Coal in the Indian energy future – emissions and policy considerations

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Preface

The IEA Clean Coal centre is an Energy Technology Initiative, which is endorsed by the International Energy Agency. It provides a means for international co-operation on clean coal related issues, and provides objective and independent information on the efficient and sustainable use of coal. This focuses on how to use coal more effectively, efficiently and cleanly, to minimise its environmental impact while providing cost-effective energy. This includes the impact of coal related policies and regulations, clean coal technology developments and deployment, emissions control technologies and global coal markets. It is supported by members and sponsors from Australia, Austria, China, the European Commission, Germany, India, Italy, Japan, Poland, Russia, South Africa, Thailand, the UK and the USA.

This report has been produced by the IEA Clean Coal Centre and is based on a survey and analysis of published literature, and on information gathered in discussions with interested organisations and individuals. Their assistance is gratefully acknowledged. It should be understood that the views expressed in this report are our own, and are not necessarily shared by those who supplied the information, nor by our member countries.

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Abstract

India is going through a period of intense growth whilst at the same time proposing to move quickly to tighten environmental standards on the very sources that are being relied upon to support this growth. How can the country achieve its aims of both expansion of electrification and cleaning up of the power sector simultaneously? This brief report, reviewing the challenges faced in India, was presented at a workshop in Chennai, India, on Monday 16th November 2015. Corrections and comments from that meeting have been included in this updated version of the report.

Efficiency improvement is the subject of a separate report by Colin Henderson. This complementary report concentrates on the current emissions in India, the emergence of new policy and possible options for emissions reduction.

Acronyms and abbreviations

APEC	Asia-Pacific Economic Cooperation
APP	Asia-Pacific Partnership
A-USC	advanced ultra-supercritical
BAU	business as usual
BCS	best case scenario
BHEL	Bharat Heavy Electrical Ltd
CCC	Clean Coal Centre
CCS	carbon capture and storage
CEA	Central Energy Authority
CERC	Central Electricity Regulatory Commission
CPCB	Central Pollution Control Board
ESP	electrostatic precipitator
EU	European Union
FGD	flue gas desulphurisation
GRP	Green Rating Project
GW	gigawatts
HELE	high efficiency low emissions
HP	high pressure
IEA	International Energy Agency
IP	intermediate pressure
kWh	kilowatt hour
LHV	lower heating value
LP	low pressure
MCR	maximum continuous rating
MOD	merit order dispatch
NAMP	National Ambient Monitoring Programme
NAPCC	National Action Plan on Climate Change
NASA	National Air and Space Agency, USA
NTPC	National Thermal Power Corporation
O&M	operation and maintenance
OECD	Organisation for Economic Cooperation and Development
PAT	Perform and Achieve Trade Scheme
PIE	Partnership in Excellence
PLF	Plant Load Factor (utilisation or capacity factor)
PM	particulate matter
PPIP	Plant Performance Improvement Plan
PV	photo volteic
Rs	Indian Rupees
SCR	selective catalytic reduction
SNCR	selective non-catalytic reduction
SWBS	smart wall blowing system
tce	tonnes of coal equivalent
TTPL	Transparent Technologies Private Ltd
UMPP	ultra mega power project
UNDP	United Nations Development Programme
UNEP	United Nations Environment Programme
USAID	United States Agency for International Development

USC	ultra-supercritical
WEC	World Energy Council

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1 Introduction

India is the second most populated country in the world and this population continues to grow. Prime Minister Modi has pledged to bring electricity to every one of the 300 million Indians (almost 25% of the population) currently living without access to electrical power (Carrington, 2014; Bhushan, 2015).

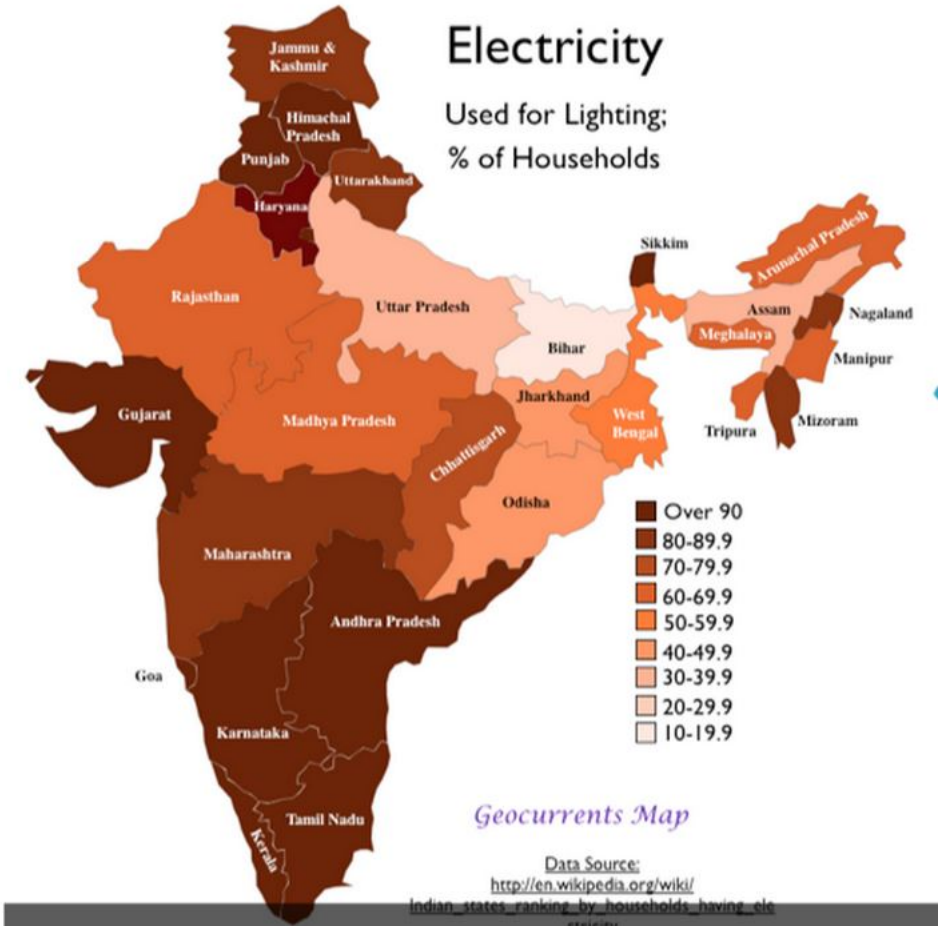

Figure 1 Electricity used for lighting: % of households in different regions of India (Geocurrents, 2013)

Figure 1 shows the areas, mainly in the northeast, which are still awaiting electrification. Bringing power to these regions is a significant challenge. Unchecked, this growth in the power sector could pose significant environmental consequences.

However, India is already taking steps to reduce the pollution which will be associated with this growth. This short report reviews the current state of the energy sector in India and looks at how India may grow its power sector with minimal environmental cost. Although this report concentrates only on coal for large-scale energy production, reducing emissions from coal in India will require a far broader approach than simply focusing on the power sector.

2 The changing energy mix in India

Before considering the evolution of the energy mix in India, it is important to understand some of the unique challenges faced by the country. The consumption of electricity in India increased at an annual rate of 2.4% between 2001 and 2010. However, the generation rate increased by 5.1% annually during the same period indicating issues with high transmission and distribution losses. Figure 2 shows a common sight in India – complex cabling masking a significant amount of illegal electricity use. It has been estimated that as much as 80% of the power losses in India are a result of theft, costing the industry $17 billion in lost revenue every year (Bloomberg, 2014). At a time when electrification is the goal, such theft is means a loss of revenue which may have a significant effect on investment in the power sector.

Figure 2 An electrical linesman repairs cables in Allahabad, India. Illegal subsidiary wires are tangled into main cables (WSI, 2009)

The expansion of India's grid to incorporate new fossil and renewable energy sources is a challenge. In addition to building new plants and capacity, the distribution grid will need to be expanded and upgraded.

India is heavily reliant on coal and, as this chapter shows, will continue to be so for the foreseeable future. But there is also a clear intention to add generation capacity from renewable technologies. The following sections briefly summarise the growth in different energy sectors in India.

2.1 Renewables

India also has ambitious targets for renewables, with $20 billion investment in the past year in just one joint venture firm alone (SBG Cleantech). The targets for solar alone have been described as "drastic"

(CNBC, 2015) with an aim to install 100 GW by 2022, five times the previous target of 20 GW in the same time period. This would mean an installation rate of 14 GW/y which is equivalent to more than the total solar added in the US and China together in 2014. As 100% foreign investment is permitted in the renewables sector, pressure for funding is eased somewhat, although most investors seek joint ventures with Indian companies to reduce risk, increase transparency and to establish a local presence. The Indian solar industry is expected to grow by 250% in 2015 alone. Interestingly, India recently announced the first 100% solar powered airport with Cochin International Airport powered by a 12 MW solar PV (photovoltaic) plant over 50 acres (20 ha; CleanTechnica, 2015). However, only 4 GW of solar were installed between Sep 2013 and June 2015 suggesting slow initial progress (CNBC, 2015). This may change soon, and possibly towards the end of the target timeframe, as it has been suggested that the cost of solar could become competitive with coal in India by 2019 (Shrimali and others, 2015). As shown in Figure 3, the cost of wind power and imported coal is expected to continue to increase whereas the cost of solar continues to decline to the point where it becomes competitive by 2019 and then becomes even more cost effective into the next decade.

