

# Relevance of Clean Coal Technology for India's Energy Security: A Policy Perspective

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**Abstract.** Climate change mitigation regimes are expected to impose constraints on the future use of fossil fuels in order to reduce greenhouse gas (GHG) emissions. In 2015, 41% of total final energy consumption and 64% of power generation in India came from coal. Although almost a sixth of the total coal based thermal power generation is now super critical pulverized coal technology, the average CO<sub>2</sub> emissions from the Indian power sector are 0.82 kg-CO<sub>2</sub>/kWh, mainly driven by coal. India has large domestic coal reserves which give it adequate energy security. There is a need to find options that allow the continued use of coal while considering the need for GHG mitigation. This paper explores options of linking GHG emission mitigation and energy security from 2000 to 2050 using the AIM/Enduse model under Business-as-Usual scenario. Our simulation analysis suggests that advanced clean coal technologies options could provide promising solutions for reducing CO<sub>2</sub> emissions by improving energy efficiencies. This paper concludes that integrating climate change security and energy security for India is possible with a large scale deployment of advanced coal combustion technologies in Indian energy systems along with other measures.

## 1. Introduction

India is an emerging economy with an average GDP growth of 6.7% over the last ten years and a projected rate of 7-7.3% for 2015-16. This is expected to significantly increase the demand for energy as per-capita energy consumption (PEC) (the ratio of the estimate of total energy consumption during the year to the estimated mid-year population of that year) increased from 13695 Mega Joules (MJ) in 2005-06 to 22725MJ in 2014-15, a CAGR of 5.59% [1]. The energy elasticity of the Indian economy has traditionally been above unity due to relatively lower energy efficiency in many energy intensive sectors and high coal dependence. To maintain its economic growth, India needs forward-looking energy efficiency enhancement policies combined with an integrated development of the energy sector. In view of climate change concerns, energy and technology choices in developed countries are being determined based on their capabilities to mitigate greenhouse gases (GHG) emissions. However, in India, the major focus is still on fulfilling energy demand while addressing local pollution concerns. Climate change security through lower GHG emissions and energy security due to higher energy availability need not be competing policy goals. Various clean coal technologies could provide an integration of these two policy goals. This paper tries to explore this through a bottom-up modelling analysis.



Coal being the dominant player of energy mix in India has various reasons for much wider acceptance. Its diverse geological distribution, abundant availability, matured industrial base, available technical competence makes it an obvious contender for leading the list of energy resources. Growing demand for energy and power in rapidly growing economy of the country is theoretically believed to be achieved with sustained domestic sources especially in a highly uncertain and fluctuating international energy markets. Suitability and safety of nuclear projects have been questioned in view of Fukushima accident in Japan. Renewable energy production options are unlikely to assume more than 20-30% of share in total energy supply in various estimated visions. Hydro potential is limited by the fact that country has limited perennial water bodies and most of them cater to the basic purpose of drinking, agriculture and other domestic uses. Therefore, hydro capacities alone cannot serve the growing demand. Due to very short switching time hydro power is preferable for meeting peak demands. Other fossils fuels like natural gas and oil are scarce and have very uncertain availability, pricing and trade treaties. Further these fuels have other important uses in domestic and transport sectors. Hence, coal is an obvious winner and leader in utility fuels in the country and likely to remain in future. But future concerns are directed towards greening coal in order to achieve sustainable development. Thus, coal-based clean technologies can be a sustainable choice to be adopted in Indian energy systems to meet growing energy needs.

In 2005, 72% of the CO<sub>2</sub> emissions in India came from coal, with a significant contribution from power and steel plants. The top three sectoral contributors were power plants (51.9%), steel plants (8.4%) and cement plants (8%) [2]. Many researchers [3,4,5,6] have analysed the contribution from various sectors. Some researchers have also analysed the contribution of different industrial plants. Garg and Shukla (2009) [2] indicated that the 25 largest emitters contributed 34% of the total all-India CO<sub>2</sub> emissions in 2005 and this number has grown by around 10% per annum during 1990–2005. This analysis shows that emissions are getting increasingly concentrated in a few major industrial units called large point sources (LPS), which provide focused mitigation opportunities.

