GHG Inventory Information

Chapter 2

The UNFCCC was adopted in 1992, in recognition of the concern that food security and economic development in the future may be adversely affected as a result of the discernable change observed in the climate since pre-industrial times. This change is mainly attributed to the continuously increasing concentration of GHGs in the atmosphere resulting from anthropogenic activities[1]. Therefore, central to any climate change study is the assessment of GHG inventory that identifies and quantifies a country's primary anthropogenic sources and sinks of GHGs.

The UNFCCC stipulates that each party to the convention should develop, periodically update, publish and make available to the Conference of Parties, a national inventory of anthropogenic emissions by sources and removals by sinks of all GHGs not controlled by the Montreal Protocol, using comparable methodologies. The Convention also notes that the largest share of historical and current global emissions of GHGs has originated in developed countries and that the share of the global emissions originating in developing countries will grow to meet their social and developmental needs.

India has ratified the Convention in November 1993. As a non-Annex 1 nation under the Convention, the inventory information to be provided by India is according to the guidelines stipulated for Parties not included in Annex I to the UNFCCC. In this chapter, the information on India's GHG emissions by sources and removals by sinks for the base year 1994, is presented to the extent India's capacities permit, and is in accordance with the Articles 4.1a and 12.1a of the Convention. For a transparent and comparable emission inventory, the Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories (IPCC, 1996) has been used in the present exercise. The sources from which the emissions have been estimated include energy, industrial processes, agriculture, land use, land-use change and forestry and waste. The gases covered are CO_2, methane (CH_4) and nitrous oxide (N_2O).

The rigour of any emission inventory relies on the quality of its activity data, the emission coefficients and inventory methodologies used. In the present inventory assessment, the authenticity of data is ensured by sourcing the primary activity data for various sectors from reports of the concerned government ministries, such as the Ministry of Coal, Oil and Natural Gas, Coal Mining, Road Transport and Highways, Heavy Industries and Public Enterprises, Railways, Civil Aviation, Agriculture, Steel, Science and Technology, and others (see References). Activity data, wherever possible have been cross - verified from multiple sources including, government documents, publications of industry associations and research institutions of repute, and in some cases, directly from the manufacturers. An important contribution of this national communications exercise is the estimation of indigenous emission coefficients in several key sectors through direct field measurements using rigorous scientific methodologies. The inventory assessment has contributed to the accuracy and reliability of the GHG budget estimates reported here.

For estimating GHG inventories, the IPCC (1996 Guidelines) Tier-I, II and III approaches were used. The choice of the approach for a sector, depended on the quality and availability of activity data and emission coefficient as required by each approach. For example, in the case of coal consumption in the energy sector, Tier-II approach was applied, wherein

[1] Since 1750, globally, concentration of CO_2, CH_4 and N_2O have increased by 31,151 and 17 % respectively (IPCC, 2001a).

fuel consumption data at sub-sectoral levels were used along with measured emission coefficients for different grades of domestic coal. Alternatively, for petroleum products combustion, the Tier-I approach was employed since the default emission coefficients for these fuels are fairly accurate due to consistent quality of these fuels across the globe. In the case of methane emissions from enteric fermentation from animals, a Tier-II approach was used, whereby the cattle were segregated into dairy and non-dairy segments and the emission coefficients were estimated for each age group.

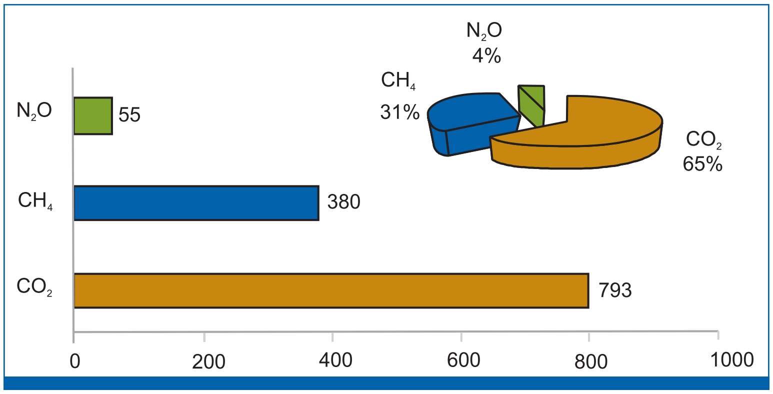


Figure 2.1: Relative emissions of GHGs from India in 1994.

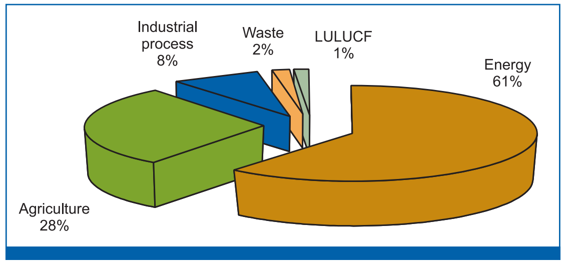


Figure 2.2: Percentage contribution of different sectors to the total GHG emissions.

Inventory estimates are inherently uncertain and are high due to the multiplicative effect of the uncertainties associated with the emission coefficient and activity data. The uncertainty in emission coefficient estimates arises from measurement inaccuracies and variable background conditions. In case of activity data, the key factors contributing to uncertainty are the aggregation errors, incompleteness of data and mismatch of data definitions. In developing countries, the accuracies are also added by the paucity of data for informal, traditional, and unrecognized sectors. Considerable uncertainties thus would exist in the present emission estimates of GHGs from various sectors.

INDIA'S GREENHOUSE GAS INVENTORY FOR THE YEAR 1994 — A SUMMARY

In 1994, the aggregate emissions from the anthropogenic activities in India amounted to 7,93,490 Gg of CO_2; 18,083 Gg of CH_4; and 178 Gg of N_2O. In terms of CO_2 equivalent[2] (Tg-CO_2 eq.), these emissions amounted to 12,28,540 Gg. The per capita CO_2 emissions were 0.87 t-CO_2 in 1994, four per cent of the US per capita CO_2 emissions in 1994, eight per cent of Germany, nine per cent of UK, 10 per cent of Japan and 23 per cent of the global average. CO_2 emissions contributed, 65 per cent of total GHGs; CH_4 contributed 31 per cent and four per cent of emissions were contributed by N_2O (Figure 2.1). On a sectoral basis (Figure 2.2), 7,43,820 Gg CO_2-eq. of GHGs were emitted from energy sector (61 per cent); 3,44,485 Gg of CO_2-eq. emissions came from the agriculture sector (28 per cent); 1,02,710 Gg of CO_2-eq. were contributed by the industrial processes (8 per cent); 23,233 Gg from waste disposal (2 per cent) activities and 14,292 Gg were generated from land use, land-use change and forestry sector (1 per cent). Table 2.1 summarizes the GHG emissions from various sectors by sources and removals by sinks for India for the base year 1994.

7,43,820 Gg of CO_2-eq GHGs, i.e., 61 per cent of the total GHG, emitted from all energy activities were mainly from the combustion of fossil fuels. Among

[2] Each of the GHGs has a unique average atmospheric lifetime over which it is an effective climate-forcing agent. Global warming potential (GWP) indexed multipliers have been established to calculate a longevity equivalency with carbon dioxide taken as unity. The GWP of methane and nitrous oxide are 21 and 310, respectively (IPCC, WKI, 1996). By applying unique GWP multipliers to the annual emissions of each gas, an annual CO_2 equivalency may be summed that represents the total GWP of all climate-forcing gases considered.

Table 2.1: India's initial national greenhouse gas inventories of anthropogenic emissions by sources and removals by sinks of all greenhouse gases not controlled by the Montreal Protocol for the base year 1994.

GHG source and sink categories (Gg per year)	CO_2 emissions	CO_2 removals	CH_4	N_2O	CO_2 eq. emissions*
Total (Net) National Emission	**817023**	**23533**	**18083**	**178**	**1228540**
1. All Energy	**679470**		**2896**	**11.4**	**743810**
Fuel combustion					
Energy and transformation industries	353518			4.9	355037
Industry	149806			2.8	150674
Transport	79880		9	0.7	80286
Commercial/institutional	20509			0.2	20571
Residential	43794			0.4	43918
All other sectors	31963			0.4	32087
Biomass burnt for energy			1636	2.0	34976
Fugitive Fuel Emission					
Oil and natural gas system			601		12621
Coal mining			650		13650
2. Industrial Processes	**99878**		**2**	**9**	**102710**
3. Agriculture			**14175**	**151**	**344485**
Enteric Fermentation			8972		188412
Manure Management			946	1	20176
Rice Cultivation			4090		85890
Agricultural crop residue			167	4	4747
Emission from Soils				146	45260
4. Land use, Land-use change and Forestry*	**37675**	**23533**	**6.5**	**0.04**	**14292**
Changes in forest and other woody biomass stock		14252			(14252)
Forest and grassland conversion	17987				17987
Trace gases from biomass burning			6.5	0.04	150
Uptake from abandonment of managed lands		9281			(9281)
Emissions and removals from soils	19688				19688
5. Other sources as appropriate and to the extent possible					0
5a. Waste			**1003**	**7**	**23233**
Municipal solid waste disposal			582		12222
Domestic waste water			359		7539
Industrial waste water			62		1302
Human sewage				7	2170
5b. Emissions from Bunker fuels #	**3373**				**3373**
Aviation	2880				2880
Navigation	493				493

Not counted in the national totals.

*Converted by using GWP indexed multipliers of 21 and 310 for converting CH_4 and N_2O respectively.

the fossil fuels, coal combustion had a dominant share of emissions, amounting to about 4,75,530 Gg of CO_2-eq GHGs i.e., about 64 per cent of all energy emissions. The non-CO_2 emissions in this category are from biomass burning and fugitive emissions released from coal mining and handling of oil and natural gas systems. An analysis of the distribution of the total CO_2-eq emissions across all the sub components of all energy activities (Figure 2.4) indicates that the major emitters were energy and transformation industries (47 per cent) constituting mainly electric power generation, industry (20 per cent) and the transport sector (11 per cent).

Of the total GHGs released in 1994, eight percent i.e., 1,02,710 Gg CO_2-eq were from the industrial process sector. These include CO_2, CH_4 and N_2O emissions from production processes of chemicals, metals, minerals, cement, lime, soda ash, ammonia, nitric acid, calcium carbide, iron and steel, ferro alloys, aluminium, limestone and dolomite use. Of the total CO_2-eq GHGs emitted from the industrial processes, 42 per cent was from iron and steel production, 30 per cent from cement production, 14 per cent from ammonia production, 6 per cent from limestone and dolomite use and the rest of the processes contributed the remaining 8 per cent.

