PERGAMON

Atmospheric Environment 36 (2002) 213–224

ATMOSPHERIC ENVIRONMENT

www.elsevier.com/locate/atmosenv

Large point source (LPS) emissions from India: regional and sectoral analysis

A. Garg[a], M. Kapshe[a,*], P.R. Shukla[a], D. Ghosh[b]

[a] *Indian Institute of Management, Vastrapur, Ahmedabad 380 015, India*
[b] *Centre De Sciences Humaines, New Delhi, India*

Received 23 April 2001; received in revised form 17 August 2001; accepted 24 August 2001

Abstract

Indian large point sources (LPS) contribute to CO_2 and SO_2 emissions to a large extent (above 65%) and to CH_4, N_2O and NO_X emissions to some extent (around 10%). The former emissions are primarily from fossil fuel combustion while the latter have agriculture sector dominance, explaining the drastic difference in LPS contributions to all India emissions. The present paper covers 509 LPS for India. These are well distributed across the country. However, there are some regions of very few LPS (like the western desert and the hilly areas of north, northeast and coastal west) and some regions of high LPS concentration (Mumbai–Ahmedabad corridor, Delhi and near coal mine mouths). There is a dominance of power plants in Indian LPS emissions for CO_2 and SO_2 (47% each), with cement (9% and 5%) and steel (6% and 7%) plants being the other major contributors. Moreover, due to growing population, increasing urbanization and higher consumption levels, these LPS emissions are growing much faster than the national average. The present analysis would be useful for policy-making to mitigate these pollutants and their associated impacts.

Keywords: Emissions; Large point sources; Greenhouse gases; Local pollutants; Mitigation policy

1. Introduction

India is a vast country with diverse mix of resources and economic activities. Large and modern urban centers coexist with traditional rural and agrarian economy. The varying sectoral growth rates, consumption patterns and resource endowments have led to widely different regional and sectoral emission distributions. Some gases and sectors are characterized by large point sources (LPS) of emission. Typically, a significant fraction of carbon dioxide (CO_2) and sulfur dioxide (SO_2) emanating from fossil fuel combustion and specific industrial activities (IPCC, 1996) is emitted by LPS like thermal power plants, steel plants, cement plants, sulfuric acid manufacturing, smelting of copper, zinc and lead ores, etc. On the other hand, emission sources for some gases like methane (CH_4) and nitrous oxide (N_2O) are widely dispersed. In India these are emitted primarily from dispersed and small activities in rural and agriculture sectors like enteric fermentation in animals, rice paddy cultivation, use of synthetic fertilizer, biomass burning. While the emission sources for transport sector are also very small, dispersed and moving, a good fraction of aggregate emissions is concentrated in urban conglomerations.

Our earlier studies have indicated that Indian emissions were 778 Tg (CO_2), 18 Tg (CH_4), 0.26 Tg (N_2O), 4.64 Tg (SO_2) and 3.46 Tg (nitrogen oxides, NO_X) in 1995 (Garg et al., 2001a, b). LPS contribute to CO_2 and SO_2 emissions to a large extent and to CH_4, N_2O and NO_X emissions to some extent. Moreover, due to growing population, increasing urbanization and higher consumption levels, the emissions from LPS are growing

*Corresponding author. Tel.: +91-79-630-6450; fax: +91-79-630-6896.

E-mail address: kapshe@fpmlan.iimahd.ernet.in (M. Kapshe).

1352-2310/02/$ - see front matter
PII: S 1 3 5 2 - 2 3 1 0 (0 1) 0 0 4 3 9 - 3

much faster than the national average. Many large power plants have inefficient operations without advanced emission controls resulting in excessive emissions. Therefore, for cost-effective mitigation efforts, it would be prudent to target LPS emissions initially.

2. Methodology

We have estimated the Indian LPS emissions for 1990 and 1995. However, only the 1995 analysis is presented in this paper since the distribution and contribution of LPS emissions across sectors and regions were almost similar for these 2 years. The following equation is used to estimate the total emissions of a particular gas from an LPS, which is in line with the recommended Intergovernmental Panel on Climate Change methodology (IPCC, 1996) and follows the same approach as used by Li et al. (1999) and Garg et al. (2001a, b).

$$\text{Total emissions} = \sum_{\text{source category}} (\text{activity level} \times \text{emission coefficient}).$$

The methodology involves collection of basic data, collation and estimation of emissions for individual LPS, and aggregation of LPS emissions. We have employed Geographical Information System (GIS) for Indian LPS emission coverage. Layered LPS information has been developed covering LPS for various sectors, source categories and gases for 1990 and 1995 (Fig. 1). Thus, a powerful analytical tool for LPS emission status, trends and mitigation has been synthesized for India.

3. Emission coefficients

The emission coefficients for various gases are same as those used in Garg et al. (2001a, b). Almost all the existing plants in India use subcritical pulverized coal technology and we have used technology-specific emission coefficients in this paper. Average ash content of Indian coal is taken to be 45% and the sulfur content as 0.51% (CMIE, 1999). The average emission coefficient for sulfur is net of sulfur retained in ash after coal combustion and also does not consider use of any emission control equipment by LPS since Indian environmental regulations do not require any emission control equipment at the existing plants (Biswas, 1999). NO_X coefficients are internationally accepted default values in absence of better estimates for India (IPCC, 1996; WB, 1997).

Similarly for cement sector LPS; the dominant technology is dry process accounting for almost 90% of total production capacity in India. Lime stone use varies between 1.2 and 1.6 ton per ton of clinker production (ICRA, 1995). We have assumed an average value of 1.5 ton for emission estimation purpose. Steel sector LPS use coking coal that has higher net calorific value than that for coal used in other sectors resulting in higher CO_2 emission coefficient (2.75 ton CO_2 per ton coal) as compared to all other LPS (1.76 ton CO_2 per ton coal).

