THERMAL POWER PLANTS IN INDIA:
Technical opportunities for improving efficiency and reducing emissions




SHAKTI SUSTAINABLE ENERGY FOUNDATION

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ABOUT
SHAKTI SUSTAINABLE ENERGY FOUNDATION

Shakti Sustainable Energy Foundation works to strengthen the energy security of the country by aiding the design and implementation of policies that encourage energy efficiency as well as renewable energy.

DISCLAIMER

ACKNOWLEDGEMENT

ICF International, places on record its sincere gratitude to Shakti Sustainable Energy Foundation for providing the opportunity to undertake an assessment of the existing regulatory framework of efficiency and emission standards for Thermal Power Plants in India, and globally, and identify gaps, barriers, opportunities and potential areas of intervention in this sector.

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ABSTRACT

Thermal Power Plants account for a major share of power generation in India. The sector has witnessed rapid addition of capacity over the last few decades, both at central and state levels. Major contributors to this mix are coal and gas based thermal power stations. By the end of 11th Five year plan, thermal power plants alone contributed 85% to the total installed capacity of thermal power plants, as against 14% of gas-based power plants. In fact, coal based power accounts for a major share to total actual generation too. Vast reserves and low purchase price of coal have made coal one of the cheapest sources of power generation in the country. In contrast, the uncertainty around domestic gas reserves, its availability and price have adversely impacted existing gas based power plants and prospective investments.

The report of the Planning Commission's Expert Group on Low Carbon Strategies for Inclusive Growth has also projected a clear dominance of thermal power plants in the country over the next two decades. Coal based thermal plants in India also present a significant opportunity both with regards to efficiency and emissions improvement over the inherently much less emissions-intense gas-based power plants. Given this, and lack of sufficient data inputs for gas based thermal power generation, the study has focused on coal thermal power plants for assessing technical opportunities for improvements in plant efficiency and reductions in emissions.

It is worth mentioning here that over the last few years, the coal sector has been hit with severe issues relating to coal availability, both in terms of quantity and quality. This has led to an increased down time or under-utilization of power plants, resulting in the sub-optimal utilization of India's existing capacity. In many cases, the coal quality also does not meet design specifications, resulting in poor performance of thermal power plants. The growing dependence on imported coal highlights the low quality of indigenous coal. Therefore, optimizing the use of coal is of paramount importance as it not only influences the operating cost but emissions from power plants also significantly pollute the environment.

Past interventions have improved the operating performance of power plants. Power plant efficiency, typically characterized by heat rate and Auxillary Power Consumption (APC) has been addressed through various guideline/regulations introduced over the years. National and state level institutions have been created to ensure compliance so that performance levels are maintained. A recent mandatory regulation, the Perform, Achieve & Trade (PAT) Scheme under National Mission on Enhanced Energy Efficiency (NMEEE), requires that all thermal power plants in the country reduce their operating heat rates by specified percentages by March 2015 from a 2010 baseline. Despite mandatory regulations and voluntary initiatives by thermal power plants, India's thermal power plants can still achieve further improvements in efficiency. These improvements can

be in the form of simple heat rate improvement, APC reduction identified through energy audits, and cost-intensive Renovation & Modernization (R&M) and Life Extension (LE) approaches. This study assesses the efficiency improvement and proposes an implementation plan for the existing fleet of coal-based thermal power plants in the country. The study also investigates the norms and standards for efficiency performance parameters of new plants, commissioned post 2007.

Coal-based thermal power plants are a significant source of emissions which is of great concern to India, due to their resultant impacts on human health and the environment. Power generation from coal emits harmful pollutants such as Suspended Particulate Matter (SPM), Sulphur Oxides (SOx), Nitrous Oxides (NOx) and Mercury (Hg) as well as Greenhouse Gases (GHG) like Carbon Dioxide (CO_2). In order to curb emissions, relevant regulatory authorities at the centre and state level need to revise the existing emission standard for SPM, introduce new standards for other pollutants and ensure compliance. This study reviews the existing emission norms for power plants in India and based on a comparison with norms in other countries and a techno-economic assessment of available emission control technologies, suggests new norms for existing as well as new power plants. Since deployment of emission control measures can negatively impact the operating efficiency of a power plant, the interplay between efficiency and emission control is taken into account in the analysis presented in this study.

To summarise, this study characterizes the current performance level of coal-based thermal power plants, both on efficiency and emissions. The analysis presented is supported by case studies and findings from actual energy audits of power plants completed by reputed agencies. New norms for efficiency and pollutant emissions have been proposed based on a careful investigation of various technologies and their implementation and penetration possibilities in existing and new thermal power plants.

CONTEXT

Thermal Power Plants account for a major share of power generation in India. The sector has witnessed rapid addition of capacity over the last few decades, both at central and state levels. Major contributors to this mix are coal and gas based thermal power stations. By the end of 11th Five year plan, thermal power plants alone contributed 85% to the total installed capacity of thermal power plants, as against 14% of gas-based power plants. In fact, coal based power accounts for a major share to total actual generation too. Vast reserves and low purchase price of coal have made coal one of the cheapest sources of power generation in the country. In contrast, the uncertainty around domestic gas reserves, its availability and price have adversely impacted existing gas based power plants and prospective investments.

The report of the Planning Commission's Expert Group on Low Carbon Strategies for Inclusive Growth has also projected a clear dominance of thermal power plants in the country over the next two decades. Coal based thermal plants in India also present a significant opportunity both with regards to efficiency and emissions improvement over the inherently much less emissions intense gas based power plants. Given this, and lack of sufficient data inputs for gas based thermal power generation, the study has focused on coal thermal power plants for assessing technical opportunities for improvements in plant efficiency and reductions in emissions.

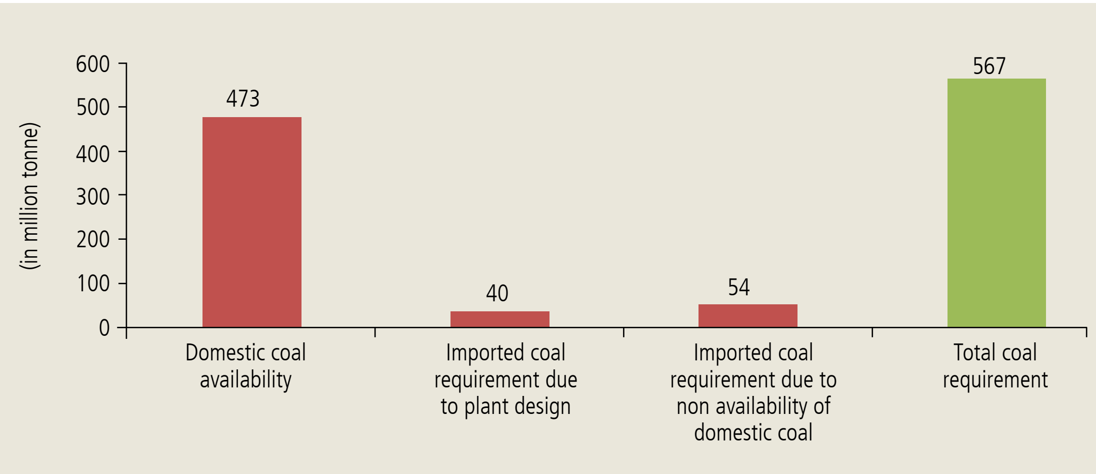
As on July 2014, thermal power plants constituted around 70% of the total installed capacity in India. Of which, thermal power plants accounted for 149GW, i.e. almost 60%, of the total installed capacity while contributing around 73% in the total generated electricity[1]. Coal has been a preferred fuel choice and is expected to be mainstay fuel for thermal power generation in the near future. However, over the last few years, a shortage in domestic coal aggravated by its poor quality (in terms of ash and moisture content) has resulted in lower operating plant load factor (PLF) of power plants.

Various studies have indicated a substantial potential for efficiency improvement in existing thermal power plants. The sector is presently operating at net efficiency of around 27.3% and gross efficiency of 30.01%. This has improved from 15.6% to 27.3% over the last five decades. The enhancement in efficiency is attributable to various factors – larger unit size, improved design parameters, advanced O&M practice, R&M and Life Extension approach. Diagnostic studies through energy audits have helped the generating plants to identify priority intervention options. The improvement in efficiency has not only saved input fuel (coal) but also helped in injecting more electricity to the grid and reduced emissions. Advanced O&M practices have also increased

[1]Central Electricity Authority of India

the availability of the generating plants. However, there is still potential for improvement when we compare the operating parameters with design. As the demand for electricity is directly related to economic growth, the need for higher generation is always a point of focus of the government. In view of limited coal reserves in India, the importance of efficiency improvement cannot be ignored and should be tried to maximise the potential. Moreover, the deviation of operating efficiency from design is also impacted by coal quality. The trend over the last few years has indicated a sharp increase in the share of imported coal. Despite increasing imports, about 25,000 Mega Watts (MW) of new capacity is lying stranded due to coal unavailability.[2] It is estimated by Central Electricity Authority (CEA) that India would need about 573 million tonnes (MT) of coal in 2014-15 to meet its generation target, out of which about 94 MT will have to be met through imports (Exhibit 1).[3] The cost of imported coal is comparatively higher than domestic coal and would further increase the generation cost. This is an additional cost burden to the utility, which makes it far more important to ensure that the coal is consumed efficiently. It is possible to reduce the imported coal requirement with an aggressive focus on enhancing efficiency of power plants, especially by plants which were commissioned before 2007. A reduction in coal demand can lower the requirement of imported coal due to non-availability of domestic coal (Exhibit 1).

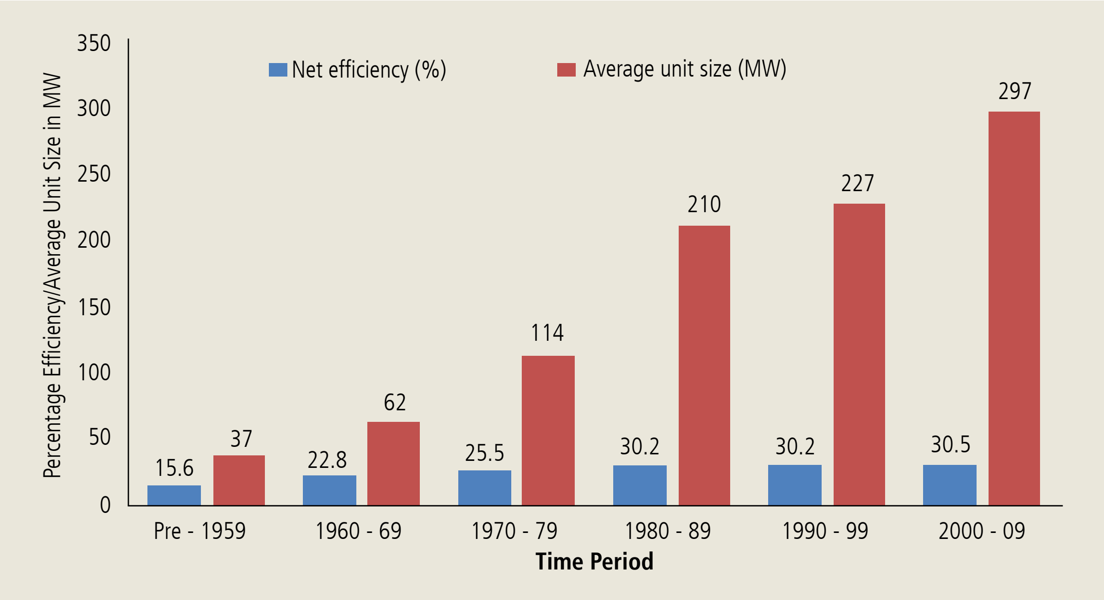
Exhibit 1: Coal Demand Supply Situation Estimated in 2014-15 (CEA)



The power generation sector in India is divided into three broad categories based on ownership i.e. Centre-owned plants such as those owned by National Thermal Power Corporation (NTPC) and Damodar Valley Corporation (DVC), plants owned by State Electricity Boards (SEBs) or state power generation utilities, and plants owned by private players. India's fleet of power plants pre-1970, were characterized by small capacities (upto 200 MW) and poor generation efficiencies (upto 20%) as illustrated in Exhibit 2.[4]

2 ICF's analysis
3 http://articles.economictimes.indiatimes.com/2014-05-15/news/49873287_1_power-sector-planning-body-domestic-coal-coal-demand
4 ICF analysis based on historic capacity addition

Exhibit 2: Trend in unit size and efficiency



Over the last two decades, the focus has slowly shifted towards installation of higher capacity units (200 MW and greater). Even so, approximately 15 Giga Watts (GW) of capacity comprises generators of capacity less than 200 MW.[5] In terms of technology, pulverised coal combustion is the most widely used technology in coal-fired power plants. The main developments involved in pulverised combustion were due to higher steam temperature and pressure. Pulverized Thermal Power Plants are mainly of two types - subcritical and supercritical. By 2013, 90% of the installed capacity of India was based on subcritical technology. Supercritical plants make up only about 14 GW of the existing coal-fired capacity.

