and Non-Energy Products from Fuels and Solvent Use. Major chemical industries in Kerala are involved in the production of ammonia, caprolactam, carbon black, titanium dioxide and soda ash. The Mineral Industry in Kerala is largely dominated by the production of cement and lime. Similarly, steel and zinc production dominated the metal industry in Kerala. The Non-Energy Products from the Fuels and Solvent Use sub-sector comprise lubricants and paraffin wax used in the State. GHG emissions from the IPPU sector of Kerala declined from 1.47 $MtCO_2e$ in 2005 to 1.32 $MtCO_2e$ in 2021 (*see figure ER-13).*

The key sub-sector contributing to Kerala's IPPU sector emissions was the Chemical Industry with a total emission of 1.05 $MtCO_2e$, constituting 80% of the total IPPU sector emissions of Kerala, and 5% of the State's gross emissions in 2019 and 2021. The second highest contributor to the IPPU sector emissions was emissions from the Mineral Industry with a total emission of 0.20 $MtCO_2e$, constituting 15% of the total IPPU sector emissions of Kerala, in 2021, and 1% of the State's gross emissions.

The decline in Chemical Industry emissions can be attributed to the decrease in Caprolactam production in the state during the evaluation period. Similarly, the decline in metal industry emissions could be attributed to the closure of the only zinc-producing plant that was operating in Kerala.

Within the Chemical Industry, the Production of Ammonia was the key contributor to GHG emissions in the IPPU sector, throughout the reference period. Its share of emissions in the IPPU sector increased from ~49% in 2005, to ~55% in 2021 (*see figure 14*). This was followed by the emissions due to the production of Carbon Black and Cement. The share of emissions from Carbon Black, within the IPPU sector, decreased from ~19% in 2005 to ~15% in 2021. Whereas the share of emissions from Cement industries, within the IPPU sector, increased from ~12% in 2005 to ~14% in 2021.

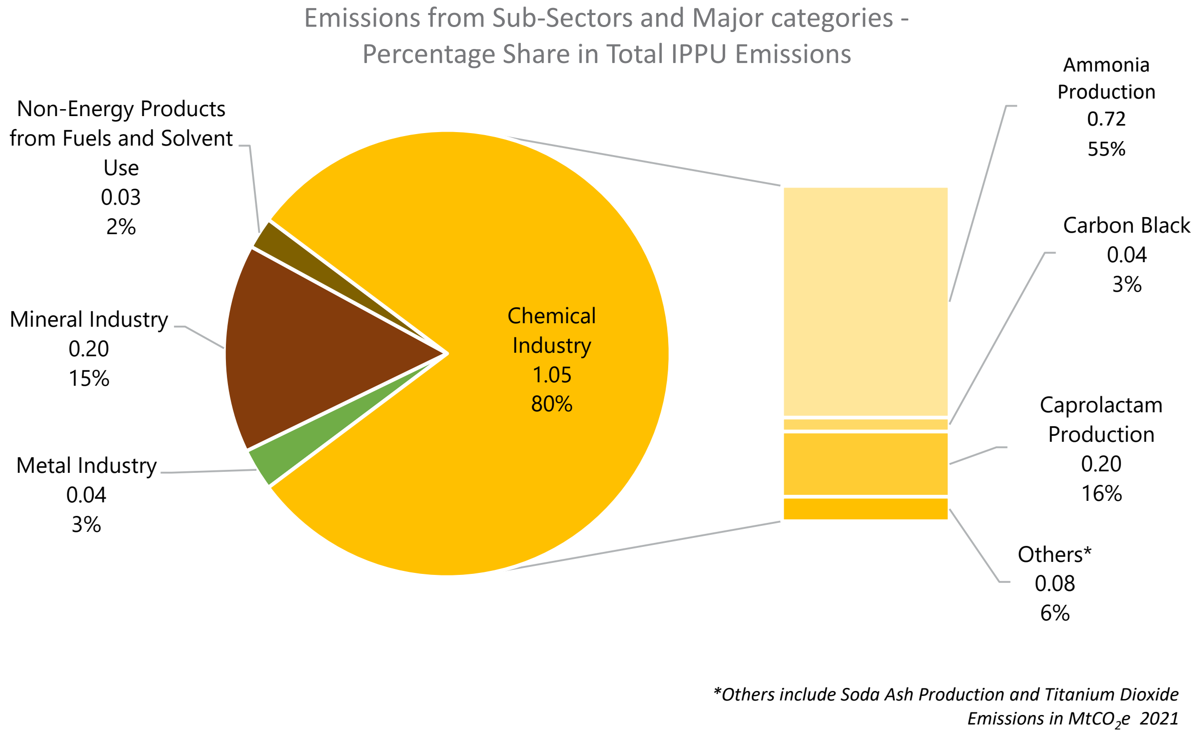


Figure-ER-14: *Emissions from Sub-Sectors and Major Categories - Percentage Share in Total IPPU Emissions- Chemical Industry accounting for 80% of the emissions in IPPU is mainly from the production of Ammonia and Caprolactam. (both being produced by Fertilizers and Chemicals Travancore Limited (FACT).*

8.3 Agriculture Sector

The Agriculture sector emissions arise broadly from two sub-sectors: Agriculture Practices and Livestock. The major sources of emissions from the Agricultural sector are, enteric fermentation in domestic livestock, livestock manure management, agricultural soil management, rice cultivation, urea fertilization, liming, and field burning of agricultural residues[24].

In 2021, agricultural activities were responsible for 1.56 $MtCO_2e$ of GHG emissions, which was 7% of total gross greenhouse gas emissions in the State. Emissions from the Agriculture Practices sub-sector have been accounted for from Agriculture Soils, Biomass Burning in Cropland and from Rice Cultivation. The Livestock sub-sector emissions have been accounted for from Enteric Fermentation and Manure Management emissions.

It has to be noted that the GHG emissions from the Agriculture sector show a declining trend in the long term. From 2.02 $MtCO_2e$ in 2005, it fell ~23% to 1.56 $MtCO_2e$ in 2021 (*see Figures ER-15 &ER-16*). The overall decline in Agriculture sector emissions between 2005 to 2021 was primarily due to the decline in the livestock population and the corresponding fall in methane emissions from enteric fermentation.

The Long-term Agriculture emissions trend in the State is led by Livestock emissions.

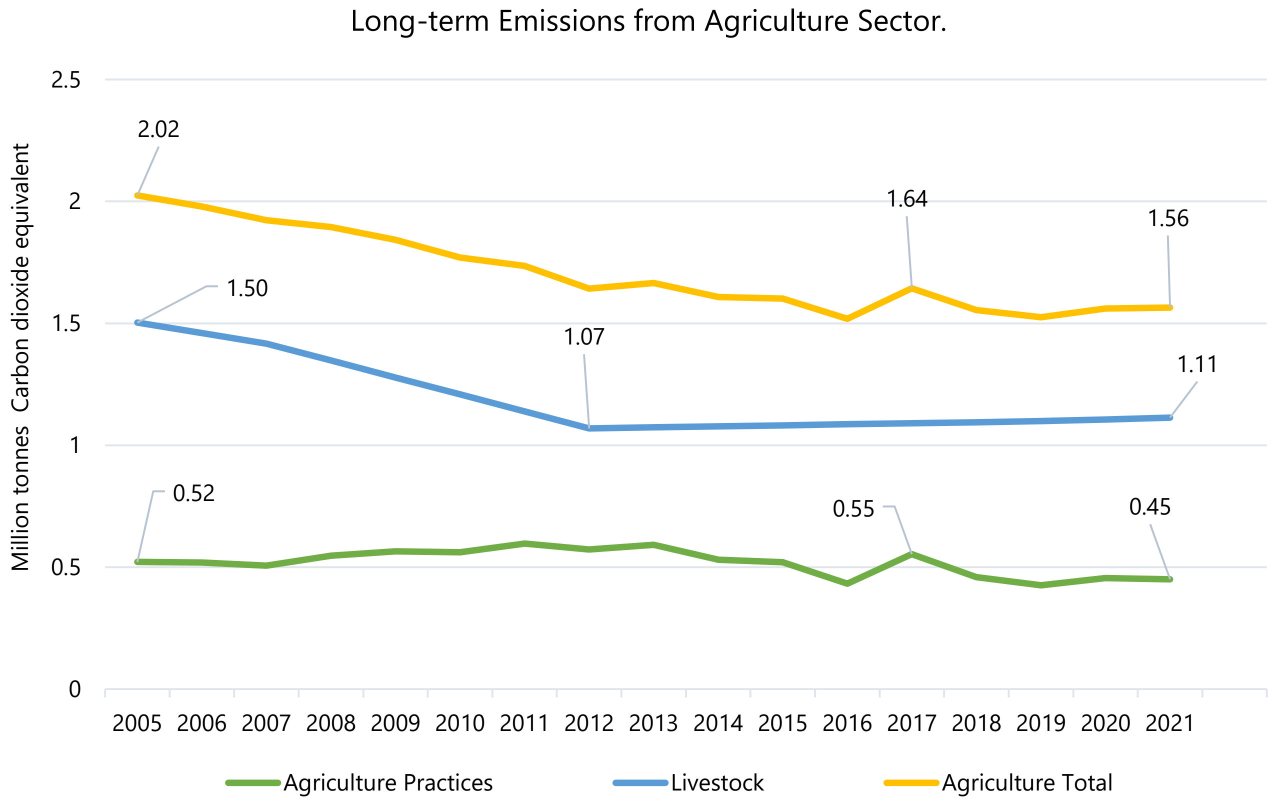


Figure-ER-15: *Long-term emissions from the Agriculture Sector.*
Agriculture total is the cumulation of emissions from agricultural practices and Livestock.

24 Agriculture releases significant amounts of CO_2, CH_4, and N_2O to the atmosphere (Cole et al., 1997; IPCC, 2001; Paustian et al., 2004). CO_2 is released largely from microbial decay or burning of plant litter and soil organic matter (Janzen, 2004). CH_4 is produced when organic materials decompose in oxygen-deprived conditions, notably from fermentative digestion by ruminant livestock, from stored manures, and from rice grown under flooded conditions (Mosier et al. 1998). N_2O is generated by the microbial transformation of nitrogen in soils and manures and is often enhanced where available nitrogen (N) exceeds plant requirements, especially under wet conditions (Oenema et al., 2005; Smith and Conen,2004).

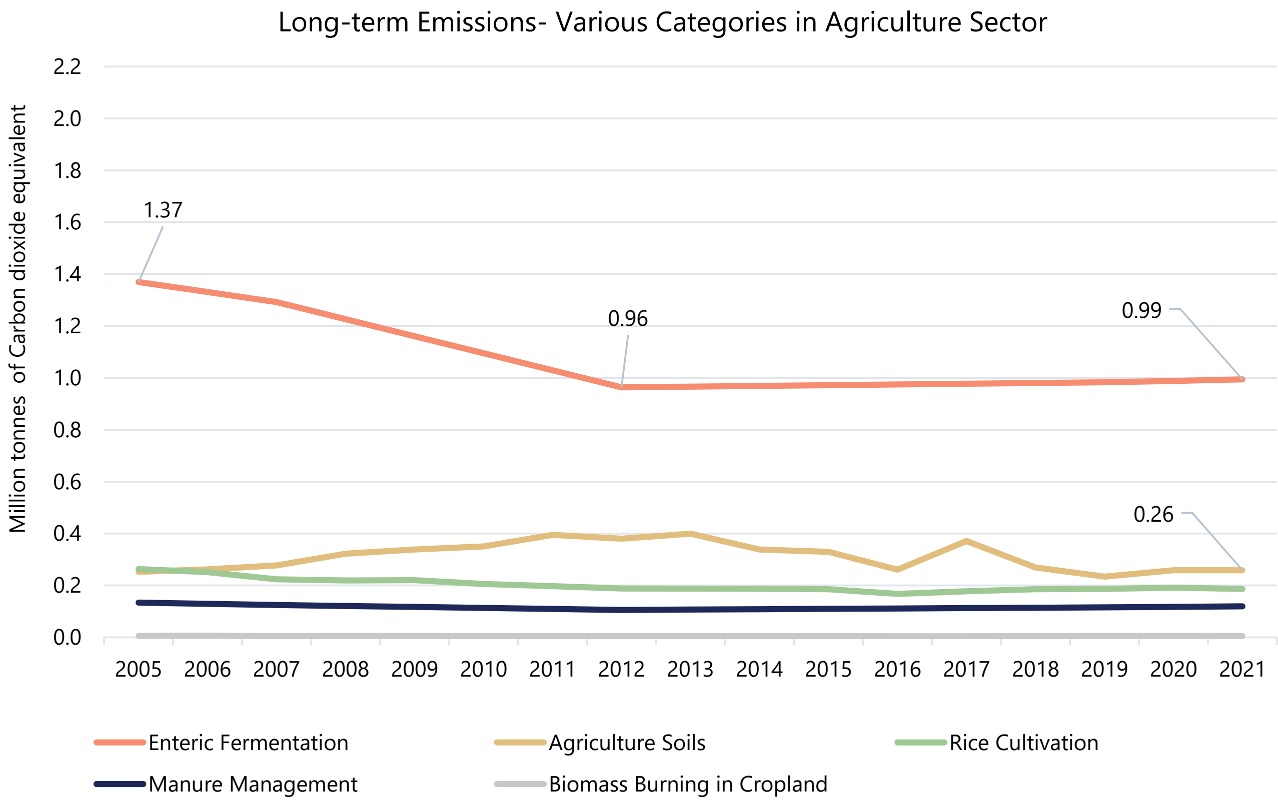
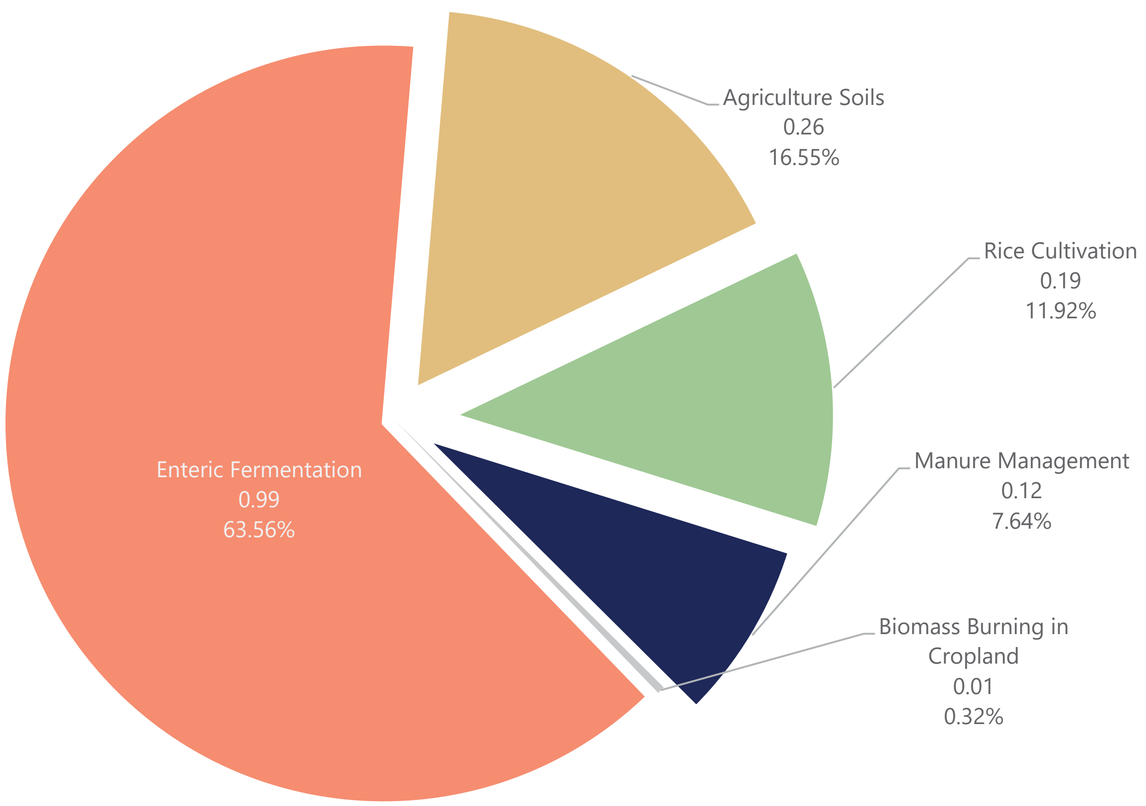


Figure-ER-16: *Long-term Emissions- Various Categories in the Agriculture Sector*



** Emissions in $MtCO_2e$. 2021*

Figure-ER-17: *Recent- Category-based Emissions in Agriculture and Percentage Share*

Within the Livestock sub-sector, the Enteric Fermentation category was the major contributor to the total Agriculture emissions, with a Long-term average share of ~63%. Between 2005 and 2021, the emissions from this category declined ~24% from 1.37 $MtCO_2e$ to 0.99 $MtCO_2e$ recording an average decline of 2% per year. Considering the recent trend, the livestock sub-sector emitted 1.11 $MtCO_2e$, in 2021 constituting ~71% of the total emissions from the sector. The remaining ~29% share of the state's agriculture emissions was from Agriculture Practices, arising out of activities including rice cultivation, biomass burning and soil management amounting to a total emission of 0.45 $MtCO_2e$.

A sharp dip in overall emissions in 2016 and an immediate rebound in 2017 can be observed which may be attributed to the change in fertilizer consumption pattern in these years (*see figure ER-17*). No traceable impacts of the pandemic can be observed in the recent emission trend in the Agriculture sector. Within the Agriculture Practices, Agricultural Soils and Rice Cultivation were the key contributors to Agriculture emissions, with average shares of ~18% and ~12%, respectively, throughout the reference period. The emissions from Agriculture Soils showed a nominal growth of 0.12%, while emissions from Rice Cultivation decreased at an average rate of 2% in the long term.

8.4 Land Use, Land-Use Change and Forestry (LULUCF)

The LULUCF sector includes removals and emissions of CO_2 from managed lands and emissions of CH_4 and N_2O from Biomass Burning in Forestland. Consistent with the 2006 IPCC Guidelines, emissions and removals

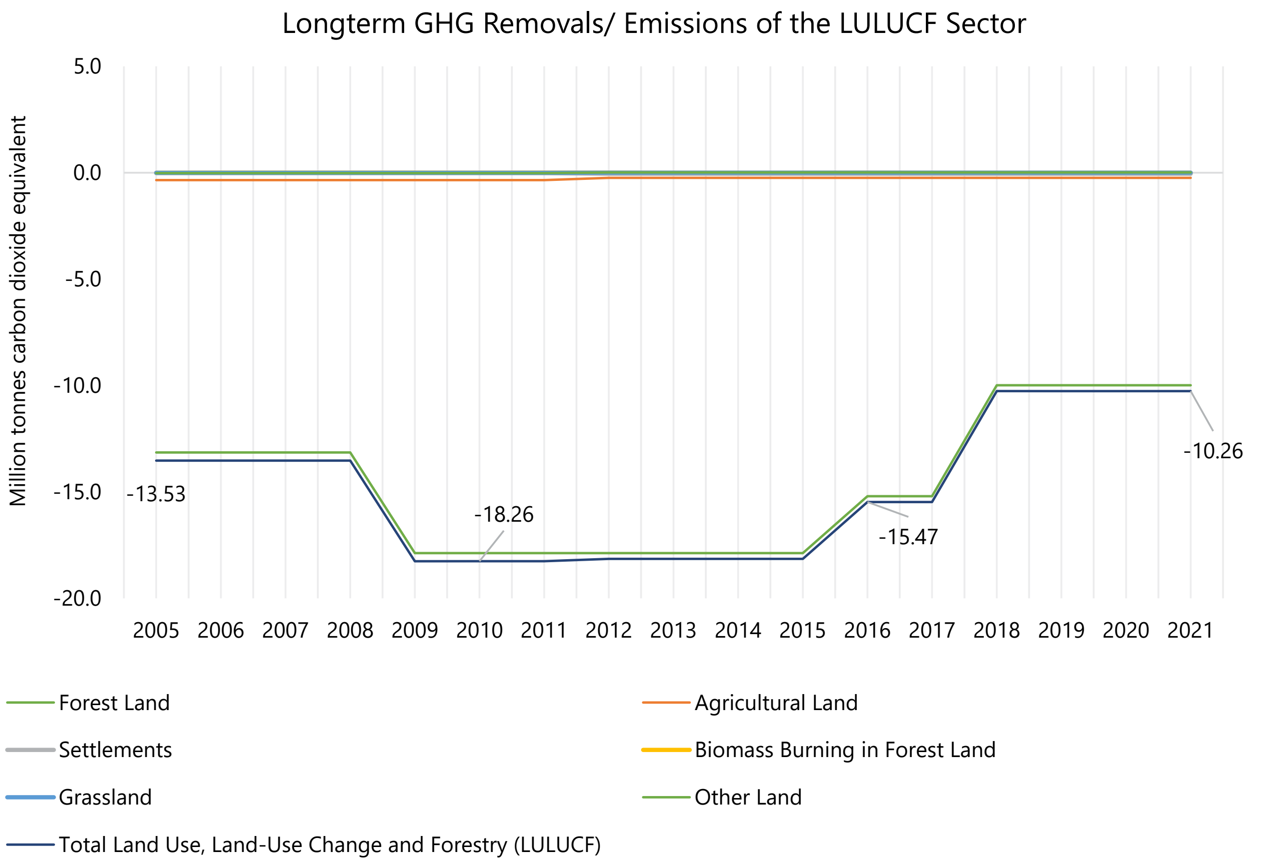


Figure-ER-18: *Long-term GHG Emissions/ Removals of the LULUCF sector. Shows removals from all land use classes and emissions from Biomass Burning in Forestland, Grassland and Other Land categories. The removals from Forest Land and the overall removals from LULUCF sector are visible in the graph. Emissions from various source categories in the LULUCF Sector are proportionately very less in the case of Kerala. (~0.14% of total CO2 sequestered) thus it cannot be represented in comparative scales.*

from managed lands are considered to be anthropogenic, while emissions and removals from unmanaged lands are considered to be natural.[25]

The LULUCF sector acted as a net sink for CO_2 (carbon sequestration) for the entire reference period in Kerala. On average, land category in the LULUCF has sequestered ~14.91 $MtCO_2e$ yearly across the reference period. In 2021 the land category has sequestered 47% of the gross CO_2e emissions from the State. Primary drivers of fluxes on lands include forests, and the main drivers for forest carbon sequestration include increase in carbon stock density and forest cover. Thus, Forest land becomes the major sink category in the LULUCF sector.

There are emissions accounted for in the LULUCF sector, which include emissions from Agriculture Land, Forest Land, Grassland, Other Land[26], Settlements[27] and Biomass burning in Forestland. Biomass burning in Forestland remained an emitting source throughout the reference period.

As seen in *Figure ER-18,* Forest Land has been the major source of carbon sequestration in the long period. Between 2009 and 2015, there was a noticeable increase in the net sink which can be attributed to the increase in forest cover. After 2015, there is a lesser increase in the forest cover and a reduction in the forest carbon stock density[28] (see *Appendix 5* for Forest cover and Carbon stock density). Due to this a declining trend in carbon stock density and, a decline in sequestration from the Forest Land may be observed. Between 2015 and 2019 the carbon stock density declined by ~20%[29].

Emissions from Biomass burning in the forestland category declined considerably in the long term. These reductions in emissions could be attributed to the decline in the forest area burnt.

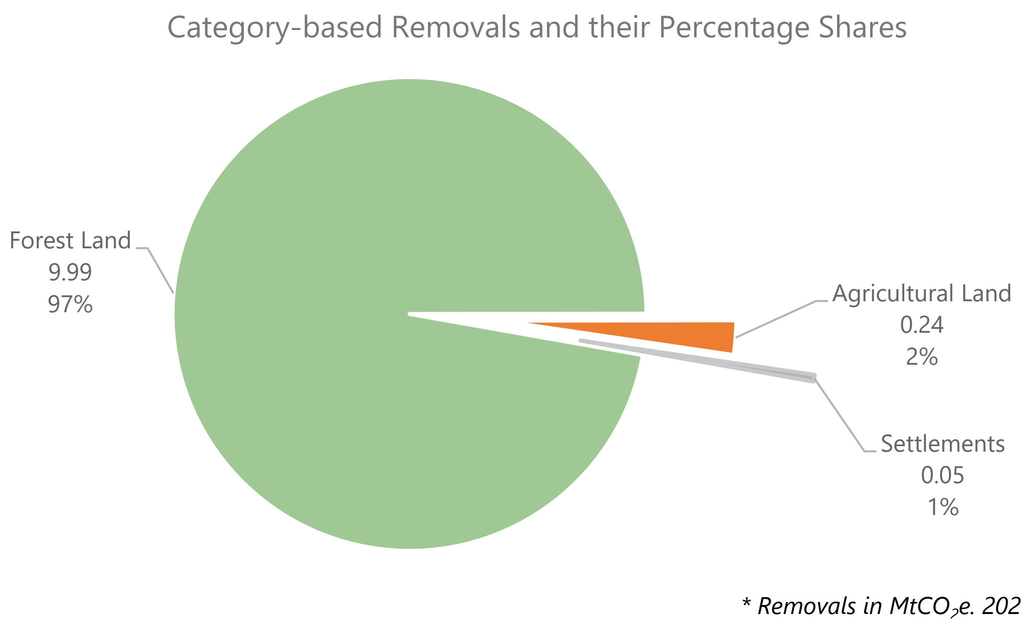


Figure-ER-19: *Category-based Removals and their Percentage Shares (2021). Emissions from the LULUCF sector are proportionately very less in the case of Kerala. (~0.14% of total CO2 sequestered)*

25 See http://www.ipcc-nggip.iges.or.jp/public/2006gl/pdf/4_Volume4/V4_01_Ch1_Introduction.pdf

26 Other Land includes Barren Land/ Unculturable/wastelands

27 Settlements are defined as all developed lands -- i.e., residential, transportation, commercial, and production (commercial, manufacturing) infrastructure of any size, unless it is already included under other land-use categories. Settlements includes soils, herbaceous perennial vegetation such as turf grass and garden plants, trees in rural settlements, homestead gardens and urban areas. (IPCC, 2006)

28 As reported by the India State of Forest Reports, (*Various*), of Forest Survey of India (FSI). The changes in soil carbon stock density as in the FSI data have impacted the variations in the sink estimates than can be observed across periods, 2008-2017. This may require detailed assessments at the micro level which is not in the purview of this report.

29 ISFR, FSI *Various*

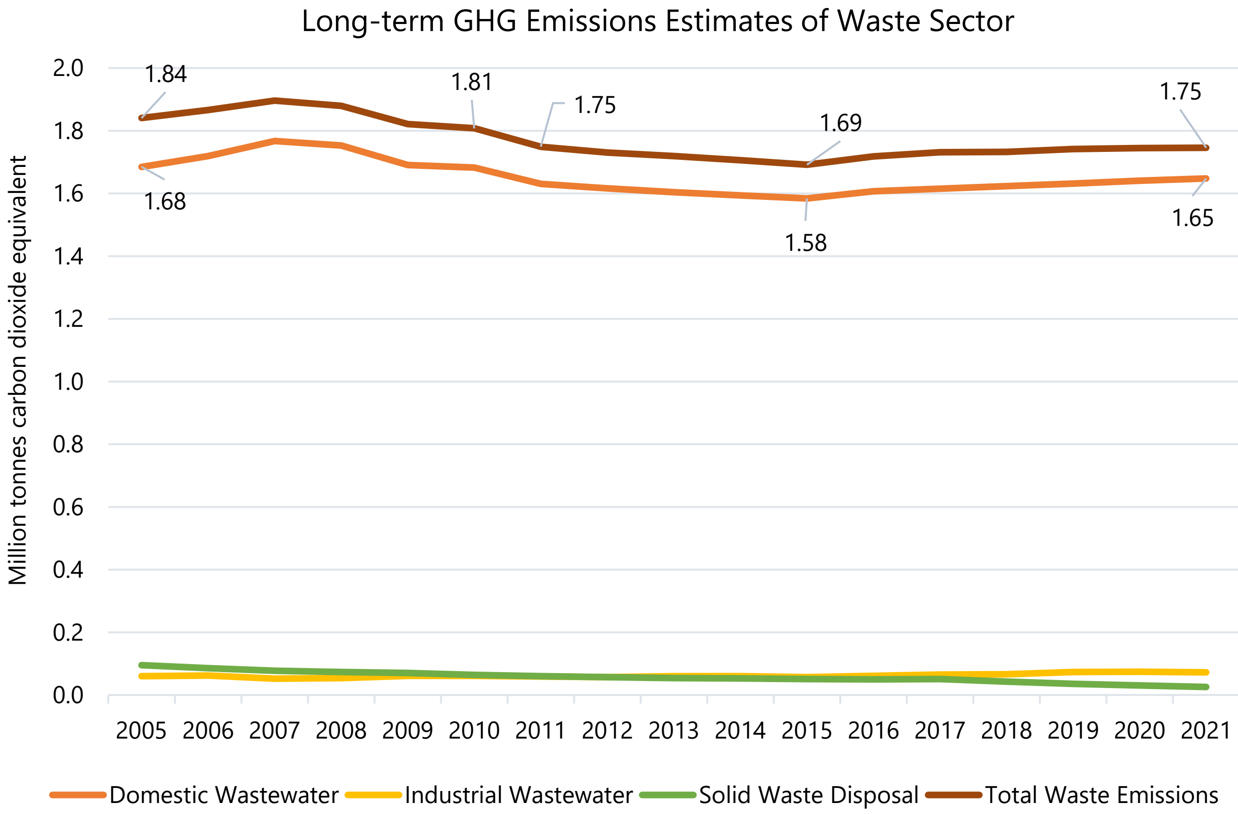


Figure-ER-20: *Long-term GHG Emissions Estimates of Waste Sector*

Removals from the Agricultural land declined at a rate of 2% from 0.35 $MtCO_2e$ to 0.24 $MtCO_2e$. Whereas, removals from Settlements increased at a rate of 6.01% from 0.02 $MtCO_2e$ to 0.05 $MtCO_2e$. Grassland and Other Land categories remained a sink until 2011. However, from 2012 these two categories became sources of emissions. Together, they emitted 0.014 Mt CO_2e annually, between 2012 and 2021. This was due to the conversion of *Forest Land* to *Other land* and *Grassland*, and the conversion of *Wetlands* to *Other Lands*, between 2005-06 and 2015-16[30]

The overall net flux from LULUCF (i.e., the net sum of all CH_4 and N_2O emissions to the atmosphere plus net carbon stock changes in units of $MtCO_2e$) resulted in a removal of 10.26 $MtCO_2e$ in 2021.

30 As per the Land Use Land Cover Change Matrix of Kerala, obtained from the Envistats 2018 and 2020 (Supplement of Environmental Accounts)- Ministry of Statistics and Programme Implementations (MOSPI). Govt of India

8.5 Waste Sector

The waste sector accounted for 1.75 $MtCO_2e$ emissions in the State which was ~8% of the gross emissions in the State. Solid Waste Disposal, Domestic Wastewater and Industrial Wastewater are the key categories of GHG emissions in the Waste sector.

Industrial wastewater emissions from Kerala have been estimated for fertilizer, meat, paper and pulp, petroleum, dairy, tannery, and fish processing industries. The industry categories that have been identified for estimating Kerala's industrial wastewater emissions are in line with those that have been listed in India's National Communications/ 2006 IPCC guidelines for National GHG inventories.

GHG emissions from the Waste sector of Kerala declined from 1.84 $MtCO_2e$ in 2005, to 1.75 $MtCO_2e$ in 2021 at an average rate of 0.32% (*see figure ER-20*).

Domestic Wastewater with total emissions of 1.65 $MtCO_2e$ constitutes 94% of the total Waste

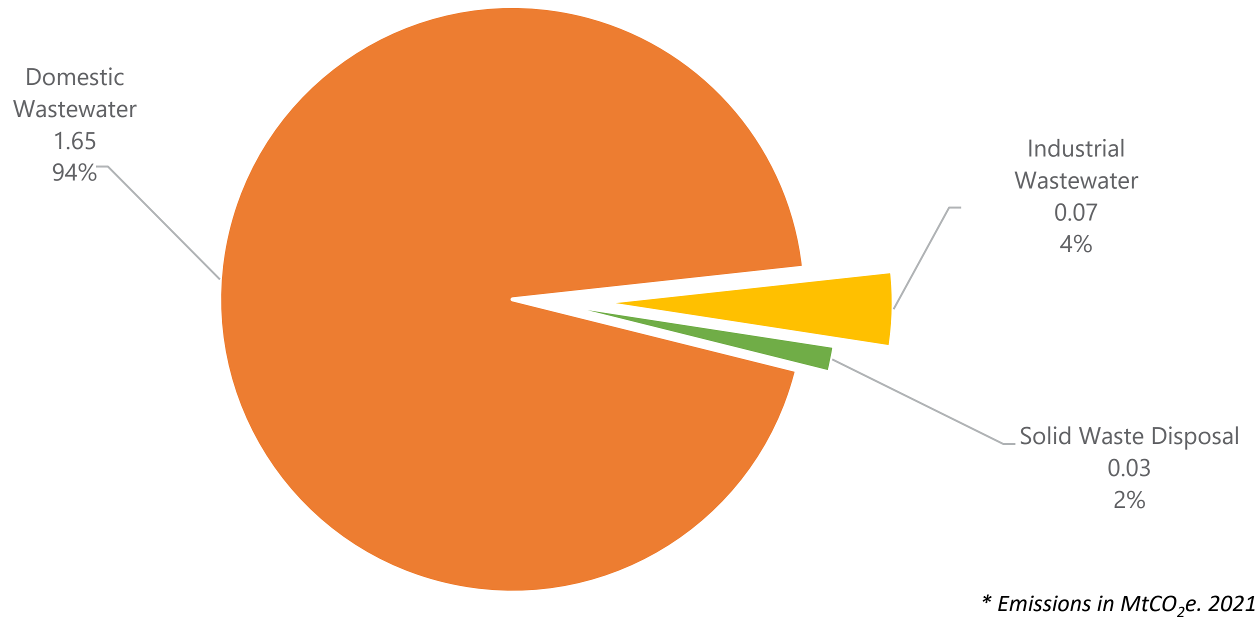


Figure-ER-21: *Category-based Emissions and Percentage Shares in Total Waste Sector Emissions.*

sector emissions of Kerala, and ~8% of the gross emissions of Kerala in 2021.

