AIR POLLUTANT EMISSIONS SCENARIO FOR INDIA

EDITORS

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The Energy and Resources Institute

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Suggested format for citation

Sharma S., Kumar A. (Eds), 2016, Air pollutant emissions scenario for India,.The Energy and Resources Institute. New Delhi.

Chapter Citation

Chapter Authors, Chapter name, In : Sharma S., Kumar A. (Eds), 2016, Air pollutant emissions scenario for India, The Energy and Resources Institute

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Printed in India

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PREFACE

ACKNOWLEDGEMENTS

We gratefully acknowledge the support provided by the UK Aid for carrying out research to develop air pollutant emission inventories in India and coming up with this publication. The support was crucial in developing this important database of spatially distributed multi-sectoral air pollutant emission inventories for India. However, the views expressed do not necessarily reflect the official policies of the UK government.

The project team thankfully acknowledges the cooperation extended by various government departments/organizations in providing relevant data and information. We gratefully acknowledge the reviewers of the book who provided their unconditional and unbiased comments and suggestions to improve the quality of the estimates. Finally, the project team thankfully acknowledges the kind support, guidance and cooperation by TERI colleagues during the entire study duration.

CHAPTER 1

Introduction

Sumit Sharma and Atul Kumar

India is following a steep trajectory of economic growth. This makes it essential to plan for optimal energy use and reduced impact over the environment. Energy consumption in different sectors is linked to emissions of various air pollutants that deteriorate air quality at different scales. Some of the pollutants are linked to inefficiency in the combustion processes and others are due to inadequate tail-pipe controls required for their treatment. There are market-driven improvements that have happened on energy efficiency fronts in the industrial sector, which have led to some control of pollutant emissions. Some efforts have been made to control emission of air pollutants and betterment of air quality at the city and national scale. However, rapid growth in different sectors has negated the effects of these interventions and led to further deterioration of air quality.

The health impacts of the deteriorating ambient air quality, especially in urban cities of India are of serious concern. Violation of ambient air quality standards for particulate matter (PM) in about 80 per cent of the Indian cities conveys a grim picture of the prevalent ambient air quality across the country (CPCB 2014). Air pollutants, such as PM, carbon monoxide (CO), oxide of sulphur (SO_2), hydrocarbons (HCs), oxide of nitrogen (NO_x), are emitted from variety of sources and have adverse health effects. The impacts of some of the pollutants can be seen at the regional scale. Ground level ozone formed by reactions of NOx and HC can lead to detrimental impacts on agricultural productivity of a region. The various impacts of air pollution are documented in a number of studies.

One of the preliminary step towards forming an air quality management plan is to generate source-wise emission inventories of different pollutants. These inventories are generally compiled for emissions from energy use in different sectors such as transport, industries, power, residential, etc., and fugitive emissions from non-energy sources, such as road dust, storage and handling of fuels, etc. The emission

inventories are developed for a base year and could be projected for future years under different growth scenarios. Emission inventory is one of the fundamental components of air quality management plan to assess the progress or changes over time to achieve the cleaner air goal. Also, emission inventories are an important input to the atmospheric models for simulation of atmospheric pollutants.

For India, efforts have been made in past (Chatani *et al.* 2014; EDGAR 4.2 ((http://edgar.jrc.ec.europa.eu/); Garg and Shukla 2002; Garg *et al.* 2006; Klimont *et al.* 2009, Kurokawa *et al.* 2013; Lu *et al.* 2011; Ohara *et al.* 2007; Purohit *et al.* 2010; Sahu *et al.* 2012; Sharma *et al.* 2015; Streets *et al.* 2003; Zhang *et al.* 2009) to estimate emissions for different sources and pollutants. However, limited efforts are being made to understand the possible future trajectory of emissions for different sectors and pollutants, using integrated modelling approach. This study has used an integrated modelling approach for achieving the above-mentioned goal. The integration of energy modelling exercise with emission assessment models helps to understand the overall energy mix in India and inventorize the air pollutant loads from different sectors (from energy-based and non-energy-based sources) at a suitable resolution after taking into account all the macro-economic changes in future in an integrated manner. In this study, the TERI MARKAL Model is linked with the emission estimation models to develop multi sectoral emission inventories in an integrated manner.

Goal

To develop and document air pollutant emission inventories for different sources in India for a base year and future. This study does not include emissions of greenhouse gases and only focusses on air pollutant inventories.

Research Objectives

- To prepare a baseline of emission inventories of air pollutant loads across different energy- and non-energy-based sources.
- To prepare grid-wise high-resolution dataset of air pollutant emissions inventory for India.
- To project the future emission inventories using integrated energy and emission modelling approaches.
- To draft specific policy recommendations for emission control in India.

Approach and Methodology

The overall framework used in this study is shown in Figure 1.1. Energy system modelling is carried out using the MARKet ALlocation (MARKAL) model (Loulu

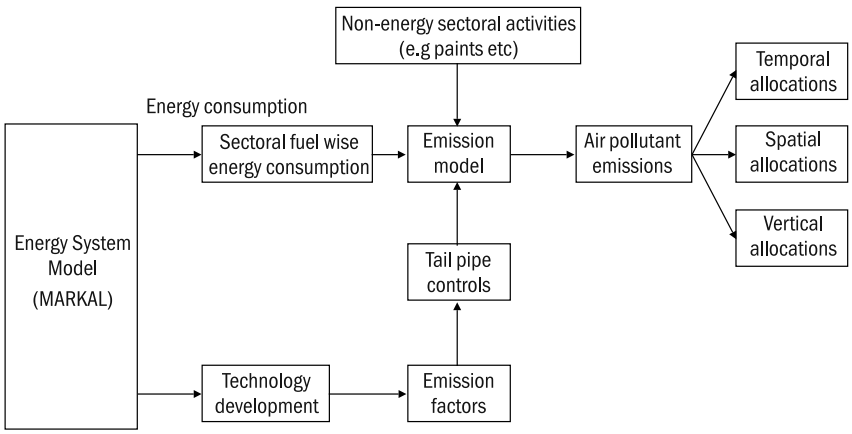

Figure 1.1: Overall framework for emission estimation

et al. 2004) for India, which is fed into the emission model to estimate emissions. The estimated emissions are spatially allocated at the finest possible resolutions.

The broad approach used in this study is further is explained by Equation 1.

$$E_k = \Sigma_l \Sigma_m \Sigma_n A_{k,l,m.}(1 - \eta_{l,m,n}) X_{k,l,m,n} \quad (1)$$

where,

k, *l*, *m*, *n* are region, sector, fuel, or activity type, abatement technology; *E* denotes emissions of pollutants (*kt*); *A* the activity rate; *ef* the unabated emission factor (*kt* per unit of activity); η the removal efficiency (%); and *X* the actual application rate of control technology *n* (%) where $\sum X = 1$ (Klimont *et al.* 2002).

Energy use information from the MARKAL model results is fed into the emission modelling equations to derive emission estimates for India. The main sectors considered in the analysis are residential, transport, industries, power, and non-energy under the fuel categories of coal, diesel, gasoline, natural gas, liquefied petroleum gas, and biomass. The emission inventory was prepared for pollutants, such as PM, NOx, SO_2, CO, and NMVOC. PM emissions are also speciated into different fraction of PM10, PM2.5, black carbon (BC), and organic carbon (OC).

The schematic for steps followed for emission inventorization is presented in Figure 1.2. This includes

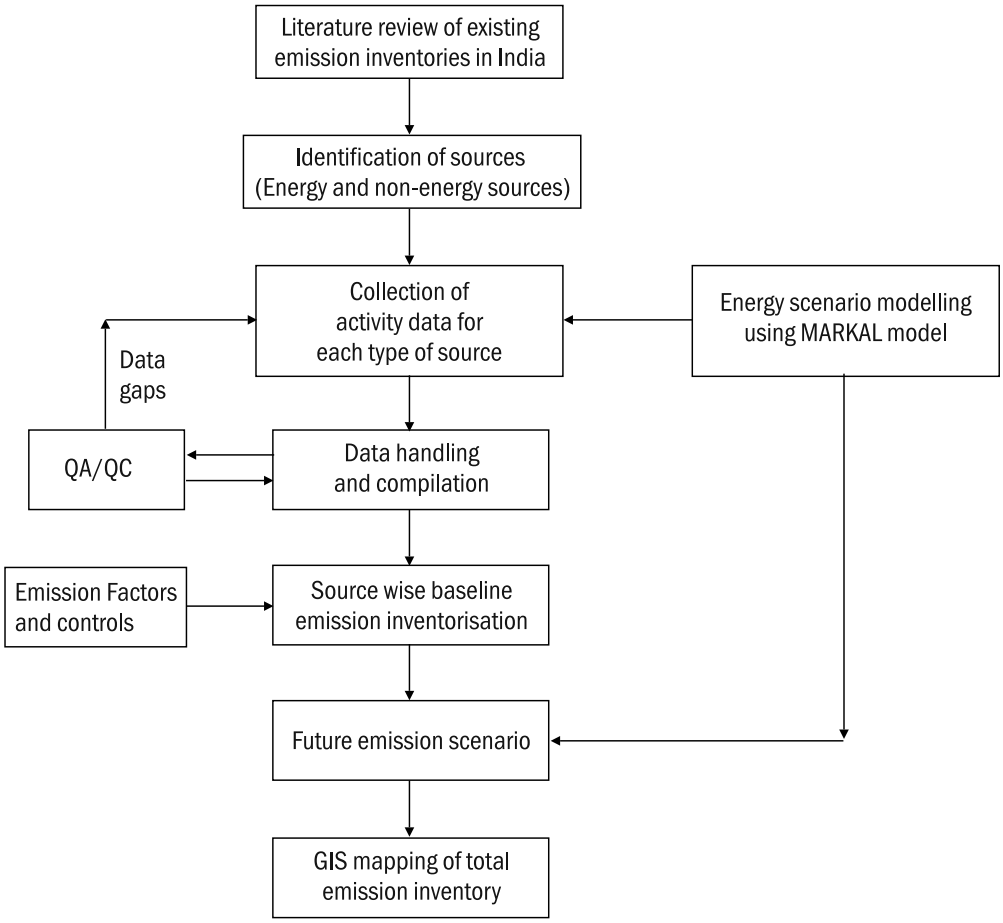

Figure 1.2: Overall framework for emission estimation

a literature review of the existing inventories in India and identification of key sources. These sources include energy and non-energy sources contributing to atmospheric pool of pollutants. Activity data are collected at the finest possible resolution for different sectors, and data quality checks are performed. A detailed review of emission factors is carried out for all the major sources. Emission factors are selected from the literature (mainly indigenous sources). Baseline emission inventories are prepared for the year 2011 for different administrative regions and are gridded using geographic information system (GIS). Future energy scenarios till 2051 are developed using the TERI MARKAL model results. Emission projections are made for the next four decades till 2051. Based on assessment of emission inventories, some recommendations are made for reduction in emissions.

Structure

In this publication, baseline and future trends of emissions are presented for various sectors in India. Chapter 2 focuses on current energy use patterns in India and future projections using the TERI-MARKAL models. Thereafter, Chapter 3 to 10 present the emissions inventories for Residential, Industries, Power, Transport, DG sets, Agricultural residue burning, Evaporative, and others sectors, respectively. The final Chapter 11 summarizes the report and presents overall findings including sectoral contributions to the emission inventories. Emission intensities are discussed in global context and finally recommendations are provided for control. The chapters also presents spatial distribution of emissions at a fine grid resolution of 36×36 km^2.

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CHAPTER 2

Energy Outlook for India

Ilika Mohan, Atul Kumar, and Saptarshi Das

Introduction

India's commercial energy consumption has almost doubled in the past decade growing at a rate of 7 per cent per annum from 179 Mtoe (million tonnes of oil equivalent) in 2001–02 to 354 Mtoe in 2011–12 (TERI 2006a; 2015a). India is one of the fastest growing economies in the world. Energy consumption is among the key inputs in attaining such growth. India's growth experience is somewhat different from that of the developed countries as its energy requirements are growing faster, leading to energy insecurity and pollution impacts. (Ramakrishna & Rena 2013). Being a developing country, with 27 per cent of its population below the poverty line, access to energy is yet another important issue that requires attention (Planning Commission 2009). Commercial energy supply in India is highly dependent on fossil fuels. In 2011–12, 97 per cent of our commercial supply was from fossil fuels (coal, oil, and natural gas). Figure 2.1 below provides a break-up of the commercial energy supply by fuel share. With the current consumption mix the role of fossil fuels is expected to grow.

Energy consumption has environmental implications as well. Increased usage of fossil fuels leads to a rise in air pollutants emission load in the country. India's greenhouse gas emissions grew by 2.9 per cent per annum between 1994 and 2007, with total emissions, including land use, land-use change, and forestry, being 1,728 million tonnes of CO_2 equivalent in 2007 (MOEF 2010). In 2011, the CO_2 emissions due to energy usage from the power, residential, commercial, industry, transport, and agriculture sectors was 1.7 billion tonnes, which was equivalent to 1.38 tonnes per capita.

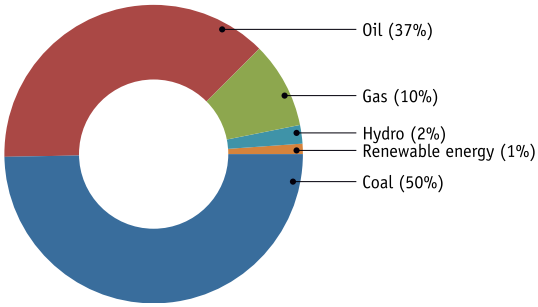

Figure 2.1: Commercial energy supply mix in 2011–12
Source: (TERI 2015a)

Modelling Framework and Scenario Description[1]

The scenario analysis and energy projections for the Indian energy sector have been carried out with the aid of the MARKet ALlocation (MARKAL[2]) model. This study builds on and integrates work that has already been undertaken by TERI using the MARKAL modelling framework for India and the knowledge base existing within TERI. TERI has developed a relatively detailed bottom-up MARKAL model database for India over the last two decades and has been using it extensively for the analysis of energy technology at the national level. The following sections describe the modelling framework, the rationale for choosing this model, how the reference energy scenario has been structured, and the assumptions that define it.

Modelling Framework

MARKAL is a bottom-up dynamic linear programming model. It depicts both the energy supply and demand sides of the energy system, providing policy makers and planners in the public and private sectors with extensive details on energy producing and consuming technologies. It also provides an understanding of the interplay between the various fuel and technology choices for given sectoral end-use demands. As a result, this modelling framework has contributed to national and local energy planning and to the development of carbon mitigation strategies. The MARKAL family of models is unique with applications in a wide variety of settings and global technical support from the international research community.

MARKAL interconnects the conversion and consumption of energy. This user-defined network includes:

- All energy carriers involved in primary supplies (e.g., mining, petroleum extraction, etc.),
- Conversion and processing (e.g., power plants, refineries, etc.), and
- End-use demand for energy services (e.g., automobiles, residential space conditioning, etc.).

These may be disaggregated by sector (i.e., residential, manufacturing, transportation, and commercial) and by specific functions within a sector (e.g., residential air conditioning, lighting, water heating, etc.).

The optimization routine used in the model's solution selects from each of the sources, energy carriers, and transformation technologies to produce the least-cost solution, subject to a variety of constraints. The user defines technology costs, technical characteristics (e.g., conversion efficiencies), and energy service demands.

As a result of this integrated approach, supply-side technologies are matched to energy service demands. Some uses of MARKAL include

1. Identifying least-cost energy systems and investment strategies;
2. Identifying cost-effective responses to restrictions on environmental emissions and wastes under the principles of sustainable development;
3. Evaluating new technologies and priorities for research and development;
4. Performing prospective analysis of long-term energy balances under different scenarios;

1 It should be noted this exercise builds on the database set up for the publication '*Energy Security Outlook - defining a secure and sustainable future for India*' (TERI, 2015b). Authors would like to acknowledge the support and input received from several research professionals and sector experts across TERI.

2 MARKAL was developed in a cooperative multinational project over a period of almost two decades by the Energy Technology Systems Analysis Programme (ETSAP) of the International Energy Agency. Available at <http://www.iea-etsap.org/web/Markal.asp>.

5 Examining reference and alternative scenarios in terms of the variations in overall costs, fuel use, and associated emissions.

A detailed representation of the modelling framework is shown in Figure 2.2.

The MARKAL database for this exercise has been set up over a 50-year period extending from 2001 to 2051 at five-yearly intervals coinciding with the duration of the Government of India's Five-Year plans. The base year of the exercise is 2001–02 and the data for 2001–02, 2006–07, and 2011–12 has been calibrated and matched to the existing and published data.

In the model, the Indian energy sector is disaggregated into five major energy consuming sectors, namely agriculture, commercial, industry, residential, and transport. Each of these sectors is further disaggregated to reflect the sectoral end-use demands. The model is driven by the demands from the end-use side.

On the supply side, the model considers the various energy resources that are available both domestically and from abroad for meeting various end-use demands. This includes both conventional energy sources, such as coal; oil; natural gas; hydro and nuclear; as well as the renewable energy sources, such as wind, solar, etc. The level of domestic availability of each of these fuels is represented as constraints in the model.

The relative energy prices of various forms and sources of fuels dictate the choice of fuels, which play an integral role in capturing inter-fuel and inter-factor substitution within the model. Furthermore, various conversion and process technologies characterized by their respective investment costs, operating and maintenance costs, technical efficiency, life, etc. to meet the sectoral end-use demands are also incorporated in the model.

The model run and analysis that has been carried out provides outcomes in terms of fuel mix, technology deployment, primary energy requirement, power generation, and CO_2 emission levels. In order to understand the model results, it is important to understand the assumptions made to construct the scenario.

Reference Scenario (RES)

This scenario is structured to provide a baseline that shows how the nation's energy trajectory could evolve provided current trends in energy demand and supply are not changed. It takes into account existing policy commitments and assumes that those recently announced are implemented. However, wherever necessary, a diversion from government projections and forecasts has been assumed. The key assumptions made to construct the RES have been made in consultation and discussion with several organizations, relevant stakeholders, and sector experts across the country. These are described in the following sections.

Macroeconomic parameters

The energy demand of the end-use sectors are an exogenous input in to the model. The calculation of each of these end-use energy demands is in itself an extensive exercise. The demands are primarily derived as a function of the gross domestic product (GDP) and population. For this, both GDP and population have been projected and the same have been used across all sectors in this publication.

Gross Domestic Product (GDP)

The GDP is assumed to grow at a rate of about 8 per cent rising from INR 19.7 trillion in 2001 to INR 741.58 trillion in 2051 at 1999–2000 prices. The sectoral GDP has been calculated based on a regression analysis that establishes the relationship between sectoral GDP and the total GDP. The share of agriculture, industry, and services GDP in the total GDP is seen to vary over the years. The share of agriculture falls from 26 per cent in 2001 to 6 per cent in 2051 while the share of industry rises from 23 per cent in 2001 to 34 per cent in 2051 and the service sector rises from 51 per cent in 2001 to 60 per cent in 2051. Table 2.1 shows the gross GDP (in trillion, at 1999–2000 prices) and shares of various sectors in the GDP.

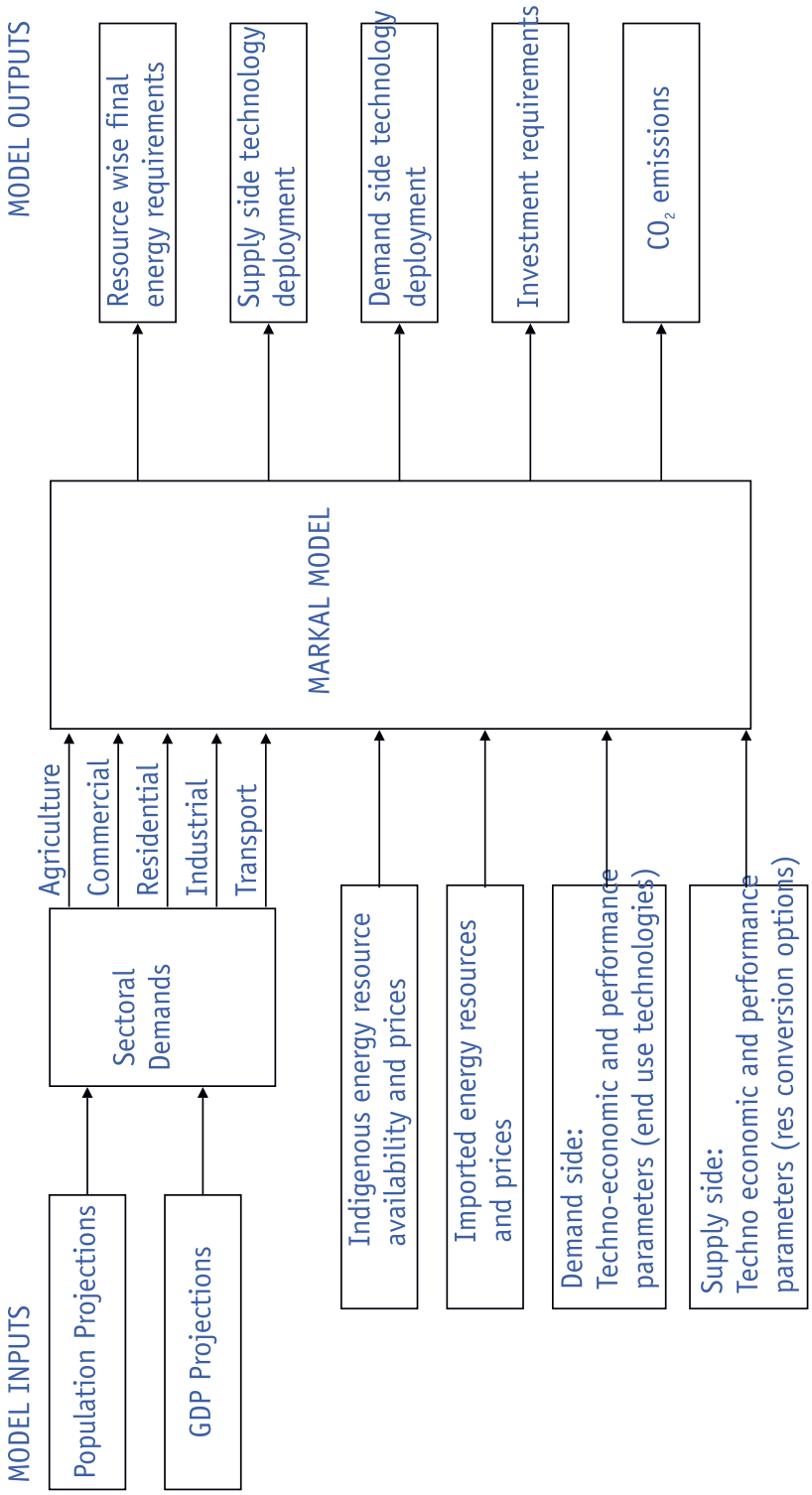

Figure 2.2: MARKAL modelling framework
Source: (TERI 2006b)

Table 2.1: Gross GDP (in trillion, at 1999–2000 prices) and sector shares

Year	Gross GDP	Sector Shares		
		Agriculture (%)	Industry (%)	Services (%)
2001	19.7	26	23	51
2011	43.4	19	26	55
2021	97.6	16	28	56
2031	211.7	12	30	58
2041	414.1	9	32	59
2051	741.5	6	34	60

Source: TERI Analysis

Population

There are many studies that have projected population of India at national and state level. The Population Foundation of India (PFI) has carried out projections in two scenarios, viz scenario A and Scenario B (PFI, 2007). PFI has used a component method to make the projections. The Component Method is the universally accepted method of carrying out population projection where the population is broken down into its three major components- survived population, number of births taking place and net migration. This method takes into account separately future course of fertility, mortality and migration and is therefore considered more accurate than any mathematical method based on past trends. The ability to provide age sex break-up of the projected population is an added advantage of this method.

Among all the projections studied, PFI scenario B assumptions have been agreed upon as the most likely trajectory for India after expert consultation and extensive literature review. This study has therefore used PFI scenario B projection.

The Scenario B of the PFI projections, assume that the states of India with total fertility rate (TFR) more than that of the replacement level TFR will reach a target level of 1.85 by 2101, while those states with very low levels of TFR like Kerala and Tamil Nadu are assumed to have a constant TFR at the existing level. Table 2.2 shows the decadal population (in billion) of India.

Table 2.2: Population (in billion) of India

Year	Total	Rural	Urban
2001	1.03	0.74	0.29
2011	1.20	0.84	0.36
2021	1.37	0.93	0.44
2021	1.37	0.93	0.44
2031	1.52	1.01	0.52
2041	1.65	1.06	0.59
2051	1.75	1.09	0.67

Source: (PFI 2007)

End-use demand

The end-use demands, as described earlier, are divided in to five sectors: agriculture, industry, residential, commercial, and transport. Future demand for each of these sectors is calculated using different econometric methods and is then fed in to MARKAL as input.

The population and GDP projections are used as the main driving force for estimating the end-use demands in each of the energy-consuming sectors.

Also, on the demand side, assumptions are made on the end-use technological levels. It involves inclusion of new technologies, efficiency improvements in the existing ones, and their changing penetration levels.

Demand for the industry sector has been calculated for 10 of its most energy-consuming sub-sectors, namely iron and steel, cement, brick, glass, aluminium, textile, fertilizers, chlor-alkali, petrochemicals, and paper. Other energy-consuming industries that include small-scale industries, such as food-processing, ceramics, sugar mills, foundry, leather/tanning, etc., are grouped in a single sub-sector collectively called 'other industries'. Production (as a proxy of demand) in each of these industrial sub-sectors is projected using econometric techniques. Econometric analysis has been carried out for each of the major industry sub-sectors, taking production as the dependent variable and using various macroeconomic indicators, such as GDP (aggregate), GDP of industrial sector, services, and agriculture, etc. as independent variables.

In the RES, efficiency improvement is considered as per the past trend and in line with commercially available technological options in the industry sector. Due to liberalization and opening up of domestic markets, large scale industries, such as cement, iron and steel, petrochemicals, and other chemicals, assumed to improve their energy efficiency levels by adoption of state-of-art technologies. Small-scale manufacturing enterprises adopt energy efficient technologies at slower rate.

The transportation demand (disaggregated further into mode-wise passenger kilometre demand and freight kilometre demand) is projected using various socioeconomic indicators, such as per-capita income (indicator of purchasing power), population, and so on. To project the passenger and freight kilometres from each mode, their estimated vehicle population is multiplied with the occupancy rates and utilization levels. The estimation of occupancy rates and efficiency for each mode of transport has been made after extensive stakeholder consultation and discussion with sector experts.

Assumptions regarding fuel and technology penetration in RES for the transport sector have been made keeping the present situation in mind. We consider that the share of CNG (Compressed Natural Gas) in cars and public transport rises to 4 per cent, from present levels of 1 per cent, by 2051. Share of railways in passenger movement is taken to drop from 14 per cent in 2011 to 12 per cent in 2051 while that in freight is assumed to decrease to 23 per cent (2051) from 39 per cent (2011). An increase in electric traction in freight movement from 65 per cent (2011) to 70 per cent (2051) and in passenger movement from 50 per cent (2011) to 52 per cent (2051) has been built in the model. Role of biofuels is minimal in the RES.

In the agriculture sector, demand is estimated for land preparation and irrigation pumping. Demand for land preparation is calculated by estimating the number of tractors and tillers that will be required in future. The demand for irrigation pumping is calculated by estimating the future water demand of the agriculture sector. This has been done in accordance to the current and expected cropping patterns.

In the RES, the share of efficient tractors in land preparation is assumed to be the same as the current levels with no improvement. The share of efficient electric pump sets in irrigation is assumed to rise from negligible levels in 2011 to about 40 per cent in 2051.

In the residential sector, the demand is projected for lighting, cooking, space conditioning, and refrigeration separately for urban and rural households to account for the differences in lifestyle and choice of fuel and technology options. Each of these end-use demands is estimated using a bottom-up methodology wherein they are calculated across different monthly per capita expenditure classes and these are further aggregated to give the final demand.

Various assumptions have been made on the level of penetration of efficient appliances in the RES. The share of efficient air conditioners, fans, coolers, and refrigerators is taken to rise in both the rural and urban households from about 9 per cent in 2011 to 50 per cent in 2051. It is also assumed that 100 per cent electrification will be achieved post 2016. By 2031, we assume that 90 per cent of the lighting demand would be met by CFLs (Compact Fluorecscent Lamps). The share of improved cook stoves rises to 20 per cent from negligible levels in 2011 by 2051 in the RES.

In the commercial building sector, the demand is projected for cooking, lighting, and space conditioning based on built-up area, energy performance index (EPI), and the value added by the services sector as an explanatory variable. Along with the energy demand arising from commercial buildings, energy demand for public lighting, public water and sewage pumping is included in the commercial sector. The commercial buildings sector's energy demand for the study was calculated using EPI numbers and the built-up area.

In the RES, we assume no improvement in the EPI and limited GRIHA[3] penetration in the new buildings (from 1 per cent in 2011, 3 per cent by 2021, 6 per cent by 2031, and 10 per cent by 2051).

3 GRIHA is an acronym for Green Rating for Integrated Habitat Assessment. Available at <http://grihaindia.org/>. last accessed on July 1, 2015.

Energy supply

As a result of problems currently constraining the production of coal, it is assumed that the production of non-coking coal will reach a maximum of about 700 MT by 2021 (i.e., representing a compounded annual growth rate (CAGR) of 3.7 per cent) and increase by 3 MT annually up to 2031. It is assumed that the present trend in the production of metallurgical coal will continue, and the production will reach a maximum of 19 MT by 2021–22 and stay at that level thereafter. We see that the overall constraints in production of coal will impact the production of non-metallurgical coal as well. Therefore, it is assumed that the production of non-metallurgical coal will peak at nearly 50 MT by 2021–22 and increase by 0.5 MT each year thereafter till 2031. For the production of lignite, we take conservative estimates, with projections that the production will increase at a rate of 4 per cent between 2011–12 and 2021–22, reaching approximately 63 MT by 2021–22. Thereafter, it is assumed to grow by 2 MT each year. Total domestic coal production reaches a maximum of about 880 MT by 2036.

In order to estimate constraints on our domestic crude oil production for the RES, we assume that in the short term (up to 2021) ONGC's offshore crude output remains constant, and its onshore crude output continues to decline steadily. OIL's onshore crude production stays at around 4.5 MT. Private/joint venture (JV) onshore crude output increases steadily up to 10 MT in 2015–16 and offshore crude output by private/JV companies continues to decline as has been the case over 2000–01 to 2011–12.

In the medium to long term (2021–51), assumptions are made on the total domestic crude oil production and not on production by individual companies. Total production remains relatively stagnant at a little above 40 MT after 2021.

Natural gas assumptions are based on a similar analysis. In the short term (up to 2021), we assume Reliance's KG-D6 gas output continues to fall steadily. Private/JV companies' production of natural gas remains constant at 11 billion cubic metres (BCM) from 2016 to 2017. ONGC's gas output stays constant and increases moderately after 2015–16 due to new discoveries coming on-stream, and OIL's natural gas output stays constant at 2.8 BCM.

In the medium to long term (2021–51), assumptions are made on total domestic gas production and not on production by individual companies. If the natural gas scenario continues as usual, we do not consider a very significant rise in domestic gas production. Domestic production is assumed to reach a maximum of 50 BCM by 2031.

With regards to technology penetration in the power sector, large scale deployment of supercritical technology for coal-based generation is considered. Further, it is also assumed that ultra-supercritical technology would be available at commercial scale only by 2031. In view of increasing concern about rehabilitation and relocation issues, the capacity realizations of large hydroelectric plants to a moderate level of around 94 GW by 2031 and 148 by 2051 is predicted.

Table 2.3: Tentative programme for capacity additions to grid-interactive renewable power under the XII Five-Year Plan (2012–17) and XIII Five-Year Plan (2017–22)

Source/system	Capacity addition (MW), XII Plan	Capacity addition (MW), XIII Plan
Wind power	15,000	15,000
Biomass power	2,100	2,000
Small hydropower	1,600	1,500
Solar power	10,000	16,000
Waste to energy	500	
Tidal power	7	
Geothermal power	7	
Total	29,214	34,500

Nuclear energy in the RES is projected to rise from an installed capacity of 5 GW in 2011 to 28 GW in 2031 and 103 GW in 2051. Delays in land acquisitions, slow expansion, and commercialisation of Fast Breeder technology and uncertainties (from the supplier's perspective) surrounding the nuclear liability law are the major considerations for such modest projections.

Till now, renewable energy capacity addition targets have always been achieved in each of the five-

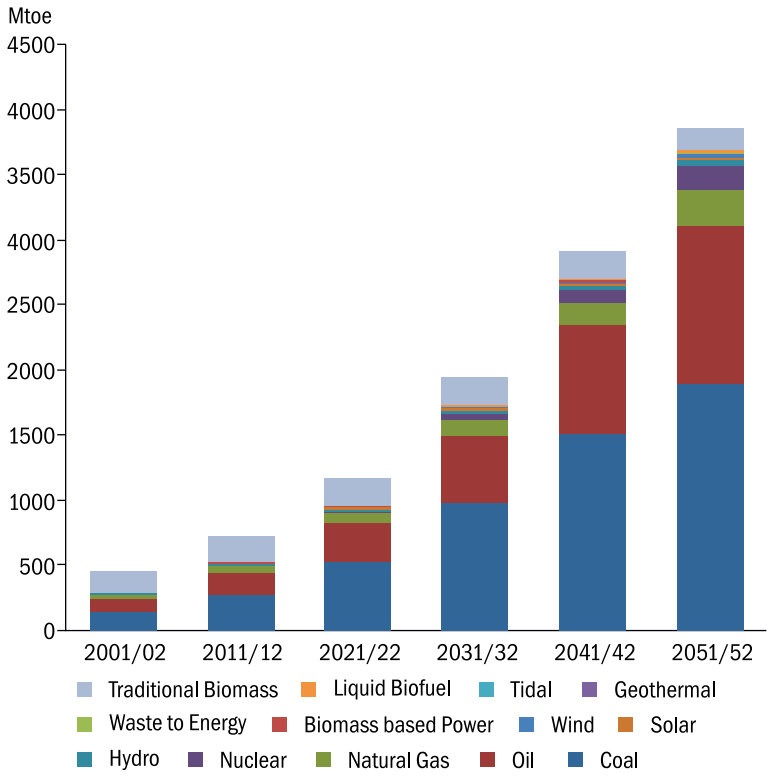

Figure 2.3: Primary energy supply
Source: TERI Analysis, 2015

year plans. This scenario assumes that this positive trend will continue and there will be no shortfall in targets. The targets of the five-year plans taken in to consideration are mentioned in Table 2.3.

Modelling Results for the RES

The following sections enumerate the results obtained from the model for the RES.

Primary Energy Supply[4]

Figure 2.3 reflects the primary energy supply by fuel. The primary energy supply in the RES grows almost five times over from 717 Mtoe in 2011 to 3,851 Mtoe by 2051 at a CAGR of 4.3 per cent. In the RES scenario, coal continues to remain the dominant fuel in the supply mix throughout the modelling period with its share rising from 39 per cent in 2011 to 50 per cent by 2031 and remaining so for the rest of the modelling period. Coal supply grows from 280 Mtoe in 2011 to a staggering 1,897 Mtoe in 2051. The share of oil in the supply mix rises from 22 per cent in 2011 to 26 per cent in 2031 and 31 per cent by 2051. Even though it is projected that the magnitude of natural gas in the supply mix will increase about five times from 58 Mtoe in 2011 to 271 Mtoe by 2051, its share in the mix drops from 8 per cent in 2011 to 7 per cent by 2051. Share of nuclear energy is predicted to see a slight increase from 1 per cent in 2011 to 5 per cent by 2051. Thus by 2051, 88 per cent of the primary commercial energy comes from coal, oil, and gas; 4

4 As per the glossary of statistical terms of the Organisation for Economic Co-operation and Development (OECD), primary energy consumption refers to the direct use at the source or supply to users without transformation, of crude energy, that is, energy that has not been subjected to any conversion or transformation process.

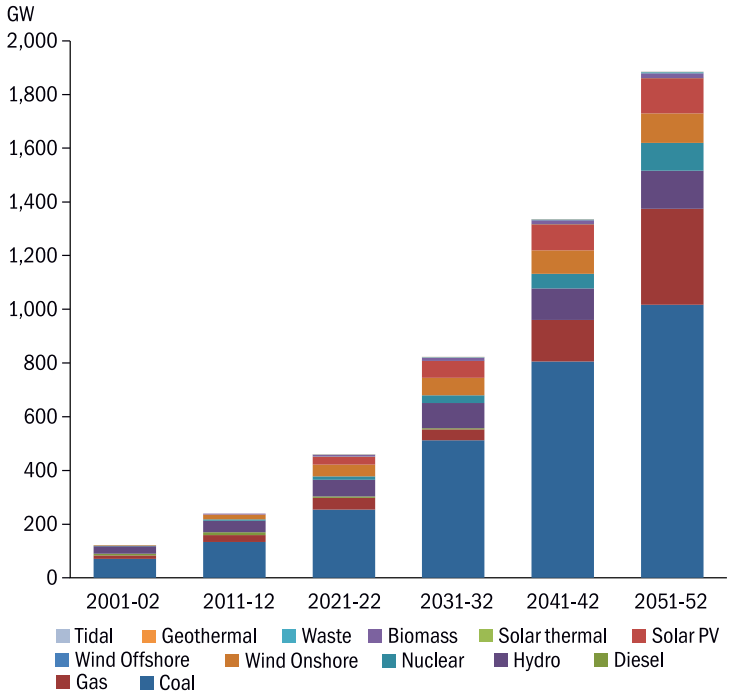

Figure 2.4: Power generation capacity (centralized and decentralized)
Source: TERI Analysis, 2015

per cent from traditional biomass;[5] 5 per cent from nuclear energy; and remaining from renewables and large hydro.

Power Generation

Figure 2.4 shows the growth of power generation capacity (centralized and decentralized). In the RES, the generation capacity grows thrice from 239 GW to 821 GW in 2031 and almost eight times over to 1,884 GW by 2051. In 2051, 54 per cent of this generation capacity is based on coal and the share of gas-based generation capacity rises from 11 per cent in 2011 to 19 per cent in 2051. Diesel-based generation is seen to slowly disappear. Nuclear capacity grows over 21 times from 5 GW in 2011 to 103 GW by 2051. It is also seen that even though the target potentials for hydro power are realized and its capacity grows from 42 GW in 2011 to 142 GW by 2051. As was the assumption, targets set out in the XII and XIII five-year plans for the development of renewable energy capacity have been achieved, increasing the renewable-based capacity from 22 GW (sum total of solar, wind, biomass, waste, tidal, and geothermal energy-based capacity) in 2011 to 142 GW in 2031 and to 265 GW by 2051; hence, their share rises from 9 per cent (2011) to 14 per cent (2051).

Final Energy Demand[6]

Figure 2.5 shows the final energy demand by sectors over the modelling framework. Our energy demand in the RES grows from 549 Mtoe in 2011 to 1,460 Mtoe in 2031 and 2,812 Mtoe in 2051, increasing by five times in 40 years. Energy consumption of the commercial sector grows at the fastest pace, with a CAGR of 8 per cent. In terms of magnitude, industry and transport sector are the two main energy-consuming sectors with the energy consumption of the transport sector increasing by about 10 times by 2051.

5 Traditional biomass includes fuel wood, animal dung, and crop residue.

6 End use energy demand.

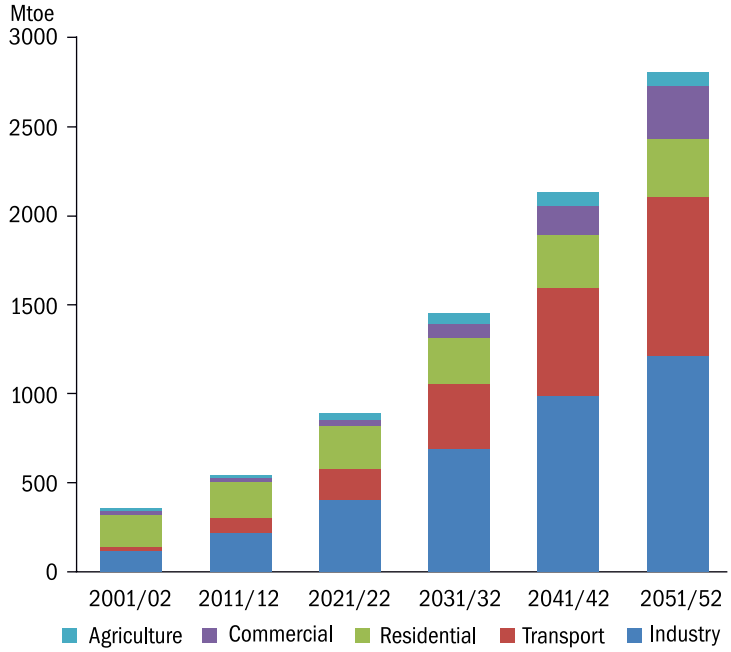

Figure 2.5: Final energy demand (inclusive of traditional biomass)
Source: TERI Analysis, 2015

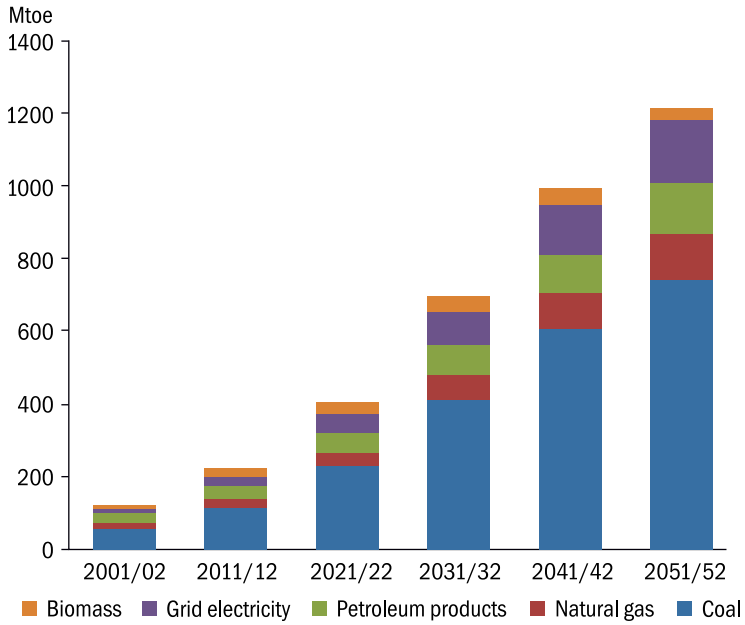

Figure 2.6: Final energy demand by fuel—Industry sector
Source: TERI Analysis, 2015

The energy consumption trajectories, by fuel, of each demand sector are discussed in details below.

Industry sector

Figure 2.6 shows the final energy demand by the industry sector by fuel. Industry demand has been projected to grow from 221 Mtoe in 2011 to 697 Mtoe in 2031 to 1,215 Mtoe by 2051 at a CAGR of 4 per cent over 40 years. This rapid growth in energy consumption in the industrial sector is largely on account of the growth in infrastructural demands of the country (steel, cement, and brick demands). Coal is used to meet more than half of the sector's energy demand and its consumption increases by seven times over in 40 years. Coal in this sector is also used to generate decentralized electricity. Petroleum products and natural gas are the next most popular fuels that are used in the sector. The share of petroleum products, however, is seen to decrease slightly from 16 per cent in 2011 to 11 per cent by 2051, while that of natural gas from 12 per cent in 2011 to 10 per cent by 2051.

Transport sector

Figure 2.7 reflects the final energy demand by the transport sector by fuel. The energy demand of the transport sector grows from 86 Mtoe in 2011 to 360 Mtoe in 2031 and over 10 times to 900 Mtoe by 2051. This sizeable growth in the transport sector can be attributed to a shift towards more energy-intensive modes of transport for both passenger and freight movement. This 10-fold increase is mainly due to the rapid growth in the consumption of petroleum products in the transport sector, which has grown at a CAGR of 6 per cent. In 2011, petroleum products were used to meet over 97 per cent of the sector's energy demand and this falls to 95 per cent in 2051, which still is a very significant share. There is a slight increase in the use of CNG and electricity. Role of biofuels in this scenario is minimal.

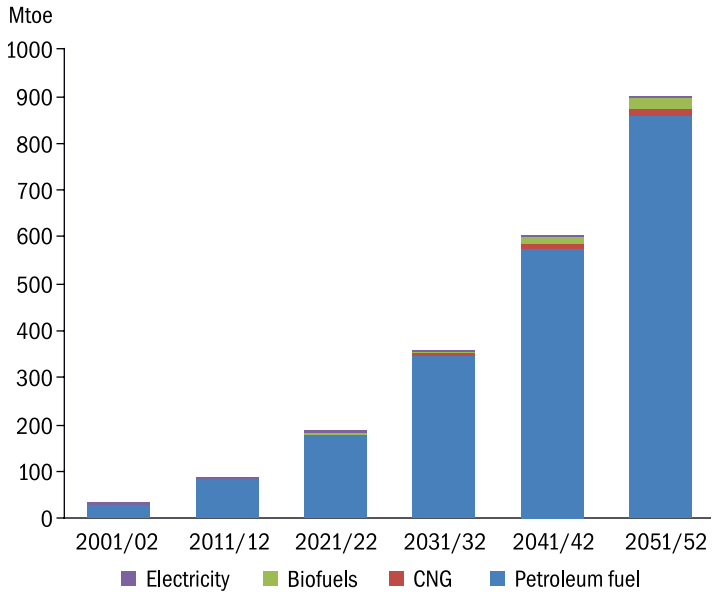

Figure 2.7: Final energy demand by fuel—Transport sector
Source: TERI Analysis, 2015

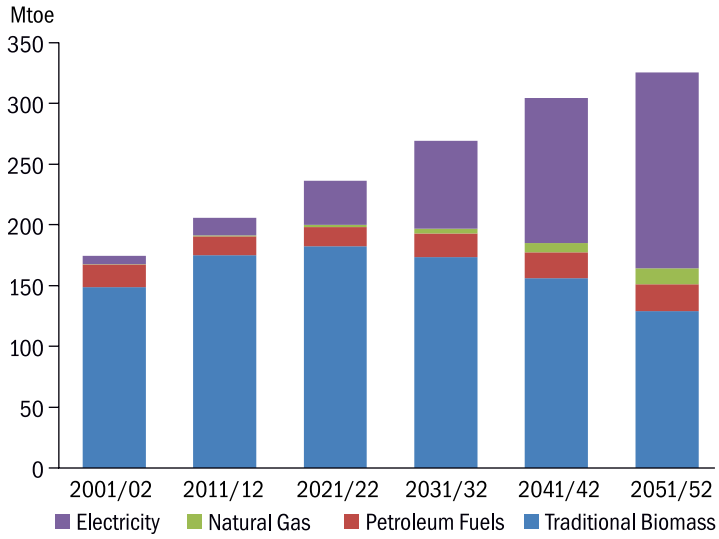

Figure 2.8: Final energy demand by fuel- Residential sector
Source: TERI Analysis, 2015

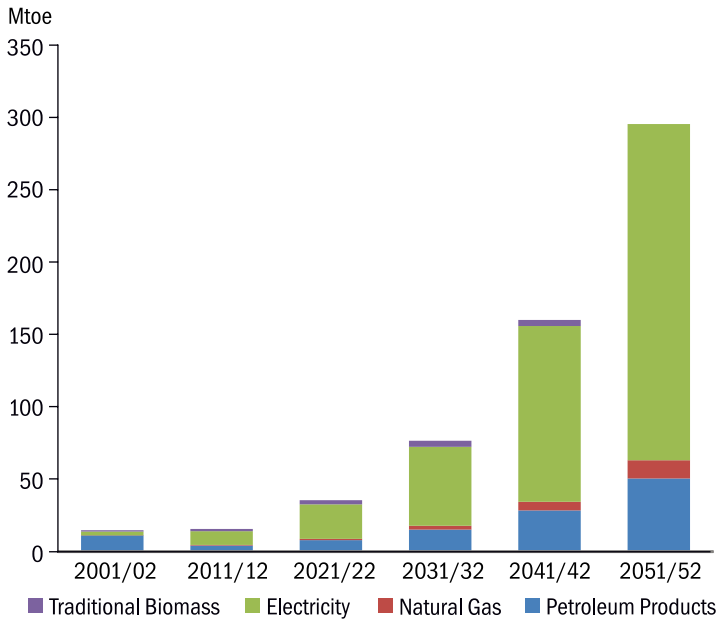

Figure 2.9: Final energy demand by fuel—Commercial sector
Source: TERI Analysis, 2015

Residential sector

Figure 2.8 depicts the final energy demand by the residential sector by fuel. The final energy demand of the residential sector increases from 206 Mtoe in 2011 to 269 Mtoe in 2031 and about 1.6 times to 325 Mtoe in 2051. About 40 per cent of the energy demand in the sector is met by traditional biomass even in 2051. Traditional biomass is an important

fuel primarily used for cooking in the residential sector. Also, due to greater appliance penetration and electrification, the electricity consumed by the sector rises over 11 times from 15 Mtoe in 2011 to 161 Mtoe in 2051.

Commercial sector

Figure 2.9 reflects the final energy demand of the commercial sector by fuel. The final energy demand of the sector grows from 16 Mtoe in 2011 to 77 Mtoe in 2031 and grows by 19 times to 295 Mtoe in 2051. Petroleum products and electricity are the two most popular fuel choices of the sector. Use of petroleum products is inclusive of DG sets used in the sector. It should be noted that in the RES no reduction of EPI of commercial buildings is considered and limited penetration of GRIHA-rated buildings is assumed in new buildings. Thus, we see that the use of electricity grows by about 24 times and its share in the sector's fuel mix grows form 61 per cent in 2011 to 79 per cent by 2051. Hence, electricity is the prime fuel used to fulfil energy demands of this sector.

Agriculture sector

Figure 2.10 depicts the final energy demand of the agriculture sector by fuel. The final energy demand of the sector rises almost three times over from 21 Mtoe in 2011 to 58 Mtoe in 2031 and 76 Mtoe by 2051 in the RES. Electricity and petroleum products are the only two fuels used to meet the energy demand of the sector, with diesel being used mainly for land preparation and electricity for irrigation purposes. Overtime, the share of petroleum products is seen to fall while that of electricity rises.

CO_2 emissions

Figure 2.11 shows the level of CO_2 emissions throughout the modelling period. The CO_2 emission levels reported by the model are the emissions that result from fuel use across the economy both for energy and non-energy purposes. In the RES, the CO_2 emission levels rise from 1.7 billion tonnes (2011) to 5.5 billion tonnes in 2031 and 11.3 billion tonnes in 2051. Thus, the per capita emissions grow from 1.38 tonnes (2011) to 3.64 tonnes (2031) and 6.45 tonnes (2051). Our per capita emissions in 2051 still are

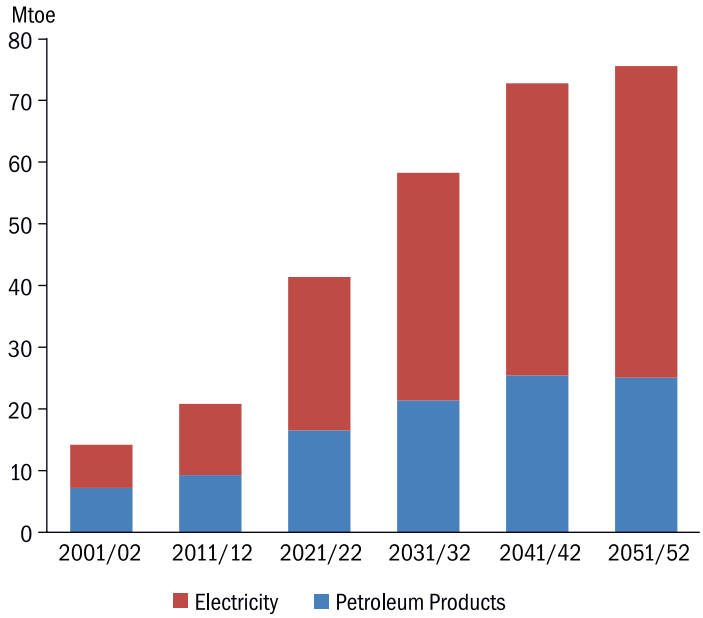

Figure 2.10: Final energy demand by fuel—Agriculture sector
Source: TERI Analysis, 2015

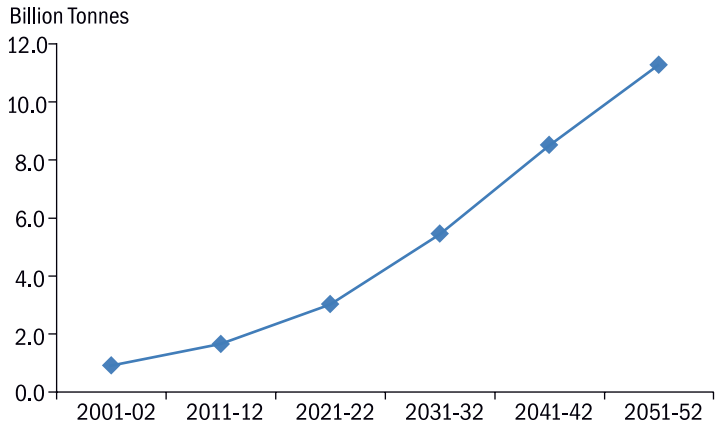

Figure 2.11: CO_2 emission levels
Source: TERI Analysis, 2015

lower than then the present per capita emissions of many developed nation but whether or not the RES is a most sustainable pathway is subject to debate in light of the results shown in the preceding sections. There is no doubt that a lot more needs to be done for India to move towards an energy secure future.

Conclusion

The modelling exercise clearly points towards India's increasing dependence on fossil fuels in a 'Business-As-Usual' scenario. It indicates that coal would continue to play a key role in meeting the country's energy requirements. This may push India's dependence on import of fossil fuels. The growth in usage of fossil fuels is coupled by a ten-fold increase in the level of CO_2 emissions in 40 years.

India's demand energy is also going to grow tremendously in the future. It is seen that one of the major consumers of commercial energy in India is the transport sector. The sector is also the largest consumer of petroleum-based fuels. This is a particular cause of concern owing to the large dependence of the country's refining sector on imported crude oil. The Industry sector is also a major consumer of coal. Another point to note is the continued reliance of the residential sector on traditional biomass to meet its cooking needs.

Thus, it is imperative that efforts are focussed towards focussing simultaneously on the demand and supply sides for the economy to attain the most efficient utilization of its resources and moving towards a sustainable growth.

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CHAPTER 3

Residential

Arindam Datta, Ilika Mohan, and Sumit Sharma

Introduction

Energy use in the residential sector has drawn global concerns in the past decades for its effect on atmospheric pollution, human health, and climate change due to the emission of particulate matter and other pollutants (Koe et al. 2001). The sector is one of the largest consumers of energy, especially the traditional biomass-based energy in the developing and underdeveloped countries around the world (ABS 2012; EEA 2012; EIA 2014; Howley et al. 2008; TERI 2014). Inefficient combustion process leads to emissions of different air pollutants with varying degree of effects on the air quality and health (Bingemer et al. 1991). While ambient air pollution is an issue, pollutant concentrations in the indoor environment sometime go 100 times higher than the outdoors (EPA 2013). In general, people spend more than 70% of their daily time in the indoor environment (elderly and children spend even more time indoors) (Myers and Maynard 2005), and hence, are exposed to the prevailing indoor air pollutant levels. Many studies have linked inefficient cooking, lighting, and heating activities in the residential sector with ill health of the residents (Smith et al. 2000a). Countries around the world have developed their ambient air quality standards based on the WHO

Air Quality Guidelines (WHO 2000); however, there are limited efforts to develop standards for indoor air quality.

Energy use in the residential sector can broadly be classified as (i) energy used for the cooking, (ii) energy used for the lighting, and (iii) energy used for space heating. Variety of fuel (solid, liquid, and gaseous) is used in the sector on a variety of cooking/lighting devices that usually have different combustion efficiencies. Solid fuels, generally used in the residential sector include fuel wood, dung cake, crop residue, and coal. Kerosene is generally used as liquid fuel and LPG, natural gas, biogas are used as gaseous fuels in the sector. Among different biomass materials, fuel wood remained the main solid biomass fuel since the historical time. Fuel wood is derived from the forest residues (such as dead trees, branches, and tree stumps), yard clippings, wood chips, and even municipal solid waste. However, dry dung cake and crop residues are also used in the residential sector as a source of solid biomass energy for cooking. Fuel wood use in India was even higher than that of China and Brazil in 2013 (FAOSTAT 2014). TERI (2014) also reported similar high figures for fuel wood consumption in India. This is mainly because more than 60% of the rural households rely on fuel wood followed by crop-residues (12%) and cow dung cakes (11%) (India Census 2011). Other than this, an estimated 500 million households rely on kerosene or other liquid fuels for lighting around the world, which amounts to ~7.6 billion litre consumption of liquid fuel annually (Mills 2005). In India, 31.4% households use kerosene for the lighting and nearly 3% households (mainly in the urban areas) use kerosene for cooking (India census 2011).

Combustion of the solid biomass fuels and kerosene is rather incomplete in the type of burning system (e.g., cook stove or wick lamp) that are mainly used in the developing countries. This leads to emissions of pollutants in significant quantities. Various studies have reported the mean 24-hour concentration of particulate matter (PM) in the indoor environment in the range of 300–3,000 $\mu g/m^3$ (Bruce et al. 2000), whereas the ambient $PM_{2.5}$ standard of USEPA for 24 hours mean concentration is 35 $\mu g/m^3$ (USEPA 2012). Patel and Aryan (1997) have estimated the indoor levels of CO in an Indian kitchen during cooking with dung cake, wood, coal, kerosene, LPG, and reported their concentrations as 3.56, 2.01,0.55, 0.23, and 0.13 mg/m^3, respectively. In a similar study, Gautam et al. (2013) have reported the indoor concentrations of $PM_{2.5}$ and PM_{10} with different types of cooking fuels (Figure 3.1).

Carbonaceous fine fraction of PM is generally partitioned into two major classes, organic carbon (OC) and black carbon (BC). About 40–45% of global emission of BC is originated from the residential sector (Bond et al. 2004; Kulkarni et al. 2015). Globally, residential sector accounts for about 42% of atmospheric non-methane volatile organic compounds (NMVOC) (Li et al. 2014). Among different countries of Asia, the contribution of the residential sector to the total atmospheric NMVOC is significantly higher in India (Li et al. 2014). Incomplete fuel combustion in the residential sector also emits large amount of carbon monoxide (CO). Generally, while it caters to the basic necessity of cooking, lighting, and heating, the residential sector in India is one of the biggest sources of atmospheric pollutants (Jayalakshmi 2015; Sharma et al. 2015).

There are some studies carried out to estimate emissions from residential sector in India (Klimont et al. 2002; Pandey et al. 2014; Reddy and Venkataraman 2002a,b) and large uncertainties have been reported in estimation of residential sector emissions on account of varying estimates of energy use and emission factors due to variety of fuel-wood usage. In this study, *bottom-up* estimates for energy consumption have been made for spatial distribution of national level estimates derived from TERI MARKAL Energy model. The emissions of different pollutants from residential sector in India are estimated using indigenous emission factors based on literature review. Projections have also been made for the future emissions from the sector. The uncertainties in this emission inventory have also been evaluated.

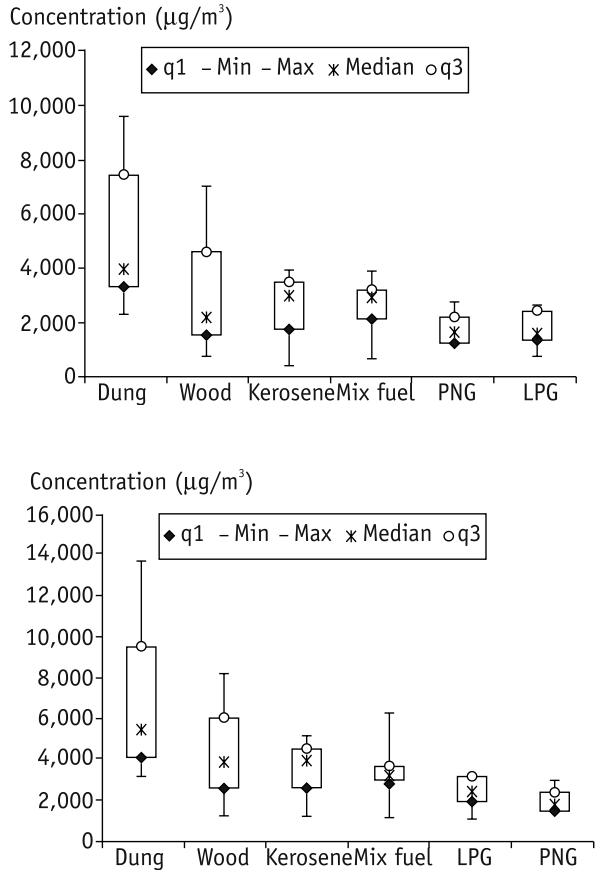

Figure 3.1: Fuel-wise estimation of pollutant concentrations in a rural kitchen of Ballabhgarh, India **A**. $PM_{2.5}$; B. PM_{10}

Source: Gautam et al. (2013)

Methodology

The national level estimates of energy consumption in residential sector are presented in chapter 2. The spatial distribution of energy use and emissions in the residential sector is carried using a *bottom-up* approach. The basic equation employed for emission estimation from the residential sector is

$$E_p = \sum_{(S=1)}^{35} \sum_{(D=1)}^{n} \sum_{(f=1)}^{n} A_f \times EF_{p,f} \qquad 3.1$$

where, E_p = Emission of a particular pollutant (p) with a particular fuel type (f); A_f = Activity data of the particular fuel type (f); $EF_{p,f}$ = Emission factor of the particular pollutant (p) of the particular fuel type (f). D is the number of district in a particular state (S). There are 35 states/union territories in India at present.

