Chapter 18
Strategic Approach for Emission Reduction from Coal-Fired Thermal Power Plants in India

Shipra and Asim Kumar Pal

18.1 Introduction

Secure, reliable and affordable energy supplies are fundamental to global economic stability and growth. Energy consumption is directly related with the development of the society. Being a developing country, consumption of the energy in India is increasing very fast. India is the third largest producer of electricity.[1] In India per person per year electricity consumption is 957 kWh which is very less compared to world average electrical energy per capita that is about 2700 kWh.[2] As the country is developing the energy requirement of the society will enhance which needs to be met in upcoming years. Since consumption of energy is increasing, there is a need to give more stress on development, thereby consuming more energy with associated higher emission of carbon. India needs economic development that is conducted without damaging the natural resources which in turn requires energy efficiency, i.e., to use the limited resources in such a manner that energy demand is fulfilled. More than 61.44% of India's energy demand is met through the coal-based thermal power plant (Central Electricity Authority Report 2016).

[1] **Businessstandard**. http://www.business-standard.com/article/economy-policy/now-india-is-the-third-largest-electricity-producer-ahead-of-russia-japan-118032600086_1.htm.

[2] **User guide for India's 2047 energy calculator coal and gas power stations.**

Shipra (✉)
Electricity Supply Sub Division Motipur, North Bihar Power Distribution Company Ltd., Muzaffarpur, Bihar 843111, India
e-mail: nehushipra@gmail.com

A. K. Pal
Department of Environmental Science and Engineering, IIT(ISM), Dhanbad, India
e-mail: palasim2003@yahoo.co.in

S. M. Shiva Nagendra et al. (eds.), *Urban Air Quality Monitoring, Modelling and Human Exposure Assessment*, Springer Transactions in Civil and Environmental Engineering,
https://doi.org/10.1007/978-981-15-5511-4_18

Table 18.1 Regionwise total Capacity of coal-based thermal power plant in (MW) in India as on 31.03.2016

Regions	Sector	Coal-Based
Northern Region	State private central (total)	**45644.50**
Western Region	State private central (total)	**72153.01**
Southern Region	State private central (total)	**36442.50**
Eastern Region	State private central (total)	**30622.87**
North Eastern Region	State private central (total)	**310.00**
All India	State	64320.50
	Private	69462.38
	Central	51390.00
	Subtotal	185172.88

Source CEA Report (2016)

National Thermal Power Corporation (NTPC), Public sector undertaking and several other state level power generating companies are engaged in operating coal-based thermal power plants. Apart from NTPC and other state level operators, some private companies are also operating the power plants. All India installed capacity of coal-based thermal power plants as on 31.03.2016 is shown in Table 18.1. India had estimated coal reserves of 306.6 billion metric tons, the fifth largest coal reserves in the world (EnergyStatistics 2016). The production of coal in the country has grown from a little over 341 million tons in 2002–03 to over 557.5 million tons in 2012–13. The growth in production of coal in the 10th plan was 5.6% and in the 11th Plan was 4.6% and in the year 2014–15, the production of coal was 612.44 million tons in a growth of 8.25% over the previous year (Prasad and Anand 2013).

However, the rapid growth in coal production has not been sufficient to meet the demand for coal, which has resulted in demand gap. These gaps are met through imports of coal, as per the economics Times report India's coal import increase to 35% in September from previous fiscal year. A Summary of coal production and consumption in India from 2001 to 2013 in (million tons) is shown in Table 18.2.

As per Annual Report 2015–16 Ministry of Coal, Govt. of India, 70% of the coal is consumed in power sector, 7% in steel industry, 3% in cement industry and remaining 20% in other area, most of these are high ash content coal in the calorific value range of 3000 kilo calorie per kilogram to 4500 kilo calorie per kilogram and ash content in the range of 30–45%. Using the high ash coal for the power sector is a major challenge, from the point of view of achieving high level of efficiency of consumption, and more particularly, from the point of view of environmental management due to fly ash emissions. Release of high quantum of pollutants from coal-based power plants contributes significant impacts to health and environment. Coal combustion during electricity generation releases various pollutants into the