Out of the 80 GW capacity addition planned in the 12th five year plan, about 80%[6] is expected to be met from coal plants, thereby further increasing the reliance on coal. Hence, it is necessary to focus on higher efficiency of the new fleet of Thermal Power Plants being added into the system. India's first plant based on supercritical technology was commissioned in 2011. Countries such as Japan and South-Korea have focused on improving the efficiency of their coal fleets by aggressively opting for Supercritical (SC) and Ultra-Supercritical (USC) technologies. Since the mid-2000s, China has experienced high growth in the coal-fired generation, with the share of SC and USC increasing rapidly. As per ICF's assessment, future capacity addition will witness a paradigm shift towards supercritical technology, which is promising.

On the emission side, coal-fired generation is the biggest single source of GHG emissions in India. Out of the total 1,100 MT of GHG emissions from the energy sector in 2007, emissions from electricity generation was 719 MT Carbon Dioxide (CO_2-eq) and 90% of this came from Thermal Power Plants.[7] As per ICF's estimates, the total GHG emissions from Thermal Power Plants in 2013 were 833 CO_2-eq. In addition to GHG, there are a variety of air pollutants which are generated as a result of thermal power plant operation. These pollutants are of different types and have a

[5] ICF analysis of installed capacity
[6] National electricity plan, CEA
[7] India Greenhouse Gas Emissions 2007, Ministry of Environment & Forest

variety of negative impacts on ambient air quality and correspondingly on human health and the environment. SPM, NOx, SOx and Hg are the critical air pollutants of concern from a coal power plant. However, in India emission standards for power plants are defined only for SPM, unlike other countries such as Australia, China, European Union, and US, where emission standards are defined for most major air pollutants. There is also no publically available, continuous emission monitoring data at the plant level, which leads to poor enforcement of the existing standards. ICF's analysis of SPM emission in 2011 indicates that 20% of the units exceeded emissions over the prescribed limits.[8] Apart from SPM, there is no official record on emissions of other air pollutants.

Given the fact that coal has been the mainstay fuel for India and will remain an integral component of India's electricity mix in the years to come, cleaner and more efficient use of coal is of paramount importance to ensure a better resource position and clean environment for India. A marked increase in efficiencies in electricity generation by Thermal Power Plants can reduce the emissions of GHGs and other pollutants. Use of emission control technologies to convert or capture direct emissions will help further reduce the environmental impact of coal-based generation. Over the years, government agencies such as CEA, Central Pollution Control Board (CPCB), and Bureau of Energy Efficiency (BEE) have taken policy initiatives to define efficiency and emission standards for Thermal Power Plants. Some of the standards and norms have been in place for over two decades. So the effectiveness and adequacy of these regulations need to be reviewed given advancements in technology and an ever increasing focus on the environment. On one hand, ensuring full compliance with the existing regulations on efficiency and emission performance should be of top priority and on the other hand, new policies and regulations to identify opportunities for efficiency and emission control is essential for sustainability of the sector.

In this context, this study analyzes the efficiency and emission norms for coal-based thermal power plants in India and identifies potential areas for improvement. The objectives of this study are:

- Identify available technologies/best practices that enable energy and emissions intensities to reduce further
- Analyze the interplay between efficiency and emissions control and resultant implications on costs
- Propose achievable emission standards for air pollutants
- Assess the way forward for this sector in terms of technological and regulatory interventions

The study team conducted an in-depth literature review, primary research and analysis to gather background information. Regulators, research and development (R&D) centres and organizations, power producers, and individual experts were consulted to bring additional insights to the analysis. In case of non-availability of data, assumptions were made based on literature review and stakeholder consultations to carry out the analysis. This paper highlights the key findings of the study.[9] The recommendations suggested in the paper are intended to support relevant policy makers in improving efficiency and emission performance of the sector, which in turn will reduce India's coal import dependency and yield a better standard of health for its citizens.

[8] Based on emission data submitted by power plants to CEA
[9] This paper is a summary of key issues being faced by thermal power plants in India. A more illustrative explanation with respect to current scenario, technology gaps and implementation road map has been addressed in the comprehensive report on this subject, to be made available online.

KEY OBSERVATIONS

EFFICIENCY OF THERMAL POWER PLANTS

The efficiency of a coal power plant is defined in terms of net efficiency, which is the energy input required for generating one unit of useful electricity injected into the grid. It is important to note that the net efficiency is a function of Heat Rate (HR)[10] and Auxiliary Power Consumption (APC).[11] Gross Heat Rate is defined by the Original Equipment Manufacturer (OEM) and is dependent on the technology type. APC expressed in percentage, is a measured value dependent upon various factors such as unit mix, plant layout and type of coal.

Another metric to express net efficiency of a plant is operating Net Heat Rate. This is calculated for a given performance period taking into account the net electricity generation (gross generation minus APC) and the total fuel input (quantum of fuel consumption multiplied by the average fuel calorific value). Relation between net efficiency and net heat rate is shown below:

Net Efficiency (in %) = 860*(1-APC)/ Gross Heat Rate; or Net Efficiency (in %) = 860/ Net Heat Rate
Where: APC is expressed in percentage; gross station heat rate and net station heat rate are expressed in kcal/kWh

By virtue of design, every plant has a designed efficiency level which could be different from the efficiency achieved during operation. Deviation of operating efficiency from the designed efficiency gives an indication of the variation in the plant performance and thus the level of inefficiency. Net efficiency or operating net heat rate is commercially sensitive information and is generally not available in the public domain. For the efficiency analysis, plants which were commissioned pre-2007 have been considered, since the operating heat rate figures for these plants (for 2007-08 to 2009-10) were available. Key findings are discussed below:

Design Gross Heat Rate (DGHR) of Indian coal plants varies considerably due to reasons like different OEM technology, unit size, vintage, PLF, operational availability and coal quality. NTPC has a better DGHR of 2,346 kcal/kWh due to adoption of better design technology and focus on commissioning of higher unit sizes. Over the years, the trend of improvement of DGHR has been encouraging. The state owned and private players have shown an average improvement of

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[10] Heat is the quantity of thermal energy required (in Calorie or Joule) to produce one unit of electrical energy. Therefore a plant with lower heat rate is more efficient and requires less coal to generate one unit of electricity. It is expressed in kcal/kWh.

[11] The quantum of electricity required by thermal power plants to run various systems such as coal handling, milling, pumping, and cooling. It is expressed as a percentage of total gross electricity generated by the plant. Net electricity generation of a station is its gross generation minus APC. Higher APC implies more power consumption in the station equipments and thus a reduction in useful electrical energy supplied to the grid.

Exhibit 3: Improvement in DGHR of Indian Thermal Power Plants

Parameter	NTPC	State	Private
Design GHR improvement per annum (%) from 1981 to 2009	0.42	0.91	0.79
Average design GHR (kcal/kWh) in 2009	2,346	2,408	2,467

0.91% and 0.79% per year respectively. Although this trend of improvement is higher than that of NTPC plants (0.42% per year), still the state and private owned plants have not reached the level of DGHR of NTPC plants (Exhibit 3).

For the existing plants, this gap would remain and the same also indicates lower operating efficiency levels in case of state and private plants as compared to NTPC plants. The upcoming fleet of plants show comparable design parameters for state, central and private owned plants. But enhanced focus in terms of Operation and Maintenance (O&M) is still called for to ensure a plant's operation is closer to its design parameters.

Operating APC - The operating APC of 82 thermal power plants covered under Perform-Achieve-Trade or PAT scheme (National scheme under National Mission for Enhanced Energy Efficiency (NMEEE) ranges from 5.5% to 15% with an average of 9.52% (Exhibit 4). About 20 plants are operating in optimum range of APC, i.e. 5.5% to 7.5%, and about 54 plants are operating at APC varying between 8 to 12%

The PAT scheme covers thermal power plants (coal, oil, gas, and lignite based) to reduce their net heat rates by a certain percentage from 2010 baseline within a period of 3 years. All thermal power plants with an annual energy consumption of more than 30,000 Metric Tonnes of Oil Equivalent (MTOE) are covered under this scheme. 84 coal based power plants are covered under this scheme

Exhibit 4: Bandwidth of Operating APC

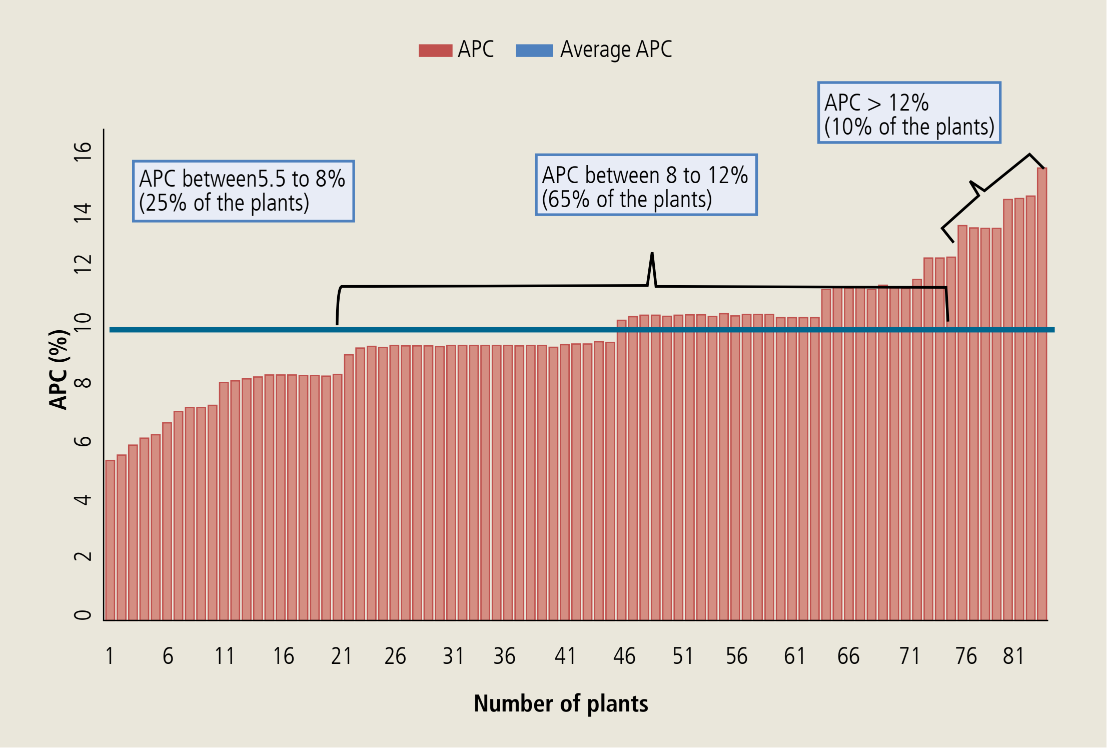
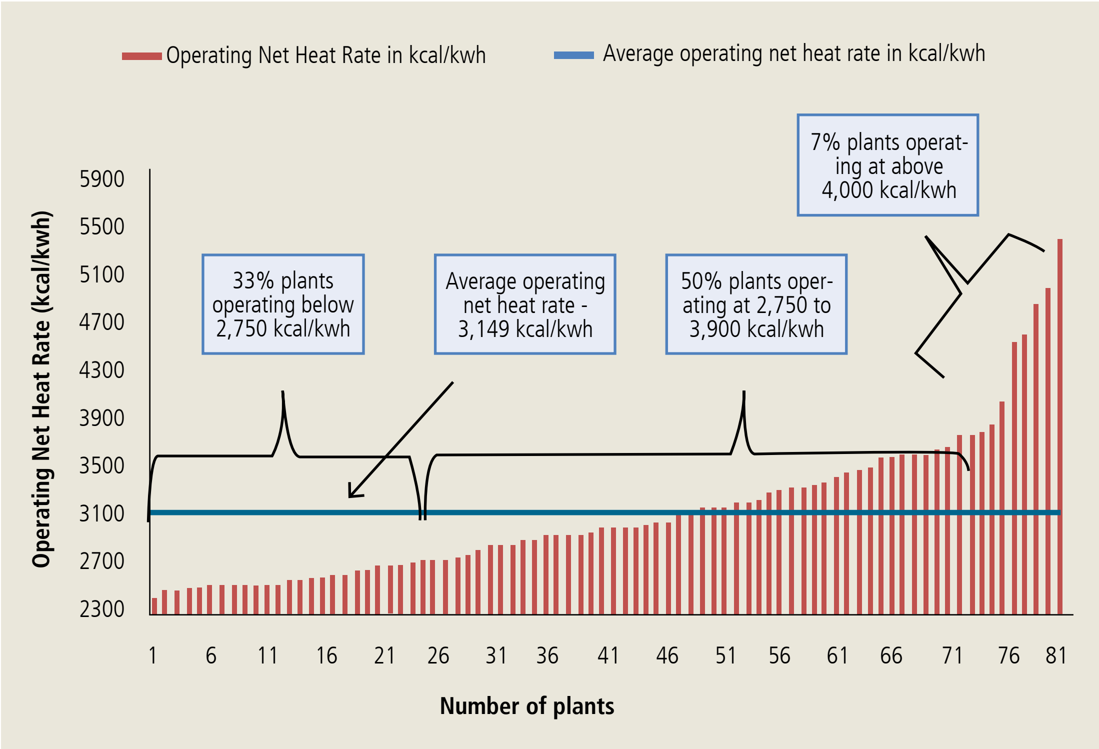


Exhibit 5: Bandwidth of Operating Net Heat Rate



and have to meet the notified targets by March 2015. The minimum threshold of 30,000 MTOE of annual energy consumption is equivalent to a 20 MW power plant. This ensures coverage of all power plants commissioned before 2007 under this scheme. Energy reduction targets are given to each plant on the basis of its deviation of Operating Net Heat Rate (ONHR) from Design Net Heat Rate (DNHR).

