GHG Platform INDIA

Building Sustainable National and Sub National Greenhouse Gas Estimates

ENERGY Sector

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Abbreviations

Acronym	*Abbreviation*
ATF	Aviation Turbine Fuel
BESCOM	Bangalore Electricity Supply Company Limited
BMTC	Bangalore Metropolitan Transport Corporation
CAGR	Compounded Annual Growth Rate
CDM	Clean Development Mechanism
CEA	Central Electricity Authority
CEEW	Council on Energy, Environment and Water
CH_4	Methane
CMFRI	Central Marine Fisheries Research Institute
CNG	Compressed Natural Gas
CO_2	Carbon dioxide
CSTEP	Center for Study of Science, Technology and Policy
EF	Emission Factor
FO	Furnace Oil
FOWIND	Facilitating Offshore Wind in India
GAIL	Gas (India) Limited
GDP	Gross Domestic Product
GGGI	Global Green Growth Initiative
GHG	Greenhouse Gas
GoI	Government of India
GoK	Government of Karnataka
kT	Kilo Tonnes
HSDO	High Speed Diesel Oil
ICLEI	International Council for Local Environmental Initiatives
IISD	International Institute for Sustainable Development
INCCA	Indian Network on Climate Change Assessment
IPCC	Intergovernmental Panel on Climate Change
LDO	Light Diesel Oil
LPG	Liquefied Petroleum Gas
LSHS	Low Sulphur Heavy Stock
MoC	Ministry of Coal
MoPNG	Ministry of Petroleum and Natural Gas
N_2O	Nitrous Oxide
NDC	Nationally Determined Contribution
NSSO	National Sample Survey Office
OC	Open Cast
PCMC	Per Capita Monthly Consumption
PNG	Piped Natural Gas
QoL	Quality of Life
SAPCC	State Action Plan on Climate Change
T	Tonnes
TJ	Tera Joule
tCO_2e	Tons of Carbon dioxide equivalent
UG	Under Ground

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Version Control

Version	Date	Description
01.0	September 28, 2017	This methodology note includes an estimation and analysis of India's annual national-level GHG emissions for the period 2005-2014 for the Energy Sector, prepared by CSTEP under the GHG Platform India initiative (www.ghgplatform-india.org). This sector has estimated GHG emissions for 2014 in addition to the estimates calculated for other sectors. Industry Sector includes emissions from IPPU and emissions from fuel combustion within industries. However, emissions from electricity generation by auto producers (non-utilities) that are attached to industrial units, are accounted in Energy sector. To maintain consistency with national estimates published by Government of India, vide Biennial Update Report (BUR-2010) and Indian Network for Climate Change Assessment (INCCA-2007), 'autoproducers which produce electricity for their own use are reported in electricity generation (1A1ai) sector under fuel combustion emissions (1A) in energy. This document is undergoing a peer review process, however, any changes that may be made further will not have an impact on the figures and estimates. Once the review process is completed, the final document will be uploaded and the same shall be updated in this section.

Executive Summary

Brief Information of GHG estimates:

India's total GHG emissions for the Energy sector (excluding energy use in Industries) was estimated to be 1667.46 Million tCO_2e in 2014, in comparison to 964.50 Million tCO_2e in 2005; a 72.88% increase compared to base year level. In 2014, GHG Emissions from transport, others and fugitive sector witnessed an increase of 77.48%, 21.93% and 5.71% respectively, in comparison to 2005.

Table 1: Summary of GHG emissions

Sector	Sub-sector	Base Year (2005), (Million tCO_2e)	Current Year (2014), (Million tCO_2e)	% change	Base Year (2005), (Million tCO_2e)	Current Year (2014), (Million tCO_2e)
		GWP-AR2[a]			GWP-AR5[b]	
Energy	Electricity Generation (1A1ai)	666.71	1232.96	84.93	666.35	1232.27
	Transport (1A3)	138.73	245.79	77.17	138.49	245.44
	Others (1A4)	123.40	150.45	21.93	131.32	156.29
	Fugitive (1B)	35.51	37.54	5.71	47.35	50.05
Total		964.35	1666.74	72.83	983.51	1684.05
*a) **CH_4-21; N_2O-310 b) CH_4-28; N_2O-265***						

Major Inventory developments and Calculations:

2006 IPCC guidelines for national GHG inventories methodology has been followed for calculating emissions from the sub-sectors under Energy sector. Emissions are obtained by multiplying activity data for a specific fuel or fuel type with its associated Emission Factor (EF). A combination of Tier I and Tier II EFs are employed from national EF (INCCA) and IPCC good practice guidance documents (IPCC, 2006). All activity data and emission factors employed in this exercise remain unchanged in comparison to the Phase I exercise. Few assumptions used to estimate activity data, in select sectors, have been revised based on reliable sources, which are covered in detailed manner in later sections.

Summary of GHG Trends:

Around 69% of emissions from the energy sector can be attributed to electricity generation in 2005; however, this attribution increased by 3%, totalling 72% in the year 2013. Emission from energy sector which includes four sub-sectors is depicted in Figure 1. Between 2005 and 2014, energy sector based emissions grew at around 6.27%, according to GHGPI estimates.

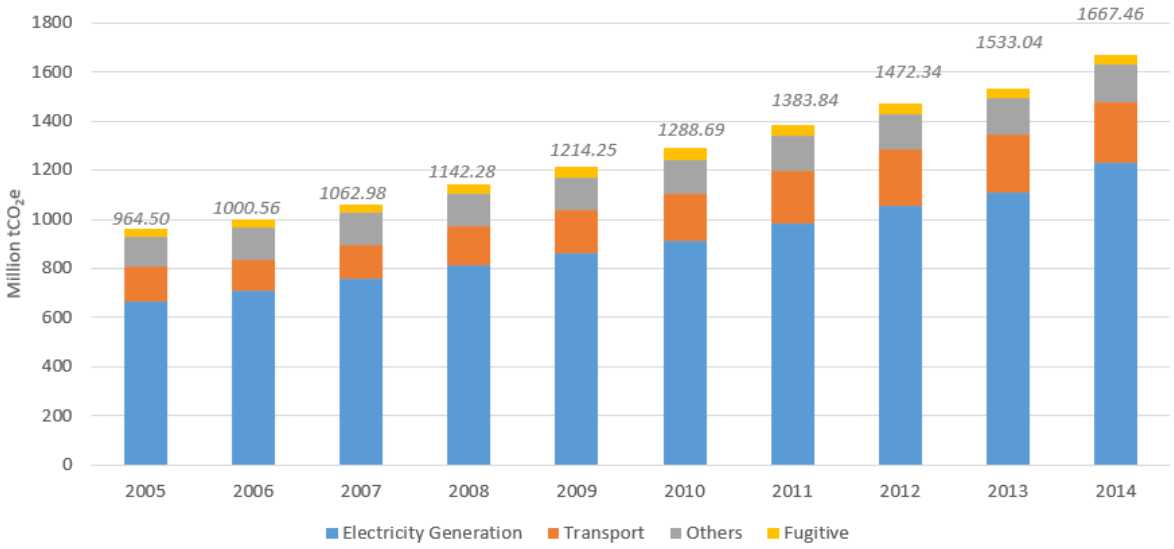

Figure 1: Emissions from Energy Sector

Highlights on major emitting source categories:
In 2014, electricity generation is estimated to be the largest contributor of GHG emissions in the energy sector (72%), followed by transport (15%), others (10%) and fugitive emissions from fuel production (3%). The energy sector emissions majorly include emissions generated from electricity generation from grid connected and auto producers, burning of fuels in transportation vehicles, emissions from cooking, heating and lighting. A detailed performance of these sub-sectors, in the context of emissions is tabulated below:

Table 2: Time-series GHG Emissions (2005-2014)

Level 1	Level 2	Level 3	Level 4	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
Energy (Million tCO_2e (GWP) – AR2	Fuel Combustion Emissions (1A)	Public Electricity Generation(1A1ai)		594.05	627.69	673.50	717.45	755.76	794.20	852.11	916.34	964.47	1041.76
		Industries(1A1ai)		72.65	80.07	84.85	97.24	104.54	119.23	130.27	138.96	145.36	191.20
		Transport(1A3)	Road (1A3b)	120.24	106.49	113.98	133.15	149.69	163.08	186.37	203.10	209.60	217.44
			Railways(1A3c)	6.13	6.46	7.10	7.64	8.01	8.39	8.64	8.98	9.33	9.57
			Aviation(1A3a)	9.74	11.93	13.70	13.99	14.29	15.02	16.58	15.99	16.38	16.61
			Navigation(1A3d)	2.62	2.69	2.87	3.59	3.90	4.18	3.25	2.38	2.17	2.17
			Other Transportation (1A3e)	0.0076	0.0081	0.0089	0.0065	0.0055	0.0038	0.0041	0.0043	0.0040	0.0039
		Others(1A4)	Residential(1A4b)	101.15	105.73	104.42	103.31	102.66	103.60	104.36	103.26	103.48	106.75
			Commercial(1A4a)	3.73	4.67	5.46	6.11	6.99	7.79	8.44	9.11	8.71	8.17
			Agriculture (1A4ci,1A4cii)	15.31	16.19	17.53	19.20	21.38	22.64	25.01	27.77	29.63	30.44
			Fisheries(1A4ciii)	3.21	3.41	3.60	3.79	3.97	4.15	4.36	4.58	4.82	5.09
	Fugitive Emissions from Fuel Production (1B)		Coal(1B1)	19.71	19.62	20.12	20.82	21.49	21.12	20.62	20.78	20.62	21.03
			Oil(1B2a)	0.26	0.26	0.27	0.27	0.27	0.30	0.30	0.30	0.30	0.30
			Natural Gas(1B2b)	15.55	15.42	15.54	15.69	21.36	25.18	23.94	20.64	17.68	16.21
	Total			**964.35**	**1000.62**	**1062.96**	**1142.25**	**1214.32**	**1288.88**	**1384.25**	**1472.18**	**1532.56**	**1666.75**

Introduction

Background Information on GHG estimates

GHG estimates reporting: The main objective of GHG India Platform is to provide estimates of continuous time-series GHG emissions for India, based on the IPCC methodology. This report encompasses energy sector's emission estimations between 2005 and 2014.

Gases: The GHGs accounted for are Carbon Dioxide (CO_2), Methane (CH_4) and Nitrous Oxide (N_2O), with a total CO_2 equivalent using Global Warming Potential based on IPCC Assessment Report 2.

Key Source Categories/ Sub-categories: 1A1ai- Electricity Generation (Public Electricity Generation and auto producers in Industries, as indicated in the version control); 1A3- Transport (1A3aii Domestic Civil Aviation, 1A3b- Road Transportation (Fuel based-covering sub sectors 1A3bi to 1A3bvi), 1A3c- Railways and 1A3dii- Domestic Water borne navigation); 1A4- Other Sectors (1A4a- Commercial/Institutional, 1A4b- Residential, 1A4ci- Agriculture-Stationary, 1A4ciii- Fishing-mobile combustion) and 1B- Fugitive Emissions from Fuels (1B1a- Coal mining and handling 1B1ai *Underground Mines* - 1B1ai1 Mining, 1B1ai2 Post-mining gas emissions, 1B1aii *Surface Mines* - 1B1aii1 Mining, 1B1aii2 Post-mining gas emissions, 1B2 Oil and Natural Gas 1B2a Oil 1B2b Natural Gas)

GHG Estimation period: The GHG Estimation period is 2005 to 2014. The baseline year for achieving nationally determined contribution (NDC) targets is reported to be 2005 as per the commitments proposed by the Ministry of Environment, Forest and Climate Change to UNFCCC (MoEFCC, 2015). In this backdrop, all the targets proposed including emission intensity reduction that needs to be realised are compared to 2005 levels. Therefore, we identified 2005 as the base year in this exercise.

Institutional Arrangement and Capacity

Institutional, legal and procedural arrangements: A schematic representation of institutional arrangement is presented below:

Registered Office Address:
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Note: The registered office address is responsible for carrying out the current assignment.

Few relevant projects of CSTEP, in the context of emissions calculations and estimations, are explained below:

a. CSTEP evolved the Green Economy Strategy for Karnataka, which was released by the Chief Minister and endorsed by the Government of Karnataka (GoK). It quantitatively examined the various options provided in the State Action Plan on Climate Change (SAPCC) and provided baseline inventories, mitigation potential by 2030 and the co-benefits (jobs, land and water use, inclusivity, local pollution) of the most promising options. The study prepared a roadmap for pursuit of the most promising technology and policy options in Karnataka. Subsequently, CSTEP also worked closely with GoK to provide technical support to the Electric Bus pilot project in Bengaluru, held capacity-building workshops for mid- and senior-level bureaucrats on green growth planning, and knowledge dissemination for Waste Heat Recovery options in the state's cement and steel industries. CSTEP's Quality of Life (QoL) Report released in August 2015 approached India's Climate Policy from a sustainable development perspective. Our research found that India can reduce emissions intensity in energy and energy related sectors by 30% of 2005 levels, with a 44% contribution of fossil-free capacity in the electricity generation mix. At the same time, it could also meet its developmental targets of providing affordable housing, increasing manufacturing's contribution to Gross Domestic Product (GDP), ensuring access to electricity and clean cooking fuels, and achieving significant improvements in resource-use efficiency (land, water, raw materials).

b. CSTEP has undertaken a project to conduct a benefit cost assessment of emission standards for thermal power plants in India. This project aims to examine the overall impact of emissions standards, implemented in 2015, and analyse the role of pollution control technologies to abate emissions (SO_x, NO_x, Particulate Matter). Furthermore, the study attempts to propose a framework to quantify the health benefits, in comparison with accrued costs, using plant-level data.

c. CSTEP is undertaking research studies to understand the sector-wise implications of Nationally Determined Contributions (NDCs) and the commitments related to the creation of additional sink and non-fossil capacity. Our initial findings (refer to this link) indicate that:
   i. Energy and Industry sectors will need to contribute 85–88% mitigation envisaged by the NDCs
   ii. Despite ambitious RE targets, the emissions intensity of energy supply (CO_2/Energy) will increase owing to growth in Liquefied Petroleum Gas (LPG) access and transportation demands
   iii. Energy Intensity of GDP (Energy/GDP) will need to reduce to half by 2030 to compensate for the increase in CO_2/Energy.

