Let the role of coal technology in redefining India’s climate change agents and other pollutants

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Abstract

It is well established that carbon dioxide (CO₂) is the most prominent agent of climate change. The level of CO₂ in the atmosphere has been increasing persistently over the last few decades due to rising dependence on fossil fuels for energy production. India is facing a potential energy crisis. India has large coal reserves and coal is currently the linchpin of the Indian power sector, making Indian coal-derived emissions a focus of global attention. Further, India’s journey from a challenging energy security situation to the ‘Make in India’ initiative is expected to drive energy needs exponentially. Thus, in the context of a rapidly changing climate, it has become imperative to quantify the emissions of greenhouse gases (GHGs) from emerging coal-based energy plants in India. The present work attempts not only to do this, with the intention of highlighting India’s commitment to reducing CO₂ emissions, but also to redefine India’s future emissions. We draw attention to India’s attempt to transform the coal technology used in coal-based thermal power plants. We have tried to adopt a holistic approach to quantify the past (2010), present (2015) and future (2025) emission trends for important GHGs like CO₂ and other critical air pollutants from rapidly penetrating low-emission advanced coal technology. Our estimation shows that CO₂ emissions will increase from 1065 Tg yr⁻¹ (2015) to 2634 Tg yr⁻¹ (2025), which is approximately 147% of the current value. This rapid increase is largely attributed to rising energy demand due to industrial development, followed by demand from the domestic and agricultural sectors. The present trend of CO₂ emissions is sure to propel India to become world’s second largest emitter of GHGs in 2025, dislodging the United States. We have also estimated the emission of other pollutants like NOₓ, SO₂, black carbon, organic carbon, particulate matter (PM₂.₅, PM₁₀), volatile organic compounds and CO. Our findings seem to suggest that India will able to cut CO₂ emission from the traditionally dominant thermal power sector by at least 19% in 2025. Present attempts at emission reduction, along with the government’s massive initiatives towards building renewable energy infrastructure, could be well aligned to India’s Intended Nationally Determined Contribution submission to COP21 of the United Nations Framework Convention on Climate Change. With such a rapid expansion of energy production it can be assumed that cost-effective and uninterrupted power (i.e. 24/7) can be provided to all citizens of the country well before 2025.

Introduction

Across the globe, few issues are more contentious than climate and energy. Access to energy is one of the basic needs for human beings and lays the foundation for a nation’s economy. Adequate and uninterrupted power is an essential requirement at the forefront of most of the challenges that India has been facing in the last couple of decades. Fossil fuel is used to produce the majority of energy in India and demand is...
steadily growing. It is interesting that India accounts for just 2.4% of the world’s geographical area but supports nearly 17.5% of the world’s population. India is the third largest emitter of CO₂ with a global share of just 3%. Two-thirds of India’s CO₂ emissions come from coal-based power plants (coal is cost-effective and abundant and easily available in India) and coal-fired power plants generate nearly 41% of the world’s electricity (IEA 2008). India’s energy mix is dominated by coal, with coal plants generating around 65%–68% of India’s electricity (IBEF 2014). Further it may be stated that coal will remain the linchpin of the Indian power sector in the future. Hence, attention in recent times has been given to the adverse impact of coal-based power generation on climate (Francey et al 2013, IPCC 2007, IEA 2010a, Ebinger 2016, Rai et al 2013). Direct GHGs like CO₂ are important anthropogenic forcing agents (Myhre et al 2013); contributions from indirect GHGs are also relevant. Numerous studies have reported a linear relationship between the effect of cumulative CO₂ emission and increase in mean temperature across the globe (Allen et al 2009, Meinshausen et al 2009). CO₂ emission, especially from fossil fuels, has been reported as the driving factor contributing to anthropogenic global climate change (Friedlingstein et al 2014, Feng et al 2015).