Table 18.2 Summary of coal production and consumption (million tons) in India

Year	Production	Consumption
2001	385.39	406.17
2002	401.18	422.68
2003	425.97	435.68
2004	452.38	484.18
2005	482.00	511.05
2006	509.40	543.71
2007	541.30	592.56
2008	578.91	639.54
2009	624.03	716.76
2010	628.79	746.26
2011	641.86	782.86
2012	665.69	853.86
2013	675.47	886.05

Source http://www.indexmundi.com/

environment. As a consequence, emissions of green house gases and other pollutants are increasing in India with the increasing demand for electricity. Though there are different sources of electricity generation major part of electricity generated from coal-fired power plants and result a tremendous produce the highest rate of CO_2 per kilowatt hour (Department of Energy and Environmental Protection Agency, Washington DC 2000). Evidence has shown that the climate change will affect the natural resources in different ways, which will ultimately threaten the livelihoods of the most poor and marginalized sector of the population who are closely tied to India's natural resource base. During the combustion of coal in thermal power plant mercury present in the coal is released. Mercury is one of the most dangerous heavy metal for human being as well as ecosystem. Mercury is invisible hazardous pollutants; whose effects are visible after a long time so it becomes very difficult to identify its effects.

The important problem in this world is the reduction of non renewable energy source and increase in the pollution level due to power plant. Both situations can be controlled if the efficiency of the energy system is improved. Every power plant losses their efficiency due to its continuous operations, age and many more reasons. This efficiency deterioration causes an increase in CO_2 emission. Economics of power generation does not only require designing an efficient power plant, but also following proper operation and maintenance strategy such that the energy conversion efficiency of the plant throughout its life cycle remains high.

In terms of carbon emission the contribution of Coal-based power plants is approximately 60% of the total carbon emissions in India. In 2014, a study carried out by Guttikunda and Jawahar (2014), about the status of operational coal-fired thermal power plants in India. The key findings from that study are as summarized below:

- The total coal consumption at the 111 coal-fired power plants was 500 million tons for the year 2010–11, leading to significant emissions of PM, SO_2, NO_2, CO_2, and VOC.
- **The higher $PM_{2.5}$ concentration resulted deaths of more than 80,000 people.**
- **The emissions standards practiced here were at-least 5–10 times worse than those practiced in developed countries like US, China, Australia**.

Technology used in the power plants are mostly subcritical type so emissions from coal-based thermal power plants in the country are increasing day by day and it will continue to go up in the near future. These plants are inefficient and release considerable air pollution in the surrounding atmosphere. In order to reduce air pollution by these coal-fired thermal power generation units, Ministry of Environment Forests and Climate Change (MoEF and CC) has formulated stricter pollution control norms for these units. As per the guideline released by MoEF and CC Indian power plants will have to cut the emission of particulate matter by 25%, Sulfur dioxide by 90%, oxide of nitrogen by 70% and mercury by 75% to improve air quality status in and around thermal power plant. As per this standard, power plant is categories into three different section.

- Started before December 31, 2003.
- Started after 2003 up to December 31, 2016.
- Going to be start after December 31, 2016.

In the earlier rules particulate matter was allowed up to 150 mg per normal cubic meter for units having generation capacity of 210 MW or more and 350 mg per Nm^3 for units less than 210 MW capacity. Now for the first category the permissible limit is 100 mg per Nm^3, 50 mg for the second and 30 mg for new units. The main purpose of imposing the rule is to control emissions of particulate matter (PM), sulfur dioxide, nitrogen oxides and mercury and also cut water use by coal-based thermal power plants. The proposed standard of Ministry of Environment and Forest and Climate Change is shown in Table 18.3.