Technical competence of staff:

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GHG Estimation Preparation, Data Collection, Process and Storage

GHG Estimates preparation: Extending the time series emissions estimation for all the subsectors at the national level for years 2005, 2006 and 2013. It is important to note that, during the first phase of the project, national estimates for years 2007, 08,09,10,11, and 12 were estimated (GHG Platform India, 2016). Based on the literature survey and moderation call between partner institutions, 2006 IPCC guidelines for national GHG inventories Methodology is employed to estimate emissions based on fuel sources, sub-sectoral activities and emission factors. As described in section '1.A.1 Energy Industries', this exercise employs a combination of tier I and tier II emission factors from national reports (INCCA) (MoEF, 2010) and IPCC good practice guidance documents (IPCC, 2006). Finally, to convert all the non-CO_2 gases into CO_2e unit, global warming potential of 21 (CH_4) and 310 (N_2O) are employed, as per the IPCC second assessment report. As per the need, we have engaged with experts to resolve technical difficulties in data identification and processing.

Planning and methodology improvement: Activity data were collected for all the four sub-sectors in Energy sector.

a. To estimate emissions from electricity generation (1A1ai), fuel wise electricity generated from 2004 to 2014 was collected from CEA reports. Electricity generated from public electricity generation and auto producers, in industries, are collected. Data reported in other sources published by Ministry of Power were used to validate the quality of data from CEA reports. As per 2006 IPCC guidelines on national GHG inventories, emissions from Combined Heat and Power Generation (CHP) (141aii) must be reported under 1A1a Main activity electricity and heat production. However, electricity from biomass (bagasse based cogeneration) based CHP is reported in CEA under Renewable Energy System. As a carbon neutral source, since biomass acts as both source and sink, emissions from biomass based CHP electricity is not applicable in this exercise. According to 2006 IPCC guidelines, emissions from auto producers (undertakings which generate electricity wholly or partly for their own use, as an activity that supports their primary activity) should be assigned to the sector where they were generated and not under 1 A 1 a. But, in this exercise, emissions from electricity generation from auto producers are considered in 1A1a to maintain consistency with national estimates published by Government of India.

b. 2006 IPCC guidelines on national GHG inventories employs vehicle wise activity data to estimate emissions from transport sector (1A3). However, in this exercise, we have adopted an alternative strategy due to paucity of data pertaining to type of fuel used in every vehicles. Fuels used in each mode (road, rail, air and water) is collectively reported as four entities by Ministry of Petroleum and Natural Gas (MoPNG). These values are collected for identified periods and validated with reports published by Ministry of Road Transport and Highway (MoRTH).
c. Emissions from 'Other' sector require activity data i.e., energy consumed at households and commercial/institutional establishments. To ascertain fuels consumed in households, we have resorted to National Sample Survey Office (NSSO) datasets that provides quantity of fuel consumed at households across urban and rural levels. MoPNG statistics indicate the amount of fuel (LPG, NG, Kerosene and Diesel) consumed in commercial sector; this is used as the activity data. Energy consumption in agricultural sector can be categorised into two types: stationary combustion (1A4ci) of diesel for pumping and mobile combustion (1A4cii) of diesel in farm mechanisation. Activity data prepared takes into account of diesel consumed in both pumpsets and tractors obtained from MoPNG. Emissions from fisheries (1A4ciii) include diesel and kerosene consumed by fishing fleets.
d. Activity data required to estimate fugitive emissions from fuel production (1B) include production data of coal, oil and natural gas. These data are obtained from provisional coal statistics report published by Ministry of Coal (MoC) and MoPNG statistics report. However, underground coal production data with degree of gassiness is unavailable; thus, a 33.33% distribution across three levels of degree of gassiness was assumed to apply activity (mining and post mining) based emission factors (MoEF, 2010).

Data collection, processing and storage: Hard copies and soft copies of reports and datasets are obtained to estimate emissions from electricity generation and 'other' sector. The fee paid were the transaction fee required to procure the data from government agencies. CEA All India Electricity statisticsreport for year 2004-05, 2005-06, 2012-13, 2013-14, 2014-15 are purchased to account for fuel-wise electricity generated in corresponding years. In addition, consumer expenditure reports and raw data sets published by National Sample Survey Office (NSSO) for rounds[1]' 61, 62, 63, 64, 66 and 68 were requested to be obtained, by paying transaction fee, in order to estimate specific fuel consumed in residential sector for select years. Various reports (refer to data sources) available in public domain from MoPNG and MoC were downloaded to obtain activity level data for transport and fuel production. In few instances, Right to Information (RTI) was filed with respective agencies to avail disaggregated fuel consumption numbers. This data was also helpful to validate data obtained from public domain.

General description of methodology and data sources

Estimation methods: The methodology used for estimating the GHG emissions employs a combination of country-specific data, emission factors and the methodologies that are in-line with 2006 IPCC guidelines on national GHG inventories.

Data Sources: All major sources of activity data are listed in the table below. Emission factors are obtained from INCCA report (government sources), fuel emission factors (MoEF, 2010) and IPCC good practice document (IPCC, 2006).

Table 3: Principal Data Sources

NAME OF SECTOR	SUB-SECTOR	PRINCIPAL DATA SOURCE	PRINCIPAL COLLECTION MECHANISM
Energy	Electricity Generation (1A1ai)	Central Electricity Authority (CEA) General Review (CEA, 2007; CEA, 2008; CEA, 2009; CEA, 2010; CEA, 2011; CEA, 2012; CEA, 2014)	Published data from CEA website (Hard Copies)
	Others – Residential (1A4b)	NSSO Consumer Expenditure (Type 2) Reports and Raw Data for rounds (61, 62, 63, 64, 66 and 68)	Report (Hard Copies) for 62, 63, 64 Soft copies of raw data in CD for 61, 66 and 68th round

[1] The National Sample Survey Office (NSSO) conducts nationwide socio-economic surveys as part of its 'rounds'. Here each round indicate the duration in years. The surveys are usually a household survey, the respondent households being selected at random through a scientific statistical design covering practically the entire geographical area of the country. These data are further refined into reports that cover several aspects of household capital expenditure by type of expenditure, source of finance etc. The raw data sets created during the survey is also available for users to conduct analyses.

	Fugitive – Solid Fuels (1B1)	Provisional Coal Statistics report published by Ministry of Coal (2012-13, 2013-14, 2014-15)	Online reports from MoC
	Transport (1A3); Others (1A4a, 1A4c); Fugitive – Oil and Natural Gas (1B2)	Petroleum Planning and Analysis Cell (PPAC) published by MoPNG	Online reports

Brief description of key source categories

Between 2005 and 2014, the share of emissions from solid fuels increased from 69.25% to 74.61% in the energy sector (save industries). In 2014, the total emissions from solid fuels in energy sector were estimated to be 1244.12 Million tCO_2e. Combustion of coal and lignite in electricity generation (1A1ai) contributed to around 95.5% of CO_2 equivalent emissions from solid fuels. Emissions from combustion of liquid fuels (Motor Spirit, High Speed Diesel Oil (HSDO), Light Diesel Oil and Furnace Oil) in transport (1A3) accounted for 222.97 Million tCO_2e in 2014. Liquid fuels (Kerosene, Diesel, HSDO and Furnace Oil) accounted to 43.06% of emissions in the other sector, in addition to 23.21% from solid fuels (fuelwood, coke, coal and charcoal) and 33.74% from gaseous fuels (LPG and Natural Gas) application, in the year 2014.

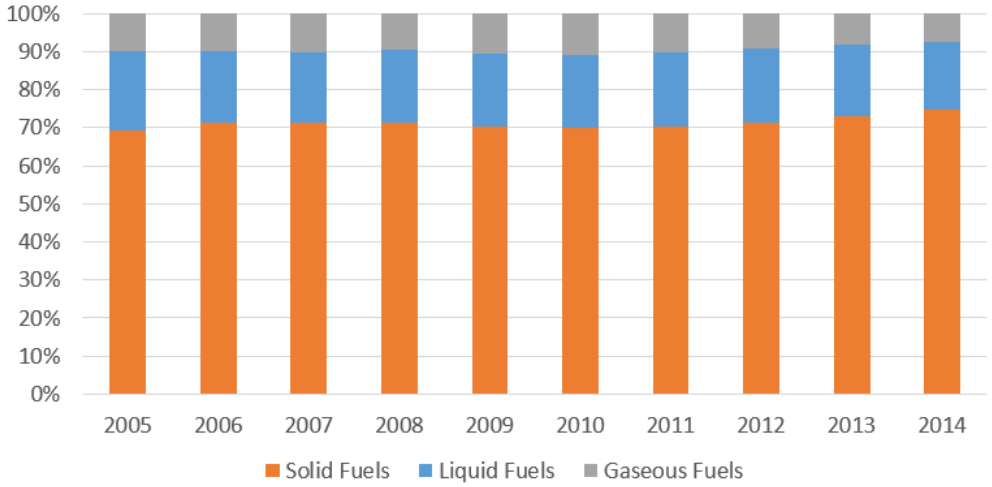


Figure 2: Emissions Contribution from Combustion of Fuels

Uncertainty Evaluation

Uncertainty arises when multiple data sources are used, across several sub-sectors, to estimate total emissions from energy sector. Activity data and emission factors are derived from measurement data from various sub-sectors. Emission estimates, therefore, present high uncertainties due to inaccuracies and variations with processes established to measure data points. Other factors include aggregation errors, incomplete data and mismatches that arise while compiling the activity data from measured data. Table 4 shows uncertainty calculated from activity data and emissions factors using propagation of errors approach, published by GoI in NATCOM II (MoEF, 2012). The uncertainty in activity data were derived based on expert solicitation, and the emission factor uncertainty are computed from a combination of both statistical (standard deviation) and secondary literature.

Table 4: Uncertainty in emissions from fuel combustion

IPCC Source Category	Sector	Gas	Activity data uncertainty (%)	EF uncertainty (%)	Combined uncertainty (%)
Electricity production	Energy	CO_2	10	5	11.18
Road Transport	Energy	CO_2	5	0	5
Residential	Energy	CO_2	25	5	25.49
Agriculture/Fisheries	Energy	CO_2	25	5	25.49
Residential	Energy	CH_4	10	150	150.33

General Assessment of Completeness

Electricity Generation (1A1ai)
Although CEA All India Electricity statistics publishes yearly activity data pertaining to different fuels used for electricity generation sector but data for the Financial Year (FY) 2011-12 was not available. In cases where activity data were unavailable for intermediate years, linear interpolation of data was used to calculate the activity data. Linear interpolation implies taking an average of previous year and next year to calculate the intermediate year.

Transport Sector (1A3)
The activity data for sector specific and mode specific for the FY 2004 – 05, 2005 – 06 and 2006 - 07 were not available from the Ministry of Petroleum and Natural Gas (MoPNG) reports, due to change in reporting structure. Owing to the structural changes in the report, share of fuels recorded in 2007-08 is attributed to years mentioned above.