In the past two decades, developing countries like India and China have been growing rapidly. They are responsible for about 45% of current world coal consumption, and it is estimated that they will to be accountable for over three-quarters of the increase in consumption by 2030 (IEA 2015). The global focus has therefore shifted to Asian countries and their energy consumption patterns. India has been facing potential problems of energy security in a growing challenge to maintain sustainable economic growth. According to World Bank and World Energy Outlook reports, nearly 20%–25% of people in India do not have access to electricity (IEA 2014). Per capita energy consumption in India is still a quarter of the global average and is expected to remain 40% below the average by 2040. This indicates a huge potential for growth (IJC 2014, IEC 2014). One of the biggest challenges in India, therefore, is to provide cost-effective energy to all sections of society; this is a high priority for government and will enable the standard of living to increase. Thus, coal remains India’s most important fossil fuel and is predominantly used in the power sector. Between 2001 and 2011, power consumption in India increased by an average of 125%, with the industrial sector showing the highest increase (~200%), followed by the commercial (180%) and domestic sectors (105%) (Indiastat 2015, IASRI 2015, MOSPI 2015). As per the International Energy Agency (IEA) report, India is expected to experience its highest ever growth in fossil fuel consumption under the new policies scenario 2014–2023 (WEO 2014). The Indian government’s ‘Make in India’ initiative is attracting huge investment and promoting India as an international manufacturing hub (Make in India 2015). Such programs put an extra burden on energy security but will also impact the environment through emission of pollutants. The projected energy consumption for India in 2021–22 is 1.59 million GWh, nearly 125% higher than the 0.71 million GWh in 2010–11 (LSUQ 2010). A multifold increase in energy supply is of utmost priority to service the booming economy. However, Indian thermal power plants have a low operational efficiency compared with other plants across the globe (IEA 2008). Recently, the Centre for Science and Environment’s (CSE) Green Rating Project (GRP) reported that India’s thermal power plants are the most inefficient (CSE 2015). Aging power plants with subcritical technology and the use of low-grade coal as fuel are the two most important factors driving low operational efficiency and higher emission of GHGs. However, the prime objective of providing affordable power (i.e. a 24/7 power supply) has not yet been achieved. In our view, this can only happen with improved operational efficiency of power plants in the energy sector. There will be huge environmental and social costs associated with coal use patterns in India in the future. If Indian power plants continue to depend on poor subcritical technology like that available in 2010 it will be nearly impossible to achieve the commitments made on GHG reductions in the Intended Nationally Determined Contribution (INDC) to the United Nations Framework Convention on Climate Change (UNFCCC) in Paris.

Emissions from the Indian thermal power sector are crucial, due to low operational efficiency. For coal to play an important role in India’s energy sector, the operational efficiency of power plants must be improved significantly to allow them to play a vital role in GHG reduction. In the last decade, thermal power capacity increased rapidly and exponential growth is possible in the next decade. Concurrently, by adopting low-emission coal technology India has been making a great effort to improve operational efficiency, thereby reducing GHGs. It is extremely important, in fact essential, to evaluate the magnitude of past, present and future emissions. To our knowledge, the present study is the first of its kind to quantify emission of GHGs for the emerging Indian thermal power sector by evaluating the rapid penetration of transmuting coal technology during the period 2010–2025. This study will also attempt to clarify environmental performance with respect to energy security. This will redefine India’s part in future emission reductions as per the climate policy discussion in the 21st Session of the Conference of Parties (COP21) to the UNFCCC towards GHG emission reduction pledged by countries across the globe.