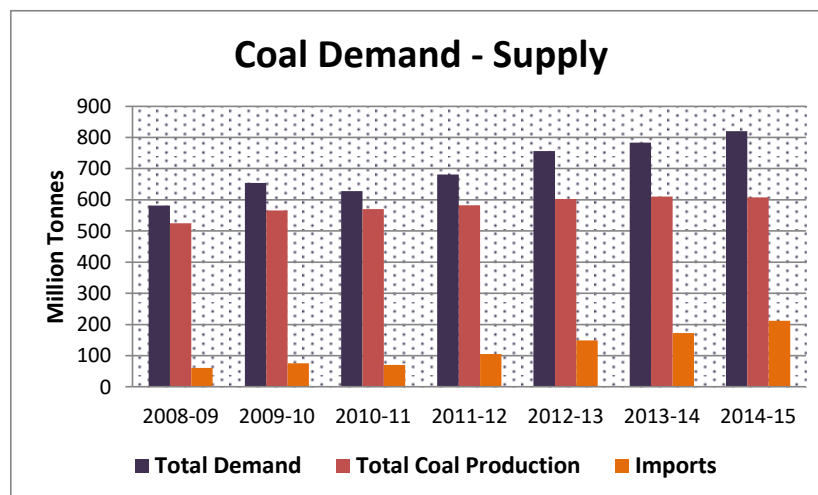
Various international climate studies have indicated that the carbon dioxide (CO<sub>2</sub>) proportion in the atmosphere has increased significantly due to heavy industrial activity during the last century. In 2013, global CO<sub>2</sub> emissions due to fossil fuel use (and cement production) were 36 gigatonnes (Gt CO<sub>2</sub>); this is 61% higher than 1990 (the Kyoto Protocol reference year) and 2.3% higher than 2012 [7]. However, the repercussions of this increasing concentration have become apparent only recently. The major contributors to emissions which have adversely impacted the environment need to be identified and a suitable mechanism to tackle them has to be developed. Globally, the talks about finding solutions for mitigating energy related emissions have mainly emphasised three aspects, 1) improving efficiencies of technical systems, 2) promoting renewable energy sources in mainstream choices and 3) discouraging fossil use through regulation and taxation. Due to the prevailing energy dynamics in India, the use of fossil fuels, especially coal, is inevitable. Sustainable coal use can be ensured in three possible ways, 1) conditioning of coal before use, 2) efficient technology choices and 3) post combustion carbon capture.

The next section gives an overview of the coal use in India. In the third section, we provide the methodology and setting-up of the model for coal sector analysis and GHG emission mitigation possibilities under BAU scenario. The fourth section discusses the results followed by conclusions.

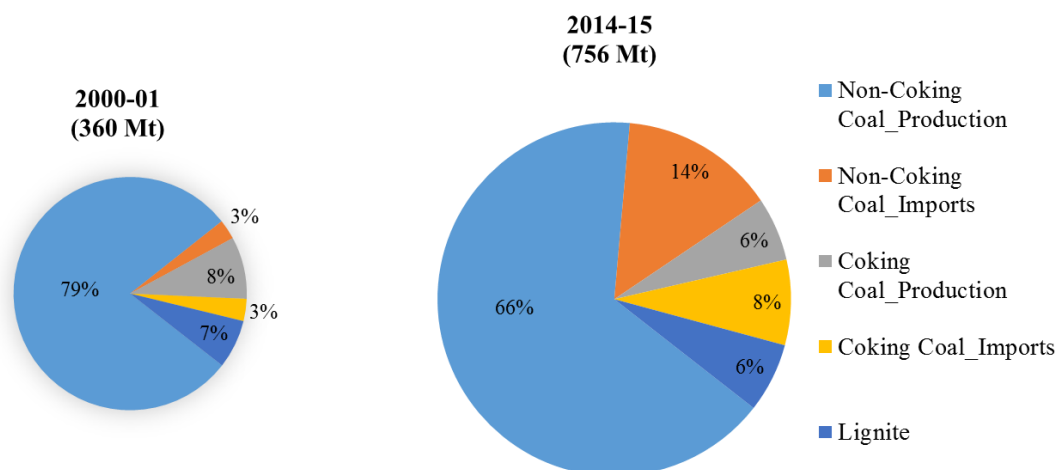
## **2. Coal demand and supply in India**

The Indian coal industry is the fourth largest in terms of reserves and third largest by production in the world. Coal is accounting for about 70 per cent of the total energy consumption in the country. Coal deposits in India occur mostly in thick seams and at shallow depths. Indian coal has high ash content (15-45%) and low calorific value. With the present rate of daily coal extraction in the country, the reserves are likely to last over 100 years. India's coal production has increased to 612.44 million tonnes in 2015, more than the 565.77 million tonnes the country produced in the previous year.

As per the report of the Working Group on Coal [8], the demand for coal is likely to continue in the long term due to its dominance in the evolving energy mix, given the domestic availability of coal and improvement in the plant load factor of existing plants. The coal requirement has been projected at 980.5 Mt for 2016-17 implying a CAGR of 7.1% during 2012-2017, with 738 Mt for power, 67.2 Mt for steel and almost 48 Mt for cement [8]. Total coal supply has grown at 5.9% annually during 2000-2014 wherein coal imports have grown faster than domestic coal supply (Figure 1 and Figure 2). This has not only affected the country's trade deficit and energy security, but has also resulted in an increase in power generation costs and led to contractual disputes among producers and regulators on allowing pass through of increased cost of power generation to consumers.



