INCCA Indian Network for Climate Change Assessment

India: Greenhouse Gas Emissions 2007

सत्यमेव जयते
Ministry of Environment and Forests
Government of India

May 2010

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Annexures

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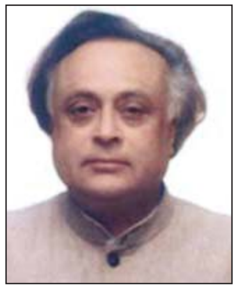
Jairam Ramesh

Minister of State (Independent Charge)
Environment & Forests
Government of India



Foreword

I am pleased to introduce the publication – **India's Greenhouse Gas Emissions 2007**. This Report, being brought out by the Indian Network of Climate Change Assessment (INCCA), provides updated information on India's Greenhouse Gas Emissions for the year 2007. Until today, the only official emissions estimates available were for the year 1994. This was very inadequate. I had been keen that to enable informed decision-making and to ensure transparency, we should publish updated emissions estimates. I am glad that our team of scientists took up this challenge and have prepared this report with estimates for 2007 in record time. More than 80 scientists from 17 institutions across India have contributed to this Assessment. I am particularly pleased that with this publication, **India has become the first "non-Annex I" (i.e. developing) country to publish such updated numbers.** I am also happy to announce that we will publish our emissions inventory in a two-year cycle going forward. We will be the first developing country to do so.

According to the results, India ranks 5th in aggregate GHG emissions in the world, behind USA, China, EU and Russia in 2007. **Interestingly, the emissions of USA and China are almost 4 times that of India in 2007. It is also noteworthy that the emissions intensity of India's GDP declined by more than 30% during the period 1994-2007, due to the efforts and policies that we are proactively putting in place.** This is a trend we intend to continue. As you are aware, we have already announced our intent to further reduce the emissions intensity of our GDP by 20-25% between 2005 and 2020 even as we pursue the path of inclusive growth.

INCCA, launched on 14th October 2009, is a network comprising 127 research institutions, tasked with undertaking research on the science of climate change and its impacts on different sectors of the economy across the various regions of India. As I mentioned at the launch, we must make the "3 M's" – Measurement, Modelling and Monitoring – the essence of our policy making and we must build indigenous capacity for this. This report is a step in this direction. I look forward to INCCA's next major publication – a "4X4" assessment of the impacts of climate change on four sectors – water resources, agriculture, forests and human health – in four critical regions of India – the Himalayan region, North east, Western Ghats and Coastal India, which will be released in November 2010.

Once again, I congratulate our team of scientists who have put this assessment together. I look forward to the results of the other upcoming studies of INCCA.

Jairam Ramesh

Executive Summary

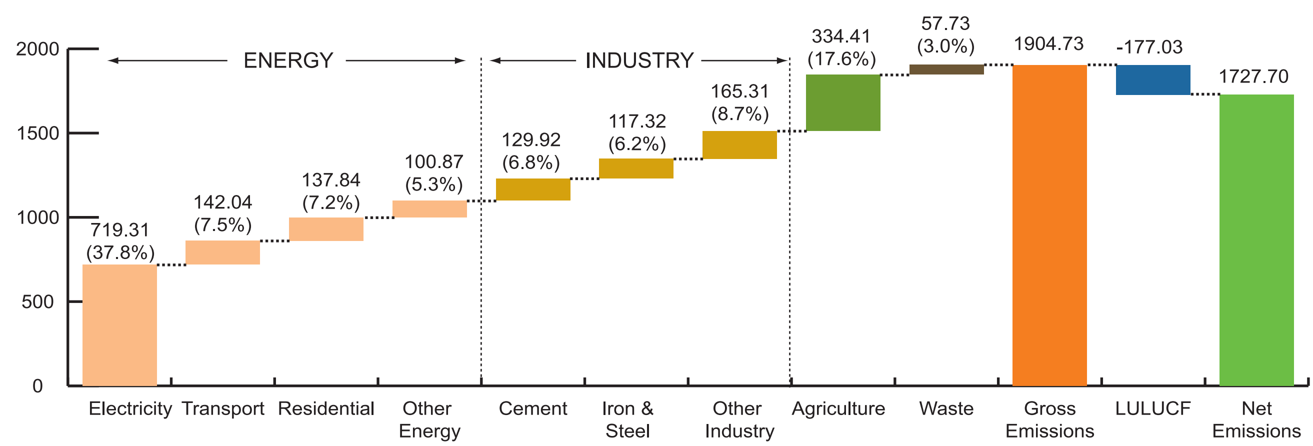
This assessment provides information on India's emissions of Greenhouse gases (Carbon Dioxide [CO_2], Methane [CH_4] and Nitrous Oxide [N_2O]) emitted from anthropogenic activities at national level from:

- Energy;
- Industry;
- Agriculture;
- Waste; and
- Land Use Land Use Change & Forestrmy (LULUCF).

The distribution of GHG emissions by sector are shown in Figure ES1. Detailed emissions estimates are provided in Annexure.

A. KEY RESULTS

- The net Greenhouse Gas (GHG) emissions from India, that is emissions with LULUCF, in 2007 were 1727.71 million tons of CO_2 equivalent (eq) of which
  - CO_2 emissions were 1221.76 million tons;
  - CH_4 emissions were 20.56 million tons; and
  - N_2O emissions were 0.24 million tons
- GHG emissions from Energy, Industry, Agriculture, and Waste sectors constituted 58%, 22%, 17% and 3% of the net CO_2 eq emissions respectively.
- Energy sector emitted 1100.06 million tons of CO_2 eq, of which 719.31 million tons of CO_2 eq were emitted from electricity generation and 142.04 million tons of CO_2 eq from the transport sector.
- Industry sector emitted 412.55 million tons of CO_2 eq.
- LULUCF sector was a net sink. It sequestered 177.03 million tons of CO_2.
- India's per capita CO_2 eq emissions including LULUCF were 1.5 tons/capita in 2007.



Note:

Other Energy: includes GHG emissions from petroleum refining, manufacturing of solid fuel, commercial & institutional sector, agriculture & fisheries and fugitive emissions from mining, transport and storage of coal, oil and natural gas.

Other Industry: includes GHG emissions from production of glass and ceramics, soda ash, ammonia, nitric acid, carbides, titanium dioxide, methanol, ethylene oxide, acrylonitrile, carbon black, caprolactam, ferro alloys, aluminium, lead, zinc, copper, pulp and paper, food processing, textile, leather, mining and quarrying, non specific industries and use of lubricants and paraffin wax.

Agriculture: includes GHG emissions from livestock, rice cultivation, agricultural soils and burning of crop residue.

Waste: includes GHG emissions from municipal solid waste (MSW), industrial and domestic waste water.

LULUCF: includes GHG emissions and removals from changes in forest land, crop land, grass land, wet land, settlements and combustion of fuel wood in forests.

Figure ES1: GHG emissions by sector in 2007 (million tons of CO_2 eq). Figures on top indicate the emissions by sectors and in brackets indicate % of emission of the category with respect to the net CO_2 equivalent emissions. See glossary for defination of CO_2 equivalent.

B. 1994 AND 2007 GHG EMISSIONS - A COMPARISON

The 1994 assessment is available in India's Initial National Communication to the UNFCCC. Both the 1994 and 2007 assessments have been prepared using the IPCC guidelines for preparation of national greenhouse gas emissions by sources and removal by sinks. The distinctive key features of the two assessments and the improvements in the 2007 assessments are indicated in Box ES1.

The total GHG emissions without LULUCF have grown from 1251.95 million tons in 1994 to 1904.73 million tons in 2007 at a compounded annual growth rate (CAGR) of 3.3% and with LULUCF the CAGR is 2.9%. Between 1994 and 2007, some of the sectors indicate significant growth in GHG emissions such as cement production (6.0%), electricity generation (5.6%) and transport (4.5%). A comparative analysis of GHG emissions by sector is shown in Table ES1.

C. IMPLEMENTATION ARRANGEMENT

This assessment has been prepared under the aegis of the Indian Network for Climate Change Assessment (INCCA). An initiative being coordinated by the Ministry of Environment and Forests, Government of India. (Box ES2 & Figure ES2).

Table ES1: A comparison of GHG emissions by sector between 1994 and 2007 in million tons of CO_2 eq.

	1994	2007	CAGR (%)
Electricity	355.03 (28.4%)	719.30 (37.8%)	5.6
Transport	80.28 (6.4%)	142.04 (7.5%)	4.5
Residential	78.89 (6.3%)	137.84 (7.2%)	4.4
Other Energy	78.93 (6.3%)	100.87 (5.3%)	1.9
Cement	60.87 (4.9%)	129.92 (6.8%)	6.0
Iron & Steel	90.53 (7.2%)	117.32 (6.2%)	2.0
Other Industry	125.41 (10.0%)	165.31 (8.7%)	2.2
Agriculture	344.48 (27.6%)	334.41 (17.6%)	-0.2
Waste	23.23 (1.9%)	57.73 (3.0%)	7.3
Total without LULUCF	1251.95	1904.73	3.3
LULUCF	14.29	-177.03	
Total with LULUCF	1228.54	1727.71	2.9

Note: Figure in brackets indicate percentage emissions from each sector with respect to total GHG emissions without LULUCF in 1994 and 2007 respectively

Box ES1: 2007 and 1994 - Key Methodological Features and Improvements

1994 Assessment	2007 Assessment
■ Estimates made using only revised 1996 IPCC guidelines.	■ Estimates made using revised IPCC 1996 guidelines (1997), IPCC Good Practice Guidance (2000), the LULUCF Good Practice Guidance (2003).
■ LULUCF included emissions from changes in forest land.	■ Carbon pools in addition to forests have been considered in the LULUCF sector (crop land, grass land, settlements).
■ Emission factors were a mix of default factors taken from IPCC and country specific (CS) emission factors. 26% of the source categories used CS factors.	■ Emission factors were also a mix of default and CS but leading to improved accuracy as more number of CSs have been used in this assessment (35% of the source categories used CS factors).
■ The 1994 assessment splits the emissions from industry in to two parts - fossil fuel and process. The fossil fuel emissions are reported in Energy and process emissions in Industry.	■ The 2007 assessment reports both fossil fuel related and process based emissions from Industry as a part of the Industry sector.
■ In 1994, 7% of the total CO_2 eq emissions were made using Tier III approach.	■ In 2007, 12% of the emissions are made using Tier III approach, implying greater accuracy.

Box ES2: Indian Network for Climate Change Assessment (INCCA)

Launched on October 14, 2009, the network comprises of 127 institutions and 228 scientists across India

Role

- Assess the drivers and implications of climate change through scientific research
- Prepare climate change assessments once every two years (GHG estimations and impacts of climate change, associated vulnerabilities and adaptation)
- Develop decision support systems
- Build capacity towards management of climate change related risks and opportunities

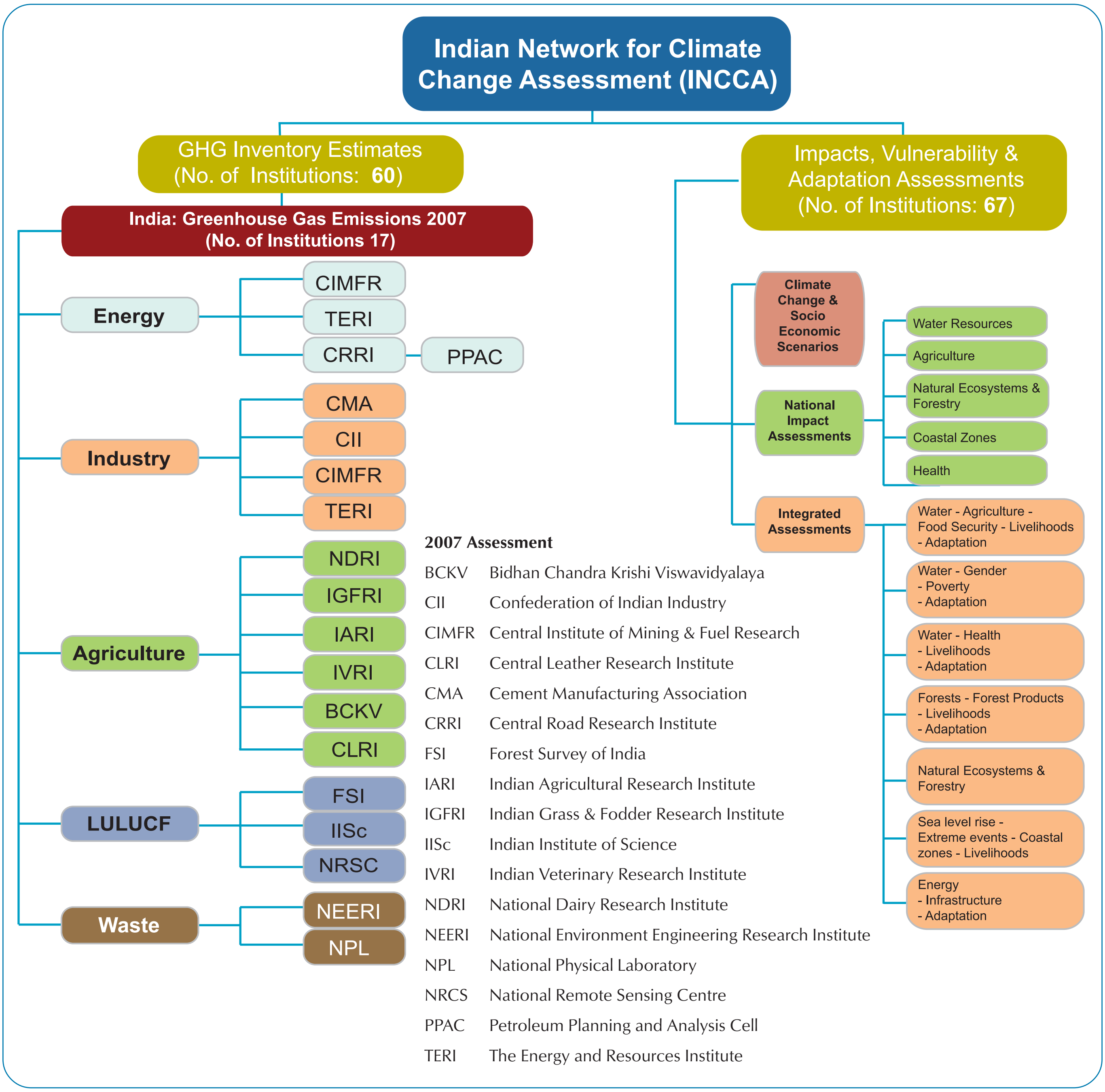


Figure ES2: INCCA and Network for preparing the Greenhouse Gas Emissions – 2007. For the complete list of institutions participating in INCCA, see Annexure 4.

D. SECTORAL DESCRIPTION OF THE EMISSIONS

Energy: The energy sector emitted 1100.06 million tons of CO_2 eq due to fossil fuel combustion in electricity generation, transport, commercial/Institutional establishments, agriculture/fisheries, and energy intensive industries such as petroleum refining and manufacturing of solid fuels, including biomass use in residential sector. Fugitive emissions from mining and extraction of coal, oil and natural gas are also accounted for in the energy sector. The distribution of the emissions across the source categories in energy sector is shown in Figure ES3.

Electricity Generation: The total greenhouse gas emissions from electricity generation in 2007 was 719.31 million tons CO_2 eq. This includes both grid and captive power. The CO_2 eq emissions from electricity generation were 65.4% of the total CO_2 eq emitted from the energy sector. Coal constituted about 90% of the total fuel mix used.

Petroleum Refining and Solid Fuel Manufacturing: These energy intensive industries emitted 33.85 million tons of CO_2 eq in 2007. The solid fuels include manufacturing of coke & briquettes.

Transport: The transport sector emissions are reported from road transport, aviation, railways and navigation. In 2007, the transport sector emitted 142.04 million tons of CO_2 eq. Road transport, being the dominant mode of transport in the country, emitted 87% of the total CO_2 equivalent emissions from the transport sector. The aviation sector in comparison only emitted 7% of the total CO_2 eq emissions. The rest were emitted by railways (5%) and navigation (1%) sectors. The bunker emissions from aviation and navigation have also been estimated but are not counted in the national totals. (Figure ES4).

Residential & Commercial: The residential sector in India is one of the largest consumers of fuel outside the energy industries. Biomass constitutes the largest portion of the total fuel mix use in this sector. Commercial and institutional sector uses oil & natural gas over and above the conventional electricity for its power needs. The total CO_2 eq emission from residential & commercial/institution sector was 139.51 million tons of CO_2 eq in 2007.

Agriculture & Fisheries: The agriculture/ fisheries activities together emitted 33.66 million tons of CO_2 eq due to energy use in the sector other than grid electricity.

Fugitive Emissions: CH_4 escapes into the atmosphere due to mining of coal, and due to venting, flaring, transport and storage of oil and natural gas. The total CO_2 eq emissions from this source category in 2007 was 31.70 million tons CO_2 eq.

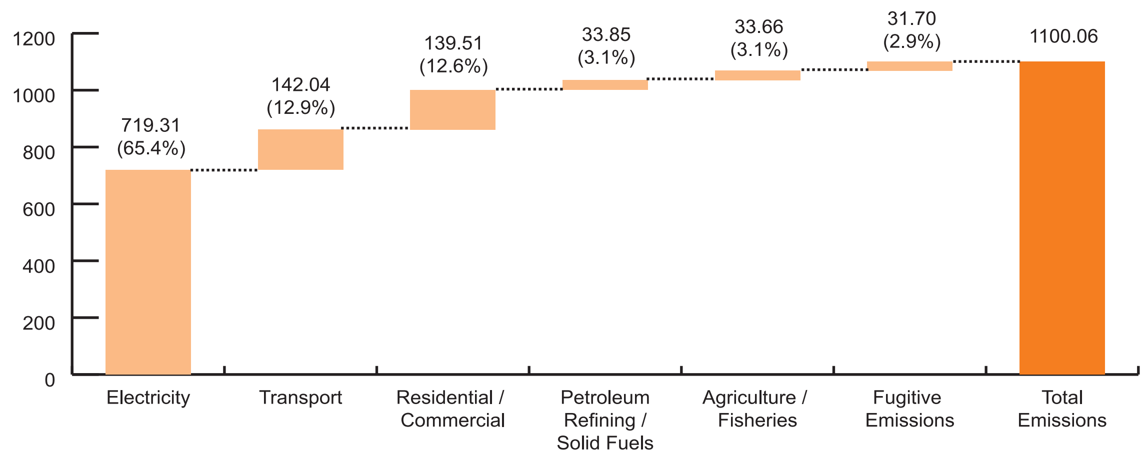
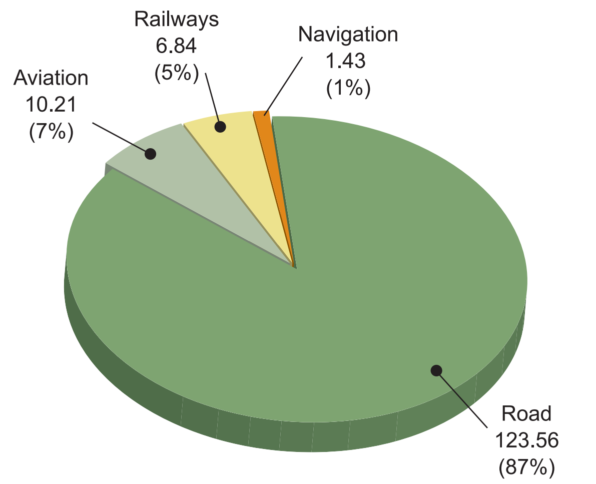


Figure ES3: GHG emissions from Energy Sector (million tons of CO_2 eq).



Figurse ES4: GHG emissions from Transport Sector by mode of transport in 2007 (million tons of CO_2 eq).

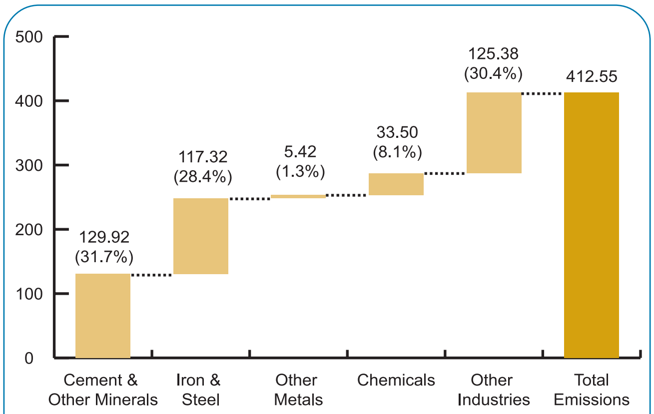
Industry: Industrial activities together emitted 412.55 million tons of CO_2 eq of GHG in 2007. Industry sector emissions have been estimated from manufacturing of minerals, metals, chemicals, other specific industries, and from non-energy product use. The emissions covered in the industry sector include fossil fuel combustion related emissions as well as the process based emissions. (Figure ES5).

Cement and Other Minerals: The cement industry emitted 129.92 million tons of CO_2, which is 32% of the total CO_2 eq emissions from the Industry sector. The emissions cover the entire technology mix for manufacturing of cement in the country covering large, medium and white cement plants. The other minerals like glass and ceramic production and soda ash use together emit 1.01 million tons of CO_2 eq.

Iron and Steel and Other Metals: The iron and steel industry emitted 117.32 million tons of CO_2 eq. The estimate covers integrated and mini steel plants. The production of other metals, namely, aluminum, ferroalloys, lead, zinc and copper production lead to an emission of 5.42 million tons of CO_2 eq.

Chemicals: The chemical industries together emitted 8.1% of the total GHG emissions from the industry sector (33.50 million tons). See figure ES5 and glossary for sub categories included.

Other Industries: Other industries comprising of pulp/ paper, leather, textiles, food processing , mining and quarrying, and non specific industries comprising of



Note:
Other Metals: includes GHG emissions from production of ferroalloys, aluminium, lead, zinc and copper.
Chemicals: includes GHG emissions from production of ammonia, nitric acid, adipic acid, caprolactam, carbide, titanium dioxide, petrochemicals and black carbon, methanol, ethylene, ethylene oxide, acrylonitrile, ethylene diochloride and vinyl chloride, monomer and other chemicals (see glossary for details).
Other Industries: includes GHG emissions from pulp and paper, food processing, textile and leather, mining and quarrying and non specific industries. It also includes emissions from non-energy product use.

Figure ES5: GHG emissions from Industry Sector (million tons of CO_2 eq).

rubber, plastic, watches, clocks, transport equipment, furniture etc., together emitted 124.53 million tons. The rest of the emissions in the Industry sector came from the non-energy product uses and this sector emitted 0.85 million tons of CO_2 eq, and was mainly from use of oil products and coal-derived oils primarily intended for purposes other than combustion.

Agriculture: The agriculture sector emitted 334.41 million tons of CO_2 eq in 2007. Estimates of GHG emissions from the agriculture sector arise from enteric fermentation in livestock, manure management, rice paddy cultivation, agricultural soils and on field burning of crop residue. (Figure ES6)

Livestock: Enteric fermentation in livestock released 212.10 million tons of CO_2 eq (10.1 million tons of CH_4). This constituted 63.4% of the total GHG emissions (CO_2 eq) from agriculture sector in India. The estimates cover all livestock, namely, cattle, buffalo, sheep, goats, poultry, donkeys, camels, horses and others. Manure management emitted 2.44 million tons of CO_2 eq.

Rice Cultivation: Rice cultivation emitted 69.87 million tons of CO_2 eq or 3.27 million tons of CH_4. The

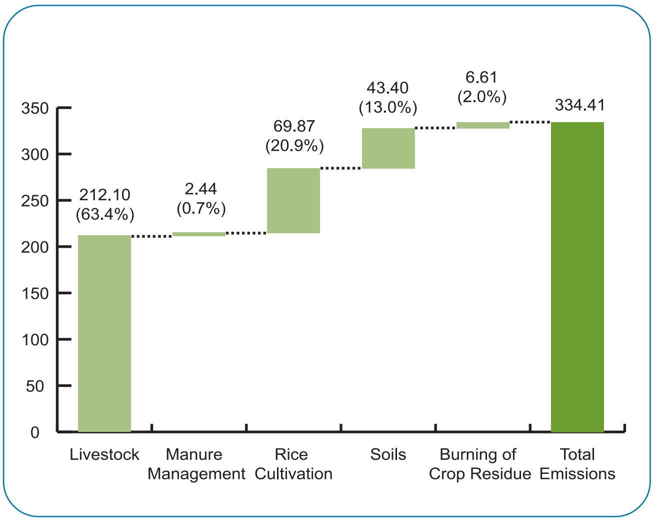


Figure ES6: GHG emissions from Agriculture Sector (million tons of CO_2 eq).

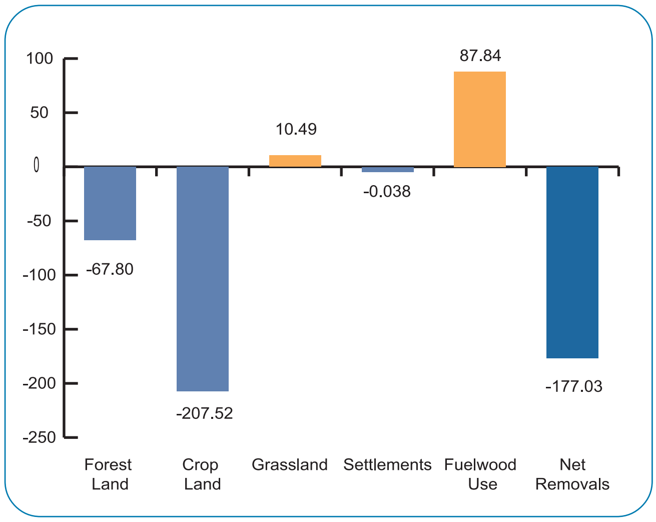


Figure ES7: GHG emissions and removals from LULUCF sector (million tons of CO_2 eq).

emissions cover all forms of water management practiced in the country for rice cultivation, namely, irrigated, rainfed, deep water and upland rice. The upland rice are zero emitters and irrigated continuously flooded fields and deep water rice emit maximum methane per unit area.

Agricultural Soils and Field Burning of Crop Residue: Agricultural soils are a source of N_2O, mainly due to application of nitrogenous fertilizers in the soils. Burning of crop residue leads to the emission of a number of gases and pollutants. Amongst them, CO_2 is considered to be C neutral, and therefore not included in the estimations. Only CH_4 and N_2O are considered for this report. The total CO_2 eq emitted from these two sources were 50.00 million tons.

Land Use Land Use Change and Forestry: The estimates from LULUCF sector include emission by sources and or removal by sinks from changes in forest land, crop land, grassland, and settlements. Wet lands have not been considered due to paucity of data. The LULUCF sector in 2007 was a net sink. It sequestered 177.03 million tons of CO_2. (Figure ES7)

Forest Land: This includes estimates of emissions and removal from above and below ground biomass in very dense, moderately dense, open forests, and scrub lands. Estimates indicate that forest land sequestered 67.8 million tons of CO_2 in 2007. However, fuel wood extracted non-sustainably from forests lead to an emission of 67.80 million tons of CO_2 in 2007.

Crop Lands: The emission estimates have been made from net sown area as well as fallow land. The crop land sequestered 207.52 million tons of CO_2 in 2007.

Grassland: Changes in Grassland resulted in the emission of 10.49 million tons of CO_2 due to decrease in grass land area by 3.4 million ha between the two periods.

Settlements: Land converted to settlements though increased by 0.01 million ha during the period, however, the conversions did not lead to an emission but a net removal of 0.04 million tons.

Waste: The waste sector emissions were 57.73 million tons of CO_2 eq from municipal solid waste management, domestic waste water and industrial waste water management. (Figure ES8)

Municipal Solid Waste (MSW): Systematic disposal of solid waste is carried out only in the cities in India resulting in CH_4 emissions due to aerobic conditions generated due to accumulation of waste over the years. It is estimated that the MSW generation and disposal resulted in the emissions of 12.69 million tons of CO_2 eq in 2007.