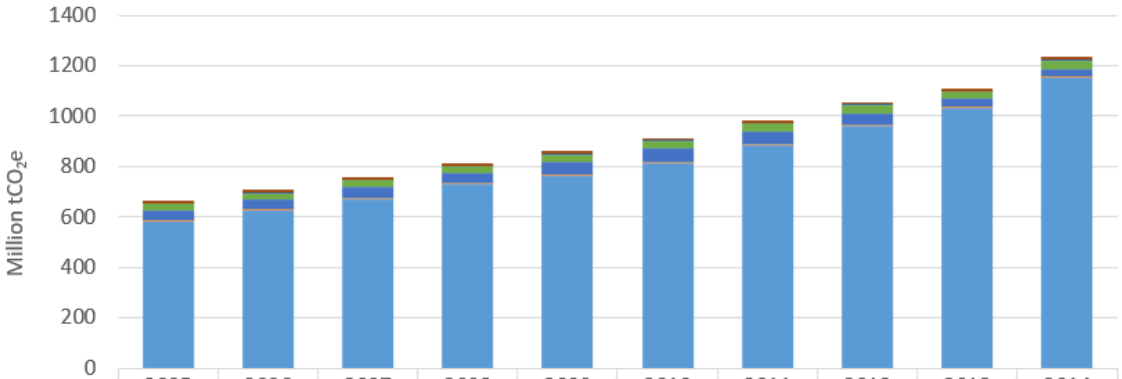
Other Sector (1A4)
The GHG estimates are calculated based on activity data available from reports published by government agencies. Due to lack of certain data in public domain, linear interpolation and extrapolation method has been applied. Since NSSO survey on household expenditure is not conducted every year, consumption data on fuelwood, coke, coal and charcoal in residential sector for the years 2008-09, 2010-11, 2012-13, 2013-13 and 2014-15 are not available in the public domain. The diesel consumption in generator sets (commercial and residential sectors) and in agricultural pump sets and farm mechanization are not accounted by any government agencies. About 80% of the diesel sold is accounted under 'Miscellaneous' sector which includes the diesel consumption in DG sets and agriculture sector. Based on Nielson's survey for PPAC in 2012-13, the sharing of diesel sales among various sectors were accounted for. This is the only report that mentions the sector wise sharing of diesel and petrol in Indian sector. The same sharing pattern is assumed from 2004-05 to 2014-15 due to lack of data in other years. Similarly, the sales of Piped Natural Gas (PNG) in commercial sector is not available in the public domain and this is considered to be the left over after considering the total sales in residential and transport sector from the total sales on City Gas Distribution companies. In case of fisheries sector, there is no information pertaining to the total sales of diesel and kerosene for fishing fleets. The GHG estimates for this sector was calculated based on data available from academic journal papers.

Fugitive Emissions (1B)
Most of the data were available from reliable government sources, except few activity data such as leakage rate in natural gas production and breakup of coal production from UG mines based on the depth of mining. The leakage rate is assumed to be 1.65% of the production, and share of coal produced from UG mines is assumed to be three equal shares of 33.33%, each covering a level of gassiness.

A detailed temporal coverage of activity data is provided in Appendix I

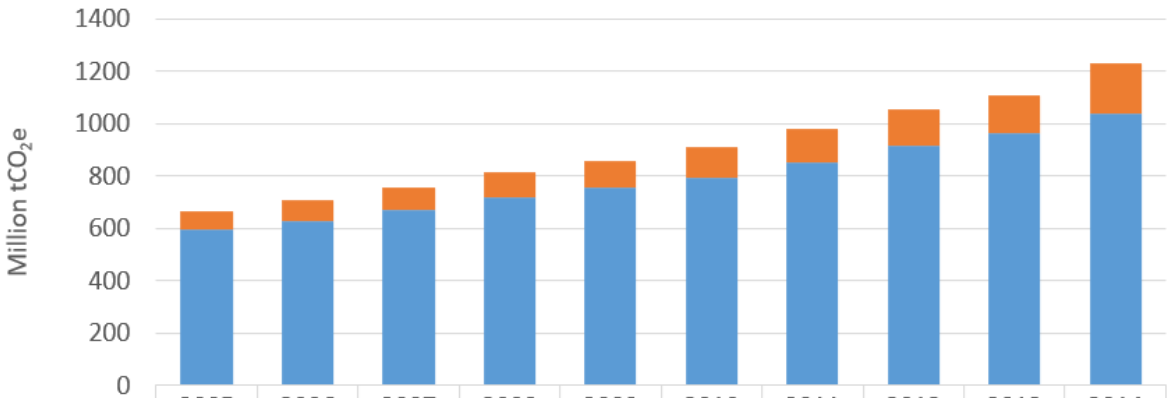
Trends in Emissions

Electricity Generation: The increasing trend of emissions from coal, gas, lignite and naphtha based power plants indicate increased usage of solid and gaseous fuels. Further, a decreasing trend of emissions was witnessed in the consumption of liquid fuels such as fuel oil, diesel and Low Sulphur Heavy Stock (LSHS).



	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
Diesel	12.80	11.07	11.07	10.75	9.11	8.26	8.31	8.55	9.13	9.98
Naptha	2.40	1.89	1.87	3.25	3.02	1.74	1.88	2.54	1.80	1.35
Lignite	24.08	23.97	26.25	26.19	27.24	29.35	31.02	32.52	27.24	33.42
Natural gas	36.58	36.50	42.36	37.65	49.14	55.60	51.56	45.35	34.22	30.60
LSHS/ HHS	2.33	2.30	2.31	2.58	2.09	1.38	1.13	1.02	0.87	0.75
LDO/HSD	1.62	1.93	2.16	1.89	1.79	1.59	1.53	1.54	0.76	0.69
Furnace Oil	3.57	3.37	3.83	4.05	3.29	2.78	2.55	2.35	1.91	1.44
Coal	583.31	626.74	668.50	728.33	764.63	812.74	884.40	961.44	1033.91	1154.75

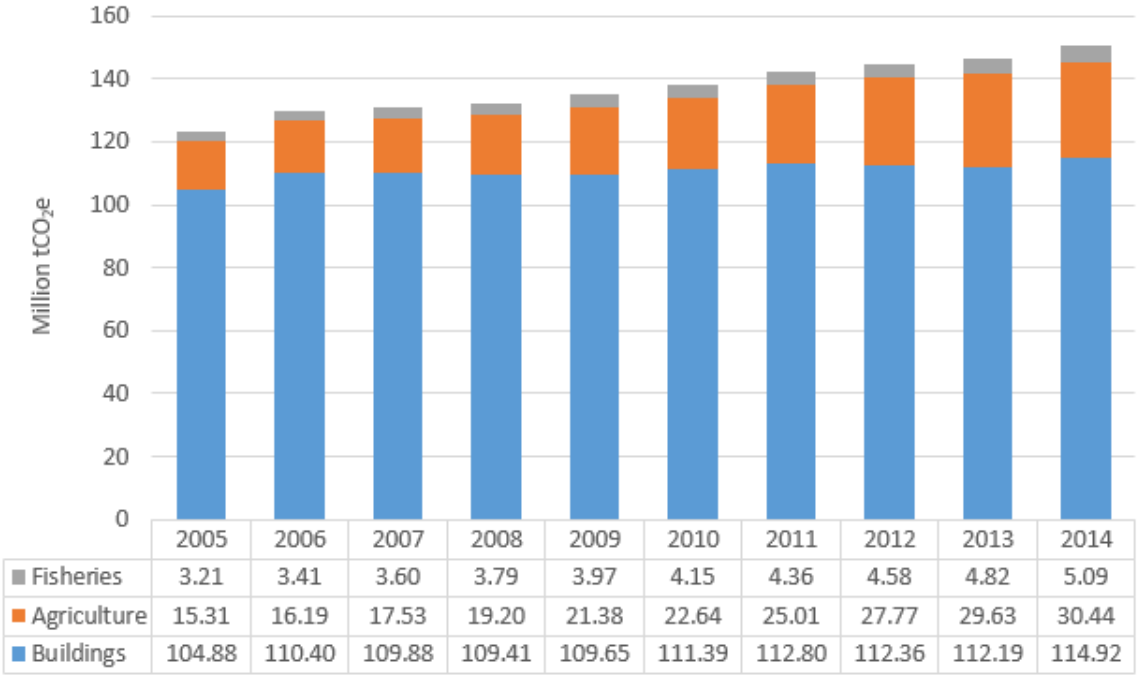
Figure 3: Emissions from Electricity Generation (2005-2014)



	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
Industries	72.65	80.07	84.85	97.24	104.54	119.23	130.27	138.96	145.36	191.20
PEG	594.06	627.69	673.50	717.45	755.76	794.20	852.11	916.34	964.47	1041.76

Figure 4: Emissions from Public Electricity Generation and Industries

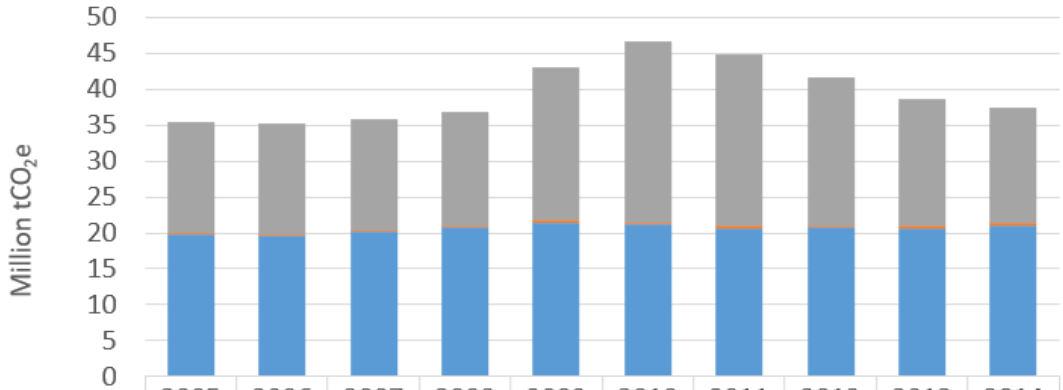
Other sector: Emissions from residential sector is primarily attributed to combustion of LPG, natural gas, diesel, fuelwood and kerosene. Diesel and gas (natural gas and LPG) showcased an increasing trend, while consumption of fuelwood and kerosene decreased between 2005 and 2014. Diesel usage in agricultural sector accounted for more than 95%, while the other fuels (LPG, Furnace oil and LSHS) accounted for the remaining 5%.



	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
Fisheries	3.21	3.41	3.60	3.79	3.97	4.15	4.36	4.58	4.82	5.09
Agriculture	15.31	16.19	17.53	19.20	21.38	22.64	25.01	27.77	29.63	30.44
Buildings	104.88	110.40	109.88	109.41	109.65	111.39	112.80	112.36	112.19	114.92

Figure 5: Emissions from the Other Sector (2005-2014)

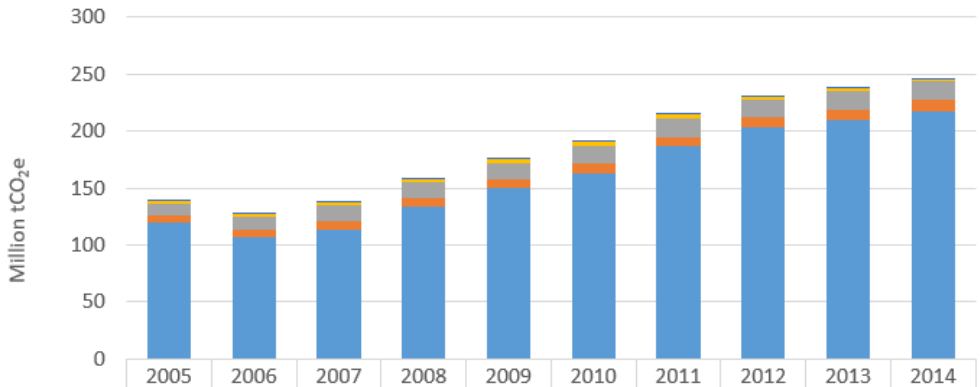
Fugitive: Coal production increased from 400.93 Mt in 2005 to 598.32 Mt in 2014. The share of coal produced from underground mines to surface mines changed from 15% and 85% in 2005 to 8% and 92% in 2014. The increase in the share of emissions from oil and gas extraction between 2009 and 2011 can be attributed to increased production of crude oil and natural gas.



	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
Gaseous Fuels	15.55	15.42	15.54	15.69	21.36	25.18	23.94	20.64	17.68	16.21
Liquid Fuels	0.26	0.26	0.27	0.27	0.27	0.30	0.30	0.30	0.30	0.30
Solid Fuels	19.71	19.62	20.12	20.82	21.49	21.12	20.62	20.78	20.62	21.03

Figure 6: Emissions from Fuel Production - Fugitive (2005-2014)

Transport: Periodical increase in the consumption of motor spirit and HSDO is ascribed to the increasing demand of two wheelers and four wheelers at households. The motor spirit consumption almost doubled between 2005 and 2013, from 8.5 Million tons to 16.7 million tons. Road transport sector contributed to 88% of emissions from transport sector in 2013.



	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
Other Transportation	0.0076	0.0081	0.0089	0.0065	0.0055	0.0038	0.0041	0.0043	0.0040	0.0039
Navigation	2.62	2.69	2.87	3.59	3.90	4.18	3.25	2.38	2.17	2.17
Aviation	9.74	11.93	13.70	13.99	14.29	15.02	16.58	15.99	16.38	16.61
Railways	6.13	6.46	7.10	7.64	8.01	8.39	8.64	8.98	9.33	9.57
Road	120.24	106.49	113.98	133.15	149.69	163.08	186.37	203.10	209.60	217.44

Figure 7: Emission from Transport (2005-2014)

1 ENERGY

Overview of the Sector

The energy sector emissions are broadly classified into two categories: 1A Fuel Combustion Activities and 1B Fugitive Emissions from Fuel Production. Furthermore, 1A examines emissions from energy industries (1A1), Transport (1A3) and Other Sectors (1A4). The total emissions from the energy sector were estimated to be 1667.46 Million tCO_2e in 2014. The associated GHG emissions from all the aforementioned sub-sectors, in 2014, are tabulated below.

