5 INDUSTRY SECTOR

Air pollutant emissions from industries are the result of different categories of manufacturing activities. Different air pollutants are released to the atmosphere through industrial chimneys/stacks. Emissions from industries can be broadly classified as: i) combustion-related emissions due to the burning of fuels, *viz.,* coal, petcoke, biomass, furnace oil, diesel and natural gas in different types of boilers, furnaces, etc., ii) non-combustion emission related to the use of naptha, natural gas, etc., as feedstock, and iii) fugitive emission related to manufacturing processes, storage, and handling of materials, etc.

Combustion-related emissions from industries are function of quality of fuel, boiler type, and emission controls. Emissions from industries are estimated based on the following equation (Eq. 12):

$$[E_p]_I = \sum_{a=1}^{n} \sum_{f=1}^{n} [C_f]_a \times EF_{(f,p)} \times (1-RE_a) \quad (12)$$

where, $[E_p]_I$ is the emission of a particular pollutant (p) from the industry sector; C_f is annual consumption of a particular fuel in industry type a; $EF_{(f,p)}$ is emission factor of pollutant p of the fuel type f related to the boiler type; and RE_a is percentage removal efficiency of installed pollution control device in industry type a. $EF_{(f,p)}$ was developed based on review of published literature.

Fugitive emissions (*f*) from industrial arc furnace and induction furnaces was estimated using the following equation (Eq. 13):

$$f\,[E_p]_I = \sum_{u=1}^{2} [M_u]_a \times EF_{(p,u)} \times (1-RE_u) \quad (13)$$

where, M is the amount of materials processed in a particular type of furnace (*u*); EF is emission factor for a particular pollutant p; and RE is the efficiency of the control device used. *u*=1 is arc furnace while *u*=2 is induction furnace in the above equation.

Emissions were estimated separately for large-scale industries, *viz.,* cement, iron and steel, fertilizers, paper, aluminium, and glass. For each category of large-scale industries, emissions due to process and combustion were estimated separately. Production capacity of each category of industry was taken from the MARKAL model (*Annexure V*). In order to estimate emissions due to the combustion of different fuel types, fuel-wise actual energy consumed data were taken from the MARKAL model. Based on the calorific value of each type of fuel, this actual energy consumed by each fuel type is then converted into fuel consumed. The remaining small- and medium-scale industries were clubbed into the 'Other industries' category. Actual energy consumed in these industries was taken from the MARKAL model. Emissions were estimated following Eq. 12 and Eq. 13. Apart from these emissions of different industries, the emissions from the brick kiln and mines were estimated separately. The estimation of emissions from each category of industry is explained in subsequent sections.

5.1 Large-scale industries

5.1.1 Cement industry

Cement manufacturing processes lead to emissions of PM and other gaseous pollutants. The emissions from cement manufacturing processes are:

- *Fugitive emissions*: Due to handling and storage of raw, intermediate, and final materials
- *Process emissions*: Due to operation of kiln, clinker coolers, and mills.

Major emissions occur in the kilns during production through physical and chemical reactions involving the raw materials and the combustion of fuels. Emissions were estimated based on the production, energy or fuel consumed, emission factor per unit of cement production, and efficiency of controls. The indigenous emission factors per unit of cement production were adopted from Infrastructure Leasing & Financial Services Limited (ILFSL, 2010) and CPCB (2007) (Table 10). Bag filter and ESPs are the common air pollution control devices used by cement industries to control stack emissions. The estimated emissions of different pollutants from the cement industries are shown in Figure 4. The emissions also include pollutants emitted during captive power generation activities.