An improvement in APC from current average of 9.5% to 8.5% is envisaged due to existing initiatives such as the first phase of PAT scheme. Focus on operation and maintenance, higher penetration of proven technologies in plant auxillaries, use of condition monitoring and diagnosis techniques, and adoption of new technologies (such as magneto drives) have the potential to further reduce the operating APC upto 7.5%. These additional measures may be considered for specifying targets under the second cycle of PAT scheme.

Operating Net Heat Rate (ONHR) as previously discussed, is an indicator of net efficiency. Due to various factors (technical and operational), there is a deviation in operating heat rate when compared with the design values. This parameter has been used for target setting of coal fired plants in PAT scheme. The net heat rate of thermal power plants has a wide bandwidth because of fuel quality, design and vintage of the plant, technology adoption, O&M practices, and even climatic conditions. Analysis of operating net heat rates of 82 thermal power plants is shown in Exhibit 5.

It is observed that a majority (around 50%) of the thermal power plants in the country have ONHR varying between 2,750-3,900 kcal/kWh. A few plants (around 7%) are highly in-efficient at ONHR 4,000 kcal/kWh. The poor performance is mainly in vintage state owned utilities. However, some of the best operating plants are also state owned. Reduction in the operating NHR is possible in most cases by adoption of energy efficient technologies and optimized operating parameters. Despite being commercially available, so far most of these technologies have found low penetration in the current system. As discussed in the later sections, a vast scope for improvement is possible for optimizing operating efficiency; however the deviation from design efficiency represents the actual potential for improvement. This deviation is expressed in terms of percentage variation of operating NHR from design (Exhibit 6).

Around 50% of the plants are operating at deviation of more than 15% from the designed heat rate and there emanates an urgent need for intervention to optimize efficiency. The deviation from design efficiency based on ownership type is shown in Exhibit 7 which shows the better efficiency performance level of centrally owned plants. As discussed earlier, centrally owned plants have better design parameters and also have enhanced focus on O&M to ensure operational performance closer to design parameters

Exhibit 6: Bandwidth of Operating NHR and % Deviation from Designed NHR

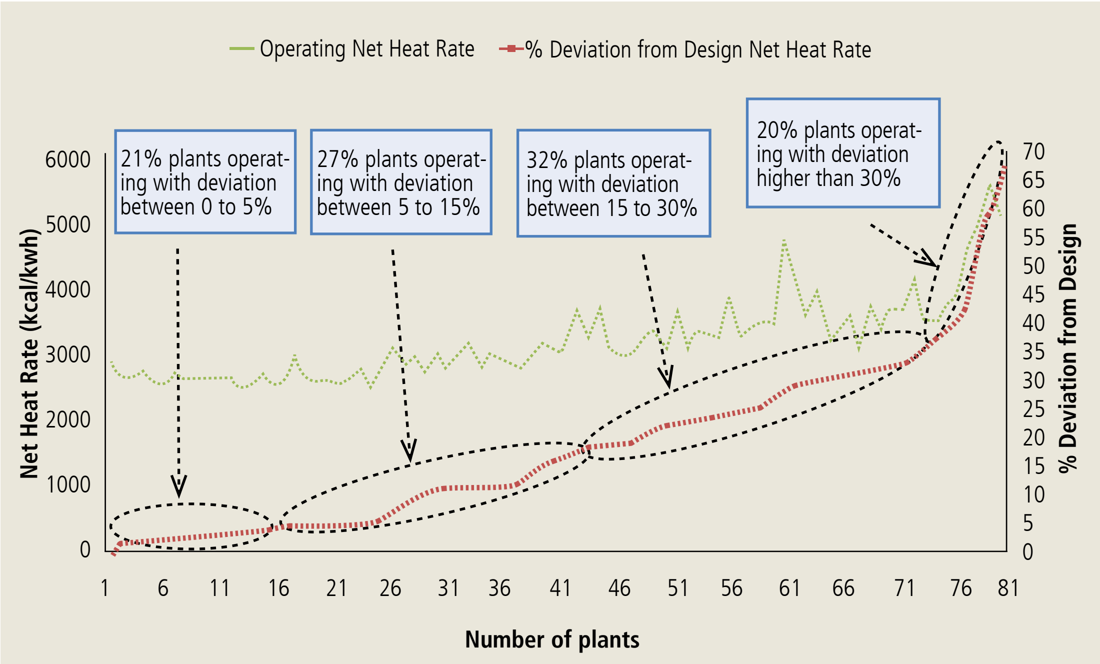
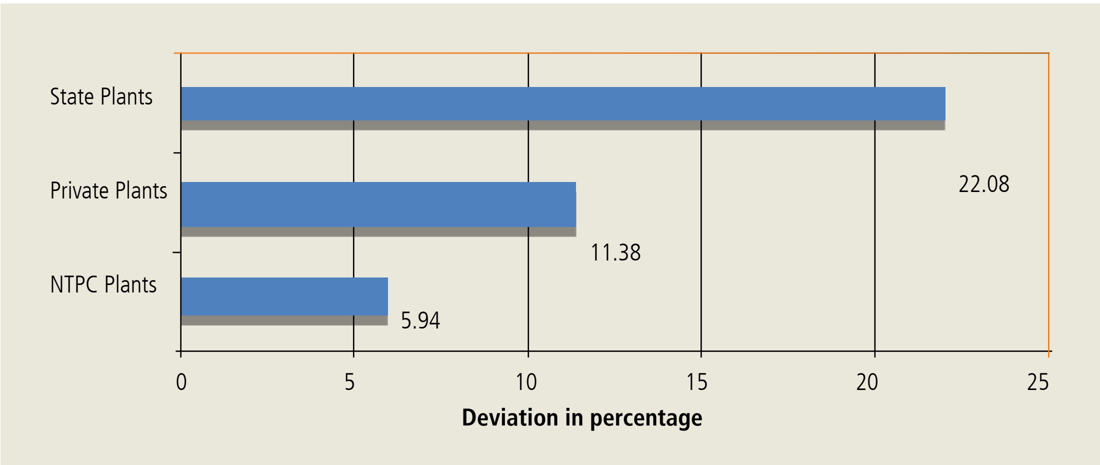


Exhibit 7: Deviation of Heat Rate Based on Ownership



Reasons for Inefficiencies

The project team has identified some critical reasons for inefficiencies. These reasons are based on energy audit findings, efficiency assessment and benchmarking work done by several agencies including the National Productivity Council (NPC). Power plant efficiency is a holistic function of heat rate, APC, vintage, PLF & fuel quality. The following observations are derived from a set of "case studies":

1. **Heat Rate: A 10% increase in Gross Heat Rate would reduce the net efficiency by about 9%.** As a result, more coal will be burned to generate the same electricity. Reasons for variations in heat rate are:

    a. *Un-optimized boiler combustion, excess air and energy loss in the draft system*: A 10% reduction in excess air/air ingress (typically from 14% to 12.6%) results in reduction of ID fan power consumption by 1.7 to 2%; A 10% increase in excess air (say from 40% to 50%) impacts boiler efficiency in the range of 0.5% to 1%. This has an impact both on the Heat Rate as well as APC.

    b. *Low turbine cylinder efficiency*: An increase of isentropic efficiency by 10%, from 75% to 85%, implies a reduction in specific steam consumption of the turbine by around 5-6%. Lack of focus on O&M and deviation from design parameters results in lower turbine cylinder efficiency, impacting both the turbine Heat Rate and overall plant Heat Rate and efficiency.

    c. *Inefficient air pre-heaters*: There is a potential to save 5 to 10 kcal/kWh in operating gross station heat rate, through elimination of leakages and optimization of APH operation as per various energy audit studies conducted by NPC.

    d. *Un-optimized performance of Low Pressure (LP) & High Pressure (HP) heaters*: For every 1°C loss in feed water temperature, heat rate increases by 0.67 kcal/kWh. If there is non-operation of any of the heaters, there is loss of 15°C in feed water temperature, and the loss in heat rate will be approximately 10 kcal/kWh. Energy audit studies conducted in various power plants by NPC reveal that there exists an opportunity for improving feed water temperature by 15°C in almost 60% of the cases.

    e. *Deviations from Design Condenser Vacuum*: Condenser vacuum is critically monitored in all thermal power plants. However, in various energy audit studies conducted by NPC it has been found that the vacuum loss is nearly 3 mm Hg in nearly 60% of the plants. It has been established that for every 1mm Hg loss in condenser vacuum, there is an increase of 2 kcal/kWh in heat rate.

    f. *Variation in steam temperature at Turbine Stop Valve (TSV)*: It is noticed during various field visits that a 5°C drop exists in main steam temperature at TSV in nearly 50 % of the present thermal power plants. Every 1°C drop in main steam temperature results in 0.5 kcal/kWh increase in heat rate.

    g. *Variation in make-up water consumption from design parameters*: Usually, as per the design, makeup water requirement is a maximum of 2%. It has been established that for every 1% increase in make-up water consumption, the heat rate increases by 6 kcal/kWh. From various energy audit studies conducted by NPC in thermal power plants, nearly 5% excess makeup water consumption exists in nearly 60% of the coal fired power plants.

2. **Auxiliary Power Consumption (APC): A 10% increase in APC would reduce the net efficiency by about 1%.** Reasons for poor APC are:

   a. *Losses in Feed Water System*: Optimization of Boiler Feed Pump parameters and use of Variable Frequency Drives (VFDs) has a potential for reducing power consumption of BFP by 3 to 5%.

   b. *Losses in Draft System*: Pressure loss in the draft system due to choked ducts is a common phenomenon in most of the power plants. This results in increasing power consumption of the draft system. In many plants, there are additional problems of deployment of wrong dimensions of fans, leading to the need of throttling and thus an in-efficient mode of operation. It is possible to save 10 to 20% power consumption in the draft system through adoption of more efficient fans, use of VFDs and correct selection of fans based on the desired head and flow parameters.

   c. *Losses in Cooling Tower System*: Cooling water system accounts for 15 to 20% of total APC. Based on energy audit studies conducted by NPC, it has been identified that the energy losses in most of the vintage state owned units are in the range of 10 to 20% of the power consumption in cooling water pumps. Thus, there is a potential to optimize the same and reduce APC.

3. **Plant Load Factor (PLF): A 10% change in PLF (or load) would result in a change in the efficiency by 1.3%.** A reduced PLF can adversely impact the operating efficiency of a plant. For instance, at 50% operating load, the heat rate of subcritical units deteriorates by about 10%. The project's analysis, based on 9 case studies, shows that a 10% change in PLF (or load) would result in decrease in the efficiency in the range of 0.16% to 2.7% the average being 1.3%. For plants where the operating efficiency is lower, the impact of change in PLF on efficiency is much higher.