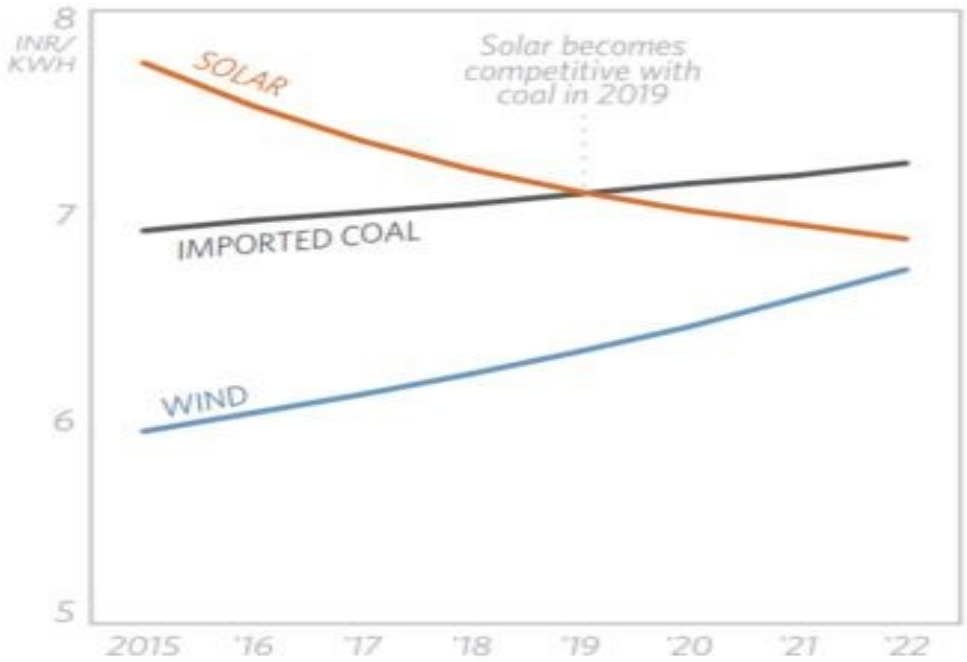

Figure 3 Forecast levelised cost of electricity in India (Shrimali and others, 2015)

Prime Minister Modi's government has ordered some of the country's oldest coal-fired power plants to help make solar farms more competitive by bundling together electricity from both technologies for sale to the grid. The state-controlled National Thermal Power Corporation (NTPC) must sell cheaper coal power along with more expensive solar as a single unit. Singrauli in North India is the first coal plant to take part - the 1700 MW unit's output will be sold along with power from 3 GW of solar installations. The new rule means that older, less efficient coal plants cannot depress wholesale energy prices by selling power at a low rate without including solar energy (Williams, 2015).

India is also investing significantly in wind power. However, there are limitations imposed by grid demands and transmission bottlenecks. For example, in recent years Tamil Nadu lost up to 15% of total wind generation as a result of congestion and a shortage of power evacuation facilities. Many wind farms are located remotely and the country has limited transmission capacity and limited local power demand. Funding for upgrading the grid and integrating new capacity is lacking. Planning needs to be coordinated and rapid – new wind farms can be built within 6 months, whereas the lead time for the development of transmission lines is between 3 and 15 years (Mills, 2011).

2.2 Coal

Coal is currently the most important fuel in the energy mix and will continue to provide up to 70% of India's electricity until 2021/22. Figure 4 shows that coal is by far the dominant source of energy in the country. However, the majority of coal is actually used in the industrial and residential sectors, not covered in this report.

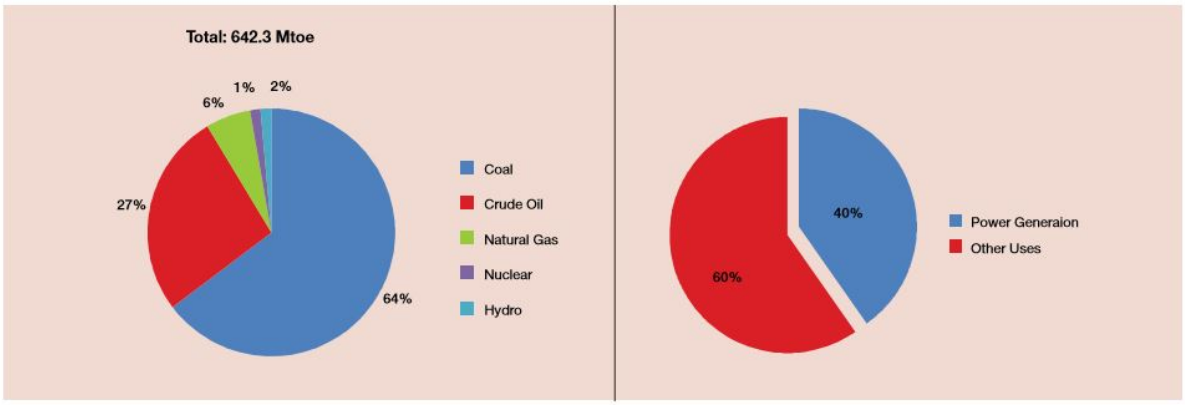

Figure 4 India's energy sources and consumption, 2012-13, official government statistics (Bhushan and others, 2015)

The coal capacity is expected to double in the decade between 2011/12 and 2021/22 and to triple by 2035 (Bhushan and others, 2015).

The national low carbon growth strategy involves renovation and modernisation of old electricity generating units and retirement of small, old and less efficient non-reheat plants, as well as the introduction of the more advanced technologies.

Figure 5 shows the existing and future coal capacities in different states with the majority of additions happening either in regions where coal is abundant or in coastal regions (allowing imports) (Bhushan and others, 2015).

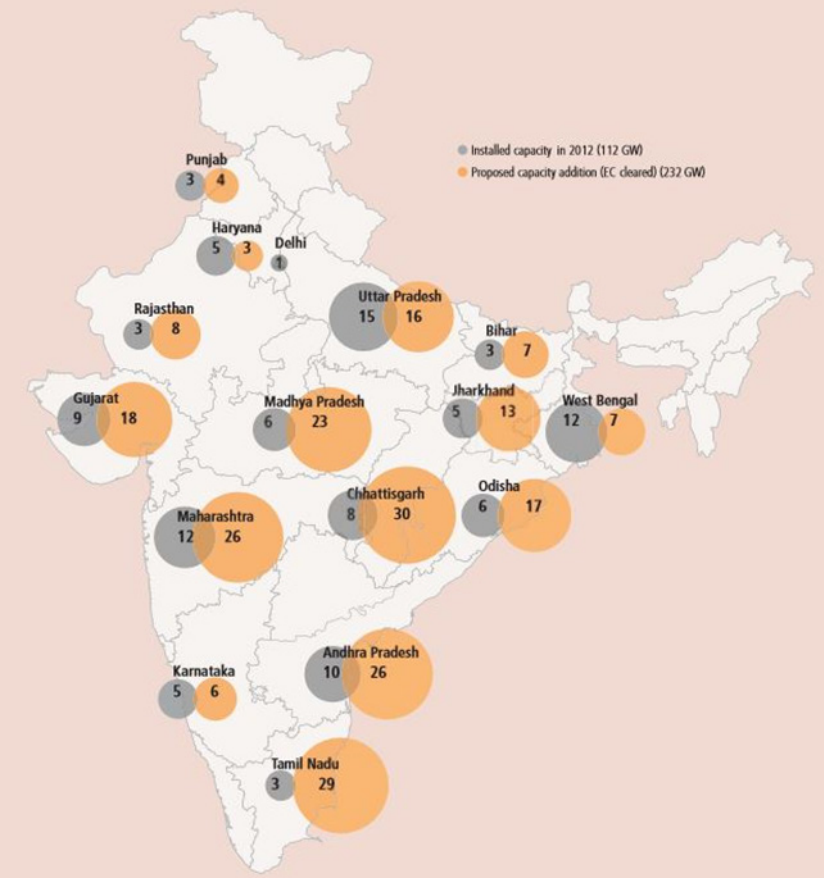

Figure 5 State-wise coal-based power plants: existing and upcoming capacities (Bhushan and others, 2015)

Data for the current 12th Five-Year Plan (ending 2017) show that the country has achieved 73% of its aimed capacity additions, with 61 GW of thermal capacity built of the planned 72 GW. Other sectors have not fared so well - hydro build is only at 1 GW of almost 11 GW planned and nuclear is at 1 GW of a planned 5.3 GW (CEA, 2015).

According to the combined IEA CCC (Clean Coal Centre) and Platt's databases, 130 GW of coal-fired plants have come online in India since 2000 and 73 GW of new construction should come online between 2015 and 2019. Of these plants under construction, around 48 GW are supercritical or ultra-supercritical. Of the 288 GW planned coal capacity only 6 GW seem certain to commence, others await approval and have no firm dates for construction. Around 29 GW have been deferred and 39 GW shelved or cancelled (Baruya, 2015). A previous report from the CCC (Barnes, 2014) also notes that most of the existing coal fleet is sub-critical, with super-critical plants only being introduced within the last few years. Between 2010 and 2013 almost 68 GWe of capacity was added with a further 44 GWe planned or under construction, based on 2013 data (*see* Figure 6). This means that, as of 2013, the total capacity in India was divided into almost 190 GWe of subcritical plants and 111 GWe of supercritical plants. There were no ultra-supercritical plants. This confirms that there is a definite move towards the building of more efficient supercritical plants but that more could be done. The 12th Five-Year Plan (2012-2017) specifies a target of 50-60% of coal plants based on supercritical technology. Whilst there are certainly an increasing number of supercritical plants being built, this target may not be reached within the time

frame. There are suggestions that the next Five-Year Plan (2017-2022) may stipulate that all new plants must be supercritical and that no subcritical plants will be allowed. However, this may be a challenge considering the high ash content and low calorific values of Indian coals (Barnes, 2014; India Energy 2015).