Table 5: GHG Emissions in reporting year (2014)

IPCC ID	GHG Source categories	Million tCO_2	Million tCH_4	Million tN_2O	Million tCO_2e
1	Energy				
1A	Fuel Combustion Activities				
1A1	Energy Industries	1595.77	0.97	0.04	1667.46
1A1ai	Electricity Generation	1227.28	0.01	0.02	1232.96
1A3	Transport	240.29	0.04	0.01	245.79
1A4	Other Sectors	127.48	0.91	0.01	150.45
1B	Fugitive Emissions from Fuels				
1B1	Solid Fuels	-	1.00	-	21.03
1B2	Oil & Natural Gas	-	0.79	-	16.51

Boundary of the GHG estimates

The emissions generated in energy sector is estimated and reported within the national boundary of the Republic of India. The total geographic land area 3287469[2] sq.km, as per the 2011 census, with a population of 1210193422 and population density of 382. Between 2001 and 2011, the decadal growth rate of population was estimated to be 17.64[3]. In 2011-12, the Gross Domestic Product at constant 04-05 prices was accounted to be 5351831

[2] Office of the Registrar General and Census Commissioner of India

[3] http://censusindia.gov.in/2011-prov-results/data_files/india/table_1.pdf

crores. The contributions of agriculture, industry, mining & quarrying, and services were 739495, 1442498, 108249, and 3061589 respectively[4].

Overview of Source Categories and Methodology

The energy sector includes emissions from the fuel combustion (1A) and fugitive emissions from fuel production (1B). The sub-sectors within 1A include electricity generation (both public and auto producers) (1A1ai), transport (1A3) and other sector (1A4). The key sources of GHG emissions are both stationary and mobile combustion of fuels (solid, liquid and gaseous fuels) in aforementioned sectors. The methodology for estimating emissions from energy sector is consistent with a combination of tier 1 and tier 2 approaches specified by IPCC. Each sector explained below will provide in-depth explanation on the process adopted to estimate emissions, including emission and conversion factors, as applicable. The following sections provide category and sub-category wise details on the activity data and emission factors.

1.A.1 Energy Industries

1.A.1a Electricity Generation

Category Description

Emissions in this sector pertain directly to the amount of fossil fuels (coal, oil and gas) used for generating electricity in utility-based and auto producer (non-utility) power plants of 1 Mega-Watt (MW) or above. The activity data were sourced primarily from CEA All India Electricity statistics books.

IPCC ID	GHG source & sink categories	Type	Quality	Source
1.	Energy			
1A	Fuel Combustion			
1A1a	Electricity Generation	Secondary	High	CEA All India Electricity statistics

The Net Calorific Value (NCV), Emission Factor (EF) and density of select fuels[5] pertaining to different fuels for generating electricity in Utility and Non-utility power plants are described below.

Table 6: Net Calorific Value and Emission Factors of Fuels

(MoEF, 2010)***(NCV, CO_2)***			(IPCC, 2006)***(CH_4, N_20)***	
Fuel	NCV (TJ/kt)	CO_2 EF (t/TJ)	CH_4 EF (kg/TJ)	N_2O EF (kg/TJ)
Coking coal	24.18	93.61	1.00	1.40
Non-coking coal	19.63	95.81	1.00	1.40
Lignite	9.69	106.15	1.00	1.40
Diesel/LDO[6]	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/ Naptha	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

[4] https://data.gov.in/visualize/?inst=197d689e4c81c5698a48f09a0a98cecd&vid=499#

[5] ppac.org.in/WriteReadData/userfiles/file/conversion_factor.xls

[6] High Speed Diesel (HSD), in this context Diesel and Light Diesel Oil (LDO) are two main grades of diesel fuel that are available in markets in India. The HSD is a 100% distillate fuel, hence referred as diesel, while the LDO is a blend of distillate fuel with select proportion of residual fuel. Gas turbines uses HSD, while LDO is used in diesel engines that are stationary

Aviation Turbine Fuel (ATF)	44.10	71.50	3.00	0.60
LSHS[7]	40.20	73.30	3.00	0.60

Methodology

A mix of Tier 1 and Tier 2 approach of the IPCC methodology is followed to calculate GHG emissions in electricity generation sector. Tier 2 approach is followed for fuels like coal and lignite as India specific emission factors are available. For rest all fuels, Tier 1 approach is followed using internationally available emission factors as summarised above.

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

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

Utilities

- Year-wise activity data is obtained from CEA All India Electricity statistics Reports 04-05 to 14-15 (CEA, 2006; CEA, 2007; CEA, 2008; CEA, 2009; CEA, 2010; CEA, 2011; CEA, 2012; CEA, 2014; CEA, 2015; CEA, 2016).

Non-Utilities

- Year-wise data on electricity generation from auto producers was obtained from CEA All India Electricity statistics.
- To estimate quantity of fuel use, heat rates in industrial plants were assumed to be five percent higher than utilities for each fuel type, based on International Development Finance Corporation's (IDFC) India Infrastructure Report (IDFC, 2010). This translates to lower the capacity of boiler, in MW, higher the station heat rate. Typically, industrial plants operate at low capacity of 10-15 MW; and thus, a conservative five percent increase in heat rate is applied.
- Data on heat rates from utility plants to quantify was obtained from CEA All India Electricity statistics reports (for coal), CEA CO_2 baseline studies (CEA, 2016) (for diesel) and CSE's Challenge of the New Balance (2010) report (for gas) (Bhushan, 2010).

Electricity Generation sector follows a bottom up approach where activity demand of different fuels at state level is specified and it is summed to form the national activity demand. This national fuel-wise activity demand is then multiplied by their respective Net Calorific Value (NCV) and gas specific Emission Factor (EF) to obtain the emission value. The formula used to calculate Greenhouse gas emissions is described below:

$$\text{Emissions}_{\text{Gas}} = \text{Activity Data}_{\text{Fuel}} \times \text{NCV}_{\text{Fuel}} \times \text{Emission Factor}_{\text{Gas}}$$

A set of sample calculation using this equation is provided in Appendix II. Since activity data were available in the financial year format, the data were apportioned by taking the weighted average of one-fourth of preceding year and three-fourth of the succeeding year, to convert into calendar year format.

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

Uncertainty

The activity data is obtained from data collected by government agencies from several power plants that are located across India. These activities take into account of fuels used to generate electricity, in addition to operating hours. Uncertainty in electricity generation arises due to inconsistencies while aggregating numbers and measurement reporting errors. Other reasons for uncertainty could be unit conversion errors associated with reporting data. The below mentioned table shows uncertainty calculated from activity data and emissions factors using propagation of errors approach, published by GoI in NATCOM II (MoEF, 2012).

IPCC Source Category	Sector	Gas	Activity data uncertainty (%)	EF uncertainty (%)	Combined uncertainty (%)
Electricity production	Energy	CO_2	10	5	11.18

Source Category specific QA/QC

Researchers at CSTEP, who worked in this exercise, are well aware of data sources and patterns exhibited by published data on yearly basis. Several measures were undertaken towards quality control process of the estimates. Firstly, to ensure highest level of accuracy, each activity data point was compared with other alternative publications. For instance, in case of electricity generation, fuel consumption data is primarily obtained from Central Electricity Authority. These numbers are compared with other sources such as ministerial reports, and journal articles. Other variables such as heat rate, fuel consumption rate and electricity generated is employed as proxy variables to determine the natural range of the data point.

In select cases, due to lack of activity data, we resort to interpolation methods. Upon calculation, the derived numbers were compared with other sources to ensure that the deviation range is not significant (more than 5%). Despite these control measures, it is important to note that all values are subjected to errors – owing to methods of reporting at the site. This is represented as uncertainty in previous section.

Typically, activity data is reported in a combination of units across different fuels. In such cases, we compute the conventional mass based units, from volumetric units, using suggested conversion factors and physical parameters. All these measures are broadly applied to ensure transparency in data collation, effective representation of activity data and application of data to estimate emissions.

Recalculation

All activity data pertaining to electricity generation are complete and high quality in nature. Therefore, the scope for recalculation in national level estimates is nil, compared to the previous version.

Verification

The GHG estimates were calculated within the national boundary of India. The emissions were calculated using the IPCC 2006 methodology and the methodology was applied consistently in the calculations. The activity data are sourced from credible sources and have been referenced appropriately in the document. The official estimates provide aggregate emissions from electricity generation in the country. The emissions from utility-based and auto producers are not separately provided.

Emissions (Million tCO_2e)	INCCA 2007	CSTEP 2007	% deviation	BUR 2010	CSTEP 2010	% deviation
Total	719	758	5%	820	913	11%

CSTEP's 2006-07 aggregate emission estimates (721 Million tCO_2e) roughly match with the official estimates for 2007. However, the 2009-10 estimates (871 Million tCO_2e) are 6% higher than official numbers. It is worthwhile to note that the 2008-09 estimation (829 Million tCO_2e) is much closer to official estimate for 2010. Since no information about activity data is provided in the BUR, it is possible that the activity data for 2008-09 may have

been used in the 2010 official estimates of emissions from electricity generation, or part of the emissions may have been accounted elsewhere (for example, industry).

Planned improvements

The activity data for 2011-12 will be obtained from CEA officials, on the basis of availability. Further, assumptions on heat rates will be revised depending on the availability of individual plant data (industries).

1.A.3 Transport

Category Description

Emissions from the transport sector are reported under four modes: Road Transportation, Railways, Civil Aviation and Water –borne Navigation. Within each of these modes, emissions from different fuels are separately estimated. The activity data are sourced from Ministry of Petroleum and Natural Gas (MoPNG), Ministry of Statistics and Program Implementation (MoSPI), Ministry of Railways (MoR) and the Emission Factors for each fuel has been sourced from 2006 IPCC Guidelines for National Greenhouse Gas Inventories (IPCC, 2006) . The activity data for the transport sector covers the following sub sectors: 1A3aii (Domestic Civil Aviation), 1A3b (Road Transportation (Fuel based-covering sub sectors 1A3bi to 1A3bvi)), 1A3c (Railways) and 1A3dii (Domestic Water borne navigation)

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	High	MoPNG, MoSPI
1A3c	Railways	Secondary	High	Ministry of Railways, MoPNG, MoSPI
1A3d	Water-borne Navigation	Secondary	High	MoPNG, MoSPI

Methodology

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

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

IPCC 2006 methodology has been followed for calculating emissions from the transport sector. Emissions are obtained by multiplying activity data for a specific fuel or fuel type with its associated Emission Factor (EF).

Emissions = Activity Data * Emission factor

The GHGs accounted for are Carbon Dioxide (CO_2), Methane (CH_4) and Nitrous Oxide (N_2O). Fuel calorific values are obtained from INCCA (2010) report (MoEF, 2010). In case of liquid and gaseous fuels, density assumptions are taken from the Ministry of Petroleum and Natural Gas (MoPNG). The CO_2 emissions ('000 Tonnes) from transport sector are calculated based on the formula given below for each fuel type:

$$Emission_{Coal} = \frac{Coal\ consumption\ (000\ Tonnes) * NCV_{Coal}\left(\frac{Tj}{Kt}\right) * CO_2EF_{Coal}\left(\frac{t}{Tj}\right)}{10^3}$$

$$Emission_{Diesel} = \frac{Diesel\ consumption\ (000\ Tonnes) * NCV_{Diesel}\left(\frac{Tj}{Kt}\right) * CO_2EF_{Diesel}\left(\frac{t}{Tj}\right)}{10^3}$$

$$Emission_{CNG} = \frac{CNG\ consumption\ (MCM) * Density_{CNG}\left(\frac{Kg}{SCM}\right) * NCV_{CNG}\left(\frac{Tj}{Kt}\right) * CO_2EF_{CNG}\left(\frac{t}{Tj}\right)}{10^3}$$

$$Emission_{LPG} = \frac{LPG\ consumption\ (000\ Tonnes) * NCV_{LPG}\left(\frac{Tj}{Kt}\right) * CO_2EF_{LPG}\left(\frac{t}{Tj}\right)}{10^3}$$

$$Emission_{ATF} = \frac{ATF\ consumption\ (000\ Tonnes) * NCV_{ATF}\left(\frac{Tj}{Kt}\right) * CO_2EF_{ATF}\left(\frac{t}{Tj}\right)}{10^3}$$

$$Emission_{Gasoline} = \frac{Gasoline\ consumption\ (000\ Tonnes) * NCV_{Gasoline}\left(\frac{Tj}{Kt}\right) * CO_2EF_{Gasoline}\left(\frac{t}{Tj}\right)}{10^3}$$

$$Emission_{Fuel\ Oil} = \frac{Fuel\ Oil\ consumption\ (000\ Tonnes) * NCV_{Fuel\ Oil}\left(\frac{Tj}{Kt}\right) * CO_2EF_{Fuel\ Oil}\left(\frac{t}{Tj}\right)}{10^3}$$

$$Emission_{LDO} = \frac{LDO\ consumption\ (000\ Tonnes) * NCV_{LDO}\left(\frac{Tj}{Kt}\right) * CO_2EF_{LDO}\left(\frac{t}{Tj}\right)}{10^3}$$

Similarly, for calculating the CH_4 and N_2O emissions the same equations for each fuel have been considered. The emission factors for CO_2 and the specific emission factors with respect to road transportation, railways, water-borne navigation and civil aviation for CH_4 and N_2O are given in detail in the table below:

Emission Factors										
***Net Calorific Value (NCV) & CO_2 Emission Factor* (MoEF, 2010)**			***Road Transportation*** (IPCC, 2006)		***Railways*** (IPCC, 2006)		***Water –borne Navigation*** (IPCC, 2006)		***Civil Aviation*** (IPCC, 2006)	
	NCV	CO_2 EF	CH_4 EF	N_2O EF	CH_4 EF	N_2O EF	CH_4 EF	N_2O EF	CH_4 EF	N_2O EF
	TJ/kt	t/TJ	kg/TJ	kg/TJ	kg/TJ	kg/TJ	kg/TJ	kg/TJ	kg/TJ	kg/TJ
Coal	19.63	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	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 Transportation

- Fuels used: Motor Spirit (petrol), High Speed Diesel Oil (HSDO), Liquefied Petroleum Gas (LPG), Light Diesel Oil (LDO), Furnace Oil (FO), and Compressed Natural Gas (CNG)

- The main source for fuel consumption estimates was MoPNG's Indian Petroleum and Natural Gas Statistics (2011-12 to 2014-15) (MoPNG, 2012) (MoPNG, 2013) (MoPNG, 2014) (MoPNG, 2015)
- For FY 2004-05, 2005-06, 2006-07 sector-wise and mode-wise fuel estimates are not available in the MoPNG reports mentioned above, due to differences in the reporting structure. In this case the 2007-08 shares specific to transport sector of different fuels were considered for 2004-05, 2005-06 and 2006-07. The share considered for ATF and Gasoline was 100% for civil aviation and road transportation. For other fuels, such as HSDO direct, LDO, FO, LPG the shares considered are for the transportation sector are given in detail in the table below:

Transport fuel share estimation									
Fuel Type (000 Tonnes)	2004-05	2005-06	2006-07	2007-08	2007-08 (Transport sector)	%	2004-05	2005-06	2006-07
ATF	2813	3296	3983	4543	4543	100%	2813	3296	3983
HSDO	39650	40191	42896	47669	5002	10%	4161	4217	4501
LDO	1477	883	720	667	36	5%	79	47	38
Motor Spirit	8251	8647	9286	10332	10332	100%	8251	8647	9286
FO	9136	8921	9257	9469	315	3%	304	297	308
LPG	10245	10456	10849	12165	202	2%	170	173	180

Activity wise fuel share estimation								
Fuel Type (000 Tonnes)	2004-05	2005-06	2006-07	2007-08 (Fuel consumption)	2007-08 (% activity wise shares)		2004-05	2005-06	2006-07
ATF	2813	3296	3983	4542.69					
Civil Aviation					100%		2813	3296	3983
HSDO (All Modes of Transport - Direct)	4161	4217	4501	5002.03					
Road				2345.42	46.89%		1951	1977	2111
Railways				2.85	0.06%		2	2	3
Civil Aviation				618.00	12.35%		514	521	556
Water Borne Navigation				2035.76	40.70%		1693	1716	1832
LDO (All Modes of Transport - Direct)	79	47	38	35.54					
Road				0.00	0.00%		0	0	0
Railways				2.35	6.61%		5	3	3
Water Borne Navigation				33.19	93.39%		73	44	36
Motor Spirit	8251	8647	9286	10331.96					
Road					100%		8251	8647	9286
FO	304	297	308	315.02					
Road				54.85	17.41%		53	52	54
Railways				0.00	0.00%		0	0	0
Water Borne Navigation				260.17	82.59%		251	245	254
LPG	170	173	180	201.84					
Road				200.90	99.53%		169	173	179
Railways				0.94	0.47%		1	1	1

- For HSDO, only direct sales are reported in the MoPNG statistics and the retail shares are reported under 'miscellaneous' category. In such a case, the All India Sectoral Demand of Diesel and Petrol report (Nielsen, 2013) by Petroleum Planning Analysis Cell (PPAC) was used to estimate the share of HSDO for retail consumption in road transport in FY 2011-12 and 2012-13 and 2013-14. The retail consumption in road transportation for the years 2006-07 to 2010-11 has been calculated from the aggregate HSDO (direct and retail) reported in MoPNG statistics 2010-11 (MoPNG, 2011). For the

remaining years (2004-05 & 2005-06), statistics from National Institute of Public Finance and Policy's (NIPFP) paper on Diesel Pricing in India (2012) (Anand, 2012) were used.

- For CNG, MoPNG statistics on Natural Gas Activities in India for FY 2007-08 to 2011-12 (MoPNG, 2009) (MoPNG, 2011) (MoPNG, 2012) and Ministry of Statistics and Programme Implementation's (MoSPI) All India Energy Statistics (CSO, 2015) for FY 2012-13 were used. For the year 2013-14, MoPNG statistics was referred for the CNG consumption. FY 2006-07 and 2007-08 data on CNG consumption was abnormally low as per these reports, so historical consumption trends were considered to determine the fuel-use, which turned out to be roughly 64% of total CNG consumption in the domestic sector. For the year 2005-06, CNG consumption for transport sector was considered from the report of the working group for 11th plan on Petroleum and Natural Gas (MoPNG, 2006).

Railways

- Fuels Used: HSDO, LPG, LDO, FO and coal.
- Coal is used for traction in Railways sector.
- The main source for the fuel consumption estimates was the Ministry of Petroleum and Natural Gas' (MoPNG) Indian Petroleum and Natural Gas Statistics (2011-12 to 2014-15) (MoPNG, 2012) (MoPNG, 2013) (MoPNG, 2014) (MoPNG, 2015). As the difference in activity data reported by MoPNG and Indian Railways was comparatively less, MoPNG statistics were used in the analysis. When Indian Railways data were used, the emissions in transport sector varied only by 0.6%. In addition, CSTEP wanted to ensure that the difference between state and national estimates is low and data sources are uniform across both the estimations; therefore, the decision to choose MoPNG over Railways data.
- For FY2004-05, sector-wise and mode-wise fuel estimates are not available in the above reports due to difference in the reporting structure. In this case for transport sector the 2007-08 shares of different fuels were attributed for 2004-05, 2005-06 and 2006-07 (refer to the table above titled 'activity wise fuel share estimation').
- Coal use for traction was obtained from the Ministry of Railways, Indian Railways Year Books 2004-05, 2006-07 to 2013-14 (MoR, 2005) (MoR, 2007) (MoR, 2008) (MoR, 2009) (MoR, 2010) (MoR, 2011) (MoR, 2012) (MoR, 2013) (MoR, 2014)

Civil Aviation

- Fuels Used: ATF and HSDO
- The main source for the fuel consumption estimates was the Ministry of Petroleum and Natural Gas' (MoPNG) Indian Petroleum and Natural Gas Statistics (2011-12 to 2014-15) (MoPNG, 2012) (MoPNG, 2013) (MoPNG, 2014) (MoPNG, 2015)
- For FY2004-05, sector-wise and mode-wise fuel estimates are not available in the reports mentioned above due to difference in the reporting structure. In this case, for transport sector the 2007-08 shares of different fuels were considered for 2004-05, 2005-06 and 2006-07. The share considered for ATF was 100% for civil aviation and for other fuels such as HSDO direct 10% share was considered. Refer to activity share allocation refer to the activity wise fuel share estimation table above.

Water – borne Navigation

- Fuels Used: HSDO, LDO, and FO
- The main source for the fuel consumption estimates was the Ministry of Petroleum and Natural Gas' (MoPNG) Indian Petroleum and Natural Gas Statistics (2011-12 to 2014-15) (MoPNG, 2012) (MoPNG, 2013) (MoPNG, 2014) (MoPNG, 2015)For FY2004-05, sector-wise and mode-wise fuel estimates are not available in the reports mentioned above due to difference in the reporting structure. In this case for transportation sector the 2007-08 shares of different fuels were considered for 2004-05, 2005-06 and 2006-07. Refer to activity share allocation refer to the activity wise fuel share estimation table above.

Since activity data were available in financial year format, the data were apportioned by applying the weighted average of three-fourth of preceding year and one-fourth of the succeeding year, to convert into calendar year format, using the equation below:

CY Emissions $_t$= (1/4 x FY Emissions $_t$) + (3/4 x FY Emissions $_{t+1}$)

Uncertainty

Uncertainty could have arisen due to lack of completeness in activity data, especially of fuels such as HSDO retail which has a dominant share of fuel consumption in road transportation sector. In order to minimise the uncertainty, activity data has been compiled from multiple sources (Nielsen, 2013) (MoPNG, 2011) (Anand, 2012). Other reasons include measurement error, misreporting (HSDO retail versus HSDO) and missing data points in the activity data. Below mentioned table shows uncertainty calculated from activity data and emissions factors using propagation of errors approach, published by GoI in NATCOM II (MoEF, 2012).

IPCC Source Category	Sector	Gas	Activity data uncertainty (%)	EF uncertainty (%)	Combined uncertainty (%)
Road Transport	Energy	CO_2	5	0	5

Source Category specific QA/QC

Activity data for transport sector was obtained from MoPNG statistics and other peer reviewed journal papers and reports. It was evident that the datasets were inundated with gaps and aberrations. Having worked in this sphere, we resorted to alternative sources of publications to iron out aberrations and inconsistencies. In addition, with the use of Right to Information act, we filled request to data for activities that required additional validation. Upon receipt, gaps in HSDO consumption in Railways, for example, was resolved and verified with Indian Railways Statistics Publications (MoR, 2014-15).

In select cases, like civil aviation, CO_2 emissions estimates were validated with the Civil Aviation's Carbon footprint of Indian Aviation report (Director General of Civil Aviation, 2013) and similarly IPCC default emission factors for mobile combustion were validated with International Civil Aviation Organisation's Guidance Material for the Development of State Action Plan report (2011) (International Civil Aviation Organisation, 2011). These validations played a significant role is asserting quality control on the emissions estimates, due to heavy reliance on activity data.

Recalculation

The national level emission estimations were revised from Phase I due to the inclusion of new sources that assures accurate and complete estimates. As agreed by the consortium partners, sub-sectoral emissions with more than 5% deviation in Phase II estimates when compared with Phase I is reported under recalculation section.

S.No	IPCC Category	Values/Assumptions in Phase I	Recalculation in Phase II
I	1A3b	The share of retail HSDO consumption was calculated based on assumptions from various sources as documented in phase I methodology note.	For the years 2006-07 to 2010-11, MoPNG statistics (MoPNG, 2011), gives HSDO direct and retail consumption as aggregate value. The values were segregated using the methodology detailed above.

The difference in GHG emissions as compared to the previous reporting years are tabulated below.

Comparison	2007	2008
Emissions from Road Transportation (Million tCO2e)		
Phase II estimates	113.98	133.15

Phase I estimates	140.39	142.60
Difference (%)	-18.81%	-6.63%
Emissions from Transportation sector (Million tCO2e)		
Phase II estimates	137.66	158.38
Phase I estimates	164.10	167.87
Difference (%)	-16.11%	-5.65%

Changes in activity data:

Sector	Fuel	Estimates	Unit	2007	2008
Road-Transport	HSDO-Retails	Phase II	000 tonnes	22283	27131
		Phase I	000 tonnes	30433	30046
		Deviation	%	27%	10%

Verification

Activity data and emission factor data has been considered from government reports that are available in public domain and the reference for each report was given along with the assumptions considered.

The total emissions for 2007 and 2010 were compared with INCAA and BUR values. CSTEP's 2007 aggregate emission estimates are almost 3% lesser than official numbers. However, for 2010, estimates have increased by 1% than the official numbers. From the tables above, it is evident that road transport sector is the highest contributor to the total emissions. The higher estimates for 2006-07 can be attributed to the assumption of HSDO retail share from road transport.

Emissions (Million tCO_2e)	INCCA 2007	CSTEP 2007	% deviation	BUR 2010	CSTEP 2010	% deviation
Road	124	114	-8%	164	163	-1%
Aviation	10	7	-29%	12	8	-30%
Rail	7	14	96%	8	15	85%
Navigation	1	3	187%	4	4	5%
Total	142	138	-3%	188	190	1%

Planned improvements

The latest primary survey conducted by PPAC on HSDO retails is available only for 2012-13. The data from the survey has been used for calculating the activity data for 2013 and 2014. This data can be updated based on the new primary surveys conducted after 2012-13. Any revisions in activity data is credible, if and when revised fuel consumption estimates get published by government agencies or peer-reviewed journals.

1.A.4 Other sectors

Category Description

Other sectors include energy consuming activities in residential, commercial, agricultural and fisheries sectors. The activity data for this sector represents the fuel consumption used for specific applications such as cooking, lighting, heating, use of small (< 1 MW) Diesel Generator (DG) sets, drying of field produce, operation of tractors, diesel pump-sets, other farm implements, and fishing fleet. The main sources considered for the activity data in other sectors were from MoPNG and MoSPI.