Waste Water: The waste water generation emissions are the sum total of emissions from domestic waste water and waste water disposal in industries. Waste water management in both these categories together emitted 45.03 million tons of CO_2

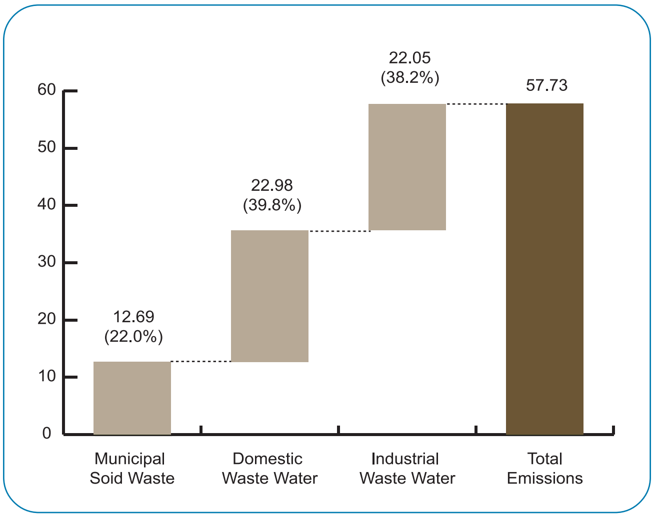


Figure ES8: GHG emissions from waste (million tons of CO_2 eq).

E. FUTURE DIRECTIONS

The robustness of the GHG inventory making process is dependent on the Tier of methodology used. Higher the Tier, more representative is the emission estimated of the actual emissions. Of the total 1727.71 million tons of CO_2 equivalent emissions from India in 2007, 21% of the emissions have been estimated using Tier I methodology, 67% by Tier II and 12% by Tier III.

Riding the Tier Ladder: For improving the inventory estimations of key categories using Tier II and Tier I methodologies, there is a need to move up the Tier ladder. Strategies needed include improvement in assimilation of activity data representing national circumstances, bridging data gaps, and eliminating uncertainties by developing country specific GHG emission factors.

Capacity Building and National Greenhouse Gas Inventory Management System: Capacity building is essential at institutional and individual levels. Capacity at the institutional level addresses the needs of inventory preparation at national, sectoral and point source level that requires collection and archiving of data on a continuous basis. Establishment of a National Inventory Management System is therefore necessary. It is also important to involve additional institutions with varied research experience, to widen the pool of researchers and enable the integration of latest practices.

Greenhouse gas emissions by sources and removal by sinks from India in 2007 (thousand tons)

	CO_2 emissions	CO_2 removals	CH_4	N_2O	CO_2 equivalent
GRAND TOTAL	**1497029.20**	**275358.00**	**20564.20**	**239.31**	**1727706.10**
ENERGY	**992836.30**		**4266.05**	**56.88**	**1100056.89**
Electricity generation	715829.80		8.14	10.66	719305.34
Other energy industries	33787.50		1.72	0.07	33845.32
Transport	138858.00		23.47	8.67	142038.57
Road transport	*121211.00*		*23.00*	*6.00*	*123554.00*
Railways	*6109.00*		*0.34*	*2.35*	*6844.64*
Aviation	*10122.00*		*0.10*	*0.28*	*10210.90*
Navigation	*1416.00*		*0.13*	*0.04*	*1431.13*
Residential	69427.00		2721.94	36.29	137838.49
Commercial / Institutional	1657.00		0.18	0.04	1673.18
Agriculture/ Fisheries	33277.00		1.20	1.15	33658.70
Fugitive emissions			1509.40		31697.30
INDUSTRY	**405862.90**		**14.77**	**20.56**	**412546.53**
Minerals	**130783.95**		**0.32**	**0.46**	**130933.27**
Cement production	129920.00				129920.00
Glass & cermic production	277.82		0.32	0.46	427.14
Other uses of soda ash	586.12				586.12
Chemicals	**27888.86**		**11.14**	**17.33**	**33496.42**
Ammonia production	10056.43				10056.43
Nitric acid production				16.05	4975.50
Carbide production	119.58				119.58
Titanium dioxide production	88.04				88.04
Methanol production	266.18		0.91		285.37
Ethylene production	7072.52		9.43		7270.64
EDC & VCM production	198.91				198.91
Ethylene Oxide production	93.64		0.19		97.71
Acrylonitrile production	37.84		0.01		37.98
Carbon Black production	1155.52		0.03		1156.07
caprolactum				1.08	336.22
Other chemical	8800.21		0.56	0.20	8873.97
Metals	**122371.43**		**0.95**	**1.11**	**122736.91**
Iron & Steel production	116958.37		0.85	1.09	117315.63
Ferroalloys production	2460.70		0.08		2462.29
Aluminium production	2728.87		0.01	0.00	2729.91
Lead production	84.13		0.00	0.01	86.38
Zinc production	76.11		0.00	0.01	77.99
Copper	63.25		0.01	0.00	64.70
Other Industries	**123969.17**		**2.37**	**1.65**	**124530.44**
Pulp and paper	5222.50		0.05	0.08	5248.35
Food processing	27625.53		1.12	0.22	27717.25
Textile and leather	1861.11		0.03	0.02	1867.94
Mining and qurrying	1460.26		0.06	0.01	1464.62
Non-specific industries	87799.77		1.11	1.32	88232.28

(contd...)

	CO_2 emissions	CO_2 removals	CH_4	N_2O	CO_2 equivalent
Non energy product use	**849.49**				849.49
Lubricant	776.75				776.75
Paraffin wax	72.75				72.75
AGRICULTURE			**13767.80**	**146.07**	**334405.50**
Enteric fermentation			10099.80		212095.80
Livestock Manure management			115.00	0.07	2436.70
Rice cultivation			3327.00		69867.00
Soils				140.00	43400.00
Burning of crop residue			226.00	6.00	6606.00
LULUCF	**98330.00**	**275358.00**			**-177028.00**
Forestland		67800.00			-67800.00
Cropland		207520.00			-207520.00
Grassland	10490.00				10490.00
Settlement		38.00			-38.00
Wetland	NE				NE
Other land	NO				NO
Fuel wood use in forests	87840.00				87840.00
Waste			**2515.58**	**15.80**	**57725.18**
Municipal Solid waste			604.51		12694.71
Domestic waste water			861.07	15.80	22980.47
Industrial waste water			1050.00		22050.00
Bunkers*	**3454**		**0.03**	**0.10**	**3484.45**
Aviation Bunkers	3326		0.02	0.09	3355.31
Marine bunkers	128		0.01	0.003	129.14

Note: LULUCF: Land Use Land Use Change & Forestry
**Not included in the national totals.*
NE: Not estimated; NO: Not occuring

1

Context and Relevance

Climate change is recognized both as a threat and a challenge. The impact of human activities on climate and climate systems is unequivocal. Climate has a significant role in the economic development of India. Many sectors of the economy are climate sensitive. Climate change has origins in anthropogenic activities and is engaging the attention of planners, governments, and politicians worldwide. It is no longer a scientific question as to whether the climate is changing, but the question is the timing and magnitude of Climate Change. The governments of the countries across the world are engaged in working out the impacts and associated vulnerabilities of their economies to impending projected climate change.

In India, the meteorological records indicate rise in the mean annual surface air temperature by 0.4°C with not much variations in absolute rainfall. However, the rates of change in temperatures and precipitation have been found to be varying across the region. The intensity and frequency of heavy precipitation events have increased in the last 50 years. The tide gauge observations in the last four decades across the coast of India also indicate a rise in sea level at the rate of 1.06-1.25 mm/year. Further, some preliminary assessments point towards a warmer climate in the future over India, with temperatures projected to rise by 2-4°C by 2050s. No change in total quantity of rainfall is expected, however, spatial pattern of the rainfall are likely to change, with rise in number and intensity of extreme rainfall events.

The sea level is also projected to rise with cyclonic activities set to increase significantly with warmer oceans. The continuous warming and the changing rainfall pattern over the Indian region may jeopardize India's development by adversely impacting the natural resources such as water forests, coastal zones, and mountains on which more than 70% of the rural population is dependent.

The physiographic features and the geographic location, which control the climate of the country, bestows it with great wealth of its natural resources, surface and ground water availability, forestry and vegetation. The region abounds in very rich collection of flora and fauna, and some of these locations exhibit a high degree of species endemism and constitute biodiversity hotspots of the world. There is an ever increasing recognition of the need for national level assessments which provides an opportunity to enhance our knowledge and understanding about the implication of both the current climate variability as well as the projected adverse impacts of climate change.

2

Climate Change Assessments in India

Recognition of the need for assessing the implications of Climate Change in India coincides with the emergence of the issue of global warming in late eighties and early nineties. Globally, the decade of 1990's which saw the adoption of the United Nations Framework Convention on Climate Change (UNFCCC) and the publication of the update on Climate Change 1992 by the Inter Governmental Panel on Climate Change (IPCC) could be taken as the beginning of preparation of the dedicated assessments of climate change. In the Indian context, researchers initiated work in their own limited fields. By all means the information was scattered, diffused and fragmented on various aspects of Climate Change. The only source of information on climate was available through India's Meteorology Department (IMD) and the Indian Institute of Tropical Meteorology (IITM) and certain premier institutes such as Indian Institute of Science (IISc) and the Indian Space Research Organization (ISRO) and its associated institutions.

For the first time information on Climate Change was consolidated for the preparation of India report of the Asian development Bank's study on Climate Change (ADB 1994). The study was limited to the compilation of literature and certain studies on impacts of Climate Change on Agriculture, Water and Forests besides sea level rise. During this period a nation wide campaign was instituted by MoEF to access the emission of CH_4 from rice paddy cultivation in India. The study had an international impact on the global as well as national emissions of CH_4 (Parashar et al., 1994). The Asian Development Bank study: Asia Least Cost Greenhouse Gas Abatement Strategy (ALGAS) was yet another important assessment on Greenhouse Gases at the 1990 level (ALGAS, 1998). These studies in effect provided the impetus to the work relating to impacts of Climate Change in the country. Publications such as Climate Change and India in 2002, 2003 and 2004 (Shukla et al., 2002 and 2003; Mitra et al., 2004) documented a consolidated picture on Climate Change Assessments. The chronology of greenhouse gas emission estimates made in the country is shown in Table 2.1.

In 2004, for the first time in a well coordinated and dedicated effort was made to produce assessing Greenhouse Gases of anthropogenic origin from sectors such as Energy, Agriculture, Industry, Land Use, Land Use Change and Forestry and Waste and efforts were also made to assess the climate change Impacts and vulnerability of key sectors of economy in India's Initial National Communication to the UNFCCC (NATCOM, 2004).

Currently, 127 institutions are working on different aspects of climate change. The National Action Plan on Climate Change (NAPC, 2008) calls for launch on missions on Agriculture, Water, Solar, Energy, Forestry, Himalayan Ecosystems and Strategic Knowledge on Climate Change. The mission programmes are at advanced stages of preparation and would contribute to advancing the state of knowledge in the various aspects of Climate Change.

Table 2.1: Chronology of greenhouse gas assessments carried out in India

Gases	CO_2, CH_4	CO_2, CH_4	CH_4	CO_2, CH_4, N_2O, NO_X, CO, NMVOC	CH_4	CO_2, CH_4, N_2O	CO_2, CH_4, N_2O
Sectors	Fossil fuel Rice Animals	Transport Coal mines Rice Livestock	All India Campaign Rice - seasonally integrated approach and water regimes defined	Biomass Cement Oil & natural gas, manure Crop residue, soils, MSW	Rice – extended campaign (organic and non organic soils)	All sources (1996 guidelines)	All sources (1996 guidelines)
Emission Factors	Published Emission Factors	Used published Emission Factors	Developed	Default and developed	Developed	Default IPCC	30% Country Specific and 70% Default
Base Year	1990	1990	1992	1990	1998	1990-1995	1994
Reference	Mitra et al., 1991	Mitra et al, 1992	Parashar et al, 1994, 1997	ALGAS India, 1998	Gupta et al., 1999	Garg , Bhattacharya & Shukla, 2001	NATCOM 2004

3

Indian Network for Climate Change Assessment

A national workshop towards preparation of a Comprehensive Climate Change Assessment was organized by the Ministry of Environment & Forests at New Delhi on October 14th, 2009. The workshop was chaired by Hon'ble Minister of Environment & Forests and attended by nearly 200 scientists/ experts representing premier institutions such as IIT, IIM, IISc, Universities, and research development institutions under the Council of Industrial Research, Indian Council of Agricultural Research, government Ministries / Departments, autonomous institutions, Non-governmental Organizations and private companies. The workshop was also attended by representatives of the media. Scientists presented their work on multidisciplinary aspects of Climate Change presently supported by the MoEF. Principal Scientific Adviser to the Government of India addressed the workshop and released the document titled, 'Towards Comprehensive Climate Change Assessment'. The workshop was also addressed by Secretary, Environment & Forests.

During this workshop, Hon'ble Minister Jairam Ramesh announced the establishment of Indian Network for Climate Change Assessment (INCCA). Emphasizing the need for INCCA, Minister underscored the significance of availability of authentic national data for analysing the implications of Climate Change vis-a-vis the understanding of Science of Climate Change, Impacts, Vulnerability, Adaptation and Mitigation of Climate Change. In this context, it was emphasized that the '3 Ms - Measuring, Modelling and Monitoring" are the hallmarks of the initiatives relating to Climate Change.

The Indian Network for Climate Change Assessment (INCCA) has been conceptualized as a network based scientific programme designed to:

- Assess the drivers and implications of climate change through scientific research
- Prepare climate change assessments once every two years (GHG estimations and impacts of climate change, associated vulnerabilities and adaptation)
- Develop decision support systems
- Build capacity towards management of climate change related risks and opportunities

It is visualized as a mechanism to create new institutions and engage existing knowledge institutions already working with the Ministry of Environment and Forests as well as other agencies. Currently, the institutions of the various Ministries such as that of Ministry of Environment & Forests, Ministry of Earth Sciences, Ministry of Agriculture, Ministry of Science & Technology, Defence Research and Development Organisation etc., along with the research institutions of the Indian Space Research Organisation, Council of Scientific and Industrial Research, Indian Council of Agriculture Research, Department of Science & Technology, Indian Council of Medical Research, Indian Institute of Technology, Indian Institute of Managements and prominent state and central Universities, and reputed Non Governmental Organisations and Industry Associations are working in the various studies on Climate Change

The scope of the programmes under INCCA has been developed on the basis of the fundamental questions that we ask ourselves for climate proofing systems and the society dependent on climate and include, inter alia:

- Short, medium and long-term projections of climate changes over India at sub regional scales
- The impacts of changes in climate on key sectors of economy important at various regional scales
- The anthropogenic drivers of climate change i.e. greenhouse gas and pollutants emitted from various sectors of the economy

- The processes through which GHGs and pollutants interact with the climate system and change the bio-physical environment

The mandate of INCCA would continue to evolve to include the new science questions that confront humanity including the population living within the Indian region. The aim of scientific research under INCCA is envisaged to encompass research that will develop understanding on the regional patterns of climate across India, how it is changing over time and likely to behave in the future. Consequently, INCCA will also focus on the impacts of the changing climate on regional ecosystem hotspots, human systems and economic sectors. The following programmes are initially contemplated to be carried out under the aegis of INCCA:

- A provisional assessment of the Green House Gas emission profile of India for 2007 by sources and removal by sinks presented in this document;
- An assessment of the impacts of climate change on water resources, agriculture, forests and human health in the Himalayan region, North eastern region, Western ghats and Coastal regions of India;
- Undertake an assessment of black carbon and its impact on ecosystems;
- Undertake a long-term ecological, social, and economic monitoring of ecosystems to identify patterns and drivers of change that influences the sustainability of livelihoods dependent on these systems across India;
- Build capacity through thematic workshops and training programmes; and
- Synthesize information thus generated in appropriate communication packages for informed decision making

A schematic representation of the programmes in INCCA are shown in figure 3.1.

The approaches of the scientific programmes under INCCA would be to further develop network of Indian institutions drawing upon knowledge institutions that have so far contributed towards scientific knowledge and expand the same encompassing more number of institutions in the country. Besides, INCCA would harness Involvement of Indian as well as Indian expertise abroad and would focus on four zones, namely, the Himalayan region, the North eastern plains, the Western Ghats & the Coastal region. The assessment would stress to develop climate projection scenarios and their impacts on systems to evaluate the associated vulnerabilities for developing adaptation strategies.

The Ministry of Environment and Forests, would coordinate the activities under INCCA, taking advantage

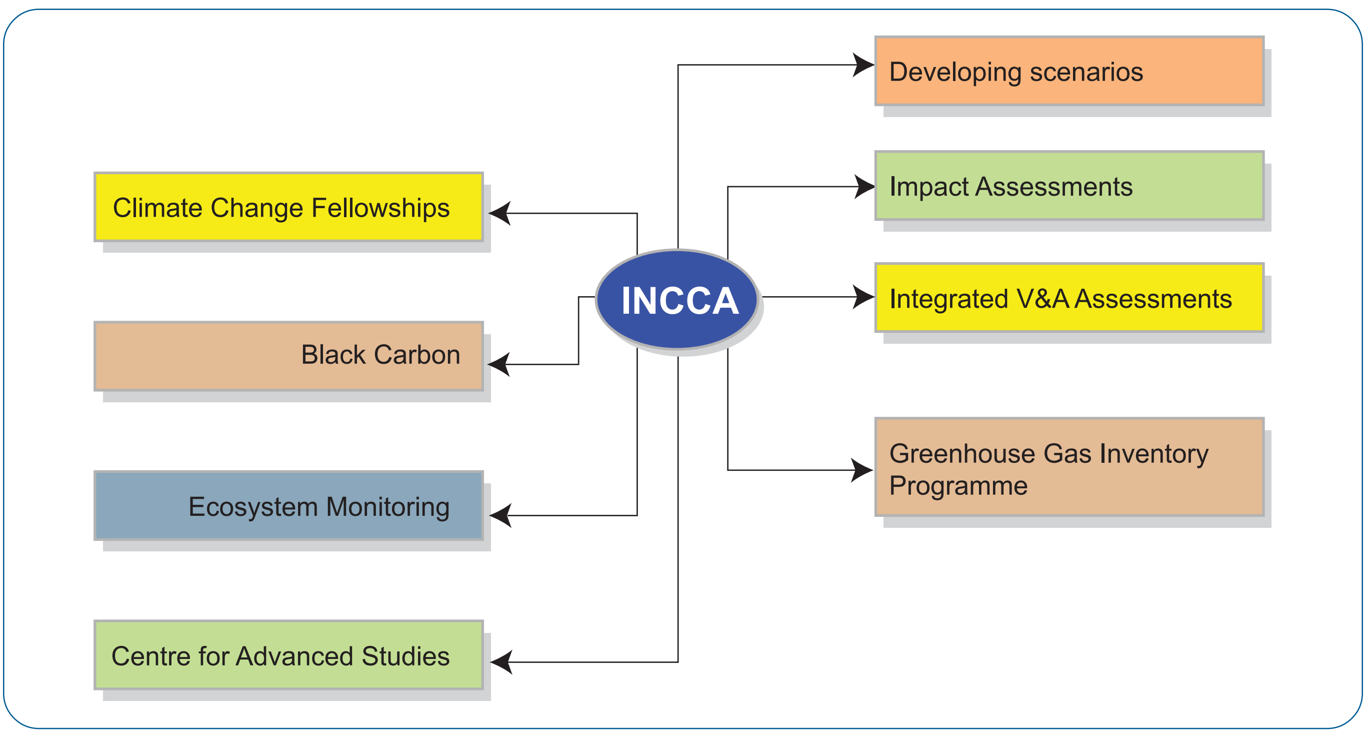


Figure 3.1: Programmes envisaged under INCCA

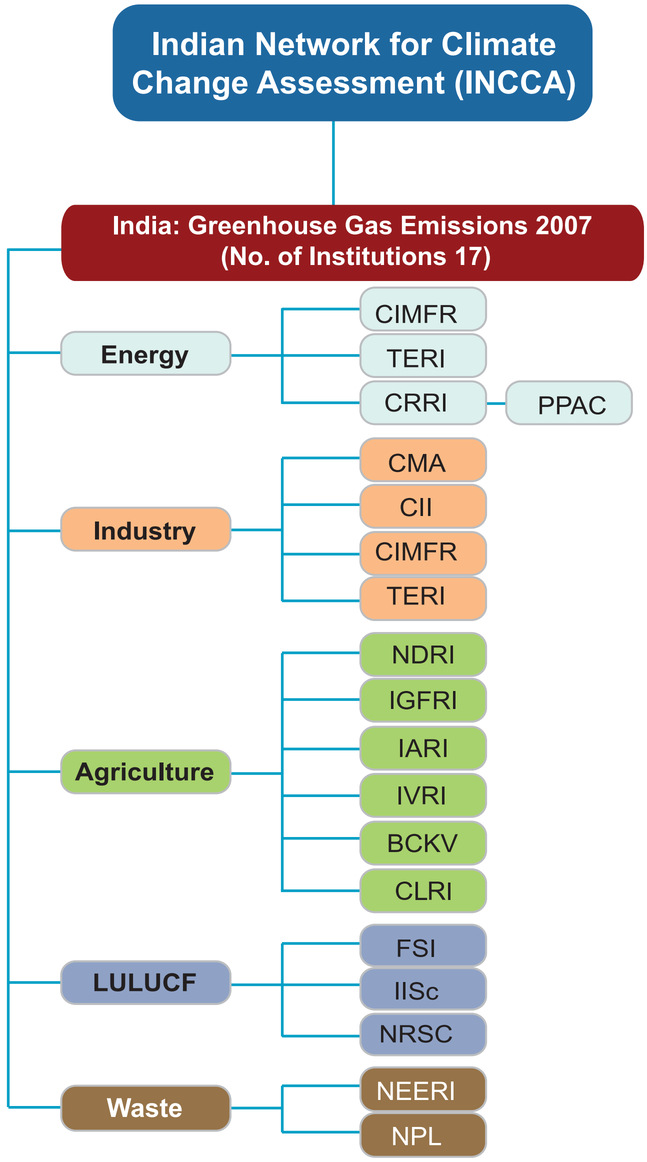
of the wide spread network of knowledge institutions established by the Ministry for carrying out various projects in areas related to climate change such as the science and impacts of climate change and associated policy issues.

The MoEF, through a system of a wide consultative process with scientists and experts, envisages formulating the emerging scientific questions in the area of climate change research that will govern the development of the programmes. A more comprehensive implementation arrangement will be put in place during the operational phase of the programme which will include a scientific advisory committee for guidance and review of the activities of the various programmes.

THE 2007 ASSESSMENT & IMPLEMENTATION ARRANGEMENT

The official Greenhouse gas Emission Profile of India at 1994 level was prepared for the India's Initial National Communication submitted to the UNFCCC in June, 2004. The reason for restricting the estimation upto 1994 was in pursuance of the requirement of reporting towards implementation of the obligations under the UNFCCC and the guidelines enjoining upon all the developing countries to provide information on Greenhouse gas emissions by sources and removals by sinks at 1994 level using Intergovernmental Panel on Climate Change guidelines 1996 (Revised). This is for reasons of comparability of data across countries for calculation of global emission trends. The next level of common year of reporting is the year 2000.

This assessment of greenhouse gas profile 2007 has been worked out by a number of scientists/ experts drawn from the institutions which were involved in previous estimation as well as currently engaged in the preparation of inventories of greenhouse gases (see Annexure 3). These estimates though provisional fill the long felt need for the latest emission data. For preparing the GHG emission inventory estimates presented in this document, expertise of a number of institutions has been pooled in across the country and a network has been created that can generate information on a regular basis. The network includes institutions that have been working in the area of greenhouse gas emission inventory development including the process of generation of country specific emission factors of GHGs for various anthropogenic activities. It indeed makes the inventory scientifically robust. The network of institutions is drawn from a diverse mix of premier national institutions currently working under various aspects of Climate Change with MoEF. (figure 3.2)



2007 Assessment

BCKV	Bidhan Chandra Krishi Viswavidyalaya
CII	Confederation of Indian Industries
CIMFR	Central Institute of Mining & Fuel Research
CLRI	Central Leather Research Institute
CMA	Cement Manufacturing Association
CRRI	Central Road Research Institute
FSI	Forest Survey of India
IARI	Indian Agricultural Research Institute
IGFRI	Indian Grass & Fodder Research Institute
IISc	Indian Institute of Science
IVRI	Indian Veterinary Research Institute
NDRI	National Dairy Research Institute
NEERI	National Environment Engineering Research Institute
NPL	National Physical Laboratory
NRCS	National Remote Sensing Centre
PPAC	Petroleum Planning and Analysis Cell
TERI	The Energy and Resources Institute

Figure 3.2: INCCA and Network for preparing the Greenhouse Gas Emissions 2007.

4

Greenhouse Gas Estimation - 2007

Towards fulfillment of its obligations of furnishing information relating to implementation of the Convention in accordance with Article 4.1 and 12(1) of the United Nations Framework Convention on Climate Change, India has communicated its first national communication to the UNFCCC in 2004 with GHG emission data for the year 1994. Currently, India is preparing its second national communication for the base year 2000. However, there is a need for latest data on GHG emissions from the country, especially for informed decision making. In this direction a network of institutions have been put in place to prepared the 2007 GHG inventory (Refer to Figure 3.1).

4.1 COVERAGE

The 2007 assessment presents the estimates of CO_2, CH_4 and N_2O emitted as a result of anthropogenic activities from various sectors of the economy at national level for the year 2007. The sectors included are Energy, Industry, Agriculture, Land Use Land Use Change & Forestry and Waste. A schematic representation of the sectors, source categories and the gases included in the present assessment is shown in Figure 4.1.

An assessment of the collective emissions of CO_2, CH_4 and N_2O expressed as Carbon Dioxide equivalent ($CO_{2\ eq}$) has also been presented here, wherein CO_2 equivalent is the sum total of CO_2, CH_4 and N_2O emitted in terms of their respective global warming potentials (GWP). Relative values of GWP of CO_2, CH_4 & N_2O are presented in Table 4.1. For definition of GWP, see glossary.