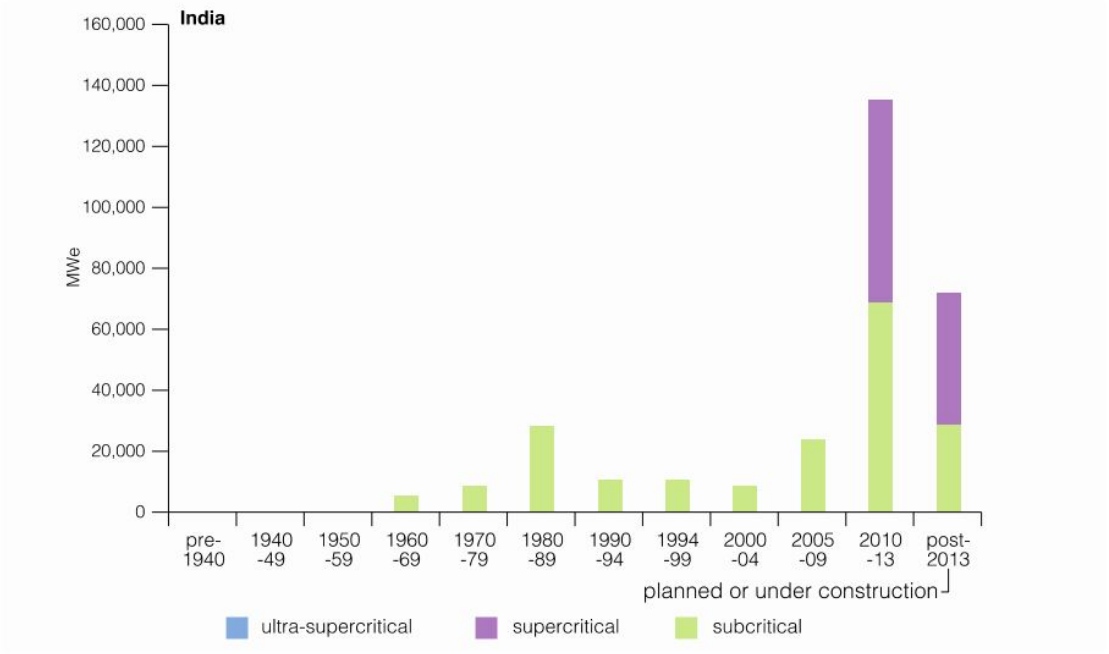

Figure 6 Indian coal-fired power plant by age and steam cycle (Barnes, 2014)

Figure 7 shows the growth in subcritical versus supercritical build in India over recent years (IEA, 2011). This confirms that the deployment of supercritical systems is somewhat sluggish due to challenges incurred with firing Indian coals (high ash and low calorific values) (India Energy, 2015). The continued construction of subcritical plants will lock in less efficient combustion for several decades. This is discussed in more detail later in the report.

Funding is a crucial issue for determining the nature of India's new coal build. Super- and ultra-supercritical plants are more expensive to build than subcritical units. The World Bank has ceased all funding to any coal-related project in India, funding neither mines nor coal plants (Economic Times, 2015). Whilst this is intended to reduce new coal build, it may instead result in increased build of cheaper, less efficient plants. However, Japan has stepped in and is investing $1 billion in coal plants in Asia, including India. Takako Ito, a spokeswoman for the Foreign Ministry, is quoted as saying: *"Japan is of the view that the promotion of high-efficiency coal-fired power plants is one of the realistic, pragmatic and effective approaches to cope with the issue of climate change*," (Aljazeera, 2015).

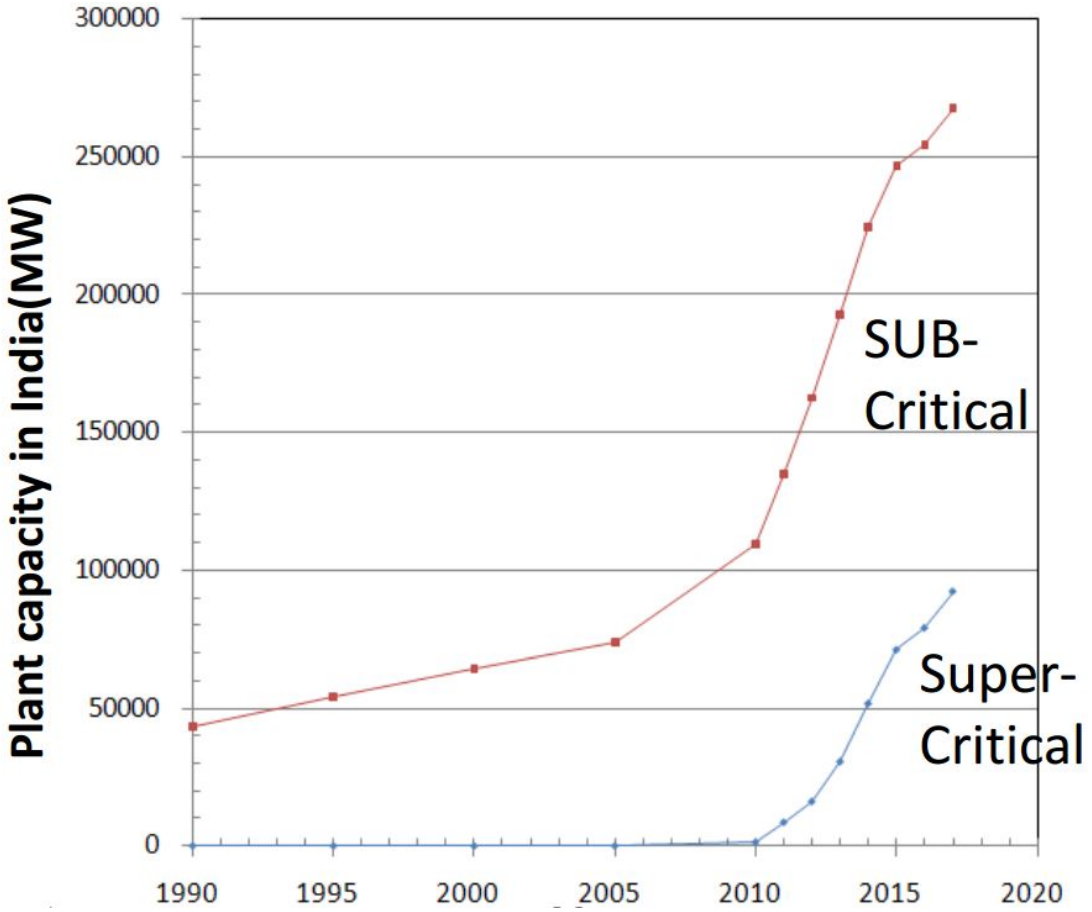

Figure 7 Breakdown of coal-fired capacity in India (IEA, 2011)

The future for the Indian power sector is therefore complex. Increased power production is imperative but must take into account the idiosyncrasies of the Indian situation. The Integrated Energy Policy of 2008 aimed "*to prepare an integrated energy policy linked with sustainable development that covers all sources of energy and addresses all aspects of energy use and supply including energy security, access and availability, affordability and pricing, as well as efficiency and environmental concerns*". Within this, coal was confirmed as the primary energy source for the long term (Barnes, 2014).

The following chapters concentrate on different aspects of the Indian coal sector in an effort to clarify the major areas where changes could have the most beneficial effect.

3 Coal production

In 2014 the Indian coal production sector was rocked by 'Coalgate' – a corruption scandal which demonstrated that every coal mining licence allocated by the government between 1993 and 2009, a total of 194 licences, had been granted in a "flawed and ad hoc" manner (Inamdar, 2013). Many companies lost licences and had to re-bid. Officials were jailed. Prime Minister Modi has pledged to improve the system but the events have contributed to the continuing problems with coal demand and supply in the country. India is therefore currently going through some major changes in terms of coal production, distribution and management.

3.1 Expansion in coal production

As outlined in Chapter 2, coal use is still increasing in India. The state coal company aimed to more than double coal production to 1.5 billion t/y by 2020. However, this target has since been revised down to 900 Mt/y (Rowland, 2015). Fossil fuel subsidies still amount to over $40 billion/y. Coal demand in India itself is expected to reach about 980 Mt/y in 2016-2017 and could reach 1,373 Mt/y by 2021-2022 (Prasad and Prasad, 2015).

India has large quantities of indigenous coal. However, supply chain problems have left many plants stranded without a steady coal feed (Carrington, 2014). Prasad and Prasad (2015) suggest that delays on environmental clearances for new coal mines are the reason for the gaps between supply and demand. The state owned Coal India provides 80% of the coal but has faced significant production delays – 60 of the country's 103 coal-fired power plants had less than a week's supply of coal on hand in 2013/2014. It is therefore not surprising that many Indian companies are investing in overseas coal mines (Shearer and others, 2015). Indian ports reportedly saw 24% increase in coal imports between April and July 2015 (Rowland, 2015). There is also the issue of the transport and supply chain – a lack of road, rail and ship interconnectivity causes significant delivery issues and investment in new equipment, both in the mining and transport sector (Prasad and Prasad, 2015).

Back in 2012, the IEA produced a report on energy in India which suggested that the coal sector was the most inefficient energy sector in the country and the least open to private investment, despite being the primary source of fuel. The monopoly of a small number of coal companies was criticised along with the lack of private company participation in the mining sector (IEA, 2012). It would appear that, since this IEA report was published, changes have been made. The Coal Mines Special Provisions Bill was passed by the Indian Government in March 2015, allowing coal mining by private companies as well as easing environmental restrictions and permitting processes (Rowland, 2015). Funds for expansion of the coal sector, as much as $3.3 billion, will be raised from selling a 10% stake in Coal India (Das, 2015).

In a new report being prepared by the CCC, Nalbandian-Sugden (2015) agrees that supply is the main reason for the shortfalls in electricity generation in recent years with widespread blackouts being common. Although India has the fifth largest coal reserves in the world, there are only really two

government owned companies running the coal production sector and greater competition a rather than just investment may be required to improve the supply chain.

The World Energy Council (WEC, 2015) suggest that there are uncertainties in investment in the Indian coal sector due to potential restrictions which may arise from the 2015 climate negotiations. It is perhaps for this reason that India is looking more to imported coals and even to investment in coal overseas. In addition to needing coal for the expanding power sector, India also plans to triple its steel capacity to 300 Mt by 2025. Coal India is reported to be in negotiations to buy coking coal mines in South Africa (Das, 2015).

3.2 Coal quality

Most indigenous Indian coals are bituminous, with a high ash content, much of which is inherent, and so difficult to remove below 30%. Indian coals generally have 35-40% ash as compared with 25% ash in China and 10% in the USA. This is one of the reasons why Indian coal-fired power plants consume around 0.7 kg coal/kWh whereas plants firing low-ash coals consume only 0.45 kg coal/kWh (lower average thermal efficiency is the other main reason) (Bhushan and others, 2015; Barnes, 2014). The whole of the coal chain is therefore involved – from the production, movement and handling of coal, much of which is incombustible, to the disposal of excess ash. However, data suggest that coal washing to remove ash (*see* Section 3.3) is only economical for plants which are bringing in coal from over 400 km away. The CPCB (Central Pollution Control Board) has set a cap of 34% on ash in coals which must travel over 1000 km. According to the discussion at the Chennai workshop, this limit may still be exceeded at some sites.

