



# International Journal of Engineering Research and Science & Technology

ISSN : 2319-5991  
Vol. 2, No. 3  
August 2013



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Review Article

# THERMAL POWER PLANTS: POLICY FRAMEWORK FOR CO<sub>2</sub> EMISSION REDUCTION

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To meet the developmental needs of the country and to raise the basic standards, the electricity generation has to be increased manifold. Considering the huge coal reserves in the country, coal based thermal power plants are going to be the major contributor of energy sector. Coal based thermal power plants are the major GHG gas emitters. To meet the international commitment to reduce the GHG gases, a balance has to be drawn between energy needs vis a vis efforts to reduce GHG emissions. This paper underlies the policy imperatives, which will help achieve the balance between increasing electricity demand and reducing GHG emissions.

**Keywords:** Energy, GHG emissions, CO<sub>2</sub>, Climate change, Coal

## INTRODUCTION

The issue of climate change and consequent global warming has drawn more attention in recent years due to rising sea levels, glacier retreat, Arctic shrinking, and altered patterns of agriculture. Human activities add to global warming through carbon dioxide released by using coal, petroleum, natural gas, and other sources to produce energy for human consumption. Global warming has become an issue of concern because of its negative effects on the environment, human health, and economic well-being of all the people of the world.

In 2007, the Intergovernmental Panel on Climate Change (IPCC) issued its Fourth

Assessment Report. Based on physical, chemical, and biological measurements and observations, the IPCC concluded that global warming is unequivocal. The IPCC also concluded that atmospheric concentrations of gases with significant influence on earth's solar radiative processes have increased substantially. The most significant of these gases is CO<sub>2</sub>, which has risen from a pre-industrial level of about 280 ppm to more than 380 ppm, a level substantially higher than any level during the last 650,000 years.

The IPCC has set the goal of reducing carbon dioxide to 350 ppm (parts per million) by 2025. Nations and the international community as a

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whole are trying to bring the rate of increase in emissions of greenhouse gases under control, or to mitigate the effects of such emissions.

The net Green house Gas emissions from India that is emissions with Land Use Land Use Change & Forestry (LULUCF) in 2007 were 1727.71 million tons of CO<sub>2</sub> eq of which CO<sub>2</sub> emissions were 1221.76 million tons. Thus the contribution of CO<sub>2</sub> alone was 70.72% of total net green house emissions. The total CO<sub>2</sub> emissions from Energy sector was 1100.06 million Mt, i.e., 90 % of total CO<sub>2</sub> emissions. And the total Green house gas emissions from electricity generation were 719.31 million tons eq., i.e., 41.63% of net green house emissions of India. Coal constitutes 90% of total fuel mix used. The land use change and forestry sector was a net sink. It sequestered 177.03 million tons of CO<sub>2</sub> eq.

Most electric power plants utilize coal as the principal fuels. The CO<sub>2</sub> emissions from coal burned power plants are highest among other alternatives. As such the reduction of CO<sub>2</sub> from coal based power plants by means of change in technology in thermal power plants and policy frameworks should be emphasized.

Globally, power generation emits nearly 10 billion tons of CO<sub>2</sub> per year. The US with over 8,000 power plants out of the more than 50,000 worldwide, accounts for about 25% of that total or 2.8 billion tons. The contribution of India is hardly 0.7 billion tons, i.e., 7 % of total CO<sub>2</sub> emissions worldwide.

## **POWER SCENARIO IN INDIA**

To meet the development needs of the country, electricity production in India has to be increased manifold. The total power generation capacity in India has increased from 1362 MW in 1947 to

2,23,343 MW as on March 2013 excluding captive power plants having generation capacity of 34,444 MW. In the 12<sup>th</sup> Plan Period (2012-17) another 88425 MW capacity is proposed to be added. The per capita average annual domestic electricity consumption (2009) has a worldwide figure of 2600 KWh, for European Union the same is 6200 KWH. The per capita consumption of electricity in India has increased from 15.6 KWH in 1950 to about 756 KWH during 2009-10. The national Electricity policy of Govt. of India stipulated that this is to be increased to over 1000 KWH per annum by 2012, which could not be achieved.

