Greenhouse gas emissions from India: A perspective

Subodh Sharma[1], Sumana Bhattacharya[2,]* and Amit Garg[3]

[1]Ministry of Environment and Forests, Government of India, New Delhi, India
[2]Project Management Cell, India's Initial National Communication to the UNFCCC, 1, Navjeevan Vihar, New Delhi 110 017, India
[3]UNEP RISO Centre, Copenhagen, Denmark

Climate change arising due to the increasing concentration of greenhouse gases in the atmosphere since the pre-industrial times has emerged as a serious global environmental issue and poses a threat and challenge to mankind. The United Nations Framework Convention on Climate Change enjoins upon the Parties to the Convention to protect the climate system according to their common but differentiated responsibilities. The parties to the convention are also required to report to the convention on a regular basis a comprehensive and comparable inventory of anthropogenic greenhouse gases and the steps taken to protect the climate. Towards the fulfillment of its obligations, India submitted its initial national communication to the UNFCCC in June 2004.

This paper analyses the improvements made in greenhouse gases (GHG) inventory estimation reported in the Initial National Communication with respect to the earlier published estimates and highlights the strengths, the gaps that still exist and the future challenges for inventory refinement. An assessment of the current and projected trends of GHG emission from India and some selected countries indicates that though Indian emissions grew at the rate of 4 per cent per annum during 1990 and 2000 period and are projected to grow further to meet the national developmental needs, the absolute level of GHG emissions in 2020 will be below 5 per cent of global emissions and the per capita emissions will still be low compared to most of the developed countries as well as the global average.

Keywords: Greenhouse gas emissions, greenhouse gas inventory, national emission trends.

THE rising concentrations of greenhouse gases (GHGs) of anthropogenic origin in the atmosphere such as carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O) have increased, since the late 19th century. According to the Third Assessment Report (TAR) of the Intergovernmental Panel on Climate Change[1], because of the increase in concentration of greenhouse gases in the atmosphere (for e.g., CO_2 by 29 per cent, CH_4 by 150 per cent and N_2O by 15 per cent) in the last 100 years, the mean surface temperature has risen by 0.4–0.8°C globally. The precipitation has become spatially variable and the intensity and frequency of extreme events has increased. The sea level also has risen at an average annual rate of 1–2 mm during this period. The continued increase in concentration of GHG in the atmosphere is likely to lead to climate change resulting in large changes in ecosystems, leading to possible catastrophic disruptions of livelihoods, economic activity, living conditions, and human health[2].

The United Nations Framework Convention on Climate Change[3] requires the parties to protect the climate system in accordance with their 'common but differentiated responsibilities' and respective capabilities. It enjoins upon developed countries to take the lead role for combating climate change and the adverse effects thereof, considering their historically higher contribution to the total anthropogenic load of greenhouse gases in the atmosphere. In the year 1990, the developed world (Australia, Canada, USA, Europe, former USSR and Japan) emitted around 66 per cent of the total global GHG emissions, which though has reduced to 54 per cent in 2000, mainly offset by the rise in Chinese emissions (see Figure 1). The South Asian region, including three-fourths emission share of India, contributed only 3 per cent of the total global GHG emissions in 1990 and the share of emissions from South Asia has grown merely by 4 per cent in 2000.

In accordance with the Article 12 of the climate convention, the parties are required to report on a continuous basis an information on implementation of the convention inter alia an inventory of greenhouse gases by sources and removals by sinks (see note 1) and also the steps taken to address climate change. Towards the fulfillment of the obligations under the convention, India submitted its Initial National Communication to the UNFCCC on 22 June 2004.

This paper analyses the improvements made in GHG inventory estimation reported therein with respect to earlier published estimates and highlights the strengths, the gaps that still exist and the future challenges for its refinement. Further, the paper examines the key sources where efforts are needed to develop a more refined inventory with attendant reduction in uncertainties. The paper also makes an assessment of the current and projected trends of GHG emission from India and some selected countries.

