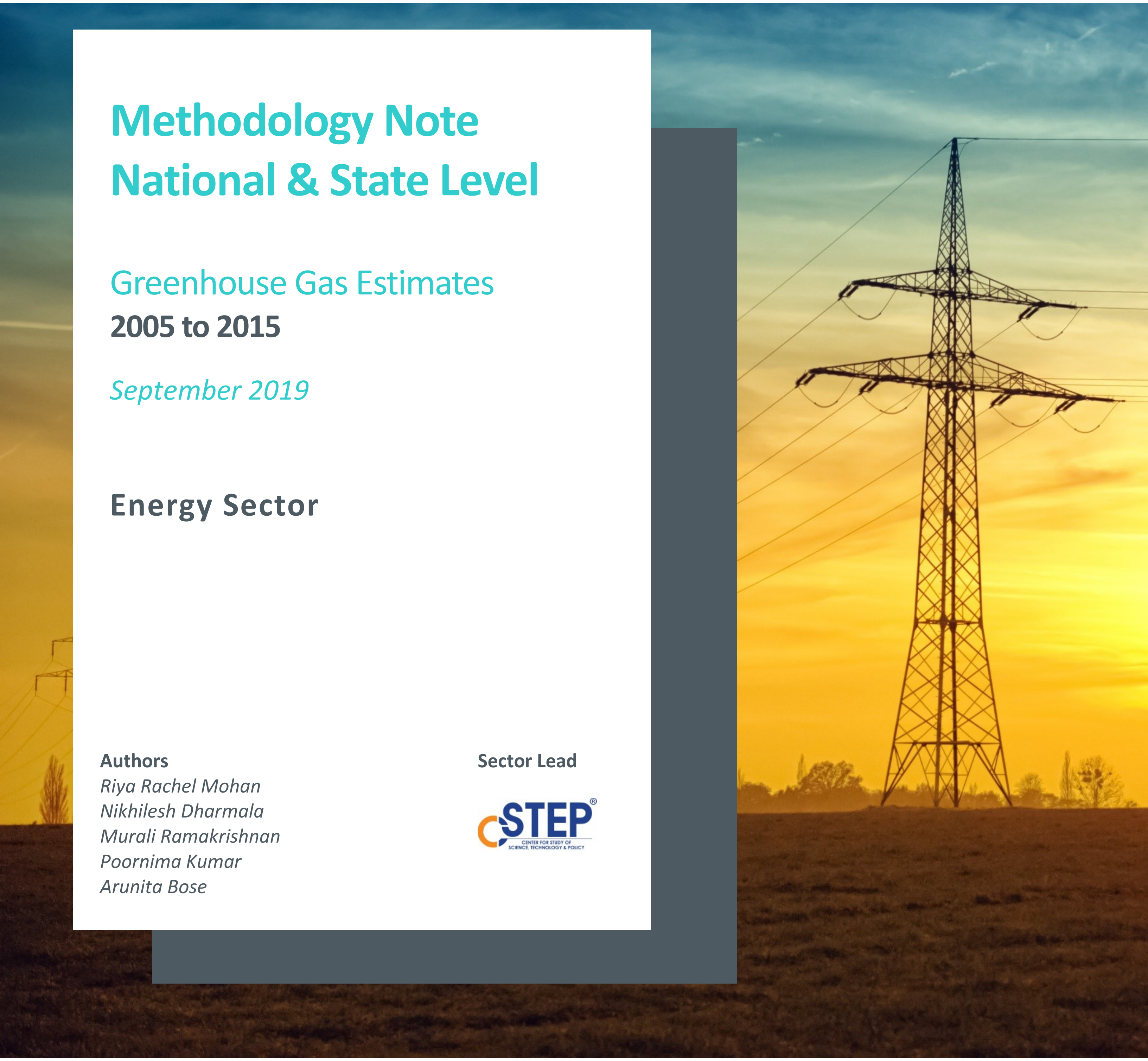

Methodology Note
National & State Level

Greenhouse Gas Estimates
2005 to 2015

September 2019

Energy Sector

Authors
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Sector Lead

An initiative supported by

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Version Information / Revision History

Version	Date	Brief description on changes from previous version
3.0	08 August 2019	This document contains information on assumptions and the methodology followed to estimate emissions from the energy sector at the national level for the extended time period of 2005-15.
2.0	28 Sep 2017	This document contains information on assumptions and the methodology followed to estimate emissions from the energy sector at the national level for the extended time period of 2005-13.
1.0	15 July 2016	This document contains information on assumptions and the methodology followed to estimate emissions from the energy sector at the national level for the time period of 2007-13.

Foreword

On December 2015, the international community took a significant step towards addressing the global challenge of climate change by endorsing the Paris Agreement at the 21st session of the Conference of Parties (COP) to the United Nations Framework Convention on Climate Change. The milestone Paris Agreement will serve as a foundation for concerted international action to address the threat posed by climate change.

It is evident that climate change is not the responsibility of only national governments. It will impact every aspect of society and, therefore, the role of non-state actors is more crucial in these testing times. Non-state actors such as civil society and research organisations can inform and help the national government in devising climate actions and strategies. The first step towards devising a robust climate action plan is creating greenhouse gas (GHG) estimates for all relevant economic sectors for recent years.

With the background described above, a few Indian research organisations came together to form the GHG Platform – India, which is a civil society initiative, providing independent estimation and analysis of India's GHG emissions. The platform has been conceptualized to assist the national government by addressing existing data gaps and data accessibility issues, extending beyond the scope of national inventories, and increasing the volume of analytics and policy dialogue on India's GHG emissions sources, profile, and related policies.

The platform hosted GHG estimates for all key economic sectors for the period of 2005–2013 by estimating carbon dioxide, methane, and nitrous oxide, both at national and state levels. In the present edition, the time-series has been extended and the report now presents GHG estimates for the period 2005–2015, across all key economic sectors. The report also highlights the trend in GHG emissions across the sectors and transparently documents all the assumptions, activity data, and emission factors that were used to arrive at the GHG estimates.

The GHG estimates presented in the report follow methodologies provided in the 2006 Intergovernmental Panel on Climate Change (IPCC) guidelines for the national GHG inventories, and the associated good practice guidance. Further, the report went through a rigorous peer review and independent technical review process to ensure accuracy, transparency, consistency, completeness, and relevance. We hope that the report will be useful to all relevant stakeholders.

Credits

Led and coordinated by

Riya Rachel Mohan
Nikhilesh Dharmala
Murali Ramakrishnan
Poornima Kumar
Arunita Bose

Peer Reviewer

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- Dr Narasimhugari T.L Reddy - *Director of Civil Supplies, Kerala*
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- Mr Vinu Balakrishnan - *GAIL Gas Limited, Karnataka*

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Executive Summary

Key Highlights

- From the energy sector, electricity generation was the largest emitting category in 2005–2015. It accounted for 68.3% of the total emissions from the energy sector (excluding industrial energy use[1]) in 2015, followed by the transport sector (which contributed to 17.8% of emissions).
- Coal (followed by diesel) was the fuel that contributed most to emissions from the energy sector in the 2005–2015 period, contributing to 65% of the emissions in 2015.
- The transport sector has been growing rapidly at a Cumulative Annual Growth Rate (CAGR) of 7.4%, followed by electricity generation at 5.7%, between the years 2005 to 2015.

ES 1. Background information on GHG emission estimates

Fuel combustion and fugitive emissions contributed to GHG emissions in the energy sector. GHG emissions were estimated for three gases: carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O). The carbon dioxide equivalent (CO_2e) emissions for CH_4 and N_2O were calculated based on their global warming potential, as reported in the Intergovernmental Panel for Climate Change's (IPCC) Second Assessment Report (SAR). These are reported in the table below.

Table ES 1: A snapshot of GHG estimates by gases for the energy sector

IPCC ID	Key source category	GHG emissions for 2015			
		Million tCO_2	Million tCH_4	Million tN_2O	Million tCO_2e
1A	Fuel combustion	1346	1.04	0.04	1382
1A1	Energy industry				
1A1a	Main activity electricity and heat production				
1A1ai	Electricity generation	954	0.01	0.01	958
1A3	Transport	245	0.05	0.01	252
1A4	Other sectors	147	0.99	0.01	172
1B	Fugitive emissions	0.0	1.73	0.00	36

ES 2. Summary of GHG sources

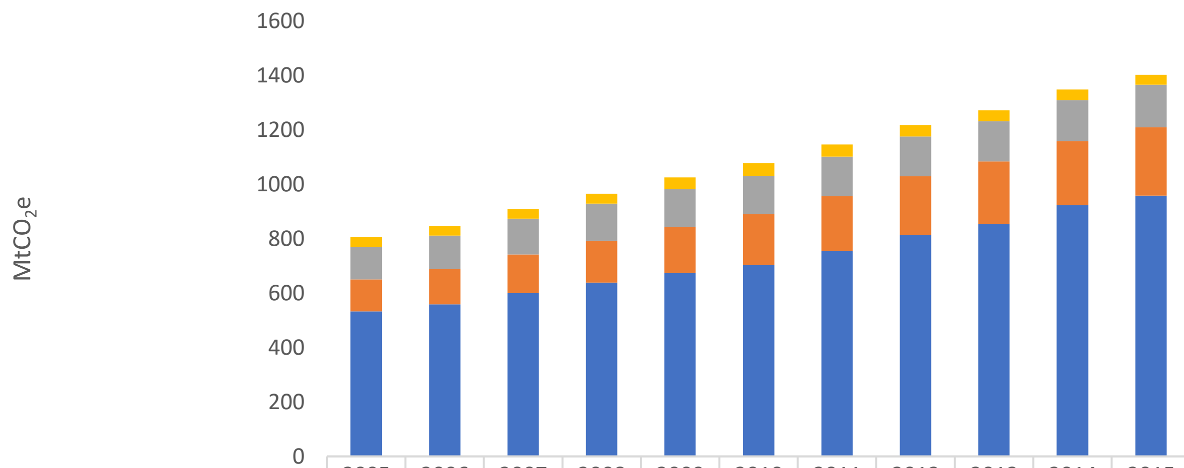
Electricity generation (utilities), transport, other sectors (residential, commercial, agriculture, and fisheries), and fuel production are key source categories that contribute significantly to energy-based GHG emissions. Among the key source categories, electricity generation accounted for the highest share of emissions in both 2005 and 2015. However, emissions increased only marginally (from 66.3% to 68.3%) during this period. This can be attributed to the efforts to decarbonise India's electricity generation sector, through various policy measures such as the National Solar Mission (NSM) and accelerated deployment of new renewable energy capacity. The share of transport-based emissions increased from 14.6% in 2005 to 17.8% in 2015. The emissions share from other sectors (residential, commercial, agriculture/fisheries, etc.) decreased from 14.8% in 2005 to 12.1% in 2015.

---

[1] While IPCC methodology recommends reporting emissions from the industrial energy use in this sector, due to ease of data gathering and reporting, they were reported along with the Industrial Process and Product use (IPPU) emissions.

ES 3. Summary of GHG trends

The emissions from electricity generation grew at a Compound Annual Growth Rate (CAGR) of 5.7%, while the emissions from the transport sector grew at a high CAGR of 7.4%. Between 2005 and 2015, transport emissions were estimated to have more than doubled because of increased transport demand and use of private vehicles. The other sectors grew at a rate of 3.6% per annum between 2005 and 2015. Fugitive emissions (emissions due to fuel production) recorded the lowest growth, of less than 1%. Their share in overall energy emissions declined from 4.4% to 2.6% between 2005 to 2015. We attribute this to the shift from underground mining to open-cast mining, and the production of coal and natural gas, which has increased from 84.9% in 2005 to 92.6% in 2015. The emission intensity of GDP for the energy sector decreased from 14.9 kgCO_2e/1000 INR to 13.6 kgCO_2e/1000 INR between 2005 to 2015. The figure below provides the time-series emission estimates across key source categories in the energy sector.



	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
Fugitive Emissions	35	35	36	37	43	46	45	42	40	38	36
Other Sectors	119	123	131	136	139	141	144	145	147	151	156
Transport	117	130	142	154	169	187	202	216	229	236	251
Public Electricity Generation	534	559	600	639	674	704	755	814	855	923	958

Public Electricity Generation Transport Other Sectors Fugitive Emissions

Figure ES 3: Emissions from Energy Sector

1. Introduction and Background

1.1 Context

The GHG Platform – India, is a collective civil-society initiative providing an independent estimation and analysis of India's greenhouse gas (GHG) emissions across key sectors. The Platform aims to provide continuous time-series estimates for India's GHG emissions. It relies on guidance provided by the 2006 Intergovernmental Panel on Climate Change (IPCC) guidelines for the national GHG inventories[2] for national-level GHG emission estimates and covers the period from 2005 to 2015. The Platform aims to support the existing efforts of the Indian government in activities such as the process of submitting National Communications to the United Nations Framework Convention on Climate Change (UNFCCC). It aims to address existing data gaps and data accessibility issues, extending beyond the scope of national inventories, and increasing the volume of analytics and policy dialogue on India's GHG emissions sources, profile, and related policies. A detailed state-level emission estimates was calculated and aggregated further to estimate the national-level emissions.

1.2 GHG coverage

The GHG emission estimates in this report include emissions from carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O). For the study, we used Global Warming Potential (GWP) values as per IPCC's SAR and Fifth Assessment Report (AR5) (provided in Table 1.2.A). These values were used to convert and report emissions in each sector and sub-sector, in terms of their carbon dioxide equivalent (CO_2e).

Table 1.2.A: Global warming potential as per IPCC assessment reports[3]

Name of the gas	**Formula**	**Global Warming Potential (GWP)**	
		SAR	**AR5**
Carbon dioxide	CO_2	1	1
Methane	CH_4	21	28
Nitrous oxide	N_2O	310	265

1.3 Key economic sectors covered

Emissions in the energy sector are mainly caused by conversion of primary energy sources into useable energy forms in refineries and power plants, transmission and distribution of fuels, and use of fuels in stationary and mobile applications.

The key source categories covered in this study are as follows:

- IA: Fuel combustion activities
    - 1A1- Energy industries
        - 1A1a Main activity electricity and heat production
            - 1A1ai- Electricity generation;
    - 1A3- Transport

[2]As per the Paris Agreement (Article 13 paragraph 7(a)), countries party to the agreement should use the IPCC methodology for preparing their emission estimates.

[3]https://www.ghgprotocol.org/sites/default/files/ghgp/Global-Warming-Potential-Values%20%28Feb%2016%202016%29_1.pdf

        - 1A3a- Civil aviation
            - 1A3aii Domestic aviation,
        - 1A3b- Road transportation (Fuel-based covering sub-sectors 1A3bi to 1A3bvi),
        - 1A3c- Railways
        - IA3d-Water-borne navigation
            - 1A3dii- Domestic water–borne navigation;
    - 1A4- Other sectors
        - 1A4a- Commercial/Institutional
        - 1A4b- Residential
        - 1A4c- Agriculture/Forestry/Fishing/Fish Farms

- 1B: Fugitive emissions from fuels
    - 1B1- Solid fuels
        - 1B1a- Coal mining and handling (All sub-sectors from 1B1ai to 1B1aii)
    - 1B2- Oil and piped natural gas (PNG) (All sub-sectors from 1B2a to 1B2b)

1.4 Boundary of GHG estimates

This study assesses India's GHG emissions. The emission estimates were analysed at the state level and aggregated to the national level. In terms of sectoral boundaries, this particular exercise looks at the energy sector.