There is also the issue of increased volumes of ash waste, which is significantly higher for high ash coals. Coal ash is the 2nd largest industrial waste stream in India after mining waste. Ash utilisation in India has increased from 50% in 2010 to 57% in 2012; the majority is used in the cement industry. There is a requirement for plants in some regions to use more of their fly ash, but the target of 100% by 2014 was not reached. There is now a grace period until 2019/20. New plants have targets of 50, 70 and 90% use of fly ash within the first, second and third years of production, respectively (Bhushan and others, 2015).

Indian coal sulphur content is generally about 0.5% or lower, as received. Coastal stations can take imported international grade coals and some of these have sea-water scrubbing FGD (flue gas desulphurisation).

3.3 Coal washing

Coal washing can be expensive, uses significant quantities of water and creates a whole new issue of washery rejects. The distributed nature of the ash in Indian coals makes washing to below 30% ash difficult, but achieving ash contents similar to those of the original design fuels, at 30–34%, is possible. Blending with imported coals has emerged recently in India as a means to improve overall coal quality.

The US Department of Energy has been promoting washeries development in India. For example, the Bilaspur Washery was built by a consortium of Indian and American companies. This has been operating

for some years, but has not been without opposition on environmental grounds. As of 2010 there were a total of 52 washeries in operation in India with total installed capacity of 126 Mt/y, including both coking (26.69 Mt/y) and non-coking coal (96.32 Mt/y). This suggests that only around 7-8% of coal used in India is washed (UNEP, 2014). Considering the low quality of Indian coals, significant improvements in efficiency could be achieved through the whole coal chain by considering more coordinated coal washing and blending. This would include a reduction in the wasteful transport of non-combustible ash materials as well as increasing plant efficiency and reducing overall emissions.

4 Coal combustion

Power plant performance in terms of operation and efficiency and options for improvement are discussed in more detail in the complementary report by Henderson (2015). However, to put the effect of efficiency on emissions into context, it is important to also briefly discuss the issue here.

4.1 Plant efficiency

Bhushan and others (2015) note that emissions in India are exacerbated by the way that coal plants are operated. Some plants do not run at full capacity due to a lack of demand for electricity, leading to lower efficiency and higher pollutant emissions. This occurs in areas where the weak financial position of some state distribution companies means that they have limited funds to purchase power from plants. Further, Indian coal plants work in a 'merit order dispatch', that is – the plants producing the lowest cost power feed the grid first. In general terms, this means that older and less efficient plants burning cheaper coal, with no pollution control systems in place, are able to produce the least costly power and therefore tend to produce the most power. This current tariff structure increases pollution. The introduction of the requirement of older plants to bundle electricity sales in with solar power, as mentioned in Section 2 may go some way to changing the way the Indian grid is organised to ensure the prioritisation of clean energy.

As discussed in Chapter 3, until five years ago, all coal-fired power plants in India were subcritical, but now a number of supercritical units operate, as discussed in Section 2.2. Steam parameters of units supplied by BHEL (Bharat Heavy Electrical Ltd) have reached 25.6 MPa/568°C/596°C (Sukumar, 2011), and Toshiba have recently announced that they will supply ultra-supercritical (USC) technology at Harduaganj in Aligarh district, Uttar Pradesh. More recently China Light and Power have invested $2 billion in a 2 GW coal-fired plant in Guijarat (India Times, 2015). This may be indicative of a wave of new international investment in the Indian power sector.

The Perform and Achieve Trade scheme (PAT) was announced under the National Action Plan on Climate Change (NAPCC) in 2008. The scheme was the first attempt to introduce the concept of energy efficiency in thermal power plants in India. Out of the total 144 thermal power plants covered under the PAT scheme, 97 are coal or lignite fired units (Bhushan and others, 2015).

Despite power demand being at an all-time high in the country, average plant load factors of the existing plants have declined since 2007/8. This is reportedly due to stagnant domestic coal production bottlenecks in the railways constraining deliveries to power plants, as discussed in Chapter 3. Over and above this, state distribution companies have faced financial constraints which have limited their ability to purchase power (Bhushan and others, 2015).

The move towards larger, more efficient plants will mean more power from less coal and a concomitant reduction in pollutant emissions and ash waste. An increase of 1–2% in heat rate improvements, leading to efficiency improvements, will results in a concomitant reduction of 1–2% in emissions (Mittal and others, 2014).

4.2 Emissions of pollutants

Since there are currently no emission standards for SO_2 and NOx in India, there is no requirement to measure or monitor emissions from coal-fired plants. This means that there are little or no official data relating to these emissions from the coal sector.

Uncontrolled SO_2 emissions have been estimated at 2.5 Mt/y in 2001, and 3.8 Mt/y in 2010. NOx emissions have also increased from 0.98 Mt/y to 1.5 Mt/y during the same period (Mittal and others, 2014). Without action to install control technologies, these emissions will continue to grow with the planned increased use of coal.

According to Mohan (2015) coal-fired power plants account for 60% of particulate emissions in India, 45-50% of SO_2 emissions, 30% of NOx emissions and 80% of mercury emissions. Figure 8 shows the global change in SO_2 emissions between 2005 and 2010. Countries shaded red have significantly higher emissions than those in yellow or blue. Clearly India stands out as a region with the greatest emissions of SO_2 globally. Much could be achieved with appropriate pollution control strategies.

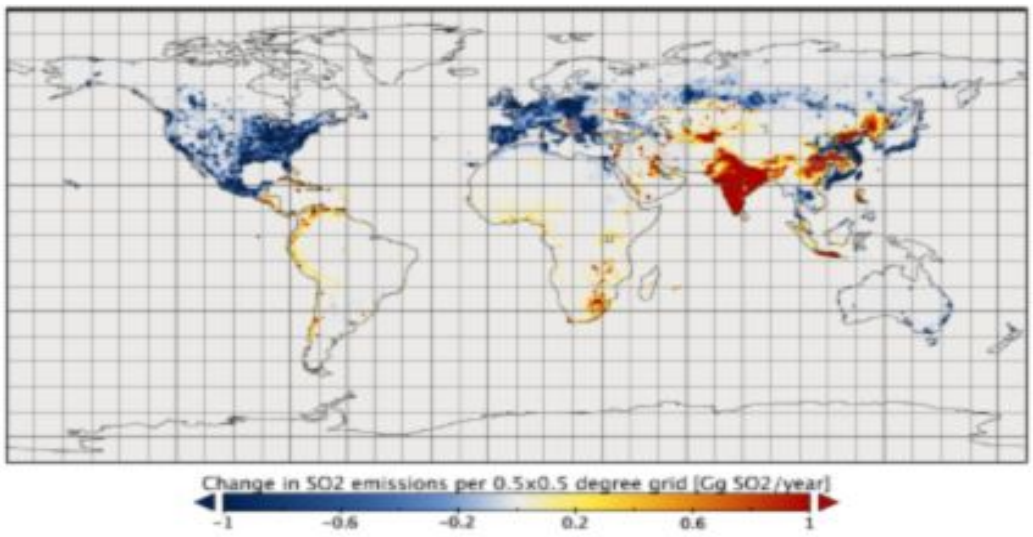

Figure 8 Change in regional distribution of anthropogenic land based SO_2 emissions between 2005 and 2010 (Klimont and others, 2013)

It is likely that similar maps could be presented representing emissions of particulates, NOx and mercury, since all of these pollutants relate similarly to the rate of uncontrolled coal combustion. Guttikunda and others (2015) reported that in 2011, coal-fired plants in India together emitted:

- 2100 kt SO_2;
- 2000 kt of NOx;
- 665 Mt CO_2.

It has been estimated that emissions of particulates, SO_2 and NOx could double by 2030 due to the growth in the use of coal during the same period. This may be offset to some extent, depending on the success of

implementation of the new emission standards that have been proposed (*see* Section 4.3) and the construction of increasingly efficient coal-fired plants (UEI, 2015).

Mittal (2012) has estimated the possible increase in pollutant emissions under India's energy expansion programme. Based on nationally published date from the Central Electricity Authority, Mittal calculated expected emissions based on a BAU (business as usual) scenario, where coal consumption is expected to increase and policy does not change. Under the BCS (best case scenario) the rate of increase of electricity production from coal and lignite will actually slow due to increased plant efficiencies and greater use of nuclear and renewables. However, this scenario does not take into account the proposed new emission limits (Section 4.3). The two scenarios are summarised in Figure 9.

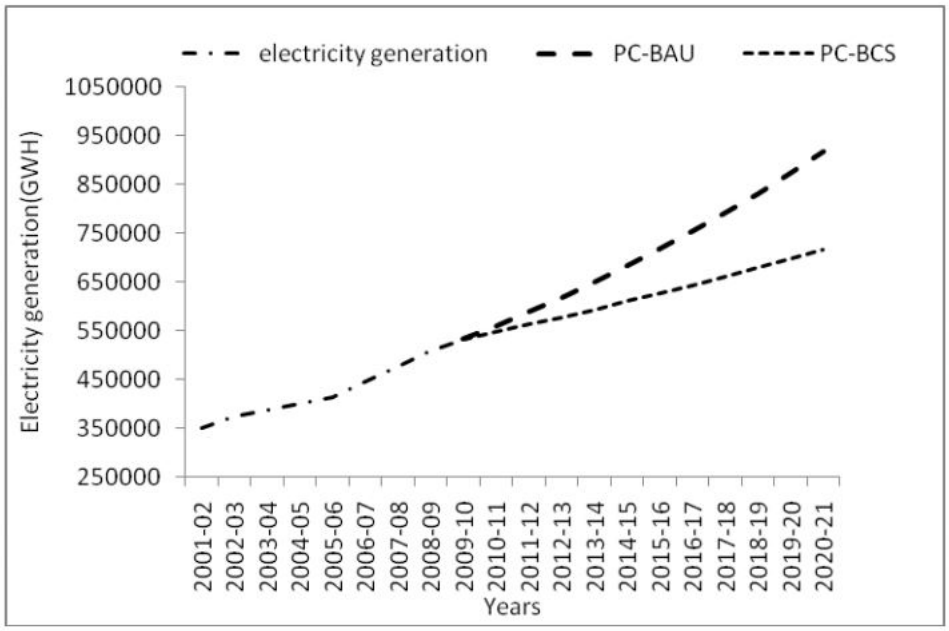

Figure 9 Scenarios of electricity generation from coal based thermal power plants in India (Mittal, 2012)

Figures 10 and 11 show the predicted increases in SO_2 and NOx emissions respectively under both scenarios. Even with a reduction in the proposed expansion of the coal sector, emissions of both pollutants are expected to increase significantly. This emphasises the importance of policies to control of emissions from coal combustion through flue gas cleaning technologies.