In 1994, the agriculture sector contributed 29 per cent of the total CO_2-eq GHG emissions, amounting to 3,44,485 Gg CO_2-eq. The agriculture sector primarily emitted CH_4 and N_2O. The CO_2 emissions due to the energy use in the agriculture sector are accounted for as a part of all energy emissions. The emissions sources accounted for in the agriculture sector are enteric fermentation in livestock, manure management, rice cultivation, agricultural soils and burning of agricultural crop residue. The bulk of the GHG emissions from the agriculture sector were from enteric fermentation (59 per cent), followed by rice paddy cultivation (23 per cent), and the rest were contributed by manure management, burning of agriculture crop residue and application of fertilizers to soils.

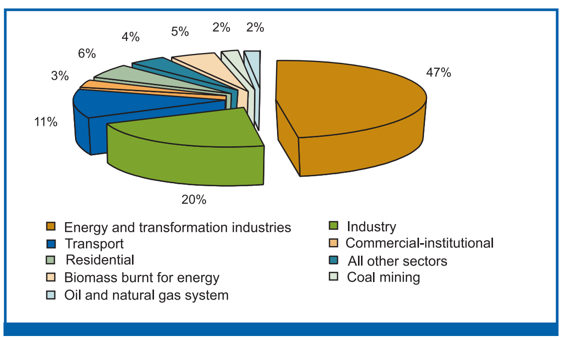


Figure 2.3: Relative GHG emissions from energy sector activities in 1994.

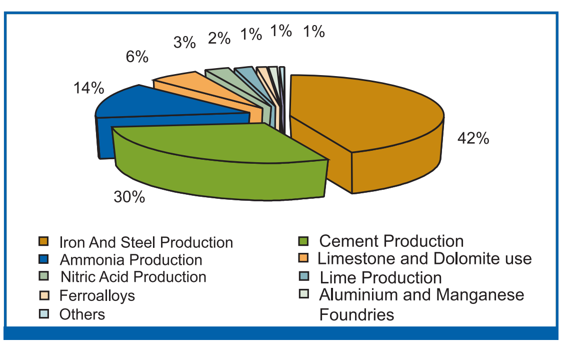


Figure 2.4: Relative GHG emissions from industrial processes in 1994.

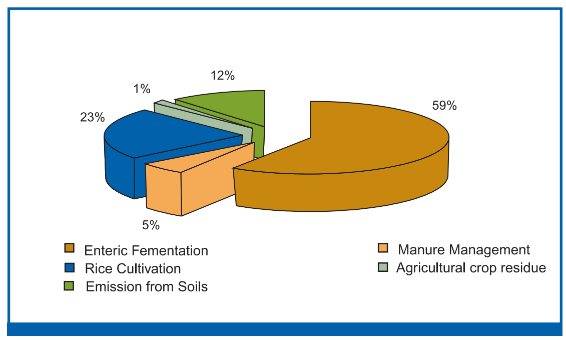


Figure 2.5: Relative GHG emissions from agriculture sector activities in 1994.

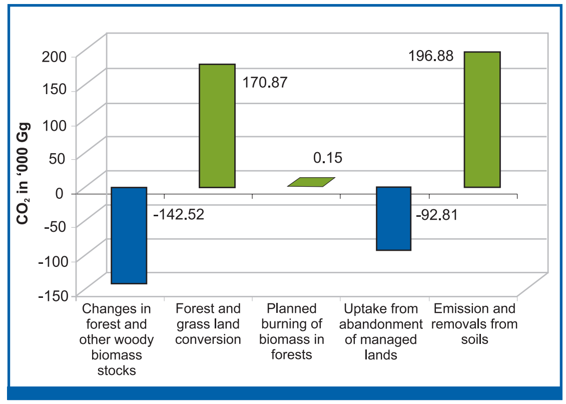


Figure 2.6: Relative GHG emissions from land use, land-use change and forestry sector activities in 1994.

GHG emissions from land use, land-use change and forestry (LULUCF) sector are an aggregation of emissions from changes in forests and other woody biomass stock, forest and grassland conversion, abandonment of managed lands and forest soils. The net CO_2-eq. emission from this sector was 14,292 Gg, which includes CO_2 emission and sequestration, as well as the emission of CH_4 and N_2O. The LULUCF sector emitted 14,142 Gg net CO_2 in 1994. Methane and N_2O emissions from this sector in terms of CO_2 equivalent, were 136.5 Gg CO_2-eq and 12.4 Gg CO_2-eq respectively.

The disposal of waste and the processes employed to treat these wastes give rise to GHG emissions. The two main sources of GHGs from the waste sector in India are municipal solid waste disposal and waste-water handling for commercial and domestic sectors. The collection of waste primarily takes place in large cities. In smaller cities and towns, waste decomposes under aerobic conditions and thus, methane is not emitted. Industrial waste-water in India is treated as per the mandate of the MoEF by large industrial units. The total GHGs emitted from the waste sector in 1994 was 23,233 Gg CO_2-eq, which is 2 per cent of the total national CO_2 equivalent emissions. Out of this, the major contribution was from municipal solid waste disposal activities (53 per cent), followed by domestic waste water, which contributed 32 per cent of the total GHG emissions from the sector (see Figure. 2.7).

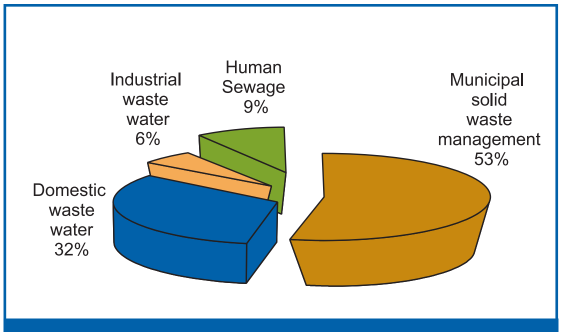


Figure 2.7: Relative GHG emission (in terms of CO_2 eq.) from waste disposal activities.
Note: MSW: Municipal Solid Waste, DMW: Domestic Waste-water, IWW: Industrial Waste Water and HS: Human Sewage.

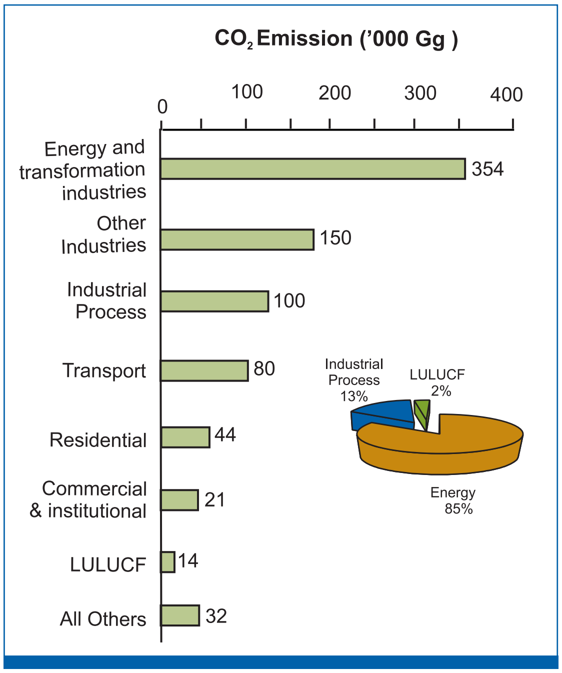


Figure 2.8: Relative CO_2 emissions from different sectors in 1994.

GAS BY GAS EMISSION INVENTORY

The following section details a gas-by-gas inventory of CO_2, CH_4 and N_2O emitted from the all energy, industrial processes, agriculture, LULUCF and waste sectors.

CO_2 emissions

CO_2 emissions from all energy, industrial processes and LULUCF activities constituted 65 per cent of the total GHG emissions in 1994. The relative contribution of the three activities to the net CO_2 released from India were 85 per cent, 13 per cent and 2 per cent respectively (Figure 2.8). CO_2 emissions from the energy sector include those from fossil fuel combustion. CO_2 emissions from biomass are treated as carbon-neutral at the combustion point. Change in biomass is accounted separately in the LULUCF sector. The industrial processes, which includes processes like iron and steel manufacturing and cement production are also major sources of CO_2 emission. The total CO_2 emissions from India in 1994 were 8,17,023 Gg and removals by sinks were around 23,533 Gg (Table 2.2).

Energy

Fossil fuels contributed 95 per cent of the total commercial energy consumed in India in 1994, with the remaining 5 per cent derived from sources like

Table 2.2: CO_2 emissions from India in 1994

GHG source and sink categories (Gg)	CO_2 (Emissions)	CO_2 (Removals)
Total CO_2	**817023**	**23533**
1. All Energy	**679470**	
Energy and transformation industries	353518	
Industry	149806	
Transport	79880	
Commercial/institutional	20509	
Residential	43794	
All other sectors	31963	
2. Industrial Processes	**99878**	
Cement production	30767	
Lime production	1901	
Lime stone and dolomite use	5751	
Soda ash use	273	
Ammonia production	14395	
Carbide production	302	
Iron and steel production	44445	
Ferro alloys production	1295	
Aluminium production	749	
3. Land use, Land-use change and Forestry	**37675**	**23533**
Changes in forest and other woody biomass stock		14252
Forest and grassland conversion	17987	
Uptake from abandonment of managed lands		9281
Emissions and removals from soils	19688	
4. Emissions from Bunker fuels #	**3373**	
Aviation	2880	
Navigation	493	

not included in national totals.

hydropower, nuclear and renewable energy (Planning Commission, 2002). Fossil fuels combustion contributed 91 per cent to total CO_2 emissions, with coal accounting for nearly 62 per cent.

Fossil fuel Combustion

During fossil fuel combustion, the carbon stored is emitted almost entirely as CO_2. The amount of carbon in fuels per unit of energy content varies significantly by fuel type for example coal contains the highest amount of carbon per unit of energy, while petroleum products in comparison have about 25 per cent less carbon than coal and natural gas about 45 per cent less.

In India, domestic coal is the main energy source. Coal contributed 62 per cent to the total CO_2 emissions in 1994. In comparison, petroleum products contributed 31 per cent and natural gas seven per cent.

The power sector is the highest contributor to Indian GHG emissions.

Keeping in view the importance of coal in the Indian energy system, and the fact that there is a wide variation in the ash content, moisture content and petrographic makeup of Indian coal, it is vital to estimate the Net Calorific Values (NCVs) and Carbon Emission Factors (CEF) used for estimating the CO_2 emission due to coal combustion under indigenous conditions. In India the coal is classified in three main categories — coking, non-coking and lignite. The NCV for each has been estimated separately, rather than assuming the identical average values for each category. The NCV values of the coals were derived from the Gross Calorific Value (GCV) of the fuel and its available hydrogen content. Both these parameters vary with the type, grade and maturity (rank) of coal.

