Regulating Air Pollution from Coal-Fired Power Plants in India

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Coal remains the main fossil fuel for power generation in India. The health impacts of air pollution from these coal-fired power plants include numerous premature deaths and frequent asthma attacks. In the future, the amount of power generated from coal will remain high, at least through 2030, and unless we find a better way to manage these power plants, the environmental effects of growing air pollution, greenhouse gas emissions and the cost to human health will all be high.

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The Indian economy is the third largest in the world at $4.7 trillion (purchasing power parity, PPP at 2012 estimates) spurred by growth across manufacturing, construction, and service sectors. Not coincidentally, it is also the fourth largest consumer of electricity in the world. The demand for electricity from a growing economy of this scale is huge – peak demand was approximately 122 gigawatts (GW) of power in 2011. Peak supply (at 110 GW) could barely keep up with peak demand in 2011. The gap between the supply and demand for electricity is crucial to understand the power sector in India.

In India a third of the population in rural areas does not have access to electricity and those areas on the grid are not assured of uninterrupted supply. The blackout in July 2012, that paralysed 600 million people in 22 states in the northern, eastern, and north-eastern India, is testament to how tenuous the power situation is in the country. According to the Northern Regional Load Dispatch Centre, Uttar Pradesh, Punjab, and Haryana were responsible for overdraw that led to tripping in the transmission lines, and resulted in a shortage of over 32 GW on 30-31 July 2013 and a blackout for three days. While this was the major episode that drew attention to the grid, there are frequent power cuts in most parts of the country. In the urban sector, these cuts are severe in the winter and summer months, when heaters or air conditioners are in full service. These needs are usually supplemented by in situ large, medium, and small diesel generator sets at hotels, hospitals, malls, markets, large institutions, apartment complexes, cinemas, and farmhouses and these form an additional source of air pollution to the already deteriorating quality of air in cities.

The power sector in India is consequently dealing with two competing priorities: (a) to provide necessary power to fuel a growing economy, and (b) to reduce the environmental and social costs of providing this power.

In this article, we draw attention (or lack thereof) towards addressing the environmental costs of electricity generation, assess the air-pollution-related health impacts of emissions from coal-fired power plants, and an analysis of the current environmental regulatory framework for coal-fired power plants in India.

Coal-Fired Power Plants

India has the fifth largest electricity generation sector in the world at 210 GW in 2012. In the Twelfth and Thirteenth Five-Year Plans, additional capacity of 76 GW and 93 GW are planned (Prayas 2013). Of the total electricity generated, thermal power plants (gas and coal) account for 66%, hydroelectricity for 19%, and the remaining 15% from other sources including natural gas and nuclear energy.

We used the list of thermal power plants documented by the Central Electricity Authority (CEA) as a starting point to build our database of operational coal-fired power plants in the country (CEA 2011, 2012). We updated this database for 2011-12 representing a total generation capacity of 121 GW. We also include in the database geographical location in latitude and longitude, the number of boiler units and size of all known power plants operated by both public and private entities. The power plant characteristics by state are presented in Table 1 (p 63). The geographical distribution of the coal-fired power plants in India is presented in Figure 1 (p 63).

- The Korba cluster (Chhattisgarh) has a combined generation capacity of 4,380 megawatt (MW) between four power plants located within a 10 km radius. Major cities in the Korba region are Ranchi, Jamshedpur, Rourkela, Jabalpur, Nagpur, and the capital Raipur.
- The Jhajjar cluster (Haryana) has a combined generation capacity of 2,700 MW between two power plants within

the radius of 10 km, with an additional power plant with 1,000 MW under construction. Delhi is 70 km from the Jhajjar cluster.