There is no standard limit of CO_2 emission from thermal power plant. Major contributor of CO_2 to the environment is thermal power plants. To improve the

Table 18.3 MOEF CC proposed standard for coal-fired thermal power plants

Pollutants	Older units		Older new		Future
	Before December 31, 2003		After 2003–2006		From January, 2017
	$<$500 MW	$\geq$500 MW	$<$500 MW	$\geq$500 MW	
PM	100 mg/Nm^3		50 mg/Nm^3		30 mg/Nm^3
SO_2	600 mg/Nm^3	200 mg/Nm^3	–	200 mg/Nm^3	100 mg/Nm^3
NO_X	600 mg/Nm^3		300 mg/Nm^3		100 mg/Nm^3
Hg	–	0.03 mg/Nm^3	0.03 mg/Nm^3		0.03 mg/Nm^3

Source www.moef.nic.in

condition of coal-fired plant, measurements of these pollutants are very much essential so that a necessary major can be taken for the reduction of such harmful gases. In developing country like India Power generating facilities are quite old and very poorly maintained due to which the carbon emissions are increasing. The need to mitigate these environmental impacts has driven the development of a variety of technologies designed to burn coal more cleanly and efficiently. From this scenario Clean Coal Technologies comes into picture. The term Clean Coal Technologies (CCT) is used to mean every option capable of reducing emissions upstream, downstream, or within the power generation process. Adoption of different clean coal technology such as supercritical (SC) stream cycle, ultra-supercritical stream cycle (USC), integrated gasification combined cycle (IGCC) will increase the efficiency of the plant. These technologies are more environmentally benign and would help meet increased energy demands. These are highly efficient technologies and consequently use less coal hence released less amount of pollutant to the environment.

18.2 Materials and Methods

Population growth (existing as well as projected) of the country for the year 2010–2020 was collected from statistical portal of India. A research analysis carried out by Energy and Resources Institute (TERI) about the Indian energy scenario and they have suggested a tactical approach for sustainable development. As per their research, the electricity demand, growth rate was taken as 5.7%/year during the period 1997–2019 and 3.9%/year during the period 2020–2047. The same growth rate was used in this study to forecast electricity demand. Population of India from 2010 to 2020 (existing as well as projected) and projected electricity demand is shown in Table 4.15. This table shows the trend of annual electricity demand in India, nearly 63% of the total electricity demand met through coal-based thermal power plant. Heat rate (i.e., heat required to produce one unit of electricity), calorific value of coal and efficiency of coal-based thermal power plant were used to calculate the amount of coal required to produce 1 kW of electricity and on the basis of this, total annual coal requirement of coal-fired plant was calculated. Indian thermal power plants use bituminous/sub-bituminous coal with gross calorific value ranging in between 3000 and 5000 kcal.

$$\begin{aligned}
&\text{Average calorific value taken in this study} \\
&= (3000 + 5000)/2 \\
&\approx \mathbf{4000 kcal/kg} \\
&= 16800\ \text{kJ/kg} \quad (1\ \text{kcal/kg} = 4.2\ \text{kJ/kg})
\end{aligned} \tag{18.1}$$

In this study it was assumed that energy conversion in power plant is 100% efficient hence one unit of electricity generation requires 3600 kJ of energy. Average efficiency of coal-based thermal power plants of different combustion technology is

Table 18.4 Average efficiency of coal-based thermal power plant of different technology

Combustion technology	Efficiency
Subcritical	32.8[a]
Supercritical	38.5[b]
Ultra-supercritical	43.3[b]

Source [a]Centre for Science and Environment (February 21, 2015)
[b]"The Future of Coal", MIT (2007)

Table 18.5 Heat rate and per kWh coal requirement of different technology

Combustion technology	Heat rate	Coal requirement in kg per kWh
Subcritical	10975.60976	0.653310105
Supercritical	9350.649351	0.556586271
Ultra-supercritical	8314.08776	0.494886176

shown in Table 18.4.

$$\text{Heat rate} = \frac{3600\frac{\text{kJ}}{\text{h}} = 10975.6\ \text{kJ/h}}{32.8} \tag{18.2}$$

To produce 1 kWh of electricity coal requirement in kg/kWh is

$$= \frac{10,975.6\ \text{kJ/h}}{16,800\ \text{kJ/kg}}$$
$$= 0.653\ \text{kg of coal per kWh} \tag{18.3}$$

As per the above information heat rate and amount of coal required per kWh are calculated as shown in Tables 18.5 and 18.6.