Data on proximate, ultimate and heat value of different types of coal were collected from primary sources and secondary sources such as technical reports of Central Fuel Research Institute, a premier institute in India researching on coal for many decades. The analysis used the data collected over the past one and a half decades. Carbon content of the different coals – were measured on – a dry mineral matter free basis (dmmf) by taking into consideration the moisture contents and Gross Calorific Value (GCV). For non-coking coal, data were segregated on the basis of major coalfields, like Eastern coalfields, Western coalfields, South Eastern Coalfields, Central Coalfields. The NCV was calculated using the formula, NCV= GCV- 53 x H, where H is the available hydrogen. GCV and hence NCV vary with type and grade of coal and depend on the maturity (rank).

Ash and moisture contents of coal have significant influence on the NCV estimates. The internationally accepted norm of estimating NCV at 96 per cent moisture level of coal, called capacity moisture, was used in the present estimates. The ratio of Carbon to

Table 2.3: India-specific CO_2 emission coefficients.

	India-specific	
	NCV	**CEF**
	TJ/Kt	t CO_2/TJ
Coking coal	24.18±0.3	25.53
Non-coking coal	19.63±0.4	26.13
Lignite	9.69±0.4	28.95

heat content (NCV) was computed to arrive at the CEF. The NCVs used in the Indian estimates is given in Table 2.3.

In order to estimate CO_2 emissions from the burning of petroleum and natural gas, the IPCC default emission coefficients were used. Time and resource limitations did not permit the measurements to be carried out for refineries that convert crude to refined products. In the case of petroleum products and natural gas, the use of default emissions would be fairly accurate due to relatively low variation in quality of these fuels across the globe, as compared to coal. The future refinements of inventory estimations would consider specific measurements to assess the CO_2 emission factors from petroleum as well as refined products, such as liquefied petroleum gas, gasoline, naphtha, jet kerosene, other kerosene, diesel oil, residual fuel oil, lubricants and other oils.

CO_2 emissions from fossil fuel combustion in various sectors are presented next.

Energy and Transformation Industries

CO_2 emissions from the energy and transformation industries mainly include the power generation and petroleum refining industries. These sectors together emitted 3,53,518 Gg of CO_2 in 1994.

Industry

CO_2 emissions from the industry sector are estimated by taking into account emissions from paper, sugar, cement, iron and steel, textile, bricks, fertilizer, chemical, aluminium, ferroalloys, non-ferrous, food and beverages, leather and tannery, jute, plastic, mining and quarrying, rubber, and all other industries. Coal and petroleum oil products are used in these industries as energy sources in substantial quantities. The total CO_2 emitted from this sector in 1994 was 1,49,806 Gg.

Commercial

End-use activities like cooking, lighting, space heating, space cooling, refrigeration and pumping characterize the commercial sector. The fuels consumed by the commercial sector are electricity (for lighting, heating, cooling, and pumping), LPG (for cooking), kerosene (for lighting and cooking), diesel (for generating power for pumping and lighting), coal,

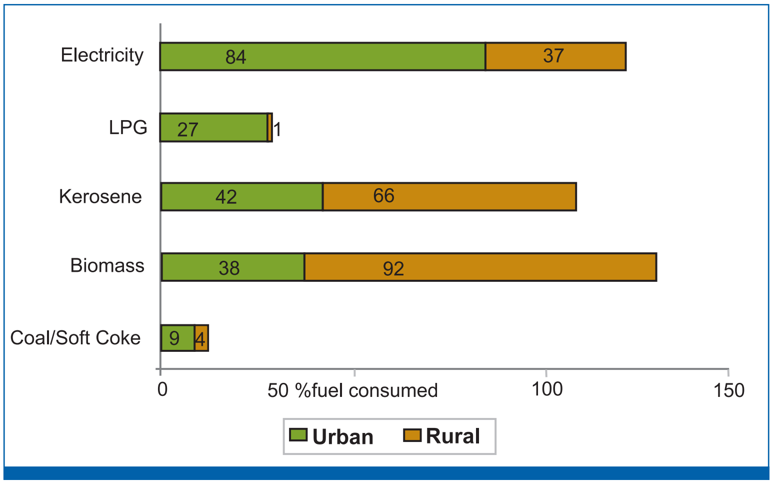


Figure 2.9: Share of fuels for cooking and lighting in rural and urban households.
Source: *Fifty-fourth National Sample Survey conducted by National Sample Survey Organization, 1998-1999.*

charcoal and fuel wood (for cooking). The total CO_2 emission from this sector in 1994 was 2,05,09 Gg.

Residential

Energy consumed in the domestic or the residential sector is primarily for cooking, lighting, heating and household appliances. The energy ladder for residential cooking in India follows the classic pattern vis-à-vis income, moving from the bottom-rung biomass (dung cakes, crop residues and fuel wood) to coal, kerosene, LPG and electricity. There are significant urban-rural differences in the energy profile of households, in terms of supply as well as consumption. Figure 2.9 gives the share of various fuels for cooking and lighting needs in Indian urban and rural households. The total CO_2 emission from this sector in 1994 was 4,37,94 Gg. This excludes CO_2 emission from biomass burning, since biomass is considered to be carbon neutral.

Improved *chullah.*

Transport

Another major sector contributing to GHG emissions is transportation, which includes road, rail, aviation and navigation. The total CO_2 emissions from this sector in 1994 were 79,880 Gg. Among transport sub-sectors, road transport is the main source of CO_2 emissions and accounted for nearly 90 per cent of the total transport sector emissions in 1994. Road transport is characterized by heterogeneous gasoline-fuelled light vehicles and diesel-fuelled heavier vehicles. According to the survey by the Indian Market Research Bureau on behalf of the Ministry of Petroleum and Natural Gas (MoPNG, 1998), the transport sector consumed nearly all (98.3 per cent) of gasoline in the country (see Figure 2.10 and Table 2.4). The share of vehicle

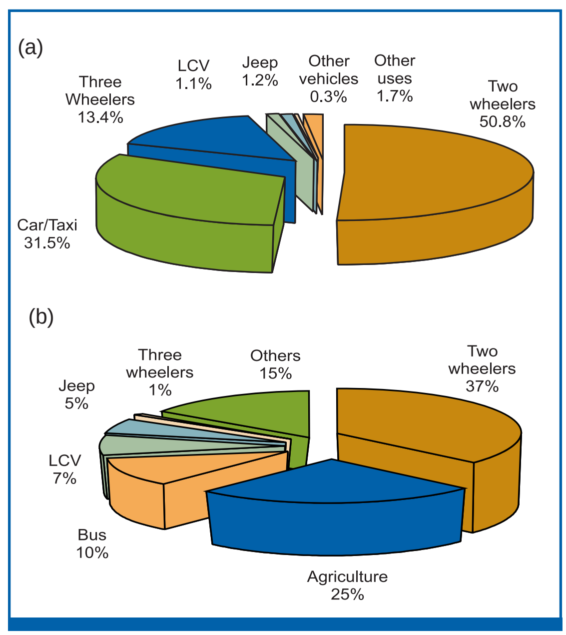


Figure 2.10: All-India end-use consumption of (a) gasoline and (b) diesel use in the transport sector.
Source: Ministry of Petroleum and Natural Gas, Government of India, 2002.

Table 2.4: Share of diesel and gasoline demand from retail outlets in various sectors.

End-use Segment	(%)
DIESEL	
1. Road Transport	
Car / Taxi	4.8
Jeep	5.2
Three-wheeler	1.2
Truck	34.7
LCV	6.7
Bus	9.2
Sub-Total	**61.8**
2. Agriculture	
Tractor	14.3
Pump set	5.2
Tiller/Thresher/Harvester	4.0
Sub - Total	**23.5**
3. Others	
Power generation	7.8
Industrial applications	3.0
Others / Miscellaneous	3.9
Sub-Total	**14.7**
Total	**100.0**
GASOLINE	
1. Road Transport Sector	
Two-wheelers	50.8
Three-wheelers	13.4
Car / Taxi	31.5
LCV	1.1
Jeep	1.2
Other Vehicles	0.3
Sub-total	98.3
2. Other uses	
Truck	0.1
Tractor	0.4
Pump set	0.2
Power	0.3
Others	0.7
Sub-total	1.7
Total	**100.0**

Source: MoPNG (1998), All India Survey of Gasoline and Diesel Consumption. A survey conducted by the Indian Market Research Bureau for the Ministry of Petroleum and Natural Gas, Government of India, New Delhi.

categories in gasoline consumption was two-wheelers (50.8 per cent), car/taxi (31.5 per cent) and three-wheelers (13.4 per cent).

Diesel is consumed in both private and public modes of transport (trucks, buses, jeeps, cars/taxis, etc.), as well as in agriculture (tractors, irrigation pumps, etc.). The all-India survey (MoPNG, 1998) indicated that 61.8 per cent of the diesel sold through the network of retail outlets was consumed by road transport. Shares of different end-uses in diesel and gasoline consumption are detailed in Table 2.4 and the consumption in Figure 2.11.

Automotive exhaust emissions are amongst the major sources of toxic pollutants, besides producing GHG emissions like CO_2, CH_4 and N_2O. The vehicular emissions norms, first introduced in India in 1991-1992, were focused on reducing the toxic pollutants. The norms were subsequently upgraded in 1996 and 2000. Presently, the emission norms equivalent to Euro — I prevail in the entire country, and Euro — II in the metropolitan cities. The Government of India has made significant policy interventions, including

The technology-level activity data for the road transport sector requires refinement.

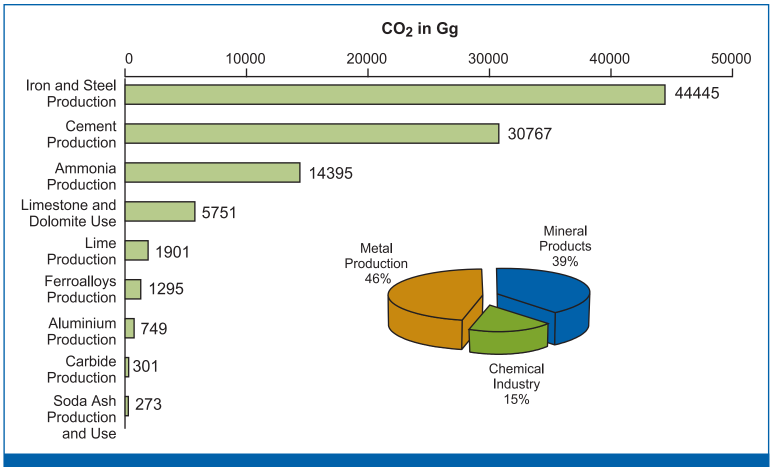


Fig. 2.11: Relative emission of CO_2 from various industrial processes in India in 1994. Others include CO_2 emissions from soda ash and carbide productions.