By assigning a GWP value to a GHG, allows scientists and policy makers to compare the potency of each gas to trap heat in the atmosphere relative to other gases. The heat trapping potential of other greenhouse gases are measured and compared with CO_2. The GWP of CO_2

Table 4.1: Global Warming Potential (GWP) of the GHGs

Industrial Designation or Common Name (years)	Chemical Formula	Lifetime (years)	Radiative Efficiency (W m^{-2} ppb^{-1})	Global Warming Potential for Given Time Horizon (100 yr)
Carbon dioxide	CO_2	Upto 100 yrs	$1.4x10^{-5}$	1
Methane	CH_4	12	$3.7x10^{-4}$	21
Nitrous oxide	N_2O	114	$3.03x10^{-3}$	310

Source: IPCC AR4, 2007a

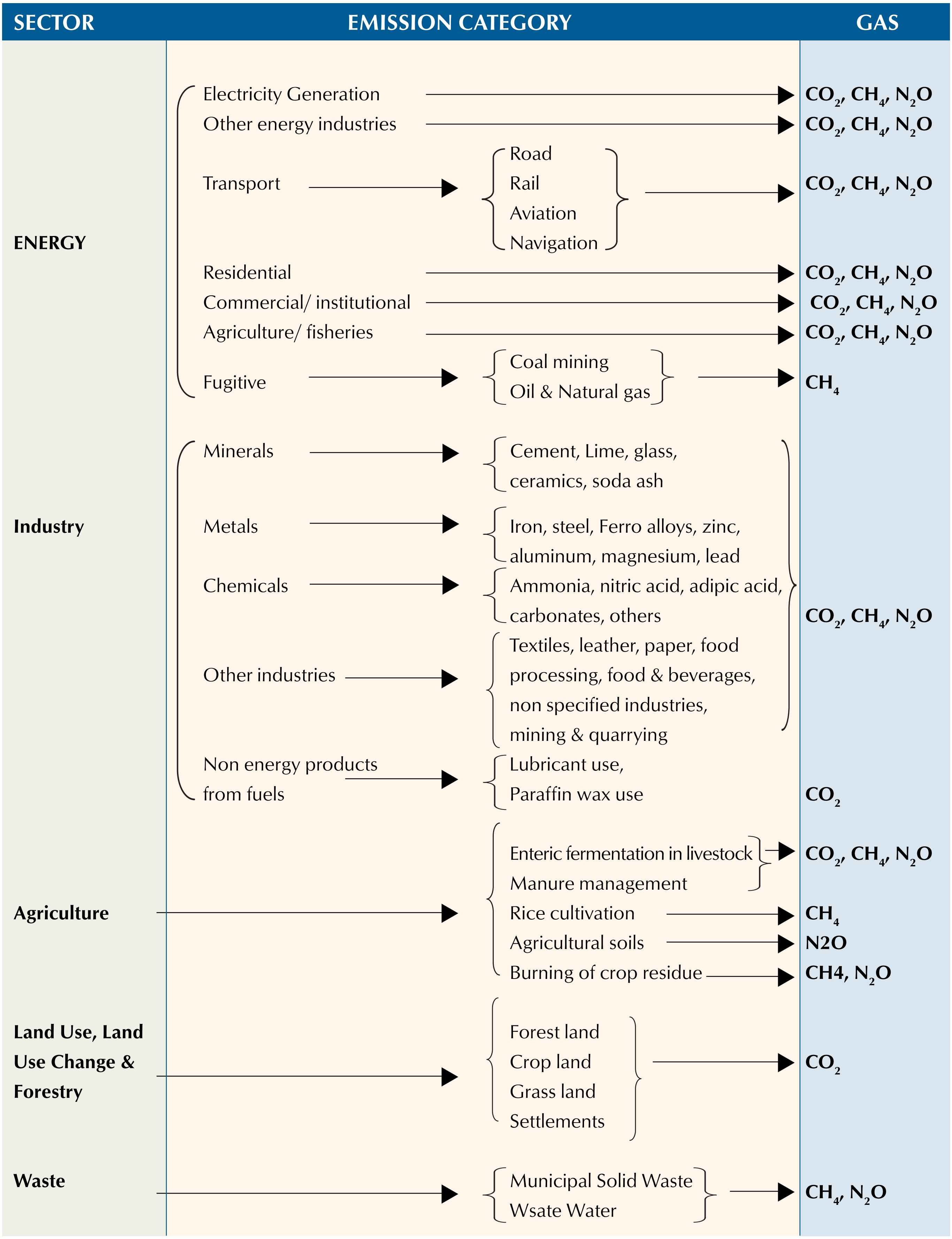


Figure 4.1: Sectors, emission categories and emissions presented in this assessment (Also see glossary for details)

is taken as one and accordingly CH_4 has a GWP of 21 and N_2O has a GWP of 310.

4.2 METHODOLOGY, ACTIVITY DATA AND EMISSION FACTORS

Methodology: The estimates presented here have been calculated using standard methodologies contained in the Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories (IPCC, 1997), the IPCC Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories (IPCC 2000), and the IPCC Good Practice Guidance for Land Use, Land-Use Change, and Forestry (IPCC 2003).

The simplest representation of the methodology used for estimating particular GHG emission from each source category is when activity data for a source category is multiplied by respective emission factor to obtain emissions from that source category for a specific gas. To calculate the total emissions of a gas from all its source categories, the emissions are summed over all source categories (see equation below).

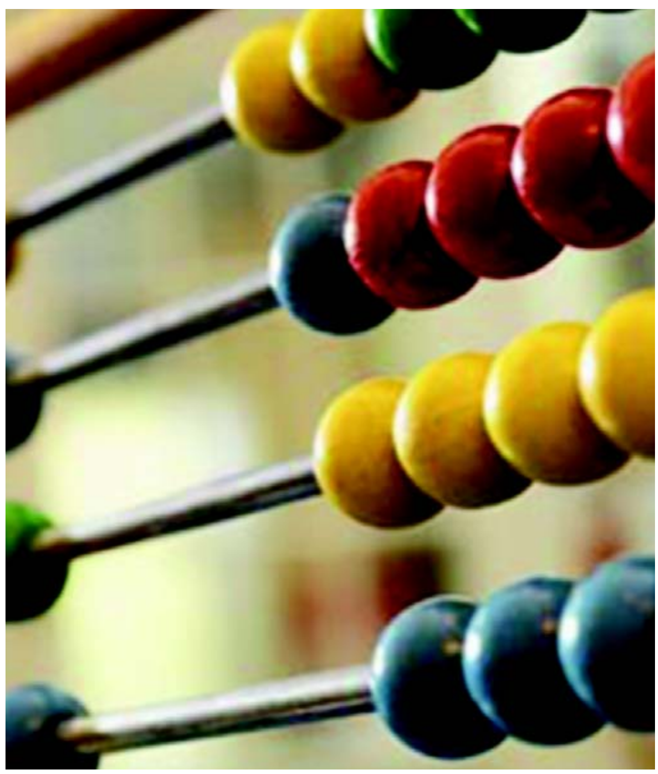
$$\text{Emissions}_{\text{Gas}} = \sum_{\text{Category}} A \times EF$$

Here $\text{Emissions}_{\text{Gas}}$ is the emissions of a given gas from all its source categories, A is the amount of individual source category utilized that generates emissions of the gas under consideration, EF is the emission factor of a given gas by type of source category (emissions per unit of activity data utilized).

Activity data: Activity data for 2007 have been primarily derived from the published documents of the various ministries and organizations of the Government of India, from industry associations (such as the Cement Manufacturers' Association (CMA) of India) and from reputed data organizations such as the CMIE. See Annexure 1 for a comprehensive list of activity data sources.

Emission factors: The emission factors used in this report are a mix of default emission factors available in IPCC publications (1997, 2000, 2003 and 2006) and country specific emission factors. Default emission factors have been used for gases and categories where country specific factors are not available. Some of the country specific emission factors used in this document include emissions factors of CO_2 from coal (Choudhury et al., 2004), CH_4 from coal mining (Singh A K, 2004), N_2O from nitric acid production (Rao et al. ,2004), CO_2 from cement (Rao et al., 2006), CH_4 from rice (Gupta et al., 2004), CH_4 from enteric fermentation in livestock (Swamy et al., 2006), N_2O from soils (Pathak et al., 2002); CH_4 from Municipal solid waste (Jha et al., 2007) amongst others. See Annexure 2 for complete list of references.

Tier of estimation: Tiers of estimation of GHGs is an IPCC parlance suggesting the level of complexity applied in estimating the GHG emissions from a particular source category. The Tiers of estimate range between Tier I. II, & III. Higher Tier implies a more data intensive effort (see box 4.3). For example, CH_4 from rice cultivation is estimated by using Tier III approach, where by the total rice area is divided into areas characterizing different water management practices in the country. The GHG emission factors used for estimating CH_4 from these areas are actual measurements carried out that represent CH_4 emission/unit area covering a each different water management practice. Efforts are generally made to use a Tier II or III (i.e a data intensive approach) for categories that are identified as key emissions categories (see Chapter 11, for more details on key categories).



Box 4.3: Methodology Tiers

Tier I approach employs activity data that are relatively coarse, such as nationally or globally available estimates of deforestation rates, agricultural production statistics, and global land cover maps.

Tier 2 use the same methodological approach as Tier 1 but applies emission factors and activity data which are defined by the country.

Tier 3 approach uses higher order methods are used including models and inventory measurement systems tailored to address national circumstances, repeated over time, and driven by disaggregated levels.

In this report, Tier III approach has been applied to estimate CH_4 from enteric fermentation in livestock, CH_4 from rice paddy cultivation, CO_2 from cement, and CH_4 from coal mining. Tier II approach has been used for estimating CO_2 from coal combustion for electricity generation, CO_2 from iron and steel production, CO_2 from road transport sector, N_2O from soils, GHGs from crop residue burning, and CH_4 from industrial waste water and municipal solid waste. Rest of the emission categories use Tier I methodology.

5

Energy

The energy systems of most economies are largely driven by the combustion of fossil fuels, namely, coal, oil and natural gas and are the major sources of emissions amongst all other sectors. Fossil fuel combustion oxidizes the carbon in the fuel and it is emitted as CO_2. Some C is also released in the form of CO, CH_4, and non-methane hydro carbons which is oxidised to CO_2 in 10-11 years. Also emitted are N_2O, SO_2, and black carbon. This document includes CO_2, CH_4 and N_2O emitted from fossil fuel combustion in

- Electricity generation;
- Transportation including road, rail, aviation & navigation;
- Commercial, institutional, residential, agriculture and fisheries and;
- Fugitive emissions from coal mining & handling, and from exploration of oil and natural gas and their transport and storage are also accounted for in this sector.

5.1 METHODOLOGY AND CHOICE OF EMISSION FACTORS

The IPCC 1996 revised guidelines (IPCC, 1997) methodology has been used for estimating the GHG emission from various types of fossil fuel combusted in the energy sector. The general equation representing the emissions is shown in the box below.

The emission factors of the fossil fuels such as coal, oil and natural gas are the most important considerations in estimating the GHG emissions from combustion of these fuels. In India, coal as a fuel constitutes more than 50% of the total fossil fuel mix of the country used for energy related activities. This document uses the country specific CO_2 emission factors derived on the basis of Net Calorific Values (NCVs) of different types of coal produced in the country, namely, coking, non coking and lignite (NATCOM, 2004; Choudhry et al., 2006). See Table 5.2 for the list of NCVs and CO_2 emission factors used for various fuels for the present estimations. The non-CO_2 emissions have been estimated using non-CO_2 default emission factors for different fuel types published in IPCC, 1997 & 2006.

Carbon emissions = $\sum_{\text{Fuel type}}$ fuel consumption expressed in energy units for electricity generation x carbon emission factor - carbon stored x fraction oxidised

Non CO_2 emissions = $\sum_{\text{Fuel type}}$ fuel consumption x Net Calorific value of Fuel x gas-specific emission factors

5.2 OVERVIEW OF GHG EMISSIONS FROM THE ENERGY SECTOR

In 2007, the energy sector in India emitted 1100.06 million tons of CO_2 equivalent. Out of this 992.84 million tons were emitted as CO_2, 4.27 million tons as CH_4 and 0.057 million tons as N_2O (Table 5.3). About 65.4% of the total CO_2 equivalent emissions from the energy sector was from the electricity generation. This includes emission from electricity produced for distribution through grids as well as for captive generation of electricity in various industries (Figure 5.1). The transport sector emitted 12.9% of the total CO_2 equivalent emissions in 2007. The residential sector has a rural and urban spread, and therefore it combusts both fossil fuel as well as biomass which together emitted 12.6% of the total GHG emitted from the energy sector. Rest of the 9.2% GHG emissions were from fuel combusted in the commercial and residential sector, in agriculture and fisheries, the fugitive emissions from coal mining, and from extraction, transport and storage of oil and natural gas. (figure 5.1)

5.3 ELECTRICITY GENERATION

The Total installed capacity for electricity generation from thermal power plants in India in 2007 was 89275.84 MW (CEA, 2008). Additionally captive power generation, especially used in the industries for dedicated power supply was around 11600 MW. For electricity generation in 2007, coal utilization was 90% of the total fuel mix. Natural gas and oil constituted 8% and 2% of the fuel mix respectively. It is estimated that in 2007, the total GHG emissions from electricity generation was 719.31 million tons CO_2 eq of which 715.83 million tons was

Table 5.2: NCV and CO_2 emission factors of different types of fuel used for estimation

	NCV (Tj/kt)	CO_2 EF (t/Tj)
Coking coal	24.18	93.61
Non-coking Coal	19.63	95.81
Lignite	9.69	106.15
Diesel	43	74.1
Petrol	44.3	69.3
Kerosene	43.8	71.9
Fuel oil	40.4	77.4
Light distillates	43.0	74.1
CNG	48	56.1
LPG	47.3	63.1
Lubricants	40.2	73.3
ATF	44.1	71.5

Note: NCV- Net Calorific Value; EF- Emission Factor; Tj = 10^{12}Joule; 1 Joule = 2.39x 10^{-4}Kcal

Table 5.3: GHG emissions in '000 tons (or Giga gram) from the energy sector in 2007

	CO_2	CH_4	N_2O	CO_2 equivalent
GRAND TOTAL	**1497029.20**	**20564.20**	**239.31**	**1727706.10**
ENERGY	**992836.30**	**4266.05**	**56.88**	**1100056.89**
Electricity generation	715829.80	8.14	10.66	719305.34
Other energy industries	33787.50	1.72	0.07	33845.32
Transport	138858.00	23.47	8.67	142038.57
Road transport	*121211.00*	*23.00*	*6.00*	*123554.00*
Railways	*6109.00*	*0.34*	*2.35*	*6844.64*
Aviation	*10122.00*	*0.10*	*0.28*	*10210.90*
Navigation	*1416.00*	*0.13*	*0.04*	*1431.13*
Residential	69427.00	2721.94	36.29	137838.49
Commercial / Institutional	1657.00	0.18	0.04	1673.18
Agriculture/ Fisheries	33277.00	1.20	1.15	33658.70
Fugitive emissions		1509.40		31697.30
Bunkers*	**3454**	**0.03**	**0.10**	**3484.45**
Aviation Bunkers	3326	0.02	0.09	3355.31
Marine bunkers	128	0.01	0.003	129.14

Note: '000 tons= 1Giga Gram = 10^9 grams and 1 million ton = 10^{12} grams
**Bunkers not added to the total emissions from the energy sector nor to the national totals*

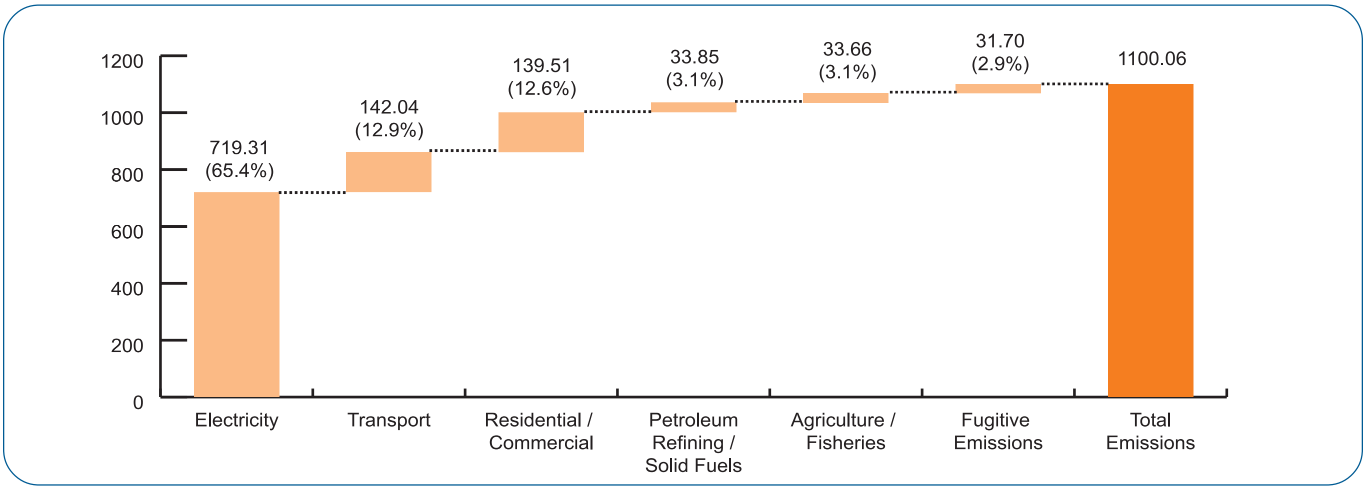


Figure 5.1: GHG emission distribution from the energy sector (million tons of CO_2 eq)

emitted as CO_2, 8.14 thousand tons as CH_4 and 10.66 thousand tons as N_2O. The distribution of the emissions by fuel type are shown in figure 5.2. It is clear that 90% of the emissions of CO_2, CH_4 and N_2O were due to coal combusted in this activity.

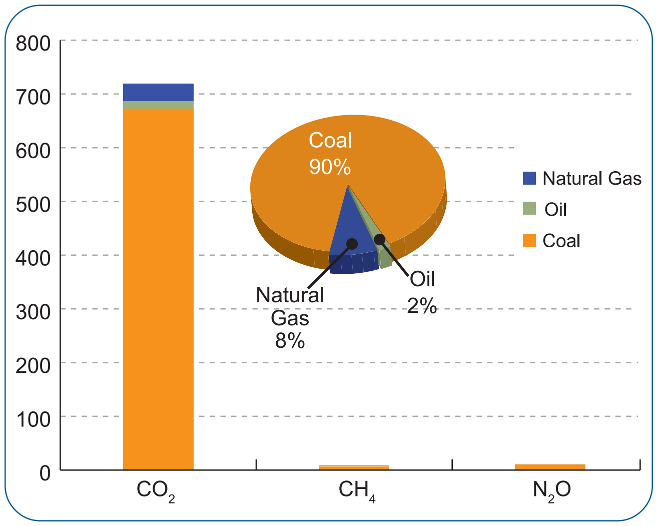


Figure 5.2: Fuel mix and GHG emissions in million tons from electricity generation

5.4 PETROLEUM REFINING & SOLID FUEL MANUFACTURING

All combustion activities supporting the refining of petroleum products is included here. Does not include evaporative emissions occurring at the refinery. These emissions are reported separately under fugitive emissions. It also includes emissions arising from fuel combustion for the production of coke, brown coal briquettes and patent fuel. The total CO_2 equivalent emissions from solid fuel manufacturing and petroleum refining in 2007 was 33.85 million tons, and out of this 97% of the emissions were from solid fuel manufacturing.

5.5 TRANSPORT

The transport sector emissions include all GHG emissions from road transport, railways, aviation and navigation. Due to rapid economic growth in India over the last two decades the demands for all transport services, particularly road transport and aviation has increased manifold, it has a share of 4.5% in India's GDP. The total number of registered vehicles in the country has increased from 5.4 million in 1981 to 99.6 million in 2007 (figure 5.3). Two wheelers and cars constitute nearly 88% of the total vehicles at the national level (MoRTH, 2008).

The total commercial energy consumption in the transport sector in 2007 is estimated to be 1766.6 PJ, that includes an array of fuels, such as diesel, petrol, coal, ATF, kerosene, LDO, FO, CNG, and LPG. Diesel comprises 65% of total energy used in the road transport sector, followed by petrol (24%) and ATF (7%) respectively. The rest (4%) constitute of coal, LDO, FO, CNG & LPG (Figure 5.4).

Consequently, it is estimated that the transport sector emitted 142.04 million tons of CO_2 eq in 2007, of which 138.86 million tons were emitted as CO_2, 0.023 million tons as CH_4 and 0.009 million tons as N_2O (refer to table 5.1). The road transport sector emitted 123.55 million tons of CO_2 eq, which is 87% of the total emissions from the transport sector. In terms of specific gases, the road transport sector emitted, 121.21 million tons of CO_2,

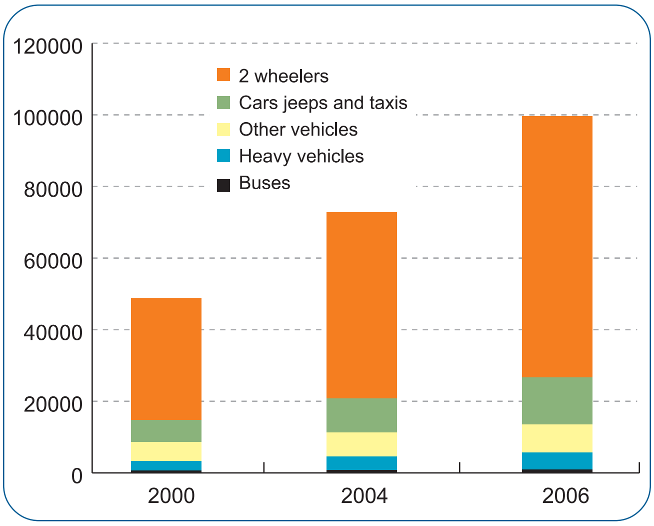


Figure 5.3: Growth in transport sector ('000 number of vehicles)

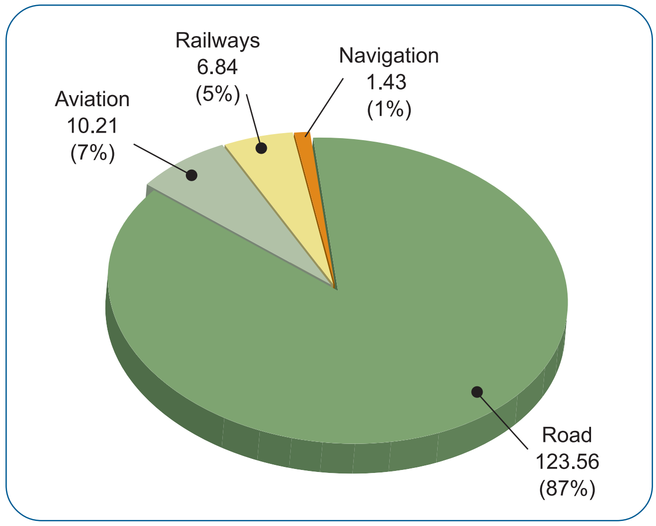


Figure 5.5: CO_2 equivalent emission distribution from various modes of transport within the transport sector

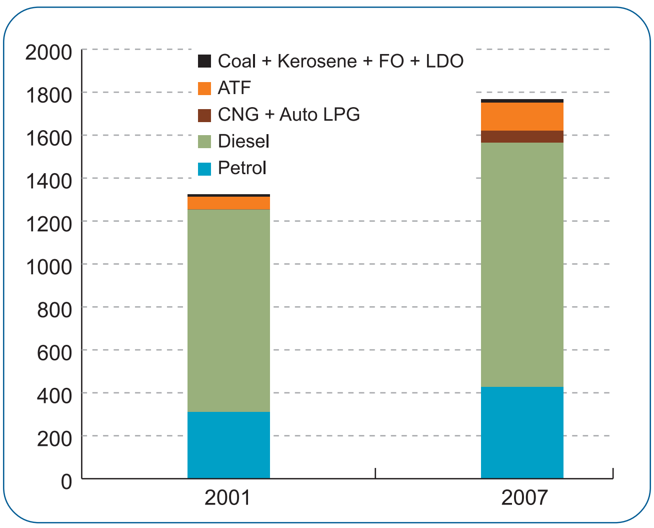


Figure 5.4: Distribution of fuel use in the transport sector in 2007 (in PJ)

0.023 million tons of CH_4 and 0.006 million tons of N_2O. Aviations emitted 10.21 millions of CO_2 equivalent in 2007 and is the second largest emitter in transport sector. Almost the entire emissions from aviation sector was emitted as CO_2 (10.12 million tons). The railways emission are mostly driven by diesel, with very small use of other liquid fuels. The coal use in railways has become minimal. The railways emitted 6.84 million tons of CO_2 eq in 2007, and again more than 90% of the emissions were in the form of CO_2. The navigation emitted 1.43 million tons of CO_2 equivalent and out of this 1.41 million tons were emitted as CO_2. (Figure 5.5).

5.6 RESIDENTIAL/ COMMERCIAL AND AGRICULTURE/FISHERIES

Energy consumed in the residential sector is primarily used for cooking, lighting, heating and household appliances. Usage of LPG as the primary source of cooking by households in urban India exceeded consumption of the same by rural households by 48%. Biomass fuels such as fuel wood, crop residues, and animal dung continue to be the dominant fuels used by rural households. In the commercial sector, key activities include lighting, cooking, space heating/cooling, pumping, running of equipments and appliances. Sources of energy for the sector are grid based electricity, LPG, kerosene, diesel, charcoal and fuel wood. Data for LPG and Kerosene have been obtained from Ministry of Petroleum and Natural Gas (MoPNG).

Commercial and institutional sector also sees extensive use of captive power generation across the country due to frequent power shortages in various seasons. These power generation units generally run on diesel. In urban sector the important sources of energy are kerosene (10%), firewood & chips (22%) and LPG (57%). Biomass fuels such as fuel wood, crop residue and animal dung continue to be the dominant fuel used by rural households.

In 2007, the residential sector emitted 137.84 million tons of CO_2 equivalent, of which 69.43 million tons were in the form of CO_2 emissions, mainly from fossil fuel use in the residential sector (refer to table 5.3). The CH_4 and N_2O emissions were 2.72 million tons and 0.036 million tons of CH_4 and N_2O respectively. The CH_4 emissions are driven by the biomass consumption in the residential sector.

The commercial/institutional sector used fossil fuel for its energy needs and emitted 1.67 million tons of CO_2 eq, of which more than 99% was CO_2 (1.65 million tons). The agriculture and fisheries sector emitted 33.7 million tons of CO_2 equivalent, and again more than the 99% of the emissions were in the form of CO_2.

5.7 FUGITIVE EMISSIONS

Fossil fuels such as coal, or natural gas when extracted, produced, processed or transported, emit significant amount of methane to the atmosphere. The total emission from these two sources, comprise only of CH_4 emission and India emitted 31.69 million tons CO_2 eq. It constitutes 97.8% of the total CH_4 emitted from the energy sector. CH_4 emissions from both surface mining and underground mining of coal have been estimated by using country specific emission factors measured in sample coal mines of different gassiness across the India. Further the emission estimates combine the emissions during mining and post mining activities. (Table 5.4) : coal mining lead to 0.73 million tons

CH_4 emission from oil and natural gas industries occur due to leakage, evaporation and accidental releases from oil and gas industry. Emissions from venting and flaring are activities that are managed as part of normal operations at field processing facilities and oil refineries. Each of these three major categories is in turn divided into several subcategories. Venting and flaring emissions occur at several stages of the oil and gas production process. The structure of the categories means that a single process can contribute greenhouse gas emissions to two or more categories of emissions. Emission factors for estimating CH4 from oil and natural gas systems is given in Table 5.5.

Table 5.4: Country specific emission factors for estimating CH_4 emission from coal mining activities

			Emission Factor (m^3 CH_4/ tons)
Underground Mines	Mining	Deg. I	2.91
		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

Table 5.5: CH_4 emission from Oil and natural gas systems

	Emission factor/ unit of activity
No. of Wells	0.003 Gg/well
Oil Production	0.000334 Gg/'000 tons
Refinery Throughput	6.75904×10^{-5} Gg/million tons
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

Source : IPCC (2000,2006)

6

Industry

The industry sector includes emissions from fossil fuel combustion and the emissions related to various process to manufacture industrial goods. The categories covered under this sector are:

- Minerals - Cement, glass production, ceramics;
- Chemicals - Ammonia, nitric acid, Carbides, Titanium Oxide, Methanol, Ethylene, EDC and VCM production, Carbon black, and Caprolactam etc.;
- Metal - Iron and steel, Ferro alloys, Aluminum, lead, zinc & copper;
- Other industries - textiles, leather, food & beverages, food processing paper & pulp, non specified industries and mining and quarrying;
- Non energy product uses of Lubricant and paraffin wax.

While the GDP has increased in India, the share of industry in the increased GDP has remained constant at 27% between 1990 and 2007. The annual growth of the overall Index of Industrial Production (IIP), a measure of the absolute level and percentage growth of industrial production, has shown a steady increasing trend between 2000 and 2007. The growth rate has doubled with growth rate increasing from 5% to 10.6% (Ministry of Statistics & Programme Implementation, 2009), a sign of a fast emerging economy.

6.1 METHODOLOGY AND CHOICE OF EMISSION FACTORS

For estimating the GHG emissions from the Industry sector, the IPCC 1996 revised guidelines (IPCC, 1997) have been used for each of the categories. The activity data for the various industries are sourced from national statistical organizations, from listed companies, the annual reports of ministries of the Government of India, research organizations, trade magazines and other publications of the sector associations (see Annexure 1).

The energy conversion units and the emission factors used for fossil fuel combustion related to fossil and biomass are same as indicated in table 5.2 in the energy sector. The emission factors used for the process part of the emissions are presented in Table 6.1. For cement and nitric acid production the CO_2 and N_2O are based on country specific circumstances (Rao et al., 2004).