One of the contributing factors to these emissions could be the absence of piped sewer systems in rural areas, and its relatively low coverage in urban areas.

The second highest contributor to the Waste sector emissions was the Industrial Wastewater category with total emissions of 0.07 $MtCO_2e$, constituting 4% of the total Waste sector emissions. This was followed by Solid Waste Disposal with total emissions of 0.03 $MtCO_2e$,

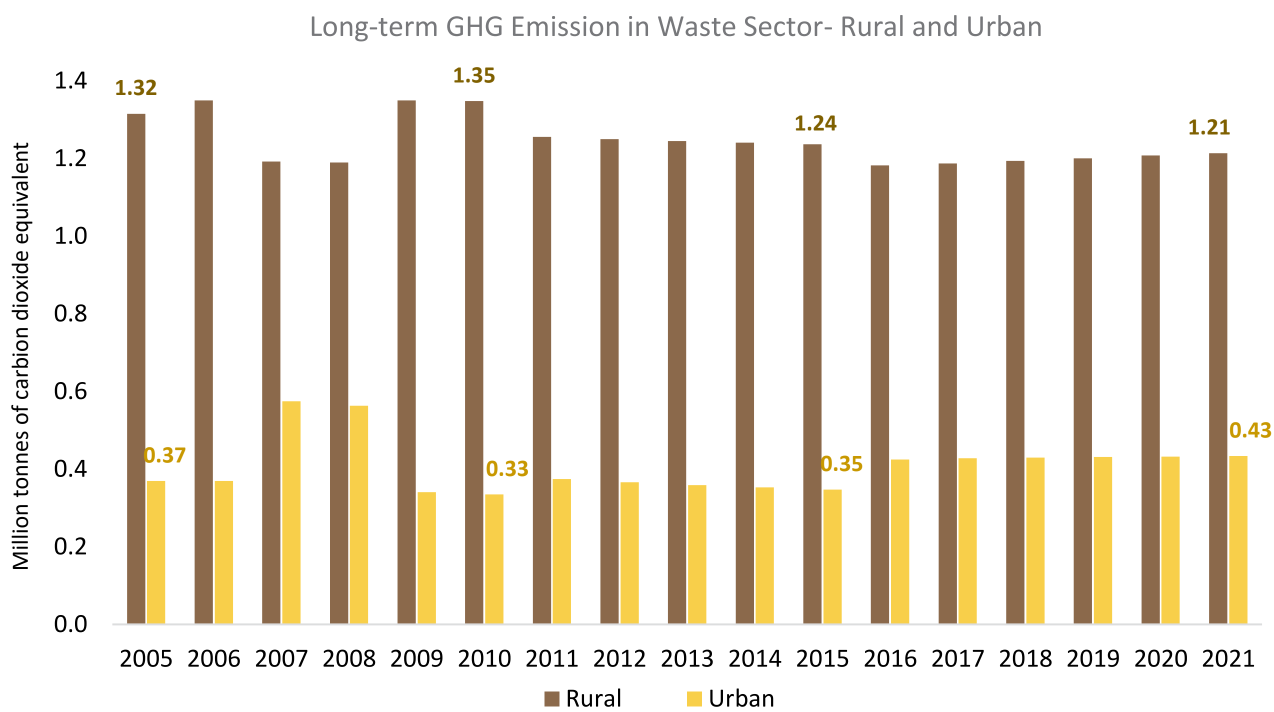


Figure-ER-22: *Long-term GHG Emission in Waste Sector- Rural and Urban* constituting ~2% of the total waste sector emissions of Kerala, in 2021 (*see figure ER-21*).

The emissions from Solid Waste Disposal declined at a rate of 7.9% from 0.10 $MtCO_2e$ in 2005, to 0.03 $MtCO_2e$ in 2021. It has to be noted that the Solid waste management in the State has improved to a great extent. For instance, the Municipal Solid Waste treatment was 52 per cent in 2019-20, which has increased to 93 per cent in 2022-23 (GoK, 2023). The Haritha Karma Sena Self Help Groups (SHGs) have played a pivotal role in this regard in managing waste in the rural and urban areas.

Emissions from Domestic Wastewater in both rural and urban areas declined at a rate of 0.14 % from 1.68 $MtCO_2e$ in 2005, to 1.65 $MtCO_2e$ in 2021. Almost 74% of Domestic wastewater emissions were from the rural areas of Kerala in 2021, as shown in Figure ER-22. Discharge of untreated wastewater and use of septic tanks are the key sources of emissions in the Domestic Wastewater category.

Kerala Water Authority (KWA) that has the management systems for collection and disposal of waste water is having only 4% coverage in the sewage sector of the State, which is mainly confined to Thiruvananthapuram and Kochi Corporations. The need for more focused attention in sewerage sector is essential. However, issues related to funds, public protest against sewage plants and pump houses, delay in getting land and sanctions for road cutting, causes delay in initiating sewerage projects (GoK, 2023) However, KWA envisages new small-scale projects sufficient for 2 to 3 ward clusters. Latest technologies incorporating the reuse of treated effluent as specified by National Green Tribunal (NGT) is proposed to be used in these projects.

Emissions from industrial wastewater grew at an average rate of 1.38% from 0.06 $MtCO_2e$ in 2005 to 0.07 $MtCO_2e$ in 2021. The Fertilizer Industry was the major contributor to Industrial Wastewater emissions with a share of ~45% in 2021. This was followed by Pulp and Paper (~28%) and Petroleum Industries (~22%) as illustrated in *Figure ER-23*.

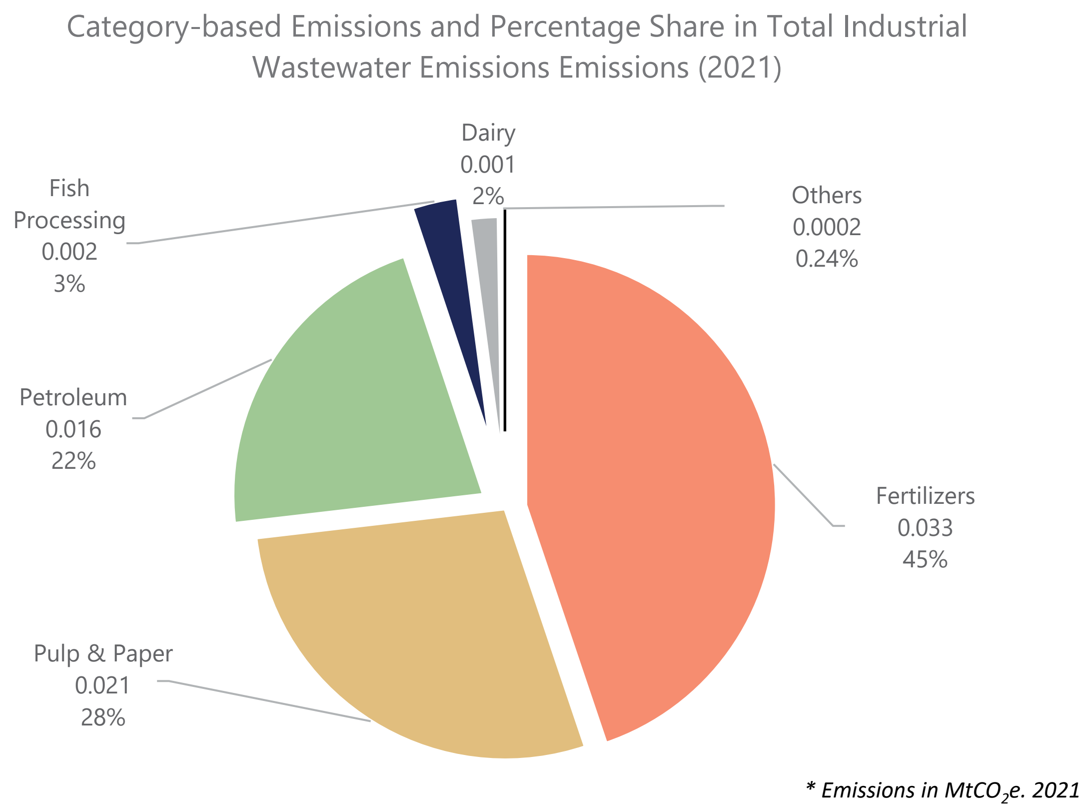


Figure-ER-23: *Category-based Emissions and Percentage Share in Total Industrial Wastewater Emissions.*

9

Key Categories

Of the 35 categories[31] considered in this assessment across five sectors (Appendix 1A), the Transport and Residential categories were the major contributors to the overall gross emissions of the State with shares of 49% and 15% respectively (Figure ER-24). Even if the emissions are considered based on economic sectors, it has to be noted that transport and residential emissions score high above emissions from industries, agriculture, commercial and public utility emissions in Kerala.

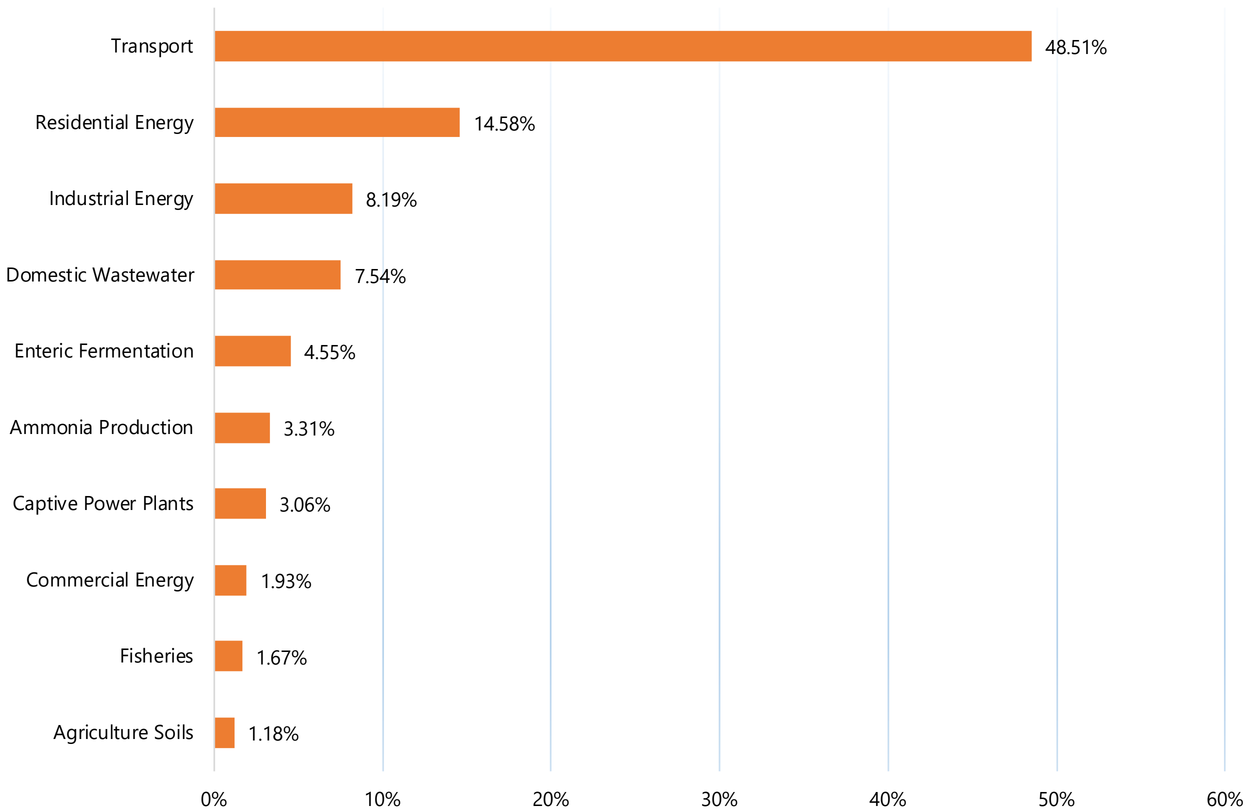


Figure-ER-24: *Percentage share of Key Categories in overall Gross Emissions (2021)*
Shows the Key categories as per the 2006 IPCC Guidelines for National Greenhouse Gas Inventories are "inventory categories which individually, or as a group of categories are prioritized within the inventory system because their estimates have a significant influence on the total inventory of greenhouse gases in terms of the absolute level or the trend. (IPCC 2006).

31 Chapter 4 "Methodological Choice and Identification of Key Categories" in IPCC (2006)

10

Summary Inferences

The Energy sector activities accounting for the overall carbon dioxide emissions lead the emissions profile in the State. The strategies based on the assessment given here shall be detailed in the emissions pathway that is being developed. However, the policy direction that needs to be highlighted in the State's climate change policy, as proposed in the SAPCC 2.0 shall be primarily in envisaging clean transport mechanisms, including strategies like shared mobility and enhanced public transport infrastructure.

P1 Carbon neutrality in the State largely depends upon, emission reductions from the transport sub-sector, specifically in the road transport category.

P2 About 13 per cent of the road network in Kerala handles almost 80 per cent of the traffic in the State (GoK, 2023b). Hence besides greenhouse gas emissions reduction, alternative transport mechanisms have added relevance in Kerala. It has to be noted that a total length of 1926.87 km of navigable waterways is available in the State.[32]

P3 The dominance of emissions from diesel in the fuel category is prominent. A transition from diesel to comparatively cleaner fuel types is a necessity in the long run as diesel dominates the emission profile. Moreover, electrification of the transport sector is the key for decarbonization.

P4 The average long-term net emissions in Kerala are 6.72 $MtCO_2e$. The recent net emissions amount to ~11.60 $MtCO_2$ and show an increasing trend. To achieve carbon neutrality, essential pathways need to be derived to establish the directions and route map towards net zero emissions.

P5 If sub-sector-based emissions are compared, the residential sub-sector in the Energy sector is an emitter much higher than the Waste Sector as a whole.

P6 Forest Land category is the fundamental sink in the state, hence maintaining the quality of the forests has much significance in sustaining its sequestration potential.

P7 It is to be noted that as per India's Long-term Low-Emissions Development Strategy (LT-LEDs), agriculture is not included in LT-LEDs, given its predominantly adaptation-related character; especially in the context of India's agriculture which has predominance of small and marginal farmers. "The absence of large-scale or "industrial agriculture" in India indicates that the burden of mitigating GHG emissions from other sectors cannot be passed on to the agricultural sector"(MoEFCC 2023). In Kerala, the average land holding size is 0.13ha. Thus, in the context of the above and the relative share of emissions from agricultural practices in the State, as detailed in this report, policies and programmes in the agriculture sector aiming at carbon neutrality need thorough re-alignment in retaining agricultural productivity.[33]

32 Of which NW-3 is the longest water way. The volume of cargo on National Water Ways-3 alone has increased to 16.95 lakh tonnes in 2021-22 from 7.38 lakh tonnes in 2020-21 recording an increase of 129.54%.

33 Article 4, Para 19 of the Paris Agreement

11

Quality Control and Quality Assurance

The GHG inventory development for Kerala adhered to a rigorous approach aimed at ensuring the publishing of high-quality results. The process prioritized the reusability of the published datasets and emphasized transparency in both methodology and activity data used for emissions estimation.

Key quality control and quality assurance measures followed include:

- Activity data and data sources used for all related categories across sectors were verified for their time-series consistency and transcription errors on a sample basis.
- Where applicable, alternate sources of information were explored not only to plug the data gaps but also to validate the activity data, before finalizing the emissions estimates, ensuring accuracy and reliability.
- Verification of data, methodology, and emissions estimates was done at the category level by both the Vasudha team and the Directorate of Environment and Climate Change to maintain accuracy and consistency.
- Regular meetings with relevant line departments were conducted to verify emissions trajectories, identification of anomalies, and ensure the reasonability of assumptions.
- For most key categories, emissions trends were closely examined for abrupt deviations from the business-as-usual scenario.
- The best available activity data following IPCC guidelines had been used to develop this inventory.
- Country-specific and state-specific emission factors or studies were employed where relevant and available, enhancing the accuracy of estimates.
- The worksheets were standardized with properly linked and labelled cells for easy tracking and validation of input data.
- Sources for activity data and emission/ conversion factors used across all sectors were referenced in the methodology notes, most with weblinks, for accessibility and transparency.
- All identified gaps in the inventory were documented under limitations in the methodology notes for each sector, ensuring transparency and accountability.

12

Refinements and Insights

As in most of the assessments of GHG inventory, data was the most difficult part of the present assessment. Since most of the data for this assessment were retrieved from the State-owned entities, any data limitations arising at that end eventually has resulted in seeking proxies or relying on available data which may not be the latest or the most accurate data suitable for higher tier assessment. As an instance, the land use matrix of the State as available from various sources could not be relied upon as it was found to be inconsistent with ground features in the majority of the attributes. This might have affected the assessments in the LULUCF sector. For the IPPU sector assessments, a major bottleneck was the unavailability of reliable industrial production data, which was complemented with installed capacity data. Above all, an assessment like a State Level GHG inventory may require voluminous data to be analyzed across years. A precondition for such assessments is the existence of databases that can be readily engaged. This was lacking in many cases even where it was possible using limited time and resources. It was felt the necessity of systematic database management systems in the stakeholder arms that would facilitate easy retrieval of data whenever in need. Despite these shortcomings, the inventory network has engaged the best information available at the time of assessment in this report. Suggestions regarding any future improvements in the assessments are welcome.

13

Way Forward

The assessment presented here shall be foundational to prioritize the sectors and actions for reducing GHG emissions in the State to achieve the 2050 Net Zero target. In this regard, the emission pathways shall be modelled. The pathway modelling shall enable the State to identify the gap between the business as usual and the policy scenario and shall help identify the measures that are required to leverage the necessary actions to achieve the policy scenario and the feasible timelines and finance. This shall also be supporting the stakeholder units to redesign their systems and portfolios to achieve the policy objective. The State shall also identify the possible risks and scopes in adopting the pathways to safeguard and supplement the near-term and Long-term development trajectory of the State. The Inventory exercise has generated a large pool of data which has the possibility of continuous updating and monitoring. In this context, there is potential to enhance existing state capacity in sourcing high-quality activity data across sectors, particulary focusing on industrial processes/product use and industrial energy consumption. Such efforts would significantly enhance the robustness of the GHG inventory. An actionable initiative could involve expanding the scope of the annual survey of industries conducted by the Department of Economics and Statistics, Government of Kerala, to gather precise industrial fuel-wise consumption data, thereby enhancing the accuracy of industrial energy emissions estimations. As part of the knowledge-sharing initiative of DoECC, the data and the assessment shall be fed to the State Climate Change portal for wider access and usability.

14

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Appendices

Appendix-1

Sub-sectors/categories identified under each sector

Sr. No	Category Title
	Energy sector
1.	Energy Industries
a.	Public Electricity Generation
b.	Captive Power Plants
2.	Industrial Energy
3.	Transport
a.	Civil aviation
b.	Road transportation
c.	Railways
d.	Water-borne navigation
4.	Other Sectors
a.	Commercial/Institutional
b.	Residential
c.	Agriculture/Fisheries
5.	Fugitive Emissions from Fuels
	Industrial Processes and Product Use sector (IPPU)
1.	Mineral Industry
a.	Cement Production
b.	Lime Production
c.	Other uses of soda ash
2.	Chemical Industry
a.	Ammonia Production
b.	Caprolactam Production
c.	Titanium Dioxide Production
d.	Soda Ash Production
e.	Carbon Black
3.	Metal Industry
a.	Iron and Steel Production
b.	Zinc Production
4.	Non-Energy Products from Fuels and Solvent Use
a.	Lubricant Use
b.	Paraffin Wax Use
	Agriculture Sector
1	Agriculture Practices
a.	Direct N_2O emissions from Managed Soils
b.	Indirect N_2O emissions from Managed Soils
c.	Biomass burning in Cropland
d.	Rice Cultivation
2	Livestock

Sr. No	Category Title
a.	Enteric Fermentation
b.	Manure Management
	Land Use, Land Use Change and Forestry (LULUCF) Sector
1.	Agriculture Land
2.	Biomass burning in Forestland
3.	Forestland
4.	Grassland
5.	Other Land
6.	Settlements
	Waste sector
1.	Solid Waste Disposal
2.	Domestic Wastewater Treatment and Discharge
3.	Industrial Wastewater Treatment and Discharge

Appendix 1A

Type of emission factor and level of methodological tier employed for GHG estimation

Sl. No.	GHG Sources and sink categories	CO_2		CH_4		N_2O	
		Method Applied	Emission Factor	Method Applied	Emission Factor	Method Applied	Emission Factor
				ENERGY			
1.	**Energy Industries**						
a.	Public Electricity Generation	Tier 1 (T1), Tier 2 (T2)	Country specific (CS)	T1	IPCC Default (D)	T1	IPCC Default (D)
b.	Captive Power Plants	T1, T2	CS	T1	D	T1	D
2.	Industrial Energy	T2	CS	T1	D	T1	D
3.	Transport	T1, T2	CS	T1	D	T1	D
4.	Other Sectors	T1, T2	CS	T1	D	T1	D
5.	Fugitive Emissions from Fuels	-	-	T2	CS	-	-
				IPPU			
1.	**Mineral Industry**						
a.	Cement Production	T1	CS	-	-	-	-
b.	Lime Production	T1	D	-	-	-	-
c.	Other uses of soda ash	T1	CS	-	-	-	-

Sl. No.	GHG Sources and sink categories	CO_2		CH_4		N_2O	
		Method Applied	Emission Factor	Method Applied	Emission Factor	Method Applied	Emission Factor
2.	**Chemical Industry**						
a.	Ammonia Production	T1	CS	-	-	-	-
b.	Caprolactam Production	-	-	-	-	T1	CS
c.	Titanium Dioxide Production	T1	CS	-	-	-	-
d.	Soda Ash Production	T1	D	-	-	-	-
e.	Carbon Black	T1	CS	-	-	-	-
3.	**Metal Industry**						
a.	Iron and Steel Production	T1	CS	-	-	-	-
b.	Zinc Production	T1	CS	-	-	-	-
4.	**Non-Energy Products from Fuels and Solvents Use**						
a.	Lubricant Use	T1	CS	-	-	-	-
b.	Paraffin Wax Use	T1	CS	-	-	-	-
			AGRICULTURE				
1.	**Agriculture Practices**						
a.	Biomass burning in Cropland	-	-	T1	D	T1	D
a.	Direct N_2O emissions from Managed Soils	-	-	-	-	T1	CS
b.	Indirect N_2O emissions from Managed Soils	-	-	-	-	T2	CS
c.	Rice Cultivation	-	-	T2	CS	-	-
2.	**Livestock**						
a.	Enteric Fermentation	-	-	T1,T2	D, CS	-	-
b.	Manure Management	-	-	T1,T2	D, CS	T1,T2	D, CS
			LULUCF				
1.	Cropland	T2	D, CS	-	-	-	-

Sl. No.	GHG Sources and sink categories	CO_2		CH_4		N_2O	
		Method Applied	Emission Factor	Method Applied	Emission Factor	Method Applied	Emission Factor
2.	Biomass burning in Forestland	-	-	T2	D, CS	T2	D, CS
3.	Forestland	T2	CS	-	-	-	-
4.	Grassland	T2	D, CS	-	-	-	-
5.	Other Land	T2	D, CS	-	-	-	-
6.	Settlements	T2	D, CS	-	-	-	-
	WASTE						
1.	Solid Waste Disposal	-	-	T1, T2	D, CS	-	-
2.	Domestic Wastewater Treatment and Discharge	-	-	T1	D	T1	D
3.	Industrial Wastewater Treatment and Discharge	-	-	T2	CS	-	-
	T1: Tier 1, T2: Tier 2, D: IPCC Default, CS: Country-Specific						

Appendix 2

Global Warming Potential, Factors Used

GHG	GWP 100 as per IPCC AR2 WGI	GWP 100 as per IPCC AR6 WGI	GTP AR6
CO_2	1	1	1
CH_4	21	27.9	5.38
N_2O	310	273	233

The Global Warming Potential (GWP) serves as a quantified metric indicating the globally averaged relative radiative forcing of a specific greenhouse gas. It is defined as the cumulative radiative forcing over a specific time horizon resulting from the emission of 1 kilogram (kg) of the gas, in comparison to the reference gas, CO_2.[34] Direct radiative effects occur when the gas itself absorbs radiation, while indirect radiative forcing takes place through chemical transformations that produce greenhouse gases or influence other radiatively significant processes, such as the atmospheric lifetimes of other gases. All computations in the current report are based on the GWP of greenhouse gases for a 100-year timeframe, as per IPCC AR2 (IPCC, 1995).

34 MoEFCC. (2023). India: Third National Communication and Initial Adaptation Communication to the United Nations Framework Convention on Climate Change. New Delhi: Ministry of Environment, Forest and Climate Change, Government of India.

Appendix 3

Category-level detailed GHG emissions (in kilotonnes) (2005 to 2021)

Category	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
Energy	18124	16193	15332	15580	16086	15947	15628	16102	15900	16314	17044	18043	19162	19135	20046	16960	17237
Fuel Combustion Emissions	18124	16193	**15332**	**15580**	**16086**	**15947**	**15628**	**16102**	**15900**	**16314**	**17044**	**18043**	**19162**	**19135**	**20046**	**16960**	**17237**
Agriculture	74	75	270	365	398	421	468	517	560	576	578	576	588	585	578	275	181
Captive Power Plants	404	399	378	428	438	456	489	517	534	770	834	716	702	706	928	655	669
Commercial	650	660	663	654	679	723	778	804	625	618	785	855	912	964	1007	539	422
Fisheries	381	346	316	308	347	350	414	342	226	300	328	311	478	343	339	246	364
Industrial Energy	2112	1863	1538	1865	2040	1921	1717	1782	1194	804	1094	1743	1794	1762	1772	1779	1792
Public Electricity Generation	336	645	936	1094	1357	1195	623	650	735	703	285	62	37	11	3	34	15
Residential	1738	1912	2032	2051	2163	2303	2345	2301	2280	2404	2578	2785	3015	2875	2936	3107	3188
Transport	12430	10293	9200	8814	8664	8578	8795	9188	9745	10139	10562	10995	11636	11888	12484	10325	10607
Fugitive Emissions	**0.01**	**0.01**	**0.01**	**0.01**	**0.01**	**0.01**	**0.01**	**0.01**	**0.01**	**0.01**	**0.02**	**0.02**	**0.02**	**0.02**	**0.02**	**0.02**	**0.02**
Industrial Processes and Product Use	**1474**	**1472**	**1403**	**1392**	**1449**	**1447**	**1437**	**1383**	**1334**	**1312**	**1343**	**1345**	**1334**	**1268**	**1222**	**1216**	**1317**
Chemical Industry	**1194**	**1191**	**1121**	**1111**	**1165**	**1193**	**1188**	**1136**	**1088**	**1078**	**1078**	**1079**	**1069**	**1069**	**1024**	**1016**	**1047**
Ammonia Production	724	724	724	724	724	724	724	724	724	724	724	724	724	724	724	724	724
Caprolactam Production	116	113	43	33	97	122	110	59	11	0	0	2	1	0	0	0	44
Carbon Black	277	277	277	277	277	277	277	277	277	277	277	277	277	277	237	229	204

Category	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
Soda Ash Production	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
Titanium Dioxide Production	75	75	75	75	65	68	75	75	75	75	75	75	66	66	62	61	75
Metal Industry	**59**	**59**	**59**	**59**	**59**	**59**	**54**	**54**	**51**	**40**	**40**	**40**	**40**	**40**	**40**	**40**	**40**
Iron and Steel Production	40	40	40	40	40	40	40	40	40	40	40	40	40	40	40	40	40
Zinc Production	19	19	19	19	19	19	14	14	11	0	0	0	0	0	0	0	0
Mineral Industry	**196**	**195**	**195**	**195**	**195**	**166**	**167**	**164**	**167**	**166**	**196**	**196**	**197**	**129**	**129**	**130**	**199**
Cement Production	184	184	184	184	184	155	156	152	152	152	184	184	184	116	115	115	184
Lime Production	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11
Other Uses of Soda Ash	1	1	0.16	0.02	0.01	0.01	0.02	1	3	2	2	2	2	3	3	4	4
Non-Energy Products from Fuels and Solvent Use	**25**	**27**	**29**	**28**	**29**	**29**	**29**	**28**	**28**	**29**	**30**	**30**	**29**	**30**	**29**	**30**	**30**
Lubricant Use	21	23	24	23	25	25	24	24	24	25	25	25	24	25	25	26	26
Paraffin Wax Use	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4
Agriculture	**2024**	**1979**	**1923**	**1894**	**1842**	**1769**	**1735**	**1642**	**1665**	**1608**	**1602**	**1519**	**1643**	**1554**	**1525**	**1561**	**1564**
Agriculture Practices	**521**	**519**	**506**	**547**	**564**	**561**	**597**	**573**	**592**	**530**	**520**	**432**	**553**	**460**	**426**	**455**	**450**
Agriculture Soils	253	262	277	322	339	351	395	380	400	338	329	261	371	269	234	258	259
Biomass Burning in Cropland	5.62	5.59	4.92	5.13	5.33	4.85	4.98	4.64	4.88	4.96	4.86	4.09	4.39	4.94	5.12	5.44	5.07
Rice Cultivation	263	251	224	219	220	206	197	188	187	187	186	167	178	186	187	191	187

Category	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
Livestock	**1503**	**1460**	**1417**	**1347**	**1278**	**1208**	**1139**	**1069**	**1073**	**1078**	**1082**	**1086**	**1090**	**1095**	**1099**	**1106**	**1114**
Enteric Fermentation	1369	1331	1292	1226	1161	1095	1029	964	966	969	972	975	978	980	983	988	994
Manure Management	134	129	125	121	117	113	109	105	107	108	110	111	113	114	116	117	120
Land Use, Land-Use Change and Forestry (LULUCF)	**-13527**	**-13527**	**-13527**	**-13526**	**-18258**	**-18257**	**-18257**	**-18147**	**-18148**	**-18148**	**-18148**	**-15475**	**-15475**	**-10261**	**-10261**	**-10261**	**-10261**
Agricultural Land	-346	-346	-346	-346	-346	-346	-346	-240	-240	-240	-240	-240	-240	-240	-240	-240	-240
Biomass Burning in Forest Land	1.09	1.30	1.13	2.07	1.38	2.12	1.40	1.13	0.85	0.77	0.86	1.21	0.75	0.73	0.43	0.23	0.18
Forest Land	-13144	-13144	-13144	-13144	-17875	-17875	-17875	-17875	-17875	-17875	-17875	-15202	-15202	-9988	-9988	-9988	-9988
Grassland	-3.17	-3.17	-3.17	-3.17	-3.17	-3.17	-3.17	0.79	0.79	0.79	0.79	0.79	0.79	0.79	0.79	0.79	0.79
Other land	-17	-17	-17	-17	-17	-17	-17	13	13	13	13	13	13	13	13	13	13
Settlements	-19	-19	-19	-19	-19	-19	-19	-47	-47	-47	-47	-47	-47	-47	-47	-47	-47
Waste	**1840**	**1866**	**1896**	**1880**	**1821**	**1808**	1749	1730	1719	1706	1692	1718	1731	1732	1741	1745	1746
Solid Waste Disposal	95	85	77	73	70	64	60	57	54	52	51	50	50	42	36	30	26
Domestic Wastewater	1685	1719	1767	1753	1690	1683	1630	1617	1604	1594	**1584**	**1607**	**1616**	**1624**	**1632**	**1640**	**1648**
Rural	1316	1350	1192	1190	1349	1348	1256	1250	1245	1241	1237	1182	1187	1194	1201	1208	1214
Urban	369	369	575	563	341	335	374	366	359	353	347	425	428	430	431	432	434
Industrial Wastewater	**60**	**62**	**52**	**54**	**61**	**61**	**59**	**57**	**60**	**60**	**57**	**61**	**65**	**66**	**73**	**74**	**73**
Dairy	1.36	1.36	1.36	1.36	1.36	1.36	1.36	1.36	1.36	1.36	1.36	1.36	1.36	1.36	1.36	1.36	1.36
Fertilizers	28	29	19	22	28	27	25	22	25	25	21	24	26	25	32	35	33
Fish processing	2.19	2.19	2.19	2.19	2.19	2.19	2.19	2.19	2.19	2.19	2.19	2.19	2.19	2.19	2.19	2.19	2.19
Meat	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01

Category	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
Petroleum	8	8	9	8	8	9	10	10	11	11	11	12	14	16	17	15	16
Pulp & Paper	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21
Rubber	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Tannery	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16
Net Emissions (with LULUCF)	**9936**	**7983**	**7027**	**7220**	**2941**	**2714**	**2292**	**2709**	**2471**	**2792**	**3533**	**7150**	**8396**	**13428**	14273	11220	11603
Gross Emissions (without LULUCF)	23463	21510	20554	20746	21198	20971	20550	20857	20618	20940	21681	22625	23871	23689	24534	21482	21864