1.5 Reporting period

The period covered in this exercise is from 2005–2015. We have considered 2005 as the base year, in accordance with the base year for India's Nationally Determined Contribution (NDC) commitments to the UNFCCC (MoEFCC, 2015).

1.6 Outline of GHG estimates

This exercise entails a time-series emission estimate for sectors mentioned in section 1.3 at the state (sub-national) level, for the period 2005–2015. The estimations were based on literature review and followed the 2006 IPCC Guidelines for National GHG Inventories, and other internationally acceptable guidance. Emissions were estimated based on fuel sources, sub-sectoral activities, and emission factors. Chapter 2 provides the trends in GHG emissions and the key drivers of emission trends in various sectors. Chapter 3 provides the overview of the energy sector, detailed analysis of the sectoral emissions, methodology involved, source of activity data, and emission factors. Chapter 4 broadly compares the emissions estimated for 2007, 2010, and 2014 with the emissions reported by MoEFCC.

1.7 Institutional information

Center for Study of Science, Technology and Policy (CSTEP) is responsible for carrying out the current assignment. The details of the team involved in the emissions estimation work is given below.

Riya Rachel Mohan is a Research Scientist in the climate and energy policy domain. She is the energy sector lead for the GHG Platform - India project. She has been working in the field of energy and emissions-based modelling in CSTEP.

Nikhilesh Dharmala is a researcher who has anchored the transport sector emissions inventory in this exercise. He has varied experience in modelling decarbonisation strategies for transport and industries sectors in India.

Poornima Kumar and Arunita Bose are research analysts and have worked on the emission estimates of other sectors, which include residential, commercial, and agriculture/fisheries. They have been working in the field of climate policy in CSTEP.

Murali Ramakrishnan Ananthakumar, a senior researcher at CSTEP, worked on the emission estimates from electricity generation and fugitive emission estimates in this study. He worked on low-carbon energy policy, climate policy, economic assessment of energy efficiency in industries and energy systems modelling, energy efficiency in industries (especially cement, iron, and steel manufacturing, mobile telecom industry), and operational performance standards and technologies for thermal power plants.

1.8 Data collection process and storage

Reports and datasets for electricity generation and other sectors were obtained in the form of hard and soft copies. Where deemed necessary, the fees paid included transaction fees necessary to obtain data from government agencies.

- CEA's annual All India Energy Statistics reports were purchased for the years 2005-06, 2011-12, 2013-14, 2014-15, and 2015-16, to capture fuel-wise electricity generation in the corresponding years.
- Consumer Expenditure Reports and raw data sets were purchased from the National Sample Survey Office (NSSO), for rounds 61-64, 66, and 68, to estimate specific fuel consumption in the residential sector for certain years.

Details of the purchased data for various sectors are listed in the Table 1.8.A. All data, including purchased data, is archived according to CSTEP's internal data and document management system to facilitate a detailed and transparent review of the inventory process.

Table 1.8.A Sources of purchased data

Sector	Source	Agency	Hard/Soft Copy	Years
Electricity Generation	CEA General Review Book	Central Electricity Authority (CEA)	Hard Copy	2005-06 to 2010-11 and 2012-13 to 2015-16
Residential	Household Consumer Expenditure Survey (62nd, 63rd, 64th Rounds)	National Sample Survey Organization (NSSO)	Soft Copy	2005-06 to 2007-08

Electricity Generation:

Fuel-wise electricity generation data from 2005-06 to 2010-11 and 2012-13 to 2015-16 was obtained from CEA reports for public electricity generation (utilities-based). Emissions from combined Heat and Power Generation (CHP) (1A1ai) are required to be reported under 1A1a Main Activity Electricity and Heat Production, as per the 2006 IPCC Guidelines for National GHG Inventories. Bagasse-based cogeneration (biomass-based CHP), however, is reported by CEA under Renewable Energy Systems. Being a CO_2-neutral source, biomass acts both as a source and as a sink. Therefore, emissions from biomass-based CHP electricity were not considered in this exercise.

Transport Sector:
The 2006 IPCC Guidelines for National GHG Inventories suggest using vehicle-wise activity data to estimate emissions from this sector (1A3). Here, owing to lack of data, an alternative strategy had to be adopted. Fuel consumption data was collected mode-wise (road, rail, air, and water), as reported by the Ministry of Petroleum and Natural Gas (MoPNG). This was validated against reports published by the Ministry of Civil Aviation and no deviations were observed through this method.

Other Sectors:
Data on energy consumption at the household level and at commercial/institutional establishments is required to calculate emissions from these sectors. NSSO data sets were used to determine household fuel consumption. These data sets provide data across urban and rural households. The MoPNG's Statistics Handbook, which has been used to collate activity data for the commercial sector, provides details on the quantity of fuel consumed by the residential sector too.

Energy consumption in the agriculture sector is categorised into stationary combustion (IA4ci) of diesel for pumping, and mobile combustion (IA4Cii) of diesel, in farm mechanisation. Diesel, consumed by pump sets and tractors, has been taken into account for this sector as well. Emissions from the fisheries sector are accounted for by diesel and kerosene consumption, by fishing fleets.

Fugitive Emissions:
Fuel production (IB) estimates include production data for coal, oil, and PNG. These estimates were obtained from reports published by the Ministry of Coal (MoC) and MoPNG. Underground coal production data with degree of gassiness was unavailable.

1.9 Quality Control (QC) and Quality Assurance (QA)

Quality Control (QC):
A system consisting of routine technical activities was put in place to ensure that the inventory was of good quality. To ensure data integrity, correctness, and completeness, periodic checks were conducted during the inventory preparation process. These checks were applied irrespective of the type of data used to develop the emissions inventory, and helped identify and address errors and omissions.

The following procedures were adopted for quality control:

- Ensuring that units were labelled correctly in calculation sheets
- Ensuring that units were consistent throughout calculations
- Ensuring consistency in data between key source categories and sub-categories
- Two-level manual validation for data available in paper format only
- Ensuring that all calculations and estimations are explained in this document
- Confirming that bibliographical references were properly cited using Zotero

Quality Assurance (QA)
CSTEP has an independent and objective review process in place, to ensure that the inventory is of good quality and to eliminate any inherent bias in the inventory. This process comprises two layers, including a technical and editorial review, which supplements an external peer review and independent audits.

The technical review or internal-expert peer review consists of an independent review of assumptions, calculations and/or documentation by a group of knowledgeable experts in the technical field. The process includes periodic reviews of the methodology of the inventory process, along with corresponding documentation and calculations. The reviews ensure that the methodology and assumptions used in the study are reasonable, as judged by the expert group, but does not certify the data or references.

1.10 General assessment of completeness

As mentioned in section 1.2, three greenhouse gases (CO_2, CH_4, and NO_2) were covered by this study. The remaining four greenhouse gases prescribed by the IPCC were not covered, as their emissions are relatively low in India. Carbon capture and storage technologies (sub-sector 1C Carbon Capture, Transport, and Storage) were not covered either, as India does not currently have much activity in this regard.

Electricity Generation (1A1ai)
Only utilities-based emission estimates were covered under this sector. All non-utilities, including industries, are covered under the Industries sector, in a separate report.

Transport Sector (1A3)
Sections 1A3e (Other transportation), 1A3ai (International aviation: International bunkers) and 1A3di (International water-borne navigation: International bunkers) were not covered due to a lack of data in the public domain.

Other Sectors (1A4)
All key source categories were covered under this section.

Fugitive Emissions (1B)
The following sub-sectors were not covered under Fugitive Emissions, owing to a lack of data: 1B1ai3 (Abandoned underground mines), 1B1ai4 (Flaring of drained methane or conversion of methane to CO_2), 1B2aiii7 (Exploration), 1B2biii1 (Exploration), 1B2biii6 (Other), and 1B3 (Other emissions from energy production).

Table 1.10.A Details of key source categories excluded from present GHG estimates

Sector	IPCC ID	Category description	Reason for exclusion
1. Energy	1C	Carbon Dioxide Transport and Storage	Absent in India
	1A2	Manufacturing Industries and Construction	Covered elsewhere
	1A3e	Other Transportation	Lack of data
	1A3ai	International Aviation (International Bunkers)	Lack of data
	1A3di	International Water-borne Navigation (International Bunkers)	Lack of data
	1A5	Non- Specified	Lack of data
	1B1ai3	Abandoned Underground Mines	Lack of data
	1B1ai4	Flaring of Drained Methane or Conversion of Methane to CO_2	Lack of data
	1B1b	Spontaneous Combustion and Burning Coal Dumps	Lack of data
	1B2aiii6	Other	Low relevance and poor data
	1B2aiii7	Exploration	Low relevance and poor data
	1B2biii1	Exploration	Low relevance and poor data
	1B2biii6	Other	Low relevance and poor data
	1B3	Other Emissions from Energy Production	Lack of data

1.11 Recommended improvements

To improve the robustness of the inventory, activity data can be obtained through primary surveys. Also, capacity building for the Platform needs to be done to conduct these surveys. This can help close the data gaps and validate data sourced from literature.

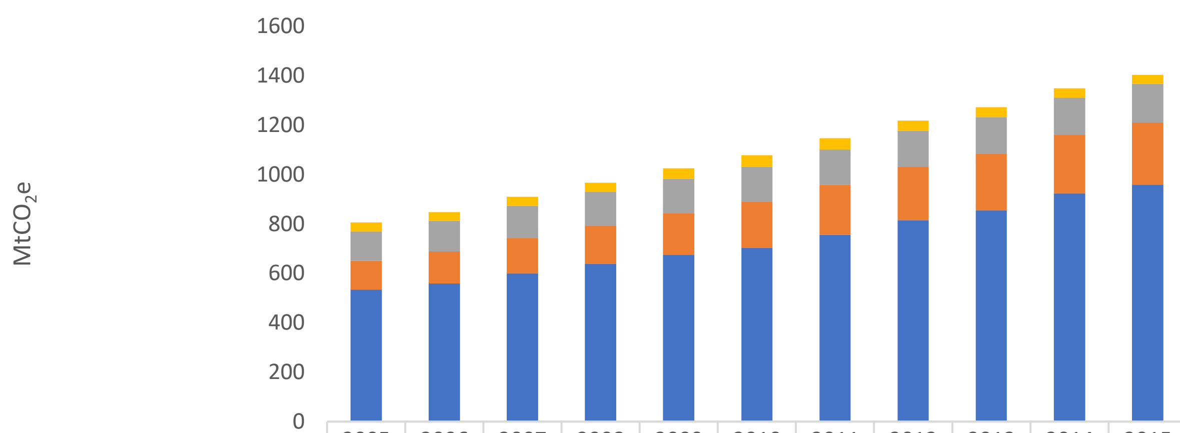
2. Trends in GHG Emissions

2.1 Trends in aggregated GHG emissions

Between 2005 and 2015, GHG emissions from the energy sector grew at a rate of about 5.5% annually (increasing by almost 1.76 times over 2005 levels). The per capita energy-based emissions during this time increased by over 1.49 times over 2005 levels - i.e. from 0.74 tCO_2e/capita in 2005 to 1.09 tCO_2e/capita in 2015. The per capita emissions have been increasing over the years, while the population growth abated at a rate lower than the decline of energy-based emission estimates. Among the key source categories, Electricity Generation (EG) accounted for the highest share of emissions in both 2005 and 2015, increasing marginally from 66.3% to 68.3%. This indicates a fruitification of efforts to decarbonise India's electricity generation sector through various policy measures such as the National Solar Mission (NSM) and accelerated deployment of new renewable energy capacity.

The transport sector saw the highest annual growth rate (13% p.a in registered vehicles (*Vahan Database*, 2018)), increasing its share in energy emissions from 14.6% to 17.8%. During this 10-year period, transport emissions were observed to have more than doubled on account of increased transport demand and greater use of private transport.

The share of overall emissions from the residential, commercial, and agriculture/fisheries sectors, categorised as 'Other Sectors', decreased from 14.8% in 2005 to 12.1% in 2015. However, the absolute emissions from 'other sectors' grew at about 3.6% between 2005 and 2015. Emissions due to fuel production (fugitive emissions) recorded the lowest growth (less than 1%). Their share in overall energy emissions declined from 4.4% to 2.6% from 2005 to 2015. This is mainly due to a shift from underground mining to open-cast mining. The trends in emissions from the various categories are shown in Figure 2.1.A.



	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
Fugitive Emissions	35	35	36	37	43	46	45	42	40	38	36
Other Sectors	119	123	131	136	139	141	144	145	147	151	156
Transport	117	130	142	154	169	187	202	216	229	236	251
Public Electricity Generation	534	559	600	639	674	704	755	814	855	923	958

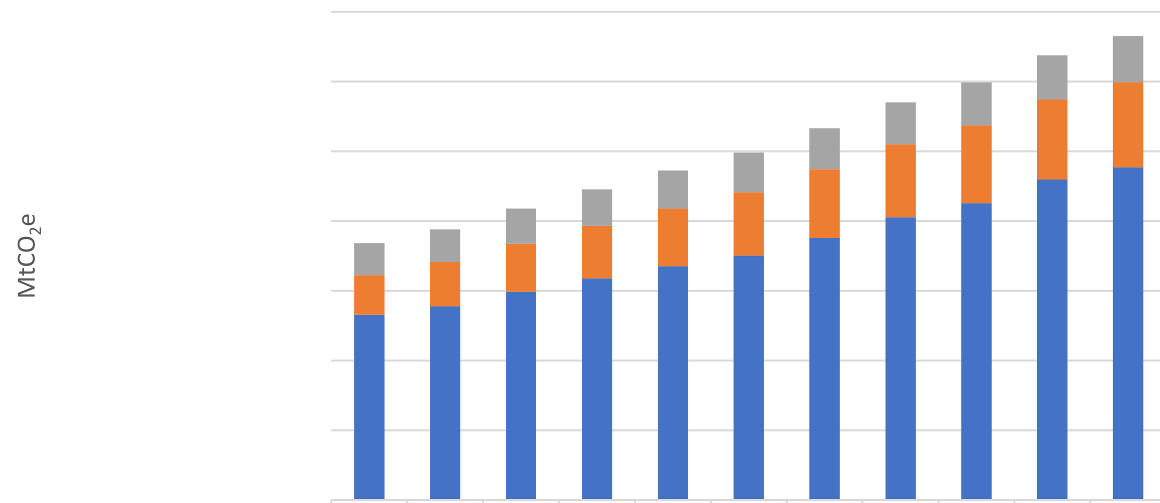
Public Electricity Generation Transport Other Sectors Fugitive Emissions