4. Data sources

There is no comprehensive database covering all the types of emitters for India, therefore many diverse data sources covering various sectors and fuels were utilized. Most of the data sources are published documents of the government of India (Garg et al., 2001a, b). The main problems faced were consistency checking of LPS emission source data and finding the location of many LPS. We have tried to cross-verify each LPS data using more than one data source providing a profound richness and robustness to the base data. The emissions from an LPS are aggregates from its various individual units/stacks since fine grain information about stacks and their spatial location is not available to reliably and accurately represent them as individual LPS.

5. Coverage

Large point sources covered may be classified under four broad categories: energy, industrial processes, fossil fuel extraction and others. We estimate emissions from 509 LPS for India including 94 fossil power plants (81 coal, 12 gas and one oil based), 11 steel plants, 85 cement plants, 31 fertilizer plants, 12 petroleum refineries, 33 paper mills, 28 sugar mills, 63 H_2SO_4 manufacturing plants and many other LPS including petrochemicals and smelting units (Table 1). These cover almost all the major LPS for Indian emissions. The longitude and latitude identification for each LPS was a difficult task since this information was provided only for a few LPS in the base data. For most sources, longitude and latitude were found by identifying the nearest city/town or other geographical feature indexed in base data. In some cases the topology available with the Space Application Center, Ahmedabad was utilized.

6. Regional emission distribution

The distribution of LPS locations is relatively uniform across the country (Fig. 2). This is a contrast to that for the other Asian giant China where LPS are concentrated in the eastern part of the country (Hu et al., 2000). India also has some regions of very few LPS like the northern

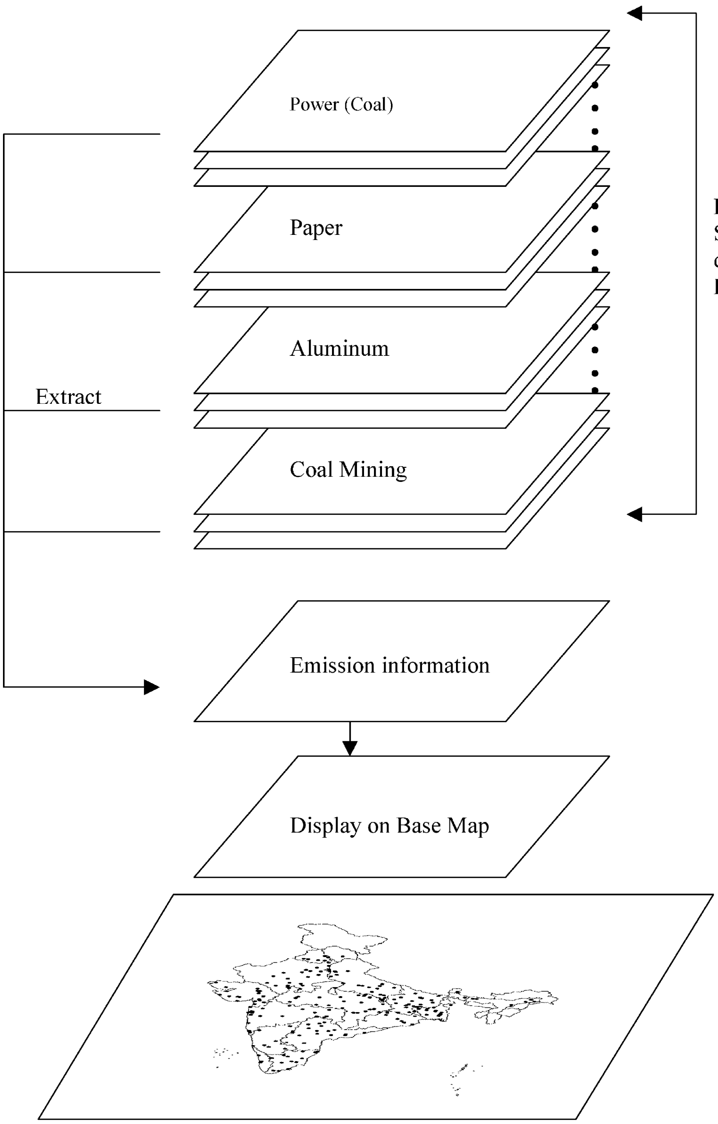


Fig. 1. GIS database layers.

hilly states of Jammu and Kashmir and Himachal Pradesh, the seven hilly northeast states, the west coastal hills and the Thar desert in the northwest. All these are thinly populated regions with low accessibility. On the other hand, there are dense LPS clusters near Delhi, the Golden corridor in west, southern India, and near coal mine mouths in central and eastern India (Fig. 3). These six regions together have about 120 LPS accounting for almost 32% of all India SO_2 emissions. These regions also have high discharge of other pollutants like hazardous chemicals, industrial wastewater, chemical slurry, land degradation due to coal mining, etc. These make them prime targets for pollution mitigation in India.

The regional distributions for CO_2 and SO_2 LPS emissions correspond to coal consumption pattern for India. Coal is the mainstay of the Indian energy system contributing almost 75% of total CO_2 and 63% of SO_2 emissions. About 70% of all India coal consumption is for power generation. The regional spread of SO_2 emissions from power sector LPS reflects this pattern where the largest 100 LPS have 64 coal-based power plants (Fig. 3). Methane LPS are mainly from fossil fuel extraction that is unevenly distributed across India and depends upon the natural resource endowment of various regions.