International Energy Agency (IEA) estimates India will add between 6,00,000 MW to 12,00,000 MW of new power generation capacity before 2050. The technologies and fuel sources India adopts as it adds electricity generation capacity, may make significant impact to global resources usage and environmental issues.

## **POWER PRODUCTION TECHNOLOGY**

Thermal power plants convert energy rich fuel in to electricity and heat. Coal and lignite account for about 57% of India's installed capacity. India's electricity sector consumes about 80% of the coal produced in the country. It is expected that the projected rapid growth in electricity generation over the next couple of decades will be met largely by thermal power plants.

A large part of Indian Coal reserves is similar to Gondwana Coal. It is of low calorific value and high ash content. The natural fuel value of Indian coal is poor. On an average, the Indian Power Plants using India's coal supply consume about 0.7 kg of coal to generate 1 KWH ( 1 unit) of

electricity, whereas US thermal power plants consume about 0.45 kg of coal per KWH. This is because of the difference in the quality of coal, as measured by the Gross Calorific Value (GCV). On average, Indian Coal has a GCV of about 4200 Kcal/kg, whereas the quality elsewhere in the world is much better, for example in Australia, the GCV is 6500 Kcal/kg, approximately.

The high ash content in India's coal affects the thermal power plants potential emissions. Therefore India's Ministry of Environment & Forest ( MoEF) has mandated the use of beneficiated coal whose ash content has been reduced to 34% ( or lower) in power plants located beyond 1000 km from their coal source, urban area, eco sensitive and other critically polluted areas, and ecologically sensitive areas.

Thermal power plants can deploy a wide range of technologies. Some of the major technologies include:

- i. Steam Cycle facility ( Most commonly used for large utilities).
- ii. Gas turbines ( Commonly used for moderate sized peaking facilities).
- iii. Cogeneration and combined cycle facility ( the combination of gas turbines or internal combustion engines with heat recovery systems).
- iv. Internal Combustion Engines ( Commonly used for small remote sites or standby power generators).

## **EFFICIENCY IMPROVEMENT**

Increased generating efficiency translates directly into lower CO<sub>2</sub> emissions per kWh of electricity produced. Currently, Pulverized Coal (PC) combustion is the primary technology used to

generate electricity. For new plants, significant efficiency gains for PC technology are realized by increasing the peak temperatures and pressures of the steam cycle, albeit at higher capital cost for the advanced materials these systems require.

Supercritical plants are commercial technology and have an efficiency of approximately 39% (relative to 30-35% for most existing PC plants). Ultra-supercritical PC power plants have an efficiency of approximately 43% with the potential to increase to approximately 48% with improved, high-temperature materials. While no ultra-supercritical plants have been built in the India, higher fuel costs have led to the construction of almost a dozen plants in Europe and Japan. Compared with subcritical plants, supercritical plants have 10% lower CO<sub>2</sub> emissions and ultra-supercritical plants have 25% lower CO<sub>2</sub> emissions.

Integrated Gasification Combined Cycle (IGCC) plants, a relatively new option for power generation, have efficiencies of 38 to 42%. With technology advancements such as membrane-based oxygen separation, advanced steam and gas turbine designs, and integrated solid oxide fuel cells, IGCC plant efficiencies could approach 50%. Four coal-based IGCC demonstration plants have been built in the US and Europe.

Improvements in the efficiency of coal-fueled power plants can greatly reduce GHG emissions. The older, less efficient units have higher CO<sub>2</sub> emissions per megawatt-hour (MWh) of electricity produced than plants built more recently. Current Research and Development (R&D) focused on advanced materials has the goal of enabling the construction of Ultra-Supercritical Pulverized Coal (USPC) plants with efficiencies of up to

47%—for comparison, plants built in the 1970s and 1980s have an average efficiency of only 36%. These USPC plants would have CO<sub>2</sub> emissions roughly 20% lower per MWh than even new subcritical units.

Emissions may be reduced through more efficient and higher combustion temperature and through more efficient production of electricity within the cycle. Carbon Capture and Storage (CCS) of emissions from coal-fired power stations is another alternative but the technology is still being developed and will increase the cost of fossil fuel-based production of electricity. CCS may not be economically viable, unless the price of emitting CO<sub>2</sub> to the atmosphere rises.