4. **Vintage: In plants having been in operation for more than 25 years, efficiency degrades by around 1 to 2% and capacity gets reduced by around 5 to 10%.** About 45 units with 200/210 MW capacity, have operated for more than 25 years. Similarly, in the category of 500 MW units, the average operated life for almost 40% of the units is more than 15 years. Presently, 19% of the capacity has been in operation for more than 25 years. It is observed in with more than 25 years of operation, efficiency degrades by around 1 to 2% and capacity reduces by around 5 to 10%.

5. **Fuel Quality:** Coal quality is characterized in terms of its heating value which is generally expressed as Gross Calorific Value (GCV or Higher Heating Value – HHV) or Net Calorific Value (NCV of Lower Heating Value – LHV), together with its moisture, ash and volatile content. For Indian coal, the NCV is typically 7 to 12% of the GCV. The main fuel characteristic affecting plant efficiency is the moisture content and the carbon to hydrogen ratio of the fuel's combustible component. With the increase in moisture content, there is a variation in GCV as well as NCV of the fuel. Apart from moisture, the ash content in coal also impacts boiler performance. High ash content coal results in lower GCV and thus leads to higher specific fuel consumption (kg per kWh).

Efficiency Standards for Thermal Power Plants in India

Efficiency standards and guidelines for thermal power plants are set by government bodies such as Central Electricity Authority (CEA), Central Electricity Regulatory Commission (CERC), and Bureau of Energy Efficiency (BEE). CEA assists the Ministry of Power (MoP) in technical and economic matters whereas BEE's mission is to "institutionalize" energy efficiency activities to reduce energy intensity of the economy. CERC is an independent statutory body with quasi-judicial powers. CERC's mandate is to advise the central government on formulation of the national tariff policy and promote competition in the electricity sector. The following acts empower these agencies in setting up of standards and norms pertaining to thermal power plants (Exhibit 8).

Exhibit 8 : Major Acts Addressing Efficiency Norms for Thermal Power Plants

Act	Coverage	Nodal Agency
Energy Conservation Act, 2001 (Amended 2010)	Empowers central government to specify norms on energy usage and mandatory compliance; establishment of standards and norms for energy usage in thermal power plants	MoP, BEE
Electricity Act, 2003 (including National Tariff Policy and National Electricity Policy)	Setting mandatory technical standards and guidelines for design and operation of power plants, guidelines and norms to set tariffs for new/ existing thermal plants	CEA, CERC

Central Electricity Authority was constituted under the Electricity (Supply) Act 1948, but was later superseded by the Electricity Act, 2003. CEA's major role is to advise the central government on matters relating to National Electricity Policy and formulate short term and prospective plans. CEA has notified technical standards for construction of electrical plants and electrical lines, Regulations, 2010. Given below are the major points addressed in these standards pertaining to thermal power plants.

a. Norms for Maximum Continuous Rating (MCR) for steam generators
b. Formula for Minimum Boiler Efficiency
c. Norms for minimum gross turbine cycle heat rate for subcritical and supercritical units
d. Technical Guidelines for Balance of Plant (BoP):

In order to further support this, CEA has created Standard Technical Features of Boiler Turbine Generator (BTG) system for supercritical power plants (of 660/800 MW) in July 2013. These standards specify major quality and performance parameters with a view to evolve common understanding amongst utilities, manufacturers, and consultants on design and sizing philosophy for super critical units.

Central Electricity Regulatory Commission is the apex power sector regulator that determines tariffs of regulated entities. CERC issues tariff regulations applicable to a performance period of 5 years. The following operational attributes are covered under tariff regulations:

a. *Gross Operating Station Heat Rate*: Limits for operating gross station heat rate defined for different plant sizes ranging from 200/210 MW to 500 MW. Relaxation given to some plants on account of vintage and coal linkages.

b. *Plant Availability Factor*: Permissible operating availability defined for power plants. Some relaxation is given to vintage plants in terms of having a lower permissible operating PLF as compared to the general majority of power plants.

c. *APC*: Operating limits are defined for different plants with exemption in some cases.

Bureau of Energy Efficiency is empowered to specify norms on energy usage and enforce compliance for energy intensive industrial sectors. As per the provisions of Energy Conservation Act 2001, amended in 2010, BEE was instrumental in developing technical framework for the PAT scheme that covers power plants. PAT scheme aims to reduce the deviation of net operating heat rate of a coal power plant from the design net heat rate as shown in Exhibit 9.

Exhibit 9: Heat Rate Reduction Target in PAT Scheme

Deviation in Operating Net Station Heat Rate from Design Net Heat Rate	Target to Reduce Deviation
Upto 5%	10%
More than 5% and Upto 10%	17%
More than 10% and Upto 20%	21%
More than 20%	24%

EMISSIONS FROM THERMAL POWER PLANTS

A variety of pollutants are generated as a result of coal power plant operation. These pollutants have negative impacts on ambient air quality and therefore on human health and the environment. SPM, NOx, SOx, and Hg are the critical air pollutants from a coal power plant. These pollutants are emitted through stack and their quantum or emission rate is a function of coal quality, combustion temperature, and excess air used for combustion. India has specified a mandatory maximum limit on discharge rate of SPM emission from coal plants.[12] The current limit for SPM emission is shown in Exhibit 10.

Exhibit 10: SPM Emission Norms of CPCB for Thermal Power Plants

Unit size	Maximum Emission Limit
Less than 210 MW	350 mg/Nm^3
Greater than 210 MW	150 mg/Nm^3

This norm has resulted in widespread use of Electro Static Precipitator (ESP) technology for limiting outlet SPM concentration. Exhibit 11 represents the SPM performance of thermal power plants as per data reported by various plants to CEA in the year 2011-12.[13]

It is understood that institutionalizing a provision of mandatory third party inspection and verification of the reported data may reveal a worse situation.

For other critical pollutants, i.e., NOx, SOx, and Hg, there are no norms in the present regulatory system and thus there is no official record of the quantum or emission rate of these pollutants. Even

[12] The SPM norm however does not capture fugitive emissions happening in coal handling plant and coal milling. ICF's analysis shows that fugitive emissions could be 10 to 15% of the total SPM emissions.

[13] It is mandatory for thermal power plants to submit SPM emission data to CEA on a monthly basis. The data reported by plants is published as it is by CEA. There is no provision of third party inspection or verification

Exhibit 11: Bandwidth of SPM Emisison from Thermal Power Plants

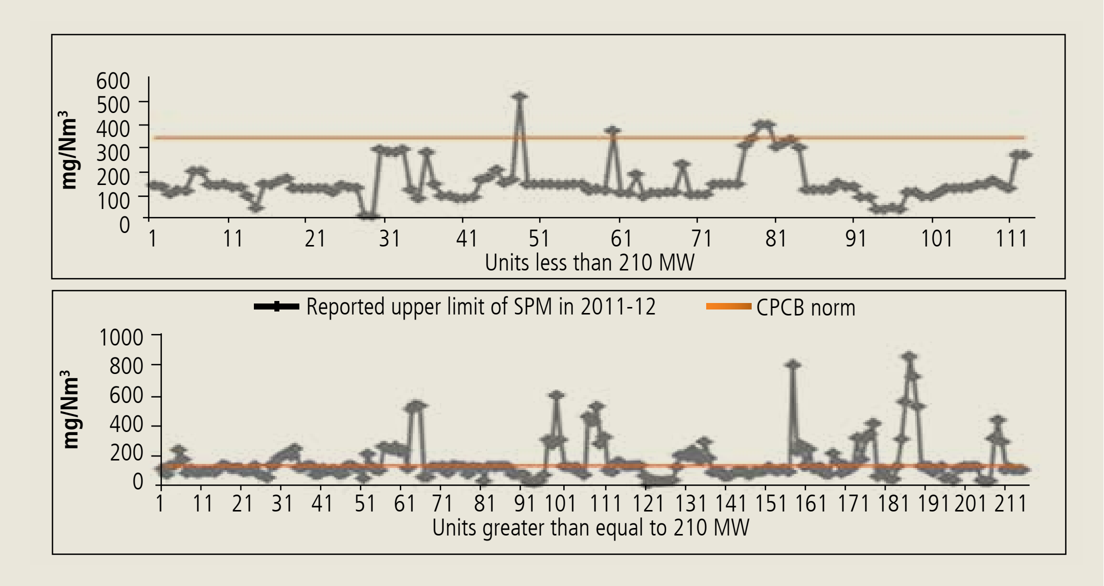


Exhibit 12: Summary of Reported SPM Values of TPP's for the Year 2011-12

Parameters	<210 MW	>=210 MW
Number of Units that Reported Data	119	219
Number of Units Complying	109	158
Number of Units Not Complying	10	61
Average Reported SPM of Complying Units	147	112
Lower Limit of Reported SPM Value (as a % of Upper Limit)	67	71

though CPCB mandates a minimum stack height to ensure dispersion of SOx emission, it does not address the issue of source reduction, which is the need of the hour considering the fact that many power plants are located in densely populated areas and dispersion alone does not ensure that the surrounding neighborhood is not impacted by these pollutants.

Most developed countries have long standing norms for critical pollutants such as NOx and SOx. A few countries such as the US (only for lignite plants) and China have taken a giant leap toward introducing norms for Hg emission. If India is to set maximum emission limits for these pollutants, the first step will be to define the current baseline and then establish a target/limit based on the reduction potential available through technically feasible and economically viable technologies. Even though the present process of Environment Impact Assessment (EIA) calls for mandatory installation of emission monitoring devices, the data for NOx, SOx, and Hg is not available. The project approach to establish a baseline was based on previous studies conducted by various agencies to estimate emissions based on type of boiler technology, coal quality, and assuming a certain operating condition (flame temperature and excess air). Since there are variations in the emission estimates between the studies, a simple average of these estimates was used to define baseline emission rates of SOx, NOx and Hg for existing plants. The only exception was for SPM, for which emission rates are notified and thus baseline SPM emission was arrived at by using the data reported by various plants to CEA/CPCB. The project's analysis is shown in Exhibit 13.

Exhibit 13: Summary of Pollutant Emissions Estimated by Different Studies

	SPM (mg/Nm3)	SOx (gm/ kWh)	NOx(gm/ kWh)	Hg (gm/ kWh)
CEA (2011-12)	147 (< 210 MW) 112 (> 210 MW)	NA	NA	NA
University of South Florida (Northern & Eastern Region 2009-10)[14]	NA	5.77 – 6.48	4.22 – 4.39	NA
IEA (2010)[15]	NA	6.5	3	NA
NPC[16]	NA	5.9	2.4	NA
ARCADIS Report[17]	NA	NA	NA	0.000371
Average	**129.5**	**6.18**	**3.23**	**0.000371**

For new plants, the project's approach to define baseline was based on estimation of anticipated emissions derived from the above identified baseline emission rates while applying a multiplication factor taking into consideration higher operating efficiency of new plants. This estimation is done for both subcritical and supercritical plants. The multiplication factor applied is the percentage improvement in net efficiency from the existing baseline case. An illustration of the same is represented here (Exhibit 14).

Exhibit 14: Estimation of Baseline Emission Levels for New Plants

	APC (%)	GHR (kcal/ kWh)	Net Efficiency (%)	Multiplication Factor for New Emission Rate	
Existing Baseline Case	**9.5**	**2,849**	**27.3**	-	
New subcritical Plant	7.3	2,300	34.6	0.731	
New supercritical Plant	7.0	2,100	38.1	0.606	
Resulting Emission Rate (in gm/kWh)					
	NOx		SOx	SPM	Hg
New subcritical Plants	2.36		4.52	0.94	0.000271
New supercritical Plants	1.96		3.74	0.78	0.000225

Although relying on actual measurements would have been preferable, the use of estimates from previous studies does enable a reasonably informative picture to emerge of the existing baseline. In subsequent sections of this paper, potential reduction in emission from the established baseline has been analyzed through deployment of promising emission control technologies and an approach has been discussed to specify limits/norms for these pollutants.

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[14] Estimates of emissions from coal fired thermal power plants in India, Moti L Mittal, Chhemendra Sharma, Richa Singh

[15] Report by IEA "Technology roadmap: High efficiency, Low emissions coal fired power generation", 2012

[16] Database of NPC, collected through various environmental audits conducted in Indian thermal power plants.