*For correspondence. (e-mail: sumana@winrockindia.org)

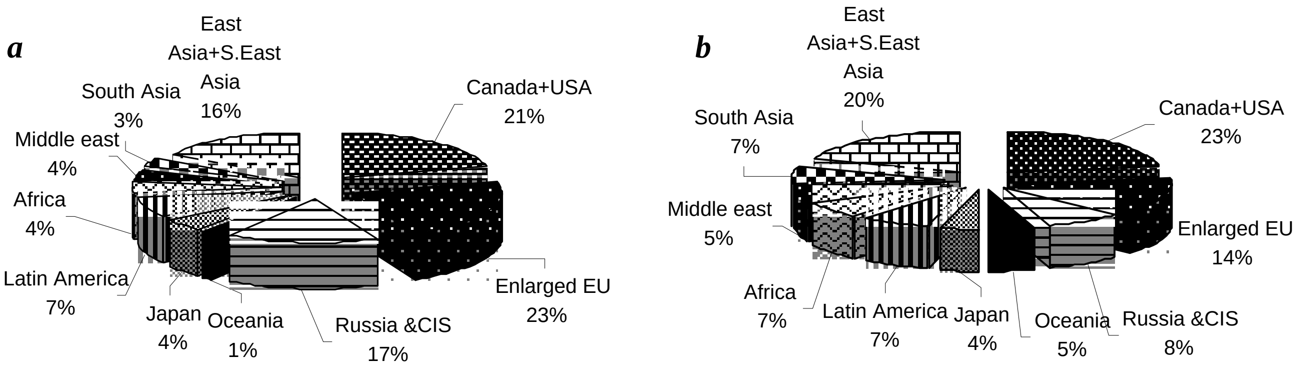

Figure 1. Regionwise GHG emissions in (***a***) 1990 and (***b***) 2000. Source: http://www.rivm.nl/edgar/model/ghg/index.jsp; http://europa.eu.int/comm/environment/climat/pdf/staff_work_paper_sec_2005_180_3.pdf

Table 1. Summary of greenhouse gas emissions in Gg (thousand tonnes) from India in 1994 by sources and sinks

Greenhouse gas source and sink categories	CO_2 (emissions)	CO_2 (removals)	CH_4 emissions	N_2O emissions	CO_2 equivalent emissions*
All energy	679,470		2896	11.4	743,820
Industrial processes	99,878		2	9	102,710
Agriculture			14,175	151	379,723
Land use, land-use change and forestry	37,675	23,533	6.5	0.04	14,292
Waste			1003	7	23,233
Total national emission (Giga gram per year)	817,023	23,533	18,083	178	1,228,540

*Converted by using global warming potential (GWP) indexed multipliers of 21 and 310 for converting CH_4 and N_2O respectively[11].

Greenhouse gas inventory estimation

Estimations of anthropogenic GHG emission inventories in India, began in a limited scale in 1991, which were enlarged and revised and the first definitive report for the base year 1990 was published[4] in 1992. Since then, several papers and reports have been published which have upgraded the methodologies for estimation, included country-specific emission factors (see note 2) and activity data (see note 3)[5], accounted for new sources of emissions and new gases or pollutants[6–10]. A comprehensive inventory of the Indian emissions from all energy, industrial processes, agriculture activities, land use, land use change and forestry and waste management practices has recently been reported in India's Initial National Communication to the UNFCCC[11] for the base year 1994. All these emission estimates reported have been made using the IPCC guidelines for preparing national greenhouse gas inventories, either by Tier I (see note 4), Tier II (see note 5) or Tier III (see note 6)[12]. The use of any of these tiers depended upon the level of disaggregated activity data available for a particular source of GHG emissions and its relative importance as a GHG emission source with respect to the total emissions from the country. Table 1 summarizes the GHG inventory estimates reported under the aegis of India's initial national communication[11].

In 1994, 1228 million tonnes of CO_2 equivalent (see note 7) emissions took place from all anthropogenic activities in India, accounting for 3 per cent of the total global emissions. About 794 million tonnes, i.e. about 63 per cent of the total CO_2 equivalent emissions was emitted as CO_2, while 33 per cent of the total emissions (18 million tonnes) was CH_4, and the rest 4 per cent (178 thousand tonnes) was N_2O. The CO_2 emissions were dominated by emissions due to fuel combustion in the energy and transformation activities, road transport, cement and steel production. The CH_4 emissions were dominated by emissions from enteric fermentation in ruminant livestock and rice cultivation. The major contribution to the total N_2O emissions came from the agricultural soils due to fertilizer applications. At a sectoral level, the energy sector contributed 61 per cent of the total CO_2 equivalent emissions, with agriculture contributing about 28 per cent, the rest of the emissions were distributed amongst industrial processes, waste generation, and land use, land use change and forestry.