Figure 2.1.A Trend in Emissions from Energy Sector

2.2 Trends in GHG emissions by type of GHG

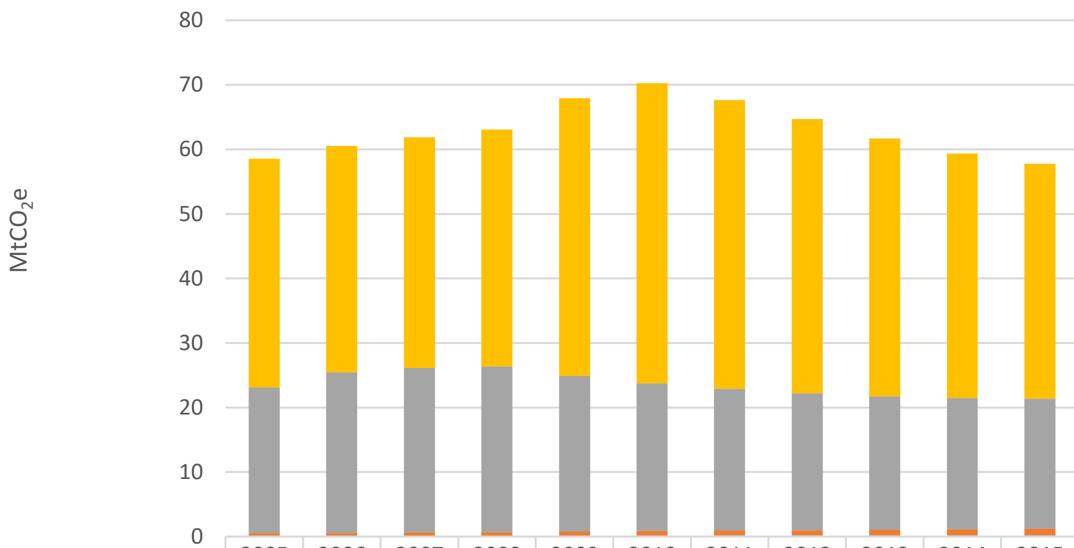
2.2.1 Energy

Energy sector emissions, including emissions from fuel combustion (electricity generation, transport, and other sectors) and fuel production (fugitive), are mentioned in section 1.3. CO_2 constitutes around 95% of the fuel combustion activities in 2015. Fugitive emissions account only for methane emissions, which contribute less than 3% to the overall energy emissions. CO_2, CH_4, and N_2O emissions (in terms of Mt CO_2e) from the various sectors, and their contribution to the total emissions are provided in Figure 2.2.A, Figure 2.2.B, and Figure 2.2.C, respectively.



	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
Fugitive Emissions	0	0	0	0	0	0	0	0	0	0	0
Other Sectors	92	94	101	105	110	114	118	120	123	126	132
Transport	113	126	138	150	165	182	196	210	223	230	244
Public Electricity Generation	531	556	597	636	671	701	752	811	851	919	954

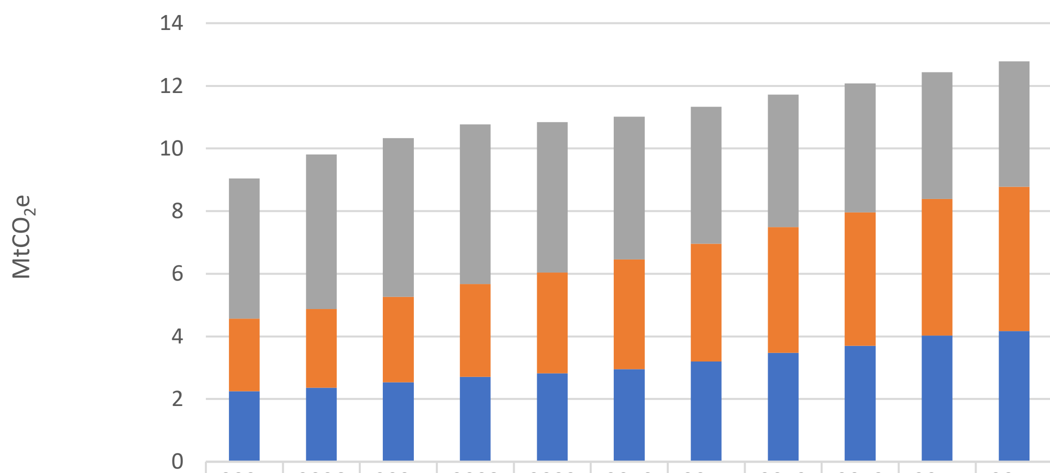
Figure 2.2.A: CO_2 Emissions from Energy Sector



	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
Fugitive Emissions	35.47	35.14	35.75	36.66	43.01	46.49	44.74	42.47	39.95	37.90	36.37
Other Sectors	22.60	24.85	25.48	25.70	24.13	22.90	21.97	21.22	20.67	20.31	20.14
Transport	0.39	0.43	0.49	0.54	0.62	0.70	0.76	0.82	0.87	0.94	1.04
Public Electricity Generation	0.13	0.13	0.14	0.15	0.16	0.16	0.17	0.19	0.19	0.20	0.21

Public Electricity Generation Transport Other Sectors Fugitive Emissions

Figure 2.2.B: CH_4 Emissions from Energy Sector



	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
Fugitive Emissions	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Other Sectors	4.48	4.94	5.07	5.10	4.80	4.56	4.37	4.23	4.12	4.04	4.01
Transport	2.31	2.52	2.73	2.95	3.22	3.51	3.76	4.02	4.26	4.37	4.60
Public Electricity Generation	2.25	2.36	2.54	2.71	2.83	2.95	3.20	3.47	3.70	4.02	4.17

Public Electricity Generation Transport Other Sectors Fugitive Emissions

Figure 2.2.C: N_2O Emissions from Energy Sector

Table 2.2.A: Energy: Emissions contribution by sector for 2015

IPCC ID	Key source category	%CO_2	%CH_4	%N_2O
1A1ai	Electricity generation	99.5%	0%	0.4%
1A3	Transport	97.7%	0.4%	1.8%
1A4	Other sectors	84.6%	12.9%	2.6%
1B	Fugitive emissions	0%	100%	0%

2.3 Key drivers of emission trends in various sectors

2.3.1 Electricity generation

Electricity generation emissions are driven by coal, gas, lignite, and naphtha-based power plants. Electricity consumption in residential, commercial, and industrial sectors has increased. To meet this increased demand, the capacity of electricity generation has also increased. The key drivers of increased electricity generation are population growth, urbanisation, and industrialisation.

2.3.2 Transport

Increasing disposable income and expanding road transport infrastructure has resulted in a steady increase in demand for two and four wheelers (Gupta, Huddar, Iyre, & Moller, 2018). Consequentially, the consumption of motor spirit and high-speed diesel oil (HSDO) has also increased. Motor spirit consumption has nearly doubled during the study period, with road transport contributing to nearly 88% of the overall emissions from the transport sector.

2.3.3 Other sectors

The use of liquefied petroleum gas (LPG), PNG, diesel, fuelwood, and kerosene combustion, drive emissions in the residential sector. Consumption of diesel, PNG, and LPG in particular, have shown an upward trend while, fuelwood and kerosene consumption has declined between 2005 and 2015. The Pradhan Mantri Ujjwala Yojana and the National Biomass Cookstoves Programme[4] have helped reduce the amount of biomass consumed. These schemes focused on improving efficiency of biomass consumption and increasing penetration of LPG. In agriculture, diesel consumption contributes to over 90% of emissions, triggered by farm mechanisation towards increasing productivity.

2.3.4 Fugitive emissions

The demand from electricity generation and the industries sector is the primary reason for the increase in coal production. The increase in emissions from coal, oil, and gas production in 2009 and 2010 can be attributed to the increased coal, crude oil, and PNG production (refer Figure 2.2.B).

3. Energy

3.1 Overview of the sector

Energy sector emissions are broadly classified into two categories: 1A (Fuel combustion activities) and 1B (Fugitive emissions from fuel production). Fuel combustion activities include emissions from electricity generation (1A1ai), transport (1A3), and other sectors (1A4). Emissions from the energy sector increased from 806 million tCO_2e in 2005 to 1,419 million tCO_2e in 2015. Associated GHG emissions from all the aforementioned key source categories, in 2015, are tabulated in Table 3.1.A.

[4] https://mnre.gov.in/national-biomass-cookstoves-programme

Table 3.1.A: GHG estimates for base year and current year in million tCO_2e

IPCC ID	Source Category	GWP – SAR			GWP – AR5		
		2005	2015	% change[5]	2005	2015	% change
1A1ai	Electricity generation	583	1039	78%	582	1038	78%
1A3	Transport	117	252	115%	116	250	115%
1A4	Other sectors	119	172	44%	126	178	41%
1B	Fugitive emissions	35	36	3%	47	48	3%

3.2 Analysis of sectoral emissions

Electricity generation (utilities-based) is the biggest contributor to emissions in the energy sector. It contributed to about 68.3% of the energy-based emissions in 2015. Chhattisgarh, Gujarat, and Haryana are the highest emitting states, in terms of per capita[6] emissions, primarily because of coal-based electricity generation. These states have added thermal capacity up to 3.9 GW, 7.9 GW, and 4GW, respectively, after 2010-11 (CEA, 2012). Large states like Chhattisgarh, Gujarat, Haryana, Orissa, undivided Andhra Pradesh, Maharashtra, Madhya Pradesh, Tamil Nadu, and Punjab are some of the other states with higher per capita emissions, compared to the national average (1.10 tCO_2e/capita) in 2015[7]. Apart from the rise in electricity generation, the growth of emissions can be attributed to the growth in registered vehicles (13%) between 2005 and 2015[8]. Table 3.2.A provides an analysis of sectoral GHG emission estimates for the entire time-series (2005-2015), while Table 3.2.B provides estimates of state-wise emissions per capita.

Table 3.2.A: GHG estimates 2005–2015 in $MtCO_2e$

IPCC ID	Category description	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
1A1ai	Electricity generation	533.56	558.73	600.04	638.96	673.75	703.72	755.24	814.35	855.09	923.19	958.37
1A3	Transport	117.50	130.04	142.77	155.21	170.60	187.90	203.14	216.88	230.14	237.00	252.38
1A4	Other sectors	119.37	123.51	131.44	136.30	138.73	141.22	143.98	146.43	151.00	158.66	171.71
1B	Fugitive emissions	35.47	35.14	35.75	36.66	43.01	46.49	44.74	42.47	39.95	37.90	36.37

[5] Indicates % change of 2015 from 2005 values.
[6] Population figures have been interpolated (for between the years 2002 to 2010) and extrapolated (from between 2012 to 2015) using census 2001 and 2011. Further, note that while calculating the per capita emissions, emissions from fuel, burnt to generate electricity within the country, has been considered. Import and export are not included while calculating per capita emissions.
[7] The national average has been calculated by considering the emissions in 2015, and dividing it by the total population in the same year. The same calculation has been followed for all the states, i.e., by considering the emissions of that state and the total population of the state in 2015.
[8] https://vahan.parivahan.gov.in/vahan4dashboard/

The public electricity generation sector contributes to 68.3% of the emissions from the energy sector, followed by transport (17.9%), other sectors (11.1%), and fugitive emissions (2.6%) in 2015. Road sector emissions are the highest within the transport sector. In case of residential and commercial sectors, DG sets contribute to the highest emissions.

Table 3.2.B: State-wise emissions estimates ($MtCO_2e$) per capita (2005 - 2015)

State	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
Andaman & Nicobar	1.00	1.16	1.31	1.05	1.21	1.35	1.42	1.50	1.77	1.90	1.94
Andhra Pradesh[9]	0.97	1.02	1.09	1.16	1.23	1.31	1.39	1.46	1.49	1.46	1.50
Arunachal Pradesh	0.27	0.28	0.29	0.30	0.33	0.34	0.34	0.34	0.36	0.36	0.37
Assam	0.26	0.27	0.27	0.28	0.28	0.29	0.30	0.29	0.30	0.32	0.33
Bihar	0.17	0.17	0.17	0.21	0.25	0.28	0.29	0.29	0.30	0.32	0.35
Chandigarh	0.57	0.59	0.60	0.63	0.66	0.69	0.69	0.66	0.64	0.66	0.74
Chhattisgarh	1.59	1.65	1.77	2.29	2.72	2.98	3.15	3.38	3.44	3.70	3.90
Dadra & Nagar Haveli	0.92	0.86	0.80	0.76	0.76	0.77	0.76	0.79	0.90	1.07	1.29
Daman & Diu	1.36	1.22	1.12	1.08	1.13	1.16	1.24	1.45	1.66	1.70	1.70
Delhi	1.80	1.45	1.49	1.45	1.36	1.31	1.37	1.39	1.28	1.22	1.15
Goa	1.13	1.26	1.37	1.40	1.42	1.44	1.48	1.46	1.47	1.55	1.60
Gujarat	1.03	1.04	1.13	1.12	1.12	1.20	1.34	1.51	1.57	1.68	1.68
Haryana	0.91	1.03	1.09	1.19	1.34	1.45	1.59	1.73	1.78	1.84	1.67
Himachal Pradesh	0.27	0.28	0.30	0.30	0.31	0.32	0.33	0.35	0.35	0.36	0.38
Jammu & Kashmir	0.23	0.24	0.25	0.25	0.25	0.26	0.28	0.29	0.30	0.31	0.32
Jharkhand	0.78	0.82	0.85	0.85	0.88	0.87	0.91	0.99	1.02	0.92	0.95
Karnataka	0.46	0.51	0.53	0.55	0.62	0.65	0.70	0.77	0.84	0.87	0.88
Kerala	0.28	0.30	0.32	0.35	0.38	0.39	0.41	0.42	0.45	0.47	0.47
Lakshadweep	0.60	0.70	0.92	1.07	1.13	1.16	5.53	11.47	4.38	1.62	1.72
Madhya Pradesh	0.79	0.81	0.89	0.95	0.95	0.96	0.98	0.97	1.00	1.15	1.36
Maharashtra	1.01	1.03	1.10	1.14	1.15	1.16	1.20	1.23	1.26	1.33	1.40
Manipur	0.15	0.15	0.15	0.16	0.17	0.15	0.16	0.20	0.23	0.26	0.27
Meghalaya	0.36	0.36	0.37	0.38	0.39	0.42	0.46	0.46	0.47	0.43	0.40
Mizoram	0.23	0.23	0.23	0.24	0.25	0.26	0.27	0.28	0.28	0.28	0.28
Nagaland	0.20	0.19	0.19	0.20	0.19	0.19	0.20	0.20	0.20	0.20	0.20
Orissa	1.11	1.21	1.27	1.25	1.27	1.26	1.36	1.43	1.50	1.59	1.70
Pondicherry	1.02	1.14	1.15	1.12	1.18	1.19	1.13	1.05	1.05	1.00	1.10
Punjab	1.00	1.03	1.11	1.17	1.25	1.20	1.16	1.12	1.08	1.12	1.14
Rajasthan	0.55	0.57	0.58	0.60	0.62	0.67	0.71	0.75	0.78	0.90	0.91
Sikkim	0.31	0.29	0.28	0.30	0.35	0.41	0.41	0.39	0.41	0.41	0.43
Tamil Nadu	0.97	1.01	1.07	1.07	1.16	1.17	1.15	1.16	1.16	1.24	1.27
Tripura	0.52	0.55	0.54	0.54	0.56	0.58	0.66	0.74	0.65	0.69	0.80
Uttar Pradesh	0.57	0.60	0.63	0.65	0.65	0.67	0.70	0.73	0.77	0.78	0.77
Uttarakhand	0.22	0.24	0.26	0.27	0.28	0.29	0.30	0.31	0.32	0.33	0.37

[9] The analysis considers emissions from undivided Andhra Pradesh

West Bengal	0.79	0.82	0.83	0.88	0.90	0.95	1.00	1.07	1.13	1.12	1.07

3.3 State-wise analysis of emissions

Table 3.3.A provides the state-wise emission estimates from 2005 to 2015.