Table 1: Summary of Annual Coal Consumption at the Power Plants in India in 2011-12

State	Number of Plants	MW	Coal (Million Tonnes)	kg coal/kWh 2006-07	Installed Units <210 MW (%)
Andhra Pradesh	8	10,523	47.4	0.72	65
Bihar	3	2,870	10.2	0.94	77
Chhattisgarh	8	9,480	44.5	0.72	39
Delhi	2	840	4.8	0.77	100
Gujarat	11	14,710	55.9	0.65	69
Haryana	5	5,860	23.9	0.70	35
Jharkhand	6	4,548	12.0	0.75	86
Karnataka	5	3,680	14.6	0.69	64
Madhya Pradesh	4	6,703	33.1	0.79	79
Maharashtra	13	17,560	71.5	0.73	51
Odisha	8	8,943	40.7	0.73	76
Punjab	3	2,620	13.2	0.66	82
Rajasthan	4	3,490	13.2	0.67	44
Tamil Nadu	8	6,210	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	1,20,727	503	0.73±0.10	70

- The Mundra cluster (Gujarat) has a combined generation capacity of 9,620 MW from two private sector power plants located within a 5 km radius. Major cities in the Mundra region are Jamnagar (major industrial port), Rajkot, and Ahmedabad (300 km away, with two local power plants of 1,000 MW).
- The Mumbai cluster (Maharashtra) has one coal-based power plant in Trombay and multiple gas-powered plants.

This data was gathered from websites and annual reports of the state electricity boards for public[1] and private sectors.[2]

Emissions and Health Impacts

Air pollution is a complex mixture of pollutants with sources ranging from fossil fuel burning in transportation, power generation, industries, and domestic sectors to natural sources such as dust storms and forest fires. In this study, our objective was to isolate the health impacts of the emissions from the coal-fired power plants. In 2011, we estimated that the 111 coal-fired power plants consumed 503 million tonnes of coal in total – emitting 580 kilotonnes particulates with diameter less than 2.5 micrometres ($PM_{2.5}$), 2,100 kilotonnes of sulphur dioxides (SO_2), 2,000 kilotonnes of nitrogen oxides (NO_x), 1,100 kilotonnes of carbon monoxide (CO), 100 kilotonnes of volatile organic compounds (VOCs) and 665 million tonnes of carbon dioxide (CO_2).

These emissions resulted in an estimated 80,000 to 1,15,000 premature deaths and more than 20 million asthma cases from exposure to total $PM_{2.5}$ pollution, which cost the public and the government an estimated Rs 16,000 crore to Rs 23,000 crore ($3.2 to $4.6 billion). The health impacts analysis of these emissions was carried out via state-of-the-art dispersion modelling system (CAMx) and the use of health risk coefficients established by epidemiological studies (Guttikunda and Jawahar 2013). We believe that the health impacts discussed here is an underestimation, and does not include the impacts of the water run-off and soil contamination due to the release of heavy metals like zinc, copper, manganese, cobalt, cadmium, selenium, mercury, arsenic, iron, lead, and chromium.

The particulate matter (PM) pollution from coal-fired power plants (presented in Figure 2, p 64) in central India covering Madhya Pradesh, Jharkhand, Odisha, and Chhattisgarh, is the highest due to the density of the power plants in the region and higher installed generation capacity because of its proximity to coal mines. The Delhi-Haryana region with the highest population density, with more than 21.5 million inhabitants in Delhi and its satellite cities, also experiences substantial PM pollution from coal-fired power plants.

The coastal regions experience the least of the PM pollution due to strong

Figure 1: Geographical Location of the Operational Coal-based Public and Private Power Plants in India in 2012