**Activity data and method**

For the present analysis, activity data have been assembled from numerous sources such as government...
websites, individual power plant sites, government/ ministry/company reports and scientific reports and journals. Some micro-level fuel activity data were also collected from various paid-for websites like Indiastat as well as free-access sites. The data used show large temporal variation, including activity details like the spatial location of plants, fuel type/size, consumption patterns, technology used, etc. It is worth noting here that the preparation of such a multi-year data set is not only a time-consuming but also a painstaking task. Indian coal-fired thermal power plant capacity increased from 7508 MW in 1971 to 190 516 MW in 2015, and will reach 408 203 MW well before 2025, as shown in figure 1. The spatial location of each power plant is identified and mapped in a GIS environment. The temporal growth of power plant capacity can be seen in the images depicted in figure 2, where the size of the circles indicates power capacity. Here the bigger the circle the higher the capacity, and vice versa. It is clear from figure 2 that the capacity of Indian power plants has doubled in the last 5 years (2010–15) and is expected to expand much more rapidly in the next decade (i.e. 2015–25). We would like to make it very clear that the activity data projected for the year 2025 are assumed to be trustworthy future scenario data: they were compiled based on information collected from authenticated government/ministry/company websites which include information on ongoing thermal projects, allocation of land for new projects, environmental clearance, approved projects/sites, etc.

In general Indian power plants consume on average between 0.70 and 0.75 kg of coal to generate 1 kWh of power: this is very high in comparison with the 0.45 kg kWh⁻¹ in developed countries across the globe (Rai et al 2013, WEO 2014). The main reason for such high consumption is the use of substandard coal with a high fraction of ash and moisture, leading to a very low net calorific value (NCV) of just 3000–4200 kcal kg⁻¹. The NCV of Indian coal is significantly lower than the average (6500 kcal kg⁻¹) for coal available in the USA, Australia, Indonesia, etc. Further, the widely deployed subcritical and otherwise poor technology in aging plants is responsible for poor operational efficiency. Operational efficiency and the coal consumption pattern change significantly with changing coal technology (see supplementary information table S2 online available at stacks.iop.org/ERL/12/105006/mmedia). The future coal consumption pattern is highly dependent on the penetration of low-emission coal technology. In 2014, the increase in coal consumption in India was the highest in the world (11.1%) (BPSRWE 2015). We estimate that the amount of coal required was 487 MT in 2010 and nearly 710 MT by the end of 2015 (provisional), even though growth was tepid during this period. In 2014 India was very dependent on imported coal to bridge the gap between demand and supply: domestic production was nearly 620 MT and 169 MT of coal were imported (MoC 2014, Indiastat 2015). India’s reliance on imported coal increased three-fold to 212 MT (in 2015) from 73.25 MT (in 2009–10). This shortage of coal was mainly due to change in coal policy, followed by inefficiencies in the transport of coal from mining areas to power plants and slow reforms within the coal industry. The growth in coal imports of nearly 300% in just 5 years (2010–15) is enormous. To meet future demand, India already envisages the production of 1 billion tons of coal by 2019 to feed upcoming and existing power plants (Indiastat 2015). Coal India Ltd, India’s largest coal-producing government agency, is expecting to increase production capacity from 590 MT in 2015 to 908 MT in 2020 to meet the demand for coal from various sectors. Our new estimate shows that projected coal consumption will be 1756 MT in 2025, which is in close agreement with projected coal demand estimated by the planning commission (i.e. between 1500 MT and 2500 MT by 2031–32) (PCIEP 2006). Due to gaps in demand and supply, the actual coal consumption...
pattern during the period 2011–14 was rather low due to low capacity utilization of just 55% (CEA 2015). But the consumption pattern will improve substantially with better coal technology in all new upcoming power projects in 2025.

Indian thermal power plants have been adopting various technologies with different operating conditions and different grades of coal as fuel. This has led to a unique payload and operational efficiency for each plant (IEA 2014, CEA 2015).
are three broadly categorized power units used in the Indian power sector, i.e. subcritical, supercritical and ultra-supercritical. Traditionally, until 2010 power generation was dominated by pulverized coal-based subcritical/other lower technology-based power plants. More than 73% of the boilers use subcritical technology. Moreover, in many cases thermal plants were operated beyond their lifespan of 25 years, ultimately resulting in lower operational efficiency and greater release of pollutants. Half of the thermal power plants are at the end of their lifespan, while 80% have been operating for between 15 and 25 years. In order to meet rising energy demand, India has envisioned a multi-fold growth in energy production in the next decade. At the same time there is a need to control emissions, which is an essential task if future generations are to carry on using the same technology (i.e. pulverized coal combustion). This can be achieved by adopting cutting-edge low-emission sophisticated coal technologies with improved operational efficiency.