Appendix 4

Detailed GHG Emissions/Removals of Kerala in 2021 (in kilotonnes)

Sector/Category	CO_2 Emission	CO_2 Removals	CH_4	N_2O	CO_2 Equivalent
Total Emissions	18282.69	-10275.377	122.911	3.27	11,602.732
1. Energy	16995.94		3.14	0.57	17237.38
A. Fuel Combustion Activities	16995.94		3.14	0.57	17237.36
Agriculture	180.27		0.02	0.001	181.23
Captive Power Plants	667.20		0.01	0.004	668.57
Commercial	420.38		0.04	0.002	421.82
Fisheries	357.39		0.14	0.013	364.38
Industrial Energy	1787.29		0.06	0.010	1791.67

Sector/Category	CO_2 Emission	CO_2 Removals	CH_4	N_2O	CO_2 Equivalent
Public Electricity Generation	14.55		0.001	0.0001	14.60
Residential	3170.41		0.44	0.026	3187.87
Transport	10398.45		2.43	0.509	10607.20
B. Fugitive Emissions from Fuels	NO		0.001	NO	0.0211
2. Industrial Product and Process Use Sector (IPPU)	1272.84		0.0047	0.141	1316.53
Mineral Industry	199.08		0.0	0	199.08
Cement Production	183.51		0.0	0	183.51
Lime Production	11.10		0.0	0	11.10
Other Uses of Soda Ash	4.47		0.0	0	4.47
Chemical Industry	1003.56		0.0047	0.141	1047.25
Ammonia Production	723.59		0	0	723.59
Caprolactam Production	0.00		0	0.141	43.60
Carbon Black	203.45		0.0047	0	203.55
Soda Ash Production	1.51		0.0	0	1.51
Titanium Dioxide Production	75.00		0.0	0	75.00
Metal Industry	40.05		0.0	0	40.05
Iron and Steel Production	40.05		0.0	0	40.05

Sector/Category	CO_2 Emission	CO_2 Removals	CH_4	N_2O	CO_2 Equivalent
Zinc Production	0.00		0.0	0	0.00
D.Non-Energy Products from Fuels and Solvent Use	30.14		0.0	0	30.14
Lubricant Use	25.90		0.0	0	25.90
Paraffin Wax Use	4.25		0.0	0	4.25
3. Agriculture			60.90	0.92	1564.15
Agriculture Practices			9.06	0.84	450.48
Agriculture Soils			NA	0.84	258.89
Biomass Burning in Cropland			0.17	0.0045	5.07
Rice Cultivation			8.88	NA	186.52
Livestock			51.84	0.08	1113.68
Enteric Fermentation			47.34	NO	994.10
Manure Management			4.51	0.08	119.58
4. Land Use, Land-Use Change and Forestry (LULUCF)	13.91	10275.37	0.001	0.0001	-10261.27
Agricultural Land		240.47			-240.47
Biomass Burning in Forest Land			0.001	0.0001	0.18
Forest Land		9987.63			-9987.63
Grassland	0.79				0.79

Sector/Category	CO_2 Emission	CO_2 Removals	CH_4	N_2O	CO_2 Equivalent
Other land	13.12				13.12
Settlements		47.27			-47.27
4. Waste			58.87	1.64	1745.94
Solid Waste Disposal			1.21		25.50
Domestic Wastewater			54.20	1.64	1647.89
Rural			39.07	1.27	1213.75
Urban			15.13	0.38	434.14
Industrial Wastewater			3.45		72.55
Dairy			0.06		1.36
Fertilizers			1.55		32.51
Fish processing			0.10		2.19
Meat			0.001		0.013
Petroleum			0.75		15.76
Pulp & Paper			0.98		20.56
Rubber			0.00		0.00
Tannery			0.01		0.16

Appendix 5

Carbon Stock Density and Forest Cover of Kerala

(a) Carbon Stock Density of Kerala

Parameter/Years	2008	2015	2017	2019
Carbon Stock Density (tonnes/ hectare)	127.95	125.92	100.72	96.70

(b) Forest Cover of Kerala

Years	Reported Forest Cover (sq.km)
2004	15595
2006	17324
2008	17300
2010	17922
2013	19239
2015	20321
2017	21144.29
2019	21253.49

ANNEXURE

Kerala GHG Inventory

TABLE OF CONTENTS OF ANNEXURES

ACRONYMS

ATF	Aviation Turbine Fuel
BUR 2	India Second Biennial Update Report to The United Nations Framework Convention on Climate Change
BUR 3	India Third Biennial Update Report to The United Nations Framework Convention on Climate Change
CAGR	Compounded Annual Growth Rate
CEA	Central Electricity Authority
CSD	Carbon Stock Density
CNG	Compressed Natural Gas
FO	Furnace Oil
FACT	The Fertilizers and Chemicals Travancore Limited
GTP	Global Temperature Potential
GWP	Global Warming Potential
HSD(O)	High Speed Diesel (Oil)
IPCC	Intergovernmental Panel on Climate Change
INCCA	Indian Network on Climate Change Assessment
KSPCB	Kerala State Pollution Control Board
KMML	Kerala Minerals and Metals Limited
LDO	Light Diesel Oil
LSHS	Low Sulphur Heavy Stock
MoPNG	Ministry of Petroleum and Natural Gas
MoSPI	Ministry of Statistics and Programme Implementation
Mt CO_2e	Million tonnes of carbon dioxide equivalent
NATCOM 2	India Second National Communication to United Nations Framework Convention on Climate Change
NCV	Net Calorific Value
PPAC	Petroleum Planning and Analysis Cell
TTPL	Travancore Titanium Products Limited

INTRODUCTION

The GHG inventory has been developed for the period 2005 to 2021, accounting for carbon-dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O) emissions. The inventory covers all the four sectors, namely, Energy, IPPU (Industrial Processes and Product Use), AFOLU (Agriculture, Forestry & Other Land Use) & Waste, and all relevant sub-sectors that contribute to the GHG emissions, as per the Intergovernmental Panel on Climate Change (IPCC) methodology and guidelines.[1,2] However, for reporting purposes AFOLU has been bifurcated into Agriculture and LULUCF sectors, in alignment with the Government of India's GHG inventory reports.

The estimations are largely based on IPCC's Tier 1 and Tier 2 approaches of emissions estimation. In most cases, the Tier 1 (T1) or IPCC-suggested standard approach (by using default emission factors) is followed in the absence of country-specific emission factors. However, the best efforts were made to source both activity data and emission factors that are available at the state level. Wherever possible, the focus was on following a Tier 2 approach rather than a Tier 1 approach.

Detailed sector-wise information on activity data, emission factors, methodology/tiers followed and equations are given in the chapters below. The methodologies for each sub-sector/category are provided in the order of their IPCC category code.

<u>Reporting Period:</u>
The time period for the state-level GHG emission estimations and subsequently aggregated state- level GHG estimates is from 2005 to 2021. This inventory follows the base year of 2005 to align with the base year followed in India's Updated First Nationally Determined Contribution Under Paris Agreement.

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[1] 2006 IPCC Guidelines for National Greenhouse Gas Inventories https://www.ipcc-nggip.iges.or.jp/public/2006gl/

[2] 2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories https://www.ipcc-nggip.iges.or.jp/public/2019rf/

ENERGY SECTOR

Key Highlights

- Energy sector accounts for ~79% of the gross GHG emissions (excluding LULUCF) in 2021 in Kerala.Emissions from the Energy sector declined from 18.12 Mt CO_2e in 2005 to 17.24 Mt CO_2e in 2021.
- Emissions from this sector peaked in 2019 at 20.05 Mt CO_2e, and declined significantly to 16.96 Mt CO_2e in 2020. This significant decline in emissions could be attributed to reduction in emissions from the Transport sector, primarily due to the strict imposition of Covid-19 related mobility restrictions in the state.
- Within the Energy sector, the Transport sector was the key contributing sub-sector in 2021, accounting for ~62%. This was followed by the Residential sub-sector (~19%) and Industrial Energy (~10%).

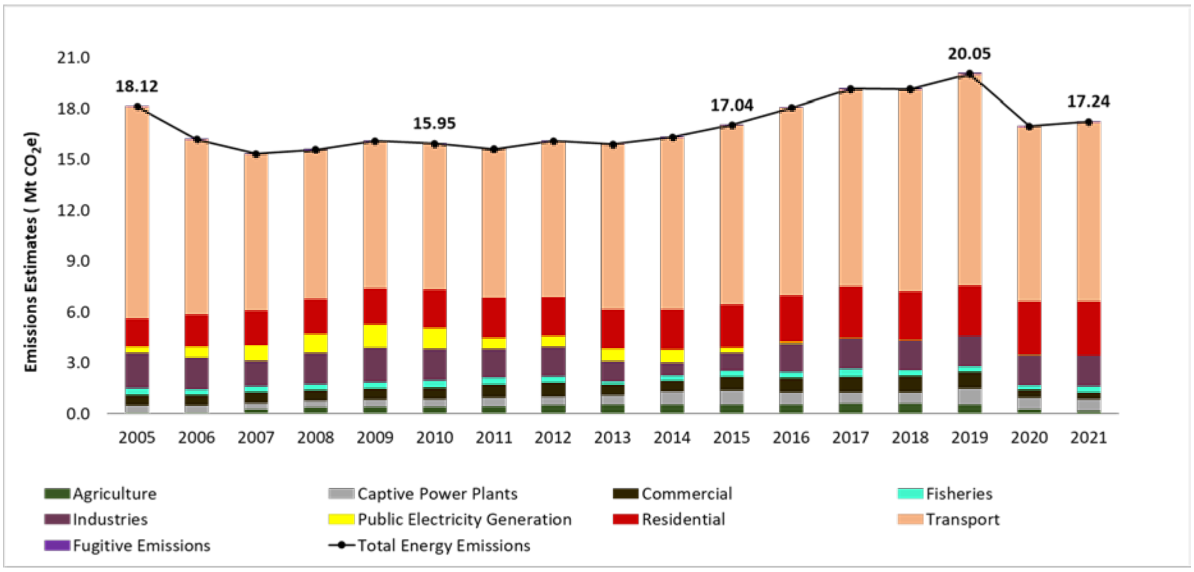

Figure 1 : GHG Emissions Estimates of Energy Sector – Kerala (2005 to 2021)

Sector Description:

Energy systems are for most economies largely driven by the combustion of fossil fuels. During combustion the carbon and hydrogen of the fossil fuels are converted mainly into carbon dioxide (CO_2) and water (H_2O), releasing the chemical energy in the fuel as heat. This heat is generally either used directly or used (with some conversion losses) to produce mechanical energy, often to generate electricity or for transportation.[3](IPCC,2006)

[3] 2006 IPCC Guidelines for National Greenhouse Gas Inventories,Volume 2, Chapter-1
https://www.ipcc-nggip.iges.or.jp/public/2006gl/pdf/2_Volume2/V2_1_Ch1_Introduction.pdf

The Energy sector emissions comprises emissions from Fuel Combustion and Fugitive emissions. The following are the key sub-sectors/categories covered in the Energy sector's emissions estimates:

- 1A1 Energy Industries
  - o 1A1 ai Public Electricity Generation
  - o 1A1 aii Captive Power Plants

- 1A2 Industrial Energy

- 1A 3 Transport
  - o 1A3a Civil aviation
  - o 1A3b Road transportation
  - o 1A3c Railways
  - o IA3d Water-borne navigation

- 1A4 Other Sectors
  - o 1A4a Commercial/Institutional
  - o 1A4b Residential
  - o 1A4c- Agriculture/Fisheries

- 1B Fugitive Emissions From Fuels

Methodology:

The sources of activity data used for estimating emissions from the Energy sector is detailed below in Table 1. The fuel consumption data used for estimating emissions from sector/category for the years 2019, 2020, 2021 is detailed in Table 2.

Table 1: Source of activity data[4] used for estimating emissions from Energy sector

Sub-sector/ Category	Fuels	Years	Sources/ Assumptions
Energy Industries			
Public Electricity Generation	1. High Speed Diesel (HSD) and Naphtha fuels from State/ Private-owned Gas power plants; LSHS and Diesel Oil from State/Private -owned Diesel power plants	(a) 2004-05 to 2010-11 and 2012-13 to 2017-18 (b) 2011- 12 (c) 2018-19 to 2021-22	(a) Central Electricity Authority. *All India Electricity Statistics: General review* Reports *(accessed from hardcopy)* (b) CAGR method (c)Central Electricity Authority. *All India Electricity Statistics: : General review* Reports 2020 , 2021, 2022 and 2023
	2. High Speed Diesel (HSD) and Naphtha fuels from Centrally- owned NTPC- Rajiv Gandhi Combined Cycle Power Plant	(a) 2004-05 to 2016-17 (b) 2017-18 and 2021-22	(a) NTPC- Rajiv Gandhi Combined Cycle Power Plant's Proforma (b) HSD fuel data estimated using CAGR method. Whereas, the Naphtha fuel data was estimated based on Electricity Generation data from Kerala State Electricity Board's Power Statistics and Specific Gas consumption. (derived from Generation and Fuel Consumption value given in the Pro-forma)
Captive Power Plants	Coal, Gas and Diesel	(a) 2004-05 to 2010-11 and 2012-13 to 2017-18 (b) 2011- 12 (c) 2018-19 to 2021-22	(a) Central Electricity Authority. *All India Electricity Statistics: : General review* Reports *(accessed from hardcopy)* (b) CAGR method (c) Central Electricity Authority. *All India Electricity Statistics: : General*

4 Activity data provided in financial year (FY) format was converted to calendar year (CY) format using the following equations:

$$\text{CY Activity data} = [\tfrac{1}{4} * \text{FY Activity Data}_{\text{Preceding year}}] + [\tfrac{3}{4} * \text{FY Activity Data}_{\text{Succeeding year}}]$$

Sub-sector/ Category	Fuels	Years	Sources/ Assumptions
			review Reports 2020 , 2021, 2022 and 2023
Industrial Energy			
Industrial Energy	1. Naphtha	(a) 2007-08 to 2017-18 (b) 2004-05 to 2006-07 (c)2018-19 to 2021-22	(a) Pillai, V. & AM Narayanan. (2019) (b) Naphtha consumption was assumed to be the same as the value reported for 2007-08. (c) CAGR method
	2. High Speed Diesel (HSD)	(a) 2007-08 to 2017-18 (b) 2004-05 to 2006-07 and 2018-19 to 2021-22	(a) Pillai, V. & AM Narayanan. (2019) (b) CAGR method
	3. Light Diesel Oil (LDO)	(a) 2007-08 to 2017-18 (b) 2004-05 to 2006-07 and 2018-19 to 2021-22	(a) Pillai, V. & AM Narayanan. (2019) (b) CAGR method
	4. Furnace Oil (FO)/ Low Sulphur Heavy Stock (LSHS)	(a) 2007-08 to 2017-18 (b) 2004-05 to 2006-07 and 2018-19 to 2021-22	(a) Pillai, V. & AM Narayanan. (2019) (b) CAGR method
	5. Natural Gas	(a) 2007-08 to 2017-18 (b) 2004-05 to 2006-07	(a) Pillai, V. & AM Narayanan. (2019) (b) Natural Gas consumption was assumed to be zero considering the values reported in year 2007-08

Sub-sector/ Category	Fuels	Years	Sources/ Assumptions
		(c) 2018-19 to 2021-22	(c) Average value was applied based on 2016-17 and 2017-18 estimates.
Transport			
Civil Aviation	Aviation Turbine Fuel (ATF)	(a)2003-04,2005-06, 2007-08 to 2010-11 and 2012-13 to 2021-22 (b)2004-05, 2006-07 and 2011-12.	(a) Ministry of Petroleum and Natural Gas, Economic and Statistic Division, Government of India. *Indian Petroleum and Natural Gas statistics* 2003-04, 2005-06, 2007-08, 2008-09,2009-10,2010-11, 2012-13 ,2013-14, 2014-15, 2015-16, 2016-17, 2017-18, 2018-19, 2019-20, 2020-21 and 2021-22 reports. (b) Interpolation method
Road Transport	1. Compressed Natural Gas (CNG)	(a) 2017-18 to 2020-21 (b) 2016-17 and 2021-22 (c) 2015-16 (d) 2004-05, 2006-07 and 2011-12.	(a) Ministry of Petroleum and Natural Gas, Economic and Statistic Division, Government of India. *Indian Petroleum and Natural Gas statistics* 2020-21, 2019-20, 2018-19, 2017-18 reports. (b) Ministry of Petroleum and Natural Gas, Economic and Statistic Division, Government of India. *Indian Petroleum and Natural Gas statistics* 2021-22 report. (c) Data not available hence assumed to be zero. (d) Indian Petroleum and Natural Gas Statistics reports have not been published for these years.

Sub-sector/ Category	Fuels	Years	Sources/ Assumptions
	2. AutoLPG	(a) 2007-08 to 2017-18 (b) 2004-05 to 2006-07 (c) 2018-19 to 2021-22	(a) Pillai, V. & AM Narayanan. (2019) (b) Auto LPG consumption was assumed to be zero considering the values reported in year 2007-08. (c) CAGR method.
	3. Motor Spirit/ Petrol	**(a) Motor Spirit/ Petrol consumption data of Kerala** (i) 2003-04, 2005-06, 2007-08 to 2010-11 and 2012-13 to 2021-22 (ii) 2004-05, 2006-07 and 2011-12.	(i) Ministry of Petroleum and Natural Gas, Economic and Statistic Division, Government of India. *Indian Petroleum and Natural Gas statistics* 2003-04,2005-06,2007-08,2008-09, 2009-10,2010-11,2012-13,2013-14, 2014-15,2015-16,2016-17,2017-18, 2018-19,2019-20,2020-21 and 2021-22 reports. (ii) Interpolation method
		(b)Petrol-Retail (percentage share) consumption in Road Transport sector of Kerala 2012-13	All India study on sectoral demand of Diesel and Petrol Report, 2013 *(Petroleum Planning and Analysis Cell, 2013)*

Sub-sector/ Category	Fuels	Years	Sources/ Assumptions
		(c) National level Motor Spirit/Petrol consumption in retail 2012-13 to 2021-22	Ministry of Petroleum and Natural Gas, Economic and Statistic Division, Government of India. *Indian Petroleum and Natural Gas statistics* 2012-13,2013-14,2014-15,2015-16, 2016-17,2017-18,2018-19,2019-20, 2020-21 and 2021-22 reports.
	4. High Speed Diesel Oil (HSD)	**(a) National-level HSD consumption data:** (i) 2004-05 to 2021-22 for Road Transport sector and Retail sector (ii) 2004-05 to 2006-07 of private sales sector	(i)Ministry of Petroleum and Natural Gas, Economic and Statistic Division, Government of India. *Indian Petroleum and Natural Gas statistics* 2005-06,2007-08,2008-09, 2009-10,2010-11,2012-13,2013-14, 2014-15,2015-16,2016-17,2017-18, 2018-19,2019-20,2020-21 and 2021-22 reports (ii) Ministry of Petroleum and Natural Gas, Economic and Statistic Division, Government of India. *Indian Petroleum and Natural Gas statistics* 2005-06 and 2009-10
		(b) HSD consumption data of Kerala (i) 2003-04, 2005-06, 2007-08 to 2010-11 and 2012-13 to 2021-22	(i) Ministry of Petroleum and Natural Gas, Economic and Statistic Division, Government of India. *Indian Petroleum and Natural Gas statistics* 2003-04,2005-06,2007-08,2008-09, 2009-10,2010-11,2012-13,2013-14, 2014-15,2015-16,2016-17,2017-18, 2018-19,2019-20,2020-21 and 2021-22 reports (ii)Interpolation method.

Sub-sector/ Category	Fuels	Years	Sources/ Assumptions
		(ii) 2004-05 , 2006-07 and 2011-12	
		(c)Diesel-Retail (percentage share) consumption in Road Transport sector of Kerala (i) 2012-13 (ii) 2021-22	(i) All India study on sectoral demand of Diesel and Petrol Report, 2013 *(Petroleum Planning and Analysis Cell, 2013)* (ii) All India study on sectoral demand of Diesel and Petrol Report (PPAC), 2021 *(accessed from hard copy)*
Railways	1. HSD	**(a) Railways Consumer Depot (RCD)/Kannur** (i) 2007 to 2021 (ii) 2005 to 2006	(i) Southern Railway Department. (ii) CAGR method
		(b) Railways Consumer Depot (RCD)/ Palakkad (i) 2014 to 2021 (ii) 2005 to 2013	(i) Southern Railway Department. (ii) CAGR method
	2. Diesel	**Thiruvananthapuram Division** (i) 2019 to 2021 (ii) 2005 to 2018	(i)Southern Railway Department. (ii) CAGR method
	3. LDO	**Electrical (GS) Palakkad Division** (i) 2014 to 2022 (ii) 2005 to 2013	(i) Southern Railway Department. (ii) CAGR method
Water-borne Navigation	1. Diesel	(a) 2010 and 2022	(a) Kerala Maritime Board (b) CAGR method

Sub-sector/ Category	Fuels	Years	Sources/ Assumptions
		(b) 2011 to 2021	
	2. Petrol	(a) 2010 and 2022 (b) 2011 to 2021 (c) 2005 to 2009	(a) Kerala Maritime Board (b) CAGR method (c) Average fuel consumption value (of years 2010 to 2016)
	3. High Speed Diesel (HSD)		2005 to 2021 fuel consumption data estimated based on the thumb-rules provided by the State Water Transport Department.
Other Sectors (Energy)			
Commercial/Institutional	1. Liquified Petroleum Gas (LPG)	**(a) National Level Commercial sector LPG consumption data:** (i) 2003-04, 2009-10 to 2021-2022 (ii) 2004-05 to 2008-09	(i) Ministry of Petroleum and Natural Gas, Economic and Statistic Division, Government of India. *Indian Petroleum and Natural Gas statistics* 2003-04,2009-10,2010-11,2012-13, 2013-14,2014-15,2015-16,2016-17, 2017-18,2018-19,2019-20,2020-21 and 2021-22 reports (ii) CAGR method
		(b) National level Total LPG consumption data: 2003-04 to 2021-22	Ministry of Petroleum and Natural Gas, Economic and Statistic Division, Government of India. *Indian Petroleum and Natural Gas statistics* 2003-04,2005-06,2007-08,2008-09, 2009-10,2010-11,2012-13,2013-14, 2014-15,2015-16,2016-17,2017-18, 2018-19,2019-20,2020-21 and 2021-22 reports

Sub-sector/ Category	Fuels	Years	Sources/ Assumptions
		(c) LPG consumption data of Kerala: (i)2003-04,2005-06, 2007-08 to 2010-11 and 2012-13 to 2021-22 (ii) 2004-05 and 2006-07	(i) Ministry of Petroleum and Natural Gas, Economic and Statistic Division, Government of India. *Indian Petroleum and Natural Gas statistics* 2003-04,2005-06,2007-08,2008-09, 2009-10,2010-11,2012-13,2013-14, 2014-15,2015-16,2016-17,2017-18, 2018-19,2019-20,2020-21 and 2021-22 reports (ii) Interpolation Method
	2. High Speed Diesel Oil (HSDO)	**(a) Commercial sector HSDO consumption data:** (i) 2007-08 to 2017-18 (ii) 2004-05 to 2006-07 and 2018-19 to 2019-20	(i) Pillai, V. & AM Narayanan. (2019) (ii) CAGR method
		(b) National level HSDO consumption data: 2020-21 and 2021-22 for the retail sector and total national-level consumption.	Ministry of Petroleum and Natural Gas, Economic and Statistic Division, Government of India. *Indian Petroleum and Natural Gas statistics* 2020-21 and 2021-22 reports
		(c)HSDO consumption data of Kerala 2020-21 and 2021-22	Ministry of Petroleum and Natural Gas, Economic and Statistic Division, Government of India. *Indian Petroleum and Natural Gas statistics* 2020-21 and 2021-22 reports

Sub-sector/ Category	Fuels	Years	Sources/ Assumptions
		(d) Diesel Consumption (percentage share) in Non- Transport sector of Kerala 2021-22	All India study on sectoral demand of Diesel and Petrol Report (PPAC) 2021 *(accessed from hard copy)*
		(e) National-level Diesel (percentage share) in Commercial sector	GHGPI Phase III[5]
Residential	1. Kerosene	(a) 2007-08 to 2017-18 (b) 2004-05 to 2006-07 and 2018-19 to 2021-22	(a) Pillai, V. & AM Narayanan. (2019) (b) Estimated using Pillai, V. & AM Narayanan. (2019) study and Economic Review Reports (2004-05,2005-06,2006-07, 2018-19, 2019-20, 2020-21 and 2021-22) of Kerala
	2. Liquified Petroleum Gas (LPG)	**(a) LPG consumption data of Kerala** (i) 2007-08 to 2017-18 (ii) 2003-04, 2005-06, 2007-08 and 2018-19 to 2021-22 (iii) 2004-05 to 2006-07	(i) Pillai, V. & AM Narayanan. (2019) (ii) Ministry of Petroleum and Natural Gas, Economic and Statistic Division, Government of India. *Indian Petroleum and Natural Gas statistics* 2003-04,2005-06,2007-08,2018-19, 2019-20,2020-21 and 2021-22 reports (iii) Interpolation Method

[5] Mohan, R.R., Dharmala, N., Ananthakumar, M. R., Kumar, P., Bose, A. (2019). *Greenhouse Gas Emission Estimates from the Energy Sector in India at the Subnational Level (Version/edition 2.0)*. New Delhi. GHG Platform India Report - CSTEP. Available at https://www.ghgplatform-india.org/wp-content/uploads/methodology/phase-3/GHGPI-PhaseIII-Methodology%20Note-Energy-Sep%202019.pdf

Sub-sector/ Category	Fuels	Years	Sources/ Assumptions
		(b) National level LPG consumption data (i) 2004-05 to 2007-08 and 2018-19 to 2021-22 of domestic LPG (ii) 2004-05 to 2006-07 of Private sales sector	Ministry of Petroleum and Natural Gas, Economic and Statistic Division, Government of India. *Indian Petroleum and Natural Gas statistics* 2005-06, 2007-08, 2018-19, 2019-20, 2020-21 and 2021-22 reports
Agriculture	Diesel/High Speed Diesel Oil	**(a) HSDO consumption data of Kerala** (i) 2003-04, 2005-06, 2007-08 to 2010-11 and 2012-13 to 2021-22 (ii) 2004-05, 2006-07 and 2011-12	(i)Ministry of Petroleum and Natural Gas, Economic and Statistic Division, Government of India. *Indian Petroleum and Natural Gas statistics* 2003-04, 2005-06, 2007-08, 2008-09, 2009-10, 2010-11, 2012-13, 2013-14, 2014-15, 2015-16, 2016-17, 2017-18, 2018-19, 2019-20, 2020-21 and 2021-22 reports (ii) Interpolation method.
		(b) National level HSDO consumption of Agriculture Sector (i) 2007-08 to 2021-22	(i) Ministry of Petroleum and Natural Gas, Economic and Statistic Division, Government of India. *Indian Petroleum and Natural Gas statistics* 2007-08, 2008-09, 2009-10, 2010-11, 2012-13, 2013-14, 2014-15, 2015-16, 2016-17, 2017-18, 2018-19, 2019-20, 2020-21 and 2021-22 reports

Sub-sector/ Category	Fuels	Years	Sources/ Assumptions
		(ii) 2004-05 to 2006-07	(ii) CAGR method
		(c)National level HSDO consumption of Retail sector 2004-05 to 2021-22	Ministry of Petroleum and Natural Gas, Economic and Statistic Division, Government of India. *Indian Petroleum and Natural Gas statistics* 2005-06,2007-08,2008-09,2009-10, 2010-11,2012-13,2013-14,2014-15, 2015-16,2016-17,2017-18,2018-19, 2019-20,2020-21 and 2021-22 reports
		(d) Diesel Consumption (percentage share) in Non- Transport sector of Kerala (i) 2012-13 (ii) 2021-22	(i) All India study on sectoral demand of Diesel and Petrol Reports (PPAC), 2013 (ii) All India study on sectoral demand of Diesel and Petrol Reports (PPAC),2021 *(accessed from hard copy)*
Fisheries	1. Kerosene	(a) 2007-08 to 2017-18 (b) 2004-05 to 2006-07 and 2018-19 to 2021-22	(a) Pillai, V. & AM Narayanan. (2019) (b) CAGR method
	2. Diesel	2005 to 2021	Fisheries Department-Govt of Kerala
	3. Petrol	2005 to 2021	Fisheries Department-Govt of Kerala
Fugitive Emissions from Fuels			
Refinery Throughput		2004-05 to 2021-22 *(BPCL Kochi)*	Ministry of Petroleum and Natural Gas, Economic and Statistic Division, Government of India.

Sub-sector/ Category	Fuels	Years	Sources/ Assumptions
			Indian Petroleum and Natural Gas statistics 2005-06,2007-08,2008-09,2009-10, 2010-11,2012-13,2013-14,2014-15, 2015-16,2016-17,2017-18,2018-19, 2019-20,2020-21 and 2021-22 reports.

Table 2: Fuel Consumption data used for estimating emissions from Energy sector

IPCC ID	Sub-sector/ Category	Fuels	Units	2019	2020	2021
1A1	**Energy Industries**					
1A1ai	**Public Electricity Generation**	Naphtha	kilolitres	36.45	12491.55	4163.85
		LSHS	kilolitres	791.25	1469.50	1649.00
		HSD	kilolitres	141.53	64.48	24.16
1A1 aii	**Captive Power Plants**	Diesel	kilotonnes	13.36	14.04	13.49
		Gas	kilotonnes	129.78	142.55	168.36
		Steam	kilotonnes	322.42	135.84	103.33
1A 2	**Industrial Energy**	Natural Gas	kilotonnes	230.93	230.93	230.93
		FO/LSHS	kilotonnes	242.21	241.07	239.95
		LDO	kilotonnes	0.51	0.32	0.20
		HSD	kilotonnes	116.97	121.71	126.64
		Naphtha	kilotonnes	2.42	1.59	0.00
1A3	**Transport**					
1A3a	Civil Aviation	ATF	kilotonnes	518.50	269.08	271.78
1A3b	Road Transport	CNG	kilotonnes	4.71	4.73	10.09

IPCC ID	Sub-sector/ Category	Fuels	Units	2019	2020	2021
		Auto LPG	kilotonnes	5.10	4.78	4.49
		MotorSpirit/ Petrol	kilotonnes	1501.52	1387.10	1433.11
		High Speed Diesel Oil	kilotonnes	1751.77	1545.05	1577.67
1A3c	Railways	LDO	kilotonnes	0.024	0.017	0.014
		HSDO	kilotonnes	102.49	8.83	11.05
1A3d	Water-borne Navigation	Petrol	kilotonnes	1.42	1.44	1.47
		Diesel	kilotonnes	10.67	10.72	10.86
1A4	**Other Sector (Energy)**					
1A4a	Commercial/ Institutional	LPG	kilotonnes	100.40	80.65	84.21
		HSDO	kilotonnes	220.74	92.88	53.05
1A4b	Residential	LPG	kilotonnes	894.70	959.23	994.64
		Kerosene	kilotonnes	32.34	22.00	12.09
1A4c	Agriculture	HSDO	kilotonnes	19.23	16.09	14.67
		Diesel- Retail	kilotonnes	161.06	69.70	41.91
1A4c	Fisheries	Kerosene	kilotonnes	24.80	22.23	19.92
		Diesel	kilotonnes	77.14	51.55	88.77
		Petrol	kilotonnes	2.85	2.34	3.84
1B	**Fugitive Emissions from Fuels**		kilotonnes	16399	14090.25	14872

1A1 Energy Industries

The emissions arising from the fuel usage primarily for Electricity Generation are estimated under this category. For Kerala, the emissions have been estimated for Public Electricity Generation and Captive Power Plants sub-sectors and use a combination of Tier 1 (T1) and Tier 2 (T2) approaches. The activity data, methodology and emission factors used for emission estimations are detailed below:

1A1ai Public Electricity Generation

The emissions from the Public Electricity Generation category were estimated from the electricity generating utility-based power plants.

Methodology:

Emissions from the Public Electricity Generation category were estimated using a combination of Tier 1 (T1) and Tier 2 (T2) approaches (see Table 3)

Table 3: Type of emissions factors and the level of methodological tier employed for GHG estimation

IPCC ID	GHG Sources and sink categories	CO_2		CH_4		N_2O	
		Method Applied	Emission Factor	Method Applied	Emission Factor	Method Applied	Emission Factor
1A1 ai	Public Electricity Generation	T1, T2	CS	T1	D	T1	D
T1: Tier 1 , T2: Tier 2, D: IPCC Default, CS: Country-Specific							

The Net Calorific Value (NCV) of fuels and emission factors of Carbon dioxide (CO_2) were taken from INCCA Report (2010) and the emission factors of Methane (CH_4) and Nitrous Oxide (N_2O) were taken from 2006 IPCC Guidelines.[6] Density of Diesel and Low Sulphur Heavy Stock (LSHS) were obtained from a Petroleum Planning and Analysis Cell, (2022) report, while the density of Naphtha was obtained from Central Electricity Authority, (2010) Annual fuel consumption report (see Table 4 and Table 5)

6 Emission Factors for Methane (CH4)and Nitrous oxide (N2O) were obtained from the 2006 IPCC Guidelines. There were no refinements made in the 2019 IPCC Guidelines.