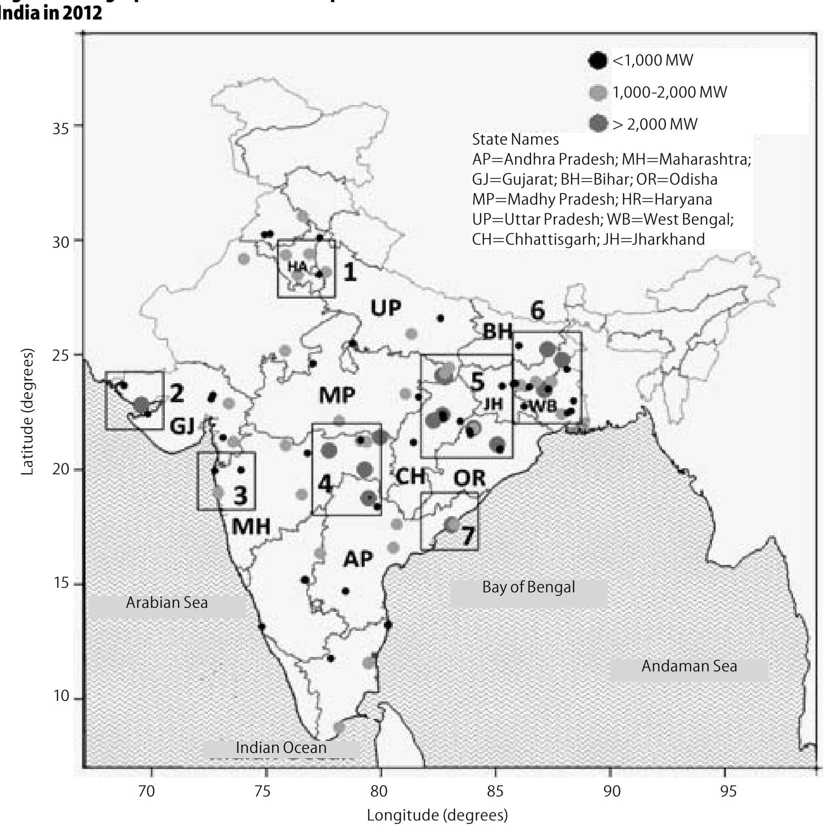
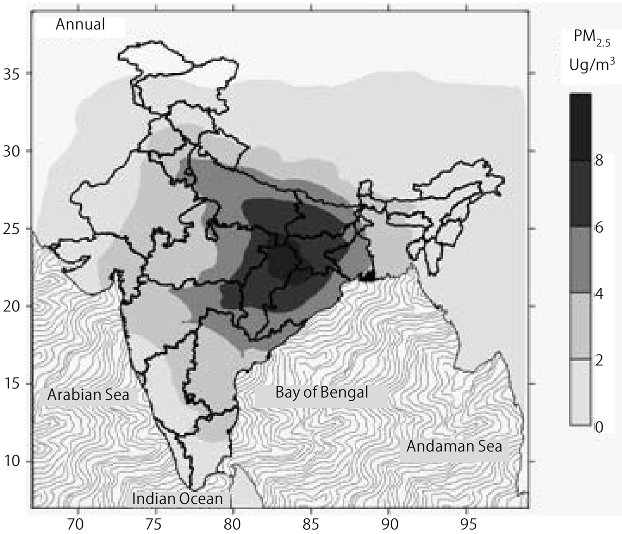
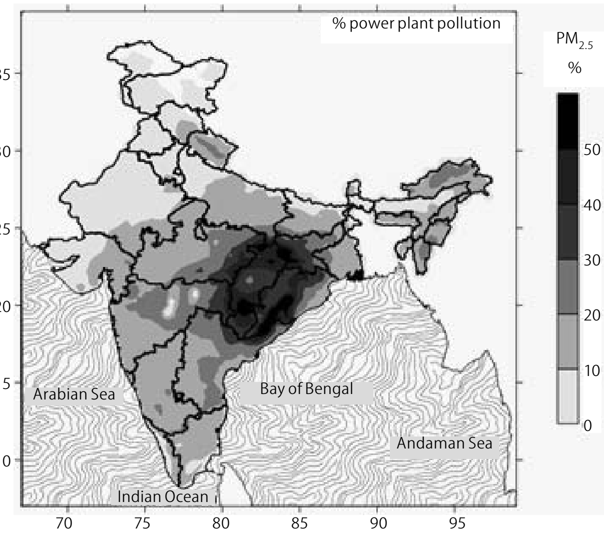


Figure 2a: Modelled Annual Average Ambient $PM_{2.5}$ Concentrations due to the Emissions from Coal-Fired Thermal Power Plants in India



(Based on Satellite Measurements – van Donkelaar et al 2010).