Estimation of Activity Data

As discussed earlier, five different types of fuel (e.g., biomass, coal, kerosene, electricity, and LPG) are mainly consumed in the residential sector in India. The consumption of different types of fuels in India was estimated based on following equations:

$$A_{c(f,Y)} = P(Y) \qquad 3.2$$

$$A_{l(f,Y)} = P(Y) \times C_{l(f,Y)} \qquad 3.3$$

$$A_f = A_{c(f,Y)} + A_{l(f,Y)} \quad 3.4$$

where, $A_{c(f,y)}$ and $A_{l(f,y)}$ are the activity data of a particular type of fuel in a district (*D*) during a particular year (*Y*) for cooking (*c*) and lighting (*l*) purposes, respectively. *P* is the total population distributed in urban or rural regions in a district (*D*) during the year (*Y*). $C_{c(f,y)}$ and $C_{l(f,y)}$ are the per capita consumption of fuel for cooking and lighting purposes, respectively, for a particular fuel (*f*) in the state (s) during the year (*Y*). We have calculated the $A_{c(f,y)}$ and $A_{l(f,y)}$ separately for the rural and urban area of a district using the Equation 3.2 and 3.3. However, the sum of $A_{c(f,y)}$ and $A_{l(f,y)}$ was used to derive the A_f of the particular district (*D*). A_f was derived separately for the rural and urban areas of every district to use the value in the Equation 3.1.

The dataset of district wise rural and urban population in India was collected from the India census data of the year 2001 and 2011 (www.censusindia.gov.in). Per capita consumption of different types of fuel for residential use in rural and urban areas of different states of India is collected from different sources (MoHA 2014; NARI 2013; NSSO 2007; 2010; 2012). This was used to estimate energy consumption in the sector during 2001 and 2011. The energy use estimates were compared with other existing estimates.

Emission Factors

Emission factors of different pollutants (e.g., PM_{10}, $PM_{2.5}$, OC, BC, SO_x, NO_x, NMVOC, and CO) emitted during combustion of different types of fuel in the residential sector were derived from an exhaustive literature review. Emissions of different pollutants depend on the types of fuel used and the devices used for domestic cooking and lighting in different parts of India. A comprehensive literature review is carried out to collate the emission factors reported in recent (after 2000) research studies focussed on India. However, there is paucity of reported literature on emission factors from burning of coal, kerosene, and LPG in the residential sector of India (Pandey et al. 2014). Reported emission factors of different pollutants emitted during burning of these fuels in other south Asian countries, China, and other developing countries were included. While kerosene has been used as a fuel for both cooking and lighting in India, there are large differences in the emission of PM and BC from the two activities (Lam et al. 2012a, b). Hence, separate estimates of PM and BC emission from kerosene combustion in cooking and lighting have been made. Detail of the literature review for emission factors of different pollutants from different fuels used in the residential sector is given in Annexure 3.1. The variation of emission factors as reported in different studies is presented in Figure 3.2.

There are wide variations in the reported emission factors of different pollutants. The full range of collated emission factors along with a mean value ($EF_{p,f}$) was used in the present study. Few studies earlier have also used the mean of the collated emission factors from literature to estimate emission from burning of biomass fuel in the residential sector (Saud et al. 2012; Sen et al. 2014). A Monte Carlo analysis was performed with the activity data (A_f) and different emission factors ($EF_{p,f}$) of a pollutant from a specific fuel collated from the literature to estimate the range of emissions from the residential sector.

Future Projections

Future energy scenarios were developed considering the current plans and policies of the government of India and are used to estimate the emissions. These are based on the results of energy modelling exercise based on TERI-MARKAL model results (TERI 2015).

Energy Use and Emissions from Residential Sector of India

This section presents the estimates of fuel consumption and emission of air pollutants from the residential sector. The pollutant emissions from the residential sector are estimated for the years 2001–2051 at an interval of 10 years. While,

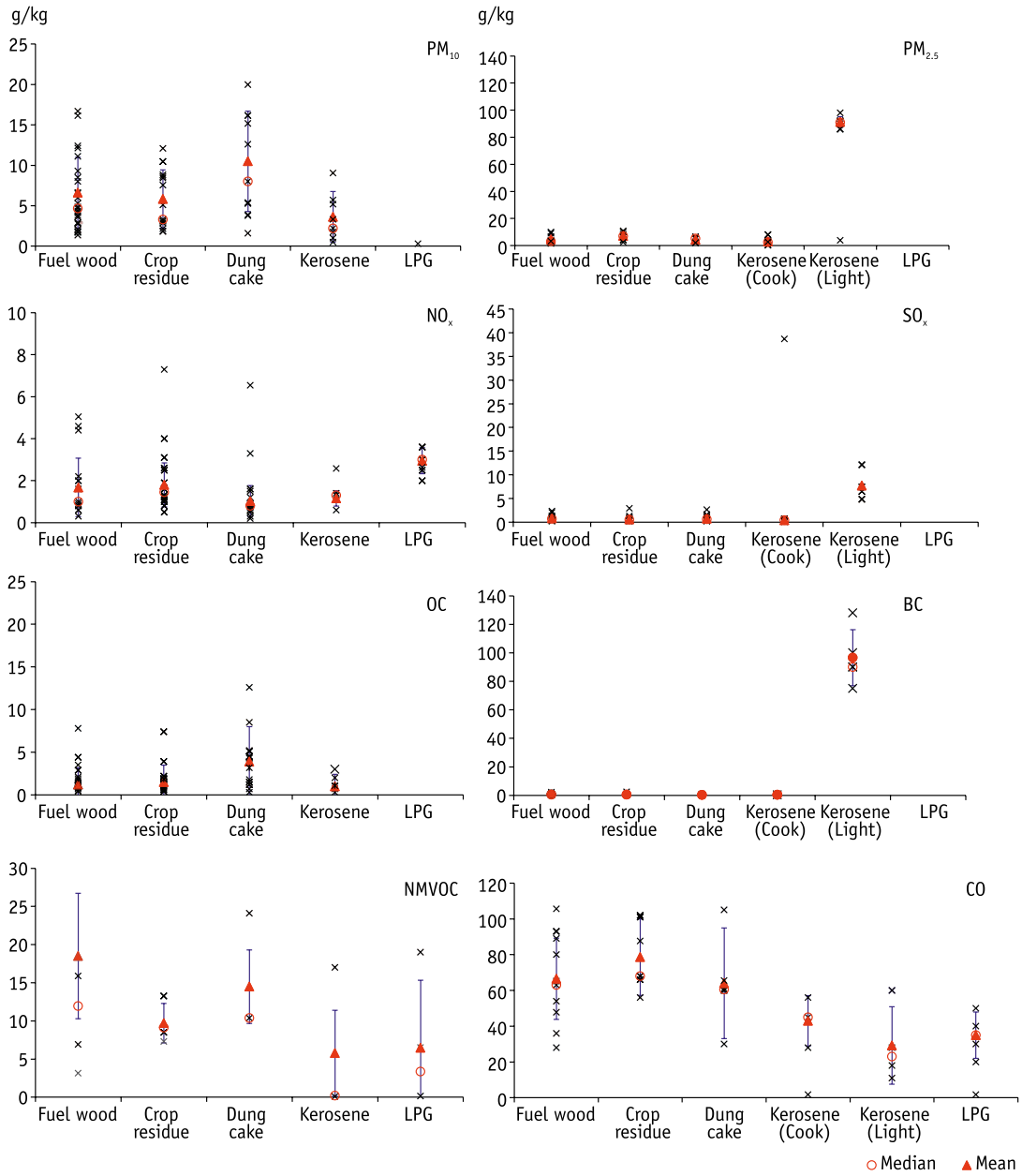

Figure 3.2: Collated emission factors of different pollutants based on literature review

Kerosene (Cook): Kerosene used for cooking; Kerosene (Light): Kerosene used for lighting. The emission factors of the Kerosene (Light) were not collated from literature for the pollutants in the left hand side and Kerosene indicates Kerosene (Cook) for them.

'×' indicates values from literature survey and the bar indicates standard deviation of the mean.

the years 2001 and 2011 correspond to the actual population and fuel use information, the future year projections are based on energy projections using TERI-MARKAL model.

Energy Used in Residential Sector

The main factors influencing emissions from the residential sector are population growth, availability of fuels in urban and rural regions, affordability

and their consumption patterns (Elias and Victor 2005). Average decadal population growth in India after independence is 35.1% and 18.7% in urban and rural areas, respectively (Figure 3.3). However, there is a decline in the population growth rate in both urban and rural areas during 2001 to 2011 (India census 2001; 2011). There is a high rate of migration from rural areas to urban cities (Masanad 2008). In India, 13.7% people in the urban areas live below the poverty line (INR 1,000/month), whereas about 25.7% population in the rural area is below poverty line (INR 816/month) (RBI 2012). According to the 68th round of the Household Consumer Expenditure Survey (NSSO 2012), rural India's average monthly per capita expenditure (MPCE) rose to INR 1,278.94 in 2012, while that of urban India stood at INR 2,399.24. However, the rural-urban division is much smaller (35.2%) when the MPCE on energy consumption is considered (NSSO 2012). The rural population primarily use conventional fuels for cooking and lighting energy due to lack of access to cleaner fuels. Fuel-wise energy use pattern in India is discussed in following sections.

Solid biomass fuel

There is significant variation in the type of solid biomass fuel used in different parts of the country based on their availability and cultural practices (Saud et al. 2011a, b). The per capita consumption of fuel wood in the rural area was higher in the north-eastern states (e.g., Nagaland, Arunachal Pradesh, Mizoram, and Tripura) ranging from 681 to 774 kg/year during 2011. While per capita consumption of crop residue and dung cake was significantly higher in the states of Bihar (244.9 kg/year) and Uttar Pradesh (193.8 kg/year), respectively (NSSO 2012).

Kerosene

Since the mid-19th century, kerosene (synonyms: paraffin, paraffin oil, fuel oil no. 1, lamp oil) has become a major commercial household fuel with the belief that it is a much cleaner fuel than the conventional solid biomass and fossil fuels (Mills 2005). In India, 31.4% households use kerosene for lighting and nearly 3% households (mainly in the urban areas) use kerosene for cooking (India census 2011). Total consumption of kerosene in India has decreased by ~68% during last two decades; whereas, the consumption has decreased by 36.3% in the rural areas compared to ~84% decrease in the urban areas (Figure 3.4). Compared to the urban areas, the monthly per capita kerosene consumption in the rural area has increased nearly four times during the last two decades (Figure 3.4). During the first half of the 20th century, the prevalence of kerosene for lighting has greatly reduced, as electrification and availability of gaseous fuels

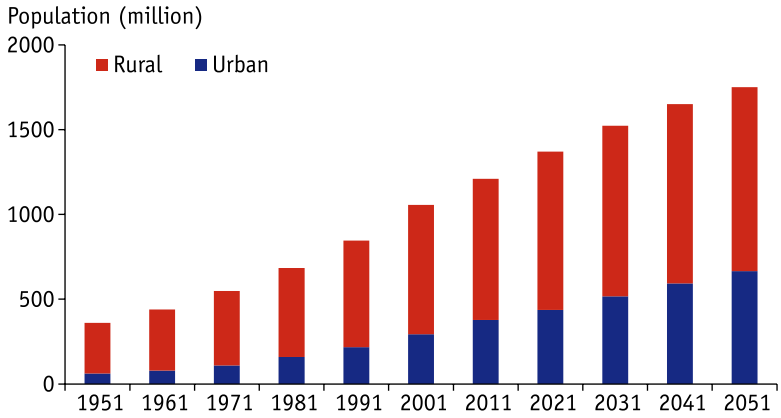

Figure 3.3: Decadal growth of rural and urban population of India

Source: India census (2011); TERI (2015a)

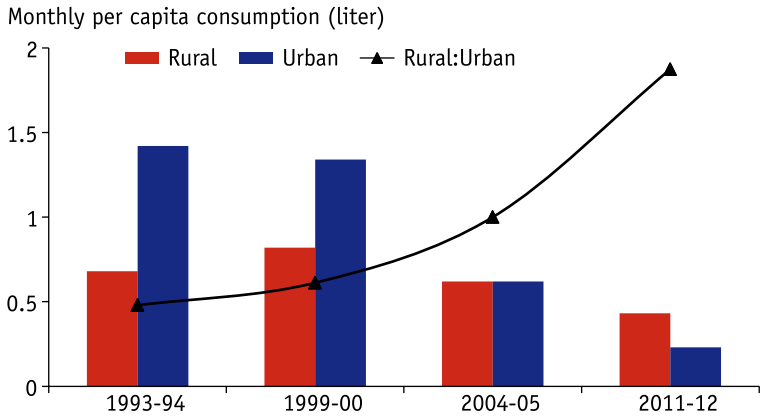

Figure 3.4: Annual changes in the monthly per capita consumption of kerosene in the rural and urban areas of India. Compiled from NSSO dataset

spread, particularly in developed countries. Towards the beginning of 20th century, liquid petroleum gas (LPG) was introduced for cooking, the consumption of kerosene in the urban areas gradually declined.

Gaseous and other fuels

LPG is considered as a relatively cleaner and efficient cooking option presently available in India (D'Sa and Murthy 2004). There is a steady growth of 8% p.a. in LPG consumption during the last decade in India. At present, 28.5% (rural: 11.4% and urban: 65.0%) of total households in India use LPG for cooking purpose (India census 2011). Rural areas showed an increase of 83% in the proportion of LPG-consuming households and an increase of 75% in the consumption of LPG per person during 2004–05 and 2011–12. Urban areas has shown a rise of 20% both in the proportion of LPG-consuming households and in the quantity of LPG consumption per person during the period (NSSO 2012).

Apart from these, about 1.4% households in India use coal as a fuel for cooking purpose (India census 2011). The use of coal (including coke and charcoal) in the residential sector has increased in both rural and urban areas during 2001 to 2011. Increased use of coal in Jharkhand, Odisha, and Bengal may be attributed to the availability in these states. The rate of increase in the coal consumption in urban areas of Bengal was significantly higher during the period. However, with respect to other fuels, the consumption of coal in the residential sector is small.

About 74% households in the rural area and 96% households in urban areas use electricity for the lighting purpose (NSSO 2012). There was a rise of 36% in the electricity consuming household in the rural areas during the period 2004–05 and 2011–12, (compared to a rise of 6% in urban areas). Electricity at the users end is generally regarded as the 'cleanest fuel' (Brander et al. 2011); however, consumption of electricity in the hotplates/burners for the cooking purpose may produce NO_x (EPA 2007). In India, such uses of electricity for cooking purpose in the residential sector is minimal (<1%), so the emissions due to the consumption of electricity were not considered in the present study. Similarly, solar power and wind power was not considered in the estimation of pollutant emission from the residential sector. Burning of biogas although releases some pollutants; its consumption in India is also negligible.

Fuel Consumption in Residential Sector using bottom-up approach

Figure 3.5 shows the use of different kinds of fuel in the residential sector in different states of India during 2001 and 2011. The consumption of different fuels in the residential sector has increased

significantly during 2001 to 2011. Especially, the consumption of fuel wood in the rural areas has increased by 12.5%. The consumption of dung cake has significantly increased in Bihar and Uttar Pradesh (more than five times) followed by Madhya Pradesh, West Bengal, and Punjab during 2001–11. Consumption of crop residue in the rural areas has also significantly increased in the states like Bihar, Assam, Uttar Pradesh, Maharashtra, Madhya Pradesh, and Bengal (Figure 3.5). The use of coal in the residential sector has increased in the states of Jharkhand, Odisha, and West Bengal. This may be attributed to local availability of coal.

The present estimation suggests that the total consumption of biomass (fuel wood, crop residue, and dung cake) in the domestic sector during 2011 was 436 Mt (Figure 3.5) (TERI 2015). Total consumption of fuel wood in the residential sector was earlier reported as 307 Mt during 2011 (FAOSTAT 2014). On the other side, Woodbridge et al. (2011) have reported the annual consumption of fuel wood in the residential sector of India as 206 Mt based on the NSSO (2007). However, Ravindranath and Hall (1995) have reported 218 Mt of fuel wood consumption in the residential sector of India during 1990. They have also reported that the total crop residue consumption in the residential sector as 96 Mt during 1990.

Emission Inventory for Residential Sector

The district-wise annual activity data (A_i) of different types of fuel derived through the Equation 3.4 was fed into Equation 3.1 along with the respective

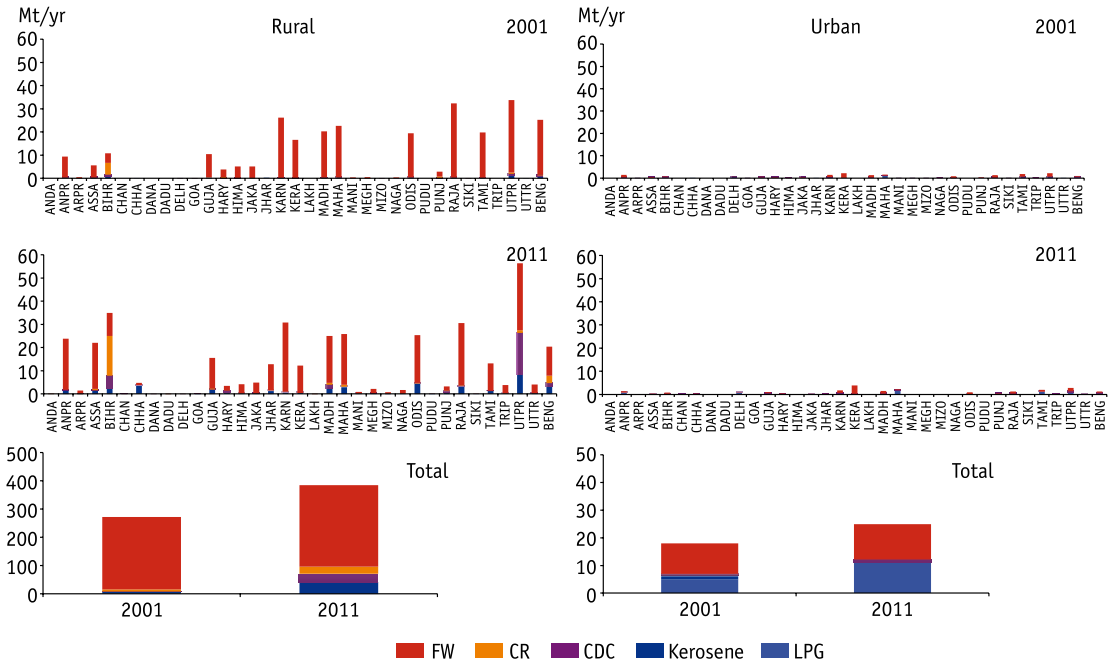

Figure 3.5: Consumption of different fuels in the residential sector in the rural and urban areas of different states and in the country during 2001 and 2011 as estimated using the bottom-up approach (following Equation 3.4).

FW: fuel wood; CR: crop residue; CDC: dung cake; LPG: liquid petroleum gas. ANDA: Andaman & Nicobar Islands; ANPR: Andhra Pradesh; ARPR: Arunachal Pradesh; ASSA: Assam; BIHR: Bihar; CHAN: Chandigarh; CHHA: Chhattisgarh; DANA: Dadra & Nagar Haveli; DADU: Daman & Diu; DELH: Delhi; GOA: Goa; GUJA: Gujarat; HARY: Haryana; HIMA: Himachal Pradesh; JAKA: Jammu & Kashmir; JHAR: Jharkhand; KARN: Karnataka; KERA: Kerala; LAKH: Lakshadweep; MADH: Madhya Pradesh; MAHA: Maharashtra; MANI: Manipur; MEGH: Meghalaya; MIZO: Mizoram; NAGA: Nagaland; ODIS: Odisha; PUDU: Puducherry; PUNJ: Punjab; RAJA: Rajasthan; SIKI: Sikkim; TAMI: Tamil Nadu; UTPR: Uttar Pradesh; UTKR: Uttarakhand; BENG: West Bengal.

pollutant emission factor to estimate emissions of different pollutants from the residential sector in rural and urban areas. Total emission of different pollutants from residential sector of the rural area was more than 10 times higher than that in the urban areas during 2001 and 2011 (Figures 3.6 and 3.7). Emissions of different atmospheric pollutants increased significantly by 2011 as compared to 2001, which can be attributed to increased consumption of different fuels in 2011. Emissions of the particulates (e.g., PM_{10}, $PM_{2.5}$, BC, and OC) were significantly higher from fuel wood combustion. Gaseous emissions, such as $SO_{2,}$ from the rural area were significantly higher with the consumption of kerosene. This is attributed to significant increase in the consumption of kerosene during 2011 in the rural area. On the other side, the NO_x emissions were significantly higher from LPG/PNG stoves in the urban area compared to others (Figure 3.7).

During both years total PM_{10} and $PM_{2.5}$ emissions from the rural areas of different states followed the order; Uttar Pradesh > Bihar > Karnataka > Rajasthan. Saud et al. (2011a, b) have also reported significantly higher particulate matter emission from the rural areas of the state of Uttar Pradesh followed by Bihar; however, they had considered only the solid biomass fuel in their estimation. This study also indicates that nearly 95% of total PM_{10} and $PM_{2.5}$ emission from the residential sectors due to consumption of solid biomass fuel in rural areas (Figure 3.6). PM_{10} and $PM_{2.5}$ emissions from residential sector in rural area have increased by more than 40% during the period of 2001–2011. This may be attributed to increase in the consumption of solid biomass fuel in the rural area. Significant increase in OC emission (more than 50%) in rural areas during the period also points to the increased consumption of solid biomass fuel. Among the gaseous pollutants, SO_2 emission has nearly doubled in the rural areas (Figure 3.7) due to substantial increase in the consumption of kerosene during 2001–2011. Similarly, increased consumption of kerosene in the rural area also attributed to significantly higher increase in the emission of NO_x (37.3%) and CO (38.9%) from the rural areas compared to that in the urban areas (Figure 3.7). Table 3.1 summarizes the total emission of different pollutants due to combustion of various fuels in the residential sector of India during 2011.

The baseline estimates of $PM_{2.5}$, BC, CO, and NMVOC are comparable to those reported by Pandey et al. (2014) for the year 2010. They have reported the $PM_{2.5}$, BC, CO, and NMVOC as 2,656 Kt, 488 Kt, 30,594 Kt, and 5,100 Kt, respectively. On the other hand, the estimation of OC, SO_x, and NO_x were higher in the present study compared to that of the Pandey et al. (2014). However, Sharma et al. (2015), Pandey et al (2014) have reported that the NMVOC emission from the residential sector of India as 5,863 Kt and 5100Kt, respectively, during 2010, which are comparatively lesser present estimation (6,637 Kt). This may be attributed to different emission factors of NMVOCs reported in recent studies.

The emissions are spatially distributed using GIS at a resolution of 36×36 km^2. The spatial distribution of different pollutant emissions in the residential sector of India is presented in Figure 3.8. Among the 640 districts (India census 2011) of India, higher PM_{10} emission (19.41 kt) was estimated from the rural area of 24 paraganas (S), West Bengal during 2011 (Figure 3.8).

Future Projections

Future energy consumption estimates from the residential sector are adopted from TERI-MARKAL model results (*vide* Chapter 2) to estimate emissions in the future. The residential energy consumption data as projected by the TERI-MARKAL indicates (Figure 3.9) a decrease of traditional biomass energy use in the residential sector after 2021. This is due to enhanced penetration of the fossil fuel in the residential sector.

The same set of emission factors for each pollutant (Figure 3.4) was used to estimate the future emission of different pollutants using Equation 3.1. Figures 3.10 and 3.11 show that the total emission of all pollutants from the residential sector will decrease after 2021, as the use of traditional biomass fuel (e.g., fuel wood,

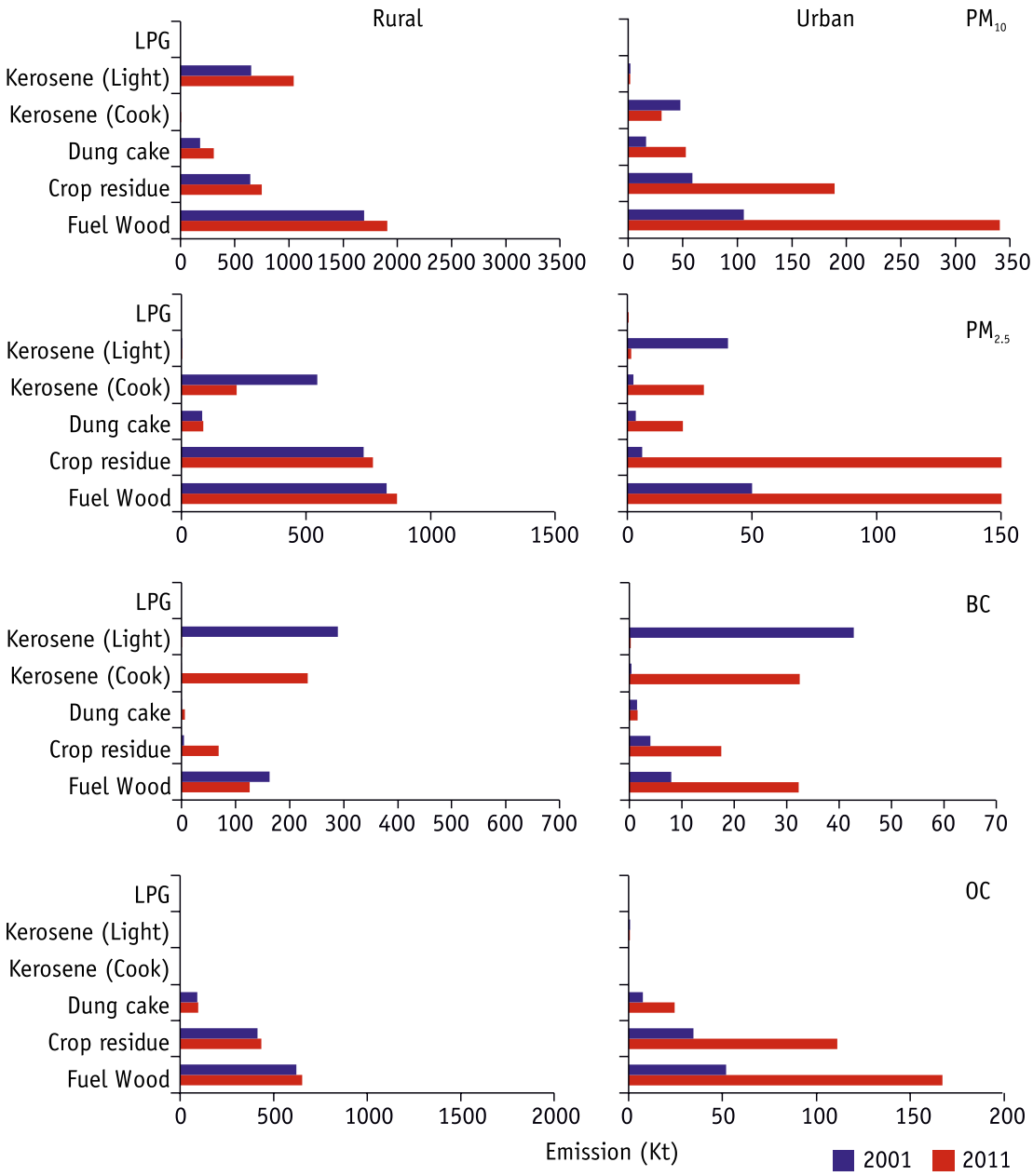

Figure 3.6: Total emission of PM and its constituents from the rural and urban areas of India during 2001 and 2011using the bottom-up approach

Note: The x-axis scale of the urban area is 10 times lower than that of the rural area.

dung cake, crop residue) decreases. The PM_{10} and $PM_{2.5}$ emissions from residential sector are projected to decrease by 14% over the period 2001–51. The projected emissions of BC and OC also follow the same pattern (Figure 3.10). However, NO_x emissions due to panetration of LPG in the rural areas is expected to increase more than 10 times during the 50 years period. Significant decrease in the consumption of

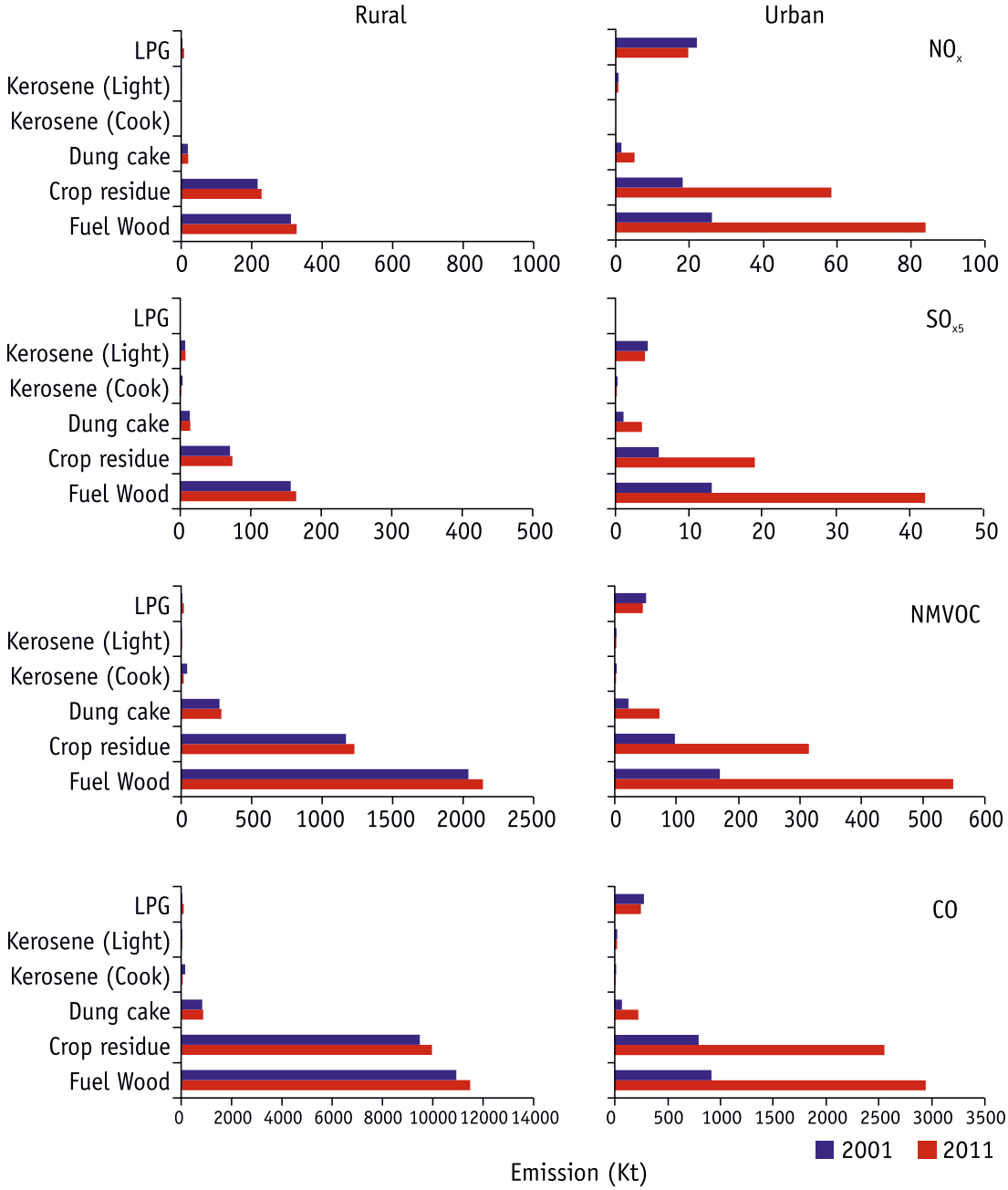

Figure 3.7: Total emission of NO_x, SO_x, NMVOC, and CO from the domestic sector in the rural and urban areas of India during 2001 and 2011 using the bottom-up approach

Note: The x-axis scale of the urban area is 10 times lower than that of the rural area.

Table 3.1: Emission inventory (Kt/yr) of different pollutants from the residential sector of India during 2011 using TERI-MARKAL energy consumption estimates

	PM_{10}	$PM_{2.5}$	OC	BC	NO_X	SOx	NMVOC	CO
Fuel wood	1,671	1,152	820	161	424	198	4,671	16,801
Crop Residue	928	1,141	545	86	287	93	1,544	12,511
Dung cake	259	110	121	8	25	18	358	1,579
Kerosene (Light)	252	252	0	266	0	21	0	81
Kerosene (Cook)	5	4	2	1	2	1	0	64
LPG	1	1	0	0	29	0	64	348
TOTAL	3,115	2,660	1488	521	766	330	6,637	31,385

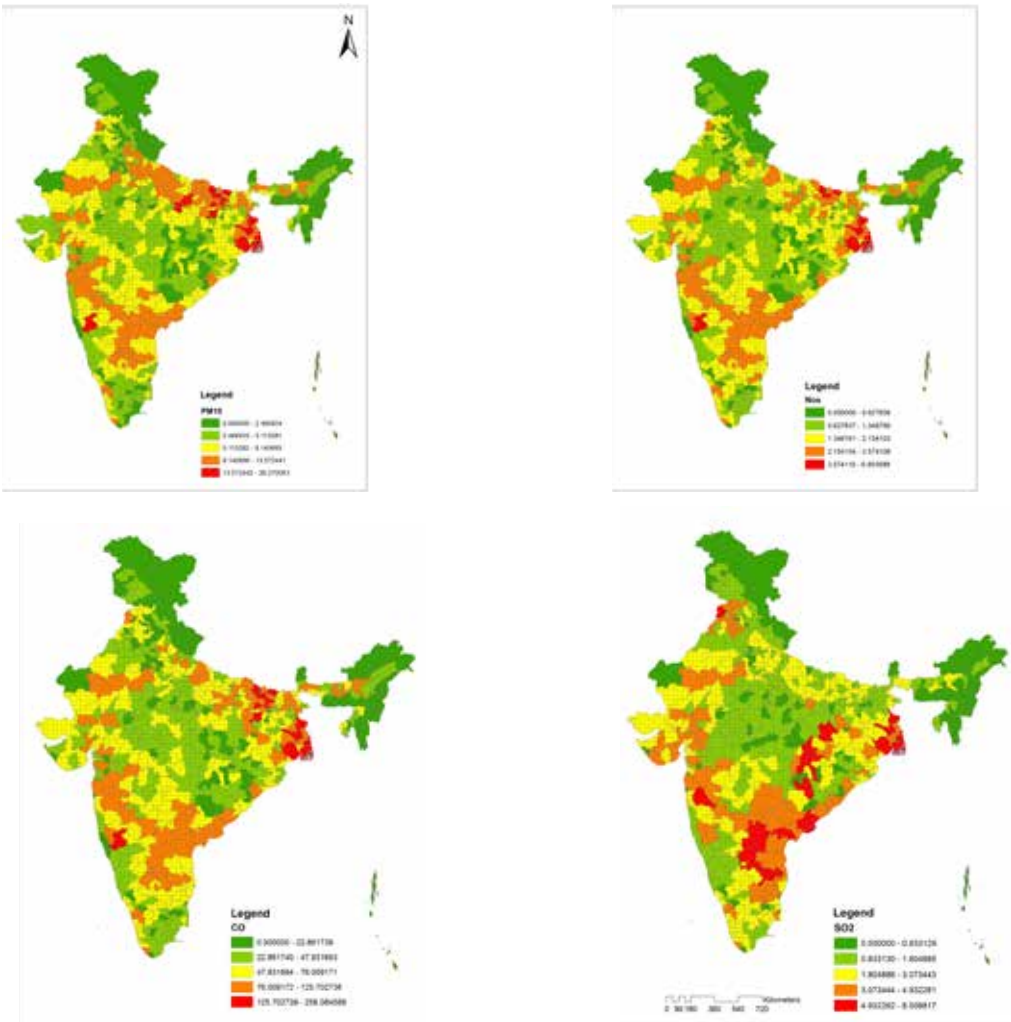

Figure 3.8: Estimated spatial distribution of emission of different pollutants (Kt/yr) from the residential sector of India during 2011

kerosene will lead to 27% decrease in the SO_2 emission from the sector (Figure 3.11).

Uncertainty of Estimation

As mentioned earlier, the mean of collated emission factors was used to estimate the emission of pollutants from the residential sector using Equation 3.1. When $EF_{p,f}$ of the equation is constant then E_p is directly proportional to the activity data (A_f). This indicates that the estimation uncertainty of emission of pollutants from the residential sector is directly related to the uncertainty in the fuel consumption data.

The uncertainties in fuel consumption in the residential sector for a given fuel used for cooking consisted of uncertainties in food consumption, specific cooking energy, the fraction of households using that fuel type, stove efficiency, and calorific value of the fuel. However, the use of bottom-up approach to estimate the fuel consumption in the residential sector, has reduces the uncertainty in the estimation of fuel consumption in the present study.Apart from this, there lies uncertainty related to emission factor itself. In this analysis, an attempt has been made to estimate uncertainties in the emission factors. The upper bound and lower bound along with the mean value of the collated published emission factors have been used to estimate the estimation uncertainty of different pollutants. Emission factor-related uncertainty estimation in the emission budget of pollutants from the residential sector indicates that the uncertainty in the estimation is significantly higher with OC among the different pollutants (Figure 3.12); whereas, the estimation uncertainty is lower with CO (0.5), NMVOC (0.6), and $PM_{2.5}$ (0.6).

Conclusion

Residential sector in India is one of the largest consumers of energy (see Chapter 2). Large amounts of pollutants are released in the atmosphere due to inefficient consumption of fuels in the residential sector. These pollutants lead to adverse effects on human health. In this study, a *bottom-up* approach was used to estimate the fuel consumption in the residential sector. Emission factor of different pollutants were derived by collating emission factor data from the published literature. District-wise and thereafter grid-wise (36 × 36 km²) emission estimates are prepared for different pollutants from the residential sector. The analysis shows that currently the emissions are very high from the residential sector mainly due to dependence on solid fuels. The analysis clearly highlights the need for strategies to reduce emissions form the sector. Some of the strategies that can be employed for reduction of emissions from residential sector are :

- Enhanced and faster penetration of cleaner fuels such as LPG.
- Increased penetration of improved biomass based challahs with higher efficiencies and lower emissions.
- R&D efforts to develop clean technologies.

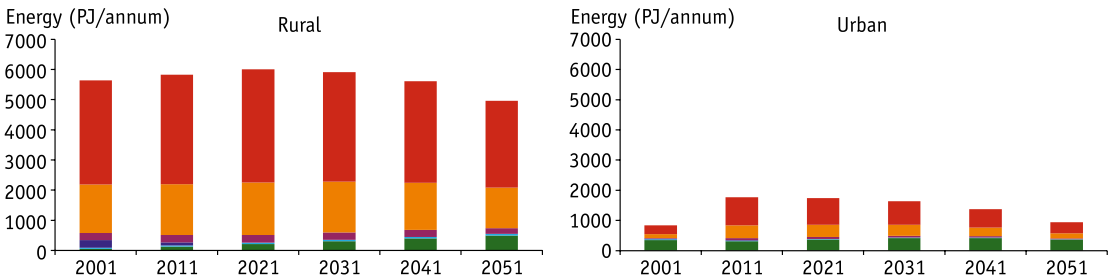

Figure 3.9: Future projections of energy consumption in the residential sector
Source: TERI-MARKAL model output.

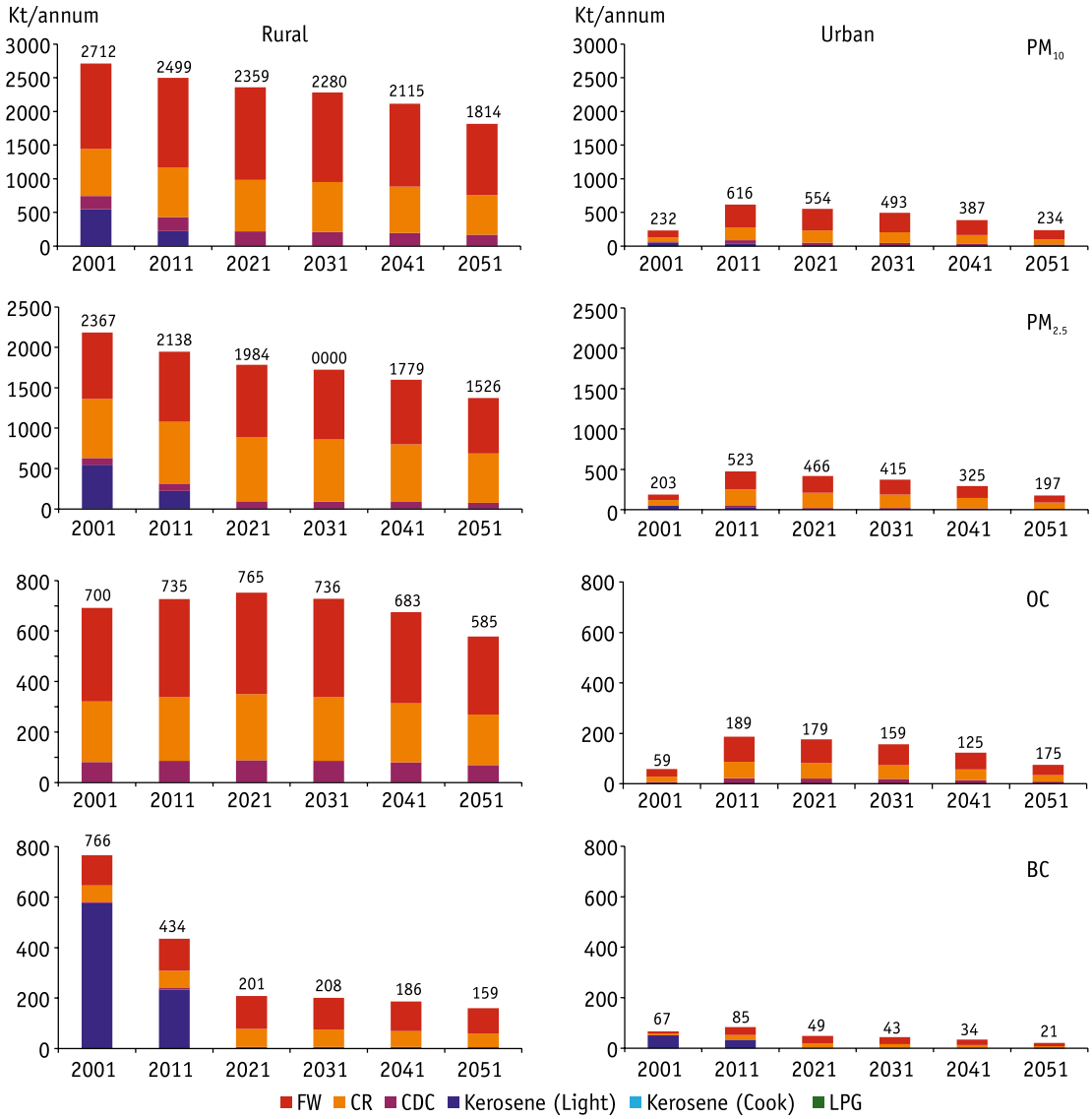

Figure 3.10: Future projection of different PM constituents from the domestic sector

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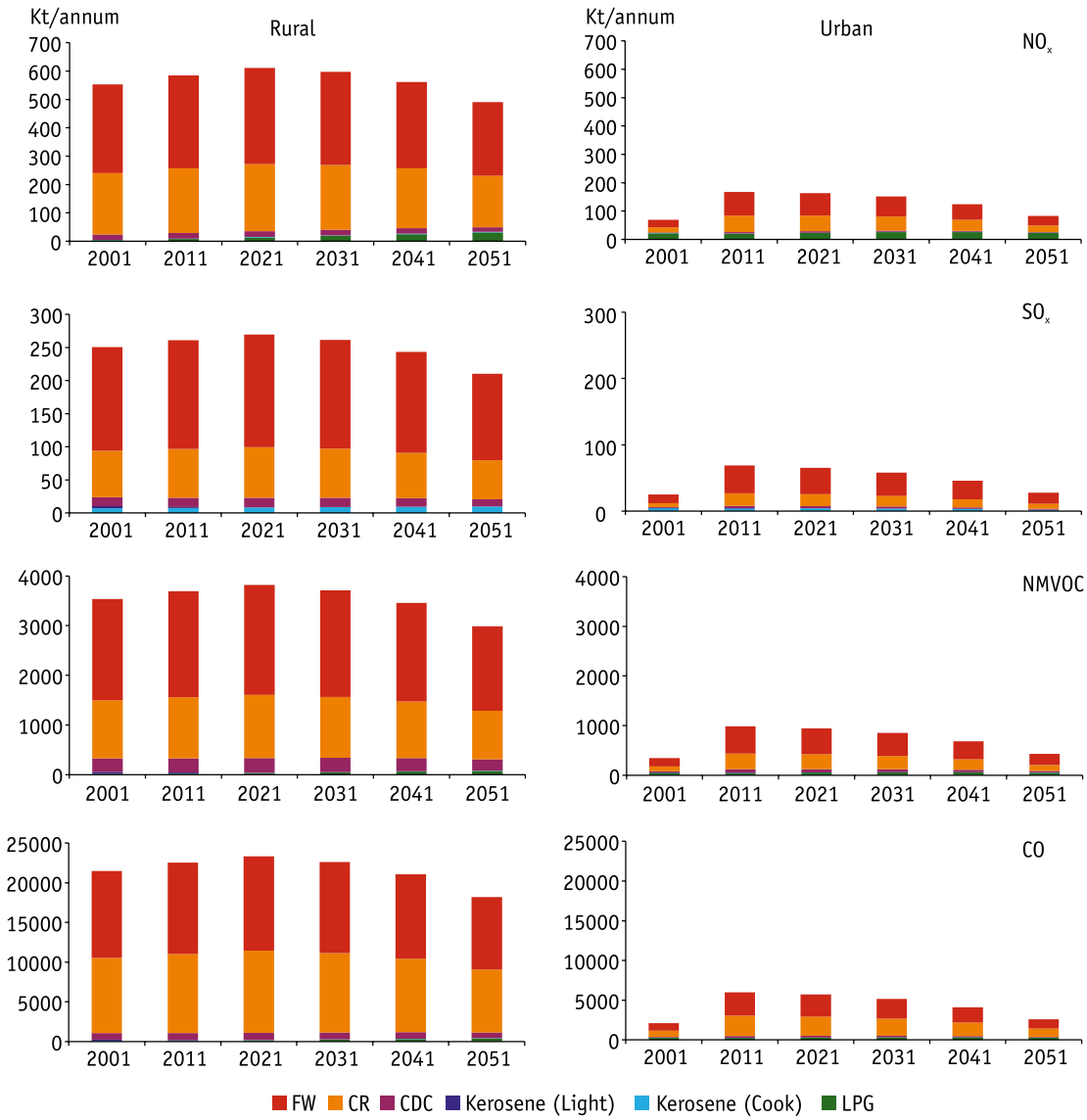

Figure 3.11: Future projection of NOx, SOx, NMVOC, and CO from the domestic sector

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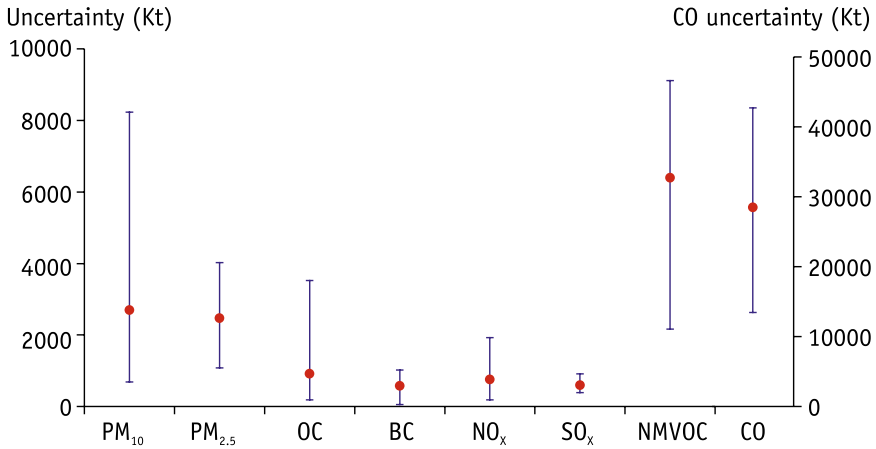

Figure 3.12: Emission factor related uncertainty in the estimation of different pollutants using the Equation 3.1

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Annexure: 3.1

Review of Emission Factors of Different Pollutants from the Combustion in Residential Sector in India

In the rural areas of developing countries, solid fuels are mainly burnt in traditional residential stoves (chulhas) or cookers with low combustion efficiency. In the developing countries, burning of solid biomass fuel could lead to significant quantities of emissions at regional and global levels. It is important to develop emission factors (EF) of different pollutants from burning of fuels in the residential sector to develop a reliable inventory of pollutants emitted due to the energy consumption in the residential sector. The EF is the amount of pollutant released per unit fuel consumed, expressed in units of gram per kilogram (Andrae and Merlet 2001). People from different countries have worked on the development of emission factor of different gaseous and particulate pollutants from the burning of the solid biomass (Andrae and Merlet 2001; Lemieux et al. 2004; Reid et al. 2005; Smith et al. 2000a; Venkatraman et al. 2006) in the residential sector. However, very limited studies have been conducted in India (Saud et al. 2011a). The concentration of PM_{10} ranges from 500 to 2000 $\mu g/m^3$ inside the kitchen during cooking with solid biomass fuel in typical Indian households (Balakrishnan et al. 2002). The emission factors vary significantly with type of fire wood and crop residue (Akagi et al. 2011; Saud et al. 2013). Saud et al. (2013) have also reported significant spatial variation in the emission from dung cake and same type of fire wood. They have reported

Table A3.1 : Collated Emission factors of PM10 (g/kg)

Country	Fuel wood	Crop residue	Dung cake	Kerosene	Source
India	1.74	2.16	5.36		Sen et al. (2014)
India	1.36	1.82	1.6		Sen et al. (2014)
India	1.81	3.09	8.00		Sen et al. (2014)
India	2.05	1.85	5.26		Sen et al. (2014)
India	1.69	2.85	5.37		Sen et al. (2014)
India	4.34	7.54	3.87		Saud et al. (2011b)
India	3.78	12.09	19.98		Saud et al. (2011a)
India	5.99	8.83	16.17		Saud et al. (2011a)
India	4.11	3.09	15.17		Saud et al. (2011a)
India	4.85	10.47	16.14		Saud et al. (2011a)
India	4.66	3.29			Saud et al. (2011a)
India	8.5	5.1	12.6		Parashar et al. (2005)
India		8.6			Garg et al. (2001)
India	6.64				Akagi et al. 2011)
India	11.1				Roden and Bond (2006)
India	16.7				Roden and Bond (2006)
India	8.5				Roden and Bond (2006)
India	6.5				Roden and Bond (2006)
India	5.28				Arora et al. (2013)
India	12.13				Arora et al. (2013)
India	2.05				Arora et al. (2013)

Table A3.1 : Collated Emission factors of PM10 (g/kg)

Country	Fuel wood	Crop residue	Dung cake	Kerosene	Source
India	16.14				Arora et al. (2013)
India	2.89				Arora et al. (2013)
India	12.4				Arora et al. (2013)
India	2.89				Arora et al. (2013)
India	2.77				Arora et al. (2013)
India	10.0				Arora et al. (2014a)
World				0.5	UNDP (2003)
World				9.04	Lam et al. (2012)
World				5.2	Apple et al.(2010)
India				1.0	Smith et al. (2000a–c)
India				2.2	Pandit et al. (2001)
World				1.74	Traynor et al. (1990)
Guatemala				5.7	Schare and Smith (1995)

significant higher emission of PM (15.64 g/kg), organic carbon (4.32 g/kg) and elemental carbon (0.51 g/kg) from burning of dung cake compared to other two solid biomass fuels used in the residential sector. They have also reported significantly higher and lower emission of PM from burning of dung cake in Delhi and West Bengal, respectively. Six different types of crop residues and fire woods that are prevalently used for residential cooking in the Indo-Gangetic plain (IGP) of India are associated with significantly different emission factors for different pollutants (Saud et al. 2013). Sen et al. (2014) have also reported significantly higher PM and BC due to burning of dung cake in residential sector in western India. The collated emission factors of PM_{10}, $PM_{2.5}$, BC and OC are summarized in Table A3.1 to A3.4. In addition to PM, burning of different types of fuel for household purpose generates high level of gaseous pollutants such as carbon monoxide (CO), oxides of nitrogen (NO_x) and sulphur (SO_2), formaldehyde, benzo(α) pyrene benzene, etc., which are hazardous to human health (Smith et al. 2000a–c). Significantly higher emission of SO_2 (0.74 g/kg) from burning of dung cake and higher emission of NO_x from burning of crop residue (1.41 g/kg) were reported in the Western India (Sen et al. 2014). Fossil fuel such as Coal (mainly lignite) is used for cooking purpose in few households in the rural and urban areas of India, based on its local availability. CO is emitted from burning of coal in residential cook stoves. Large amount of PM and polyaromatic hydrocarbon are released during burning of kerosene for cooking and lighting purposes. LPG is one of the popular residential fuels used for the cooking purpose in the urban areas of India. LPG is also regarded as a clean fuel, but certain pollutants are released during the combustion of LPG also (USEPA 2008). The collated emission factors of NOx, SOx, CO and Non-Methane Volatile Organic Carbon (NMVOC) are summarized in Table A3.5 to A3.8.

Table A3.2 : Collated Emission factors of PM2.5 (g/kg)

Country	Fuel wood	Crop residue	Dung cake	Kerosene (Cooking)	Kerosene (Lighting)	Source
World	9.1	6.3	6.6			Akagi et al. (2011)
World	1.6					Bond et al. (2004)
China	2.2	4.4				Li et al. (2009)
China	3.1	8.2				Shen et al. (2010)
South Asia	3.8	9.9	5.4			Stone et al. (2010)
South Asia	2.0	10.9				Stone et al. (2010)
Sweden	10.0					Hedberg et al. (2002)
USA	2.6					Larson and Koenig (1993)
India		7.5				Rajput et al. (2014)
India		3.9	5.0			Reddy and Venkataraman (2002a)
India			2.1			Mukherji et al. (2002)
India			2.1			Mukherji et al. (2002)
India			1.9			Swin et al. (2002)
India			6.1			Saud et al. (2011a, b)
India			6.3			Saud et al. (2011a, b)
China				2.4		Zheng et al. (2010)
India				3.3		Reddy and Venkataraman (2002b)
World				0.3		Veranth et al. (2000)
Chile				1.6		Ruiz et al. (2010)
Chile				2.5		Ruiz et al. (2010)
Guatemala				8.0		Schare and Smith (1995)
World					86.0	Lam et al. (2012)
World					98.0	Lam et al. (2012)
World					92.0	Lam et al. (2012)
World					90.0	Lam et al. (2012)

Table A3.3 : Collated Emission factors of OC (g/kg)

Country	Fuel wood	Crop residue	Dung cake	Kerosene	LPG	Source
India	1.0	1.5	3.9			Saud et al. (2012)
India	1.2	2.2	5.2			Saud et al. (2012)
India	1.1	1.2	4.3			Saud et al. (2013)
India	0.7	0.6	4.5			Saud et al. (2013)
India	1.4	1.4	4.5			Saud et al. (2013)
India	1.2	1.7	3.8			Saud et al. (2013)
India	0.9	1.0	3.7			Saud et al. (2013)

Table A3.3 : Collated Emission factors of OC (g/kg)

Country	Fuel wood	Crop residue	Dung cake	Kerosene	LPG	Source
India	0.4	0.4	0.7			Sen et al. (2014)
India	0.5	0.8	1.5			Sen et al. (2014)
India	2.1	1.9	5.1			Sen et al. (2014)
India	4.4	3.9	12.6			Parashar et al. (2005)
India		7.4	8.5			Parashar et al. (2005)
India	7.8		0.3			Venkatraman et al. (2005)
India	1.7		1.2			Venkatraman et al. (2005)
India	3.5					Venkatraman et al. (2005)
China				0.7		Lu et al. (2011)
India				0.3		Lu et al. (2011)
India				1.0		Lu et al. (2011)
Uganda				2.0		Lam et al. (2012b)
Uganda				3.0		Lam et al. (2012b)

Table A3.4 : Collated Emission factors of BC (g/kg)

Country	Fuel wood	Crop residue	Dung cake	Kerosene (Cooking)	Kerosene (Lighting)	Source
India	0.4	0.6	0.9			Saud et al. (2012)
India	0.4	0.3	0.5			Saud et al. (2012)
India	0.4	0.4	0.6			Saud et al. (2012)
India	0.3	0.4	0.4			Saud et al. (2012)
India	0.3	0.4	0.2			Saud et al. (2012)
India	0.4	0.2	0.5			Saud et al. (2012)
India	0.4	0.4	0.3			Saud et al. (2012)
India	0.1	0.1	0.2			Sen et al. (2014)
India	0.4	0.2	0.1			Sen et al. (2014)
India	0.3	0.3	0.1			Sen et al. (2014)
India	0.3	0.2	0.1			Sen et al. (2014)
India	1.1		0.1			Parashar et al. (2005)
India	0.4		0.1			Venkatraman et al. (2005)
India	0.6		0.2			Venkatraman et al. (2005)
India	1.0		0.3			Venkatraman et al. (2005)
China	0.9	2.4				Shen et al. (2012)
China	0.8					Guofeng et al. (2012)
China	1.2					Guofeng et al. (2012)
China	2.2	0.4				Li et al. (2009)

Table A3.4 : Collated Emission factors of BC (g/kg)

Country	Fuel wood	Crop residue	Dung cake	Kerosene (Cooking)	Kerosene (Lighting)	Source
World	0.83	0.8	0.53			Akagi et al. (2011)
World		1.0				Bond et al. (2004)
India				0.2		Habib et al. (2008)
India				0.3		Habib et al. (2008)
India				0.2		Lu et al. (2011)
India				0.7		Lu et al. (2011)
India				0.6		Lu et al. (2011)
India				0.9		Lu et al. (2011)
South Asia					90.0	Lam et al. (2012b)
South Asia					128.0	Lam et al. (2012b)
South Asia					75.0	Lam et al. (2012b)
South Asia					100.0	Lam et al. (2012b)
Uganda					90.0	Lam et al. (2012a)

Table A3.5: Collated Emission factors of NOx (g/kg)

Country	Fuel wood	Crop residue	Dung cake	Kerosene	LPG	Source
India	2.0	1.9	1.6			Sen et al. (2014)
India	4.4		1.5			Sen et al. (2014)
India	0.6	0.5	0.6			Sen et al. (2014)
India	0.9	1.2	0.9			Sen et al. (2014)
India	4.6	4.0	3.3			Sen et al. (2014)
India	0.8	1.1	0.6			Saud et al. (2011a, b)
India	1.6	2.6	1.2			Saud et al. (2011a, b)
India	1.0	1.0	0.8			Saud et al. (2011a, b)
India	0.3	1.3	0.3			Saud et al. (2011a, b)
India	0.6	0.8	0.2			Saud et al. (2011a, b)
India	2.0		0.9			Garg et al. (2001)
India	2.2	1.6	0.8			Gadi et al. (2003)
India	0.8					Smith (1988)
India			0.8			Kumari et al. (2011)
India			1.6			Venkataraman et al. (1999)
World			0.7			Spiro et al. (1992)
World		3.1	0.5			Akagi et al. (2011)
World		2.5				Andrae and Marlet (2001)
India				1.3		Apte et al. (1989)

Table A3.5: Collated Emission factors of NOx (g/kg)

Country	Fuel wood	Crop residue	Dung cake	Kerosene	LPG	Source
World				0.6		Lam et al. (2012)
World				1.3		Lam et al. (2012)
World				1.4		Girman et al. (1982)
India					2.5	Shankar and Mohanan (2011)
India					2.0	Bisen and Suple (2013)
World					3.6	USEPA (2011)

Table A3.6: Collated Emission factors of SO_2 (g/kg)

Country	Fuel wood	Crop residue	Dung cake	Kerosene (Cooking)	Kerosene (Lighting)	Source
India	0.3	0.3	0.3			Saud et al. (2011a, b)
India	0.4	0.3	0.3			Saud et al. (2011a, b)
India	0.2	0.4	0.4			Saud et al. (2012)
India	0.5	0.2	0.2			Saud et al. (2013)
India	0.7	0.9	0.8			Sen et al. (2014)
India	0.4	0.5	0.3			Sen et al. (2014)
India	0.8	1.3	0.9			Sen et al. (2014)
India	0.9	0.9	1.1			Sen et al. (2014)
India	1.3	0.5	1.4			Gadi et al. (2003)
India	0.8	0.6	0.6			Garg et al. (2001)
India			0.8			Reddy and Venkataraman 2002a
India		0.5				Reddy and Venkataraman (2002)
India	2.3		1.6			Venkataraman et al. (1999)
World		0.6				Akagi et al. (2011)
World			0.6			Bond et al. (2004)
India					7.4	Kandpal et al. (1995)
India					6.5	Kandpal et al. (1995)
India					4.8	Kandpal et al. (1995)
India					12.1	Raiyani et al. (1993)
China				0.1		Zhang et al. (2000)
China				0.1		Zhang et al. (2000)
World				0.7		Leaderer (1982)
World				0.6		Leaderer et al. (1999)
World				0.4		Leaderer et al. (1999)

Table A3.7: Collated Emission factors of CO (g/kg)

Country	Fuel wood	Crop residue	Dung cake	Kerosene (Cooking)	Kerosene (Lighting)	LPG	Source
India	28.0						Arora et al. (2014b)
India	36.0						Arora et al. (2014b)
India	65.2						Arora et al. (2014b)
India	80.0	68.0	60.0			20.0	Smith et al. (2000b)
China	54.0	56.0	61.0				Zhang et al. (2000)
China	89.0	66.0	30.0				Zhang et al. (1999)
China	47.8						Wei et al. (2012)
China	63.0	101.0					Zhang et al. (1999)
World	93.0	102.0	105.0				Akagi et al. (2011)
India					11.0		Apte et al. (1989)
China					18.0		Zhang et al. (1999)
China					60.0		Zhang et al. (1999)
World					28.0		Hobson and Thistlethwaite (2003)
India						30.0	Shankar and Mohanan (2011)
India						40.0	Bisen and Suple (2013)
World						50.0	USEPA (2008)
India				28.0			Smith et al. (2000 a–c)
India				56.0			Smith et al. (2000 a–c)
India				45.0			Smith et al. (2000a–c)

Table A3.8 :Collated Emission factors of NMVOC (g/kg)

Country	Fuel wood	Crop residue	Dung cake	Kerosene	LPG	Source
India	15.89	13.26	10.37	0.08	0.14	Sharma et al. (2014)
India	6.9	8.5	24.1	17.0	19	Pandey et al. (2014)
China	3.13	7.3			6.51	Wei et al. (2008)
World	8		9	0.2	0.2	IPCC (2006)
World	19.32	9.73				Andrae and Marlet (2001)
World	57.7					Akagi et al. (2011)

CHAPTER 4

Industries

Richa Mahtta, C Sita Lakshmi, Sumit Sharma, Atul Kumar, and Saptarishi Das

Introduction

Indian economy has grown manifolds since independence in 1947. The agriculture sector dominated the GDP of India till 1980s, when India slowly opened up its markets through economic liberalization. The perecentage contribution of different sectors to national GDP during 1981–2013 is presented in Figure 4.1 which shows that

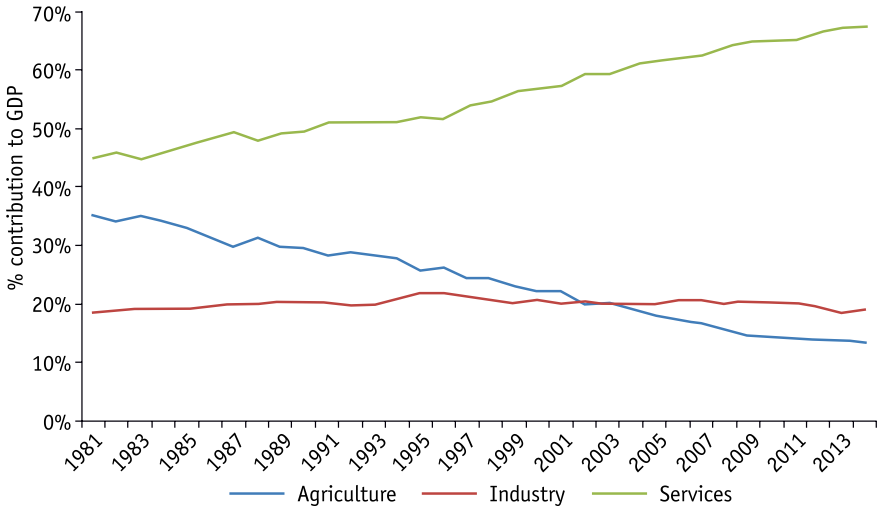

Figure 4.1: Growth rates of different sector contributing to Indian economy in different timeframes.
Source : RBI (2014–15)

industry and services sectors have broadend their shares in last two decades. Over all a healthy growth rate of about 7.5% is achieved in post 2000 era, which is sufficient to double the average income in a decade. There are certain states such as Tamil Nadu (9.9%), Gujarat (9.6%), Haryana (9.1%), or Delhi (8.9%) that have shown highest growth rates during 1999–2008, while there are states that have lagged behind. Now, India is the 10th biggest economy in the world and the third largest by purchasing power parity adjusted at market exchange rates (World Bank 2015). Over the years, the share of primary sector has gone down and industrial manufacturing sector has shown tremendous growth. While on one hand, it has led to improved per capita incomes and quality of life, it has also contributed to deterioration of air quality. Inefficient combustion of fuels (with high ash content), limited tail-pipe controls, and fugitive process emissions have led to release of huge quantities of air emissions, which lead to deterioration of air quality. A Comprehensive Environmental Pollution Index was formulated in 2009 that showed that 43 industrial areas/clusters out of the 88 investigated were critically polluted, with respect to one or more environmental component (CPCB 2009). Air quality was one of the important criteria that were evaluated.