Table 18.6 Total projected electricity demand in India from 2010 to 2020

Year	Population (billion)	Electricity demand (billion kWh/year)
2010	1.19	927.01
2011	1.21	979.85
2012	1.24	1035.70
2013	1.26	1094.73
2014	1.28	1157.13
2015	1.29	1223.08
2016	1.31	1292.79
2017	1.32	1366.47
2018	1.34	1444.35
2019	1.36	1526.67
2020	1.38	1583.20

Table 18.7 Amount of coal used in thermal power plants

Electricity generated from coal-based thermal power plant (MW)	Year	Coal used (million tons/year)
66668.53	2010	381.36
70468.66	2011	403.10
74485.27	2012	426.08
78730.58	2013	450.36
83218.25	2014	476.03
87961.23	2015	503.16
92974.62	2016	531.84
98273.53	2017	502.15
103874.50	2018	594.19
109794.80	2019	628.06
113860.30	2020	651.31

Amount of coal used in the coal-fired plant was calculated based on above information as shown in Table 18.7.

18.3 Result and Discussion

Emission rate of CO_2 was calculated using the formula given by Coal Swarm coverage of India and coal (2016). As per this formula

$$\text{Emissions per kWh} = CO_2 \text{ emissions per unit of energy in coal (expressed in Btu)} \times \text{(Btu to kWh)/(Plant efficiency)} \quad (18.4)$$

In India most of the coal are of sub-bituminous rank, approximately 214.3 lb of CO_2 is emitted per million British Thermal units (Btu) of energy for sub-bituminous coal (US Energy Information Administration).

For 2010 to 2020, emission rate and the estimated annual CO_2 emissions are evaluated as presented in Tables 18.8 and 18.9.

The annual emission data in Table 18.9 shows that CO_2 emissions are increasing at rate of 5% per year on all India basis in these power plants during the period 2010–2020. A research estimate total annual CO_2 emissions from all the coal-fired power plants in India as 395 million tons in 1997–98 (Mittal and Sharma 2003).

Table 18.8 Emission rate for different technology (kg of CO_2/kWh)

	Subcritical	Supercritical	Ultra-supercritical
Emission rate	1.01	0.85	0.76

Table 18.9 Summary of predicted annual CO_2 emission (million tons CO_2/year) in different technology at the power plants in India in 2010–20

Year	Subcritical	Supercritical	Ultra-supercritical
2010	589.86	496.41	443.85
2011	623.48	524.71	469.15
2012	659.02	554.62	495.89
2013	696.58	586.23	524.16
2014	736.28	619.64	554.03
2015	778.25	654.96	585.61
2016	822.60	692.29	618.99
2017	869.48	731.74	654.27
2018	919.04	773.45	691.55
2019	971.42	817.53	730.97
2020	1007.39	847.80	758.04

These estimates were based on the installed plant capacity, since the actual electricity generation data was not available at that time. Plant having subcritical technology releases heavy CO_2 but penetration of supercritical and ultra-supercritical technology helps in 19 and 33% emission reduction respectively.

Indian coals have less sulfur content (0.3–0.55%) compared to coal import from Indonesia and other country. Emission of SO_2 mostly depend upon the sulfur content in the coal whereas emissions of CO_2 and NO depends on the operating conditions and the design type of the plant (Mittal et al. 2012). Since sulfur contains of coal is very low so there is of no practical significance in reducing SO_2 emissions to the atmosphere (Rees et al. 1966). Hence all the sulfur in the coal is considered to have been converted to SO_2. Table 18.10 shows the estimated SO_2 and NO emissions from thermal power plants in India using the emission factor of SO_2 (0.00521 kg/kWh) and NO (0.00154 kg/kWh) (Chakraborty et al. 2008). Annual SO_2 emission has

Table 18.10 Summary of SO_2 and NO emissions (million tons) during 2010 to 2020 from coal-fired plant

Year	SO_2	NO
2010	3.04	0.90
2011	3.22	0.95
2012	3.40	1.00
2013	3.59	1.06
2014	3.80	1.12
2015	4.01	1.19
2016	4.24	1.25
2017	4.49	1.33
2018	4.74	1.40
2019	5.01	1.48
2020	5.20	1.54