A comparison of the GHG inventory reported in the Initial National Communication[11] with respect to the one prepared in a former effort[7], indicates that the improvements and refinements made in the latter are in terms of inclusion of more emission sources in the energy sector such as combustion in industrial/commercial/institutional and residential sectors. Further, the inclusion of sources in the industrial process sector such as the production of lime, lime stone and dolomite use, soda ash use, ammonia, carbide, iron and steel, ferro alloys, aluminum, black carbon, styrene, etc., have added to the comprehensive-

Table 2. Trends of GHG emission in India

Greenhouse gas sources and sinks (G g)	1990[7] (CO_2 eq. mt)	1994[11] (CO_2 eq. mt)	2000* (CO_2 eq. mt)	CAGR in % (1990–2000)
All energy	622,587	743,820	959,527	4.4
Industrial processes	24,510	102,710	168,378	21.3
Agriculture	325,188	344,485	328,080	0.1
Land use, land use change and forestry	1467	14,291	–	–
Waste management	14,133	23,233	28,637	7.3
Total emissions (Gg)	987,885	1,228,539	1,484,622	4.2
Population (million)	853	914	1000	–
Per capita emissions (tonnes/capita)	1.2	1.3	1.5	–

Preliminary estimates made by the authors.

Table 3. Comparative trends of greenhouse gas emissions for some countries

	CO_2 eq. emissions in mmt		
Country	(1990)	(2000)	CAGR (%)
Russian Federation	3208	1833	–3
Germany	1246	1019	–2
United Kingdom	738	640	–1
Japan	1103	1297	2
USA	5080	6209	2
India	988	1485	4
China	3837	4820*	5
Brazil	1187	1477**	6

Source: National Inventory Reports[11], *Data available up to 1994, **Data available up to 1995.

ness of the GHG inventory. Further, the inclusion of country-specific emission factors and use of higher levels of disaggregation has made the inventory more robust.

GHG emissions from about quarter of the source categories reported in the initial national communication were based on the country-specific emission factors, developed during project period. The emission factors thus developed were the net calorific value (NCV) based CO_2 emission factors for combustion of coking coal, non-coking coal and lignite[13] which took into account the wide variation in the ash content, moisture content and petrographic makeup of Indian coal types; the CO_2 emission factors for the transport sector[14] which captured the different types of vehicles, their vintages and fuel mix plying on Indian roads; the production technology specific (dry, wet and semi dry) CO_2 emission factor for cement production[15], the N_2O emission factor for nitric acid production[15] based on measurements carried out at small and large production plants; the CH_4 emission factor for all coal mining process[16] such as surface mining as well as underground mining for various levels of gassiness in coal seam; CH_4 emission factors for enteric fermentation[17] in dairy and non-dairy cattle capturing the typical low level of feed intake by the Indian cattle in comparison to the cattle from the western countries; and CH_4 emission factors from rice cultivation[18] for various water management practices pursued by farmers in India.

Comparative national emission trends

The compounded annual growth rate of CO_2 equivalent emissions from India between 1990 and 2000 (preliminary estimates made by authors) show[7,11] an overall increase by 4.2 per cent per annum (see Table 2). On a sectoral basis, the maximum growth in emissions is from the industrial process sector (21.3 per cent per annum), followed by the emissions from the waste sector (7.3 per cent per annum). The energy sector emissions have only grown by 4.4 per cent per annum with almost no increase in emissions registered from the agriculture sector. Significant increase in emissions from the industrial process sector can be attributed to the growth in cement and steel production in India over the decade. Similarly, increase in emissions from the waste sector can be attributed to increase in quantity of waste generated due to the large influx of population from villages to cities[19] in 2000 with respect to 1990, where because of systematic waste disposal practices, anaerobic conditions are created leading to CH_4 emissions.

Data from some of the developed countries (see Table 3) indicate that between 1990 and 2000, there has been a decline in the compounded annual growth rates of GHGs (see note 8) such as in the case of Russian federation, Germany and UK were the growth rates have decreased by –2.8, –2.0 and –1.4 per cent per annum respectively. In comparison, the emissions from Japan, USA and India have grown by 1.6, 2.0 and 4.2 per cent per annum respectively within the same period. Even the emissions from China and Brazil for the period 1990–1995 show a high compounded annual growth rate of 5 and 6 per cent respectively.

Though the compounded annual growth rates of CO_2 equivalent emissions from India are on a higher side (4.2 per cent per annum), the absolute value of these emissions is still 1/6th of that of USA. Also, the per capita GHG emissions from India are one of the lowest (see Table 4). In the year 2000, the US per capita CO_2 equivalent emission was 15.3 times more than that of India. The German per capita emissions were 8.0 times higher. Similarly, the Japanese per capita CO_2 equivalent emissions were 6.7 times higher than that of India. Even when compared with developing countries such as China and Brazil, the