Table 2.5: Road Map for New Vehicles.

Coverage	Passenger Cars, light commercial vehicles & heavy duty diesel vehicles!	2 and 3 wheelers
All-India	Bharat Stage II * - 1.4.2005 EURO III Equivalent - 1.4.2010	Bharat Stage II - 1.4.2005
111 major cities (Delhi / NCR, Mumbai, Kolkata, Chennai, Bangalore, Hyderabad, Ahmedabad, Pune, Surat, Kanpur & Agra)	Bharat Stage II - 1.4.2003 EURO III Equivalent - 1.4.2005 EURO IV Equivalent - 1.4.2010	Bharat Stage III + - Preferably from 1.4.2008 But not later than 1.4.2010

* EURO II equivalent Indian vehicular emissions norms
+ To be reviewed in 2006 for enhanced implementation
! Bharat Stage II norms to come into force for two wheelers and 3 wheelers manufactured on or after 1.4.2005

Source: Auto Fuel Policy, Ministry of Petroleum & Natural Gas, Government of India, New Delhi, October 2003.

continuous improvements in the emissions norms to alleviate the air quality in the urban centres in the wake of rapidly growing vehicular population. The recent years have witnessed a phenomenal growth in road transport vehicles (see Table 2.5). This increasing trend in vehicle population is expected to continue, with rising incomes and enhanced vehicular choices before the consumers. The emissions of local pollutants in urban centres have therefore, continued to grow along with the rising GHG emissions.

The deterioration in urban air quality led to several response measures, like the introduction of CNG vehicles, improvement in auto fuel quality and enhancement of road infrastructure. The Government of India announced the Auto Fuel Policy in 2003, which comprehensively addresses the issues of vehicular emissions, vehicular technologies and the provision of cleaner auto fuels in a cost-efficient manner while ensuring the security of fuel supply. The policy includes the road map for reduction in emission norms for new vehicles (Table 2.5). Besides proposing the enhanced quality of liquid fuels, the policy encourages the use of CNG/LNG in the cities affected by high vehicular pollution to enable the vehicle owners a wider choice of fuel and technology. The policy envisages the accelerated development of alternate technologies, like battery and fuel cell-powered vehicles and a comprehensive programme for research and development support and other measures for zero emissions vehicles. The implementation of the Auto Fuel Policy would accrue significant improvement in local air quality and also contribute to the reduction in emissions of GHG.

The 1994 emissions inventory assessment, had to take into account a mix of vehicle technologies that was distinctly different from the present vehicular stock. The emission coefficients for different types of vehicle using gasoline and diesel were estimated by assessing emissions from the vehicles of 1994 vintage, a mix of vehicles and road conditions similar to those in 1994 (Table 2.6).

Table 2.6: India-specific CO_2 emission coefficients developed for the road transport sector.

Categories	t CO_2/TJ
Gasoline	
2W/3W	43.9 ± 7.3
Car/Taxi	61.5 ± 4.0
Diesel Oil	
MCV/HCV	71.4 ± 0.55
LCV	71.4 ± 0.5

All other sectors

All other sectors cover those areas of the economy that are not included elsewhere for the purpose of accounting energy consumption. The total emission of CO_2 from this sector in 1994 is estimated to be 31,963 Gg.

Industrial Processes

Emissions are produced as a by-product of many non-energy related activities, such as industrial processes that chemically transform raw materials. The major industrial processes that emit CO_2, include cement production, iron and steel production, lime production, lime stone and dolomite use, soda ash manufacture and consumption, ammonia production, ferroalloys production, aluminium and manganese foundries, and calcium carbide production.

The total CO_2 emissions from the industrial processes in India were estimated at 99,878 Gg in 1994. Cement and iron and steel manufacturing processes were the key source categories for CO_2 emissions in the industrial processes sector. These two contributed nearly three-quarters, i.e., about 75,212 Gg CO_2. Emissions from these sectors were estimated following the IPCC Tier-II methodology. The rest of the emissions from ammonia production, limestone and dolomite use, production of lime, ferroalloys, manufacturing, aluminium and manganese foundries and others were estimated using the IPCC Tier-I methodology. The relative emission of CO_2 from the industrial process sector is shown in Figure 2.11. CO_2 emissions from metal production had a dominant share at 46 per cent, the production of mineral products contributed 39 per cent and the remaining were contributed by the chemical industry.

Cement Manufacture

Cement production in India has risen from about 45 Mt in 1990 to about 106 Mt in 2001 (CMA, 2002), however the per capita cement consumption in India remains among the lowest in the world (100 kg per capita as compared to a world average of 267 kg per capita).

In view of the significant contribution of CO_2 emission from cement manufacturing process, an indigenous CO_2 emission coefficient was developed (Box 2.1). Clinker samples were collected from various plants of different technologies and sizes. Based on the analysis of this data, the average CO_2 emission coefficient for cement production process in 1994 was estimated to be 0.537 tonne CO_2 per tonne of clinker for India. Using this, the total CO_2 emitted in the country in the year 1994, was estimated to be 30,767 Gg.

Lime production

Lime is used in the steel and construction industry, pulp and paper manufacturing, sugar production, the fertilizer industry, and for water and sewage treatment plants. It is manufactured by heating limestone, mostly $CaCO_3$, in kilns, producing calcium oxide (CaO) and CO_2, which is normally emitted into the atmosphere. The lime-producing sector in India consists of unconsolidated, small-scale enterprises. The main constraint for GHG inventory estimation for this sector is the paucity of data. The industries considered as 'high lime industries', not using limestone as flux, are sugar and paper, and emissions from lime production in these industries have been accounted for under this sector (Indian Mineral Year Book, 1995). The lime content (or CaO) in limestone generally varies between 40 per cent and 50 per cent. As all varieties of limestone are used in lime kilns, the average lime content in limestone, for the purpose of assessing the quantity of lime produced, has been estimated at 45 per cent. Under these assumptions, the amount of CO_2 emitted in 1994 from limestone production is estimated to be 1901 Gg.

Limestone and dolomite use

Limestone ($CaCO_3$) and dolomite ($Ca\,Mg\,(CO_3)_2$) are basic raw materials used by a wide variety of industries, including construction, agriculture, chemicals and metallurgical industries. For example,

Box 2.1: Process for determination of CO_2 emission coefficient

Carbon dioxide emissions in the cement manufacturing process originate from the calcination of limestone at very high temperatures. The CO_2 emission factor is estimated from this process by using CaO content and CKD (Clinker-to-Dust) loss. Magnesium carbonate ($MgCO_3$) present in limestone also liberates CO_2 during calcination. Therefore the MgO content of the limestone used also needs to be estimated. The CaO content in Indian clinkers normally varies from 62 to 66 per cent. The CaO content from each plant varies because the source materials are different. The MgO content, in Indian clinkers, varies from 0.5 to 6.0 per cent. This value is dependent on the raw material source. Though IPCC considers a default cement kiln dust (CKD) loss at 2.0 per cent of clinker produced, however, due to the stringent control on particle emission by Indian pollution control boards (PCBs), most of the cement kilns are provided with appropriate pollution control measures to keep the CKD within the prescribed limits of as low as 0.03 per cent.

For estimating the CO_2 emission coefficient due to the manufacturing of cement, clinker samples were collected from various plants of different technologies and analyzed using the X-Ray Fluorescence method (XRF) for CaO and MgO for on-line process control. Hourly cement samples were pooled in each shift, and analyzed using the wet method for CaO and MgO contents. The yearly average values of CaO and MgO contents were then used to estimate the emission factor. Using these methods the emission factor, which is a product of CO_2, generated from CaO and MgO, the content of the clinker and the correction factor for CKD losses from the plant was estimated by using the equation:

Emission factor = (Fraction of CaO content in clinker * 0.7848 + Fraction of MgO content in clinker * 1.0915) *(1+ CKD losses from the plant)

The average CaO and MgO content of the raw material was found to be 64.7 per cent and 2.01 per cent respectively in 2001-2002 which have been actually maintained more or less at the same level, right from inception. However, as the technology of production has changed from the wet to semi-wet, to the dry process, the CKD losses have reduced from a level of 2 per cent in 1980, to an average of 0.025 in 2001-2002. By interpolation between these periods with an average of 1.0 per cent of the capacities created from 1980 up to 1985; 0.5 per cent of the capacities created from 1985 to 1990; 0.05 of the capacities created from 1990 to 1995; and 0.05 per cent of the capacities created from 1995 to 2000; and 0.025 per cent till now, the weighted average CKD loss can be calculated. Based on this assumption, the CKD loss for 1994 will be 1.38 per cent. Using this data, it was estimated that the weighted average emission factor for the cement industry in India is in the range of 0.534 to 0.539 tonnes per tonne of clinker for large cement manufacturers, for the year 1994.

limestone is used in the case of iron ore, where limestone heated in a blast furnace reacts with the impurities in the iron ore and fuels, generating CO_2 as a by-product. Limestone is also used in refractories.

CO_2 emissions were estimated for major manufacturers, which account for 75 per cent of the total dolomite consumption. The activity data (Indian Mineral Year Books, 1982-2001) used for the estimation of emissions is the quantity of limestone and dolomite used annually. The estimates exclude the use of limestone by cement and high lime industries such as sugar, paper and lime kilns, as emissions from these sectors have been reported under 'lime production'. The total CO_2 emitted due to limestone and dolomite use in 1994 is estimated at 5,751 Gg.

Soda ash use

Soda ash has diverse applications in industries like glass, soap and detergents, textiles and food. Since the data for specific application areas is not reliable, the uncertainty associated with the emissions estimates for this sector is likely to be very high. The total CO_2 emitted in 1994 from soda ash use is estimated at 273 Gg.

Ammonia production

The majority of ammonia production takes place in fertilizer manufacturing units in India. The Tier-I approach was adopted to estimate emissions from this sub category, using an average of IPCC default emission factors. The total CO_2 released due to ammonia production is 14,395 Gg.