Table 4 : Emissions Factors of Fuels

Fuels	INCCA		2006 IPCC	
	NCV (Tj/kt)	CO_2 EF (t/TJ)	CH_4 (kg/TJ)	N_2O (kg/TJ)
Diesel/High Speed Diesel	43.00	74.10	3.00	0.6
Low Sulphur Heavy Stock (LSHS)	40.20	73.30	3.00	0.6
Naphtha	43.00	74.10	3.00	0.6

Table 5 : **Density of Fuel used for the emissions estimates**

Density of Fuels	Value
Naphtha*	1.35 kL/t
Diesel	1.21 kL/t
Low Sulphur Heavy Stock (LSHS)	1.042 kL/t

*As per CEA Annual Fuel consumption Report (2010) , 1 KL of Naphtha = 0.74 MT

The Activity data provided in financial year (FY) format was converted to calendar year (CY) format using the following equations:

$$\text{CY Activity data} = [\tfrac{1}{4} * \text{FY Activity Data}_{\textit{Preceding year}}] + [\tfrac{3}{4} * \text{FY Activity Data}_{\textit{Succeeding year}}]$$

Equations used for emissions estimates:

The emissions from this category were estimated by applying the Net Calorific Value (fuel type-wise) and corresponding fuel type-wise emission factor to the type of fuel consumed for generating electricity. The equations used for estimations are mentioned below:

$$Emissions_{Gas} = Activity\ Data_{Fuel} \times Net\ Calorific\ Value_{Fuel} \times Emission\ Factor_{Gas}$$

(slightly modified version of IPCC 2006 Equation 2.1)

Emissions in terms of CO_2e (both GWP and GTP) were calculated using the following equations:

$$Emissions_{CO2e}\ (GWP) = Emissions_{CO2} + (GWP_{CH4} \times Emissions_{CH4}) + (GWP_{N2O} \times Emissions_{N2O})$$

$$Emissions_{CO2e}\ (GTP) = Emissions_{CO2} + (GTP_{CH4} \times Emissions_{CH4}) + (GTP_{N2O} \times Emissions_{N2O})$$

1A1 cii Captive Power Plants

Emissions from the Captive Power Plant category were estimated based on the non-utility power plants.

Methodology:

Estimation of Specific Fuel Consumption:

Specific fuel consumption for Captive Power Plants have been estimated using national estimates as reported in CEA General Review Report. The fuel- wise specific consumption calculations are explained below :

a. Specific diesel consumption was estimated from the generation and fuel consumption data of diesel power plants for 2018.[7]
b. Since the gas-based power was almost entirely generated from consumption of natural gas, the specific gas consumption was estimated based on natural gas consumption and the corresponding electricity generated.
c. For coal/lignite (steam) based generation, year-wise specific fuel consumption were provided in General Review 2021, 2022 and 2023 for the years 2009-10 to 2021-22.

A mix approach of Tier 1 (T1) and Tier 2 (T2) was used for estimating GHG emissions from the Captive Power Plant category (see Table 6)

Table 6: Type of emissions factor and the level of methodological tier employed for GHG estimation

IPCC ID	GHG Sources and sink categories	CO_2		CH_4		N_2O	
		Method Applied	Emission Factor	Method Applied	Emission Factor	Method Applied	Emissio n Factor
1A1 a ii	Captive Power Plants	T1,T2	CS	T1	D	T1	D
T1: Tier 1 , T2: Tier 2, D: IPCC Default, CS: Country-Specific							

The Net Calorific Value of fuels and emission factors of Carbon dioxide (CO_2) were taken from INCCA Report (2010) and BUR (Biennial Update Report) 2 (2018). The emission factors of Methane (CH_4) and Nitrous Oxide (N_2O) were taken from 2006 IPCC Guidelines. The Density of Diesel and Gas were obtained from the Petroleum Planning and Analysis Cell, (2022) Report. (see Table 7 and Table 8).

7 Majority of generation in 2018 was by diesel and not by other petroleum fuels such as LSHS or Diesel oil. Also, the specific diesel consumption may not vary much as the Gross Calorific Value of Diesel, LSHS, LDO and HSD are more or less the same.

Table 7 : Emissions Factors of Fuels

Fuels	INCCA and BUR 2		IPCC	
	NCV (Tj/kt)	CO_2 EF (t/TJ)	CH_4 (kg/TJ)	N_2O (kg/TJ)
Non-coking Coal	17.09	96.76	1.00	1.40
Diesel/ Light Diesel Oil (LDO)	43.00	74.10	3.00	0.60
Compressed Natural Gas (CNG)	48.00	56.10	1.00	0.10

Table 8 :Density of Fuel used for the emissions estimates

Density of Fuels	Value
Diesel (HSD)	1.21 kL/t
Natural Gas	0.76 kg/scm

Source *: Petroleum Planning and Analysis Cell, (2022)*

Limitations:

The current emission estimates are based on the generation data of Captive Power Plants above 1 MW as the generation data of Captive Power Plants less than 1MW was not available.

Equations used for emissions estimates:

The equations used for estimations are mentioned below:

$Emissions_{Gas}$ = *Fuel-wise electricity generated x Specific Fuel Consumption*$_{Fuel}$ *x Net Calorific Value*$_{Fuel}$ *x Emission Factor*$_{Gas}$ *(slightly modified version of IPCC 2006 Equation 2.1)*

Emissions in terms of CO_2e (both GWP and GTP) were calculated using the following equations:

$$Emissions_{CO2e}\ (GWP) = Emissions_{CO2} + (GWP_{CH4} \times Emissions_{CH4}) + (GWP_{N2O} \times Emissions_{N2O})$$

$$Emissions_{CO2e}\ (GTP) = Emissions_{CO2} + (GTP_{CH4} \times Emissions_{CH4}) + (GTP_{N2O} \times Emissions_{N2O})$$

1A2 Industrial Energy

The emissions from the Industrial Energy sub-sector were estimated for Naphtha, High Speed Diesel (HSD) , Light Diesel Oil (LDO), Furnace Oil (FO)/ Low Sulphur Heavy Stock (LSHS) and Natural Gas fuels. The emissions from these fuels have been estimated using the activity data (see Table 1) and the following assumptions

<u>Assumptions</u>:

1. **<u>Naphtha:</u>**

   a. The Naphtha consumption reported in the study conducted by Pillai, V. & AM Narayanan, (2019) is assumed to be inclusive of the Naphtha consumption accounted under Public Electricity Generation.
   b. For years 2004-05 to 2006-07, the Naphtha consumption was assumed to be the same as the value reported for 2007-08. This was because the derived value using CAGR appeared to be out of proportion.
   c. The final values of Naphtha consumed for industrial usage, for the years 2004-05 to 2021-22 was adjusted based on the Naphtha consumption data already accounted under the Public Electricity Generation category.
   d. Since the reported/estimated quantity of naphtha for industry usage were miniscule in comparison to other years, and adjusted figures resulted in negative values, naphtha consumption for the years 2016-17, 2017-18, and 2020-21 was considered as zero.

2. **<u>High Speed Diesel (HSD):</u>**
   a. HSD consumption reported by Pillai, V. & AM Narayanan, (2019) is assumed to be inclusive of the HSD consumption accounted under Public Electricity Generation and Captive Power Plants.
   b. Hence, the final HSD values for industrial usage for the years 2007-08 to 2017-18 was calculated by adjusting the Diesel consumption data accounted under Public Electricity Generation and Captive Power Plants categories.
   c. For the period 2004-05 to 2006-07 and 2018-19 to 2020-21, the High Speed Diesel consumption data was estimated using the CAGR method.

3. **<u>Furnace Oil (FO)/ Low Sulphur Heavy Stock (LSHS)</u>**

   a. The FO/LSHS consumption reported by Pillai, V. & AM Narayanan, (2019) is assumed to be inclusive of the LSHS consumption from the Public Electricity Generation category.
   b. Hence, the FO/LSHS consumption for industrial usage for the years 2007-08 to 2017-18 was estimated by adjusting with the LSHS consumption values already accounted under Public Electricity Generation.
   c. For the years 2004-05 to 2006-07 and 2018-19 to 2020-21, the FO/LSHS consumption data was estimated using the CAGR method.

4. **<u>Natural Gas :</u>**

a. For the years 2004-05 to 2006-07, the Natural Gas consumption was assumed to be zero considering the values reported in year 2007-08.
b. The Natural Gas consumption reported by Pillai, V. & AM Narayanan, (2019) is assumed to include the Natural Gas consumption from Captive Power Plants.
c. The consumption data reported by the Pillai, V. & AM Narayanan, (2019) was minuscule between 2013-14 and 2015-16. Thus, the Natural Gas consumption values for industrial

use were adjusted only for the period 2016–18 by deducting corresponding values accounted under Captive Power Plant category.

d. Since the Natural Gas consumption data was not available for the 2018-19 to 2021-22, an average value of 230.93 kt (based on 2016-17 and 2017-18 estimates) was applied.

Methodology:

Emissions from the Industrial Energy category was estimated using the Tier 1 (T1) and Tier (2) approaches (see Table 9)

Table 9: Type of emissions factor and the level of methodological tier employed for GHG estimation

IPCC ID	GHG Sources and sink categories	CO_2		CH_4		N_2O	
		Method Applied	Emission Factor	Method Applied	Emission Factor	Method Applied	Emissio n Factor
1A 2	Industrial Energy	T2	CS	T1	D	T1	D
T1: Tier 1 , T2: Tier 2, D: IPCC Default, CS: Country-Specific							

The Net Calorific Value (NCV) of fuels and emission factors of Carbon dioxide (CO_2) were taken from INCCA Report (2010) and the emission factors of Methane (CH_4) and Nitrous Oxide (N_2O) were taken from 2006 IPCC Guidelines. (see Table 10)

Table 10 : Emissions Factors of Fuels

Fuels	INCCA		IPCC	
	NCV (Tj/kt)	CO_2 EF (t/TJ)	CH_4 (kg/TJ)	N_2O (kg/TJ)
Naphtha	43.0	74.1	3	0.6
Diesel	43.0	74.1	3	0.6
Furnace Oil/LSHS	40.4	77.4	3	0.6
Natural Gas	48	56.1	3	0.6

Equations used for emissions estimates:

The emissions from this category was estimated by applying the Net Calorific Value (fuel type-wise) and corresponding fuel type-wise emission factor to the type of fuel consumed . The equations used for estimations are mentioned as follows:

$$Emissions_{Gas} = Activity\ Data_{Fuel} \times Net\ Calorific\ Value_{Fuel} \times Emission\ Factor_{Gas}$$

(slightly modified version of IPCC 2006 Equation 2.1)

Emissions in terms of CO_2e (both GWP and GTP) were calculated using the following equations:

$$Emissions_{CO2e}\ (GWP) = Emissions_{CO2} + (GWP_{CH4} \times Emissions_{CH4}) + (GWP_{N2O} \times Emissions_{N2O})$$

$$Emissions_{CO2e}\ (GTP) = Emissions_{CO2} + (GTP_{CH4} \times Emissions_{CH4}) + (GTP_{N2O} \times Emissions_{N2O})$$

Activity data provided in financial year (FY) format was converted to calendar year (CY) format using the following equations:

$$CY\ Activity\ data = [¼*FY\ Activity\ Data_{Preceding\ year}] + [¾*FY\ Activity\ Data_{Succeeding\ year}]$$

Limitations:

The Industry-wise and Fuel type-wise fuel consumption data were not available for this category, emissions were estimated based on overall fuel consumed in this sub-sector.

1A 3 Transport

The Transport sector emissions covers four different modes of transport viz Aviation, Road Transport, Railways and Water-borne Navigation sub-sector. The Transport sector emissions estimates used a combination of Tier 1 (T1) and Tier 2 (T2) approaches. The activity data for emissions estimation were obtained from Indian Petroleum and Natural Gas statistics (Ministry of Petroleum and Natural Gas) ; study conducted by Pillai, V. & AM Narayanan, (2019); Southern Railways Department- Indian Railways; Kerala State Water Transport and Kerala Maritime Board. The data sources, methodology, assumptions and emission factor considered for these 4 sub-sectors have been detailed below:

1A3a Civil Aviation

The emissions from this category arise due to combustion of fuels and for current assessment Aviation Turbine Fuel (ATF) was considered for emissions estimates.

Methodology

The GHG emissions were estimated based on the Tier 1 (T1) and Tier (2) approaches (2006 IPCC Guidelines)[8] (see Table 11).

[8] Emissions from the aviation category were estimated based on 2006 IPCC Guidelines, since no refinements were made in 2019 IPCC Guidelines.

Table 11: Type of emission factor and the level of methodological tier employed for GHG estimation

IPCC ID	GHG Sources and sink categories	CO_2		CH_4		N_2O	
		Method Applied	Emission Factor	Method Applied	Emission Factor	Method Applied	Emissio n Factor
1A3a	Civil Aviation	T1,T2	CS	T1	D	T1	D
T1: Tier 1 , T2: Tier 2, D: IPCC Default, CS: Country-Specific							

The Net Calorific Value (NCV) of fuels and emission factors of Carbon dioxide (CO_2) were taken from INCCA Report, (2010) and the emission factors of Methane (CH_4) and Nitrous Oxide (N_2O) were taken from 2006 IPCC Guidelines (see Table 12)

Table 12 : Emissions Factors of Fuel

Fuel	INCCA		IPCC	
	NCV (Tj/kt)	CO_2 EF (t/TJ)	CH_4 (kg/TJ)	N_2O (kg/TJ)
Aviation Turbine Fuel (ATF)	44.10	71.5	0.50	2.00

Equations used for emissions estimates

The emissions from this category is estimated by applying the Net Calorific Value (fuel type-wise) and corresponding fuel type-wise emission factor to the type of fuel consumed. The equations used for estimations are mentioned below:

$$Emissions_{Gas} = Activity\ Data_{Fuel} \times Net\ Calorific\ Value_{Fuel} \times Emission\ Factor_{Gas}$$

(slightly modified version of IPCC 2006 Equation 2.1)

Emissions in terms of CO_2e (both GWP and GTP) were calculated using the following equations:

$$Emissions_{CO2e}\ (GWP) = Emissions_{CO2} + (GWP_{CH4} \times Emissions_{CH4}) + (GWP_{N2O} \times Emissions_{N2O})$$

$$Emissions_{CO2e}\ (GTP) = Emissions_{CO2} + (GTP_{CH4} \times Emissions_{CH4}) + (GTP_{N2O} \times Emissions_{N2O})$$

1A3b Road Transport

Emissions from the Road Transport category are estimated for fuels such as Compressed Natural Gas (CNG), Auto LPG, Motor Spirit/Petrol and High Speed Diesel Oil (HSDO) . The following steps and assumptions have been used for estimating the emissions from Road Transport sector:

1. **<u>Compressed Natural Gas (CNG) :</u>**

<u>Assumptions:</u>

i. CNG sales data of Kerala (reported in Indian Petroleum and Natural Gas statistics) is considered as consumption activity data solely for road transport.

ii. For the years 2005-16, the CNG sales data for the state of Kerala was not available from Indian Petroleum and Natural Gas Statistics. Therefore, CNG consumption for the said period has been assumed to be zero.

(2) <u>Auto LPG :</u>

<u>Assumptions:</u>

i. For the years 2004-05 to 2006-07, the Auto LPG consumption data was assumed to be Zero considering the values reported in the year 2007-08.

ii. The Auto LPG consumption data for the years between 2018-19 to 2021-22 was calculated using the CGAR method.

(3) <u>Motor Spirit/ Petrol</u> :

a. <u>Steps followed to estimate state's Motor Spirit consumption activity data:</u>

i. The national-level percentage share of Motor Spirit consumption in the retail sector was calculated for the period 2012-13 to 2021-22 using Indian Petroleum and Natural Gas Statistics (MoPNG) .

ii. This estimated percentage share (nation-level) of Motor spirit consumption in retail sector and the percentage share of Petrol-Retail consumption data in Kerala's road transport sector *(as published in PPAC 2013 report)* was then applied to the Motor Spirit consumption data of Kerala to derive consumption data in Kerala's road transport sector.

<u>Scope for improvement</u> : *The estimations can be refined if the year-on-year percentage share of fuels consumed in transport and retail sectors at national level is replaced with their state-level equivalence.*

b. <u>Assumptions:</u>

i. The percentage share of Petrol-Retail consumption data of year 2012-13 was applied for years between 2004-05 to 2021-22, due to unavailability of data for any other year in the evaluation period.

ii. Since the National-level Motor Spirit consumption data in retail sector was not published in Indian Petroleum and Natural Gas Statistics for the period 2004-05 to 2011-12, the percentage share (national-level) of Motor Spirit consumption in retail sector of year 2012-13 was used to calculate Kerala's Motor Spirit consumption in road transport sector for the said period.

4. **High Speed Diesel Oil (HSDO) :**

a. **Steps followed to estimate state's HSDO consumption activity data:**

i. The percentage share of HSDO consumption in the Road transport and in Retail sector at national level was calculated for the period 2004-05 to 2021-22.

ii. The national level percentage share in Road transport was applied to HSDO consumption data of Kerala to derive the consumption data in Kerala's road transport sector.

iii. The national level percentage share in Retail sector and the end-use percentage share of Diesel in retail *[as published in PPAC 2013 and 2021 report]* were applied to HSDO consumption data of Kerala to derive the consumption data in Kerala's retail sector.

iv. The percentage share of HSDO consumption by the private sales sector at national level was calculated for the years 2004-05 to 2006-07.

v. This percentage share (national level) of the private sales sector was then applied to the HSDO consumption data of Kerala to derive the consumption data by private sales sector in Kerala for the period 2004-05 to 2006-07.

vi. The total HSDO consumption in Road transport was calculated by adding HSDO consumption data by private sales sector and from road transport and retail sector.

Scope for improvements : *The estimations can be refined if year-on-year percentage share of fuels consumed in transport and retail sectors at national level is replaced with their state-level equivalence.*

b. **Assumptions:**

Since fuel sales through retail stream was not provided in the MoPNG's Indian Petroleum and Natural Gas Statistics for the years 2004-05 to 2009-10, sales reported under Miscellaneous category were used, assuming it includes retail sales as well. However, for the years 2010-11 to 2021-22, retail sales of fuel was separately reported in the Indian Petroleum and Natural Gas Statistics, and was thus used as one of the activity data.

c. **Limitations:**

i. The HSDO consumption data by Private sales sector was not available for the period 2007-08 to 2021-22 from Indian Petroleum and Natural Gas statistics

ii. The HSDO consumption data by the Private imports sector (reported in Indian Petroleum and Natural Gas Statistics) were negligible, and hence was not considered for emissions estimations.

Methodology:

A combination of Tier 1 (T1) and Tier 2 (T2) approaches were used for emissions estimation (see Table 13)

Table 13:Type of emissions factor and the level of methodological tier employed for GHG estimation

IPCC ID	GHG Sources and sink categories	CO_2		CH_4		N_2O	
		Method Applied	Emission Factor	Method Applied	Emission Factor	Method Applied	Emissio n Factor
1A3b	Road Transport	T1,T2	CS	T1	D	T1	D
T1: Tier 1 , T2: Tier 2, D: IPCC Default, CS: Country-Specific							

The Net Calorific Value (NCV) of fuels and emission factors of Carbon dioxide (CO_2) were taken from INCCA Report, (2010) and the emission factors of Methane (CH_4) and Nitrous Oxide (N_2O) were taken from 2006 IPCC Guidelines (see Table 14)

Table 14 :Emissions Factors of Fuels

Fuels	INCCA		IPCC	
	NCV (Tj/kt)	CO_2 EF (t/TJ)	CH_4 (kg/TJ)	N_2O (kg/TJ)
Diesel	43.00	74.10	3.90	3.90
Compressed Natural Gas (CNG)	48.00	56.10	92.00	3.00
Liquified Petroleum Gas (LPG)	47.30	63.10	62.00	0.20
Gasoline	44.30	69.30	33.00	3.20

Equations used for emissions estimates

The emissions from this category is estimated by applying the Net Calorific Value (fuel type-wise) and corresponding fuel type-wise emission factor to the type of fuel consumed.The equations used for estimations are mentioned below:

$$Emissions_{Gas} = Activity\ Data_{Fuel} \times Net\ Calorific\ Value_{Fuel} \times Emission\ Factor_{Gas}$$

(slightly modified version of IPCC 2006 Equation 2.1)

Emissions in terms of CO_2e (both GWP and GTP) were calculated using the following equations:

$$Emissions_{CO2e} (GWP) = Emissions_{CO2} + (GWP_{CH4} \times Emissions_{CH4}) + (GWP_{N2O} \times Emissions_{N2O})$$

$$Emissions_{CO2e} (GTP) = Emissions_{CO2} + (GTP_{CH4} \times Emissions_{CH4}) + (GTP_{N2O} \times Emissions_{N2O})$$

1A3c Railways

The emissions of Railways category was estimated for the High Speed Diesel Oil (HSDO) and Light Diesel Oil (LDO) fuels and have been provided below:

Methodology

The Railways category's emissions were estimated using the Tier 1 (T1) and Tier (2) approaches for fuels such as High Speed Diesel Oil (HSDO) and Light Diesel Oil (LDO) as provided in Table 15

Table 15:Type of emissions factor and the level of methodological tier employed for GHG estimation

IPCC ID	GHG Sources and sink categories	CO_2		CH_4		N_2O	
		Method Applied	Emission Factor	Method Applied	Emission Factor	Method Applied	Emission Factor
1A3c	Railways	T1,T2	CS	T1	D	T1	D
T1: Tier 1 , T2: Tier 2, D: IPCC Default, CS: Country-Specific							

The Net Calorific Value (NCV) of fuels and emission factors of Carbon dioxide (CO_2) of Diesel and LDO were taken from INCCA Report (2010) and the emission factors of Methane (CH_4) and Nitrous Oxide (N_2O) were taken from 2006 IPCC Guidelines (see Table 16)

Table 16 : Emissions Factors of Fuels

Fuels	INCCA		IPCC	
	NCV (Tj/kt)	CO_2 EF (t/TJ)	CH_4 (kg/TJ)	N_2O (kg/TJ)
Diesel	43.00	74.10	4.15	28.60
Light Diesel Oil (LDO)[9]	43.00	74.10	10	0.6

[9] Factors for LDO were taken from IPCC methodology note for Road Transportation as the section on Locomotives had only values available for Diesel

Equations used for emissions estimates

The emissions from this category is estimated by applying the Net Calorific Value (fuel type-wise) and corresponding fuel type-wise emission factor to the type of fuel consumed. The equations used for estimations are mentioned below:

$$Emissions_{Gas} = Activity\ Data_{Fuel} \times Net\ Calorific\ Value_{Fuel} \times Emission\ Factor_{Gas}$$

(slightly modified version of IPCC 2006 Equation 2.1)

Emissions in terms of CO_2e (both GWP and GTP)* were calculated using the following equations:

$$Emissions_{CO2e}\ (GWP) = Emissions_{CO2} + (GWP_{CH4} \times Emissions_{CH4}) + (GWP_{N2O} \times Emissions_{N2O})$$

$$Emissions_{CO2e}\ (GTP) = Emissions_{CO2} + (GTP_{CH4} \times Emissions_{CH4}) + (GTP_{N2O} \times Emissions_{N2O})$$

1A3d Water-borne Navigation

The emissions from this category was estimated for Diesel and Petrol fuels. The activity data for emission estimation were sourced from Kerala Maritime Board and State Water Transport Department.

Methodology

1. **Source- Kerala Maritime Board**

   a. Vessel type-wise registration and fuel consumption data were obtained from the Kerala Maritime Board for the years 2010 to 2022.

   b. Diesel and Petrol fuel consumption data of Inland Vessels were estimated for the years 2010 to 2022 by applying the thumb-rules provided by Kerala Maritime Board-Govt. of Kerala.

   The thumb-rules include vessel type-wise average hourly fuel consumption and vessel type-wise average annual operational hours.

   c. The vessel type-wise Diesel fuel consumption data for years 2011 to 2021 was estimated using the CAGR method.

   d. The Petrol consumption data was estimated for the years 2011 to 2021 using the CAGR method and for years 2005 to 2009, the average fuel consumption value of years 2010 to 2016 were taken.

Limitation:

In the absence of year-on-year active/live vessels, the cumulative number of registered vessels were considered to be in operation for each year of the evaluation period, starting from 2010, the year since when the fleet data was available.

2. Source- State Water Transport Department

High Speed Diesel (HSD) fuel consumption data was estimated between 2005 and 2021 using thumb-rules provided by the State Water Transport Department – Govt. of Kerala.

a. Thumb-rules include fuel-wise average number of boats in operation, average operation hours per day, number of days in operation in a year and average fuel consumption per hour.

b. The thumb-rules to estimate HSD fuel consumption was considered to be same from 2005 to 2021 due to unavailability of other supporting data

C. Estimation of Total Diesel fuel consumption activity data for years 2005 to 2021

a. The total diesel fuel consumption activity data for years 2005 to 2021 was calculated by adding the diesel consumed through above two sources.

b. For the years 2005 to 2009, the total diesel consumption was calculated using the CAGR method.

Emissions from Diesel and Petrol fuels consumption were estimated for the Water-borne Navigation sub-sector using the Tier 1 (T1) and Tier 2 (T2) approaches (see Table 17).

Table 17:Type of emissions factor and the level of methodological tier employed for GHG estimation

IPCC ID	GHG Sources and sink categories	CO_2		CH_4		N_2O	
		Method Applied	Emission Factor	Method Applied	Emission Factor	Method Applied	Emission Factor
1A3d	Water-borne Navigation	T1,T2	CS	T1	D	T1	D
T1: Tier 1 , T2: Tier 2, D: IPCC Default, CS: Country-Specific							

The Net Calorific Value of fuels and emission factors of Carbon dioxide (CO_2) of Diesel and Petrol fuels were taken from INCCA Report (2010). Emission factors of Methane (CH_4) and Nitrous Oxide (N_2O) for Diesel and Petrol fuel were taken from 2006 IPCC Guidelines. Density of Diesel and Petrol fuels were obtained from PPAC Report,(2022) (see Table 18 and Table 19).

Table 18 : Emissions Factors of Fuels

Fuels	INCCA		IPCC[10]	
	NCV (Tj/kt)	CO_2 EF (t/TJ)	CH_4 (kg/TJ)	N_2O (kg/TJ)
Diesel / High Speed Diesel	43	74.1	3.9	3.9
Petrol	44.3	69.3	33	3.2

Table 19 : Density of Fuel used for the emissions estimates

Density of Fuels	Value
Diesel (HSD)	1.210 kL/t
Petrol	1.411 kL/t

Source *: Petroleum Planning and Analysis Cell, (2022)*

Equations used for emissions estimates

The emissions from this category is estimated by applying the Net Calorific Value (fuel type-wise) and corresponding fuel type-wise emission factor to the type of fuel consumed. The equations used for estimations are mentioned below:

$$Emissions_{Gas} = Activity\ Data_{Fuel} \times Net\ Calorific\ Value_{Fuel} \times Emission\ Factor_{Gas}$$

(slightly modified version of IPCC 2006 Equation 2.1)

Emissions in terms of CO_2e (both GWP and GTP) were calculated using the following equations:

$$Emissions_{CO2e}\ (GWP) = Emissions_{CO2} + (GWP_{CH4} \times Emissions_{CH4}) + (GWP_{N2O} \times Emissions_{N2O})$$

$$Emissions_{CO2e}\ (GTP) = Emissions_{CO2} + (GTP_{CH4} \times Emissions_{CH4}) + (GTP_{N2O} \times Emissions_{N2O})$$

The activity data of Aviation Turbine Fuel provided in financial year (FY) format was converted to calendar year (CY) format using the following equations for emissions estimations *(2005 to 2021)* :

$$CY\ Activity\ data = [\tfrac{1}{4} * FY\ Activity\ Data_{Preceding\ year}] + [\tfrac{3}{4} * FY\ Activity\ Data_{Succeeding\ year}]$$

[10] The emissions factor of Methane (CH_4) and Nitrous oxide (N_2O) for Diesel and Petrol fuels is assumed to be the same as that of Road Transport due to unavailability of emission factors specific to water-borne navigation

1A4 Other Sectors (Energy)

The Other Sectors (Energy) consist of three sub-sectors, viz. Commercial, Residential and Agriculture/Fisheries. The emissions from this sector arise due to combustion of fuels used for various activities. Emissions from this sector have been estimated using the Tier 1 (T1) and Tier 2 (T2) approaches. The activity data for Other Sectors' emissions estimates were obtained and calculated using Indian Petroleum and Natural Gas statistics (Ministry of Petroleum and Natural Gas) ; Centre for Development Study Report, Kerala and Economic Review Reports (State Planning Board-Govt of Kerala). The data sources, methodology and assumption used for emission estimations have been outlined below:

1A4a Commercial/Institutional

Liquified Petroleum Gas (LPG) and High Speed Diesel Oil (HSDO) were the fuels for which emissions were estimated under the Commercial sub-sector. The following steps/assumptions were used for estimating the emissions in Commercial sector:

1. **Liquified Petroleum Gas (LPG) :**

Steps followed to estimate LPG consumption activity data :

i. The percentage share of LPG consumption by the commercial sector at national level was calculated for the years 2004-05 to 2021-22 using the Indian Petroleum and Natural Gas Statistics reports (MoPNG).

ii. This estimated national-level percentage share was then applied to the state's overall LPG consumption data to estimate state's LPG consumption at commercial level, for the period 2004-05 to 2021-22.

iii. The derived LPG consumption data was in financial years which was converted into calendar years format using the following equations (2005 to 2021) :

$$\text{CY Activity data} = [\tfrac{1}{4}*\text{FY Activity Data}_{\textit{Preceding year}}] + [\tfrac{3}{4}*\text{FY Activity Data}_{\textit{Succeeding year}}]$$

Scope for improvement : The estimations can be refined if year-on-year percentage share of fuels consumed in the commercial sector at national level is replaced with their state-level equivalent.

2. **High Speed Diesel Oil (HSDO) :**

a. **Steps followed to estimate HSDO consumption activity data of years 2020-21 to 2021-22** :

i. The percentage share of HSDO consumption by the retail sector at national level was calculated for the period 2020-21 to 2021-22.

ii. The national level percentage share in *Retail sector* and percentage share of Diesel consumption in Non-Transport sector[11] *[as published in PPAC report 2021]* was applied to HSDO consumption data of Kerala to estimate the state's retail sector consumption data.

(Percentage share of Diesel in Non-Transport sector data were applied for the years 2020-21 and 2021-22).

iii. For the years 2020-21 and 2021-22, the national-level percentage share of Diesel in the Commercial sector (GHGPI Phase III[12]) was then applied to the state's overall HSDO consumption data to estimate the consumption data in the Commercial sector.

iv. The estimated total HSDO consumption data in financial years was converted into calendar years format using the following equations (2005 to 2021) **:**

CY Activity data = [¼*FY Activity Data$_{Preceding\ year}$] + [¾*FY Activity Data$_{Succeeding\ year}$]

<u>Scope for improvement</u> *: The estimations can be refined if 2020-21 and 2021-22's percentage share of fuels consumed in retail and commercial sectors at national level is replaced with their corresponding state-level values.*

b. <u>Limitations:</u>

i. The HSDO consumption data by Private sales sector was not available for the period 2020-21 to 2021-22 from Indian Petroleum and Natural Gas statistics

ii. The HSDO consumption data by the Private imports sector (reported in Indian Petroleum and Natural Gas Statistics) were negligible, and hence was not considered for emissions estimations.

<u>Methodology:</u>

The Tier 1 (T 1) and Tier 2 (T2) approaches were used to estimate emissions from the Commercial category (see Table 20)

[11] The Non-transport sector includes Gensets and Others (include Mobile Tower and other segments).

[12] Mohan, R.R., Dharmala, N., Ananthakumar, M. R., Kumar, P., Bose, A. (2019). *Greenhouse Gas Emission Estimates from the Energy Sector in India at the Subnational Level (Version/edition 2.0)*. New Delhi. GHG Platform India Report - CSTEP. Available at

Table 20: Type of emissions factor and the level of methodological tier employed for GHG estimation

IPCC ID	GHG Sources and sink categories	CO_2		CH_4		N_2O	
		Method Applied	Emission Factor	Method Applied	Emission Factor	Method Applied	Emission Factor
1A4a	Commercial	T1,T2	CS	T1	D	T1	D
T1: Tier 1 , T2: Tier 2, D: IPCC Default, CS: Country-Specific							

The Net Calorific Value (NCV) and Carbon dioxide (CO_2) emission factors of fuels were taken from INCCA Report (2010). Emission factors of Methane (CH_4) and Nitrous Oxide (N_2O) for Diesel and LPG fuels were taken from 2006 IPCC Guidelines. The state- level Diesel consumption data of other sectors for the year 2020-21 was taken from the PPAC Report (2021) and the national-level percentage-share of Diesel consumption data by Commercial sector was taken from GHGPI Phase III[13] (see Table 21, Table 22 and Table 23).