Table 3.3.A State-wise GHG estimates 2005-2015

State	Unit	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
Andaman & Nicobar	$MtCO_2e$	0.4	0.4	0.5	0.4	0.5	0.5	0.5	0.6	0.7	0.7	0.8
Andhra Pradesh[10]		77.3	77.2	77.3	77.3	77.4	77.4	77.3	77.4	77.2	100.9	109.8
Arunachal Pradesh		0.3	0.3	0.4	0.4	0.4	0.5	0.5	0.5	0.5	0.5	0.5
Assam		7.4	7.8	8.0	8.2	8.6	9.0	9.3	9.3	9.6	10.2	10.8
Bihar		15.8	16.0	16.7	20.4	25.1	28.9	30.3	30.9	32.3	35.4	39.1
Chandigarh		0.6	0.6	0.6	0.6	0.7	0.7	0.7	0.7	0.7	0.7	0.8
Chhattisgarh		36.1	38.3	41.8	55.3	67.0	74.7	80.5	87.8	91.2	99.6	107.1
Dadra & Nagar Haveli		0.2	0.2	0.2	0.2	0.2	0.3	0.3	0.3	0.3	0.4	0.5
Daman & Diu		0.3	0.2	0.2	0.2	0.3	0.3	0.3	0.4	0.4	0.5	0.5
Delhi		27.1	22.2	23.2	23.1	22.0	21.6	23.0	23.7	22.2	21.5	20.6
Goa		1.6	1.8	1.9	2.0	2.0	2.1	2.2	2.1	2.2	2.3	2.4
Gujarat		56.0	57.8	63.6	64.3	65.7	71.3	81.0	92.8	97.7	106.6	108.1
Haryana		20.8	23.8	25.7	28.8	32.8	36.2	40.2	44.7	46.5	48.8	45.2
Himachal Pradesh		1.7	1.8	1.9	2.0	2.1	2.2	2.3	2.4	2.5	2.5	2.7
Jammu & Kashmir		2.5	2.7	2.9	3.0	3.0	3.2	3.5	3.8	4.0	4.1	4.3
Jharkhand		22.8	24.7	25.8	26.6	27.9	28.1	30.1	33.2	34.8	32.0	33.5
Karnataka		26.0	29.1	30.8	32.3	37.0	39.4	42.9	47.5	52.7	55.4	56.9
Kerala		9.1	9.8	10.6	11.5	12.6	13.1	13.6	14.2	15.1	15.8	16.0
Lakshadweep		0.0	0.0	0.1	0.1	0.1	0.1	0.4	0.7	0.3	0.1	0.1
Madhya Pradesh		51.7	53.5	60.1	65.5	66.5	68.6	71.0	71.4	75.2	88.1	105.4
Maharashtra		104.1	107.8	116.9	122.8	125.6	128.3	134.5	139.7	145.3	155.8	165.6
Manipur		0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.6	0.6	0.7	0.8
Meghalaya		0.9	1.0	1.0	1.0	1.1	1.2	1.3	1.4	1.4	1.3	1.3
Mizoram		0.2	0.2	0.2	0.2	0.3	0.3	0.3	0.3	0.3	0.3	0.3
Nagaland		0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4
Orissa		43.0	47.7	50.6	50.5	52.0	52.1	57.0	60.8	64.5	69.0	74.7
Pondicherry		1.1	1.3	1.3	1.3	1.4	1.4	1.4	1.3	1.4	1.3	1.5
Punjab		25.6	26.9	29.3	31.2	33.8	33.0	32.1	31.3	30.6	32.1	33.1
Rajasthan		33.8	35.6	37.2	39.0	41.1	44.8	48.8	52.5	55.2	65.0	66.9
Sikkim		0.2	0.2	0.2	0.2	0.2	0.2	0.3	0.2	0.3	0.3	0.3
Tamil Nadu		64.4	67.9	73.1	73.8	81.1	83.1	83.1	84.9	85.7	93.0	96.8
Tripura		1.7	1.9	1.9	1.9	2.0	2.1	2.4	2.7	2.5	2.6	3.1
Uttar Pradesh		102.5	110.5	118.0	122.6	125.5	131.6	139.8	148.1	157.9	164.0	163.9
Uttarakhand		2.0	2.3	2.5	2.6	2.7	2.9	3.0	3.2	3.3	3.5	4.0
West Bengal		67.1	70.0	72.4	77.8	80.6	85.9	91.0	98.6	105.3	105.8	102.5

[10] This includes emissions from Telangana as well. Due to the combined reporting structure of the activity, data splitting of emission between the two states was not conducted.

Electricity Generation: Uttar Pradesh (123.80 $MtCO_2e$) was the highest contributor to electricity-based emissions in 2015, followed by Maharashtra (107.14 $MtCO_2e$) and Chhattisgarh (92.94 $MtCO_2e$). This pattern can be observed in emissions from coal-based thermal power plants as well. Around 98% (122 $MtCO_2e$) of Uttar Pradesh's emissions from the energy sector can be attributed to the combustion of coal in thermal power plants.

Other Sectors:

Residential: In the residential sector, Uttar Pradesh had the highest emissions (13.69 $MtCO_2e$) in 2015. This was followed by West Bengal (11.73 $MtCO_2e$) and Maharashtra (9.60 $MtCO_2e$). The overall emissions from this sector amounted to 110.23 $MtCO_2e$ in 2015.

Commercial: In 2015, the highest contributors to emissions from the commercial sector were Tamil Nadu (1.36 $MtCO_2e$), Maharashtra (1.19 $MtCO_2e$), and Uttar Pradesh (1.03 $MtCO_2e$). This sector contributed a total of 10.51 $MtCO_2e$ in 2015.

Agriculture: Uttar Pradesh showed the highest emissions from the agriculture sector in 2015 (4.93 $MtCO_2e$). This was followed by Punjab (3.04 $MtCO_2e$) and Haryana (2.88 $MtCO_2e$). The total emissions from this sector were 29.91 $MtCO_2e$ in 2015.

Fisheries: Maharashtra (1.47 $MtCO_2e$), Gujarat (1.39 $MtCO_2e$), and Tamil Nadu (0.67 $MtCO_2e$) were the highest emitters in the fisheries sector, in 2015. This sector contributed a total of 5.68 $MtCO_2e$ in 2015.

Transport Sector: Maharashtra emitted the highest amount of GHGs (34.39 $MtCO_2e$) in the transport sector (2015), among all the Indian states and union territories. This was followed by Tamil Nadu (21.57 $MtCO_2e$) and Uttar Pradesh (20.20 $MtCO_2e$). The top 16 states accounted for about 90.7% of transport sector emissions in India in 2015. This pattern continued in the road transport sector, which contributed to about 88.4% of the overall transport emissions in 2015. Urbanisation and rise in disposable income have resulted in an increase in transport demand, which in turn, has led to an increase in emissions. During the study, we saw a direct correlation between states' GDP contribution and their emission rates. The states with the highest emissions were also the highest contributors to the national GDP.

The aviation sector was the second highest contributor to emissions in the transport sector (7.3%). Delhi, Maharashtra, Tamil Nadu, Karnataka, and Kerala contributed to over 70% of emissions from this sector. Delhi and Maharashtra alone, accounted for about 50% of the emissions from civil aviation.

Fugitive Emissions: In 2015, coal production contributed to around 58.5% of the total fugitive emissions from fuel production. Emissions from activities related to oil production amounted to less than 1%, whereas emissions from PNG production equated to the remaining 40.7% of fugitive emissions in 2015. Chhattisgarh and Jharkhand—the chief coal mining states in India—are responsible for over 40% of emissions from coal production. Maharashtra contributed to 60.7% (8.6 $MtCO_2e$) of the fugitive emissions from oil and PNG production.

3.4 Sectoral Quality Control (QC) and Quality Assurance (QA)

In accordance with the quality control and quality assurance guidelines of the IPCC 2006 reporting format, a summary of the methods used and references to data sources have been clearly provided in the subsequent chapters, to ensure transparency in the calculation of reported emissions estimates. The subsequent sections also provide observations on the completeness of the data sets used in the inventory process. For country-specific emissions factors, the sources of calorific value and carbon content have also been clearly mentioned, with citations.

The activity data for electricity generation (utilities-based), sourced from CEA, was validated further for each type of power plant (coal, diesel or gas-based) in each state, published by the Thermal Performance Evaluation & Climate Change Division, CEA[11]. This data was validated using specific fuel consumption in each type of power plant. It was also cross-checked with the generation data. We verified the activity data (coal consumption) from Table 7.1 - *Fossil Fuel Consumption* with Table 7.7 – *Coal Consumption in Thermal Electricity Generation Plants* reported by CEA (MoP, 2006, 2007, 2008, 2009, 2010, 2011, 2012, 2014, 2015, 2016, 2017), and found the activity data to be the same.

In the transport sector, CO_2 emissions were estimated using the fuel usage statistics. Data on vehicle kilometre travelled by each category of vehicle, normally used to estimate emissions, was unavailable to compare the emissions estimated using fuel statistics data. As discussed in detail in Section 3.6, emissions have been estimated using the reported fuel usage statistics and fuel sold. The default fuel emissions factors used in the inventory process have also been verified for their applicability in the transport sector. The source of the activity data was verified using CSTEP's own internal review process, which ensured consistency and accuracy.

In case of the other sectors, the activity data, emission factors, and assumptions made have been collected from reports published by government departments, peer-reviewed international statistics documents, individual peer-reviewed and published academic research works, and information disseminated by technology suppliers. Due to limited data available on select fuels like fuelwood, charcoal, and kerosene (household), the linear interpolation method was applied to fill the identified gaps. These data points have been validated with experts' solicitation, through interviews and other literature.

In case of fugitive emissions, the activity data, emission factors, and assumptions made have been collected from reports published by government and research institutes or individual academic research works. Barring validations, typical production trends have been used to compare and validate data points. For example, a general 1.65% leakage rate was assumed to quantify the total amount of natural gas leaked in a year. These numbers were further validated with global estimates, to ensure that the resultant values are within the acceptable range.

As a part of quality assurance, an independent and objective review of all the calculations, assumptions, and documentation (a peer review of the emissions estimates), was conducted by WRI India, a third-party independent reviewer.

[11] http://www.cea.nic.in/tpeandce.html

3.5 Electricity generation (1A1ai)

3.5.1 Category description

Emissions from electricity generation are primarily due to the combustion of fossil fuels in thermal power plants. These fossil fuels include coal, oil (diesel and fuel oil), PNG, and other petroleum derivatives. The source-wise data collated from the Central Electricity Authority (CEA, 2007, 2012, 2017) and the Ministry of Power (MoP, 2006, 2007, 2008, 2009, 2010, 2011, 2012, 2014, 2015, 2016, 2017) has been tabulated in Table 3.5.A. The quality of the data is considered high, as it has been compiled and maintained by a government agency and is updated annually.

Table 3.5.A Source category-wise details on type of data, quality and source

IPCC ID	GHG Source & Sink Categories	Type	Quality	Source
1A1	Energy Industries			
1A1a	Electricity Generation	Secondary	High	CEA All India electricity statistics

The net calorific value (NCV), emission factor (EF), and density of select fuels for generating electricity in utility-based power plants have been sourced from the Ministry of Environment, Forest and Climate Change and the Intergovernmental Panel on Climate Change for each fuel (GoI, 2010; IPCC, 2006a). The emission factor of the fuels are of medium quality as it is a mix of country-specific emission factors and the default values reported by the IPCC.

Table 3.5.B NCV and emission factors of fuels

Fuel	(NCV, CO_2) (GoI, 2010)		(CH_4, N_20) (IPCC, 2006a)	
	NCV (TJ/kt)	CO_2 EF (t/TJ)	CH_4 EF (kg/TJ)	N_2O EF (kg/TJ)
Coking coal	23.66	93.61	1.00	1.50
Non-coking coal	17.09	95.81	1.00	1.50
Lignite	9.80	106.15	1.00	1.50
Diesel/LDO[12]	43.00	74.10	3.00	0.60
Kerosene	43.80	71.90	3.00	0.60
Fuel oil	40.40	77.40	3.00	0.60
Light distillates/Naphtha	43.00	74.10	3.00	0.60
Compressed natural gas (CNG)	48.00	56.10	1.00	0.10
LPG	47.30	63.10	3.00	0.60
Lubricants	40.20	73.30	3.00	0.60
Aviation turbine fuel (ATF)	44.10	71.50	3.00	0.60
LSHS[13]	40.20	73.30	3.00	0.60
Wood/Biomass	0.00	0.00	30.00	4.00

[12] HSDO (in this context Diesel) and Light Diesel Oil (LDO) are the two main grades of diesel fuel that are available in markets in India. HSDO is a 100% distillate fuel, and hence, is referred to as diesel, while LDO is a blend of distillate fuel, with a select proportion of residual fuel. Gas turbines use HSDO, while diesel engines (which are stationary) use LDO.

[13] Low Sulphur Heavy Stock (LSHS) and Hot Heavy Stock (HHS) are used in lieu of furnace oil in boilers/air preheaters. LSHS has a higher pour point and a lower sulphur content.

3.5.2 Methodology

A combination of Tier 1 and Tier 2 approaches, as per the IPCC guidelines (IPCC, 2006b, 2006a), was adopted, to estimate GHG emissions from electricity generation. Emissions from the use of solid fuels (coal and lignite) were estimated using the country-specific Tier 2 approach. The Tier 1 approach was employed to estimate emissions from the use of liquid and gaseous fuels. Details on emission factors used and approaches adopted are tabulated below.

Table 3.5.C: Source category-wise details on tier approach and type of emission factor used

IPCC ID	**GHG source & sink categories**	**CO_2**		**CH_4**		**N_2O**	
		Method Applied	**Emission Factor**	**Method Applied**	**Emission Factor**	**Method Applied**	**Emission Factor**
1.	Energy						
1A	Fuel Combustion						
1A1	Energy Industries						
1A1a	Electricity Generation	T1, T2	D, CS	T1	D	T1	D

Note: T1: Tier 1; T2: Tier 2; T3: Tier 3; CS: Country-specific; D: IPCC default

We followed a bottom-up approach towards assessing emission estimates for this key source category (electricity generation), which involved aggregating the total consumption of different fuels at the state level to the national demand. Typically, emissions from electricity generation are a product of fuel consumed, net calorific value (NCV) of the fuel, and the corresponding emission factor for each gas (refer to Equation 1 below). An example is provided in Appendix I to illustrate how emissions were estimated using this formula.