Industrial Pollution

Air pollution in industries in India is an important issue that if not addressed can lead to severe deterioration of air quality. Seventeen categories of highly polluting industries have been identified in India. CPCB had carried out an inventorization of the post-91 large and medium scale industries under these 17 categories. It was considered mandatory for these units to have been allowed only if they had the requisite pollution control facilities The state-wise status of 17 categories of highly polluting industries in India (as on May 19, 2014) is presented in Table 4.1.

Manufacturing of products require energy, which is produced in the industries through combustion of fuels such as coal, fuel oil, biomass, and diesel. Emissions from industries are function of quality of fuel, combustion efficiency, and tail-pipe controls. High sulphur fuels result in oxides of sulphur, while high ash content in fuels leads to particulate matter (PM) emissions. Inefficient combustion also leads to PM, while high temperature combustion forms NOx in the industrial stacks. In Indian scenario, tail-pipe controls and their efficiencies play a very important role in defining the emission, as the fuels combusted are of high ash content. Other than due to combustion of fuels, emissions also take place in manufacturing processes of some products such as cement, lime, etc.

Other than large industrial units, there are 36 million micro, small, and medium enterprises. Their contribution to GDP is about 8% besides 45% to the total manufacturing output and 40% to the exports from the country (MMSME 2015). Although big industries are somewhat capable of controlling emissions through installations of air pollutant control devices, pollution from small scale industries is an issue. Financial and technical capacities are major constraints for control of pollution in small scale industries.

Energy Consumption in Industries

Based on the actual energy consumed in various industries such as paper and pulp, iron & steel production, chemical production, non-metallic minerals and non-ferrous minerals, and other industries, TERI-MARKAL model is used to derive future projections of energy use in the industrial sector. Estimated fuel-wise energy consumed in the sector is shown in Figure 4.2, which clearly shows around 51% of energy demand in industries is met by coal, followed by petroleum products (16%), and electricity (13%).

The sub-sector–wise distribution of energy consumed in Industries is shown in Figure 4.3. Other than cement, iron & steel, brick, aluminium, glass, paper, and fertilizer industry, significant energy consumption takes place in other small and medium scale industries. In 2011, iron and steel sector has the maximum share of 26%, followed by the brick, fertilizers, and cement industries.

Table 4.1: State-Wise Status of 17 Categories of Highly Polluting Industrial Units in India (as on May 19, 2014)

Sl No	State	Complying	Non-Complying	Closed	Total
1	Andhra Pradesh	359	74	39	472
2	Arunachal Pradesh	2	0	0	2
3	Assam	36	12	1	49
4	Bihar	16	4	0	20
5	Chattisgarh	71	6	1	78
6	Chandigarh	0	0	0	0
7	Daman & Diu	1	1	1	3
8	Delhi	2	0	0	2
9	Goa	13	2	0	15
10	Gujarat	302	7	8	317
11	Haryana	119	6	16	141
12	H.P.	14	0	3	17
13	Jharkhand	103	48	22	173
14	Jammu & Kashmir	7	0	3	10
15	Karnataka	175	30	26	231
16	Kerala	21	11	19	51
17	Lakshadeep	0	0	0	0
18	Madhya Pradesh	65	16	2	83
19	Maharashtra	317	145	58	520
20	Meghalaya	4	12	1	17
21	Mizoram	1	0	0	1
22	Nagaland	0	0	0	0
23	Orissa	37	17	11	65
24	Puducherry	5	2	0	7
25	Punjab	57	12	18	87
26	Rajasthan	69	31	18	118
27	Sikkim	3	1	0	4
	Total	1799	437	247	2483

Source: CPCB (2014)

Other than combustion of fuels, they are also used in non-combustion activities. There are certain fuels that are used in industry as feedstock and other non-energy uses. Naphtha (part of GSL) and natural gas are used as feedstock in fertilizers and petrochemical industries. This non-combustion fuel usage also leads to emissions. Data pertains to these uses is presented in the Table 4.2.

Table 4.2: Fuel Used in Non-Energy Sector during Year 2009–10

	Natural gas Million m^3 (MCM)	Naphtha (000 tonnes)
Fertilizer	13168	13168
Petrochemical	1264	1264

Source: MoPNG (2010)

Emission Inventorization of Industries

Energy estimates made in the previous section are used to estimate emissions of various pollutants during different industrial processes. The calculations are based on the following Equation 4.1.

Emissions = Activity level × Abated emission factor × Percentage of capacity controlled 4.1

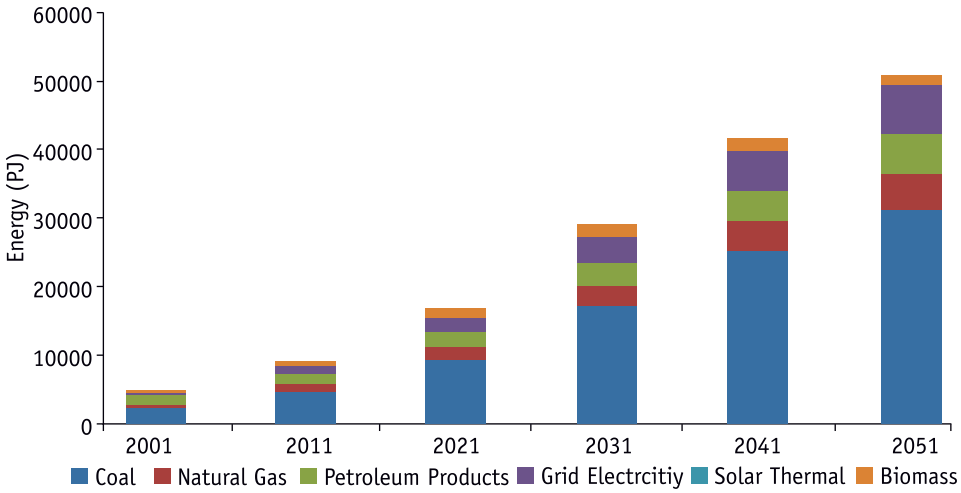

Figure 4.2 Estimated energy consumption in industry sector (PJ) during 2001-2051
Source: TERI (2015), TERI-MARKAL model results

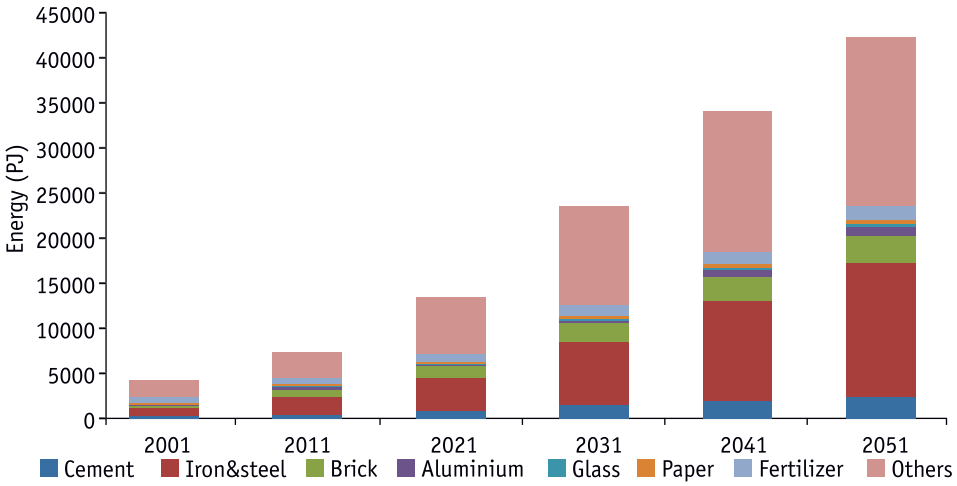

Figure 4.3: Past and projected energy consumption in the industrial sector (2001-2051)

where

Abated emission factor = Unabated emission factor × (1 – Percentage removal efficiency of the control system).

Other than fuel combustion, there are a number of industries for which emissions are estimated based on the processes followed rather than the fuel consumed in the sector. In this study, emissions are estimated separately for cement, iron and steel, fertilizers, paper, brick, aluminium, and glass industries and rest of the industries are clubbed in 'others' categories.

Cement Industry

With growing economy, the demands for construction material has grown multi-folds. The cement production in India has grown from about 50 MT in 1993–94 to 169 MT in 2011. India is the second largest producer of cement in the world after

China (Planning Commission 2011). Major clusters of cement industry in India are:

- 1. Satna in Madhya Pradesh
- 2. Chandrapur in Maharashtra
- 3. Gulbarga in Karnataka
- 4. Yerranguntla in Andhra Pradesh
- 5. Nalgonda in Andhra Pradesh
- 6. Bilaspur in Chattisgarh
- 7. Chandoria in Rajasthan

There are 183 large cement plants and more than 360 mini cement plants. The Ordinary Portland Cement (OPC) and Portland Pozzolana Cement account for 93% of the total production (Figure 4.4).

In India, the housing sector is the biggest driver of cement demand, accounting for about 67 per cent of the total consumption. The other major consumers of cement include infrastructure (17%), commercial construction (13%), and industrial construction (9%) (IBEF 2015).

TERI analysis (TERI 2015) on future projections of the sector shows bright prospects for growth of the sector. The cement production is expected to grow about 6.5 times and will reach to about 1300 MT in 2051 (Figure 4.5).

Manufacturing of cement is a process which leads to emissions of PM and gaseous pollutants. The process flow diagram of cement manufacturing is shown in Figure 4.6. There are a number of stages which can lead to emissions in a cement manufacturing process including

- handling and storage of raw, intermediate and final materials,
- operation of kiln systems, clinker coolers, and mills.

The major release of emissions happens in the kilns during the production through physical and chemical reactions involving the raw materials and combustion of fuels. The indigenous emission factors per unit of cement production for this study are adopted from ILFS, 2010 and CPCB (2007) (Table 4.3)

In a cement kiln, solid material moves counter currently to the hot combusted gases. This counter current flow affects the release of pollutants, since it acts as a built-in circulating fluidized bed. Most cement plants have made considerable efforts in controlling the stack emissions using most efficient control systems like bag filter and Electrostatic Precipiators (ESPs) and these plants generally meet the environmental regulations for stack emissions.

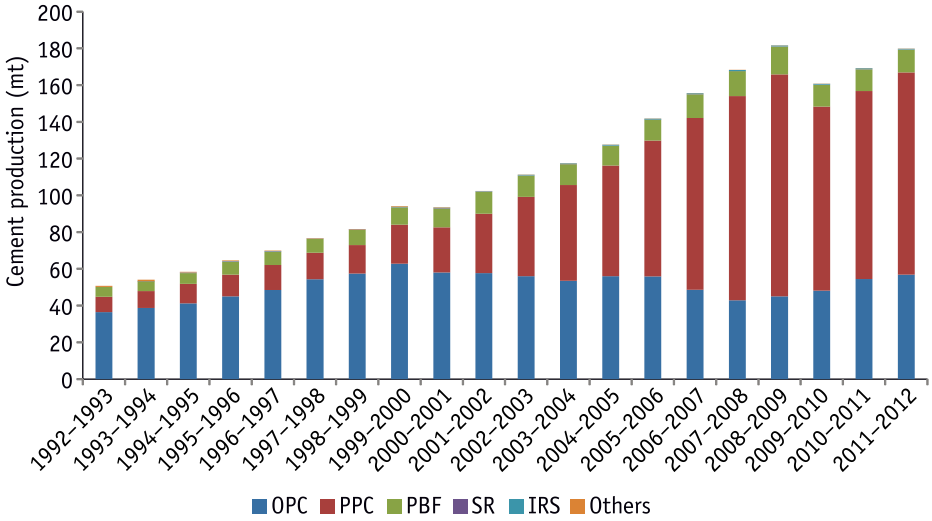

Figure 4.4: Variety-wise cement production in India

Source: Cement Manufacturers' Association

OPC, Ordinary Portland Cement; PPC, Portland Pozzolana Cement; PBF, Portland Blast Furnace Slag Cement; SR, Sulphate Resistant; IRS, Indian Railway Standard; Others

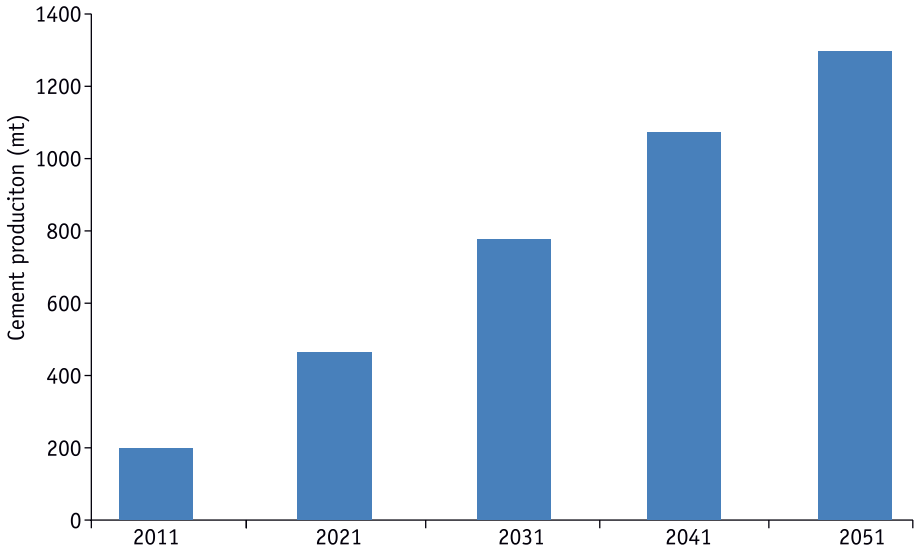

Figure 4.5 Projected growth of cement production in India (TERI, analysis)

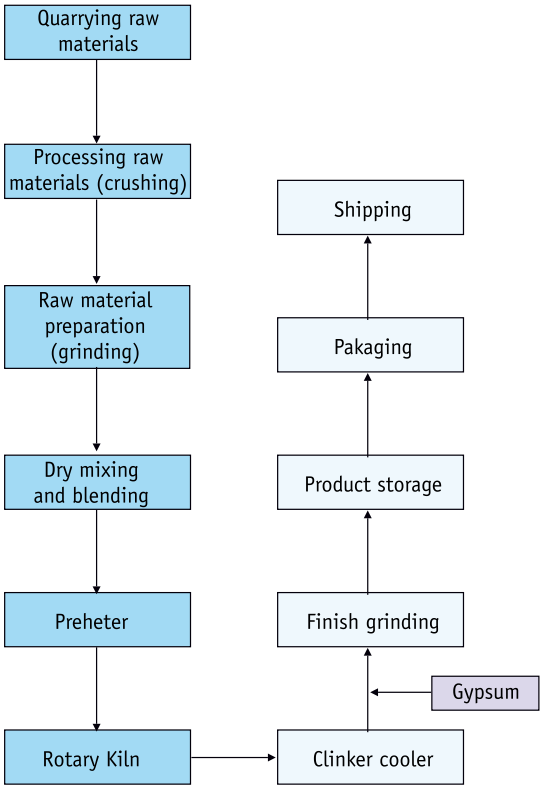

Figure 4.6: Process flow diagram for the cement manufacturing process

Source: Adapted from Huntzinger, D.N. and Eatmon, T.D., 2008. A life-cycle assessment of Portland cement manufacturing: comparing the traditional process with alternative technologies, J Clean Prod, doi:10.1016/j.jclepro.2008.04.007

Table 4.3: Emission Factors for Cement Sector

Emission factors (kg/t)					
Dry process					
	PM		NO_X	SO_2	CO
	w/o APCD	With APCD	w/o APCD	w/o APCD	w/o APCD
Klin	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					
	w/o APCD	APCD	w/o APCD	w/o APCD	w/o APCD
Klin	174	0.2			
Grinding	123	0.02			
Others	6	0.03			
Total	303	0.25	4	3.75	0.27

Source: ILFS, 2010, CPCB (2007)
APCD: Air pollution control devices
* Ratios for $PM_{2.5}$, BC, OC are used from EEA 2009 and EPA 2012.

However, fugitive emissions from various sources in cement plants still remain an area of concern (CPCB 2007). Based on the emission factors and controls, the emissions coming out of the cement plant are estimated and presented in Figure 4.7. These emissions include pollutants emitted during captive power generation activities.

The PM_{10} emissions are projected to go up from 354 Kt in 2011 to 2446 Kt in 2051. The ratio of $PM_{2.5}$ emissions to the PM_{10} emissions is about 0.56. While, the presence of air pollution control (APC) equipment for PM leads to control of emissions, NO_x emissions are projected to go up uncontrolled by about 7 times from the current levels of 450 Kt. This highlights the need for emission control norms for NO_x in industries.

The SO_2 emissions are expected to increase from about 1044 Kt in 2011 to about 7327 Kt in 2051. It is to be noted that in last few years, many cement industries have started co-processing of hazardous and other high calorific value material like petcoke. This leads to higher emissions of SO_2 due to high sulphur content of the fuel (petcoke) used in the sector. Present estimates do not assume the influx of FGD technology in the sector. However, with influx of FGDs in the sector, the SO_2 emissions can reduce considerably. The use of pet coke has resulted in substantial reduction in conventional fuel and present study has taken this into account for current and future scenarios.

Iron and steel Industry

The iron and steel industry in India caters to the demands of key sectors like construction and automobiles. The sector is mainly divided into two types; the first one comprises of a few large integrated steel providers producing primary products billets, slabs and hot rolled coils, and secondary smaller units producing value-added products such as cold rolled coils, galvanised coils, angles, columns, beams and other re-rollers, and sponge iron units. The sector has seen enormous growth in the recent past with India becoming the fourth largest producer of crude steel and the largest producer of soft iron in the world. The per capita consumption is about 58 kg in 2013 which is expected to rise with increased industrialization throughout the country. The report of the Working Group on Steel for the 12th Five Year Plan envisages

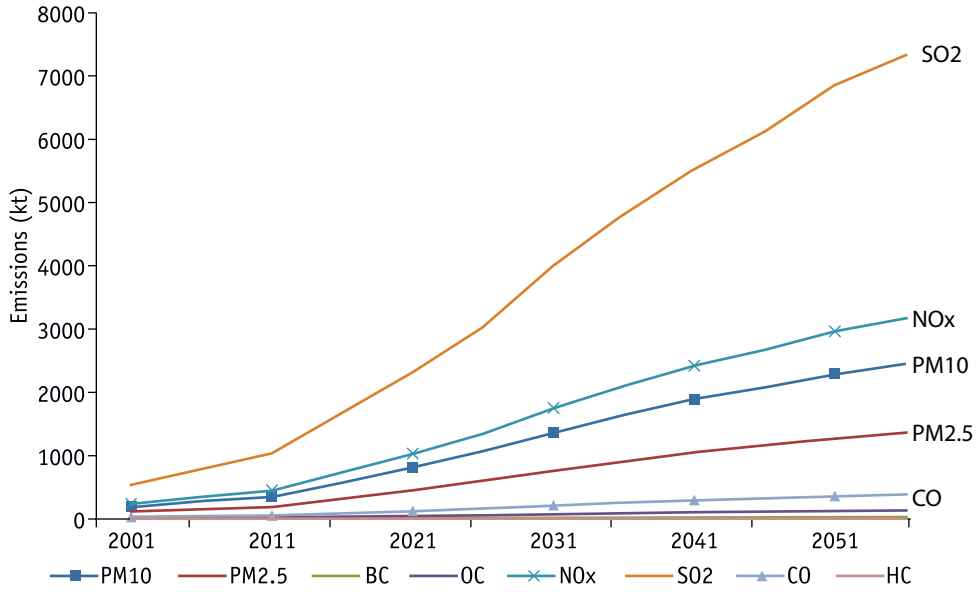

Figure 4.7: Past and projected growth of emissions (Kt) from cement manufacturing in India

increase in the per capita steel consumption in the country on the basis of high infrastructure investment, high projected growth of manufacturing sector, increasing urban population, and emergence of the rural markets. The Working Group on Steel for the 12th Five Year Plan made projections for domestic crude steel capacity in the county to be about 140 MT by 2016–17 and has the potential to reach 149 MT. The MARKAL model estimates are close to the projections. The model projected the finished steel production to 388 MT in 2031 and 779 MT in 2051 (Figure 4.8).

Various processes involved in iron and steel manufacturing are metallurgical coke production,

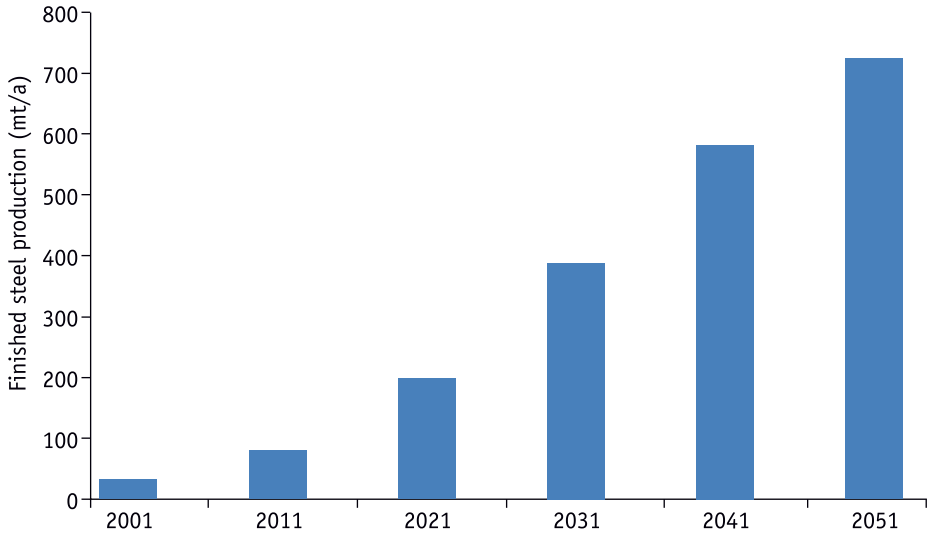

Figure 4.8: Past and projected finished steel production (MT) in India (2001-2051)

Source: TERI-MARKAL model

sinter production, pellet production, iron ore processing, iron making, steel making, steel casting, and sometimes combustion of blast furnace and coke oven gases for other purposes. The raw steel is produced using a basic oxygen furnace from pig iron produced by the blast furnace and then processed into finished steel products (Figure 4.9).

Emissions occur at all the stages of the production and emission factors are chosen for different processes followed in the iron and steel sector in India (Table 4.4).

Basic oxygen furnaces use pig iron and electric arc furnace is used for steel produced from scrap. Based on emission factors, the emissions for different pollutants from iron and steel plants are estimated and presented in Figure 4.10.

The iron and steel plants are generally equipped with high efficiency APC equipment and the PM_{10}

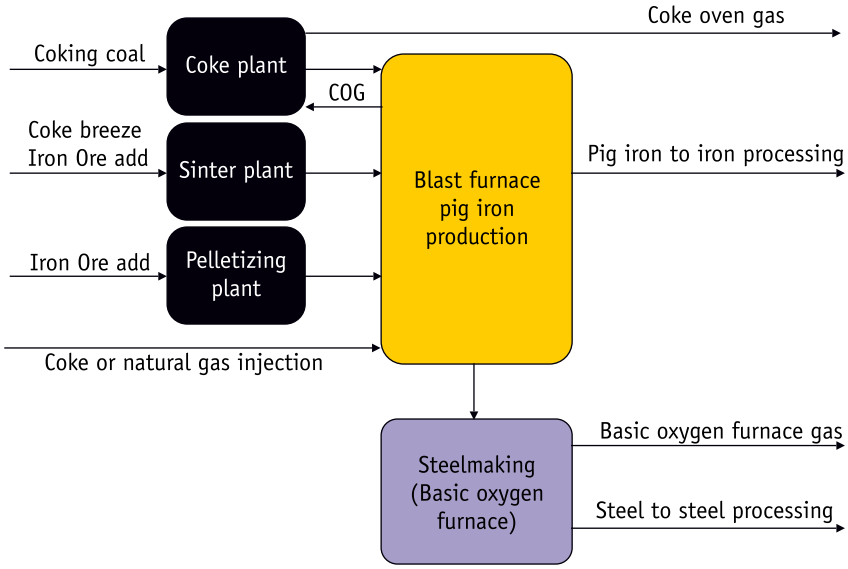

Figure 4.9: Processes in iron and steel production industry

Adopted from EEA (2009)

Table 4.4: Emission Factors for Different Pollutants from Various Processes in Steel Making

Emission Factors	Sintering	Pig Iron	Basic Oxygen Furnace with ESP	Electric Arc Furnace with ESP
	Kg/t	Kg/t	Kg/t	Steel making
PM2.5	0.08	0.025	0.021	0.021
PM10	0.1	0.04	0.024	0.024
BC	0.00017	0.0024	0.00036	0.00036
OC	–	–	0.002484	0.003168
NOx	0.5	–	0.01	0.13
SO2	1	–	–	0.06
CO	12	10	7	0.0017
NMVOC	0.138	–	–	0.046

Source: EEA, 2.C.1 Iron and steel production , GAINS ASIA model

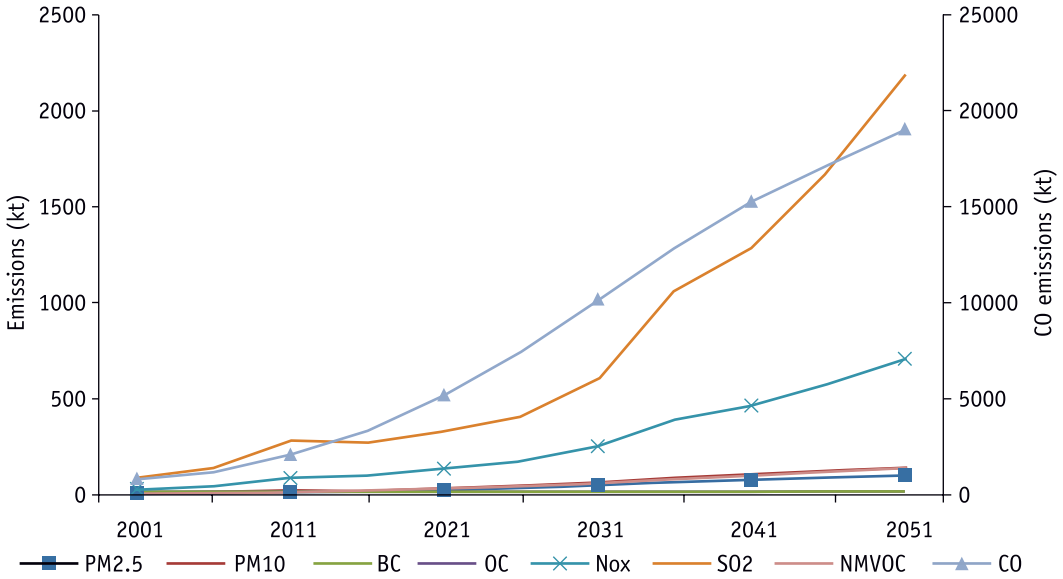

Figure 4.10: Emissions (Kt) from iron and steel industry in India (2001–51)

emissions are projected to go up from 24.2 Kt in 2011 to 144 Kt in 2051. This is mainly due to the growth expected in the sector. NO_x emissions are projected to grow from 86 Kt to 707 Kt during 2011- 2051.

Aluminium Industry

In India, aluminium is mainly produced in large integrated plants such as Hindalco and National Aluminium Company, and Bharat Aluminium, etc. The main energy inputs are in the form of electricity, coal, and furnace oil and the standard Bayer–Hall–Heroult technology is used for aluminium production. The production process is described in Figure 4.11. Captive power plants are installed to provide uninterrupted power. Presently, India accounts for 6% of the total deposits and 2.1 million tons of aluminium production in 2011. Aluminium production has grown steadily in India and is projected to grow to about 9 MT in 2051 (Figure 4.12). Aluminium production is expected to increase due to demands from packaging, construction, automobiles, and electrical sectors.

The emission factors used for estimating emissions form aluminium production in India are shown in Table 4.5. The emission factors are applied to the activity data to estimate emissions during 2001–51 for different pollutants (Figure 4.13).

The emissions from aluminium industry are comparatively less than cement and iron and steel industries, except for CO. The CO emissions are expected to grow from 194 Kt to 1,096 Kt during 2011–51.

Glass Industry

Glass industry caters to the demands of key sector such as construction, automotive, consumer goods, and pharmaceuticals. Apart from few big

Table 4.5: Emission Factors for Aluminium Production

Pollutant	Unabated Emission factor (kg/t)
PM_{10}	2
$PM_{2.5}$	1
BC	0.023
OC	0.0391
NOx	1
SO_2	6
CO	120
NMVOC	-
Source: EEA 2009, EPA 2012, GAINS	

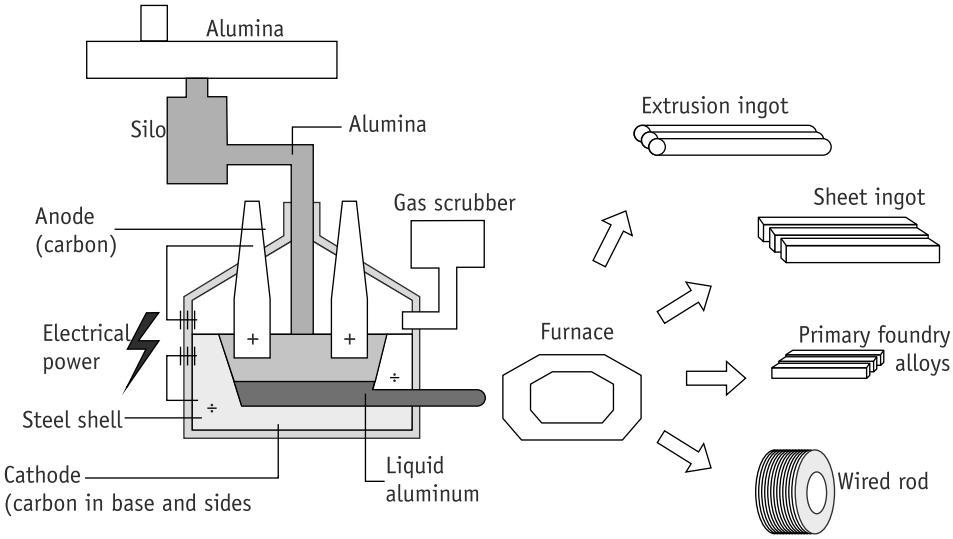

Figure 4.11: Aluminium production process flow chart

Source: Adapted from Halvor and Per Arne (2014)

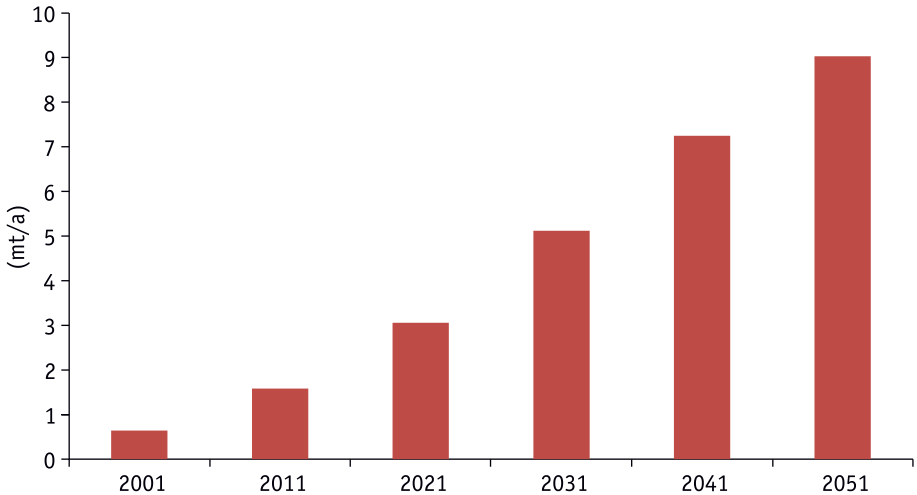

Figure 4.12: Aluminium production in India (2001-2051)

Source: TERI (2015)

manufacturers there are more than 1,000 small and medium scale enterprises involved in glass production in India. The glass consumption in India is just 1.2 kg/c/yr in 2010–11 in comparison to 30–35 kg in the US (TERI 2015).

Glass industry is highly energy intensive and the melting and refining processes account for 60–70% of the energy consumed in production. Furnace oil and natural gas are mainly used in India as the thermal energy source. The emission factors used to estimate emissions from glass manufacturing in India are shown in Table 4.6 and emissions are presented in Figure 4.14. The PM_{10} emissions are expected to grow from 1 Kt in 2011 to 5 Kt in 2051. NO_x emissions will grow from 34 Kt to 153 Kt during 2011–51.

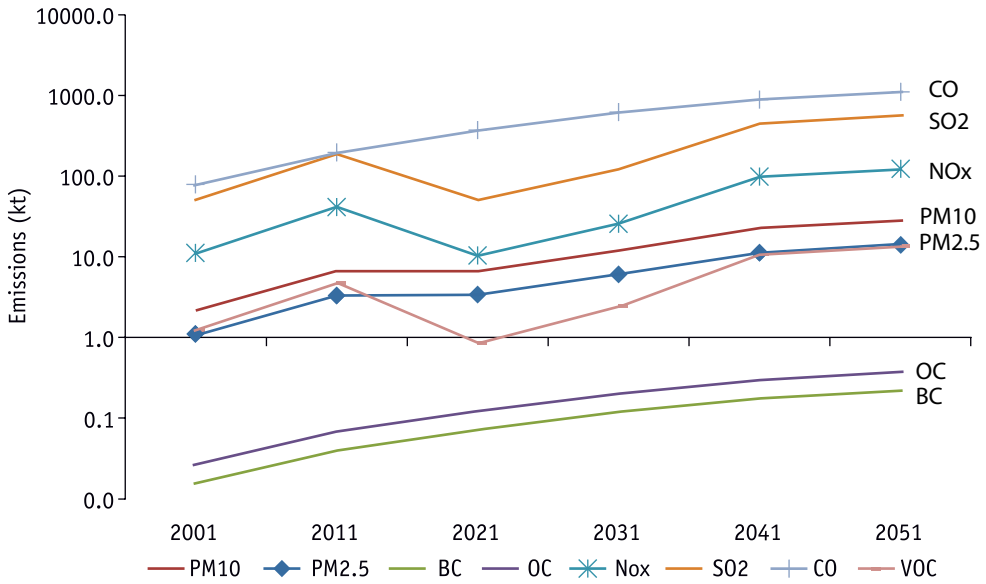

Figure 4.13: Emissions (kilotonnes) from aluminium industry in India (2001–51)

Paper and Pulp Industry

The Indian paper industry accounts for about 2.6% of the world's paper production. The technologies used in the paper mills show wide variations ranging from oldest to the most modern. A variety of raw material are used including wood, bamboo, recycled fibre, bagasse, wheat straw, rice husk, etc. Of the total paper production, 31% is based on chemical pulp, 47% on recycled fibre, and 22% on agro-residues (IPMA 2015). Paper industry is heavily dependent on the industrial growth and literacy rates in the country. Presently, the per capita paper consumption is just 9.3 kg in India as against 42 kg in China and 312 kg in US (TERI 2015). However, with growing literacy and middle class, the consumption is expected to grow. Production of paper is projected to grown from 7.5 MT in 2011 to about 20 MT in 2051 (Figure 4.15).

There are about 720 paper mills in India of which 621 are in operation (Ministry of Commerce & Industry 2010–11). Gujarat has the maximum number of paper mills followed by Uttar Pradesh. Majorly operating mills in India falls under three categories (CPCB 2011; Ministry of Commerce & Industry 2010–11):

- Large Integrated Wood Based: It includes newsprint, rayon grade pulp, bleached and unbleached varieties. Scale of operation for these mills is 100–700 tpd.
- Medium Agricultural Residue Based: It includes bleached varieties with and without recovery system and unbleached varieties without recovery system. Scale of operation for these mills is 50–100 tpd.
- Small Recycled Fibre and Market Pulp Based: It includes unbleached craft, writing and printing

Table 4.6: Emissions Factors for Glass Manufacturing

Pollutant	Unabated emission factor (kg/t)
PM_{10}	0.27
$PM_{2.5}$	0.24
BC	0.0038
NOx	8.12
SO_2	1.74
CO	0.1
NMVOC	–
Source: EEA 2009, GAINS	

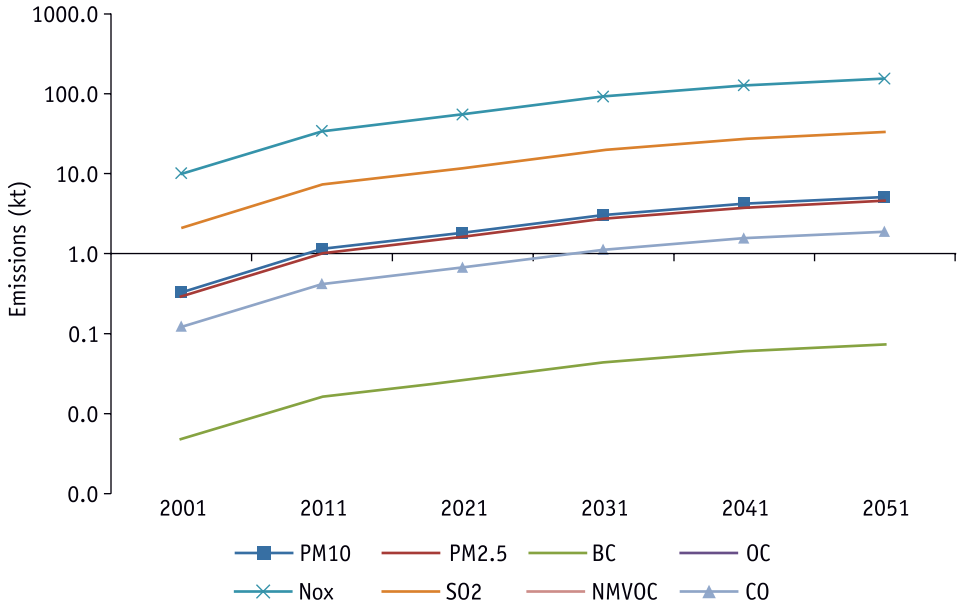

Figure 4.14: Emissions (kilotonnes) from glass industry in India (2001–51)

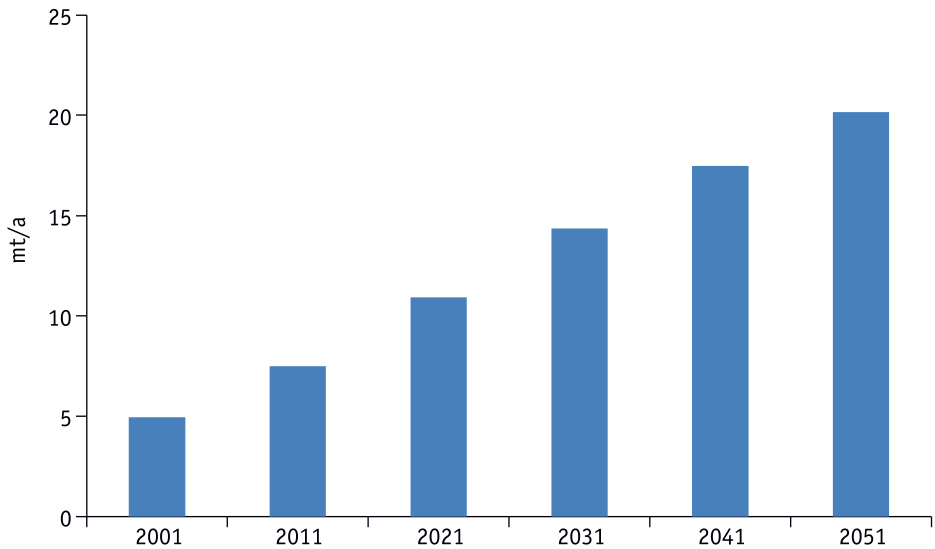

Figure 4.15: Past and project growth of paper industry in India

Source: TERI Analysis

varieties with and without deinking, unbleached crafts, and paper board. Scale of operation for these mills is 5–50 tpd.

Kraft method is broadly used in India for paper production. In this, the white liquor (water solution of sodium sulphide and sodium hydroxide) is subjected to high temperature and pressure. The lignin that binds the cellulose fibres of the wood is chemically dissolved. Thereafter, the pulp is washed, screened, and dried or further delignified and bleached, if required based upon the intended use of the product.

The rest of the Kraft processes are there for chemicals and heat recovery. The black liquor formed during the process is concentrated through evaporation, which is then combusted for recovery of heat and chemicals. Broadly, the emissions produced from different processes in paper and pulp industry are shown in Figure 4.16.

The emission factors used to estimate emissions of different pollutants from Kraft pulping process are presented in Table 4.7. It is evident from the Figure 4.17 that emissions from the paper and pulp industry will grow; PM_{10} will grow from 8 Kt to 17 Kt during 2011–51, while CO emissions from 42 Kt to 112 Kt in the same period.

Table 4.7: Emission Factors for Paper Industry

Pollutant	Unabated emission factor (kg/t)
PM_{10}	0.8
$PM_{2.5}$	0.6
BC	0.012
OC	0.0408
NOx	1
SO_2	2
CO	5.5
NMVOC	2
Source: EEA 2009, EPA 2012	

Fertilizer Industry

Chemical fertilizers are important to improve or sustain agricultural production in the country. Government of India has consistently persuaded policies conducive to increased availability and consumption of fertilizers at affordable prices in the country (MoCF 2012). The consumption of fertilizers, in nutrient terms (N, P, & K) has increased from 0.07 million MT in 1951–52 to more than 28 million MT in 2010–11 and per hectare consumption, has increased from less than 1 Kg in 1951–52 to the level of 135 Kg now. The overall production of fertilizers in India is expected to grow to 56 MT/a by 2051 (Figure 4.18).

About 78 per cent of Urea production is through natural gas used as feedstock. Fuel oil and naptha are also used in the sector. Thakkar (2013) has found high levels of pollutant emissions from industrial sector in India. The emission factors used in this study for emission estimation are presented in Table 4.8.

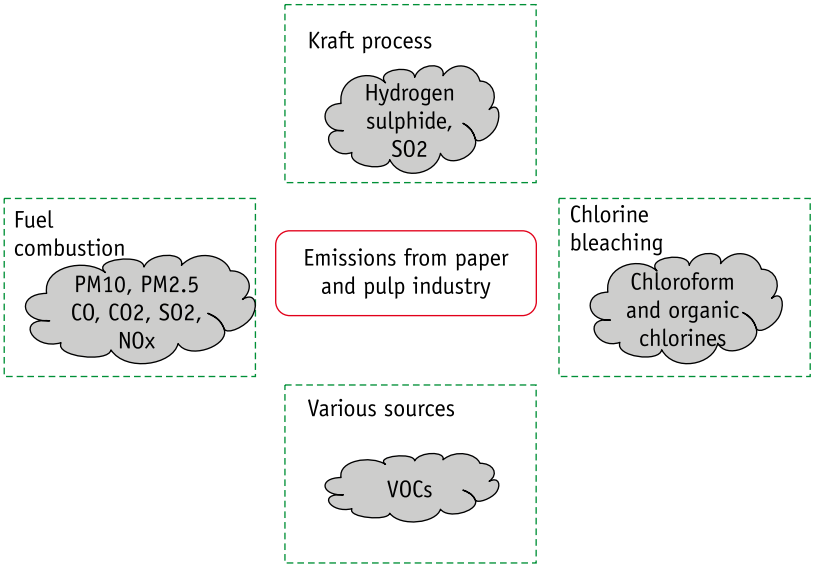

Figure 4.16: Emissions produced from paper production process

Source: Reproduced from CPCB (2011)

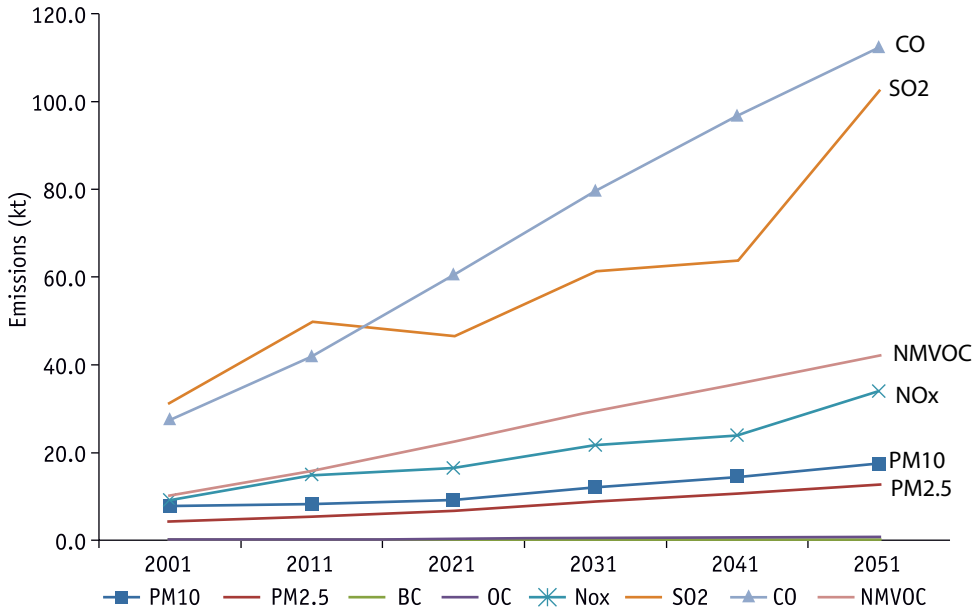

Figure 4.17: Emissions from paper industry in India (2001–51)

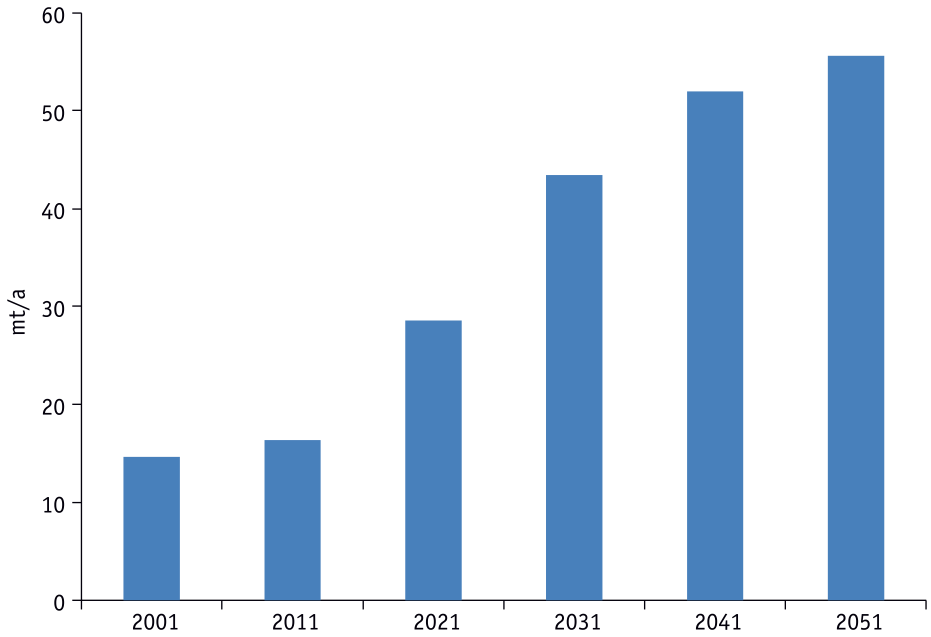

Figure 4.18: Past and future projections of fertilizer production in India (2001-2051)

Source: TERI Analysis

The estimated emissions are shown in Figure 4.19 for the period 2001–51. The CO emissions from the fertilizer industry are expected to go up from 1,020 Kt in 2011 to 3,462 Kt in 2051. SO_2 emissions that are coming from captive power generation using coal will gradually diminish in the future.

Table 4.8: Emission Factors (kg/t) for Fertilizer Industry

Pollutant	Emission factor (kg/t)
PM_{10}	0.33
$PM_{2.5}$	0.2145
BC	–
OC	–
NO_X	2
SO_2	0.04
CO	62.25
VOC	–
Source: AP42, Section 6.10 phosphate fertilizers	

Brick Industry

Brick industry is a small scale traditional and unorganized industry in India (Maithel 2013; Pandey et al. 2014; Rajarathnam et al. 2014). But over time, it has become one of the largest consumers of coal in the country. Around 17.14 tonnes of coal is required to produce one lakh bricks. Incomplete combustion of coal results in the release of several air pollutants in atmosphere such as CO, SO_2, NO_X, and PM. At local level (in the vicinity of a brick kiln) some of these pollutants are injurious to human health, animal, and plant life. At global level, CO_2 and BC contribute to global warming and climate change.

There are about 300,000 brick kilns across the world that produce around 1,350 billion bricks across the year (MNRE 2013). Brick production is mainly focused in four countries across the world. Among these countries, China holds the maximum share of brick production followed by India, Pakistan, and Bangladesh (Figure 4.20). In India, total number of brick kilns are estimated to be around 1.4 lakh with a production of 280 billion brick annually (Rajarathnam et al. 2014). It is reported that during 2000–01, about 80 billion bricks were produced in India (TERI 2002).

As a result of increasing demand for infrastructure, commercial, and residential buildings, the demand for bricks is also increasing at a high rate. Brick making in India is concentrated in Indo-Gangetic plains and in some scattered pockets in other states (Figure 4.21). Maximum number of the brick kilns is located in the rural areas lying adjacent to rapidly expanding cities.

Brick kiln industry in India started with the clamp technology having non-fixed structures. The practice was to take clay and mud from fields, moulding them, and heating them in inefficient furnaces using

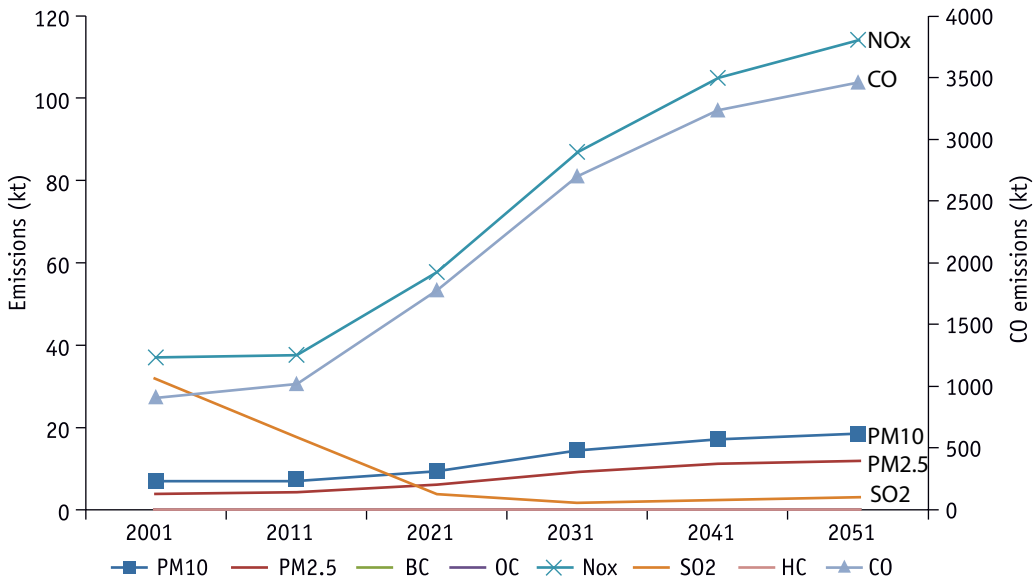

Figure 4.19: Emissions from fertilizer industry in India (2001-2051)

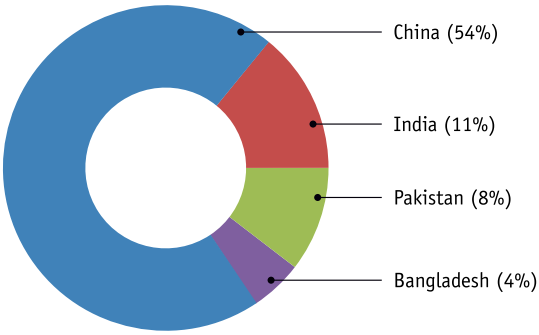

Figure 4.20: Worldwide production of bricks in major producing industries
Source: MNRE (2013)

any fuel that is easily available. There was no control technology involved in these temporary structures. The brick manufacturing is known as one of the major polluting sectors. Studies have pointed out that around 9% of black carbon emissions in India are from brick sector. Many technologies with varied designs have been introduced from time to time in order to reduce the huge environmental cost associated with the sector.

Brick production involves moulding, drying, and firing processes. These bricks are heated between 600°C and 1,100°C to get the desired product (TERI 1999). Different types of kilns are used for firing bricks, which are broadly divided into intermittent and continuous categories (Figure 4.22).

Continuous kilns are generally more efficient as fire is always burning and bricks are being warmed, fired, and cooled simultaneously in different parts of the kiln. Heat in the flue gas is utilized for heating green bricks and the heat in fired bricks is used for heating air for combustion. On the other hand, fire is allowed to die out and the bricks to cool after they have been fired in intermittent kilns. The kiln are emptied, refilled, and a new fire is initiated for each load of bricks. In intermittent kilns, most of the heat contained in the hot flue gases and the fired bricks is lost.

Different types of Brick kiln technologies practiced in India are Clamps (scove, scotch), Moving Chimney Bull's Trench kiln (MC-BTK), Fixed Chimney Bull's Trench kiln (FCBTK), Vertical Shaft Brick kiln (VSBK), Zig-Zag, and Tunnel Kilns (Figure 4.23). Clamp and downdraught kilns are examples of intermittent kilns, while, rest are continuous in nature.

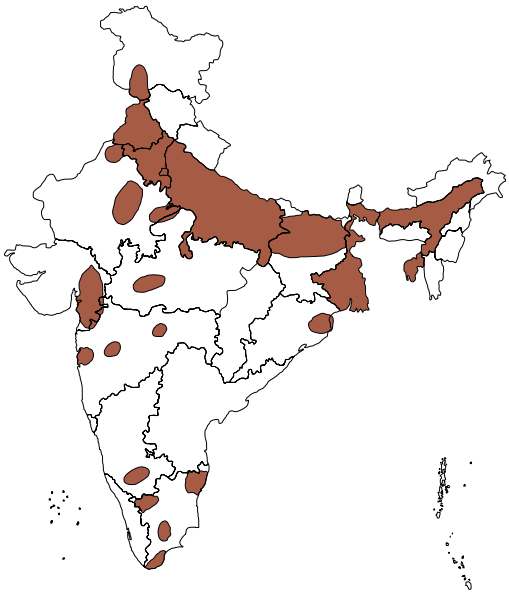

Figure 4.21: Brick production sites in India.
Source: Adapted from http://www.ecobrick.in/brickmakinginindia.aspx

Figure 4.22: Brick production in India
Photo credit: R Suresh

A transition has been observed in last two decade with the introduction of new technologies in the country, which are shown in Figure 4.24. These different types of brick kilns differ in terms of specific energy consumption (SEC). SEC is expressed in terms of energy required for firing per Kg of bricks. A study conducted by SDC (2008) has come up with SEC values for few technologies, shown in Table 4.9.