## **CONSEQUENTLY, POLICIES THAT ENCOURAGE THE CONSTRUCTION OF HIGHLY EFFICIENT PLANTS CAN HELP LIMIT GHG EMISSIONS FROM COAL-FUELED ELECTRICITY GENERATION**

Carbon dioxide emissions have an estimated atmospheric half-life of 27 years, which means almost one-third of today's emissions will remain in the atmosphere for 100 years. Action taken now to reduce emissions can limit the maximum concentration (and consequent impacts) or delay the point at which higher concentrations are realized.

Modern day coal power plants pollute less than older designs due to new "scrubber" technologies that filter the exhaust air in smoke stacks; however emission levels of various pollutants are still on average several times greater than natural gas power plants. In these modern designs, pollution from coal-fired power plants comes from

the emission of gases such as carbon dioxide, nitrogen oxides, and sulfur dioxide into the air.

Electricity generation using carbon based fuels is responsible for a large fraction of carbon dioxide (CO<sub>2</sub>) emissions worldwide. Of the fossil fuels, coal is much more carbon intensive than oil or natural gas, resulting in greater volumes of carbon dioxide emissions per unit of electricity generated. The emission figure of the CO<sub>2</sub> as published by Central Electricity Authority (CEA) reveal that power plants in India emitted 0.82 Mt CO<sub>2</sub> per MWh of electricity generated.

Coal-based power plants account for over 60% of the total carbon emissions from India. The country's power plants emitted 548 million tons of CO<sub>2</sub> in 2008-09. India has proposed a 20-25% cut in its emission intensity by 2025 and the government has already chalked out plans for investing around Rs. 74,000 cr within the next five years to cut down carbon emissions from its power sector.

This investment would be directed at a host of measures to cut down energy intensity of the domestic economy including increasing efficiency of the existing power plants and introduction of clean coal technologies. These initiatives would result in the reduction of 98.5 mt of CO<sub>2</sub> emission over the entire period, according to the Bureau of Energy Efficiency and the power ministry.

Indian economy is believed to be one of the least energy intensive globally. The energy Gross Domestic Product (GDP) elasticity index for the country, a measure of the rise in energy demand for every 1% increase in GDP, has dipped to 0.8 currently, compared to over 1 in the early 1990s, according to the Planning Commission.

CEA maintains that the increased rate of CO<sub>2</sub> emission from power plants is mainly due to less

nuclear and hydro power generation in the last financial year.

While India's per capita greenhouse gas emissions at 1.5 tons remain well below the world average of 4.25 tons, a bulk of its power generation comes from coal-based stations.

Another issue in cutting down future emissions is the low efficiency of older plants. Currently, over 5,000 MW of power capacity in India has a low capacity utilisation of less than 5%. While these units are being retired. The government plans to retire another 10,000 MW capacity in the Twelfth Plan (2012-17).

## FUTURE SCENARIO

In order to estimate how much electricity India's proposed coal plants will generate, we need first to make a projection about how heavily the plants will actually be run. This figure is called "capacity factor" or "load factor." A capacity factor of 100% means that a plant is run at its maximum capacity for every hour of the year. Actual capacity factors are lower than 100% because of routine maintenance, fuel availability problems, and variations in demand. In 2010, India's coal plants totaled 159,398 MW of capacity and generated 771,173 GWh of electricity, implying a system wide capacity factor of 55%. This compares to average capacity factors in the United States of 66% to 75% in recent years.

Since new coal plants tend to be run more heavily than older, less efficient plants, it is reasonable to assume that India's proposed new coal plants will feature capacity factors higher than the current national average, perhaps in the range of 65%-75%. For the purposes of this estimate of carbon dioxide generation from proposed coal plants in India, it is assumed that the average

capacity factor will be 70%. Estimating carbon dioxide output rate depends on the following factors:

- Carbon dioxide emission per million Btu from various types of coal.
- Plant efficiency (i.e., heat rate) expressed in kWh/Btu.

Carbon dioxide emission factor from various types of coal.