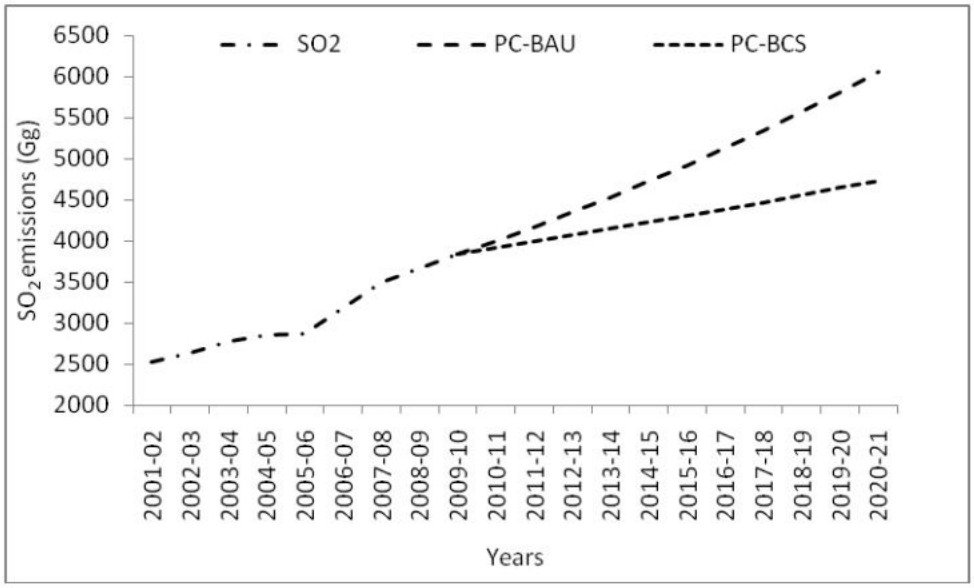

Figure 10 Scenarios of SO_2 emissions from coal based thermal power plants in India (Mittal, 2012)

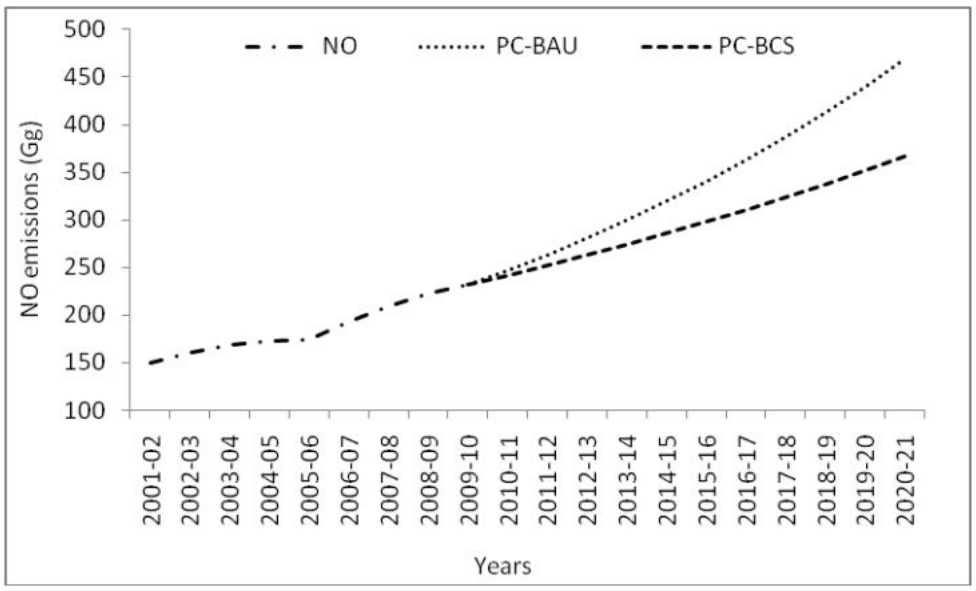

Figure 11 Scenarios of NO emissions from coal based thermal power plants in India (Mittal, 2012)

The National Ambient Monitoring Programme (NAMP), managed by the CPCB, collects 24 hour average concentrations of PM_{10}, SO_2 and NOx, 2–3 times a week at 400 manual monitoring stations in 150 cities in India. In most cities, the smaller plants within 30–50 km of the city limits have been converted to run on gas to keep concentrations below the required limits (UEI, 2015).

NASA (National Air and Space Agency, USA) have monitored emissions from India and other countries via satellite in recent years. Recent data suggest that SO_2 emissions from Indian power plants have increased by more than 60% between 2005 and 2012, surpassing the USA as the 2nd largest emitter of SO_2 from power plants. This is contrary to the data from India's Central Pollution Control Board (CPCB) which

claims that SO_2 declined from 2001 to 2010. This discrepancy is thought to be due to the way that these emissions were monitored. The CPCB data came from 361 ground-based monitoring stations largely located in urban areas where regulations have indeed reduced pollution, but only on a local basis (NASA, 2014). Since India, to date, has no SO_2 emission limits for coal-fired plants (*see* Section 4.3) there is no requirement for emissions monitoring. As new limits are introduced, motoring will be required and will provide more accurate data on trends in emissions.

UNEP estimated total emissions of mercury from India at around 161 t/y in 2005 (139 t/y from stationary combustion, mainly coal) and estimated that this could reach over 208 t/y by 2020 if left unabated. In 2014 UNEP published a report on mercury specifically from the coal utility sector in India, based on monitoring at three full-scale plants in Korba, Chhattisgarh and West Bengal. The study demonstrated that between 27% and 81% of the mercury introduced via the coal was released from the stack. Previous studies on other coal plants in the country had shown a range from 48-78% mercury release. Using the UNEP default emission factor for mercury from coal (0.9) suggested that mercury emissions from coal combustion in India would amount to 92 t/y in 2016 and could increase to almost 150 t/y by 2021, based solely on increased coal use. However, using the emission factor produced from the measurements made at Indian coal plants (0.58) an updated mercury emission estimate of 29–41 t/y in 2010 was produced along with lower projected emissions of 59 t/y for 2016 and just under 96 t/y for 2021. However, it was emphasised that this total could be reduced significantly through increased coal washing, improved plant efficiency and the installation of advanced control technologies such as FGD.

A previous report by Sloss (2014) summarises the challenges in obtaining a valid emission estimate for mercury from the Indian utility sector due to limited data and recommends the establishment of an Indian coal and coal plant database to improve the accuracy of emissions data.

4.3 Energy policy and emission standards

Back in 1995 the 'Mega Power Policy' was introduced in India to provide additional incentives to those building plants over 1000 MW in capacity. The Electricity Regulatory Commission Act of 1998 resulted in the formation of the Central Electricity Regulatory Commission (CERC) and encouraged individual states to establish their own commissions to regulate and rationalise regional tariffs. However, according to the IEA (2012), despite these initial changes, the power sector remained commercially unviable and there was little investment until new policies appeared during the 2000s.

The Electricity Act of 2003 created a policy framework which encouraged more competition in the sector by, among other things, delicensing generation and allowing open access to transmission lines to all generators. Metering was introduced along with policies to punish theft and power loss. The National Electricity Policy of 2005 and the National Tariff Policy of 2006 followed to promote rural electrification and attract investment. In 2005 the Ultra Mega Power Projects (UMPP) was launched to accelerate power capacity expansion of plants over 4,000 MW in capacity through competitive tariff-based bidding. Special conditions were put in place to ensure UMPPs obtained the necessary clearances on land and coal to

speed up the move to actual build. Although 16 UMPPs were planned, only 4 were awarded and only 1, the Mundra Unit, had been commissioned by 2012 (IEA, 2012).

At the moment, India has no national emission limits or regulations for SO_2 and NOx and it has relatively lenient standards for particulates (Nalbandian-Sugden, 2015). Particulate emission limits are between 150 and 350 mg/m^3 depending upon the size and age of the plant. The emission limit for SO_2 is based on a minimum stack height to maximise dispersal of the pollutant. Although there are over 100 coal-fired plants in operation, only three have FGD (flue gas desulphurisation) systems. There are no requirements for NOx control.

New emission standards have been proposed for India (MOEF, 2015), as shown in Table 1, which are similar to the levels seen in the EU and China. Although the draft table seems somewhat incomplete it does indicate a significant move towards driving major reductions in emissions of the acid gases, SO_2 and NOx. The target limit for mercury may seem less than challenging but, as with the situation in China, it should be possible to reduce mercury emissions at the same time as a co-benefit if measures are introduced to control the acid gases.

Table 1 Proposed emission standards for Indian coal-fired power plants (MOEF, 2015)

Coal-fired plants	Pollutant	Plant size	Standard, mg/m^3
Units installed before 31/12/2003[1]	Particulates	All	100
	SO_2	<500 MW	600
		>500 MW	200
	NOx	All	600
	Mercury	<500 MW	–
		>500 MW	0.03
Units installed after 2003 and before 31/12/2006[1]	Particulates	All	50
	SO_2	>500 MW	200
	NOx	All	300
	Mercury		0.03
Units installed after January 2017†	Particulates	All	30
	SO_2	All	100
	NOx	All	100
	Mercury	All	0.03

[1] Units to meet the limits within 2 years from the date of notification
† Includes all units, which have been accorded environmental clearance and are under construction

These standards are expected to reduce particulate emissions from new plants by 25% (above existing reductions), SO_2 by 90%, NOx emissions by 70% and mercury emissions by 75% '*compared with existing state of the art plants*' (DNA, 2015). The legislation also requires the restriction of water use in cooling towers which will have a significant effect in reducing the freshwater usage by thermal plants by up to 80%.