The regional distribution of power and cement sector LPS are well spread over the country. Power sector

Table 1
Large point source coverage for India

Sector	Subsectors	LPS covered	Major emissions
Energy	Power (coal)	81	CO_2, SO_2, NO_X
	Power (natural gas)	12	CO_2, NO_X
	Power (oil)	1	CO_2, SO_2, NO_X
	Steel	11	CO_2, SO_2, NO_X
	Cement[a]	85	CO_2, SO_2, NO_X
	Fertilizer	31	CO_2, SO_2
	Paper	33	CO_2, SO_2, NO_X
	Sugar	28	CO_2, SO_2, NO_X
	Caustic soda	19	CO_2, SO_2, NO_X
	Crude refinery	12	CO_2, SO_2
Industrial processes	Petrochemical	14	CH_4, N_2O, SO_2
	HNO_3 manufacturing	5	NO_X, N_2O
	H_2SO_4 manufacturing	63	SO_2
	Aluminum (Al)	3	CO_2
	Copper ore smelting (Cu)	8	SO_2
	Lead ore smelting (Pb)	5	SO_2
	Zinc ore smelting (Zn)	3	SO_2
	Alcohol production	14	CH_4
Fossil fuel extraction	Coal mining	32	CH_4
	Natural gas production	9	CH_4
	Natural gas transportation and handling	12	CH_4
	Crude oil production	7	CH_4
Others	Municipal solid waste	14	CH_4
	Other industries	7	CO_2, SO_2, NO_X
Total		509	

[a] The non-energy component (CO_2 due to calcination process) is also included here.

structure in India has developed around state utilities and therefore plants are well spread. Distributed demand and low financial viability of transportation (due to low value-to-weight ratio) have resulted in wide spread distribution of cement producing capacity across the country.

7. Sectoral distribution

Table 2 summarizes the LPS emissions for various gases and compares these with the all India total emissions. The relatively lower shares of LPS in CH_4, N_2O and NO_X emissions are due to the dominance of agriculture and transport sectors in these emissions, respectively. Agriculture contributes above 80% of Indian methane and N_2O emissions while transport contributes 32% of NO_X. These mostly consist of small and dispersed sources.

The largest 100-point sources for CO_2 contribute 57% of all India CO_2 emissions (Table 3). These include 73 power plants, 7 steel plants and 16 cement plants, 3 fertilizer plants and a petrochemical plant. The five largest sources are coal-based power plants and they contribute 11% of all India CO_2 emissions. The largest 100-point sources for SO_2 contribute 2.73 million-ton of SO_2 with the largest five LPS contributing 11% and largest 10 contributing 20% of all India SO_2 emissions. There are 64 coal-based power plants, 7 steel plants, 8 cement plants, 13 fertilizer plants, 2 petrochemical plants, one oil refinery and 5 smelting units in the top 100. The number of cement plants is lower here than the CO_2 list since calcination process in cement manufacturing produces relatively more CO_2 than SO_2. The top 100 LPS list for these two gases had 84 common sources including 64 power plants, 7 steel plants and 8 cement plants. The other 9 power plants in CO_2 list are gas based and are missing from the SO_2 list since gas combustion emits no sulfur.

LPS for NO_X emission are mostly power plants. The top 50 LPS for methane emission had 14 solid waste dumping sites in large urban centers, 16 coal-mining clusters, 1 gas production site, 5 gas transportation, 6 oil production sites and 8 oil-refining sites. We now analyze the LPS emissions from various sectors in detail.

7.1. Energy sector

Electric power sector is the dominant component of Indian energy sector. India's power generation mix is

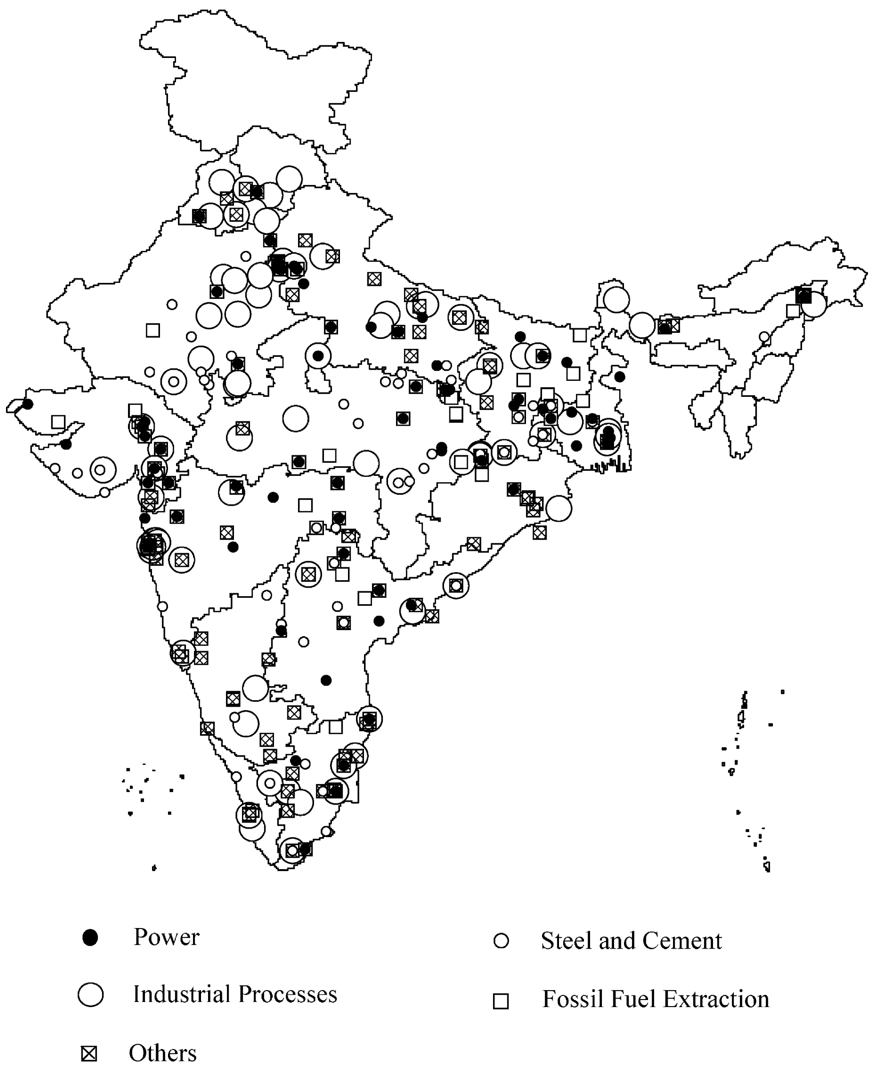
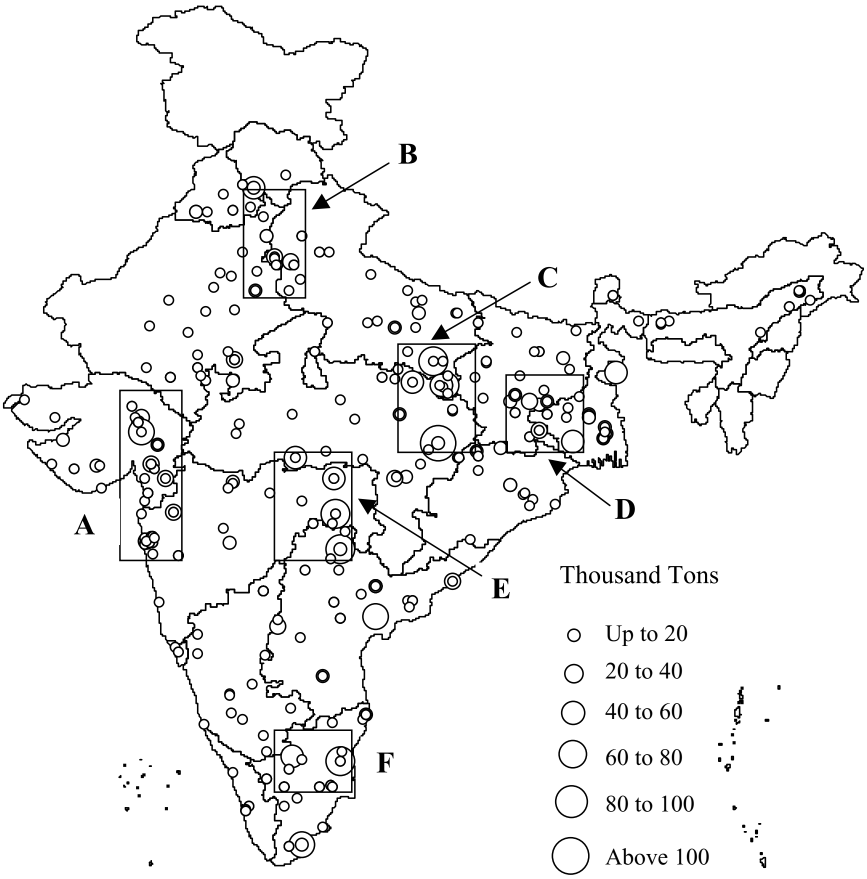