Table 18.11 Estimated Hg emissions (tons) during 2010 to 2020 from coal-fired plant

Year	Coal used (million tons/year)	Hg emission (tons/year)
2010	381.36	202120.8
2011	403.10	213643.0
2012	426.08	225822.4
2013	450.36	238690.8
2014	476.03	252295.8
2015	503.16	266674.8
2016	531.84	281875.2
2017	502.15	266139.5
2018	594.19	314920.7
2019	628.06	332871.8
2020	651.31	345194.3

increased from 3.04 million tons in 2010 to 5.20 million tons in 2020 at an average annual rate of 0.22 million tons per year and annual NO emission has increased from 0.9 million tons in 2010 to 1.54 million tons in 2020 at an average annual rate of 0.06 million tons per year.

Coal-fired thermal power plants are the 2nd largest mercury emission in India (Rai et al. 2013). The residence time of Hg in elemental state varies between 0.5 and 2 years whereas in oxidized and particulate form much less (Schoeder and Munthe 1988). Hg contents in coal varies from 0.01 to 0.5 mg/kg depends upon the type of coal used in combustion (Pacyna et al. 2006). In this study emission factor of mercury is considered as 0.53 mg/kg (Rai et al. 2013) for estimating the total Hg emission from coal-fired thermal power plants.

Mercury estimation from the Indian Thermal power plants was done on the basis of annual consumption of coal and emission factor (EF) of Hg used in this sector.

$$\text{(EHg)Year} = \text{(coal consumption)Year} \times \text{(EF)Hg} \tag{18.5}$$

where

$(E_{Hg})_{Year}$ = Annual emission of mercury (million tons) from thermal power plants.

Annual Hg emission has increased from 202.12 tons in 2010 to 345.19 tons in 2020 at an average annual rate of 14.3 tons per year. Total estimated emission of mercury from coal-fired thermal power plants as shown in Table 18.11.

18.3.1 Cost Analysis

To compare the cost of electricity production of different technologies, the total specific cost of each technology is calculated over the entire lifetime of the power plant and an average levelized cost of energy (LCOE) is calculated. Levelized cost of energy measure the lifetime cost involves in energy production. It allows the comparison of different technologies of unequal life spans and capacities, so that the minimum price at which energy can be sold will be determined. The cost for electricity produced by different power generation technologies is calculated under different assumptions. For simplification the methodology applied is based on a single input parameter overall years considered.

$$\text{LCOE} = \frac{\text{Capital cost} \times \text{CRF}(1 - \text{TDpv})}{8760 \times \text{CF} \times (1 - T)} + \frac{\text{Fixed OM}}{8760 \times \text{CF}} + \text{Variable OM} + \text{Fuel price} \times \text{Heat rate} \quad (18.6)$$

Source: Transparent cost database (4/14/2016) where,
Capital cost = Cost of the plants CRF = Capital expenditure.

$$\text{CRF} = D(1 + D)N/((1 + D)N-1) \quad (18.7)$$

Source: Transparent cost database (4/14/2016) where,

D = Discount rate, i.e., used to attribute a value to future cash flows.

N = Lifetime of the investment, T = Tax rate, Dpv = Depreciation, CF = Capacity factor (The ratio between average power and peak capacity), In this study it was assumed that plant is running at full capacity for exactly 80% time in a year.

Fixed OM = Fixed operation and maintenance cost includes staffing and other costs that are independent of operating hours.

Variable OM = Variable operation and maintenance cost, which are a function of operating hours Assumption, Source: Transparent cost database (4/14/2016).

Dpv = 0.59, D = 7%, N = 30 Years, 8760 = Number of hours in a year, Fixed OM = 0.0048 $/kWh

Variable OM = 0.022 $/kWh, Fuel price = 2.34 $/mmBTU, CF = 80%, T = 33%, Heat rate = 0.01008 mmBTU CRF = 0.08 (Calculated)

There are different modes of levelized cost calculation but this study is based on normalized mode in which single discount rate and other cost for all technologies are considered. Capital cost of subcritical, supercritical and ultra-supercritical is 1150, 1350 and 1190 $/kw.[3]

Calculated levelized cost of estimation for different technology is shown in Table 18.12.