IPCC ID	GHG SOURCE & SINK CATEGORIES	TYPE	QUALITY	SOURCE
1.	**Energy**			
1A	**Fuel Combustion**			
1A4	Other Sectors			
1A4a	Commercial/ Institutional	Secondary	High	MoPNG, MoSPI
1A4b	Residential	Secondary	High	MoPNG, MoSPI
1A4c	Agriculture/ Fishing[8]	Secondary and Tertiary	High	MoPNG, MoSPI

The emission factors and Net Calorific Value (NCV) are obtained from INCAA report (MoEF, 2010) and IPCC 2006 guidelines (IPCC, 2006)

Fuel type	NCV (TJ/kt)	Emission Factors		
		CO_2 EF (t/TJ)	CH_4 EF (kg/TJ)	N_2O EF (kg/TJ)
Coking coal/Coke	24.18	93.61	300.00	1.40
Diesel/LDO	43.00	74.10	10.00	0.60
Charcoal	29.50	112.00	200.00	1.00
Kerosene	43.80	71.90	10.00	0.60
Fuel oil	40.40	77.40	10.00	0.60
Natural Gas/PNG	48.00	56.10	5.00	0.10
LPG	47.30	63.10	5.00	0.10
LSHS	41.91	74.68	10.00	0.60
Wood/Biomass	15.67	0.00	300.00	4.00

In select fuels, density is used to determine the quantity (activity data), and these factors are provided in the below table.

Fuel type	Density	Unit	Source
Diesel	1.21	kL/t	PPAC[9]
PNG	0.76	kg/SCM	PPAC[10]

Methodology

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

[8] Energy related aspects of agriculture and fishing, e.g. use of diesel/ electricity in agricultural pumps and use of diesel for mobile combustion related to fishing.

[9] http://petroleum.nic.in/docs/readyrecknor_May14.pdf

[10] ppac.org.in/WriteReadData/userfiles/file/conversion_factor.xls

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

IPCC 2006 methodology has been followed for calculating emissions from the sectors mentioned above. The reporting structure followed is similar to INCCA (2010) report. Emissions are obtained by multiplying activity data for a specific fuel or fuel type with its associated Emission Factor (EF). The GHGs accounted for are Carbon Dioxide (CO_2), Methane (CH_4) and Nitrous Oxide (N_2O). The emissions were converted into its equivalent terms of GWP and GTP. Fuel calorific values are obtained from INCCA (2010) report. In case of liquid and gaseous fuels, density assumptions are taken from the Ministry of Petroleum and Natural Gas (MoPNG).

$$Emissions_{CO2}(t) = Activity\ Data(TJ) * Emission\ factor_{CO2}(\frac{t}{TJ})$$

$$Emissions_{CH4}(t) = \frac{Activity\ Data(TJ) * Emission\ factor_{CH4}(\frac{kt}{TJ})}{1000}$$

$$Emissions_{N2O}(t) = \frac{Activity\ Data(TJ) * Emission\ factor_{N2O}(\frac{kt}{TJ})}{1000}$$

$$Emissions_{Co2e}(GWP) = Emissions_{CO2} + GWP_{CH4} *\ Emissions_{CH4} +\ GWP_{N2O} * Emissions_{N2O}$$

$$Emissions_{Co2e}(GTP) = Emissions_{CO2} + GTP_{CH4} *\ Emissions_{CH4} +\ GTP_{N2O} * Emissions_{N2O}$$

Residential and Commercial

Fuelwood, Coke Coal and Charcoal

- Per Capita Monthly Consumption (PCMC) of fuelwood, coke, coal and charcoal for rural and urban households were obtained from NSSO's 61st (2004-05) 62nd (2005-06), 63rd (2006-07)[11], 66th (2009-10) and 68th (2011-12) rounds (NSSO, 2007; NSSO, 2012; NSSO, 2015)
- PCMC for 2008-09 was taken from NSSO's 64th round which was cited in TERI Energy Data Directory & Yearbook (TEDDY) (TERI, 2010)
- PCMC for 2007-08 was linearly interpolated by taking the average value from 2006-07 and 2008-09 data, and PCMC for 2012-13, 2013-14 and 2014-15 were extrapolated using CAGR (2009-10 to 2011-12)
  CAGR was calculated using the following formula:
  $$CAGR = (\frac{Ending\ Value}{Beginning\ Value})^{\frac{1}{No\ of\ years}} - 1$$
- The PCMC was converted to aggregate absolute fuel consumption using population data from Census 2001 and 2011 rounds (Chandramouli, 2011) and World Bank Database, and year-wise urbanization rate from United Nations Department of Economic Affairs (2014) (World Urbanization Prospects: The 2014 Revision, n.d.; Data: Population growth (annual %), n.d.).

  For example, the total consumption of fuelwood consumed in residential sector is calculated as shown below:
  $$Fuelwood_{RURAL} = PCMC_{FUELWOOD\_RURAL} * Rural\ Population * No\ of\ months\ in\ a\ year$$
  $$Fuelwood_{URBAN} = PCMC_{FUELWOOD\_URBAN} * Urban\ Population * No\ of\ months\ in\ a\ year$$
  $$Total\ Fuelwood\ Consumption\ (kg) = Fuelwood_{RURAL} +\ Fuelwood_{URBAN}$$
  $$Total\ Fuelwood\ Consumption\ (TJ) = TotalFuelwood\ Consumption\ (kg) *\ NCV_{FUELWOOD}\ (TJ)/1000$$

  The same formula is applied to calculate the total consumption of coke, coal and charcoal too.

LPG

[11] Raw data from Household Consumer Expenditure, NSS 62nd and 63rd rounds were procured from National Sample Survey Office and were analyzed for the following household cooking and lighting fuels: LPG, Firewood and chips, Kerosene, Coke, Coal and Charcoal

- Data for FY 2004-05 to 2013-14 was obtained from three MoPNG's Petroleum and Natural Gas Statistics Reports –
    - FY 2004-05 to 2006-07 - (MoPNG, 2009)
    - FY 2007-08 to 2013-14 - (MoPNG, 2014)
    - FY 2014-15 - (MoPNG, 2016)
- Data for commercial sector in FY 2004-05 was obtained from an MoPNG presentation (Chandra, 2010)
- Data point for commercial sector consumption in 2006-07 was linearly interpolated between the data of 2004-05 and 2007-08. The difference in value between 2004-05 and 2007-08 were divided equally for the years 2005-06 and 2007-08

Kerosene

- Data for FY 2004-05 to 2013-14 obtained from MoPNG's Petroleum and Natural Gas Statistics (MoPNG, 2009; MoPNG, 2014; MoPNG, 2016)

Natural Gas

- Data for domestic usage of Piped Natural Gas (PNG) for FY 2005-06 to 2014-15 was obtained from NITI Aayog website (NITI Aayog, 2015)
- Data for PNG in FY 2004-05 was taken from SITI Energy Limited (SITI Energy Limited, 2017)
- Quantity of commercial sales of PNG was calculated as a residual after deducting domestic and transport sectors share from the total sales of City Gas Distribution (CGD) as reported in MoPNG statistics

$$PNG\ Sales_{\ COMMERCIAL} = Total\ sales\ by\ CGD\ - Sales\ of\ CNG\ -\ PNG\ Sales_{DOMESTIC}$$

Diesel

Diesel consumption from Diesel Generator (DG) sets is not directly available.

A study conducted by Nielson for PPAC observes that 4.3% of diesel retails account for the DG sets in residential and commercial sector (Nielsen, 2013).

The different quantities of diesel consumed by DG sets of different capacity categories (1-19 kilo-Watt (kW), 19-75 kW, and 75-800 kW) in 2012-13 were obtained from a study by ICF International (ICF International, 2014).

Based on expert consultation, DG sets in the categories up to 75 kW are assumed to operate in households; higher sizes used in commercial enterprises. The percentage share of diesel sold to DG sets up to 75kW (33.9%) was taken as a thumb rule to calculate the diesel used in residential sector. The remaining percentage was accounted to calculate the diesel consumption in commercial sector. The shares of diesel in residential (33.9%) and commercial sectors (66.1%) were calculated from the values reported in study by ICF International for various capacities of DG sets (ICF International, 2014)

ThereT are veryvery few studies available in public domain on the 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 as representative of growth in diesel consumption across the years.

Agriculture

LSHS, Furnace Oil and LPG

- Data for FY 2004-05 to 2013-14 obtained from MoSPI's Petroleum and Natural Gas Statistics Reports (MoPNG, 2009; MoPNG, 2014; MoPNG, 2016).

Diesel (HSDO and LDO)

- Bulk sale of diesel to the sector for FY 2007-08 to 2012-13 obtained from MoPNG's Petroleum and Natural Gas Statistics Reports of 2013-14 and 2014-15 (MoPNG, 2014; MoPNG, 2015)

- According to the study conducted by Nielson for PPAC, the share of diesel consumed by tractors, agricultural pump sets and implements from retail sale in 2012-13 was 14.11% (Nielsen, 2013). The total diesel consumed in agricultural sector for FY 2008-09, 2009-2010, 2010-11 and 2012-13 were reported by National Institute of Public Finance Policy (NIPFP) and Nielson (Anand, 2012; Nielsen, 2013). The percentage share of diesel (retails) consumed in agriculture sector were calculated for the remaining years.

$$Share\ of\ diesel\ consumed\ from\ retails\ (\%) = \frac{Share\ of\ diesel\ consumed\ in\ agriculture\ sector\ *\ share\ of\ diesel\ consumed\ from\ retails_{2012-13}}{Share\ of\ diesel\ consumed\ in\ agriculture\ sector_{2012-13}}$$

Fisheries

Diesel

- Total diesel consumption (in Million Litres) by Indian fishing fleets in 2005 and 2010 were reported in an academic research journal paper (E. Vivekanandan, 2013).
- The intermediate and future years up to 2014 are obtained through interpolation and extrapolation method by applying the CAGR of 6.64% between the time period of 2005 and 2010.
- Diesel consumption (in Million Litres) is converted in terms of '000 tonnes by dividing it with density of diesel.

Kerosene

- 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 motorized vessels (inboard engines) versus mechanized 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 motorized boats in India. So, this state is taken as representative for India, and absolute kerosene consumption is for India is estimated. Tamil Nadu, Kerala and Andhra Pradesh have 27%, 20% and 15% of the total motorized boats in India in 2014-15.

In cases where activity data were unavailable for intermediate years, existing data was interpolated linearly to calculate the activity data. The difference in the data between two years was equally distributed in the intermediate years.

Since activity data were available in financial year format, the data were apportioned by taking the weighted average of three-fourth of preceding year and one-fourth of the succeeding year, to convert into calendar year format.

Uncertainty

Given the average quantity of LSHS consumed in the other sector, the implications LSHS will have on emissions will be insignificant. However, it is imperative to state that LSHS is used only in the agricultural sub-sector.

Charcoal and natural gas are used in residential and commercial establishments for cooking activity, and uncertainty in these fuels represents a small fraction of emissions from residential sector. Other reasons may include aggregation errors and measurement inaccuracy. Below mentioned table shows uncertainty calculated from activity data and emissions factors using propagation of errors approach, published by GoI in NATCOM II (MoEF, 2012).

IPCC Source Category	Sector	Gas	Activity data uncertainty (%)	EF uncertainty (%)	Combined uncertainty (%)
Residential, Agriculture & Fisheries	Energy	CO_2	25	5	25.49

Residential	Energy	CH_4	10	150	150.33

Source Category specific QA/QC

The quality of data is maintained by the reliability of the source of the data. The activity data, emission factors and assumptions made are collected from reports published by government departments, peer-reviewed international statistics documents, peer-reviewed and published academic research works and information disseminated by technology suppliers. The data were validated from other publicly available sources. For example, kerosene consumption data in residential sector for 2006-07 was validated from a report published by International Institute for Sustainable Development (IISD) (Clarke, 2014). Owing to limitations in availability of select fuels like charcoal and kerosene (household) data, interpolation method was applied to bridge identified gaps. These data points are validated with experts' solicitation through interviews and other literature. Similarly, India State of Forest (2011) report published by Forest Survey of India (FSI) reported some data on household fuel-wood consumption, which was found to be in line with NSSO's consumption surveys (FSI, 2011).

Recalculation

The national level emission estimations were revised from Phase I due to the inclusion of new sources that assures accurate and complete estimates. As agreed by the consortium partners, sub-sectoral emissions with more than 5% deviation in Phase II estimates when compared with Phase I is reported under recalculation section.

IPCC Code	Name of sub-sector	Values/Assumptions in Phase I	Recalculation in Phase II
1A4a	Commercial/ Institutional	Kerosene oil consumption in commercial sector didn't account for the 'other 'category accounted by MoPNG which includes the small commercial activities like painting, termite protection, etc.	Kerosene oil consumption in commercial sector recalculated by adding the quantity specified in 'other' category in line with MoPNG and PPAC.
1A4a	Commercial/ Institutional	Natural gas consumption in commercial sector was not accounted for in the earlier version.	Natural gas consumption in commercial sector is assumed as the quantity consumed by City Gas Distribution (CGD) after excluding CNG in transport and PNG for domestic usage.
1A4a	Commercial/ Institutional	Diesel consumption in DG sets of commercial sectors were calculated based on ICF report	The values are recalculated based on PPAC's Nielson report.

The difference in GHG emissions as compared to the previous reporting years are tabulated below.