The efficiency of a power plant depends upon the steam parameter being used. Most conventional subcritical power plants operate at a steam pressure in the range of ≤170 bar, which is far less than the critical point of water, i.e. 220.6 bar and 374 °C. Power plants which operate above this critical point are called supercritical power plants. In this case, the latent heat of vaporization is zero and water converts directly to steam without boiling. Supercritical plants have a higher efficiency than subcritical ones due to their lower fuel consumption. Ultra-supercritical plants represent the most advanced coal technology; the steam and temperatures could reach up to 350 kg cm⁻² and 700 °C, respectively, due to use of superior materials to build boilers and turbines. The cost of such expensive advanced technology could be offset by lower coal consumption. India is now aggressively deploying higher-efficiency ultra-supercritical technology in most upcoming power projects. Apart from ultra-supercritical technology, the integrated coal gasification combined cycle (IGCC) and fluidized bed combustion (FBC) are other advanced coal technologies capable of substantially reducing CO₂ emissions. However, IGCC technology is not suitable for Indian conditions due to the high ash content of Indian coal (Doucet and Batoo 2007). An increase in the efficiency of power generation is vital in tackling emission issues. A 1% improvement in the operational efficiency of a power plant leads to a 2%–3% reduction in CO₂ emissions (WCA 2015). The operational and other parameters of three different broadly categorized coal technologies are provided in table S1 as online supplementary material. Until 2010 the Indian power industry was dominated by smaller thermal units of up to 250 MW which fall into the sub-critical category. Between 2010 and 2015, the majority of newly installed thermal units were supercritical, with private and government organizations having a nearly equal share. However, rapid transformation of coal technology is expected to happen in the next decade, and ultra-supercritical units of up to 800 MW will be deployed in most upcoming projects as well as in old projects. Table 1 summarizes the size distribution of 1115 power units during the period 2010–25.

For emission analysis, a bottom-up approach has been adopted to develop a multi-year technological emission inventory in which technological factors such as boiler size, fuel type and quantity, along with geographical information, electricity generation, year of operation, etc are taken into account. Information for nearly 1100 coal- and lignite-based power units has been compiled. In order to extrapolate missing information, existing data are applied to plants having similar capacity and technology. The present approach is similar to emission from point sources used in our previous studies (Sahu et al 2015, Sahu et al 2008). The emission factor EF is a sensitive parameter and is elaborated further in the supplementary material. All the EFs used are also tabulated in table S2. The total emission from the present sector is given by the following equation (1).

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T = \sum_{a} \sum_{b} F_{a,b} \left( \sum_{c} EF_{a,b,c} Z_{a,b,c} \right)
\]

Table 1. Size distribution of Indian power units between 2010 and 2025.

| Capacity | By end of 2010 | 2011–15 | 2016–25 |
|----------|---------------|---------|---------|
| Unit size (USA) | Unit No. | Generation in MW (proportion in %) | Unit No. | Generation in MW (proportion in %) | Unit No. | Generation in MW (proportion in %) |
| US < 150 MW | 213 | 21,889 (22.5%) | 79 | 8654 (9%) | 32 | 2787 (1%) |
| 150 MW ≤ US < 250 MW | 201 | 43,350 (44.5%) | 30 | 7335 (8%) | 26 | 6125 (3%) |
| 250 MW ≤ US < 500 MW | 21 | 6620 (7%) | 21 | 6390 (7%) | 27 | 8630 (4%) |
| 500 MW ≤ US < 800 MW | 51 | 26,060 (7%) | 119 | 71,020 (76%) | 295 | 198,170 (92%) |
| Total | 486 | 97,117 (100%) | 249 | 93,399 (100%) | 380 | 215,712 (100%) |
| Grand total | By end of 2010 | 735 | 190,516 | 1115 | 408,203 |

US, ultra-supercritical.