Table 10 Emission factor (kg/Mg) for cement sector

	PM		NOx	SO_2	CO
	W/o APCD	APCD	W/o APCD	W/o APCD	W/o APCD
Dry Process					
Kiln	94	0.98			
Grinding	257	0.21			
Others	7	0.01			
Total	358	1.2	2.2	4.9	0.27
Fugitive		0.56			
Wet process					
Kiln	174	0.2			
Grinding	123	0.02			
Others	6	0.03			
Total	303	0.25	4	3.75	0.27

APCD: Air Pollution Control Devices; W/o APCD: without Air Pollution Control Devices

Source: ILFS (2010), CPCB (2007)

5.1.2 Iron and Steel industry

Production of coke, sinter and pellets, iron ore processing, making of iron and steel, steel casting, combustion of blast furnace and coke oven gases are the major processes involved in iron and steel manufacturing that result in the emissions of different pollutants. Emissions are estimated based on the production, energy/fuel consumed, and emission factors. The emission factors were adopted from the European Environmental Agency (EEA) and GAINS-Asia and are shown in Table 11. Generally, iron and steel plants in India are equipped with efficient air pollution control devices such as ESPs and wet scrubbers for reduction of PM and gaseous emissions. oHThe estimated emissions from iron and steel manufacturing process are shown in Figure 4.

Table 11 Emission factors (kg/Mg) for different pollutants from various processes in iron and steel making

Pollutant	Process		Steel making with ESP	
	Sintering	Pig-iron	Basic oxygen furnace	Electric arc furnace
$PM_{2.5}$	0.08	0.025	0.021	0.021
PM_{10}	0.1	0.04	0.024	0.024
NO_x	0.5		0.01	0.13
SO_2	1	0		0.06
CO	12	10	7	0.0017
NMVOC	0.138	0	0	0.046

5.1.3 Aluminium industry

Emissions from this sector were estimated using activity data (production and energy/fuel consumed) and emission factor. The emissions include pollutants emitted during captive power generation activities also. The emission factor for aluminium production was taken from EEA (2009), EPA (2012), and GAINS-Asia (Table 12). The estimated emissions are shown in Figure 4.

5.1.4 Glass industry

The glass industry is highly energy intensive, and the melting and refining process accounts for 60–70% of the energy consumed in production. Natural gas is the fuel used in India as the thermal energy source in this sector. The emissions from this sector are estimated based on the production data and emission factor. The production data for the year 2016 was taken from GAINS-Asia. About 4.54 Mt of glass was produced during the year 2016. The emission factors of different pollutants for glass manufacturing was adopted from EEA (2009) and GAINS-Asia (Table 12). The estimated emissions of different pollutants are presented in Figure 4.

5.1.5 Paper and pulp industry

The Kraft method is broadly used in India for paper production. Pollutants are emitted from different processes in paper and pulp manufacturing as well as from combustion of coal in boilers. Emissions from processes and combustion are estimated using activity data (production and energy/fuel consumed) and emission factors. The emission factors of different pollutants in the paper industry are taken from EEA (2009) and EPA (2012) and are presented in Table 12. The estimated total emissions from process and combustion in the paper and pulp industrial sector are shown in Figure 4.

5.1.6 Fertilizer industry

Emissions from fertilizer industry were estimated from activity data (production) and emission factors. The emission factors for different pollutants for estimation of emissions in the fertilizer industry is taken from AP 42 (USEPA, 1995). The emission factors used in this study for estimation of emissions from large-scale industries are presented in Table 12 and estimated emissions are shown in Figure 4.

Table 12 Emission factors (kg/mg) of different pollutants from various large-scale industries

Parameter	Aluminium production	Glass manufacturing industry	Paper & pulp industry	Fertilizer industry
PM_{10}	2.0	0.27	0.8	0.33
$PM_{2.5}$	1.0	0.24	0.6	0.22
NO_x	1.0	8.12	1.0	2.00
SO_2	6.0	1.74	2.0	0.04
CO	120.0	0.10	5.5	62.25
NH_3				8.37*
NMVOC			2.0	

* kg/mg of urea produced.

Source: USEPA, 1995.