The following carbon dioxide emission factors were estimated by the US Department of Energy for coals in the United States. In MKS system, the values are as below:

- Lignite (i.e., brown coal): 0.34 kg of carbon dioxide per KWh.
- Sub bituminous coal: 0.33 kg of carbon dioxide per KWh.
- Bituminous coal: 0.32 kg of carbon dioxide per KWh.
- Anthracite: 0.35 kg of carbon dioxide per KWh.

It is worthwhile to note that carbon dioxide emission factors are not necessarily lower for higher quality coals. For example, anthracite coal, which is the highest quality coal, produces more carbon dioxide per KWh than low-quality lignite. This is because anthracite lacks hydrogen, which is a small portion of the content of lower grade coals. When burned, hydrogen is transformed into water vapor (H<sub>2</sub>O) rather than carbon dioxide (CO<sub>2</sub>). Therefore, nearly all the energy in anthracite comes from the combustion of carbon, resulting in higher carbon dioxide emission rates per unit of energy than when lower grade coals containing some hydrogen are burned. (Of

course, on a *tonnage* basis, lower grade coals do produce more carbon dioxide than higher grade coals.)

Domestic coal in India is typically sub-bituminous with GCV of about 4,200 kcal/kg, while imported coal is typically bituminous with GCV of about 6,665 kcal/kg. For purposes of estimating carbon dioxide emissions for proposed coal plants in India, it is assumed that these plants will use 2/3 domestic coal and 1/3 imported coal, for a carbon dioxide emission rate of 0.33 kg of carbon dioxide per KWh.

### Plant Efficiency

MIT's "Future of Coal" study provides the following estimates of coal plant efficiency (i.e., percent of energy content of fuel converted into electricity) for various coal plant technologies, assuming no carbon capture:

- Subcritical - 34.3%
- Supercritical - 38.50%
- Ultra-supercritical - 43.3%

For purposes of estimating carbon dioxide emissions for proposed coal plants in India, it is assumed that 2/3 of the plants will use supercritical technology and 1/3 will use subcritical technology, for a weighted plant efficiency of 37.1%.

### Formula

$\text{CO}_2$  emissions per unit of energy in coal (expressed in kg per KWh) / Plant efficiency = Emissions in kg per KWh

### Calculation

$0.325 \text{ kg CO}_2 \text{ per KWh} / 37.1\% = 0.876 \text{ kg CO}_2 / \text{kWh}$

Thus, by the end of 12<sup>th</sup> Plan Period, i.e., 2017,

the  $\text{CO}_2$  emissions from the Thermal Power plants will in fact increase and this will put pressure on other sectors to reduce the GHG emissions to meet the India's commitment level of 20-25% reduction of GHG gases by 2020.

## CONCLUSION

Public policy is vital to successfully reduce  $\text{CO}_2$  emissions. Appropriate policies must be developed. A policy framework to address  $\text{CO}_2$  emissions include:

- Upcoming power plants emission criteria to be enforced strictly and drastic reduction up to 500 g/KWh to be made mandatory.
- No new power plants are allowed to come with old technologies and ultra super critical plants be encouraged.
- Flexible approaches to motivate achieving  $\text{CO}_2$  emission limits that may vary by economic sector, and could include, depending on the sector, market-based incentives; governmental loan guarantees; investment tax credits; performance standards; tax reform; incentives for technology research, development and deployment; and other appropriate policy tools.
- Old power plants, which are less efficient and have completed their life should be phased out and New higher efficiency plants with latest technology only should be built.
- Investments in research to develop cost-effective and efficient energy technologies, improve the performance of carbon energy systems, and support the research for new, clean energy systems and processes.
- Increased emphasis and investment in education and training of the workforce in all

advanced energy technologies and their deployment.

- Enhanced development of infrastructures that are required to implement technologies that reduce CO<sub>2</sub> emissions.
- Mandatory, progressive targets to reduce emissions associated with power generation, focusing on near-, mid-, and long-term timeframes.
- Thermal power Plants should start carriage of coal from coal stocks of coal mines like other consumers and the job of coal beneficiation be done by Thermal Power Plants instead of Coal Companies so that the avoidable impurities are removed with more care and concern and the cost of transportation of extraneous materials are saved for all the plants and ash content is finally reduced and plant efficiency is also increased. This single step will go a long way to help achieve the commitment of GHG reductions of the India.

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