Equation 1

$$Emissions_{Gas} = Activity\ Data_{Fuel} \times NCV_{Fuel} \times Emission\ Factor_{Gas}$$

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

Equation 2

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

Equation 3

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

Data:

- Activity data (fuel consumed) was obtained from the All India Electricity Statistics (MoP, 2006, 2007, 2008, 2009, 2010, 2011, 2012, 2014, 2015, 2016, 2017), published by the Central Electricity Authority (CEA).
- Electricity generation from public utilities includes three types of power plants—coal stations, gas stations, and diesel stations. These plants are classified based on the primary fuel used in the power plant. For coal stations, the PNG consumption was reported in metric tonnes and converted into standard cubic metres, using conversion factors (PPAC, 2018).
- Fuel consumption for each state considers the fuel consumed by all thermal power plants owned by government (state and central) and private companies. The state-level activity data (except for central power plants) was sourced from the CEA's general review books. The CEA reports central sector power plant fuel consumption at the regional level for all five regions. To apportion the central power plant activity data at the state level, a comprehensive list of central power plants

published by the CEA (CEA, 2007, 2012, 2017) was used. The central sector plants' consumption, as reported, was apportioned to each state in each region. To do so, a proxy (net electricity generation) was used. The primary and secondary fuels indicated in the database were used as a proxy to apportion the net electricity generated in each state. Net electricity generation was taken from the CEA database at the state level. Since fuel consumption is not reported at the state level, the share of electricity generation was calculated for states in each region. Thus, the fuel consumed in each state for the central sector was derived by determining the ratio of the state's electricity generation contribution to the regional contribution (sum of all states in the region).

- Furthermore, these percentage shares were used to allocate the final amount of fuel consumed in each state, as reported in the CEA's statistics reports. In select cases, the percentage computed was not applied directly; instead, the entire quantity of fuel was allotted to a state. This decision was based on the type of power station listed. For instance, the HSDO share in the southern region of India was directly allotted to Kerala because diesel is used as a secondary fuel in gas power stations only in Kerala. Equation 4 was used to calculate coal consumption at the state level.

Equation 4

$$Fuel\ Consumption_{State-Coal} = \frac{Net\ Generation\ (Coal\ Based)_{State} \times Fuel\ Consumption_{Region-Coal}}{Net\ Generation\ (Coal\ Based)_{Region}}$$

<u>Assumptions and Calculations:</u>

- Since the report was not published in 2013 (detailing activity data for 2011-12), the activity data was interpolated from 2012 and 2014 data points.
- As per CEA statistics, from 2004-05 to 2012-13, the coal-based power station in Karnataka generated electricity through combustion of waste gases from the blast furnace and corex units. Since emissions from COREX gases are not accounted for in GHG estimations, their emissions are considered to be zero (UNFCCC, 2013).
- In the case of Tripura, the PNG consumed to generate electricity in gas stations was unnaturally high in 2010-11, which indicates an error/inconsistency in the records/data. To resolve this, we calculated the ratio of electricity generated (GWh) to PNG consumed (MMSCM) in 2009-10 and applied the same retrospectively to adjust the misrepresented data.

Activity data is provided in the financial year (FY) format for all years. To convert it into the calendar year (CY) format, one-fourth of the preceding year's, and three-fourth of the succeeding year's activity data was used (refer to Equation 5 below).

Equation 5

$$\text{CY}\ Activity\ data_t = \left[\left(\frac{1}{4}\right) FY\ Activity\ data_t\right] + \left[\left(\frac{3}{4}\right)\ \text{FY}\ Activity\ data_t\right]$$

3.5.3 Recalculation

Revisions in the methodology, in terms of apportionment of fuels consumed by central power plants to states in the corresponding region, resulted in differences (refer to Table 3.5.D) between Phase II and Phase III estimates. As agreed by the Consortium partners, sub-sectoral emissions with more than 5% deviation in Phase III estimates, when compared with Phase II, has been reported in the recalculation section.

Barring 2005, Phase II estimates decreased by an average of around 3.4% from Phase III emissions. The key reasons for the change are listed below:

Based on the reported primary and secondary fuel consumed in each central plant, the net electricity generated is apportioned to each state within the identified region. The derived percentage share of contribution (ratio of state to regional contribution) has been used to allocate the amount of fuel consumed in each state, from the central sector.

- In the current analysis, the quantity of COREX gas used was subtracted when estimating Karnataka's emissions (CEA, 2017). Since this gas was accounted for in the earlier estimate (Phase II), there has been a difference of about 25% between the two estimates.
- Alternative methods were used to validate the reported fuel usage in few states, such as Chhattisgarh, Gujarat, Madhya Pradesh, Bihar, and Jharkhand. As stated in the previous section, the reported fuel use and electricity generation were disproportionate. Hence, we used the ratio of electricity generated to fuel consumed from previous years to arrive at a comparable activity data. These numbers conform to the observed trend in these states.

Table 3.5.D: Source category-wise details on the difference between GHG estimates

Year	Key source category	GHG estimates ($MtCO_2e$)		% difference
		Phase III	Phase II	
2005	1A1a Public Electricity Generation	533.56	729.13	-25.15%
2006		558.73	626.91	-2.87%
2007		600.04	673.04	-2.87%
2008		638.96	717.21	-2.80%
2009		673.75	755.73	-2.70%
2010		703.72	794.20	-3.56%
2011		755.24	852.11	-3.86%
2012		814.35	916.33	-3.88%
2013		855.09	964.28	-4.48%

3.6 Transport (1A2)

3.6.1 Category description

Transport sector emissions are reported under four different modes: road transportation, railways, civil aviation, and water-borne navigation. Emissions from various fuels in each of these modes have been estimated separately. The activity data was sourced from the MoPNG, the Ministry of Statistics and Programme Implementation (MoSPI), the Ministry of Railways (MoR), and the Petroleum Planning and Analysis Cell (PPAC). Data from the PPAC was processed further for road transport using available literature to arrive at the final activity data. Since some of the data had to be processed, the data quality can be categorised as 'medium'. In other sub-sectors such as rail, aviation, and navigation, data from corresponding ministries was directly used to arrive at the final activity data. Hence, this data can be categorised as 'high quality'. The emission factors for each fuel were sourced from the 2006 IPCC Guidelines for National Greenhouse Gas Inventories, and the India Greenhouse Gas Emissions 2007 report **(GoI, 2010)**. The details on the type of data, quality, and sources are listed in

Table 3.6.A. The activity data, which has been sourced directly from government agencies, are considered to be high quality. In cases where the fuel quantity was derived from parameters reported in government reports, the activity data can be considered as being of medium quality. The emission factor of the fuels are of medium quality, as it is a mix of country-specific emission factors and the default values reported by IPCC.

Table 3.6.A: Source category-wise details on the type of data, quality, and source

IPCC ID	GHG Source & Sink Categories	Type	Quality	Source
1.	Energy			
1A	Fuel combustion			
1A3	Transport			
1A3a	Civil aviation	Secondary	High	MoPNG, MoSPI
1A3b	Road transportation	Secondary	Medium	PPAC, MoPNG
1A3c	Railways	Secondary	High	MoR, PPAC
1A3d	Water-borne navigation	Secondary	High	PPAC

3.6.2 Methodology

To calculate emissions from the transport sector, we followed the IPCC 2006 methodology (IPCC, 2006a). According to this, emissions are a product of the activity data of fuel type and its corresponding emission factor, as represented in Equation 1. Table 3.6.B presents the emission factor used and the source category-wise method applied for estimating emissions. The calorific value and density of fuels have been sourced from the Indian Network on Climate Change Assessment (INCCA) (GoI, 2010) and from the Ministry of Petroleum and Natural Gas (MoPNG, 2017).

Table 3.6.B: Source category-wise details on tier type and type of emission factor used

IPCC ID	GHG source & sink categories	CO_2		CH_4		N_2O	
		Method Applied	Emission Factor	Method Applied	Emission Factor	Method Applied	Emission Factor
1.	Energy						
1A	Fuel combustion						
1A3	Transport						
1A3a	Civil aviation	T1	D	T1	D	T1	D
1A3b	Road transportation	T1	D	T1	D	T1	D
1A3c	Railways	T1	D	T1	D	T1	D
1A3d	Water-borne navigation	T1	D	T1	D	T1	D

Note: T1: Tier 1; T2: Tier 2; T3: Tier 3; CS: Country-specific; PS: Plant-specific; D: IPCC default

We calculated GHG emissions for each type of fuel ($Emissions_{Fuel}(t)$) using Equation 1. The corresponding emission factors for each mode of transport are listed in Table 3.6.C.

Table 3.6.C NCV and emission factors for fuels used in the transport sector

Net Calorific Value (NCV) & CO_2 Emission Factor for all uses in transport (MoEF, 2010)			**Road Transportation (IPCC, 2006)**		**Railways (IPCC, 2006)**		**Water-borne Navigation (IPCC, 2006)**		**Civil Aviation (IPCC, 2006)**	
	NCV (TJ/kt)	**CO_2 EF (t/TJ)**	**CH_4 EF (kg/TJ)**	**N_2O EF (kg/TJ)**	**CH_4 EF (kg/TJ)**	**N_2O EF (kg/TJ)**	**CH_4 EF (kg/TJ)**	**N_2O EF (kg/TJ)**	**CH_4 EF (kg/TJ)**	**N_2O EF(kg/TJ)**
Coal	18.26	93.91			2.00	1.50				
Diesel	43.00	74.10	3.90	3.90	4.15	28.60	3.90	3.90	3.90	3.90
CNG	48.00	56.10	92.00	3.00						
LPG/Auto LPG	47.30	63.10	62.00	0.20						
ATF	44.10	70.00							0.50	2.00

Gasoline/Motor Spirit	44.30	69.30	33.00	3.20						
Fuel Oil	40.19	77.40	3.00	0.60	3.00	0.60	7.00	2.00		
LDO/ HSDO	43.00	74.10	10.00	0.60	10.00	0.60	10.00	0.60		

Road

Data:

- MoPNG's Indian Petroleum and Natural Gas Statistics and data sourced from the PPAC are the primary source of information for fuel consumption estimates, which are available in the time-series 2004-05 to 2015-16 (MoPNG, 2006, 2008, 2009, 2010, 2011, 2012, 2013, 2014, 2016b, 2017). Fuels used in the road transport sector are: motor spirit, HSDO, LPG, furnace oil (FO), and compressed natural gas (CNG).
- For auto LPG, LDO and FO, state-wise data was obtained from the PPAC, through expert consultations.

Assumptions and Calculations:

- Motor spirit consumption was directly considered for road transport, as over 99.5% of the total motor spirit was consumed in the transport sector (PPAC, 2013).
- HSDO consumption in transport can be split into two categories: retail consumption and direct or bulk consumption. HSDO data for transport was estimated using data available from MoPNG statistics. Only direct or bulk consumption is reported at the national level, under transport, and the rest is reported at the national level under retail or miscellaneous. Retail includes retail consumption for all the sectors.
- Subsequently, at the state level, only total HSDO consumption is reported in the MoPNG statistics. These statistics do not provide a share of sectoral or bulk/retail consumption of HSDO.
- To estimate the transport sector retail HSDO consumption, state-wise HSDO retail consumption shares estimated in the 'All India Study on Sectoral Demand of Diesel & Petrol'[14] was used (PPAC, 2013). MoPNG engaged Nielsen India to conduct this study across 16 states, in four different zones in India.
  Based on the overall national-level HSDO retail share and state-wise transport retail consumption share from the 'All India Study on Sectoral Demand of Diesel & Petrol', state-wise transport HSDO retail consumption was estimated.
- The zonal share reported in the study was used as a proxy to estimate the HSDO retail consumption shares for the states that were not covered in the aforementioned study.
- State-wise HSDO bulk sales in road transport was estimated by apportioning the share of bulk sales (total HSDO consumption obtained from the PPAC), based on reported retail HSDO consumption.

State-wise CNG consumption in the transport sector, as reported by MoPNG, was used to determine activity data. However, for the years 2004-05 and 2005-06, CNG consumption was estimated using CAGR (using

[14] This report provides information on diesel consumption patterns across various sectors, for state, zonal, and national levels.

- Equation 6) between the years 2003-04 and 2006-07.

Equation 6

$$CAGR = \left(\frac{End\ value}{Beginning\ value}\right)^{\left(\frac{1}{Years-1}\right)} - 1$$

Railways

Data:

- Fuels considered for activity data in this sector were HSDO, LDO, and FO. HSDO accounted for around 99.9% of the total fuel consumption in railways. LDO and FO contributed to the rest of the share.
- State-wise data on the consumption of HSDO was obtained from PPAC. State-level disaggregated consumption data of other fuels (coal and LPG) used in this sector was not available.
- Data on LPG and coal (for traction) is not available at the state level and hence, not considered in the analysis.

Civil Aviation

Data:

- Aviation Turbine Fuel (ATF) and HSDO are the fuels used in the aviation sector.
- ATF quantity has been sourced from statistics published by MoPNG (MoPNG, 2006, 2008, 2009, 2010, 2011, 2012, 2013, 2014, 2016b, 2017).

Assumptions and Calculations:

- Due to the unavailability of state-wise data for HSDO consumption in this sector, this fuel has not been considered for activity data estimation.

Water-borne Navigation

Data:

- LDO, HSDO, and FO are the fuels used in this sector.
- Data on state-wise fuel consumption in this sector has been obtained from the PPAC.

Assumptions and Calculations:

- Data on LDO and FO consumption at the state level is available, whereas data on HSDO is unavailable. Hence, the latter has not been considered for activity data estimation.

All activity data that was reported in the financial year format was converted into a calendar year format using Equation 5.

3.6.3 Recalculation

In the current phase, the emissions from all states and union territories were aggregated to the national-level estimates. State-level estimates obtained from Phase II were also updated by including new sources of activity data. In Phase II, CNG consumption in road transport was not accounted for because of the lack of data at the state level. This has been included in the estimates in Phase III. Additionally, estimates for HSDO retail consumption in road sector have been revised from Phase II, based on expert consultation. The details on the recalculation has been provided in

Table 3.6.D.

As mentioned in Section 3.5.3, sub-sectoral emissions with more than 5% deviation in Phase III estimates, in comparison with Phase II, need to be reported in the recalculation section. However, the change observed in the emissions from the transport sector is roughly 4%.

Table 3.6.D Recalculation in transport sector

S.No	IPCC	Values/Assumptions in Phase II	Recalculation in Phase III
1	1A3b	Due to the unavailability of state-level data on CNG consumption for all the inventory years, this was not accounted for in the inventory.	With the availability of data from MoPNG statistics, CNG consumption for road transport has been accounted for in the GHG estimates, based on the methodology detailed above.
2	1A3b	The share of retail HSDO consumption was calculated based on assumptions from various sources, as documented in the Phase II methodology note.	HSDO consumption for 2006-07 to 2010-11 was reported as an aggregate of HSDO direct and retail consumption in the MoPNG statistics. Additionally, disaggregated data on transport sector retail consumption of HSDO was not provided in the statistics. Hence, the split for transport sector retail consumption of HSDO was based on expert consultation and the methodology detailed earlier.