5.1.7 Emission inventory of large-scale industries

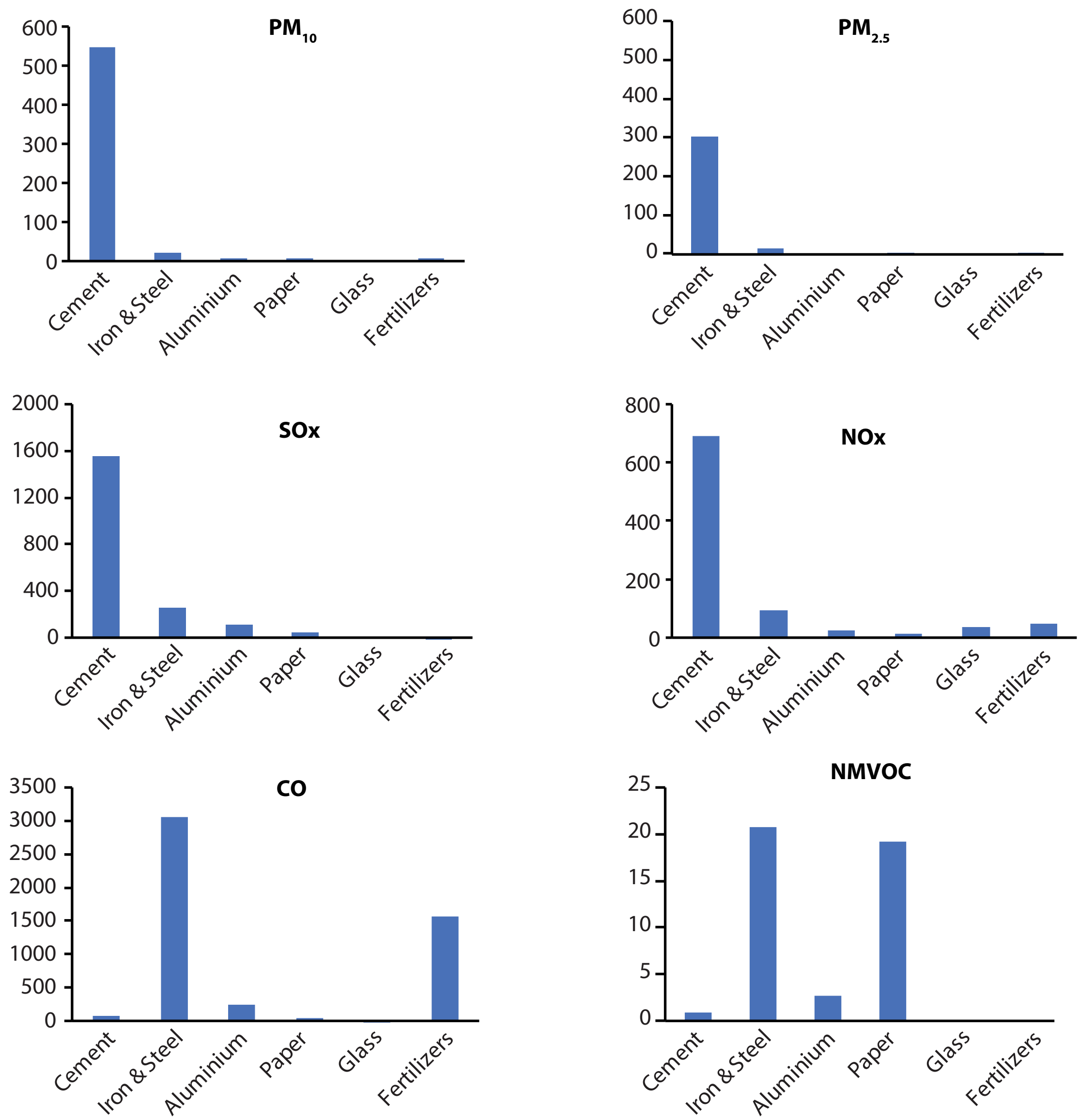
Estimated emissions of different pollutants from the large-scale industries during 2016 are summarized in Figure 4.