6.2 OVERVIEW OF GHG EMISSIONS FROM INDUSTRY

The summary of GHG emissions from the Industry sector is given in Table 6.2. In 2007, the total CO_2 equivalent emission from this sector was 412.55 million tons. It emitted 405.86 million tons of CO_2, 0.15 million tons of CH_4 and 0.21 million tons of N_2O. 31.7% of the total CO_2 equivalent emissions from Industry sector were from mineral industries where as 28.4% of the total GHG emissions were from metal industries. About 8.1% of the

Table 6.1: Emission factors used for estimating process emissions

Category	Gas	Emission factor	Source
Cement production	CO_2	0.537 t CO_2/t Clinker produced (incorporates CKD)	CMA, 2010
Glass production	CO_2	0.21 t CO_2/t glass (Container Glass); 0.22 t CO_2/t glass (Fibre Glass); 0.03 t CO_2/t glass (speciality glass)	IPCC 2006
Other sources of soda ash	CO_2	0.41492 t CO_2/t carbonate	IPCC 2006
Ammonia production	CO_2	Carbon content of natural gas has been taken as 99.5% and carbon oxidation factor has been taken as 14.4 kg C/GJ	NATCOM 2004
		Fuel requirement = Middle point value of the range 7.72 - 10.5 million Kcal/tonne of Ammonia	Oral communication by Fertilizer Association of India
Caprolactam production	N_2O	9 kg N_2O/t chemical produced	IPCC 2006
Carbide production	CO_2	1.1 t CO_2/t CaC_2 produced	IPCC 2006
Titanium dioxide production	CO_2	1.385 tons CO_2/tons TiO2 produced	IPCC 2006 (Avg. of EFs)
Methanol	CO_2	0.67 tons CO_2/tons methanol produced	IPCC 2006
	CH_4	2.3 kg CH_4/tons methanol produced	IPCC 2006
Ethylene	CO_2	1.73 t CO_2/tons ethylene produced	IPCC 2006
	CH_4	3 kg CH_4/t ethylene produced	IPCC 2006
EDC & VCM	CO_2	0.296 t CO_2/tons EDC produced; 0.47 tons CO_2/tons VCM produced	IPCC 2006
Ethylene Oxide	CO_2	0.863 tons CO_2/t Ethylene oxide produced	IPCC 2006
	CH_4	1.79 kg CH_4/tons Ethylene oxide produced	IPCC 2006
Acrylonitrile	CO_2	1 ton CO_2/ton acrylonitrile produced	IPCC 2006
	CH_4	0.18 kg CH_4/ton acrylonitrile produced	IPCC 2006
Carbon black	CO_2	2.62 ton CO_2/ton carbon black produced	IPCC 2006
	CH_4	0.06 kg CH_4/ton carbon black produced	IPCC 2006
Iron & Steel production	CO_2	1.46 ton CO_2/ton production (BOF); 0.08 ton CO_2/ton production (EAF); 1.72 ton CO_2/ton production (OHF); 0.7 ton CO_2/ton production (DRI)	IPCC 2006
Ferroalloys production	CO_2	4.8 ton CO_2/ ton ferrosilicon produced; 1.5 ton CO_2/ton ferromanganese produced; 1.1 kg CH_4/ t ferrosilicon produced	IPCC 2006
	CH_4	1.1 kg CH_4/ton ferrosilicon produced	IPCC 2006
Aluminium	CO_2	1.65 ton CO_2/ton aluminium produced production	IPCC 2006 (Avg. of EFs)
Lead production	CO_2	0.58 ton CO_2/ton lead produced (Imperial smelting furnace); 0.25 t CO_2/ton lead produced (direct smelting); 0.2 ton CO_2/ton lead produced (secondary production)	IPCC 2006
Zinc production	CO_2	0.53 ton CO_2/ton zinc produced (pyro-metallurgical process)	IPCC 2006
Lubricant use	CO_2 *during*	20 ton-C/TJ (Carbon content); 0.2 (ODU factor -*oxidised* *use* factor)	IPCC 2006
Paraffin wax use	CO_2	20 ton-C/TJ (Carbon content); 0.2 (ODU factor -oxidised during use factor)	IPCC 2006

Table 6.2: GHG emissions from the Industry sector in '000 tons (or Giga Gram)

	CO_2	CH_4	N_2O	CO_2 eq
INDUSTRY	**405862.90**	**14.77**	**20.56**	**412546.53**
Minerals	**130783.95**	**0.32**	**0.46**	**130933.27**
Cement production	129920.00			129920.00
Glass & ceramic production	277.82	0.32	0.46	427.14
Other uses of soda ash	586.12			586.12
Chemicals	**27888.86**	**11.14**	**17.33**	**33496.42**
Ammonia production	10056.43			10056.43
Nitric acid production			16.05	4975.50
Carbide production	119.58			119.58
Titanium dioxide production	88.04			88.04
Methanol production	266.18	0.91		285.37
Ethylene production	7072.52	9.43		7270.64
EDC & VCM production	198.91			198.91
Ethylene Oxide production	93.64	0.19		97.71
Acrylonitrile production	37.84	0.01		37.98
Carbon Black production	1155.52	0.03		1156.07
caprolactam			1.08	336.22
Other chemical	8800.21	0.56	0.20	8873.97
Metals	**122371.43**	**0.95**	**1.11**	122736.91
Iron & Steel production	116958.37	0.85	1.09	117315.63
Ferroalloys production	2460.70	0.08		2462.29
Aluminium production	2728.87	0.01	0.00	2729.91
Lead production	84.13	0.00	0.01	86.38
Zinc production	76.11	0.00	0.01	77.99
Copper	63.25	0.01	0.00	64.70
Other Industries	**123969.17**	**2.37**	**1.65**	124530.44
Pulp and paper	5222.50	0.05	0.08	5248.35
Food processing	27625.53	1.12	0.22	27717.25
Textile and leather	1861.11	0.03	0.02	1867.94
Mining and quarrying	1460.26	0.06	0.01	1464.62
Non-specific industries	87799.77	1.11	1.32	88232.28
Non energy product use	**849.49**			849.49
Lubricant	776.75			776.75
Paraffin wax	72.75			72.75

total GHG emissions were from chemical industries. The other industries consisting of pulp and paper, food & beverage, non-specific industries, textile & leather, and mining/ quarrying together constituted 30.4% of the total GHG emission from the energy sector. Absolute values of the emissions by sub category in the energy sector is shown in Figure 6.1.

6.3 MINERALS

Minerals like, cement, glass, ceramics and soda ash use emitted 130.78 million tons of CO_2 eq of which the cement production lead to an emission of 129.9 million tons of CO_2 eq., glass & ceramics production emitted 0.43 million tons and soda ash use emitted 0.59 million tons

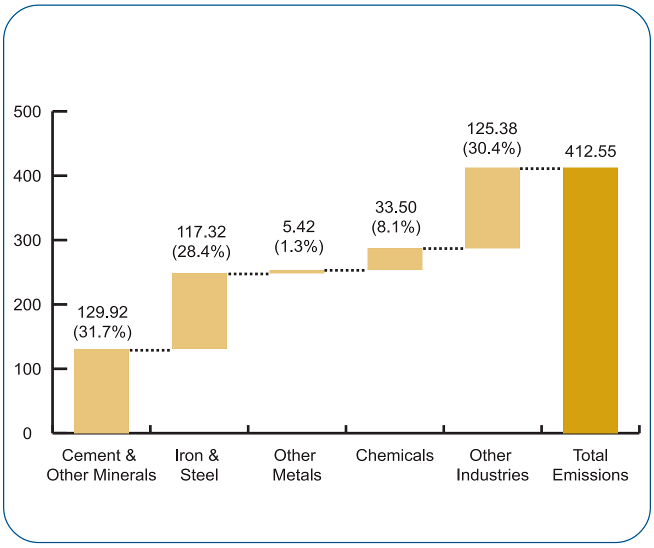


Figure 6.1: CO_2 emission in Million tons from Industry

6.4 CHEMICALS

Emission estimates have been made on account of combustion of fossil fuel and processes involved in the production of chemicals such as ammonia, nitric acid, carbide, methanol, titanium dioxide, adipic acid, ethylene, carbon black and caprolactam. The total amount of GHG emitted from this sector in 2007 was 33.50 million tons of CO_2 equivalent. Total amount of CO_2 produced from this sector was 27.89 million tons. CH_4 and N_2O emissions were 0.11 & 0.17 million tons respectively.

6.5 METALS

The metal production emissions are estimated from production of iron and steel, aluminum and from other metals such as zinc, lead, magnesium, ferro alloys and copper. The total GHG emission from this sector was 122.74 million tons which constituted 29.7% of the total GHG emitted from this category in the industry sector. The total amount of CO_2 emitted from this category is 122.37 million tons; miniscule emissions are emitted in the form of CH_4 and N_2O.

6.6 OTHER INDUSTRIES

These include emissions from pulp and paper production, food and beverage, textile & leather, non-specified industries, and mining/quarrying activities. The non-specified industries include Manufacture of rubber and plastics products, medical, precision and optical instruments, watches and clocks, other transport equipment, furniture, recycling etc. for which data is not available separately. Other industries emitted together 124.5 million tons of CO_2 equivalents in 2007, of which 123.9 million tons were emitted as CO_2. Miniscule amounts of CH_4 and N_2O were also emitted from this sector, which constituted less than 1% of the total GHG emission from this sector.

6.7 NON-ENERGY PRODUCT USE

Includes emission of GHGs due to use oil products and coal-derived oils primarily intended for purposes other than combustion. This category includes CO_2 emissions from use of paraffin wax and lubricant and together they emitted 849.5 thousand tons of CO_2 which is 0.2% of the total GHG emission from this sector.

6.8 A DESCRIPTION OF FOSSIL FUEL AND PROCESS BASED EMISSIONS

This section highlights the differences in process and fossil fuel combustion related CO_2 emissions from industries. As an example, the major industries such as cement, iron and steel, chemicals and non-ferrous metal production have been included. Figure 6.2 depicts the relative emissions due to fossil fuel combustion and process emissions in these industries.

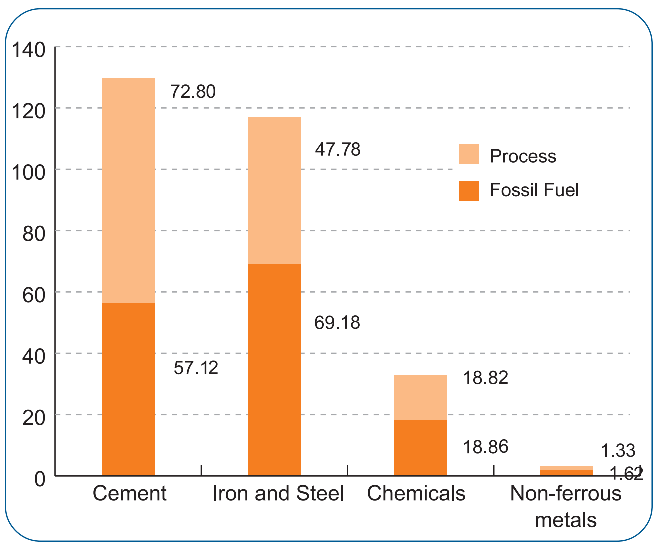


Figure 6.2: Relative CO_2 emissions in million tons due to fossil fuel combustion and process emissions in different industries

Cement industry - emitted 129.92 million tons of CO_2. 56% of these emissions were from process and 44% from fossil fuel combustion. These emissions are from diverse types technologies for manufacturing cement in India. See Table 6.3 for the technological status of Indian cement industry. (Figure 6.2)

Iron and steel - Emits 116.96 million tons of CO_2. The fossil fuel combustion and process related emissions constitute 59% and 41% of the total emissions related from this industry respectively, (Figure 6.2)

Chemicals - All chemicals, together emit 37.9 million tons of CO_2. Out of this 49.6% is from process related emissions and 50.4% of the CO_2 emissions are due to fossil fuel combustion. (figure 6.2)

Non-Ferrous metals - Constituting of aluminium, zinc, lead and copper together emitted 2.95 million tons of CO_2. 45% of these emissions were from process and 55% from fossil fuel combustion in non-ferrous metal industries. (Figure 6.2)

Table 6.3: Technological Status of Indian Cement Industry as of Dec, 2007

	Mini-Vertical Shaft Kiln	Mini-Rotary kiln	Wet Process	Semi-Dry	Dry	Grinding Units
No of Plants	193	17	26	4	107	29
Total Capacity (million tones)	1.51	3.11	5.71	1.80	146.56	20.3
Percent of total cement capacity	0.84	1.73	3.18	1.00	81.87	11.34
Average kiln Capacity [TPD]	30 -75	200-800	150-900	600-1300	2400-10,000	**600-2500
Fuel consumption (Kcal/kg. Clinker)	850-1000	900-1000	1200-1400	900-1000	670- 775	Nil (except for captive power plants)
Power Consumption (Kwh/tonne of cement)	110-125	110-125	115-130	110-125	85-92	**35-45

***Grinding capacity*
Source: CMA Basic Data, Annual Publication – 1994 to 2009

7

Agriculture

The GHG emissions from the agriculture sector are emitted mainly in the form of CH_4. These are due to enteric fermentation and from rice paddy cultivation. N_2O is also emitted from this sector and is mainly from the agricultural fields due to application of fertilizers. The sources of emissions included in the agriculture sector are:

- Livestock
  - Enteric fermentation
  - Animal manure
- Rice cultivation
  - Upland
  - Irrigated - continuously flooded, singular aeration, multiple aeration
  - Rainfed - drought prone, flood prone
  - Deep water
- Agriculture soils
  - Direct emissions
  - Indirect emissions
- Field burning of agriculture crop residue

7.1 OVERVIEW OF THE AGRICULTURE SECTOR EMISSIONS

Agriculture sector emitted 334.41 million tons of CO_2 equivalent, of which 13.76 million tons is CH_4 and 0.15 million tons is N_2O. Enteric fermentation constituted 63% of the total CO_2 equivalent emissions from this sector, 21% of the emissions were from rice cultivation. Crop soils emitted 13% of the total CO_2 equivalent emission from agriculture. Rest 2.7% of the emissions are attributed to Livestock manure management and burning of crop residue (Table 7.1 and Fig. 7.1).

Table 7.1: Summary of GHG emissions from the agriculture sector in thousand tons

	CH_4	N_2O	CO_2 eq.
	13767.80	**146.07**	**334405.50**
Enteric fermentation	10099.80		212095.80
Manure management	115.00	0.07	2436.70
Rice cultivation	3327.00		69867.00
Soils		140.00	43400.00
Crop residue	226.00	6.00	6606.00

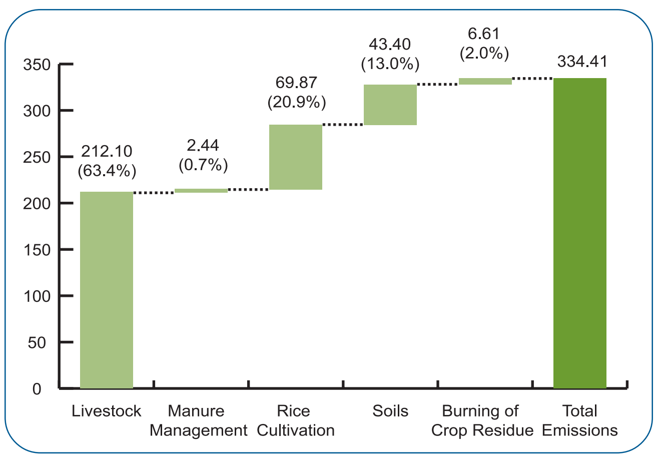


Figure: 7.1: CO_2 equivalent emissions from Agriculture sector (million tons)

7.2 ENTERIC FERMENTATION

In India, livestock rearing is an integral part of its culture and is an important component of the agricultural activities. Although the livestock includes cattle, buffaloes, sheep, goat, pigs, horses, mules, donkeys, camels and poultry, the bovines and the small ruminants are the most dominant feature of Indian agrarian scenario, and constitute major source of methane emissions. Traditionally cattle are raised for draught power for agricultural purposes, and cows and buffaloes for milk production. The cattle and buffaloes provide economic stability to farmers in the face of uncertainties associated with farm production in dry land/rain-fed cropped areas. Currently, most of the cattle are low-producing non-descript, indigenous breeds and only a small percentage (5-10 per cent) is of a higher breed (cross-bred and higher indigenous breeds). Even in the case of buffaloes, there are very few high yield animals (10–20 per cent). Sheep rearing is prevalent in many areas because of smaller herd sizes, which are easy to raise and manage, providing year-round gainful employment to the small and marginal farmers.

Cattle and buffalo, which are the main milk-producing animals in the country, constitute 61 per cent of the total livestock population in India. The average milk produced by dairy cattle in India is 2.1 kg/day, Whereas, buffaloes produce 3.5 kg/day (MOA, 2004), which is much less than the milk produced by cattle in the developed countries (IPCC Revised Guidelines, 1997). This is mainly due to the poor quality of feed available to the cattle, specially domesticated in rural households, in spite of the low-energy value of feed intake.

The livestock census is carried out every 5 years. The last census data is available for 2003. To estimate the livestock population for 2007, the 2003 data is extrapolated using the compounded annual growth rate of each type of livestock between 1997 and 2003 (see table 7.2).

In order to estimate the CH_4 emission from livestock, at a higher tier, the cattle population has been divided into dairy and nondairy categories, with sub classification into indigenous and cross-bred types for different age groups (MOA, 2005). The dairy cattle has been characterized as cross bred, it has high milk yield and calves once in a year. The indigenous cattle have the typical characteristic of having lower body weights as compared to cross breds and they have lower milk yield and also calve once a year. The Lactating buffalo are classified as dairy buffalo. Non dairy cattle & buffalo include calves below one year, adults beyond calving age, and those within one to two years of age.

Table 7.2: Livestock population estimates for 2007

Species	Livestock population (in '000)			
	1997	2003	CAGR	2007
Crossbred cattle	20099	24686	3.48	28306.0
Indigenous cattle	178782	160495	-1.7	148348.2
Total cattle	**198881**	**185181**	**-1.2**	**176654.2**
Buffaloes	89918	97922	1.4	103522.0
Yaks	59	65	1.6	69.3
Mithuns	177	278	7.8	176136.0
Total bovines	**289035**	**283446**	**-0.3**	**279727.1**
Sheep	57494	61469	1.1	64320.0
Goats	122721	124358	0.2	125546.0
Pigs	13291	13519	0.3	13635.0
Horses & ponies	827	751	0.01	800.0
Mules	221	176	-0.1	200.0
Donkeys	882	650	-6.5	458.0
Camels	912	632	-6.2	465.0
Total livestock	**485385**	**485002**	**-0.01**	**484733.5**

Source: MOA, 2005

Using the emission factors provided in the report (NATCOM, 2004), it is estimated that the Indian livestock emitted 9.65 million tons in 2007 (see table 5.10). This constitutes 96% of the total CH_4 released from this sector. Buffalo is the single largest emitter of CH_4, as it constitutes 60% of the total CH_4 emission from this category, simply because of its large number compared to any other livestock species and also because of the large CH_4 emission factor with respect to others.

Using the same approach for extrapolating the population of other livestock, namely, goats, sheep, chicken, camels, and others, and using the IPCC default CH_4 emission factors for these species (IPCC, 2002), it is estimated that the total CH_4 emitted from these categories is 36 thousand tons. The total CH_4 emitted from enteric fermentation in livestock is thus 10.09 million tons.

7.3 MANURE MANAGEMENT

Not much systematic management of manure from livestock is done in India. It is mainly converted into dung cakes and is used for energy purposes in rural areas. It is estimated that about 0.115 million tons of CH_4 and 0.07 thousand tons of N_2O are emitted from this source.

Methodology and emission factor choices: The dung management practices vary in different regions depending upon the need of the fuel and manure as well as the available fuel resources and climatic conditions of the regions. Dung management systems, generally followed in India, are as follows:

Dung cakes

The dung of stall fed cattle and buffaloes, irrespective of their age, production status, and feeding is collected and on an average 50% is converted in dung cake daily in the morning mainly by the women folk of the household in India. The collected dung is mixed with the residual feed (mainly straws) of animals and dung cake of circular shape (weighing 0.5 to 2.5 kg) is prepared by hand and put out in the sun for drying. Drying is generally completed within 3-5 days during summer season and 7-10 days during winter season. After drying, the dung cakes are staked in to a conical structure, which is plastered with dung on the upper surface before on setting the monsoon season. Some farmers store this source of fuel in the closed rooms. Under the prevailing situation methane emission is not expected from the dung cake. It is contrary to the IPCC (1997) which indicates 5-10% methane emission during the course of drying of dung cake.

Dung cake making is practiced almost in all the states in India except in Himachal Pradesh, Jammu & Kashmir and North-Eastern regions. Fuel requirements in these states are generally met through fuel wood. Dung of all other species such as pigs, camel, goat, sheep etc. is not utilized for making the dung cake. Manure: Indian farmers still depend upon organic manure for maintaining the soil fertility as this system is sustainable for the economy of the farmers. To convert the cattle and buffalo dung into manure, excess dung remaining from dung cake making is collected on the heap nearby to the cattle shed. The residual feed (unfit for mixing in dung cake) and ash (available due to the use of dung cake as source of fuel) are also put on the heap. However during monsoon season when dung cake making practice is stopped due to the rains, whole quantity of daily collection of dung goes to this heap. The dung, thus collected is exposed to the weather conditions and methane emission is expected from the inner core of the heap due to the anaerobic fermentation of organic matter. IPCC (1997) also attributed this fact. The manure thus prepared is generally carted to the fields at the time of soil preparations after the monsoon season or at the time of need.

Daily deposition on the soil

Part of the dung of cattle and buffaloes goes directly to the soil and deposited on the soil during the course of their grazing. Though grazing practice in major part of country is decreasing due to the shrinking of community lands and natural pastures. However, animals are allowed to graze on road side, canal bunds, fellow lands and harvested fields. In states/regions have forest areas and natural pastures, animals still survive on grazing as mentioned earlier. The excreta of grazing animals dry up quickly due to the mixing with soil during the trampling by the animals and do not produce methane as suggested by IPCC (1997).

The dung of goat and sheep goes directly to the soil and Indian farmer's value for this source of Nitrogen (N), Phosphorous (P), and Potassium (K) for their soil. In certain areas, farmers invite the nomadic shepherds along with their flock after the harvesting is over so that the flock can sit on the harvested field and consume the stubble and provide the nutrients from their dung and urine to the field. Shepherds are obliged with money, food and shelter till their flock sits on the field. The dung of other species such as donkey, horses, camel etc. directly goes to the soil deposition due to their daily mobility. The pig excreta are not utilized for manure purposes as pigs are being maintained under scavenging system.

Other systems

Efforts were made to develop the technology for biogas production from dung and popularize it the as it is a renewable source of energy but the farmers due to some inherent problems do not accept it. Therefore, only negligible part of the dung is utilized for biogas production.

According to the livestock census, the total amount of dung produced in 1997 and 2003 was 270 and 268 million tons respectively. Methane production from dung cake is taken as zero, only 50% of total dung therefore is considered for estimating methane and nitrous oxide emissions (Mahdeswara swami, 2004).

7.4 RICE CULTIVATION

India emitted 3.3 million tons of CH_4 in 2007 from 43.62 million ha cultivated for this purpose (MOA, 2008). Of the total rice area cultivated, 52.6% was irrigated 32.4% was rain-fed lowland, 12% was rain-fed upland and 3% was deepwater rice (Huke at el., 1997; WRS, 2008). The annual amount of CH_4 emitted from a given area of rice is a function of the crop duration, water regimes and organic soil amendments. The CH_4 emissions from rice cultivation have been estimated by multiplying the seasonal emission factors by the annual harvested areas. The total annual emissions are equal to the sum of emissions from each sub-unit of harvested area using the following equation.

$$CH_4\ Rice = \sum_{i,j,k} (EFi, j, k \times Ai, j, k \times 10\text{-}6)$$

Where CH_4 Rice = annual methane emissions from rice cultivation, Gg CH_4 /yr; EFijk = a seasonal integrated emission factor for i, j, and k conditions, kg CH_4 /ha; Aijk = annual harvested area of rice for i, j, and k conditions, ha /yr; i, j, and k = represent different ecosystems, water regimes, type and amount of organic amendments, under which CH_4 emissions from rice may vary. Separate calculations were undertaken for each rice ecosystems (i.e., irrigated, rainfed, and deep water rice production).

In 2007, 43.62 million ha area was cultivated for rice using various water management practices, where by the rice fields are either continuously flooded with water received from irrigation canals, or they are at times aerated - singular aeration and multiple aerations. Rice also grows in upland areas in the country, as well as in deep water where the depth of the water may be more than or equal to half a meter. The distribution of rice area in India is shown in figure 7.2. It is seen that maximum land are (9640000 ha is under rainfed flood prone conditions,

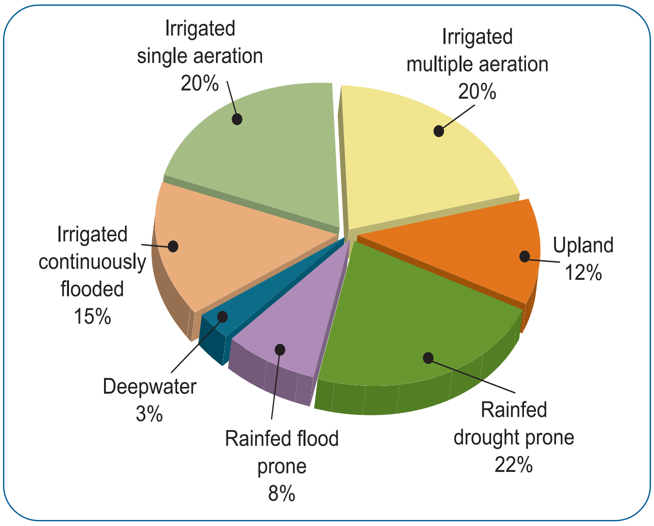


Figure 7.2: Distribution of rice area under various water management practices in India in 2007. Here MA- Multiple aeration, SA- Single aeration and CF- Continuously flooded

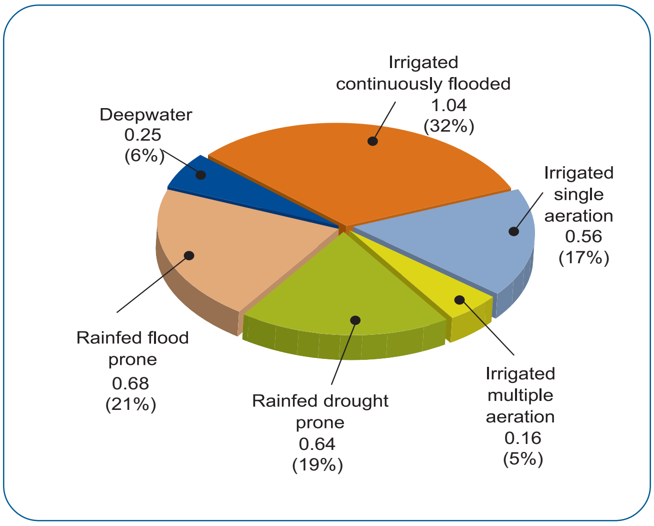


Figure 7.3: CH_4 emission distribution in million tons from rice cultivation in 2007

Table 7.3: Methane emission from rice cultivation

Ecosystem	Water regime	Rice Area 2007 (000' ha)	Emission Coeff. 2007 (kg ha^{-1})	Methane ('000 tons)
Irrigated	CF*	6427	162	1042
	SA	8517	66	562.1
	MA	8898	18	160.1
Rainfed	DP	3577	70	635
	FP	9640	190	679
Deep water	DW	1309	190	249
Upland		5234	0	0
Total				**3327**

Note: CF - Continuously flooded
SA - Single Aeration
MA - Multiple Aeration
DP - Drought Prone
FP - Flood Prone

and 20% each of the area are cultivated under irrigated multiple aeration or single aeration condition. The continuously flooded land is only 15% of the total area available for rice cultivation. The upland rice area is 5234000 ha and is a net sink of CH_4, as no anaerobic conditions are generated at these heights.