	2007	2008	2009	2010	2011	2012
Emissions from commercial sector (Million tCO_2e)						
Revised estimates	5.46	6.11	6.99	7.79	8.44	9.11
Old estimates	6.82	7.51	8.46	9.44	10.34	11.26
Difference (%)	-19.94%	-18.64%	-17.38%	-17.48%	-18.38%	-19.09%

Changes in Activity Data:

Sector	Fuel	Estimates	Unit	2007	2008	2009	2010	2011	2012

Commercial	Kerosene	Phase II	000 tonnes	204	179	195	205	189	160
		Phase I	000 tonnes	139	79	63	68	63	43
		Deviation	%	-47%	-127 %	-212%	-204%	-203%	-272%
Commercial	HSDO	Phase II	000 tonnes	997	1098	1208	1330	1464	1611
		Phase I	000 tonnes	1490	1640	1805	1987	2186	2407
		Deviation	%	33.1%	33.1%	33.1%	33.1%	33.1%	33.1%
Commercial	Natural gas	Phase II	BCM	1.29	1.30	1.96	2.34	2.90	3.00
		Phase I	BCM	0.00	0.00	0.00	0.00	0.00	0.00
		Deviation	%	100%	100%	100%	100%	100%	100%

Verification

The GHG estimates were calculated within the national boundary of India. The emissions were calculated using the 2006 IPCC guidelines for national GHG inventories methodology and the methodology was applied consistent in the calculations. The activity data are sourced from credible sources and have been referenced appropriately in the document.

The emissions reported in 2007 INCAA and 2010 BUR were compared with the calculated emission estimates for the residential, commercial, agriculture and fisheries sectors. It can be seen that the emissions from residential and agriculture/fisheries sector have reduced by 24% and 56%, respectively from 2007 to 2010. Given that non-electric energy consumption in these sectors has increased over the years based on official documents, it can be inferred that the reduction reported between 2007 and 2010 can be attributed to change in accounting and/or reporting method. The emissions from commercial sector have increased by 42% during this period, whereas the overall emissions have reduced by 47%.

Emissions (Million tCO_2e)	**INCCA 2007**	**CSTEP 2007**	**% deviation**	**BUR 2010**	**CSTEP 2010**	**% deviation**
Residential	138	104	-24%	85	104	22%
Commercial	2	5	173%	5	8	56%
Agriculture/Fisheries	34	21	-38%	3	27	793%
Total	173	131	-24%	92	138	50%

CSTEP's 2007 estimates for residential and agriculture/fisheries sector are 24 and 38% less, whereas the commercial sector estimates are over two times more than official estimates. CSTEP's 2010 estimates are 50% higher than the official estimates. The emissions from residential, commercial and agriculture/fisheries sector are higher by 22%, 56% and 793% respectively compared to official estimates.

Our activity data suggests that in the residential sector, while the growth of some dominant fuels such as fuelwood and kerosene was negative 2007 and 20102, others such as LPG, coke, coal, natural gas and diesel registered a healthy growth3. This is owing primarily to increased electrification, higher share of modern cooking fuels (LPG, PNG) and increased use of Diesel Generator (DG) sets. As a result, emissions from this sector have increased between 2007 and 2010. In the commercial sector, our analysis indicates that the use of captive DG sets has been growing at 10% CAGR over the past decade, and they contribute to around 70% emissions from this sector. In the agriculture and fisheries sector, 98% of emissions are from diesel use, which has grown at around 6% CAGR between 2007 and 2010. The retail sales of diesel and other oil products that form a substantial part of end-use are not segregated sector-wise in the annual statistics of MoPNG. This may be the reason why emissions from such activities may not be accounted for in the official documents.

Given the multiplicity of data sources and requirement of making various assumptions and interpolations to arrive at the time series of activity data (due to different reporting formats and incompleteness of data), it is

possible that the assumptions between CSTEP's and MoEF's estimates, vary, leading to inconsistent results. CSTEP has used publically available and official sources for activity data to the extent possible. Neither application-wise, non-sector-wise activity data is provided in any of the MoEF documents for this sector, so any further conjecture on the observed differences is not feasible.

Planned improvements

Since, the latest NSSO 'Consumer Expenditure' survey on fuel used in household cooking and lighting was conducted in 2011-12, PCMC of fuelwood, coke, coal and charcoal were extrapolated using CAGR between 2009-01 and 2011-12. The PCMC of these fuels for the time period after 2011-12 will be updated based on the next round of NSS 'Consumer Expenditure' survey. Similarly, latest PNG sales data for domestic and commercial sectors will be updated based on the data that will be published by PPAC.

1.B Fugitive emissions from fuels

Category Description

Fugitive (Fuel Production) emissions are estimated from mining, transportation, storage and processing of solid, liquid and gaseous fuels. The activity data were sourced from Ministry of Coal and MoPNG.

IPCC ID	GHG SOURCE & SINK CATEGORIES	TYPE	QUALITY	SOURCE
1.	**Energy**			
1B	Fugitive emissions from fuels			
1B1	Solid fuels	Secondary	High	Ministry of Coal
1B1a	Coal mining and handling			
1B2	Oil & Natural Gas	Secondary	High	Ministry of Petroleum and Natural Gas
1B2a	Oil			
1B2b	Natural Gas			

Activity wise emission factors are obtained from government report published in 2010 (MoEF, 2010). This includes emissions from both solid (coal) fuels and oil & natural gas production, as listed below:

Type of Fuel		Activities		Emission factor	Unit (CH_4)
Solid Fuels	Underground Mines	Mining	Deg I	2.91	m^3/tons
			Deg II	13.08	
			Deg III	23.64	
		Post-Mining	Deg I	0.98	
			Deg II	2.15	
			Deg III	3.12	
	Surface Mines	Mining		1.18	
		Post-Mining		0.15	
Oil & Natural Gas	Oil	Number of Wells		0.003	Gg/well
		Oil Production		0.000334	Gg/'000tons
		Refinery Throughput		6.75904×10^{-5}	Gg/Mt
	Natural Gas	Gas Production		0.003556	Gg/MMCM
		Gas Processing		0.010667	Gg/MMCM
		Gas Distribution		0.010667	Gg/MMCM
		Leakage		0.006482	Gg/MMCM
		Flaring		0.000641	Gg/MMCM

To convert one volume of methane from coal mining to ton (weight), a conversion factor of 0.0006802[12] is applied as per the US Environmental Protection Agency Interactive Units Converter Coalbed Methane Outreach Program (CMOP).

[12] http://www.mdpi.com/2071-1050/4/9/1966/htm

Methodology

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	D	T1	D	T1	D
1B2	Oil & Natural Gas	T1	D	T1	D	T1	D
1B3	Other emissions from energy productions	T1	D	T1	D	T1	D

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

Solid Fuels

- Data for total coal mined from Underground (UG) and Open Cast (OC) mines, in addition to the share of UG and OC coal, are obtained from Provisional Coal Statistics report published by Ministry of coal (Coal Controller's Organisation, 2016).
- As per the activity list obtained from INCCA report ((MoEF, 2010), emissions occur at two stages while coal is produced – (a) during coal mining and (b) post-mining within the boundary of coal mines.
- To estimate emissions from coal mining in OC mines, share of coal produced from OC mines is multiplied with the emission factor (mining and post mining as two different activities) to obtain volume of methane emissions generated. This value is further converted to weight, in tons, using a conversion factor of 0.0006802 (referred in category description).
- It is important to note that coal production from UG mines is not available at various depths, Typically, coal production from UG mines occur at three levels of depth, and emission factors are provided at three levels – in this case referred as 'degree of gassiness'. Therefore, we have assumed a share of 33.33% at each level, to account for total coal produced from UG mines. The same can be noted in the formula given below:

$$Emissions\ from\ UG\ Coal\ Mining_{CH4}(t) = \sum_{i=0}^{3}(Activity\ Data(tons) * EF\ Mining_{i_{CH4}}\left(\frac{m^3}{tons}\right) * 0.0006802 tonsCH4 * Share_i)$$

$$Emissions\ from\ UG\ Coal\ Post\ Mining_{CH4}(t) = \sum_{i=0}^{3}(Activity\ Data(tons) * EF\ Post\ mining_{i_{CH4}}\left(\frac{m^3}{tons}\right) * 0.0006802 tonsCH4 * Share_i$$

$$Emissions\ from\ OC\ Coal\ Mining_{CH4}(t) = \left(Activity\ Data(tons) * EF\ Mining\ _{CH4}\left(\frac{m^3}{tons}\right) * 0.0006802 tonsCH4\right)$$

$$Emissions\ from\ OC\ Coal\ Post\ Mining_{CH4}(t) = \left(Activity\ Data(tons) * EF\ Post\ mining\ _{CH4}\left(\frac{m^3}{tons}\right) * 0.0006802 tonsCH4\right)$$

Liquid and Gaseous Fuels

- Data on the number of wells, oil produced and refinery throughput are obtained from MoPNG's Petroleum and Natural Gas Statistics reports (MoPNG, 2016).
- Data on the amount of natural gas produced, flared, processed, and distributed is also derived from MoPNG's Petroleum and Natural Gas Statistics reports (MoPNG, 2016). Natural gas processed is what is available after deducting the portion of gas flared from total production. Own consumption of natural gas is deducted from this figure to arrive at the amount of natural gas distributed. The leakage rate is 1.65% of the gross production of natural gas as reported in a memo titled 'Fugitive Methane and Greenhouse Warming' (Muller).

$$Emissions\ from\ Oil\ Extraction_{CH4}(t) = \left(Oil\ Production('000tons) * EF_{CH4}\left(\frac{Gg}{'000tons}\right)\right) + \left(Refinery\ Throughput(MMTA) * EF_{CH4}\left(\frac{Gg}{Milliontons}\right)\right) + \left(Number\ of\ Wells * EF_{CH4}\left(\frac{Gg}{well}\right)\right)$$

$$Emissions\ from\ Natural\ Gas\ Extraction_{CH4}(t) = \left(NG\ Production(MMCM) * EF_{CH4}\left(\frac{Gg}{MMCM}\right)\right) + \left(NG\ Distribution(MMCM) * EF_{CH4}\left(\frac{Gg}{MMCM}\right)\right) + \left(NG\ Consumption(MMCM) * EF_{CH4}\left(\frac{Gg}{MMCM}\right)\right) + \left(Flaring(MMCM) * EF_{CH4}\left(\frac{Gg}{MMCM}\right)\right) + \left(Leakage(MMCM) * EF_{CH4}\left(\frac{Gg}{MMCM}\right)\right)\right)$$

Since activity data were available in financial year format, the data were apportioned by taking the weighted average of one-fourth of preceding year and three-fourth of the succeeding year, to convert into calendar year format.

Uncertainty

Uncertainty in fuel production can be attributed to missing data (leakage) and detailed coal production data from UG mines (on the basis of depth). Other sources include aggregation errors and measurement inaccuracies. Furthermore, methane emissions from venting, flaring and coal mines (seam gas) must be collected in different time-intervals to establish additional relationships with activity data and emission factors.

Source Category specific QA/QC

The quality of data is maintained by the credibility of the source of the data. The activity data, emission factors and assumptions made are collected from reports published by government and research institutes/individual academic research works. Barring validations, typical production trends are used to compare and validate data points. For example, a general 1.65% leakage rate was assumed to quantify 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.

Recalculation

Based on the current estimates reported by MoPNG (MoPNG, 2016), the activity data pertaining to number of wells (oil) and natural gas distribution (NG) are updated from 2009 onwards. In this table below, the revised estimates indicate the current results, while the old estimates represent the results from Phase I exercise.

	2009	2010	2011	2012
Emissions from Oil Extraction (Million tCO_2e)				
Revised Estimates	0.2714	0.2950	0.3030	0.3004
Old Estimates	0.2720	0.2960	0.3054	0.3032
Emissions from Natural Gas Extraction (Million tCO_2e)				
Revised Estimates	21.3626	25.1786	23.9359	20.6360
Old Estimates	21.3605	25.1775	23.9359	20.6360

Verification

The GHG estimates were calculated within the national boundary of India. The emissions were calculated using the IPCC 2006 methodology and the methodology was applied consistent in the calculations. The activity data are sourced from credible sources and have been referenced appropriately in the document. For select years (2007 and 2010), the results are verified with government estimations; with less than 5% deviation. CSTEP's estimates for 2007 and 2010 are comparable to the national estimates published by GoI (INCCA and BUR). The slight difference may be due to the assumptions considered for natural gas leakage and distribution.

Emissions (Million tCO_2e)	INCCA 2007	CSTEP 2007	% deviation	BUR 2010	CSTEP 2010	% deviation
Fugitive	32	36	12%	49	47	-5%

Planned improvements

Rather than equal apportionment, the real values of production of coal from UG mines for all three degrees must be used to improve the estimates of emissions from coal production from UG mining and post mining. We hope to integrate this change, depending on the response from coal controllers' organisation in Kolkata.

Public Consultation & Outreach

As part of the outreach activity, the following experts were contacted to collect the activity data and relevant assumptions.