Carbide production

CO_2 is produced during the manufacturing process of calcium carbide and silicon carbide. Calcium carbide is made by heating calcium carbonate and subsequently reducing CaO with carbon derived from petrol coke. Both these steps lead to the emission of CO_2. The most important application of calcium carbide is the production of acetylene. CO_2 is released in the production of silicon carbide as a by-product of a reaction between quartz and carbon.

Emissions from the three stages of calcium carbide and use, namely, the use of coal as a reducing agent, the use of limestone and use of calcium carbide for different applications were estimated. IPCC Tier-I methodology and IPCC default emission factors have been applied for all three stages. The total CO_2 emitted from this sector in 1994 was 302 Gg.

Iron and steel production

The iron and steel production process contributed a little more than half the CO_2 emissions from the industrial processes sector in 1994. Process emission of CO_2 in an iron and steel plant takes place during coke oxidation. Additional emissions occur as the limestone flux gives off CO_2 during reduction of pig iron in the blast furnace, but this source is covered as emissions from the limestone use. There are two processes of production that are common in India, namely integrated steel plants (technically defined as blast furnace open hearth and basic oxygen furnace), and mini steel plants scrap or sponge iron based Electric Arc Furnaces (EAF).

The coal consumption data in this sector is accessed directly from the consumption end (SAIL, 1984, 1986, 1988, 1990, 1992, 1994, 1996, 1998, 2000). Emissions from this sub-sector can be ascribed to three distinct sources from the use of coal as reducing agents in the blast furnace, from the production of steel from pig iron and from graphite electrodes in EAF.

Tier-II methodology was used to estimate emissions from the production of steel from pig iron. Emissions factors for reducing agents based on NCV of coal (of 2.26 t-C/t coal) and communication with different EAF units in the country (14 kg C/t) was used. Thus, the total CO_2 released due to manufacturing of iron and steel in India in 1994 was estimated to be 44,445 Gg.

Ferroalloys production

In ferroalloys production, raw ore, coke and slagging materials are smelted together under high temperature. During the smelting process, a reduction reaction takes place. Carbon captures the oxygen from metal oxides to form CO while the ores are reduced to molten base metals. The component metals are then combined in the solution. In covered arc furnaces, the primary emissions are entirely CO, however, it is assumed that all CO is converted into CO_2 within days afterwards.

The activity data is ideally, the quantity of the reducing agent consumed or alternatively, it is the quantity of ferroalloys produced (SAIL, 2000; IFAPA, 2000). In the present calculations, the annual production volumes of the different types of ferroalloys were used as activity data. Using IPCC default emissions factors for the various types of ferroalloys produced in the country, the total CO_2 emission estimated due to smelting of ores was 1,295 Gg.

Aluminium production

Aluminium is produced in two steps. First, the bauxite is ground, purified and calcinated to produce alumina. It is then electrically reduced to aluminium by smelting. CO_2 is emitted during the electrolysis of alumina to aluminium using a graphite electrode as the source of carbon for reduction.

To estimate CO_2 emissions from the production of aluminium, the activity data used is the quantity of aluminium produced annually. Data on aluminium production (MoSM, 1988-1999) has been obtained according to the technology used in each manufacturing unit. IPCC default emission factors for the Soderberg and pre-backed anode processes have been applied to estimate emissions from this industry. Aggregate production from all manufacturing units has been used to estimate emissions at the national level. The total CO_2 emitted from aluminium production in 1994 was 749 Gg.

Land use, land-use change and forestry

In this sector, the fundamental basis for GHG inventory estimates rests upon the fact that the flux of CO_2 to or from the atmosphere is assumed to be equal to the changes in carbon stocks in existing biomass and soils, and that changes in carbon stocks can be estimated by first establishing rates of change in land use and the practices used, to bring about the change (e.g., burning, clear cutting and selective felling etc.). The IPCC approach involves four estimates of carbon stock changes due to; (a) changes in forest and other woody biomass stocks; (b) forest and grassland conversion; (c) uptake from abandonment of managed lands; and (d) emissions and removals from soils.

The methods adopted and quality of data used for the present Indian inventory falls into the Tier-II category. All activity data and most emission/sequestration factors used are from national sources. Some of the data used is from field measurements and forest inventory sources, normally associated with Tier-III. India presently does not have a National Forestry Inventory (NFI) Programme which undertakes repeated measurements from the same plots for estimating rates of changes for several parameters, such as average annual biomass growth rate, changes in soil carbon density and growing stock of biomass.

The area under forests (including tree plantations) in India was estimated to be 63.33 Mha in 1994. The forest area in India is categorized into 22 strata according to the Forest Survey of India (FSI), based on the dominant tree species. The forests which could not be categorized as any other forest strata, are included under 'Miscellaneous Forest', which accounts for 64

Land use, land-use change.

per cent of the forest area. The distribution of forests, excluding miscellaneous forests, is dominated by *Shorea robusta* (Sal) and *Tectona grandis* (Teak) species occupying 12 per cent and 10 per cent of the total forest area, respectively. The area under different forest type is shown in Figure 2.12.

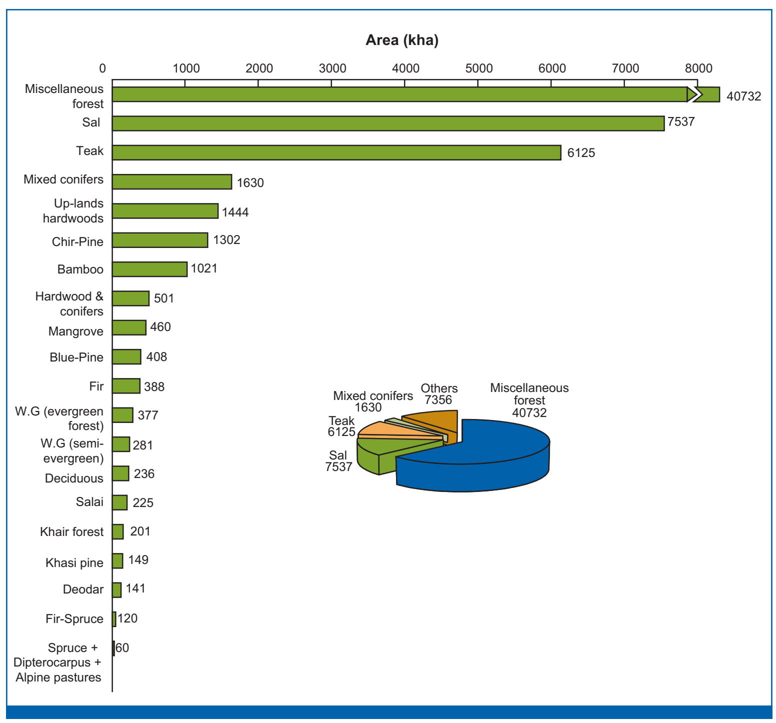


Fig. 2.12: Area under different forest types in India (miscellaneous forests are not included).
Source: *FSI, 1993, 1994 and 1995. State of Forest Report, Forest Survey of India, Dehradun.*

Changes in forest and other woody biomass stock

The CO_2 emission from changes in forest and other woody biomass stocks is the result of net changes in carbon stock from the growth in biomass and losses from extraction of biomass. The total carbon uptake in forests is estimated first by categorizing forest area into different strata, then by estimating the area under each of the forest stratum and by obtaining an average annual growth rate from the literature and field measurements. Thus, the total carbon uptake is estimated by multiplying the area under each forest stratum and average annual biomass increment and aggregating the overall 22 forest strata. The annual biomass increment was estimated to be 77.0 Tg-C and the total carbon release due to commercial extraction of timber and traditional wood use is 73.2 Tg-C. The net CO_2 uptake in 1994 from changes in forest and other woody biomass stock was 14.2 Tg-CO_2, or 14,252 Gg

Forest and grassland conversion

The annual loss of biomass due to forest conversion was estimated to be 12.09 Tg, in 1994. In India, the quantity of biomass lost due to on-sit*e* burning is due to the conversion of forests to agriculture on account of shifting cultivation mainly in the north-eastern region. The woody biomass left for decay after conversion is assumed to be insignificant or nil, as all woody biomass is likely to be collected and used as fuelwood by the local communities. The total quantity of carbon dioxide released from on-site and off-site burning and biomass left for decay is estimated to be 17,987 Gg.

Uptake from abandonment of managed lands

The total CO_2 uptake is estimated by multiplying the area of abandoned land and the mean annual biomass growth rate. Thus, the total CO_2 uptake in managed land that is abandoned and subjected to regeneration is estimated to be 9281 Gg. Area left abandoned for over 20 years is assumed to be nil, as no such lands may exist due to the following reasons: (a) if the land has acquired a tree crown of over 10 per cent, it would have been classified as forest and included under forests; (b) land may have been converted to cropland or non-agricultural lands; and (c) in a 20-year period, the land may have completely degraded and turned into barren land with no above ground biomass growth.

Emission and removals from soils

The sources and sinks of CO_2 in soils are associated with changes in the amount of organic carbon stored in soils. The release of CO_2 also occurs from inorganic sources, either from naturally occurring carbonate minerals, or from applied lime. Therefore, estimations under this category take into account: (a) estimates of change in soil carbon from mineral soils; (b) CO_2 emissions from intensively managed organic soils; and (c) CO_2 emission due to liming of agricultural soils. Change in soil carbon from mineral soils due to change in land management or use is estimated by taking into account the total land area categorized into 22 forest strata and seven other land use systems[3] covering cropland, fallow land, non-agricultural land, etc. The area under these forest and non-forest land-use systems is estimated for 1984 and 1994 (http://planningcomission.nic.in/data/dataf.htm). Soil carbon density (tC/ha) in the top 30 cm for each land-use system is obtained from literature as well as field measurements. The total soil carbon stock is estimated for all land-use systems for 1984 and 1994. The difference in carbon stock averaged over 10-year period is estimated as net emission of CO_2 for 1994. Following this methodology, the net change in soil carbon stock in mineral soils averaged over a 10-year period (1984 to 1994) for 1994 is estimated to be 19.68 Tg CO_2. CO_2 emissions from intensively managed organic soils could not be estimated as the area under organic soils, subjected to change is marginal or zero due to the fact that area under organic soil is very limited. Further, such lands may have been converted long before 1994, or are likely to be under protection, and data available on changes, if any is limited. For example, there is no data available on lime application to soil at the national level. Lime application is not prevalent on any significant scale in India and is thus not considered. Therefore, CO_2 emissions from liming ($CaCO_3$) of

[3] The soil carbon for forest types is based on literature for the 22 forest strata compiled by Forest Research Institute of India and carbon density (t C/ha) for the seven non-forest land use categories was deduced from field soil sampling and laboratory measurements up to a depth of 30 cm.

agricultural soils is not estimated. Considering all these aspects, the net CO_2 emission from agriculturally impacted soils (land-use management) is estimated to be 19,788 Gg.