3.7 Other sectors (1A4)

3.7.1 Category description

The 2006 IPCC Guidelines for National GHG Inventories (IPCC, 2006) have been used to calculate GHG emissions for this key source category. The category ‘Other Sectors’ consists of three key sub-source categories: Commercial/Institutional (1A4a); Residential (1A4b), and Agriculture/Fishing (1A4c) (Agriculture and Fishing have been calculated separately). The sections that follow, outline the methodology used for data collection and to calculate emissions for these sub-sectors.

In the Commercial/Institutional and Residential sub-sectors, some activity data was obtained from MoPNG, while others were calculated from other survey data, such as the National Sample Survey (NSS) and surveys by the PPAC. Surveys often take only sample sets into account and in most cases, comprehensive data is unavailable. Therefore, although government data was used, certain values had to be inferred from the available data for the years in which it was not available. Therefore, data quality in these sub-sectors has been marked as ‘medium’, as shown in Table 3.7.A. The same is true of the Agriculture/Fisheries sub-sector, in which we relied on interpolation and extrapolation methods in the absence of accessible, relevant data. Since government data was only partially available, and the rest had to be approximated, data quality in this sub-sector too has been marked as ‘medium’. For example, data on fuel consumed in the thermal power plants are reported by CEA on an annual basis, while household fuel consumption reported by NSSO are available only for intermittent years. The emission factors used are a mix of country-specific and IPCC default factors, and hence, considered as medium quality.

Table 3.7.A Source category-wise details on the type of data, quality, and source

IPCC ID	GHG Source & Sink Categories	Type	Quality	Source
1A	Fuel Combustion			

1A4	Other Sectors			
1A4a	Commercial/Institutional	Secondary	Medium	PPAC, MoSPI
1A4b	Residential	Secondary	Medium	PPAC, MoSPI
1A4c	Agriculture/Fishing	Secondary and Tertiary	Medium	PPAC, MoSPI

3.7.2 Methodology

Tier 1 approach was primarily applied for emission calculations in this sub-sector. The details on the tier approach and type of emission factor used in each key sub-source categories have been provided in Table 3.7.B

Table 3.7.B Source category-wise details on tier approach and type of emission factor used

IPCC ID	**GHG source & sink categories**	**CO_2**		**CH_4**		**N_2O**	
		Method Applied	**Emission Factor**	**Method Applied**	**Emission Factor**	**Method Applied**	**Emission Factor**
1	Energy						
1A	Fuel Combustion						
1A4	Other Sectors						
1A4a	Commercial/Institutional	T1	D	T1	D	T1	D
1A4b	Residential	T1, T2	D, CS	T1	D	T1	D
1A4c	Agriculture/Fishing	T1	D	T1	D	T1	D
1A4	Other Sectors						

Note: T1: Tier 1; T2: Tier 2; T3: Tier 3; CS: Country-specific; D: IPCC default

Residential Sector

Data:

- The fuels considered under the residential sector are LPG, kerosene, fuelwood, coke, coal, charcoal, Piped Natural Gas (PNG), and diesel.
- Fiscal year data for LPG and kerosene for the years 2004-05 to 2015-16 was obtained from the PPAC.
- The NSSO's 61st (2004-05), 62nd (2005-06), 63rd (2006-07), 66th (2009-10), and 68th (2011-12) rounds (NSSO, 2007, 2012, 2014, 2014) were used for state-wise per capita monthly consumption (PCMC) data on fuelwood, coke, coal, and charcoal.
- State-wise domestic PNG connection data was obtained from the PPAC.
- Fuel consumption in diesel sets was estimated based on data obtained from the PPAC, findings from Nielsen study (PPAC, 2013), and ICF International (ICF International, 2014).

Assumptions and Calculations:

- The PCMC for fuelwood for 2007-08 and 2008-09 were linearly interpolated, and differences in values between 2006-07 and 2009-10 was apportioned equally between 2005-06, 2006-07, and 2007-08. PCMC for 2012-13 through 2015-16 was extrapolated using CAGR (
-
- Equation 6) for 2009-10 to 2011-12.
- The state-wise PCMC was then converted into aggregate absolute fuel consumption, through multiplication with state-wise population data.
- The CAGR approach was used to interpolate and extrapolate state-wise population data from the 2001 and 2011 censuses (Census of India, 2001, 2011) . The urbanisation rate of each state was calculated using the same approach. To calculate the urban population, the urbanisation rate was

multiplied by the population for each year. The urban population was then subtracted from the total population to obtain the rural population.

- The method used to calculate the total state-wise fuelwood consumption for the residential sector (both urban and rural) has been shown in Equation 7 through Equation 10. The same method was used to calculate coke, coal, and charcoal consumption as well. The number of months per year is taken as 12.

Equation 7

$$Fuelwood_{rural} = PCMC_{fuelwood\_rural} \times Rural\ population \times No.of\ months\ per\ year$$

Equation 8

$$Fuelwood_{urban} = PCMC_{fuelwood\_urban} \times Urban\ population \times No.of\ months\ per\ year$$

Equation 9

$$\boldsymbol{Total\ fuelwood\ consumption\ (kg) = Fuelwood_{rural} + Fuelwood_{urban}}$$

Equation 10

$$Total\ fuelwood\ consumption\ (TJ) = Total\ fuelwood\ consumption\ (kg) \times \frac{NCV_{fuelwood}\ (TJ)}{1000}$$

- PNG consumption data for the national level was apportioned at the state level, based on connection data.
- Since diesel consumption data from diesel generator (DG) sets was not directly available, it was estimated from data provided in various reports. A study commissioned to Nielsen India in 2013 by the PPAC observed that 4.3% of total diesel retails are accounted for by residential and commercial DG sets in major Indian states (PPAC, 2013). Diesel consumption quantities for different DG set capacity categories were based on the findings of a study by ICF International (ICF International, 2014). The major categories were taken to be 1–19 kilo-Watt (kW), 19-75 kW, and 75-800 kW in 2012-13.
- Based on consultation with sector experts, it was assumed that DG sets in the first two categories (up to 75 kW) operate in households, while those in the third category (75-800 kW) are operated commercially. Using the ICF International report, as well as through expert consultation, we calculated that the percentage share of diesel consumed in the residential sector could be taken as 33.9%, and the remaining, in the commercial sector.
- The data for diesel $_{\text{(total, state-wise)}}$ and percentage of diesel retails $_{\text{(DG sets)}}$ was obtained from the PPAC and MoPNG (MoPNG, 2011, 2012, 2013, 2014, 2016b, 2017) for the respective years. The percentage of fuel use$_{\text{(residential DG sets)}}$ was calculated from information in the PPAC's Nielsen report (PPAC, 2013). A weighted average of zonal share was used as proxy for the states not covered under this study. Equation 11 has been used to calculate the Diesel Retails $_{\text{(DG sets)}}$:

Equation 11

$$Diesel\ Retails_{(DG\ sets)} = Diesel_{total\ statewise} \times \%\ Diesel_{retail} \times \%\ Fuel\ consumption_{residential\ DG\ sets}$$

- A limitation to this calculation was the lack of adequate data in the public domain on diesel consumption in DG sets. This made it necessary to use the calculated growth in market size of DG sets between 2009–10 and 2012–13 (i.e. 10.06%) as representative of the growth in diesel consumption in these years (ICF International, 2014). The values for the remaining years were extrapolated based on these calculations(Ananthakumar, Riya Rachel Mohan, Paladugula, & Malik, 2017).

Commercial

Data:

- The primary fuels used in the commercial sector are LPG, kerosene, HSDO, and PNG.
- The fiscal year activity data for LPG and kerosene was obtained from PPAC.
- The data for diesel$_{\text{(total, state-wise)}}$ and percentage of diesel $_{\text{(retail)}}$ were obtained from the PPAC and MoPNG (MoPNG, 2011, 2012, 2013, 2014, 2016b, 2017) for the respective years.

Assumptions and Calculations:

- Diesel annual activity data was calculated using data on total diesel consumption, which was obtained from the PPAC. The retail sales of diesel used in DG sets was calculated (using Equation 12) by multiplying the total diesel sold in the state with the percentage of diesel (sold as retail) for that year (Diesel $_{\text{retail}}$) and the percentage of diesel used in commercial sector DG sets.

Equation 12

$$Diesel\ Retails_{DG\ sets} = Diesel_{total\ statewise} \times \%\ Diesel_{retail} \times \%\ Fuel\ consumption_{Commercial\ DG\ sets}$$

- The diesel consumption $_{\text{(commercial DG sets)}}$ was calculated from the information in PPAC's Nielsen report (PPAC, 2013). A weighted average of zonal share was used as proxy for the states not covered under this study.
- Based on consultations with experts, DG sets in the categories higher than 75 kW were assumed to operate in commercial enterprises. The percentage share of diesel sold to DG sets between 75 and 800 kW (66.1%) was considered as the current share to calculate the diesel used in the commercial sector. The share of diesel in residential (33.9%) and commercial sectors (66.1%) was calculated from the values reported in the study by ICF International for various capacities of DG sets (ICF International, 2014). There are very few studies available in the public domain on diesel consumption in DG sets. Hence, the growth in market size of DG sets between 2009-10 and 2012-13 (i.e., 10.06%) (ICF International, 2014) has been used to represent the growth in diesel consumption across the years (Ananthakumar et al., 2017).
- Activity data for PNG (for any given year) was apportioned using state-wise connection data, as shown in Equation 13 :

Equation 13

$$Natural\ gas\ consumption_{state} = \frac{No.of\ connections_{state}}{No.of\ connections_{total}} \times Natural\ gas\ consumption_{national}$$

- Connection data for most states was obtained either from the PPAC or from the MoPNG Statistical Handbook for that particular year.
- Data for total natural gas consumption (of PNG and CNG) and transport sector consumption (CNG) at the national level was obtained from the MoPNG Statistical Handbook. Since the share of natural gas being used for the transport sector was known, this was subtracted from the total natural gas consumption value to obtain the PNG quantity being used for residential/commercial purposes.

- The quantity of PNG being used in the residential sector was obtained from the India Energy Dashboard (NITI Aayog, 2016). This was then subtracted from the total residential/commercial PNG quantity to obtain the values for the commercial sector. Since there was no data for this before 2008-09, the share consumed in 2009-10 (59%) was assumed for 2004-05 to 2008-09. Commercial PNG consumption was then apportioned using connection data, as discussed above.

Agriculture

Data:

- The main fuels used in this sector are LPG, HSDO, LDO, FO, LSHS, and diesel (retails).
- The fiscal year (FY) data up to 2014-15 for these fuels was obtained from the PPAC.

Assumptions and Calculations:

LPG consumption for 2015-16 was calculated for each state using the CAGR method (refer to

- Equation 6).
- The annual activity data for diesel (retails) was calculated using data on total diesel consumption, which was obtained from the PPAC. Diesel (retails) for DG sets was calculated by multiplying the state HSDO total (data from the PPAC) with the percentage of diesel in retail for that particular year, and percentage of diesel used in the agricultural sector for pumps. Equation 14 was used to calculate diesel retails for each state.

Equation 14

$$Diesel\ Retails_{agri\ pumpsets} = HSDO_{statewise} \times \%\ Diesel_{retail} \times \%\ Fuel\ consumption_{agri\ pumpsets}$$

- The data for HSDO $_{\text{(statewise total)}}$ and % diesel $_{\text{(retail)}}$ was obtained from the PPAC and from the MoPNG (MoPNG, 2011, 2013, 2014, 2016b, 2017). Data for % fuel consumption $_{\text{(agri pumps)}}$ was calculated from the Nielsen study (sum of percentage of fuel used for tractors, agricultural implements, and pump sets).

Fisheries

Data:

- The main fuels used in this sector are kerosene and diesel. Kerosene is used for motorised fishing fleets, while diesel is used for mechanical fishing fleets. In India, only a few states are coastal and support fishing activities.
- Department of Fisheries and the Department of Food Civil Supplies & Consumer Affairs provided the diesel (2010-11 to 2014-15) and kerosene (2004-05 to 2014-15) consumption data for fishing fleets in Karnataka.
- The state-wise diesel (2004-05 to 2010-11) and kerosene (2010-11) consumption data for fishing fleets in Kerala was obtained from an academic journal paper (Aswathy et al., 2013). The numbers from the graph were extracted using the Graph Digitizer software.
- State-wise numbers of motorised and mechanised fishing fleets in 2005, 2010, and 2016 were obtained from the Marine Census (DAHD, 2014) (The World Bank, 2010) and from the Department of Fisheries, Karnataka.

Assumptions and Calculations:

- The kerosene supplied for the fisheries sector by the public distribution system and Matsyafed (Kerala State Co-operative Federation for Fisheries Development Ltd) in Kerala was obtained from the Civil Supplies Department, Kerala, for the period from 2011-12 to 2014-15. Since this contributes to only a part of the total kerosene consumed by fishing fleets in Kerala, this primary data was not considered in the emissions calculation.

- Since state-level diesel and kerosene consumption for other states is not available in the public domain, the national level consumption of diesel and kerosene consumed in the fisheries sector is apportioned to each state. This was done using the number of fishing fleets used in each state.
- The number of fishing fleets for the intermediate years were calculated using linear interpolation between 2005 and 2010, and between 2010 and 2016. The difference between the two years considered was then equally distributed among the intermediate years. The total estimated kerosene and diesel consumption at the national level was then apportioned among the states based on the share of motorised and mechanised fishing fleets. This was done by multiplying the ratio of the number of fleets in a particular state to the total number of fleets in the country, by dividing the total fuel consumption in the country (for this sector).

- Activity data for fuel consumption for any particular year (fiscal year) by these states was calculated using Equation 15.

Equation 15

$$Fuel\ consumption_{state} = \frac{No. of\ fleets_{state}}{No. of\ fleets_{India}} \times Total\ fuel\ consumption_{India}$$

- Diesel and kerosene consumed by the fishing fleets at the national level was determined using the below methodology (Ananthakumar et al., 2017).
    - Total diesel consumption (in million litres) by Indian fishing fleets in 2005 and 2010 was reported in an academic research journal paper (E. Vivekanandan, 2013).
    - The intermediate and future years, up to 2014, were obtained through the interpolation and extrapolation method, by applying the CAGR of 6.64% between the time period of 2005 and 2010.
    - Diesel consumption (in million litres) has been converted in terms of '000 tonnes by dividing it with the density of diesel.
    - According to the Central Marine Fisheries Research Institute (CFMRI), kerosene consumption has declined to 10% of diesel consumption in the sector. This is due to a decline in the share of motorised vessels (inboard engines) versus mechanised vessels (outboard engines), as per the paper titled "Total Factor Productivity Growth in Marine Fisheries of Kerala" (2013), published in the *Indian Journal of Fisheries* (N. Aswathy, 2013).
    - The rate of decline in kerosene share between 2005 and 2010 for Kerala was reported in an academic journal paper (N. Aswathy, 2013). According to the Marine Census of India, Kerala has the second highest number of motorised boats in India. So, this state is taken as a representative for India, and absolute kerosene consumption for India is estimated. Tamil Nadu, Kerala, and Andhra Pradesh respectively have 25.4%, 21.1% and 14.4% of the total motorised boats in India in 2014-15.