5.2 Micro-, small- and medium-scale industries

The energy consumed in the small- and medium-scale industry sector such as manufacturing of apparel wearing, food and beverages, sugar industry, pharmaceuticals, chemical, hosiery, textile, furniture making, plastic and paper-based industry, etc., was collected from the MARKAL model. PM_{10} and $PM_{2.5}$ emission factors for coal combustion in industries was calculated based on ash content and efficiency of air pollution control devices using Eq. 14:

$$EF_C = A_c \times R \times fPM \times (1- RE_a) \qquad (14)$$

where, EF_c is the emission factor of coal combustion; Ac is the ash content of the coal (***Table 13***); R is the ratio of fly ash and bottom ash during the combustion of coal; and fPM is the fraction of PM_{10} or $PM_{2.5}$ in total PM.



CEM: Cement industry; IRS: Iron & steel industry; ALU: Aluminium industry; GLA: Glass manufacturing industry; PAP: Paper & pulp industry; FER: Fertilizer industry.

Figure 4 Emissions of different pollutants from the large-scale industries during 2016

Table 13 Coefficient of coal combustion in small- and medium-scale industries

Coefficient	High control (e.g. ESP)	Medium control	Low control
Ash content (Ac)	35%	35%	35%
F/B ash ratio (R)	80:20	80:20	80:20
PM_{10}/PM (fPM_{10})	0.71	0.48	0.39
$PM_{2.5}$/PM ($fPM_{2.5}$)	0.35	0.29	0.21
Efficiency of control (%)	99.90	70.00	40.00

Emission factors of other fuels used in the small- and medium-scale industries were taken from CPCB (2011) and GAINS-Asia (Table 14).

Table 14 Emission factors (Kt/PJ) of different pollutants from different fuels used in the small- and medium-scale industries

Fuel	PM_{10}	$PM_{2.5}$	NO_x	SO_2	CO	HC
Coal	3.75	2.03	0.13	0.57	0.01	0.02
Natural gas	0.002	0.002	0.07	0.02	0.04	
Biomass	0.12	0.11	0.03		0.30	0.80
Furnace oil	0.11	0.07	0.15	1.73	0.01	0.09
Diesel	0.77	0.26	0.08	0.94	0.04	
Light diesel oil	0.77	0.26	0.08	0.94	0.04	
Naptha	0.10	0.10	0.07	0.02	0.04	

5.2.1 Emission inventory of micro-, small- and medium-scale industries

Currently, in India only large-scale industries are equipped with high efficient equipment, *viz.,* ESPs and bag filters. Based on expert consultation and industrial survey during the present study, it was found that the efficiency of the control equipments varies from 10% (e.g., gravity settling chamber) to as high as 99% (e.g., ESP and bag filters), which are rarely used in small- and medium-scale industries. Most of these industries use cyclones (60%), multi-cyclones (80%) and dust collectors (10%) and a very good percentage of small- and medium-scale industries are running without APCDs and if at all they are using APCDs, then it is not properly maintained. Based on these, it was assumed that all micro- and small-scale industries were equipped with APCDs with efficiency of 40% and medium-scale industries were equipped with APCDs with efficiency of 70%. The estimated emissions from micro-, small- and medium-scale industries are shown in Table 15.

Table 15 Total emissions of different pollutants from the micro-, small- and medium-scale industries during 2016

Pollutant	PM_{10}	$PM_{2.5}$	SO_2	NO_x	CO	VOCs	NH_3
Emission (Gg)	4126.1	2231.7	1551.6	283.9	44.1	56.9	0.29

Industries are mostly concentrated in different industrial zones of India. Industrial emissions were spatially distributed based on their locations all over the country (Figure 5).