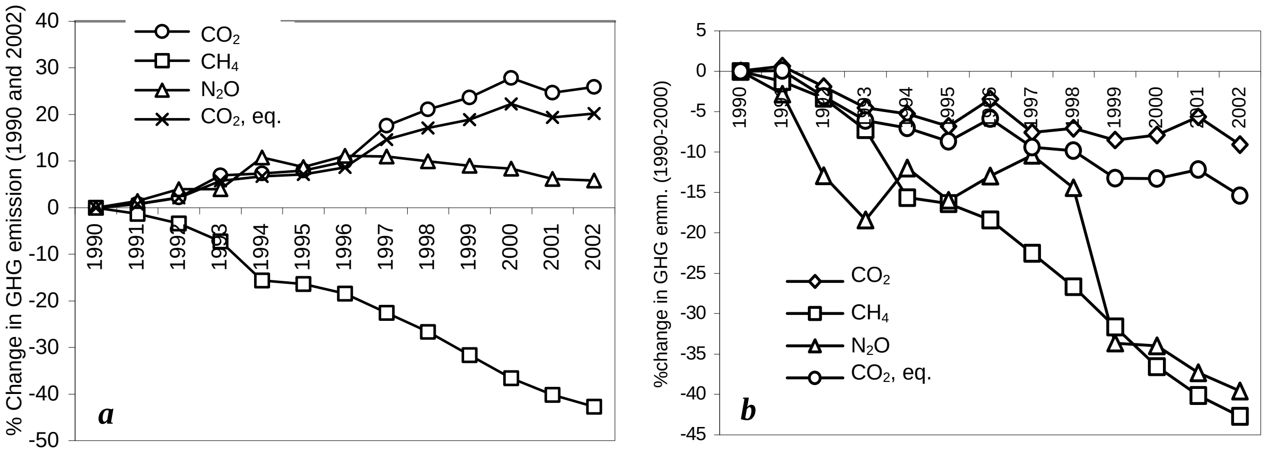

Figure 2. Trends of CO_2 equivalent, CO_2, CH_4 and N_2O emissions from (***a***) USA, (***b***) UK. Note that the CO_2 emissions are increasing continuously and the CH_4 and N_2O emissions are actually decreasing over the period 1990 and 2000. Source: National Inventory Reports, of USA and UK[22,23].

Table 4. Per capita CO_2 equivalent emissions in 2000

Country	Per capita CO_2 equivalent emission in 2000 (tonnes/capita)	Ratio of per capita emissions wrt Indian emissions	Percentage of Indian emissions
USA[22]	23	15.3	6.5
Germany[23]	12	8.0	12.5
United Kingdom[24]	11	7.3	13.6
Japan[25]	10	6.7	15.0
India[11]	1.5	1.0	100.0
Brazil[26]	1.9	1.3	78.9
China[27]	3.3	2.2	45.5
Global[26]	3.9	2.6	38.5

Indian per capita emissions were 2.2 and 1.3 times lower respectively.

For almost all the countries, the share of CO_2 emissions is actually increasing continuously between the period 1990 and 2000 and it is the CH_4 and N_2O emissions which have decreased in this period, resulting in an overall decrease in the growth rates of the CO_2 equivalent emissions (Figure 2 depicting the trends of emission of these gases between 1990 and 2000 for the USA). Exceptions are in the case of India, where the N_2O emissions are also increasing, and in the case of UK and Germany, where all three emissions are declining. Further the decrease in emission trends in Germany and the UK, is due to the fact that the solid and liquid fuel use in these countries is on the decline and the natural gas consumption is increasing. Japan is the only country amongst all the countries considered, where the solid fuel use has increased between 1990 and 2000. In the USA, the fuel mix has remained same between 1990 and 2002, with maximum use of liquid fuel, followed by gaseous and solid fuel. In India too, the commercial fuel mix has remained almost the same between 1990 and 2002, wherein 10 per cent of the fuel used is solid fuel, 81 per cent is liquid fuel and the rest is gaseous fuel. Penetration of commercial biomass as a main fuel source is still very low.

The Indian climate-friendly initiatives

The GHG intensity of the Indian economy in the year 2000, in terms of the purchasing power parity, is estimated to be little above 0.4 tonne CO_2 equivalent per 1000 US dollars, which is lower than that of the USA and the global average[11]. The Indian Government has targeted an 8% GDP growth rate per annum for 2002–07 to achieve its development priorities[19]. In order to achieve these developmental aspirations, substantial additional energy consumption will be necessary and coal, being the abundant domestic energy resource, would continue to play a dominant role. Since GHGs emissions are directly linked to economic growth, India's economic activities will necessarily involve increase in GHGs emissions from the current levels. The CO_2 equivalent emissions from India are set to increase[20] up to 3000 million tonnes by 2020. Any constraint will hamper the economic development.