Table 7.3 gives the CH_4 emission estimates made and details the emission factors used and area covered under each water management regime. Irrigated flood prone emissions constituted 45% of the total CH_4 emission from this category. The next highest emitting source was irrigated continuously flooded (26%) and irrigated single aeration constituted 14% of the emission. Rainfed drought prone, deep water and irrigated multiple aeration contributed 6%, 5% and 4% of the CH_4 emitted from this source (see figure 7.3).

7.5 AGRICULTURE SOILS

Nitrous Oxide is produced naturally in soils through the processes of nitrification and denitrification. Nitrification is the aerobic microbial oxidation of ammonium to nitrate, and denitrification is the anaerobic microbial reduction of nitrate to nitrogen gas (N_2). Nitrous oxide is a gaseous intermediate in the reaction sequence of denitrification and a by-product of nitrification that leaks from microbial cells into the soil and ultimately into the atmosphere. One of the main controlling factors in this reaction is the availability of inorganic Nitrogen (N) in the soil. This methodology, therefore, estimates N_2O emissions using human-induced net N additions to soils (e.g., synthetic or organic fertilizers, deposited manure, crop residues, sewage sludge), or of mineralization of N in soil organic matter following drainage / management of organic soils, or cultivation/land-use change on mineral soils (e.g., Forest Land/Grassland/Settlements converted to Cropland).

The emissions of N_2O that result from anthropogenic N inputs or N mineralization occur through both a direct pathway (i.e., directly from the soils to which the N is added/released), and through two indirect pathways: (i) following volatilization of NH_3 and NO_x from managed soils and from fossil fuel combustion and biomass burning, and the subsequent redeposition of these gases and their products NH_4^+ and NO_3^- to soils and waters; and (ii) after leaching and runoff of N, mainly as NO_3^- from managed soils. Therefore total N_2O emitted from soils can be represented as:

$$N_2O\text{-}N_{TOTAL} = N_2O\text{-}N_{DIRECT} + N_2O\text{-}N_{INDIRECT}$$

Using the above methodology the total N_2O emissions from India is estimated to be 0.14 million tons in 2007. With respect to 1994, N_2O emissions from this category have significantly reduced (by 16%). This is mainly due to the use of India specific emission factors that are lower by almost 30% than the IPCC default values. The previous emission factors were 0.93 kg ha_{-1} N_2O–N for all types of crop regimes. The revised emission factors used for rice–wheat systems are 0.76 for rice and 0.66 kg ha^{-1} N_2O –N for wheat for urea application without any inhibitors (Pathak et al., 2002).

7.6 BURNING OF CROP RESIDUE

Crop residue is burnt in the fields in many Indian states such as Uttar Pradesh, Punjab, West Bengal, Haryana, Bihar, Madhya Pradesh, Himachal Pradesh, Maharashtra, Gujarat Chhattisgarh, Jharkhand, Tamil Nadu, Uttaranchal and Karnataka producing CO, CH_4, N_2O, NOx, NMHCs, SO_2 and many other gases. In this report only the CH_4 and N_2O emissions have been reported.

Non-CO_2 emissions from crop residue burning were calculated using the equation given below.

$$EBCR = \sum crops\ (A \times B \times C \times D \times E \times F)$$

Where, EBCR= Emissions from residue Burning

A = Crop production

B = Residue to crop ratio

C = Dry matter fraction

D = Fraction burnt

E = Fraction actually oxidized

F = Emission factor

The estimation of emission of targeted species was arrived at by first estimating the amount of biomass actually burnt in the field using the IPCC revised inventory preparation guidelines (IPCC, 1996). Currently, wastes from nine crops viz., rice, wheat, cotton, maize, millet, sugarcane, jute, rapeseed-mustard and groundnut, are subjected to burning. The state-wise crop production figures for 2007 (MOA, 2008) were used as the basic activity data. The dry matter fraction of crop residue is taken as 0.8 (Bhattacharya and Mitra, 1998), 0.25 as fraction burned (IPCC, 1997) in field and 0.9 as the fraction actually oxidized (IPCC, 1997). Crop specific values of carbon fraction were as per IPCC default values. The default N/C ratios were taken from IPCC (2006). Further, the emission ratio was calculated using emission factors given by Andreae and Merlet (2001) which are the default factors mentioned in IPCC (2006) national inventory preparation guidelines. Using this methodology, 0.23 million tons of CH_4 and 0.006 million tons of N_2O was emitted from burning of crop residue in India in 2007.

8

Land Use, Land Use Change and Forestry

Land Use, Land Use Change and Forestry (LULUCF) is a key component of the Greenhouse Gas Emission Profile. It involves estimation of carbon stock changes, CO_2 emissions and removals and non-CO_2 GHG emissions. The IPCC has developed three GHG inventory guidelines for land use sector viz. Revised 1996 Guidelines for LUCF (IPCC, 1997); IPCC Good Practice Guidelines for LULUCF (IPCC, 2003); and the latest IPCC, 2006 guidelines which includes Agriculture Forest and Other Land Categories (AFOLU).

India used the *Revised 1996 Guidelines for LULUCF sector* for preparation of GHG inventory information for its Initial National Communication. The inventory showed that LUCF sector was a marginal source of GHG emissions (14.2 million tons of CO_2 eq) for the inventory year 1994. The revised *1996 IPCC Guidelines* has many limitations and the inventory estimation is incomplete since all land categories are not included and the uncertainty of GHG inventory is estimated to be high. Thus IPCC developed Good Practice Guidance (GPG) for the land use sectors covering all the land use categories for the inventory. The developed countries (Annex I Countries in UNFCCC) are required to use the GPG approach for LULUCF sector. Further, the developing countries (Non-Annex I countries) such as India are encouraged to use the GPG approach.

India has an option of using the *Revised 1996 IPCC Guidelines* or the IPCC – *2003 GPG* approach or the *IPCC – 2006, AFOLU Guidelines*. Even though India has a choice to use the elements of *IPCC – 2006 AFOLU Guidelines*, however, the reporting tables are not yet developed for the *IPCC 2006 Guidelines* by the UNFCCC. India has decided to shift to *IPCC – 2003 GPG* approach since the reporting tables are available for the LULUCF sector.

8.1 METHODOLOGY – GPG APPROACH

IPCC GPG2003 adopted three major advances over *IPCC 1996 Guidelines*. They include:

- Introduction of three hierarchical tiers of methods that range from default data and simple equations to use of country-specific data and models to accommodate national circumstances
- Land use category based approach for organizing the methodologies
- Provides guidelines for all the 5 carbon pools.

IPCC GPG2003 adopted six land categories to ensure consistent and complete representation of all land categories, covering the total geographic area of a country. The land use categories and the sub-categories, and the relevant gases and C-pools used in the GPG2003 are given below:

- Land Categories
  - o Forest land, crop land, grassland, wetland, settlements and others.
  - o Sub-categories:
- Land remaining in the same category (eg. Forest land remaining forest land)
- Land converted to other category (eg. Crop land converted to Forest land)
- CO_2 emissions and removal is estimated for all the Carbon-pools namely;
  - o *Above ground biomass (AGB), below ground biomass (BGB), soil carbon, dead organic matter (DOM) and woody litter*
- Non-CO_2 gases estimated include;
  - o *CH_4, N_2O, CO and NO_x*

Table 8.1 highlights the differences between the GPG 2003 and IPCC 1996 Guidelines. The description of the carbon pools is given in the Table 8.2.

8.2 ESTIMATING CARBON STOCK CHANGES

CO_2 emissions and removals or the Carbon stock change is the dominant source of GHG in LULUCF sector. Carbon stock change is the sum of changes in stocks of all the carbon pools in a given area over a period of time, which could be averaged to annual stock changes. A generic equation for estimating the changes in carbon

Table 8.1: Methods adopted in GPG2003 and IPCC 1996

GPG 2003	IPCC 1996
■ Land category based approach covering forest land, cropland, grassland, wetland, settlement and others	■ Approach based on four categories namely 5A to 5D (refer to Section 5.1of IPCC 1996) All land categories not included such as coffee, tea, coconut etc. Lack of clarity on agro-forestry
■ These land categories are further sub divided into; - land remaining in the same use category - other land converted to this land category	■ Forest and grassland categories defined in 5A and 5B differently
■ Methods given for all carbon pools; AGB, BGB, dead organic matter and soil carbon and all non-CO_2 gases	■ Methods provided mainly for above ground biomass and soil carbon. -Assumes as a default that changes in carbon stocks in dead organic matter pools are not significant and can be assumed to be zero, i.e. inputs balance losses. - Similarly, below ground biomass increment or changes are generally assumed to be zero
■ Key source/sink category analysis provided for selecting significant - land categories - sub-land categories - C-pools - CO_2 and non-CO_2 gases	■ Key source/sink category analysis not provided
■ Three tier structure presented for choice of methods, Activity Data and Emission Factors	■ Three tier structure approach presented but its application to choice of methods, AD and EF not provided
■ Biomass and soil carbon pools linked particularly in Tier 2 and 3	■ Changes in stock of biomass and soil carbon in a given vegetation or forest type not linked

Table 8.2: Definition of carbon pools according to GPG (2003)

Carbon Pool		Description
Living biomass	Above-ground biomass	All biomass of living vegetation, both woody and herbaceous, above the soil including stems, stumps, branches, bark, seeds and foliage.
	Below-ground biomass	All biomass of live roots. Fine roots of less than 2 mm diameter (the suggested minimum) are often excluded because these often cannot be distinguished empirically from soil organic matter.
Dead organic matter	Deadwood	All non-living woody biomass not contained in the litter, either standing, lying on the ground, or in the soil. Deadwood includes wood lying on the surface, dead roots, and stumps larger than or equal to 10 cm in diameter.
	Litter	All non-living biomass with a size greater than the limit for soil organic matter (the suggested minimum is 2 mm) and less than the minimum diameter chosen for deadwood (e.g. 10 cm) lying dead and in various states of decomposition above or within the mineral organic soil. This includes the litter layer as usually defined in soil typologies. Live fine roots above the mineral or organic soil (of less than the suggested minimum for below-ground biomass) are included whenever they cannot be empirically distinguished from the litter.
Soil	Soil organic matter	Organic carbon in mineral soils to a specified depth chosen and applied consistently through a time series. Live and dead fine roots within the soil (of less than the suggested minimum for below-ground biomass) are included wherever they cannot be empirically distinguished from the soil organic matter.

stock for a given land-use category or project is given below:

Annual carbon stock change for a land-use category is the sum of changes in all carbon pools

$$\Delta C_{LUi} = \Delta C_{AB} + \Delta C_{BB} + \Delta C_{DW} + \Delta C_{LI} + \Delta C_{SC}$$

Where:

ΔC_{LUi} is carbon stock change for a land-use category, AB = above-ground biomass, BB = below-ground biomass, DW = deadwood, LI = litter and SC = soil carbon

The equation requires the stock change to be estimated for each of the pools. The changes in the carbon pool could be estimated using the two approaches based on IPCC guidelines (IPCC 2003 and IPCC 2006).

Carbon 'Gain–Loss': Annual carbon stock change in a given pool as a function of gains and losses ('Gain–Loss' Method)

$$\Delta C = \Delta C_G - \Delta C_L$$

Where:

ΔC is annual carbon stock change in the pool, ΔC_G is the annual gain of carbon and ΔC_L is the annual loss of carbon.

Carbon 'Stock–Change' or 'Stock–Difference': Carbon stock change in a given pool as an annual average difference between estimates at two points in time (Stock-Difference method)

$$\Delta C = \frac{(C_{t2} - C_{t1})}{(t_2 - t_1)}$$

Where:

ΔC is the annual carbon stock change in the pool, C_{t1} the carbon stock in the pool at time t_1 and C_{t2} the carbon stock in the same pool at time t_2.

8.3 INVENTORY ESTIMATION

India has estimated GHG inventory for the year 2007. India has adopted Tier – II approach, where much of the activity data and emission and removal factors were obtained from national sources.

Table 8.3: Main and sub land categories, carbon pools and non-CO_2 gases for GHG inventory for LULUCF sector

Main land categories	Sub-categories (based on transformation)	Disaggregated level	C-pools	Non-CO_2 gases
Forest land	Forest land remaining forest land	- Tropical Wet Evergreen - Tropical Dry Deciduous - Tropical Thorn Forest - Plantations - etc	Above ground biomass, Below ground biomass, and Dead organic matter, litter and soil carbon	CH_4, N_2O
	Land converted to forest land			
Crop land	Crop land remaining crop land	- Irrigated, unirrigated - Annual crops - Plantation; Coconut, coffee, tea, etc.		
	Land converted to crop land			
Grassland	Grassland remaining grassland	- Climatic regions		
	Land converted to grassland			
Wetland	Wetland remaining wetland	- Wetland, Peat land		
	Land converted to wetland	- Flooded land		
Settlements	Settlement remaining settlement	- Rural		
	Land converted to settlements	- Urban		

Activity Data: GHG inventory is estimated for the year 2007, by taking the activity data for area for 2007-08. Land use change matrix is prepared using land use data for 2006-07 and 2007-08. Area under forest is obtained from FSI, 2009 and area under other land categories for years 2006-07 and 2007-08 is obtained from NRSC land use data. Approach -2 of IPCC GPG-2003 was adopted. Activity data is required for the land categories, sub-categories and final disaggregated land use systems according to Table 8.3. The crucial data required for estimating inventory is the land use change matrix that provides data on area remaining in the same category and area converted from one land use category to the other during the inventory year.

The activity data for the land use categories is given in Table 8.4. Cropland dominates the land use system in India followed by forestland.

8.4 LAND USE CHANGE MATRIX

GHG inventory is estimated for the land use category remaining in the same category as well as land use category subjected to land use change. Table 8.5 provides the land use change matrix for the inventory year 2007, based on data from Forest Survey of India (FSI, 2009) and National Remote Sensing Centre (NRSC, 2008). It can be observed that forest area has marginally increased, whereas the net sown (cropped) area has declined. The grassland area has also decreased. Figure 8.1 shows the land use map of India generated from AWiFS.

Table 8.4: Land use pattern of India in 2007

Land use	Sub-category	Area (M ha)
Forest	Very dense	8.35
	Moderately dense	31.90
	Open	28.84
	Land converted to forest	0.07
	Sub total	**69.16**
Cropland	Net sown area	139.72
	Fallow	41.29
	Sub total	**181.01**
Grassland	Grazing land	8.05
	Scrub	21.12
	Other wasteland + Gullied / Ravines	31.85
	Shifting cultivation	0.26
	Sub total	**61.28**
Wetland / Flooded Land	Wetland	6.08
Settlement	Settlement	2.07
Other land	Other land	9.05
GRAND TOTAL		**328.65**

Table 8.5: Land-use change matrix for 2007 (Area in Mha)

Land-use	Sub-category/strata	2006	2007	Change in area
Forest	Very dense[1]	8.35	8.35	0.00
	Moderately dense[1]	31.99	31.90	-0.09
	Open[1]	28.68	28.84	0.16
	Land converted to forest			0.07
	Sub total Forest area	**69.02**	**69.16**	**0.14**
Cropland	Net sown area	141.06	139.72	-1.34
	Fallow (current fallow)	40.84	41.29	0.45
	Sub total	**181.9**	**181.01**	**-0.89**
Grassland	Grazing land	8.06	8.05	-0.01
	Scrub	21.31	21.12	-0.19
	Other wasteland + Gullied / Ravines	30.73	31.85	1.12
	Shifting cultivation	0.20	0.26	0.06
	Land converted to grassland			0.98
	Sub total	**60.30**	**61.28**	**0.98**
Wetland	**Wetland (flooded land)**	**6.28**	**6.08**	**-0.20**
Settlement	Settlement[2]	**2.06**	**2.07**	**0.01**
	Land converted to Settlements			0.01
Other land	**Other land**	**9.09**	**9.05**	**-0.04**
	Land converted to other land			-0.04
GRAND TOTAL		**328.65**	**328.65**	**—**

[1]*FSI area for 2005 and 2007 is used;*
[2]*Built-up lands, including urban and rural*

8.5 AREA UNDER FORESTS

FSI has stratified the area under forests based on ecological features using the Champion and Seth (1968) classification system. The forest area under each stratum is further stratified into dense and open forests. Table 8.6 provides the area under different forest types and according to crown density.

Forest cover

The remote sensed data of IRS PC LISS-3 at 1:50,000 scale for the period November 2006 to March 2007 has been used to arrive at the forest cover mosaic at the starting of 2007. The forest cover data is grouped into two canopy density classes, namely, open forests (10%-40% crown cover) and dense forests (more than 40% crown cover). Forest cover includes patches of tree cover up to the size of 1 ha. Figure 8.2 show the forest cover as observed from satellite and its interpretation in terms of open and dense forests. The country wide forest cover mosaic has been prepared especially for the purpose of this study.

Forest type

The detailed classification of forest types of India has been given by Champion and Seth (1968). This classification categorizes forests of India into 16 type groups and 200 types. Recently, Forest Survey of India has completed mapping of forest types on 1: 50,000 scale. For the purpose of this study merging as well as splitting of type groups has been done in an analytical manner taking consideration of the species types, terrain, region, climate etc. to arrive at an appropriate number of strata (as indicated below) for estimating Carbon stock in India's forests.

The forests in India constitute Tropical wet evergreen forests, tropical semi evergreen forests, tropical moist deciduous forests, Littoral and swamp forests, tropical dry deciduous forests, tropical thorn forests, tropical dry ever green forests, Sub tropical broad leaved hill forests,

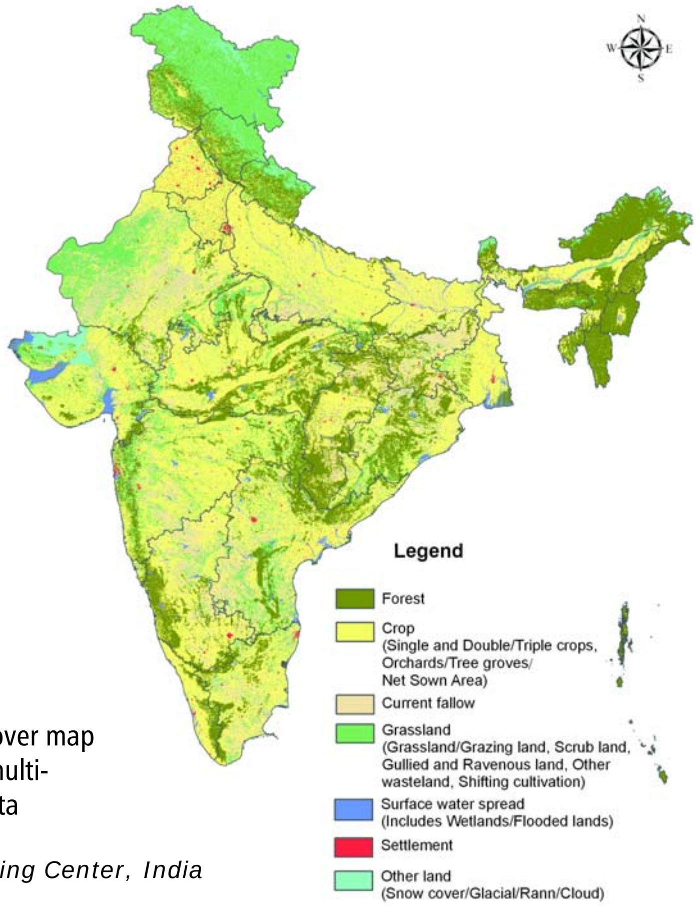


Figure 8.1: Land use and land cover map of India (2007-2008) using multi-temporal IRS P6 AWiFS data

Source: National Remote Sensing Center, India

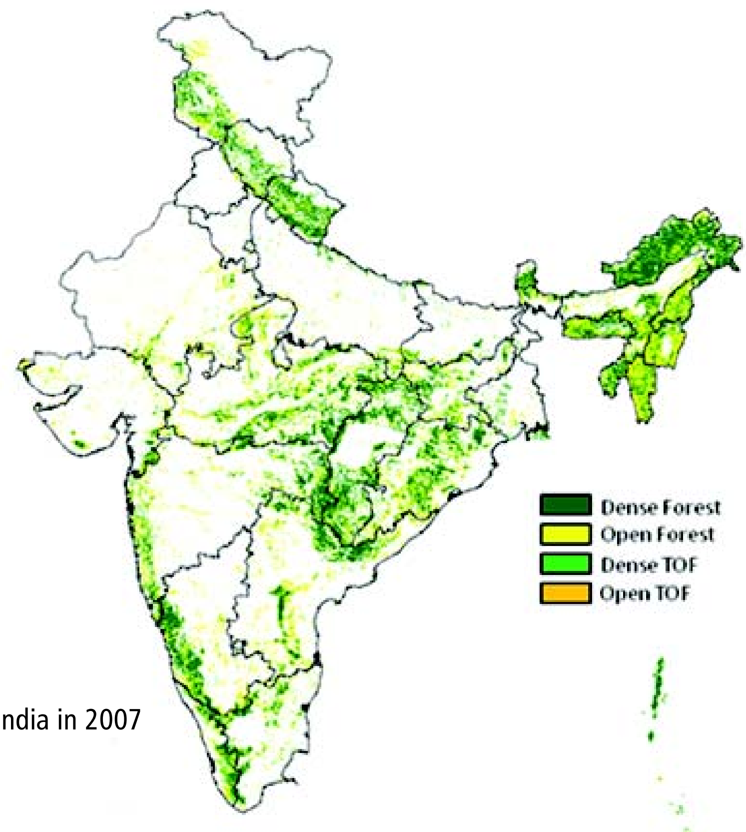


Figure 8.2: Digitized forest cover of India in 2007

Source: Forest Survey of India

Sub tropical pine forests, Sub tropical Dry evergreen forests, Montane wet temperate forests, Himalayan Moist temperate forests, Himalayan dry temperate forests, Sub alpine forests, Moist Alpine scrub, Dry Alpine scrub, Plantations and tree outside forests.

Strata

Stratification for this study has been done taking the above two layers, namely, forest cover and forest type. The stratification was done in GIS framework by overlay of the two layers. Thus the forest types were further classified into two canopy density classes and each such class represented a strata. The total number of strata is 30. Figure 8.6 shows the distribution of these 30 forest strata spread across India in the beginning of 2007.

Emission and removal factors

The rate of growth or change for different carbon pools for different land categories and land use change categories is obtained from literature and field measurements. The carbon stocks and rates of change values on an annual basis are likely to vary for different regions, management practices and land use systems. Very limited data is available for rates of change in different carbon pools for different land use categories. Some of the references used for this work are Puri 1950; Sekhar and Rawat, 1960; Pant, 1981; John, 2000; Dhand et al., 2003 and Gupta et al., 2003. Inventory is estimated largely using tier 2 approach using nationally available data.

Assessment of Carbon stock from forests

For assessing the Carbon stock in forests of the country, data from 15439 sample plots have been analysed (see the spread of the plots in figure 8.4). For this, the sample plots were overlaid on the above strata layer in GIS. Through GIS, strata information of each plot was attached. In the sample plot layer, the information attached includes woody biomass, foliage, litter, humus, dead wood, climbers, shrubs, herbs and Soil Carbon.

The equations used for estimating growing stock, biomass and the C stock are as follows:

Growing Stock = Total area of each strata x Average volume of the corresponding stratum

Here growing stock refers to woody volume that includes all trees above 10 cm DBH.

Further Biomass of the woody growing stock is estimated using the following equation:

Biomass = Growing stock x Specific Gravity
where
Specific gravity = Oven dry weight/ Green volume

and
C stock = Biomass x Carbon fraction
Where the carbon fraction corresponds to the different types of biomass in the forest.

The Carbon stock has been estimated for the following levels:

The total Carbon stock estimates have been made in terms of

- Above ground biomass
- Below ground biomass
- Soil Carbon

8.6 CARBON STOCK CHANGE IN FOREST LANDS

In order to estimate the change in C stock in Indian forests during 2007 a comparison with C stock in 2005 has been made by distributing the forest cover in 2005 into the different 30 strata in the same ratio as in 2007. A net CO_2 removal during 2007, based on 2005 and 2007 stock changes, is estimated to be 67.8 million tons (or Tg) by Indian forests, (Table 8.6).

8.7 CO_2 EMISSIONS AND REMOVAL FROM NON-FOREST LAND CATEGORIES

The net emissions/removals from non-forest land categories are given in Table 8.7 The emissions and removals are estimated using nationally available data CO_2 stock change on per hectare basis in land remaining

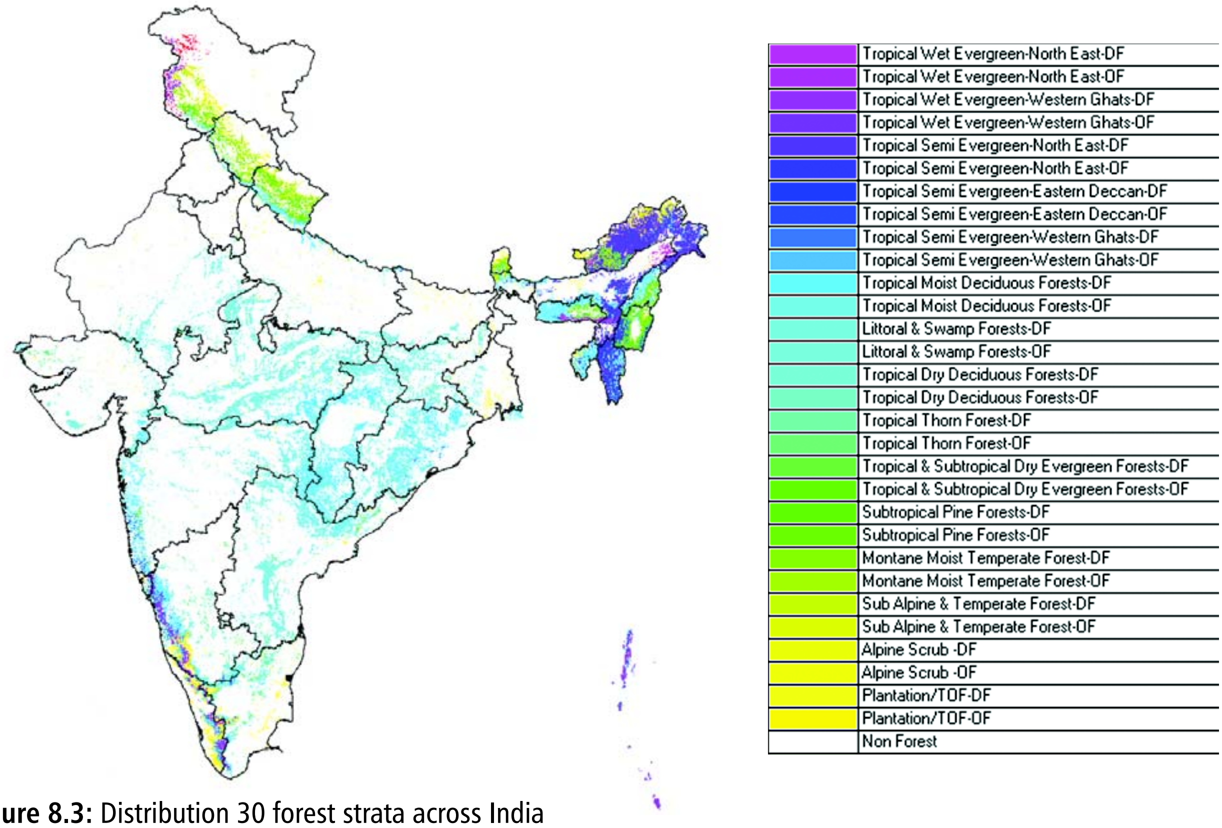


Figure 8.3: Distribution 30 forest strata across India

Source: Forest Survey of India

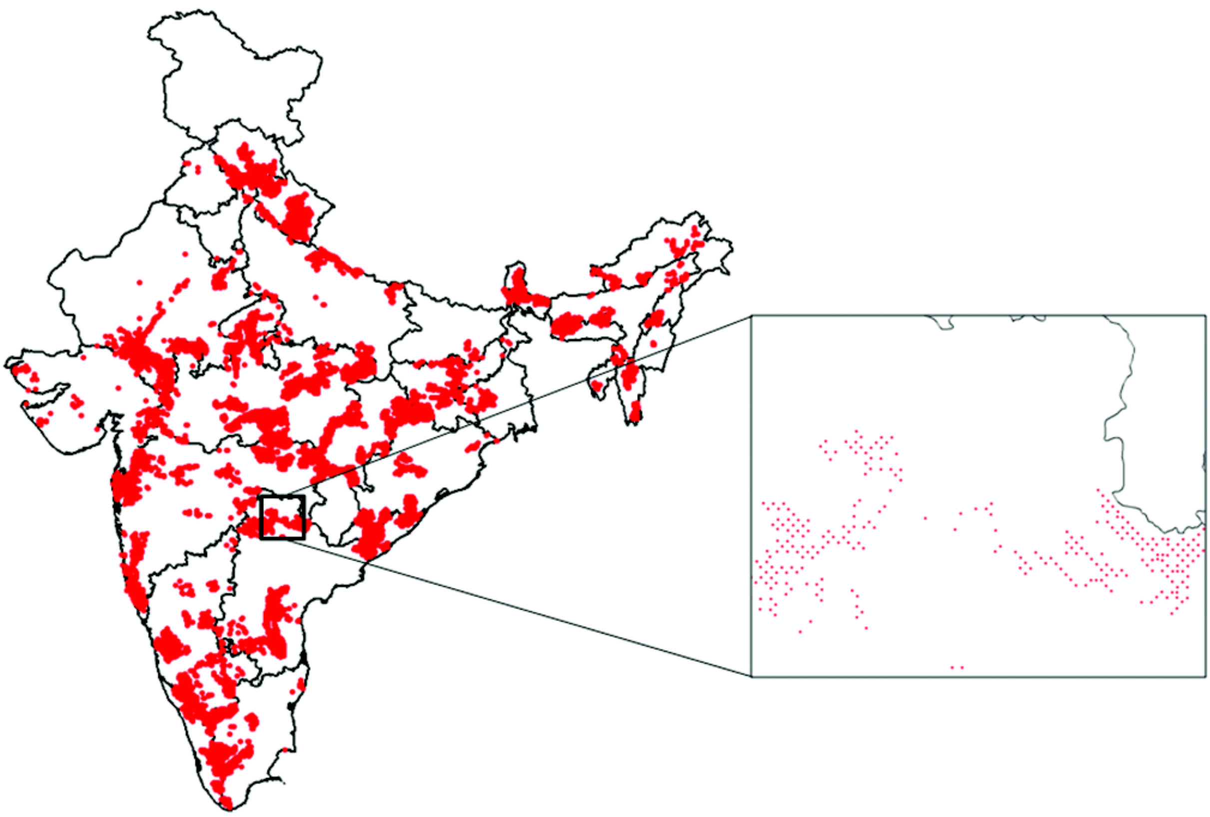


Figure 8.4: Spread of forest sample plots

Source: Forest Survey of India

in the same category. Grassland remaining grassland is a net source of about 10 Mt CO_2, whereas cropland and settlements land categories are a net sink.