Name	Designation and Institution	Date
Mr. Rohit Dawar	Additional Director (Demand & Economic Studies), Petroleum Planning & Analysis Cell (PPAC)	06-12-2016
Dr.Udaya S Mishra	Professor, Centre for Development Studies	08-03-2017
Mr.Balakrushna Padhi	PhD student, Jawaharlal Nehru University	22-03-2017
Dr.Leela Edwin	Principal Scientist, Central Marine Fisheries Research Institute	18-04-2017
Dr.Gopalakrishnan	Director, Central Marine Fisheries Research Institute	05-05-2017
Dr.Kaushik Basu	Assistant Professor, National Law School of India University	05-05-2017
Dr.Indrajit Bairagya	Assistant Professor, Institute for Social and Economic Change	05-05-2017
Mr. A.V. Srinivasan	Consultant-Engine and genset manufacturing (Cooper Corporation)	30-05-2017

Apart from individual meetings with experts, CSTEP researchers organised (refer S.no. 1 in table below) and participated in stakeholder consultations organised by partner institutions in the GHG India Platform.

S.No	Title	Organiser	Date	Venue
1	Workshop on GHG Platform – India: Energy	CSTEP and CEEW	Jan 24, 2017	Hotel Taj Vivanta, Bangalore
2	Workshop on GHG Platform – India: Waste and Industrial Emissions	ICLEI	Feb 3, 2017	Hotel Kenilworth, Kolkata
3	Workshop: GHG Platform India (Energy, IPPU, Waste and AFOLU)	WRI India	Mar 17, 2017	WRI Office, Mumbai
4	Roundtable Consultation of "GHG Emission Estimations Experts"	Vasudha Foundation	April 6, 2017	Amaltas Hall, India Habitat Center, New Delhi

Recommendations

Though government reports provide data required for building emission inventory, there are various data gaps in activity data and country specific emission factors. To build a robust database, the following recommendations are made.

a. In order to increase the reliability of data on national emissions, MoEFCC should consider developing 'country-specific' emission factors using real-time measurements across all the sectors. At present, most of the factors employed are either defaults or global estimates.
b. The activity data specific to diesel consumption in the transport sector needs to be disaggregated, instead of aggregating into 'miscellaneous' header. Thus, itit is recommended that when the related ministry collects data, the aggregated numbers must be broken down based on sectoral consumptions such as transport, telecom, commercial, fisheries etc.
c. CNG and PNG consumption across different sectors needs to be captured and cited diligently in assessment reports (BUR, INCCA), since the usage of alternative fuels is gaining traction within the economy. At present, all gaseous fuels are listed as one item – Natural Gas City sector in MoPNG reports.
d. In order to estimate reliable sector-specific emissions, the respective ministries should consider providing the absolute quantity of subsidized fuels. For example, in fisheries sector, the quantity of subsidized kerosene and diesel consumed by fishing fleets is unavailable in the public domain.
e. MoPNG should consider making information available in their reports, the total quantity of natural gas (in MMCM) leaked during extraction and distribution.

Few of the activity data in commercial, residential, agriculture and fisheries sector were calculated using secondary and tertiary data sources. To improve the emission estimates from these sectors, it is recommended that the following data are collected by its corresponding ministries monthly.

Agency	Data type	Frequency of data collection
Ministry of Petroleum and Natural Gas	PNG sales of domestic and commercial sector	Monthly
Ministry of Petroleum and Natural Gas	Capacity of DG sets, operating hours of DG sets and quantity of diesel consumption in generator sets in domestic and commercial sector	Monthly
Ministry of Petroleum and Natural Gas	Quantity of diesel from retails consumed in agriculture sector by tractors, pumpsets and agriculture implements.	Monthly
Ministry of Petroleum and Natural Gas/ Department of Animal husbandry, dairy and fisheries	Kerosene consumption in fishing fleets	Monthly
Ministry of Petroleum and Natural Gas/ Department of Animal husbandry, dairy and fisheries	Diesel consumption in fishing fleets	Monthly

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APPENDIX I

Sources of Activity Data

Key source categories		Fuel/ Activity data	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
Public Electricity Generation(1A1ai)		Coal	(CEA, 2006) (CEA, 2007)	(CEA, 2007) (CEA, 2008)	(CEA, 2008) (CEA, 2009)	(CEA, 2009) (CEA, 2010)	(CEA, 2010) (CEA, 2011)	(CEA, 2011)	Interpolated	(CEA, 2014)	(CEA, 2014 2015)	(CEA, 2015) (CEA, 2016)
		Furnace Oil										
		LDO/HSD										
		LSHS/HHS										
		Natural Gas										
		Lignite										
		Naptha										
Industries(1A1ai)		Coal	(CEA, 2006) (CEA, 2007)	(CEA, 2007) (CEA, 2008)	(CEA, 2008) (CEA, 2009)	(CEA, 2009) (CEA, 2010)	(CEA, 2010) (CEA, 2011)	(CEA, 2011)		(CEA, 2014)	(CEA, 2014) (CEA, 2015)	(CEA, 2015) (CEA, 2016)
		Diesel										
		Natural gas										
Transport (1A3)	Road (1A3b)	Motor Spirit	(MoPNG, 2009)		(MoPNG, 2009) (MoPNG, 2014)	(MoPNG, 2014)						(MoPNG, 2014) (MoPNG, 2016)
		HSDO										
		Auto LPG										
		LDO										
		Furnace Oil										
		CNG	Extrapolation		(MoPNG, 2009)			(MoPNG, 2011)				(MoPNG, 2014)
		HSDO -Retails	(MoPNG, 2009) (Anand, 2012)		(MoPNG, 2009) (MoPNG, 2011) (Nielsen, 2013)						(MoPNG, 2014) (Nielsen, 2013)	
	Railways(1A3c)	HSDO	Extrapolation		(MoPNG, 2009)			(MoPNG, 2011)				(MoPNG, 2014)
		LDO										
		LPG										

		Furnace Oil										
		Coal	(MoR, 2005)	(MoR, 2005)	(MoR, 2007) (MoR, 2008)	(MoR, 2009) (MoR, 2008)	(MoR, 2009) (MoR, 2010)	(MoR, 2010) (MoR, 2011)	(MoR, 2011) (MoR, 2012)	(MoR, 2012) (MoR, 2013)	(MoR, 2013) (MoR, 2014)	(MoR, 2014)
	Aviation(1A3a)	ATF	Extrapolation		(MoPNG, 2009)			(MoPNG, 2011)				(MoPNG, 2014)
		HSDO										
	Navigation (1A3d)	HSDO	Extrapolation		(MoPNG, 2009)			(MoPNG, 2011)				(MoPNG, 2014)
		LDO										
		Furnace Oil										
Others(1A4)	Residential (1A4b)	LPG	(MoPNG, 2009)		(MoPNG, 2014)							(MoPNG, 2016)
		Kerosene										
		Fuelwood	(NSSO, 2007)	(NSSO, 2008)	(NSSO, 2008)	(NSSO, 2010) (TERI, 2010)	Interpolated	(NSSO, 2012) (NSSO, 2015)	(NSSO, 2015)	Extrapolation		
		Coke										
		Coal										
		Charcoal										
		Natural gas	(SITI Energy Limited, 2017) (NITI Aayog, 2015)	(NITI Aayog, 2015)								
		Diesel	(Nielsen, 2013) (ICF International, 2014)									
	Commercial(1A4a)	LPG	(Chandra, 2010)	Interpolated	(MoPNG, 2014)							(MoPNG, 2016)
		Kerosene	(MoPNG, 2009)									
		HSDO	(Nielsen, 2013) (ICF International, 2014)									
		Natural gas	(NITI Aayog, 2015), extrapolated values in transport		(MoPNG, 2009) (NITI Aayog, 2015)			(MoPNG, 2011) (NITI Aayog, 2015)				(MoPNG, 2014) (NITI Aayog, 2015)

	Agriculture (1A4ci,1A4cii)	LPG	(MoPNG, 2009)	(MoPNG, 2011)				(MoPNG, 2014)
		HSDO						
		LDO						
		Furnace Oil						
		LSHS						
		Diesel-Retails	(Nielsen, 2013) (MoPNG, 2009)	(Nielsen, 2013) (MoPNG, 2011)				(Nielsen, 2013) (MoPNG, 2014)
	Fisheries(1A4ciii)	Kerosene	Interviews, (N. Aswathy, 2013)					
		Diesel	(E. Vivekanandan, 2013)	Interpolated		(E. Vivekanandan, 2013)	Extrapolated	
Fugitive Emissions	Coal(1B1)	Coal Mining	(Coal Controller's Organisation, 2014)	(Coal Controller's Organisation, 2016)				
		Coal Post-Mining	(Coal Controller's Organisation, 2014)	(Coal Controller's Organisation, 2016)				
	Oil(1B2a)	Oil Production	(MoPNG, 2009)	(MoPNG, 2011)	(MoPNG, 2012)	(MoPNG, 2013)	(MoPNG, 2016)	
		Refinery Throughput	(MoPNG, 2009)	(MoPNG, 2011)	(MoPNG, 2012)	(MoPNG, 2013)	(MoPNG, 2016)	
		Number of wells	(MoPNG, 2009)	(MoPNG, 2011)	(MoPNG, 2012)	(MoPNG, 2013)	(MoPNG, 2016)	
	Natural Gas(1B2b)	NG Production	(MoPNG, 2009)	(MoPNG, 2011)	(MoPNG, 2012)	(MoPNG, 2013)	(MoPNG, 2016)	
		NG Distribution	(MoPNG, 2009)	(MoPNG, 2011)	(MoPNG, 2012)	(MoPNG, 2013)	(MoPNG, 2016)	
		NG Consumption	(MoPNG, 2009)	(MoPNG, 2011)	(MoPNG, 2012)	(MoPNG, 2013)	(MoPNG, 2016)	

		Flarred NG	(MoPNG, 2009)	(MoPNG, 2011)	(MoPNG, 2012)	(MoPNG, 2013)	(MoPNG, 2016)
		NG Leakage	(MoPNG, 2009) (Muller)	(MoPNG, 2011) (Muller)	(MoPNG, 2012) (Muller)	(MoPNG, 2013) (Muller)	(MoPNG, 2016) (Muller)

APPENDIX II

Sample Calculation: This section provides a set of sample calculations of emissions in each sub-sector for 2005.

Electricity Generation

$$Emission_{Coal} = \left(Coal\ consumption\ (000\ Tonnes) *\ NCV_{Coal}\left(\frac{Tj}{Kt}\right) * CO_2EF_{Coal}\left(\frac{t}{Tj}\right)\right)$$

CO_2 $Emission_{Coal}$ (2005) = 2,81,555 (000 Tonnes) * 19.63 (Tj/Kt) * 95.81 (t/Tj)

= 52,95,34,651 Tonnes

Transport – Road

$$Emission_{Gasoline} = \left(Gasoline\ consumption\ (000\ Tonnes) *\ NCV_{Gasoline}\left(\frac{Tj}{Kt}\right) * CO_2EF_{Gasoline}\left(\frac{t}{Tj}\right)\right)$$

CO_2 $Emission_{MotorSpirit}$ (2005) = 8,548 (000 Tonnes) * 44.3 (Tj/Kt) * 69.3 (t/Tj)

= 2,62,42,275 Tonnes

Residential

$$Emission_{LPG} = \left(LPG\ consumption\ (000\ Tonnes) *\ NCV_{LPG}\left(\frac{Tj}{Kt}\right) * CO_2EF_{LPG}\left(\frac{t}{Tj}\right)\right)$$

CO_2 $Emission_{LPG}$ (2005) = 9,802 (000 Tonnes) * 47.3 (Tj/kT) * 63.1 (t/Tj)

= 2,92,55,343 Tonnes

Commercial

$$Emission_{LPG} = \left(LPG\ consumption\ (000\ Tonnes) *\ NCV_{LPG} \left(\frac{Tj}{Kt}\right) * CO_2EF_{LPG} \left(\frac{t}{Tj}\right)\right)$$

CO_2 $Emission_{LPG}$ (2005) = 250.6 (000 Tonnes) * 47.3 (Tj/kT) * 63.1 (t/Tj)

= 7,47,948 Tonnes

Agriculture

$$Emission_{LDO} = \left(LDO\ consumption\ (000\ Tonnes) *\ NCV_{LDO} \left(\frac{Tj}{Kt}\right) * CO_2EF_{LDO} \left(\frac{t}{Tj}\right)\right)$$

CO_2 $Emission_{HSDO}$ (2005) = 426 (000 Tonnes) * 43 (Tj/kT) * 74.1 (t/Tj)

= 13,56,143 Tonnes

Fisheries

$$Emission_{Kerosene} = \left(Kerosene\ consumption\ (000\ Tonnes) *\ NCV_{Kerosene} \left(\frac{Tj}{Kt}\right) * CO_2EF_{Kerosene} \left(\frac{t}{Tj}\right)\right)$$

CO_2 $Emission_{Kerosene}$ (2005) = 191.33 (000 Tonnes) * 43.8 (Tj/kT) * 71.9 (t/Tj)

= 6,02,526 Tonnes

Fugitive Emissions

$$Emissions\ from\ Oil\ Production_{CH4}(t) = \left(Oil\ Production('000tons) * EF_{CH4} \left(\frac{Gg}{'000tons}\right) * 1000\right)$$

CH_4 $Emission_{Oil}$ (2005) = 32,637.75 (000 Tonnes) * 0.000334 (Gg/'000 tonnes) * 1000

= 10,901 Tonnes