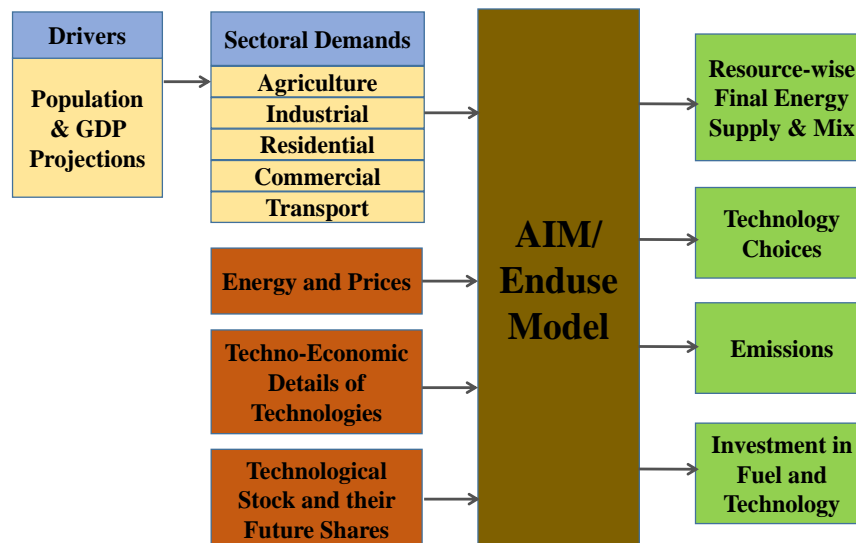
**Figure 1 Coal Demand, Supply and Imports in India. Source: Ministry of Coal Annual Report (2015)**



**Figure 2 Coal Supply in year 2000 and 2014. Source: Ministry of Coal Annual Report (2014)**

The failure to meet coal production and power generation targets over the last decade has raised many concerns for India's economic growth that need to be resolved. However, with the growing use of coal, increasing CO<sub>2</sub> emission is also a cause for concern. The future of coal sector would also depend on synchronizing coal use with GHG emission mitigation. This would require a detailed study of technology choices using coal and their likely emission trajectories, in order to analyse mitigation options in present and future scenarios. In this paper, a bottom-up view of the energy system using the AIM/Enduse model has been taken which is suitable for a disaggregated analysis of economic sectors for analysing energy and technology changes in different policy regimes.

### 3. Setting-up of the AIM/Enduse Model for the Indian Coal Sector



**Figure 3** Model structure of AIM/Enduse model. Source: AIM/Enduse Manual (2003)

The AIM/Enduse model, a bottom-up energy and technology optimisation model, has been used in this study (Figure 3). It accounts for final energy consumption and CO<sub>2</sub> emissions in end-use sectors based on actual energy use and the way energy services are performed by energy devices [9]. It focuses on the end-use technology selection in energy consumption as well as energy production. It calculates the future demand of energy services for several sectors, determines the optimal set of technologies that can be used to satisfy the service demand through total cost optimisation and then it estimates future energy consumption [10]. The model minimizes the net present value of all system costs including capital, fuel, O&M and all other cost components. In this study, an analysis of the timing of fuel and technology switchover, the level of emission and different ways of mitigating it by adopting countermeasures has also been carried out. This has helped in assessing the requirements for transition in the coal sector in view of achieving mitigation benefits while providing continuous energy security.

The model facilitates the analysis of the energy consumption, technology choices, emission trajectories etc. in a given context using linear optimisation. [11, 12]. We have set up the country-level AIM/Enduse model for India that requires selection of sectors, services, technologies, reference years and discount rates. In this study, we have taken up five commonly classified sectors, namely, the industrial, transportation, agriculture, residential and power sectors for the bottom-up modelling analysis [3, 4, 13]. Also one additional sector namely the ‘coal sector’ has been added for specialised treatment of coal and provided a detailed description of the coal sector, since coal is a primary energy source in various intermediary and end-use technologies. Multiple services in each sector have been taken for better understanding of the sector. Most technological competition can be described as a substitution of one technology for another. The technologies considered in the model range from the ones currently available to those that are still in the research and development stage.

Service demands are the main external drivers that trigger technology selection decisions based on information on costs. Energy-mix and material-mix are derived from the technology-mix. Finally, CO<sub>2</sub> emissions are derived from the information on the emission characteristics of energy, materials and technologies. The service demand estimates have been done exogenously. The methodology for demand projection used by Kapshe et al [4] has been adopted in this study.

The maximum share in the model is the estimation of the future scenario in the sector. The maximum shares for the base year are taken from various government and research publications. The model provides enough scope for accommodating changes in figures on demand, shares, etc. as demand elasticity changes or a particular policy push is observed in due course. The coal based power

generation technologies included in the model are of four generic types – Sub critical PC, Super-critical PC, IGCC and Fluidized Bed Combustion. Their fuel efficiency and CO<sub>2</sub> output assumptions are indicated in Table 1.