* 50 US units comprise 40,000 MW.
Results

The rapid transformation of the spatial pattern of CO$_2$ emission from the thermal power sector in India between 2010 and 2025 is depicted in figure 3. The estimated emission of major GHGs as well as other pollutants is tabulated in table 2. As the spatial pattern of emission of various pollutants is similar only one pollutant, i.e. CO$_2$, is discussed here. The first estimated CO$_2$ emission is 1065 Tg yr$^{-1}$ in 2015, nearly 46% higher than the emission in 2010 (i.e. 730 Tg yr$^{-1}$). During 2010, high CO$_2$ emission of the order of 15–25 kt yr$^{-1}$ was confined over the eastern region of Central India followed by relatively lower amounts of 5–10 kt yr$^{-1}$ over some parts of western, northern, southern and south-eastern regions of Central India (figure 3(a)). In 2015, except for a couple of places, a similar pattern of CO$_2$ emission hotspots with relatively higher magnitude, i.e. 10–25%, are observed over the same regions compared with 2010 (figure 3(b)). The emissions are uniformly well scattered due to the addition of a large number of new mega power projects. It is also observed from figures 3(a) and (b) that extremely high emissions within the range of 25–30 kt yr$^{-1}$ are found over the eastern region of Central India. This is attributed to the existence of many high-capacity thermal plants over the major mining region of India. Between 2010 and 2015 some regions over the southern part of Central India, western India and the north-western region experienced an increase in emissions of 5–10 kt yr$^{-1}$ due to the addition of new capacity to existing plants followed by an increase in lignite consumption.

CO$_2$ emission is expected to increase to 2634 Tg yr$^{-1}$ in 2025, and the same can be seen in the spatial pattern of emission in figure 3(c). Future growth of nearly 147% is extremely high compared with the recent base year, i.e. 2015. The spatial pattern shows that emissions of the order of 25–35 kt yr$^{-1}$ are confined to major mining regions lying over the eastern part of Central India. Most of existing old power projects will have received new power units leading to high emission of GHGs. An intense CO$_2$ emission of the order of 10–20 kt yr$^{-1}$ covers the major geographical regions except some parts of north-western, northern tip, southern tip and north-eastern regions and the Western Ghats. The above regions are found to have relatively very low emissions of 1–3 kt yr$^{-1}$. The growth in CO$_2$ emission was just 46% between 2010 and 2015, which is not very significant compared with growth between 2015 and 2025. The present analysis highlights the major factors behind the tepid growth in emissions between 2010 and 2015. Changing coal policy led to a gap between supply and demand for coal, which may drive lower operational efficiency and greater dependence on better-quality imported coal. The relatively large fraction of better-quality imported coal is another important factor behind the moderate growth of emissions. Coal imports increased three-fold during the same period (2010–15). The domestic coal supply issue was a temporary problem, and domestic coal production has increased again during the last 1–2 years. Between 2001 and 2011 energy demand from the industrial sector increased by nearly 200%, followed by the commercial (183%), domestic (105%) and agricultural (49%) sectors (CEA 2015). However, growth was found to be moderate (i.e. 20–25%) for all other sectors between 2011 and 2015. In the next decade, the growth of coal-based power and associated emissions is expected to be nearly 147% to fulfill energy demand, especially from the industrial sector followed by domestic and agricultural sectors. The agricultural sector makes a significant contribution to the national GDP and requires huge amounts of energy due to the adoption of advanced agricultural technology. Despite robust growth of coal consumption, the Indian thermal power sector, which is one of the largest sources of climate change agents, will reduce emission by nearly 19% compared with the 2010 level. GHG reduction could become a reality due to the deployment of advanced coal technologies followed by use of better-quality fossil fuel.