Considering gross CO_2 emissions and removals for the land use, land-use change and forestry sector, the net CO_2 emissions, for the inventory year 1994 is estimated to be 14,142 Gg of CO_2, which is less than 2 per cent of national CO_2 emissions.

Methane (CH_4) emissions

Atmospheric methane is an integral component of the greenhouse effect, second only to CO_2 as a contributor to the total anthropogenic GHG warming in the atmosphere. The overall contribution of CH_4 to global warming is 21 times more effective at trapping heat in the atmosphere with respect to CO_2 (IPCC, 1996). From the pre-industrial times to the present, the concentration of CH_4 in the atmosphere has increased 151 times (IPCC, 2001a). The main factors contributing to this increase are: proliferation in activities related to exhaustive mining of coal for energy use; emissions due to handling of oil and natural gas systems; dependence on products derived from livestock; waste management; increased production of rice to meet the demand of the growing population; on-site burning of crop residue for preparing the fields for the next cropping; cycle management of solid waste; and waste water from the domestic and the industrial sectors. In the following section, the CH_4 emissions in India from these sources are presented in Table 2.7.

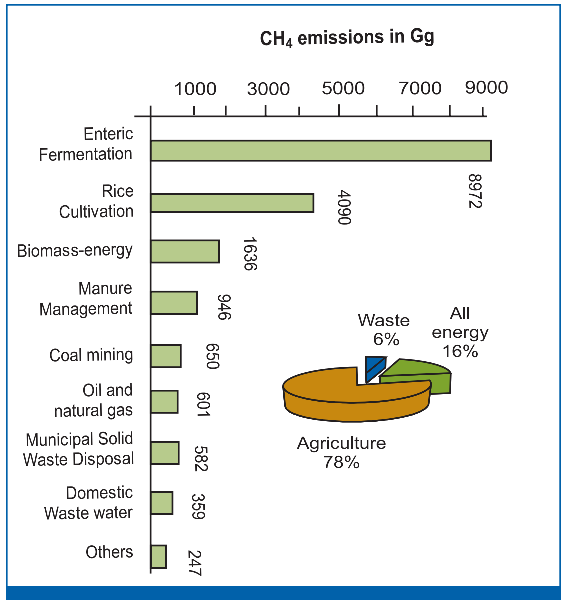


Figure 2.13: Relative methane emission from different anthropogenic activities in 1994.

Table 2.7: National Methane emissions in 1994.

Total national CH_4 Emission in Gg	18083
1. All Energy	**2896**
Transport	9
Fuel combustion	
Biomass burnt for energy	1636
Fugitive Fuel Emission	
Oil and natural gas system	601
Coal mining	650
2. Industrial Processes	**2**
Production of carbon black and styrene	2
3. Agriculture	**14175**
Enteric fermentation	8972
Manure management	946
Rice cultivation	4090
Agricultural crop residue	167
4. Land use, Land-use change and Forestry	**6.5**
Trace gases from biomass burning	6.5
5. Waste	**1003**
Municipal solid waste disposal	582
Domestic waste water	359
Industrial waste water	62

The total national CH_4 emission in 1994 from the above-mentioned sources was 18,083 Gg. The agriculture sector dominated with 78 per cent of the total national CH_4 emissions, within which emissions due to enteric fermentation (8,972 Gg) and rice cultivation (4,090 Gg) were the highest. Of such emissions 16 per cent came from the energy systems comprising emissions due to biomass burning, coal mining and handling and flaring of natural gas systems. Waste disposal activities contributed about 6 per cent of the total CH_4. Methane emissions from the LULUCF sector were minor in nature, mainly due to the burning of biomass in forests. Similarly, the contribution of the industrial process sector to the total national CH_4 emissions is miniscule in comparison with other sources and is only around 2 Gg. The sectoral distributions of CH_4 emissions from India in 1994 are shown in Figure 2.13.

Energy

Biomass burning

The combustion of biomass leads to emission of methane and other trace gases. In India, about 60 per cent of households depend on traditional sources of energy, like fuelwood, dung cake and crop residue for meeting their cooking and heating needs (Planning Commission, 2002). Using IPCC default emission coefficients, the amount of CH_4 released in 1994 was 1,636 Gg. High uncertainties are associated with this estimate as biomass activity data are based only on small surveys carried out at different points of time. More exhaustive surveys are required to establish the quantity of various types of biomass used in the country.

Coal mining

Methane trapped in the coal seams during its formation million of years ago, is released when it is mined. The quantity of methane released depends primarily on the depth of and type of coal that is being mined. India's total coal resources are estimated at 206 Bt up to a depth of 1200 metres. The recoverable coal reserves, estimated at 75 Bt are capable of supplying coal for over 250 years at current levels of production, or more than 125 years at double the existing rate of production, which may very likely be the demand of coal a decade later. Lignite reserves in the country have been estimated at around 34,763 Mt out of which 30,275 Mt are recoverable. About 425 mines are the major producers of coal in India, contributing approximately 90 percent of national coal production. The production programme from the existing coal producers includes both opencast and underground methods of mining.

Based on mine-specific rate of emission of methane, all the underground coal mines in India have been categorized into Degree I, Degree II and Degree III (see Box 2.2 and Figure 2.14) by the Directorate General of Mines Safety (DGMS, 1967). There is no such classification for opencast coal mines, as the associated methane emission is not very high and emitted gas immediately diffuses into the atmosphere.

Considering the vast deposits of coal with varying degrees of gas content, it was deemed necessary to estimate the CH_4 emission coefficients representing the indigenous conditions. Extensive field investigations were carried out, involving the measurement of velocity of air passing through the return airways separately in each ventilating district and in the main body, with the help of the

Box –2.2: Gassiness of Indian mines

Degree I: means a coal seam or part thereof within the precincts of a mine not being an opencast working, whether or not inflammable gas is actually detected in the general body of the air at any place in its workings below ground, or when the percentage of the inflammable gas, if and when detected, in such general body of air does not exceed 0.1 and the rate of emission of such gas does not exceed one cubic meter per tonne of coal produced.

Degree II: means a coal seam or part thereof within the precincts of a mine not being an opencast working in which the percentage of inflammable gas in the general body of air at any place in the workings of the seam is more than 0.1 or rate of emission of inflammable gas per tonne of coal produced exceeds one cubic meter but does not exceed ten cubic meters.

Degree III: means a coal seam or part thereof within the precincts of a mine not being an opencast working in which the rate of emission of inflammable gas per tonne of coal produced exceeds ten cubic meters.

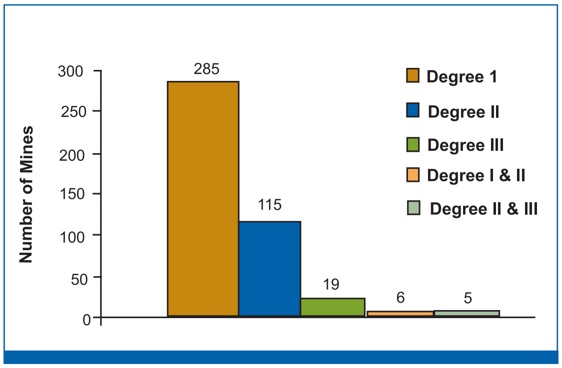


Figure 2.14: Number of mines in India according to their gassiness.

Von Anemometer. The cross-sectional area of each return airway was determined by multiplying the average width and height of the airway. The percentage of methane in the air samples collected in the return airway, and also in the general body air was determined using the Gas Chromatography technique

An alternative approach was taken to measure the CH_4 emission coefficient from opencast mining. Rectangular chambers were placed on the benches of opencast mines for a pre-determined period of time and methane percentage inside the chamber was determined by Gas Chromatography. The area of coal faces exposed earlier or freshly-exposed were also measured in the opencast mines to calculate methane flux. The emission measurements from post-mining activities were also taken. Also, the emission factors for coal-handling activities were determined for different categories.

Through the above measurements and collection of data on methane emission during mining and post mining activities, emission factors for opencast and under-ground mines were generated for Indian geologic and mining conditions (Table 2.8). Using these emission coefficients, the total CH_4 released in 1994 from Indian coalmines was estimated at 650 Gg.

Table 2.8: CH_4 emission coefficients derived for coal mining in India.

Type of mining	m^3 CH_4 /t coal mined
Underground mining	
During Mining	
degree 1	2.9
degree 2	13.1
degree 3	23.6
Post Mining	
degree 1	1.0
degree 2	2.2
degree 3	3.1
Surface Mining	
During mining	1.8
Post mining	0.2

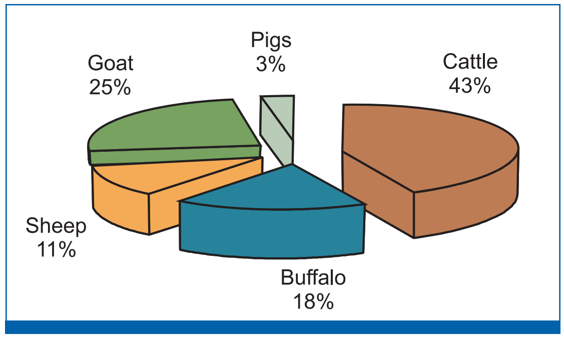
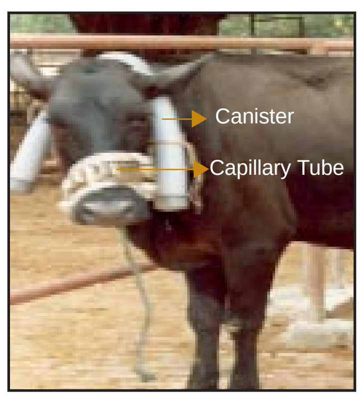


Figure 2.15: Distribution of Indian Livestock.

Agriculture

Enteric fermentation

In India, livestock rearing is an integral part of its culture, as well as for most 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 the major source of methane emissions (Figure 2.15). Traditional 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,



Methane measurements from enteric fermentation.

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, 1996). 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, CH_4 produced from this source in India is the highest amongst all agricultural sources, contributing about 55 per cent of the total CH_4 emissions. Out of this, the dairy cattle and buffaloes contribute to about 40 per cent.