**Table 1.** Performance of coal-based technologies

Parameter	Year	Technology			
		Sub-Critical	Super-Critical	IGCC	Fluidized Bed
<b>Coal</b> (kg/kWh)	2005	0.616	0.568	0.549	0.549
	2030	0.494	0.474	0.457	0.457
	2050	0.441	0.431	0.416	0.416
<b>Emissions</b> (kg-CO <sub>2</sub> /kWh)	2005	1.159	1.069	1.032	1.032
	2030	0.930	0.891	0.860	0.860
	2050	0.829	0.810	0.782	0.782

### 3.1. Scenario narratives

The continuing trend of development in India is energy intensive. Currently, the carbon emission limits have not been implemented in India, however, there is a high likelihood of its imposition based on the envisaged high growth in future. The model development has been done in commensurate with on-going measures and future targets. Alternate strategies and development path could be studied through various scenarios. The Business-as-Usual (BAU) scenario in the current study includes INDC's and reflects the continuance of policies and practices with moderate changes. It is an attempt to consider the role of advanced technologies in achieving the targets of energy security and climate security together. This goal in continuance with on-going efforts will require impetus on necessary sector specific actions to reduce emissions intensities.

The policies have been selected on the basis of their potential to reduce carbon dioxide emissions. The present study considers only the BAU scenario for analysing the fuel, technology and emission trends. However, other scenarios may also be worked upon which will further bring down the emissions. Our modelling also captures the latest commitments by the Government of India in its Intended Nationally Determined Contributions (INDC) report to the UNFCCC on October 1, 2015 [14]. The INDC initiatives on GHG mitigation and clean energy cover the period 2005-2030.

Clean coal constitutes a major part of these initiatives. INDC (2015) [15] indicates that “coal based power as of now accounts for about 60.8% (167.2 GW) of India's installed capacity. In order to secure reliable, adequate and affordable supply of electricity, coal will continue to dominate power generation in future. Government of India has already taken several initiatives to improve the efficiency of coal based power plants and to reduce its carbon footprint. All new, large coal-based generating stations have been mandated to use the highly efficient supercritical technology. Renovation and Modernization (R&M) and Life Extension (LE) of existing old power stations are being undertaken in a phased manner. About 144 old thermal stations have been assigned mandatory targets for improving energy efficiency. Coal beneficiation has been made mandatory. Introduction of ultra-supercritical technology, as and when commercially available, is part of future policy. Besides, stringent emission standards being contemplated for thermal plants would significantly reduce emissions.” INDC has also identified Pulverized Combustion Ultra Super Critical, Pressurized Circulating Fluidized Bed Combustion, Super Critical, Combine Cycle, Integrated Gasification Combined Cycle and Fuel Cell as priority clean coal technologies for India. These technologies are well represented in our model.

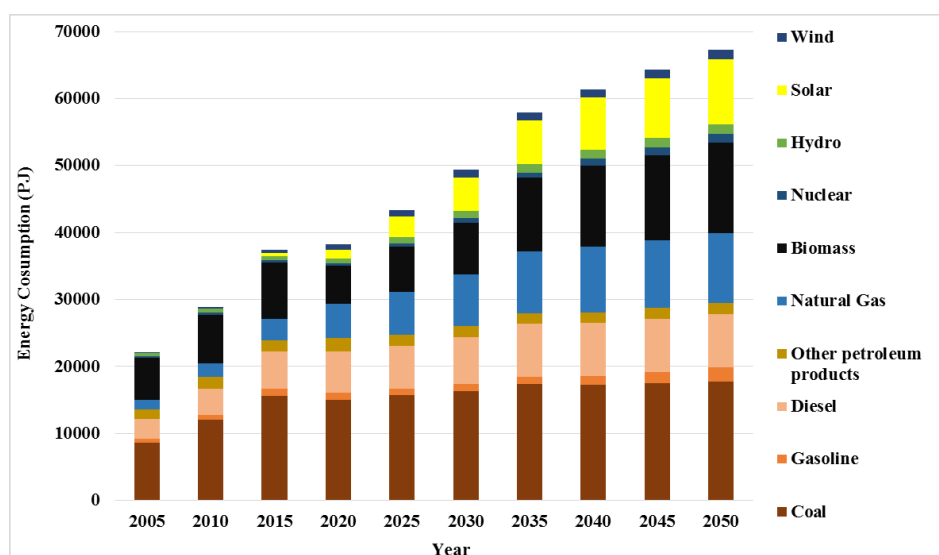
Our results provide an analysis of Indian coal futures under alternate scenarios during 2000-2050 and therefore we divide our analysis for the 2005-2030 period to synchronise with Indian INDCs. The other future period in our analysis for 2030-2050 provides the long-term coal scenario for India.