Fig. 2. Regional spread of LPS locations.

biased in favor of thermal, which in turn is coal dominated. The gross power generation in India has increased by 44%, thermal power generation by 69% and CO_2 emissions from power sector by 64% between 1990 and 1995. The marginally lower rate of CO_2 emissions vis à vis thermal power is due to efficiency improvement of power generation. Fig. 4 indicates the CO_2 emissions per unit of thermal power generation (kg CO_2/kWh) for largest power plants.

A similar analysis for SO_2 emissions is shown in Fig. 5. The national average was 7 ton of SO_2 per GWh of thermal electricity generated in 1995. The emissions per unit power generated have increased for some LPS between 1990 and 1995 indicating a reduction in performance. It may be due to various reasons including high coal consumption per unit of power generated, poor quality of coal used, use of inefficient thermal generation technologies, lower plant load factors indicating inefficient operations, coal pilferage which may be reported as coal consumed for power generation, etc. The last reason is ironical in that even though it indicates economic losses for the power plants, the actual emissions from the power generation sector would be lesser than that estimated here.

The environmental performance of large power plants with respect to their age is also analyzed (Fig. 6). The average age of a particular plant represents the average of all of its units and it is 13 years for Indian thermal power sector. Almost all the plants in India use subcritical pulverized coal technology without any emission control equipment for SO_2 and NO_X. The newer plants contribute more to total power generation



Region Details		No. of LPS	LPS/Total SO_2 (%)	Main Sources
A	The Golden corridor	32	6.1	Power, H_2SO_4
B	Delhi region	20	2.4	Power, Cement
C	Northeast India coal mine region	21	7.9	Power, Cement
D	East India coal mine region	18	5.5	Power, Steel, Cement
E	Central India coal mine region	16	6.1	Power, Steel
F	Southern region	13	3.9	Power, Cement

Fig. 3. Regional distribution of SO_2 emissions from LPS.

Table 2
Share of LPS in all India emissions

Emission	LPS covered	LPS emissions (Tg)	LPS/all India emissions (%)
CO_2	340	506	65
SO_2	430	3.1	66
NO_X	261	0.45	13
CH_4	86	1.73	9
N_2O	261	0.015	6

Table 3
Distribution range of LPS emissions as a percentage of all India emissions

Largest LPS	CO_2	CH_4	N_2O	NO_X	SO_2
1–25	34	7.2	4.3	6.1	34
26–50	13	1.9	0.7	2.9	14
51–75	7	0.4	0.4	1.6	7
76–100	4	0	0.2	1.0	4
101–200	6	0	0.3	1.2	6
All others	1	0	0	0	1

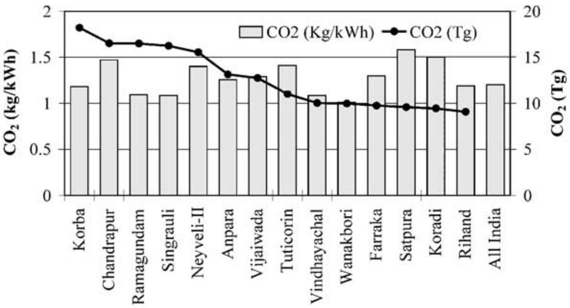


Fig. 4. CO_2 emissions from largest power plants.