[17] Mercury emissions from India and South East Asia, report prepared by ARCADIS, study funded by US Department of State, October 2012

Emission Standards for Thermal Power Plants in India

Ministry of Environment and Forests (MoEF): The Ministry of Environment and Forests is the nodal agency in the administrative structure of the Central Government, in terms of planning, promotion, co-ordination and overseeing the implementation of environmental and forestry programmes. MoEF's broad objectives include prevention and control of pollution and environment protection. The **Central Pollution Control Board (CPCB)** is a statutory organisation under MoEF which provides technical support to MoEF to improve the quality of air and to prevent, control or abate air pollution in the country. The CPCB is responsible for introducing, implementing, and ensuring compliance of the emission standards. The various parameters covered in the present regulatory framework for thermal power plants are shown in Exhibit 15.

Exhibit 15: Emission Norms for SPM And Sox for Thermal Power Plants

Parameter	Sub-Parameter	Remark
Air Pollution	SPM	Limit for maximum emission rate defined for unit size: • 350 mg/Nm^3 (less than 210 MW) • 150 mg/Nm^3 (210 MW and above)
	SOx	Minimum stack height depending on unit size: • 220 m stack height (200 to 500 MW) • 275 m stack height (500 MW and above) • $H= 14 Q^{0.3}$ where Q is emission rate of SO_2 in kg/hr, and H is Stack height in metres (less than 200 MW)

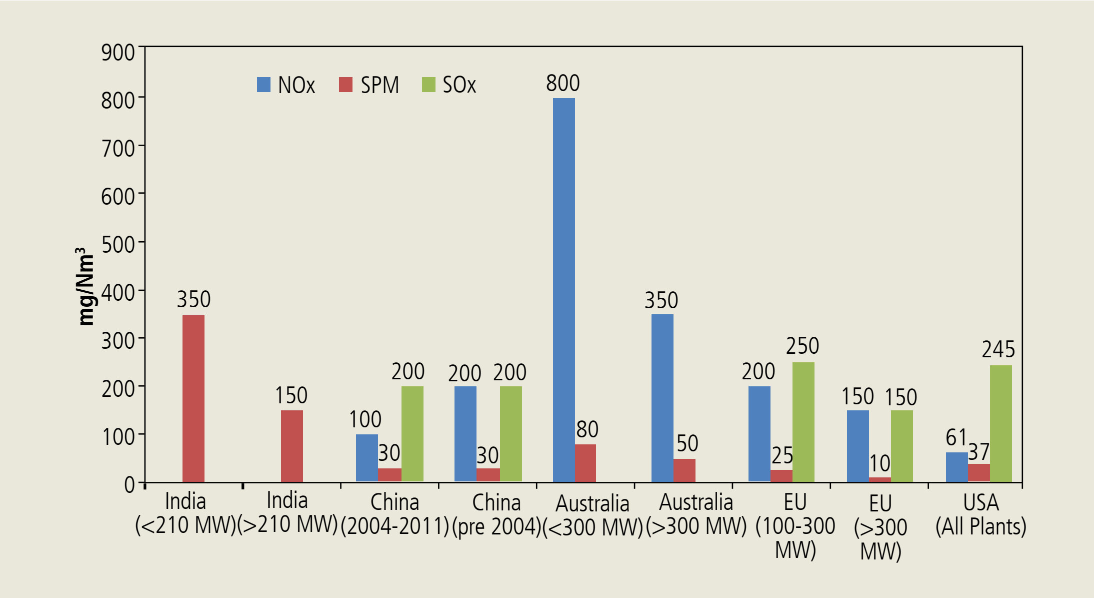
Emission norms for coal based power plants are set for particular pollutants based on the desired level of control that needs to be achieved from particular sources or activities. These standards in many countries are determined by the policy of promotion of best available technology, or state of the art technology or best practicable means, apart from ensuring protection of environment and human health. The comparison of emission standards applicable to existing plants (Exhibit 14) in India and other countries (developed and developing) is shown in Exhibit 16.

Exhibit 16: Existing Plant Categories for Comparison of Emission Norms

Country	Description
India	All plants having capacity below 210 MW All plants having capacity 210 MW and above
China	All existing plants commissioned between 2004 and 2011 All existing plants commissioned before 2004
Australia	All existing plants having capacity upto 300 MW All existing plants having capacity higher than 300 MW
Europe	All existing plants having capacity between 100 to 300 MW All existing having capacity higher than 300 MW
USA	All existing plants

Emission norms for coal based thermal power plants in India are defined only for SPM. For SOx emissions, the present norms are aimed at dispersion through stack height and not source control. Most of the developed countries have defined norms for SOx and NOx as well (Exhibit 17). Recently China, has introduced norms for Hg. Even in the US, new norms have been defined for Hg emission control, but currently are limited to lignite based plants.

Exhibit 17: Comparison of Indian Norms with Other Countries for Existing Plants[18]



[18] ICF's analysis based on review of reports from several sources such as CPCB, US EPA, IEA, Greenpeace International

ANALYSIS OF POSSIBLE INTERVENTIONS

To devise a plan for possible interventions, the following steps were identified:

Step 1: Possible measures (technologies and practices) for improving the efficiency and controlling emissions were identified. Applicability of these measures for an existing plant and a new plant was explored. A library of measures was prepared based on literature review, analysis of several energy audit reports conducted by NPC in past 5 years, and NPC's practical experience of working towards energy efficiency and controlling emissions of thermal power plants.

Step 2: Promising measures were shortlisted based on their feasibility of implementation, commercial availability, current penetration level, and savings potential. The shortlisted measures are shown in Exhibit 18.

Exhibit 18: Shortlisted Measures for Economic Analysis

Efficiency Improvement				
Index	**Measures**	**Resulting Efficiency (Baseline 27.3%)**	**Potential for implementation (%)[19]**	**Impacts On**
M1	Online Process Monitoring & Control through Plant Monitoring System	27.7%	30	Heat Rate, APC
M2	Control of main steam parameters/reheat steam/attemperation/turbine efficiency improvement	28.1%	50	Heat Rate
M3	Optimization of secondary air through advanced monitoring system	28.4%	55	Heat Rate
M4	Use of Condition Monitoring and Diagnosis System	29.0%	90	Heat Rate, APC, PLF

[19] Potential for implementation implies the percentage of plants in which the shortlisted measures can be implemented. A 30% potential implies the measure can be applied and implemented in only 30% of the plants.

Efficiency Improvement				
Index	**Measures**	**Resulting Efficiency (Baseline 27.3%)**	**Potential for implementation (%)[19]**	**Impacts On**
M5	Re-introduction of HP heaters in feed water circuit	29.3%	60	Heat Rate
M6	Optimization of draft system/EE/VFD	29.5%	70	APC
M7	Mathematical modelling of tubular air heaters	29.8%	99	Heat Rate
M8	Use of micro-processor based control system for dry ash handling	29.8%	40	APC
M9	Introduction of vibro - grizzly feeders/fine seperators	29.9%	40	APC
M10	Optimization of CHP operation through micro - processor based control system	30.0%	100	APC
M11	Effectiveness enhancement of cooling tower/improving condensor vacuum/ improving turbine heat rate	30.0%	60	Heat Rate, APC
M12	Use of magneto drives	31.39%	100	APC
M13	Use of VFD for CEP/ optimization of operating parameters	31.40%	50	APC
M14	Optimization of BFP parameters and use of VFD	31.43%	85	APC

Emission Control				
Index	**Measures**	**Resulting efficiency (Baseline 27.3%)**	**Potential for Implementation (%)**	**Impact on Pollutant Reduction**
EM1	Coal washing	28.50%	85	SPM
EM2	Activated Carbon Injection	27.29%	100	Hg
EM3	Upgrade to High Removal Efficiency (99.7 %) ESP from existing ESP	26.99%	30	SPM
EM4	Replacement of Existing ESP With Bag Filters	26.74%	100	SPM
EM5	Semi Dry Flue Gas Desulphurization	26.97%	100	SOx
EM6	Sea Water FGD	26.80%	100	SOx, Hg, SPM
EM7	Low NOx burners	26.78%	100	NOx

EM8	Selective Non Catalytic Reduction	27.20%	100	NOx
EM9	Wet Flue Gas Desulphurization	26.85%	100	SOx, Hg, SPM
EM10	Selective Catalytic Reduction	27.15%	100	NOx
EM11	ROFA ROTAMIX	27.17%	100	SOx, NOx, Hg
EM12	SO_2 Sorbents	27.17%	100	SOx
EM13	Electro Catalytic Oxidation	26.17%	100	SOx, NOx, Hg

Step 3: The economic impact due to the application of shortlisted measures were evaluated. For the purpose of economic analysis, an MS-excel based model was developed, which takes into account the attributes such as capital cost, O&M cost, life of measure, and weighted average capital cost. In order to understand the economic feasibility of shortlisted measures, the impact on per unit generation cost post implementation of these measures was identified as an output metric for this analysis. The total quantity of fuel supplied was assumed to be the same before and after implementation of measure. The impact of efficiency improvement was captured through increase in net generation. The steps followed for economic impact assessment are shown below. Other assumptions for modelling are shown in Exhibit 19.

a. A typical size plant was considered as a baseline plant with national average performance level

b. Capital cost of option was annualized using the weighted average capital cost and the life time of options. This annualized capital cost was added to the increase/decrease in the annual O&M cost due to implementation of measure.

c. Annual benefit/loss due to change in generation output (in the form of increased generation due to energy efficiency (EE) or decrease in generation from emission control measure) was calculated. *The analysis does not capture any benefits likely to accrue due to reduced health effects.*

d. Impact on per unit generation cost and new emission factor for each pollutant was calculated.

Exhibit 19: Assumptions for Economic Assessment

Before the measure is applied			
	Existing Plant	New Sub Critical Plant	New Super Critical Plant
Average plant size (MW)	210	500	660
Net Efficiency (%)	27.3	34.6	38.0
Average PLF	0.78	0.85	0.85
Average cost of generation (INR/kWh)	2.0[20]	2.5	2.5
Average Hg emission(gm/kWh)	0.000371	0.000271	0.000225
Average NOx emission(gm/kWh)	3.23	2.36	1.96
Average SO_2 emission(gm/kWh)	6.18	4.52	3.74
Average SPM emission (gm/kWh)	1.29	0.94	0.78

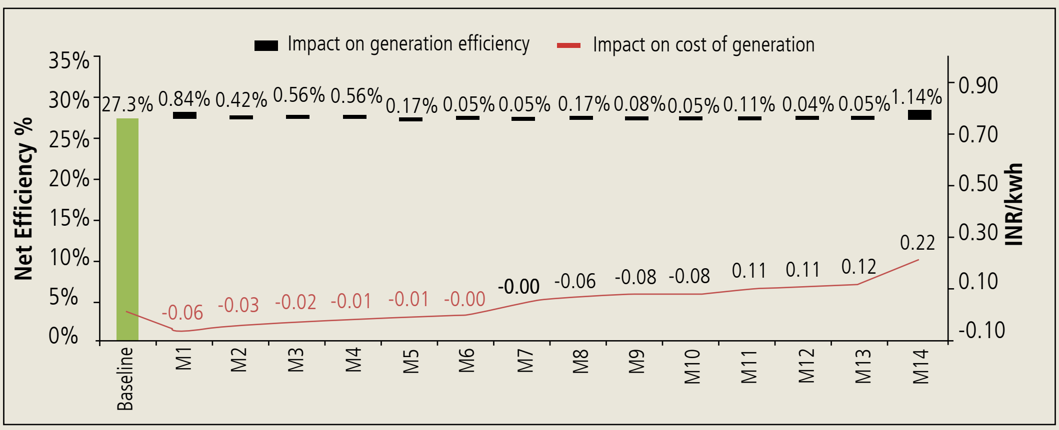
[20] For existing plants, the generation cost is assumed to be INR 2.0/kWh, assuming the cost of capital being already recovered post operation of 15 years or more. For new plants, which have been commissioned post 2007 the generation cost is assumed to be 2.5 INR/kWh, and thus having a higher generation cost as compared to existing plants.

After the measure is applied	
Capital cost, Annual O&M cost of measure	Depending on the measure
Life of measure	
Impact on efficiency	
Average PLF	
Average emission reduction	
Weighted average capital cost	15%

RESULTS OF ECONOMIC ANALYSIS FOR EFFICIENCY IMPROVEMENT

For existing plants, the result of economic analysis for individual application of efficiency measures and simultaneous/collective use of measures at the plant level is shown in Exhibit 20 and Exhibit 21. In order to analyze the collective impact of measures, bundling of measures was done only for feasible combination of measures. While bundling of measures, care was taken not to overestimate the savings by simply adding the individual impact of each measure. It is seen that if one measure is implemented, the baseline for remaining measures changes. It is therefore, important to capture the impact of bundled measures properly so as not to double count the possible benefits. Another cross check was done to ensure that these measures are mutually exclusive in order to correctly estimate the resulting cumulative benefits.