8.8 NET GHG REMOVAL FROM LULUCF SECTOR

The net CO_2 emission / removal for LULUCF sector is given in Table 8.8. This includes CO_2 net emissions and removals from land categories. The net CO_2 emissions include gain and loss of CO_2. The loss of CO_2 is largely due to extraction and use of fuelwood from felling of trees. Thus the net CO_2 emissions / removal estimate shows that the sector is a net sink of 177.03 million tons CO_2. The sector is a net sink due to uptake of CO_2 by the cropland followed by forest land.

This is a preliminary estimate, likely to be subjected to high uncertainty, and may change with improved activity data and emission factor estimates.

Table 8.6: Change in C stock between 2005 and 2007 in forest land category

Carbon pools	C stock in million tons 2005	C stock in million tons 2007	Change in C stock in million tons (2005 - 2007)	CO_2 removal in million tons during 2007
	A	B	C=A-B	D=C*44/12
Above ground biomass	2337	2349	6	22.0
Below ground biomass	682	685	1.5	5.5
Soil Carbon	4270	4292	11	40.3
Total	**7289**	**7326**	**18.5**	**67.8**

Net change in carbon stock of 37 Mt during 2005 and 2007 is divided by two years to get 18.5 Mt for the year 2007, which is further multiplied by 44/12 to convert to CO_2

Table 8.7: CO_2 emissions and removals for biomass and soil carbon for land categories with land remaining in the same categories

Land use categories	MAI in perennial aboveground biomass (t/ha/y) A	MAI in perennial belowground biomass (t/ha/y)[1] B	MAI in total perennial biomass (t/ha/y) A+B	MAI in soil carbon (t/ha/y) C	MAI in total carbon (t/ha/y) *D = (A +B)/2+C*	*Net* DC (Mt C) E = D x Area	Net change in CO_2 (Mt) F = E x 3.6666 *[+ is emission; - is removal]*
Cropland—Cropland	0.130	0.046	0.176	0.220	0.308	56.60	- 207.52
Grassland—Grassland	0.003	0.001	0.004	-0.056	-0.054	-2.86	+10.49
Settlement—Settlement	0.008	0.002	0.010	0.000	0.005	0.01	- 0.038
Wetland—Wetland	—	—	—	—	—	—	—
Other land	—	—	—	—	—	—	—

[1]Below ground biomass was calculated as a fraction (0.26) of the total biomass: IPCC default conversion factor
MAI: Mean Annual Increment

Table 8.8: Total GHG emissions from LULUCF for 2007 in Gg

Land use categories	*CO_2 emissions/ removals (Gg CO_2)*	*CO_2 loss due to fuelwood use (GgCO_2) leading to net CO_2 emission*	*Net CO_2 emissions/ removal (GgCO_2)*
Forestland	-67,800	+87,840	
Cropland	-207,520		
Grassland	+10,490		
Wetland (Flooded land)	NE		
Settlement	-38		
Other land	NO		
TOTAL	**-264,868**	**+87,840**	**-177,028**

Removal (-) Emission (+)
Source of fuelwood is not known, so assumed to come from all land categories. About 8.7% of the fuelwood consumption is estimated to come from felling of trees leading to net CO_2 emission.
Non-CO_2 estimates are not reported due to absence of activity data and emission data. Non-CO_2 emissions from crop residue burning is reported in Agriculture sector.

9

Waste

The main greenhouse gases emitted from waste management is CH_4. It is produced and released into the atmosphere as a by-product of the anaerobic decomposition of solid waste, where-by methanogenic bacteria break down organic matter in the waste. Similarly, wastewater becomes a source of CH_4 when treated or disposed anaerobically. It can also be a source of nitrous oxide (N_2O) emissions as well due to protein content in domestically generated waste water .

The greenhouse gases and their source categories considered in this document include:

- Municipal solid waste disposal resulting in CH_4 emission
- Domestic waste water disposal emitting CH_4 and N_2O
- Industrial waste water disposal leading to CH_4 emissions

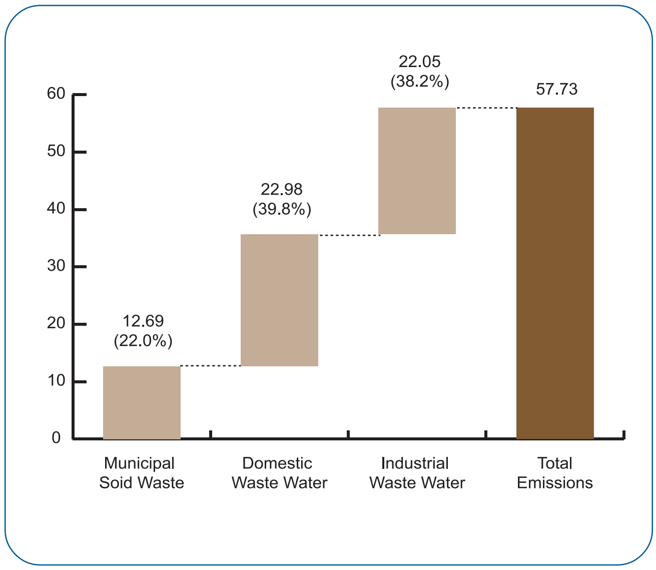


Figure 9.1: GHG emission from waste sector in thousand tons and its distribution across sub categories

9.1 SUMMARY OF GHG EMISSIONS FROM WASTE

The total GHG released from waste sector in 2007 was 57.73 million tons of CO_2 equivalent, of which, 2.52 million tons was emitted as CH_4 emitted and 0.16 million tons as N_2O (table 9.1). Domestic waste water is the dominant source of CH_4 emission in India, it emitted 40% of the total CO_2 equivalent emissions from the waste sector. 38% of the emissions came from disposal and treatment of Industrial waste water and 22% of the emissions were from Municipal solid waste disposal. Figure 9.1 shows the absolute values of GHG emission from this sector and also the emission distribution across its sub categories.

Table 9.1: GHG emissions from waste sector (thousand tons)

	CH_4	N_2O	CO_2 eq
	2515.58	**15.8**	**57725.18**
Municipal Solid waste	604.51		12694.71
Domestic waste water	861.07	15.8	22980.47
Industrial waste water	1050		22050

9.2 MUNICIPAL SOLID WASTE

In India, waste is only systematically collected and disposed at waste disposal sites in cities, resulting in CH_4 emission from anerobic conditions. In rural areas, waste is scattered and as a result the aerobic conditions prevail with no resulting CH_4 emission. MSW in Indian cities is disposed in landfills by means of open dumping, however a small fraction is used for composting in some of the cities. In the mega cities such as Delhi, Mumbai, Kolkata and Chennai the MSW generation rate is over riding the population growth rate. As an example of CH_4 emissions from solid waste management in a mega city is given in Box 9.1. The rate of disposal of MSW varies from city to city therefore the estimation of CH_4 generated from MSW at a national level becomes highly uncertain unless year wise data on MSW generation is incorporated in the estimates. In the present estimate IPCC 2000 guidelines have been used and an average CH_4 emission factor derived from a study by NEERI in 69 cities (NEERI, 2005) has been applied.

Methodology, choice of emission factors and CH_4 emission: The first order decay methodology has been used for estimating CH_4 from land fills (IPCC, 2002). According to this methodology CH_4 generated in the disposal sites is represented as

Methane emitted$_T$ = (ΣCH_4 generated – R_T) x (1 – OX_T)

R_T = Methane recovered in year T, Gg
OX_T = Oxidation factor in year T (fraction)

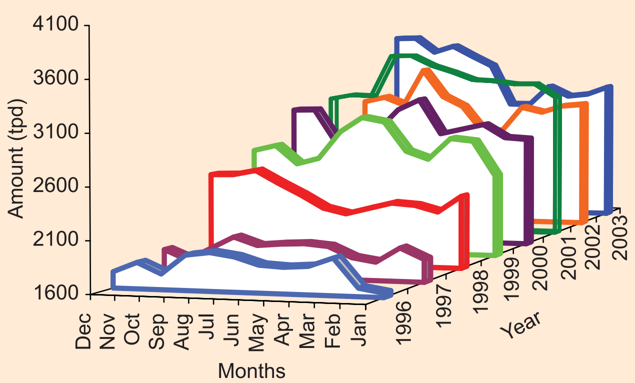
For all practical purposes the methane recovered from waste is taken to be zero as methane recovery is almost non-existent, except for in few (2-3) small pilot projects being carried out in metro cities.

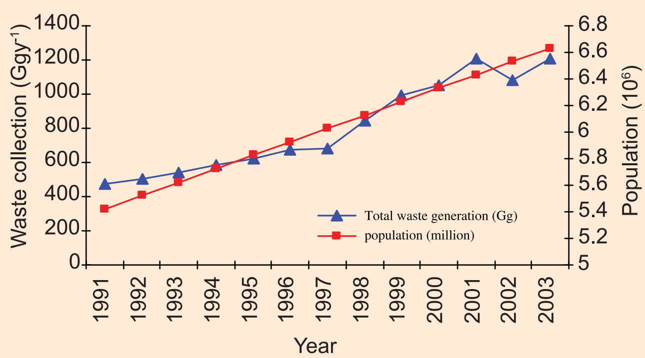
Box 9.1: Estimation of CH_4 generated from MSW – A Case Study of Chennai

Greenhouse gas emission inventory from two landfills of Chennai has been generated by measuring the site specific GHG emission factors in conjunction with relevant activity data as well as using the IPCC methodologies for CH_4 inventory preparation. Chamber technique was used for GHG flux sampling. Ambient and MSW temperatures at the study sites were also recorded. MSW soil samples were analyzed for moisture contents. Gas samples were analyzed for CH_4 and CO_2 by Gas Chromatograph.

In Chennai, emission flux have been found to be ranged from 1.0 to 23.5 mg CH_4 m^{-2} h^{-1}, 6 to 460 µg N_2O m^{-2} h^{-1} and 39 to 906 mg CO_2 m^2 h^{-1} at Kodungaiyur (KDG) landfill and 0.9 to 433 mg CH_4 m^{-2} h^{-1}, 2.7 to 1200 µg N_2O $m^{-2}h^{-1}$ and 12.3 to 964.4 mg CO_2 $m^{-2}h^{-1}$ at Perungudi (PDG) landfill. Total annual CH_4 emission has been estimated, based on these measurements, to be about 0.12 Gg in Chennai from municipal solid waste management for the year 2000 which is lower than the value computed using IPCC, 1996Tier 2 methodologies.

The GHG emission fluxes showed wide variations within each site and between the KDG and PGD dumping grounds although the composition of MSW was largely similar. This may be due to the heterogeneous nature of landfill and uneven height and compaction across the landfill areas. Other reasons for variation in fluxes at different points within a site (KDG or PGD) may be attributed to the changes in moisture content, compaction and age of the MSW. Maximum CH_4 flux was observed at the locations with 1.5-2.5 m of top layer containing wastes dumped over a period of 1 to 3 years. Lower emission of CH_4 has been attributed to lower height of MSW deposits in the landfill area, uncontrolled leaching of organic matter, open burning of MSW in landfill and climatic conditions.





Source: Jha et. al., 2007

CH_4 generation potential of the waste that is disposed in a certain year decreases gradually throughout the following decades. In this process, the release of CH_4 from this specific amount of waste also decreases. The present estimates are based on the first order decay model which is an improvement over the mass balance approach used in earlier reports, and is based on an exponential factor that describes the fraction of degradable material which degrades into CH_4 each year. One key input in the model is the amount of degradable organic matter (DDOCm) in waste. It is represented as

$$DDOCm = W \times DOC \times DOC_f \times MCF$$

where

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

The CH_4 potential that is generated throughout the years is estimated on the basis of the amounts and composition of the waste disposed and the waste management practices at the disposal sites. The basis for the calculation is the amount of Decomposable Degradable Organic Carbon (DDOCm) as defined above. DDOCm is the part of the organic carbon that degrades under the anaerobic conditions in solid waste disposal sites.

Thus methane generated in a year can be calculated as

Methane generated in year T

$$CH_4 = DDOC_m\ decopom_T \times F \times 16/12$$

where
F = Fraction of CH_4 by volume
16/12 = molecular weight ratio, CH_4/C

$$CH_4\ Emitted_T = (\Sigma\ CH_4\ generated_{X,T} - R_T) \times (1 - OX_T)$$

where
R_T = recovered CH_4 in year T, Gg
OX_T = oxidation factor in year T, (fraction)

On an average for all cities waste generation rate is 0.55 kg/capita/day and that 70% of the waste is reaching the landfill site (NEERI, 2005). Further IPCC default factors (IPCC, 2002) such as the methane correction factor of 0.4, fraction of degradable organic carbon that decomposes (DOCf) as 0.5, fraction of methane in landfill gas as 0.5, rate constant (K) as 0.17 year^{-1} are used in the estimation. The factor related to degradable organic carbon fraction (DOC) in the waste disposed is taken as 0.11 (NEERI, 2005). Considering that the amount of recovered methane is zero and oxidation factor is zero, the total methane emitted in 2007 from solid waste disposal site is estimated to be 604.51 Gg (see table 9.2).

Table 9.2: CH_4 emitted from land fill sites in India

Year	2007
Urban population (million)	352.8
Waste generation rate (kg/capita/day)	0.55
MSW generated ('000 tons)	70818
Quantity of waste reaching the landfill site ('000 tons)	49572
DDOCm disposed ('000 tons)	1082.46
DDOCm Accumulated ('000 tons)	5843.00
DDOCm decomposed ('000 tons)	906.77
Methane emitted ('000 tons)	604.51

9.3 WASTE WATER TREATMENT AND DISPOSAL

CH_4) is emitted from waste water when it is treated or disposed anaerobically. Wastewater originates from a variety of domestic, commercial and industrial sources and may be treated on site (uncollected), sewered to a centralized plant (collected) or disposed untreated nearby or via an outfall. In this document the following estimates have been made:

- CH_4 and N_2O from domestic waste water
- CH_4 from Industrial waste water

Over view of GHG emission from waste water in India

Total CO_2 equivalent emissions from waste water generating sources in India in 2007 was 45 million tons, which is 82% of the total CO_2 equivalent emissions from the waste sector. The total methane emitted in 2007 was 1.9 million tons and N_2O emitted was 15.8 thousand tons. See Table 9.3

Table 9.3: GHG emitted from waste water sector ('000 grams)

Activity	CH_4	N_2O	CO_2 equivalent
Domestic	861	15.8	22979
Industrial	1050		22050
Total	**1911**	**15.8**	**45029**

Methodology and choice of emission factors

This section describes the methodological aspects and choice of emission factors for estimating CH_4 and N_2O emissions from domestic and industrial waste water management.

Domestic waste water

Emissions from domestic wastewater handling are estimated for both urban and rural centers. Domestic wastewater have been categorized under urban high, urban low & rural, since the characteristics of the municipal wastewater vary from place to place & depend on factors, such as economic status, food habits of the community, water supply status and climatic conditions of the area. In India, it is estimated that about 22,900 million liters per day (MLD) of domestic wastewater is generated from urban centers (class I and II cities) against 13,500 MLD industrial wastewater. The rural water generated is not handled in any way therefore as it decomposes in an aerobic condition, it is not a source of CH_4. Waste water treatment and discharge pathways for the wastewater generated in the urban areas is substantial and about 49.2% of the wastewater generated from the urban centers is not collected and treatment is provided to only 72% of what is collected. Anaerobic route as a treatment is used in about a quarter of the wastewaters treated. It yields about 0.6 kg of methane per kg BOD (NSS. 2002) treated theoretically. Use of advanced technologies in wastewater treatment in India is still at infancy as wastewater treatment is provided only in Class I and II cities. Sewage contributes to 60% of the total pollution load in terms of biological oxygen demand which is beneficial if recovered through the anaerobic route.

CH_4 emissions estimates have been made using Tier II approach of IPCC by incorporating country specific emission factors and country specific data. Emission estimates have been arrived at by using reliable and accepted secondary data generated by various Government and Private Agencies working in the respective areas in the country. The annual methane emissions from domestic wastewater can be expressed as (IPCC, 2002):

$$Td = \{\sum_{i,j} (Ui \times Tij \times EFi)\} (TOW - S) - R$$

Where,

Td – *Total domestic methane emission*
Ui – *Fraction of population in income group i in inventory year*
Tij – *Degree of utilization of treatment/discharge pathway or system*
i – *Income group: rural, urban high income and urban low income.*
j – *Each treatment/discharge pathway or system*
EFi – *Emission factor, kg* CH_4 */ kg BOD.*
TOW – *Total organics in wastewater in inventory year, kg BOD/yr*
S – *Organic component removed as sludge inventory year, kg BOD/yr*
R – *Amount of* CH_4 *recovered in inventory year, kg* CH_4*/yr.*

N_2O emissions occur as emission from wastewater after disposal of effluent into waterways, lakes, or the sea. The simplified general equation to estimate N_2O from wastewater is:

$$N_2O_{Emissions} = N_{Effluents} \times EF_{Effluents} \times 44/28$$

Where,

N_2O emissions - *N_2O emissions in inventory year, kg N_2O /yr*
$N_{EFFLUENT}$ - *Nitrogen in the effluent discharged to aquatic environments, kg N/yr*
$EF_{EFFLUENT}$ - *Emission factor for N_2O emissions from discharged to wastewater, kg N_2O -N/ kg N*

The factor 44/28 is the conversion of kg N_2O -N into kg N_2O

Here the total nitrogen in the effluent is estimated by using the following equation

Where,

NEFFLUENT – Total annual amount of nitrogen in the wastewater effluent, kg N/yr

P – Human population

Pr – Annual per capita protein consumption, kg/person/yr

F_{NPR} – Fraction of nitrogen in protein, default = 0.16, kg N/kg protein

$F_{NON\text{-}CON}$ – Factor for non-consumed protein added to the wastewater

$F_{IND\text{-}COM}$ – Factor for industrial and commercial co-discharged protein into the sewer system

N_{SLUDGE} – Nitrogen removed with sludge (default = zero), kg N/y.

Industrial waste water: The general equation to estimate CH_4 emissions from industrial wastewater is presented in equation below:

$$Ti = \sum_i (TOWi - Si)\, EFi - Ri$$

Where,

Ti – CH_4 emission in inventory year, kg CH_4/yr; i – Industrial sector.

TOWi – Total organically degradable material in waste water for industry i in inventory year, kg COD/year.

Si – Organic component removed as sludge in inventory year, kg COD/year (Default Value 0. 35).

EFi – Emission factor for industry i, kg CH_4 kg/COD for treatment/discharge pathway or system used in inventory year.

Ri – Amount of CH_4 recovered in inventory year, kg CH_4/year.

Industrial waste water

CH_4 emission from waste water has been estimated based on the waste water produced in Industries. Steel, fertiliser, beer, meat production, sugar, coffee, soft drinks, pulp and paper, petroleum refineries, rubber and tanney industries together emit 95% of the methane generated from waste water in India. These industries have been included for estimating CH_4 from industrial waste water. Table 9.4 gives the waste water generated from these industries in 2007. In some industries, CH_4 is recovered, and in the present calculations, CH_4 recovered for energy purposes in sugar, beer and dairy industries has been subtracted from the total CH_4 estimated to be emitted from these industries (recovery rate was 70%, 75% and 75% respectively).

Table 9.4: Waste water generated in major industries in India

Industry	Unit	Waste water generated
Iron & Steel	Million tons	76.55
Fertilizers	Thousand tons	23417
Beer	Thousand liters	560556.5
Meat	Million tons	3.5
Sugar	Thousand tons	38112
Coffee	Tons	386778.5
Soft Drink	Million bottles	2187.3
Pulp & Paper	Thousand tins	6242.5
Petroleum	Million tins	208.5
Rubber	Thousand tons	3015
Leathers	Thousand tons	104515

10

Greenhouse Gas Emission Profile: Key Features

10.1 OVERVIEW

India emitted 1727.71 million tons of CO_2 equivalents (CO_2 eq.) in 2007 with LULUCF. CO_2 eq. is the sum total of CO_2, CH_4 and N_2O emitted in terms of their respective global warming potentials. See Box 10.1 for the key results. This section describes the emissions by gases, by sector and also compares 2007 emissions with the 1994 emissions that was published in India's Initial National Communication to the UNFCCC.

Box 10.1: Key Results

- The total net Greenhouse Gas (GHG) emissions from India in 2007 were 1727.71 million tons of CO_2 equivalent (eq) of which
  - CO_2 emissions were 1221.76 million tons;
  - CH_4 emissions were 20.56 million tons; and
  - N_2O emissions were 0.24 million tons
- GHG emissions from Energy, Industry, Agriculture, and Waste sectors constituted 58%, 22%, 17% and 3% of the net CO_2 eq emissions respectively.
- Energy sector emitted 1100.06 million tons of CO_2 eq, of which 719.31 million tons of CO_2 eq were emitted from electricity generation and 142.04 million tons of CO_2 eq from the transport sector.
- Industry sector emitted 412.55 million tons of CO_2 eq.
- LULUCF sector was a net sink. It sequestered 177.03 million tons of CO_2.
- India's per capita CO_2 eq emissions including LULUCF were 1.5 tons/capita in 2007.

10.2 GAS BY GAS EMISSIONS

Carbon dioxide: The total CO_2 emitted from India was 1497.03 million tons. Of this the energy sector emitted 923 million tons. The industry sector emitted 405.9 million tons of CO_2 and the land use land use change and forestry (LULUCF) sector emitted 98.3 million tons. The LULUCF sector also sequestered 27.5 million tons. (Figure 10.1)

Methane: Total CH_4 emitted in 2007 was 20.5 million tons. The energy sector emitted 4.27 million tons of CH_4. The industry sector emitted 0.15 million tons of CH_4. 13.77 million tons and 2.52 million tons of CH_4 were emitted from agriculture and waste sectors respectively. CH_4 emissions from the agriculture sector is the largest and it is 77.1% of the total CH_4 emitted in 2007 (figure 10.2). Within the agriculture sector CH_4 emitted due to enteric fermentation in livestock constitutes more than half (56.6%) of the total of CH_4 emitted in 2007.

Nitrous oxide: The total N_2O emissions from India in 2007 were 0.24 million tons. The energy sector emitted 0.06 million tons of N_2O. The industry sector emitted 0.02 million tons. The agriculture sector emitted 0.15 million tons and the waste sector contributed 0.02 million tons to the total N_2O emitted in 2007. The agriculture sector alone contributes more than half (60%) of the total N_2O emitted from the country. N_2O from agricultural soils alone constitute 58% of the total N_2O emitted in 2007 from all sectors. (Figure 10.3)

10.3 SECTORAL EMISSIONS

Energy: The energy sector emitted 1100.06 million tons of CO_2 eq due to fossil fuel combustion in electricity generation, transport, commercial/Institutional establishments, agriculture/fisheries, and energy intensive industries such as petroleum refining and manufacturing

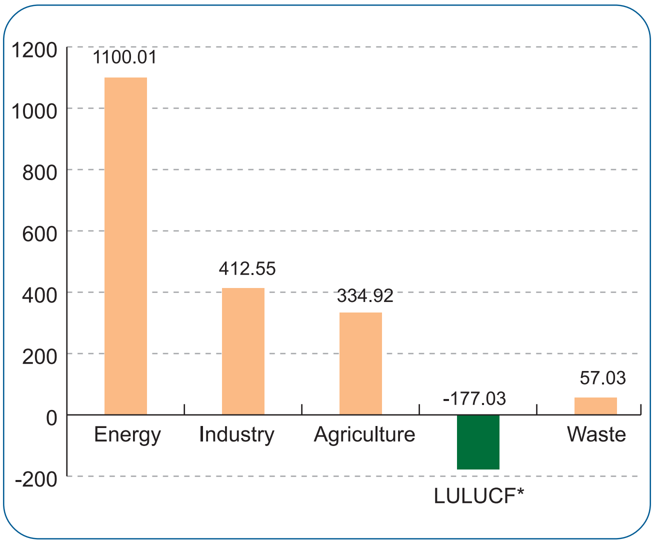


Figure 10.1: GHG emissions and removals (CO_2 eq) and its distribution across sectors

**Change between 2005-2007*

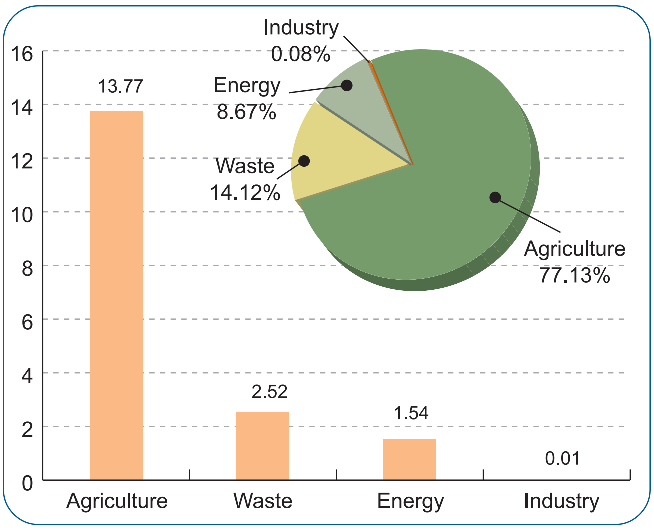


Figure 10.2: CH_4 emission and distribution by sector in million tons

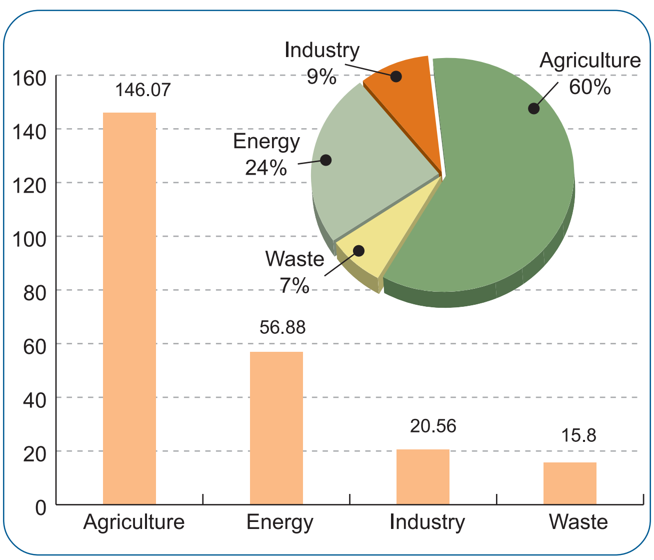


Figure 10.3: N_2O emitted by sector in '000 tons in 2007

of solid fuels, including biomass use in residential sector. Fugitive emissions from mining and extraction of coal, oil and natural gas are also accounted for in the energy sector. The distribution of the emissions across the source categories in energy sector is shown in Figure 10.4.