Several initiatives such as the wide-ranging reforms in the past decade have accelerated the economic growth and lowered the barriers to efficiency. Energy and power sector reforms, for instance, have helped to enhance the technical and economic efficiency of energy use. Policies adopted by India for a sustainable development, such as energy efficiency, improvement measures in various sectors, increasing penetration of cleaner fuels. And a thrust for renewable energy technologies have all contributed towards GHG emission reduction since the last decade.

Past few years have also witnessed introduction of landmark environmental measures that have targeted cleansing of rivers, enhanced forestation, installed significant capacity of hydro and renewable energy technologies and

Table 5. Key source analysis of the 1994 GHG inventory[11]

Sources of emission	CO_2 equivalent (Gg)	Percentage of total emissions	Cumulative emission (Gg)	Cumulative emission vs total emission (%)	Tier used	EF used
Energy and transformation industries	355,037	28.9	355,037	28.9	Tier II	CS
Enteric fermentation	188,412	15.3	543,449	44.2	Tier III	CS
Fossil fuel combustion in industry	150,674	12.3	694,123	56.5	Tier I	D
Rice cultivation	85,890	7.0	780,013	63.5	Tier III	CS
Transport	80,286	6.5	860,299	70.0	Tier II	CS
Emission from soils	45,260	3.7	905,559	73.7	Tier I	D
Iron and steel production	44445	3.6	950,004	77.3	Tier I	D
Energy use in residential sector	43,918	3.6	993,922	80.9	Tier I	D
Biomass burnt for energy	34,976	2.8	1,028,898	83.7	Tier I	D
All other energy sectors	32,087	2.6	1,060,985	86.4	Tier I	D
Cement production	30,767	2.5	1,091,752	88.9	Tier II	CS
Energy consumed in commercial-institutional	20,571	1.7	1,112,323	90.5	Tier I	D
Manure management	20,176	1.6	1,132,499	92.2	Tier I	D
Ammonia production	14,395	1.2	1,146,894	93.4	Tier I	D
Land use, land-use change and forestry	14,292	1.2	1,161,186	94.5	Tier II	CS
Coal mining	13,650	1.1	1,174,836	95.6	Tier III	CS
Oil and natural gas system	12,621	1.0	1,187,457	96.7	Tier I	D
Municipal solid waste disposal	12222	1.0	1,199,679	97.7	Tier I	D
Domestic waste water	7539	0.6	1,207,218	98.3	Tier I	D
Lime stone and dolomite use	5751	0.5	1,212,969	98.7	Tier I	D
Agricultural crop residue	4747	0.4	1,217,716	99.1	Tier I	D
Nitric acid production	2790	0.2	1,220,506	99.3	Tier II	CS
Human sewage	2170	0.2	1,222,676	99.5	Tier I	D
Lime production	1901	0.2	1,224,577	99.7	Tier I	D
Industrial waste water	1302	0.1	1,225,879	99.8	Tier I	D
Ferro alloys production	1295	0.1	1,227,174	99.9	Tier I	D
Alluminium production	749	0.1	1,227,923	99.9	Tier I	D
Carbide production	302	0.0	1,228,225	100.0	Tier I	D
Soda ash use	273	0.0	1,228,498	100.0	Tier I	D
Black carbon and styrene production	42	0.0	1,228,540	100.0	Tier I	D

CS: Country-specific emission factor, D: IPCC default emission factor.

introduced world's largest urban fleet of CNG (compressed natural gas) vehicles in Delhi. The Indian government has simultaneously introduced clean coal technologies like coal washing and introduced the use of cleaner and lesser carbon intensive fuel, like introducing auto LPG and setting up of Motor Spirit-Ethanol blending projects in selected states. These and similar measures, affirmed by the democratic and legislative processes, have been implemented by committing additional resources as well as by realigning new investments. These pro-active actions, by consciously factoring in India's commitment to UNFCCC, have re-aligned economic development to a more climate-friendly path.

Challenges ahead in inventory estimation for India

For non-Annex 1 parties to the UNFCCC, like India, continuous reporting of the national communication containing information on its GHG emissions by sources and sinks is the only commitment at the moment. So the challenge lies in reporting a refined inventory of GHG emissions every time, which is also transparent, comprehensive, comparable and accurate. The refinement in the inventories can be in terms of bridging the gaps identified in the latest exercise, making the inventory reporting more comprehensive by including as many activities as capacities permit and by reducing uncertainties in the emission estimates. Though uncertainties are inherent in such exercises, the level of uncertainties can be reduced in several ways, such as making use of country-specific GHG emission factors for estimating the emission inventories and by riding the tier ladder (i.e. focusing on using methodologies which take into account emissions from point sources, as compared to aggregated sources) etc.