Table 21 : Emissions Factors of Fuels

Fuel	INCCA		IPCC	
	NCV (Tj/kt)	CO_2 EF (t/TJ)	CH_4 (kg/TJ)	N_2O (kg/TJ)
Diesel	43	74.1	10	0.6
Liquified Petroleum Gas (LPG)	47.3	63.1	5	0.1

Table 22 : State-level Diesel consumption of other sectors

Parameter	2020-21
Gensets	0.27
Others (include Mobile Tower and other segments)	4.23
Total	**4.50**

Source: *PPAC Report,2021*

Table 23 : Nation-level percentage share of Diesel in Commercial sector

Sector	Diesel (%)
Commercial	66.1

13 Mohan, R.R., Dharmala, N., Ananthakumar, M. R., Kumar, P., Bose, A. (2019). *Greenhouse Gas Emission Estimates from the Energy Sector in India at the Subnational Level (Version/edition 2.0)*. New Delhi. GHG Platform India Report - CSTEP. Available at

-     *Source :* GHGPI Phase III[14]

Equations used for emissions estimates

The emissions from this category is estimated by applying the Net Calorific Value (fuel type-wise) and corresponding fuel type-wise emission factor to the type of fuel consumed. The equations used for estimations are mentioned below:

$$Emissions_{Gas} = Activity\ Data_{Fuel} \times Net\ Calorific\ Value_{Fuel} \times Emission\ Factor_{Gas}$$

(slightly modified version of IPCC 2006 Equation 2.1)

Emissions in terms of CO_2e (both GWP and GTP) were calculated using the following equations:

$$\text{Emissions}_{CO2e}\ (\text{GWP}) = \text{Emissions}_{CO2} + (\text{GWP}_{CH4} \times \text{Emissions}_{CH4}) + (\text{GWP}_{N2O} \times \text{Emissions}_{N2O})$$

$$\text{Emissions}_{CO2e}\ (\text{GTP}) = \text{Emissions}_{CO2} + (\text{GTP}_{CH4} \times \text{Emissions}_{CH4}) + (\text{GTP}_{N2O} \times \text{Emissions}_{N2O})$$

1A4b Residential

The emissions from Kerosene and Liquified Petroleum Gas (LPG) fuels were estimated for the Residential category.The following assumptions and steps were used for estimating the emissions from the Residential sector:

1. **Kerosene:**
   a. Kerosene consumption data for the residential sector of Kerala were obtained for the years 2007-08 to 2017-18 from the study conducted by Pillai N, V., Am, N. (2019).
   b. For the years 2004-05 to 2006-07 and 2018-19 to 2021-22, the quantity of Kerosene consumption in the residential sector was calculated by applying its average consumption in the state for domestic usage to the overall consumption of Kerosene in the state.

      i. The average percentage share (60%) of Kerosene consumption of Domestic usage in the state was calculated from the study conducted by Pillai N, V., Am, N. (2019).

      ii. The overall consumption of Kerosene in the state was obtained from Economic Review Reports of Kerala.

2. **Liquified Petroleum Gas (LPG) :**

[14] Mohan, R.R., Dharmala, N., Ananthakumar, M. R., Kumar, P., Bose, A. (2019). *Greenhouse Gas Emission Estimates from the Energy Sector in India at the Subnational Level (Version/edition 2.0)*. New Delhi. GHG Platform India Report - CSTEP. Available at https://www.ghgplatform-india.org/wp-content/uploads/methodology/phase-3/GHGPI-PhaseIII-Methodology%20Note-Energy-Sep%202019.pdf

Steps followed to estimate LPG consumption activity data of years 2004-05 to 2006-07 and 2018-19 to 2021-22

i. The percentage share of LPG consumption by domestic sector at national level was calculated for the period 2004-05 to 2006-07 and 2018-19 to 2022.

ii. The national level percentage share by domestic sector was then applied to the state's total LPG consumption data to derive residential sector consumption data.

iii. The percentage share of LPG consumption by private sales sector at national level was calculated for the year 2004-05 to 2006-07.

iv. This percentage share (national level) of private sales sector was then applied to the LPG consumption data of Kerala to derive the consumption data by private sales sector in Kerala for the period 2004-05 to 2006-07.

v. The total LPG consumption in Residential sector was calculated by summing up LPG consumption data of private sales and domestic sector.

Methodology

The Tier 1 (T1) and Tier 2 (T2) approaches were used to estimate emissions from the Residential category (see Table 24)

Table 24:Type of emissions factor and the level of methodological tier employed for GHG estimation

IPCC ID	GHG Sources and sink categories	CO_2		CH_4		N_2O	
		Method Applied	Emission Factor	Method Applied	Emission Factor	Method Applied	Emission Factor
1A4b	Residential	T1,T2	CS	T1	D	T1	D
T1: Tier 1 , T2: Tier 2, D: IPCC Default, CS: Country-Specific							

The Net Calorific Value (NCV) and Carbon dioxide (CO_2) emission factors of fuels were taken from INCCA Report (2010). Emission factors of Methane (CH_4) and Nitrous Oxide (N_2O) for Kerosene and LPG fuels were taken from 2006 IPCC Guidelines (see Table 25)

Table 25 : Emissions Factors of Fuels

Fuels	INCCA		IPCC	
	NCV (Tj/kt)	CO_2 EF (t/TJ)	CH_4 (kg/TJ)	N_2O (kg/TJ)
Kerosene	43.8	71.9	10	0.6
Liquified Petroleum Gas (LPG)	47.30	63.10	5	0.1

Equations used for emissions estimates:

The emissions from this category is estimated by applying the Net Calorific Value (fuel type-wise) and corresponding fuel type-wise emission factor to the type of fuel consumed. The equations used for estimations are mentioned below:

$$Emissions_{Gas} = Activity\ Data_{Fuel}\ x\ Net\ Calorific\ Value_{Fuel}\ x\ Emission\ Factor_{Gas}$$

(slightly modified version of IPCC 2006 Equation 2.1)

<u>Emissions in terms of CO_2e (both GWP and GTP) were calculated using the following equations</u>:

$$Emissions_{CO2e}\ (GWP) = Emissions_{CO2} + (GWP_{CH4}\ x\ Emissions_{CH4}) + (GWP_{N2O}\ x\ Emissions_{N2O})$$

$$Emissions_{CO2e}\ (GTP) = Emissions_{CO2} + (GTP_{CH4}\ x\ Emissions_{CH4}) + (GTP_{N2O}\ x\ Emissions_{N2O})$$

Activity data provided in financial year (FY) format was converted to calendar year (CY) format using the following equations:

$$CY\ Activity\ data = [¼*FY\ Activity\ Data_{Preceding\ year}] + [¾*FY\ Activity\ Data_{Succeeding\ year}]$$

1A4c Agriculture Energy

For current assessment ,the emissions from Agriculture category have been estimated only for Diesel fuel, due to unavailability of other fuels consumption data. The activity data for this category were taken from Indian Petroleum and Natural Gas Statistics (MoPNG) and the have been detailed below:

(1) <u>Diesel/ High Speed Diesel Oil:</u>

a. <u>Steps followed to estimate consumption activity data</u> :

i. The percentage share of HSDO consumption in Agriculture sector and in the Retail sector at national level was calculated for the period 2004-05 to 2021-22 using Indian Petroleum and Natural Gas Statistics (MoPNG).

ii. The national level percentage share in the Agriculture sector was applied to HSDO consumption data of Kerala to derive consumption data in the agriculture sector.

iii. The national level percentage share in Retail sector and state's percentage share of Diesel consumption in Non-Transport sector[15] *[as published in PPAC reports - 2013 and 2021]* were applied to HSDO consumption data of Kerala to estimate the state's retail sector consumption data.

iv. The estimated HSDO consumption data *(Agriculture and Retail sectors)* in financial years were converted into calendar years format using the following equations (2005 to 2021) :

$$CY\ Activity\ data = [¼*FY\ Activity\ Data_{Preceding\ year}] + [¾*FY\ Activity\ Data_{Succeeding\ year}]$$

[15] The Non- Transport sector includes the Tractors, Agri Implements and Agri pumpsets

b. Assumptions:

i.Since fuel sales through retail stream was not provided in the MoPNG's Indian Petroleum and Natural Gas Statistics for the years 2004-05 to 2009-10, sales reported under Miscellaneous category were used, assuming it includes retail sales as well. However, for the years 2010-11 to 2021-22, retail sales of fuel was separately reported in the Indian Petroleum and Natural Gas Statistics, and was thus used as one of the activity data.

ii. The percentage share of Diesel consumption data in the Non- Transport sector of Kerala was obtained for the years 2012-13 and 2021-22 from All India study on sectoral demand of Diesel and Petrol Reports (PPAC) 2013 and 2021.

- *Percentage share of Diesel in Non-Transport sector data were applied in following format:* The 2012-13 data was applied for the years 2004-05 to 2019-20 and 2020-21 data was applied for the years 2020-21 to 2021-22.

Methodology:

For the Agriculture category, Tier 1 (T1) and Tier 2 (T2) approaches has been used for emission estimations (see Table 26)

Table 26: Type of emissions factor and the level of methodological tier employed for GHG estimation

IPCC ID	GHG Sources and sink categories	CO_2		CH_4		N_2O	
		Method Applied	Emission Factor	Method Applied	Emission Factor	Method Applied	Emission Factor
1A4c	Agriculture	T1,T2	CS	T1	D	T1	D
T1: Tier 1 , T2: Tier 2, D: IPCC Default, CS: Country-Specific							

The Net Calorific Value (NCV) and Carbon dioxide (CO_2) emission factors of fuel were taken from INCCA Report (2010). Emission factors of Methane (CH_4) and Nitrous Oxide (N_2O) for Diesel were taken from 2006 IPCC Guidelines. The state- level Diesel consumption data of Agriculture sector for the year 2012-13 and 2020-21 were taken from the PPAC Report (2013 and 2021) (see Table 27 and Table 28)

Table 27: Emissions Factors of Fuels

Fuel	INCCA		IPCC	
	NCV (Tj/kt)	CO_2 EF (t/TJ)	CH_4 (kg/TJ)	N_2O (kg/TJ)
Diesel	43.00	74.1	10	0.6

Table 28 : State-level Diesel consumption in Agriculture sector

(a) Percentage share of Diesel from Non-Transport Sector in Kerala : 2012-13

Parameter	**2012-13**
Tractor	3.76
Agri Implements	2.15
Agri Pumpsets	1.43
Total	**7.34**

Source : PPAC, 2013

(b) Percentage share of Diesel from Non-Transport Sector in Kerala : 2020-21

Parameter	**2020-21**
Tractor	0.71
Agri Implements	0.33
Agri Pumps	1.31
Total	**2.35**

Source : PPAC, 2021

Equations used for emissions estimates

The emissions from this category is estimated by applying the Net Calorific Value (fuel type-wise) and corresponding fuel type-wise emission factor to the type of fuel consumed. The equations used for estimations are mentioned below:

$$Emissions_{Gas} = Activity\ Data_{Fuel} \times Net\ Calorific\ Value_{Fuel} \times Emission\ Factor_{Gas}$$

(slightly modified version of IPCC 2006 Equation 2.1)

Emissions in terms of CO_2e (both GWP and GTP) were calculated using the following equations:

$$Emissions_{CO2e}\ (GWP) = Emissions_{CO2} + (GWP_{CH4} \times Emissions_{CH4}) + (GWP_{N2O} \times Emissions_{N2O})$$

$$Emissions_{CO2e}\ (GTP) = Emissions_{CO2} + (GTP_{CH4} \times Emissions_{CH4}) + (GTP_{N2O} \times Emissions_{N2O})$$

1A4c Fisheries

The emissions from Kerosene Diesel and Petrol fuels were estimated for the Fisheries category using the following thumb-rules,equations and assumptions

1. **Kerosene**

Equations used for estimating Diesel fuel consumption data

$$Emissions_{Gas} = Activity\ Data_{Fuel} \times Net\ Calorific\ Value_{Fuel} \times Emission\ Factor_{Gas}$$

2. **Diesel**

a. **Thumb-rules followed**:

i. The thumb-rules to estimate Diesel fuel consumption was directly obtained from the Fisheries Department-Govt. of Kerala for the years 2005 to 2021. The thumb-rules contain:

- Fuel consumption and operations data comprising Fuel type-wise craft, engine type and horsepower of craft; average fuel consumption (Liters/hour and Liters/Trip) and average trip/month data.
- The number of active months of fishing in the state was taken based on the inputs received from the Fisheries Department-Govt of Kerala.

ii. Craft type-wise and fuel type-wise fleet registration *(ReALCRaft)* data was directly obtained from Fisheries Department-Govt. of Kerala for the years 2005 to 2021.

b. **Equations used for estimating Diesel fuel consumption data for years 2008 to 2021**

$$Fuel\ consumed = Fleet\ Stock_{(craft\text{-}based)} \times Average\ Fuel\ consumption_{(Trips/Month)} \times Months\ of\ Active\ Fishing$$

c. **Assumptions:**

i. Based on the availability of reliable data , the diesel fuel consumption data was estimated only for the period 2008 to 2021.

ii. For years 2005,2006 and 2007 the diesel consumption data was estimated using the CAGR method.

iii. The average diesel consumed (Trips/Month) was calculated based on the thumb-rules provided for Total Motorised Mechanical craft, since the category-wise fleet stock data for Motorised Mechanical craft (Trawlers,Thanguvallam and Gill netters) were not provided.

3. **Petrol** :

a. **Thumb-rules followed:**

i. The thumb-rules to estimate Petrol fuel consumption was directly obtained from the Fisheries Department-Govt. of Kerala for the years 2005 to 2021. The thumb-rules contain:

- Fuel consumption and operations data comprising Fuel type-wise craft, engine type and horsepower of craft; average fuel consumption (Liters/hour and Liters/Trip) and average trip/month data.

- The number of active months of fishing in the state was taken based on the inputs received from the Fisheries Department-Govt of Kerala.

ii. Craft type-wise and fuel type-wise fleet registration *(ReALCRaft)* data was directly obtained from Fisheries Department-Govt. of Kerala for the years 2005 to 2021.

b. <u>Equations used for estimating Petrol fuel consumption data for years 2008 to 2021</u>

Fuel consumed= Fleet Stock $_{(craft\text{-}based)}$ x Average Fuel consumption (Liters/Trip) $_{Lowest\ HP\ of\ engine}$ x Average Trip/Month $_{Lowest\ HP\ of\ engine}$ x Months of Active Fishing

c. <u>Assumptions:</u>

i. Based on the availability of reliable data , the diesel fuel consumption data was estimated only for the period 2008 to 2021.

ii. For years 2005,2006 and 2007 the petrol consumption data was estimated using the CAGR method.

iii. The Average fuel consumption (Liters/Trip) and Average Trip/Month data of crafts with lowest HP of engine *(provided in the thumb-rules)* were considered for calculations based on inputs received from the Fisheries department.

<u>Scope for Improvement</u> :

The Diesel and Petrol fuel consumption data for the entire evaluation period can be refined if fuel sold data is provided by Matsyafed.

Methodology:

The emissions from the Fisheries category was estimated using Tier 1 (T1) and Tier 2 (T2) approaches (see Table 29)

Table 29 :Type of emissions factor and the level of methodological tier employed for GHG estimation

IPCC ID	GHG Sources and sink categories	CO_2		CH_4		N_2O	
		Method Applied	Emission Factor	Method Applied	Emission Factor	Method Applied	Emission Factor
1A4c	Fisheries	T1,T2	CS	T1	D	T1	D
T1: Tier 1 , T2: Tier 2, D: IPCC Default, CS: Country-Specific							

The Net Calorific Value (NCV) and Carbon dioxide (CO_2) emission factors of fuels were taken from INCCA Report (2010). Emission factors of Methane (CH_4) and Nitrous Oxide (N_2O) for Diesel were taken from 2006 IPCC Guidelines. Density of Diesel and Petrol were obtained from PPAC (2022) Report and the data on the estimated number of active months of fishing was taken based on the inputs received from the Fisheries Department- Govt. of Kerala (see Table 30, Table 31 and Table 32).

Table 30 : Emissions Factors of Fuels

Fuels#	INCCA		IPCC	
	NCV (Tj/kt)	CO_2 EF (t/TJ)	CH_4 (kg/TJ)	N_2O (kg/TJ)
Diesel	43.00	74.1	33	3.2
Kerosene	43.8	71.9	10	0.6
Petrol	44.3	69.3	3.9	3.9

Note: The Fisheries sub-sector is considered under mobile combustion.

(a) For Diesel and Petrol fuels, emission factors of Methane (CH4) and Nitrous Oxide (N2O) were not available for fishing-mobile combustion in IPCC guidelines. Therefore, the emission factor was assumed to be the same as that of Road transportation.

(b) Due to unavailability of Methane(CH_4) and Nitrous Oxide (N_2O) emission factors for Kerosene specific to fishing-mobile combustion activity , corresponding proxy factors from fishing-stationary combustion were used.

Table 31: Density of Fuel used for the emissions estimates

Density of Fuel	Value
Diesel	1.210 kL/t
Petrol	1.411 kL/t

Source *: Petroleum Planning and Analysis Cell, (2022)*

Table 32: Number of active months of Fishing in the state

Parameter	Data
Estimated no. of active months of fishing	10

Equations used for emissions estimates

Emissions in terms of CO_2e (both GWP and GTP) were calculated using the following equations:

$$Emissions_{CO2e}\ (GWP) = Emissions_{CO2} + (GWP_{CH4} \times Emissions_{CH4}) + (GWP_{N2O} \times Emissions_{N2O})$$

$$Emissions_{CO2e}\ (GTP) = Emissions_{CO2} + (GTP_{CH4} \times Emissions_{CH4}) + (GTP_{N2O} \times Emissions_{N2O})$$

1B Fugitive Emissions from Fuels

Fugitive emissions arise from various activities in fossil fuel production at mines and wells, where coal, oil, and natural gas are produced (Mohan, R.R, 2019). However, in Kerala, BPCL Kochi Refinery was the only source identified for the fugitive emissions.

Methodology

The current assessment uses the Tier 2 method to estimate the Methane (CH_4) emissions from the refinery's crude throughput (see Table 33). The country-specific emission factor of refinery Throughput was obtained from the INCCA (2010) report (see Table 34).

Table 33: Type of emissions factor and the level of methodological tier employed for GHG estimation

IPCC ID	GHG Sources and sink categories	CO_2		CH_4		N_2O	
		Method Applied	Emission Factor	Method Applied	Emission Factor	Method Applied	Emission Factor
1B	Fugitive Emissions	-	-	T2	CS	-	-
T2 : Tier 2, CS: Country-Specific							

Table 34: Emission Factors used for Methane (CH_4) estimation

Parameter	Emission Factor (INCAA)	Emission Factor used
Refinery Throughput	6.75904×10^{-5} Gg / million tons	0.0675904 tons/Mt

Note : Gg refer to Gigagrams

Equations used for emissions estimates

The equation used for estimating Fugitive Emissions are as below:

$$Emissions_{Gas} = Refinery\ Throughput \times Emission\ Factor_{Gas}$$

Emissions in terms of CO_2e (both GWP and GTP) were calculated using the following equations:

$$Emissions_{CO2e}\ (GWP) = Emissions_{CH4} \times GWP_{CH4}$$

$$Emissions_{CO2e}\ (GTP) = Emissions_{CH4} \times GTP_{CH4}$$

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INDUSTRIAL PROCESSES AND PRODUCT USE (IPPU) SECTOR

Key Highlights

- In Kerala, the IPPU sector represented ~6% of the gross GHG emissions (excluding LULUCF) in 2021.
- The total IPPU emissions declined from 1.47 Mt CO_2e to 1.32 Mt CO_2e between 2005 and 2021
- Within IPPU emissions, almost 55% of emissions emanated from ammonia production in 2021 . This was followed by emissions from carbon black (~15.46%) and cement (~14%).

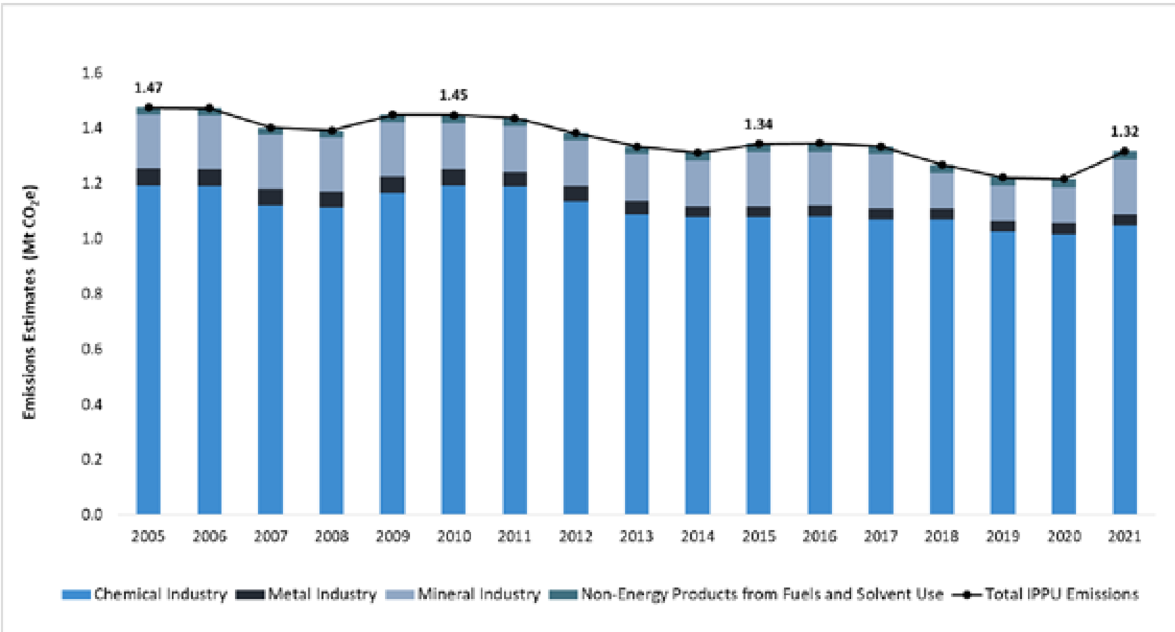

Figure 2: GHG Emissions Estimates of IPPU Sector – Kerala (2005 to 2021)

Sector Description

The category of Industrial Processes and Product Use (IPPU) encompasses emissions of greenhouse gases resulting from industrial processes, the utilization of greenhouse gases in products, and non-energy applications of fossil fuel carbon. Greenhouse gas emissions stem from a diverse array of industrial activities, with primary sources being the release of gases during processes that chemically or physically transform materials. These processes can yield various greenhouse gases, including carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), hydrofluorocarbons (HFCs), and perfluorocarbons (PFCs) (IPCC, 2006).

The key economic sectors/categories included in the emission estimates are

- 2A: Mineral Industry
  - 2A1 Cement production
  - 2A2 Lime production
  - 2A4b Other Uses of Soda ash

- 2B Chemical Industry
    - 2B1 Ammonia Production
    - 2B4 Caprolactam Production
    - 2B6 Titanium Dioxide Production
    - 2B7 Soda ash Production
    - 2B8f Carbon Black
- 2C Metal Industry
    - 2C1 Iron and Steel Production
    - 2C6 Zinc Production
- 2D Non-Energy Products from Fuels and Solvent Use
    - 2D1 Lubricant Use
    - 2D2 Paraffin Wax Use

Methodology

The table 35 below details the sources of activity data used for estimating emissions from the IPPU sector.The production data used for estimating emissions from each product for the year 2019, 2020, 2021 is detailed in table 36 .

Table 35: Source of activity data[16] used for estimating emissions from IPPU sector

Production	**Year**	**Source***
Mineral Industry		
Cement	2005 to 2009, 2015 to 2017, 2021	Kerala State Pollution Control Board (Malabar Cements)
	2009-10 to 2014-15, 2017-18 to 2020- 21	Government of India, Ministry of Mines, Indian Bureau of Mines. Indian Minerals Yearbook IBM 2012 (for 2010-11, 2011-12) IBM 2013 (for 2012-13) IBM 2014 (for 2013-14) IBM 2015 (for 2014-15) IBM 2018 (for 2017-18) IBM 2011 (for 2009-10) IBM 2021 (2020- 21) IBM 2019 (2018-19) IBM 2020 (2019-20)
Lime	2005-2021	KSPCB

[16] Activity data provided in financial year (FY) format was converted to calendar year (CY) format using the following equations:

CY Activity data = [¼*FY Activity Data$_{\text{Preceding year}}$] + [¾*FY Activity Data$_{\text{Succeeding year}}$]

Production	Year	Source*
Other uses of soda ash -consumption	2004-05 to 2005- 06, 2007-08, 2009-10 to 2015-16	GHGPI Phase III
	2006-07, 2008-09	Interpolation
	2016-17 to 2021- 22	CAGR calculated between 2012-13 and 2015-16
Chemical Industry		
Ammonia	2005- 2021	KSPCB
Caprolactam	2004-05	GHGPI Phase III Methododology- Annexure 9
	2005-06 to 2021-22	Annual Reports of The Fertilisers and Chemicals Travancore Limited 2014-15, 2015-16, 2016-17, 2017-18, 2018-19, 2019-20, 2020-21, 2021-22
Titanium Dioxide	2005-2008 2011-2016 2021	KSPCB (Kerala Minerals and Metals Limited (KMML) and Travancore Titanium Products Limited (TTPL)
	2009-2010	Indian Minerals Yearbook 2011
	2017-2020	KMML master plan 2030 and KSPCB (TTPL)
Soda ash	2005-2021	KSPCB (FACT Udyogamandal)
Carbon black	2005-2018	KSPCB (Philips Carbon black and BDT Industries)
	2019-2021	Department of Economics and Statistics, GoK (Philips carbon black) and KSPCB (BDT Industries)
Metal Industry		
Iron and steel	2005-2021	KSPCB
Zinc	2005- 2010	KSPCB (Binani Zinc Ltd)
	2010-11 to 2013-14	Indian Minerals Yearbook 2012,2014
	2014-15 to 2021-22	Production is zero since the plant is shut down.
Non-energy Products from Fuels and Solvent Use		
Lubricant use	2005-06, 2007-08 to 2010-11, 2012-13 to 2021-22	Indian Petroleum and Natural Gas statistics, Ministry of Petroleum and Natural Gas, Economic and Statistic Division, Government of India 2020-21,2021-22, 2018-19, 2019-20, 2017-18, 2016-17, 2015-16, 2014-15, 2013-14, 2012-13, 2010-11, 2009-10, 2008-09, 2007-08, 2005-06

Production	Year	Source*
	2004-05, 2006-07, 2011-12	Interpolation and CAGR
Paraffin wax use		Kerala Small Industries Corporation SIDCO website Data applied to all the years between 2005 and 2021

*Wherever direct data was not available, suitable statistical methods were applied for estimation of annual production. These are mentioned against the applicable cases.

Table 36 : Production/Consumption data (000 tonnes) used for estimating emissions from IPPU sector

IPCC ID	Industrial product	2019	2020	2021
2A	**Mineral Industry**			
2A1	Cement Production	400	400	638.75
2A2	Lime Production	14.80	14.80	14.80
2A4b	Other uses of soda ash	7.51	9.00	10.78
2B	**Chemical Industry**			
2B1	Ammonia Production	361.35	361.35	361.35
2B4	Caprolactam Production	0.00	0.00	15.63
2B6	Titanium Dioxide Production	45.04	44.39	54.15
2B7	Soda Ash Production	10.95	10.95	10.95
2B8f	Carbon Black	90.33	87.51	77.65
2C	**Metal Industry**			
2C1	Iron and Steel Production	500.67	500.67	500.67
2C6	Zinc Production	0.0	0.0	0.0
2D	**Non-Energy Products from Fuels and Solvent Use**			
2D1	Lubricant Use	41.8	44.43	43.93
2D2	Paraffin Wax Use	7.2	7.2	7.2

Assumptions

- Wherever year on year actual production/consumption data was not available, the installed capacity or average annual production data were obtained from Kerala State Pollution Control Board (KSPCB) and other line departments concerned.
- As per expert opinion from KSPCB the installed capacity itself was taken as the average production quantity where average production data was not available.

Table 37 provides insights on the tier level of methodology and emission factors used in estimating GHG emissions.

Table 37: Tier approach followed for the IPPU category

IPCC ID	GHG Source and Sink categories	CO_2		CH_4		N_2O	
		Method applied	Emission factor	Method applied	Emission factor	Method applied	Emission factor
2A	**Mineral Industry**						
2A1	Cement Production	T1	CS	NA	NA	NA	NA
2A2	Lime Production	T1	D	NA	NA	NA	NA
2A4b	Other uses of soda ash	T1	CS	NA	NA	NA	NA
2B	**Chemical Industry**						
2B1	Ammonia Production	T1	CS	NA	NA	NA	NA
2B4	Caprolactam	NA	NA	NA	NA	T1	CS
2B6	Titanium Dioxide Production	T1	CS	NA	NA	NA	NA
2B7	Soda Ash Production	T1	D	NA	NA	NA	NA
2B8f	Carbon Black	T1	CS	T1	CS	NA	NA
2C	**Metal Industry**						
2C1	Iron and Steel Production	T1	CS	NA	NA	NA	NA
2C6	Zinc Production	T1	CS	NA	NA	NA	NA

IPCC ID	GHG Source and Sink categories	CO_2		CH_4		N_2O	
		Method applied	Emission factor	Method applied	Emission factor	Method applied	Emission factor
2D	**Non-Energy Products from Fuels and Solvent Use**						
2D1	Lubricant Use	T1	CS	NA	NA	NA	NA
2D2	Paraffin Wax Use	T1	CS	NA	NA	NA	NA
T1: Tier 1; T2: Tier 2; T3: Tier 3; CS: Country-specific; D: IPCC Default; NA: Not Applicable							

2A Mineral Industry

2A1:Cement

Equation used

$$CO_2\,Emissions = \left[\sum_i (M_{ci} \bullet C_{cli}) - Im + Ex\right] \bullet EF_{clc} \quad \textit{(IPCC 2006 Equation 2.1)}$$

Where:

CO_2 Emissions = emissions of CO_2 from cement production, tonnes

M_{Ci} = weight (mass) of cement produced of type i, tonnes

C_{cli}= clinker fraction of cement of type i, fraction

Im = imports for consumption of clinker, tonnes

Ex = exports of clinker, tonnes

EF_{clc}= emission factor for clinker in the particular cement, tonnes CO_2/tonne clinker

The table below provides the emission factor and clinker fraction used

Table 38: Factors used for estimating emissions from Cement industry

Factors	Value	Source
Emission factor for CO_2 (EF_{clc})	0.537 t CO_2/t clinker	NATCOM 2
Clinker fraction of Portland pozzolana cement (C_{cli})	53.5%[17]	IPCC 2006

[17] The percentage clinker was taken as 53.5% considering the only source of cement production in Kerala i.e., Malabar Cements produces Portland pozzolana.

Emissions from the production of imported clinker cannot be included in emissions estimates as these emissions were produced and may have accounted for in another state. Similarly, emissions from clinker that are ultimately exported should be factored into estimates of the state where the clinker is produced. Based on expert opinion from KSPCB , there is no export of clinker from Kerala. As such based on expert inputs from KSPCB, the export and import of clinker was entirely not accounted for within these emission estimates.

2A2 Lime

Equation Used

$$E_{CO2} = PP \bullet EF$$ *(slightly modified version of IPCC 2006 Equation 2.6)*

Where:

E_{CO2}= CO_2 emissions from production of lime, tonnes

PP= annual production of lime, tonnes

EF = CO_2 emission factor for lime, tonnes CO_2 /tonne lime produce (high calcium lime)

The table 39 below provides the emission factor used in estimating emissions from production of lime.

Table 39: Emission factor used for emissions estimation

Factors	Value	Source
Emission factor for CO_2 (high calcium lime) (E_{CO2})	0.75 t CO_2/t lime	IPCC 2006

2A4b Other uses of soda ash

Equation Used

$$CO_2\ Emissions = M_c \bullet \left(0.85EF_{ls} + 0.15EF_{d}\right)$$ *(IPCC 2006 Equation 2.14)*

Where:

CO_2 Emissions = emissions of CO_2 from other process uses of carbonates, tonnes

M_c = mass of carbonate consumed, tonnes

EF_{ls} or EF_d= emission factor for limestone or dolomite calcination, tonnes CO_2/tonne carbonate

Soda ash is primarily sodium carbonate, not limestone or dolomite. Therefore, the Tier 1 method for soda ash does not require the default fraction of 85%/15%. Emissions are estimated by multiplying the quantity of soda ash consumed on the state level by the emission factor (see table 40) for sodium carbonate.

Table 40: Emission factor used for emissions estimation

Factors	Value	Source
Emission factor for CO_2	0.41492 t CO_2 /t carbonate	NATCOM 2

<u>2B Chemical Industry</u>

2B1 Ammonia

<u>Equation Used</u>

$$E_{CO2} = AP \bullet FR \bullet CCF \bullet COF \bullet 44/12 - R_{CO2}$$ *(IPCC 2006 Equation 3.1)*

Where:

E_{CO2} = Emissions of CO_2, kg

AP = Ammonia production, tonnes

FR = fuel requirement per unit of output, GJ/tonne ammonia produced

CCF = carbon content factor of the fuel, kg C/GJ

COF = carbon oxidation factor of the fuel, fraction

R_{CO2} = CO_2 recovered for downstream use (urea production), kg

Table 41: Factors used for emissions estimates

Factors	Value	Source
Fuel requirement per unit of output	38.11624 GJ/t ammonia	NATCOM 2
Carbon content factor of the fuel	99.5%	NATCOM 2
Carbon oxidation factor of the fuel	14.4 Kg C/GJ	NATCOM 2
CO_2 recovered for downstream use (urea production)	0	IPCC 2006

2B4 Caprolactam

Equation Used

$$E_{N2O} = EF \bullet CP$$ *(IPCC 2006 Equation 3.9)*

Where:

E_{N2O} = N_2O emissions, kg

EF = N_2O emission factor (default), kg N_2O/tonne caprolactam produced

CP = caprolactam production, tonne

Table 42: Emission factor used for emissions estimation

Factors	Value	Source
Emission factor for N_2O	9 kg N_2O/tonne caprolactam	NATCOM 2

2B6 Titanium Dioxide

Equation Used

$$E_{CO2} = \sum_i \left(AD_i \bullet EF_i\right)$$ *(IPCC 2006 Equation 3.12)*

Where:

E_{CO2} = emissions of CO_2, tonnes

ADi = production of titanium slag, synthetic rutile or rutile TiO_2 (product i), tonnes

EFi = CO_2 emissions per unit of production of titanium slag, synthetic rutile or rutile TiO_2 (product i), tonnes CO_2/tonne product.