The date set for promulgation of these standards is January 2017. This standard is seen to be somewhat ambitious, not only in the timeline for promulgation (less than two years) but also in terms of stringency. As summarised by Nalbandian-Sugden (2015), efficiency improvements remain the most cost-effective

way to achieve significant cuts in CO_2 from coal-based power plants in India and are a means to move towards lower emissions of all pollutants until flue gas control technologies become more common.

Open discussion at the Chennai workshop raised some interesting discussion topics. The new Indian emission limit values have been out for discussion and now the final decision on the acceptance and subsequent enforcement of the limits lies with the Ministry, including the timeframe for implementation. There was general agreement that the limits would be likely to come into force but that it was not possible to say when this would happen or how stringently the standards would be applied. It was agreed that installation of control technologies for SO_2 and NOx in India would be expensive and possibly a challenge in some areas with limited water availability. The SO_2 control could create a new waste stream of gypsum, although this could be dealt with by creating a new market for wall-board type materials.

Like the USA, India has a federal system for environmental regulation with central as well as state standards. States can set standards and limits which are more stringent than those set at the national level. In India, action taken at the state level is often more important than that taken at the national level since implementation and monitoring of compliance is largely dealt with at the state level. State Pollution Control Boards could be targeted with state-specific emission reduction plans, particularly in large coal burning states like Tamil Nadu and Maharashtra.

4.4 Pollution control technologies

Indian coal plants firing Indian high ash coals face a significant challenge in reducing particulate emissions, especially in older units with dated technologies. Current emission limits for particulates at coal plants are as high as 350 mg/m^3. According to Bhushan and others (2015) around 30% of units are allowed to continue operation despite exceeding set particulate emission limits. However, it is reported that these plants are being monitored and are requested to comply with the limits.

With a few exceptions, most environmental control systems currently are for particulates removal only, but, even at most of these, enhancements to existing particle collection systems are needed to reach standards set in the European Union (EU).

ESP (electrostatic precipitators) are the most common particulate control systems in India. Indian coals may be lower in sulphur than some international coals but since more coal must be burned to compensate for the high ash content, the effect on sulphur emissions is limited. It was highlighted during the Chennai workshop that baghouses are more suitable for mercury control using sorbents and so this option becomes less applicable to existing plants in India.

“A few” plants firing imported coal are reported to have FGD (flue gas desulphurisation) systems installed. Coastal stations can take imported international grade coals and some of these have seawater scrubbing FGD. Delegates at the Chennai workshop confirmed that eight plants in India have FGD installed already (most are seawater based) and more are planned. Attendees of the workshop noted the new challenge for India of obtaining the requisite volumes of limestone. Dry sorbent injection is a more economic option than installing FGD. However, a factor to consider is the increased loading on ESPs.

Pai (2015) reported that the air pollution control equipment sector in India was expected to grow from $300 million in 2008 to almost $700 million by 2013. ESP installations dominate the market but orders for FGD are anticipated to increase as a result of the new emission limits. There are currently no plants in India with SCR or SNCR (selective catalytic reduction or selective non-catalytic reduction) for NOx control.

Alstom is providing the limestone based FGD system which is being installed at the 500 MW Vindyachal plant in Pradesh. This is the first full scope limestone FGD for such a plant in India and the fourth FGD for Alstom in the country. The contract was estimated at around $25 million and will provide 90% sulphur reduction at the plant (Alstom, 2014). Indian company TTPL (Transparent Technologies Private Ltd) is the first FGD manufacturer within India to commission an FGD plant (wet limestone) at a 100% pet coke power plant in North India, which has been operating since February 2012 (TTPL, 2015). In May of this year, Ducon Technologies announced that it had secured the order for FGD installation at a 2 x 600 MW plant (unspecified) (Business Wire, 2015).

Because of the limited installation rate of flue gas cleaning technologies for SO_2 and NOx, the current co-benefit reduction of mercury emissions, which can be well controlled in such systems, is minimal. Giang and others (2014) suggest that efficiency improvements in existing plants could reduce mercury emissions by up to 7%. Coal cleaning could achieve a 13–40% mercury reduction. Further installation of cold-side ESP (electrostatic precipitators) for particulate controls could also result in a reduction of 19–73% in mercury emissions conditions, based on the known characteristics of Indian coals. This is a insignificant amount for a sensible co-benefit pollution control option. These options are not necessarily additive. However, Giang and others (2014) also suggest that a combination of all three options could reduce overall mercury emissions by 58%. The addition of wet FGD could increase overall mercury control to 70.5%.

Pollution control technologies are expensive and take time to install. It would therefore make sense for India to coordinate pollution control systems and to focus as much as possible on multi-pollutant control systems which will reduce emissions of several pollutants simultaneously. However, cost and water availability are also important considerations in the decision making process.

According to Rao and Kumar (2014) the application of CCS (carbon capture and storage) to Indian coal plants could lead to an energy penalty of 17–22% (gross). This would necessitate a significant increase in output and fuel use to compensate for the energy penalty which could have serious impacts on energy access and energy security. The additional cost to both the government and users would be significant. Rao and Kumar (2014) therefore suggest that priorities should remain currently on expanding capacity and increasing energy efficiency. For the moment, CCS remains impossible for India without significant investment and incentives.

In a previous report produced by the CCC for the US State Department, a list was produced of the challenges faced by the Indian coal sector to reduce emissions (Sloss, 2012). Although these challenges were collated with mercury in mind, they apply to emissions of all pollutants:

- Indian coals are particularly low grade (35–45% ash) and therefore more coal needs to be fired to produce power. This results in increased emissions of all pollutants.
- the majority of Indian coal-fired plants are running below their designed efficiency and most are not fitted with any flue gas cleaning systems that could achieve mercury co-benefit reduction
- Current (existing) environmental legislation in India will not have a great effect on future mercury emissions. However, the proposed new emission limits could have significant co-benefit effects.

Discussion at the Chennai workshop focussed heavily on options for mercury control at coal-fired plants in India. Many existing coal-fired plants in India fire low quality coals and are relatively inefficient (due to age, and/or low coal quality), compared to similar plants elsewhere. However, because of this, the unburnt carbon in the fly ash at these plants is high and acts as an inherent sorbent to capture mercury in the ash. The UNEP 2014 report found that mercury emissions to air are closer to 58% of the mercury in the coal, much less than the 90% predicted in the iPOG,(a mercury emission calculation tool distributed at the workshop and available from UNEP and the CCC) although more data are necessary to confirm these values. Such partitioning to the unburnt carbon could be enhanced to great effect. Bromine application at existing/older plants could achieve up to 70% Hg reduction due to this high unburned carbon, without the addition of FGD or SCR. Bromine solution addition as an option for mercury control has a low capital installation cost ("minimal compared with FGD and SCR") and low operating costs. There are several national source of bromine within India, although this product needs to be further processed to calcium bromide. However potential corrosion issues due to bromine addition would have to be considered in some equipment, particularly at the cold side of the air pre-heater. The Electric Power Research Institute (EPRI) in the USA has conducted a study of potential corrosion due to the large volumes of calcium bromide in use in the USA.

The bromine addition which could have significant effects on mercury emissions from older, less efficient plants will not work as effectively in newer, more efficient plants. This would be as a result of lower unburnt carbon from more efficient systems burning higher quality coals.

If the new proposed emission limit values for SO_2, NOx and mercury in India are adopted then FGD and SCR/SNCR (selective catalytic and non-catalytic reduction) technologies could become standard on new plants. This would have a significant co-benefit effect on Indian mercury emissions which could be anything from 40-80%. Co-benefit effects due to similar controls on new plants in China have had a significant effect on mercury emissions.

India is unlikely to set Hg reductions on new plants without dealing with SO_2 and NOx emissions first. If SO_2 and NOx controls are implemented, co-benefit effects for mercury could be obtained and this could provide at least partial BAT/BEP for new Indian plants at no extra mercury-specific cost. Conversely BAT/BEP requirements for new plants could be a Minamata Convention deal-breaker for India if SO_2 and NOx legislation is not implemented. Installing FGD and SCR could increase incremental per unit cost of power by 20% in addition to the substantial capital cost. It is imperative that the new proposed emission

limit values are adopted and implemented - the adoption of the new legislation for SO_2 and NOx is the key to potential Hg control in new plants in India.

Delegates agreed that a cost analysis study could be useful to understand affordable Hg control options in India for both new and existing plants.

4.5 Monitoring and compliance

According to Pande (2015), India faces a huge challenge in implementing emission controls policy. This is largely due to the lack of resources – Government Agencies have only 200–300 technical staff available to monitor at least 50,000 plants. This means that, even though plants are required to install pollution monitoring equipment to demonstrate compliance with emission limits, these are inspected at most once or twice per year. There are allegations that some plants simply bypass pollution control equipment. Further, the Indian system works in such a way that violations of pollution standards are considered criminal offences. So rather than work through fines or taxes, regulators must file criminal charges which can result in extended court involvement. In fact, Pande goes so far as to suggest that "*convincing plants to turn on their pollution control equipment may be one of the quickest and cheapest ways to reduce pollution across India*". A new programme to encourage the use of continuous monitoring equipment across targeted regions in India, run by the Harvard Kennedy School, hopes to show that enhanced information sharing within India will improve pollution abatement (Pande, 2015).

Open discussion at the Chennai workshop highlighted that CEM equipment is now required in all plants or particulate monitoring but regulatory requirements and capacity building/training for use are not yet in place. However, it was agreed that the extent to which they are being operated is not clear. New guidelines for monitoring are being prepared and the existing systems are currently in testing and set up phase in many plants.

Monitors for SO_2 and NOx may be required to ensure compliance, should India adopt the proposed new emission limits. Delegates from India were keen to discuss the relative costs and ease of use of different monitoring systems. Systems for monitoring SO^2 and NOx are available "off the shelf" and should not be an issue in terms of cost or operation. Systems for mercury monitoring vary – there are CEM systems, wet chemistry systems and sorbent traps. Although real-time online CEM systems are available, these can be expensive and require operator skill. Since Indian coals are challenging, it may be the case that sorbent traps are the most suitable monitoring method. Sorbent traps are relatively simple to use and low cost. The US EPA has developed a mercury monitoring tool-kit and details of this system were presented and discussed during the workshop.