Table 4.9: Comparison of SEC for Different Kilns

Type of Kiln	SEC (MJ/kg of fired bricks)
Clamp and other batch kilns (Asia)	2.0-4.5
MC-BTK (India)	1.2-1.75
FCBTK (India)	1.1-1.5
VSBK (India, Nepal, Vietnam)	0.7-1.0
Tunnel Kiln (Vietnam)	1.4-1.6

In this study, bricks production has been estimated by assuming growth in brick production same as growth of construction sector, which is 6.6% for the time period 2005–30 (MNRE 2013) in the country. For further projections, growth rates have been taken from TERI MARKAL model outputs. However, in the past few decades, it has been observed that other walling materials such as fly-ash bricks, fly-ash lime gypsum blocks, autoclaved aerated concrete blocks have entered the Indian market and replaced bricks to some extent. In future, it is expected that these alternate walling materials could decrease the share of fired bricks to some extent in the construction sector. For 2010, the share of other walling materials has been estimated as 7.8%, which is expected to increase to 14.1% in 2030 (Enzen & Greentech Knowledge Solutions 2011). The current and expected brick production in India is shown in Figure 4.25.

State-wise allocation is done on the basis of reported number of brick kilns in the states in TERI (2007). Based on consultation with experts, it is

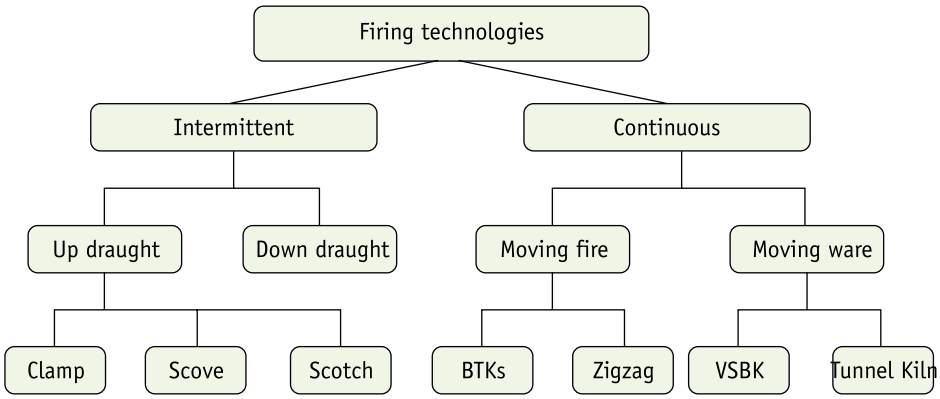

Figure 4.23: Brick kilns categorization on basis of firing technology

Source: CSE (2015)

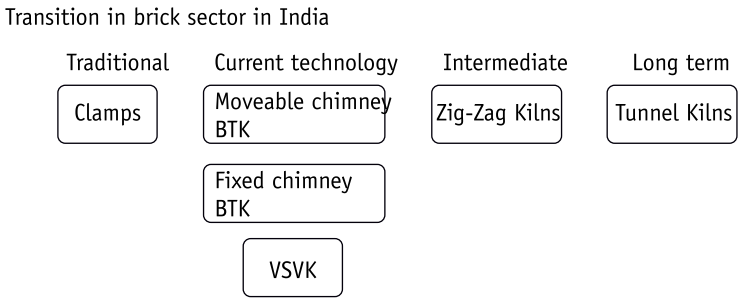

Figure 4.24: Technology transition in brick sector in India

Source: Maithel (2013)

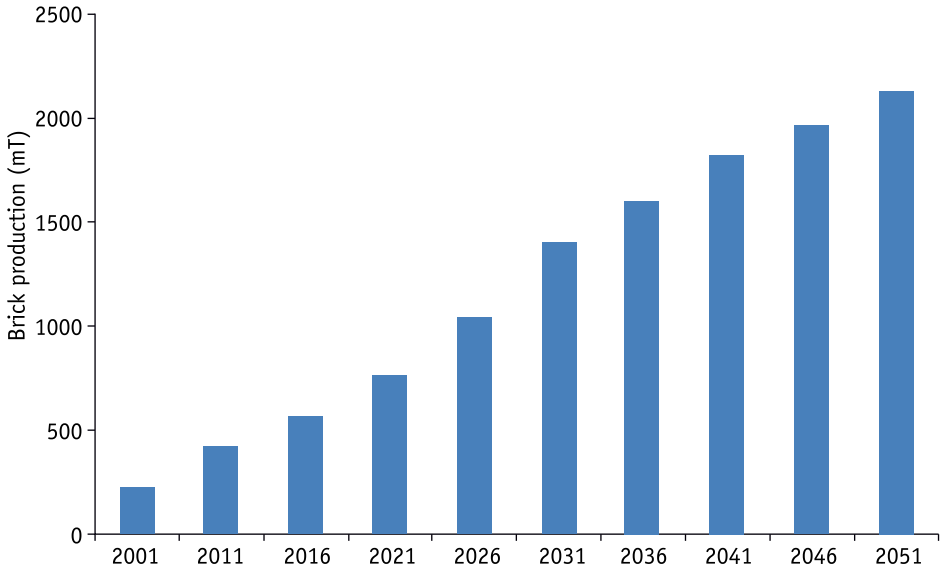

Figure 4.25: Current and projected brick production in India (2001–51)

assumed that 32% of the bricks in the country are manufactured using clamps, 61% are manufactured using Bull's trench kiln, 3% with moving chimney BTK (BTK-MC), and 1% for Holfmann kiln for the baseline year (2011). Vertical Shaft Brick Kilns (VSBKs) contribute very little in the total share of kilns across India (Table 4.10).

With the advent of advanced technologies such as Zig-Zag firing and tunnel kilns, it is expected that these cleaner technologies will penetrate into Indian Brick industry and numbers of clamps will gradually reduce (Figure 4.26). Thus, on consultation with experts, it is assumed that for 2030, 12% of the bricks will be produced from Clamps, 65% from FCBTKs, 19% from zig-zag kilns, and 3% through tunnel kilns. Considering the field performance of VSBKs in India, it is being assumed that their number will not increase much with time. Further in 2050, it is assumed that percentage of brick kilns with Zig-Zag technology will increase to 45% and FCBTK to be 55%. Clamps will diminish and tunnel kilns with economical constraints will be negligible in number.

Emissions from brick manufacturing facilities include PM (PM_{10} , PM $_{2.5}$, SO_2, nitrogen oxides (NOx),

Table 4.10: Estimated Kiln Technology–Wise Distribution of Brick Production in India in 2011

Kiln Technology	Number of Kilns (Approx.) 2010	Capacity Ratio (Thousand bricks/day)	Total number of Bricks produced/day
DDK	300	3	900
MCBTK	2,000	20	40,000
FCBTK	32,000	30	9,60,000
Zig-Zag	2,000	30	60,000
Holfman Kiln	500	30	15,000
VSBK	100	7	700
Clamp	100,000	5	5,00,000
Tunnel Kiln (Coal)	0	45	0

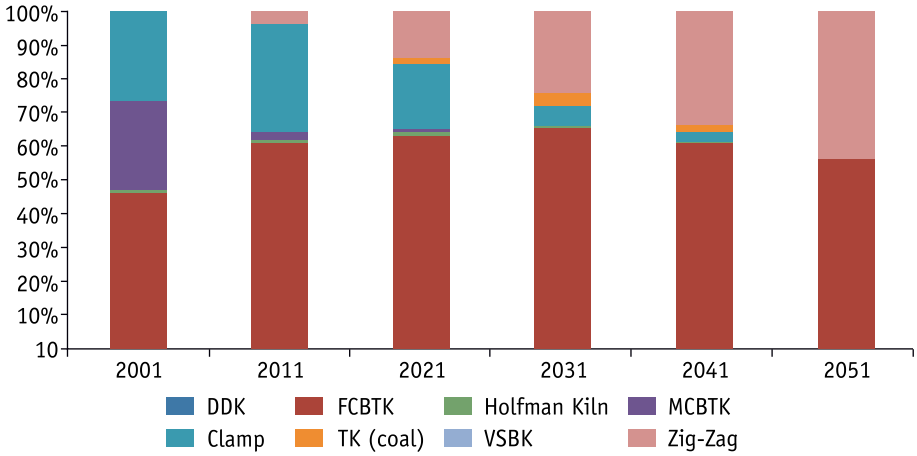

Figure 4.26: Projected kiln technology–wise distribution of brick production in India till 2051

Source: Expert consultations

carbon monoxide (CO), carbon dioxide (CO_2), metals, organic compounds (including methane, ethane, volatile organic compounds [VOC], hydrochloric acid (HCl), and fluoride compounds) (EPA 1997) (Figure 4.27). Factors that may affect emissions from brick industry include raw material composition, moisture content, kiln fuel type, kiln operating parameters, and plant design. Emissions of each gas depends on different steps involved in the production of bricks in kilns.

In a recent study conducted by Greentech Knowledge solutions, nine brick kilns were monitored in India and Vietnam in order to understand energy consumption and emissions using different

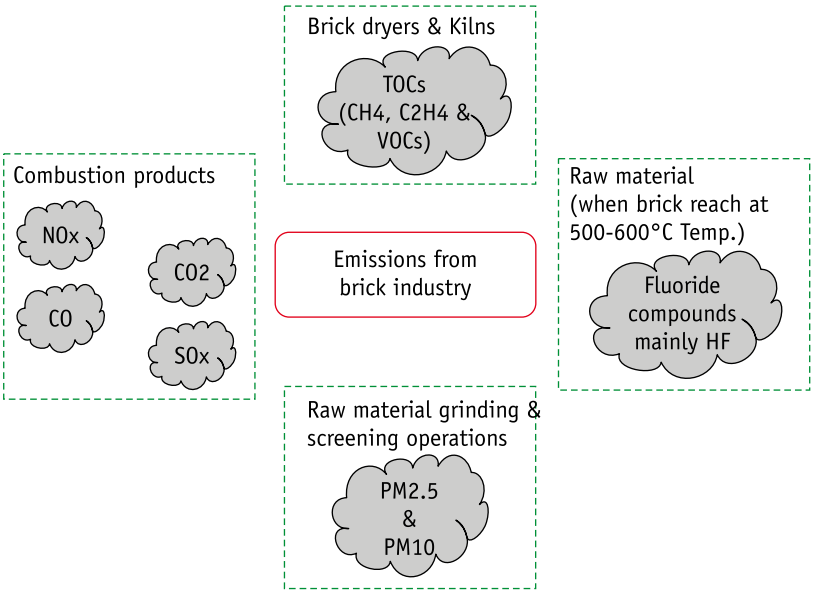

Figure 4.27: Emissions from brick industry

Source: Reproduced from EPA (1997)

technologies. Table 4.11 presents emission factors for different brick manufacturing technologies.

Based on the brick production rates and expected influx of technologies, the emissions from Brick kiln industry for India are estimated and are shown in Table 4.12. In 2011, 294 Kt of PM_{10} and 226 Kt of PM2.5 emissions are estimated. It is observed that PM emissions will increase two folds by 2031 and stabilize thereafter with marginal increase till 2051. Similarly black carbon and organic carbon emissions are expected to increase and will double by 2051.

These emission estimates take into account the influx of improved technologies; however, in absence of these, the emissions from the sector will be much higher. Ministry of Environment, Forest, and Climate Change in India has brought up PM emission standards and stack height specifications based on the kiln's production capacity. Along with control of emissions from brick industry, newer options for alternative walling material should be explored which are environmentally sustainable.

Other Industries

Other than cement, iron & steel, brick, aluminium, glass, paper, and fertilizer industry, significant energy consumption takes place in small and medium scale industries. The energy consumed in these 'other industries' in comparison to the major sectors is shown in Figure 4.3. The energy consumed in the other industry sector is multiplied with emission factors listed in Tables 4.13 and 4.14 to estimate emissions. Table 4.13 shows the PM emission factors for coal combustion in industries based on the ash content and efficiency of tale pipe controls.

Table 4.11: Emission Factor for Different Type of Brick Kilns

	Technology		Unabated emission Factors (g/kg of fired brick)			
		PM_{10}	$PM_{2.5}$	SO_2	CO	CO_2
Greentech energy solutions (2012)[a]	FCBTK	0.86	0.18	0.66	2.25	115
	Zig-zag	0.26	0.13	0.32	1.47	103
	VSBK	0.11	0.09	0.54	1.84	70
	DDK	1.56	0.97	n.d	5.78	282
	Tunnel	0.31	0.18	0.72	2.45	166
Rajarathnam et al. (2014)[b]	FCBTK	0.89		0.52	3.63	179
	NDZZ	0.22		0.06	0.35	119
	FDZZ	0.24		0.24	2.04	96
	VSBK	0.09		0.10	4.14	118
	DDK	1.56		0	5.01	526

[a]Study was conducted on seven brick kilns in India and two (modified VSBK and Tunnel Kiln) in Vietnam in 2011.
[b]Study was performed on 15 brick kilns in India.
Ratios of $PM_{2.5}$, BC, OC and EF of NO_X and NMVOC are adopted from GAINS Asia

Table 4.12: Emissions (Kt) from Brick Kiln Industry in India

	2001	2011	2021	2031	2041	2051
PM_{10}	164	294	430	588	678	691
$PM_{2.5}$	126	226	331	453	522	531
BC	38	68	99	136	156	159
OC	44	79	116	158	183	186
NO_x	0	0	0	0	0	0
SO_2	38	68	99	136	156	159
CO	1263	2261	3307	4526	5216	5312
VOC	19	34	50	68	78	80

Table 4.13: PM Emission Factor for Coal Combustion in Industrial Sector

PM_{10}				$PM_{2.5}$			
	Large Scale (High Controls e.g. ESP)	Medium (medium controls)	Small (low controls)		Large Scale (ESP)	Medium (medium controls)	Small (low controls)
Ash content	35%	35%	35%	Ash content	35%	35%	35%
Fly/Bottom ash ratio	80:20	80:20	80:20	Fly/Bottom ash ratio	80:20	80:20	80:20
PM_{10}/PM	0.71	0.48	0.39	PM2.5/PM	0.35	0.29	0.21
Efficiency of control	99.90%	70%	40%	Efficiency of control	99.90%	70%	40%
Emission factor (t/PJ)**	11	2314	3753	Emission factor (t/PJ)**	6	1379	2026

*PM_{10}/PM and $PM_{2.5}$/PM ratios are taken as an average of wet and dry bottom boilers
BC and OC are assumed to be 0.1% and 0.2% of PM_{10} fractions; adopted from emission factor ratios in GAINS
** Emission Factors = Ash content × Fly/Bottom ash ratio × PM fraction ratio × (1–efficiency of control)

Table 4.14: Fuel- and Pollutant-Wise Emission Factors (Kt/PJ) for NOx, SO_2, CO, and HC

Fuel	NO_x	SO_2	CO	HC	PM_{10}
Coal	0.13	0.57	0.01	0.02	
Natural Gas	0.07	0.02	0.04	-	
Biomass	0.03	0.00	0.3	0.80	0.12
Fuel oil	0.15	1.73	0.01	0.09	0.11
Diesel	0.08	0.94	0.04	-	0.77
Light Diesel Oil	0.08	0.94	0.04	-	0.77
Naphtha	0.07	0.02	0.04	-	0.10

Source: CPCB 2011, GAINS Asia

Based on the energy consumption and respective emission factors, the emissions for different years are estimated (Figure 4.28). It is expected that with industrial growth the emissions will grow considerably. However, with improved enforcement of existing standards for PM, there will be increased penetration of APC technologies. Presently, only large scale industries are assumed to be equipped with high efficiency APC equipment such as ESPs and Bag-filters. As per the consent to establish and consent to operate requirements for industries, all

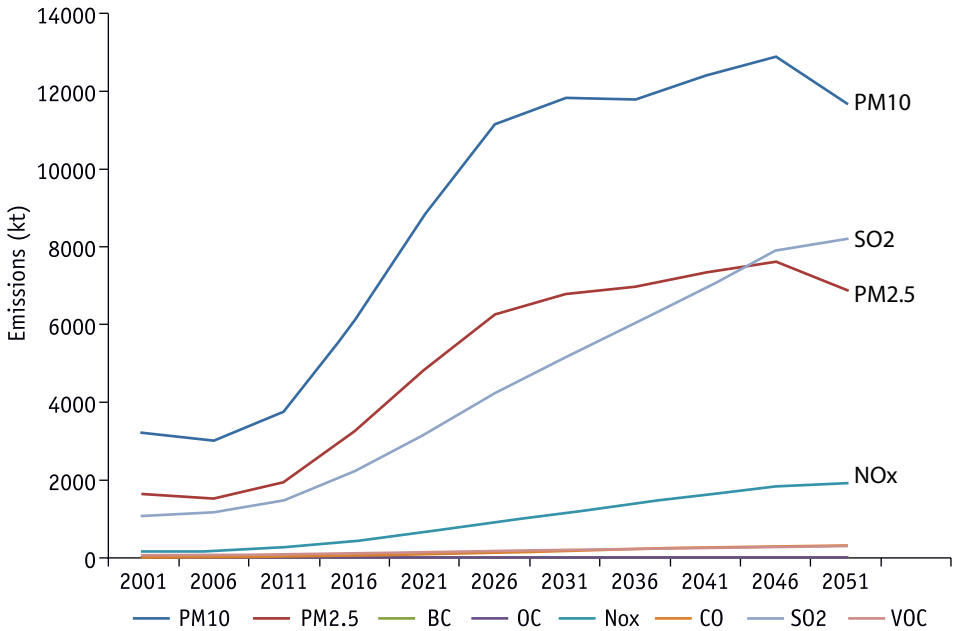

Figure 4.28: Emissions of different pollutants from other industrial fuel consumption (Kt)

polluting industries need to install emission control equipments. Although, the efficiency of controls vary with the requirements and type of APCE installed. Based on expert consultations, micro, small, and medium industries are assumed to be equipped with APCs with an efficiency of 40%. Based on the growth of the current APCE industry, and growing concerns over air pollution in Indian cities, penetration of high efficiency APC equipments in industries is assumed to increase to about 50% by 2051. However, there will be variation in degree of control with the type of APC technologies installed.

PM_{10} emissions from 'other' industries will grow from 3,791 Kt in 2011 to 11,700 Kt in 2051, with an increase of 209%. However with influx of control technologies, the intensity of emission per unit of production is expected to go down significantly. In absence of suitable standards for NO_x and SO_2, the emissions will grow by eight to nine folds by 2051.

Mining

Coal and iron scenario in India

Coal along with other fossil fuels continues to be the primary source of energy in India, despite its environmental impacts both at local as well as regional level. Among all the ores and industrial minerals, iron ore (along with bauxite and copper) is of the most quantitative importance in terms of its mass flows in the Indian economy (Singh et al. 2012). Mining of coal along with other minerals is an important economic activity though burdened by severe environmental impact particularly on air and water quality, and forest resources including biodiversity and green cover. The growing demand for natural resources such as coal and iron ore, from developed as well as rapidly developing countries such as India and China, have led to increasing shortages of these resources in the global economy (Planning Commission 2013). In this scenario, making a robust supply of domestic resources is all the more necessary.

The geological coal reserves have been estimated to be 301.56 billion tonnes (as on 1st April 2014) in India according to the Ministry of Coal (MOC), Government of India. Of the total reserves of coal in India, the majority (88%) are comprised of non-coking coal and about 11.5% are coking coal, while a minimal share (0.5%) is of tertiary coal reserves (Indian Chamber of Commerce & PwC 2012). Indian coal is characterized by its high ash content (as high as 45%), along with low sulphur content (0.2–0.7%), and low calorific values (between 2,500–5,000 kcal/kg) (IEA 2002). The total production of coal in India in the year 2013–14 was 565.64 Million tonnes (MoC 2013). The largest consumer of coal in India is power sector, accounting for almost 70% of coal consumption in 2011 (MOC 2014). Steel production and cement industries are other significant coal consumers in the country.

India is ranked third in coal, lignite, and bauxite production and fourth in iron ore production in the world in the year 2009–10 (Ministry of Mines, Government of India). Public sector continues to play a dominant role in mineral production, and accounts for 74.5% of all minerals produced and a sizeable 91% of the total coal produced. Data of major coal mines along with their production capacities is presented in Table 4.15 (MoC, 2014). The major coal field locations are shown over the map of India in Figure 4.29.

Past trends and future growth of mining in India

Mining and mineral extraction in India can be traced back to the days of the ancient civilizations residing in the region. The country is known to be endowed with rich and widely available resources of many metallic and non-metallic minerals; hence mining sector plays a key role in the Indian economy. India produces as many as 87 minerals, which include four fuels among others (Ministry of Mines 2011). Coal mining became an important part of the public sector in India during the years 1971–73 with the enactment of the Coal Mines (Nationalization) Act, 1973. In the same year, the Coal Mines Authority Ltd. was set up and was made responsible for all the operation and maintenance of the nationalized non-coking coal mines in India (Dutt 2007).

Mainly there are two kinds of methods for coal extraction: opencast (surface) mining and underground mining. In India, the predominantly

Table 4.15: Major Coal Mines along with their Production Capacities in India in 2012–13

Unit	Production (in Million Tonnes)
Eastern Coal fields	33.9
Bharat Coking Coal Ltd.	31.2
Central Coalfields Ltd.	48.1
Northern Coalfields Ltd.	70.0
WCL western Coalfields Ltd.	42.3
SECL South Eastern Coalfields Ltd.	118.2
MCL Mahanadi Coalfields Ltd.	107.9
NEC North Eastern Coalfields.	0.6
Total CIL	452.2
SCCL Singareni Collieries Co. Ltd	53.2
Other Public	3.9
Total Public	509.2
Total Private	47.2
All India	556.4

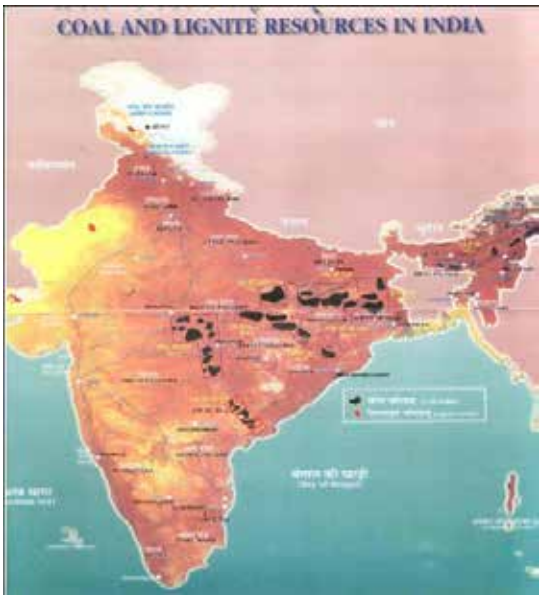

Figure 4.29: Major coal fields in India
Source: CMPDI, Coal India

used method is opencast extraction; and mining in the country has grown with a 4% annual average growth rate over the past decade. Opencast mining involves mining coal in an earth-moving operation by excavating the overburden up to the coal seams and then removing the coal using draglines, shovels, and dump trucks. This method of extraction is overall more advantageous due to the following factors:

- greater extraction rate of coal
- higher productivity compared to the other method of extraction
- lower in costs and labour intensity
- and better workplace conditions

However, opencast mining is infamous for having greater impact on the local environment; such as large-scale land use, overburden disposal, disturbance of hydrology and run-off, increased erosion, acid mine drainage, noise, and possible damage to the ecosystems.

On the other hand, underground mining is employed for extraction of very deep coal seams, involves construction of a vertical shaft or slope mine entry to the coal seam and then extracting the coal using various standard techniques. About 9% of India's coal production was from underground mines in the year 2012–13 (MoC, 2014).

In 2010, India produced the world's third largest volume (532 MT) of coal domestically, which was more than double of the 1990 level of 205 MT; however, the production has more or less plateaued in recent years (Ahn and Graczyk 2012). The 12th Five-Year Plan aims to further increase coal production to 715 MT in FY 2016/17, a 33% increase from the level of 2010. According to the World Energy Council, the demand and supply gap of coal was around 85 million tons in 2011–12 and it is expected to gradually increase to as much as 140 million tons by 2017.

On the consumption side, power sector in India has been increasingly dependent on coal; in 2009, 73% of domestic coal was consumed by the power sector, while in 1991, the figure was much lower at 61% (IEA 2012). Coal Vision 2025 estimates that the power sector alone would require 916 MT of coal in 2025. The Figure 4.30 illustrates the trend of coal

consumption by different sectors in India from 2001 to 2010 (Qaisar and Ahmad 2014) showing a steady and significant growth in the consumption by power/electricity sector over the years.

The Planning Commission in 2006 put together different projections from various agencies for coal and other fossil fuel demands in future years in a specific scenario, which estimates the coal demand in 2031–32 to be 1,397 MT (for both power and non-power use) in India. On the production side, TERI has estimated the domestic coal production in India in the same year 2031–32 to be in the tune of 868 MT, again showing that the demand and supply gap in coal is expected to increase in the future as well. Under this likelihood of consistently increasing coal demand, it becomes even more imperative to curb the emissions from coal mining and production activities to limit its environmental impact. Figure 4.31 shows the increasing trend in production of coal in India and future projections (TERI 2015).

Among all the principal metallic ores mined in India, iron ore has the major share. The total value of metallic minerals extracted in India in the year 2010 was 322.74 billion INR, of which iron ore's contribution was 268.65 billion INR (Ministry of Mines 2011). Production of iron ore registered a 2.67% increase from the previous year, at 218.64 million tonnes in 2010. While in the year 2011 it again decreased slightly and was recorded as 207 million tonnes by the Ministry of Mines, Government of India. In contrast to the coal scenario, only 27% of the total iron production was shared by public sector companies like SAIL, NMDC, etc. While the private sector owned the major share of 63% including companies like Tata steel (8%) and Jindal steel, etc. Almost 96% of the iron ore in India is produced in Orissa, Karnataka, Chhattisgarh, Goa, and Jharkhand during the year 2010. Iron ore mining is also predominantly carried out by opencast mining (both manual and mechanized) in India. The iron ore industry in India is highly fragmented and prior to the ban imposed by the Supreme Court in Karnataka on iron ore mining, there were 336 operating mines reporting production in 2011–12 (Firoz, 2014).

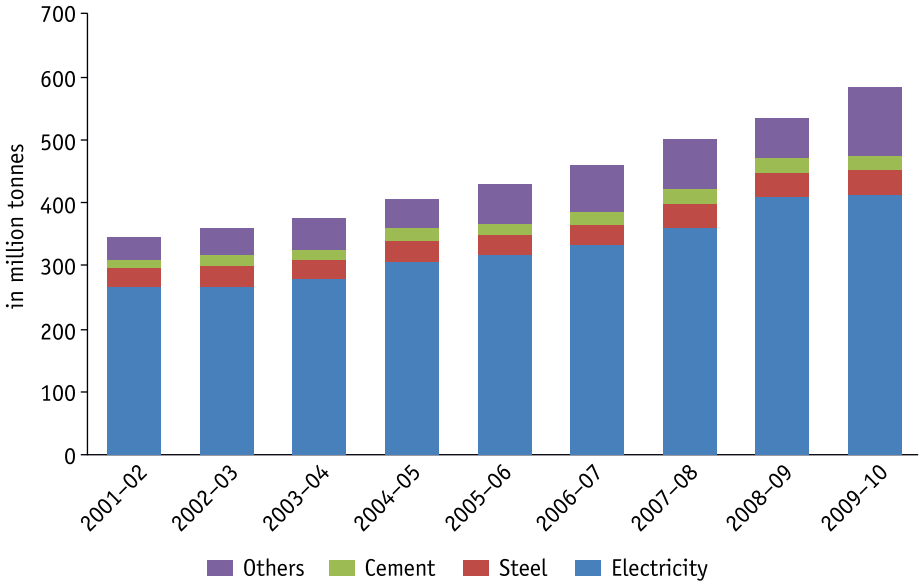

Figure 4.30: Consumption of raw coal (in million-tons) by different sectors from the period 2001–02 to 2009–10

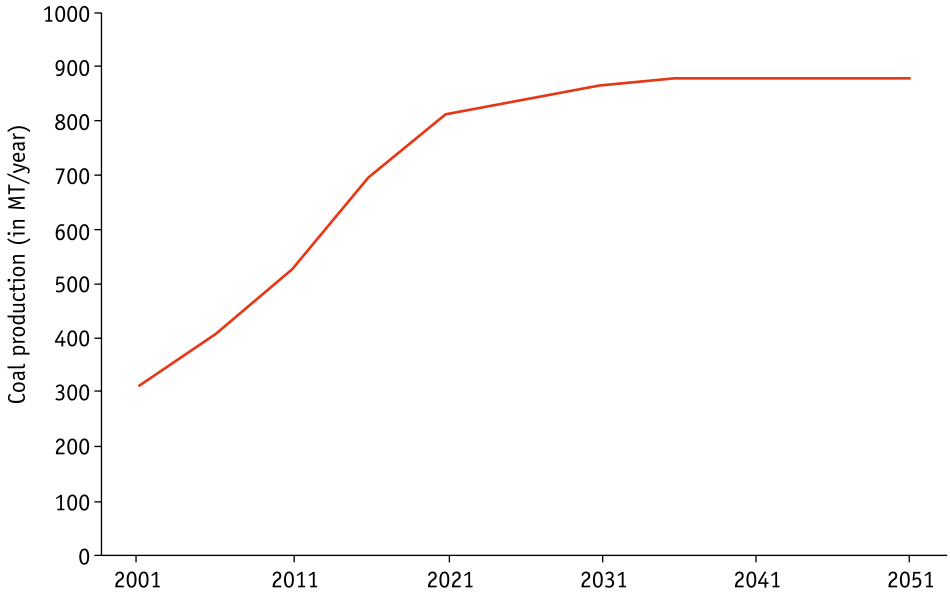

Figure 4.31: Current and future trends of coal production in India (2001–51)
Source: TERI Analysis, 2015

Sources of emissions from mining

The major causes of air pollution from mines are fugitive emissions of PM and gases including CH_4, SO_2, NO_x, and CO, although in lesser concentrations. All major activities (overburden removal, drilling, blasting, crushing, hauling, loading, transportation, etc.) carried out in the mines produces a lot of dust.

As stated in the earlier sections of this chapter, opencast mining has a more severe impact on air quality compared to underground mining, with high levels of suspended PM associated with opencast mines. A number of studies have repeatedly reported that as high as 50–80% of the total dust emitted in open cast coal mines can be attributed to vehicular movement on unpaved haul roads, followed by loading and unloading of dumpers (Ghose and Majee 2001).

The dust not only affects the ambient air quality in and around the mines but also pollutes the nearby surface waters and stunts crop growth by shading and clogging the pores of the plants (Singh 2006).

Despite such huge emissions of dusts from opencast mining, there is no well-defined methodology to calculate these emissions from mining activities. Many independent studies have been undertaken in different parts of the world to calculate dust emissions from different mines and have also developed relevant emission factors; however, these are highly site-specific owing to the highly variable conditions prevalent in different mines in different regions and countries. Estimation of the amount of dust actually generated in mining is an important first step towards mitigating and managing the emissions effectively.

A significant piece of work in this field was carried out by Chakraborty et al. in 2002 in which they developed empirical formulae to calculate the emission rate of various opencast mining activities. In this study, they selected seven coal and three iron ore mining sites across India to generate emission data for major mining activities by considering various factors. We have adopted the empirical formula

developed by Chakraborty et al. (2002), to quantify the national emissions from opencast mining of coal and iron ore in this study.

Methodology to estimate emissions from mining activities

This study employed the empirical formulae derived by Chakraborthy et al. (2002) to calculate the national emissions of different pollutants from coal and iron ore mining in India. The empirical formulae used for calculating the emission rates of different pollutants for the overall mines are listed below:

PM

$$E=[u^{0.4} a^{0.2} \{9.7+0.01p+b/(4+0.3b)\}]$$

SO_2

$$E=a^{0.14}\{u/(1.83+0.93u)\}\times[\{p/(0.48+0.57p)\}+\{b/(14.37+1.15b)\}]$$

NO_X

$$E=a^{0.25}\{u/(4.3+32.5u)\}[1.5^{p}+\{b/(0.06+0.08b)\}]$$

Where, *E = Emission rate for overall mine*
u = wind speed (m/s)
a = area of pit (Km^2)
p = mineral production (MT/year)
b = OB handling (Mm^3/year)

The production and overburden removal and the number of mines for each coal mining company for the year 2011 were acquired from MoC, 2013. Since the data on the mining area for each mine in India is not available, the ratio of coal production to area of production 0.039 MT/Km^2 (calculated for the state of Orissa; TERI 2013) is used to calculate area per mine for the whole country. Wind speed datasets were obtained from the nearest IMD stations using Climatological Tables of India, published by the IMD. Using this data and the empirical relationship described above, the PM, SO_2, and NO_X emissions for each mine was calculated. Ratios of PM_{10} and $PM_{2.5}$ in the total PM were adopted from GAINS database, which were 0.5 and 0.1, respectively.

In order to validate the results obtained using these formulae, the total emissions from open-cast coal mining in India was also estimated using emission factors developed by Ghose (2004). These emission factors were developed by Ghose for various open-cast mining activities (Table 4.16).

The PM emissions for India from open-cast coal mining was also calculated by this method using the average emission factor for OB removal and coal mining along with emission factors for transportation of OB and coal.

Emissions from mining sector in India

The national emissions from coal and iron ore mining are estimated using the methodology described above for the years 2001 to 2051. The national level emissions of different pollutants from coal mining sector for India in the year 2011 are shown in Table 4.17. For validating these emissions, the overall emissions of PM were also calculated

Table 4.16: Emission Factors for Mining Operations (Ghose 2004)

Mining Activity	Material	Emission Factor for PM
Overburden (topsoil) removal	Overburden	0.029 kg/t
Dumper loading of overburden (by power shovel)	Overburden	0.018 Kt/t
Unloading	Overburden	0.001 kg/t
Total emission factor for OB removal	**Overburden**	**0.048 kg/t**
Transportation in haul road	Overburden	2.25 kg/vKt*
Loading	Coal	0.014 kg/t
Unloading	Coal	0.033 kg/t
Total emission factor for coal mining	**Coal**	**0.047 kg/t**
Transportation in haul road	Coal	2.25 kg/vKt**

*For overburden, it is assumed that average length of haul road (h) is 0.5 km and the average capacity (c) of each dumper used to transport it is 85t
**For coal, it is assumed that average length of haul road is 0.7 km and the average capacity of each dumper used to transport it is 58 t

So, VKT is calculated for both overburden and coal as:
VKT= h ×c×total quantity of material transported in tonnes

using the emission factors developed by Ghose (2004) as mentioned in the methodology section. PM_{10} and $PM_{2.5}$ emissions calculated from both the methodologies are almost the same hence proving that the estimations in this study are reliable.

Due to lack of detailed data on mine-wise area and location of each mine for iron ore mining, their emissions were only calculated using the emission factors developed by Ghose (2004). For open-cast iron ore mining, the total emissions of different pollutants across India are presented in Table 4.18.

The emissions from open-cast mining have also been estimated for the past and future years. Considering 2011 as the base year, estimates were made for each 10-year interval from 2001 to 2051. TERI 2015 has estimated the total coal production and steel production in India for the future years, till 2051. Using this data for total coal and steel production in India from the recent TERI analysis (TERI 2015) for future years and employing the same emission factors mentioned in the methodology section, the emissions were estimated for future years (Figures 4.32 and 4.33). For estimating the amount of iron ore mined from the projected steel production in future years, the ratio of 1.93 (of iron ore to finished steel) was used. This ratio was based on the actual 2011 domestic iron ore consumption of 117 MT to produce 60.51 MT of finished steel (12th Annual Five Year Plan, Iron and Steel). However, for the past years (2001, 2006) and the base year 2011, the actual production numbers (from Ministry of mines for iron ore and coal directory for coal) were used.

As evident from Figures 4.32 and 4.33, the total emissions from open-cast mining of coal and iron ore

Table 4.17: Emissions of PM from Open-Cast Coal Mining in India in 2011

Pollutant	Total Emissions (kT/year)	
	Chakraborty (2002)	Ghose (2004)
PM10	90.29	90.42
PM2.5	18.06	18.08

Table 4.18: Annual emissions from open-cast iron ore mining in India in 2011

Pollutant	Total Emissions (kT/year)
PM_{10}	49.92
$PM_{2.5}$	9.98
SO_2	9.54
NO_X	3.08

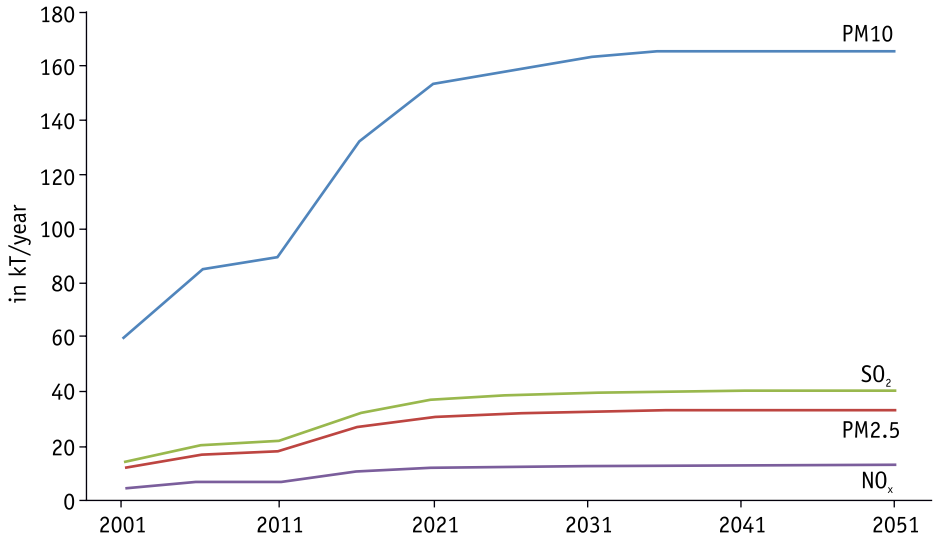

Figure 4.32: Annual emission trends from 2001 to 2051 in India from open-cast coal mining sector

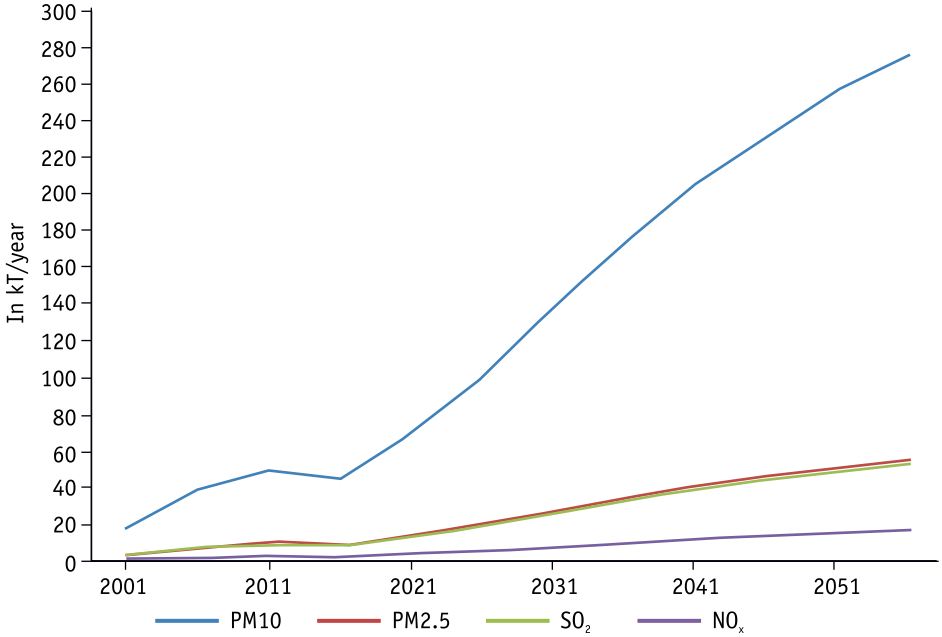

Figure 4.33: Annual emission trends from 2001 to 2051 in India from iron ore open-cast mining

in India have an increasing trend over the years. In future also, they are expected to be growing further considering the growing demand for coal and iron ore as raw material for various industrial sectors as well as for generating power.

Total Emissions from Industrial Sector in India

Total emissions (process , combustion, and fugitive) from the industrial sector are shown in Table 4.19. While, there is some control of PM emissions envisaged in the future scenario, the gaseous pollutants in absence of control standards, are expected to grow multi-folds in future. The majority of emissions are from coal consumption in industries. Highest increase of about six times is expected in NO_x and SO_2 emissions, while other pollutants will increase by 2.6–5.4 times during 2011–51.

Spatial Allocation of Emissions

The estimated emissions are spatially allocated to the district levels using the industrial fuel consumption data from MoSPI, 2011. However, for some of the key sectors such as Cement, Iron & Steel, the emission are allocated at the grid locations using the actual coordinates of the manufacturing plants. The emissions maps for industrial emissions for PM_{10} and SO_2 emissions are shown in Figure 4.34.

The PM_{10} emissions from coal and iron ore mining sectors in India where also allocated spatially using the mining data of coal and iron ore in different districts. The amount of coal or iron ore mined from

Table 4.19: Total Industrial Sector Emissions (kilotonnes) in India

Pollutant	2001	2011	2021	2031	2041	2051
PM_{10}	3685	4562	10212	13953	15230	15093
$PM_{2.5}$	1923	2351	5507	7816	8706	8546
BC	44	62	88	113	138	161
OC	63	90	143	198	248	290
NOx	520	950	1980	3405	4877	6038
SO_2	1901	3160	6070	10118	14478	18147
CO	3196	5229	9921	16751	23370	28335
HC	74	115	194	305	425	532

these districts was used to distribute emission loads in these districts. The emission maps from mining sector for PM_{10} emissions are shown in Figure 4.35. Since mining is limited to few states in India, most of the regions in the map show nil emissions and only in the districts where coal or iron ore mining was prevalent in 2010–11, the emissions have been distributed based on activity level.

Emission from brick industry in India are spatially distributed based on major regions of brick manufacturing as shown in Figure 4.21. The main regions for brick manufacturing are located in the Indo-Gangetic plains, Gujarat, West Bengal, and some regions of west and south of India (Figure 4.36).

Conclusions

Industrial emissions are substantial and are of important concern to India. Inefficient combustion of fuels, high ash content, and limited control of pollution are the major causes for high emissions from the sector. The emissions are expected to grow in future with rise in manufacturing activities. However, it is also expected that in future there will be better enforcement of the standards with enhanced penetration of the APC technologies. For this, there is an urgent need for capacity building and strengthening of the pollution control boards for better enforcement of standards. There is also a need for development of standards for gaseous pollutants such as NO_x and SO_2, which are increasing gradually with the growing industrial production. Many of these gaseous pollutants such as NOx not only just have their own health impacts, but they also lead to secondary pollutant formation such as Ozone and secondary particulates.

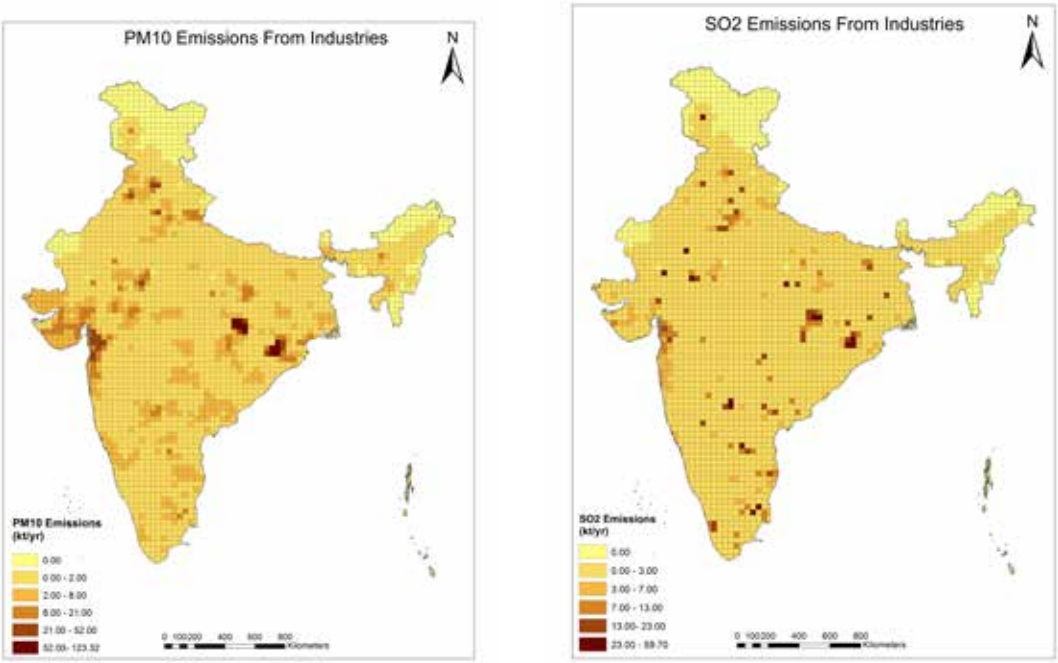

Figure 4.34: Spatial distribution of PM10 and SO2 emissions from industrial sector in India in 2011

Note: Brick and mining sector emissions not included

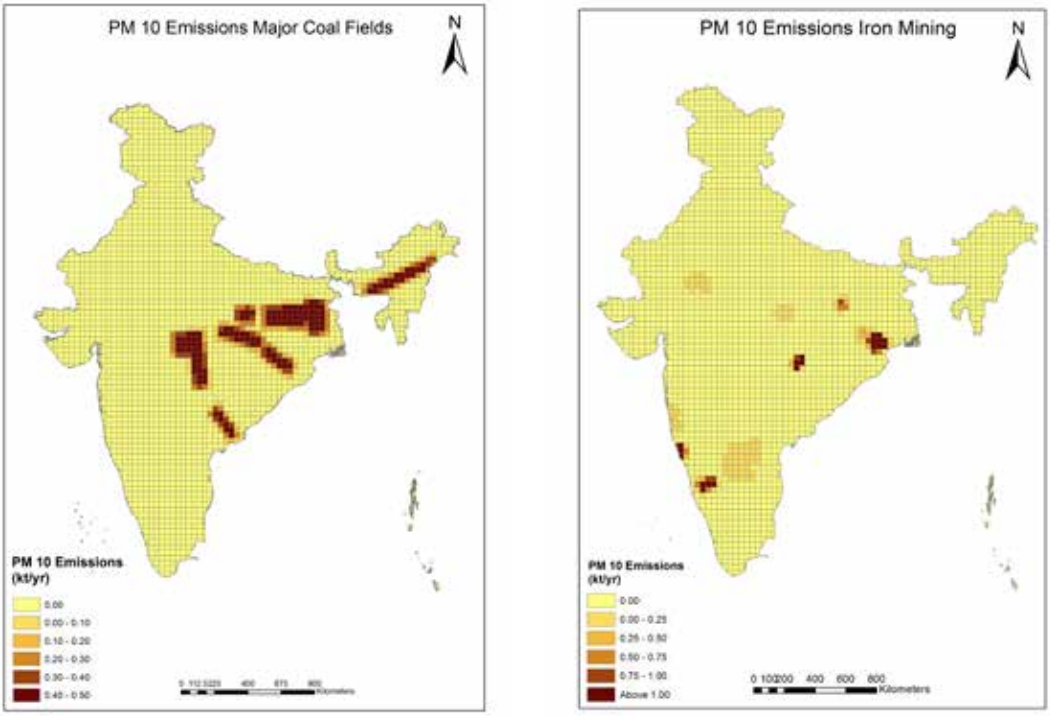

Figure 4.35: Spatial distribution of PM10 emissions from coal and iron ore mining in India in 2011

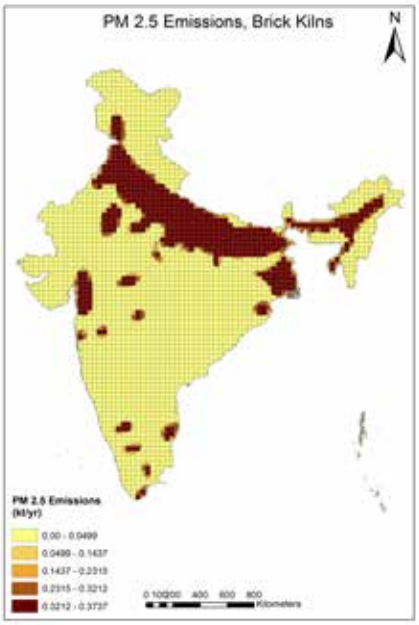

Figure 4.36: Spatial distribution of PM10 emissions from brick industry in India in 2011

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CHAPTER 5

Power

Richa Mahtta, Sumit Sharma, and Atul Kumar

Introduction

Power sector in India is undergoing a rapid change not only in terms of installed capacity and transmission and distribution, but also with the introduction of advanced technologies such as deployment of supercritical technology. The total power generating capacities of utilities and non-utilities in India have grown from 1,362 MW in 1947 to 243 GW in 2014. However, demand of power has crossed the production levels leading to shortages in the country. At consumer level in utilities, industries are the largest consumer of electricity with a share of 45 per cent, followed by domestic (22 per cent), and agriculture (18 per cent) sectors. Efforts are underway to bridge the gap of demand–supply of electricity by increasing the share of renewables, private sector participation, and improved governance.

In India, more than 50 per cent of this electricity production (utilities) is met through coal-based thermal power plants (TPP) (Singh and Siddique 2013; TERI 2015). To meet the electricity

Photo Credit: R Suresh

requirements, huge quantity of coal is burnt annually. In 2010-11, around 360 MT of coal was burnt that produced around 100 MT of fly ash and 25 MT of bottom ash annually (CEA 2012) which is one of the major reasons for increasing air pollution levels in India (Bhanarkar et al. 2008; Guttikunda and Jawahar 2014; Ohara et al. 2007). Guttikunda and Jawahar 2014, reported that TPP produced 1,200 kt of PM_{10} emissions in the year 2010–11. Also, SO_2 emitted from TPP is a major source of environmental pollution and has huge impact on health and agriculture (Burney and Ramanathan 2014). Similarly NOx emissions from power plants in India have increased by 70 per cent during 1996–2010 (Lu and Streets 2012), which is a prime precursor for Ozone formation in India.

PM emissions from coal-based TPP are linked to high ash content (30–50 per cent) in Indian coal along with 7–20 per cent moisture content (Shail et al. 1994). Ash, being a non-combustible part of the coal, if present in large quantity, increases the coal demand to produce the same amount of electricity. This leads to increased specific coal consumption in power plants in India. Specific coal consumption (SCC) for TPP in India during 2011–12 was 0.72 Kg/KWh and it varied from 0.60 (Ramagundam Thermal Power Station in Andhra Pradesh) to 1.28 for Bhusawal plant in Maharashtra (CEA 2012). However, due to high calorific value of imported coal, SEC for imported–coal based TPPs is comparatively quite less. For example, Torangallu TPP has a SEC 0.33 Kg/KWh. High SECs of Indian TPP leads to high emission levels too. Although Electrostatic precipitators (ESPs) are installed in all the TPP, but the efficiencies and inspection and maintenance system for these units is a major concern. Also, emission standards are only available for PM in India for TPP. There are no standards available for NO_x, SO_2, CO, etc. pollutants from TPP.

This chapter briefly present review on available literature on methods used to compute emissions from coal-based TPP, available emission factors from existing studies, and emissions computed using unit-based approach.

Power Generation in India

Indian Power Sector, with an electricity generation capacity of 243 GW as on March 2014, is the fourth largest producer in the world. Despite a growth of 11.75 per cent in the total installed generating utilities in power sector during 2012–13 and 15 per cent in 2011–12, there are still gaps in demand and supply (CEA 2013). In 2013–14, there was 4.2 per cent shortfall of energy as shown in Table 5.1.

Table 5.1: Energy Status in India (2013–14)

	Energy (GWH)	Peak (MW)
Requirement	1,002,257	135,918
Availability	959,829	129,815
Shortage	42,428	6,103
Shortfall	4.2%	4.5%

Of the total power produced in India, coal power plants makes up for 57.42 per cent of the installed capacity in India, followed by hydro (18.62 per cent), renewable energy sources (12.2 per cent), natural gas (8.92 per cent), nuclear plants (2.25 per cent), and oil (0.56 per cent) (CEA 2013; Pryas 2011). Electricity production from different energy sources in India in past three decades is shown in Figure 5.1(a).

Power generation using coal has grown significantly from 100 TWh in 1980 to around 670 TWh in 2012. The projections of future energy demands and coal consumption for power generation in India are made using the TERI-MARKAL model. It is observed that coal consumption in power plants will continue to grow in future (Figure 5.1(b) as per the reference scenario (RES) (TERI 2015).

The share of natural gas and hydroelectric plants has increased in electricity production in India after 1990. But as evident from the Figures 5.1(a) and (b), despite growth of other sectors and renewables, coal will remain to be the major fuel used for electricity production in India. Thus, emissions from the sector are expected to increase in future.

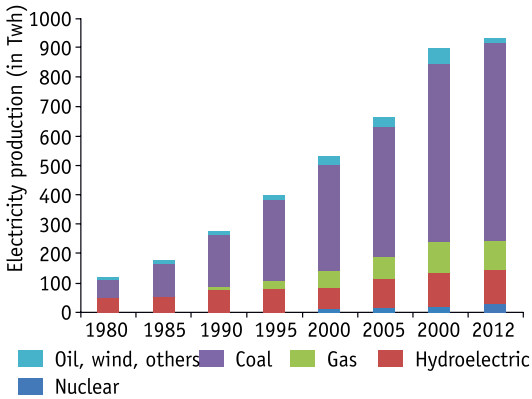

Figure 5.1(a): Electricity production from all energy sources in India

Figure 5.1(b): Present and future projections of coal consumption in power sector in India

Sources: The Shift project Data Portal; Baseline: CEA 2012, Future projections: TERI 2015 Markal Model

Methodology for Emission Estimation from Power Generation Sector in India

Different approaches have been used across the world to estimate emissions from power sector. The approaches used for emission estimation are conventionally classified as bottom-up and top-down approaches. In the past two decades, a series of studies have been carried out using top-down method to compute emissions of PM, NO_x, and SO_2 (Hao et al. 2002; Purohit et al. 2010; Streets et al. 2003; Tian 2003; Wang 2001; Yi 2006; Zhang et al. 2007 a, b).

However, all of these studies focused on power sector as a single source in the emission inventory framework. Over time, it was felt that different technologies and fuel characters among specific power units can greatly affect emission levels from power sector (Zhao 2008). Following this, unit-based bottom-up approach came into practice. In this approach, annual emission of each unit is calculated based on emission factor and specific fuel consumption of each unit. These emissions are then aggregated at regional level. Zhao et al. (2008) calculated SO_2, NOx, and PM emissions over 31 provinces of China using this approach for the year 2005. It was based on detailed information on fuel, control technology, and geographical location of each unit types in China. Chen et al. (2014) calculated emissions of SO_2, NOx, and PM_{10} and $PM_{2.5}$ for entire China for the year 2011 to be 7,251 kt, 8,067 kt, 1,433 kt, and 622 kt, respectively, using unit-based approach.

Emission factors (kg/ton) for different pollutants used in all these studies are summarized in Table 5.2a. Table 5.2b provides emission factors for different pollutants from gas-based power plants (GAINS Asia database).

Unit-Based Methodology in this Study

In this study, a unit-based approach is adopted to compute emissions from power sector. All the TPP in India are taken into account to calculate emissions from the sector. Emissions from power plant are dependent on the quality of fuel (ash and sulphur content), type of boilers, the type of air pollution control equipment, and their efficiencies.

The equations (5.1–5.3) used for emission estimation are listed below

$$E_{PM} = \sum P_j \times AC_j \times (1-ar) \times f \times (1-C_j) \quad \text{.....} (5.1)$$

$$E_{NOx} = \sum P_j \times EF \times (1-C_j) \quad \text{.....} (5.2)$$

$$E_{SO2} = \sum Pj \times EF \times (1-C_j) \quad \text{.....} (5.3)$$

Table 5.2(a): Different Studies Reporting Emission Factors for Coal-Based Power Generation Activity in India

Source	Year	Units	PM_{10}	$PM_{2.5}$	SO_2	NOx
Streets et al. (2003)	2000	kg/ton			4.04–7.69	2.22–5.68
Ohara et al. (2007)	2000	kg/ton			5.09	2.71
Garg et al. (2006)	2000	kg/ton	2.54		3.71	2.07
GAINS (2012) base	2000–05	kg/ton	0.18–3.78	0.54–2.64	0.70–13.94	1.01–2.73
GAINS (2012) controlled	2000–05	kg/ton	0.19–0.43	0.13–0.27	0.27–0.70	0.20–0.55
Lu and Streets (2012)	1996–2006	kg/ton				1.79–4.14
Guttikunda and Jawahar (2014)	2010-11	kg/ton	0.91–1.39	0.49–0.69	1.76–1.94	1.79–1.81
Zhao et al. (2008) Uncontrolled	2005	kg/ton				6.17–11.75
Control		kg/ton				4.07–11.17
Zhao et al. (2010) uncontrolled	2005	kg/ton	0.26–1.54A A= Ash Content	0.1–0.45A	13.0S–18.0S S= sulphur content	5.30–9.90
Zhao et al. (2010) controlled	2005	kg/ton		0.008A–0.034A	0.9S–15.0S	3.50–6.81
Chen et al. (2014) Controlled	2011	kg/ton		0.021A–0.064A		4.08–11.50
This study (uncontrolled)	2015	kg/ton	0.12-3.46**	0.38**	4.86*	2.23*

*Emission factor (EF) for NOx and SO_2 have been adopted based on various studies.
**For PM10 and PM2.5, EF has been calculated by using unit level approach based on ash content and efficiency of ESPs.

Table 5.2(b): Emission Factors for Gas-Based Power Plants

	EF (t/PJ
PM_{10}	0.10
$PM_{2.5}$	0.10
NOx (with selective catalytic reduction [SCR])	10.00
CO	10.00
HC	1.00
Source: GAINS Asia Database	

Where, *P*= coal consumption, *AC* = ash content of fuel, ar = ratio of bottom ash to total ash, *C* = efficiency of control equipment, *f* = particulate mass fraction by size, *EF* = unabated emission factor, *j* = power plant units in India.

Activity data *viz.* coal consumption in each power plant (102 in total) for the year 2010–11 has been taken from CEA (2012) database. Plant-wise ash content data has also been taken from CEA. Expert consultations were held to understand the type of boilers. Ratio of bottom to fly ash is adopted from AP-42 as 20 per cent. The size fractions of the PM emissions are again adopted from USEPA (2015) for the pulverized coal-fired, wet-bottom boilers. A ratio of 0.4 is used for $PM_{2.5}$ to PM_{10} and 0.75 for PM_{10} to total suspended particulates (TSP). Ratios of black carbon (BC) and organic carbon (OC) to $PM_{2.5}$ are adopted from GAINS database as 0.12 and 0.19, respectively.

After expert consultations, it is concluded that all the TPP in India are equipped with ESPs as the air pollution control equipment. ESP efficiencies for 40 units have been adopted from Chandra (2008) and for rest of the plants an average efficiency has been assumed. For future scenario, coal consumption has been projected using the TERI MARKAL model (TERI 2015). In this study, emission factors for SO_2 and NO_X are taken as 4.86 kg/ton and 2.23 kg/ton, respectively (based on existing studies for India). Emission factors for carbon monoxide (CO) and hydrocarbons (HC) are adopted from GAINS Asia database.

Control Measures

Sulphur emission–control system ranges from limestone injection through control in furnaces, wet scrubbing of flue gas, or high-efficiency regeneration process (by capturing SO_2 in the flue gas through industrial processes). Limestone injection process produces huge amount of waste material. On the other hand, high-efficiency regeneration process is very expensive. Wet flue gas desulphurization (FGD) units are the most commonly used process with sulphur removal rate of 90 per cent. There are only four TPP in India that have FGD units in operation (Guttikunda and Jawahar 2014; Prayas 2011). Among those, three are in Maharashtra and one in Karnataka.

- Tata Power in Trombay (Maharashtra)
- BSES/Reliance at Dabanu (Maharashtra)
- Jindal TPP at Ratnagiri (Maharashtra)
- Udupi TPP (coastal Karnataka)

Till 2020, seven TPP which are just 3.2 per cent of the total thermal power capacity in India have been granted clearance for installation of FGD units. However, this is to be noted that the coal used in India is low in sulphur content (~0.5 per cent).