To ascertain the requirement for refinement of GHG emission estimates by sources, the first step is to define the key sources, in order to enable the party to focus its resources. A key source is defined as any source category which, when summed in descending order of magnitude for a given year, cumulatively add up to 95 per cent of the total level assessment for that year[21]. In this process, the source categories considered are sorted in decreasing order of emission, so that the source categories with the highest-level assessments appear first. The level assessments are summed until the threshold of 95 per cent is reached. All source categories that fall within this cumulative 95 per cent are considered key source categories.

Applying this methodology to the emission sources reported in India's Initial National Communication[11], 15 sources qualify as key source categories (shaded in Table 5). The key amongst the key categories is the energy and transformation industries, i.e. power generation, which emits about 29 per cent of the total CO_2 equivalent emissions from India. This is followed by enteric fermentation, which contributes 15.3 per cent of the total CO_2 equivalent emissions. The rest of the key sources in the order of their decreasing order of emissions are: energy intensive industries, rice cultivation, transport (mainly road transport within that), iron and steel production, residential sector using fuel for energy, biomass burnt for energy, cement production, commercial and institutional combustion, manure management, ammonia production and lastly land use, land use change and forestry sector.

Based on this analysis, it emerges that improvements are required in the methodologies as well as emission factors for reducing uncertainties in the emission estimates of these key categories. The improvements may be necessary in terms of the activity data, emission factor or the methodology of the estimate itself. However, it must be noted that the country-specific emission factors have already been used to estimate the GHG emissions from 40 per cent of the key source categories and the GHG emission estimates have been made using Tier II and III methodologies for 20 per cent and 13 per cent of the key sources respectively (see Table 5). Therefore, GHG emissions estimated from some of the key sources using country-specific emission factors and higher levels of disaggregation, may seem to be precise and therefore may not require further effort to reduce uncertainties. However, expert judgement needs to be applied, in order to ascertain the level of efforts to be made for refining the emission estimates of all key source categories.

One step towards the refinement of the emission sources of these key sources is the refinement in the activity data. In the initial national communication, gaps in availability of appropriate activity data have been identified and these include a comprehensive assessment of biomass consumption data in terms of fuel wood and commercial round wood consumption, dung cake production/consumption, and agriculture crop residue consumption. Similarly in the transport sector data on kilometer run on roads by different road transport vehicles was not available. In the agriculture sector, it is essential for evaluation of sources and sinks of greenhouse gases at disaggregated level. Therefore, the year-wise and age-wise livestock for different agro-climatic regions, assessment of the actual land area cultivated under each water management practices each year are some of the gaps which need to be bridged. In the land use, land use change and forestry sector, a high resolution data of area under different forest types as well as a land use change matrix, describing the extent of land use change from one category to another is lacking.

Other than refining the emission estimates of key sectors through improvement in activity data, steps like improving estimates through higher sectoral disaggregation, introducing good practices in inventory development like steps for quality assurance and quality control efforts will go a long way in reducing uncertainties in inventory estimates. Comparisons with national and regional inventories at sectoral level will help identify the inconsistencies, and a comparison with the national emission factors, activity data, or algorithms will provide clues as to why the emission estimates differ. Building technical capacity through continuous and improved networking and developing centers for development of emission factor data base and validation of inventories will enable India to develop a robust comprehensive and comparable inventory in the future.

Conclusion

Considerable improvements have been made in the GHG emission inventory reported in the Indian initial national communication to the UNFCCC[11] with respect to the ones reported earlier[7]. The improvements are mainly in the nature of more comprehensive reporting of sources and sinks, the use of a wider emission factor database representing country specific circumstances, and following a bottom up approach. The total amount of GHGs emitted in India, according to this report, was 1228 million tonnes, which accounted for only 3 per cent of the total global emissions, and of which 63 per cent was emitted as CO_2, 33 per cent as CH_4, and the rest 4 per cent as N_2O.

The GHG emissions in the years 1990, 1994 and 2000 increased from 988 to 1228 to 1484 million tonnes respectively and the compounded annual growth rate of these emissions between 1990 and 2000 has been 4.2 per cent. Emissions from the industrial sector registered the highest rate of growth per annum within this period. A comparison of the Indian emissions with some of the largest global emitters, indicates that the absolute value of Indian emissions is 24% of the US emissions, 31% of China and 80% of the USSR in 2000. The Indian per capita emissions are only 7% of the US, 13% of Germany, 14% of UK, 15% of Japan, 45% of China and 38% of global average in 2000 (refer to Table 4). When the Indian emissions are compared with some of the rapidly developing countries such as China and Brazil, it is seen that their compounded annual emission growth rates are 5 and 6 per cent respectively as compared to the 4.2 per cent per annum for India.