Table 43: Emission factor used for emissions estimation

Factors	Value	Source
Emission factor for CO_2	1.385 tCO_2/t TiO_2 produced	NATCOM 2

2B8f Carbon black

Equation Used

$$E_{CO2} = PP \bullet EF$$ *(IPCC 2006 Equation 3.15)*

Where:

E_{CO2} = CO_2 emissions from production of carbon black, tonnes

PP = annual production of carbon black, tonnes

EF = CO_2 emission factor for carbon black, tonnes CO_2/tonne product produced

$ECH4 = PP_i \bullet EF$ *(IPCC 2006 Equation 3.23)*

Where:

ECH_4 = emissions of CH_4 from production of carbon black, kg

PP = annual production of carbon black, tonnes

EF= CH_4 emission factor for carbon black, kg CH_4/tonne product

Table 44: Emission factors used for emissions estimation

Factors	Value	Source
Emission factor for CO_2	2.62 tCO_2/t carbon black produced	NATCOM 2
Emission factor for CH_4	0.06 kg CH4 /t carbon black produced	NATCOM 2

2B7 Soda Ash

Equation Used

$E_{CO2} = AD \bullet EF$ *(IPCC 2006 Equation 3.14)*

Where:

ECO_2 = emissions of CO_2, tonnes

AD = tonnes natural soda ash produced

EF = emission factor per unit of natural soda ash output

Table 45 : Emission factor used for emissions estimation

Factors	Value	Source
Emission factor for CO_2	0.138 tCO_2/t natural soda ash produced	IPCC 2006

2C Metal Industry

2C1 Iron and steel

Equation Used

CO_2 Emissions from Iron and Steel Production *(IPCC 2006 Equation 4.4)*

Iron & Steel: $E_{CO2,\ non\text{-}energy} = BOF \bullet EF_{BOF} + EAF \bullet EF_{EAF} + OHF \bullet EF_{OHF}$

Where:
E_{CO2}, non-energy = emissions of CO_2 to be reported in IPPU Sector, tonnes
BOF= quantity of BOF crude steel produced, tonnes
EAF = quantity of EAF crude steel produced, tonnes
OHF = quantity of OHF crude steel produced, tonnes
EFx= emission factor, tonnes CO_2 /tonne x produced

Table 46 : Emission factor used for emissions estimation

Factor	Value	Source
Emission factor -EAF	0.08 t CO_2/t production	NATCOM 2

As per expert opinion from KSPCB, it has been understood that the Iron and Steel making process in the state uses only Electric Arc Furnaces (EAF). Therefore, CO_2 emissions from the Iron and steel industry have been estimated by using Equation 4.4.

Further, as per KSPCB, there has been no occurrence of emissions from production of Pig iron, direct reduced iron , sinter and pellets, due to the absence of such processes in the respective industries. Hence, CH_4 and CO_2 emissions for these categories are regarded as zero.

2C6 Zinc

Equation Used

CO_2 Emissions from Zinc Production *(IPCC 2006 Equation 4.33)*

$$E_{CO2} = Zn \bullet EF_{default}$$

Where:
E_{CO2} = CO_2 emissions from zinc production, tonnes
Zn = quantity of zinc produced, tonnes
$EF_{default}$ = default emission factor, tonnes CO_2 /tonne zinc produced

Table 47: Emission factor used for emissions estimations

Factor	Value	Source
CO_2 emission factor	0.53 t CO_2/t zinc produced	NATCOM 2

2D Non- Energy Products from Fuels and Solvent Use

2D1 Lubricant Use

Equation Used

$$CO_2\ Emissions = LC \bullet CC_{Lubricant} \bullet ODU_{Lubricant} \bullet 44/12$$ *(IPCC 2006 Equation 5.2)*

Where:
CO_2 Emissions = CO_2 emissions from lubricants, tonne CO_2
LC = total lubricant consumption[18], TJ
$CC_{Lubricant}$ = carbon content of lubricants (default), tonne C/TJ (= kg C/GJ)
$ODU_{Lubricant}$ = Oxidised During Use (ODU) factor (based on default composition of oil and grease),
fraction 44/12 = mass ratio of CO_2/C

Table 48: Emission factor used for emissions estimates

Factor	Value	Source
Carbon content of lubricants	20 t-C/TJ	NATCOM 2
Oxidised During Use (ODU) factor	0.2	NATCOM 2

Limitation
Due to lack of segregated data, lubricants' consumption by 2-stroke engines have also been accounted for within the IPPU sector. Due to this, the emissions from this category were calculated using a Tier-1 approach.

2D2 Paraffin wax use

Equation Used

$$CO_2\ Emissions = PW \bullet CC_{Wax} \bullet ODU_{Wax} \bullet 44/12$$ *(IPCC 2006 Equation 5.4)*

Where:
CO_2 Emissions = CO_2 emissions from waxes, tonne CO_2
PW = total wax consumption[19], TJ
CC_{Wax} = carbon content of paraffin wax (default), tonne C/TJ (= kg C/GJ)
ODU_{Wax} = ODU factor for paraffin wax,
fraction (44/12) = mass ratio of CO_2/C

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[18] Lubricant consumption data was multiplied by NCV (40.2 Tj/Kt) (Indian Network for Climate Change Assessment, 2010) to get consumption data in TJ

[19] Paraffin wax consumption data was multiplied by NCV (40.2 Tj/Kt) *(Conversion factors, 2013)* to get consumption data in TJ

Table 49: Emission factors used for emissions estimates

Factor	Value	Source
Carbon content of paraffin wax	20 t-C/TJ	NATCOM 2
ODU factor	0.2	NATCOM 2

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AGRICULTURE SECTOR

Key Highlights

- In Kerala, the Agriculture sector represented ~7% of the gross GHG emissions (excluding LULUCF) in 2021.
- In 2021, GHG emissions from the Enteric Fermentation category was the highest and accounted to 994.10 kt CO_2e, constituting ~63.56% of the total Agriculture sector emissions.
    - Similarly, GHG emissions from Agriculture Soils accounted to 258.89 kt CO_2e, constituting ~16.55% of the total Agriculture sector emissions, in 2021. GHG emissions from Rice Cultivation accounted to 186.52 kt CO_2e, constituting ~11.92% of the total Agriculture sector emissions.
    - GHG emissions from manure management category accounted to 119.58 kt CO_2e, constituting ~7.64% of the total Agriculture sector emissions, in 2021.

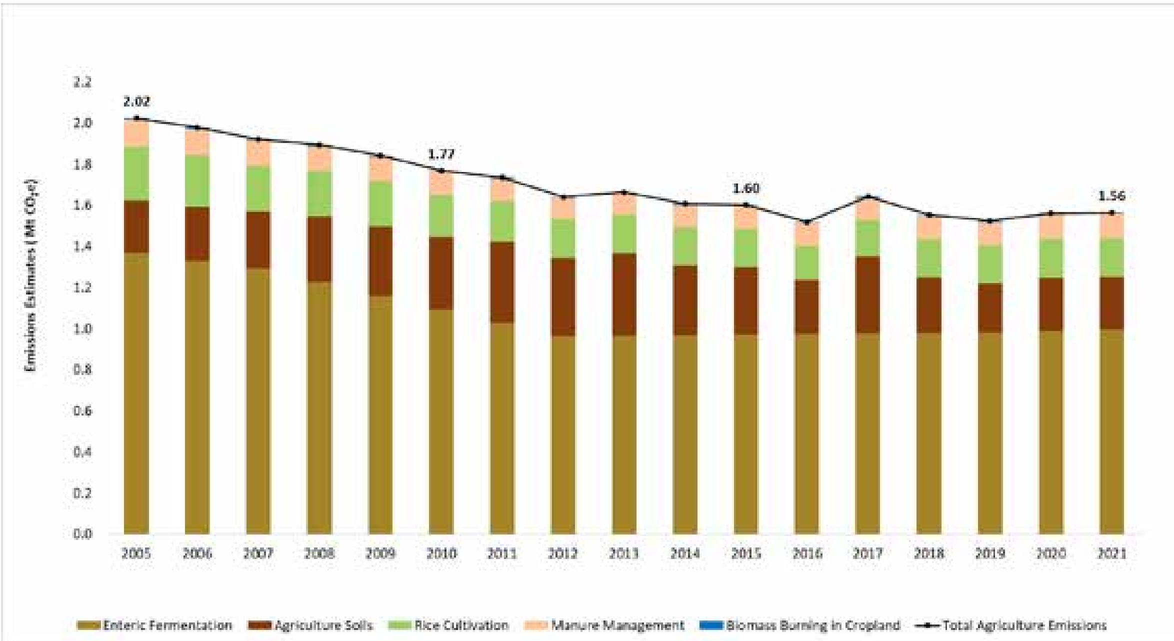

Figure 3 : GHG Emissions Estimates of Agriculture Sector – Kerala (2005 to 2021)

Sector Description

Emissions from the Agriculture sector arise from two main sub-sectors, namely Livestock, and Agriculture Practices.

The key economic sectors/categories included in the emission estimates are:

- 3A Livestock
    - 3A1 Enteric Fermentation
    - 3A2 Manure Management

- Agriculture Practices
    - 3C1b Emissions from biomass burning in croplands
    - 3C4 Direct N_2O emissions from managed soils
    - 3C5 Indirect N_2O emissions from managed soils
    - 3C7 Rice Cultivation

Methodology

The table 50 below details the sources of activity data used for estimating emissions

Table 50: Source of activity data[20] used for estimating emissions from Agriculture sector

Category	Parameter	Year	Source
Livestock	Livestock Population	2003, 2007, 2012 and 2019	Livestock Census of India, Department of Animal Husbandry and Dairying
		2004 to 2006, 2008 to 2011 and 2013 to 2018	Interpolation method
		2020 and 2021	CAGR method
Biomass burning in cropland	Crop production	2004-05 to 2021-22	Department of Economics & Statistics, Government of Kerala Agriculture Statistics
	Groundnut production	2004-05	Directorate of Economics and Statistics, Department of Agriculture and Farmers welfare, Ministry of Agriculture and Farmers Welfare, Govt of India
Agriculture Soils	Nitrogen Consumption	2004-05 to 2020-21	Economics,Statistics and Evaluation Division, Department of Agriculture and Farmers Welfare, Ministry of Agriculture and Farmers Welfare, Government of India. 2007 (for 2004-05, 2005-06, 2006-07) 2009 (for 2007-08, 2008--09)

[20] Activity data provided in financial year (FY) format was converted to calendar year (CY) format using the following equations:

CY Activity data = [¼*FY Activity Data$_{\text{Preceding year}}$] + [¾*FY Activity Data$_{\text{Succeeding year}}$]

			2012 (for 2009-10, 2010-11, 2011-12) 2013, 2014, 2015, 2016, 2017, 2018, 2019, 2020 and 2021
		2021	CAGR calculated between 2005 and 2020
	Urea Consumption	2004-05 to 2017-18	GHGPI Phase 4 datasheet which is sourced from Indian Fertilizer Scenario, Department of Fertilizers, Ministry of Chemicals and Fertilizers, Govt of India (currently reports are not available on the public domain)
		2018-2021	CAGR calculated between 2005-2017
Rice Cultivation	Rice Cultivated area	2005-2021	Department of Economics & Statistics, Government of Kerala Agriculture Statistics
	The proportions of rice cultivated area under different water regimes.		Directorate of Agriculture Development and Farmers Welfare, Kerala

3A Livestock

3A1 Enteric Fermentation

Category Description

Methane emissions from Enteric Fermentation arise due to the process of ingesting and digesting food eaten by the herbivores, mainly bovines and ovines (Dhingra et al., 2019). Similarly, Methane and Nitrous Oxide emissions from the Manure management systems arise due to decomposition of manure under the anaerobic conditions due to storage and treatment or due to management of large numbers of animals in a confined area such as dairy farms, swines and poultry farms.

The livestock population activity data for both enteric fermentation and manure management emission estimations were obtained from Livestock Census of India. The detailed assumptions and emission factors used for emissions estimation are given below:

Methodology

The emissions resulting from Enteric Fermentation and Manure Management due to Livestock production in Kerala, have been estimated using the Tier 1 and Tier 2 approaches (See Table 51) .

Due to lack of data on excretion of animals, livestock population (N_t) was multiplied by emission factor (for each type of animal category) in order to calculate the N_2O emissions from Manure Management.

Table 51 : Type of emissions factor and the level of methodological tier employed for GHG estimation

Table 51 a: Enteric Management

IPCC ID	GHG Sources and sink categories	CO_2		CH_4		N_2O	
		Method Applied	Emission Factor	Method Applied	Emission Factor	Method Applied	Emission Factor
3A1	**Enteric Fermentation**						
a.	Cattle	-	-	T2	CS	-	-
	Dairy (Indigenous and Crossbred Cattle)	-	-	T2	CS	-	-
	Non-Dairy (Indigenous and Crossbred Cattle)	-	-	T2	CS	-	-
b	**Buffalo**	-	-	T2	CS	-	-
c	Sheep	-	-	T2	CS	-	-
d	Goats	-	-	T2	CS	-	-
e	Camels	-	-	T1	D	-	-
f	Horses and ponies	-	-	T1	D	-	-
g	Donkeys	-	-	T1	D	-	-
h	Pigs	-	-	T1	D	-	-
T1 : Tier 1 ;T2: Tier 2; CS:Country Specific ; D:IPCC Default							

Table 51 b : Manure Management

IPCC ID	GHG Sources and sink categories	CO_2		CH_4		N_2O	
		Method Applied	Emission Factor	Method Applied	Emission Factor	Method Applied	Emission Factor
3A2	**Manure Management**						
a.	Cattle	-	-	T2	CS	T1	D
	Dairy (Indigenous and Crossbred Cattle)	-	-	T2	CS	T1	D
	Non-Dairy (Indigenous and Crossbred Cattle)	-	-	T2	CS	T1	D
b	**Buffalo**	-	-	T2	CS	T1	D
c	Sheep	-	-	T2	CS	T1	D
d	Goats	-	-	T2	CS	T1	D
e	Camels	-	-	T1	D	T1	D
f	Horses and ponies	-	-	T1	D	T1	D
g	Donkeys	-	-	T1	D	T1	D
h	Pigs	-	-	T1	D	T1	D
T1 : Tier 1 ;T2: Tier 2; CS:Country Specific ; D:IPCC Default							

<u>**Emission Factors**</u>

1. The country-specific emission factors for indigenous cattle, cross-bred cattle and buffalo were taken from NATCOM 2 (MoEFCC,2012). For the remaining categories, default emissions factors were obtained from 2006 IPCC guidelines (see Table 52).

Table 52: Emission Factors used

Category	Sub-category	Age group	Methane Emission Factor (NATCOM 2 and IPCC Guidelines)		Nitrous Oxide Emission Factor (GHGPI Phase 4)
			Enteric Fermentation (kg/CH_4/head/ year)	Manure Management (kg/CH_4/head/ year)	Manure Management (kg/head/year)
Indigenous Cattle	Dairy Cattle		28	3.5	0.0006

Category	Sub-category	Age group	Methane Emission Factor (NATCOM 2 and IPCC Guidelines)		Nitrous Oxide Emission Factor (GHGPI Phase 4)
			Enteric Fermentation (kg/CH_4/head/ year)	Manure Management (kg/CH_4/head/ year)	Manure Management (kg/head/year)
Indigenous Cattle	Non-Dairy Cattle	0-1 year	9	1.2	0.0004
Indigenous Cattle	Non-Dairy Cattle	1-3 year	23	2.8	0.0004
Indigenous Cattle	Non-Dairy Cattle	Adult	32	2.9	0.0004
Crossbred Cattle	Dairy Cattle		43	3.8	0.0006
Crossbred Cattle	Non-Dairy Cattle	0-1 year	11	1.1	0.0004
Crossbred Cattle	Non-Dairy Cattle	1-3 year	26	2.3	0.0004
Crossbred Cattle	Non-Dairy Cattle	Adult	33	2.5	0.0004
Buffalo	Dairy Buffalo		50	4.4	0.0006
Buffalo	Non-Dairy Buffalo	0-1 year	8	1.8	0.0004
Buffalo	Non-Dairy Buffalo	1-3 year	22	3.4	0.0004
Buffalo	Non-Dairy Buffalo	Adult	44	4	0.0004
Sheep	-	-	5	0.2	0
Goat	-	-	5	0.22	0
Horses and Ponies	-	-	18	2.19	0
Donkeys	-	-	10	0.9	0
Camels	-	-	46	2.56	0
Pigs	-	-	1	4	0.0074

Category	Sub-category	Age group	Methane Emission Factor (NATCOM 2 and IPCC Guidelines)		Nitrous Oxide Emission Factor (GHGPI Phase 4)
			Enteric Fermentation (kg/CH_4/head/ year)	Manure Management (kg/CH_4/head/ year)	Manure Management (kg/head/year)
Poultry	-	–	0	0	0.0025

Equation Used

3A1 Enteric Fermentation

$$CH_{4\ Enteric} = \Sigma EF_{(T)} \bullet (N_{(T)} / 10^6) \quad \textit{(IPCC 2006 Equation 10.19)}$$

Where,

$Emissions$ = methane emissions from Enteric Fermentation, Gg CH_4 yr^{-1}

$EF_{(T)}$ = emission factor for the defined livestock population, kg CH_4 $head^{-1}$ yr^{-1}

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

T = species/category of livestock

3A2 Manure Management

I. Methane Emissions from Manure Management

$$\text{Total } CH_{4\ Manure} = EF_{(T)} \bullet (N_{(T)} / 10^6) \quad \textit{(IPCC 2006 Equation 10.22)}$$

Where,

$CH_{4\ Manure}$ = methane emissions from Manure Management, Gg CH4 yr^{-1}

$EF_{(T)}$ = emission factor for the defined livestock population, kg CH_4 $head^{-1}$ yr^{-1}

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

T = species/category of livestock

II. Nitrous Oxide Emissions from Manure Management*

$$N_2O_{animals} \text{ Emissions } \textit{(Gg/ Year)} = EF_{(kg/\ head/\ year)} \text{ x population/ } 10^6 \text{ (kg/ Gg)}$$

Where,

N_2O Emissions = N_2O emissions from Manure Management, Gg N_2O yr^{-1}

$EF_{(T)}$ = emission factor for the defined livestock population, kg N_2O $head^{-1}$ yr^{-1}

** Slightly modified version of equation 10.25 provided in the IPCC was used due to the type of EF provided in Indian Literature*

Emissions in terms of CO_2e (both GWP and GTP) were calculated using the following equations

$Emissions_{CO2e}$ (GWP) = $Emissions_{CO2}$ + (GWP_{CH4} x $Emissions_{CH4}$) + (GWP_{N2O} x $Emissions_{N2O}$)

$Emissions_{CO2e}$ (GTP) = $Emissions_{CO2}$ + (GTP_{CH4} x $Emissions_{CH4}$) + (GTP_{N2O} x $Emissions_{N2O}$)

Agriculture Practices

3C1b Biomass burning in Cropland

Category Description

From a climate change perspective, the combustion of crop residues leads to the release of N_2O and CH_4 gases. It is important to note that CO_2 emissions are not factored in, as they are offset by the absorption of CO_2 during the photosynthesis process that initially prompted the growth of biomass (IPCC, 2006).

Methodology

The crops considered for biomass burning in cropland are rice, wheat, cotton, maize, millets, sugarcane, jute, mustard and groundnut.

The methodological tiers adopted for estimating emissions from Biomass Burning in Cropland are as under:

Table 53: An overview of tier and emission factors used for biomass burning in cropland

IPCC ID	GHG Source and sink categories	CH_4		N_2O	
		Method applied	Emission factor	Method applied	Emission factor
3C1b	Biomass Burning in Cropland	T1	D	T1	D
T1: Tier 1, D: IPCC Default					

In the absence of data on the amount of area burnt the methodology used here for estimating emissions from biomass burning in cropland is adopted from the MoEFCC,(2012).

Steps followed

Emissions from crop residue burning was calculated using the following equation from Bhatia et al., (2013)

$$FBCR = \sum Crops(A \cdot B \cdot C \cdot D \cdot E \cdot F)$$

Where,

FBCR is the emissions from residue burning (t)

A is the crop production (t)
B is the residue to crop ratio
C is the dry matter fraction,
D is the fraction burnt
E is the fraction oxidized
F is the emission factor for CH_4 and N_2O (g/kg)

Residue to crop ratio and dry matter fraction was taken from TIFAC & IARI,(2018), millet and jute were taken from MoEFCC, (2021) (see table 54). Fractions burnt for rice were taken from Gadde et al. (2009), and for the rest of the crops from MoEFCC, (2021) (see table 54). Fractions of residues oxidized were obtained from Garg et al. (2011). (see table 54)

Table 54: Fractions used for estimation of emissions from biomass burning in cropland

Parameter	**Rice**	**Wheat**	**Maize**	**Cotton**	**Sugarcane**	**Jute**	**Rapeseed & mustard**	**Groundnut**	**Millets**
Residue to crop ratio	1.60	1.70	1.50	1.00	0.43	2.15	3.0	2.10	1.50
Dry matter fraction	0.86	0.88	0.88	0.80	0.88	0.80	0.80	0.80	0.88
Combustion factor	0.80	0.90	0.80	0.80	0.80	0.80	0.80	0.80	0.80
Fraction burnt	0.10	0.10	0.10	0.10	0.25	0.10	0.10	0.10	0.10

Default emission factors for different pollutants emitted from residue burning were taken from IPCC 2006, Chapter 2 (see table 55).

Table 55: Emission factors used for estimating biomass burning in cropland

Category	**CH_4 (g/kg)**	**N_2O (g/Kg)**
Biomass burning in cropland	2.7	0.07

Limitations

- The fraction of rice burnt used for these calculations could be updated.

Estimation of Emissions from Agricultural Soils, including from:

3C4 Direct N_2O emissions from managed soils and

3C5 Indirect N_2O emissions from Managed Soils

Category Description

Soil N_2O emissions can be categorized into two types: direct and indirect. A portion of nitrogenous fertilizers applied in agricultural soils are lost into the atmosphere through direct emissions of N_2O through nitrification and denitrification. In addition, there are also indirect emissions of N_2O through volatilization losses, leaching and runoffs (IPCC, 2006).

Methodology

The fertilizer consumption data used for estimating emissions from this category for the year 2019, 2020, 2021 is detailed in table 57 .The methodological tiers adopted for estimating emissions from Biomass Burning in Cropland are given in table 56:

Table 56: Methodological tier and emission factors used for biomass burning in cropland

IPCC ID	GHG Source and sink categories	N_2O	
		Method applied	Emission factor
3C4	Direct N_2O emissions from Managed Soils	T1	CS
3C5	Indirect N_2O emissions from Managed Soils	T2	CS
T1: Tier 1, T2: Tier 2, CS: Country specific			

Table 57 : Fertilizer consumption Data used for Emission Estimation ('000 tonnes)

Consumption of Fertilizer	2019	2020	2021
Urea	128.77	129.03	129.29
Nitrogen	77.73	85.86	85.99

Steps followed

Total N_2O = N_2O direct + N_2O indirect [21]

---

21 The equations used for estimating direct N_2O emissions is slightly modified from IPCC equation based on the format of available dataset

Calculation of direct N_2O emission

Step 1:
Quantity of nitrogen in other nitrogen fertilizers= Total N quantity consumed - Quantity of N in urea consumed
For calculating the quantity of nitrogen in urea, the total urea consumption was multiplied by 46 percent as urea contains 46% nitrogen. So, N consumed by other fertilizers was found by subtracting the N consumed in urea from the total N consumption.

Step 2:
Fraction loss= (Quantity of N in urea consumed *Fraction of gas loss through volatilised N from urea application) + (Quantity of nitrogen in other nitrogen fertilizers *Fraction of gas loss through volatilized N from Other fertilizer application)

Step 3:
N_2O direct= (Total N quantity consumed – Fraction loss) *Emission factor (EF1) * (44/28)

Calculation of indirect N_2O emission:

Indirect Emission from NH_3 Deposition on Soil from Urea = Quantity of N in Urea Consumed* Fraction of gas loss through volatilized N from Urea application* Emission factor (EF4)* (44/28)

Indirect Emission from NH_3 Deposition on Soil from Other fertilizer = Quantity of N in Other Nitrogen Fertilizers* Fraction of gas loss through volatilized N from Other fertilizer application* emission factor (EF4)* (44/28)

Indirect Emissions from Leaching of Fertilizers = Total N Quantity Consumed* Fraction of leaching loss of N applied fertilizer * emission factor (EF5) * (44/28)

The country specific emission factors and fractions used for estimating emissions from Agriculture Soils are as in Table 58

Table 58 : Emission factor used for Emissions Estimation of Agriculture Soil category

Parameter	**Gas**	**Emission factor**
Direct Emissions	N_2O	0.0058 Kg N20-N/Kg N
Indirect Emissions - Atmospheric Deposition, Urea or Other fertilizers		0.005 Kg N20-N/Kg N
Indirect Emissions - Leaching		0.005 Kg N20-N/Kg N

Fraction of gas loss through volatilized N from Urea application		0.15 Kg N/kg N
Fraction of gas loss through volatilized N from Other fertilizer application		0.15 Kg N/kg N
Fraction of leaching loss of N applied fertilizer		0.1 Kg N/kg N

Source: BUR 3 (MoEFCC,2021)

Limitations

N_2O emissions could not be estimated due to the lack of availability of data for the following sub-categories :

- Nitrogen from compost
- Nitrogen from crop residue
- Manure nitrogen other than poultry
- Nitrogen input from below-ground biomass

3C7 Rice Cultivation

Category Description

This category includes emissions of methane by the anaerobic decomposition of soil organic material in flooded rice paddies (IPCC, 2006).

Methodology

The proportions of rice cultivated area under different water regimes as per the data provided by Directorate of Agriculture Development and Farmers Welfare, Kerala (see table 59) was applied to the cultivated area from 2005-2021 to get the area of rice under different water regimes from 2005-2021.

Table 59: Area of rice cultivated under different water regimes

Region	Area of rice cultivated	Water Regime
Kuttanad	33801	Single aeration (SA)
Pokkali	507	Single aeration (SA)
Kole	14724.3	Single aeration (SA)
Kaippad	3740	Single aeration (SA)
Palakkad plains and other paddy region	40736.7	Multiple aeration (MA)
Upland rice	511	Upland

Of the total land under rice cultivation, 56.13 per cent is under single aeration, 43.33 per cent under multiple aeration, and 0.54 percent is upland

The methodological tiers adopted for estimating emissions from Rice Cultivation are given in Table 60:

Table 60: An overview of tier and emission factors used for Rice Cultivation

IPCC ID	GHG Source and sink categories	CH_4	
		Method applied	**Emission factor**
3C7	Rice Cultivation	T2	CS
T1: Tier 1, T2: Tier 2, D: IPCC Default, CS: Country specific			

The methodology used was the same as that used in MoEFCC, (2012). It has been referred from Gupta et al., (2009) and Pathak et al., (2010) using 2006 IPCC guidelines. The methane emissions are estimated by multiplying the total paddy rice area under different water management regimes (ha) with corresponding Emission Factor.

Equation Used

$$E_{RC} = A_C \times EF_W \times 10^{-6}$$

Where, E_{RC} = CH_4 emissions from rice cultivation (Gg $year^{-1}$),
A_C = area of rice cultivation under management C (ha)
EF_W = factor applied for different types of water management (kg CH_4 ha^{-1})
10^{-6} = to convert Kg into Gg

The specific emission factors used were as follows:

Table 61: Country specific emission factors used for estimating emissions from Rice Cultivation

Water Regime	Type of gas	Emission factor
Single aeration	CH_4	66 kg CH_4/ha
Multiple aeration	CH_4	18 kg CH_4/ha
Upland	CH_4	0 kg CH_4/ha

Source: Pathak, et al. (2010)

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LAND USE, LAND-USE CHANGE AND FORESTRY (LULUCF) SECTOR

Key Highlights

- In Kerala, the Land Use, Land-Use Change and Forestry (LULUCF) sector remained a sink between 2005 and 2021.
- Forestland was the major contributor to GHG removals between 2005 and 2021. However, these GHG removals declined at a rate of 1.7 % (compounded annually) in the evaluation period, from -13.14 Mt CO_2e to -9.99 Mt CO_2e.
- The GHG removals from Settlements increased between 2005 and 2021 at a rate of 6.01% (compounded annually) from -0.02 Mt CO_2e to -0.05 Mt CO_2e.
- The Grassland and Other Land* category remained a sink until 2011. However, during the period 2012 - 2021, total annual emissions from these categories were 0.014 Mt CO_2e.

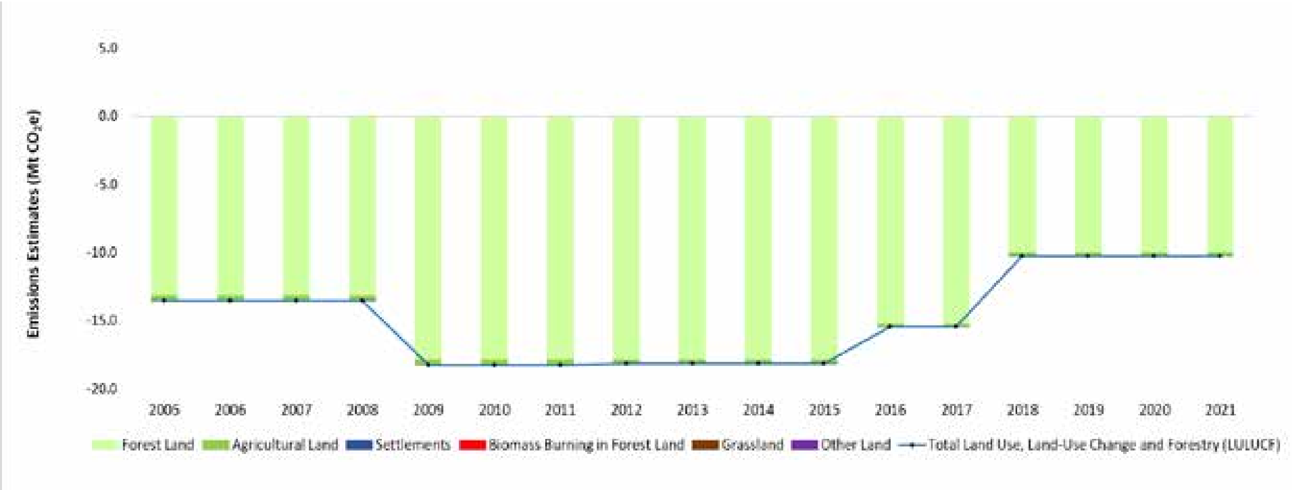

Figure 4: GHG Emissions Estimates of LULUCF Sector - Kerala (2005 to 2021)

Sector Description

Emissions from the Land Use, Land Use Change and Forestry (LULUCF) sector were estimated for Forest land and land conversions. The sub-sectors covered under LULUCF sector are listed below:

3B1. Forest Land
3C1a. Biomass burning in Forest Land
3B2 Cropland
3B3 Grassland
3B5 Settlements
3B6 Other Land

**Other Land includes Barren Land/ Unculturable/wastelands*

Methodology

The table 62 below details the sources of activity data used for estimating emissions:

Table 62: Source of activity data[22] used for estimating emissions

Category	Parameter	Year	Source
Forest Land	Forest Cover	2004, 2006, 2008, 2010, 2013, 2015, 2017 and 2019 (reported assessment years)	India State Forest Reports, Forest Survey of India 2005 , 2009, 2011, 2013, 2015, 2017 2019, 2021
	Carbon Stock Density	(a) 2008 (b) 2015, 2017 and 2019	(a) Carbon Report, Forest Survey of India (b) India State Forest Reports, Forest Survey of India
Biomass burning in Forestland		2004-05 to 2008-09	Forest Statistics 2009, Kerala Forest Department
		2009-10 to 2020-21	Kerala Forest Department
		2021-22	CAGR method
Land	Cropland, Grassland, Settlements and Other Land	LULC matrix of (a) 2005-06 to 2011-12 (b) 2011-12 to 2015-16	(a) Envistats Reports 2018 (b) Envistats India 2020 (Ministry of Statistics and Programme Implementation , Government of India, 2020)

3B1. Forest Land

This category presents the emission estimates from Forest Land due to changes in dead organic matter, biomass and soil organic matter. The forest land data and the emission factor were obtained from the 'India State of Forest Report' and emissions from this category were estimated using the Tier 2 (T2) approach of IPCC Guidelines (see Table 63).

[22] Activity data provided in financial year (FY) format was converted to calendar year (CY) format using the following equations:

CY Activity data = [¼*FY Activity Data $_{\text{Preceding year}}$] + [¾*FY Activity Data $_{\text{Succeeding year}}$]

Table 63 :**Type of emission factor and the level of methodological tier employed for GHG estimation**

IPCC ID	GHG Sources and sink categories	CO_2	
		Method Applied	Emission Factor
3B1	Forest Land	T2	CS
T2: Tier 2, CS: Country specific			

Methodology:

a. **Emissions Estimation**

The year-on-year carbon stock was calculated by multiplying the carbon stock density and the forest cover data. The carbon stock density (CSD) data was available for the assessment years 2008, 2015,2017 and 2019 from the Carbon Report and Forest Survey of India (FSI) reports.