For NOx emissions, there are no existing norms in India for coal-based power plants for control of emissions. The formation of NOx emissions depends on the temperature and residence time of the gases in the combustion chamber. Formation of NOx can be reduced by providing low nitrogen oxide burners. Only a few newly installed TPP and extensions have low NOx burners (Chikkatur et al. 2011; Guttikunda 2014). However, as per the new draft notification issued by Ministry of Environment, Forest and Climate Change (MOEF&CC), Government of India, new norms for control of SO_2 and NOx have been prescribed, which will force the use of pollution control devices for these pollutants in future years (Table 5.3).

Presently, PM is the only pollutant for which Indian emission standards exist for coal-fired TPP in India. Particulate emissions from a power plant can be categorized into flue gas emissions and fugitive dust emissions. ESPs are installed in all the TPP to remove flue gas emissions. However, fugitive dust emissions generated from coal handling units and ash ponds still comprise around 20 per cent of the PM emissions (UE and CAT 2015). For control of these emissions, the government has notified certain guidelines. To control fugitive emissions from coal handling, MoEF&CC issued a notification in June 2001 that specifies the TPP located beyond 1 km from pit heads and the ones located in urban and sensitive areas are required to use beneficiated coal containing ash not more than 34 per cent. Further, to control fugitive emissions from ash ponds, MoEF mandated through a notification in 2003 that brick kiln units coming up within 100-km radius of TPP have to use 25 per cent of ash in brick kilns and any construction in the same radius will use only fly ash bricks (Guttikunda and Jawahar 2014).

Emissions from Thermal Power Generation in India

Emissions from TPP are estimated and are presented in Table 5.4. PM_{10} emissions are estimated to be about 453 kt from coal-based power plants in India for the year 2011. Of which, around 181 kt are $PM_{2.5}$, 22 kt black carbon, and 34 kt organic carbon emissions. For the same year, SO_2 and NO_x emissions are 1,842 kt and 1,015 kt, respectively. Due to lack of stringent regulations on SO_2 and NO_x emission in past, their emissions are considerably high. As envisaged, a minor capacity (3.2 per cent) will be installed with FGD units for control of SO_2 emissions, which is accounted in projections of SO_2 emissions till 2020. However, MoEF&CC, Government of India has issued

Table 5.3: Emission Standards (mg/Nm^3) for Coal-Based TPP

Capacity of TPP	PM	NOx	SO_2
Existing			
<210 MW	350	No standards	No standards
>210 MW	150	No standards	No standards
Proposed standards in draft notification by MOEF&CC, 2015			
Plants before 2003	100	600	600/200
Plants between 2003 and 2006	50	300	200
Plants after 2017	30	100	100

Source: Guttikunda & Jawahar, 2014); MoEF & CC, 2015

Table 5.4: Emissions from Coal-Based Power Plants in India (kt/yr) for 2001–51

	2001	2011	2021	2031	2041	2051
PM_{10}	257	453	869	1016	1216	1353
$PM_{2.5}$	103	181	348	406	486	541
BC	12	22	42	49	58	65
OC	20	34	66	77	92	103
SO_2	1031	1842	3490	3981	4650	5108
NOx	570	1015	1928	3556	5773	7293
CO	19	34	65	120	194	246
NMVOC	4	7	13	24	39	49

draft notification for revised emission standards for coal-based TPP. Along with PM_{10}, standards for SO2, NOx, and Hg have also been introduced. The new emission limits are 83 per cent more stringent for power plants envisaged after 2017 in comparison to those established before 2003. Final guidelines are expected to come in force in near future and have been taken into account while estimation of emissions for future years.

It is evident that under the RES scenario (TERI 2015) of future projections, despite an increase of more than 7 times in the coal consumption, the PM emissions from power sector will increase by about three folds during 2011–51. The gaseous pollutants show even lesser increase due to consideration of stringent norms for NO_x and SO_2 controls in future from the power plants. Other than coal-based power generation, emissions are also estimated for gas power stations. Table 5.5 shows the emissions of different pollutants from gas-based power stations. This is to be noted that PM emissions are insignificant in comparison to the emissions from coal-based power plants. The gas-based power plants are required to maintain NOx standards and are generally equipped with control equipment.

Table 5.5: Emissions from Gas-Based Power Plants in India (kt/yr) for 2001–51

	2001	2011	2021	2031	2041	2051
PM_{10}	0.04	0.10	0.07	0.09	0.13	0.40
$PM_{2.5}$	0.04	0.10	0.07	0.09	0.13	0.40
NO_x (with SCR)	3.72	9.61	6.95	8.69	12.60	40.30
CO	3.72	9.61	6.95	8.69	12.60	40.30
HC	0.37	0.96	0.69	0.87	1.26	4.03

Spatial Distribution

Emissions from power plants in India are spatially put on the map of India using actual coordinates of the power plant facilities (Figure 5.2). The emissions are observed to be higher in the states of West Bengal, Orissa and Chhattisgarh, and Maharashtra. This can be due to higher coal consumption and lower efficiencies of control equipments in the power plants.

Comparison with Other Studies

The emission estimated in this study is compared with other studies for validation purpose (Table 5.6). Particulate emissions calculated in this study are

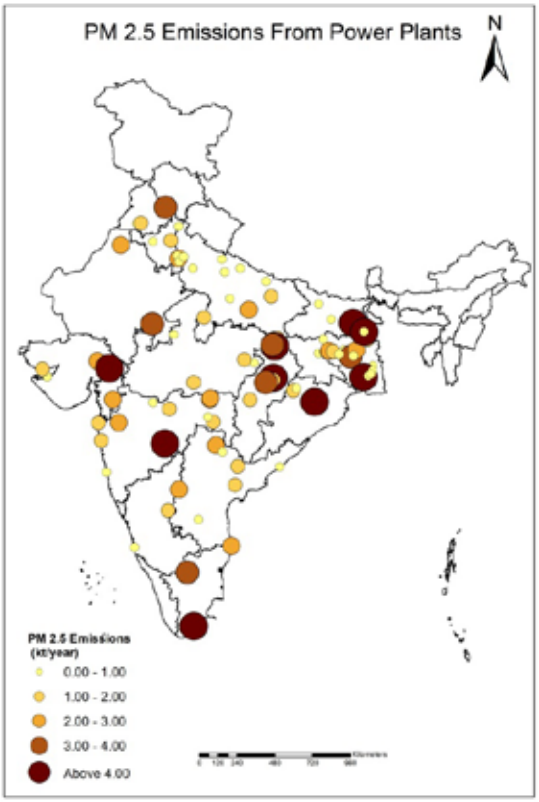

Figure 5.2: Spatial distribution of PM2.5 emissions from power plants in India (2011)

Table 5.6: Comparison of Emission Estimates (kt) with Other Studies

Studies	Year	PM_{10}	$PM_{2.5}$	SO_2	NO_x
IIASA (2010)	2010		268	3396	1821
Guttikunda and Jawahar. (2014)	2011	1200	580	2100	2000
Mittal (2009)	2009			3800	2300
This study	2011	453	181	1842	1015

lower compared to other studies. The main reason could be the different plant-wise ESP efficiencies taken into account while estimating the emissions. On the other hand, NOx emissions are in close range with other studies as no specific air pollution control equipments APCE's are assumed to be installed. Although, the estimates are derived from actual unit level data, the accuracy of the estimated emissions could be further enhanced with the use of more detailed studies on emission factor development for power plants in India. Moreover, regular updating of data on efficiencies of control equipments such as ESPs can also help to improve the accuracy.

Conclusion

The demands for power are increasing at a rapid rate. Power generation sector in India is heavily dependent on coal, which makes it emission intensive. However, air pollution control technologies (ESPs) are employed in all the power plants for control of PM emissions as per the required standards. Despite this, with growth in power generation capacities, the emissions are projected to rise in future. While PM is somewhat controlled through installation of ESPs, the gaseous pollutants are emitted uncontrolled at most of the facilities. Inventories show that significant emissions of these gaseous pollutants are released from the power generation facilities. This is mainly due to absence of strict standards for gaseous pollutants such as SO_2 and NOx for existing power plants.

Government of India has taken an important initiative towards curbing air pollution by introducing new draft standards for coal-based TPPs in India. In April 2015, MoEF&CC, Government of India issued draft notification for revision of emission standards in TPPs. Along with PM_{10}, standards for SO_2, NO_x, and Hg emissions has been introduced. Emission limits set for the TPPs are under major discussion as new standards have taken into consideration the stringent standards only for newly constructed units. Standards are still very high for older units. Final guidelines are expected to come in near future.

Other than through regulation and introduction of standards, there are strategies that could be employed for control of emissions from power plant.

- Coal beneficiation—reduction of ash content
- Regular monitoring and maintenance of ESPs and other control systems
- Introduction of control technologies (such as FGD units) should be made mandatory in all the plants for control of SO_2 as FGD not only helps in reducing SO_2 to a higher extent but also significantly reduce toxic heavy metals such as Hg, which are not usually trapped by ESPs and affect the efficiency of boilers.
- Introduction of technologies such as SCR for control of pollutants such as NOx emissions.
- Demand control measures to reduce loads on power plants.
- Shift towards renewable or cleaner sources of power generation.

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CHAPTER 6

Transport

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Introduction

Air pollution is a serious concern especially in the urban areas of India. Source apportionment studies have highlighted many sources of air pollution in urban centres, and emissions from growing number of motor vehicles play an important role in the increasing pollutant loads in the cities. This is particularly important in India, which has one of the most critically polluted cities in the world. To add to its woes, India has seen very rapid growth in vehicles, especially across its urban centres that has contributed to increase in particulate emissions from vehicular sources; accounting for up to 50 per cent in the particulate matter less than 2.5 microns ($PM_{2.5}$) concentrations in a city like Bangalore (CPCB, 2010). These $PM_{2.5}$ emissions from diesel vehicles are critically important given that the World Health Organization (WHO) has recently classified diesel engine exhaust as carcinogenic to humans since exposure to these emissions is associated with increased risk of lung cancer.

Total registered vehicles in India has grown from 5.3 million in 1981 to 159 million by 2012 (MoRTH, 2013). However, not all registered vehicles are fit to ply on road. Figure 6.1 shows the estimates of on-road vehicles in India that have grown from 4.4 million in 1981 to about 96 million by 2011. The numbers are projected to grow to 427 million by 2031 and 933 million by 2051. Private vehicle ownership in particular has grown from 6 per 1,000 people in 1981 to 75 in 2011. This is expected to grow to up to 258 per 1,000 population by 2031, and 461 by 2051.

The distribution of vehicles in Figure 6.2 shows that the share of two-wheelers has grown rapidly during the period 1981–2011. However, in future with growth in economy, the share of cars will grow and will increase from 15 per cent in 2011 to about 18 per cent by 2031 and 24 per cent by 2051.

Presently, the transport sector is the second largest consumer of commercial energy in the country. Growth of transport sector increases the dependence

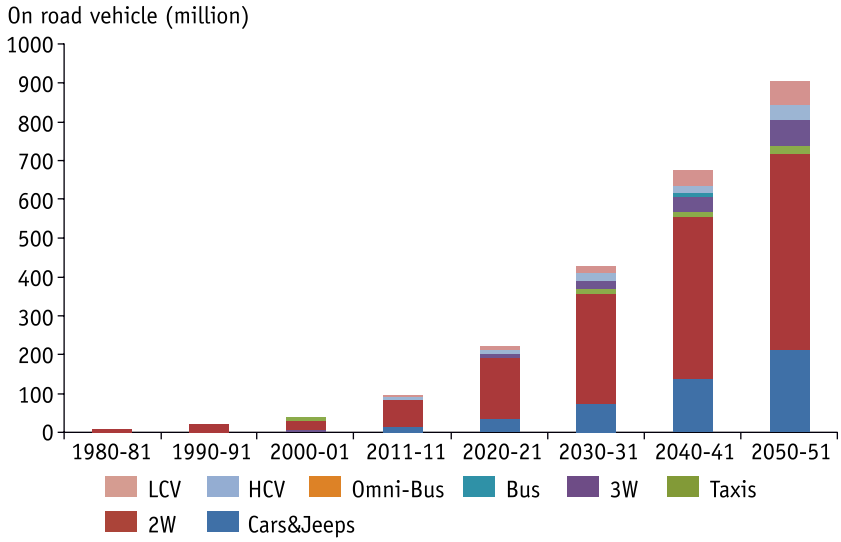

Figure 6.1: Year-wise on-road vehicular stock in India (TERI MARKAL model estimates)

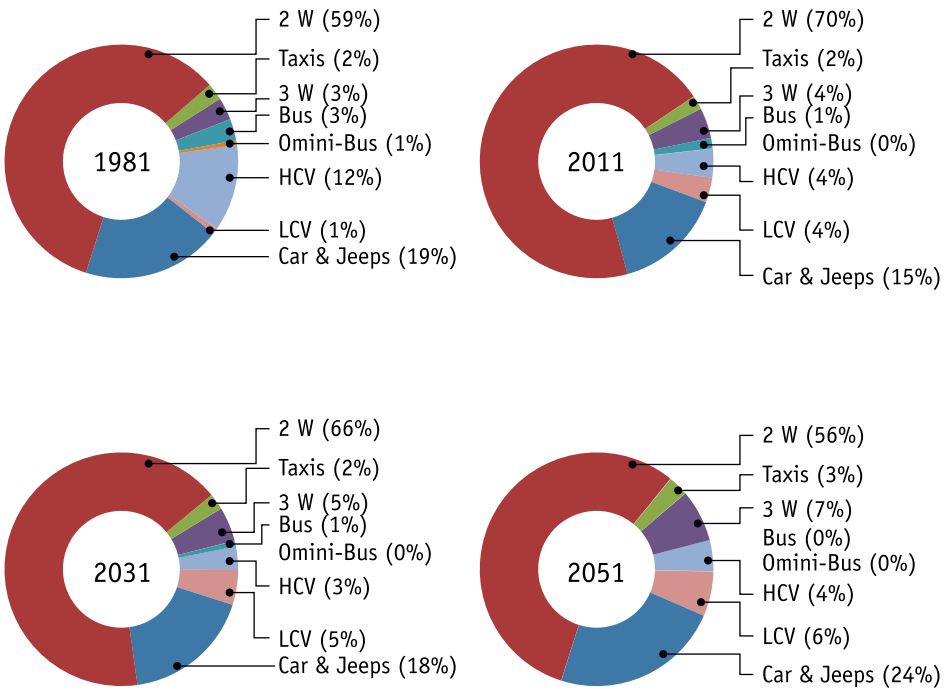

Figure 6.2: Distribution of on-road vehicles by type in past and future years (TERI MARKAL model estimates)

on imported crude. The sector is expected to grow at a steady rate for the next few decades. With further growth projected in future, the energy consumption is expected to increase considerably. In reference scenario (RES) in TERI 2015, the energy consumption in the sector is expected to grow from about 3.6 thousand PJ to more than 15 thousand PJ by 2031, and further to about 37 thousand PJ by 2051 (Figure

6.3). Currently, about 43 per cent of energy in road transport sector is consumed by heavy and light commercial vehicles (HCV and LCVs), followed by 23 per cent by buses. The share of private vehicles in energy use is expected to increase from 11 per cent in 2011 to about 19 per cent by 2051. The share of buses in energy use will reduce from 21 per cent to just 5 per cent in the same period of time. Increased energy consumption may lead to higher emissions of air pollutants in comparison to current levels, in a stagnant emission control scenario.

Methodology for Emissions Estimation

The transport sector emissions are estimated using the basic approach of emission factors.

Emissions = Energy use (PJ) × No control emission factor (kt/PJ) × (1 – Percentage of Bharat Stage emission control)

The emission factors for this exercise have been adopted from primarily three sources. CPCB (2000) reported emissions factors for various categories of vehicles with varying vintages. GAINS Asia database provides a database of emission factors for different categories of vehicles based on their classes under various emission control categories, that is, Euro-I to Euro-VI. ARAI (2008) also carried out a series of measurements to ascertain indigenous emission factors for different categories of vehicles in Indian conditions. A vehicle-wise comparison of emission factors from the three sources is shown in Figure 6.4. It is evident that while the emission factors are more or less in similar ranges, while there are considerable differences in some categories. The most recent measurements in Indian context is reported in ARAI dataset, which shows higher emissions for heavy-duty vehicles. However, lower emissions factors are derived from ARAI in case of two-wheelers categories. This is to be noted that ARAI (2008) reports emission factors in gram per kilometre units, which have been converted to gram per kilojoules based on typical vehicle mileages. Energy consumption estimated for the sector is compared and validated with actual fuel consumption estimates reported by MoPNG.

PM emissions are also estimated for four different fractions namely, PM_{10}, $PM_{2.5}$, Black Carbon (BC) and organic carbon (OC). The shares of BC and OC in PM_{10}/$PM_{2.5}$ fractions are adopted from EPA (2012).

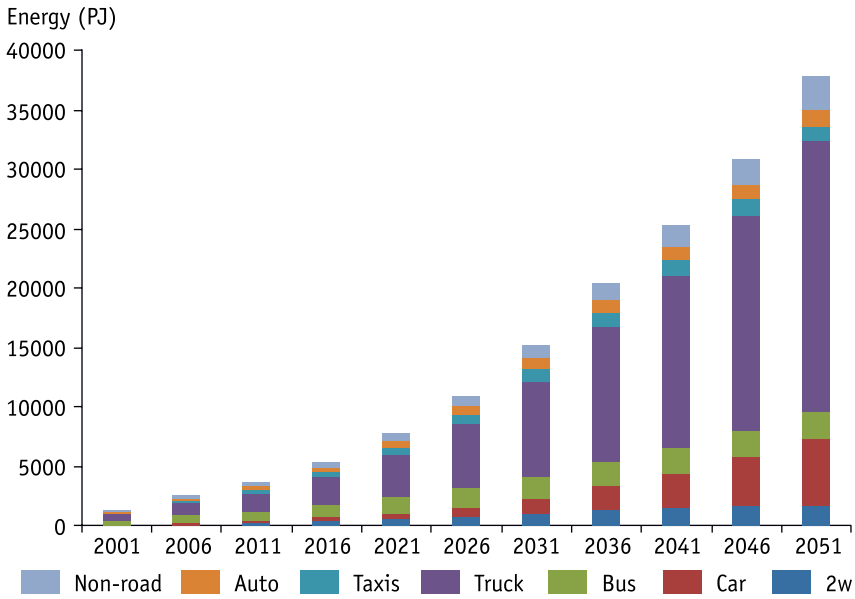

Figure 6.3: Growth in energy consumption (PJ) in transport sector in India

Source: MARKAL model results, TERI (2015)

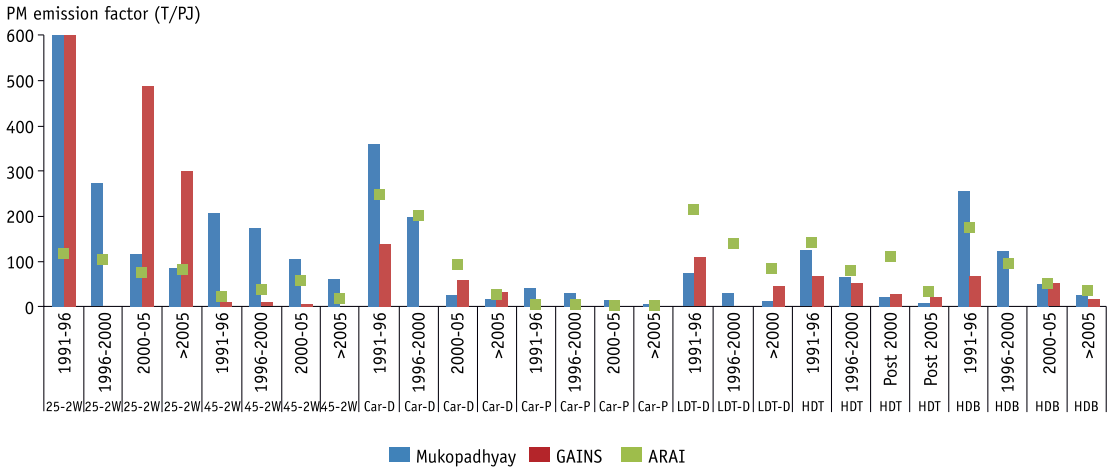

Figure 6.4: Comparison of PM emission factors from GAINS, ARAI (2008), and CPCB (2000)

Important Aspects Affecting Emissions from the Transport Sector

Other than the emission factors, there are number of aspects which affect energy consumptions and emissions from the transport sector in India. Each of these are discussed in subsequent sections.

Fuel Quality and New Vehicle Emission Standards

The quality of fuel plays an important role in determining the tail-pipe emissions of pollutants from vehicles. The sulphur and benzene content in fuels not only affect the emissions of SO_2 and hydrocarbons but also contribute to secondary particulate formation. The Auto Fuel Policy of 2002 of Government of India (MoPNG 2002) laid down a roadmap till 2010 for introduction of cleaner fuels and vehicles in the country. Under this, 13 selected cities were gradually moved to BS-IV norms by 2010, while rest of the country reached BS-III norms. This led to the establishment of one set of ambient air quality standards to determine the quality of air, and dual standards for vehicle emissions and fuel quality. It was observed that the rate of increase in PM_{10} concentrations was much higher in cities where lower quality fuel was provided (Sharma et al. 2014). More importantly, the heavy-duty trucks (which are the largest contributor to vehicular emissions) (Sharma et al. 2014) need to move all across the country and hence, remained on BS-III standards across the country, despite BS-IV norms introduced in some cities. Another Auto Fuel Vision Committee was set up in 2013 to recommend the future roadmap on advancement of fuel quality and vehicular emission standards up to 2025. The committee recommended that BS-IV and BS-V norms be introduced across the country by 2017 and 2020, respectively (AFV 2014). The road map suggested in Auto Fuel Policy 2002 and the current recommendations of the Auto Fuel Vision 2025 Committee on the future road map of auto fuel emissions are shown in Table 6.1.

However, it is to be noticed that the roadmap recommended by the Auto Fuel Vision 2025 Committee would also keep India almost 10 years behind the US and European countries. Although, recently the BS-IV fuel quality norms have been announced to be introduced in most regions of the country by 2016, the automobile manufacturers have shown their reluctance in moving to the BS-IV norms for heavy-duty vehicles with the immediate effect. The usefulness of BS-IV fuel can only be realised if the manufacturers start supplying the BS-IV complaint heavy-duty trucks and buses in the country. Moreover, the lowest emission levels can only be achieved with

Table 6.1: Road Map Suggested in Auto Fuel Policy 2002 and the Current Recommendations of the Expert Committee

Category	Bharat Stage II	Bharat Stage III	Bharat Stage IV	Bharat Stage V
Two and Three wheelers	Entire country April 2005	Entire country April 2010	Entire country April 2016	Entire country April 2020
All other new vehicles	Entire country April 2005 11 cities—April 2003	Entire country April 2010 11 cities—April 2005	Entire country 2017* 11 cities—April 2010 (20 cities) No road map beyond 2010	Entire country 2020–2021*
*Suggested by the new Auto Fuel Vision 2025 Committee in 2014.				

a move to BS-V quality of fuel (10 ppm sulphur) and BS-VI vehicular emissions standards for vehicles. Till date the Ministry of Road Transport and Highways, (Government of India) has notified BS-IV and BS-V emission norms. Based on the current scenario, the business as usual scenario in this study assumes adoption of BS-IV norms by 2016 and BS-V from 2021.

Growth of Private Vehicles vis-à-vis Enhancement of Public Transport

One of the prime factors for emissions from the transport sector is the rapid growth of private vehicles. Ghate and Sundar (2013) showed that the average level of private car ownership in India could grow from 13 per 1,000 population to 35 by 2025. While, growing number of vehicles has serious implications for energy security, road safety, and equitable allocation of road space, it also adds to the pool of air pollutants. Increasing private vehicles in India is linked to growing income levels, aspirations, and limited public transport. There is a lot to learn from the experiences of some cities like Singapore, Hong Kong, etc. to decouple vehicle ownership with economic growth. The success of these cities hinged on having efficient public transport systems to cater to the growing demands of mobility. Indian cities have however been moving in a different and unsustainable direction as compared to these international cities. The share of efficient mass transport modes have continuously gone down across most Indian urban centres.

Road transport now accounts for nearly 66–68 per cent of the total freight and 82–84 per cent of the total passenger traffic shares. The share of the energy efficient railways in freight movement have reduced from over 80 per cent in 1950–51 to about 35 per cent in 2011–12, while the share of railways in passenger traffic has reduced from over 50 per cent to barely 14 per cent in the same period. The shares of traffic on inland water ways and coastal shipping, which are the most efficient forms of transport, have almost declined to oblivion (Ramanathan et al. 2014). Without a conscious effort to increase the share of efficient transport modes, India is going to witness an increase in energy intensity in the transport sector.

State of Public Transport in India

The public transport scenario in India paints a grim picture. Most Indian cities are not equipped with effective public transport systems to meet their demand for mobility. The share of buses in the overall fleet of registered vehicles have declined from 11 per cent in 1951 to just 1 per cent in 2011 (PC 2014). The decline has been found to be rapid in the last decade mainly due to enormous growth of private vehicles. Government of India launched the National Urban Transport Policy (NUTP) in 2006 to improve the health of the urban transport systems across the country. NUTP identifies a number of public transport options such as metro-rail (Delhi, Hyderabad, Mumbai, etc.) and bus rapid transit systems (Ahmedabad, Jaipur, etc.) other than the existing suburban rail and bus systems

for mass transport solutions in cities. The Ministry of Urban Development also launched the Jawaharlal Nehru National Urban Renewal Mission (JNNURM) to provide financial assistance to cities for development of projects for improving urban mobility. The NTDPC report recommends a dense integrated system of transport for Indian cities. While metro rail systems can be considered for big cities with careful examination, bus-based systems are absolutely essential for small and medium cities. In addition to these, the Government of India has recently launched the Smart Cities Program and the AMRUT Scheme for India under which urban transport finds special significance.

In-use Vehicle Management System

While improvements have been made through introduction of emission standards for new vehicles, there are limited efforts being made in India to control emissions from in-use vehicle fleet. This requires an effective inspection and maintenance system to check and tune the vehicles to comply with the prescribed standards. Worldwide, it has been reported that on-road vehicles emit much higher levels of pollutants during their lifecycle as compared to the limits set during their certification stage. This could be mainly due to wear and tear, lack of proper maintenance, engine faults, or misuse at the hands of the driver, amongst other causes. This also points to the fact that mere switching to advanced new vehicle standards will not suffice and in-use vehicle management should go hand in hand.

Presently, the only in-use vehicle testing conducted in India is the Pollution-Under-Control (PUC) programme, which is based on idle test emission limits without any loaded mode tests. These idle mode tests do not reflect the real-life situation of a vehicle running on the road. Moreover, despite a provision of heavy penalties, merely 21 per cent of vehicles appear for PUC testing in Delhi (Sita Lakshmi et al. 2014). The current situation is not so effective in control of emissions and does not ensure on-road compliance despite compliance during manufacturing stage.

Congestion and Improving Driving Cycles

Internationally, and now in 10 Indian cities, Sharma et al. (2016) has observed that there are considerable differences between driving cycles on which vehicles are initially tested (for type approvals) and real-

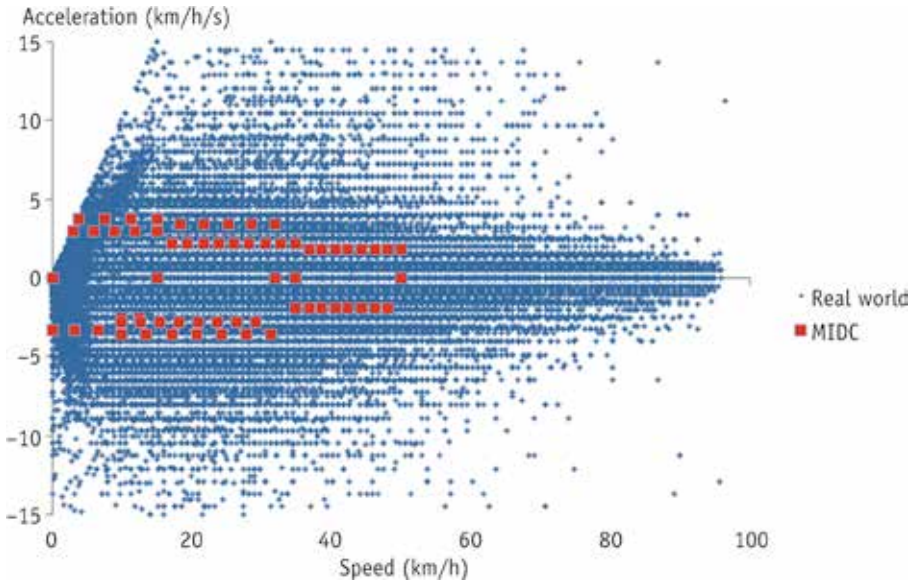

Figure 6.5: Comparison of driving patterns observed in 10 Indian cities with the prescribed driving modified Indian driving cycle ((MIDC)) for emission testing for cars in India

world driving conditions (Figure 6.5). The real world driving patterns observed in 10 cities highlight two issues. Firstly, there is a problem in the current testing procedures, which may lead to higher on-road emissions despite compliance with testing procedures and limits. This means that the vehicles may comply with emission regulations, but may emit much more under real-world conditions, hence making the policy ineffective. The second issue highlighted in the TERI study of 10 cities is of very high congestion levels, which could lead to loss of time, fuel, and enhanced exposure to very high emission levels (Sharma et al. 2013, 2016). The driving patterns show very low driving speeds mainly on account of congestion. City specific strategies will be required to address and improve the traffic flows. This will not only reduce exposure to emissions but also could save fuel and time.

Baseline and Future Emission Inventory

Based on the energy consumption (Figure 6.3), the emission factors (Figure 6.4) and factors described in section 'Important Aspects Affecting Emissions from the Transport Sector' that affect vehicular emissions in India, pollutant-wise emission estimates are made and presented in subsequent sections . It is to be noted that ARAI (2008) emission factors are used to derive emission estimates; however, the variations using other emission factor datasets is also presented in subsequent section 'Comparison of Emission Estimates with Other Studies'. For future emission norms, reduction factors are adopted from GAINS Asia Database.

NO_x Emissions

NO_x emissions from vehicles grew by more than two times during 2001–11 from 1164 kt to 2665 kt, with heavy-duty vehicles having the biggest share. The emissions are expected to grow further by 1.5 times till 2031 and 2.3 times by 2051 (Figure 6.6). Figure 6.7 shows that introduction of BS norms have arrested the growth of NOx emissions in India. BS-I/II emission norms led to a reduction of 21 per cent NOx emissions by 2051 in comparison to the no-control scenario. Further, introduction of BS-III and IV norms in 2011 and 2016 would lead to a reduction of 62 per cent NOx emissions by 2051. The RES scenario assumed in this study takes into account the current notification and assumes the introduction of BS-V in 2021. This leads to an overall reduction of 78 per cent in comparison to the No control scenario.

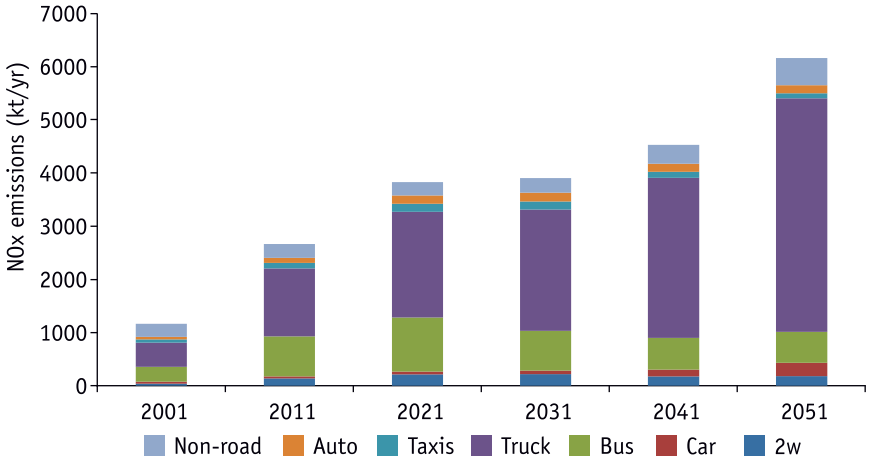

Figure 6.6: Past and projected growth of NOx emissions (kilotonnes per year) in India (2001–51)

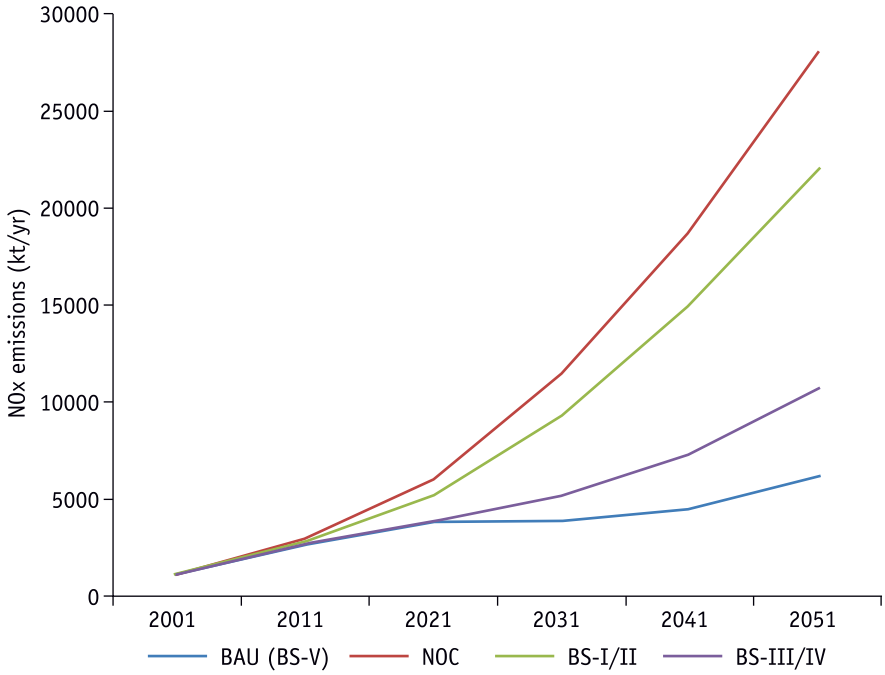

Figure 6.7: Effect of introduction of vehicle emission norms (BS-I to BS-IV) on NOx emissions in India
NOC refers to a scenario without any emission norms in the sector

PM Emissions

Emission estimates are prepared for different fractions of PM emitted from various vehicle categories. The emission estimates of PM2.5, BC, and OC are presented in Figures 6.8, 6.10, and 6.11. PM2.5 emissions grew from 191 in 2001 kt to 276 kt in 2011. Heavy-duty vehicles have the biggest share in the current emissions. The emissions are expected to increase till 2021 and are expected to reduce thereafter with introduction of BS-V norms (Figure 6.8). Figure 6.9 shows that introduction of BS norms have arrested the increase of PM emissions in India. BS-I/II emission norms led to a reduction of 49 per cent PM emissions by 2051 in comparison to the no-control scenario. Further, introduction of BS-III and IV norms in 2011 and 2016 would lead to a reduction of 83 per cent PM emissions by 2051. The BAU scenario assumed in this study takes into account the current recommendations of the expert committee and assumes the introduction of BS-V in 2021. This leads to an overall reduction of 97 per cent in comparison to the no control scenario in 2051.

The $PM_{2.5}$ emissions are speciated into BC and OC components using factors from EPA (2012). The BC emissions are dominated by diesel driven vehicles with BC to $PM_{2.5}$ ratios of 0.73–0.77. BC emissions from the transport sector are first expected to grow till 2031 and then go down from 197 kt to 111 kt during 2011–51 (Figure 6.10).

Other than major contributions from diesel driven vehicles, the organic carbon fraction receives contributions from gasoline driven private vehicles. The OC emissions from the transport sector are expected to go down from 70 kt to 35 kt during 2011–51, due to introduction of BS-V norms (Figure 6.11).

Carbon Monoxide

Carbon monoxide gas is released due to incomplete combustion of fuel. Gasoline engines have higher emission factors in comparison to diesel vehicles. The

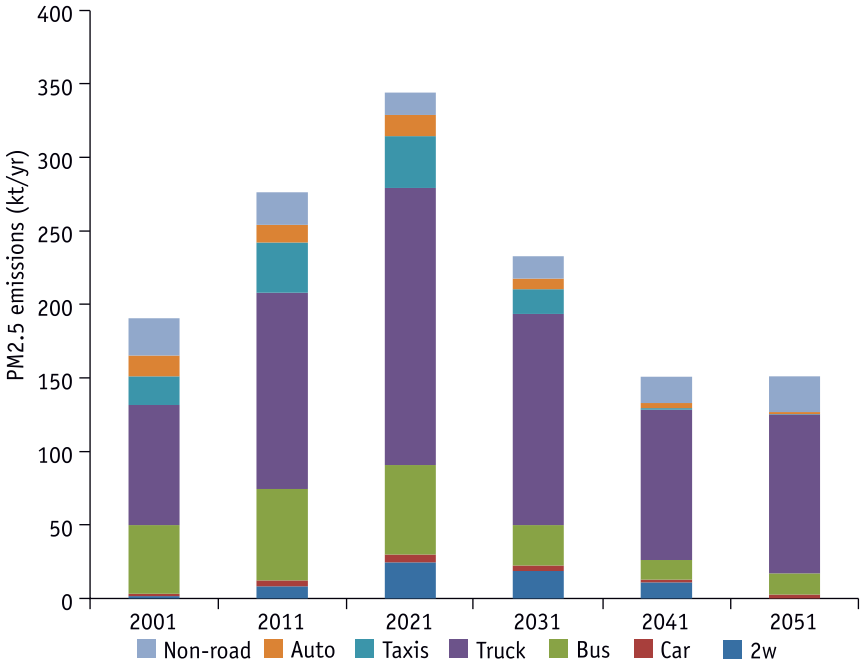

Figure 6.8: Past and projected growth of PM2.5 emissions (kilotonne per year) in India (2001–51)

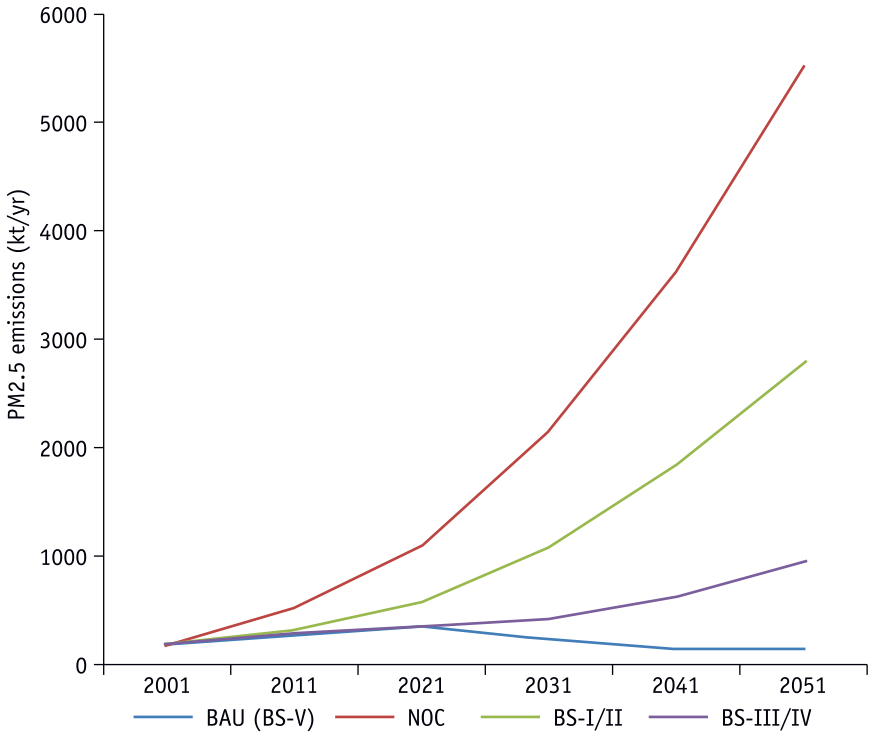

Figure 6.9: Effect of introduction of vehicle emission norms (BS-I to BS-IV) on PM2.5 emissions in India

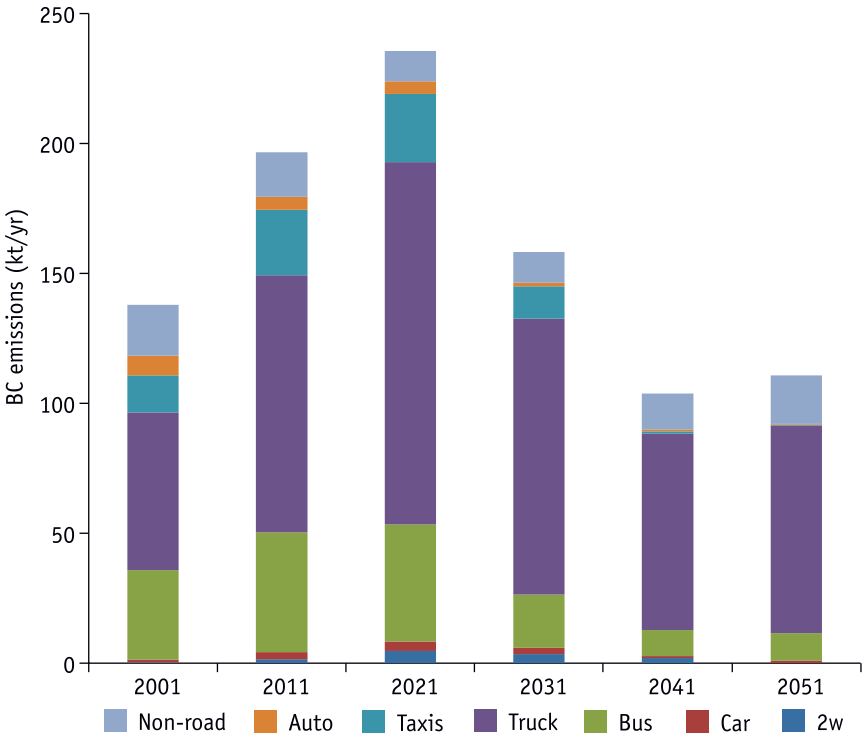

Figure 6.10: Past and projected growth of BC emissions in India (2001–51)

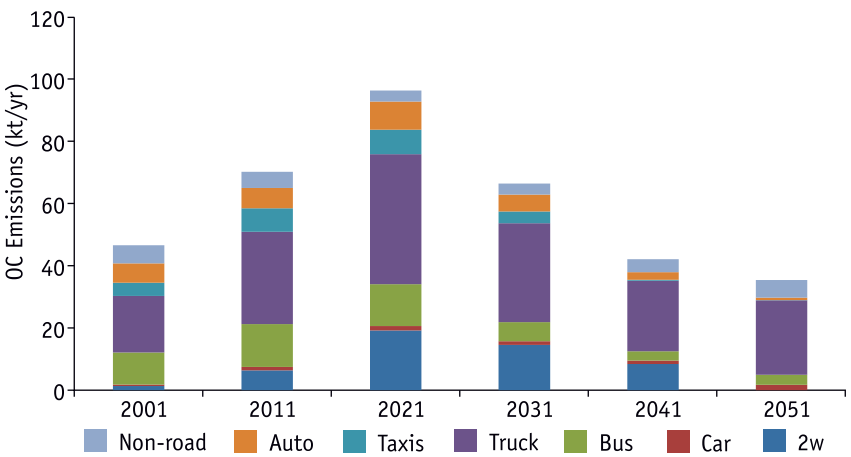

Figure 6.11 Past and projected growth of OC emissions in India (2001-2051)

emission estimates from 2001 to 2051 are presented in Figure 6.12. CO emissions grew from 1,983 in 2001 kt to 2,777 kt in 2011. Private vehicles (two wheelers and cars) have the biggest share in the current CO emissions (38 per cent). Trucks with high energy consumption also have a significant share of 33 per cent in the overall inventory. With growing energy demands, the emissions from the transport sector are projected to grow by 2.2 and 5.1 times by 2031 and 2051, respectively. The emission is expected to grow

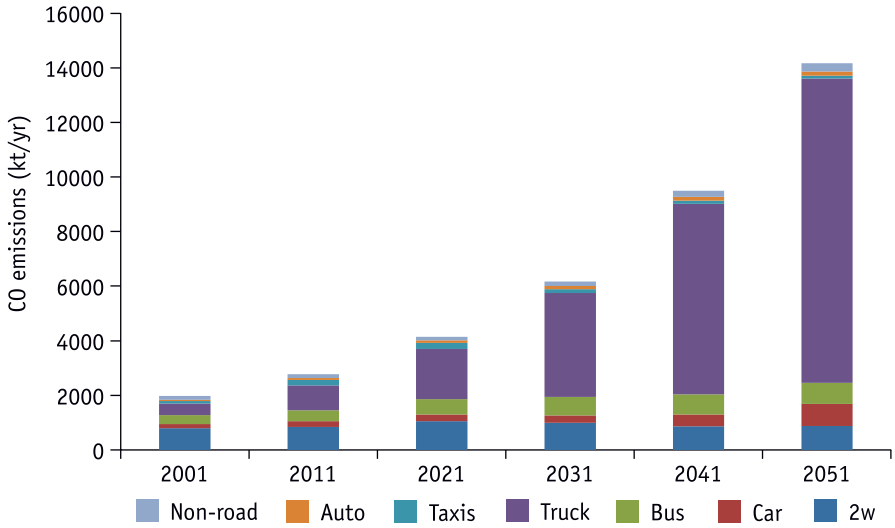

Figure 6.12: Past and projected growth of CO emissions in India (2001–51)

with the energy consumption mainly on account of no further control of CO emissions in BS-V norms in trucks. However, the emission could have been much higher without the introduction of emission control norms (BS-I to BS-IV) in India.

Hydrocarbons

Hydrocarbons are released mostly from gasoline engines that have higher emission factors in comparison to diesel vehicles. The emission estimates from 2001 to 2051 are presented in Figure 6.13. HC emissions grew from 605 in 2001 kt to 802 kt in 2011. Private gasoline driven vehicles have the biggest share (46 per cent) in the overall inventory. On account of introduction of BS-V norms, the emissions are expected to grow only marginally till 2031 and will increase to 980 kt. Despite introduction of BS-V norms, the emission will grow to 1,103 kt by 2051,

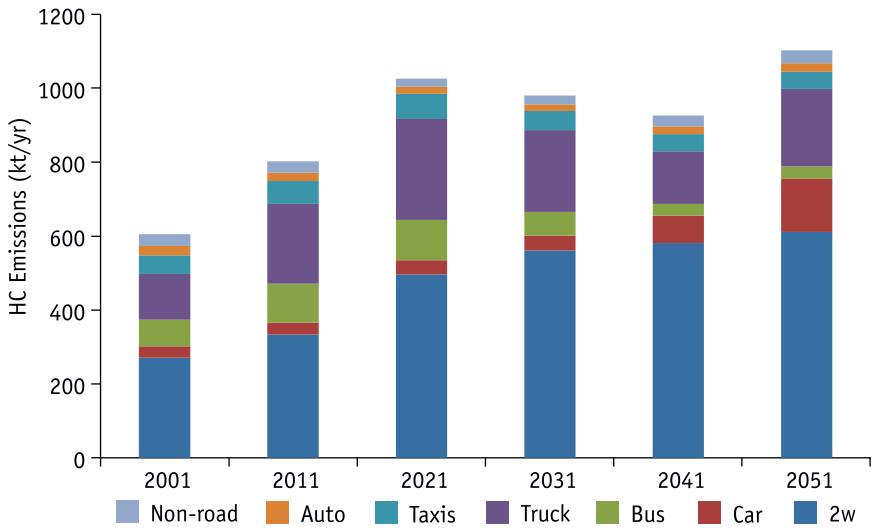

Figure 6.13: Past and projected growth of HC emissions in India (2001–51)

mainly due to growth in energy consumption. The emission could have been much higher without the introduction of emission control norms in India.

SO_2 Emissions

Sulphur dioxide emissions are related to the sulphur content in the automotive fuels. Fuel quality has gradually improved in the country and sulphur content has reduced considerably over the years (Table 6.2).

With this the sulphur dioxide emissions have come down significantly from 120 kt in 2001 to 53 kt in 2011 (Figure 6.14). It is expected to go down further with introduction of BS-V (10 ppm sulphur) fuels in 2021. However, no changes have been assumed in high sulphur fuels used in non-road sector (tractors, railways, and shipping). With 2,000 ppm sulphur assumed in non-road fuels, the emissions are expected to reach 145 kt by 2051.

Comparison of Emission Estimates with Other Studies

The emission estimates in the previous section are based on emission factors from ARAI (2008) datasets. The differences in emission esitmates using GAINS and CPCB (2000) emission factors are shown in Table 6.3. The estimates in this study are also compared with previous studies.

It is to be noted that when GAINS emission factors are used, the emissions ranges between 115 kt to 147 kt between 2001 and 2051. However, in the current study the emissions estimated using ARAI emission factor leads to higher PM2.5 emissions of 261 kt in 2011. This is due to higher emission factors reported in ARAI (2008) while testing of indigenous vehicles on Indian driving cycles.

Emissions from Road Dust Re-Suspension

When vehicles move on a road, the silt lying on the road gets re-suspended. The rate of re-suspension is dependent on the weight of the vehicles and quantity of silt lying on the road. Road dust

Table 6.2: Fuel Quality Improvement Program in India

Fuel	Date	Lead content	Area covered
Gasoline	1994	Low leaded (0.15 g/l)	NCT, Delhi, Mumbai, Kolkata, and Chennai
Gasoline	1995	Unleaded (0.013 g/l) + low lead	NCT, Delhi, Mumbai, Kolkata, and Chennai
Gasoline	1998	Ban on leaded gasoline. Only unleaded	NCT
Gasoline	1999	Unleaded only	NCR
Gasoline	2000	Unleaded only	Entire country
Fuel	Date	Benzene Content	Areas Covered
Gasoline	Pre1996	No specification for Benzene	Entire country
Gasoline	2000	3 % Benzene	Metro cities
Gasoline	2000	1% Benzene	NCT and Mumbai
Gasoline	2005	1% Benzene	Entire country
Fuel	Date	Sulphur Content	Areas Covered
Diesel	1996	0.5%	Four metros and Taj Trapezium
Diesel	1997	0.25%	Delhi and Taj Trapezium
Diesel	1998	0.25%	Delhi, Mumbai, Chennai, Kolkata
Diesel	2000	0.05%	NCR-Private Vehicles
Diesel	2001	0.05%	NCT-all diesel vehicles
Diesel	2001	0.05%	NCR-all diesel vehicles
Diesel	2001	0.05%	Chennai, Mumbai, and Kolkata
Diesel	2003	0.05%	Ahmedabad, Bangalore, and Hyderabad
Diesel	2005	0.05%	All over country
Diesel	2005	0.035%	11 cities
Diesel	2010	0.035%	All over country
Diesel	2010	0.005%	11 cites
Diesel	2016	0.005%	All over country*
Diesel	2021/2019	0.001%/	All over country*

*Planned as per AFV 2025;** As per MoRTH notification

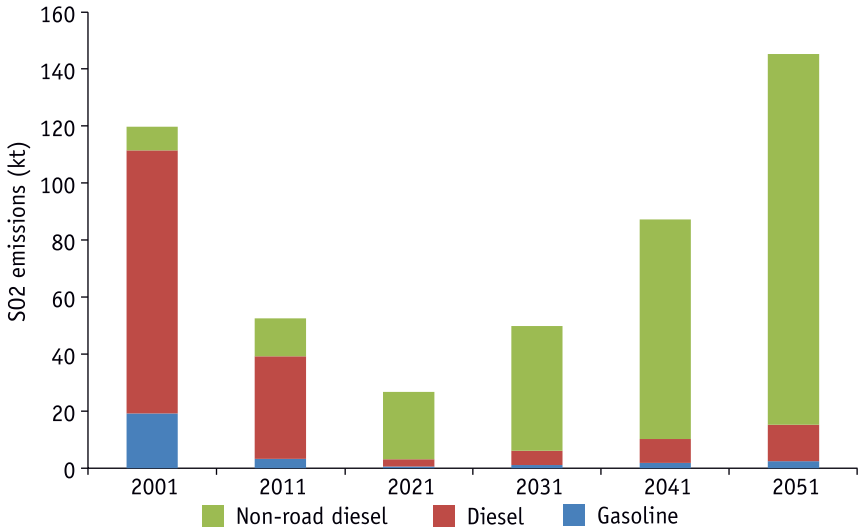

Figure 6.14: Past and projected growth of SO_2 emissions in India (2001–51)

Table 6.3: Comparison of Different Studies Reporting Emissions (kilotonnes) for Different Pollutants from Transport Sector in India

Source	Year	$PM_{2.5}$	NOx	CO	HC
ICCT, 2013	2011	220	2200		
CPCB, 2010	2003–04	153	2298	5692	723
CAIA, 2008	2008	150	2200		
Guttikunda and Mohan, 2014	2011	253	5000	5500	1850
Purohit et al., 2010	2010	319	2706		1798
This study (ARAI, 2008 efs)	2011	276	2665	2777	802
This study (GAINS efs)	2011	156	2820		
This study (CPCB, 2000 efs)	2011	235	2376		

suspension emissions in this study are estimated using the USEPA procedure specified in AP-42.

Emission loads =VKT × EF where

$EF = k\,(SL)^{0.91} \cdot (W)^{1.02}$

EF = particulate emission factor (having units matching the units of k),

k = particle size multiplier for particle size range and units of interest, for PM_{10} $k = 0.62$, $PM_{2.5}$ $k = 0.15$

SL = road surface silt loading (grams per square meter; g/m^2),

W = average weight (tons) of the vehicles travelling the road

Based on silt loadings experiments carried out by TERI in the past in various cities of India (TERI 2007, 2011, Sharma et al, 2015) a conservative SL of 0.1 g/m² is assumed in this study. Vehicle-wise VKT estimates were taken from TERI (2015) (based on TERI-MARKAL model estimates) for 2001–51. '*W*' values were derived based on fleet distributions. PM10 and PM2.5 emissions are estimated be 47.8 and 11.6 kt in 2011, respectively (Figure 6.15). The emission projections are made with an assumption that road quality and maintenance will improve at the rate of 10 per cent per annum and silt loading will reduce to 0.043 g/m² by 2051. The emissions will still grow by 12.5 times with the growing mobility demands and weight of the overall vehicular fleet.

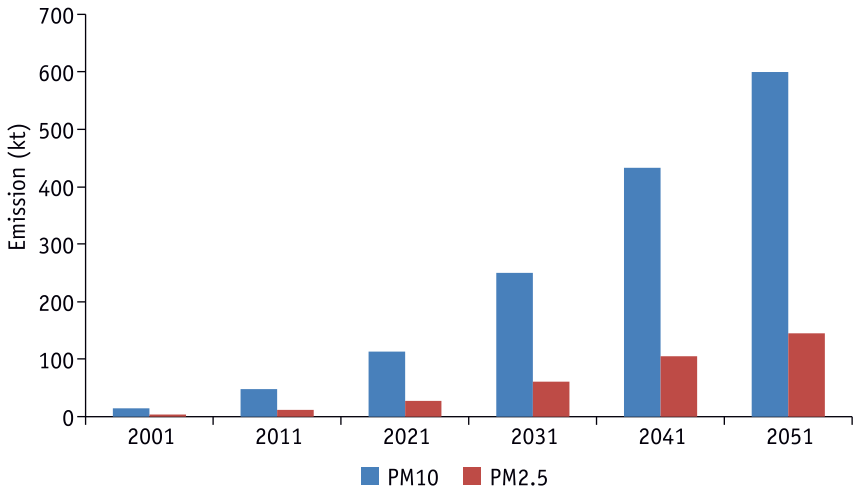

Figure 6.15 : PM_{10} and $PM_{2.5}$ emissions (kilotonnes) from road dust re-suspension in India

Spatial Allocation of Emissions in India

Emissions of different pollutants from on-road vehicles in India are allocated based on district-wise vehicular population in India. The district-wise emissions are used to allocate emissions at the grid resolution of 36 × 36 km². The national highways of India carry 40 per cent of total traffic (http://www.nhai.org/) and hence 40 per cent of the emissions are allocated at the national highways digitised using geographical information system (GIS). The spatial distribution of emissions at 36 × 36 km² resolution is shown in Figure 6.16. This is evident that high vehicular density in India is limited to urban regions and national highways. For non-road sector, the emissions are distributed at the state level. State-wise allocation of aircraft emissions is done on the basis of state-wise air craft movement. Shipping emissions are allocated state wise on the basis of total traffic handled by major and minor ports in the country. State-wise allocation of emissions from railways is done on the basis of state-wise rail route length.

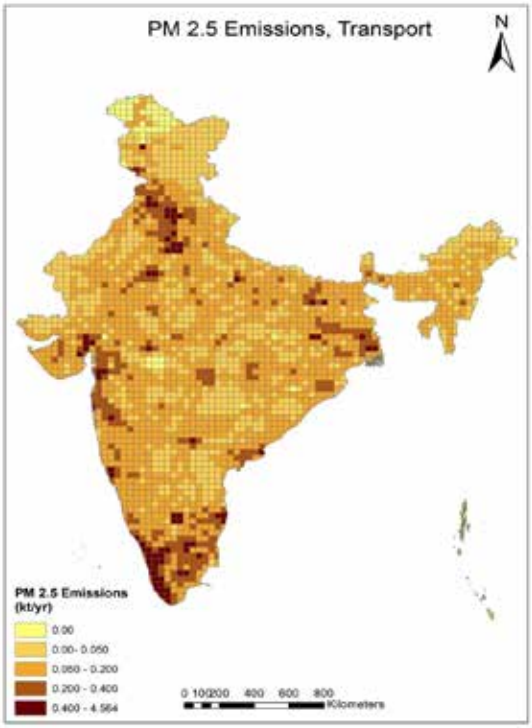

Figure 6.16: Spatial distribution of PM2.5 emissions from tail-pipe emissions in India

Conclusions

The transport sector is expected to grow multi-folds over the next four decades. Despite some fuel efficiency improvements, the energy consumption in the sector is projected to grow. The emissions from the sector has grown in the past; however, introduction of fuel quality and vehicular emissions norms has arrested the growth to some extent. Future projections show that the emissions from transport

sector will stabilize over the years mainly due to introduction of advanced vehicular emission norms (BS-V) by 2021. The inventory of emissions from transport sector is found to be comparatively lower than other sectors such as residential and industries. However, it is to be noted that transport emissions are concentrated more in the urban regions and that is why the sectoral contribution of transport may not be prominent at the National scale but will be significant at the urban scales. CPCB (2011) has shown higher contributions of the transport sector at the urban scales. Other than tail-pipe emissions, fugitive emissions due to road dust re-suspensions are also emitted from the sector. While there are norms in place for control of tail-pipe emissions, the road dust emissions are dependent on the quality of roads and maintenance.

Evidently, there are a number of steps that are required to be taken for control of vehicular pollution in India.

Improve fuel quality and vehicular standards

Considering the current state of air quality, the Government of India has notified earlier introduction of BS-V fuels than those recommended in the AFV (2014) by asking the Indian refineries to move to BS-V fuels by 2019. The GOI has also announced the possibility of leap frogging to BS-VI emissions norms. GOI should also immediately set up an expert group to prescribe BS-VI vehicle emission norms by 2017 that can be adopted by the auto industry by 2020. This would also facilitate the use of after treatment devices (e.g., diesel particle filters) as retrofits for vehicles already in use. Studies carried out by TERI and ICCT have shown that the benefits of the adoption of these advanced norms outweigh the costs of implementation and the initial costs of refinery upgradation can be met with a slight increase in the fuel price (less than a rupee per litre) (ICCT 2013; Sharma et al. 2014) .

Reduce private vehicles ownership in urban areas

Discouraging ownership of vehicles can be done through higher taxation policies, high parking fees, road usage fees, etc. However, this can only be implemented once a public transport system is in place that is attractive enough for the general public. The bus-based public transport systems are within reach of larger cities' budgets as well as state transport funding, but incentives from national programs such as the forthcoming successor to the JNNURM or the SMART cities program could motivate greater attention to buses as an important part of public transport systems. Bus-based systems are particularly well suited for most Indian cities since they are inherently more flexible than rail based ones and can accommodate unforeseen growth.

Improved in-use vehicle management system

It could be better to set up adequate numbers of well-equipped centralized inspection centres in every city, in place of the existing decentralized PUC centres. These limited number of inspection centres should be closely monitored by the respective state transport departments for quality assurance. Instead of quarterly testing, annual testing of vehicles (such as in US and China) across India can ensure higher percentage of the vehicular fleet actually appearing for inspections. For further improvement, annual I&M checks can be linked with the vehicle insurance. The total investment required for establishing inspection centres for catering to all the vehicles is estimated to be about INR 7,300 crores. Annual testing charges of INR 100 to 400 per vehicle—for different category of vehicles—should recover this cost within the next 2.3 years (Sitalakshami et al, 2014). Moreover, there is a need of an in-use vehicle compliance programme to check and ensure that vehicles actually comply with their original emission standards (type approval standards) throughout their useful life. Limited testing can be initiated at the central level to assess the compliance of in-use vehicles of different manufacturers with the type approval norms.