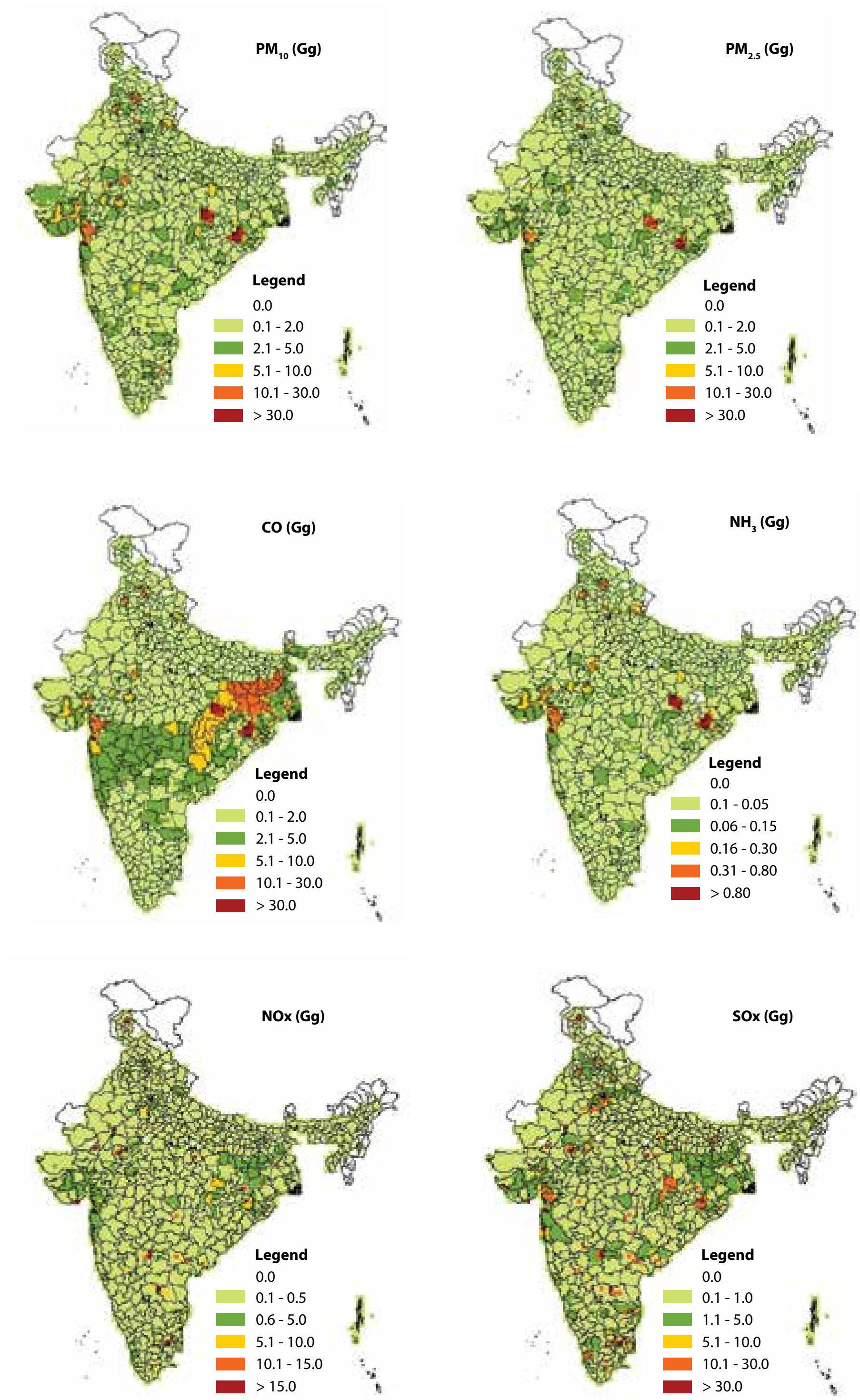


Figure 5 Spatial distribution of large-, micro-, small- and medium-scale industrial emissions during 2016

5.3 Emission inventory of brick kilns

Brick kilns are one of the largest consumers of coal in India. The brick industry in India consumed about 31 Mt of coal and 14 Mt of biomass for the year 2015 (Mahtta et al., 2016) which corresponds to a brick production of 236 billion for the same year. Bull's trench kilns (BTK) and clamp kilns are the two major brick firing technologies used in India. Other firing technologies, which are not significant in terms of brick production, are Vertical Shaft Brick Kiln (VSBK), Hoffman, Zig-zag, Down Drought Kiln (DDK), and tunnel kilns. Bull's trench kilns account for about 70% of total brick production in India (Rajaratnam et al., 2014). The brick manufacturing sector is an unorganized sector, using old technologies with low combustion efficiencies and limited control for air pollutants emissions. Due to rapid increase in brick production, the corresponding fuel consumption has also increased resulting in the emissions of pollutants such as PM, SO_2, NO_x, CO, metals, organic compounds, etc. The emissions from the brick kiln sector are estimated based on the state-wise technology-wise annual brick production data (TERI, 2016) and technology-wise emission factor. Emissions from the brick kilns were estimated using Eq. 15:

$$[E_p]_{bt} = \sum_{t=1}^{n} [W_b]_t \times EF_{pt} \qquad (15)$$

where, $[E_p]_{bt}$ denotes emissions of a particular pollutant p for fire technology t; $[W_b]_t$ is the total weight of the brick produced by a particular technology t; and EF_{pt} is the emission factor for a particular pollutant for the particular technology t. The total weight of the brick produced by a particular firing technology is estimated from the total number of bricks produced annually and weight of the fired brick. After consultation with experts, we have assumed the weight of the fired brick as 3 kg. Technology-wise emission factors for different pollutants are selected based on review of published literature (Rajarathnam et al., 2014) (Table 16).

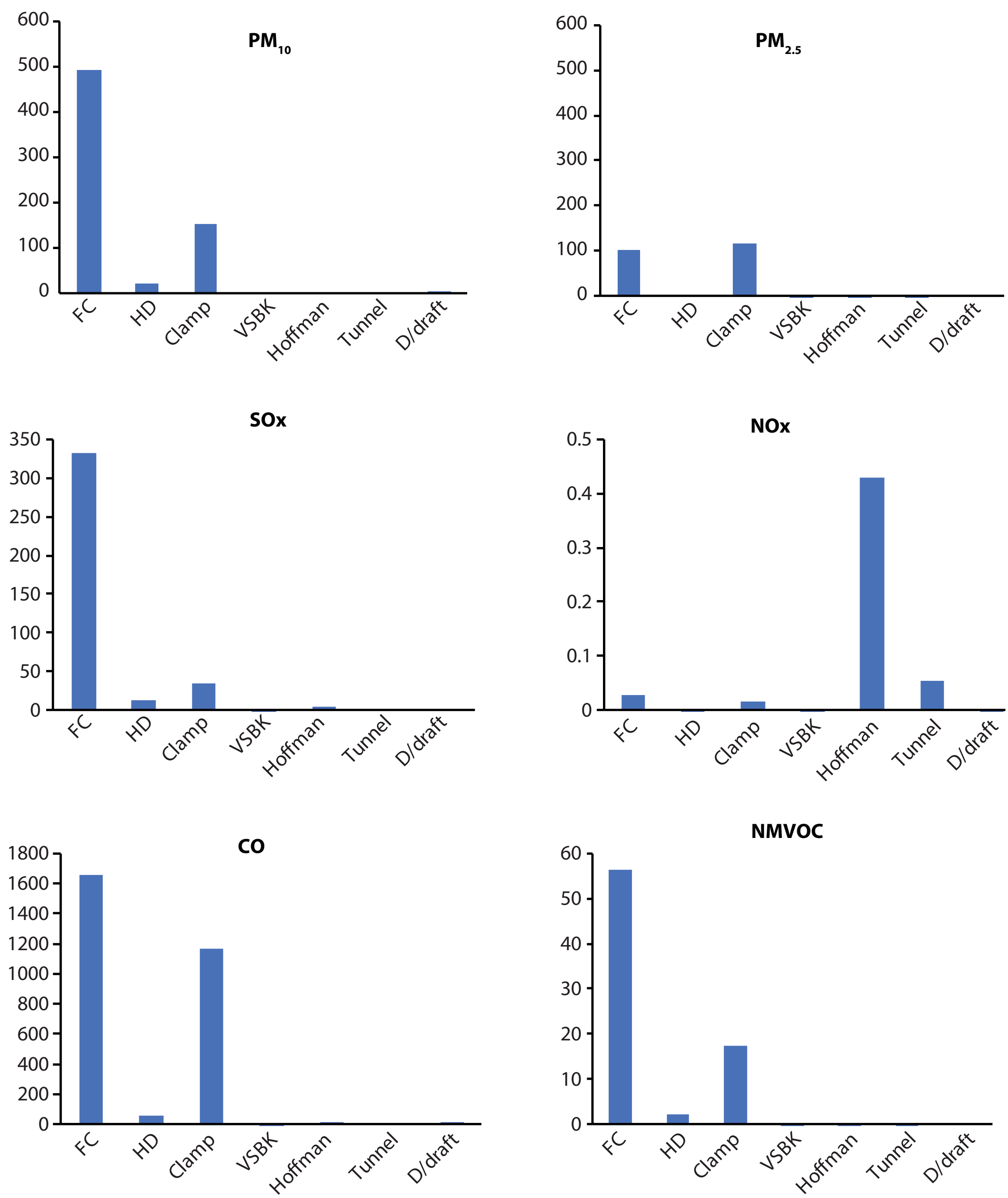
Table 16 Technology-wise emission factors for different pollutants of brick kiln