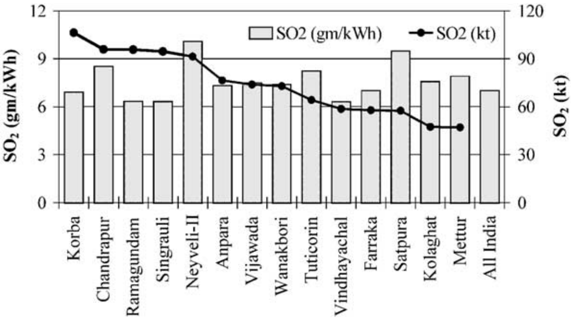


Fig. 5. SO_2 emissions from largest power plants.

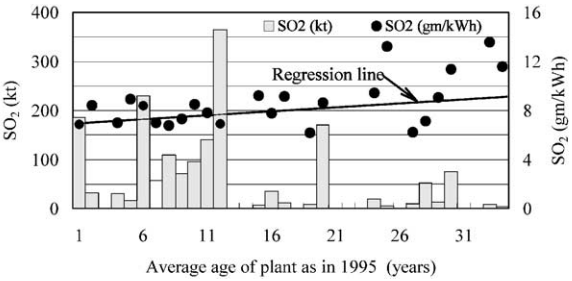


Fig. 6. SO_2 emissions and age of power plants.

and therefore to emissions. On the other hand, older plants emit more SO_2 per unit power generated which represents poor emission performance. The correlation coefficient between plant age and SO_2 per unit power generated is 0.57, which is statistically significant for cross-sectional data. The two old plants at Trombay (26 years) and Baandel (27 years) apparently are performing well for their age. However, most of their power generation takes place from their newer units that are about 12–13 years old. Their older units, however, emit more SO_2 per unit power generated. It indicates that age is a dominant factor for poor emission performance of Indian power plants. Inefficient operations and mismanagement are the other causes. The regression line in Fig. 6 indicates that emission performance of power

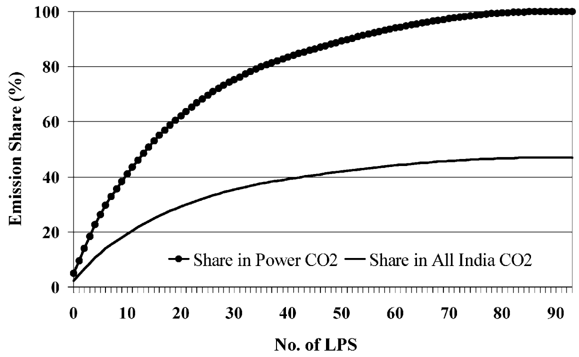


Fig. 7. Contribution of power sector LPS to CO_2 emissions.

plants improves with efficiency improvements since newer plants have higher efficiency. However, efficiency improvements alone cannot improve emission performance continuously and technological solutions like FGD are required for further improvements.

The Indian power sector LPS contributed 47% to all India emissions, 45% to SO_2 and 28% to NO_X emissions. The highest 25 LPS alone contributed 68% of power sector CO_2 emissions (Fig. 7). The combined emissions from steel and cement sectors accounted for 14.5% of all India CO_2 and 11% of SO_2 emissions. The top five LPS contributed 36% while the top 25 contributed 74% of total steel and cement sector CO_2 emissions. Table 4 gives the contribution of LPS in various energy sectors to all India emissions.

7.2. Industrial activities

We have captured 96 non-energy LPS for SO_2 emissions (Table 5). The five largest LPS include two copper ore smelters, one zinc ore smelter and two sulfuric acid plants. Sulfuric acid production is the main source of SO_2 emissions from industrial activities in India. Industrial activities, in general, contribute relatively much lower emissions than energy sector LPS. However, SO_2 mitigation from H_2SO_4 plants offers other co-benefits like reduction in water pollution and hazardous industrial wastes; therefore, these LPS are analyzed here. The energy efficiency upgradation of H_2SO_4 industry is slowly taking place but still SO_2 emission intensive one-conversion and one-absorption production processes are predominant. Copper ore smelters are spread over six states, lead in four states and zinc in two states. Rajasthan state alone had 22 LPS contributing more than one-third of the all India SO_2 emissions from non-energy sector.

7.3. Fossil fuel production

The amount of CH_4 generated during coal mining is a function of mine rank, depth and other factors such as

Table 4
LPS emission contribution for energy sectors

Emission details		Power	Steel	Cement	Fertilizer	Sugar	Paper
Number of LPS		94	11	85	31	28	33
CO_2	LPS (Tg)	365	48	68	14	0.7	2.9
	LPS/total (%)	47	6	9	2	0.09	0.37
SO_2	LPS (Tg)	2.1	0.3	0.22	0.26	0.004	0.02
	LPS/total (%)	45	7	5	6	0.09	0.43
NO_X	LPS (Tg)	0.28	0.04	0.027	0.067	—	—
	LPS/total (%)	8	1.2	0.8	2	—	—

Table 5
LPS emission contribution from industrial activities

Emission details		H_2SO_4	HNO_3	Ore smelting			Al	Petrochemicals
				Pb	Cu	Zn		
Number of LPS		63	5	5	8	3	3	14
SO_2	LPS (Gg)	51		11	42	14	6	37
	LPS/Total (%)	11	—	0.23	0.9	0.3	0.13	0.9
NO_X	LPS (Gg)	—	12.7	—	—	—	1	13
	LPS/Total (%)	—	0.36	—	—	—	0.03	0.37

moisture. We have analyzed coal production data from 32 mine clusters in India with some having more than a dozen mines. The highest methane emitting mine cluster lies in Dhanbad district contributing 80 Gg methane emissions in 1995. The other categories include emissions from the production, processing, transport and use of oil and natural gas and from non-productive combustion (like fugitive emissions, which result from the combustion of natural gas during flaring operations). The transport and use of oil and natural gas is a distributed line source along the transport route but for simplicity we have taken it to be mainly concentrated around trans-shipment points. Fig. 8 indicates the national spread of methane emission from fossil fuel production. Bombay High in the Arabian Sea off Mumbai coast is the largest LPS under this category emitting 295 Gg methane.