Improving Driving cycles

This call for further investigations and change in the current procedures and therefore improvement in the prescribed driving cycles in the vehicle emission

test procedures. In this respect, a move towards the world harmonized test procedures could be explored, which cover a variety of driving conditions and are much more comprehensive than the current ones.

Other than these, encouraging fleet modernization, promoting non-motorized means of transport (walking and cycling), increasing distribution of electric and hybrid vehicles, and integrated land-use and transport planning should also help. For control of road dust emissions, the quality of roads and maintenance levels also need to improve significantly.

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Annexure

Table A.6.1: Comparison of ARAI (2008), CPCB (2000) and GAINS Emission Factors (Tonnes/PJ)

Categories			GAINS				ARAI*				CPCB (2000)*			
Fuel	Category	Vintage	CO	HC	NOx	PM	CO	HC	NOx	PM	CO	HC	NOx	PM
Gasoline	2-W (2s)	1991–96	15000		200	1500	9449	5333	49	119	18022	10813	83	638
Gasoline	2-W (2s)	1996–2000					6719	4704	112	106	10922	9011	164	273
Gasoline	2-W (2s)	Post 2000	7500		200	487.5	4069	3412	87	76	5189	5023	165	118
Gasoline	2-W (2s)	Post 2005	1500		200	300	454	1470	60	84	2429	2290	139	87
Gasoline	2-W (4s)	1991–96	12000		108	10	7426	1856	547	24	8947	2386	924	209
Gasoline	2-W (4s)	1996–2000				9	3990	1869	758	38	7477	2013	863	173
Gasoline	2-W (4s)	Post 2000	7200		108	6	3419	1384	798	60	4564	1452	622	104
Gasoline	2-W (4s)	Post 2005	3000		96		1263	746	273	18	1739	870	373	62
Diesel	Cars	1991–96	310		350	140	1088	607	743	249	3121	158	1184	359
Diesel	Cars	1996–2000					1379	326	301	203	571	176	328	200
Diesel	Cars	Post 2000	257		350	60.9	450	116	387	95	346	50	192	27
Diesel	Cars	Post 2005	111		350	34.72	88	55	194	25	224	19	174	19
Gasoline	Cars	1991–96	6900		860	2	3185	563	637	5	6850	1188	1258	42
Gasoline	Cars	1996–2000					2765	403	458	5	2438	500	688	31
Gasoline	Cars	Post 2000	2760		249	1.1	1223	108	92	3	1048	132	106	16
Gasoline	Cars	Post 2005	828		112	1.1	341	49	37	1	537	58	46	8
Diesel	LDV	1991–96	310		350	110	663	493	655	216	2991	1773	107	75
Diesel	LDV	1996–2000					643	274	532	140	1804	1468	19	31
Diesel	LDV	Post 2000	257		350	47.8	652	241	378	85	749	357	19	14
Diesel	Truck	1991–96	900		1300	70	795	167	857	143	459	149	793	125
Diesel	Truck	1996–2000				52.7	577	94	1153	79	376	101	701	67
Diesel	Truck	Post 2000	855		904	28.3	685	130	1006	111	301	73	526	23
Diesel	Truck	Post 2005				23.1	327	23	682	33	267	73	459	10
Diesel	Bus	1991–96	900		1300	70	1132	208	975	175	470	152	1625	257
Diesel	Bus	1996–2000					352	115	1199	95	342	92	1276	121

Table A.6.1: Comparison of ARAI (2008), CPCB (2000) and GAINS Emission Factors (Tonnes/PJ)

Categories			GAINS				ARAI*				CPCB (2000)*			
Diesel	Bus	Post 2000	855		904	52.7	371	188	607	52	326	79	1088	51
Diesel	Bus	Post 2005	756		958	19.6	472	19	787	36	372	101	1278	28

*Values are originally in gram per kilometre, converted using fuel efficiency values computed using CO_2, HC, and CO concentrations.
Data source: ARAI (2008), GAINS, CPCB (2000)

Other than on-road vehicles, the emissions were also calculated for non-road transport including railways, airways, waterways transport, and tractors. The emission factors (T/PJ) are provided in below in Table A.6.2.

Table A.6.2: Emission Factors (T/PJ) for Railways, Airways, and Waterways Transport

Controls	Pollutant	Air craft	Diesel locomotives	Ship/coastal water transportation
NOC	NOx	0.008	1.16	1.16
Euro-I		0.008	0.7656	0.7656
Euro-II		0.008	0.696	0.696
Euro-III		0.008	0.522	0.522
Euro-IV		0.008	0.348	0.348
Euro-V		0.008	0.2204	0.2204
Euro-VI		0.008	0.0522	0.0522
Euro-VII		0.008	0	0
NOC	PM_2_5	0.35604	96.426	105.003
Euro-I		0.35604	64.31614	70.037
Euro-II		0.35604	48.213	52.5015
Euro-III		0.35604	14.4639	15.75045
Euro-IV		0.35604	2.89278	3.15009
Euro-V		0.35604	5.78556	6.30018
Euro-VI		0.35604	2.121372	2.310066
Euro-VII		0.35604	0	0
NOC	CO	—	0.25	0.25
Euro-I		—	0.2375	0.2375
Euro-II		—	0.21	0.21
Euro-III		—	0.1125	0.1125
Euro-IV		—	0.09	0.09
Euro-V		—	0.09	0.09
Euro-VI		—	0.09	0.09
Euro-VII		—	—	—
NOC	PM10	0	101.783	110.8365
Euro-I		0.387	67.88926	73.92795

Table A.6.2: Emission Factors (T/PJ) for Railways, Airways, and Waterways Transport

Controls	Pollutant	Air craft	Diesel locomotives	Ship/coastal water transportation
Euro-II		0	50.8915	55.41825
Euro-III		0	15.26745	16.62548
Euro-IV		0	3.05349	3.325095
Euro-V		0	6.10698	6.65019
Euro-VI		0	2.239226	2.438403

Source: GAINS

Table A.6.3 Emission Factor for Tractors (g/kwh)

Pollutant	Bharat Stage I	Bharat Stage II	Bharat Stage III	Bharat Stage III A
HC + NOx	-	15	9.5	6.2
PM	2.43	1	0.8	0.51
PM2.5	2.06	0.85	0.68	0.44
BC	1.46	0.6	0.48	0.31
OC				
NOx	18	12.6	8.0	5.2
SO2	0.24	0.060	0.060	0.042
CO	14	9	5.5	5
HC	3.5	2.44	1.55	1.01

Source: Based on prescribed emission norms

CHAPTER 7

Diesel Generator Sets

C. Sita Lakshmi and Sumit Sharma

Introduction

Unreliable power situation along with ever-increasing gap between demand and supply has been a major challenge in India for many years now. To counter these issues, diesel generator (DG) sets have become an imperative across various sectors such as industries, infrastructure, housing, IT, and telecom. Not only in India but all around the world diesel-powered generator sets are the preferred choice for standby and emergency power systems, perhaps owing to the ease of installation and operation, limited space requirement, and easy availability in the market (Iverson 2007). The total energy availability in 2010–11 in India increased by 5.6 per cent at 788,355 MU over the previous year and the peak met increased by 6.0 per cent and was reported at 110,256 MW; still the energy deficit (MU) was 8.5 per cent and peak deficit (MW) was 9.8 per cent during 2010–11 (CEA 2012). While the latest data indicates shortage situation to have improved in the country with the energy deficit (MU) reported as 3.6 per cent and the peak deficit (MW) was 4.7 per cent during 2014–15. However, the unreliability of supply necessitates the use of DG sets.

DG sets are used in number of residential complexes, factories, and businesses in India, and the estimated installed capacity in India during 2014 was about 60–90 GW, which was about 36 per cent of India's total installed generation capacity in 2014 (Pearson 2014; Sasi 2014). Despite the cost of producing electricity from DG sets steadily rising, owing to increasing prices of diesel fuel to as much as INR 24–30 per kilowatt-hour in 2014 (Chatterjee 2014), its demand is still rising.

Of the total diesel sales in India, 82 per cent was sold through retail outlets (petrol pumps) in the year 2011–12 while the remaining was directly sold by the oil marketing companies to bulk consumers such as industries, railways, and defence among others. The retail sales data shows that maximum diesel consumption is by the transport sector, with highest by heavy and light duty vehicles (HCVs, LCVs) and

buses followed by private cars and utility vehicles. While in the non-transport sector, tractors consume the maximum quantities of diesel followed by DG sets (Petroleum Planning and Analysis Cell 2013).

One of the major sectors employing the use of DG sets in India is the telecom industry. TRAI 2011 shows that there were 400,000 telecom towers across India by end of the year 2010. With as high as 60 per cent of the power requirement of telecom towers being met through the use of DG sets and towers in remote areas being powered 100 per cent by DG sets, telecom sector has an important contribution in the overall energy use and emissions from DG sets. It is estimated that in 2010, the telecom sector consumed about 2 billion litres of diesel (TRAI 2011).

The Indian DG set sector has both organized big manufacturers, along with the unorganized and small manufacturers, the latter constituting as high as 30–40 per cent of the whole market size.

Compared to the transport sector, DG sets consume a small amount of diesel; however it is a key contributor in the non-transport segment and is set to sustain in near future keeping in mind the power situation in India. DG set is an important source of emissions and many studies including the source apportionment study published by CPCB in 2011 has estimated a significant share of DG sets in the prevailing air pollution levels in the cities. In Bangalore, the share of DG sets was about 14 per cent in the ambient $PM_{2.5}$ concentrations (CPCB 2011). Other than particulate matter (PM), these devices are known to emit significant NO_x emissions. Moreover, the pollutants are emitted at low heights, and hence provide more exposure to the receptors (Figure 7.1).

Agriculture contributes to as high as 15 per cent of the overall GDP in India and employs a major proportion of the county's workforce (KPMG and Shakti Foundation 2014). Almost all Indian states heavily rely on diesel pump-sets for irrigating their croplands. Currently, there are about 7 million diesel-powered pump-sets in India (excluding grid connected electric pump-sets) consuming approximately 4 billion litres of diesel annually (KPMG and Shakti Foundation 2014). The pump-sets manufacturing market is predominantly in the unorganized sector providing low cost (less than INR 15,000) and low efficient pump-sets with efficiency between 20 per cent and 35 per cent (BEE 2011). Owing to poor efficiency,

Figure 7.1: Small diesel generator set

these pump-sets consume a lot of diesel and hence are an important source of PM emissions. This chapter provides the estimates of energy consumed by DG generator sets in India and the corresponding emissions.

Past Trends and Future Growth

FaS 2010 showed results of a market research study and states that the DG set market is estimated to grow steadily at a compounded annual growth rate of about 10.1 per cent in revenue terms between 2010 and 2015. Further, it reports a 7.2 per cent annual growth in number of DG sets in India. According to other industry estimates, the power back-up market in India is growing at an annual rate of 15–20 per cent (CWO 2010), varying within the three different segments—generators, UPS, and inverters. Annually it is estimated that roughly 2 lakh DG sets are added to the domestic market, including telecom sector. It is estimated that in the year 2000, the number of DG sets sold in India was 37,569 units, which grew to 186,531 units in 2010. Majority of the DG sets sold in India are of the capacities 15–25 KVA (56 per cent) and 62–125 (26 per cent) (Figure 7.2).

The agricultural pump-sets market is reported to be growing at the rate of 6.3 per cent annually in terms of number of units from 2009 to 2013 (KPMG and Shakti Foundation 2014). Farmers across the country use pump-sets of varying capacities depending on their specific requirement based on ground water levels and affordability. Almost 50 per cent of the market share is occupied by pump-sets in the range of 5 to 7.5 HP (Figure 7.3).

Emission Control for DG Sets in India

The Ministry of Environment and Forests set regulations and emission norms (CPCB I) for the diesel engines used in the DG sets in the year 2002 (Table 7.1), which also imposed type approval (TA) testing and conformity of production (CoP) along with labelling requirements on DG sets. These emission norms were subsequently strengthened

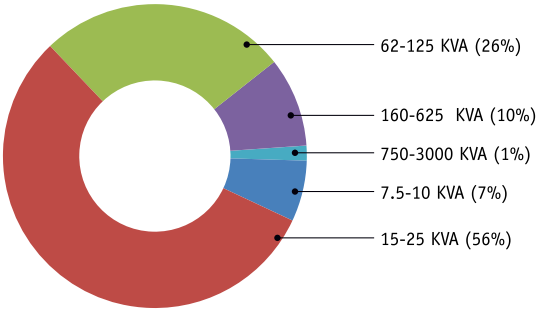

Figure 7.2: Capacity wise sales of DG sets in India, (2011)

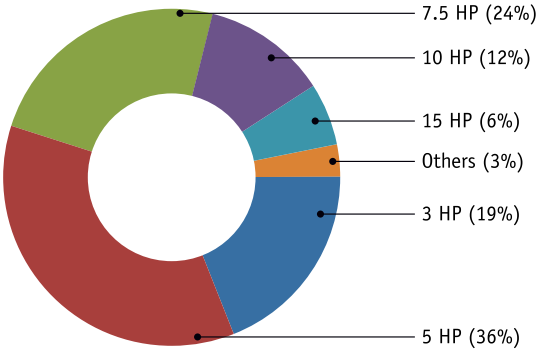

Figure 7.3: Capacity wise market share of agricultural pumps (by volume)
Source: KPMG and Shakti Foundation 2014

with revised norms (CPCB II) in the year 2013; these new norms are applicable to new DG sets being sold from 1st July 2014 (Table 7.2).

The efficiency of a DG set is expressed as a combined efficiency of its two subcomponents, namely the engine and the alternator or the AC converter; typically it varies between 30 per cent to 55 per cent depending on its design, size, capacity, mechanism for fuel control, and operating speed, among other factors (Shakti Sustainable Energy Foundation and ICF International 2014). Efficiency of the DG sets is also dependent on external factors such as load conditions, ambient conditions, and operation and maintenance (O&M) practices.

Small and medium-sized DG sets are designed to meet the existing emission standards at manufacturing stage itself, while the larger DG sets

Table 7.1: Emission Standards for Diesel Engines ≤800 kW for Generator Sets (2004–05) —CPCB I

Engine Power (P)	Date	CO	HC	NOX	PM	Smoke
		g/kWh				l/m
P ≤ 19 kW	2004.01	5.0	1.3	9.2	0.6	0.7
	2005.07	3.5	1.3	9.2	0.3	0.7
19 kW < P ≤ 50 kW	2004.01	5.0	1.3	9.2	0.5	0.7
	2004.07	3.5	1.3	9.2	0.3	0.7
50 kW < P ≤ 176 kW	2004.01	3.5	1.3	9.2	0.3	0.7
176 kW < P ≤ 800 kW	2004.11	3.5	1.3	9.2	0.3	0.7

Table 7.2: Emission Standards for Diesel Engines ≤800 kW for Generator Sets (Gazette Notification of 2013, Applicable From 2014)—CPCB II

Power category	Emission limits			Smoke limit
	$NO_x + HC$	CO	PM	
	(g/kW-hr)			Light absorption coefficient per m
Up to 19 KW	≤7.5	≤3.5	≤0.3	≤0.7
19 kW < P ≤ 75 kW	≤4.7	≤3.5	≤0.3	≤0.7
75 kW < P ≤ 800 kW	≤4.0	≤3.5	≤0.2	≤0.7

need different interventions to reduce their emissions (of NO_x, PM, CO, and HC) and meet the emission standards (Herzog 2002). Some of the most common emission control technologies for DG sets are

- More efficient combustion engines
- Catalytic after treatment systems (DOCs/DPFs)
- Low sulphur fuels
- High-pressure direct injection gas technology

However, tail pipe controls are currently not employed in India to control emissions from DG sets. The PM and NO_x emission conundrum, in controlling diesel emissions, still poses a major challenge in designing engines, since most engine technologies increase NO_x emissions to reduce PM inversely, and vice versa. Both these pollutants are inherently linked to the in-cylinder temperatures where combustion takes place: with higher temperatures favouring a reduction in PM emissions, but simultaneously increasing NO_x emissions. Lower temperatures lead to a reduction in NO_x emissions but increase in PM emissions.

Methodology

Emissions from the DG set sector across India were calculated using established emission factors (US Environmental Protection Agency; USEPA) and secondary data from various sources. The total daily energy consumption by DG sets was estimated based on the following equation.

E(kWh) = $C \times W$ (hrs).....(7.1)

Where, E = Energy

C = Installed capacity

W = Working/operating hours, (*assumed as 2 hours/day* in this study)

The installed capacity (C) for DG sets was calculated by:

C(kW) = P(kVA) × PE × Percentage of loading.....(7.2)

Where, P = Apparent power (kVA)

PE = Power factor, 0.8 in this case (i.e., 80 per cent of apparent power is converted to working power) and, 85 per cent loading (percentage of DG set in use)

The energy consumption estimated using the Equations 7.1 and 7.2 is used to estimate diesel consumption in DG sets during 2011. The fuel consumption of the DG sets varies according to their capacity (Annexure 7.1). Thus, the average fuel consumption (in Gal/hr) for the range of capacities commonly used in India was correlated with their respective sales data for the year 2010 (Figure 7.2), and the weighted average fuel consumption for different capacity ranges of DG sets was used to calculate the total diesel fuel consumption across India (Table 7.3).

Table 7.3: Capacity-Wise Average Fuel Consumption in DG Sets

Range of capacities (in kVA)	Average Fuel Consumption (Gal/hr)
7.5 and 10	0.6
15, 20 and 25 (Telecom series)	1.3
62–125	5.3
250–500	19.2
750–1500	58.6

To validate the estimates of fuel consumption, it is compared with other similar studies that have reported the diesel consumption by DG sets in India (Section "Comparison with Other Fuel Consumption Estimates").

For calculating the emissions from the DG sets and agricultural pump-sets, the total energy consumed by these two sectors is taken from TERI MARKAL model results (TERI 2015) and annual emissions are calculated according to the formula and emission factors given below:

$$EM = E(J) \times EF\ (ng/J) \quad (7.3)$$

Where, *EM* = Emissions, in Nano gram
E = Energy, in Joules
EF = Emission factor (Table 7.4)

DG Set Emissions in India

Emissions from the DG set usage in India (including agricultural pump-sets) are estimated for the years 2001, 2011, 2021, 2031, 2041, and 2051.

National Emissions

Emissions for different pollutants from DG sets sector were calculated using the methodology explained in the previous section. The national level emissions of different pollutants from DG sets (including agricultural pump-sets) for India in the year 2011 are shown in Table 7.5.

Table 7.4: Emission Factors for DG Sets

Pollutant	Emission factor (ng/J*)
PM_{10}	133.3
SO_2	124.7
NO_X	1896.3
TOC	154.8
CO	408.5
$PM_{2.5}$	85% of PM_{10}
BC	60% of PM_{10}

* ng/J: Nano gram/Joule
Source: AP-42, USEPA

Table 7.5: Emissions (in KT/year) from DG Sets and Agricultural Pump Sets Sector in 2011

2011	Total Emissions (KT/year)
PM_{10}	81.9
SO_2	76.6
NO_X	1164.4
TOC	95.1
CO	250.8
PM2.5	70.0
BC	49.0

Spatial Distribution of Emissions

Due to lack of data on installed DG set capacity across different states or districts in India, the state-wise diesel fuel consumption for DG sets (including domestic, commercial, telecom DG sets, and agricultural pump-sets) was used to distribute the state-wise emissions from this sector. The fuel consumption of DG sets in different states was obtained from secondary sources (namely Petroleum Planning and Analysis Cell and Ministry of Petroleum and Natural Gas, refer to Annexure 7.2). This state-wise diesel consumption data was used as a proxy to distribute the overall emissions of PM_{10} and NO_X from DG sets sector across different states in India (Figures 7.4 and 7.5).

It is evident from the Figures 7.4 and 7.5 that some states rely more heavily on DG sets, and hence have higher emissions from this sector, such as Punjab, Haryana, Delhi, and Uttar Pradesh in the north and Tamil Nadu and Kerala in the south.

Comparison with Other Fuel Consumption Estimates

There have been no previous estimates of national emissions of various pollutants from DG sets sector that can be used as comparative numbers to evaluate our study. In order to validate the results of our study, the total fuel (diesel) consumption by DG sets in India was used as a proxy measure. This was calculated for the baseline (2011) as 7,733 million litres per year, which is satisfactorily close to the

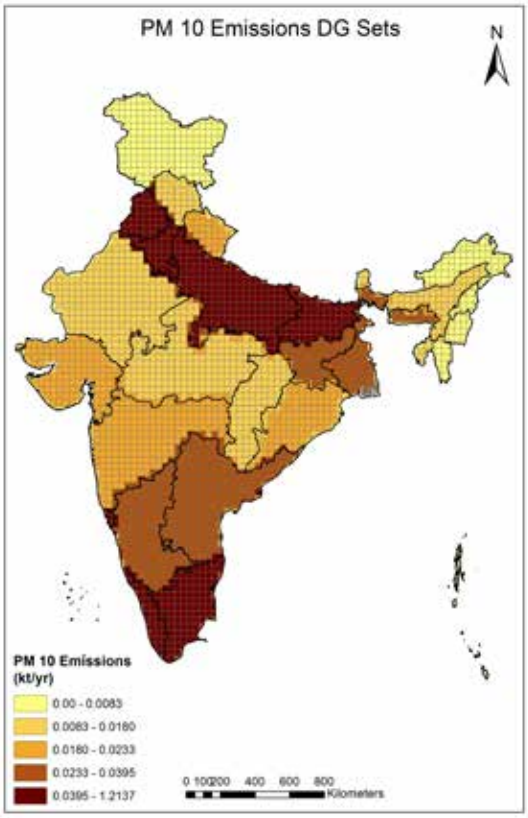

Figure 7.4: State-wise distribution of PM_{10} emissions from DG sets sector across India

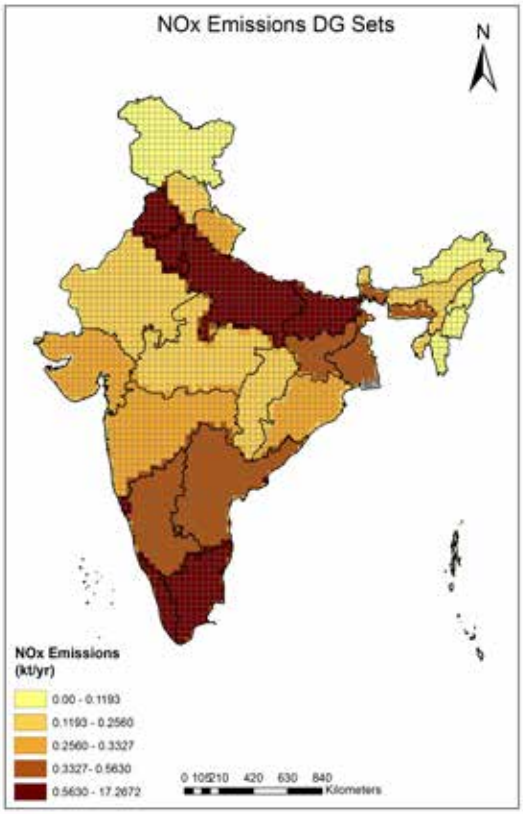

Figure 7.5: State-wise distribution of NO_x emissions from DG sets sector across India

diesel consumption data reported by MoPNG for the same year, that is, 7,426 million litres per year. Industrial and miscellaneous diesel consumption reported by MoPNG (2011) is assumed to be consumed in running DG sets. A recent study by PPAC also estimated the actual diesel fuel consumption by DG sets (in all sectors) for the year 2012 through primary surveys of retail outlets across India (Figure 7.6). Lately, another study on improving efficiency and emission performance in DGs in India, by ICF and Shakti foundation stated a lower figure of about 4,510 million litres of diesel consumption by the DG sets in India in 2012–13. The closeness of diesel consumption estimates with the reported numbers in MoPNG statistics reflects the reliability of the emission estimates in this study.

Figure 7.6: Comparative analysis with other estimates of diesel consumption by the DG sets sector

Past and Future Projections (2001–51)

The emissions from DG sets sector has also been estimated for the past and future years. Considering 2011 as the base year, estimates were made for each five-year interval from 2001 to 2051. TERI has estimated the total energy consumption by different sectors in India from 2001 to 2051 using the MARKAL model. The data for total energy consumed by DG sets sector in India was derived from this model for past and future years, and employing the same emission factors mentioned in the 'Methodology' section, the emissions were estimated for different years (Table 7.6). As evident from Figure 7.7, the total emissions from the DG sets sector has been decreasing over the years (from 2001 to 2011). In the future also, the emissions are expected to reduce, since it is expected that the power situation will improve in India. Also, the new emission norms (applicable from 2014) will further bring down the emissions in the future (hence the marked drop from 2016 to 2021 in the Figure 7.7). The estimated emissions in 2051 of PM_{10} are 77.6 KT and that of NO_X are 893 KT as compared to 82 KT of PM_{10} and 1164.4 KT of NO_X in 2011. Beyond 2031, it is estimated that DG sets will not be used in residential and commercial sectors for power back-up and that there will be continuous power supply.

Table 7.6: Past and Future Annual Emissions of Different Pollutants from DG Sets Sector in India

	PM10	SO_2	NO_X	TOC (BC + OC)	CO
Past	In KT/year				
2001	103.66	96.97	1474.66	120.38	317.67
2006	91.59	85.68	1302.89	106.36	280.67
2011	81.85	76.57	1164.44	95.06	250.84
Future*		In KT/year			
2016	102.85	96.21	1463.11	119.44	315.18
2021	72.32	15.34	832.89	67.99	288.48
2026	73.49	15.59	846.33	69.09	293.14
2031	76.19	16.16	877.47	71.63	303.92
2036	76.30	16.19	878.74	71.73	304.36
2041	80.63	17.10	928.60	75.80	321.63
2046	84.38	17.90	971.78	79.33	336.59
2051	77.56	16.45	893.14	72.91	309.35

*in context of the base year taken for this study, which is 2011

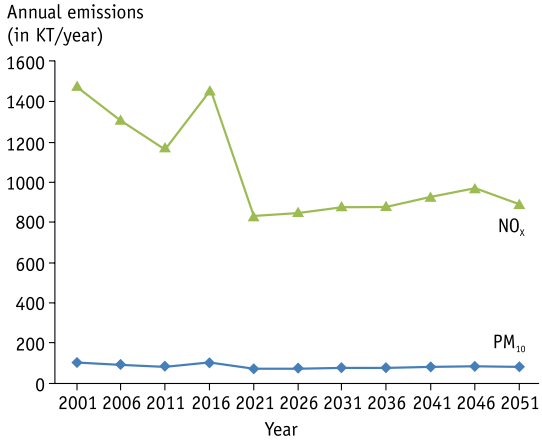

Figure 7.7: Annual PM10 and NOx emission trends from 2001 to 2051 in India from DG sets

Conclusions

It is evident from assessing the past and future growth trends for DG sets, that power back-up sector will gradually diminish over the years, though currently it contributes substantially to the PM_{10} and other emissions. In India, there is still a significant disparity between the demand and supply of power both in the urban centres as well as the developing rural set-up. Lack of alternative options for power back-up and convenience of diesel-fired engines has ensured that DG sets are the first choice for consumers to meet their needs.

The contribution of this sector in overall emissions of air pollutants is quite low compared to other important sectors such as transport, industry, and power, still it is likely to impact a large number of the population since they are most often placed in crowded and congested commercial areas that already have potent levels of air pollutants in the ambient air.

Along with manufacturing improvements, inspection and maintenance of DG sets can not only

ensure that they do not emit more than they are designed to over time but also that they function efficiently.

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Annexure – 7. 1

Capacity-Wise Fuel Consumption for DG Sets		
Generator Size (kW)	3/4 Load (gal/hr)	Full Load (gal/hr)
20	1.3	1.6
30	2.4	2.9
40	3.2	4
60	3.8	4.8
75	4.6	6.1
100	5.8	7.4
125	7.1	9.1
135	7.6	9.8
150	8.4	10.9
175	9.7	12.7
200	11	14.4
230	12.5	16.6
250	13.6	18
300	16.1	21.5
350	18.7	25.1
400	21.3	28.6
500	26.4	35.7
600	31.5	42.8
750	39.3	53.4
1000	52.1	71.1
1250	65	88.8
1500	77.8	106.5
1750	90.7	124.2
2000	103.5	141.9
2250	116.4	159.6
Source: Diesel Service and Supply, available at: http://www.dieselserviceandsupply.com/Diesel_Fuel_Consumption.aspx)		

Annexure – 7. 2

States	Diesel consumption by DG sets (litre/ year)*	Percentage distribution	Power deficit**
Andhra Pradesh	772.23	11%	3.44%
Arunachal Pradesh	11.79	0%	0.10%
Assam	81.59	1%	0.46%
Bihar	369.95	5%	2.20%
Chandigarh	9.66	0%	0.00%
Chhattisgarh	148.88	2%	0.24%
Delhi	180.85	2%	0.09%
Goa	38.80	1%	0.09%
Gujarat	281.61	4%	5.62%
Haryana	628.50	9%	2.63%
Himachal Pradesh	68.23	1%	0.36%
Jammu & Kashmir	75.52	1%	4.63%
Jharkhand	179.30	2%	0.29%
Karnataka	440.85	6%	5.26%
Kerala	312.09	4%	0.35%
Madhya Pradesh	297.48	4%	13.37%
Maharashtra	471.87	6%	29.05%
Manipur	9.47	0%	0.09%
Meghalaya	45.30	1%	0.26%
Mizoram	6.80	0%	0.07%
Nagaland	7.04	0%	0.09%
Orissa	231.70	3%	0.08%
Puducherry	42.77	1%	0.11%
Punjab	375.20	5%	3.67%
Rajasthan	222.98	3%	0.58%
Sikkim	6.79	0%	0.00%
Tamil Nadu	750.37	10%	7.12%
Tripura	10.38	0%	0.11%
Uttar Pradesh	969.94	13%	15.63%
Uttarakhand	86.91	1%	0.81%
West Bengal	196.71	3%	0.87%

* PPAC and MoPNG
** From Central Electricity Authority

CHAPTER 8

Open Burning of Agricultural Residue

Arindam Datta and Sumit Sharma

Introduction

Open (*in-situ*) burning of crop residue in agricultural lands is practiced in many part of the world for quick preparation of the land for seeding of the next crop and protection from the development of mould and variety of crop diseases (Chen et al. 2005; Korontzi et al. 2006; Sahai et al. 2007; Yan et al. 2006; Yang et al. 2008; Yevich and Logan 2003; Zhang et al. 1996). However, *in-situ* burning of crop residue has also been identified as an important local and regional contributor of particulate and trace gas emissions that affect air quality and public health (Dennis et al. 2002; Hays et al. 2005). Researchers all over the globe have reported the effects of open burning of biomass on local and regional climate (Krishna Prasad et al. 2000; Seiler and Crutzen 1980; Yevich and Logan 2003). Studies have also suggested significant linkage of the crop residue burning event with the severe asthmatic symptoms in child and elderly (Boopathy et al. 2002, Mar et al. 2004). The emissions characteristics are different from shielded combustion of biofuel in small cook-stoves or industrial boilers and *in-situ* burning of crop residue or forest fires (Bond et al. 2004; Venkataraman et al. 2005).

Biomass burning is a major source of gaseous and particulate pollution in the troposphere (Crutzen and Andrae 1990; Venkataraman et al. 2005). Earlier

studies have found a clear correlation between the ambient concentrations of fine particulate matter (PM_{10} and $PM_{2.5}$) and open burning of crop residue (Long et al. 1998; Mar et al. 2004). Satellite observations have revealed elevated levels of aerosols over wide areas of Central Africa and South America, over the tropical Atlantic, and the Indian Ocean due to long-range transport of pollutants emitted from biomass burning (Venkataraman et al. 2006). Global biomass burning dataset from the satellites such as GLOBSCAR (Hoelzemann et al. 2004; Simon et al. 2004), GBA-2000 (Tansey et al. 2004), MODIS-Terra (Sharma et al. 2010), MODIS/UMD (Venkataraman et al. 2006) have identified large scale open biomass burning in the Northern America, South America, Central Africa, and Tropical Asia (especially South Asia and South-East Asia).

Indo-Gangetic Plains (IGP) is a very important agro-economic zone in South-Asia, which occupies substantial geographic area of four countries (Pakistan, India, Nepal, and Bangladesh). Widespread adaptation of the green revolution resulted in the inception of the high-yielding varieties and increase in both crop and residues. In the IGP region of India, rice and wheat are the major crops that cover approximately 13.5 Mha of crop land (DoES 2013). Harvesting crops with 'combine harvester' (mechanical harvester) is very popular with farmers of Punjab, Haryana, and western Uttar Pradesh (Badarinath et al. 2009). These harvesters leave behind large quantities of crop residue in the field. The crop residues are subjected to *in-situ* burning on account of high labour wages to collect them from the field and their transportation to the market. Agricultural crop residues, mainly of *kharif* (wet season) rice are burnt during the months of October and November each year in the IGP, which has significant impact on pollutants and aerosol loading in the regional scale (Badarinath et al. 2009). The small window between harvest of rice crop and plantation of wheat crop forces the farmers to burn the residue in field. The wheat crops are harvested during March-April and fraction of the wheat residues are burnt in the field in the north western area of the IGP (Singh 2003). However, apart from rice and wheat, a significant fraction of the crop residues of cotton (lint), maize, soyabean, jute also undergo *in-situ* burning in different parts of India (Jain et al. 2014; Sharma et al. 2010). On the other hand, ~350 Mt of sugarcanes are produced in India from ~5.0 Mha of crop land area during 2013–14 (INDIASTAT 2015). In India, Sugarcane is mainly harvested manually (NAIP 2012). Before harvesting, the dry above ground part of the sugarcane is burnt to ensure the access of labours to harvest the crop (NAIP 2012). Large amount of sugarcane is harvested in the southern part of India and the IGP during spring and summer, respectively.

In different studies, researchers all over the globe have established release of large amount of emission of different atmospheric pollutants during the *in-situ* burning of crop residues (He et al. 2010; Lai et al. 2009; MacCarty et al. 2009; Yamaji et al. 2010). In India, Mittal et al. (2009) have reported the ground level study on the contribution of wheat and rice crop stubble burning on SO_2, NO_2, and aerosols concentration levels in ambient air at five different sites such as agricultural, commercial, and residential areas of Patiala, Punjab. Singh et al. (2010a) analysed the organic tarry matter (OTM) content in ambient air of the north-western IGP during crop residue burning months and non-crop residue burning months for the period of 2006–07. OTM are the volatile and non-volatile organic matter in the carbonaceous PM (Lighty et al. 2000). Singh et al. (2010b) have reported increase in the particulate concentration in the ambient air of Patiala, Punjab, during two rice residue burning seasons of 2006–08. Open field burning of rice straw and other crop residues in the IGP emits species such as CO, non-methane hydrocarbons, NOx, SO_2, PM, and few others species (Gadde et al. 2009). Recently, Jain et al. (2014) have reported the state-level emissions of different pollutants due to *in-situ* burning of different crop residues during 2008–09 using the state-level residue generation data and reported emission factors of different pollutants. However, burning pattern of crop residue is not uniform in all districts in a state and crop residue burning is not practiced in all states of India (Sharma et al. 2015).

There are associated uncertainties in the estimation of the emission of different pollutants during burning of crop residues. It is required to estimate the total residue burnt in each state (even in districts) to reduce the uncertainty in estimation of different pollutants emission from burning of crop residue. Estimation of total crop residue burnt with reduced uncertainty can help to develop future projections of pollutants emission from crop residue burning. It will support to develop mitigation opportunities to reduce atmospheric emissions from crop residue burning. In the present study, we have used a *bottom-up* approach using the satellite dataset to identify the district level *in-situ* burning of crop residue in different states and union territories of India. This district-level dataset was used to estimate the emissions of different pollutants from the in field burning of crop residue using respective emission factors. An exhaustive literature survey was conducted to generate emission factor of different pollutants during the burning of different crop residues.

Methodology

Estimation of base line Emissions of Different Pollutants

Emission inventory of different pollutants from the burning of different crop residues in the crop land was prepared following the IPCC (2006) inventory preparation guideline. The primary crops considered for inventory preparation were sunflower, ragi, soyabean, jute, maize, cotton (lint), wheat, rice, and sugarcane. Data was collected based on the discussion with agriculture experts from agriculture research institutions spread across India. Emission from the *in-situ* burning of crop residue was calculated using eq. (i);

$$E_{pol} = \sum_{(S=1)}^{35} \sum_{(D=1)}^{n} \sum_{(C=a)}^{n} P_a \times R_a \times fD_a \times fB_a \times EF_{pol} \quad \text{.....8.1}$$

where, E_{pol} = Emission of a particular pollutant (pol) (g); P_a is the total production of a particular crop (*C*) in a particular district (*D*) of the state (*S*); R_a is the fraction of residue generated for the production of the particular crop (*a*); fD_a is the fraction of dry matter in the residue of the particular crop (*a*); fB_a is the fraction of the crop residue that is burnt, and EF_{pol} is the emission factor of the particular pollutant. E_{pol} of PM_{10}, $PM_{2.5,}$ BC, OC, SO_x, NO_x, and NMVOC are reported in kilotonnes per annum.

District-wise different crop production (P_a) data was collected from MoCIT (2012) for the year 2001 to 2011. R_a for different crop was adopted from available literatures preferably from India (Table 8.1).

fD value of rice, wheat, maize, and sugarcane was taken as 0.86, 0.88, 0.88, and 0.88, respectively (Jain et al. 2014). For all other crops, the *fD* value was 0.80 (Jain et al. 2014). The burning fraction of different crop residues (*R*) of different states of India is different. We have estimated the burning fraction of different crop residues for different states (to the extent for the district) based on the available literature and expert judgement from the local agriculture institutes. The emission factor (EF_{pol}) of different pollutants emission from the burning of crop residues in the field was derived through the literature survey of reported field level studies (Table 8.2).

The MODIS-terra platform dataset for the year 2006–10 was used to identify districts of India where the *in-situ* burning of crop residues takes place during different cropping seasons of the year following the method of Sharma et al. (2010). A mean value of this dataset was used in the present study to identify the specific districts where *in-situ* burning of crop residue takes place during different cropping seasons. This derived mean dataset was compared with values already published in literature on open crop residue burning in India (Sharma et al. 2010; Venkataraman et al. 2006) and opinion of the agricultural expert groups from different states. District-wise emission of different pollutants due to open burning of the crop residue was estimated following the Equation 8.1 for the year 2001 and 2011.

Future Projections of Pollutants Emission

The contribution of different crops (e.g., sunflower, ragi, soyabean, jute, maize, cotton, wheat, rice, and

Table 8.1: Residue to Crop Ratio of Different Crops Included in the Present Study

Residue to crop ratio									Source
Rice	Wheat	Sugarcane	Maize	Soyabean	Cotton (lint)	Jute	Sunflower	Ragi	
1.75									Bhattacharya et al. 1993
1.87									Vimal 1979
1.50	1.50								Sidhu et al. 1995
1.25									Njie 2006
1.50	1.50								Singh and Ragnekar 1986
1.75									Koppman and Koppejan 1997
1.50	1.70	0.40	1.50		3.00	2.15			Jain et al. 2014
	1.50								Gupta et al. 2004
	1.70								Badarinath and Chand Kiran 2006
	1.70								Brown 2003
	2.30	0.60	1.85						Nelson 2002
		0.60							Hemwong et al. 2009
				3.00	3.50	2.00			Dubay and Chandra 2010
			2.00		3.80		3.00	1.30	Hiloidharia et al. 2014
1.59	1.70	0.53	1.78	3.00	3.43	2.08	3.00	1.30	Mean (Present study)

sugarcane) to the total agricultural GDP during the year 2001 and 2011 was calculated using the crop production dataset of the year 2001 and 2011, respectively. These values were used to project the crop production in different years during 2021 to 2051 based on the agricultural GDP growth depicted in Markal results (TERI 2015). The projected emissions of different pollutants during the *in-situ* burning of different crop residues were calculated using the Equation 8.1.

Crop Residue Generation in India

The amount of crop residue generated was estimated as the product of crop production (P_a), residue to crop ratio (R_a) and dry matter fraction of the crop biomass (fD_a). Total amount of dry residue generated during 2001 and 2011 was estimated as 489 Mt and 597 Mt, respectively. Sahai et al. (2011) have estimated 253 Mt of crop residue generation in the year 2010 from rice and wheat crop. On the other side, Jain et al. (2014) have estimated 620 Mt of residue production during 2008. The variation in the estimation with the

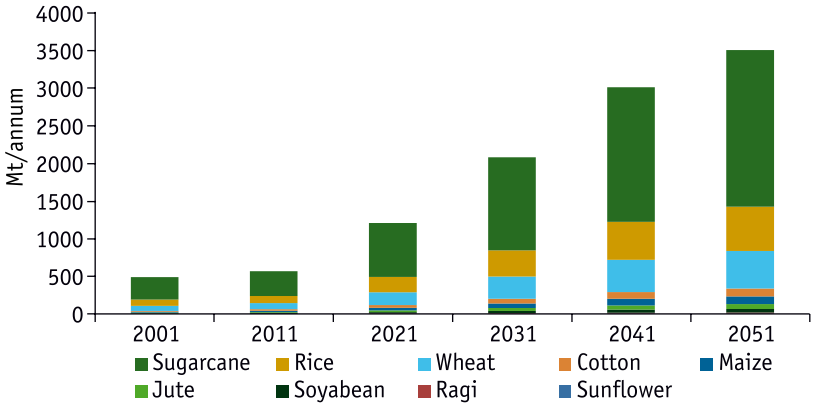

Figure 8.1: Projected production of different crops in India during 2021–51

Table 8.2: Emission Factor of Different Pollutants

Crop	Emission factor (g/kg)								Source
	PM10	PM2.5	BC	OC	CO	SOx	NOx	NMVOC	
Rice	5.8	5.5			58.9	2.4	0.5	6.3	Jenkins et al. 1996
	5.5–10.1		0.8	1.5			0.4		Venkataraman et al. 2006
	7.0	5.4							EPA 2005
	8.4	10.9			71.72		2.4	8.32	Allen and Denis 2000
Wheat	5.7	5.4			66.7	2.3	0.5	0.5	Jenkins et al. 1996
	5.5–10.1		0.8	1.3		0.6			Venkataraman et al. 2006
	11.0				64.0				EPA 2005
	4.5	4.3			30.6		2.3		Allen and Denis 2000
Maize	6.2	6.0			38.8	1.8	0.2	4.5	Jenkins et al. 1996
	7.0				54.0				EPA 2005
Sugarcane		4.1	1	2.7					Venkataraman et al. 2006
	6.9	6.7				0.5	1.5		Allen and Denis 2000
Mixed crop residue			0.2	0.3	28.1		1.7		Sahai et al. 2007
		5.5						15.7-23.4	Venkataraman et al. 2006
	4.0	5.5			88.0				EPA 2005
		3.9	0.7		91.9	0.4	2.4	15.7	Jain et al. 2014
Rice	7.1	5.45	0.8	1.5	58.9	2.4	0.45	6.3	Present Study
Wheat	8.0	5.4	0.8	1.3	65.5	1.45	0.5	0.5	Present Study
Sugarcane	6.9	5.4	1.0	2.7	28.1	0.5	1.5	0.5	Present Study
Maize	6.6	6.0	0.2	0.3	46.4	1.8	0.2	4.5	Present Study
Soyabean	10.0	5.5	0.2	0.3	28.1	0.5	1.7	19.1	Present Study
Sunflower	10.0	5.5	0.2	0.3	28.1	0.5	1.7	19.1	Present Study
Ragi	10.0	5.5	0.2	0.3	28.1	0.5	1.7	19.1	Present Study
Cotton(lint)	10.0	5.5	0.2	0.3	28.1	0.5	1.7	19.1	Present Study
Jute	10.0	5.5	0.2	0.3	28.1	0.5	1.7	19.1	Present Study

present study may be attributed to the type of crop residues considered in the present study. The amount of crop residue generation is highly variable based on the crop type (Figure 8.2). Among nine different crops selected in the present study, the contribution of rice crop residue was significantly larger to the total residue generation (29 per cent and 32 per cent, respectively during 2001 and 2011) (Figure 8.2). Jain et al. (2014) have also reported higher contribution of the rice residue to the total dry residue generation per annum in India. Rice residue generation during 2011 in different states followed the order: West Bengal (23.9 Mt), Andhra Pradesh (22.6 Mt), Uttar Pradesh (20.8 Mt), Punjab (15.7 Mt). However, the total crop residue generated from the selected nine crops was significantly higher in the state of Uttar Pradesh (115.4 Mt) during 2011. Higher crop residue generation from the state of Uttar Pradesh was also reported earlier (Jain et al. 2014).

Estimation of the Crop Residue Burnt

The total amount of *in-situ* burning of crop residue depends upon several factors such as type of crop, residue to grain ratio, fraction of residues subjected to burning, and largely area-specific usage pattern of the respective crop residue. These lead to large uncertainties in the estimates of *in-situ* burning of crop residues. The burning of rice crop residue was about 80 per cent in the states of Punjab and Haryana; on the other hand, in the states of Odisha, Andhra Pradesh, and West Bengal, the burning of rice residue is less than 0.1 per cent. About 80 to 90

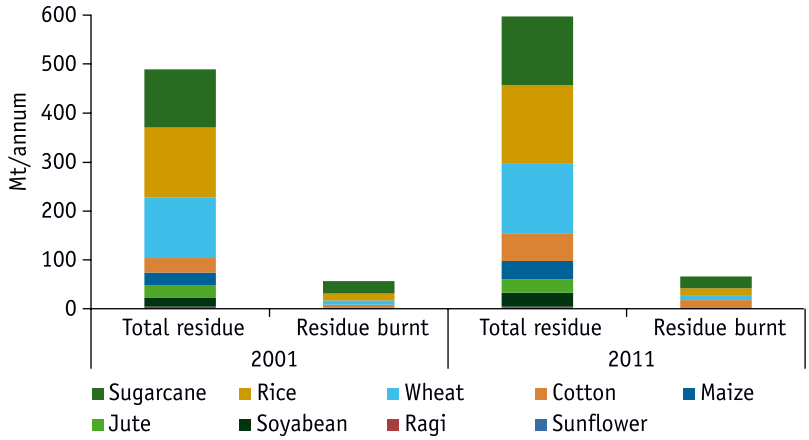

Figure 8.2: Estimated total dry crop residue generated and amount of dry crop residue burnt in situ during 2001 and 2011 in India

per cent of the sugarcane residues are burnt in the states of Bihar; whereas, sugarcane residue burning in Punjab and Haryana is about 25 per cent. Lesser amount of sugarcane residue burning in the states of Punjab and Haryana may be attributed to the use of mechanical harvesters (Gupta et al. 2003). However, due to small window between the rice crop harvest season and plantation of wheat, along with large labour cost in handling the rice crop residues, large amount of rice crop residues are burnt *in situ* in the states of Punjab, Haryana, and western Uttar Pradesh (Gupta 2014). The IPCC coefficient for the *in-situ* burning of crop residue is 25 per cent of total amount of residue produced (IPCC 2006). Following the IPCC (2006) factor, the total amount of crop residue burnt in India during 2011 was about 145 Mt. However in the present study, we have estimated that about 56 Mt and 68 Mt of crop residues were burnt during 2001 and 2011 (Figure 8.2). Sahai et al. (2011) have estimated 57 Mt and 63 Mt of crop residue burning, respectively, during 2000 and 2010 in India. Street et al. (2003) have estimated approximately 132 Mt of crop residue burning in India annually, which was about 18 per cent of total biomass burning from anthropogenic and natural sources in Asia. However, earlier studies have estimated 98.5 Mt of crop residue burning in a year in India (Jain et al. 2014). Pathak et al. (2010) have estimated 90 Mt of crop residue burning during 2008 in India. During the present study, we have identified the specific districts in India with *in-situ* burning of crop residues using the satellite data; however, most of the previous studies have estimated the amount of crop residue burnt based on the state level production data; this might have led to higher estimation of total crop residue burning in earlier studies.

Baseline Emission from Crop Residue Burning

Based on the methodology described earlier, it is estimated that the emission of all pollutants was highest from the Muzaffarnagar district of the state of Uttar Pradesh (Figure 8.3). It is estimated that significantly higher (4.4 Mt) sugarcane residues were burnt in the district. Total emission of PM_{10} was significantly higher (216 Kt) from the western region of the state of Uttar Pradesh followed by the state of Punjab (158 Kt). However, $PM_{2.5}$ emission was significantly higher from the state of Punjab (110 Kt) followed by the western region of Uttar Pradesh (100 Kt). Burning of rice crop residue (8.8 Mt) was significantly higher in the state of Punjab after the harvest of the *kharif* crop. On the other hand, burning of total crop residues was significantly higher in Uttar Pradesh (21.5 Mt) with significantly higher contribution of the sugarcane residue (17.5

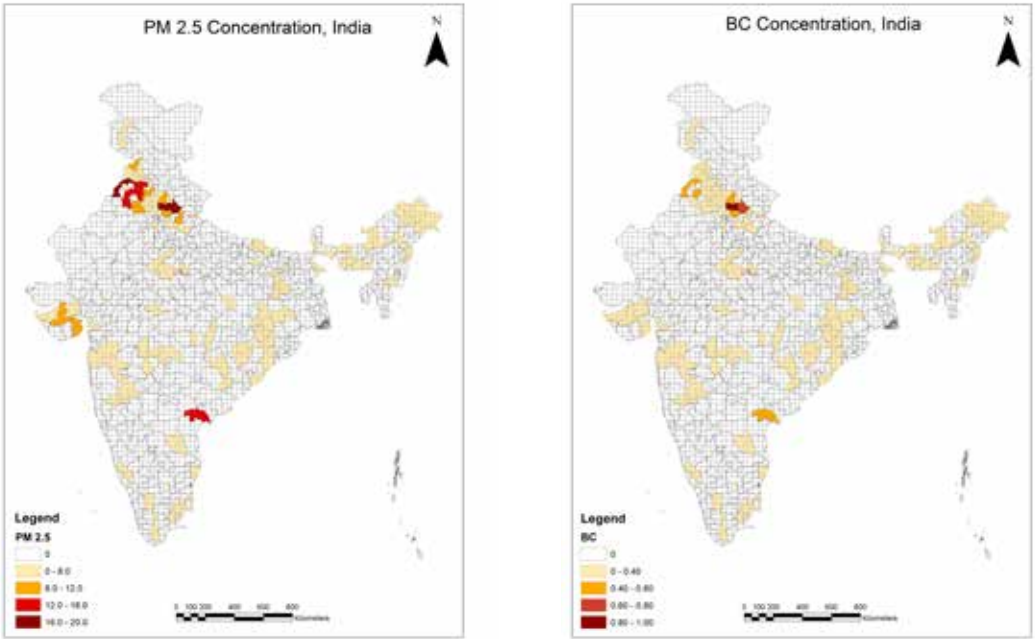

Figure 8.3: Estimation of the emission of particulate and gaseous pollutants (Kt/year) from the in-situ burning of crop residues during 2011

Mt). However, the emission factor of $PM_{2.5}$ was higher with rice crop residue (7.8 g/Kg) compared to that of sugarcane (4 g/Kg). Significantly higher burning of the crop residue in the state of Uttar Pradesh was attributed to higher PM_{10} emission; however, large amount of rice crop residue burning which has higher $PM_{2.5}$ emission factor among nine crops considered in the present study increases the $PM_{2.5}$ emission from the state of Punjab. The total emissions of PM_{10} and $PM_{2.5}$ in India during 2001 were 619 Kt and 350 Kt, respectively; whereas during 2011, emissions increased to 818 Kt and 419 Kt, respectively. The emission of different gaseous and particulate pollutants due to *in-situ* burning of crop biomass was significantly higher in the northwestern region of the IGP in India (Figure 8.3) during both 2001 and 2011. Venkataraman et al. (2006) and Sharma et al. (2010) have also reported higher emission of pollutants from the crop residue burning in the northwester IGP.

In-situ burning of crop residues contributes significantly to the atmospheric BC and OC. Total atmospheric BC emissions from the crop residue burning during 2001 and 2011 were estimated as 48 Kt and 57 Kt, respectively. During 2001, burning of sugarcane crop residue (BC: 27 Kt) was the largest contributor to total BC emission from the *in-situ* burning of the crop residue. OC emission was also significantly increased during 2011 (128 Kt) compared to 2001 (108 Kt). Similar to BC, emissions of OC was higher from the burning of the sugarcane crop residues. Overall, BC emission from the *in-situ* burning of crop residue was significantly higher from the state of Uttar Pradesh (21 Kt) followed by Punjab (10 Kt) and Haryana (6 Kt). OC emission also followed the same pattern. Higher BC and OC emission from the state of Uttar Pradesh was attributed to significantly higher crop residue burning in the state.

State-wise emissions of different gaseous pollutants from the *in-situ* burning of crop residues in the field also followed the same pattern. Significantly higher emissions of different gaseous pollutants were recorded in the state of Uttar Pradesh during 2011. Total emissions of CO, SO_x, NO_x, and NMVOC during 2011 were 3244 Kt, 40 Kt, 137 Kt, and 511 Kt,

respectively. Among different crop residues, the contribution of cotton (lint) crop residue burning towards gaseous emission of different pollutants was recorded higher during 2001 and 2011. A comparative view of the reported emission of different pollutants from the *in-situ* burning of crop residue is India is given in Table 8.3.

Emission Projections

Emissions of different pollutants were estimated to increase during 2011–51 (Figure 8.4). By the year 2051, the increase of emission of particulates and gaseous pollutants would be significantly higher from burning of soyabean crop residue (approximately four times compared to 2011 emissions) (Figure 8.4). During 2051, emissions from the *in-situ* burning of rice and wheat crop residues would increase by 60 per cent and 82 per cent, respectively, compared to their emissions during 2011.

Over all, PM_{10}, $PM_{2.5}$, NO_X, SO_2, NMVOC, CO will increase by ..... by percentage, respectively during 2011 to 2051.

However in the present estimates, we have considered burning fraction of the crop constant till 2051. This may increase with increase in productivity of an individual crop due to crunch of space to store the excess crop residues. Oppositely, the burning fraction may decrease if improved technology is developed to effectively handle the excess crop residues or develop crop varieties with lesser amounts of residue generation.

Conclusion

Large amount of particulate and gaseous pollutants are emitted during *in-situ* burning of crop residues in the crop lands in different parts of the country. Emissions of all pollutants were significantly higher in the western part of the IGP of India. However, almost all regions of the country contributed towards the gaseous emission of the atmospheric pollutants. The type of crop residue burnt varies across state. However, this study has estimated that the residue of the rice crop is mostly burnt all over the country. Future prediction of emission of different pollutants from *in situ* burning of crop residue suggests large increase in the pollution emission by the year 2050, if adequate measures to reduce the crop residue or handling the crop residues are not developed.

The key measures that are required to be taken for control of emissions from open burning of agriculutural residue in India are:

- Imposition and strict enforcement of a ban on open burning of agriculutural residue.
- Development of biomass gasification technologies for waste to energy generation from agricultural residue.
- Development of business model for collection storage and processing of agriculutral waste for waste to energy generation.

Table 8.3 Estimation of emission of different atmospheric pollutants from the in-situ burning of crop residues in India

Year of estimation	Kt annum-1								Reference
	PM10	PM2.5	BC	OC	SOx	NOx	CO	NMVOC	
1994						78	2138		Gupta et al., 2004
2000						84	2305		Gupta et al., 2004
2000			3	6		33	541		Sahai et al., 2007
2001		572-2393	86-372	211-970	46-172	289-1290	10000-74000	1818-6767	Venkatraman et al., 2006
2006	8114	472			69	344	8114	633	Gadde et al., 2009
2010								658	Sharma et al., 2014
2011		384	68		246	7	9063	39	Jain et al., 2014
2011	818	462	49	57	40	137	3244	512	Present study

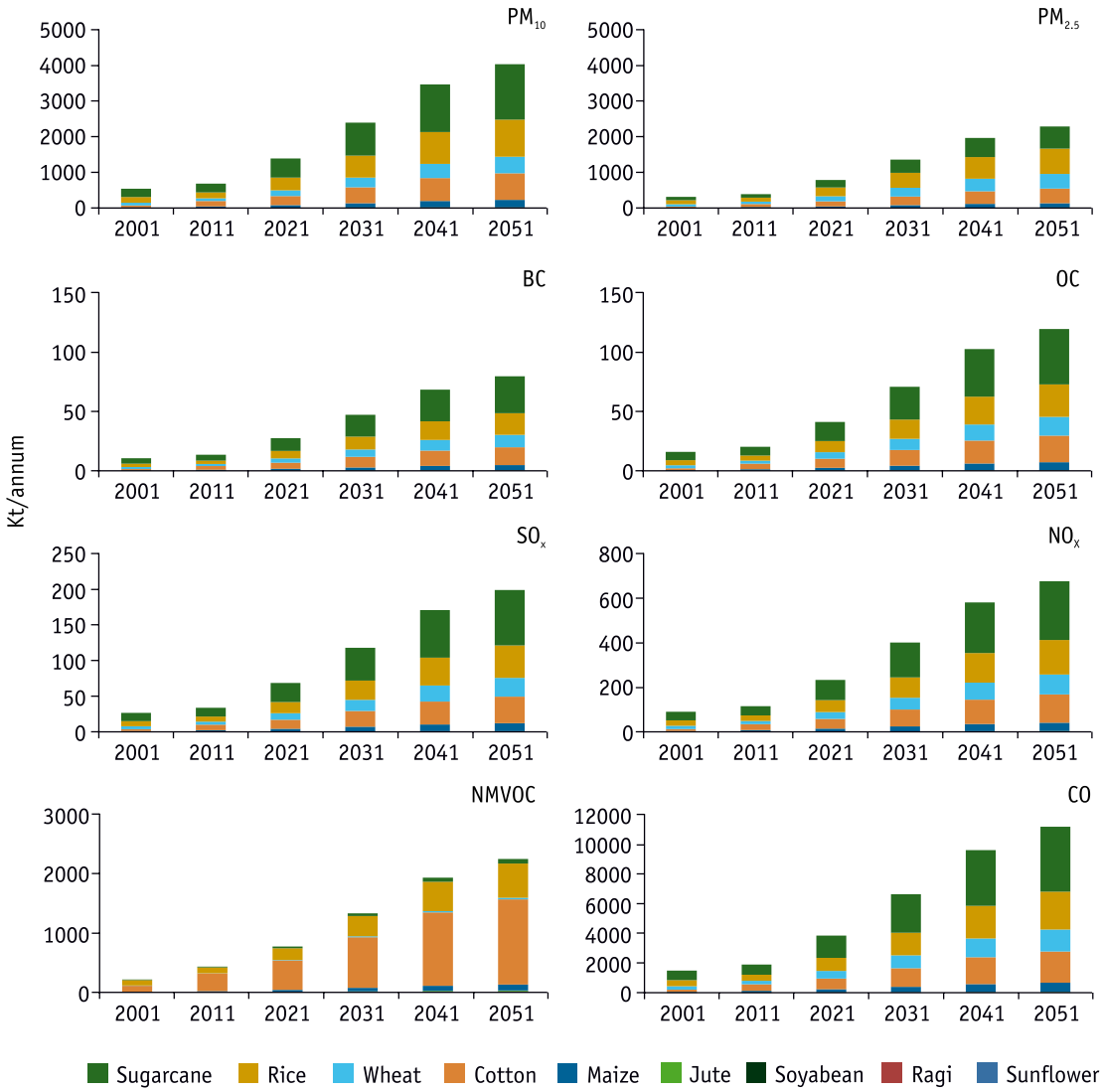

Figure 8.4: Emissions of different pollutants from the *in-situ* burning of crop residue in India

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CHAPTER 9

Evaporative Emissions

Sumit Sharma and Atul Kumar

Introduction

While there are pollutants emitted due to combustion of fuels, there are activities that lead to fugitive emissions, mainly due to volatility of the compounds used in the process. Mostly these are volatile hydrocarbons. These compounds are grouped as non-methane volatile organic compounds (NMVOCs) as the majority of them display similar behaviour in the atmosphere (DEFRA 2003). While considerable attention has been paid on control of pollutants such as particulate matter (PM), non-methane hydrocarbons have steadily grown unnoticed in India. NMVOCs not only have direct health impacts over the exposed receptors, but they also act as important precursor of ground level Ozone formation and secondary particulates known as secondary organic aerosols (SOAs). There are multiple sources of these emissions including use of paints, printing inks, personal products, etc. The solvent use in these products is small but cumulative assessment of the quantities of NMVOCs released from the use of these products leads to substantial emissions. Hence, there is a need for an accurate emission inventory of these emissions for their control.