Technology	Emission factor (g/kg of fired bricks)				
	PM_{10}	$PM_{2.5}$	SO_2	NO_x*	CO	VOCs*
FCBTK	0.875	0.18	0.59	0.00005	2.94	0.1
HD	0.875	0.18	0.59	0.00005	2.94	0.1
Clamp	1.3*	1*	0.3*	0.00015	10*	0.15
VSBK	0.1	0.09*	0.32	0.01275	2.99	0.08
Hoffman	0.12*	0.08	0.72*	0.067	2.5*	0.013
Tunnel	0.31	0.18	0.72	0.018	2.45	0.016
DDK	1.56	0.97	0.00002*	0.0001	5.395*	0.15

Source: *GAINS Asia, rest: Rajarathnam et al., 2014

5.3.1 Emission inventory of brick kilns

The estimated total emissions from brick kilns in India are summarized in Figure 6.



A = FCBTK, B = HD, C = Clamp, D = VSBK, E = Hoffman, F = Tunnel, G = DDK

Figure 6 Estimated emissions of different pollutants from different types of brick kilns during 2016

Though there is wide variation in spatial distribution of brick kilns in India, most of the brick kilns are located in the Indo-Gangetic Plain region of India. Accordingly, the emissions from the brick kilns were spatially distributed (Figure 7).