Figure 2b: Per Cent Contribution of Coal-Fired Power Plants to Annual Average Ambient $PM_{2.5}$ Concentrations in India



land-sea breezes, with much of the pollution dispersed over the seas. While the air pollution from these coastal power plants is diluted over the seas for some months, they are equally threatening to water and soil quality, due to pollution from coal washeries and ash dumps. Till date the inland power plants are still the majority in the country and a serious threat to human health and other environmental concerns.

While the impact of the emissions is felt within 200 km of the power plants, under windy conditions the influence can be tracked to distances as far as 400 km from the source region. The animated forward trajectories[3] illustrate that the emissions from these high stacks affects regions and people far from the source region. The plumes travel long distances, while the pollution levels get diluted, these receptor points still experience an increase in the ambient concentration and also an increase in the morbidity and mortality risks. Impacts also include deposition of heavy metals, sulphur oxides, and ozone on agricultural land.

Environmental Regulations

Despite the volume of coal use in the power generation sector and the corresponding emissions and health impacts, there are very few regulations in place to address the environmental and health costs of coal. Till date, pollution standards only exist for ambient air quality and not for individual power plants. Only after standards are set and regulations mandated at the plant level, can we proceed to the next steps of monitoring and enforcing policy, so as to have lesser environment and health impact due to coal-fired power plants. For particulate matter emissions, the emission standard in India lags to those implemented in China, Australia, the United States (US), and the European Union (EU) (Table 2). For other key pollutants, there are no prescribed emission standards despite the fact that India is a relatively dense country and several power plants are close to residential areas.

All the stack emissions at the power plants are monitored and regulated as concentrations only and not in terms of

Table 2: Summary of Emission Standards for Coal-Fired Power Plants

Country	PM	SO_2	NO_2	Mercury
India[a]	350 mg/Nm^3 for <210 MW 150 mg/Nm^3 for >210 MW	None	None	None
China[b]	30 mg/Nm^3 (proposed all) 20 mg/Nm^3 for key regions	100 mg/Nm^3 for new 200 mg/Nm^3 for old 50 mg/Nm^3 for key regions	100 mg/Nm^3	None
Australia[c]	100 mg/Nm^3 for 1997-2005 50 mg/Nm^3 after 2005	None	800 mg/Nm^3 for 1997-2005 500 mg/Nm^3 after 2005	In discussion based on the US standards
European Union[c]	Pre-2003 100 mg/Nm^3 for <500 MW 50 mg/Nm^3 for >500 MW Post 2003 50 mg/Nm^3 for <100 MW 30 mg/Nm^3 for >100 MW	Pre-2003 Scaled for <500 MW 400 mg/Nm^3 for >500 MW Post 2003 850 mg/Nm^3 for <100 MW 200 mg/Nm^3 for >100 MW	Pre-2003 600 mg/Nm^3 for <500 MW 500 mg/Nm^3 for >500 MW Post 2003 400 mg/Nm^3 for <100 MW 200 mg/Nm^3 for >100 MW	In discussion
US[c, d]	6.4 gm/GJ	640 gm/MWh	720 gm/MWh for old 450 gm/MWh for new	0.08 gm/MWh for lignite 0.01 gm/MWh for IGCC

a – from Central Pollution Control Board (India) (http://cpcb.nic.in/Industry_Specific_Standards.php). Last accessed 17 February 2013. Besides PM, only national ambient standards exist.
b – from standards information in Chinese (http://www.zhb.gov.cn/gkml/hbb/qt/201109/t20110921_217526.htm). Last accessed 17 February 2013. Prior to 2011, the standards were based on commissioning year (before 1996, 1997 to 2004, and after 2004) .
c – Power stations emissions handbook (http://www.ccsd.biz/PSE_Handbook). Last accessed 17 February 2013.
d – in official units; for mercury this is based on 12 month rolling average.