Once regulations are in force, timely implementation and enforcement will become critical. Regulations achieve nothing unless there is a means of confirming compliance. Compliance is established at the state level and there was some discussion over the availability of trained staff for compliance monitoring.

4.6 Coal ash

Discussion at the Chennai workshop revealed that utilities use significant land area for ash disposal. In the past, this disposal on site was in wet ponds leading to significant water and ground contamination. However, practices are changing and wet ash storage is not encouraged. In order to highlight the issue, a utility company described coal plants as “ash producing companies producing power as a by-product” (160 Mt/y). The ash utilisation rate is <60%. Ash is used in backfill and cement (dry ash – wet ash cannot be used).

5 Moving forward

Energy demand in India will continue to grow and is expected to quadruple between now and 2047. However, Indian coal production is expected to peak in 2037 and so the country could become far more reliant on imports. India Energy, an initiative of the Indian Government, provides information on potential energy futures in India and even provides an online modelling tool to allow users to see how investment in different energy sectors could affect the energy security of the country http://www.indiaenergy.gov.in/

Bhattacharya and others (2014) recommend several policy aspects to improve efficiency and overall performance of the coal sector in India. These include:

- improving efficiency of coal-fired power plants;
- switching to alternative sources of energy for generating electricity;
- greater investment in clean coal technologies;
- reducing carbon intensity and CO_2 emissions;
- implementation of adopted policies;
- reducing barriers in the coal sector in the long term.

5.1 The future coal fleet in India

The CCC report by Barnes (2014) considered the possible energy futures for India based on different scenarios:

- Base case – existing coal fleet continues with additional ultra-supercritical to meet demand;
- 50-year retirement scenario – the energy situation is reviewed in 2020, 2030 and 2040, and plants over 50 years old are retired and replaced by ultra-supercritical plants;
- 25-year retirement scenario – the energy situation is reviewed in 2020, 2030 and 2040, and plants over 25 years old are retired and replaced with ultra-supercritical units in 2020 and with advanced ultra-supercritical units in 2030 and 2040.

Results for the base case scenario are shown in Figure 12 and indicate that, should existing plants remain online in the long term, Indian emissions of CO_2 will continue to increase steadily into the future. Without emissions control on other pollutants, this will also be the case for acid gases and mercury.

Results for the 50-year retirement scenario are shown in Figure 13. Although the rate of increase in emissions will decline, overall emissions will continue to increase to 2040 and beyond.

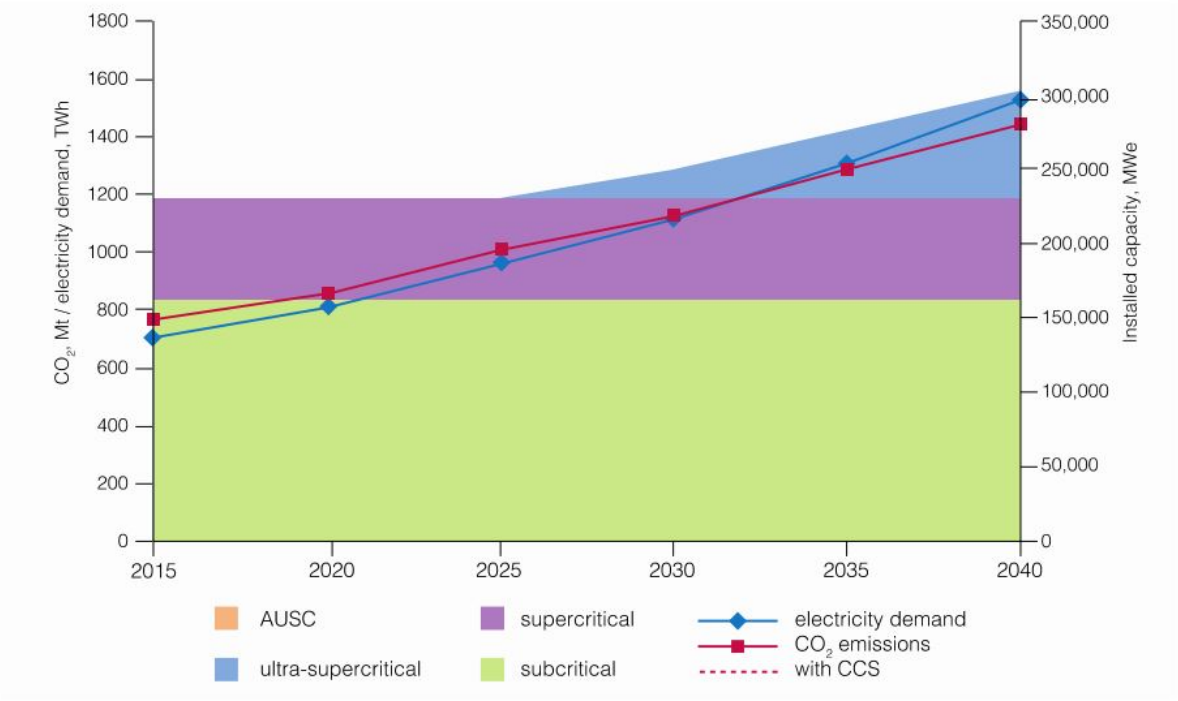

Figure 12 Indian base case scenario 2015-2040 (Barnes, 2014)

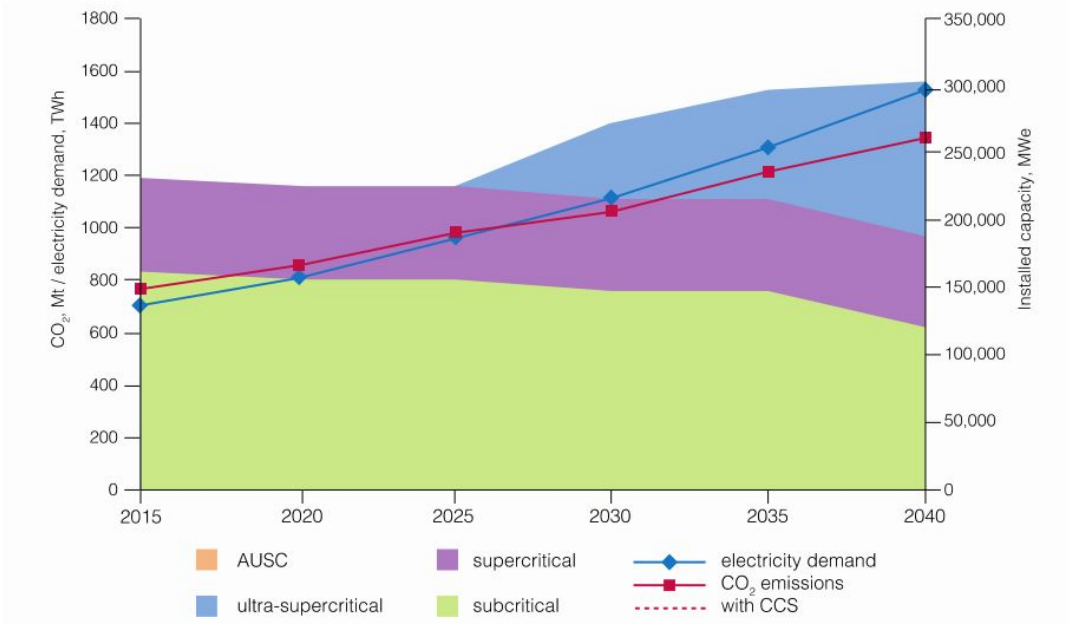

Figure 13 Indian 50-year retirement scenario 2015-2040 (Barnes, 20914)

The 50-ear retirement scenario demonstrates that the 'locking in' of older, less efficient plants into India's energy future will mean that controlling and reducing emissions will be a significant challenge. The 25-year retirement scenario results, shown in Figure 14, show a more promising future.

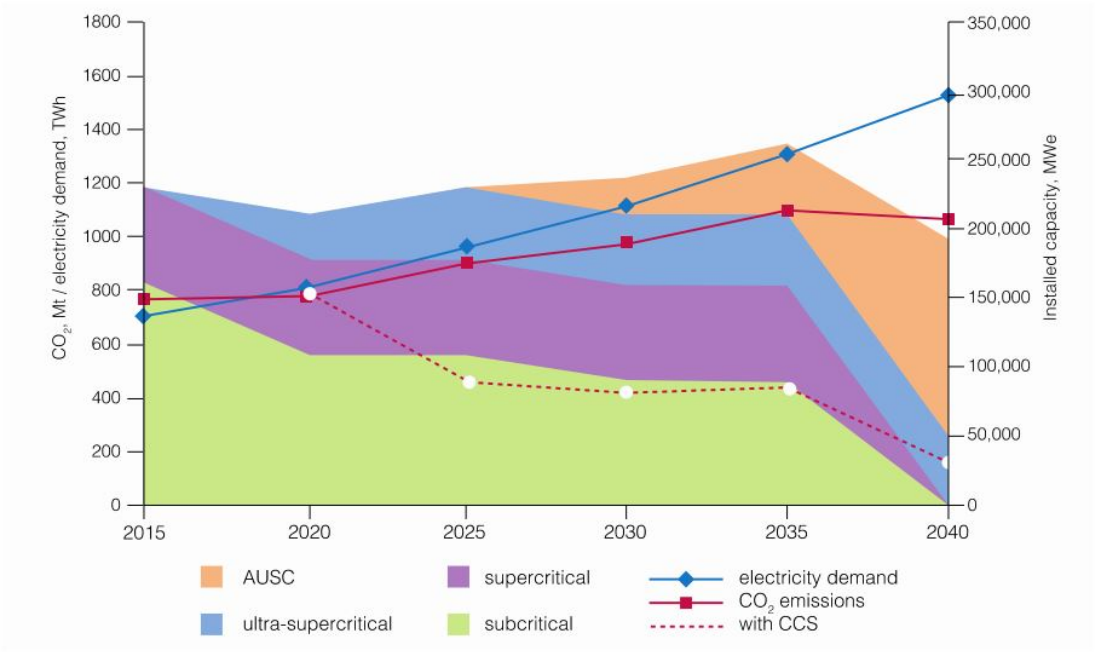

Figure 14 Indian 25-year retirement scenario 2015-2040 (Barnes, 2014)

When advanced ultra-supercritical plants are introduced into the future Indian energy mix, emissions will level out and then decline, despite the increasing demand trend. As alluded to in the graph, carbon capture and storage (CCS) would be required to reduce CO_2 emissions from India significantly within the next few decades. If the most effective CO_2 abatement pathway is followed (25-year plant retirement, advanced ultra-supercritical upgrades after 2025, CCS installation) emissions could fall to 159 Mt in 2040. Much Indian power generation coal is high in ash and there may be barriers to the adoption of ultra-supercritical technologies, but the significant gains to be had from adopting a high efficiency low emissions (HELE) pathway warrant a deeper analysis of the Indian situation (Barnes, 2014).