Using a weighted average approach, all activity data that was reported in the financial year format was converted into the calendar year format (Equation 5).

3.7.3 Recalculation

All values in the 'Other Sectors' category were recalculated for the purpose of cross-verification. Recalculation did not yield any significant variations from the values derived in Phase II at the state level for most fuels.

A minor change in calculation was made in the case of DG-set fuel consumption by residential, commercial, and agriculture sectors. The reason for recalculation was that the consumption of many states, though possibly low, was earlier considered as zero, instead of being accounted for. Another reason was the revision of the existing activity data. It was decided, in this phase, to account for these using proxy values instead of ignoring them altogether. The agreed upon significance threshold was 5%.

In Phase II, the percentage diesel consumption was given as '0' for states whose diesel consumption was not explicitly mentioned in the PPAC Nielsen report. In Phase III, this has been changed. The zonal average percentage diesel consumption (taken from the same report) has been used instead of '0'. In commercial and residential sectors, this has led to an overall increase of 20-25% in diesel consumption in most years. Diesel retails in agriculture increased by about 13% over Phase II because of the methodology used in Phase III. Table 3.7.C presents information on diesel consumption in commercial, residential, and agriculture sectors using the two different methods.

Table 3.7.C Source category-wise details on the difference between activity data

Year	**Key source category**	**Diesel ('000 tonnes)**		**% difference**
		Phase III	**Phase II**	
1A4a Commercial/Institutional				
2005	1A4a Commercial/Institutional	994.86	799.3	24%
2006	1A4a Commercial/Institutional	1067.14	851.5	25%
2007	1A4a Commercial/Institutional	1208.44	963.6	25%
2008	1A4a Commercial/Institutional	1328.43	1071.2	24%
2009	1A4a Commercial/Institutional	1449.24	1173.6	23%
2010	1A4a Commercial/Institutional	1501.01	1230.8	22%
2011	1A4a Commercial/Institutional	1607.65	1321.5	21%
2012	1A4a Commercial/Institutional	1757.49	1437.7	22%
2013	1A4a Commercial/Institutional	1871.16	1542.7	21%
2014	1A4a Commercial/Institutional	1806.79	1507.5	20%
1A4b Residential				
2005	1A4b Residential	510.22	409.9	24%
2006	1A4b Residential	547.29	436.7	25%
2007	1A4b Residential	619.76	494.2	25%
2008	1A4b Residential	681.30	549.4	24%
2009	1A4b Residential	743.26	601.9	23%
2010	1A4b Residential	769.81	631.2	22%
2011	1A4b Residential	824.50	677.8	22%
2012	1A4b Residential	901.34	737.3	22%
2013	1A4b Residential	959.64	791.2	21%
2014	1A4b Residential	926.63	773.1	20%
1A4c Agriculture/Fisheries				
2005	1A4c Agriculture/Fisheries	5993.97	4960	14%
2006	1A4c Agriculture/Fisheries	6408.07	5297	3%
2007	1A4c Agriculture/Fisheries	7769.84	6521	-8%
2008	1A4c Agriculture/Fisheries	8004.51	6768	13%
2009	1A4c Agriculture/Fisheries	8576.94	7231	2%

2010	1A4c Agriculture/Fisheries	9062.33	7638	6%
2011	1A4c Agriculture/Fisheries	9701.36	8158	3%
2012	1A4c Agriculture/Fisheries	10391.61	8804	3%
2013	1A4c Agriculture/Fisheries	10879.99	9368	5%
2014	1A4c Agriculture/Fisheries	10876.55	9279	12%

Table 3.7.D Source category-wise details on the difference between GHG estimates

Year	**Key source category**	**GHG estimates (million tCO_2e)**		**% difference**
		Phase III	**Phase II**	
		1A4a Commercial/Institutional		
2005	1A4a Commercial/Institutional	4.14	3.51	-17.9%
2006	1A4a Commercial/Institutional	4.94	4.25	-16.3%
2007	1A4a Commercial/Institutional	6.06	5.28	-14.8%
2008	1A4a Commercial/Institutional	6.84	6.02	-13.6%
2009	1A4a Commercial/Institutional	7.75	6.87	-12.8%
2010	1A4a Commercial/Institutional	8.33	7.47	-11.5%
2011	1A4a Commercial/Institutional	8.89	7.97	-11.5%
2012	1A4a Commercial/Institutional	9.57	8.55	-12.0%
2013	1A4a Commercial/Institutional	9.79	8.74	-12.1%
2014	1A4a Commercial/Institutional	9.50	8.45	-12.5%
		1A4b Residential		
2005	1A4b Residential	95.88	95.85	0.0%
2006	1A4b Residential	98.00	97.87	-0.1%
2007	1A4b Residential	100.52	100.33	-0.2%
2008	1A4b Residential	103.73	103.56	-0.2%
2009	1A4b Residential	103.45	103.2	-0.2%
2010	1A4b Residential	103.89	103.61	-0.3%
2011	1A4b Residential	104.24	103.89	-0.3%
2012	1A4b Residential	102.70	103.48	0.8%
2013	1A4b Residential	103.09	106.37	3.1%
2014	1A4b Residential	106.76	114.52	6.8%
		1A4c Agriculture/Fisheries		
2005	1A4c Agriculture/Fisheries	19.25	17.43	-10.4%
2006	1A4c Agriculture/Fisheries	20.52	18.61	-10.3%
2007	1A4c Agriculture/Fisheries	24.83	22.51	-10.3%
2008	1A4c Agriculture/Fisheries	25.65	23.34	-9.9%
2009	1A4c Agriculture/Fisheries	27.49	25.07	-9.7%
2010	1A4c Agriculture/Fisheries	28.99	26.48	-9.5%
2011	1A4c Agriculture/Fisheries	30.91	28.22	-9.5%
2012	1A4c Agriculture/Fisheries	33.05	30.11	-9.7%
2013	1A4c Agriculture/Fisheries	34.53	31.33	-10.2%
2014	1A4c Agriculture/Fisheries	34.40	31.12	-10.6%

3.8 Fugitive Emissions from Fuels (1.B)

3.8.1 Category description

Fugitive emissions arise from various activities in fossil fuel production at mines and wells, where coal, oil, and natural gas are produced. The activity data is sourced from the Ministry of Coal (MoC) (Coal Controller's Organization, 2013, 2017) and MoPNG statistics (MoPNG, 2012, 2016a, 2017). The data has been directly sourced from government reports, and hence, the activity data is considered to be of high quality. The emission factors are a mix of country-specific and default emission factors reported by IPCC. Hence, it is considered to be of medium quality.

Table 3.8.A Source category-wise details on the type of data, quality and source

IPCC ID	GHG source & sink categories	Type	Quality	Source
1A1	Energy Industries			
1B	Fugitive Emissions from Fuels			
1B1	Solid Fuels	Secondary	High	MoC (Provisional Coal Statistics)
1B1a	Coal Mining and Handling	Secondary	High	
1B2	Oil & Natural Gas	Secondary	High	MoPNG (PNG Statistics)
1B2a	Oil	Secondary	High	
1B2b	Natural Gas	Secondary	High	

Emission factors for all activities associated with solid, liquid, and gaseous fuel production are obtained from Government of India reports (GoI, 2010).

Table 3.8.B Activity-wise emission factors to estimate fugitive emissions

<table>
<tr><th colspan="2">Fuel Type</th><th colspan="2">Activities</th><th>Emission factor</th><th>Unit (CH_4)</th></tr>
<tr><td rowspan="8">Coal</td><td rowspan="6">Underground mines</td><td rowspan="3">Mining</td><td>Deg I</td><td>2.91</td><td rowspan="6">m^3/tons</td></tr>
<tr><td>Deg II</td><td>13.08</td></tr>
<tr><td>Deg III</td><td>23.64</td></tr>
<tr><td rowspan="3">Post-Mining</td><td>Deg I</td><td>0.98</td></tr>
<tr><td>Deg II</td><td>2.15</td></tr>
<tr><td>Deg III</td><td>3.12</td></tr>
<tr><td rowspan="2">Surface mines</td><td colspan="2">Mining</td><td>1.18</td><td rowspan="2"></td></tr>
<tr><td colspan="2">Post-Mining</td><td>0.15</td></tr>
<tr><td rowspan="8">Oil & Natural Gas</td><td rowspan="3">Oil</td><td colspan="2">Number of Wells</td><td>0.003</td><td>Gg/well</td></tr>
<tr><td colspan="2">Oil Production</td><td>0.000334</td><td>Gg/'000tons</td></tr>
<tr><td colspan="2">Refinery Throughput</td><td>6.759×10^{-5}</td><td>Gg/Mt</td></tr>
<tr><td rowspan="5">Natural gas</td><td colspan="2">Gas Production</td><td>0.003556</td><td>Gg/MMSCM</td></tr>
<tr><td colspan="2">Gas Processing</td><td>0.010667</td><td>Gg/MMSCM</td></tr>
<tr><td colspan="2">Gas Distribution</td><td>0.010667</td><td>Gg/MMSCM</td></tr>
<tr><td colspan="2">Leakage</td><td>0.006482</td><td>Gg/MMSCM</td></tr>
<tr><td colspan="2">Flaring</td><td>0.000641</td><td>Gg/MMSCM</td></tr>
</table>

Note: Deg I, II, III refer to Degree of Gassiness; Gg: Gigagrams; MMCM: Million Metric Standard Cubic Metre

3.8.2 Methodology

Tier 1 method is used to estimate CH_4 emissions (fugitive) from fuel production. The emission factors are country-specific (GoI, 2010), developed for each activity involved in production of solid, liquid, and gaseous fuels (refer to the previous section). Table 3.8.C provides a summary of the adopted method and emission factors employed in all source categories under fugitive emissions from fuels.

Table 3.8.C Source category-wise details on tier approach and type of emission factor used

IPCC ID	GHG source & sink categories	CO_2		CH_4		N_2O	
		Method Applied	Emission Factor	Method Applied	Emission Factor	Method Applied	Emission Factor
1	Energy						
1B	Fugitive Emissions from Fuels						
1B1	Solid Fuels			T1	CS		
1B2	Oil & Natural Gas			T1	CS		
1B3	Other Emissions from Energy Productions			T1	CS		

Note: T1: Tier 1; T2: Tier 2; T3: Tier 3; CS: Country-specific; PS: Plant-specific; D: IPCC default

Solid Fuels:

Data:

- Fugitive emissions from solid fuels occur at two stages of coal production: (a) during coal mining and (b) post-mining within the boundary of coal mines. The emission factors for these activities are obtained from Government of India reports (GoI, 2010).
- Coal mines are of two types: underground (UG) and open-cast (OC) mines. The quantity of coal mined from both these types of mines was obtained from provisional coal statistics published by the Government of India (Coal Controller's Organization, 2013, 2017).
- The quantity of coal mined from the Singareni Collieries Company Limited in 2004–05 and 2005–06 was obtained from annual reports published by the company (The Singareni Collieries Company Limited, 2006).

Assumptions and Calculations:

- To estimate the quantity of coal mined across states, company-wise production was recorded from provisional coal statistics. This was further mapped with the location of mines to derive state-wise quantity of coal mined from both UG and OC mines.
- In the case of select mines (Coal India Limited), due to paucity of data for 2004–05 and 2005–06, we estimated coal production using recorded CAGR.
- Typically, coal is extracted at three different depth levels from UG mines. Coal production data provided in provisional coal statistics is the sum of the quantities of coal mined from all three levels at UG mines. The degree of gassiness indicates the amount of gas trapped at each of these levels and is provided in the emission factor table (GoI, 2010). Because of the absence of segregated production data, we assumed a share of 33.33% at all the three levels (Equation 16, Equation 17).
- Methane emissions (in volume) from OC mines is a product of the quantity of coal mined in OC mines and the emission factor (mining and post-mining). The corresponding quantity was converted to weight (tons) using a conversion factor (Staniunas, Burinskiene, & Maliene, 2012) (Equation 18, Equation 19).

Equation 16

$$Emissions\ from\ UG\ Coal\ Mining_{CH_4}(t) = \sum_{i=0}^{3}\left[Coal\ Mined\ in\ UG\ (t) \times EF\ Mining_i\left(\frac{m^3CH_4}{t}\right) \times 0.0006802\ tCH_4 \times Share_i\right]$$

Equation 17

$$Emissions\ from\ UG\ Coal\ Post\ Mining_{CH_4}(t) = \sum_{i=0}^{3}\left[Coal\ Mined\ in\ UG\ (t) \times EF\ Post\ Mining_i\left(\frac{m^3CH_4}{t}\right) \times 0.0006802\ tCH_4 \times Share_i\right]$$

Equation 18

$$Emissions\ from\ OC\ Coal\ Mining_{CH_4}(t) = Coal\ Mined\ in\ OC\ (t) \times EF\ Mining\left(\frac{m^3CH_4}{t}\right) \times 0.0006802\ tCH_4$$

Equation 19

$$Emissions\ from\ OC\ Coal\ Post\ Mining_{CH_4}(t) = Coal\ Mined\ in\ OC\ (t) \times EF\ Post\ Mining\left(\frac{m^3CH_4}{t}\right) \times 0.0006802\ tCH_4$$

Liquid and Gaseous Fuels:

Data:

- Activity data pertaining to oil production was obtained from MoPNG Statistics (MoPNG, 2012, 2016a, 2017). This data included the number of wells, oil production, and refinery throughput across states.
- Activity data for emissions from the production of gaseous fuels includes natural gas production, flaring, processing, and distribution. This data was sourced from MoPNG Statistics (MoPNG, 2012, 2016a, 2017). Deduction of flared gas from total production yields the amount of natural gas processed. Natural gas distributed, was arrived at by subtracting the natural gas used for internal purposes from the processed natural gas.

Assumptions and Calculations:

- Crude oil production from refineries was obtained directly and mapped against each state, based on location. Oil from refineries under 'Product Sharing Contracts' was apportioned between three states, namely, Gujarat, Madhya Pradesh, and Punjab, using crude throughput.
- Refinery throughput was used as a determining indicator to ascertain the number of wells in select states, for which, data was not available. In other instances (Assam, Gujarat, and Maharashtra), linear interpolation was applied to estimate the number of wells for those years where data was unavailable.
- Owing to the unavailability of data, the natural gas leaked was estimated by multiplying the leakage rate of 1.65% to the gross production (Muller, n.d.).
- Emissions from Oil Extraction (CH_4) were calculated using the following equation:

$$\begin{aligned} &Emissions\ from\ Oil\ Extraction_{CH_4}(t) \\ &= \left(Oil\ Production\ ('000t) \times EF\left(\frac{GgCH_4}{'000t}\right)\right) + \left(Refinery\ Throughput\ (MMTA) \times EF\left(\frac{GgCH_4}{Mt}\right)\right) \\ &+ \left(Number\ of\ Wells \times EF\left(\frac{GgCH_4}{Well}\right)\right) \end{aligned}$$

$$\begin{aligned} &Emissions\ from\ Natural\ Gas\ Extraction_{CH_4}(t) \\ &= \left(NG\ Production\ (MMSCM) \times EF\left(\frac{GgCH_4}{MMSCM}\right)\right) + \left(NG\ Distribution\ (MMSCM) \times EF\left(\frac{GgCH_4}{MMSCM}\right)\right) \\ &+ \left(NG\ Consumption\ (MMSCM) \times EF\left(\frac{GgCH_4}{MMSCM}\right)\right) + \left(NG\ Flaring\ (MMSCM) \times EF\left(\frac{GgCH_4}{MMSCM}\right)\right) \\ &+ \left(NG\ Leakage\ (MMSCM) \times EF\left(\frac{GgCH_4}{MMSCM}\right)\right) \end{aligned}$$

Activity data was obtained in the financial year format for all years. We used Equation 5 to convert it into the calendar year format.