Limited work has been carried out in past on exhaustive estimation of emissions from these sources. In this study, NMVOC emissions are estimated for different years between 2001 and 2051 based on the future growth trajectories. The 'emission factor approach' is used in the current work for estimation of NMVOCs from different sectors and sources. A list of probable sources of NMVOC was compiled from literature review exercise. These sources includes paints, printing inks, dry cleaning, handling of oil and solvent use in industries. Activity data for different sectors was collected and compiled form reliable sources. Emission factors are adopted from a recent work of Sharma et al. (2015), where detailed review was carried out to choose appropriate emission factors for different sources. The source-wise emission

inventory is presented in subsequent sections using folllowing equation:

E= Activity data × Emission factor × (1–% controls)

Paints

Paints are used in both residential and industrial sectors. Due to increased urbanization, it is noticed that there is a drastic shift from semi-permanent to permanent housing structures, which has been driving growth in decorative paints segment in the domestic sector, which constitutes 77% of the 2.9 million tonne paint industry in India (Paint India 2011). Per capita consumption of paint is about 1.6 Kg. The industry has grown to about 10–15% annually in last 5 years and is consistent with the growth of real estate sector in India. There has been a recent shift towards water-based coatings in the recent past, and about 50% of the paints currently used for decorative purposes are water based. About 65 per cent of the demand for decorative paints is contributed to repainting of houses, etc. Paints most commonly used in bigger cities are premium decorative paints (acrylic emulsions) while medium range paints consisting of enamels are more popular in smaller cities and towns.

In India, nearly 11 per cent of all the decorative paints are distempers, which are economical products, mostly demanded in the suburban and rural area. Considerable growth is observed in the exterior coatings segment, under decorative paint segment. Many superior quality paints with high durability have been launched by many paint manufacturers in India. Import of paints is about 4% and export of paints is negligible. The total quantity of decorative solvent based paints consumed in India is 1.32 million tonnes (mt). Emission factor (CITEPA 2003c) used for solvent-based paint is 400 kg/kt of paint used and for water-based paints is 102 kg/kt. Total emissions estimated from the sector is 582 kt/yr.

Industrial paints include powder coatings, high performance coating, and automotive and marine paints**.** The primary factors affecting emissions from paint manufacture are care in handling dry pigments, types of solvents used, and mixing temperature. Industrial coatings in India are almost exclusively solvent based. The only applications that are currently employing water-borne technology are certain automotive primers and high-end automotive refinishes. The production of industrial paints is found to be 0.67 mt in 2009 and about 0.9 mt in 2011(PI 2010), of which 44% accounts for paint used in auto sector and coil coating, and rest is accounted for industrial painting category. The distribution of paints in plastic, general industry, continuous, and powders is adopted from PI (2011).

During manufacture of automobiles, the automobiles are painted and during this process large amount of NMVOCs are emitted in one or the other forms. The activity data in this case was total number of vehicles manufactured in India, which were about 10.4 million during 2011. Paints used and emissions generated in the automobile manufacturing and vehicle repair were estimated from the size distribution of different vehicles manufactured in India (IBEF 2008). The weighted emission factor per unit vehicle manufactured is derived as 3.18 kg per vehicle and total emissions from the automobile manufacturing sector is estimated to be 35 kt/year. The total paint consumed in the sector is 160 kt. A total of 21% of paints used in automobiles come out as NMVOC emissions.

Coil coating is another process that requires paints, as it is a continuous and highly automated process for coating metal before fabrication. According to available data, the Indian domestic market consumes colour-coated sheets in the thickness range from 0.2 to 1.2 mm and widths between 600 and 1,250 mm. Recently, the imported galvalume colour-coated products and its plain sheet (in small quantities) have gained popularity. In recent years, colour-coated coils have gained importance in the domestic market and, consequently, their consumption has accelerated during the last two years across the country. The total coil coating capacity installed in the country is 9,85,000 T/yr (Nagori and Ajemra 2006). Assuming an average thickness of 0.7 mm, total coated surface area

Table 9.1: Emission Inventory of NMVOC Emissions from Paint Usage in Different Sectors in India in 2011

Total	Percentage of Distribution	EF (kt/kt)	Emission Factor source	Paints (mt)	Emissions (kt)
Plastic	18%	0.75	CITEPA (2004)	0.09	67.5
General industry	29%	0.69		0.144	99.4
Continuous	29%	0.74		0.144	106.6
Powders	25%	0		0.126	0.0
Total industrial paints					273.4
Coil coating		Emission factor used is 0.04320 Kt/million m².	GAINS[a]	Area of coils 128 million m²	5.5
Automobile paints		3.18 kg/vehicles (weighted avg. for different vehicles)	Based on CITEPA (2003d), IBEF 2008	0.16	35
Decorative paints	50% solvent based	400 kg/kt	GAINS[a]; CITEPA (2003c)	1.33	534
	50% water based	102 kg/kt		1.33	137

[a]European version available from: http://gains.iiasa.ac.at.

amounts to 128 million sq. m in 2011. The coil coating capacity is projected using industrial GDP growth to 2,895 million sq. m in 2051.

The distribution of emissions from paints used in industrial and residential sector in 2011 is shown in Table 9.1.

Future projections of NMVOC emissions are made using regression analysis of various activities with appropriate variables. The past 15 years data of the activity levels in different sectors were regressed

Table 9.2: Surrogate Variable Used for Projections of Different Non-Energy Sectors

S.No	Sector	Dependant Variable
1	Paints: Decorative	Per capita income
2	Paints: Industrial	Industrial GDP growth
3	Vehicle manufacturing and refinishing	Vehicular growth, number of road accidents
4	Coil coating	Industrial GDP growth

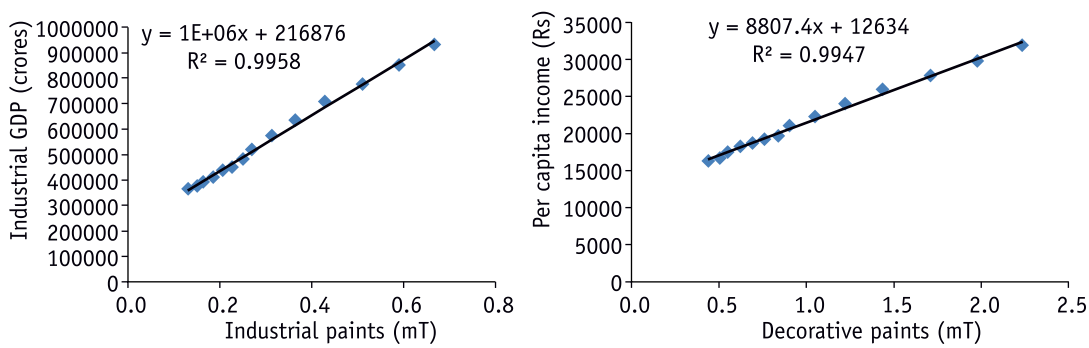

Figure 9.1: Examples of regression analysis carried out for projection of industrial and decorative paints in India

against the selected variables. In the case of paints, regression equations were derived for projections for future years after satisfactory correlations are observed between the paint consumption and dependant variables (Figure 9.1). The list of dependant variable used for projections of emissions from sectors using paints are shown in Table 9.2.

Based on the regression equations, the paint consumption in residential and industrial sector is estimated, as shown in Figure 9.2. With rise in industrial GDP and per capita income levels, the overall paint consumption will increase from 3.6 mt in 2011 to 71.6 mt in 2051. Based on the future estimates of paint use in different sectors, the emissions are estimated. The future projections of NMVOC emissions from paint used are shown in Figure 9.3. The total emission will grow from 944 kt in 2011 to 19301kt in 2051. The automotive paint emissions will grow from 34.5 kt to 54.6 kt during 2011–51 and emission form coil coating will grow from 5.5 kt to 125 kt in the same period.

Vehicular refinishing is another activity that generates NMVOC emissions. Vehicles are repainted or refinished due to different reasons. The NMVOC emissions from this category are linked to application of paint, drying operations, cleaning of equipment, and cleaning operations before the coating and between the applications of different layers. In India,

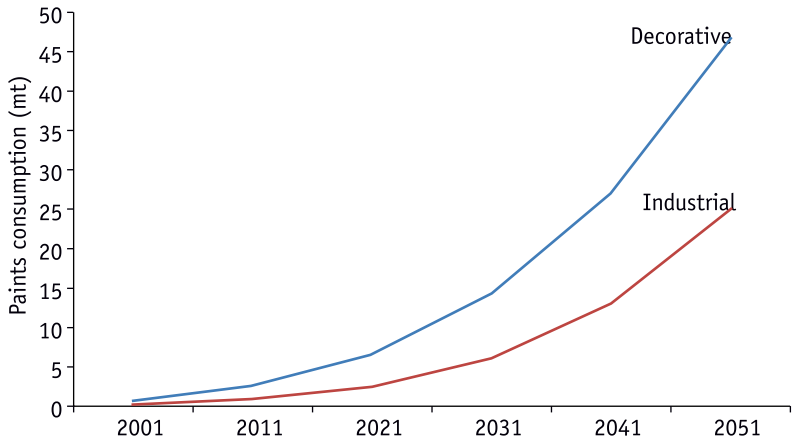

Figure 9.2: Future projections of paint consumption (mt) in India

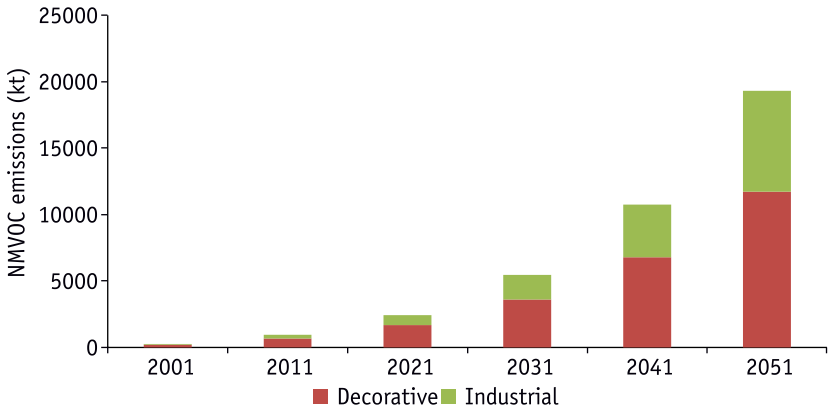

Figure 9.3: Future projections of NMVOC emissions in India

Table 9.3 Total Use of Personal Products (kt) and NMVOC Emissions (kt) in India in 2011

Products	Per Capita Consumption (g/yr)	Volume (kt)	Solvents (EF)*	Emissions (kt) 2011
Facewash	7.2	8.0	65%	5.2
Perfumes	6.1	6.8	60%	4.1
Skin care	48.9	54.7	11%	6.0
Shoe polish	1.1	1.2	45%	0.6
Floor cleaning	14.0	15.6	5%	0.8
Glass cleaning	1.0	1.1	10%	0.1
Kitchen (liquid cleaners)	16.0	17.9	35%	6.3
Kitchen (solid cleaners)	304	339.6	3%	10.2
Detergents (liquid + powder)	2700.0	3015.9	3%	90.5
Shampoos	13.0	14.5	10%	1.5
Soap	460.0	513.8	5%	25.7
Hair oil	96.2	107.5	28%	30.1
Hair dyes/colour	9.5	10.6	44%	4.7
Colour cosmetics	0.1	0.1	44%	0.0
Shaving creams/toiletries	8.1	9.1	10%	0.9
Total				186

* Based on Umweltministerium Baden-Württemberg (1993)

the number of vehicles being refinished has been estimated broadly using the data on accidents that occurred in a year with an assumption of 50% of those going for refinishing. Moreover, the paint used per vehicle is also assumed to be half of the overall paint used in manufacturing.

On this basis, the total emissions from this activity are estimated to be 3.3 kt in 2011, which reduces to almost negligible in future with anticipated reduction in the rate of accidents. The weighted emission factor used for all vehicles is 12 kg per vehicle (higher emission factor due to higher percentage of heavy vehicles going for refinishing).

Personal and Home Care Products

The solvent-based products used in houses include personal care and household care products. The personal care products such as hair care, skin care, oral care, personal wash (soaps), cosmetic and toiletries, feminine hygiene, disinfectants, room fresheners, furniture polishes are the potential source of NMVOC emissions. Other household products including detergents, floor cleaners, etc. are although having lesser solvent content but could be important source in the overall inventory. Indian personal care industry is valued at USD 4 billion including different types of products. The figures for the consumption of the personal care products are derived using:

- per capita consumption values
- by converting the monetary units (market shares of different products) to volumetric forms using market prices (Rs/mL) of the major products in each of the categories.

In abssence of readily availabel information on Indian products, the solvent content of the different types of personal and home care products is adopted from Umweltministerium Baden-Württemberg (1993). The overall estimates of different personal products

used in India and the related emissions from the solvent use in baseline year are presented in Table 9.3.

The total emissions from personal and home care products consumption in India are estimated to be 186 kt in 2011. Based on this an emission factor of 0.16 kt of NMVOCs per million populations can be derived. Use of personal products is highly dependent on per capita income levels in the region and the same is used as a variable to project the consumption of personal products and corresponding NMVOC emissions in future. With growing economy and income levels, the NMVOC emissions in future from the personal and home care product use in India is expected to grow from 186 to 2,173 kt during 2011–51 (Figure 9.4). This is assuming no interventions for control of solvent use in the products.

Dry Cleaning

It is the cleaning process for clothing and textiles using a chemical solvent other than water. The solvent typically used for this is tetrachloroethylene (perchloroethylene). Other solvents used during this process are Glycol ethers, hydrocarbons, liquid silicone, liquid CO_2, perchloroethylene, etc. In India, Mineral Turpentine Oil is commonly used while the use of perchloroethylene has also started.

The activity used to estimate emissions from this exercise is the total weight of textiles dry cleaned in India during 2011. It was estimated based on percentage of households in rural and urban India using laundry services. A total of 50% of it was assumed to be dry cleaned. NSSO (2012) shows that 4% of rural households and 11% of urban households are using dry cleaning facility. As per the per capita expenditure estimates on dry cleaning, the net weight of textile undergone for dry cleaning during 2011 was estimated to be 7.8 kt. Using average emission factor of 0.177 kt/kt weight of textiles, the NMVOC emissions are estimated to be 1.2 kt/yr. The emissions from the activity are projected for future years using per capita income as the influencing variable. It is estimated that the emissions will grow from 1.2 to 13.7 kt during 2011–51.

Extraction, Processing, and Distribution of Gaseous Fuels

The gaseous fuels are extracted directly from a gas field or as part of the mixture from an oil and gas field. During extraction by heating systems, lighting, pumps and compressors, large amount of energy (electrical energy supplied by gas turbine generators) is being consumed. Other than energy consumed, there are fugitive NMVOC emissions from not only extracting, but transport, storage, and handling of gaseous fuels. After extraction, minimal processing of natural gas is carried out at the terminals prior to the long distance transmission through pipeline network

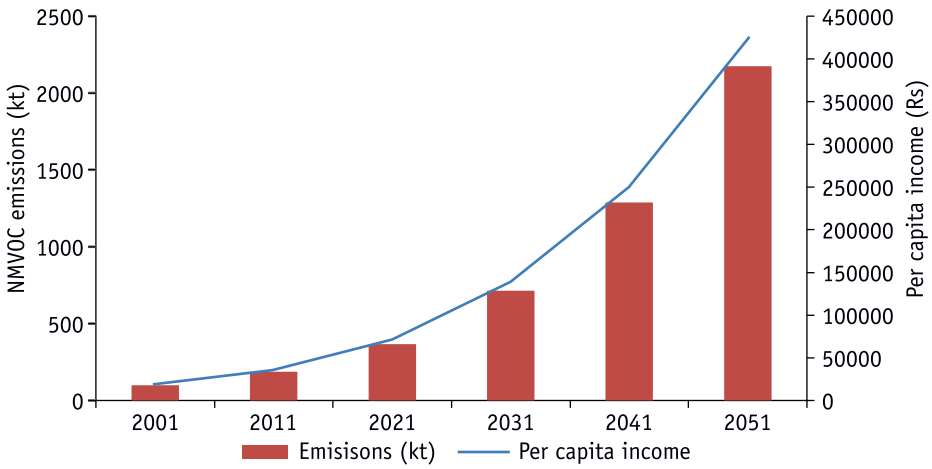

Figure 9.4 Future projections of emissions from personal and home care products in India

(distribution system). During processing, activities mainly required are removal of hydrogen sulphide from gas and drying—which results in sulphur dioxide emission as the main ingredient. After production and on-shore processing, natural gas is fed directly into the distribution system.

The activity data in this case is total natural gas production in the country, which is ~47,500 mmscm in 2010/11, of which 18% is on-shore production. The emission factors used to estimate the emissions during extraction are 0.968 g/m³ for onshore and 0.1426 g/m³ for off-shore facilities (average of many countries assumed from CORINAIR, 1990). Total NMVOC emissions are estimated at 6.3 kt/yr for 2011. NMVOC emissions are also estimated for activities such as distribution of gas and the estimation process is depicted in Table 9.4, which shows different emission factors for losses in pipelines, compressors, and others.

The emissions are projected for future years using TERI analysis for energy modelling exercise (TERI 2015) for natural gas production and use in India during 2001–51 (Figure 9.5).

Extraction, Processing, and Distribution of Liquid Fuels

The liquid fuels are mainly composed of crude oil (a complex mixture of hydrocarbons with very different chemical and physical properties). The extraction

Table 9.4: NMVOC Emissions from Gas Distribution in 2011

Activity	Natural Gas Production (MMSCM)		Emissions Factor ((g/m³)*	Emissions (kt/yr)		
	Onshore	Offshore		Onshore	Offshore	Total
Production	8684	38826	Onshore :0.0968 Offshore :0.142	0.8	5.5	6.3
Distribution**						
General			1.38	16	74	90
Pipelines			0.01	0.1	0.6	0.7
Compressors			0.07	0.8	3.6	4.4
Network			0.78	9.4	41.9	51.3
Total						146.8
*Source : EEA,1999; ** including imports						

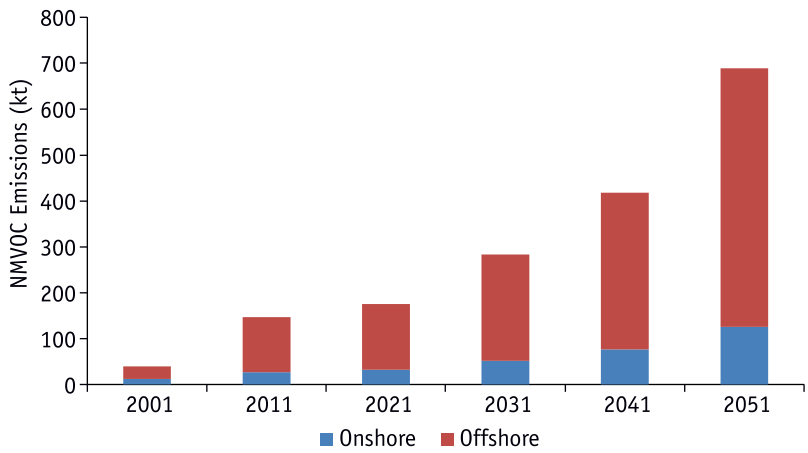

Figure 9.5: Projections of NMVOC emissions from gas extraction and handling in India (2001–51)

of crude is the first step. The route from extraction to individual use (refined components) includes storage, refining, transport, and filling of the fuel. The processing of crude oil, aimed at separating the mixture into groups of chemicals (identification of them with similar properties for use in particular applications). Refineries have many different combinations of process units such as distillation column. The last step is distribution of products (could be through combination of pipeline, road, rail, or even tanker) from the refinery to the point of end use that could be either a single- or multi-stage process.

Emissions have been estimated for each of these steps:

- Extraction: Total crude extracted in India is 39 mt in 2011 (MoPNG 2012). The emission factor used to estimate NMVOC's from extraction was taken as 475 g/tonne of crude (Lewis 1997), and NMVOC emissions from the activity is estimated to be 19 kt/yr.
- Storage of crude: Crude is stored in big tanks that are an important source of NMVOC emissions. These are called working and breathing losses. The emissions from this activity are computed using the TANKS model (http://www.epa.gov/ttnchie1/software/tanks/). Typical tank capacity of 60,000 m³ is assumed with 75% filling to arrive at the total number of tanks required. TANKS model takes into account the tank geometry, meteorological conditions (typical conditions given for Indian conditions), and the type of fluid stored. The emissions in this case are estimated for crude stored at ports and refineries and the petroleum products stored at refineries and bulk terminals. The estimated emissions due to storage of crude and other petroleum products are estimated to be around 9 kt/yr.
- Transit losses: Transit losses occur when crude/petroleum products move over road/rail. The emissions factors used for estimation are shown in Table 9.5. The transit losses are accounted for rail/road travel and not for the pipelines. In India, 30% of fuel is transported through pipelines and hence, emissions are reduced by 30%. The total emissions from transit of fuel are estimated to be 122 kt.

Table 9.5: Emission Factors for Loading and Transit Losses for Oil Handling

Transit Losses (Loading + Transit)	EF (mg/L)
Crude	580
Gasoline	1430
Others	4
Naptha	430

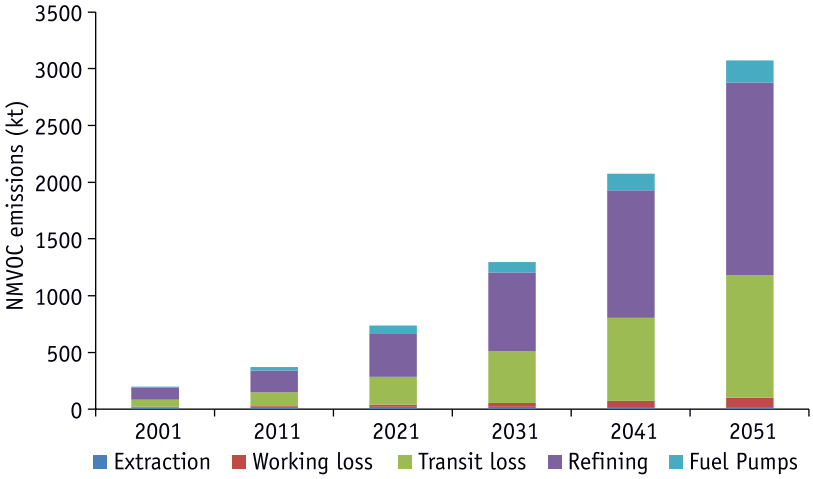

Figure 9.6: NMVOC emissions from oil extraction, refining and handling

- Refining: A total of 213 mt of crude is refined in 2011. An emission factor of 0.9 kt/mt of crude is adopted and emissions are estimated.Total NMVOC emissions from refining activities are 191 kt in 2011 and are projected to grow to 1696 kt in 2051.
- Emissions during fuel filling at the pumps: Emissions at the fuel pumps are accounted using a no-control emissions factor of 2.6 g/kg of gasoline filled. After 2030, stage-II control norms have been assumed that lowers the emission factor to 1.6 g/kg. The emissions from this activity are estimated to be about 30 kt in 2011, which is expected to go up to 197 in 2051, despite introduction of stage-II controls. Figure 9.6 shows the NMVOC emissions from fuel extraction, working , transiting, refining and filling operations in India.
- Evaporative emissions from vehicles: There are significant evaporative emissions from different categories of vehicles. Most volatile organic compound (VOC) emissions generate from fuel systems (tanks, injection systems, and fuel lines) of gasoline vehicles and emissions from diesel vehicles are considered negligible (TRL 2009). In this study, the evaporative emissions from these sources are estimated using the energy consumed in each of the vehicle category and emission factors listed in Table 9.6.

It is to be noted that there is a Type IV standard for evaporative emissions in BS III and IV four wheeled vehicles while there is no standard for two wheelers. However, two wheelers will be subjected to evaporative emission test starting from BS IV in 2016 for the first time. Based on these controls, the emissions for different years are estimated using the energy consumption projected for different category of vehicles using TERI-MARKAL model results (Figure 9.7). The evaporative emissions from vehicles are projected to increase from 279 kt in 2011 to 257kt in 2051.

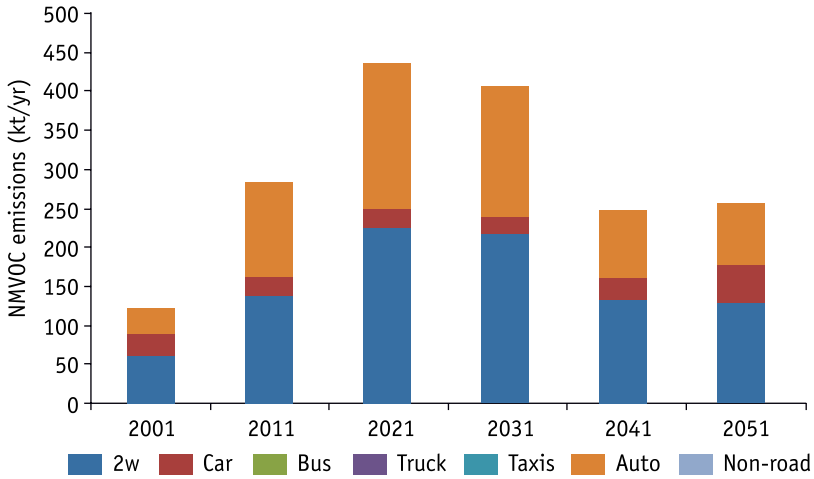

Figure 9.7: NMVOC evaporative emissions from vehicles in India during 2001–51

Table 9.6: Evaporative Emission Factors (kt/PJ) for Different Vehicles

	No-control	Euro-I	Euro-II	Euro-III	Euro-IV	Euro-V
2w/3w	0.60696	0.60696	0.60696	0.60696	0.17602	0.0789
Cars	0.60696	0.17602	0.0789	0.04856	0.02428	0.01821

Source: GAINS ASIA, 2015

Printing

Printing can be broadly categorized into four types: offset, flexography and rotogravure in packaging, rotogravure in publication, and screen printing. Major printing ink components include clear and colour concentrates (pigments or dyes), a solvent, and pigment and, a binder resin. Organic solvents are used almost exclusively with pigments. Emissions from the printing activities depend on the total amount of solvent used in inks. The sources of these VOC emissions are the solvent components in the raw inks, related coatings used at the printing presses, and solvent added for dilution and press cleaning. The data for printing ink produced in India as a whole was collected from the Prowess database. The printing ink produced during the year 2011 is estimated to be 155 kt. Exports of ink is subtracted to derive the consumption volumes in India. Based on ITALIA (2010) and further discussion with industrial experts, the usage of ink in the four categories is broadly distributed to 40% in packaging, 35% in offsetting, 20% in publications, and 5% in screen printing activities. Finally, specific emission factors (CITEPA 2003a, b) for each of the categories of printing were used to estimate NMVOC emissions as shown in Table 9.7.

Table 9.7: Printing Ink Consumption for Different Uses and Corresponding NMVOC Emission Factors

Printing Type	Ink Usage (Percentage of Total)	EF (kt/kt) No Control
Packaging	40%	2.2
Offset	35%	0.72
Publication	20%	2
Screen	5%	1

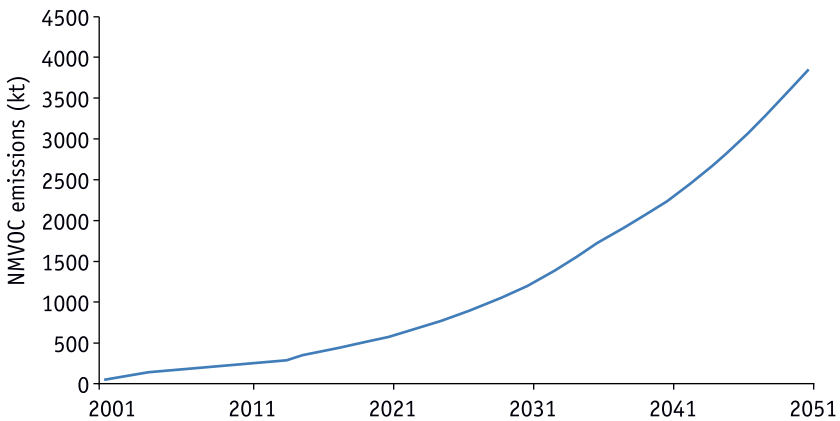

Figure 9.8: NMVOC evaporative emissions (kt) from printing activities in India during 2001-2051

The future projections of printing emissions are made using the growth of per capita incomes as it is found to be linked to the growth of printing industry. The data on consumption of printing inks in India is regressed with the per capita income levels to forecast the future production of inks. Based on this, the NMVOC emissions of 245 kt in 2011 are projected to grow to 3,842 kt in 2051 (Figure 9.8).

Industrial Process Emissions

There are number of industrial processes which generate NMVOC emissions in different quantities.

Fat, Edible, and Non-Edible Oil Extraction

Vegetable fats, edible oils, and non-edible oils are extracted from various natural products. Examples

of inedible vegetable fats and oils include processed linseed oil, tung oil, and castor oil. The estimation of NMVOC emissions from edible and non-edible oils production is made using the annual production of these commodities. In India, about 30 mt of oil seeds were produced in 2011 (MoFPI). However, only soya bean oil is recovered through the solvent extraction techniques and rest depend on crushing (with only 10% as crushed cake is processed through the use of solvents). Hence, 14.4 mt of seeds are processed using solvents. The emission factor used is 0.003 kt/kt (GAINS Asia, 2015) and total emissions are estimated to be 43.1 kt/yr in 2011,which are projected to 264kt in 2051 based on growth expected in agricultural GDP.

Food and Drink Industry

Food industry undergoes processing of food and includes methods and techniques used to transform raw ingredients into food for human consumption. India's food processing sector covers fruit and vegetables; meat and poultry; milk and milk products; alcoholic beverages; plantation; grain processing; and other consumer product groups such as confectionery, cocoa products, soya-based products, mineral water, high protein foods, etc. The processing involves use of many solvents in food and drink industry. NMVOC emissions from this sector is mainly expected from bread production and distilleries. The data for the production of food and drink was collected from the MoFPI (2012). The bread production in India is about 2.52 mt in 2010.

The method used to estimate emissions from this sector is adopted from AP-42 (Chapter 9).

$VOC\ E.F. = 0.95Yi + 0.195ti - 0.51S - 0.86ts + 1.90$

Where

$VOC\ E.F.$ = pounds VOC per ton of baked bread

Yi = initial baker's percentage of yeast (2%)

ti = total yeast action time in hours (12 hrs)

S = final (spike) baker's percentage of yeast (1%)

ts = spiking time in hours (1 hr)

Based on this, the emissions factor for bread production is estimated to be about 3.4 lb/ton of bread produced. The total emissions from bread production in India are projected using the per capita income as a surrogate. The emissions will grow from 3.6 kt in 2011 to 42.5 kt in 2051.

Beer production in India is estimated to be about 700 million litres in 2011. Emission factor is adopted from AP-42 Emission Factor Database (www.epa.gov/ttnchie1/ap42/ch09) as 0.035 kg/L. Total emission from beer production turns out to be 25 kt in 2011, which is projected to increase with growing income levels to 454 kt in 2051.

Industrial Application of Adhesives

An adhesive is a compound that adheres or bonds two items together to form a single unit. Raw materials required for adhesives are different resins, solvents, preservatives. The global market for adhesives and sealants is growing at about the rate of GDP, with significant variations between the regions. There are several commercial combinations of multi-component adhesives in use in industry such as polyester resin—polyurethane resin, polyols—polyurethane resin, Acrylic polymers—polyurethane resins. These solvents involved in adhesives result in NMVOCs generation.

The production of adhesives was found to be about 60 kt/yr in India (IP 2010). Emission factor adopted is 0.78 kt/kt for no-control conditions. Therefore, total emissions were estimated as 66 kt in 2011, which is projected to increase with the industrial GDP growth to 1,481 kt in 2051.

Production of Paints, Inks, and Adhesives

Other than the usage, the production processes of paints, inks, and adhesives also generate emissions. A general emission factor used here is 0.00715 kt/kt of production (GAINS ASIA, 2015). The emissions are estimated as 27 kt in 2011, which is projected to grow to 540 kt in 2051 with growth in production of paint, inks, and adhesives (Figure 9.9).

Organic Chemical Industry, Storage

The organic chemicals are stored in tanks to avoid hazardous effect on the environment. These tanks then release VOCs emissions because most of the

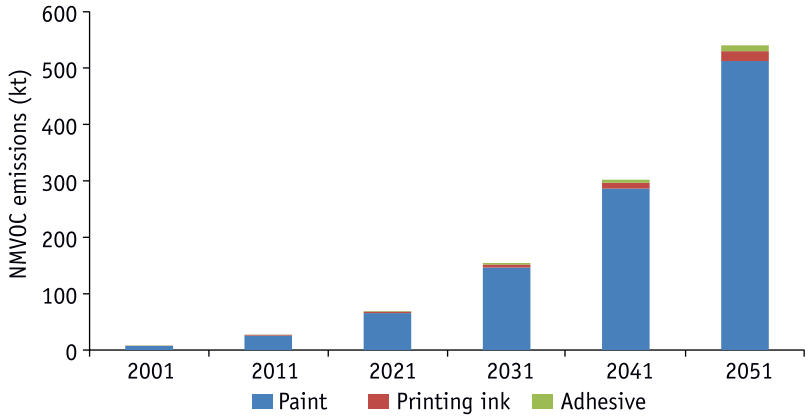

Figure 9.9 NMVOC emissions from production of paints, inks, and adhesives

compounds are volatile and evaporate at normal conditions.

Production of organic chemicals in India was 1,279 kt/yr (MoCF 2011). It was assumed that capacity of tank is about 800 m^3 and tanks are 75% filled. Based on this, total number of tanks required for storage of 40 days was estimated. TANKS model software is used to estimate the emissions during storage of organic chemicals. The emissions for 2011 are estimated to be 10 kt/yr. The organic chemical production is regressed with the industrial GDP for future projections. The emissions are projected to grow 29 kt in 2031 and 38 kt in 2051.

Polystyrene, PVC, and Ethylene Processing

Production of Polystyrene (PS), PVC, and ethylene also leads to generation of NMVOCs. PS, also called thermocole, is an aromatic polymer made from the monomer styrene, a liquid hydrocarbon that is manufactured using petroleum in the chemical industry. Foamed PS is used for packaging purposes of chemicals, but it does not come into contact with the actual solvents. The data on total PS, PVC, and ethylene manufactured for different years is taken from MoCF (2011). The emission factors used are 0.06 kt/kt, 0.03 kt/kt, and 0.0034 kt/kt for PS, PVC, and ethylene production, respectively. The PS, PVC, and

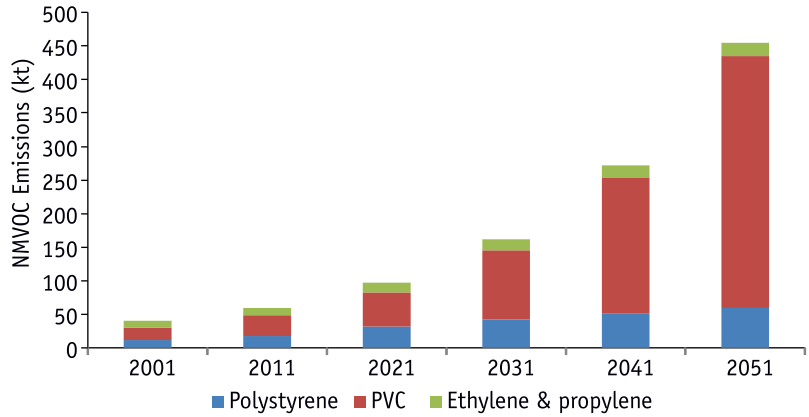

Figure 9.10: NMVOC emissions (kt) from PS, PVC, and ethylene processing in India (2001–51)

ethylene production in 2011 is about 296 kt, 1,278 kt, and 3,216 kt, respectively (MoCF 2011). Of the total PVC production, 80% is through suspension process that leads to NMVOC emissions (CPCB 2008). Seventy per cent of ethylene production is through steam cracking in India. The future estimates of production of the three compounds were made using the regression with industrial GDP. The emissions for different years are presented in Figure 9.10. The emissions are expected to grow from 59 kt in 2011 to 454 in 2051, mainly due to higher growth in PVC production.

Synthetic Rubber Production

Synthetic rubber is produced through butadiene (a by-product of petroleum refining) and styrene (captured either in the coking process or as a petroleum refining by-product). Two types of polymerization reaction are used to produce styrene-butadiene copolymers—the emulsion type and the solution type. This activity addresses VOC emissions from the manufacture of copolymers of styrene and butadiene made by emulsion polymerization processes. The amount of synthetic rubber produced in kilotonnes for the different years is estimated based on natural rubber production and its share in total rubber production from George and Chandrashekar (2014). The emission factor used is 0.021 kt/kt and total NMVOC emissions are estimated to be 8.1 kt in 2011, which is expected to increase to 20 kt in 2051.

Tire Production

There are various activities that emit VOC at certain stages of the manufacturing process of tyres and also in offset natural drying sector. The tyre production for the year 2010 was taken from the Prowess database, which is about 1,781 lakh numbers (including cycle tyres, passenger cars, etc.). Total weight of tyres produced estimated based on standard sizes and weights for different tyre categories. The total weight of tyres produced was estimated to be 1,248.32 kt. The emission factor used is 0.01 kt/kt and total NMVOC emissions are estimated to be 14 kt in 2011, which is projected to increase to 23 kt in 2051. The projections are made based on increased number of vehicles and demands for tyres.

Winding Wire Coating

In India, almost 88% of wires are in plain carbon steel grades, 5% are in stainless steel, and remaining in alloy steel wires. In the plain carbon wire category, about 20–25% is in the Galvanized Wire sector or copper-coated, bronze-coated, and others in coating materials. A total of 75–80% of this is in the form of black/uncoated wires only. During coating of wires, large amount of solvents are used, thereby releasing VOCs.

The emissions were calculated on the basis of total quantities of wire coated in year 2011. The production of wire was estimated to be around 2.68 million tonnes of which 25% is coated. The emission

Table 9.8: Sector-Wise Inventory of NMVOCs (kt/yr)

Source	2001	2011	2021	2031	2041	2051
Paints*	288	988	2484	5537	10857	19481
Personal & homecare	98	186	366	714	1287	2173
Dry cleaning	1	1	2	4	8	14
Gaseous fuel handling	43	153	181	289	424	695
Oil Handling	198	258	371	539	738	992
Printing	58	245	571	1201	2239	3842
Industrial processes	122	238	486	956	1749	2990
Total	808	2068	4460	9241	17301	30187

*Paints include decorative, industrial, coil coating and automobile paints.

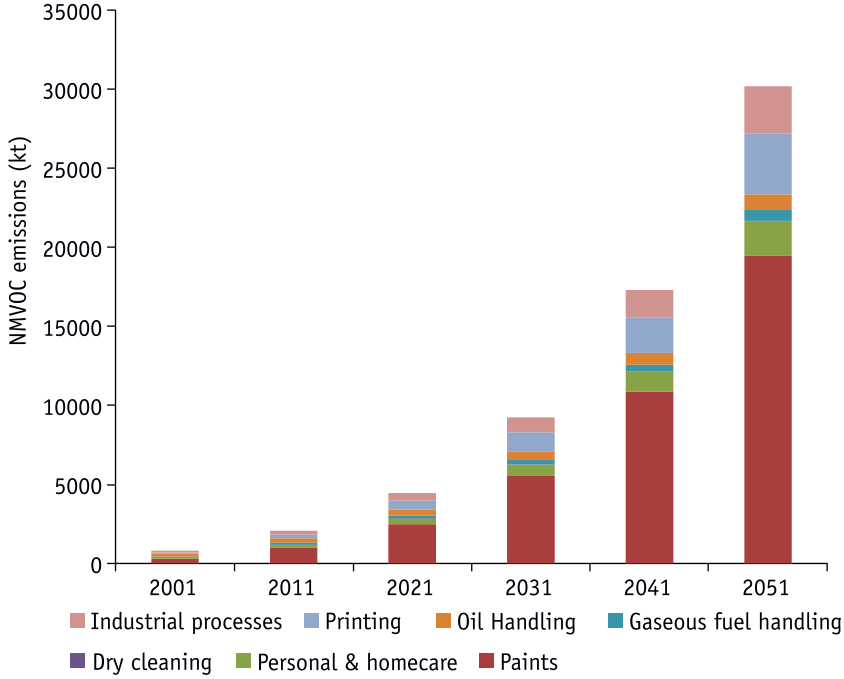

Figure 9.11: Growth of NMVOC emissions in India (2001–51)

factor used is 0.0168 kt/kt and total VOC emissions released amounts to 11.8 kt in 2011. The emissions are projected to grow to 138 kt in 2051.

Total Evaporative Emissions

The source-wise inventory of evaporative NMVOC emissions in India is presented in Table 9.8 and Figure 9.11. The evaporative NMVOC emissions are expected to grow by almost 15 times during 2011–51. Sectoral distribution shows that emissions from paints, printing, and personal products will grow significantly with rise in per capita income levels. Paint industry is expected to grow at the fastest rate and corresponding emissions will grow by 20 times during 2011–51, followed by 16 and 12 times growth in NMVOC emissions in printing and personal products sectors. Most of these sources of evaporative emissions are linked to the growth of economy and income levels. With projected economic growth and income levels, these sectors will grow and consumption of paints, printing inks, and personal products will increase significantly. While there are regulations in place for control of PM and to some extent for gaseous pollutants such as NOx and SO_2, there are hardly any regulations for control of NMVOC emissions. This is the primary reason for steady growth of projected NMVOC emissions in a business as usual scenario.

Conclusions

Evaporative emissions of NMVOCs are gradually increasing unnoticed. These emissions can have serious implications over human health, ozone formation, and SOA (Secondry Organic Aerosols) formation. There are very limited regulations in place for control of solvent use, manufacturing of low VOC products, and control of fugitive/evaporative emissions of VOCs. Some efforts are made by the industry in this direction mainly due to market demands for greener products. Projections for

Table 9.9: NMVOC Control Strategies

Sector	Control strategy
Paints	Mandating low VOC paints for decorative and industrial use
Printing	Solvent free inks and enclosure
Tyre	Process optimization
Wire	Low solvent content of enamel, and secondary measures (increased efficiency of the oven)
Dry cleaning	Dry cleaning conventional closed circuit machine
Gasoline distribution - service stations	Stage II vapour recovery systems at service stations
Fat oil	Activated carbon adsorption
Adhesives	Activated carbon adsorption
PS	Expandable PS beads consumption-incineration
PVC	Suspension process stripping and vent gas treatment
Manufacture of vehicles	Adsorption, incineration, process modification, and substitution
Coil	Incineration
Organic chemical storage	Vapour recovery systems
Refinery	Leak detection and repair programs

industrial sector show a strong competitive growth that may lead to higher use of solvents and emissions of NMVOCs. However, in attempt to keep the costs of production down, the market competition may lead to increased rate of recovery and reuse of solvents. Despite this, there is an urgent need to have specific strategies in place for control of NMVOC emissions from various sources. Table 9.9 shows a list of strategies that could be employed for their control.

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CHAPTER 10

Other Sectors

Jai Malik and Sumit Sharma

Introduction

The emissions from major pollutant sources have already been covered in the earlier chapters. However, there are certain sources of air pollution that are not covered in these heads and seem too insignificant as compared to other sources. This chapter presents the emission inventory of other unconventional and comparatively smaller sources that also contribute in deterioration of air quality. These emission are significant when considered cumulatively. Also, understanding the unconventional sources of pollution can be a cue towards filling the knowledge gaps one comes across, especially, while understanding the dynamics air pollution of a region at a local level.

This chapter focuses on following 'other sources' in terms of their contribution to air pollution:

- Handling and burning of waste;
- Storage, handling, and transportation of coal and cement;
- Agricultural activities such as soil cultivation, harvesting, cleaning, and drying;
- Waste gas flaring; and
- Crematorias.

These activities generate comparatively smaller quantities of emissions at the National scale, but could be significant at the local levels. The activity data are collected and appropriate emission factors (EFs) are applied to estimate the emissions of different pollutants from these sources. Emissions from all these sub-sectors are then cumulatively compared to the emissions from conventionally well-known sources such as transport, industries, household cooking, etc. Each of these 'other sectors' emissions are presented in subsequent sections.

Waste Handling and Burning

Management of municipal solid waste (MSW) is a major problem in India. Most of the waste produced

goes uncollected. And, most of the collected waste ends up in landfills that are not scientifically designed for proper management and disposal. Since collection efficiency is low in towns and almost negligible in rural areas, some parts of waste is also burnt in open for volume reduction and heating purposes during winters. This adds to the emissions loads in the regions. Moreover, the waste in landfills is another source of pollution. These emissions are directly linked with the quantity of waste produced. Thus, the basic information required to estimate emissions from the waste sector is the quantity of waste produced and burnt in the country. It was estimated that the per capita waste generation rate increases by 1.33 per cent annually (Pappu et al. 2007). Based on this and population projections, Figure 10.1 shows the total generation of MSW for 2001 and 2011 and projections for 2021, 2031, 2041, and 2051. The waste generation has increased from almost 42 mt in 2011 to 160 mt in 2051.

Refuse Burning

For assessment of refuse burning in India, the data on waste generated, collection effieciencies, and fraction of waste burnt, were collected. It is found that collection efficiency of MSW is about 68 per cent in urban areas. It is assumed that waste is not collected at all in rural areas. The per capita waste generation in urban India is adopted as 0.45 kg/day. (Planning Commission 2014). (Shah et al. 2012) has estimated a corresponding value for rural areas as 0.29 Kg/day. As per IPCC guidelines, it is assumed that in developing countries 60 per cent of the uncollected waste is burnt (IPCC 2006). These numbers were used to calculate the amount of MSW burnt in any given year using the following Equation 10.1.

$$W = \mathrm{MSW}_p \times \mathrm{Popl.} \times (1 - F_{\mathrm{coll.}}) \times B_{\mathrm{frac}} \quad \text{.....(10.1)}$$

W = Waste burnt

MSW_p = Per capita waste produced

Popl. = Population

$F_{\mathrm{coll.}}$ = Collection efficiency(0.68)

B_{frac} = Fraction of waste burnt (0.6)

Out of the total waste generated, Figure 10.2 shows the estimates of refuse burnt over the years in India. The refuse burnt is expected to increase from 27 MT to 44 MT during 2011–51.

Table 10.1 shows the EFs for different pollutants, which have been used to estimate the pollutant load emitted from refuse burning activity.

These EFs were used to estimate the emission load using Equation 10.2.

$$\text{Emission from refuse burning} = \mathrm{E.F} \times \mathrm{W} \quad \text{.....(10.2)}$$

Landfills

Since all kinds of waste are dumped in landfills in an unplanned manner, they practically become a huge store pile of wastes of various chemical and physical compositions. Activities like movement of trucks on unpaved roads, flaring, un-planned fires, etc. make landfills a source of air pollution. The pollutants released from landfills directly depend upon the quantity of waste. According to a report on status of

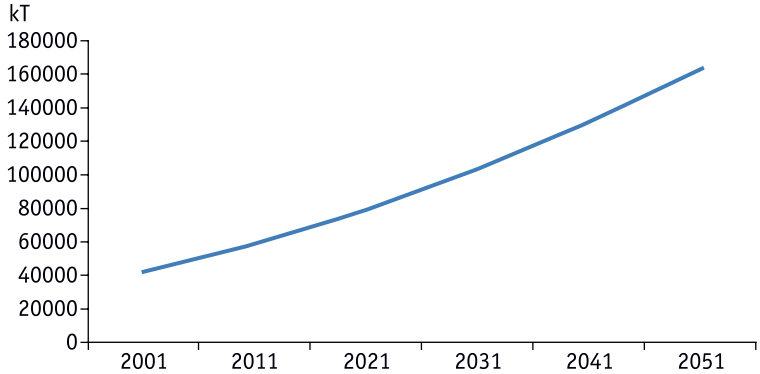

Figure 10.1: Total municipal waste (kt) produced in urban areas in India

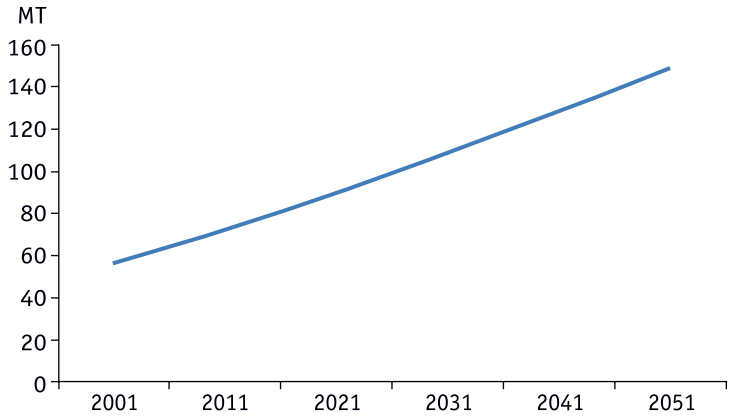

Figure 10.2 Estimates of refuse burning (mt) in India during 2001–51

Table 10.1: EFs for Burning Waste

Pollutant	Emission factor	Unit
$PM_{2.5}$	9.8	Kg/T
PM_{10}	11.9	Kg/T
NO_x	3.74	Kg/T
SO_2	0.5	Kg/T
VOC	14.5	Kg/T
CO	38	Kg/T
BC	0.65	Kg/T
OC	5.27	Kg/T

SO_2 – Sulphur Dioxide; VOC – Volatile Organic Carbon
BC – Black Carbon ; OC – Organic Carbon

Source: Woodall et al. (2012) & Pappu et al. (2007)

MSW management by CPCB in 2012, 68 per cent of the waste produced in urban areas is collected, out of which, almost 28 per cent is processed (CPCB 2012). It is assumed that the remaining unprocessed waste ends up in landfills. Thus, yearly waste in landfills can be calculated as per Equation 10.3.

Waste in landfills = Collected waste – processed waste.....(10.3)

The EFs in Table 10.2 were used to calculate pollutant emissions from landfills using Equation 10.4:

Emissions = EF × Waste in landfills.....(10.4)

Table 10.2 EFs for landfills

Pollutant	EF in Kg/MT
PM10	8
PM2.5	5.44
CO	42
SOx	0.5
NOx	3
VOC	21.5

Source: USEPA, AP42 EF database

Figure 10.3 shows the combined emissions from the waste sector in India. The most significant pollutant emitted from the waste sector is CO, and further increase in CO emissions is expected over the years; an increase from almost 2,000 kT in 2001 to 5,600 kT in 2051. VOCs and particulate matters are some other pollutants emitted from the waste sector in relatively higher quantities.

Storage, Handling, and Transportation of Coal and Cement

It is well known that pollutants such as particulate matter are generated in extraction of coal and production of cement. However, dust is also generated during storage, handling, and transportation of these products. These fugitive emissions are directly dependent on the quantity of

product produced or consumed. Figure 10.4 shows TERI's projections for coal consumption and cement production in India.

The EFs used for estimation of fugitive emissions are presented in Table 10.3.

Table 10.3 EFs for Fugitive Emissions from Coal and Cement

Product	Pollutant	EF	Source
Coal	PM10	0.042 kg/T	EEA 2013
Coal	PM2.5	0.005 k g/T	EEA 2013
Cement	PM10	0.46 kg/T	CPCB 2007
Cement	PM2.5	0.055 kg/T	Derived from PM2.5/PM10 ratios from AP42

Equation 10.5 was used to estimate fugitive emissions from coal and cement in the future as shown in Figure 10.5. It can be seen that substantial increase in the emissions of particulate matter is expected.

Emissions = EF × production.....(10.5)

Waste Gas Flaring

Oxidation of hydrocarbons in industrial waste gases at high temperature is called flaring. Flaring is used to dispose waste products from refineries and waste gases emerging from:

- Chemical industries
- Oil wells

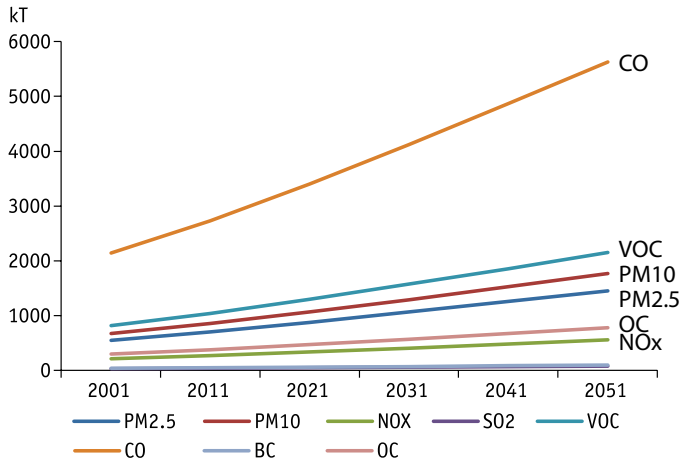

Figure 10.3: Emissions from waste (landfills and refuse burning) sector

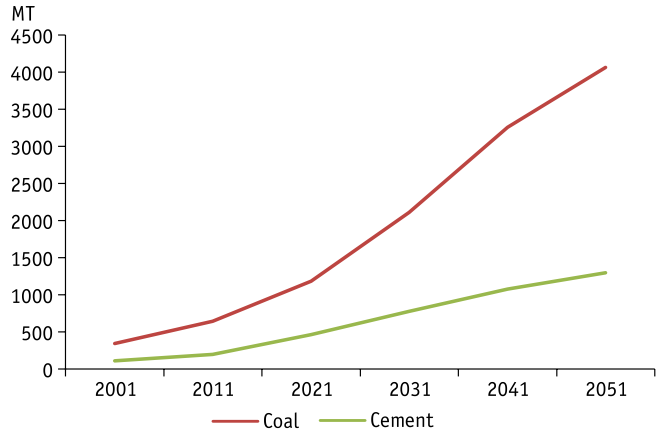

Figure 10.4 Coal consumption and Cement production in India during 2001-2051

- Blast furnaces
- Coke ovens

Apart from apparent problem of heat and noise, flares also produce pollutants such as un-burnt hydrocarbons, carbon monoxide, particulate matter, oxides of nitrogen, and sulphur dioxide, depending upon the composition of the gas. Estimates of gas flaring have been made using the outputs of the TERI-MARKAL model exercise. Figure 10.6 shows the quantity of gases (in terms of energy) that is expected to be flared in future.

EFs, as shown in Table 10.4, have been used to estimate the emissions using Equation 10.6.

$$\text{Emission} = \text{E.F} \times \text{gas flared} \qquad (10.6)$$

The estimated emission loads of various pollutants from the gas flaring activities are shown in Figure 10.7. Of all the pollutants emitted from waste gas flaring, the highest emissions are of CO, which is about 23 Kt in 2011. It is projected that emissions from this sector will be consistent in the coming years.

Dust from Agricultural Operations

Dust is generated during various agricultural operations. A large portion of the emissions from this sector can be on account of agricultural tilling, which includes soil cultivation and crop harvesting. These activities include movement of agricultural vehicles on unpaved roads, wind-blown particles, application of pesticides, etc. The settled particulate matter is also re-suspended because of activities on agricultural land. According to EEA emission inventory guidelines 2013, the emissions from this sector primarily depends upon the climatic conditions, type of activity undertaken, and the type of crop cultivated. To calculate PM_{10} and $PM_{2.5}$ emissions from this sector, the EF are selected for different types of activities on the agricultural field—soil cultivation, crop harvesting, cleaning, and drying. These emissions also depend on the types of crops cultivated. The EEA guidelines suggest emission factors for various types of crops—wheat, rye, barley, oat, grass, and others. On this basis, the crops grown in India were further divided into three broad categories—wheat, rye, and others. Some of the crops such as cotton, sugarcane,

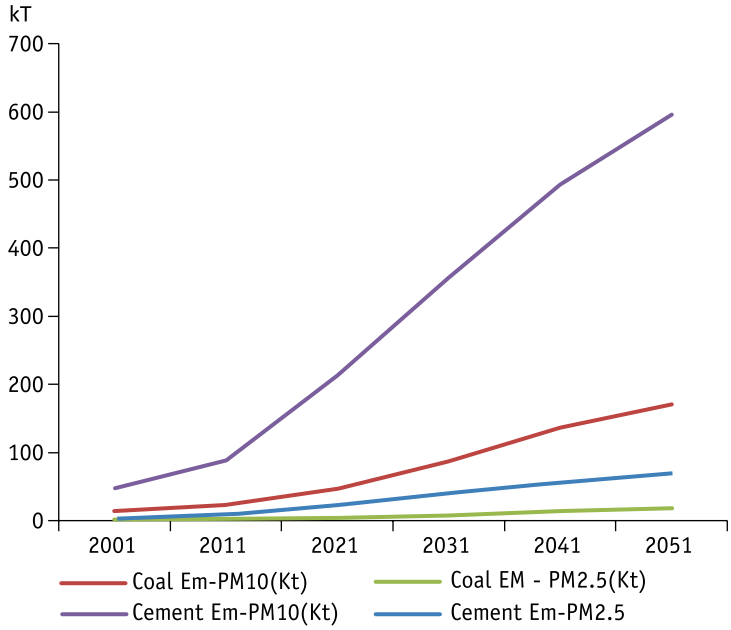

Figure 10.5: Fugitive emissions from coal and cement storage and handling during 2001–51

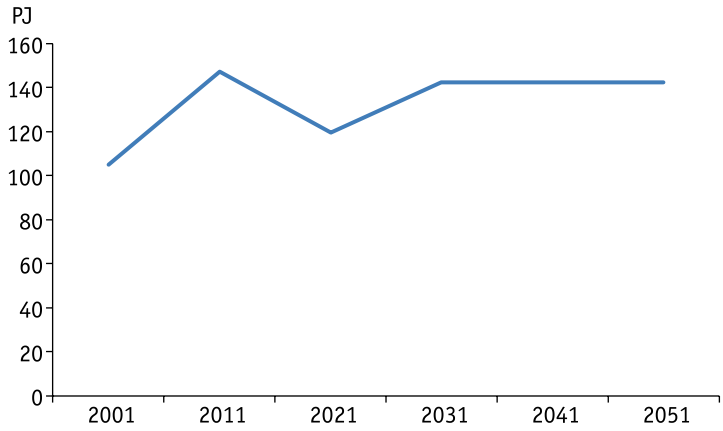

Figure 10.6 Estimates of gas flaring (PJ) in India during 2001-2051
Source: (TERI, 2015)

Table 10.4 EFs of Flaring Waste Gases	
Pollutant	EF in kg/PJ
Total HC	0.060
CO	0.159
NOx	0.029
Source: USEPA, AP42 EF database	

groundnut, maize, etc. are covered in the 'others' categories. Table 10.5 shows the EFs for PM_{10} and $PM_{2.5}$ from this activity in agriculture sector.

The data on district-wise area of cultivation is collected from MoA (2001). The estimated increase in the areas of crops cultivated based on TERI's analysis for energy sector modelling is shown in Figure 10.8. PM_{10} and $PM_{2.5}$ emissions were calculated using the following equation. The results are shown in Figure 10.9.

$$\text{Emissions} = \text{E.F} \times \text{Cultivated area} \quad \text{.....(10.7)}$$

The PM_{10} emissions are estimated to be 181 kT in 2011 and 214 kT in 2051.

Crematoria

Significant quantities of wood is combusted during creamation ceremony in the Hindu and Sikh religions. The estimates of wood burnt and corresponding emissions are made. The percentage of Hindus and Sikhs in India is about 81.3 (GoI 2001). Even though the electric crematoria have come up over the years, but because of their unpopularity and unavailability at most places, it is assumed that a very insignificant number of bodies are cremated there. On an average 350 kg of wood is burnt in each cremation (NEERI 2010). Thus, total wood burnt every year all over India was estimated using Equation 10.8, based on the population projections in TERI analysis till 2051 and death rates. Figure 10.10 shows the projections.

$$\text{TW} = P \times F \times \text{DR} \times 350 \text{ kg} \quad \text{.....(10.8)}$$

TW = Total wood burnt
P = Total population
F = Fraction of Hindus and Sikhs
DR = Death rate

The trends of crude death rate for India as reported in WHO (2012) for the years 1950 to 2005 were used to project death rate in future, as shown in Table 10.6. The fraction of Hindu and Sikh population is assumed to be constant.