#### 4. Results and discussion

An analytical interpretation of the quantitative outputs of the model for the BAU scenario has been presented in this section. The BAU scenario has been generated by running the model from the year 2000 to 2050. The results obtained in the BAU scenario indicate that huge capacity expansion is needed across sectors fuelling energy demand at a high rate. This shows that most power generation utilities continue to use coal and expand their coal-based generation capacity to meet the increasing energy demand. Given the emphasis on energy security concerns and the requirements of meeting the energy demand, the use of coal is inevitable in estimated visions. New generation options like Atmospheric Fluidised Bed Combustion (AFBC), Pressurised Fluidised Bed Combustion (PFBC) and Integrated Gasification Combined Cycle (IGCC), etc. are advocated because of their higher generation efficiency which imposes a lower environmental burden and their ability to work with any type of coal. Super-critical technologies are also preferred due to their higher efficiency compared to conventional sub-critical pulverized coal technology [16-19].

##### 4.1. Fuel-technology mix

Indian energy needs revolve around coal, ranging from power generation to industrial production, and for cooking purposes in rural areas. The total energy consumption in India increases by about 3 times over 2005-2050 (Figure 4). Because of reduced availability and increasing access to commercial fuels, the biomass consumption will decrease, however the use of commercial biomass and biomass is observed to increase in power and transport sector. Diesel and gasoline have also registered a substantial increase due to the rapid growth of the transport sector and cumulatively account for nearly 22% by 2050. The share of gas increases from 7% to 18% in 2050, thereby substituting coal due to increasing availability through international collaborations mainly in power, industry and transport sectors. The share of coal is expected to remain almost constant due to increasing reliance on coal based electricity generation and domestic availability. However, the share of coal is observed to decrease due to increase in share of gas, nuclear and renewables in the future energy mix.



**Figure 4. Fuel-wise primary energy consumption in end-use sectors in BAU**

Electricity production has been the major source of carbon dioxide emissions in India. Most of its current and future requirement is still expected to be based on coal and gas in addition to aggressive targets for renewable energy. This is mainly because given the scale at which the demand is growing, no single scheme and promotion policy can fulfil the demand generated across sectors [20]. The technology-wise electricity generation has been depicted in 2050 in India (Figure 6). Total electricity generation increases at an almost constant growth rate of 2.3% annually from 2015 to 2050. The share of coal-based technologies in electricity generation is constantly declining from around 70% in 2005



to 43% in 2030 due to inter-fuel substitution and higher availability from renewable and further decreases to 28% in 2050. The corresponding increase has been observed in gas-based generation from around 10% to 21% in 2030 and 25% in 2050. But coal still remains the mainstay for power generation followed by solar, gas, wind and hydro.

