Atmospheric Environment 92 (2014) 449–460

Contents lists available at ScienceDirect

Atmospheric Environment

journal homepage: www.elsevier.com/locate/atmosenv

Atmospheric emissions and pollution from the coal-fired thermal power plants in India

Sarath K. Guttikunda[a,b,*], Puja Jawahar[c]

[a] Division of Atmospheric Sciences, Desert Research Institute, Reno, NV 89512, USA
[b] Transportation Research and Injury Prevention Program, Indian Institute of Technology, New Delhi 110016, India
[c] UrbanEmissions.Info, New Delhi 110019, India

HIGHLIGHTS

- Review of emission factors and emissions analysis for coal-fired power plants.
- Review of environmental regulations for air pollution from coal-fired power plants.
- Particulate pollution analysis via CAMx dispersion model.
- Health impacts of particulate pollution from coal-fired power plants.

ARTICLE INFO

Article history:
Received 6 February 2014
Received in revised form
26 April 2014
Accepted 29 April 2014
Available online 2 May 2014

Keywords:
Environmental regulations
Particulates
Sulfates
Flue gas desulfurization
CAMx
Health impacts

ABSTRACT

In India, of the 210 GW electricity generation capacity, 66% is derived from coal, with planned additions of 76 GW and 93 GW during the 12th and the 13th five year plans, respectively. Atmospheric emissions from the coal-fired power plants are responsible for a large burden on human health. In 2010–11, 111 plants with an installed capacity of 121 GW, consumed 503 million tons of coal, and generated an estimated 580 ktons of particulates with diameter less than 2.5 μm ($PM_{2.5}$), 2100 ktons of sulfur dioxides, 2000 ktons of nitrogen oxides, 1100 ktons of carbon monoxide, 100 ktons of volatile organic compounds, and 665 million tons of carbon dioxide. These emissions resulted in an estimated 80,000 to 115,000 premature deaths and 20.0 million asthma cases from exposure to $PM_{2.5}$ pollution, which cost the public and the government an estimated INR 16,000 to 23,000 crores (USD 3.2 to 4.6 billion). The emissions were estimated for the individual plants and the atmospheric modeling was conducted using CAMx chemical transport model, coupled with plume rise functions and hourly meteorology. The analysis shows that aggressive pollution control regulations such as mandating flue gas desulfurization, introduction and tightening of emission standards for all criteria pollutants, and updating procedures for environment impact assessments, are imperative for regional clean air and to reduce health impacts. For example, a mandate for installation of flue gas desulfurization systems for the operational 111 plants could reduce the $PM_{2.5}$ concentrations by 30–40% by eliminating the formation of the secondary sulfates and nitrates.

1. Introduction

India, at 210 GW, has the 5th largest electricity generation sector in the world (with captive power plants generating 31 GW more), with targets of additional 76 GW in the 12th five year plan (2012–2017) and another 93 GW in the 13th five year plan (Prayas, 2011, 2013). Thermal power plants account for 66% of generation, hydro for 19% and others (including nuclear energy) for 15%. In India, coal is the primary fuel of choice and accounts for 50–55% of the power generation and will only get larger in the coming years (Chikkatur et al., 2011; WISE, 2012; Prayas, 2013).

In India, the supply of electricity lags behind the demand. According to the Central Electricity Authority (CEA), in 2010–11, of the 122 GW peak demand, only 110 GW was supplied – which amounted to a shortfall of 10% (CEA, 2012). A third of the population that lives in rural India does not have access to electricity. Even those with access in urban India have to endure frequent power

* Corresponding author. Division of Atmospheric Sciences, Desert Research Institute, Reno, NV 89512, USA.
E-mail addresses: sguttikunda@gmail.com, sarath.guttikunda@dri.edu (S. K. Guttikunda).

http://dx.doi.org/10.1016/j.atmosenv.2014.04.057
1352-2310/

cuts and load shedding, which results in use of in-situ diesel generator sets (Guttikunda and Jawahar, 2012; Guttikunda and Calori, 2013).

Coal-fired power generation comes with significant costs to environment and human health. The water runoff from coal washeries carries pollution loads of heavy metals that contaminate ground water, rivers, and lakes – thus affecting aquatic flora and fauna (Finkelman, 2007). Fly-ash residue and pollutants contaminate soil and are especially harmful to agricultural activities. Most importantly for human health, combustion of coal releases emissions of sulfur dioxide (SO_2), nitrogen oxides (NO_x), particulate matter (PM), carbon monoxide (CO), volatile organic compounds (VOCs), and various trace metals like mercury, into the air through stacks that can disperse this pollution over large areas. The 2010 global burden of disease (GBD) study listed the outdoor air pollution (PM and ozone pollution) among the top 10 health risks in India, with as estimated 695,000 annual premature deaths from respiratory illnesses, compromised immune systems, and cardiovascular conditions (IHME, 2013). The known sources of outdoor air pollution in India include emissions from power plants, manufacturing industries, vehicle exhaust, cooking and heating in the households, generator sets, nature dust, on-road dust resuspension, garbage burning, and seasonal agricultural burning.