The Indian GHG emissions are projected to increase by almost three times with respect to the 1990 emissions[26] in 2020. These emission projections are driven by the developmental needs of the country. It is perceived that the various climate-friendly initiatives introduced, such as enhancement of energy efficiency, promotion of use of renewable energy resources and introduction of environmental measures such as enhancement of afforested land area will address such climate change issues effectively. India's national developmental targets and plans have a sustainable developmental focus, wherein many climate change concerns would also be addressed. These conscious decisions require committing substantial resources for climate-friendly sustainable development.

As reporting of GHG inventory by sources and sinks to the UNFCCC is a continuing process, the challenge lies in reporting a more refined inventory every time, which is transparent, comprehensive, comparable and accurate as well. The paper thus identifies the key anthropogenic sources where resources need to be put in for an improvement in the GHG inventory estimation, and also discusses the steps for preparing such an inventory which when followed may lead to a substantial reduction in uncertainties in these estimates.

Notes

1. Removal by sinks: refers to sequestration of GHGs by certain sources such as CO_2 sequestration through afforestation and Carbon capture through various techniques.
2. Emission factor: It is the quantity of GHG emitted per unit of activity.
3. Activity data refers to the magnitude of human activity resulting in emissions or removals happening during a given period of time. Data on energy use, metal production, land areas, management systems, lime and fertilizer use and waste generation are examples of activity data.
4. Tier I: Takes into account the gross consumption and average emissions factors (factors).
5. Tier II: Refers to estimations based on sub-sectoral consumption and emissions factors developed representing specific conditions.
6. Tier III: Refers to emission estimates made using detailed activity and specific emission factors.
7. 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. GWP of methane and nitrous oxide are 21 and 310 respectively. 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.
8. Referred in terms of CO_2 equivalent of CO_2, CH_4 and N_2O.