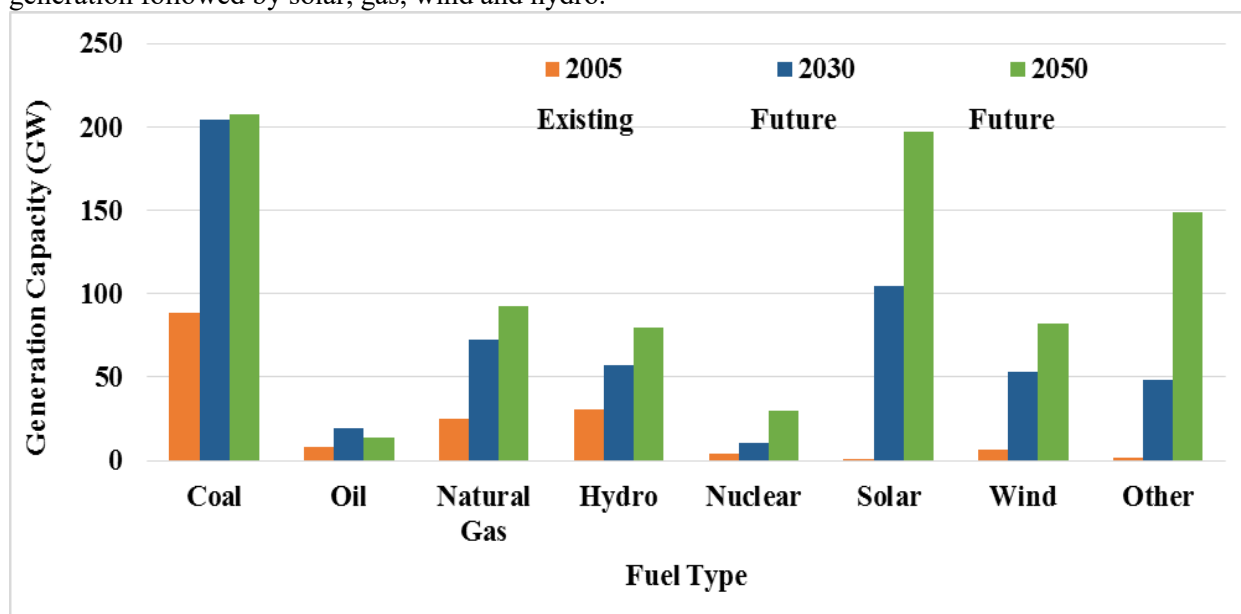


Figure 5. Existing and future generation stock in BAU

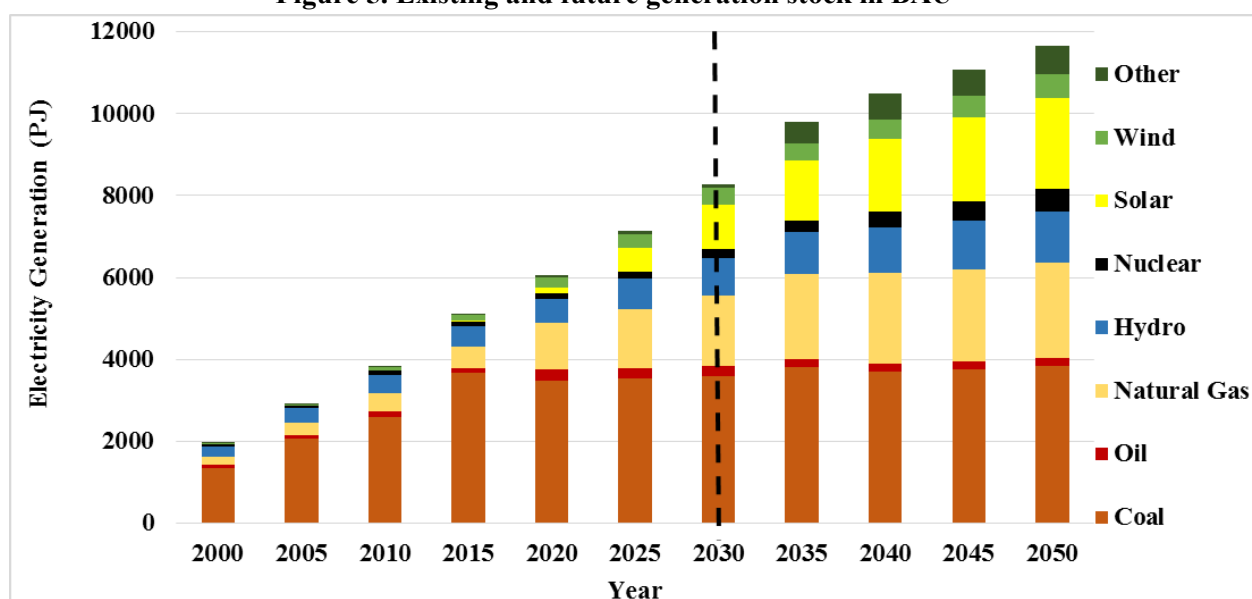


Figure 6. Technology-wise electricity generation in BAU

The total installed capacity goes up nearly five times, 568 GW in 2030 in the BAU case. The share of coal based capacity is declining from 53% to 35%, while gas based capacity marginally increases from 9.9 % to nearly 12.9% over the span of 30 years (Figure 5). There is an increase in the coal capacity till 2020, after which the old, inefficient thermal power plants will be phased out. These power plants will be replaced by efficient power plants that will use a combination of improved pulverization along with super-critical and ultra-super critical technologies. Coal beneficiation and fly ash utilization will be required to mitigate other environmental hazards of enhanced coal use in this scenario (Figure 5). Gas based generation would compete with coal in future among fossil fuel based technologies. Creating new large hydro capacity will become a challenge due to strict land acquisition

laws, and relocation and resettlement issues. Climate change is creating further stress on the overall water availability in the peninsular rivers. As a result the hydro capacity share continues to fall from around 22% in 2000 to 10% in 2030, and much below beyond that. GoI has announced the establishment of 100 GW of solar capacity by 2022, and augmentation of total wind capacity to 60 GW by 2022 [15].

The generation capacity of renewables (solar, wind, small hydro and biomass) accounts to around 40 per cent in 2030 and around 50 per cent in 2050. In the case of increasing concerns for limiting thermal generation, nuclear technologies emerge as a promising choice for meeting energy needs. However, the 'Fukushima' nuclear disaster in Japan has brought the discussion on nuclear safety to the forefront and there is a developing resistance in various countries to nuclear power. Given the current concerns and slow progress, nuclear power is expected to contribute only around 2-3% of total generation in the BAU scenario, thus limiting its scope in the BAU scenario. The present energy generation stock and plausible capacity addition in year 2030 and 2050 respectively is shown in Figure 5. It indicates that coal technologies have a major share in power generation followed by gas among fossil fuel-based generation. More than 24% of new installed capacity comes from coal while around 11% and 9% respectively is added by gas and hydro. Solar and wind generation capacity is envisaged to be more pronounced due to the policy thrust and likely to contribute around 24% and 10% over the period of 45 years to meet future requirements.