7.4. Other sectors

Methane emissions from municipal solid waste (MSW) disposal sites in large urban conglomerations are the dominant LPS under this category. However, not much organized waste collection or disposal takes place in most of the Indian urban areas. Smaller cities and towns although have well-established municipal bodies and garbage collection and handling is one of their specified function, the extent and regularity of solid waste collection is not very high. Hence a major portion of this solid waste also decomposes aerobically generating lower methane. Big urban centers and metropolitan cities, however, have much better infrastructure and solid waste disposal is more systemized. The methane emission estimates from MSW in Delhi were 106 Gg and from Mumbai were 103 Gg in 1995.

8. Urbanization and LPS emissions

Urbanization is used as a broad concept here that includes ratio of urban to rural population, income levels, income distribution, level of economic activity, and energy and material consumption habits. In general, urbanization increases energy use and therefore emissions. LPS develop near large consumption centers (towns and cities) and in turn facilitate their expansion. There are 48 districts in India that have more than four LPS each (Table 6). These 278 LPS account for more than 40% of all India CO_2 and SO_2 emissions. About 56% of Indian districts do not have even a single LPS and 23% have only one LPS each. Each of these 80% districts has less than 2.5 Tg annual CO_2 equivalent GHG emissions and over 70% of rural population with agriculture sector domination. These districts also have low absolute emission levels and low emission growth trajectories (below 2% per year). This trend is observed both in 1990 and 1995. In contrast, the LPS emissions are showing high growth rates (above 6% per year) and the 25 highest CO_2 emitting districts account for more than 37% of all India CO_2 equivalent GHG emissions. It implies that urbanization and LPS are related.

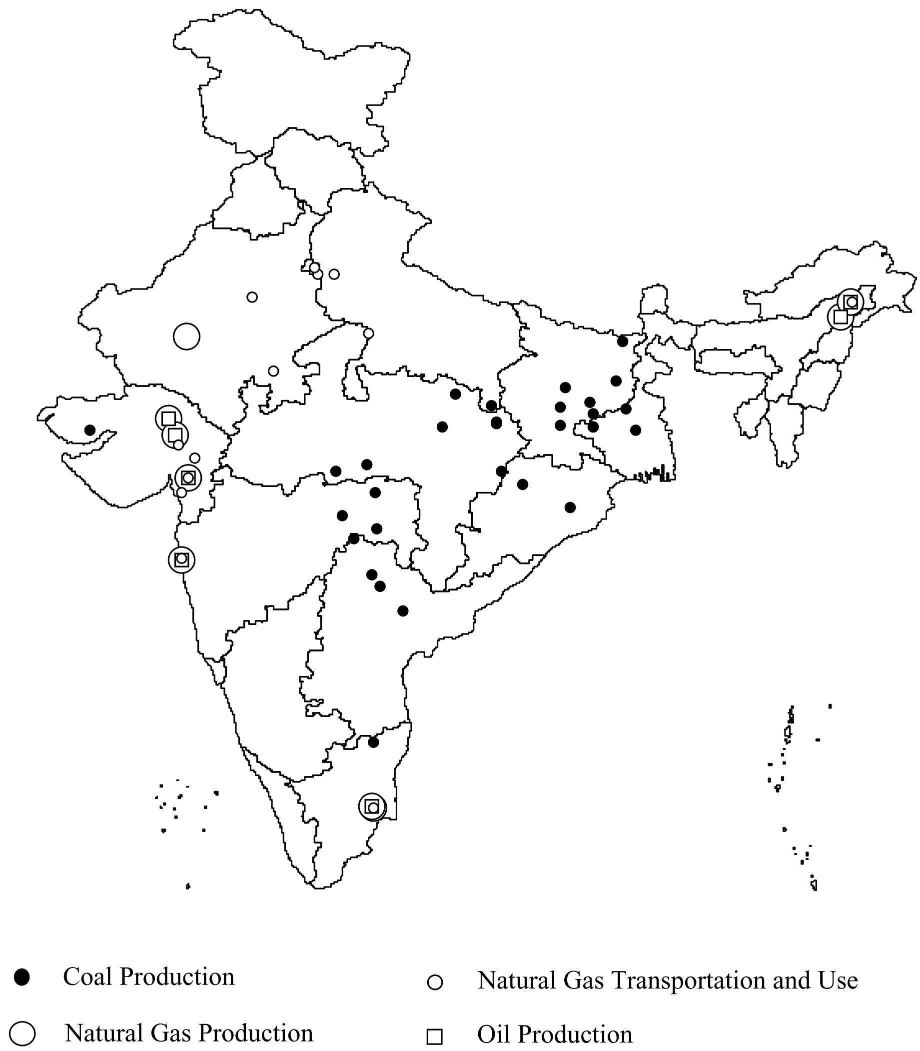


Fig. 8. Regional spread of methane emission from fossil fuel production.

A similar analysis for the four metropolitan cities of Delhi, Mumbai, Kolkata and Chennai indicates that their LPS emissions contribute above 50% to their individual CO_2, above 80% to methane and above 70% to SO_2 emissions (Table 7). They had a dominance of coal-based power plants and MSW sites except for Mumbai that had considerable share of gas and oil exploration activities contributing to methane emissions.