The Carbon Stock Density was applied in the following format: 2008 CSD was applied between 2005 and 2008, 2015 CSD was applied between 2009 and 2015, 2017 CSD was applied for 2016-2017, 2019 CSD was applied for the years between 2018 and 2021.

The GHG emissions from the forest land is estimated by applying Stock-Difference Method along with the activity data and emission factors, in-line with section 4.2.1.1 – choice of method, in Volume 4, Chapter 4, 2006 IPCC Guidelines.

The following Stock-Difference Method has been used for assessing the carbon stock changes

$$\Delta C = (Ct_2 - Ct_1) / (t_2 - t_1)$$ *(IPCC 2006 Equation 2.5)*

Where,

ΔC = Annual Carbon stock change in pool (tonnes C yr^{-1})

Ct_1 = Carbon stock in the pool at time t1 (tonnes C)

Ct_2 = Carbon stock in the pool at time t1 (tonnes C)

3C1a Biomass Burning in Forest Land

Category Description

The non-carbon dioxide emissions viz. Methane (CH_4) and Nitrous oxide (N_2O) were estimated for this category. The non-carbon dioxide emissions from biomass burning in forest land caused by both uncontrolled (wildfires) and managed (prescribed) fires. The activity data of this category were obtained form Kerala Forest Department. The data sources, assumption, methodology and emission factors are detailed below:

Methodology

The emissions from this category were estimated using the Tier 2 (T2) approach (see Table 64)

Table 64: Type of emissions factor and the level of methodological tier employed for GHG estimation

IPCC ID	GHG Sources and sink categories	CH4		N_2O	
		Method Applied	Emission Factor	Method Applied	Emission Factor
3C1a	Biomass Burning in Forest Land	T2	CS	T2	CS
T2: Tier 2, CS: Country specific					

Table 65 :Factors used and sources

Parameter	**Value**	**Source**
Mass of fuel available for combustion (t/ha)	5.483#	BUR 3
Combustion Factor	0.36	2006 IPCC Guidelines

#***Scope for improvement*** *: The estimations can be refined if the mass of fuel available for the combustion is replaced with the corresponding state-level equivalent. The mass of fuel available for combustion (5.483) is the average of biomass burnt in mild fire areas, moderate fire areas and heavy fire areas as provided in the BUR 3 report.*

Emission Factor

Country specific emission factors for methane (CH_4) and nitrous oxide (N_2O) were obtained from NATCOM 2 (MoEFCC, 2012).

Table 66: Emission Factor Used

Parameter	**Methane (CH_4)**	**Nitrous Oxide (N_2O)**
Emission factor (g/kg dry matter)	9	0.11

Limitations:

Tier 3 estimation requires use of detailed State forest inventories with details on ecological zone and climate domain specific fuel dynamics in forests (growing stock, above ground biomass, dead organic matter).

Equation used to estimate the emissions

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

Where,

L_{fire} = amount of greenhouse gas emissions from fires, tonnes of each GHG e.g. CH_4, N_2O etc.

A = area burnt, ha

M_B = mass of fuel available for combustion, tonnes ha^{-1}. This includes biomass, ground litter and dead wood.

C_f = combustion factor, dimensionless

G_{ef} = emission factor, g kg^{-1} dry matter burnt

3B2,3B3,3B5 & 3B6 Land sub-sector

Category Description

The emissions from the Land sub-sector were estimated for the Cropland, Grassland, Settlements and Other land. The emissions from this category is caused due to changes in biomass carbon stock and soil organic carbon stock due to various land use practices – Land remaining Land as well as Land converted to any other Land category.

Methodology

1. The Land Use Land Cover Change Matrix of Kerala for the years between 2005-06 to 2011-12 and 2011-12 to 2015-16 were obtained from Envistats Reports 2018 and 2020 (Supplement on Environmental Accounts) – Ministry of Statistics and Programme Implementation (MOSPI), Govt. of India.
2. The rate of change of biomass (0.045 tC/ha/year) was obtained from BUR 3 report; Soil organic carbon stocks for Grassland and Other Land were obtained from Sreenivas et al (2016) ; Soil organic carbon stock for Cropland was obtained from Gladis et al (2020); Soil organic carbon stock for Settlements was obtained from Sarkar et al (2022) and the Soil organic carbon for Wetlands was obtained from IPCC Guidelines.
3. The default stock change factors were obtained from IPCC Guidelines.

The emissions from this category have been estimated using the Tier 2 approach and country-specific emission factors (see Table 67)

Table 67 :Type of emission factor and the level of methodological tier employed for GHG estimation

IPCC ID	GHG Sources and sink categories	CO_2	
		Method Applied	Emission Factor
3B2	**Crop Land**	**T2**	**CS**
3B2a	Cropland Remaining Cropland	T2	CS
3B2bi	Forestland converted to Cropland	T2	CS
3B2bii	Grassland converted to Cropland	T2	CS
3B2biii	Wetland converted to Cropland	T2	D
3B2biv	Settlements converted to Cropland	T2	CS
3B2bv	Other Land converted to Cropland	T2	CS
3B3	**Grassland**	**T2**	**CS**
3B3a	Grassland Remaining Grassland	T2	CS
3b3bi	Forestland converted to Grassland	T2	CS
3b3bii	Cropland converted to Grassland	T2	CS
3b3biii	Wetland converted to Grassland	T2	D
3b3biv	Settlements converted to Grassland	T2	CS
3b3bv	Other Land converted to Grassland	T2	CS
3B5	**Settlements**	**T2**	**CS**
3B5a	Settlements Remaining Settlements	T2	CS
3B5bi	Forestland converted to Settlements	T2	CS
3B5bii	Cropland converted to Settlements	T2	CS
3B5biii	Grassland converted to Settlements	T2	CS
3B5biv	Wetland converted to Settlements	T2	D
3B5v	Other Land converted to Settlements	T2	CS

IPCC ID	GHG Sources and sink categories	CO_2	
		Method Applied	**Emission Factor**
3B6	**Other land**	**T2**	**CS**
3B6a	Other Land Remaining Other Land	T2	CS
3b6bi	Forestland converted to Other Land	T2	CS
3b6bii	Cropland converted to Other Land	T2	CS
3b6biii	Grassland converted to Other Land	T2	CS
3b6biv	Wetland converted to Other Land	T2	D
3b6bv	Settlements converted to Other Land	T2	CS
3B4	**Wetlands**	**Not Estimated**	
T2: Tier 2 ; CS: Country specific ; D: IPCC default			

The biomass factor used for the emission estimation have been detailed below in Table 68

Table 68 : Biomass Factor

Years applicable	Factor	
For LULC upto 2011-12	Rate of change in biomass carbon in tC/ha/yr	0.045
For LULC upto 2015	Rate of change in biomass carbon in tC/ha/yr	0.045

Source : BUR 3

Assumptions:

The biomass factor obtained from BUR 3 was derived using country specific biomass conversion and expansion factors.

Scope for improvement

Tier 3 inventories for Land (except Forest Land) can be developed using measurements and modeling – accounting for deadwood, litter along with above and below ground biomass, wood harvested products, soil organic carbon.

Equations used for emissions estimation:

The equations used to estimate the emission from Land sub-sector (except forest land) due to Land Use and Land cover Change has been explained below

Emissions from Land sub-sector (except forest land) = Change in biomass carbon stock + Change in organic carbon stock in mineral soils

The equations of Change in biomass carbon stock and Change in organic carbon stock in mineral soils is detailed below:

(a) Change in biomass carbon stock

$$\Delta C_G = \sum_{i,j} (A_{i,j} \bullet G_{Total\ i,j}\ CF_{i,j} \quad \textit{(IPCC 2006 Equation 2.9)}$$

Where,

ΔC_G = annual increase in the biomass carbon stocks in land remaining land or land changing to another land use (tonnes of C yr^{-1})

A_i = area of land remaining in land use category or area of land changed to another land use category (ha)

G_{Total} = mean annual biomass growth tonnes d. m. ha^{-1} yr^{-1}

CF = carbon fraction of dry matter , tonnes C (tonne d.m.) $^{-1}$

(b) Change in organic carbon stock in mineral soils

$$\Delta C_{Mineral} = (SOC_0 - SOC_{(0-T)}) \ / \ D$$

$$SOC = \Sigma (SOC_{REF} \bullet F_{LU} \bullet F_{MG} \bullet F_i \bullet A)$$

(IPCC 2006 Equation 2.25)

Where,

SOC_0 = soil organic carbon in the last year of the inventory period-final land use type (tC)

$SOC_{(0-T)}$ = soil organic carbon in the beginning of the inventory period-initial land use type (tC)

T = number of years over single inventory period

D = default time period (assumed to be 20 years)

SOC_{REF} = reference carbon stock (tC ha^{-1})

F_{LU}, F_{MG}, F_i = stock change factors for particular land use, management regime and input organic matter (dimensionless)

A = area of land stratum being estimated (ha)

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WASTE SECTOR

Key Highlights

- The Waste sector contributed to almost 8% of gross GHG emissions (excluding LULUCF) of Kerala in 2021.
- In the Waste sector, domestic wastewater is the major contributing key source category with an average share of 94%. It is followed by industrial wastewater (4%) and municipal solid waste (2%).
- GHG emissions from the Waste sector of Kerala declined at a CAGR of 0.33%, from 1.84 Mt CO_2e in 2005, to 1.75 Mt CO_2e in 2021.

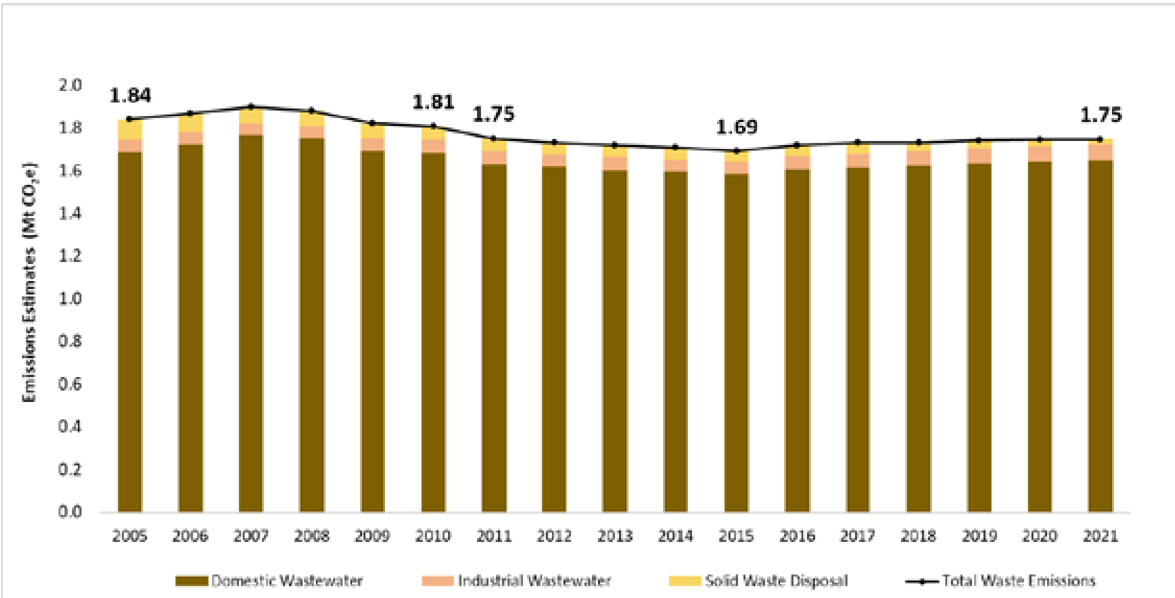

Figure 5: GHG Emissions Estimates of Waste Sector - Kerala (2005 to 2021)

Sector Description

The key economic sectors/categories included in the emission estimates from Waste sector are:

- 4A Solid Waste Disposal
- 4D Wastewater treatment and discharge
  - 4D1 Domestic Wastewater Treatment and Discharge
  - 4D2 Industrial Wastewater Treatment and Discharge

4A Solid Waste Disposal

Category Description

When solid waste is disposed of in landfills or dumpsites under anaerobic conditions, methanogenic bacteria break down the waste's degradable organic component, creating CH_4

emissions. The organic material decomposes slowly, and the CH_4 emissions from a particular quantity of dumped solid waste continue to be released for a few decades (GHGPI Phase III)[23].

The current assessment covers the disposal of municipal solid waste of Kerala. The Municipal Solid Waste includes waste from residential, commercial and institutional waste, street sweeping, parks and gardens which are either in semi-solid or solid form (excludes industrial, hazardous, bio- medical and e-waste). Further, the rural areas have not been included in estimation due to lack of reliable data.

The First order Decay (FOD) model was used in the emissions estimation and it assumes that carbon in waste decays gradually for decades to generate CH_4 emission long after it is disposed of and hence, it is necessary to estimate or collect 50-year data on waste disposal prior to the base year of 2005 (GHGPI Phase III)[24]. For Kerala, the emissions from the solid waste disposal was estimated from 1951 to 2021 keeping the FOD assumptions as reference.

Methodology

The methodology followed for the Methane (CH_4) emission estimations from solid waste disposal of Kerala includes both Tier 1 (T1) and Tier 2 (T2) approach.

Table 69: Source of activity data[25] used for estimating emissions from Waste sector

Parameter	Years	Sources
Urban Population	1987, 1991, 1993 and 2005 to 2021	Annual Vital Statistics, Department of Economics and Statistics, Government of Kerala (1987,1991,1993 and 2005 to 2021)
	1951 to 1986, 1988 to 1990, 1992 , 1994 to 2004	CAGR method
Per Capita Waste Generation	1951 to 1995	Status Of Municipal Solid Waste Generation In Kerala And Their Characteristics (Varma, 2015)
	1996	Status Of Municipal Solid Waste Generation In Kerala And Their Characteristics (Varma, 2015)
	2001 and 2006	Estimated based on Status Of Municipal Solid Waste Generation In Kerala And Their Characteristics study (Varma, 2015)

[23] Kolsepatil, N., Anandhan, S., Sekhar, A., Chaturvedula, S. (2019). Greenhouse Gases Emissions of India (subnational estimates): Waste Sector (2005-2015 series) dated September 25, 2019, Retrieved from: http://www.ghgplatform-india.org/waste-sector

[24] Ibid.

[25] Activity data provided in financial year (FY) format was converted to calendar year (CY) format using the following equations:

CY Activity data = [¼*FY Activity Data Preceding year] + [¾*FY Activity Data Succeeding year]

	2020	Suchitwa Mission (2020) Introduction And Strategic Enviromental Assessment of Waste Management Sector In Kerala (Volume I)
	1997 to 2000; 2002 to 2005; 2007 to 2019	CAGR method
Proportion going to Dumpsites	1951 to 2004	India Second National Communication to United Nations Framework Convention on Climate Change NATCOM 2
	2005 to 2016	Kerala Solid Waste Management Policy, 2018
	2017 to 2021	Based on inputs received from Kerala State Pollution Control Board.
Share of Degradable Organic Content (DOC) in Wet Waste		2006 IPCC Guidelines, Volume 5, Chapter 2 -Waste Generation, Composition, and Management Data, Table 2.4

Table 70: Type of Emission Factor and Level of Methodological Tiers adopted for Solid Waste Disposal Estimates

IPCC ID	GHG source and sink categories	CH_4	
		Method Applied	Emission Factor
4A	Solid Waste Disposal	T1, T2	D, CS
T1: Tier 1; T2: Tier 2; CS: Country-specific; D: IPCC default			

Equations used for Emissions Estimates

The following equations have been used to estimate CH_4 emissions from Solid waste disposal in accordance with 2006 IPCC Guidelines

CH_4 Emissions from Solid Waste Disposal Sites

$$CH_4\ Emissions = \left[\sum_x CH_4\ generated_{x,T} - R_T \right] \bullet (1 - OX_T)$$ *(IPCC 2006 Equation 3.1)*

CH_4 Emissions = CH_4 emitted in year T, Gg

T = inventory year

X = waste category or type/material

R_T = recovered CH_4 in year T, Gg (default value of 0) *(IPCC, 2006)*

OX_T = oxidation factor in year T, (fraction) (default value of 0) *(IPCC, 2006)*

The amount of CH_4 formed from decomposable material is found by multiplying the CH_4 fraction in generated landfill gas and the CH_4/C molecular weight ratio (16/12)

CH_4 Generated from Decayed DDOCm

$$CH_4\ generated_T = DDOCmdecomp_T \bullet F \bullet 16/12 \qquad \textit{(IPCC 2006 Equation 3.6)}$$

CH_4 generated$_T$ = amount of CH_4 generated from decomposable material
DDOCmdecomp$_T$ = Decomposable Degradable Organic Carbon (DDOC) decomposed in year T, Gg
F = fraction of CH_4, by volume, in generated landfill gas (fraction)
16/12 = molecular weight ratio CH_4/C (ratio)

Decomposable DOC from Waste Disposal Data

$$DDOCm = W \bullet DOC \bullet DOC_f \bullet MCF \qquad \textit{(IPCC 2006 Equation 3.2)}$$

Where,
$DDOC_m$ = mass of decomposable DOC deposited, Gg
W = mass of waste deposited for the state, Gg
DOC = degradable organic carbon for the respective state in the year of deposition, fraction, Gg C/Gg waste
DOC_f = fraction of DOC that can decompose (fraction)
MCF = CH_4 correction factor for aerobic decomposition in the year of deposition (fraction)

Estimated DOC using Default Carbon Content Values

$$DOC = \sum_i (DOC_i \bullet W_i) \qquad \textit{(IPCC 2006 Equation 3.7)}$$

Where,
DOC = fraction of degradable organic carbon in bulk waste, Gg C/Gg waste
DOC_i = fraction of degradable organic carbon in waste type i
W_i = fraction of waste type i by waste category

DDOCm Accumulated in the SWDS at the end of Year T

$$DDOCma_T = DDOCmd_T + (DDOCma_T - 1 \bullet e^{-k}) \qquad \textit{(IPCC 2006 Equation 3.4)}$$

DDOCm Decomposed at the end of the Year T

$$DDOCm\ decomp_T = DDOCma_T - 1 \bullet (1 - e^{-k}) \qquad \textit{(IPCC 2006 Equation 3.5)}$$

Where,

T = inventory year

$DDOCma_T$ = $DDOC_m$ accumulated in the SWDS at the end of year T, Gg

$DDOCma_{T-1}$ = $DDOC_m$ accumulated in the SWDS at the end of year (T-1), Gg

$DDOCmd_T$ = $DDOC_m$ deposited into the SWDS in year T, Gg

DDOCm $decomp_T$ = DDOCm decomposed in the SWDS in year T, Gg

k = reaction constant (0.17) , k = ln(2)/t1/2 (y-1)

t1/2 = half-life time (y)

Euler's Constant e = 2.718

Table 71: Default Values for Emissions Estimations of Solid Waste Disposal[26]

Parameter	Default Values
Fraction of Degradable Organic Carbon which decomposes ($DDOC_f$)	0.5
Methane Correction Factor *(Unmanaged shallow solid waste disposal site with depth less than 5 meter)*	0.4
Fraction of CH_4 in Generated Landfill Gas (F)	0.5
Oxidation Factor (OX)	0
Methane Recovery (R)	0
Reaction Constant (k)	0.84

Source : IPCC,2019 (Volume5, Chapter 3-Solid Waste Disposal)

Data Sources and Assumptions:

1. **Population:**

- The urban population for years 1987, 1991, 1993 and 2005 to 2021 data were obtained from Annual Vital Statistics Report, published by the Department of Economics and Statistics, Government of Kerala
- For the years in between, the urban population was calculated using the CAGR method.

2. **Mass of Waste Deposited**

The mass of waste deposited to the dumpsite was estimated using the urban population , per capita waste generation and proportion of waste going to the dumpsite.

[26] As per 2019 IPCC Guidelines, Volume 5, Chapter 3 - Solid Waste Disposal
Available at https://www.ipcc-nggip.iges.or.jp/public/2019rf/pdf/5_Volume5/19R_V5_3_Ch03_SWDS.pdf

a. Per capita waste generation

- The per capita waste generation data for the year 1996 was obtained from the study conducted in Kerala by Varma (2015) and for the years 2001 and 2006, the per capita waste generation data was derived based on the reported total waste generation data in the study.
- For the year 2020, the per capita waste generation data was derived based on the total waste generation data reported in the Suchitwa Mission Report (2020)[27].
- The per capita waste generation for all the intermediate years between 1996 and 2021 was estimated using CAGR.

Table 72: Per capita waste generation of Kerala

Year	Solid Waste Generation (TPD)	Urban Population	Per Capita Waste Generation (g/person/day)
1996	-	-	210
2001	1752	4903172	357.32
2006	1941	5411995	358.65
2020	Low land (Coastal area)– 2115 Mid Land – 1275 Highland - 365	Low land (Coastal area)– 4162180 Mid Land – 2941234 Highland - 872437	453.34 (average value)

- An Annual Growth rate in per capita waste generation (1.41%) was applied backward from 1995 to 1951 for accounting potential emissions from legacy waste. This annual growth rate in per capita waste generation was obtained from Varma (2015).

b. Proportion of Waste Going to the Dumpsites:

- The proportion of solid waste going to the dumpsite for years between 1951 and 2004 was taken as 70% (National Average) as per NATCOM 2 .
- Based on the Suchitwa Missions inputs with reference to the Kerala Solid Waste Management Policy, 2018, the proportion of non-biodegradable waste was estimated as 12.6%. This proportion was applied between 2005 to 2016, due to unavailability of data in the said period.
- The proportion of waste going to the dumpsite for the period 2017 to 2021 was applied as Zero, as per inputs from Kerala State Pollution Control Board.

3. Degradable Organic Carbon (DOC) :

Aggregate Degradable Organic Carbon (DOC) was calculated based on the shares of degradable fraction in Waste Composition (Compostable, Paper and Rags) and Default DOC content values as per 2006 IPCC Guidelines (as seen in Table 73).

[27] Suchitwa Mission (2020) Introduction And Strategic Environmental Assessment of Waste Management Sector In Kerala (Volume I)

- The Aggregate Degradable Organic Carbon (DOC) value for year 1971 was estimated using the National-level share of degradable fraction in Waste Composition (Compostable, Paper and Rags) and was applied for years between 1951 to 1994.
- The shares of degradable organic fraction in Waste Composition (Compostable, Paper and Rags) data for years 1995 and 2005 were taken from GHGPI Phase III. The calculated Aggregate Degradable Organic Carbon (DOC) value for 1995 and 2005 was applied for years 1995 to 2004 and 2005 to 2021 respectively.

Table 73: Default Degradable Organic Content (DOC) Values in Wet Waste[28]

Component	Default DOC Content values (in percentage)
Compostable Matter	15
Rags	24
Paper	40

Source: IPCC, 2006
(Volume 5, Chapter 2-Waste Generation, Composition, and Management Data, Table 2.4)

Table 74: Degradable Organic Carbon values estimated based on reported Waste composition

Reported Year	Waste Composition (in %)			Aggregate DOC Value *(in fraction)*	Applicable Years
	Compostable	Paper	Rags		
1971	41.24	4.14	3.83	0.088	1954-1994
1995	41.8	5.78	3.5	0.094	1995-2004
2005	65.15	16.86	5.87	0.129	2005-2021

4. <u>DDOC decomposed in year T</u> ($DDOC_{m,decompT}$)

The $DDOC_m$ (i.e. the Decomposable Degradable Organic Carbon) decomposed in the year T ($DDOC_{m,decompT}$) depends on the $DDOC_m$ deposited in the year T ($DDOC_{mdT}$), the $DDOC_m$ accumulated at the end of year T ($DDOC_{maT}$), and the DDOC accumulated at the end of the previous year (T-1) ($DDOC_{maT-1}$). It is assumed the DDOC accumulated in the initial year of the 50-year time period considered under the FOD model (i.e. 1954) is zero. Using the values estimated for DDOC deposited and DDOC accumulated, the $DDOC_m$ decomposed is

[28] As per 2006 IPCC Guidelines, Volume 5, Chapter 2 -Waste Generation, Composition, and Management Data, Table 2.4

Available at https://www.ipcc-nggip.iges.or.jp/public/2006gl/pdf/5_Volume5/V5_2_Ch2_Waste_Data.pdf calculated for all the 50-year period from 1954-2004 and subsequently is used to estimate CH_4 emissions from 2005-2021 (GHGPI Phase III)[29].

Limitations:

a. The per capita waste generation of Kerala data was available only for the years 2001,2006 and 2020.
b. The Aggregate Degradable Organic Carbon (DOC) was estimated using 2006 IPCC Guideline's default Degradable Organic Carbon (DOC) values,since state specific DOC values were not available.

4D1 Domestic Wastewater Treatment and Discharge

Category Description

Wastewater can be a source of methane (CH_4) when treated or disposed of anaerobically. The breakdown of protein in domestic wastewater can also be a source of nitrous oxide (N_2O) emissions. Carbon dioxide (CO_2) emissions from wastewater are not considered in the IPCC Guidelines because these are of biogenic origin and should not be included in national total emissions.[30]

Methodology

The table 75 below details the sources of activity data used for estimating emissions from the Domestic Wastewater category

Table 75: Source of activity data used for estimating emissions from Domestic Wastewater category

Activity data	Source
State population	Vital Statistics Division, Department of Economics and Statistics, Government of Kerala, Annual Vital Statistics Reports (2005-2021)
Fractions of urban and rural population	Vital Statistics Division, Department of Economics and Statistics, Government of Kerala, Annual Vital Statistics Reports (2005-2021)

[29] Kolsepatil, N., Anandhan, S., Sekhar, A., Chaturvedula, S. (2019). Greenhouse Gases Emissions of India (subnational estimates): Waste Sector (2005-2015 series) dated September 25, 2019, Retrieved from: http://www.ghgplatform-india.org/waste-sector

[30] Because the methodology is on a per person basis, emissions from commercial wastewater are estimated as part of domestic wastewater. To avoid confusion, the term municipal wastewater is not used in this text. Municipal wastewater is a mix of household, commercial and non-hazardous industrial wastewater, treated at wastewater treatment plants.

Activity data	Source
Urban degree of utilization	NSS Division, Department of Economics & Statistics, Government of Kerala. Report on NSS Socio Economic Survey Report on NSS Socio economic Survey 65th Round: Housing Conditions and amenities in Kerala 2008-2009 Report on NSS Socio economic Survey 76th Round: Drinking water, sanitation and Housing Condition in Kerala 2018
STP Status	**Ratio of treatment type (aerobic/anaerobic)** •Central Public Health and Environmental Engineering Organization (CPHEEO),Status of Water Supply, Sanitation and Solid Waste Management in Urban Areas- 1999, . •For the year 2008-09, data taken from Central Pollution Control Board, (2013)- Performance Evaluation of Sewage Treatment Plants Under NRCD- 2013 report of CPCB •Central Pollution Control Board- Inventorization of Sewage Treatment Plants 2015, 2020 and based on expert opinion from Kerala Water Authority (KWA). **% of sewer collected and not treated if any** •Based on expert opinion from Kerala Water Authority (KWA)
Rural degree of Utilization	NSS Division, Department of Economics & Statistics, Government of Kerala. Report on NSS Socio Economic Survey Report on NSS Socio economic Survey 65th Round: Housing Conditions and amenities in Kerala (2008-2009) Report on NSS Socio economic Survey 76th Round: Drinking water, sanitation and Housing Condition in kerala (2018) Percentage of piped sewer system in rural areas from 2005-2021 is considered nil based on expert opinion from Kerala Water Authority.
Protein intake (g/person/day)	National Sample Survey Organization, Ministry of Statistics & Programme Implementation, Government of India, Nutritional intake in India 2004-05, 2009-10, 2011-12
Average per capita BOD	National Environmental Engineering Research Institute (NEERI), 2010: Inventorisation of Methane Emissions from Domestic & Key Industries Wastewater – Indian Network for Climate Change Assessment

The overall methodology followed for domestic wastewater related state-level CH_4 and N_2O emissions estimates are consistent with the IPCC Tier 1 approach. While a majority of the activity data used is state specific, default values of the emission factors as per the 2006 IPCC Guidelines have been used for estimation of CH_4 and N_2O emissions.

Table 76: Type of Emission Factor and Level of Methodological Tier adopted for Domestic Wastewater Treatment and Discharge

IPCC ID	GHG source & sink categories	CH_4		N_2O	
		Method applied	Emission factor	Method applied	Emission factor
4D1	Domestic wastewater treatment and discharge	T1	D	T1	D
T1: Tier 1; D: IPCC Default					

Equation Used:

As per the 2006 IPCC Guidelines, the following equation is used to estimate CH_4 emissions from domestic wastewater treatment and discharge.

$$CH4\ Emissions\ = \left[\sum_{i,j}\left(U_i \bullet\ T_{i,j}\ \bullet\ EF_j\right)\right](TOW\ -\ S) -\ R\ (IPCC\ 2006\ Equation\ 6.1)$$

Where,

CH_4 Emissions = Methane emissions in inventory year, kg CH_4/yr

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

S = organic component removed as sludge in inventory year, kg BOD/yr (default value of 0) (IPCC, 2006)

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

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

i = income group: rural, urban residents for the respective state

j = each treatment/discharge pathway or system

EFj = emission factor, kg CH_4 / kg BOD

R = amount of CH_4 recovered in inventory year, kg CH_4/yr (default value of 0) ((IPCC, 2006)

A key parameter for this source category is the total amount of organically degradable material in the wastewater (TOW). This parameter is a function of human population and Biochemical Oxygen Demand (BOD) content of wastewater generated per person. It is expressed in terms of biochemical oxygen demand (kg BOD/year)[31]. The equation for TOW in domestic wastewater is

[31] Kolsepatil, N., Anandhan, S., Sekhar, A., Chaturvedula, S. (2019). Greenhouse Gases Emissions of India (subnational estimates): Waste Sector (2005-2015 series) dated September 25, 2019, Retrieved from: http://www.ghgplatform-india.org/waste-sector

$$TOW = P \bullet BOD \bullet 0.001 \bullet I \bullet 365$$ *(IPCC 2006 equation 6.3)*

Where,
TOW = total organics in wastewater in inventory year, kg BOD/yr
P = population in inventory year, (person)
BOD = state-specific per capita BOD in inventory year, g/person/day
0.001 = conversion from grams BOD to kg BOD
I = correction factor for additional industrial BOD discharged into sewers
(for collected the default is 1.25, for uncollected the default is 1.00)

The emission factor (see table 77) for a wastewater treatment and discharge pathway and system is a function of the maximum CH_4 producing potential (Bo) and the methane correction factor (MCF) for the wastewater treatment and discharge system. The Bo is the maximum amount of CH_4 that can be produced from a given quantity of organics (as expressed in BOD or COD) in the wastewater. The MCF, on the other hand, reflects the degree to which the methane-producing capacity (Bo) is realized in various types of treatment and discharge systems, serving as an indicator of the system's anaerobic nature[32].

$$EF_j = B_0 \bullet MCF_J$$ *(IPCC 2006 equation 6.2)*

Where:
EF_j = emission factor, kg CH_4/kg BOD
j = each treatment/discharge pathway or system
B_o = maximum CH_4 producing capacity, kg CH_4/kg BOD (Default value 0.6) (IPCC,2006)
MCF_j = methane correction factor (fraction) see table 76.

Table 77: Default MCF values by treatment type and discharge pathway

Type of treatment and discharge pathway or system	**Description**	**MCF**
Untreated system		
Sea, river and lake discharge	Rivers with high organic loadings can turn anaerobic	0.1
Stagnant sewer	Open and warm	0.5
Flowing sewer (open or closed)	Fast moving, clean. (Insignificant amounts of CH_4 from pump stations, etc.)	0
Treated system		

[32] 2006 Intergovernmental Panel on Climate Change (IPCC) Guidelines for National Greenhouse Gas Inventories , Volume 5, Waste, Chapter 6

Type of treatment and discharge pathway or system	Description	MCF
Centralized, aerobic treatment plant	Must be well managed. Some CH_4 can be emitted from settling basins and other pockets	0
Centralized, aerobic treatment plant	Not well managed. Overloaded.	0.3
Anaerobic digester for sludge	CH_4 recovery is not considered here.	0.8
Anaerobic reactor	CH_4 recovery is not considered here.	0.8
Anaerobic shallow lagoon	Depth less than 2 metres, use expert judgment	0.2
Anaerobic deep lagoon	Depth more than 2 metres	0.8
Septic system	Half of BOD settles in anaerobic tank	0.5
Latrine	Dry climate, ground water table lower than latrine, small family (3-5 persons)	0.1
Latrine	Dry climate, ground water table lower than latrine, communal (many users)	0.5
Latrine	Wet climate/flush water use, ground water table higher than latrine	0.7
Latrine	Regular sediment removal for fertilizer	0.1

Source:IPCC 2006 (Vol. 5, Chapter 6; Table 6.3)

In the emission estimates, corresponding default MCF values as per the 2006 IPCC Guidelines (given in table 77) have been used based on the applicable treatment/discharge pathways or systems for urban and rural population.

Table 78: MCF values considered for various treatment types for Urban and Rural Population[33].