The following EFs were used for calculating emissions using Equation 10.9.

$$\text{Emissions} = \text{EF} \times \text{Total wood burnt} \quad \text{.....(10.9)}$$

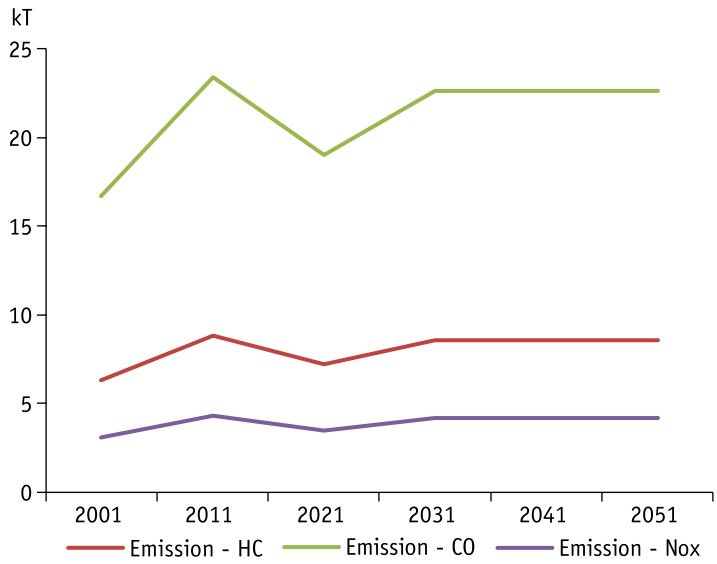

Figure 10.7: Emissions from waste gas flaring

Table 10.5: EFs for PM10 and PM2.5 (kg/ha of Agricultural Land) from Agriculture Sector

Type of crop	Soil cultivation		Crop harvesting		Cleaning		Drying		Total EFs	
	PM10	PM2.5	PM10	PM2.5	PM10	PM2.5	PM10	PM2.5	PM10	PM2.5
Wheat	0.25	0.015	0.49	0.02	0.19	0.009	0.56	0.168	1.49	0.212
Rye	0.25	0.015	0.37	0.015	0.16	0.008	0.37	0.111	1.17	0.221
Others	0.28	0.015	NA	NA	NA	NA	NA	NA	0.25	0.015

Source: (EEA 2013)

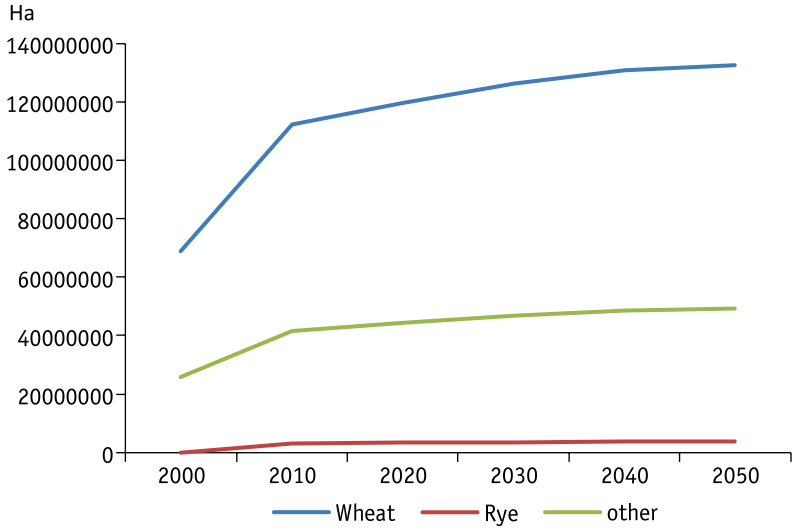

Figure 10.8 : Projected increase in cultivated area in India

Source: TERI Analysis

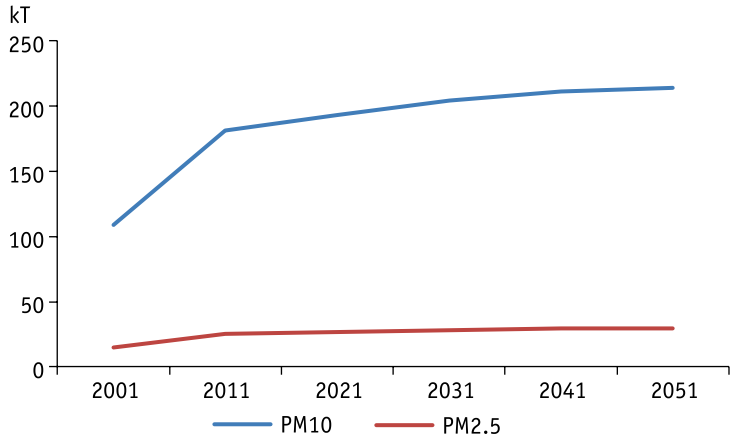

Figure 10.9: PM10 and PM2.5 emissions (kT) from agricultural sector

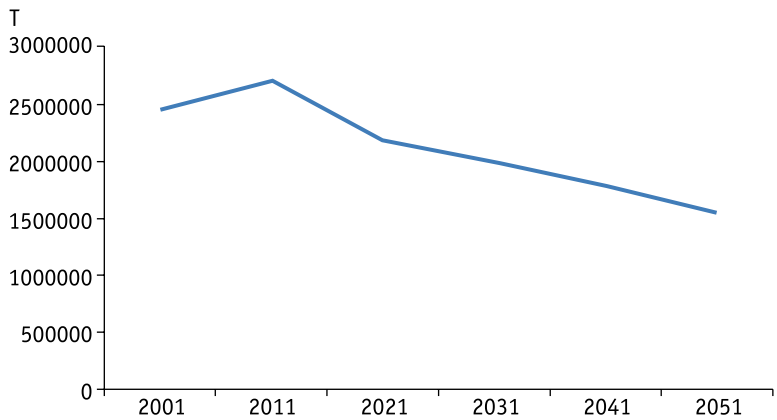

Figure 10.10: Annual projected wood combustion (T/yr) in crematoria in 2001–51

Figure 10.11 shows the emissions from crematoria all over India. Crematoria contribute to some NMVOC and PM emissions. Due to reduced death rate, the emissions will show a decline of 43 per cent during 2011–51.

Total Emissions from all Sources in 'Others' Category

This section summarizes the overall national scenario of eight major pollutants—PM10, PM2.5, BC, CO, VOC, NOx, SO_2, and OC for the sources in the 'others' category. The total estimated emissions along with the contribution of various sectors, as discussed in previous sections are summarized. Figure 10.12 shows the PM_{10} emissions in India. In 2001, the PM10 emissions from others sector were about 900 kT, with major contribution from refuse burning. However, in 2050 the emissions are estimated to increase to about 2,600 kT. In 2050, the contributions from coal and cement handling will have higher contributions.

Figure 10.13 shows $PM_{2.5}$ emission over the years. Currently, the emissions from the 'other' category sources are about 600 kT, which is estimated to increase to 1500 kT in 2050. The major contribution is again from refuse burning whereas emissions from agriculture sector, crematoria, and waste gas flaring are small.

Table 10.6: Projected Crude Death Rates (Deaths per Thousand Population) in India

Year	Crude death rate
2001	8.7
2011	7.9
2021	5.65
2031	4.63
2041	3.79
2051	3.1

Source: Based on data for 1951–2005 from (WHO 2012)

Table 10.7: EFs of Wood Burning

Pollutant	EF in kg/T
SO_2	0.4
NOx	2.55
$PM_{2.5}$	9.1
PM_{10}	18.5
NMVOC	51.9
BC	0.52
OC	4.71

Source: Akagi et al. (2011)

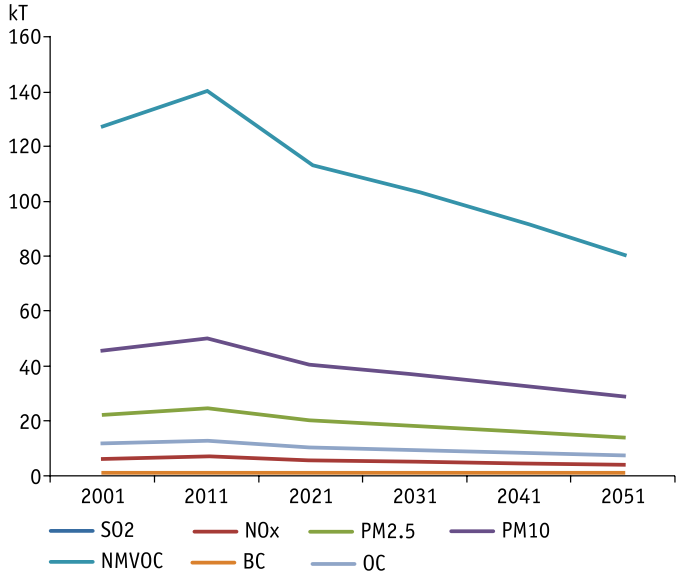

Figure 10.11: Current and projected emissions (kt) from crematoriums in India

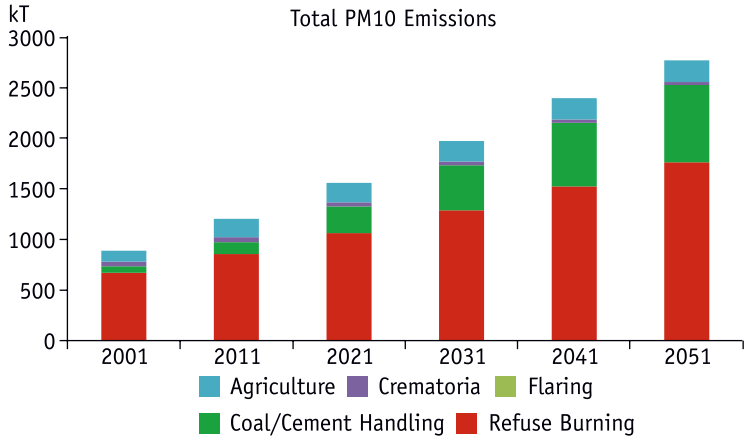

Figure 10.12: Total PM10 emissions (kt) from other sectors in India

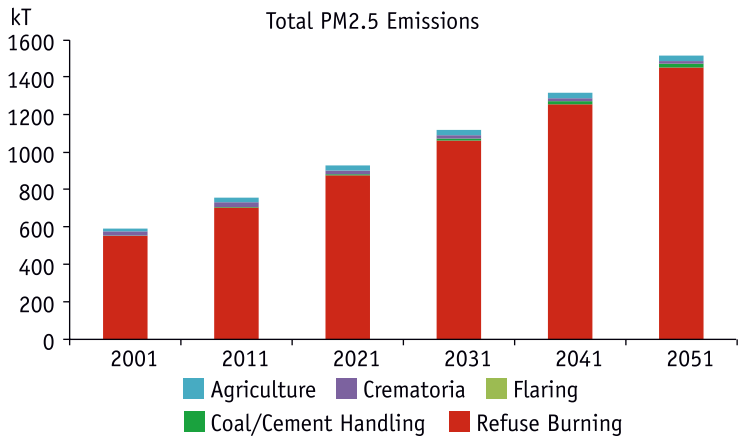

Figure 10.13: Total PM2.5 emissions (kt) from other sectors in India

The estimates of BC emissions are shown in Figure 10.14. The other category sources contribute in a small manner in case of black carbon emissions. The total emissions were of 37 kT in 2001, which are estimated to increase to above 100 kt by 2051. Refuse burning and emissions from crematoria are the only two major contributors. Comparatively, the emissions from crematoria are less and also show a decreasing trend over the years, with reduced death rates. However, refuse burning emissions are projected to grow with increasing population and waste generation rates.

NOx emissions from these unconventional sources were about 210 kT in 2001, which is estimated to increase to 570 kT in 2050 (Figure 10.15). Like other pollutants, the major source again is refuse burning with contribution from crematoria and waste gas flaring.

SO_2 emissions show an increase of almost 40 kT in next 5 decades, with refuse burning as the major source. (Figure 10.16)

An increase of almost 1200 kT is estimated in VOC emissions, as shown in Figure 10.17, with crematoria and refuse burning are the major contributors.

Figure 10.18 depicts the increase of almost 175% in the CO emission from the year 2001 to 2051. Refuse burning and crematoria are the major contributors to CO emissions.

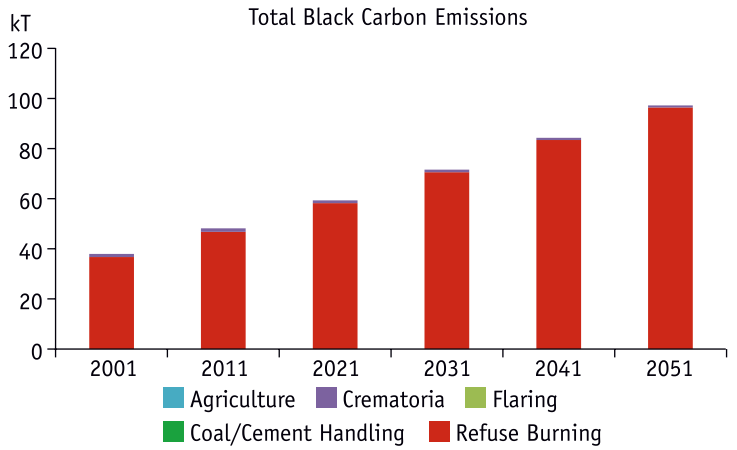

Figure 10.14: Total BC emissions (kt) from other sectors in India

Spatial allocation

Emissions of different pollutants are spatially allocated using various surrogate indicators, as suggested in Table 10.8. Thereafter, the emissions are gridded to a resolution of 36 × 36 km^2.

Conclusions

Other sectors for which emissions are estimated in this chapter are important as they cumulatively contribute significantly to the overall inventory of emissions in India. The analysis shows that some of the sectors such as refuse burning may contribute significantly to the emission loads. The emission projections also present an increase in emissions from refuse burning in a population and waste generation growth scenario. In case of all the pollutants except PM_{10}, it is clear that refuse burning is a dominant source among all sources in the 'others' category. Over all, emissions from refuse burning, and crematoria are also significant. However, the emission may show a decline over the future mainly on account of reducing death rates. Though, these sectors have small contributions, these also need to be controlled to reduce impacts over air quality.

Emissions from waste burning can be controlled by improving the collection of waste at household level. Creating awareness amongst the general

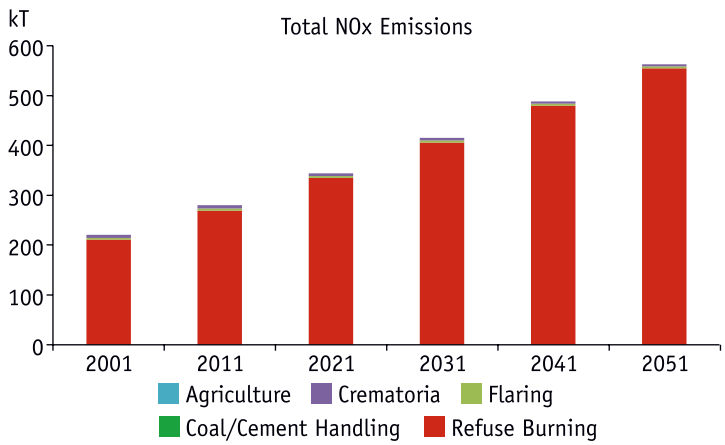

Figure 10.15: Total NOx emissions (kt) from other sectors in India

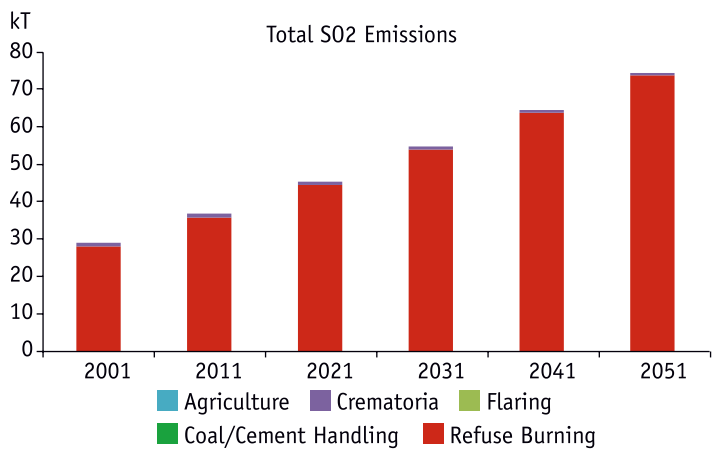

Figure 10.16: Total SO2 emissions (kt) from other sectors in India

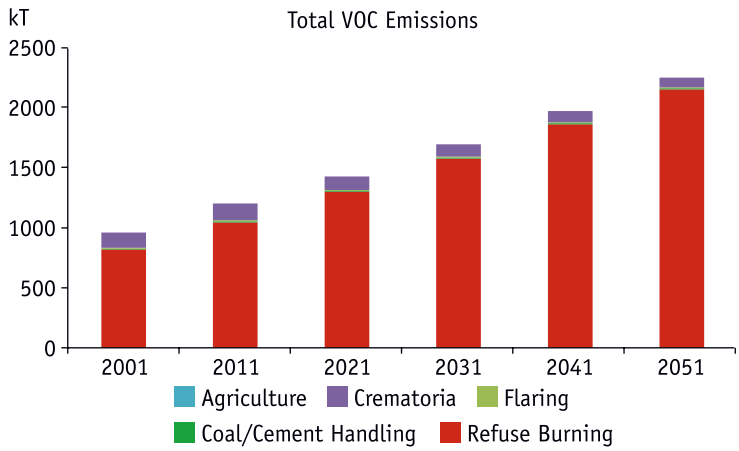

Figure 10.17: Total VOC emissions (kt) from other sectors in India

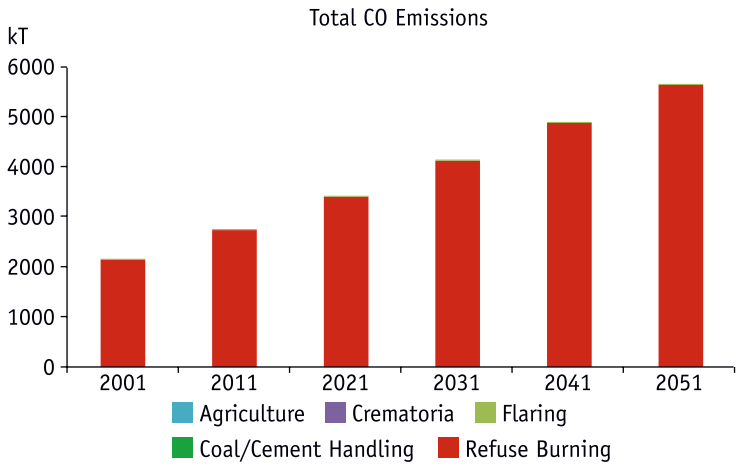

Figure 10.18: Total CO emissions (kt) from other sectors in India

Table 10.8: Surrogate Variables Used for Spatial Allocation of Emissions from Other Sectors

S.No	Sector	Surrogate variable
1	Refuse burning and emissions from landfills	District-wise urban and rural population
2	Agriculture	District-wise agricultural land area
3	Emissions from storage and handling of coal and cement	Coal and cement production units
4	Waste gas flaring	Gases flaring at different states
5	Crematoria	Number of deaths in different states

public to increase the understanding about the need of better waste management could certainly be a mitigating step towards reducing air pollution from this sector. On account of decreasing death rate, the emissions from crematoria are already on decline but promotion of electric crematoria could also help in reducing air pollution from this sector.

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CHAPTER 11

Summary and Conclusions

Sumit Sharma and Atul Kumar

Chapters 2 to 10 provided details of emissions of different pollutants from different sectors in India. The emissions are estimated for the years 2001 and 2011, and also projected for future years till 2051. It is important to understand the relative contributions of different sectors to the overall emission inventories. This chapter focuses on summarization of results and assessment of sectoral contributions to emissions of various pollutants at the National scale. The pollutant-wise results of emission inventories are presented in subsequent sections.

Particulate Matter

Growth of PM_{10} emissions during 2001–51 is presented in Figure 11.1. PM_{10} emissions in India are presently (2011) estimated to be 10,641 kt, dominated by industrial (43 per cent) and residential combustion (29 per cent) sectors. Transport contributes to just 3 per cent of PM_{10} emissions at the National scale. However, these emissions are concentrated at the urban centres where their contribution to the prevailing air quality levels could be much high. On the other hand, emissions from domestic cooking are mainly from biomass burning in rural households using traditional cook stoves. Open burning of agricultural residue in rural areas contributes 8 per cent to the total PM_{10} emissions. Other sectors cumulatively contribute 11 per cent of PM_{10} emissions. Power plant contribute 4 per cent of PM_{10} emissions, however, these may contribute significantly to pollution levels in specific zones of influence of power plants.

The future projections of PM_{10} emissions show that the emissions from industrial sector will grow significantly till 2031. It is mainly due to anticipated growth in the manufacturing sector in the next few decades. Present environmental control scenario in industries is limited considering absence of continuous monitoring, limited vigilance capacity, and limited installations of high efficiency air

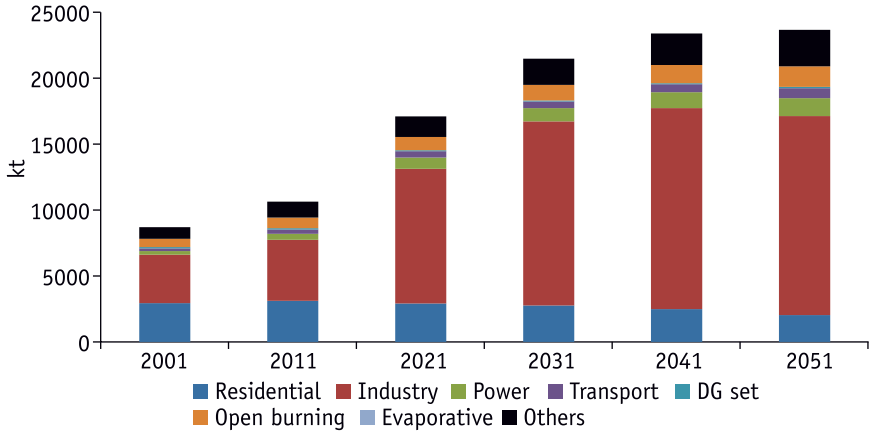


Figure 11.1: Year-wise growth of PM10 emissions (kilotonnes) during 2001–51

pollution control equipments. Enormous growth in infrastructure development sector is expected to fuel the demand for cement and brick in next few decades. Cement industry despite being assumed to be controlled with highly efficient electrostatic precipitators (ESPs) for control of PM emissions, is expected to emit 6.5 times more PM_{10} in 2051 than in 2011. In the brick sector, it is assumed that penetration of Zig-Zag technologies will increase from mere 4 per cent in 2011 to about 44 per cent in 2051, despite which, the PM_{10} emissions will be more than double in 2051 than in 2011. In the medium and small industries, further penetration of ESPs and other control technologies has been assumed. Despite these considerations, the overall emissions from industrial sector will be 3.3 times in 2051 in comparison to the 2011. However, the GDP from industrial sector will grow by 17 times in the same period. This point to tremendous reduction in emission intensity in industrial sector.

Other than industries, the emissions from combustion of fuels in residential sector will reduce because of higher penetration of cleaner fuels for cooking and lighting. On the other hand, emissions from open agricultural biomass burning are expected to go up by six times during 2011–51, with growth in agricultural sector, in a no control scenario. Power sector emissions are expected to grow despite considerations of high-efficiency supercritical technologies and installation of ESPs/flue gas desulphurisation/selective catalytic reduction for tail-pipe control. Transport sector emissions are expected to go down further with considerations of advanced (BS-V) emissions norms from 2020 onwards in India. This could contribute to significant improvements in air quality at the urban scales.

The distribution of energy-based sources have a share of about 80 per cent in PM_{10} emissions, while non-energy sources such as open burning, road dust suspension, mining, and other fugitive sources account for 20 per cent in 2011. Based on different sectoral projections, the share of energy base sources will remain to be about 80 per cent in 2051.

$PM_{2.5}$ emissions also show similar trends as shown by PM_{10} (Figure 11.2). The share of $PM_{2.5}$ emissions in PM_{10} emissions varies from 0.58 to 0.67 during all years in considerations.

Black carbon (BC) and organic carbon (OC) are the two main constituents of PM. BC emissions are mainly a product of incomplete combustions. The 2011 inventories are dominated by residential sector emissions (54 per cent), followed by 20 per cent from transport sector (Figure 11.3a). It is to be noted that while the share of transport was less in PM_{10} or $PM_{2.5}$ fractions, BC inventories show a very significant contribution from the sector mainly form diesel engines. Industries (8 per cent), open agricultural burning (6 per cent), and diesel consumed in diesel

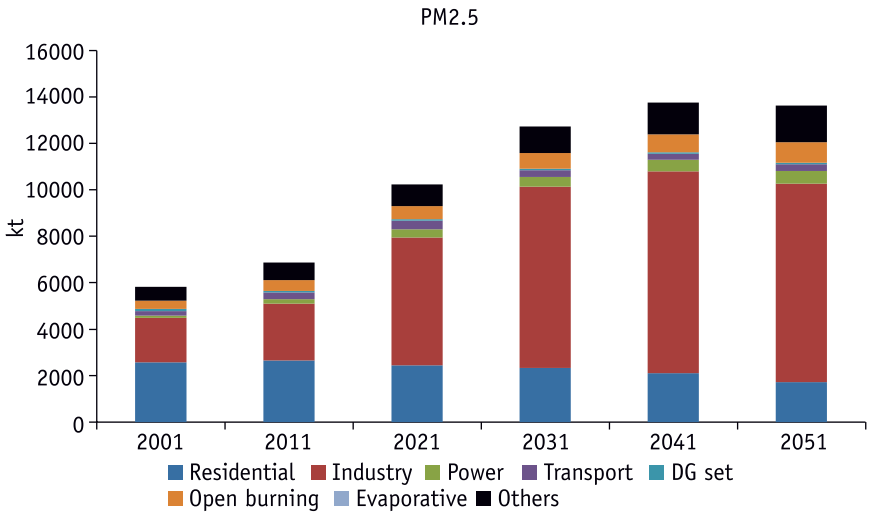


Figure 11.2: Year-wise growth of PM2.5 emissions (kilotonnes) during 2001–51

generator (DG) sets (5 per cent) also contribute to the BC inventories in 2011. The future projections show that the emissions will stabilize over the years, with decrease in contributions from residential and transport sectors. However, emissions from industrial combustion and open burning will increase. Considering the stabilization of BC emission over the years despite growing economy, there will be drastic reduction in BC emission intensity in India.

OC emissions in India are dominated by residential sector (Figure 11.3b), open burning and combustion in other sector (crematoria and refuse burning). However, with decline in biomass usage in future, the emissions are expected to go down in future. However, BC emissions could show higher reductions mainly on account of reduced kerosene usage for lighting, which is a very big source of BC emissions.

Gaseous Pollutants

Figures 11.4 to 11.7 show emission inventories of gaseous pollutants such as NOx, SO_2, CO, and non-methane volatile organic compounds (NMVOC). While PM emissions are somewhat controlled

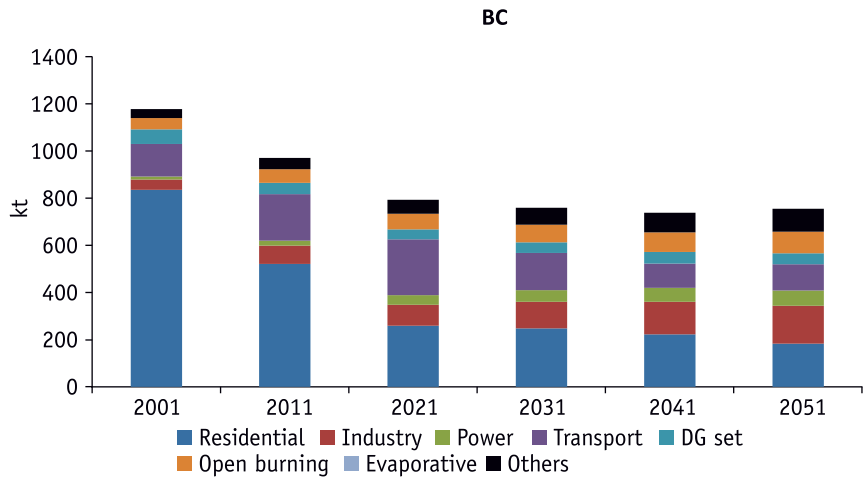


Figure 11.3a: Year-wise growth of BC emissions (kilotonnes) during 2001–51

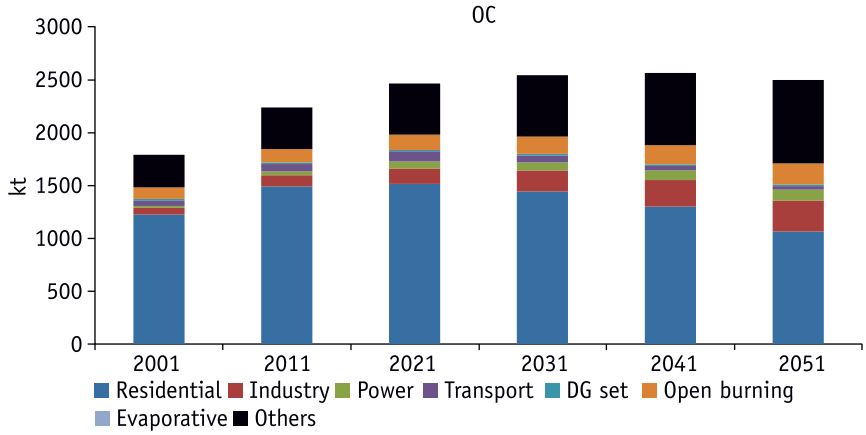


Figure 11.3b: Year-wise growth of OC emissions (kilotonnes) during 2001–51

due to adoption of emission control standards, gaseous pollutants are expected to grow gradually mainly on account of high industrial growth, power consumption, and mobility demands. The current inventories of NOx emissions are dominated by high-temperature combustion in transport sector (38 per cent), power utilities (15 per cent), and DG and agricultural pump sets (17 per cent). While it is expected that with enhanced power generation capacities, the use of small DG in residential and commercial sector set will diminish over the years, the demand for diesel will grow in transport sector. However, introduction of BS-V emission norms will reduce NOx emissions to some extent from the sector. Overall, the NOx emissions are expected to grow 3.1 times between 2001 and 2051.

SO_2 emissions are linked to sulphur content in the fuels used in different sectors. The emissions are presently and in future also will be dominated by coal combustion activities in power and industrial sectors. The sulphur content has already been considerably reduced in the automotive fuels and is planned to reduce it to 10 ppm levels by 2020. In power sector, introduction of control norms for SO_2 will somewhat

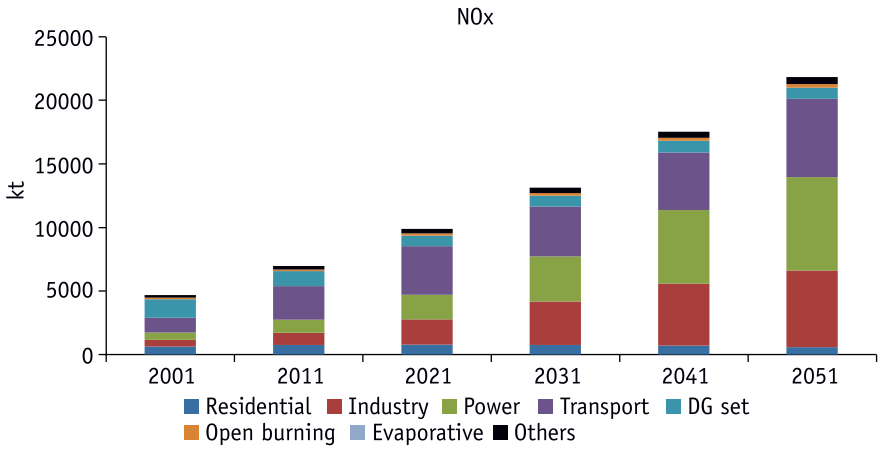


Figure 11.4: Year-wise growth of NOx emissions (kilotonnes) during 2001–51

arrest the growth of emissions. Despite this, with limited SO_2 controls in industrial sector, the emissions are projected to increase by 4.3 times during 2011–51 (Figure 11.5).

Carbon monoxide is also a product of incomplete combustion and is currently dominated by biomass burning in residential sector. However, with penetration of cleaner fuels in the sector, the emission contribution will reduce. On the other hand, the sectoral contribution from transport sector will grow substantially with enormous growth expected in private vehicle ownership. It is to be noted that CO emissions are primarily emitted from gasoline-driven vehicles. CO emissions form iron and steel sector are expected to grow significantly in future. Increased open crop-residue burning activities will add to CO emissions with higher shares in future (Figure 11.6).

Currently NMVOC emissions are dominated by residential biomass burning; however, its contribution will reduce drastically in future. Evaporative emissions from increased paints, printing activities, and use of personal products will increase dramatically in a

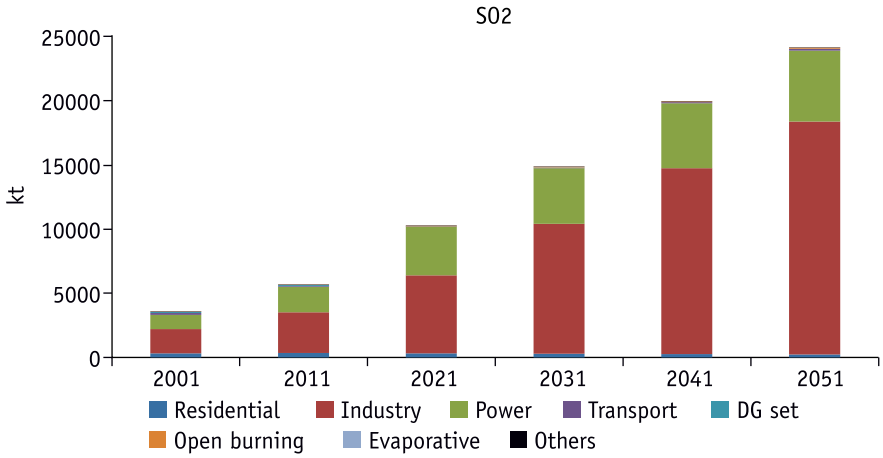


Figure 11.5: Year-wise growth of SO2 emissions (kilotonnes) during 2001–51

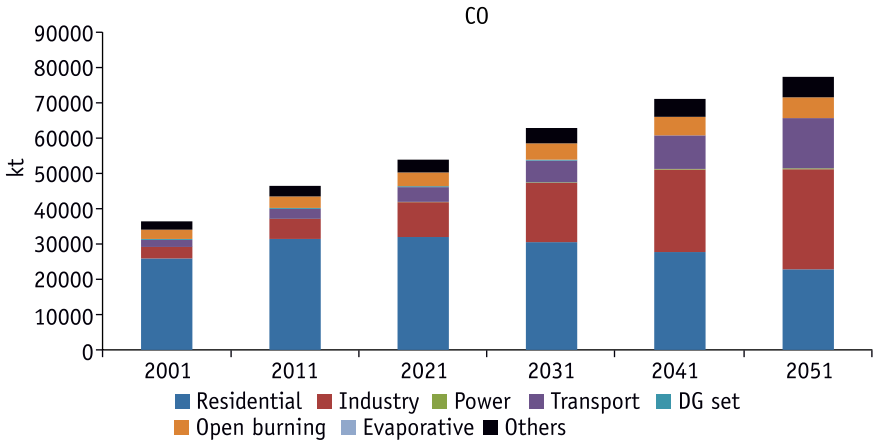


Figure 11.6: Year-wise growth of CO emissions (kilotonnes) during 2001–51

no-control business as usual (RES) scenario (Figure 11.7). The overall NMVOC emissions are projected to increase by four folds by 2051.

Comparison with Other Studies

A comparison of emissions estimated in this study with others is shown in Table 11.1. There is variation in emissions reported by different studies for various pollutants. The emissions estimated in this study show 34%,-23%, 20%, -10%, and 24% differences with the mean of emissions estimated in other studies for PM_{10}, SO_2, NOx, NMVOC, and CO, respectively. The standard deviation observed among all these studies is about 26–33 per cent of the emissions estimated in this study for various pollutants.

The variations observed are due to a number of reasons. Firstly, the estimates are for different years and this study provides the latest estimates for India-based local information. This study has used Indian emission factors for most of the emission sources and also accounts for latest information on controls. For example, introduction of improved vehicular emission norms, norms for DG sets have been accounted in this study. There are also methodological differences in estimation of energy demand in some of the sectors such as residential,

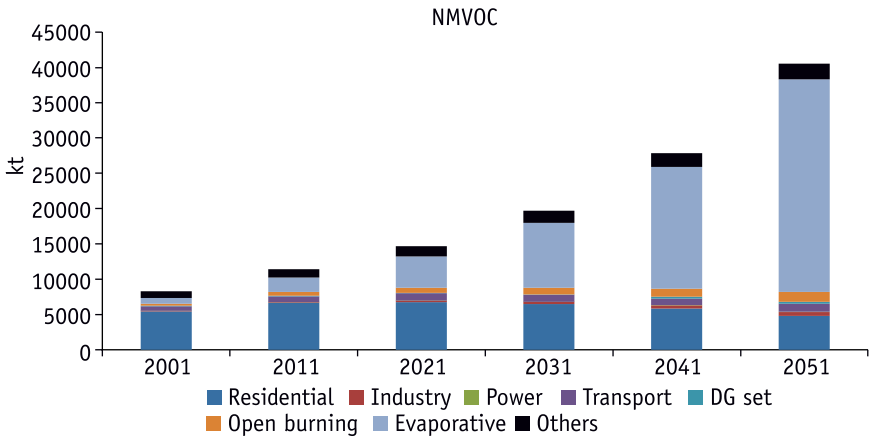


Figure 11.7: Year-wise growth of NMVOC emissions (kilotonnes) during 2001–51

Table 11.1: Comparison of Emission Inventory (Million Tonnes) in This Study with Others

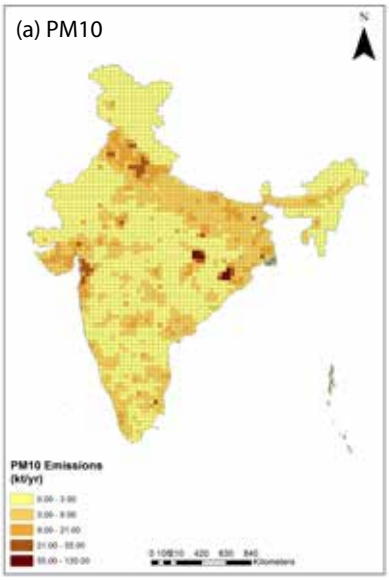
Study	Year	PM10	SO2	NOx	NMVOC	CO
This study	2011	10.6	5.6	7.0	11.4	46.4
Garg et al. (2006)	2005		4.6	4.4		41.7
Streets et al. (2003)	2000		5.5	4.0	8.6	51.1
Ohara et al. (2007)	2003		7.0	5.0	9.7	84.4
Zhang et al. (2009	2006	4.0	5.6	4.9	10.8	61.1
EDGAR 4.2a	2008	10.9	8.5	6.4	10.6	46.3
Kurokawa et al. (2013)	2008	4.7	10.0	9.7	15.9	61.8
Purohit et al (2010)		8.2	6.4	5.0	15.1	
Lu et al. (2011)	2008		8.0			
Klimont et al. (2009)	2005		6.4	5.0		

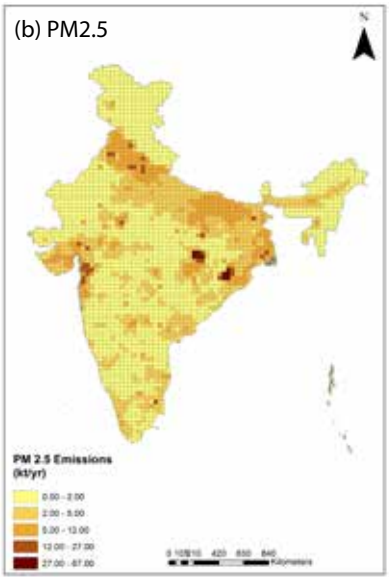
[a] http://edgar.jrc.ec.europa.eu/);

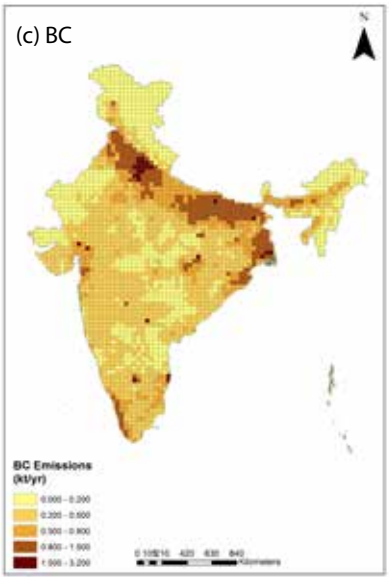
which is primarily dependent on poorly accounted firewood combustion. Moreover, this study includes many more sources such as evaporative, DG sets, agricultural pumpsets, etc., which have not been properly accounted in previous studies.

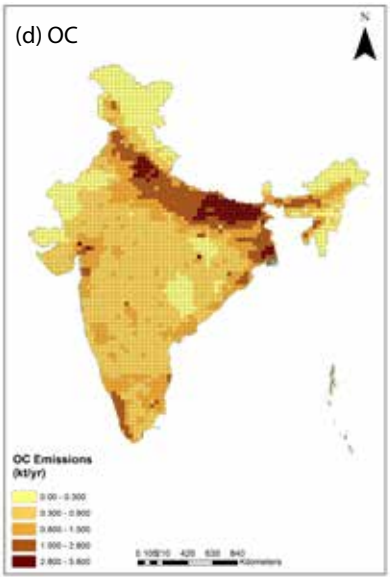
Spatial Distributions

Emissions of different pollutants for all the sectors are spatially distributed using GIS into grids of 36 × 36 km². Figure 11.8(a–f) shows the spatial distribution of different pollutants in India. PM emissions are geographically more in Indo-Gangetic plains (IGP) mainly due to high population density, dependence of biomass for cooking, vehicular density, and presence of power plants. Other than IGP, PM_{10} intensities are higher in the states of Gujarat, Tamil Nadu, and Maharashtra. NOx emissions are mainly concentrated at urban centres and highways, mainly









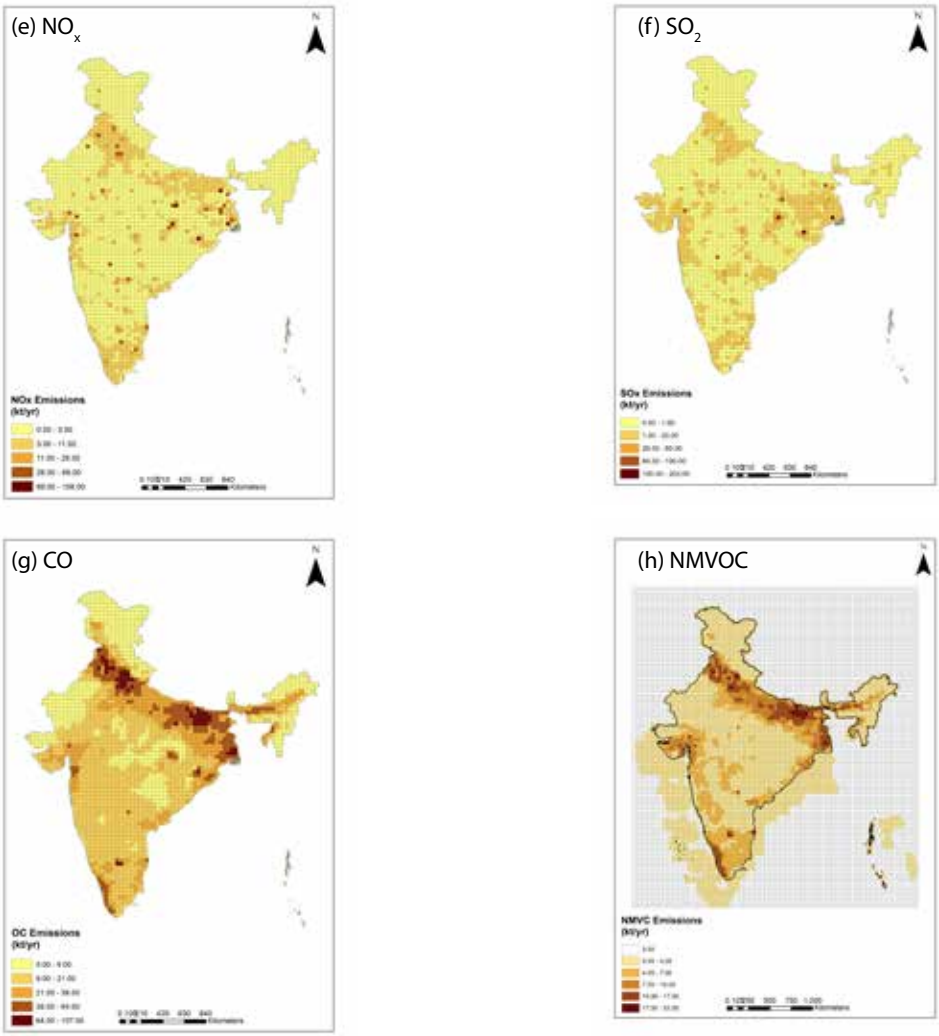


Figure 11.8(a–h): Spatial distribution of PM_{10}, $PM_{2.5}$, BC, OC, NO_x, SO_2, CO, and NMVOC emissions in 2011

due to vehicular activity. SO_2 emissions are found to be higher at locations of power plants, cement plants, iron steel manufacturing units, and other industries burning coal. CO emissions are primarily driven by incomplete combustion in rural households and hence show higher intensities in Bihar, West Bengal, and Uttar Pradesh. NMVOC emissions are also dominated by biomass burning in IGP, followed by emissions in urban centres due to vehicles and solvent use.

Economic Growth and Emissions

While there is growth in emissions projected in future for most of the pollutants, the emission intensities are expected to reduce significantly with controls in different sectors. These controls reduce the emissions intensity (kilotonnes of pollutants per unit of GDP produced) considerably over the years (Figure 11.9).

The emission intensities are also compared with other regions in the world (Figure 11.10 and 11.11).

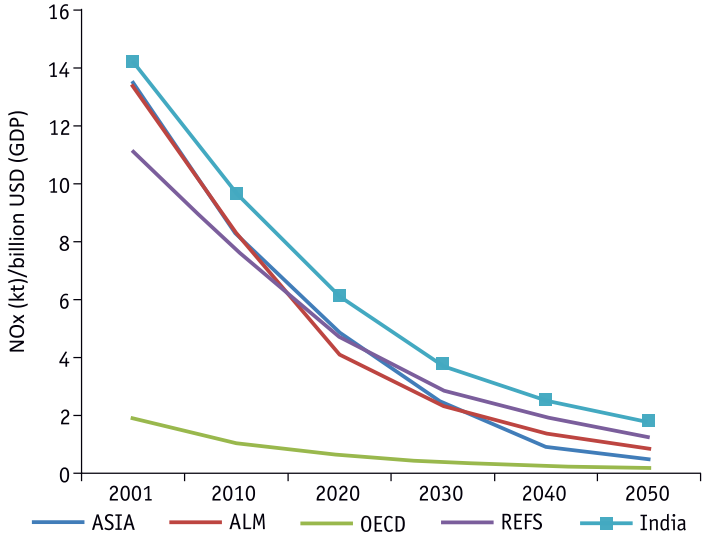


Figure 11.9: Projected emission intensity (kilotonnes/billion USD of GDP) in India over the years

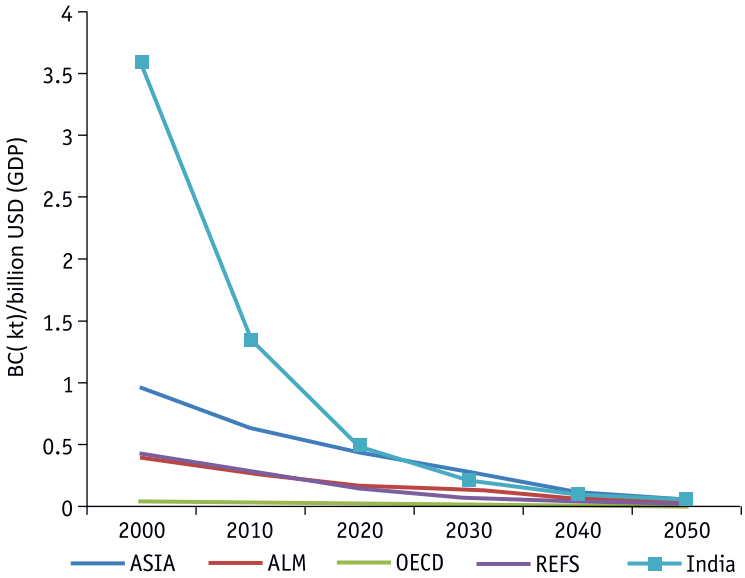


Figure 11.10: Projected NOx emission intensity (kilotonnes/billion USD of GDP) in different regions of the world over the years

Source: http://www.iiasa.ac.at/web-pps/ggi/GgiDb/dsd?Action=htmlpage&page=series

This shows that although the present emission intensities are higher in India, they are slowly reducing to converge with the emission intensities projected for other regions by the year 2050. The GDP is at market exchange rates.

Conclusions

India is on the path of rapid economic growth. While the focus is on poverty alleviation and development, emissions have gradually increased over the years. There are some interventions taken in past for control

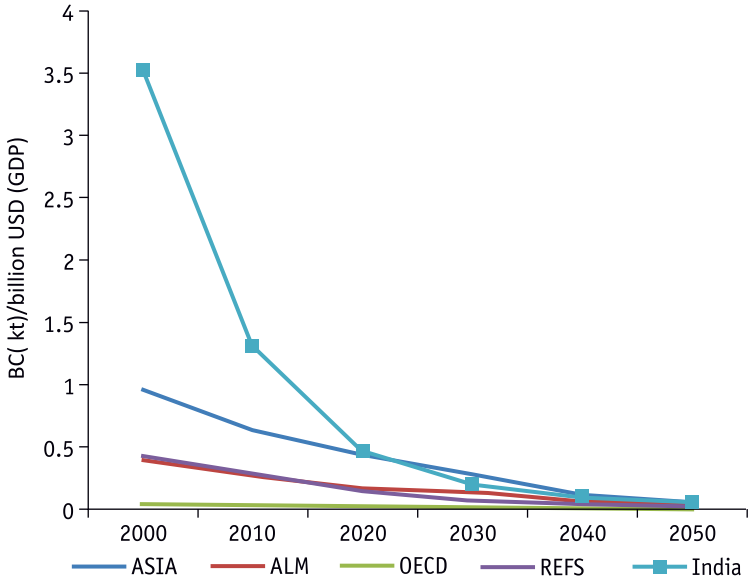


Figure 11.11: Projected BC emission intensity (kilotonnes/billion USD of GDP) in different regions of the world over the years

Source: http://www.iiasa.ac.at/web-apps/ggi/GgiDb/dsd?Action=htmlpage&page=series

OECD90 = Includes the OECD 90 countries, therefore encompassing the countries included in the regions Western Europe (Austria, Belgium, Denmark, Finland, France, Germany, Greece, Iceland, Ireland, Italy, Luxembourg, Netherlands, Norway, Portugal, Spain, Sweden, Switzerland, Turkey, United Kingdom), Northern America (Canada, United States of America), and Pacific OECD (Australia, Fiji, French Polynesia, Guam, Japan, New Caledonia, New Zealand, Samoa, Solomon Islands, Vanuatu) .

REF = Countries from the Reforming Economies region (Albania, Armenia, Azerbaijan, Belarus, Bosnia and Herzegovina, Bulgaria, Croatia, Cyprus, Czech Republic, Estonia, Georgia, Hungary, Kazakhstan, Kyrgyzstan, Latvia, Lithuania, Malta, Poland, Republic of Moldova, Romania, Russian Federation, Slovakia, Slovenia, Tajikistan, TFYR Macedonia, Turkmenistan, Ukraine, Uzbekistan, Yugoslavia).

ASIA = The countries included in the regions China + (China, China Hong Kong SAR, China Macao SAR, Mongolia, Taiwan) , India + (Afghanistan, Bangladesh, Bhutan, India, Maldives, Nepal, Pakistan, Sri Lanka) and Rest of Asia (Brunei Darussalam, Cambodia, Democratic People's Republic of Korea, East Timor, Indonesia, Lao People's Democratic Republic, Malaysia, Myanmar, Papua New Guinea, Philippines, Republic of Korea, Singapore, Thailand, Viet Nam) are aggregated into this region.

MAF = This region includes the Middle East (Bahrain, Iran (Islamic Republic of), Iraq, Israel, Jordan, Kuwait, Lebanon, Oman, Qatar, Saudi Arabia, Syrian Arab Republic, United Arab Emirates, Yemen) and African (Algeria, Angola, Benin, Botswana, Burkina Faso, Burundi, Cote d'Ivoire, Cameroon, Cape Verde, Central African Republic, Chad, Comoros, Congo, Democratic Republic of the Congo, Djibouti, Egypt, Equatorial Guinea, Eritrea, Ethiopia, Gabon, Gambia, Ghana, Guinea, Guinea-Bissau, Kenya, Lesotho, Liberia, Libyan Arab Jamahiriya, Madagascar, Malawi, Mali, Mauritania, Mauritius, Morocco, Mozambique, Namibia, Niger, Nigeria, Reunion, Rwanda, Senegal, Sierra Leone, Somalia, South Africa, Sudan, Swaziland, Togo, Tunisia, Uganda, United Republic of Tanzania, Western Sahara, Zambia, Zimbabwe) countries.

LAM = This region includes the Latin American countries (Argentina, Bahamas, Barbados, Belize, Bolivia, Brazil, Chile, Colombia, Costa Rica, Cuba, Dominican Republic, Ecuador, El Salvador, Guadeloupe, Guatemala, Guyana, Haiti, Honduras, Jamaica, Martinique, Mexico, Netherlands Antilles, Nicaragua, Panama, Paraguay, Peru, Puerto Rico, Suriname, Trinidad and Tobago, Uruguay, Venezuela).

where MAF and LAM are together, the former ALM region of the SRES scenarios

of air pollution mainly at the urban scales in India. However, the recent studies have suggested that the regional scale improvements are required to effectively control pollution levels at urban and regional scales. This calls for preparation of databases for emissions inventories to carry out simulation studies for regional scale improvement of air quality in India. This study presents a multi-scale high-resolution emission inventory for India for the baseline (2011) and future years till 2051. The estimates are based on TERI's

earlier work in developing energy use scenarios for the country. Established methodologies have been used to estimate emissions from different sectors and useful insights have been drawn. It is noted that while residential sector biomass burning–based emissions are significantly high currently, they are projected to reduce considerably in next few decades. On the other hand, rapid industrial growth will lead to significant emissions and in a limited control scenario, the emission are expected to increase in future. Transport PM emissions may not be found significantly high at the National scale but are significantly concentrated at the urban levels, leading to higher contributions there. Key sectoral recommendations that are made for control of emissions are :

Power and industries

- Development of standards for NOx and other important gaseous pollutants
- Installation and maintenance of APC devices
- Continuous monitoring and reporting of stacks
- Development emission trading schemes and other fiscal measures for performance beyond compliance levels
- Ensuring 24×7 power supply to reduce DG Set usage.

Transport

- Adoption of stringent auto fuel policy and vehicle emission norms
- On-road vehicle emission management : I&M systems, fleet modernization, retrofitment
- Enhancement of public transportation systems
- Development of fuel efficiency standards
- Electric mobility
- Promotion of non-motorized transport options

Residential

- Enhanced penetration of LPG
- Penetration of improved cook stoves, R&D

Open burning

- Development of plans for more productive energy use of the crop-residues currently burnt

Evaporative emissions

- Development of standards for control of evaporative/fugitive emissions from different product use
- Installation of stage-I/II control at oil handling units.
- Control of evaporative emissions from vehicles

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Annexure

Annexure 11.1: Sectoral emission estimates (kt/yr) of different pollutants 2001–51

PM10	Sectors	2001	2011	2021	2031	2041	2051
	Residential	2944	3115	2913	2774	2502	2048
	Industry	3685	4627	10212	13953	15230	15093
	Power	257	453	869	1016	1216	1354
	Transport	218	342	478	498	594	761
	DG set	104	82	72	76	81	78
	Open burning	620	818	1004	1190	1376	1562
	Evaporative						
	Others	890	1204	1561	1976	2399	2773
	Total	8717	10641	17110	21483	23398	23668
PM2.5	Sectors	2001	2011	2021	2031	2041	2051
	Residential	2570	2660	2450	2333	2104	1723
	Industry	1923	2451	5507	7816	8706	8546
	Power	103	181	348	407	487	542
	Transport	194	288	371	293	256	296
	DG set	88	70	61	65	69	66
	Open burning	350	462	567	672	777	882
	Evaporative						
	Others	602	756	942	1149	1363	1574
	Total	5830	6867	10246	12733	13760	13629
BC	Sectors	2001	2011	2021	2031	2041	2051
	Residential	835	521	260	247	223	183
	Industry	44	77	88	113	138	161
	Power	12	22	42	49	58	65
	Transport	138	197	235	158	104	111
	DG set	62	49	43	46	48	47
	Open burning	48	57	66	75	83	92
	Evaporative						
	Others	38	48	59	72	84	97
	Total	1178	971	794	759	739	755
CO	Sectors	2001	2011	2021	2031	2041	2051
	Residential	25942	31385	31953	30560	27696	22827
	Industry	3196	5728	9921	16751	23370	28335
	Power	23	43	72	128	207	286

	Transport	1983	2777	4149	6173	9488	14167
	DG set	318	251	288	304	0	0
	Open burning	2549	3244	3905	4565	5225	5885
	Evaporative						
	Others	2389	3006	3621	4328	5059	5799
	Total	36401	46435	53909	62809	71046	77299
NOx	Sectors	2001	2011	2021	2031	2041	2051
	Residential	633	766	789	762	699	585
	Industry	520	950	1980	3405	4877	6038
	Power	573	1015	1935	3565	5786	7334
	Transport	1164	2665	3826	3904	4530	6162
	DG set	1475	1164	833	877	929	893
	Open burning	104	137	169	200	232	263
	Evaporative						
	Others	220	280	344	415	488	562
	Total	4689	6978	9876	13129	17540	21838
SO2	Sectors	2001	2011	2021	2031	2041	2051
	Residential	303	330	314	299	270	221
	Industry	1901	3175	6070	10118	14478	18147
	Power	1031	1842	3490	3981	4650	5108
	Transport	120	53	27	50	87	145
	DG set	97	77	15	16	0	0
	Open burning	30	40	50	59	68	77
	Evaporative	0	0	0	0	0	0
	Others	29	37	46	55	65	75
	Total	3512	5553	10011	14577	19617	23773
NMVOC	Sectors	2001	2011	2021	2031	2041	2051
	Residential	5457	6637	6771	6471	5860	4824
	Industry	74	123	194	305	425	532
	Power	4	8	14	25	40	53
	Transport	605	802	1026	980	926	1103
	DG set	120	95	68	72	247	304
	Open burning	274	512	732	952	1173	1393
	Evaporative	797	2050	4431	9194	17233	30089
	Others	952	1191	1418	1684	1960	2238
	Total	8283	11418	14652	19683	27863	40536
OC	Sectors	2001	2011	2021	2031	2041	2051
	Residential	1222	1488	1513	1441	1300	1064

	Industry	63	107	143	198	248	290
	Power	20	34	66	77	92	103
	Transport	47	70	96	66	42	35
	DG set	19	15	13	14	15	14
	Open burning	109	128	145	163	180	198
	Evaporative						
	Others	309	392	482	581	684	788
	Total	1787	2234	2459	2540	2561	2493

Annexure 11.2: State-wise emission estimates (kt/yr) of different pollutants in 2011

States	PM10	PM2.5	NOx	SO2	CO	BC	OC	NMVOC
Andhra Pradesh	708	415	553	440	2956	54	126	736
Arunachal Pradesh	25	15	19	4	186	4	8	47
Assam	247	170	89	44	1594	30	72	364
Bihar	500	375	311	165	3834	65	224	891
Chhattisgarh	818	541	323	533	1222	36	34	145
Goa	22	10	19	14	42	1	2	16
Gujarat	1129	637	519	542	2509	48	99	804
Haryana	293	189	254	124	1355	30	49	322
Himachal Pradesh	92	51	65	39	392	7	16	98
Jammu & Kashmir	78	52	75	39	526	11	24	118
Jharkhand	238	153	194	210	1856	25	58	320
Karnataka	468	250	376	214	2401	42	105	657
Kerala	179	95	203	80	1250	24	54	350
Madhya Pradesh	568	384	366	246	2620	54	139	659
Maharashtra	748	469	589	528	3456	70	141	925
Manipur	12	10	14	1	93	2	4	23
Meghalaya	32	23	25	11	172	4	7	41
Mizoram	12	7	10	2	73	1	3	20
Nagaland	16	9	13	3	107	2	5	26
Orissa	963	630	307	392	2297	53	85	465
Punjab	461	280	267	149	2011	34	60	370
Rajasthan	617	421	439	354	2700	63	128	674
Sikkim	4	3	3	1	23	0	1	6
Tamil Nadu	414	246	553	418	1924	51	91	549
Tripura	27	16	13	3	218	4	9	50
Uttar Pradesh	1207	916	733	468	6985	159	391	1540
Uttaranchal	167	87	67	45	716	12	23	147
West Bengal	514	364	444	483	2858	62	138	664

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