Exhibit 20: Impact of Energy Efficiency Measures if Applied Individually

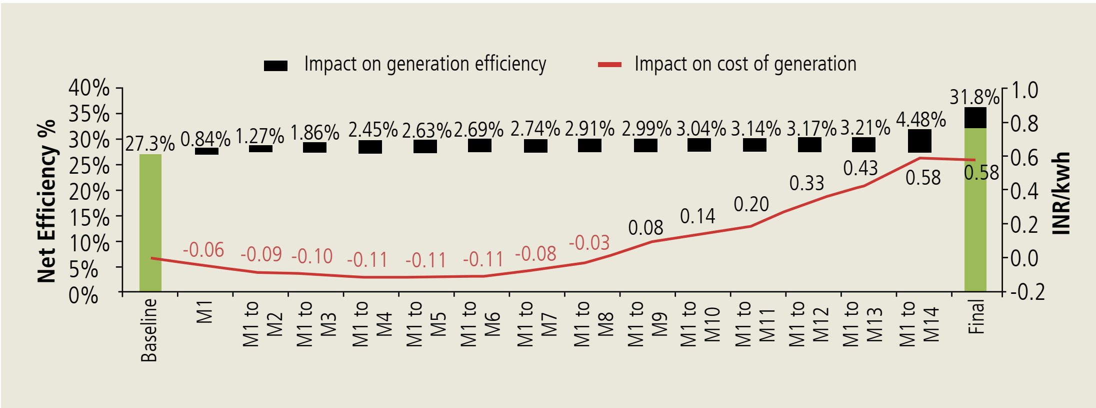


Several of the assessed measures have negative cost, as the yearly benefits due to energy savings[21] are more than the annualized cost (inclusive of both capital and O&M costs). The efficiency gains from the negative cost options range from 0.05 % to 0.84%. These options when deployed would result in a decrease in the generation cost. The option (M14) with the maximum improvement

[21] The term energy savings is used for the monetary savings on account of reduction in fuel consumption. This is possible as the increase in energy efficiency at a constant generation would lead to a corresponding reduction in fuel consumption.

potential (1.14%) is found to be the most cost intensive and result in an increase in the cost of generation by 0.22 INR/kWh. The impact of cumulative deployment of these options was also analyzed and the results are depicted in Exhibit 21.

Exhibit 21: Impact of Energy Efficiency Measures if Applied Simultaneously



The project's analysis shows that there is a potential to improve the efficiency level from 27.3% to 31.8% i.e., a 4.5% absolute improvement. However, measures M1 to M6 have the combined improvement potential of 2.69% and at the same time lead to a reduction in generation cost by INR 0.12/kWh. This is a win-win situation for plants as the investment towards these measures will be recovered through savings. M7 and M8 provide an additional improvement of 0.22% and are cost neutral. If options beyond M9 are considered, then the cost of generation increases by 0.58 INR/kWh (25% increase from baseline).

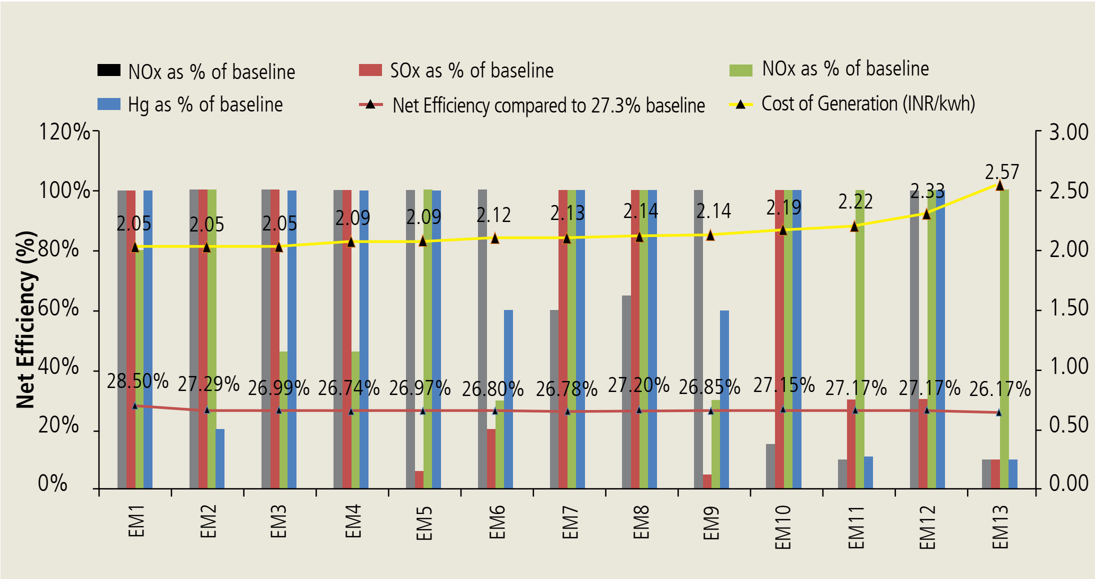
These efficiency improvement measures, when applied simultaneously would also reduce the specific emission rates. This reduction would range from 10 to 14% of the present baseline emission rates.

RESULTS OF ECONOMIC ANALYSIS FOR EMISSION REDUCTION

For emission abatement, potential emission control technologies which are commercially available globally but have yet to penetrate India, were looked into. The emission reduction from the identified baseline emission rates due to deployment of these technologies was analyzed. Since, most of the emission control technologies impact efficiency negatively (due to increase in APC), the corresponding impact on generation cost was also analyzed (Exhibit 22).

It is observed that most of the emission control technologies impact only a single pollutant and therefore, deployment of an individual technology was not presented as a potential improvement case. Some of these measures like Sea Water FGD, Wet FGD ROFA ROTAMIX, and Electro Catalytic Oxidation have a multi-pollutant emission control. For example, the deployment of electro-catalytic oxidation has a potential to reduce NOx, SOx and Hg emissions by around 90 % as compared to their existing baseline, but this technology is still in the pilot phase and is yet to be commercially available. In order to determine the potential reduction and cost impact, technically feasible combination of emission control technologies was arrived at based on commercial availability of these technologies in the global markets. Most of these technologies have a cost penalty as these lower the net efficiency. As an exception, use of washed coal improves the efficiency as it has a

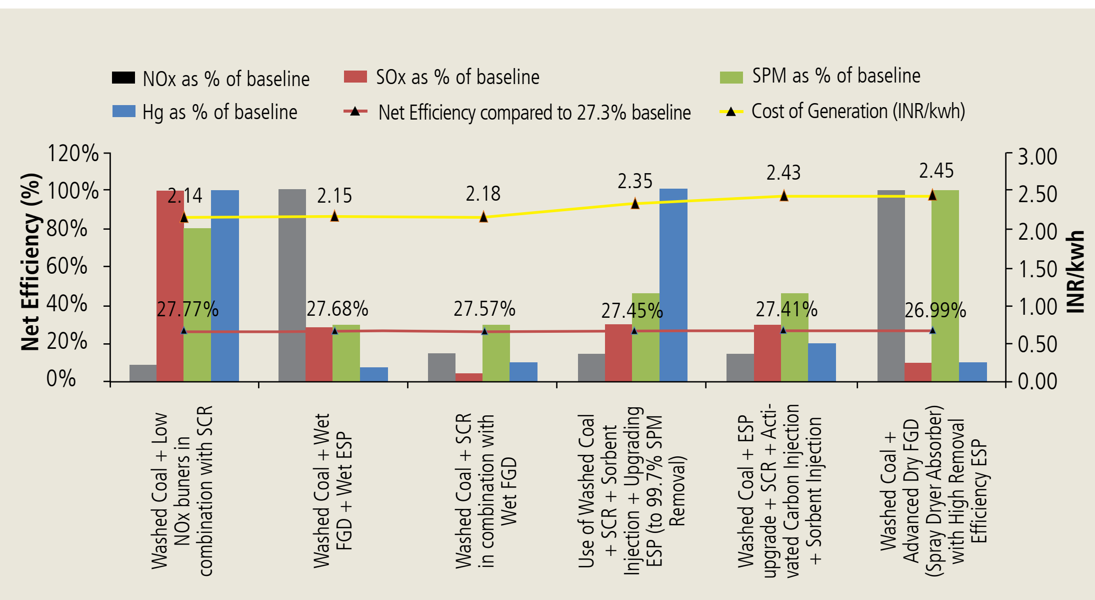
Exhibit 22: Impact of Individual Emission Measures without Considering Options for Efficiency Improvement



substantial impact on improving PLF due to reduced outage, improvement in net efficiency due to improvement in APC/heat rate, and reduction in SPM due to less ash content. Hence coal washing was considered as a universal measure in all the feasible combination of technologies. Application of washed coal has the feasibility of being considered as an efficiency improvement and emission control measure. In this study, we have considered this option as a measure for emission reduction as various other EE improvement options have been considered separately.

Different scenarios were analyzed for the deployment of feasible combinations of emission control technologies. In the first scenario, the potential impact of these measures on the existing baseline (without any efficiency improvement) was analyzed. The results are illustrated in Exhibit 23.

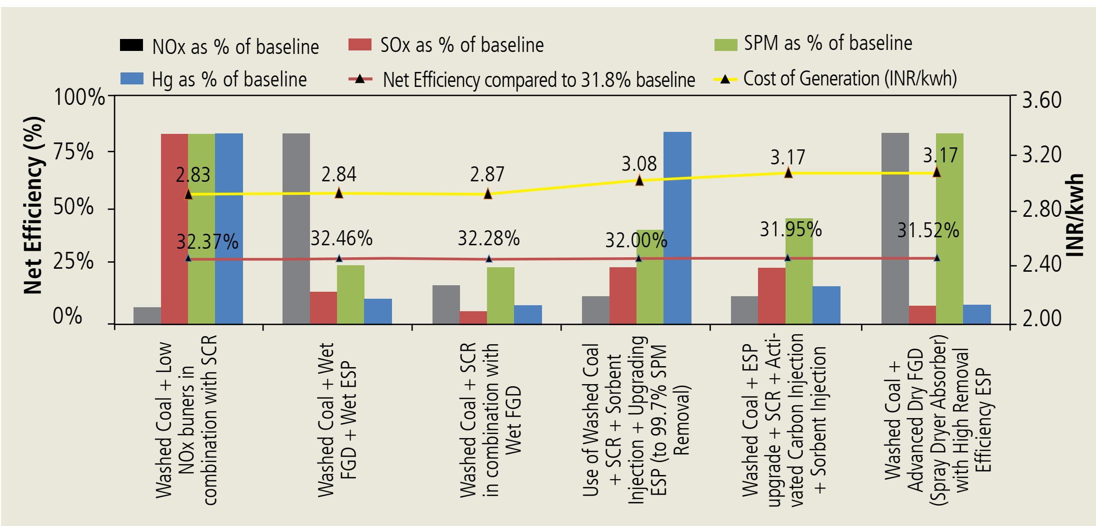
Exhibit 23: Impact of Combination of Emission Measures without Considering Options for Efficiency Improvement



Selective Catalytic Reduction (SCR) in combination with Wet Flue Gas De-sulphurization (FGD) is assessed to be techno-economically the best combination of measures for emission control, since the combination results in a reduction of critical pollutants from the present baseline by more than 75%. The increase in generation cost would be by 0.18 INR/kWh, i.e. around 9% from the present baseline generation cost of 2.0 INR/kWh. The only limitation foreseen with this combination is the space availability for FGD. Vintage plants may not have space available for installing an FGD, thus alternate combinations were explored in order to achieve maximum possible emission reduction. An alternate to FGD, is the use of Sorbent Injection (for SOx control) and Activated Carbon Injection (for Hg control). However, the reduction in pollutants would be a little less (around 60%) as compared to the use of FGD (around 75%). The resulting cost of generation through the deployment of this option would 2.43 INR/kWh.

In the second case, the impact of emission control technologies post efficiency improvement (as per maximum technical potential) was analyzed from the baseline efficiency of 31.8% after considering all EE improvement measures. In few technology combinations, the resulting net efficiency shows an increase beyond the baseline even after installation of emission control technologies (typically installation of emission control technology reduces the net efficiency as APC goes up). The reduction in efficiency supersedes the benefit from use of washed coal. The results are depicted in Exhibit 24.