[3]**Business and public administration studies**: https://www.bpastudies.org/bpastudies%20/article/view/170/318.

Table 18.12 Calculated power generation cost in different combustion Technology

Technology	LCOE (Rs/kWh)
Subcritical	4.03
Supercritical	4.32
Ultra-supercritical	4.06

18.4 Conclusion

Population of India is increasing rapidly with respect to population, electricity demand is also increasing and to overcome the demand electricity generation will also increase. Total generation from coal-fired plant is expected to increase two folds from 66,668 MW in 2010 to 113,860 MW in 2020 and total coal consumption is estimated to increase 1.5–2 times from 380 million tons/year to 651 million tons/year, accordingly the CO_2 emissions will also increase from 589 to 1007 million tons/year. This study thus provides a methodology for the development of emission inventory of different pollutants from coal combustion in thermal power plants in India and the role of supercritical and ultra-supercritical technology in emission reduction. CO_2 is the major problem of thermal power plant in India, so if the clean coal technology like supercritical or ultra-supercritical technology are used to, up to 33% of emission reduction can be achieved. Though, these technologies are costly in nature but it reduces the emission significantly.

References

Annual Report (2015–16) Ministry of Coal, Government of India. https://coal.nic.in/content/annual-report-2015-16
Central Electricity Authority Report (2016). http://cea.nic.in/reports/monthly/executivesummary/2016/exe_summary-03.pdf
Chakraborty N, Mukheriee I, Santra AK, Chowdhury S, Chakraborty S, Bhattacharya S, Mitra AP, Sharma C (Feb 2008) Atmos Environ 42:1073–1082
Coal Swarn Coverage of India and Coal (2016). https://www.sierraclub.org/sites/www.sierraclub.org/files/uploads-wysiwig/Final%20Boom%20and%20Bust%20report_0.pdf
Department of Energy and Environmental Protection Agency, Washington DC, (2000). https://www.eia.gov/energyexplained/energy-and-the-environment/where-greenhouse-gases-come-from.php
Disha (2001) Green India 2047, TERI. http://www.dae.gov.in/node/128
"EnergyStatistics 2016" (PDF)
Guttikunda SK, Jawahar P (2014) Atmospheric emissions and pollution from the coal-fired thermal power plants in India. Atmos Environ 92:449–460
India's first environmental rating of coal-based power plants by Centre for Science and Environment under CSE's Green Rating Project (GRP), 21 Feb 2015
Levelized cost calculations/Transparent cost database (14/4/2016)
Ministry of Environment, Forest & Climate Change notification (emission standards) dated April 2015
MIT (2007) The future of coal, Table 3.1, p 19

Mittal M, Sharma C (2003) Anthropogenic emissions from energy activities in India: generation and source characterization, Part I

Mittal ML, Sharma C, Singh R (2012) Estimates of emissions from coal fired thermal power plants in India. Environmental Protection Agency

Pacyna EG, Pacyna JM, Steenhwsen F, Wilson S (2006) Global anthropogenic mercury emission inventory for 2000. Atmos Environ 37:109–117

Prasad DN, Anand MR (2013), Recent trends in production and import of coal in India. Ministry of Coal Occasional Working paper Series, 13 October 2013

Rai VK, Raman NS, Chaudhary SK (2013) Mercury in thermal power plants—a case study. Int J Pure App Biosci 1(2):31–37

Rees OW, Shimp NF, Beeler CW, Kuhn JK, Helfinstine RJ (1966) Sulphur retention in bituminous coal ash. Illinois State Geological Survey, Circula 396

Schoeder MH, Munthe J (1988) Atmospheric mercury an overview. Atmos Environ 32:809–822

User guide for India's 2047 energy calculator coal and gas power stations

U.S. Energy Information Administration: https://www.eia.gov/tools/faqs/

http://www.indexmundi.com