3.8.3 Recalculation

There are no deviations for the fugitive emission estimates from Phase II estimates.

3.9 Uncertainty

This section provides a qualitative analysis of uncertainty in activity data and emission factors, based on the sources of data used. The emission factors for all the sub-sectors were sourced from INCCA and 2006 IPCC Guidelines for National GHG Inventories and hence, they have a medium level of uncertainty.

In case of activity data, the uncertainty level varies from medium to high due to various reasons. Uncertainties in activity data of electricity generation is mainly due to misreporting and missing data, while in the transport and fugitive sector, it is mainly due to incompleteness or lack of data. The activity data in the fishing sector was mainly estimated using literature review and interviews with sector experts, due to a lack of data in the public domain and hence, the uncertainty is high. Table 3.9.A provides a category-wise description of uncertainty for activity data and emission factors.

Table 3.9.A Source category-wise description of qualitative uncertainty

IPCC ID	**Source Category**	**Fuel**	**Qualitative Uncertainty**	
			Activity Data	Emission Factor
1A1ai	Electricity Generation	Coal, Natural Gas, Diesel, LSHS, FO, and Naptha,	Medium	Medium
1A3	Transport	Motor spirit, ATF, LDO, FO, CNG, HSDO	Medium	
		HSDO- Retails	High	
1A4	Other Sectors			
1A4a	Commercial/Institutional	LPG, Kerosene, PNG	Medium	
		Diesel	High	
1A4b	Residential	Kerosene, LPG, Fuelwood, Coke, Coal, Charcoal, Natural Gas	Medium	
		Diesel	High	
1A4ci	Agriculture	LPG, LDO, FO, LSHS, Kerosene, HSDO	Medium	
		Diesel Retails	High	
1A4ciii	Fishing	Kerosene, Diesel	High	
1B	Fugitive Emissions	Coal, Oil and Natural Gas	Medium	

3.10 Recommended improvements

The robustness of the emissions estimates could be further improved with the availability of time-series data and Tier 3 emission factor.

- In the transport sector, the latest primary survey conducted by the PPAC on HSDO retails is available only for 2012-13. The data from this survey has been used for calculating the activity data for 2013 and 2014. This data can be updated, based on new primary surveys that will be conducted after 2012-13. Any revisions in activity data are credible only if revised fuel consumption estimates are published by government agencies or peer-reviewed journals (Ananthakumar et al., 2017).
- In the residential sector, the latest NSSO 'Consumer Expenditure' survey on fuel used in household cooking and lighting was conducted in 2011–12. The reported PCMC of fuelwood, coke, coal, and charcoal were extrapolated using CAGR between 2009–10 and 2011–12. The PCMC of these fuels for

the time period after 2011–12 will be updated based on the next round of NSSO's 'Consumer Expenditure' survey. Similarly, the latest PNG sales data for domestic and commercial sectors will be updated, based on the data the PPAC publishes in the future.

- Data on diesel consumption in residential and commercial DG sets has not been gathered by any agency. This data is necessary to estimate the emissions from the use of diesel in these sectors and hence, should be collected and reported periodically by MoPNG or the PPAC.
- Country-specific and activity-based emission factor and calorific value of fuel is to be evaluated on sample basis.

4. Comparison with National Inventories

The emission estimates for 2007 and 2010 were compared with national estimates published by the Government of India (GoI, 2010; MoEFCC, 2015). Table 4.A provides a comparison of emission estimates and indicates the percentage deviation.

Table 4.A: Energy: Source category-wise details of deviation in GHG estimates between GHGPI and official inventories published by the Government of India

Key source category	Unit	2007			2010			2014		
		INCCA	**GHG PI**	**% deviation**	**BUR 1**	**GHG PI**	**% deviation**	**BUR 2**	**GHG PI**	**% deviation**
IA1a Public Electricity Generation	Mt CO_2e	719	600	20%	820	704	16%	1083	923	17%
1A3 Transport		142	143	-1%	188	188	0%	250	236	6%
1A3a Aviation		10	13.7	-27%	12	15	-20%	14	17	-19%
1A3b Road		124	121	2%	164	162	1%	225	209	8%
1A3c Railways		7	7.1	-1.7%	7	8.4	-11%	8	10	-20%
1A3d Water-borne Navigation		1	0.94	5.0%	4	2.3	43.0%	3	1	199%
IA4 Other Sectors		174	131	33%	93	141	-34%	129	151	-19%
IA4a Commercial/Institutional		2	6	-67%	5	8	-40%	25	10	-15%
IA4b Residential		138	101	37%	85	104	-18%	101	107	-6%
IA4c Agriculture/Fisheries		34	25	38%	3	29	-90%	2	34	-93%
IB Fugitive Emissions from Fuel Production		36	35.7	1%	49	46	5%	38	38	0%

Emissions from electricity generation reported in official inventories include emissions from utilities and non-utilities. Since GHGPI estimates for the energy sector include emissions from utility-based power generation only, official inventories are higher than GHGPI estimates.

Total emissions in the transport sector showed minimal deviations. However, when evaluated at the sub-sectoral level, civil aviation and navigation showed the highest levels of deviation, as reported inTable 4.A. This is mainly due to changes in the reporting structure of these estimates. In the navigation sub-sector, disaggregated estimates of HSDO were unavailable, which led to deviations from official estimates. In the aviation sector, the difference in estimates within official sources could be the reason for deviation. Moreover, these sectors constitute a minor share in the overall emissions compared to road transport, which is the highest emitter.

Deviations in residential sector emissions, when comparing CSTEP's calculations to the official inventories, was significant and greater than 10% in absolute terms, in all the cases examined. Deviations were calculated as the difference between an official inventory and CSTEP's calculations, and indicated as a percentage of CSTEP's estimate. While the INCCA inventory's estimate and the First Biennial Update Report's estimates are higher than CSTEP's (37% and 11% respectively), the Second Biennial Update Report's estimates are much lower (deviation of 12%). The most likely causes for these deviations are differences in biomass/fuelwood estimates. Biomass/fuelwood (as well as domestic coke, coal, charcoal, etc.) consumption data are not regularly reported by the Government of India. This unavailability of biomass data is stated as a shortcoming in the INCCA report as well. As a result, the data that was available had to be estimated (in CSTEP's case, through interpolation and extrapolation) for the remaining years under consideration in this accounting exercise.

It is, therefore, likely that the methods of estimating biomass consumption differ between CSTEP, INCCA, and the BURs. As detailed methodology notes are not available for the latter two, it is difficult to state with certainty that this is the sole cause for deviations.

In addition, the Biennial Update Reports report biomass-related emissions separately from (other) residential sector emissions. This was another reason for removing fuelwood from residential sector emissions, to understand if this reduced the deviation from official inventories.

Removing fuelwood-related emissions from residential sector emissions reduced deviations from the First Biennial Update Report (2010 inventory) from 11% to 10%, and from the Second Biennial Update Report (2014 inventory) from -12% to -7%. This could be on account of differing methods for filling data gaps, as explained above.

As a precaution, we estimated emissions sans diesel as well, even though fuelwood, as per our calculations, is one of the heaviest contributors to emissions from this sector. Diesel consumption estimates also required CSTEP to make many assumptions owing to large data gaps. Removing diesel and fuelwood increased CSTEP's deviation from BUR-I from 11% to 13%. However, it reduced the deviation from BUR-II from -12% to -3%, which is significant.

The deviations in commercial sector emissions, as per CSTEP's calculations and the official inventories, were quite significant, in all the cases examined. While the INCCA inventory's estimate and the First Biennial Update Report's estimates are lower than CSTEP's (deviation -67% and -40% respectively), the Second Biennial Update Report's estimates are much higher (deviation 168%).

Except in the case of INCCA reports, removing diesel made very little difference to the estimates. We attempted removing diesel consumption because these estimates relied upon many assumptions, owing to large data gaps. Since, neither detailed activity data nor a methodology note is available for the official inventories, it is challenging to ascertain the exact cause of deviation. The best guess is that the methodology followed in diesel calculation was very different in the commercial sector or that other fuels that CSTEP has categorised elsewhere were included within this sector in official estimates.

The deviation in CSTEP's calculations, compared to official inventories with regard to agriculture/fisheries sector emissions, was quite significant in all the cases examined. While the INCCA inventory's estimate is higher (deviation 38%) than CSTEP's, the First and Second BUR estimates are lower (deviation -90% and -93% respectively).

Since diesel consumption data in agriculture (pump sets, etc.) was not available in the required disaggregated fashion, many assumptions had to be made, based on study and consultation. Additionally, the emissions from off-road transportation, such as tractors, have been considered under road transportation, while IPCC considers it under the agriculture/fisheries category. Therefore, it is plausible that emissions resulting from diesel consumption in this sector resulted in the deviations observed. Similarly, owing to paucity of reliable data, fisheries sector emissions calculations were also based on assumptions and interpolating and extrapolating existing data. Removing LDO, HSDO, diesel retails (from agriculture), and kerosene (from fisheries) reduced deviations considerably, although they were still on the higher side compared to BUR-I (-25%) and BUR-II (-52%).

Again, owing to a lack of transparency in accounting methods in the INCCA and BUR reports, it is difficult to ascertain the exact source of deviation. It is possible that either diesel accounting methods were different or that certain activities (such as tractor use) were accounted for in a different sector.

The slight difference in fugitive emissions may be due to the assumptions made for natural gas leakage and distribution.

Different reporting formats and incompleteness of data required CSTEP to make various assumptions and interpolate data to arrive at the time-series of activity data. Therefore, it is possible that the assumptions between CSTEP's and MoEFCC's estimates vary, and this could result in inconsistencies in results. CSTEP has used publicly-available and official sources for activity data, to the maximum extent possible. Neither application-wise nor sector-wise activity data was provided in any of the MoEFCC documents for this sector. Therefore, any further conjecture on the observed differences is not feasible.

5. Additional Information

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6. Appendix

Appendix 05: Sample Calculations

To calculate emissions, the following formulas were used:

Table 3.10.A Sample calculations for emissions

Sample Calculation for Maharashtra (2014)			
Sector	Sub-sector	Fuel	Sample Calculation
Electricity Generation	Public Electricity Generation	Coal	$Emissions_{Gas} = Activity\ Data_{Fuel} \times NCV_{Fuel} \times Emission\ Factor_{Gas}$ Emissions (t CO_2) = 57344 ('000 tonnes) x 20 (Tj/kt) x 95.81 (t CO_2/Tj) = 94828788
Transport	Road	Motor Spirit	$Emissions_{Gas} = Activity\ Data_{Fuel} \times NCV_{Fuel} \times Emission\ Factor_{Gas}$ Emissions (t CO_2) = 2430 ('000 tonnes) x 44.3 (Tj/kt) x 69.3 (t CO_2/Tj) = 7460997
Others	Residential	LPG	$Emissions_{Gas} = Activity\ Data_{Fuel} \times NCV_{Fuel} \times Emission\ Factor_{Gas}$ Emissions (t CO_2) = 1950 ('000 tonnes) x 47.30 (Tj/kt) x 63.10 (t CO_2/Tj) = 5821441
	Commercial	LPG	$Emissions_{Gas} = Activity\ Data_{Fuel} \times NCV_{Fuel} \times Emission\ Factor_{Gas}$ Emissions (t CO_2) = 225 ('000 tonnes) x 47.30 (Tj/kt) x 63.10 (t CO_2/Tj) = 670351
	Agriculture	HSDO	$Emissions_{Gas} = Activity\ Data_{Fuel} \times NCV_{Fuel} \times Emission\ Factor_{Gas}$ Emissions (t CO_2) =0 ('000 tonnes) x 47 (Tj/kt) x 74.10 (t CO_2/Tj) = 0
	Fisheries	Kerosene	$Emissions_{Gas} = Activity\ Data_{Fuel} \times NCV_{Fuel} \times Emission\ Factor_{Gas}$ Emissions (t CO_2) = 1 ('000 tonnes) x 43.8 (Tj/kt) x 71.90(t CO_2/Tj) = 2319
Fugitive Emissions	Coal	Open Cast	$Emissions\ from\ open\ cast\ mining\ (t\ CH_4) = \left(Coal\ Production\ (t) \times EF\left(\frac{tCH_4}{t\ of\ coal}\right)\right)$ Emissions (tCH4) = 30962925 (tonnes) *8.03*10^-4 (tCH4/t of coal) =24852
	Oil and Natural Gas	Refinery Through put	$Emissions\ from\ Refinery\ Throughput\ (t\ CH_4) = \left(Refinery\ Throughput\ (MMTA) \times EF\left(\frac{tCH_4}{Mt}\right)\right)$ Emissions from Refinery Throughput (t CH_4) = 20 (MMTA) x 0.0675904 (tCH_4/Mt) = 0.528

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8. Abbreviations

Acronym	Abbreviation
ATF	Aviation Turbine Fuel
CY	Calendar Year
CO_2	Carbon dioxide
CSTEP	Center for Study of Science, Technology & Policy
CEA	Central Electricity Authority
CAGR	Compounded Annual Growth Rate
CNG	Compressed Natural Gas
EF	Emission Factor
FY	Financial Year
FO	Furnace Oil
GHGPI	GHG Platform India
GoI	Government of India
GHG	Greenhouse Gas
GDP	Gross Domestic Product
HSDO	High Speed Diesel Oil
INCCA	Indian Network on Climate Change Assessment
IPCC	Intergovernmental Panel on Climate Change
IISD	International Institute for Sustainable Development
kT	Kilo Tonnes
LDO	Light Diesel Oil
LPG	Liquefied Petroleum Gas
LSHS	Low Sulphur Heavy Stock
CH_4	Methane
MoPNG	Ministry of Petroleum and Natural Gas
MoR	Ministry of Railways
MoSPI	Ministry of Statistics and Programme Implementation
MoC	Ministry of Coal
NSSO	National Sample Survey Office
NDC	Nationally Determined Contribution
N_2O	Nitrous Oxide
OC	Open Cast
PCMC	Per Capita Monthly Consumption
PPAC	Petroleum Planning and Analysis Cell
PNG	Piped Natural Gas
TJ	Tera Joule
T	Tonnes
tCO_2e	Tonnes of carbon dioxide equivalent
$MtCO_2e$	Million tonnes of carbon dioxide equivalent

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