Exhibit 24: Impact of Combination of Emission Measures and Efficiency Improvement Measures



If the emission reduction options are applied in conjunction with efficiency measures, the overall reduction potential is a little higher, but the costs increase as well. As mentioned before, the deployment of any emission control measure results in increasing the APC and a corresponding reduction in net efficiency. However, in this case we have considered use of washed coal in combination with efficiency and emission control measures which results in improvement of heat rate of the plant. Even a small change in heat rate has a higher impact on net efficiency as compared to a change in APC (A 10% heat rate reduction would improve the net efficiency by about 11%, whereas a 10% reduction in APC would improve the net efficiency only by 0.9%). Thus, the increment in APC due to deployment of emission control measures is countered by the reduction in heat rate due to use of washed coal resulting in an improvement in net efficiency when washed coal is deployed along with emission control measures. Exhibit 25 shows a comparison of emission control measures with and without deployment of washed coal.

Exhibit 25: Impact on Net Efficiency with and without Washed Coal for Emission Control Measures

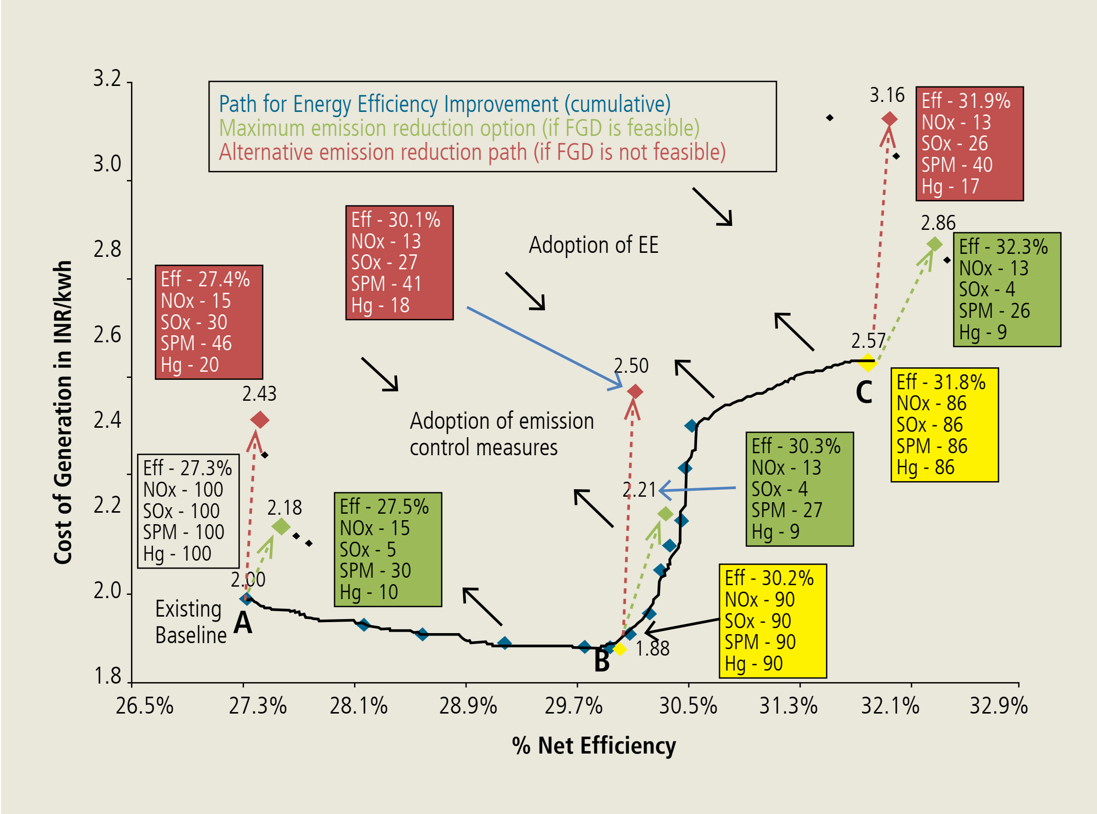
S. No.	Emission Control Technology	Resulting Net Efficiency as Compared to 31.8 % baseline – with Use of Washed Coal	Resulting Net Efficiency as Compared to 31.8 % Baseline – without Use of Washed Coal
1.	Low NOx burner in combination with SCR	32.37%	31.04%
2.	Wet FGD + Wet ESP	32.46%	31.16%
3.	SCR in combination with Wet FGD	32.28%	31.31%
4.	SCR + Sorbent Injection + Upgrading ESP (to 99.7 % SPM Removal)	32.00%	31.64%
5.	ESP upgrade + SCR + Activated Carbon Injection + Sorbent Injection	31.95%	31.67%
6.	Advanced Dry FGD (Spray Dryer Absorber) with High Removal Efficiency ESP	31.52%	31.18%

The most promising emission control technology is a combination of SCR, Wet FGD, and Use of Washed Coal. This has the potential for emission reduction varying between 70–96% (for different pollutants). However, in case of existing plants, space can become a constraint for the deployment of Wet FGD. The other option under the circumstances is using ESP Upgrade, SCR, Activated Carbon Injection, and Sorbent Injection. This is the best alternative at existing plants where Wet FGD installation may not be feasible. However, this results in a comparatively higher generation cost and a lower emission reduction potential as compared to the previous one.

In order to develop a more economically feasible case for practical implementation, all negative cost options for efficiency improvement were cumulated. The deployment of these negative cost options result in reducing the generation cost from 2.0 to 1.88 INR/kWh while improving the net efficiency from 27.3% to 30.2%. Taking this as the new base level, impact of cumulative deployment of emission control measures was analyzed. The efficiency-emission interplay for an existing plant is shown in Exhibit 26.

An attempt to arrive at the best possible efficiency and emission improvement option along with its impact on resulting generation cost is presented in the Exhibit 26. The point A indicates the existing baseline at a generation cost of INR 2.0/kWh and net efficiency of 27.3%. The existing level of all emission parameters is considered as a relative scale of 0 to 100. Two most feasible options after intervention of emission control technologies at this point shows a jump in generation cost to INR 2.18 and 2.43 per kWh with marginal increase in net efficiency, whereas the emission level reduces substantially. The path shown in red represents the case wherein FGD is not feasible. Various negative cost EE options are incorporated from point A. The best feasible option is arrived with an efficiency level of 30.2%, i.e. point B, whereas the emission level is slightly reduced. If we adopt emission control technologies at this point, again two most feasible options are arrived at - (1) efficiency level increasing to 30.3% with a generation cost of INR 2.21 per kWh and

Exhibit 26: Boundary of Efficiency-Emission Interplay



(2) efficiency level reducing to 30.1% with a generation cost of INR 2.50 per kWh, the latter being the option without FGD. However, there are still other EE improvement options which can further be deployed from the best point B, though the cost implications may not be attractive. Point C is such a point, where the efficiency improves to 31.8% and the generation cost increases to INR 2.57 per kWh. With the same logic, if emission control techniques are deployed here, two best feasible options are observed. The maximum cost of generation is observed to be INR 3.16 per kWh (without FGD) and the emission levels are substantially reduced. In the above exhibit, the path shown in black indicates the EE improvement options. Considering the feasibility of implementation and cost economics, the point B is taken as the best for suggesting new efficiency norms for existing plants.

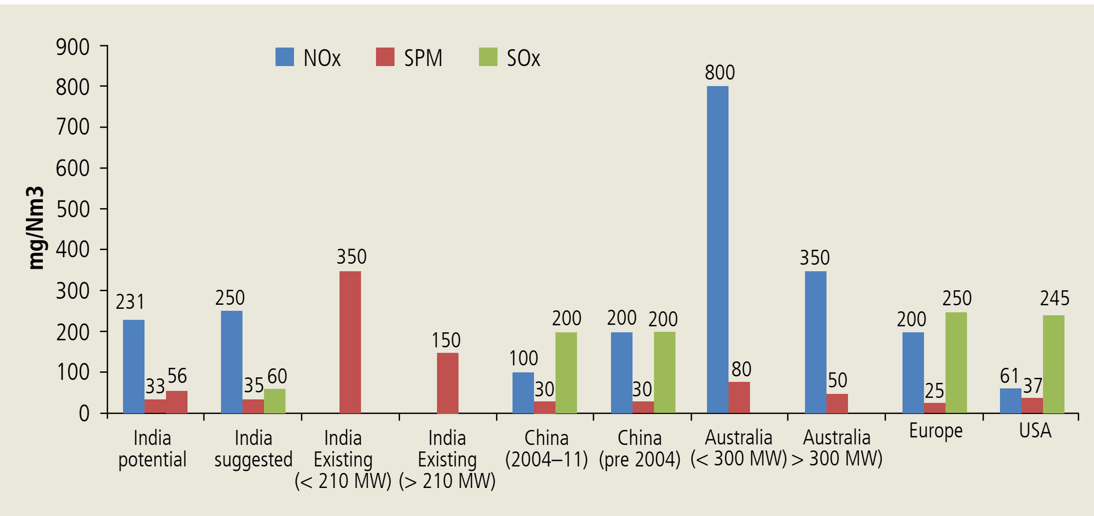
Similarly, for new plants, the impact on cost of generation is seen from the baseline (refer Exhibit 19) after deployment of selective emission control technologies (SCR, Wet FGD, and Washed Coal). For new sub critical plants, the cost of generation is INR 2.71 per kWh post deployment of emission control technologies. For new super critical plants, the suggested emission norms are further tightened as compared to new sub critical plants at a comparable generation cost. Exhibit 27 shows the baseline, and suggested emission norms for new sub and super critical plants.

Exhibit 27: Summary of Suggested Emission Norms

Criteria	Unit	NOx	SPM	SOx	Hg	Generation Cost (INR/kWh)
New Plant (subcritical)						
Baseline value	gm/kWh	2.36	0.94	4.52	0.00027	2.5
Suggested Norm	gm/kWh	0.36	0.30	0.24	0.00002	2.71
Suggested Norm	mg/Nm3	200	30	50	0.00623	2.71
New plant (supercritical)						
Baseline value	gm/kWh	1.96	0.78	3.74	0.00022	2.5
Suggested Norm	gm/kWh	0.29	0.25	0.19	0.00002	2.70
Suggested Norm	mg/Nm3	160	25	40	0.00517	2.70

A comparison between suggested norms for India, with norms in other countries is shown in Exhibit 28. The categorization of plants is same as that in Exhibit 16.

Exhibit 28: Suggested Emission Norms For India Vis-A-Vis Other Countries (Existing Plants)

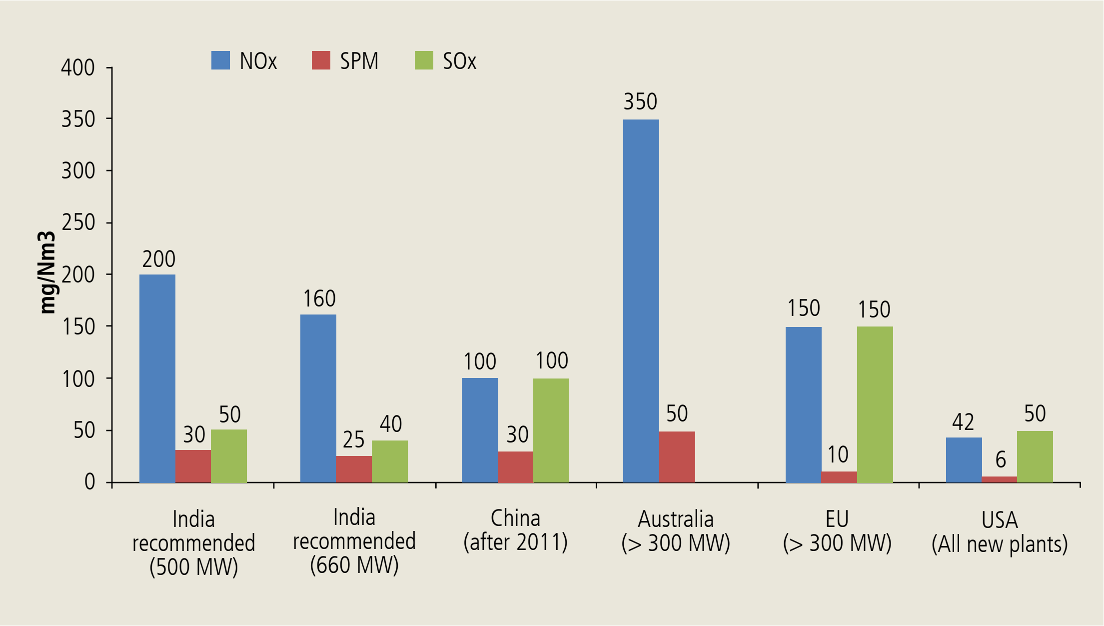


Post deployment of suggested combination of efficiency improvement and emission reduction, the emission limits of existing plants can be brought down to be at par with the norms of other developed countries and large emerging economies. For new plants, a similar comparison is done with the potentially achievable emission numbers vis-à-vis the present norms in other countries (Exhibit 29).