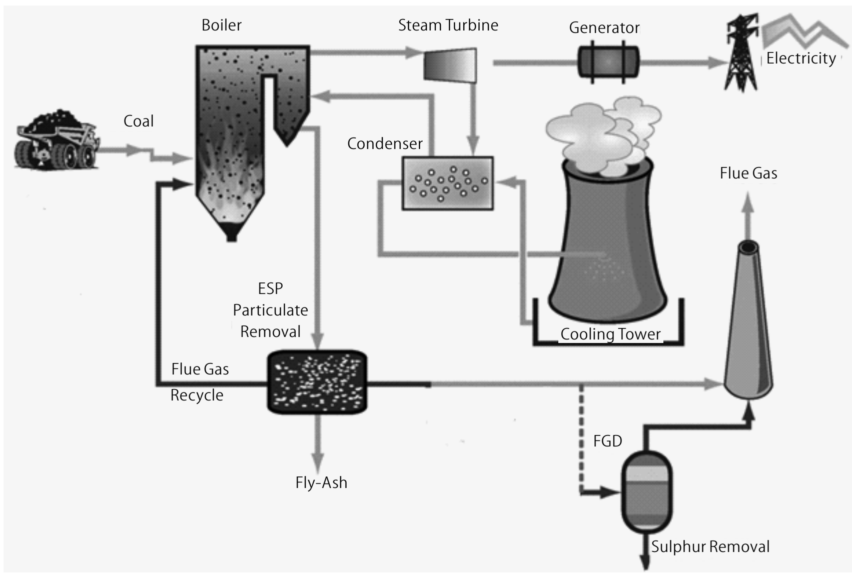
total emissions per plant. For example, for PM, the plants with generation capacity more than 210 MW, the concentration limit in the flue gas is 150 mg/Nm³ and for the plants with generation capacity of less than 210 MW, the limit is 300 mg/Nm³. These limits are much higher than those currently practiced in Australia, China, US, and EU. The limit for the smaller plants can be reverted to 150 mg/Nm³, if they are located in an urban, ecologically sensitive, and other critically polluted areas – which is at the discretion of Ministry of Environment and Forests (MoEF). A break-up in the emissions regulation at 210 MW also led to installation of smaller boilers at most of the power plants (Table 1). Approximately 70% of the operational units in the country are of the size less than or equal to 210 MW and these units tend to have the worst net efficiency and plant load factor. The newer plants are mostly 500 MW or higher with the best net efficiency of more than 33% (CEA 2012). Hence, efficiency improvement of existing, older power plants and tightening of emission standards for all sizes should become a critical component for reducing coal consumption and atmospheric emissions. Differential emission regulations also tend to result in use of control equipment with low efficiency and higher emissions.

Particulate matter is the only pollutant for which any pollution controls are widely used in India. A schematic of a coal-fired power plant is presented in Figure 3 that shows flue gas from the boilers at high temperature and velocity passing through heat exchangers to recycle the residual energy. This then enters the particulate control equipment (electro-static precipitators (ESPs), and cyclone bag filters) for removal of entrained ash. ESPs are installed in all coal-fired power plants. As removal efficiencies at ESPs are higher for coarse particles, most of the PM dispersing from the top of the stack is in the size range of respirable PM (10 mm or less). Lu, Wu and Pan (2010) measured fractions of 50-60% $PM_{2.5}$ and 90-95% PM_{10} in the total filterable PM in the flue gas at a 660 MW power plant. The PM in the flue gas also contains high concentrations of heavy metals such as arsenic, lead, cadmium, mercury, copper, and zinc, which not only contributes to potential health hazard than the bottom ash (Finkelman 2007), but also increases the resistivity and reduces the ESPs collection efficiency to as low as 98%. Reddy et al (2005) measured the chemical composition of the bottom ash, fly ash, and flue gas from a coal-fired power plant in the western India and estimated 1%-7% of zinc, 2%-7% of copper, 5%-8% of manganese, 7%-10% of cobalt, 12%-18% of cadmium, 60%-70% of selenium, 70%-80% of mercury, and traces of arsenic, iron, lead, and chromium contained in the coal was emitted in the flue gas. Similar levels of entrainment were reported in an estimate of total trace metal emissions from coal-fired power plants in China (Chen et al 2013).