Electricity Generation: The total greenhouse gas emissions from electricity generation in 2007 was 719.31 million tons CO_2 eq. This includes both grid and captive power. The CO_2 eq emissions from electricity generation were 65.4% of the total CO_2 eq emitted from the energy sector. Coal constituted about 90% of the total fuel mix used.

Petroleum Refining and Solid Fuel Manufacturing: These energy intensive industries emitted 33.85 million tons of CO_2 eq in 2007. The solid fuels include manufacturing of coke & briquettes.

Transport: The transport sector emissions are reported from road transport, aviation, railways and navigation. In 2007, the transport sector emitted 142.04 million tons of CO_2 eq. Road transport, being the dominant mode of transport in the country, emitted 87% of the total CO_2 equivalent emissions from the transport sector. The aviation sector in comparison only emitted 7% of the total CO_2 eq emissions. The rest were emitted by railways (5%) and navigation (1%) sectors. The bunker emissions from aviation and navigation have also been estimated but are not counted in the national totals. (Figure 10.5).

Residential & Commercial: The residential sector in India is one of the largest consumers of fuel outside the energy industries. Biomass constitutes the largest portion of the total fuel mix use in this sector. Commercial and institutional sector uses oil & natural gas over and above the conventional electricity for its power needs. The total CO_2 eq emission from residential & commercial/institution sector was 139.51 million tons of CO_2 eq in 2007.

Agriculture & Fisheries: The agriculture/ fisheries activities together emitted 33.66 million tons of CO_2 eq due to energy use in the sector other than grid electricity.

Fugitive Emissions: CH_4 escapes into the atmosphere due to mining of coal, and due to venting, flaring, transport and storage of oil and natural gas. The total CO_2 eq emissions from this source category in 2007 was 31.70 million tons CO_2 eq.

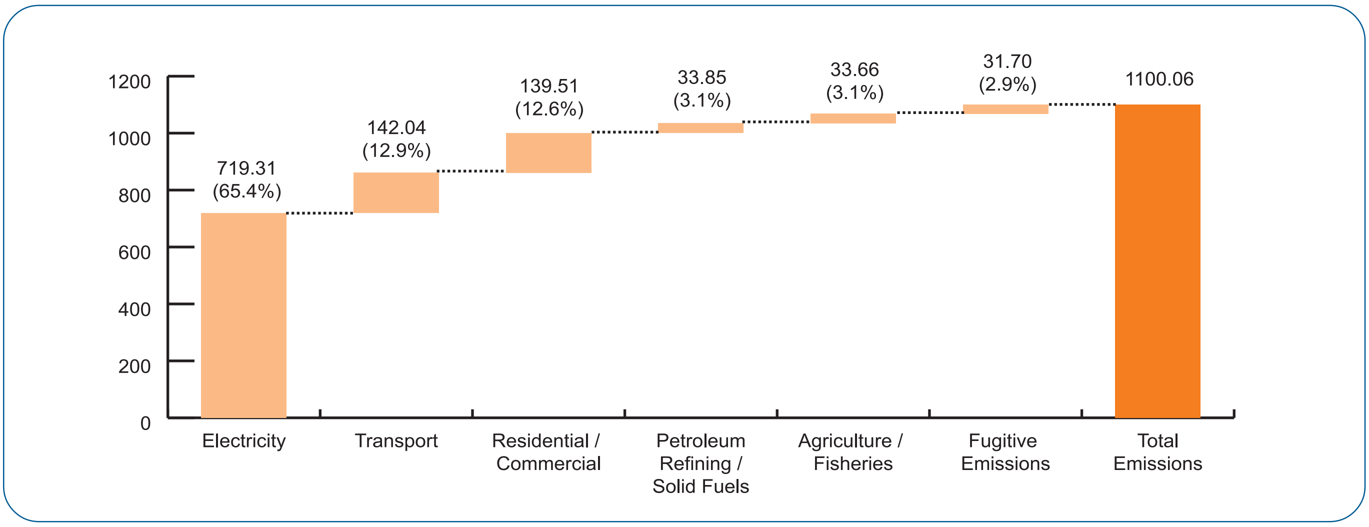


Figure 10.4: GHG emissions from Energy Sector (million tons of CO_2 eq).

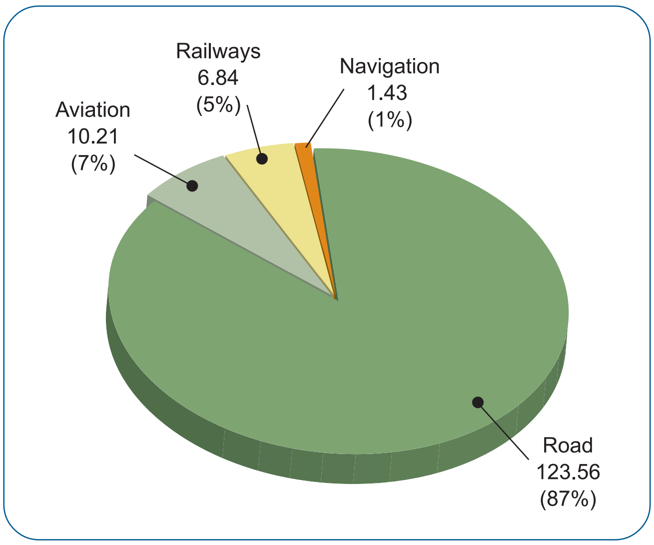


Figure 10.5: GHG emissions from Transport Sector by mode of transport in 2007 (million tons of CO_2 eq).

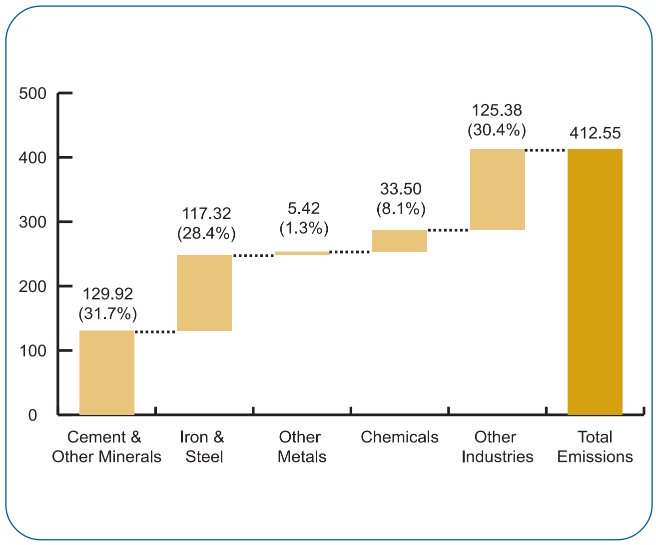


Figure 10.6: GHG emissions from Industry Sector (million tons of CO_2 eq).

Industry: Industrial activities together emitted 412.55 million tons of CO_2 eq of GHG in 2007. Industry sector emissions have been estimated from manufacturing of minerals, metals, chemicals, other specific industries, and from non-energy product use. The emissions covered in the industry sector include fossil fuel combustion related emissions as well as the process based emissions. (Figure 10.6).

Cement and Other Minerals: The cement industry emitted 129.92 million tons of CO_2, which is 32% of the total CO_2 eq emissions from the Industry sector. The emissions cover the entire technology mix for manufacturing of cement in the country covering large, medium and white cement plants. The other minerals like glass and ceramic production and soda ash use together emit 1.01 million tons of CO_2 eq.

Iron and Steel and Other Metals: The iron and steel industry emitted 117.32 million tons of CO_2 eq. The estimate covers integrated and mini steel plants. The production of other metals, namely, aluminum, ferroalloys, lead, zinc and copper production lead to an emission of 5.42 million tons of CO_2 eq.

Chemicals: The chemical industries together emitted 8% of the total GHG emissions from the industry sector (33.50 million tons).

Other Industries: Other industries comprising of pulp/ paper, leather, textiles, food processing , mining and quarrying, and non specific industries comprising of rubber, plastic, watches, clocks, transport equipment, furniture etc., together emitted 124.53 million tons. The rest of the emissions in the Industry sector came from the non-energy product uses and this sector emitted 0.85 million tons of CO_2 eq, and was mainly from use of oil products and coal-derived oils primarily intended for purposes other than combustion.

Agriculture: The agriculture sector emitted 334.41 million tons of CO_2 eq in 2007. Estimates of GHG emissions from the agriculture sector arise from enteric fermentation in livestock, manure management, rice paddy cultivation, agricultural soils and on field burning of crop residue. (Figure 10.7)

Livestock: Enteric fermentation in livestock released 212.10 million tons of CO_2 eq (10.1 million tons of CH_4). This constituted 63.4% of the total GHG emissions (CO_2 eq) from agriculture sector in India. The estimates cover all livestock, namely, cattle, buffalo, sheep, goats, poultry, donkeys, camels, horses and others. Manure management emitted 2.44 million tons of CO_2 eq.

Rice Cultivation: Rice cultivation emitted 69.87 million tons of CO_2 eq or 3.33 million tons of CH_4. The emissions cover all forms of water management practiced in the country for rice cultivation, namely, irrigated, rainfed, deep water and upland rice. The upland rice are zero emitters and irrigated continuously flooded fields and deep water rice emit maximum methane per unit area.

Agricultural Soils and Field Burning of Crop Residue: Agricultural soils are a source of N_2O, mainly due to application of nitrogenous fertilizers in the soils. Burning of crop residue leads to the emission of a number of gases and pollutants. Amongst them, CO_2 is considered to be C neutral, and therefore not included in the estimations. Only CH_4 and N_2O are considered for this report. The total CO_2 eq emitted from these two sources were 50.00 million tons.

Land Use Land Use Change and Forestry: The estimates from LULUCF sector include emission by sources and or removal by sinks from changes in forest land, crop land, grassland and settlements. Wet lands have not been considered due to paucity of data. The LULUCF sector in 2007 was a net sink. It sequestered 177.03 million tons of CO_2 in 2007. (Figure 10.8)

Forest Land: This includes estimates of emissions and removal from above and below ground biomass in very dense, moderately dense, open forests, and scrub lands. Estimates indicate that forest land sequestered 67.8 million tons of CO_2 in 2007. However, fuel wood extracted non-sustainably from forests lead to an emission of 67.80 million tons of CO_2 in 2007.

Crop Lands: The emission estimates have been made from net sown area as well as fallow land. The crop land sequestered 207.52 million tons of CO_2 in 2007.

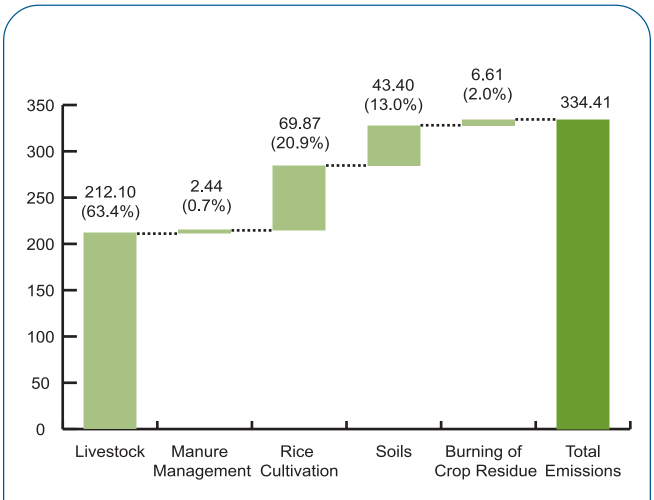


Figure 10.7: GHG emissions from Agriculture Sector (million tons of CO_2 eq).

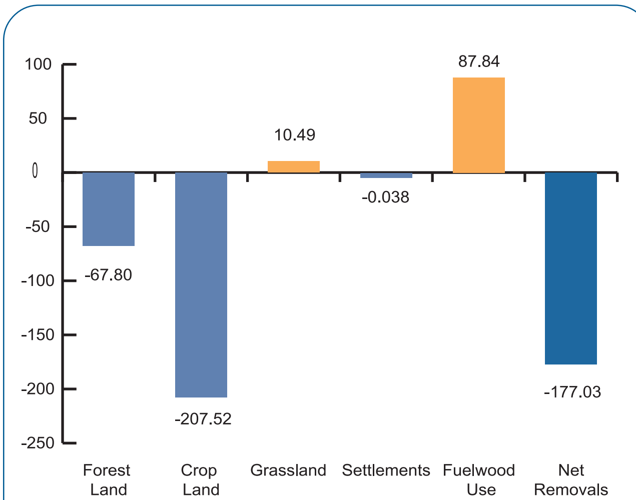


Figure 10.8: GHG emissions and removals from LULUCF sector (million tons of CO_2 eq).

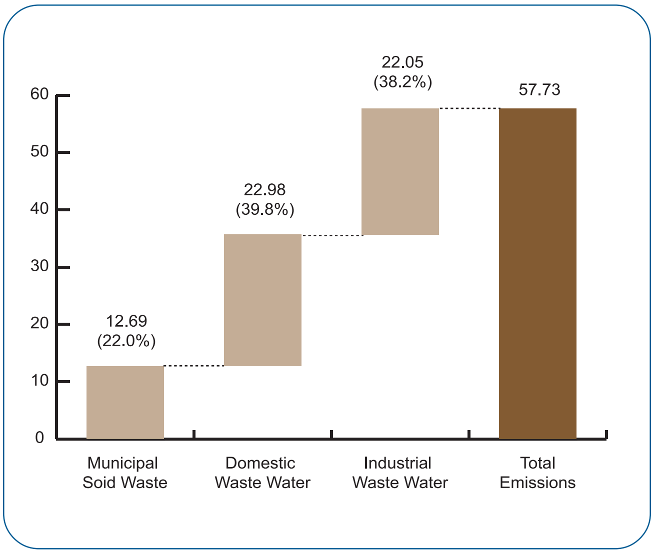


Figure 10.9: GHG emissions from Waste Sector (million tons of CO_2 eq).

Grassland: Changes in Grassland resulted in the emission of 10.49 million tons of CO_2 due to decrease in grass land area by 3.4 million ha between the two periods.

Settlements: Land converted to settlements though increased by 0.01 million ha during the period, however, the conversions did not lead to an emission but a net removal of 0.04 million tons.

Waste: The waste sector emissions were 57.73 million tons of CO_2 eq from municipal solid waste management, domestic waste water and industrial waste water management. (Figure 10.9)

Municipal Solid Waste (MSW): Systematic disposal of solid waste is carried out only in the cities in India resulting in CH_4 emissions due to aerobic conditions generated due to accumulation of waste over the years. It is estimated that the MSW generation and disposal resulted in the emissions of 12.69 million tons of CO_2 eq in 2007.

Waste Water: The waste water generation emissions are the sum total of emissions from domestic waste water and waste water disposal in industries. Waste water management in both these categories together emitted 45.03 million tons of CO_2

10.4 COMPARISON WITH 1994 GHG INVENTORY

The 1994 assessment is available in India's Initial National Communication to the UNFCCC. Both the 1994 and 2007 assessments have been prepared using the IPCC guidelines for preparation of national greenhouse gas inventories by sources and removal by sinks. The distinctive key features of the two and the improvements in the 2007 assessments are indicated in Box 10.2.

A gas by gas comparison indicates that the CO_2 emissions have increased by 381.15 million tons between 1994 and

Box 10.2: 2007 and 1994 - Key Methodological Features and Improvements

1994 Assessment	2007 Assessment
■ Estimates made using only revised 1996 IPCC guidelines.	■ Estimates made using revised IPCC 1996 guidelines (1997), IPCC Good Practice Guidance (2000), the LULUCF Good Practice Guidance (2003).
■ LULUCF included emissions from changes in forest land.	■ Carbon pools in addition to forests have been considered in the LULUCF sector (crop land, grass land, settlements).
■ Emission factors were a mix of default factors taken from IPCC and country specific (CS) emission factors. 26% of the source categories used CS factors.	■ Emission factors were also a mix of default and CS emission factors but leading to improved accuracy as more number of CSs have been used in this assessment (35% of the source categories used CS factors).
■ The 1994 assessment splits the emissions from industry in to two parts - fossil fuel and process. The fossil fuel emissions are reported in Energy and process emissions in Industry.	■ The 2007 assessment reports both fossil fuel related and process based emissions from Industry as a part of the Industry sector.
■ In 1994, 7% of the total CO_2 eq emissions were made using Tier III approach.	■ In 2007, 12% of the emissions are made using Tier III approach, implying greater accuracy.

2007 with LULUCF. Without LULUCF, CO_2 emissions have increased from 817.02 million tons in 1994 to 1497.03 million tons in 2007. The CH_4 emissions have only grown by 2.48 million tons with respect to 1994. The N_2O emissions have grown by 0.061 million tons between 1994 and 2007, A comparative analysis of the gas by gas emissions is shown in Table 10.1

A Sectoral comparison of the emissions in 1994 and 2007 is provided in Table 10.2. Emissions from electricity generation, cement and waste are growing at a faster rate with respect to others. The compounded annual growth rates are 5.6%, 6.0% and 7.3%. These are mainly associated with the needs of the growing economy. The summary of the GHG emissions of India from all sectors in 2007 emissions is provided in Table 10.3.

Table 10.1: Gas by gas comparison between 1994 and 2007 in million tons of CO_2 eq

	1994	2007	CAGR (%)
CO_2 with LULUCF	793.49	1221.70	3.4
CO_2 without LULUCF	817.02 (65.3%)	1497.03 (74.6%)	4.8
CH_4	18.08 (30.3%)	20.56 (21.5%)	1.0
N_2O	0.178 (4.4%)	0.24 (3.9%)	2.3
CO_2 eq with LULUCF	1228.50	1727.70	2.9
CO_2 eq without LULUCF	1252.00	1904.70	3.3

Note: Figures in brackets represent percentage emissions with respect to total CO_2 eq. emissions without LULUCF

10.5 PER CAPITA EMISSIONS

The population in India in 2007 was 1.15 billion approximately representing 17% of global population (UNSTAT, 2007). The per capita GHG emission without LULUCF is estimated to be 1.7 tons of CO_2 equivalent/ capita and with LULUCF it is 1.5 tons/capita. In terms of CO_2, the per capita emission was 1.3 tons CO_2 per capita or 0.35 tons of C per capita. In comparison, in 1994, the population was 897 million, comprising 15.8% of world population. The per capita GHG emissions in 1994 were accordingly 1.4 t CO_2 eq/ capita, 0.9 tons CO_2/ capita or 0.24 tons C/capita. (Figure 10.10)

Table 10.2: A comparison of emissions by sector between 1994 and 2007 in million tons of CO_2 eq

	1994	2007	CAGR (%)
Electricity	355.03 (28.4%)	719.30 (37.8%)	5.6
Transport	80.28 (6.4%)	142.04 (7.5%)	4.5
Residential	78.89 (6.3%)	137.84 (7.2%)	4.4
Other Energy	78.93 (6.3%)	100.87 (5.3%)	1.9
Cement	60.87 (4.9%)	129.92 (6.8%)	6.0
Iron & Steel	90.53 (7.2%)	117.32 (6.2%)	2.0
Other Industry	125.41 (10.0%)	165.31 (8.7%)	2.2
Agriculture	344.48 (27.5%)	334.41 (17.6%)	-0.2
Waste	23.23 (1.9%)	57.73 (3.0%)	7.3
Total without LULUCF	1251.95	1904.73	3.3
LULUCF	14.29	-177.03	
Total with LULUCF	1228.54	1727.71	2.9

Note: Figure in brackets indicate percentage emissions from each sector with respect to total GHG emissions without LULUCF in 1994 and 2007 respectively

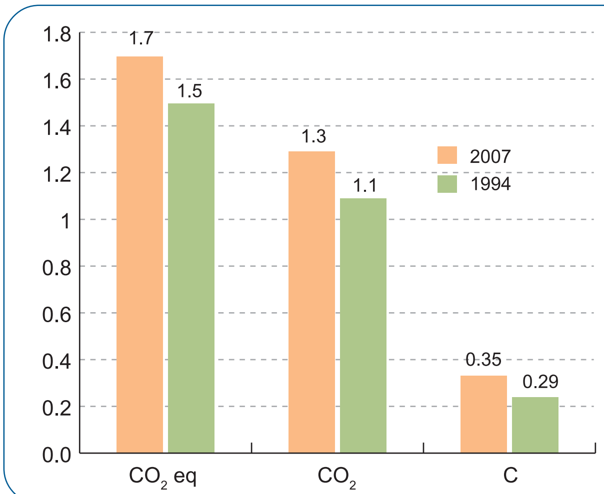


Figure 10.10: Comparison of per capita emissions (tons/capita)

Table 10.3: Greenhouse gas emissions by sources and removal by sinks from India in 2007 (thousand tons)

	CO_2 emissions	CO_2 removals	CH_4	N_2O	CO_2 equivalent
GRAND TOTAL	**1497029.20**	**275358.00**	**20564.20**	**239.31**	**1727706.10**
ENERGY	**992836.30**		**4266.05**	**56.88**	**1100056.89**
Electricity generation	715829.80		8.14	10.66	719305.34
Other energy industries	33787.50		1.72	0.07	33845.32
Transport	138858.00		23.47	8.67	142038.57
Road transport	*121211.00*		*23.00*	*6.00*	*123554.00*
Railways	*6109.00*		*0.34*	*2.35*	*6844.64*
Aviation	*10122.00*		*0.10*	*0.28*	*10210.90*
Navigation	*1416.00*		*0.13*	*0.04*	*1431.13*
Residential	69427.00		2721.94	36.29	137838.49
Commercial / Institutional	1657.00		0.18	0.04	1673.18
Agriculture/ Fisheries	33277.00		1.20	1.15	33658.70
Fugitive emissions			1509.40		31697.30
INDUSTRY	**405862.90**		**14.77**	**20.56**	**412546.53**
Minerals	**130783.95**		**0.32**	**0.46**	**130933.27**
Cement production	129920.00				129920.00
Glass & ceramic production	277.82		0.32	0.46	427.14
Other uses of soda ash	586.12				586.12
Chemicals	**27888.86**		**11.14**	**17.33**	**33496.42**
Ammonia production	10056.43				10056.43
Nitric acid production				16.05	4975.50
Carbide production	119.58				119.58
Titanium dioxide production	88.04				88.04
Methanol production	266.18		0.91		285.37
Ethylene production	7072.52		9.43		7270.64
EDC & VCM production	198.91				198.91
Ethylene Oxide production	93.64		0.19		97.71
Acrylonitrile production	37.84		0.01		37.98
Carbon Black production	1155.52		0.03		1156.07
caprolactam				1.08	336.22
Other chemical	8800.21		0.56	0.20	8873.97
Metals	**122371.43**		**0.95**	**1.11**	122736.91
Iron & Steel production	116958.37		0.85	1.09	117315.63
Ferroalloys production	2460.70		0.08		2462.29
Aluminium production	2728.87		0.01	0.00	2729.91
Lead production	84.13		0.00	0.01	86.38
Zinc production	76.11		0.00	0.01	77.99
Copper	63.25		0.01	0.00	64.70
Other Industries	**123969.17**		**2.37**	**1.65**	124530.44
Pulp and paper	5222.50		0.05	0.08	5248.35
Food processing	27625.53		1.12	0.22	27717.25
Textile and leather	1861.11		0.03	0.02	1867.94
Mining and quarrying	1460.26		0.06	0.01	1464.62
Non-specific industries	87799.77		1.11	1.32	88232.28

(contd. on next page)

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	CO_2 emissions	CO_2 removals	CH_4	N_2O	CO_2 equivalent
Non energy product use	**849.49**				849.49
Lubricant	776.75				776.75
Paraffin wax	72.75				72.75
AGRICULTURE			**13767.80**	**146.07**	**334405.50**
Enteric fermentation			10099.80		212095.80
Livestock Manure management			115.00	0.07	2436.70
Rice cultivation			3327.00		69867.00
Soils				140.00	43400.00
Burning of crop residue			226.00	6.00	6606.00
LULUCF	**98330.00**	**275358.00**			**-177028.00**
Forestland		67800.00			-67800.00
Cropland		207520.00			-207520.00
Grassland	10490.00				10490.00
Settlement		38.00			-38.00
Wetland	NE				NE
Other land	NO				NO
Fuel wood use in forests	87840.00				87840.00
Waste			**2515.58**	**15.80**	**57725.18**
Municipal Solid waste			604.51		12694.71
Domestic waste water			861.07	15.80	22980.47
Industrial waste water			1050.00		22050.00
Bunkers*	**3454**		**0.03**	**0.10**	**3484.45**
Aviation Bunkers	3326		0.02	0.09	3355.31
Marine bunkers	128		0.01	0.003	129.14

Note: LULUCF: Land Use Land Use Change & Forestry
**Not included in the national totals.*
NE: Not estimated; NO: Not occuring

11

Future Perspective

The robustness of an inventory making process is dependent on the tier of methodology used for estimating the same. Higher the tier, more representative is the emission estimated using the same with respect to the actual emissions. Of the total 1727.7 million tons of CO_2 equivalent emissions from India in 2007, 21% of the emissions have been estimated using Tier I methodology, 67% by Tier II and 12% by Tier III methodology (see figure 11.1).

In the present work, Tier III methodology has been used for the categories relating to enteric fermentation in livestock, rice cultivation and cement production. This means that the estimates are data intensive and emission factors used are very closely representing the emissions per unit of activity. For example, in the case of cement production, 85% of the cement plants have been surveyed to collect the data on coal used by type, annual Clinker & Cement production by Variety and co-generation data for large, medium and small plants to estimate the GHG emission from this source by process and from combustion of fuel. Similarly, in the case of enteric fermentation, the dairy cattle and buffalo being

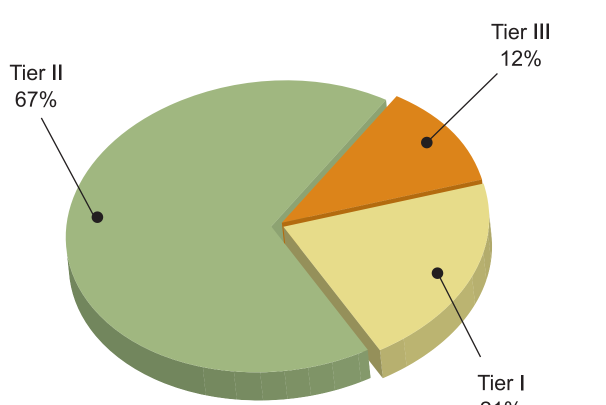

Figure 11.1: Emissions and Tiers of methodology used for 2007 GHG emission profile

the dominating source of emission within this category have been classified according to age groups, to distinguish between, lactating cattle, old and calves which have different CH_4 emitting properties. Further new born emission factors have been estimated across these age groups through measurements and using representative feed intakes in the various agro-ecological zones.