Previously, the studies on power plants in India focused on coal usage trends, resource management, greenhouse gas emissions, and innovation in use of renewable energy (Chikkatur and Sagar, 2009; Chikkatur et al., 2011; Prayas, 2011; Chaudhary et al., 2012; Ghose, 2012; WISE, 2012; Prayas, 2013) and total emissions inventories for base year 2005 or older (Streets et al., 2003; Reddy et al., 2005; Ohara et al., 2007; GAINS, 2012). Of the estimated annual anthropogenic emissions in India, the thermal power plants account for ~15% for $PM_{2.5}$, ~30% for NO_x, and ~50% of SO_2 (GAINS, 2012). Studies based on satellite measurements (Lu and Streets, 2012; Prasad et al., 2012) looked at the influence of power plant emissions on the column NO_x concentrations, including the influences of other sources, but there is limited bottom-up analysis on dispersion of emissions from the coal-fired power plants.

Given the plans to greatly expand the contribution of coal to the Indian power sector (Chikkatur et al., 2011; WISE, 2012; Prayas, 2013), it is vital that decision makers understand the hidden costs of air pollution from power plants. In this paper, we present an updated list of operational coal-fired power plants in India, their generation capacities, coal consumption rates, and evaluation of the health impacts of their pollution via dispersion modeling. We also discuss the current environmental regulations for power plants in India or their lack of.

2. Data and methods

2.1. Coal-fired power plants in India

The installed power generation capacity in India grew at an average annual rate of 8% in the 1970s and at 10% since the 1980s (WISE, 2012; Prayas, 2013). The characteristics of operational coal-fired power plants in India are presented in Table 1 and the location of these plants is presented in Fig. 1. The database of plants documented by CEA was further updated with information from websites and annual reports of the state electricity boards and private electricity generation companies (CEA, 2011; CEA, 2012). The database includes geographical location in latitude and longitude, number of boiler units and size of all known power plants operated by both public and private entities.

Power plants are clustered at pit heads of coal mines in Central India, in northern Andhra Pradesh, western Maharashtra, northern Chhattisgarh, West Bengal, Bihar, Jharkhand, and Orissa. Some large power plants are located on the coast, for the availability of cooling water from the sea and ease of importing coal. While the coastal winds are beneficial in some cases, the impacts are still at large for cities in the vicinity. For example, Chennai (Tamilnadu) and Ahmedabad (Gujarat), each host two coal-fired power plants of more than 1000 MW electricity generation and located closer to the city premises. Chennai, being a coastal city, records a smaller fraction of the power plant emissions in their ambient measurements, compared to Ahmedabad, which is in-land (Guttikunda and Jawahar, 2012). In Delhi, up to 8% of the ambient PM pollution can be attributed to the coal-fired power plants of 2000 MW, operated within 60 km from the city center (Guttikunda and Goel, 2013). Similar shares are expected for the cities of Mumbai, Ahmedabad, Kolkata, and some medium to smaller size cities like Nagpur, Raipur, Ranchi, Kota, Bhatinda, Raichur, with power plants in the vicinity of 100 km.

Table 1
Summary of annual coal consumption at the power plants in India in 2010–11.

State	Number of plants	MW	Coal million tons	kg coal/kWh 2006–07	% Installed units <210 MW
Andhra Pradesh	8	10,523	47.4	0.72	65%
Bihar	3	2870	10.2	0.94	77%
Chhattisgarh	8	9480	44.5	0.72	39%
Delhi	2	840	4.8	0.77	100%
Gujarat	11	14,710	55.9	0.65	69%
Haryana	5	5860	23.9	0.70	35%
Jharkhand	6	4548	12.0	0.75	86%
Karnataka	5	3680	14.6	0.69	64%
Madhya Pradesh	4	6703	33.1	0.79	79%
Maharashtra	13	17,560	71.5	0.73	51%
Orissa	8	8943	40.7	0.73	76%
Punjab	3	2620	13.2	0.66	82%
Rajasthan	4	3490	13.2	0.67	44%
Tamilnadu	8	6210	25.8	0.72	95%
Uttar Pradesh	11	11,997	56.0	0.80	86%
West Bengal	12	10,695	36.1	0.69	75%
Total	**111**	**120,727**	**503**	**0.73 ± 0.10**	**70%**

2.2. Coal characteristics

Indian coal (Gondwana coal) has high ash content (35–45%) and low calorific value (averaging 3820 kcal/kg in 2003–04 and 3603 kcal/kg in 2010–11). The sulfur content in Indian coals is less than those observed in the United States (1.0–1.8%) and Chinese coals (0.5–1.0%). The sulfur content in the Indian coal has a consumption-weighted average of 0.6% (Reddy and Venkataraman, 2002).

The high ash content and low calorific value affects the thermal power plant's operational efficiency and increases emissions per kWh generated. As a comparison, power plants in India use about 0.72 ± 0.10 kg of coal to generate 1 kWh, while a power plant in the USA of the same technology would consume 0.45 kg of coal per kWh (Chikkatur, 2008). The estimated annual coal consumption rates by state are listed in Table 1. The average thermal efficiency of the coal-fired power plants in India between 2004 and 2011 remained 32–33% (CEA, 2012) while this is peaking above 35% for the power plants in China (Seligsohn et al., 2009).

The high silica and alumina content in Indian coal ash is another problem, as it increases ash resistivity and reduces the collection efficiency at the electrostatic precipitators (ESPs). To address this issue, the government has mandated the use of coal whose ash content has been reduced to at least 34% in power plants in urban, ecologically sensitive, and other critically polluted areas. The