Besides flue gas PM emissions, fugitive dust from coal-handling plants and ash ponds (after disposal from the plants) is a problem. According to CEA, after the combustion and application of control equipment, ash collection at the power plants ranged 70%-80% of the total ash in the coal. It is assumed that the remaining ash is dispersed from the stacks. In 2003, an amendment notification from the MoEF mandated 25% bottom ash in all brick kilns within a 100 km radius of any coal-based thermal power plant and all building construction within 100 km for any coal-based thermal power plant to use 100%-ash-based bricks, blocks, and tiles. Till date the percentage of ash utilised in the construction industry is low.

The ambient $PM_{2.5}$ concentrations presented in Figure 2 includes two fractions – primary PM emissions, which is a result of the ash content in the coal and the secondary PM, which is a result of chemical reactions converting SO_2 and NO_x emissions to particulate forms of sulphates and nitrates. We estimate the secondary PM pollution accounts for 30%-60% of the total ambient $PM_{2.5}$ pollution from the power plants. While most of the power plants operate ESPs to control the dust emissions, only a handful a power plants operated flue gas desulfurisation (FGD) units, which are effective in controlling the SO_2 and NO_x emissions. Among those to be commissioned through 2020, only seven power plants are listed to have FGD (Prayas 2011). The FGD systems could range from in furnace control via limestone injection, wet scrubbing of flue gas (Figure 3) and is known to further aide in removal of PM. In India, there are no mandated emission standards for SO_2 and only the stack heights are mandated assuming that the emissions will disperse to farther distances, diluting the plume concentrations. For example, MoEF requires all power plants with generation capacity more than 500 MW to build a stack of 275 m; those between 210 MW and 500 MW to build a stack of 220 m; and those

Figure 3: Simplified Schematics of Coal-Fired Power Plant Operations



with less than 210 MW to build a stack based on the estimated SO_2 emissions using a thumb rule of height = $14*(Q)^{0.3}$, where Q is the estimated SO_2 emissions rate in kg/h. The stack heights for old and new power plants ranged between 150 m and 275 m.

Despite an estimated 30% of the total NO_x emissions in India originating from power generation (Garg et al 2006), currently, there are no regulations to control these emissions for coal-fired power plants. Some of the new installations and extensions are equipped with low-NO_x burners, with little details on their operational performance (Chikkatur et al 2011).

Regulating for Cleaner Power

Coal remains the main fossil fuel for power generation in India. Supplies of other fuel sources such as naphtha and natural gas are not stable and need to be imported, which led to their lesser growth in this sector. Unlike pollution from the transport or domestic sector, pollution from power plants is a point source. This means that there are a finite and known number of units from where pollution is released and thus can be controlled better. Moreover, with a majority of the power plants run by the public sector, mandating technologies that reduce pollution would seem to represent a simple solution. However, power plant regulation has thus far lagged far behind other emerging economies and power plants by themselves have no incentive to improve pollution control. Combined with a strong demand for reliable electricity and lack of supply it is doubtful that pollution will be controlled in the absence of strong regulation and enforcement.