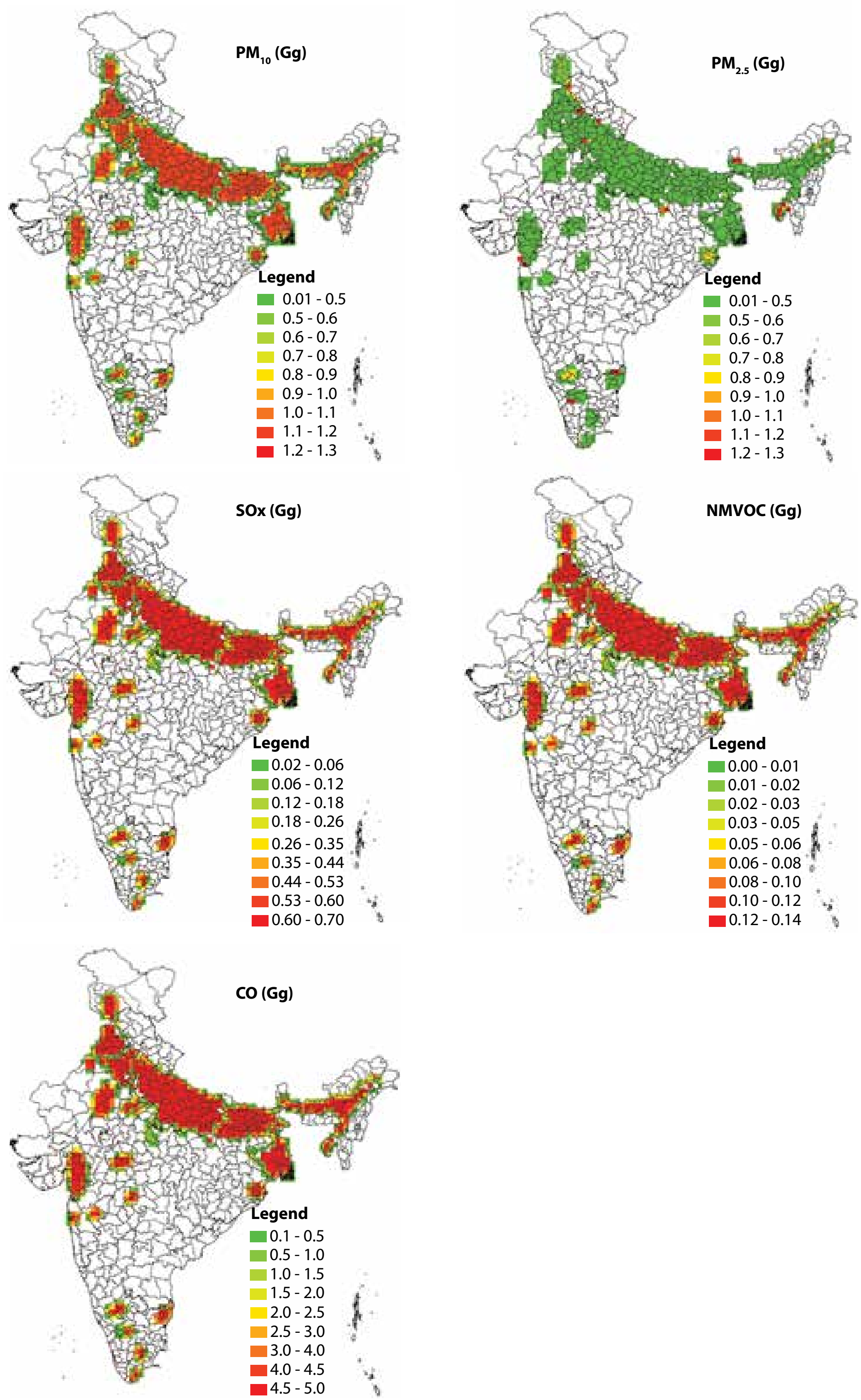


Figure 7 Spatial distribution of atmospheric particulate matter emissions from brick kilns during 2016

5.4 Total emissions from industry sector

In summary, the estimated total emissions from the industry sector are shown in *Table 17*.

Table 17 Total industrial sector emissions (Gg) in India during 2016

Sector	PM_{10}	$PM_{2.5}$	SO_2	NO_x	CO	VOCs	NH_3
Large-scale industry							
Cement	547	304	1514	672	85	1	
Iron & Steel	21	16	261	94	3056	21	
Aluminium	6	3	118	26	252	3	
Paper	8	6	45	15	51	19	
Glass	1	1	8	37	0	0	
Fertilizers	8	5	1	50	1569	0	164.5
Sub-Total	591	335	1947	894	5013	44	164.5
Micro-, Small- and Medium-Scale industries							
	4126	2232	1552	284	44	57	0.3
Brick kilns	669	225	387	1	2921	76	
Total emissions	5386	2792	3886	1179	7978	177	164.8

Micro-, small- and medium-scale industries contributed to 74% of the total PM_{10} emissions from the industry sector in India during the year 2016. Brick kilns (12%) and cement industries (10%) (Table 17) were the highest emitting sectors. Most of these industries are not equipped with APCD, and even the efficiencies of the installed APCDs in these plants are much lower (40–60%) than those in large-scale industries. This contributes to the higher emissions of pollutants in micro-, small- and medium- scale industries compared to large-scale industries, which are mostly equipped with high-efficiency APCD.

The estimated emissions from industrial sector were spatially distributed to 36 km × 36 km grids based on the district-level industrial fuel consumption in different industries (MoSPI, 2016). However, for iron and steel and cement sectors, the emissions were distributed to the grid locations using the actual coordinates of plants. The emissions from the brick kilns were distributed spatially, based on Fixed Chimney Bull's Trench Kiln (FCBTK) identified using DigitalBoard Quickbird satellite data (at 2.62 m multispectral nadir).