If we carefully look at Figure 5 and Figure 6, we observe that coal based capacity has grown at a CAGR of 2.1% annually over the span of 45 years whereas electricity generation from coal based technologies has increased at a CAGR of 3% during the same period. Also the share of coal technologies in generation has declined from 59% to 22.8% from year 2000 to 2050 while coal consumption in generation for the same period has declined from 69.5% to 27.5%. This is primarily due to the energy efficiency improvement of coal technologies and emerging competing technologies. The Union government has launched the Restructured-Accelerated Power Development and Reforms Programme (R-APDRP) to improve efficiencies across the generation sector and minimize wastage. The T&D losses have significantly improved from about 32% in 2005 to 23% in 2013. This has improved the resultant power supply by reducing the wastages. Roughly India's coal requirement is 0.7 kg/kWh. So, avoiding 10 per cent of electricity being generated saves around 70 million tonnes of coal consumption per year [21]. Natural gas consumption in BAU has increased from 10.8 % to 25% over fifty years. This inter-switching between coal and gas seems possible in view of improving international trade practices and technology improvements in transporting networks for natural gas in the future. Gas-based capacities have grown in the past and are preferred by captive producers due to their low-cost and ease of operation [22]. Bilateral contracts and agreements among countries are providing a more robust business foundation and avoiding any contingencies and disputes to a great extent. It is expected that this would facilitate strong tie-ups among countries for signing future long-term contracts.

#### *4.2. Coal-based power generation mix*

The new coal technologies improve fuel efficiency and mitigate carbon emissions at three different stages, namely pulverization of coal, production of steam and sequestration of carbon dioxide. Coal is pulverized by a combination of crushing and grinding technologies to get a desired degree of fineness of the fuel, which in turn increases the fuel efficiency by 70-80 per cent. The sieved coal is fed into a furnace to produce steam. The technologies used to pulverize coal include cyclone-fired boilers, various types of fluidized bed combustion and integrated coal gasification/combined cycle technologies. The efficiency of heating unit is increased by improved thermodynamics when water is converted to superheated steam without boiling. Super critical and ultra-super critical technologies produce steam and higher temperature and pressure, which enable more efficient operation of the turbine cycle as compared to its sub-critical counterparts. The mitigation of carbon emissions at the end of the cycle can be achieved by addition of sequestration technologies. A number of technologies exist that capture and store carbon dioxide from gas stream, however they have not yet been optimized



for the scale required to sequester the carbon in India. Apart from the conventional technologies, a combination of aforementioned pulverization, heating and sequestration technologies have also been considered in the model. The new technologies and their introduction year are based on various Indian national and international reports and expert opinions from the government and industry.

The details of coal based generation technologies and their expected capacity addition in different timeframes has been given in Table 2. It clearly indicates that the share of coal based technologies have to increase in BAU scenario since coal based power plants, with their relatively higher plant load factors (PLF) vis-à-vis renewable technologies, fulfil the maximum power demand. Fluidized bed combustion (PFBC, AFBC, CFBC) and IGCC also increase their respective capacities in future. India has already established 27.5 GW of supercritical units and around 50 GW such capacities are under construction [15].

**Table 2** Coal-based technology-wise generation capacity (GW) in BAU

Year	Sub-critical	IGCC	Fluidized Bed	Super-critical	Lignite	Coal based total capacity (GW)	Coal as % of total national generation capacity
2005	79.9	3	2.1	0	3.7	88.7	53.8
2015	128	4.9	5.3	12.1	3.8	154.1	55.9
2020	138.5	5.6	8.6	55.3	4.8	212.8	47.9
2030	111.1	8.7	12	81.9	5.7	219.4	38.4
2040	89.3	11.8	12.7	109.8	5.7	229.3	30.2
2050	67	15	22	123.9	4.2	232.1	27.2

#### 4.3. Coal demand

The coal demand in India would continue to rise at a 1.62% CAGR reaching about 1066 Mt in 2050 vis-a-vis 516 Mt in 2005 (Figure 4). But due to penetration of advanced technologies in coal intensive sectors and fuel switching, this demand may likely to go down. This analysis of alternate possibilities will be the subject matter of next part of the study.