1. *Climate Change 2001: The Scientific Basis, Contribution of Working Group I to the Third Assessment Report of the Intergovernmental Panel on Climate Change (IPCC)*, Cambridge University Press, Cambridge, 2001a.
2. *Climate Change 2001: Impacts, Adaptation and Vulnerability, Contribution of Working Group II to the Third Assessment Report of the Intergovernmental Panel on Climate Change (IPCC)*, Cambridge University Press, Cambridge, 2001b.
3. The United Nations Framework Convention on Climate Change, United Nations, UNFCCC, New York, 1992
4. Mitra, A. P. (ed.), *Greenhouse Gas Emissions in India: 1992 Update*, Scientific Report No. 4, Centre for Global Change, National Physical Laboratory, New Delhi, 1992.
5. Mitra A. P., Uncertainty Reduction in GHG Inventory Estimates in India: An Overview. In *Climate Change and India: Uncertainty Reduction in Greenhouse Gas Inventory Estimates* (eds Mitra, A. P., Sharma, S., Bhattacharya, S., Garg, A., Devotta, S. and Sen, K.), Universities Press, Hyderabad, 2004.
6. Mitra, A. P., *GHG Inventories from India*, Global Change Scientific Report No. 8. National Physical Laboratory, New Delhi, 1996.
7. Asia Least-cost Greenhouse Gas Abatement Strategy: India Country Report. Asian Development Bank. Global Environment Facility, United Nations Development Programme, Manila, Philippines, ALGAS, 1998.
8. Garg, A., Bhattacharya, S., Shukla, P. R. and Dadhwal, V. K., Regional and sectoral assessment of greenhouse gases in India. *Atmos. Environ*., 2001, **35**(15), 2679–2695.
9. Mitra, A. P. and Bhattacharya, S., Climate change and greenhouse gas inventories: Projections, impacts and mitigation strategies. In *Climate Change and India: Issues, Concerns and Opportunities* (eds Shukla, P. R., Sharma, Subodh K. and Ramana, P. V.), Tata McGraw-Hill, New Delhi, 2002.
10. Garg, A. and Shukla, P. R., *Emission Inventory of India*, Tata McGraw-Hill, New Delhi, 2002.
11. India's Initial National Communication (NATCOM) to the United Nations Framework Convention on Climate Change (UNFCCC), Ministry of Environment and Forests, New Delhi, 2004.
12. *Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories* (eds Houghton, J. T., Meira Filho, L. G., Lim, B., Treanton, K., Mamaty, I., Bonduki, Y., Griggs, D. J. and Callender, B. A.), IPCC/OECD/IEA, 1996.
13. Choudhury, A., Roy, J., Biswas, S., Chakraborty, C. C. and Sen, K., Determination of carbon dioxide emission factors from coal combustion. In *Climate Change and India: Uncertainty Reduction in Greenhouse Gas Inventory Estimates* (eds Mitra, A. P., Sharma, S., Bhattacharya, S., Garg, A., Devotta, S. and Sen, K.), Universities Press, Hyderabad, 2004.
14. Singh, A. K., Saxena, M. and Singhal, S. K., Uncertainties in emission estimates from the road transport sector. In *Climate Change and India: Uncertainty Reduction in Greenhouse Gas Inventory Estimates* (eds Mitra, A. P., Sharma, S., Bhattacharya, S., Garg, A., Devotta, S. and Sen, K.), Universities Press, Hyderabad, 2004.
15. Rao, P. V., Qureshi, M. S. and Devotta, S., GHG emission measurements in industrial processes. In *Climate Change and India: Uncertainty Reduction in Greenhouse Gas Inventory Estimates* (eds Mitra, A. P., Sharma, S., Bhattacharya, S., Garg, A., Devotta, S. and Sen, K.), Universities Press, Hyderabad, 2004.
16. Singh, A. K., Methane emission from coal mining and handling activities in India. In *Climate Change and India: Uncertainty Reduction in Greenhouse Gas Inventory Estimates* (eds Mitra, A. P., Sharma, S., Bhattacharya, S., Garg, A., Devotta, S. and Sen, K.), Universities Press, Hyderabad, 2004.
17. Swamy, M., Singhal, K. K., Gupta, P., Mohini, M., Jha, Arvind K. and Singh, N., Reduction in uncertainties from livestock emissions. In *Climate Change and India: Uncertainty Reduction in Greenhouse Gas Inventory Estimates* (eds Mitra, A. P., Sharma, S., Bhattacharya, S., Garg, A., Devotta, S. and Sen, K.), Universities Press, Hyderabad, 2004.
18. Gupta, P. K *et al*., Reducing uncertainties in methane emissions from rice cultivation. In *Climate Change and India: Uncertainty Reduction in Greenhouse Gas Inventory Estimates* (eds Mitra, A. P., Sharma, S., Bhattacharya, S., Garg, A., Devotta, S. and Sen, K.), Universities Press, Hyderabad, 2004.
19. Gaikwad, S. A., Kumar, S., Devotta, S. and R. N. Singh, Methane emissions from solid waste management in India and its uncertainty analysis. In *Climate Change and India: Uncertainty Reduction in Greenhouse Gas Inventory Estimates* (eds Mitra, A. P., Sharma, S., Bhattacharya, S., Garg, A., Devotta, S. and Sen, K.), Universities Press, Hyderabad, 2004.

20. Garg, A., Shukla, P. R. and Kapshe M., Future methane and N_2O emissions for India. In Proceedings of the Natcom Workshop on Scenarios and Future Emissions held at Indian Institute of Management on July 22, 2003, Ministry of Environment and Forests, Government of India, 2004.
21. Good practice guidance and uncertainty management in national greenhouse gas inventories, In *IPCC National Greenhouse Gas Inventories Programme* (eds Penman, J. *et al*.), Published for the IPCC by the Institute for Global Environmental Strategies, Japan, 2000.
22. Inventory of US Greenhouse Gas Emissions and Sinks: 1990–2002, United States of America, NIR, US Environmental Protection Agency, Washington DC, USA, 2004.
23. German Greenhouse Gas Inventory 1990–2002. National Inventory Report 2004. Submission under the United Nations Framework Convention on Climate Change, Germany NIR, 2004, Federal Environmental Agency (Umweltbundesamt), Berlin.
24. UK Greenhouse Gas Inventory, 1990 to 2002: Annual Report for submission under the Framework Convention on Climate Change. United Kingdom of Great Britain and Northern Ireland, NIR, Department for Environment, Food and Rural Affairs, 2004.
25. National Greenhouse Gas Inventory Report of Japan, Ministry of the Environment, Japan, Greenhouse Gas Inventory Office of Japan (GIO), Center for Global Environmental Research (CGER), National Institute for Environmental Studies (NIES), Japan, 2004.
26. CO_2 Emissions from Fuel Combustion 1971–2002; IEA Statistics, 2004, An OECD publication, 2004 Edition, pp. 560.
27. The People's Republic of China Initial National Communication on Climate Change to the United Nations Framework Convention on Climate Change (UNFCCC), 2004.