The IEA (2011) have suggested a possible roadmap for a cleaner Indian coal sector future. These include:

- closing older coal plants (including saving energy through efficiency projects);
- replacing older plants with gas and renewables;
- improving efficiency of the remaining coal fleet and employing carbon capture and storage.

This would be encompassed within a high efficiency low emissions (HELE) future, as shown in Figure 15.

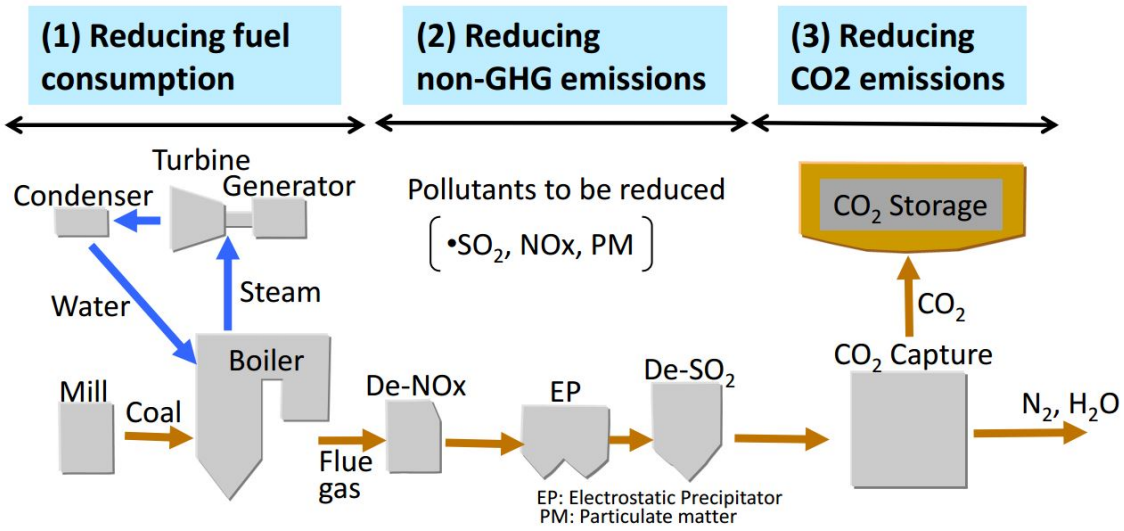

Figure 15 HELE roadmap (IEA, 2011)

The HELE future is already being demonstrated at the larger, cleaner and more efficient new plants being constructed in countries such as Japan, the USA and, most notably, China. HELE with CCS is the only way that coal use can continue in countries who commit to restricting the potential global temperature rise due to increased greenhouse gas emissions.

5.2 Feedback from the Chennai workshop

There are press reports that recent plans to replace plants over 25 years old with supercritical units of 660 MW and above could already have faltered, and that efficiency improvement at the existing units by using better operating practices is recognised as an effective way of raising system efficiency.

While market-related factors were identified as contributing to the new supercritical plants not performing to their maximum potential because they are operating at lower than base load, it may be worth adding that operating at reduced load reduces thermal efficiency, so plants are further penalised with still higher operating costs and higher emissions.

At the moment, there are few incentives for coal-fired power plants in India to clean up their emissions - plants are not rewarded for being cleaner. The current MOD (merit order dispatch) system works such that cheaper electricity (usually from less efficient plants) is prioritised as the grid buys cheapest first. Many of the cleaner plants, particularly in the private sector, are currently running well below capacity (60-70% utilisation) and running at a loss as they are not called upon as often as cheaper, less efficient plants. This is not good for private investment as companies see no benefit to building cleaner plants. Economic measures such as tax or other incentives could be applied to prioritise cleaner sources, as is the case in the USA and China. Similarly, there is a need to introduce incentives for new technologies in the power generation sector that would bring in new players in the field. For example, if there is an incentive to implement a zero or low discharge power plant by way of subsidy on the cost of generation. The money

for such a subsidy could be covered by taxes or incentives. There is definitely a case for allowing accelerated depreciation on investment in plants that use environmentally attractive technologies.

For efficiency improvement at coal plants, India has also started programmes like "Performance Achieve and Trade (PAT)" which sets efficiency improvement limits and incentivise the plants for achievement. The first phase (5 years cycle) has been just ended in 2015 and new phase will be started. More of such schemes are required.

For any plants, power purchase agreements were said to present problems in maintaining adequate revenues. The power price may be agreed in advance of fixing coal supply prices without appropriate linkage, causing reduced profits or even losses. However, NTPC have long-term fuel supply agreements to obtain the lowest prices from local sources, and the price can be controlled by the Government.

Investment in the Indian coal sector must be coordinated to ensure that priority is given to cleaner more efficient plants. A common opinion of the meeting was that international funding bodies should be encouraged to invest in clean coal rather than simply refusing to invest in any new coal, regardless of the system. The recent move by large international banks to stop funding new coal build entirely (unless they include carbon-capture) could back-fire by causing countries such as India, who intend to build new coal plants, to seek funding from elsewhere for cheaper (and potentially less clean) plants.

It was suggested that a list of low-cost measures could be created along with more expensive options in order to provide an idea of the costs involved in upgrading the efficiency of older units. It is important to confirm whether retrofitting plants to improve efficiency is more cost effective than a complete rebuild or replacement. Until the quality of Indian coals is improved through blending, cleaning or event replacement by internationally traded coals, Indian plants will struggle to reach the efficiencies achieved in other countries.

The issue of public perception and pressure was raised as being important to the speed at which legislation and implementation may occur. In China, the recent rapid move towards cleaner technologies is largely due to public backlash against rising pollution – could this happen in India? Change is possible but it could take time – China took two 5-year plans and significant public pressure to move towards the current, stringent, emission standards. The process could take longer in India. Some of the timescales required for Minamata ratification may be regarded as a challenge for India. However, according to Indian meeting participants, there is a growing public concern about pollution, health and environment, and this has resulted in that new politicians are highlighting this.

It was also suggested that action should be taken from the bottom-up, by establishing a cooperation between the industry and local government and for example conduct demonstrations of mercury reduction and plant efficiency in order to document that it is possible at relative (affordable) cost.

General discussion followed on the status of electricity generation and the energy mix in India, which a few interesting points being raised. It was suggested that new electrification in areas currently without power should focus on renewables and smart grids from the outset. It was also suggested that coal should

be included along with renewables under the definition of a “clean energy initiative”. Solar is getting priority in India because output is gauged in total MW capacity (available power) rather than, the more practical, MWh (produced energy). Solar is significantly lower in availability than coal plants and therefore cannot act as baseload.

Power theft must be dealt with to ensure revenue is raised for future investment. However the amount of electricity theft may be overestimated to cover true transmission problems and losses.

Incentive schemes for implementation of new, renewable, technologies in the power sector are being devised. India has embarked upon a massive program on the use of energy efficient lighting system that has reduced the power consumption drastically with the use of LED technology. Substantial investment has been made by the businesses in this sector because of the incentives provided by the governments (state and central) in the country. Germany is working with India on the IGEN project, largely to promote renewables and energy efficiency in industry and other end-users (GIZ, 2015).

6 Comments

India is going through a period of significant change. The country aims to bring electricity to all of its people as soon as possible and is considering how to do so in the cleanest and most cost-effective manner. Significant investment is being made in solar, including a new requirement that solar power be bundled in with energy production from older and less efficient plants. But coal will remain the dominant source of power in the country for the foreseeable future.

The proposed new emission standards for SO_2, NOx and mercury will require the retrofitting of flue gas cleaning systems to new and, eventually, older plants. This will go a long way to slowing the rate of increase in emissions which would result from increasing coal use. If India commits to the Minamata Convention then requirements on mercury control will give an extra incentive to move on with the other gas cleaning technologies to exploit their co-benefits. Mercury co-benefit reductions for plants installing FGD and SCR could be as high as 70% at no extra cost. For older, less efficient units, the unique quality of Indian coals and the resulting high carbon in ash combined with relatively low cost bromine oxidation addition could be used to facilitate cost-effective reductions of up to 70% at such plants. This may be seen as an interim method to quickly and economically reduce mercury from older units before they are upgraded or replaced.

The Indian government is tightening requirements in all links of the coal chain – from maximum ash contents of certain coals to proposed new emission limits which are almost equivalent to those seen in Europe and China. But all of these changes are happening quickly and at the same time. The question is - how can India achieve these admirable emission reduction goals whilst continuing at an incredible rate of electrification?

Proposed roadmap for mercury reduction from coal-fired utilities in India, based on open workshop discussions in Chennai:

- India must continue and strengthen its commitment to phasing out older, less efficient plants and replacing these with super and ultra-supercritical plants
- Existing plants should undergo regular efficiency testing and less efficient units should be upgraded accordingly.
- Programmes for coal washing and upgrading should be encouraged and expanded
- The proposed new norms/limits for particulates, SO_2 and NOx, should be adopted and implemented as quickly as possible. This could mean up to 70% mercury co-benefit reduction at plants where FGD and SCR systems are applied.
- Bromine use at existing/older plants could take advantage of the relatively unique high unburned carbon in Indian coals to provide a significant reduction in mercury emissions (up to 70%) at relatively low cost until these older units are phased out.

- Information on the relative costs of mercury control, specific to plants and coals in India, should be collated and disseminated widely, to ministries, regulatory bodies (national and state) and utilities in India. This would clarify the actual economics of mercury control in India.
- Demonstration projects at full-scale plants would produce India-specific examples of what can be achieved.

7 References

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