9. Mitigation flexibility

Analysis of LPS emissions highlights sectors and plants where mitigation efforts should be targeted for cost-effectiveness. The main contributors to Indian emissions are about 70 LPS (50 power, 5 steel and 15 cement plants), thus offering a good opportunity for focusing mitigation efforts (Table 8). Power sector is the predominant emission source for CO_2 and SO_2. Operational improvements (like heat rate reduction, excess air control, etc.), better maintenance, reducing transmission and distribution losses in the power sector would go a long way in emissions mitigation. The other policy options are switching from coal to lower carbon content fuels like natural gas, sequestering the emitted carbon from LPS, increasing renewable and nuclear technology penetration, etc. (Shukla et al., 1999) Table 9 lists the possible instruments and key institutions to implement these policies.

Efficiency improvement measures in other energy sector LPS like steel, cement, caustic soda, sugar and fertilizer would improve productivity while reducing

Table 6
District level distribution of LPS

LPS/district	No. of districts	Total LPS	LPS/all India emissions (%)				
			CO_2	CH_4	N_2O	NO_X	SO_2
0	259	0	0	0	0	0	0
1	108	108	7.1	1.1	0.3	1.3	7.6
2	30	60	9.3	0.4	0.4	1.7	9.4
3	21	63	7.3	0.5	0.3	1.3	6.5
4	16	64	9.1	1.2	0.9	1.8	10.0
5	9	45	8.4	0.3	0.4	1.5	8.4
6	9	54	8.2	0.8	0.4	1.4	7.9
7	8	56	11.5	0.8	1.2	2.1	10.9
8	2	16	1.4	0.8	0.1	0.2	1.3
9	2	18	1.8	0.5	0.6	0.5	2.1
10	1	10	0.7	0.4	0.0	0.2	1.0
15	1	15	0.6	2.7	0.8	0.4	1.0
Total	466	509	65.4	9.4	5.4	12.4	66.1

Table 7
Large point sources in the four metro-districts

City	No. of LPS	LPS/district emissions (%)			Major sources
		CO_2	CH_4	SO_2	
Mumbai	15	60	95	70	Power, gas and oil explorations, land fills, H_2SO_4 production
Chennai	10	67	90	77	Power, land fills
Delhi	8	52	80	77	Power, land fills
Kolkata	7	52	77	55	Power, land fills

Table 8
Main contributors to India's CO_2 equivalent GHG emissions

Source characterization	Source categories	% Share
LPS (major)	Fossil power (94)	29.6
	Steel (11)	8.8
	Cement (85)	5.0
	Land fills (14)	1.2
Many, small but concentrated sources	Transport	9.5
Many, small and dispersed sources	Livestock	12.6
	Paddy cultivation	6.8
	Biomass consumption	5.4
	Synthetic fertilizer use	4.1
Total		84[a]

overall emissions. Apart from LPS, there are many small, moving and concentrated point sources like vehicles in urban transport, and many small and dispersed sources like paddy fields and livestock in agriculture sector. Some of the policy options in Table 9, though useful for small but distributed sources as well, would not be cost-effective for them since implementation efforts would be substantial. For example, although transport sector sources contribute around 9.5% to India's CO_2 equivalent GHG emissions and 32% to NO_X emissions, their characteristics (large numbers and low emissions per source) necessitate huge mitigation efforts as compared to very focused mitigation efforts for LPS. Thus, GHG mitigation efforts may not be cost-effective for transport sector. However, measures like improving diesel and gasoline quality and stricter vehicle emission norms will reduce local pollution levels and to a certain extent GHG emissions as well.

Agriculture sector emissions, although contributing almost 29% to CO_2 equivalent GHG emissions, also consist of huge numbers (for example, livestock population was over 460 million in 1992) and are much more widely and evenly dispersed across the country. This sector is mostly unorganized in India and mitigation efforts would be that much more difficult. However, efforts like adoption of better farming practices for paddy cultivation, developing better cattle feed, etc.

Table 9
Emission mitigation for power sector LPS

Policies	Measures	Key institutions[a]	Implementation strategy
Efficiency improvements	Emission targets, emission taxes, emission standards	MOEF, CERC/SERC, EMC, ESCO	Standards, permits, emissions accounting, monitoring, non-compliance penalties
Fuel switch	Fuel tax, mandatory use	MOEF	Infrastructure development
Sequestration	Technology transfer, tax	MOP, MOEF	technology RD&D
Renewable technologies	Emission tax, subsidy, tariff, technology transfer	MNES, IREDA, Industry Associations	Grid connection, maintenance support, local skill development
Nuclear	Environment taxes, social consensus	DOAE, AEC	Technology cooperation, safer waste disposal

[a] MOEF (Ministry of Environment and Forests), CERC (Central Electricity Regulatory Commission), SERC (State Electricity Regulatory Commission), EMC (Energy Management Center), ESCO (Energy Service Company), MOP (Ministry of Power), MNES (Ministry of Non-conventional Energy Source), IREDA (Indian Renewable Energy Development Agency), DOAE (Department of Atomic Energy), AEC (Atomic Energy Commission).

Table 10
Emission mitigation for LPS in industrial activities

Policies	Measures	Key institutions	Implementation strategy
Process improvements	Standards, tax, awareness	Regulatory bodies, industry associations	Standards, emissions accounting, monitoring and correction
Raw material improvements	Industry standards, RD&D, tax	Regulatory bodies, industry associations	Industry leadership, supply chain management
Materials switching	Industry standards, RD&D	Industry associations	Manage lobbying, demonstration projects
Technology push	Technology transfer, RD&D	Technical institutes, industry associations	Financial mechanisms technology cooperation
Recycling and reuse	Standards, tax awareness	Regulatory bodies, industry associations	Civil society pressures, labeling

should continue as independent activities to improve agriculture sector productivity. Methane emission mitigation may just be consequential.

LPS emissions due to industrial activities contribute mainly to SO_2 and NO_X. Process and efficiency improvements offer substantial mitigation possibilities here as well. Reduction in other environmental externalities like toxic wastes, industrial wastewater, land degradation, etc., would be additional benefits. Other policy options are improvements in raw materials, penetration of new technology, material switching (like steel to aluminum/plastics in car industry), recycling and reuse, etc. (Table 10). Mandatory standards, awareness generation in the industry and a pollution tax are some possible instruments for implementing these policies. The industrial associations have to play a proactive role here and the government has to be a facilitator.