Tier II approach has been used for electricity generation, road transportation, agricultural soils, industrial waste water and municipal solid waste. These estimates have been made using relatively detailed data on type of vehicles and country specific emission factors for some of their components. Wherever, the Tier I approach has been used for estimating GHG emissions, the emission factors are sourced from IPCC publications, and the activity data are less detailed with respect to Tier II and Tier III approaches.

Table 11.1 below identifies the Tier of methodology and the corresponding emission factors used to estimate the greenhouse gases from each category. The table also indicates the key categories identified on the basis of their relative emissions with respect to the total CO_2 equivalent emissions from the country in 2007. This analysis does not include LULUCF categories, as per the GPG guidance 2000. A key category, essentially is the basis for planning improvements in the GHG emission inventory from various source categories.

11.1 RIDING THE TIER LADDER

About 17 categories in Table 11.1 have been identified as key categories. Of these 3 already use Tier III methodology. Six use Tier II and the rest use Tier I. It is apparent that all the key categories using Tier II and Tier I methodologies, need to move up the Tier ladder to increase the reliability of the 95% of the emissions from

Table 11.1: Key category analysis

	CO_2 eq ('000 tons)	Cumulative CO_2 eq	% of total	Tier Used	Emission factors used
Electricity generation	719305.34	719305.34	37.12065	Tier II	CS+D
Enteric fermentation	212095.8	931401.14	48.06611	Tier III	CS+D
Residential	137838.487	1069239.627	55.17944	Tier I	D
Cement production	129920	1199159.627	61.88412	Tier III	CS+D
Road transport	123554	1322713.627	68.26028	Tier II	CS+D
Iron & Steel production	117315.631	1440029.257	74.3145	Tier II	CS+D
Non-specific industries	88232.28	1528261.537	78.86784	Tier I	CS+D
Rice cultivation	69384	1597645.537	82.44849	Tier III	CS
Soils	43400	1641045.537	84.6882	Tier II	CS+D
Other energy industries	33845.32	1674890.857	86.43483	Tier I	CS+D
Agriculture/ Fisheries	33658.7	1708549.557	88.17183	Tier I	CS+D
Fugitive emissions	31697.295	1740246.852	89.8076	Tier III	CS
Food processing	27717.25	1767964.102	91.23799	Tier I	CS+D
Domestic waste water	22980.47	1790944.572	92.42392	Tier I	D
Industrial waste water	22050	1812994.572	93.56184	Tier II	CS+D
Municipal Solid waste	12694.71	1825689.282	94.21697	Tier II	CS+D
Aviation	10210.9	1835900.182	94.74391	Tier I	D
Ammonia production	10056.4336	1845956.616	95.26289	Tier I	D
Other chemical	8873.9664	1854830.582	95.72084	Tier I	D
Ethylene production	7270.63715	1862101.219	96.09605	Tier I	D
Railways	6844.64	1868945.859	96.44928	Tier I	CS+D
Burning of crop residue	6606	1875551.859	96.79019	Tier I	D
Pulp and paper	5248.35	1880800.209	97.06104	Tier I	D
Nitric acid production	4975.5	1885775.709	97.3178	Tier I	CS
Aluminium production	2729.90853	1888505.618	97.45868	Tier I	D
Ferroalloys production	2462.2939	1890967.912	97.58575	Tier I	D
Livestock Manure management	2436.7	1893404.612	97.7115	Tier I	D
Textile and leather	1867.94	1895272.552	97.8079	Tier I	D
Commercial / Institutional	1673.18	1896945.732	97.89424	Tier I	D
Mining and quarrying	1464.62	1898410.352	97.96983	Tier I	D
Navigation	1431.13	1899841.482	98.04368	Tier I	D
Carbon Black production	1156.07397	1900997.556	98.10334	Tier I	D
Lubricant	776.746667	1901774.303	98.14343	Tier I	D
Other uses of soda ash	586.120901	1902360.423	98.17368	Tier I	D
Glass & ceramic production	427.144416	1902787.568	98.19572	Tier I	D
Caprolactam	336.218963	1903123.787	98.21307	Tier I	D
Methanol production	285.369075	1903409.156	98.2278	Tier I	D
EDC & VCM production	198.9093	1903608.065	98.23806	Tier I	D
Carbide production	119.5832	1903727.648	98.24423	Tier I	D
Ethylene Oxide production	97.714015	1903825.362	98.24928	Tier I	D
Titanium dioxide production	88.037525	1903913.4	98.25382	Tier I	D
Lead production	86.3830122	1903999.783	98.25828	Tier I	D
Zinc production	77.9890514	1904077.772	98.2623	Tier I	D
Paraffin wax	72.7466667	1904150.519	98.26606	Tier I	D
Copper	64.7	1904215.219	98.2694	Tier I	D
Acrylonitrile production	37.978538	1904253.197	98.27136	Tier I	D

D- Default Emission Factor; CS – Country Specific the country. Further, an uncertainty analysis along with the key category analysis will together identify the categories that are most critical in terms of their contribution to the total GHG inventory from a sector or country itself. Once it is done, strategies need to be made to climb the tier ladder. The measures in place should be towards improving the assimilation of activity data, bridging data gaps, comparing data with all data information sources, and improving the emission factors which may be a function of several parameters contributing to the process of emission. Figure 11.2 indicates the steps necessary for improving the robustness of the inventory estimates as well as the inventory making process itself.

Some of the activities that can be carried out to make the improvements can be the following:

Energy sector

- Continuous improvement of NCV of coal
- Sampling of coal at power plant for estimating NCV of different types of coal entering the plants
- On line measurement of CO_2 emission at each stack of large power plants that constitute 90% of the total emission of CO_2 from this source
- Estimating GHG emission factor by kilometer traveled by each vehicle type and using the same data in road transport GHG emission models (e.g. COPART)
- Bridging activity data gaps, especially for ascertaining energy use in commercial, residential, agriculture sectors. Therefore ascertaining the allocation of diesel and biomass consumptions are key data requirements for these sector.

Industry

- Measuring plant specific CO_2 emission in large steel plants
- Bridging data gaps in various industries, especially non specific industries amongst others - enhance role of industry associations
- Determining CO_2 emission factor for ammonia production and improving the activity data for the same through sample survey

Agriculture

- Updating CH_4 emission factor from continuously flooded fields, by ascertaining area of flooding through remote sensing
- Focusing on measurement of CH_4 emission factor from prominent species of dairy cattle in India
- Updating N_2O emission factors for crop soils in India -extending regional coverage

Waste

- Updating data for estimating CH_4 emission factors from waste water in industries
- Measuring CH_4 emission factors from MSW in metro cities in India (Delhi, Kolkata, Chennai & Mumbai)

Land use land Use Change and Forestry

- Continuous categorisation of land use for 20 year previous to the year of estimate.

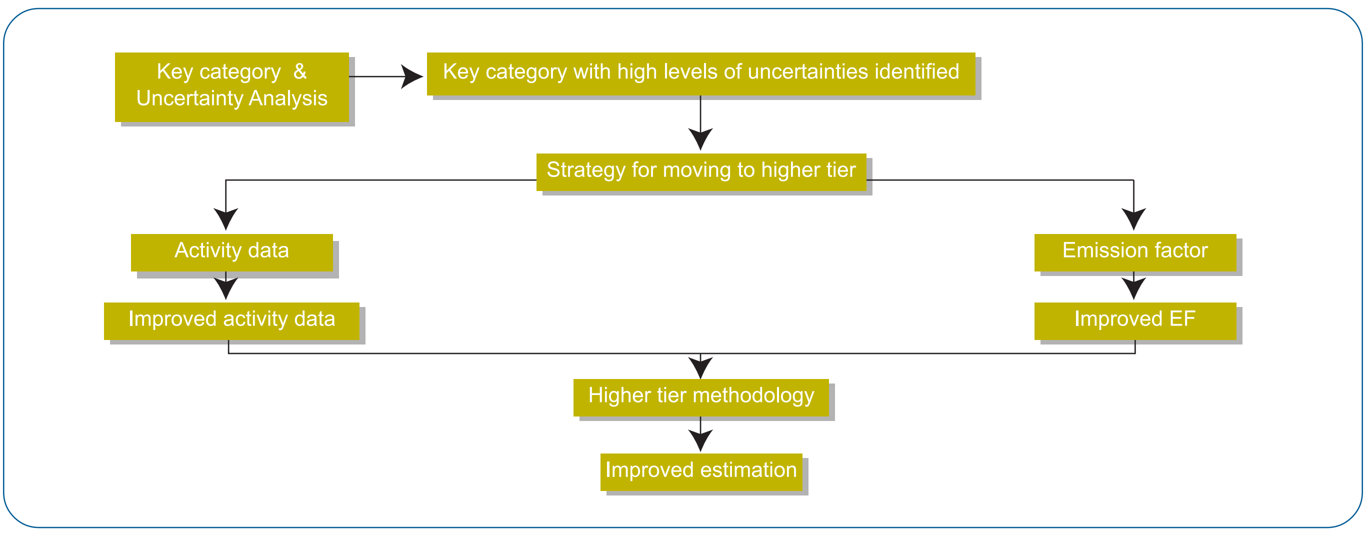

Figure 11.2: Towards improvement in the estimates

11.2 CAPACITY BUILDING

Capacity building is essential at two levels- one is building capacity at the institutional level and one at the individual level. Building capacity at the institutional level is essential to address the needs of inventory preparation for various purposes, be it at national scale, sectoral scale or at installation level. Therefore there is a need to have a National Inventory Management System. This will also include additional involvement of institutions with varied research experience to widen the pool of institutions that will look at the various aspects of inventory development. The individual capacity building is another aspect that needs improvement of the skills of individuals on a continuous basis to be in consonance with the latest developments in the process and subject of inventory preparation for various sectors, including energy, Industry, Agriculture, Land Use land use change and forests, and waste management.

Establishment of National Inventory Management System: Building on the base of knowledge institutions already engaged in the preparation of a national assessment a National Inventory Management System (NIMS) under the MoEF can be developed. The NIMS may address the requirements of documentation, archiving and continuous updating of the databases as well as the QA/QC and uncertainty management issues of the GHG inventories being developed across the years. The NIMS mandate should address the development of Systemic tools and procedures for documenting methodologies, creation of databases of emission factors and activity data for each point source and the various disaggregated sources that add up to generate the national GHG Emission profiles across each year. The NIMS mandate may include:

- Undertake data management and collection on an annual basis;
- Devise strategies for data generation and improvement;
- Establish systems for data archiving and record keeping;
- Ensure mechanisms for synchronization and cross-feeding between emission inventories, national energy balances and relevant sector surveys;
- Provide guidance for technical peer reviews, procedures for QA/ QC and uncertainty management.

A web based data base management system may further help in wider accessibility of data to concerned stakeholders and also towards visualisation of GHG data thus generated.

Enhanced networking and Individual capacity building: The present network of institutions involved in this assessment is only estimating the GHG emissions by sector. GHG inventory preparation is a much larger exercise, as it involves data generation, collection, archival, literature survey for emission factors, determination of country specific emission factors, undertaking QA/QC and uncertainty analysis amongst other activities. For each of these skilled approach is required and therefore trained manpower is necessary that will also improve methodologies of estimation with respect to the International methodologies available and may be develop new methodologies to reflect the national circumstances of specific activities that are key categories in the entire GHG inventory. This can be done by enlarging the base of institutions involved in this present activity which can skilfully steer each and every activity required for GHG inventory preparation. Other than the enhancement in the institutional base, it is also important to train manpower in the latest techniques of inventory preparation as well as bring in new capacity to carry forward the work.

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Annexure 3

Scientists/ Experts - India : Greenhouse Gas Emissions 2007

Central Institute of Mining and Fuel Research **Dhanbad, Jharkhand, India**	Mr. Subhasis Biswas Dr. Ajay Kumar Singh Mr. Ashim Choudhury Dr. Pinaki Sarkar Mr. Santi Glopal Sahu Mr. A. K. Adak Dr. J. Roy Mr. John Kispotta Mr. Vinod Atmaram Mendhe Mr. Shyam Nath Hazari
The Energy and Resources Institute (TERI) **Darbari Seth Block, India Habitat Place** **Lodhi Road, New Delhi**	Dr. Pradeep Kumar Dadhich Mr. Prabhat Upadhyaya Dr. Heena Zia Dr. Atul Kumar Mr . Shashank Jain Mr. Abhishek Nath
Central Road Research Institute **P.O. CRRI, Delhi-Mathura Road** **New Delhi**	Dr. Anil Singh Dr. S. Gangopadhyay Mr. Chander Bhan
Petroleum Planning and Analysis Cell, New Delhi	Mr. Vijay Sethi
Cement Manufacturers' Association **CMA Tower, Noida (U.P.)**	Dr. S. P. Ghosh Mr. Jainender Kumar Mr. K.K. Roy Chowdhury Mr. Piyuesh Aggarwal Mr. Ashok Sharma Mr. C.S.Pant Mr. Srinivas Kasiraju Mr. Harish Uniyal Mrs. Meenu Kalia Mr. Harish Papnai Dr. R. Bhargava Mr. B.K. Modi Mr. Naveen Sharma
Central Leather Research Institute, Chennai	Dr. T. P. Sastry Mr. D. Chandramouli Dr. A. B. Mandal Dr. Giriyappa Kollannavar Mr. S.Nithiyanantha Vasagam Ms. V. Shashirekha Dr. Mahadeswara Swamy

Confederation of Indian Industry **CII-ITC Centre of Excellence for Sustainable Development** **New Delhi**	Dr. Suman Majumdar Ms. Seema Arora Ms. Esha Sar Ms. Trayee Banerjee
Indian Agricultural Research Institute **Pusa, New Delhi**	Dr. Arti Bhati Dr. Niveta Jain Dr. Himanshu Pathak Dr. P K Aggarwal
Bidhan Chandra Krishi Viswavidyalaya, **Mohanpur, Nadia, West Bengal**	Dr. Biswapati Mandal Mr. Kaushik Batabyal Mr. Nimai Senapati
National Dairy Research Institute **Karnal, Haryana**	Dr. Madhu Mohini K. K. Singhal A.K. Tyagi
Forest Survey of India, **Kaulagarh Road** **Dehradun**	Mr.Subhash Ashutosh Mr. Rajesh Kumar Raj Kumar Bajpai
Indian Institute of Science **Bangalore**	Prof. N. H. Ravindranath Ms. Shilpa Swarnim Ms. Nitasha Shrama
National Remote Sensing Centre **Dept. of Space, GOI,Hyderabad**	Dr. M. S. R. Murthy Dr. C. S. Jha
National Environmental Engineering Research Institute, **Nagpur, Maharastra**	Mr. J.K. Bhattacharyya Mr. M. Karthik, Dr. S.P.M. Prince William Dr. Tapas Nandy Mr. Pawan Aswale
National Physical Laboratory **Dr. K. S. Krishnan Marg, New Delhi**	Dr. Prabhat Gupta Dr. C Sharma Mr. Manojeet Chakraborty Dr. Nahar Singh Mr. Shivraj Sahai
Indian Grassland & Fodder Research Institute	Dr. Sultan Singh Dr. S. K. Nag Dr. A. K. Misra Dr. B. P. Khushwaha
Indian Veterinary Research Institute, Izatnagar	Dr. A.K. Verma Dr. Putan Singh Dr. V. B. Chaturvedi
Ministry of Environment and Forests **Government of India**	Dr. Subodh K Sharma Dr. Sumana Bhattacharya, NATCOM Cell Ms. Pooja Kotiyal, NATCOM Cell Ms. Sudatta Ray

Annexure 4

INCCA Institutions

GHG INVENTORY ESTIMATES

1. Advance Research Centre For Bamboo and Rattans, Aizawl
2. Alkali Manufacturers' Association of India, New Delhi
3. Arid Forest Research Institute, Jodhpur
4. Bidhan Chandra Krishi Vishwavidyalaya, Kolkata
5. Bureau of Energy Efficiency, New Delhi
6. Cement Manufacturers' Association, Noida
7. Central Glass and Ceramic Research Institute, Kolkata
8. Central Institute of Mining and Fuel Research, Dhanbad
9. Central Leather Research Institute, Chennai
10. Central Mines Planning & Design Institute, Dhanbad
11. Central Road Research Institute, New Delhi
12. Central Statistical Organization (CSO)
13. Centre for Forest Research and Human Resource development , Chhindwara
14. Centre for Social Forestry and Eco Rehabilitation, Allahabad
15. Coal India Ltd, Kolkata
16. Confederation of Indian Industry, New Delhi
17. Damodar Valley Corporation, Jharkhand
18. Eastern Coal Field Ltd, West Bengal
19. Fertiliser Association of India, New Delhi
20. Forest Research Centre, Hyderabad
21. Forest Survey of India, Dehradun
22. Himalayan Forest Research Institute, Shimla
23. Holtec Consulting Engineers Ltd, Gurgaon
24. India Semiconductors Association, Bangalore
25. Indian Agricultural Research Institute, New Delhi
26. Indian Bureau of Mines, Nagpur
27. Indian Chemical Council, Mumbai
28. Indian Council of Forest Research and Education, Dehradun
29. Indian Grassland and Fodder Research Institute, Jhansi
30. Indian Institute of Petroleum, Dehradun
31. Indian Institute of Remote Sensing , Dehradun
32. Indian Institute of Science, Bangalore
33. Indian Lead Zinc Development Association, New Delhi
34. Indian Veterinary Research Institute, Izatnagar
35. Industries Association Of India, New Delhi
36. Institute of Forest Genetics and Tree breeding, Coimbatore
37. Institute of Forest Productivity , Ranchi
38. Institute of Wood Science and Technology , Bangalore
39. Jadavpur University, Kolkata
40. Mahanadi Coal Field Ltd, Orissa
41. Ministry of New & Renewable Energy, New Delhi
42. Ministry of Petroleum & Natural Gas, New Delhi
43. Naively Lignite Corporation Ltd., Tamil Nadu
44. National Bureau of Soil Survey Land Use Planning, Nagpur
45. National Dairy Research Institute, Karnal
46. National Environmental Engineering Research Institute, Nagpur
47. National Institute of animal nutrition and physiology, Bangalore
48. National Physical Laboratory, New Delhi
49. National Remote Sensing Centre, Hyderabad
50. Neyveli Lignit Corporation Ltd.
51. North Eastern Coal Field Ltd, Assam
52. Petroleum Conservation Research Association, New Delhi
53. Petroleum Conservation Research Association,
54. Petroleum Planning and Research Cell, New Delhi
55. Rain Forest Research Institute, Jorhat
56. South Eastern Coal Field Ltd, Chhattisgarh
57. Steel Authority of India, New Delhi
58. The Energy and Resources Institute, New Delhi
59. Tropical Forest Research Institute, Jabalpur
60. University of Agriculture Sciences, Bangalore

IMPACTS, VULNERABILITY & ADAPTATION ASSESSMENTS

1. Action for Food Production, Udaipur
2. Anand Agricultural University, Anand
3. Andaman & Nicobar Islands Forest & Plantation Corporation Limited, Port Blair
4. Arete Glaci-er & Water Consultants Pvt. Ltd, New Delhi
5. Central Inland Fisheries Research Institute, Barrackpore
6. Central Institute for Cotton Research, Nagpur
7. Central Marine Fisheries Research Institute, Kochi
8. Central Plantation Crop Research Institute, Kerala
9. Central Potato Research Institute, Jalandhar
10. Central Research Institute for Dryland Agriculture, Hyderabad
11. Central Soil & Water Conserv. Res. & Trng. Institute, Dehradun
12. Central Soil Salinity Research Institute, RRS, Lucknow, UP
13. Central Water Commission, New Delhi
14. Dr. Y.S. Parmar University of Horticulture and Forestry, Shimla
15. Forest Survey of India, Dehradun
16. Global hydrological solution, New Delhi
17. Department of Science and Technology, Government of Sikkim
18. Himachal Pradesh Krishi Viswa Vidyalaya, Palampur
19. Himalayan Institute of Mountaineering, Darjeeling
20. ICAR Complex for NE Hill Region, Meghalaya
21. ICAR Institute of Eastern Region, Patna, Bihar
22. Indian Agricultural Research Institute, New Delhi
23. Indian Institute of Horticulture Research, Bangalore
24. Indian Institute of Management Ahmadabad
25. Indian Institute of Science, Bangalore
26. Indian Institute of Soil Science, Bhopal
27. Indian Institute of Sugarcane Research, Lucknow
28. Indian Institute of Technology Bombay, Mumbai
29. Indian Institute of Technology Delhi, New Delhi
30. Indian Institute of Tropical Meteorology, Pune
31. Indian Meteorological Department, New Delhi
32. Indian Mountaineering Foundation, New Delhi
33. INRM Pvt. Lmt, New Delhi
34. Institute of Economic Growth, New Delhi
35. Institute of Home Economics, New Delhi
36. Integrated Institute of Minerals & Materials Technology, Bhubaneshwar
37. Integrated Research and action for Development, New Delhi
38. Jadavpur University, Kolkata
39. Jawahar Institute of Mountaineering and Winter Sports, Pahalgam, Kashmir
40. Kalpana Kalyan Society, Bali
41. M.S. Swaminathan Research Foundation, Chennai
42. Maharana Pratap University of Agriculture and Technology, Udaipur
43. Maulana Azad National Institute of Technology, Bhopal
44. National Bureau of Soil Survey and Land Use Planning, Nagpur
45. National Environmental Engineering Research Institute, Nagpur
46. National Institute of Malaria Research, New Delhi
47. National Institute of Oceanography, Goa
48. National Physical Laboratory, New Delhi
49. National Research Centre for Soybean, Indore
50. Navsari Agricultural University, Surat
51. NRC on Agroforestry, Jhansi, Uttar Pradesh
52. Prayatna Samiti, Bedla Road, Udaipur
53. PROGRESS, Banswara
54. Project Directorate on Poultry, Hyderabad
55. Punjab Agricultural University, Jalandhar
56. Rajasthan Bal Kalyan Samiti, Udaipur
57. Reef Watch Marine Conservation, Mumbai
58. Regional Horticulture Fruit Station, Moshobra, Shimla
59. Regional Horticulture Research Station, Sharbo, Kinaur
60. Tamil Nadu Agriculture University, Coimbatore
61. The Energy and Resources Institute, New Delhi
62. Tocklai Experiment Station, Jorhat
63. University of Agricultural Sciences, Dharwad
64. University of Kashmir, Department of Geology and Geophysics, Sri Nagar
65. Vallabhbhai Patel Chest Institute, New Delhi
66. Winrock International India, New Delhi.
67. Zoological Survey of India, Port Blair

Annexure 5

Glossary of Key Terms

Agriculture: This includes emissions from enteric fermentation, manure management, rice cultivation, managed soils and burning of crop residue.

CAGR: The compound annual growth rate is calculated by taking the n^{th} root of the total percentage growth rate, where n is the number of years in the period being considered.

Chemicals: In this document chemicals include production of ammonia, nitric acid, adipic acid, caprolactam, carbide, titanium dioxide, petrochemicals and black carbon, methanol, ethylene, ethylene oxide, acrylonitrile, ethylene dichloride and vinyl chloride, monomer and other chemicals (dyes and pigments, inorganic acids except nitric acid, acyclic hydrocarbons, basic organic chemicals, inorganic compounds, alkalies and other inorganic bases except ammonia, synthetic aromatic products, luminophores, etc).

CO_2 Equivalent: It is the sum total of all Greenhouse Gases in terms of their global warming potential. In this document the CO_2 equivalent includes the sum of Carbon dioxide, Methane multiplied by its GWP (21) and Nitrous oxide multiplied by its GWP (310).

Country Specific Data: Data for either activities or emissions that are based on research carried out on-site either in a country or in a representative country.

Emission Factor: A coefficient that quantifies the emissions or removals of a gas per unit activity. Emission factor are often based on a sample of measurement data, averaged to develop a representative rate of emission for a given activity level under a given set of operating conditions.

Emissions: The release of greenhouse gases and / or their precursors into the atmosphere over a specified area and a period of time.

Energy: This category included all GHG emissions arising from combustion of fossil fuel and fugitive release of GHG's. Emissions from the non-energy use are not included here and are reported under the industry sector. This category includes emissions due to fuel combustion from energy industries (electricity generation, petroleum refining, manufacturing of solid fuel), transport, commercial / institutional, residential, agriculture / forestry / fisheries, and fugitive emissions from coal mining and handling and from oil and natural gas.

Enteric Fermentation: A process of digestion in herbivores (plant – eating animals) which produces methane as a by-product.

Estimation: The process of calculating emissions and / or removal

Flaring: Deliberate of burning of natural gas and waste gas / vapour streams, without energy recovery.

Fossil Fuel Combustion: Is the intentional oxidation of fossil fuel that provides heat or mechanical work to process.

Fugitive Emission: Emission that are not emitted through an intentional release through stack or vent. This can include leaks from plants, pipelines and during mining.

Global Warming Potential (GWP): GWPs are calculated as a ratio of radiative forcing of 1 kilogram greenhouse gas emitted to the atmosphere to that from 1 kilogram CO_2 over a period of time (e.g.. 100 years).

Good Practice: Is a set of procedures intended to ensure that GHG inventories are accurate, that neither over nor underestimated and that uncertainties are reduced as far as possible. It covers choice estimation methods, quality assurance and quality control, quantification of uncertainties and processes for data archiving and reporting.

INCCA: Indian Network for Climate Change Assessment - an initiative being coordinated by the Ministry of Environment and Forests, Government of India.

Industry: This includes emissions from industrial processes and emissions due to fossil fuel combustion in manufacturing industries. The emissions are estimated from mineral industry (cement, lime, glass, ceramics, soda ash use), chemical industries (ammonia, nitric acid, adipic acid, caprolactam, carbide, titanium dioxide, petrochemicals and black carbon, methanol, ethylene, etc.), metal industry (iron and steel, ferroalloys, aluminium, magnesium, lead, sink, etc.), other industry and non-energy products from fuels and solvent use (paraffin wax and lubricants).

Land Cover: The type of vegetation, rock, water, etc. covering the earth surface.

Land Use: The type of activity being carried out by unit of land

Land Use Land Use Change and Forestry (LULUCF): Includes emissions and removal from changes in areas of forest land, crop land, grass land, wet land, settlements and other lands.

Million Tons: equal to 10^6 tons.

Non Energy Products: Primary or secondary fossil fuels which act as diluent. Examples, lubricants, paraffin wax, bitumen, etc.

Non Energy Use: Use of fossil fuels as feedstock, reductant or non-energy products.

Non-specific industries: Includes rubber, plastic, medical precetion equipments, watches, clocks, other transport, furniture, re-cycling etc.

Other Energy: Includes GHG emissions from petroleum refining, manufacturing of solid fuel, commercial & institutional sector, agriculture & fisheries and fugitive emissions from mining, transport and storage of coal, oil and natural gas.

Other Industry: Includes GHG emissions from production of food processing, textile, leather, mining and quarrying, non specific industries and use of lubricants and paraffin wax.

Other Minerals: In this document other minerals refer to glass and ceramics production and soda ash use.

Per Capita Emissions: GHG emissions in CO_2 eq per person.

Removals: Removal of greenhouse gases and or their precursors from the atmosphere by a sink

Sequestration: The process of storing carbon in a carbon pool.

Sink: Any process, activity or mechanism which removes greenhouse gases from the atmosphere.

Source: Any process or activity which releases a greenhouse gas.

Tier I: Its approach employs activity data that are relatively coarse, such as nationally or globally available estimates of deforestation rates; agriculture production statistics and global land cover maps.

Tier II: It uses the same methodological approach as Tier 1 but it applies emission factors and activity data which are defined by the country

Tier III: Applies higher order methods are used including models and inventory measurement systems tailored to address national circumstances, repeated over time, and driven by disaggregated levels.

Uncertainty: Lack of knowledge of the true value of a variable.

Waste: Includes methane emissions from anaerobic microbial decomposition of organic matter in solid waste disposal sites and methane produced from anaerobic decomposition of organic matter by

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