Treatment/ discharge pathway or system (j)	Classification of the system (Collected/ Uncollected and Treatment)	Specific Treatment/Discharge pathway or system (j) selected from Table 68	MCFj
Urban population			
Sewer	Collected (Anaerobic treatment)	Anaerobic reactor/Anaerobic digester for sludge	0.80
	Collected (Aerobic treatment)	Centralized, aerobic treatment plant, well managed	0
	Collected (No Treatment)	Stagnant Sewer	0.50
Other	Uncollected (No Treatment)	Sea Lake or river discharge	0.10
None	Uncollected (No Treatment)	Sea Lake or river discharge	0.10
Septic tank	Uncollected (Treatment on-site)	Septic system	0.50
Latrine	Uncollected (Treatment on-site)	Latrine (Dry climate, ground water table lower than latrine, small family (3-5 members))	0.10
Rural population			
Sewer	Collected (treated/untreated)	Flowing sewer (Open/Closed)	0
Other	Uncollected (No Treatment)	Sea Lake or river discharge	0.10
None	Uncollected (No Treatment)	Sea Lake or river discharge	0.10
Septic tank	Uncollected (Treatment on-site)	Septic system	0.50
Latrine	Uncollected (Treatment on-site)	Latrine (Dry climate, ground water table lower than latrine, small family (3-5 members))	0.10

[33] Kolsepatil, N., Anandhan, S., Sekhar, A., Chaturvedula, S. (2019). Greenhouse Gases Emissions of India (subnational estimates): Waste Sector (2005-2015 series) dated September 25, 2019, Retrieved from: http://www.ghgplatform-india.org/waste-sector

Table 79: Methane emission factor used for estimating emissions from domestic wastewater category

Type of latrine	Emission factor (kg CH_4/kg BOD)
Septic tank	0.3
Latrine	0.06
Others & none	0.06
Sewer (collected and aerobic treatment, well managed)	0
Sewer collected and not treated	0.3
Sewer (collected and anaerobic treatment)	0.48

N_2O Emissions from Domestic Wastewater

$$N_2O\ Emissions = N_{EFFLUENT} \bullet EF_{EFFLUENT} \bullet 44/28$$ *(IPCC 2006 equation 6.7)*

Where,

N_2O emissions =N_2O emissions in inventory year, kg N_2O/yr

$N_{EFFLUENT}$ = nitrogen in the effluent discharged to aquatic environments, kg N/yr

$EF_{EFFLUENT}$ = emission factor for N_2O emissions from discharged to wastewater, kg N_2O-N/kg N

The factor 44/28 is used for conversion of kg N_2O-N into kg N_2O

The total nitrogen in the effluent is estimated as follows

$$N_{EFFLUENT} = \left(P \bullet Protein \bullet F_{NPR} \bullet F_{NON-CON} \bullet F_{IND-COM}\right) - N_{SLUDGE}$$

(IPCC 2006 equation 6.8)

Where,

$N_{EFFLUENT}$ = total annual amount of nitrogen in the wastewater effluent, kg N/yr

P = human population

Protein = annual per capita protein consumption, kg/person/yr

F_{NPR} = fraction of nitrogen in protein, kg N/kg protein (default value of 1.1) (IPCC, 2006)

$F_{NON-CON}$ = factor for non-consumed protein added to the wastewater (default value of 1.1) (IPCC, 2006)

$F_{IND-COM}$ = factor for industrial and commercial co-discharged protein into the sewer system, (default value of 1.25) (IPCC, 2006)

N_{SLUDGE} = nitrogen removed with sludge, kg N/yr (default value of 0) (IPCC, 2006)

Table 80: N_20 emission factor used for estimating emissions from domestic wastewater category

Gas	Emission factor (kg N_2O-N/kg N)
N_2O	0.005

Source: IPCC 2006 (Volume 5, Chapter 6)

Assumptions

1. **Fraction of Population in income group i (Ui)**
   Population data from Annual Vital Statistics does not provide information to help estimate the distribution of urban population into two income groups- urban low income and urban high income - as classified in the 2006 IPCC Guidelines. Therefore, the two categories considered in the state emission estimation are solely based on urban/rural population.

2. **BOD**
   Year-wise values of BOD generated per person are not available for the state, hence an average national value for BOD of 40.5 gm/person/day is used across the reporting period. While converting BOD values from daily basis to an annual basis, 365 days have been assumed across all years, including for leap years, in line with the equation for TOW calculation in the 2006 IPCC Guidelines.

3. **Correction factor for additional Industrial BOD discharged into sewers (I)**
   Effluent from industries and commercial establishments is often co-discharged in sewers and mixes with domestic wastewater. This correction factor 'I' accounts for additional BOD from mixing of such industrial and commercial effluent with domestic wastewater. Based on the Second National Communication for India and the 2006 IPCC Guidelines, the default values of 1.25 for 'I' for collected wastewater and 1 for uncollected wastewater respectively are used in this assessment[34].
4. **Per Capita Protein Consumption**
   Updated year-wise values of per capita protein consumption are not available for urban and rural populations. Therefore, the available values based on NSSO surveys in 2004-05, 2009- 10 and 2011-12 are used across the emission reporting period for 2005 to 2008, 2009 to 2010, and 2011 to 2021 respectively. While converting protein consumption values from daily basis to an annual basis, 365 days have been assumed across all years, including for leap years(Kolsepatil et al., 2019)[35].

[34] Kolsepatil, N., Anandhan, S., Sekhar, A., Chaturvedula, S. (2019). Greenhouse Gases Emissions of India (subnational estimates): Waste Sector (2005-2015 series) dated September 25, 2019, Retrieved from: http://www.ghgplatform-india.org/waste-sector

[35] Ibid.

5. **Degree of Utilization of treatment/discharge pathway or system j, for each income group fraction i (Ti,j)**
The degree of utilization expresses the contribution or share (in terms of a fraction) of each discharge system in the treatment of all the wastewater generated by each income group viz., Rural and Urban. This is a key parameter since this relates to the proportion of the resident population using different wastewater treatment/discharge pathways or systems. Each of treatment/discharge pathways or systems will have different CH_4 emission factors (based on IPCC defined MCF values as listed in table 77; thereby having a varying contribution to the GHG emissions. The treatment/discharge pathways or systems are broadly classified by the 2006 IPCC Guidelines into collected systems (i.e. wherein wastewater is conveyed using a sewer network) and uncollected systems (wastewater not conveyed using a sewer network). The degree of utilization values considered for urban and rural domestic wastewater in this assessment, based on NSS Socio economic surveys are listed in table 81.

Table 81 : Urban and rural degree of utilization

Population Group	Treatment type/discharge type	Share of population using treatment/ Discharge pathway or system (2008-09)	Share of population using treatment/ Discharge pathway or system (2018)
Urban	Septic tank	51.213%	29.80%
	Pit latrine	45.90%	68.80%
	Sewer	0.687%	0.40%
	Others/None	2.30%	1.00%
Rural	Septic tank	21.9%	15.30%
	Pit latrine	76.48%	83.50%
	Sewer	0.0%	0.0%
	Others/None	1.60%	1.20%

- The treatment/discharge type across urban and rural population groups were obtained from the NSS Socio Economic Survey 2008-09 and 2018.
- The corresponding degree of utilization estimated for the urban and rural population based on the 2008-09 survey is assumed to be applicable for the period 2005-2014, and the survey results of 2018 was applied for the period 2015-2021, based on expert inputs.
- The change in latrine type-wise shares between 2005 and 2015 was applied incrementally by using CAGR.

- The categories mentioned in NSS Socio Economic Survey-Housing Condition and Amenities in Kerala 2008-09 *(Table 10 -Appendix A)* are service latrine, pit latrine, septic tank/flush, not known, others,n.r. They have been reconciled with NSS 2018 categories (see table 82) based on inputs from sector experts from Suchitwa Mission and Directorate of Environment and Climate Change (DoECC), Kerala.

Table 82:Latrine System Categories

Categorisation followed in GHG inventory	NSS 2018 categories
Piped sewer system	Flush/pour-flush to piped sewer system
Septic tank	Flush/pour-flush to septic tank
Other system	Flush/pour-flush to twin leach pit/single pit Flush/pour-flush to elsewhere
Pit latrine	Ventilated improved pit latrine
	Pit latrine with slab
	Pit latrine without slab/open pit
	Flush/pour-flush to single pit
	Composting latrine (0 for both urban and rural)
	Others
	Not used (0 for both urban and rural)

Rural degree of utilization

1. The percentage of piped sewer system in rural for 2008-09 and 2018 is considered zero based on expert opinion from Kerala Water Authority. The percentage of piped sewer system (rural) which is considered as zero is incorporated into 'others' and 'none' categories.
2. In order to get the percentage of septic tank for 2008-09 the corresponding proportions from NSS 2018 has been applied to septic tank/flush % of NSS 2008-09 data.
3. Others and none category constitute**:**

   In NSS 2008-09: service latrine, others, not known

   In NSS 2018: Others, Flush/pour-flush to twin leach pit/single pit, Flush/pour-flush to elsewhere, piped sewer system (only for rural).

Urban degree of utilization

1. In order to get the percentage of piped sewer system and septic tank for 2008-09 the corresponding proportions from NSS 2018 has been applied to septic tank/flush % of NSS 2008-09 data.
2. Others and none category constitute**:**

   In NSS 2008-09: service latrine, others, not known

   In NSS 2018: Others, Flush/pour-flush to twin leach pit/single pit, Flush/pour-flush to elsewhere, piped sewer system (only for rural).

6. Further Assessment of Degree of Utilization for 'Sewer' to account for Untreated Wastewater and Type of Treatment (Aerobic/Anaerobic):

Regarding the urban households that are served by the 'piped sewer system' category, it is necessary to further assess the proportion of wastewater discharged by this subset undergoing aerobic/anaerobic treatment or whether discharged without any treatment. This is because the quantum of CH_4 emission generated will vary for each of these discharge pathways, given that the corresponding MCF value is different for each pathway (see Table 78). Therefore, reported data on operational and non operational capacity of sewage treatment, the treatment technologies used in STPs has been analyzed for the state and subsequently the fractions for degree of utilization for 'sewer systems' have been further split up into three pathways

- Sewer - collected and not treated
- Sewer - collected and anaerobic treatment
- Sewer - collected and aerobic treatment

State information related to STPs is not available for all the years from 2005-2021. Therefore, reported state information on STPs that is available for the four years from CPCB and Central Public Health and Environmental Engineering Organization (CPHEEO) of 1999, 2008, 2014 and 2020 has been used in the assessment. All the sewage treatment plants in Kerala are aerobic and well managed and hence, the 'sewer collected and not treated' percentage will be zero (expert opinion from Kerala Water Authority).

- 1999 STP data is used to find GHG emissions from Sewer until 2007
- 2008 STP data is used to find GHG emissions from Sewer until 2010
- 2014 STP data is used to find GHG emissions from Sewer from 2011 to 2015
- 2020 STP data is used to find GHG emissions from sewers from 2016 to 2021

The degree of utilization for the three sewer pathways – sewer (collected and not treated), sewer (collected and anaerobic treatment), and sewer (collected and aerobic treatment) considered in the emission estimates is as follows:

Table 83: **Degree of Utilization for 'Sewer' to account for Untreated Wastewater and Type of Treatment (Aerobic/Anaerobic)**

	1999	2008-09	2014-15	2020
Treatment type, Aerobic (%)	100%	100%	100%	100%
Treatment type, Anaerobic (%)	0.00%	0.00%	0.00%	0.00%
Sewer collected and not treated* (%)	0.00%	0.00%	0.0%	0.0%

4D2: Industrial Wastewater Treatment and Discharge

Category Description

CH_4 is emitted from industrial wastewater when it is treated or disposed of anaerobically. Wastewater from industrial sources may be treated on-site, transferred through a sewer to a centralized treatment plant or disposed off untreated in nearby areas or via an outfall[36].

The scope of the GHG emissions estimation is limited to only those industry sectors which have substantial generation of wastewater containing organic matter, thereby leading to release of GHG emissions from treatment and/or discharge of such organic wastewater. Nine industry sectors have been included for estimating CH_4 from industrial wastewater based on a list of products identified in India's National Communications/ 2006 IPCC guidelines for National GHG inventories.[37] The product categories for the 9 industry sectors included in the estimates are listed in the table below.

[36] 2006 Intergovernmental Panel on Climate Change (IPCC) Guidelines for National Greenhouse Gas Inventories , Volume 5, Waste, Chapter 6

[37] This list was further refined based on GHGPI phase 4 methodology for the waste sector as well as inputs from the line departments concerned in Kerala.

Table 84 : Industrial Sectors and products considered[38]

Iron and steel	Production of Pig Iron, Sponge Iron and Finished steel (alloy & Non-alloy)
Fertilizer	Production of Nitrogenous and Phosphatic Fertilizers (finished product for sale)
Meat	Finished Meat production from all the registered Slaughterhouses
Paper and Pulp	Production of paper from all pulp and paper industries
Petroleum	Refining and production of Petroleum, Oil and Lubricants
Rubber	Production of Finished Natural and Synthetic Rubber
Dairy	Production of milk in the Dairy Sector
Tannery	Production of Raw Bovine, Sheep, lamb, Goat and kid skins and hides
Fish processing	Preservation and processing of different types of fish in processing facilities

Assessment of CH_4 generation potential from industrial wastewater streams is based on the concentration of degradable organic matter in the wastewater, the volume of wastewater generated, and the type of prevalent wastewater treatment systems used by the respective industrial sector[39].

Methodology

The table 85 below details the sources of activity data used for estimating emissions from the Industrial Wastewater category.The production data (2019, 2020, 2021) used in estimating emissions from the industrial wastewater category are listed in table 86.

[38] Kolsepatil, N., Anandhan, S., Sekhar, A., Chaturvedula, S. (2019). Greenhouse Gases Emissions of India (subnational estimates): Waste Sector (2005-2015 series) dated September 25, 2019, Retrieved from: http://www.ghgplatform-india.org/waste-sector

[39] Kolsepatil, N., Anandhan, S., Sekhar, A., Chaturvedula, S. (2019). Greenhouse Gases Emissions of India (subnational estimates): Waste Sector (2005-2015 series) dated September 25, 2019, Retrieved from: http://www.ghgplatform-india.org/waste-sector

Table 85: Source of activity data[40] used for estimating emissions from Industrial Wastewater category

Category	Source of production data	Effluent generation data
Fertilizer	The Fertilisers and Chemicals Travancore Limited Annual Reports 2005-06 to 2014-15, 2015-16, 2016-17, 2017-18, 2018-19, 2019-20, 2020-21, 2021-22, Kolsepatil et al. (2019) author's analysis for 2004-05	Dossier for sewage/trade effluent generation/coastal discharge/STP/ETP details in the State of Kerala, KSPCB (As of 2020) Annexure 2:Consented effluent generating and sewage & sullage generating units with their quantity.
Petroleum	Petroleum Planning & Analysis Cell (PPAC), Ministry of Petroleum & Natural Gas (2004-05 to 2008-09), Bharat Petroleum Kochi Refinery Performance, (2009-10 to 2021-22)	
Dairy	KSPCB	
Meat	KSPCB	
Fish processing	KSPCB	
Paper and pulp	KSPCB	
Tannery	KSPCB	
Rubber	GHGPI Phase III	NATCOM 2

40 Activity data provided in financial year (FY) format was converted to calendar year (CY) format using the following equations:

$$\text{CY Activity data} = [\tfrac{1}{4} * \text{FY Activity Data}_{\text{Preceding year}}] + [\tfrac{3}{4} * \text{FY Activity Data}_{\text{Succeeding year}}]$$

Table 86 : Activity data used in Industrial Wastewater category in 2019, 2020 and 2021.

Category	Industry Production (Mt)		
	2019	2020	2021
Fertilizer	0.36	0.39	0.37
Petroleum	15.45	13.34	13.92
Dairy	3.25	3.25	3.25
Meat	0.023	0.023	0.023
Fish processing	0.33	0.33	0.33
Paper and pulp	0.21	0.21	0.21
Tannery	0.005	0.005	0.005

Table 87: Type of Emission Factor and Level of Methodological Tiers adopted for Industrial Wastewater category

IPCC ID	GHG source and sink categories	CH_4	
		Method Applied	Emission Factor
4A	Industrial wastewater Treatment and Discharge	T2	CS
T1: Tier 1; T2: Tier 2; CS: Country-specific; D: IPCC Default			

Equation Used

As per the 2006 IPCC Guidelines, the following equation is used to estimate CH_4 emissions from industrial wastewater treatment.

$$CH_4\,Emissions = \sum_i \left[\left(TOW_i - S_i \right) EF_i - R_i \right]$$ *(IPCC 2006 Equation 6.4)*

Where

TOW_i = state-wise total organically degradable material in wastewater from industry i in inventory year, kg COD/yr

i = industrial sector

S_i= organic component removed as sludge in inventory year, kg COD/yr (Default value 0.35) (IPCC, 2006)

EF_i= emission factor for industry i,kg CH4/kg COD for treatment/discharge pathway or system(s) used in inventory year

R_i = amount of CH_4 recovered in inventory year, kg CH4/yr (0)(IPCC 2006)

$$TOW_i = P_i \bullet W_i \bullet COD_i \text{ (IPCC 2006 Equation 6.6)}$$

Where:

TOW_i = total organically degradable material in wastewater for industry i, kg COD/yr

i = industrial sector

P_i = state-wise total industrial product for industrial sector i, t/yr

W_i= wastewater generated, m^3/t product

COD_i= chemical oxygen demand, kg COD/m^3

Wastewater generated per tonne of product (W_i) from effluent generation data provided by KSPCB

1) Wastewater generated per tonne of product Wi (m^3/tonne product)

   = [(Effluent generated per day/ 1000) / (Industrial production per day)]

2) Effluent generated per day (litres/day)

   = Effluent generated given in million litres per day (MLD) * 10^6

3) Industrial production per day (tonnes/day)= Total industrial production for the year 2020 / 365

$$EF_j = B_o \bullet MCF_j \qquad \text{(IPCC 2006 Equation 6.5)}$$

Where

EF_j = emission factor for each treatment/discharge pathway or system used by the industry, kg CH_4/kg COD

j = each treatment/discharge pathway or system

Bo = maximum CH_4 producing capacity, kg CH_4/kg COD (0.2594) (MoEFCC 2023)

MCF_j = methane correction factor (fraction)

The value of the MCF is based on the prevalent wastewater treatment system used in the respective industrial sector. The data sources to identify the prevalent wastewater treatment technologies for the industrial sectors are indicated in Table 88 . State-level information for the emission factor related parameters is not available. Therefore, the national level values listed for each industry sector are used in the emission estimation for the state.

Table 88: COD and MCF used for estimating emissions from Industrial Wastewater category

Industry	Category	Factor	Source
Petroleum	CODi	1 Kg COD/m^3	BUR 3
	MCF	0.3	BUR 3

Industry	Category	Factor	Source
Dairy	CODi	2.24 Kg COD/m^3	BUR 3
	MCF	0.5	BUR 3
Rubber	CODi	6.12 Kg COD/m^3	NEERI (2010): Status of Methane Emissions from Wastewater and Role of Clean Development Mechanisms in India. Published in TERI Information Digest on Energy and Environment, [S.l.], p. 155-166, jun. 2010. ISSN 0972- 6721.
	MCF	0	GHGPI Phase III, ICLEI analysis of ●Central Pollution Control Board (CPCB), Pollution Control Implementation Division – III report on 'Pollution Control in Natural Rubber Processing Industry'. ● Woodard, F. (2001) Woodard, F. (2001). Industrial waste treatment handbook.
Tannery	CODi	5.9 Kg COD/m^3	BUR 3
	MCF	0.8	BUR 3
Meat	CODi	5 Kg COD/m^3	BUR 2
	MCF	0.8	IPCC 2006
Pulp and paper	CODi	5.9 Kg COD/m^3	BUR 3
	MCF	0.8	BUR 3
Fish processing	CODi	2.5 Kg COD/m^3	BUR 3

Industry	Category	Factor	Source
	MCF	0.3	BUR 3
Fertilizers	CODi	3 Kg COD/m^3	BUR 3
	MCF	0.3	BUR 3
Iron and steel	CODi	0.55	NEERI (2010): Status of Methane Emissions from Wastewater and Role of Clean 152 Kerala GHG Inventory Report Development Mechanisms in India. Published in the TERI Information Digest on Energy and Environment, [S.l.], p. 155-166, June. 2010. ISSN 0972- 6721.
	MCF	0	GHGPI Phase III, ICLEI analysis of Sirajuddin, Ahmed, Umesh Chandra, R. K. Rathi, (2010) "Wastewater treatment technologies Commonly practiced in Major Steel Industries of India" In 16th Annual International Sustainable Development Research Conference 2010, 30 May – 1 June, 2010 The University of Hong Kong, Hong Kong.

Methane Recovery Rates

CH_4 is recovered in some of the industries such as dairy for energy purposes. In such cases, the methane recovered is to be subtracted from the total CH_4 estimated to be emitted from wastewater treatment in these industries. Since state-level information on methane recovery rates is not available, national-level values from NATCOM 2 have been used for the state[41].

Dairy: 75% methane recovery rate

[41] Kolsepatil, N., Anandhan, S., Sekhar, A., Chaturvedula, S. (2019). Greenhouse Gases Emissions of India (subnational estimates): Waste Sector (2005-2015 series) dated September 25, 2019, Retrieved from: http://www.ghgplatform-india.org/waste-sector

Assumptions

- As per expert opinion from KPSCB, the installed capacity itself was taken as the average production quantity where average production data was not available.
- Except for petroleum and fertilizer, active years of production for the industrial units were not available. Hence the average production and effluent generated data provided by KSPCB was applied for the entire evaluation period (2005-2021).
- Wastewater generation per tonne of product would likely vary over the years, with improvements in production processes and technologies leading to a reduction in wastewater generation. However, due to the lack of such updated information, the constant values of wastewater generated per tonne of product have been used for all the years (2005-2021) in this assessment for the industry sectors. Wastewater generated per tonne of product (see table 89) is calculated using the 2020 production data in order to have the data almost in-sync with the effluent generated data in the most recent dossier released by Kerala State Pollution Control Board[42].
- State data on production of Petroleum is not available for 2004-05 to 2008-09. Reported data on the 'volume of crude oil processed' is available for different refineries along with their location for the period 2004-05 to 2008-09. National level data available on cumulative production of Petroleum products for 2004-05 to 2008-09 has been apportioned to the state based on the corresponding proportion of 'volume of crude oil processed' by each refinery to the 'total volume of Crude Oil processed' by all refineries[43].

Table 89: Wastewater generated per tonne of product

Category	Wastewater generated (m^3) per tonne of product
Fertilizer	18.7
Petroleum	0.72
Dairy	0.29
Meat	0.028
Fish processing	1.68
Paper and pulp	4.09
Tannery	2.52

[42] Dossier for sewage/trade effluent generation/coastal discharge/STP/ETP details in the state of Kerala, KSPCB (As on 2020), Annexure 2:Consented effluent generating and sewage & sullage generating units with its quantity

[43] Kolsepatil, N., Anandhan, S., Sekhar, A., Chaturvedula, S. (2019). Greenhouse Gases Emissions of India (subnational estimates): Waste Sector (2005-2015 series) dated September 25, 2019, Retrieved from: http://www.ghgplatform-india.org/waste-sector

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Annexure 2-Inventory Network

Inventory Network			
Sl. No.	Name	Designation	Department/Authority/Institution
1	Prof V K Damodaran	Former Director	EMC
2	Dr T Elangovan	Former Director	NATPAC
3	Rajani T S	Assistant Director	Agriculture
4	Dr Sanjay	Disease Investigation Officer, State institute for animal disease, Palode	Animal Husbandry Department
5	Anand G	Senior Manager	BPCL
6	Raghavan Nair Reghukumar	Chairperson	BSI
7	Dr V Beena	Professor and Implementing Officer	CAADECCS, KVASU
8	Dr Dileep Kumar	Programme Director	CED, INDIA
9	Dr Dhanya Nambiar	Director	CEED
10	Renjith V	Project Manager, CKCL	Clean Kerala Company
11	Remya Sudhy G	Finance Manager	Clean Kerala Company
12	Dr Manoj P Samuel	Executive Director	CWRDM
13	Dr Sruthi K V	Scientist B	CWRDM
14	Dr Surendran U	Scientist	CWRDM
15	Vijayasree S B	Assistant Director	Directorate of Agriculture Development and Farmer's Welfare
16	Dr Nishanth	RA, IAH&VB, Palode	Directorate of Animal Husbandry
17	Baby Sindhu	Statistical Assistant Gr-II	Directorate of Economics and Statistics, Govt. of Kerala (ASI)
18	R Sudharsa	Joint Director	Directorate of Economics and Statistics, Govt. of Kerala (IIP)
19	Beena R	Research Associate	Directorate of Economics and Statistics (ASI), Govt of Kerala (IIP)

Inventory Network			
Sl. No.	Name	Designation	Department/Authority/Institution
20	Sri Ramesh Chandran R	Inspector of Factories & boilers	Directorate of Factories & Boilers
21	Jose Thomas	Assistant Director	Directorate of Industries and Commerce
22	Roy Simon	Asst District Industries Officer	Directorate of Industries and Commerce
23	Shajikumar T	Geologist	Directorate of Mining & Geology
24	Deepa S	Assistant Director	Directorate of Soil Survey & Soil Conservation
25	Nousher Khan	DDF(M)	Directories of Fisheries
26	Lathakumari C S	Additional Director	Economics and Statistics
27	Sumi A D	Assistant Director	Economics and Statistics
28	Sarath Krishnan S	Energy Technologist	EMC Kerala
29	Shri Johnson Daniel	Head, NMEEE	Energy Management Centre
30	Shabujan T K	Joint Director	Factories & Boilers Department
31	Vivek J M	Technical Expert	GIZ
32	Sukesh A	Assistant Professor	Government Engineering College, Kannur
33	Salma Nazreen		Haritha Keralam Mission
34	Sanjeev S U	Assistant Co-ordinator	Haritha Keralam Mission
35	D S Pai	Director	ICCS
36	Dr T V Ramachandra	Chairperson	IISC, Bangalore
37	Dr Yogesh Tiwari	Chairperson	IITM, Pune
38	Viswanath	GM & Unit Head	IREL, Kollam
39	Dr Roy Stephen	Professor of Plant Physiology	KAU
40	Dr Jacob John	Professor, IFSRS	KAU

Inventory Network			
Sl. No.	Name	Designation	Department/Authority/Institution
42	Dr Meera A V	Assistant Professor, IFSRS	KAU
43	Dr P O Nameer	Dean, College of Climate Change and Environmental Science	KAU
44	Samuel Vanlalngheta Pachuau IFS	Conservator of Forest	Kerala Forest Department
45	Rajesh Ravindran	Additional, PCCF	Kerala Forest Department
46	John Christopher	Port Conservator	Kerala Maritime Board
47	Indu Isaac	SWM Consultant	Kerala Solid Waste Management Project
48	Dr Kannan N	Environment Expert	Kerala Solid Waste Management Project
49	Dr Vimal Kumar C S	Principal Scientific Officer	Kerala State Biodiversity Board
50	Dr C S Vimal Kumar	Principal Scientific Officer	Kerala State Biodiversity Board
51	Sajeev R S	Deputy Director	Kerala State Land Use Board
52	Arunjith P	Soil Specialist	Kerala State Land Use Board
53	Alexander George	Senior Environmental Engineer	Kerala State Pollution Control Board
54	Dr Suresh Francis	Scientist	Kerala State Remote Sensing and Environment Centre
55	Dr Sandeep S	Principal Scientist, Department of Soil Science	KFRI
56	Dr K A Sreejith	Principal Scientist, Department of Forest Ecology and Biodiversity Conservation	KFRI
57	Dr Shrikant Badole	Scientist B, Department of Soil Science	KFRI
58	Dr Rajkumar		KILA
59	Jeeva Anand	Special Officer	KINFRA
60	Anilkumar B	Manager	KINFRA
61	Antony Edward	Manager (Environmental)	KMML
62	James Wilson	Executive Engineer	KSEB
63	Vinod Jacob	Executive Engineer (PED)	KSEB
64	Sajin Ismail	Asst Engineer	KSEB

Inventory Network			
Sl. No.	Name	Designation	Department/Authority/Institution
65	Rahul Jagadish	Investor Facilitator	KSIDC
66	Liju John	Business Development Executive	KSIDC
67	Mayma Joseph	Asst Environmental Engineer	KSPCB
68	Smt Bindhu Radhakrishnan	Chief Environmental Engineer	KSPCB
69	Vinod Kumar K M	Asst Works Manager	KSRTC
70	Boby George	Depot Engineer	KSRTC
71	Sreekanth A S	Programme Officer	Kudumbasree
72	Dr. Shijo Joseph	Asst Professor	KUFOS
73	Denzil Fernandez	Deputy town Planner	LSGD (Planning)
74	Dr Ummuselma	Joint Director	LSGD (Principal Directorate)
75	Josnamol	Joint Director	LSGD (Principal Directorate)
76	Muhammed Huwaiz M	Joint Director & DD SWAG Principal Directorate, LSGD	LSGD (Urban)
77	Unnikrishnan G	AMVI	MVD, Transport Commissionerate
78	Dr Salini U	Scientist	NATPAC
79	Veena K S	Scientist, Library and Information Science	NATPAC
80	Jegan Bharath Kumar A	Scientist	NATPAC
81	Ebin Sam	Scientist	NATPAC
82	Dr James Jacob	Managing Director	Plantation Corporation of Kerala
83	Shivji K S	Environmental engineer	PWD
84	Dr Jessy M D		Rubber Research Institute of India
85	Smt Priya V P	District Soil Conservation Officer, TVM	Soil Conservation Department
86	Jayakrishnan R S	CHI/ENHM/HQ/TVC	Southern Railway, Trivandrum Division
87	Simi		State Landuse Board
88	Dr Reji D Nair	Research officer	State Planning Board
89	Reji D Nair	Research Officer	State Planning Board

Inventory Network			
Sl. No.	Name	Designation	Department/Authority/Institution
90	Jyothi S Nair	Administrative Assistant	State Water Transport Department
91	Sri Renju R Pillai		Suchitwa Mission
92	Amjad Anwar	Programme Officer	Sustera
93	Deepa A	Co-founder	Sustera Foundation
94	Dr Junaid Hassan S	Wetland Specialist	SWAK
95	Arunkumar P S	Wetland Analyst	SWAK
96	Lakshmy S	Program Co-ordinator, Research, Climate Action	Thanal
97	Anantha Padmanabhan P S	Research Fellow	Thanal
98	Bindhu	Asst Regional Manager	The Kerala State Civil Supplies Corporation
99	Sri Girish Kumar T K	District Town Planner, Kozhikode	Town and country planning
100	Joe George	Consultant	UNICEF
101	Ranjith Gopalakrishnan		University of Eastern Finland
102	Srinivas Krishnaswamy	CEO	Vasudha Foundation
103	Raman Mehta	Programme Director	Vasudha Foundation
104	Rini Dutt	Associate Director (Climate Policy)	Vasudha Foundation
105	Dr Meera Asmi	Chairwoman	We Grow Forest Foundation
106	Aparna Anand	Managing Trustee	We Grow Forest Foundation
107	Syed Ali	Trustee	We Grow Forest Foundation


APOLLO
DIMORA


ZERO
CARBON
DIMORA


Review Meeting for the GHG Inventory of Kerala State
DIMORA


DIMORA



National Greenhouse Gas Inventorying – General Guidance and Reporting
DIMORA


NOTES

NOTES

DIRECTORATE OF ENVIRONMENT
AND CLIMATE CHANGE

Department of Environment
Government of Kerala

THE DIRECTORATE OF ENVIRONMENT AND CLIMATE CHANGE (DoECC)

The Directorate of Environment and Climate Change (DoECC) under the Environment Department was constituted in December 2010. The Directorate is the nodal agency in the administrative structure of the Environment Department, responsible for planning, promoting, and coordinating the implementation of both Central and State level environmental protection and conservation policies and programs. The Directorate also serves as the nodal agency in formulating climate change-related policies, plans, programmes and their execution. The State Climate Change Cell (CCC) constituted vide G.O. (Rt) No. 27/2018/Envt dated 24-02-2018 in the Directorate coordinates all State-level programs concerning climate change.

VASUDHA
FOUNDATION
Green ways for a good earth!

VASUDHA FOUNDATION

Vasudha Foundation, a non-profit organization set up in 2010, is one of the prominent Think Tanks with the mission to conserve the environment through innovative approaches that can ensure a sustainable and inclusive future for India and Mother Earth with a mission to promote environment-friendly, socially just and sustainable models of energy by focusing on renewable energy and energy-efficient technologies and lifestyle solutions. Vasudha Foundation's approach is largely data-driven analysis, the creation of cross-sectoral data repositories along with strategic outreach to ensure resource conservation with the ultimate objective of conserving Mother Earth. Vasudha Foundation also works to limit global warming emissions by focusing on the highest emitting sectors like energy, transportation as well as industrial processes, the built environment and agriculture.

Vasudha Foundation has engaged actively with various organizations and agencies at both the national level and the State level and has forged many active partnerships. These include NITI Aayog at the national level, as well as with the Department of Environment, Forest and Climate Change, Government of Uttar Pradesh, Uttar Pradesh New and Renewable Energy Development Agency, Government of Uttar Pradesh, the Tamil Nadu Green Climate Company (TNGCC), Govt. of Tamil Nadu, Gujarat Energy Development Agency, Government of Gujarat and Department of Climate Change, Government of Gujarat, The Telangana State Renewable Energy Development Corporation Limited, Department of Finance, Government. of Odisha at the State level, to name a few.

VASUDHA FOUNDATION
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DIRECTORATE OF ENVIRONMENT AND CLIMATE CHANGE

Department of Environment
Government of Kerala