An overall four-fold increase in conventional coal energy in 15 years is huge. It will not only affect air quality and human health across the Indian Sub-continent but will also impact on global climate. India is taking all possible initiatives to shift dependence towards renewable and green energy. The Indian government’s effort at diversifying its power sector is noteworthy. Despite the government’s initiative to add another 175 GW of renewable energy by 2022, we ascertain that the present sector will remain the dominant sources of climate change agents in the future. There are limited studies available that compare recent and future emissions from the present sector.

Table 2. Multi-year estimation of emissions from Indian coal-fired thermal power plants.

| Base year (Gg yr$^{-1}$) | CO$_2$ | NO$_x$ | SO$_2$ | BC | OC | PM$_{2.5}$ | PM$_{10}$ | VOC | CO |
|-------------------------|-------|-------|-------|----|----|-----------|----------|-----|----|
| 2010                    | 731   | 1578  | 6090  | 4.4| 0.5| 292       | 1121     | 0.5 | 29.2|
| 2015                    | 1065  | 2300  | 8875  | 6.4| 0.7| 426       | 1633     | 1   | 42.6|
| 2025                    | 2634  | 5689  | 21948 | 15.8| 1.8| 1053      | 4038     | 1.9 | 105.4|

BC, black carbon; OC, organic carbon; PM, particulate matter; VOC, volatile organic compounds.

where a, b and c represent sector, fuel type and technology, $T$ is total emissions, $FS$ is the sector- and fuel-specific amount, $EF$ is the technological emission factor and $Z$ is the fraction of fuel for a sector with a particular technology ($ΣZ = 1$ for each fuel and sector).
For CO₂, our estimation for 2015 is 1065 Tg yr⁻¹ which is nearly 15% higher than the estimate made by Sadavarte and Venkataraman (2014) and nearly double the estimate in the World Energy Outlook special report on India (WEO 2014). The major discrepancy is due to different fuel activity data followed by the EF values used. Imported coal plays an important role in controlling coal emissions and accounted for nearly 20%
of total coal consumption in 2014–15. In this study an attempt has been made to calculate emissions for two different scenarios. In Scenario A it was assumed that the penetration of imported coal might increase to 30% in 2025. In Scenario B the dependence on imported coal is reduced to 10% in 2025. In both the scenarios the coal technology remains same. The penetration of imported coal could reduce CO$_2$ emissions further to around 21% under Scenario A compared with about 17.5% under Scenario B by 2025. Some uncertainty in the emission estimation is attributed to the EF rather than fuel activity data; this uncertainty could be of the order of two in the case of most pollutants except CO$_2$ (i.e. ±28%).

Conclusions

The findings presented come from a holistic approach to develop an emission inventory for the thermal power sector in India for the past (2010), present (2015) and future (2025). The study also accentuates the role of rapidly penetrating low-emission advanced coal technologies during the energy security and ‘Make in India’ initiatives. The adopted coal technology will not only reduce fossil fuel consumption but also improve operational efficiency. This is of utmost importance from the perspective of climate change, while also enabling access to energy for economic growth and a better standard of living. The present trend shows that India is liable to displace the USA to become the world’s second largest emitter of CO$_2$ (after China) by 2025. The results additionally emphasize India’s ability and intention to bring down CO$_2$ emissions of the most dominant energy sector by at least 19% over the 2010 level. This reduction could be more than 20% over the 2005 level. The transformation of coal technology in India could be revolutionary in the next decade and is on track to support the commitment made in India’s INDC submission to the UNFCCC. India’s dependence on imported coal will also further reduce CO$_2$ emissions by 2025 by up to 21% under Scenario A against ~17.5% under Scenario B. We assume that the goal of uninterrupted 24/7 power for all will be achieved well before 2025. India has also pledged to build another 175 GW of renewable energy infrastructure by the year 2022. This will not only play an important role in reducing India’s carbon footprint but will also support environmental sustainability at national and global levels. Financial and technical assistance from developed nations is needed in order to achieve these goals. India’s role in and initiatives towards reduction of climate change agents deserve to be appreciated.

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