Of all the operational coal-fired power plants in the country, 70% are of the size less than or equal to 210 MW and these units tend to have the worst net efficiency and plant load factor. We believe that a bifurcated environmental standard for PM emissions led to this different sizes of power generation units. For example, the Kolghat power plant in West Bengal has six units of 210 MW and the Raichur power plant in Karnataka state has seven units of 210 MW, each with a total generation capacity of more than 1,000 MW, are allowed to adhere to the lower emission standard, only because the individual boiler size is less than or equal to 210 MW. The efficiency improvement of existing older power plants and tightening of emission standards for all sizes should become a starting point to reduce coal consumption and atmospheric emissions. Going forward, coal-fired power plants should be subject to tighter emission standards based on those found in emerging economies (like China) and developed economies (like EU, Australia, and the US).

The stack emissions being point sources, are limited in number, and can be monitored relatively easily as compared to non-point sources (such as vehicles, garbage burning, domestic burning, and fugitive dust). Some of the larger power plants are now equipped with continuous monitors for the criteria pollutants. However, this information is not available in the public domain, either for analysis or for scrutiny of emission loads. This adds to the uncertainty of the estimates, for analysing the impacts of the emissions, understanding the contribution loads, and for planning. If the emission standards need strengthening or new policies to be introduced for clean power and clean environment, the information dissemination should be more open, otherwise, the enforcement of the limited standards that do exist is nearly non-existent.

From the power plants, we estimate 30-60% of the PM pollution is secondary in nature, with the most coming from chemical conversion of SO_2 emissions. Since a majority of the power plants in the country do not operate a dedicated

FGD system, most of the SO_2 from coal combustion is emitted and ends up in respirable PM fraction, resulting in more health impacts. In the environmental impact assessment studies, required before the commissioning of a power plant, a provision for an FGD for all power plants is discussed for future years, but not yet mandated. We believe that FGD technology should become mandatory for all new power plants and a provision should be introduced to implement the same for the larger and older power plants to control SO_2 emissions. The combined benefits of an FGD in conjunction with the already operational ESPs at most of the power plants will benefit not only ambient particulate pollution and related health impacts, but also a reduction in deposition of these gases over agricultural lands.

As part of environment impact assessment, the planning and commissioning of power plants should include influences of long distance transport, beyond 50-200 km. Since, the size of power plants is expected to increase in the coming decades, with the mandated stack heights of 275 m, the emissions can be expected to travel and influence areas even farther than that, and consequently result in additional health impacts.

What Can Be Done?

Ultimately, the government, and citizens' groups need to demand clean power, keeping in mind that health impacts of the emissions from power plants in India can be severe. An environmental outlook study concluded that a least-cost policy mix to reduce air pollution in developing economies of Brazil, China, India, and South Africa is made up of 50% end of pipe measures and 50% of shifting to cleaner energy sources (OECD 2012). In the future – while the share of power generation from coal is projected to decline (IEA 2012) – the amount of power generated from coal will remain high at least through 2030, and unless we find a better way to manage power plants, the environmental effects due to growing air and CO_2 emissions and the human health cost will be high. The way forward for coal-fired power plants in India is

- to make the emission standards for particulates more stringent and introduce new emission standards for other pollutants,
- enforce the standards by revising the current environment impact assessment procedures, which do not factor human health as a primary indicator,
- make the implementation of FGD for reduction in emissions of multiple pollutants,
- introduce continuous monitoring at the plant stacks, such that the data is in the public domain in real time.

NOTES

1 The public sector entities include – National Thermal Power Corporation; Indraprastha Power Generation Company; Haryana Power Generation Corporation; Punjab State Power Corporation; Rajasthan Rajya Vidyut Utpadan Nigam; Uttar Pradesh Rajya Vidyut Utpadan Nigam; Gujarat State Electricity Corporation; Madhya Pradesh Power Generation Company; Chhattisgarh State Power Generation Company; Maharashtra State Electricity Board; Andhra Pradesh Power Generation Corporation; Karnataka Power Corporation; Tamil Nadu Electricity Board; The West Bengal Power Development Corporation; Orissa Power Generation Corporation; and Calcutta Electric Supply Corporation.

2 The private sector entities include – Jindal Power; CPL India; Azure India; Adani Power; Reliance Power; and Tata Power.

3 Available at http://www.urbanemissions.info

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