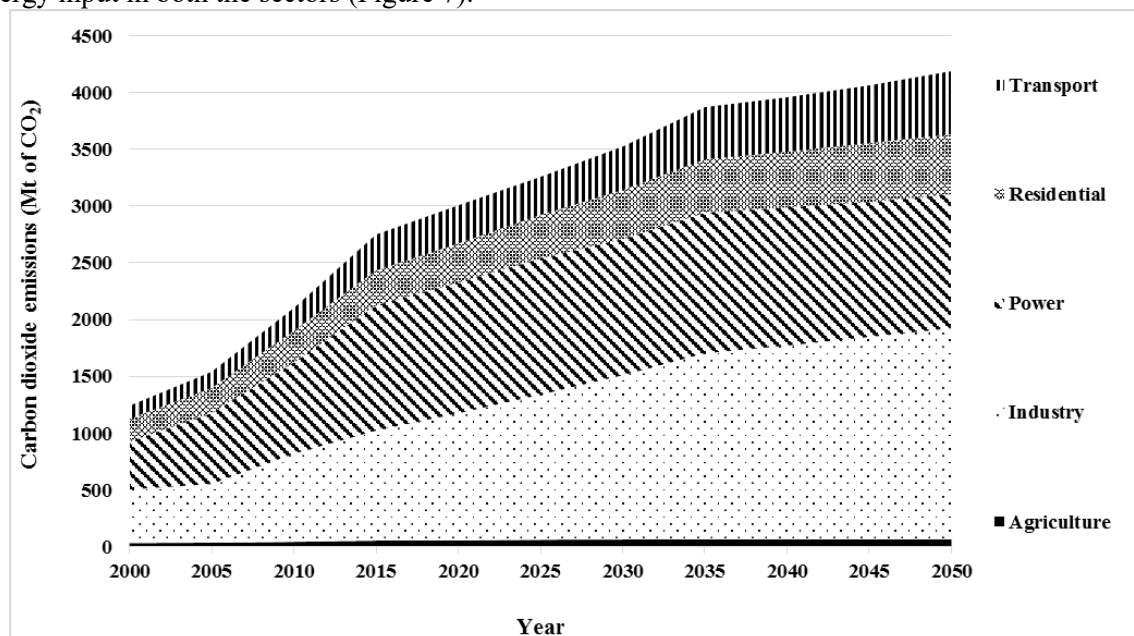
However, considering the vast geological reserves possessed by India and the government focus on low cost energy security, it is clear that coal will continue to be the mainstay energy choice for the coming few decades. Simultaneously, there is pressure from the social and government sectors to use coal in a cleaner and more efficient way. This can be achieved in one of three ways - providing clean and washed coal to industries (pre-use), using higher efficiency technologies (in-use) and capturing emissions (post-use). On the other hand, the Power and Coal Minister has indicated his plans to set up coal washeries for 500 Mt of coal every year for the next five years, indicating a total coal handling of over 2.5 billion tonnes per year by 2020 [23].

However, this raises the concern of creating massive infrastructure and relocating inhabitants, as many infrastructure projects have been contested in India lately. Project execution deficiencies reflected in slower government approval processes and resistance by social activists have only added to turning down or closure of projects. Therefore, in this tight supply situation, achieving indigenous coal production capacity is daunting. Many of the new thermal coal based capacities propose to use imported coal (mandatory bidding conditions for the power sector in some UMPP's) have led to the creation of increasing port capacities to facilitate coal imports. In view of these targets, measures to augment coal supply need greater thrust.

#### 4.4. CO<sub>2</sub> emissions

The CO<sub>2</sub> emissions from end-use sectors in India have increased from around 1545 Mt-CO<sub>2</sub> in 2005 to nearly 4183 Mt-CO<sub>2</sub> in 2050.

Despite efficient vehicular stocks and marginal fuel substitution, the transport sector emissions have increased. In the residential sector, fuel switching from kerosene to LPG and electricity has had a considerable positive impact on carbon emissions. However, a majority of emissions around 44.5 % and 28.1 % are from the industrial sectors and power generation respectively in 2050. Coal is a major energy input in both the sectors (Figure 7).



**Figure 7** CO<sub>2</sub> emissions from end-use sectors in BAU

Total coal demand has increased from around 9117 PJ in year 2005 by twice in 2050. This shows that coal will serve the major needs of energy in India and will remain the main contributor to rising CO<sub>2</sub> emissions. It is apparent that any efforts at reducing energy related emissions will have to consider the effect of increasing coal use.

## 5. Conclusion

In order to see the organised responses for tackling climate challenges in future, climate friendly policies are necessary. These policies would be enacted in due course to realize mitigation benefits. Energy security and climate change mitigation have become important in the changing global landscape of energy policy formulation and lead to identifying solutions that can survive in the long run. In the BAU scenario the requirement of coal is continuous and coal based capacity contributes nearly half of the total generation. Its share declines by almost 12% in 2030 and further by 15% in 2050 as compared to its share of 63% in 2005 though coal capacities continue to increase at a CAGR of 2.78% till 2050. Due to the continuing thrust on climate change mitigation as committed in the Indian INDC, the role of clean coal technologies would be decisive in future along with other carbon neutral technologies such as nuclear and renewable that are expected to contribute 7.5% and 13.3% respectively to total generation by 2050.

The overall change in energy mix (fossils, nuclear and renewable) under various alternate possibilities would depend upon the intended target actions decided by the Government for future growth and any GHG mitigation targets that may arise due to stricter global climate change regimes.

A major thrust is required to create a favourable policy climate, technology R&D and transfer, and international financial support for large scale penetration of clean coal technologies in India to ensure energy security with GHG mitigation.

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