10. Conclusion

The present paper is an attempt to analyze Indian LPS emissions. The results demonstrate that large point sources are responsible for considerable part of the Indian emissions. It is estimated that in 1995, the 100 largest LPS alone emitted more than 440 Tg CO_2 (57% of national CO_2 emissions), 2.73 Tg SO_2 (59%), 1.74 Tg CH_4 (9.4%), 14 Gg N_2O (5.6%) and 0.4 Tg NO_X (12%). The paper has concluded that air pollution control in India is not as horrendous as it appears. Concentrate on 70 LPS to tackle more than 50% of Indian SO_2 and CO_2 emissions (Table 3). We have indicated that mitigation efforts should be concentrated to 50 power plants, 5 steel plants and 15 cement plants initially. However, measures like stricter enforcement of electro-static precipitator norms at cement and power plants, sulfur reduction in petroleum oil products (especially diesel and fuel oil) and gradual replacement of older vehicles with at least Euro-II compliant stocks should continue simultaneously to speed up local air cleaning. These policies also constitute the priorities for reducing the adverse health impacts of local air pollution. Table 11 gives an overall emissions mitigation framework for India.

Higher emission growth rate of CO_2 (5.6% per annum presently) vis à vis methane (1.1% presently) is likely to increase the share of CO_2 from present 62% to 76% in

Table 11
Emission mitigation framework

Parameters	Large point sources	Many, small but concentrated	Many, small and dispersed
Sectors	Energy, industry, land fill	Urban transport and households	Agriculture, rural households
Main emissions	CO_2, SO_2, SPM, CH_4	CO_2, SO_2, SPM, NO_X	CO_2, CH_4, N_2O
Policies	Emission targets, taxes, technology push	Technology/fuel standards, technology push, clean fuel	Clean substitutes, improved cultivar, low CH_4 rice/cattle feed
Measures	Emission rights, accounting, clean technologies	Efficient engine, low sulfur fuel, catalytic converter, monitoring and enforcement	Local institutions, user education/ training, information program, market development
Key institutions	Government, industry associations	Government, vehicle manufacturers, consumers	Agriculture university, agriculture extension, government
Implementation strategy	Standards, permits, emissions accounting, monitoring, correction	Standards, monitoring, enabling environment, manage lobbying	RD&D projects, communication, distribution network

CO_2 equivalent GHG emissions by 2035 (Shukla et al., 1997; Garg, 2000; Garg et al., 2001c). Power generation and industry would contribute almost 75% of CO_2 emissions. Since these sectors have a natural dominance of LPS, mitigating emissions from LPS would become even more important in future. Even for methane, the increasing emissions from landfills LPS in mega-cities would offer possibilities of methane recovery for domestic use. Similarly, as coal consumption increases in future, there would be good potential for harvesting coal-bed methane from coal mine LPS.

Although GHG and local pollutant emission mitigation targets for a country are often useful as overall policy targets, the marginal mitigation cost for achieving each target varies across regions and sectors. The LPS analysis contributes to effectiveness of emissions mitigation by indicating the locations and sectors where controls can lead to maximum benefits. The present work is the first step in this direction for India.

References

Biswas, D.(Ed.), 1999. Parivesh News Letter. Central Pollution Control Board, Ministry of Environment and Forests, Government of India, New Delhi, June.

CMIE, 1999. India's Energy Sector. Center for Monitoring Indian Economy, Mumbai.

Garg, A., 2000. Technologies, Policies and Measures for Energy and Environment Future. Doctoral Thesis, Indian Institute of Management, Ahmedabad, India.

Garg, A., Shukla, P.R., Bhattacharya, S., Dadhwal, V.K., 2001a. Sub-region (district) and sector level SO_2 and NO_x emissions for India: assessment of inventories and mitigation flexibility. Atmospheric Environment 35, 703–713.

Garg, A., Bhattacharya, S., Shukla, P.R., Dadhwal, V.K., 2001b. Regional sectoral assessment of green house gas emissions in India. Atmospheric Environment 35, 2679–2695.

Garg, A., Ghosh, D., Shukla, P.R., 2001c. Integrated Energy and Environment Modelling and Analysis for India, Vol.1, No. 38. OPSEARCH, Kolkata, India, February.

Hu, Xiulian, Hongwei, Y., 2000. Disaggregate SO_2 emissions from national total to county level distributions for China. Presented at the Fifth AIM International Workshop, National Institute of Environmental Studies, Tsukuba, Japan, 24–25 March.

ICRA, 1995. The Indian Cement Industry Update. ICRA Industry Watch Series No. 1, ICRA Investment Information Publications, New Delhi.

IPCC, 1996. Revised IPCC Guidelines for National Greenhouse Gas Inventories: Reference Manual, Vol. 3. Inter Governmental Panel on Climate Change, Bracknell, USA.

Li, Y.F., Zhang, Y.J., Cao, G.L., Liu, J.H., Barrie, L.A., 1999. Distribution of seasonal SO emission from fuel combustion and industrial activities in Shanxi province, China, with $1/6^\circ \times 1/4^\circ$ longitude/latitude resolution. Atmospheric Environment 33, 257–265.

Shukla, P.R., Loulou, R., Kanudia, A., 1997. Energy and Environment Strategies for a Sustainable Future: Analysis with the Indian Markal Model. Allied Publishers, New Delhi.

Shukla, P.R., Ghosh, D., Chandler, W., Logan, J., 1999. Developing Countries and Global Climate Change: Electric Power Option in India. PEW Center on Global Climate Change, Arlington, USA.

WB, 1997. A Planner's Guide for Selecting Clean Coal Technologies for Power Plants. World Bank Technical Paper No. 387. The World Bank, Washington, DC.