Considering its key source category status, an attempt was made to estimate as well as measure the CH_4 emission coefficient for cattle. For this purpose, the cattle population has been divided into dairy and non-dairy categories, with sub classification into indigenous and cross-bred types for different age groups (MOA, 1997) (Box 2.3). CH_4 emission coefficients have been determined by three groups. The first is based on the IPCC Tier-II approach, the second on assimilation of published data on methane released from ruminants, and the third is based on a few measurements carried out using the Face Mask Technique as a part of the enabling activities carried out for the preparation of India's Initial National Communication. A summary of the emission factors is given in Table 2.9. It is clear that the indigenous varieties, whether cattle or buffalo have much lower emission coefficients than the cross-bred ones. This is mainly due to the difference in feed intake of the two. By taking a weighted average of emission factors

Box 2.3: Characterization of cattle and buffalo subgroups

Dairy Cattle

- High yield having calves once in a year (cross-bred)
- Low yield having calves once in a year (Indian)

Dairy Buffalo

- Lactating buffalo are classified in a single category i.e., Dairy Buffalo.

Non-dairy

For both Indigenous and Cross-bred cattle and buffalo

- Below one year but more than three months
- One to three years and one to two and a half years for cross-bred
- Adult

Table 2.9: CH_4 emission coefficient adopted for estimating CH_4 emission from Indian livestock

Category	g CH_4 per animal
Dairy cattle	
Indigenous	28±5
Cross-bred	43±5
Non-dairy cattle (indigenous)	
0-1 year	9±3
1-3 year	23±8
Adult	32±6
Non-dairy cattle (cross-bred)	
0-1 year	11±3
1-2 ½ year	26±5
Adult	33± 4
Dairy buffalo	50± 17
Non-dairy Buffalo	
0-1 year	8± 3
1-3 year	22± 6
Adult	44± 11

Collection of CH_4 sample from manure dump site.

produced for the various age categories of cattle and buffalo, the total CH_4 emitted from India due to enteric fermentation is estimated to be 8,972 Gg.

Manure management

The decomposition of organic animal waste in an anaerobic environment produces CH_4 and, therefore, the amount of CH_4 produced depends on how it is managed. The waste produced by non-ruminant animals in India are not collected; however those of cattle and buffalo are used for a variety of purposes. Usually, the waste of cattle is either sun dried as dung cakes for their use in rural cooking, or is stored for use as biogas. The methane produced from such systems is about 946 Gg.

Rice cultivation

Anaerobic decomposition of organic material in flooded rice fields produces CH_4, which escapes into the atmosphere primarily by diffusive transport through the rice plants during the growing season. There are large spatial and temporal variations of methane fluxes which occur due to different soil types, soil organic carbon and various agricultural practices such as choice of water management and cultivar, the application of organic amendments, the mineral fertilizer, and soil organic carbon.

Methane emission measurements from rice cultivation

In India, rice is cultivated under various water management options, depending on the availability of water across the country. In the mountainous regions, rice is grown in terraces created along the side of the mountains. In most of the northern plains and some parts of the eastern region, rice is cultivated by irrigating the fields intermittently or continuously, for a considerable period of time. In other parts of the country, however, rain-fed rice cultivation is predominant where water is only available in the fields during rains. Deep-water rice cultivation, with a water depth ranging from 50-100 cm. is also practiced in the coastal regions of West Bengal and Orissa. Methane flux measurements on a national scale in such representative water regimes have been made since 1991 under various campaigns using the Perspex box technique, whereby samples are collected and analyzed using gas chromatography. India has conducted three to four campaign mode measurements

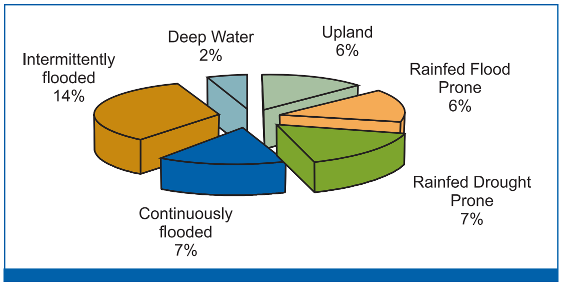


Figure 2.16: Distribution of area under rice cultivation in India.

to estimate methane emitted from various water regimes since 1991. The definition of water regimes have changed from campaign to campaign, and finally in 1996 in the IPCC revised guidelines for estimating national GHG emissions from anthropogenic sources. The total area under rice cultivation was categorized under different water regimes, namely, upland, rain fed drought and flood prone, continuously irrigated, irrigation with single or multiple aerations, and deep water (Figure 2.16). Most of these diverse water management systems are also practiced in most traditional rice-producing countries.

The seasonal integrated flux of CH_4 for ecosystems classified according to different water management practices have been averaged and integrated with earlier decadal emission data (measured since 1991) for soils without any organic amendments, and for low soil organic carbon (Box 2.4). Thus, new national methane emission coefficients were generated and is given in Table 2.10 The total CH_4 released from rice cultivation in 1994 is estimated to be 4,090 Gg.

Table 2.10: CH_4 emission coefficient for different water regimes.

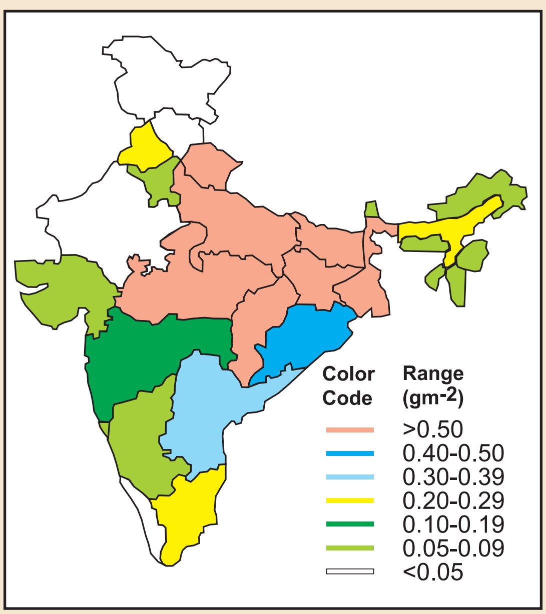
Water regime	Emission coefficient (gm^{-2})
Upland	0
Rain fed	
Flood prone	19 ± 6.0
Drought prone	7.0 ± 2.0
Continuously flooded	17.4 ± 4.0
Intermittently flooded	
Single aeration	6.6 ± 1.9
Multiple aeration	2.1 ± 1.5
Deep water	19.0 ± 6.0

Box 2.4: CH_4 measurement campaign in rice cultivation areas

Methodologies and types of emission factors used for estimating CH_4 emission from rice fields in India has undergone various changes since the 1st campaign in 1991 was launched to measure the CH_4 fluxes from this source. Based on the 1991 campaign observations, a CH_4 budget estimate was made for rain fed water logged areas, in the eastern, southern, northern and western region of India, the rest of the area was divided as deep water, irrigated and upland area. The emission factor was seasonally integrated over the entire cropping period. The 1995 IPCC guidelines indicated only three regimes namely, upland, intermittently flooded and upland rice. The emission factors were in terms of kg CH_4/ha/day. These water regimes were insufficient for representing the diverse water regimes prevalent in India and other south Asian countries. The revised IPCC guidelines (IPCC, 1996) had a much more detailed water regime consisting of upland and low land conditions, with low land further divided into rain-fed, irrigated and deep-water conditions. Each of these is again subdivided to represent the entire gamut of water flooding conditions in this region.

On site measurement of methane

Methane measurement campaigns have been carried out in India since 1991, and also under the aegis of India's Initial National Communication. The present campaign covered the rice growing regions of West Bengal, Orissa, Assam, Jharkhand, Tamil Nadu, Kerala, Andhra Pradesh and Delhi was made for Rabi 2002 and Kharif of 2003. Other than the water regime, the parameters that have been taken into account are the fertilizer doses, different rice cultivars, soil types, different soil organic carbon and different organic amendments applied.



State-wise distribution of emission coefficients determined through 2002-2003 CH_4 measurement campaign.

A static box or chamber technique was used at all sites over the entire paddy cropping seasons including fallow periods. Flux measurements were made, in the forenoon and afternoon on the same site twice a week. To reduce uncertainties in spatial variability within the cropping field, measurements using four channels/chambers for sampling were used. Samples at all sites were collected in glass vials or plastic syringes manually and CH_4 concentrations in the samples were determined using Gas chromatograph with flame ionization detector (FID) system and GC-Electron capture detector (ECD) respectively. All samples were calibrated against nationally/ internationally comparable standards and proficiency testing for methane were also carried out. The seasonally integrated flux (E_{sif}) were calculated by taking the daily mean of the flux data and integrating it over the whole cropping season from transplantation to harvest stage. Standard deviations from the daily mean flux were used to derive the minimum and maximum ranges of E_{sif}.

Burning of Agricultural crop residue

The burning of crop residue is not a net source of CO_2 as the CO_2 released into the atmosphere during burning is reabsorbed during the next growing season. However, burning of crop residue is a significant net source of CH_4 in addition to other trace gases. The amount of agricultural waste produced by a country depends on its crop management system. In India, the primary end-uses of crop residue are as animal fodder, industrial and domestic fuel, thatching, packaging, bedding, construction of walls/fences, and as green-manure and compost. The amount left is what is available for field burning, and only a fraction of this amount is actually subject to burning. This fraction is, in fact, highly uncertain and varies with local and regional climate, season, livestock distribution, availability of fuelwood, availability of fodder, weed infestation etc.

The crop residue is particularly burnt in the rice/ wheat growing regions of Punjab, Haryana, Uttaranchal, western Uttar Pradesh and Karnataka, where with the introduction of mechanized harvesters, the collection and disposal of residues is a practical problem. Consequently, farmers prefer to burn residues in the field, primarily to clear the remaining straw and stubble after the harvest and to prepare the field for the next cropping cycle. Currently, wastes from nine crops viz., rice, wheat, cotton, maize, millet, sugarcane, jute, rapeseed-mustard and groundnut, are subjected to burning. Thus, the total dry residue generation in the year 1994 was estimated to be about 203 thousand tonnes. Using IPCC emission coefficients, the CH_4 released from this source was found to be about 167 Gg.

Field measurements for GHG emissions from agriculture crop residue burning.

Municipal Solid waste management

Solid waste disposal in India takes place in two distinctively different ways. In rural areas and small towns, there is no systematic collection of waste and it is haphazard. As anaerobic conditions do not develop, no methane is generated in these areas. However, in urban towns, solid waste is disposed by land filling in low-lying areas located in and around the urban centres. Due to stacking of waste over the years, anaerobic conditions develop, and hence these dumping sites generate large quantities of biogas containing a sizeable proportion of methane. Based on secondary data on the type of solid waste produced, per capita waste produced, and the Bio-chemical Oxygen Demand (BOD) content of the waste, it is estimated that in 1994, 582 Gg of CH_4 was emitted from this source.

The per capita waste generation will require to be investigated further in the future, by carrying out

A municipal solid waste dumping site in New Delhi.

surveys in individual households in urban areas. It is necessary, that instead of applying a single value of per capita waste generation, which is averaged over highly varying values across the country, a town-by-town value should be developed and applied to reduce the uncertainty in CH_4 emission estimates from this sector. Also, it is expected that with the rapid development that India is presently experiencing, a greater number of small towns will have the facility of disposing their solid waste systematically and consequently, CH_4 emissions from this source may rise significantly in the future.

Waste water management

Domestic and industrial

The Central Pollution Control Board systematically collects data on industrial waste water and domestic waste water generation from big cities (CPCB, 1997). The amount of waste water generated in India in the domestic sector is around 135 litres per capita per day, of which industrial waste water produced for the same period is around 8 per cent of this. The total CH_4 emitted from the management of domestic as well as industrial wastewater in 1994 is estimated to be 421 Gg.

Other sectors

Methane is also produced from other sectors, such as emission from mobile sources, handling and flaring of oil and natural gas, and from industrial sources. In 1994, the amount of CH_4 emitted from the transport sector was about 9 Gg, which is only 0.2 per cent of the total CH_4 emitted from this sector. The flaring and handling of oil and natural gas systems in 1994 led to an emission of 601 Gg. This includes emission due to drilling for oil and natural gas, transport of oil and natural gas, and flaring of natural gas. In the industrial process sector, only the production of black carbon and styrene resulted in an emission of 2 Gg methane

Nitrous Oxide (N_2O) emissions

Nitrous oxide is a GHG, which is produced both naturally, from a wide variety of biological sources like soil and water, and anthropogenically by activities such as agriculture, transport, industrial and waste management sectors. The total N_2O emissions in India

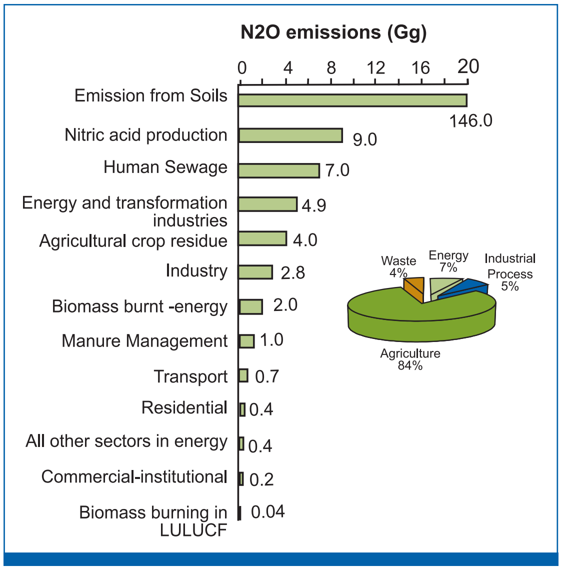


Figure 2.17: Distribution of N_2O emission across sectors.

in 1994 were 178 Gg, which is only 4 per cent of the total GHG emissions from the country. Agriculture sector accounted for 85 per cent of total N_2O emission from India in 1994, fuel combustion accounted for 6 per cent, industrial processes for 5 per cent, waste for 4 per cent and N_2O emissions from biomass burning was miniscule (Figure 2.17). The sectoral emissions are also detailed in Table 2.11.

High degrees of uncertainties are associated with N_2O emission estimates, as most of the activity data, especially in the agricultural sectors are dispersed organic sources that have not been very well quantified. Extensive surveys are required to quantify this data such as the determination of agricultural crop residue burnt on fields and direct and indirect activities leading to N_2O emissions from soil . Since N_2O emission from soils has proved to be a key source of emission in India, it is necessary to develop appropriate emission coefficients through measurements covering the different seasons in the diverse cropping systems of the country.

Fuel combustion

N_2O is a product of the reaction between nitrogen and oxygen during fuel combustion. Both mobile and stationary combustion lead to the emission of N_2O. The quantity emitted varies with type of fuel, technology, pollution control devices used and

Table 2.11: N_2O emission in 1994.

Total (Net) National Emission (Gg per year)	178
1. All Energy	**11.4**
Fuel combustion	
Energy and transformation industries	4.9
Industry	2.8
Transport	0.7
Commercial-institutional	0.2
Residential	0.4
All other sectors	0.4
Biomass burnt for energy	2.0
2. Industrial Processes	**9.0**
Nitric acid production	9.0
3. Agriculture	**151**
Manure management	1
Agricultural crop residue	4
Emission from soils	146
4. Land use, Land-use change and Forestry	**0.044**
Trace gases from biomass burning	0.044
5. Waste	**7.0**
Human sewage	7.0

maintenance and operation practices. For example, catalytic converters installed in motor vehicles to reduce pollution can lead to the formation of N_2O.

In 1994, the N_2O emission from all energy activities accounted for 5 per cent of the total N_2O emissions from India. It includes stationary combustion emissions due to fuel combustion in energy and transformation activities, industry, residential and commercial end uses, biomass burning and emission from mobile sources. Nitrous Oxide emissions from stationary combustion were 11.4 Gg, and from mobile sources about 0.7 Gg.

Nitric acid production

Nitric acid is primarily used as raw material in fertilizer production, and in the production of adipic acid and explosives. It is produced on an industrial scale by the catalytic oxidation of ammonia (Exxon Process) in the presence of air over the precious metals catalysts, for example, platinum, rhodium, and palladium at high temperature and high pressure. During the production of nitric acid (HNO_3), nitrous oxide is produced as a by-product. In the absence of abatement measures, HNO_3 production contributes large amounts of atmospheric N_2O. The worldwide HNO_3 production contributes about 0.4 Tg of N_2O to the atmosphere.

The IPCC default N_2O emission coefficients do not adequately represent the Indian conditions for production of HNO_3. Therefore, attempts were made to conduct real-time measurements of the N_2O concentrations in the tail (stack) gas of different plants operating at medium pressure at 2.5 to 4.5 bar pressure, high pressure at 6 to 12 bar pressure, and dual pressure process in which the reaction was observed at medium pressure and absorption at high pressure. The technologies employed for N_2O abatement are extended absorption, selective catalytic reduction (SCR), and non-selective catalytic reduction (NSCR). The 'NIOSH Method 6600' method was employed for the analysis of N_2O, which is a standard validated method for real-time analysis.

N_2O produced in a medium pressure plant was in the range 6.48 – 13.79 kg per tonne of HNO_3; the mean value was 10.13 kg N_2O per tonne of HNO_3 with an average uncertainty 36.0 per cent. Whereas, N_2O produced in a high pressure plant was in the range 1.54 – 4.13 kg N_2O per tonne of HNO_3; the mean value was 2.84 kg of N_2O per tonne of acid with an average uncertainty of 45.6 per cent. The high pressure plant with NSCR produced the lowest amounts of N_2O, which was in the range 0.24 – 0.57 kg per tonne of HNO_3 with a mean value 0.405 kg N_2O per tonne of acid and 41.0 per cent average uncertainty (Box 2.5). Based on these, N_2O emitted from this source was estimated at 9 Gg in 1994.

Agriculture

Manure Management

During the storage of manure, some of the nitrogen in the manure is converted into N_2O. Nitrous oxide is formed when manure nitrogen is nitrified or denitrified in animals themselves, in animal wastes during storage and treatment, and due to dung and urine deposited by free-range grazing animals. N_2O emission emitted directly from animals is not reported here. There are several animal waste management systems (AWMS) considered here which include

Box 2.5: Determination of N_2O emission coefficient from Nitric acid production

The plants in India are classified into three technology clusters:

- medium pressure process plants (MPP) operating at 2.5 to 4.5 bar pressure,
- high pressure process plants (HPP) operating at 6 to 12 bar pressure, and
- dual pressure process (there was only one plant) i.e., reaction at medium pressure and absorption at high pressure.

The technologies employed for NO_X abatement are extended absorption, selective catalytic reduction (SCR), and non-selective catalytic reduction (NSCR). In India, there are two HPP plants without SCR or NSCR, one HPP plant with NSCR, and one HPP plant with SCR. The remaining plants are based on MPP with extended absorption with or without SCR. Nitric acid is produced as by product in two plants, which have NSCR abatement technology.

The real time measurements of the N_2O concentration in the tail (stack) gas were made at selected nitric acid production plants which are normally operated near 100 per cent capacity as the start up and shut down periods are small. The plants were selected to cover, as far as possible, the full spectrum of nitric acid production technologies being currently used in India.

The concentration of N_2O in the tail gas was measured, at a fixed frequency of 1 or 2 minutes and for varied periods of 0.5 hr to 24 hrs depending on the circumstances. The above sample size was adequate for the statistical evaluation of various parameters.

anaerobic lagoons, liquid systems, daily spread, solid storage and dry lot, pasture range and paddock, used for fuel and other systems. However, care has been taken to avoid including of emissions from stable manure that is applied to agricultural soils (for example, daily spread), dung and urine deposited by grazing animals on fields (pasture range and paddock), from solid storage and dry lot, which are considered to be from agricultural soil and emission from manure used for fuel, which are reported under the energy sector. Using IPCC default values of N_2O emission coefficients for all the activities in this sector, the total N_2O emission in 1994 was 1 Gg.

Emission from soils

This is the largest source of N_2O emission in India, constituting about 81 per cent of the total N_2O in terms of CO_2 equivalent released in 1994. The emission of N_2O results from anthropogenic nitrogen input through direct and indirect pathways, including the volatilization losses from synthetic fertilizer and animal manure application, leaching and run-off from applied nitrogen to aquatic systems. The applied nitrogen includes synthetic fertilizer, animal manure and also the sewage sludge applied to soils. The volatilization of applied nitrogen as ammonia (NH_3) and oxides of nitrogen (NO_x) is followed by deposition as ammonium (NH_4) and oxides of nitrogen (NO_x) on soils and water and accounts for indirect NO_2 emissions from soils. Using the 1996 IPCC methodology and default emission coefficients, the total emission from this source is estimated to be 146 Gg. Although the IPCC default emission factors have been used in the present exercise, large uncertainties still exist in the various

Soil emissions are the largest source of N_2O emissions in India.

activities associated with the release of N_2O from this source. Therefore, in future, initiatives need to be taken to measure/estimate the respective emission coefficients.

Other sources

Other sources include N_2O emissions from burning of crop residue, and emissions from human sewage in waste water treatment systems. N_2O emitted from burning of crop residue was 4 Gg and from human sewage treatment, it was 7 Gg in 1994.