Thus, it is technically feasible to bring emissions to a comparable level with other countries through the deployment of suggested efficiency and emission control options.

The potential for improvement also comes with associated hurdles in terms of required capital, availability of technology, downtime required for installation and other associated factors at the macro level.

Exhibit 29: Suggested Emission Norms For India Vis-a-Vis Similar Category Plant in Other Countries (New Plant)



Given below are a list of identified hurdles which need to be addressed in order to ensure the suggested recommendations can be adopted in the current system –

a. Technology Barriers

- Globally and commercially available emission control technologies need to be made available in India at an optimum cost. As of now, these technologies are highly-priced, and a focus to develop indigenous manufacturing of these technologies in the immediate future may lead to cost reduction along with their widespread deployment.
- Also, most of these global emission control technologies are yet to be tried and tested on a widespread basis in India. These technologies need to be optimized in consistence with the domestic conditions. Focused R&D, long term technology transfer agreements need to be looked into at this stage to ensure easy penetration and optimization of these technologies in the current system.
- Based on the analysis presented, it is evident that Wet FGD is one of the more promising emission control technologies, having a multi-pollutant emission control. However, this may increase the water requirement of a coal plant by 20-30% and a corresponding increase in generation of waste water. Thus, there will be a need to augment the capacity of wastewater treatment plants. Technologies for recycle/reuse of this wastewater also need to be developed correspondingly to ensure minimization of waste and re-use of wastewater post chemical treatment.

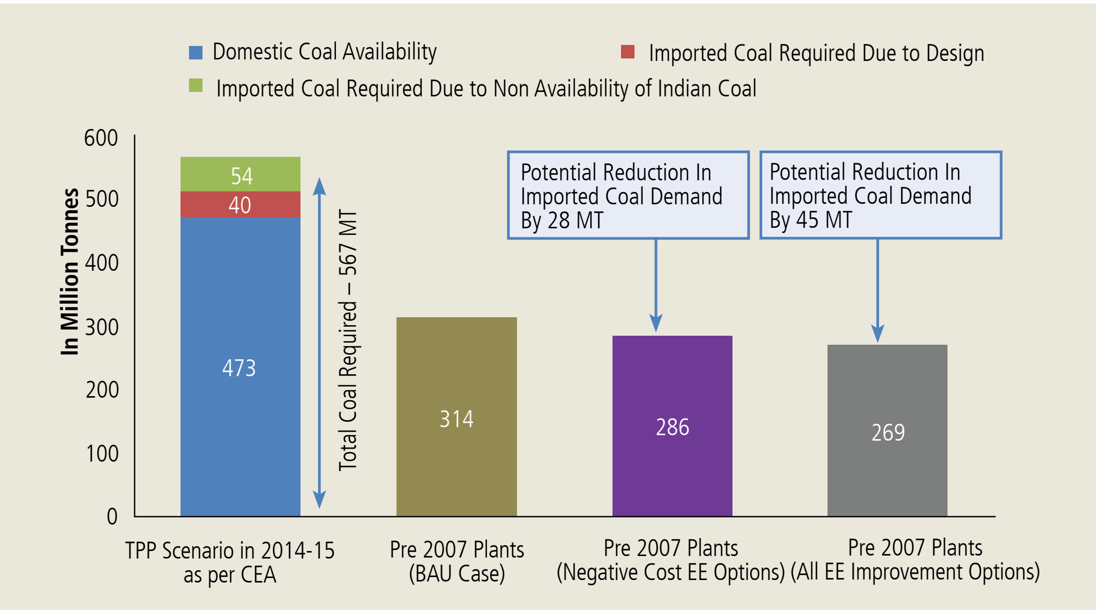
b. Implementation Barriers

- Downtime required for implementation of the suggested energy conservation measures may pose a challenge considering the present scenario of power deficit. A coordinated strategy needs to be developed to ensure phase-wise implementation of these measures in select plants to ensure that the net impact in terms of lower power output is compensated from other plants.

- The seed capital investment required is assessed to be 10,000 Million USD[22] for implementation of the proposed energy efficiency improvement measures. This may require sourcing of additional funds, considering the present scenario of financial constraint of various utilities particularly the state owned ones.
- Any post implementation measures would have impact on the resulting cost of generation. For a positive cost option, the resulting cost of generation would increase even though at an attractive payback. This may pose a constraint to the utility, as it may call for revision in their tariff agreements, and of the applicable tariff regulations of CERC/SERC.
- Most of the assessed emission control technologies result in a reduction of cost of generation and enhancement in efficiency, as use of washed coal has been considered as a precursor to deployment of these technologies. Availability of washed coal to the existing plants thus needs to be ensured.

The possible reduction in coal demand due to deployment of the identified efficiency and emission control technologies is depicted in Exhibit 30.

Exhibit 30: Potential for Reducing Imported Coal Demand (2014-15)



If the technical potential of efficiency improvement in existing plants (covered under this study) is met, it would result in reduction of annual domestic coal demand by around 45 million tonnes in 2014-15. This will reduce at least 30 MT of imported coal (from the existing requirement of 94 MT of imported coal). The efficiency improvement achieved through negative cost measures will reduce the annual domestic coal demand by about 28 million tonnes.

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[22] Budgetary estimate based on NPC & ICF's analysis on the extent of present penetration of various technologies in power plants and the possible implementation potential of various EE technologies identified in our study.

CONCLUSION AND WAY FORWARD

India has established mechanisms for regulating efficiency and emission performance of thermal power plants. While endeavours are made from time to time to improve the efficiency by different agencies such as CEA, BEE, and CERC, the efforts to reduce emissions have largely been stagnant over the years. The PAT scheme which aims to reduce about 2.8 million tonnes of Oil Equivalent (MTOE) through an average reduction of 1% APC and about 100-110 kcal/kWh in GHR is a good initiative to improve the efficiency and impact emissions. Expert opinion by the PAT Administrator indicates that 70 to 80% of the coal based thermal power plants will achieve the targets by the compliance year.

In the previous sections of this paper, measures for improving the sector level efficiency and emission have been discussed along with their cost effectiveness. Based on the analysis, the following recommendations are suggested to support relevant policy makers and implementing agencies to improve efficiency and emissions from the sector to reduce coal import dependency and provide better health standards for citizens in the years to come. In many cases, actions for specific stakeholders are identified to indicate the agency that should take the lead in such efforts.

1. Improving the average efficiency of existing plants through the following levers:

- **Increasing the efficiency of plants commissioned before 2007 through energy efficiency technologies and practices:** As per the project's analysis, such plants have the economic potential to reach a net average efficiency of 30% by 2017 from the present baseline efficiency of 27.3%. The project's analysis shows that 1st phase of PAT scheme targets to achieve 28.5% by 2015. Hence, subsequent phase of PAT may set heat rate improvement targets in such a way that the average efficiency of these plants reaches at least 30%. Any technical hurdles are not anticipated to achieve this target because technology is commercially available, measures are cost neutral, and regulatory structures exist to define the objectives. As per the analysis in this study, the technical potential of net efficiency is about 31.8% and is derived from technology options, feasibility of implementation and the penetration level of technologies. But reaching the technical potential would result in a per unit generation cost higher by 29% from the present level. BEE may have to be mindful of such considerations if subsequent phases of PAT scheme are to set ambitious targets beyond the average efficiency of 30% for these plants.

- **Setting up of a national policy for retirement of coal plants based on attributes like vintage and operating efficiency:** Vintage has a direct impact on the performance parameters of the plant as the plant size gets de-rated and heat rate and APC increases. In order to sustain the operation, R&M and LE approaches are being adopted in selected units. However these are highly cost intensive and time consuming exercises. In the past 20 years, about 5263 MW have been realized through R&M/LE programme. However, this benefit has required a capital investment over 10,000 Million USD. At times, it may be beneficial to close down vintage plants operating at much lower performance parameters rather than upgrading through cost intensive R&M/LE programmes. It is seen that plants operating for more than 25 years and having operating net heat rate above 3,500 kcal/kWh have much lower NPV as compared to an existing plant that is recently commissioned and awaiting coal. The improvement in PLF in the latter case would further improve the NPV, thus reemphasising the need to retire vintage plants and diversion of coal to recently commissioned existing plants (commissioned post 2007). A comparative table of the different cases developed are illustrated in the following Exhibit.

Exhibit 31: Comparison of NPV For Different Cases of Existing Coal Plants

Case Description*	Unit	Value
Case 1: NPV of Old & Vintage Plant With Operational Life of 25 years	INR Crores	-794
Case 2: NPV of Old & Vintage Plant With Operational Life of 25 years after performance up-gradation through R&M	INR Crores	149
Case 3: NPV of Existing Plant which is recently commissioned (post 2007) and operating at low PLF due to shortage of coal	INR Crores	948
Case 4: NPC of Existing Plant which is recently commissioned (post 2007) and operating at improved PLF. In this case it is assumed the old & vintage unit (case 1) is retired and the allocated coal is diverted to this case 4.	INR Crores	2734

*Case developed assuming existing plant (old and vintage) operating at average performance parameters and development of different cases for a recently commissioned plant (post 2007) which has a better efficiency but running at low PLF on account of coal shortage.

With this as a basis, about 8,000 MW can be retired and diverted or allocated to new plants. Old plants that can be retired are located mainly in central India (Uttar Pradesh, Madhya Pradesh, Bihar etc.) and the available coal from these plants can be allocated to newer plants awaiting for coal, located also in the central and northern India (Punjab, Chattisgarh etc). This would result in an average efficiency improvement from 27.3% to 28.8%, which means for the same quantum of generation, there will be a reduction in coal consumption by 11 million tonne per annum. The Core Working Group on Power for the 12th Plan has also recommended retirement of plants operating for more than 30 years and deviation from designed heat rate by more than 20% continuously for the last 5 years. However, the plan is to retire capacity of about 4,000 MW each during 12th and 13th plan which is not encouraging. India, no doubt is in need of power to support its growth, but retirement will not affect generation, because a capacity of 25 GW is lying idle and other plants are running at low PLF because of shortage of coal. Hence, policies in favour of closing older and less-efficient units should be adopted and transfer of coal linkage to other plants which are efficient and waiting for coal supply should be done. China had retired around 70 GW capacity in last 7 years by mandating closure of small, inefficient coal-fired power generation units.

- **Improvement in the plant load factor:** The project's analysis shows that a 10% reduction in PLF (or load) would result in decreasing the efficiency by 1.3%. This means that improving operating PLF to 85% (from the present baseline of 78%) will improve the net efficiency by absolute 0.6%. Hence, the resolution of fuel supply problems related to availability of coal will be critical. While improving efficiency and retiring old inefficient plants will reduce the coal supply burden, encouraging power producers to purchase expensive coal by providing tariff adjustment might be another means. CERC/SERC tariff mechanisms can allow generation cost based on imported or expensive coal.

  Improving PLF would also entail availability of good coal quality. Using washed coal has a number of benefits including lower plant maintenance and lesser handling of coal and ash. The project's analysis shows that washed coal increases the efficiency by absolute 3-4%. The project's analysis shows that the current availability of washed coal is around 20 million tonne and complying with MoEF's notification of using washed coal in plants located beyond 1000 km would require 200 million tonnes. The analysis also shows that increase in fuel cost due to washed coal usage gets offset by increased PLF and efficiency. Hence, 100% adherence to norms for washed coal should be ensured.

- **Explore the possibility of heat rate improvement using renewable energy technologies:** This could provide heat to reduce heat losses at various points in the steam cycle, or to provide power to the equipment to curb these heat losses, thus curbing on-site equipment electricity use. Having hotter water entering the boiler means less coal is needed to heat and produce the steam that turns the turbine to generate electricity. This is in sync with the Planning Commission's guidance in 12th plan for utilisation of renewable energy in specific process/ plant/colony applications. One such hybrid coal-solar demonstration power plant is already in operation in the United States at Colorado. The demonstration project is expected to cut the use of coal at the power plant by around 2 to 3% and could be scaled up to cut it by 10% altogether. Feasibility of such options needs to be analyzed.

2. Revision in existing SPM norm and notification of norms for NOx, SOx and Mercury

- **Tighter norms for SPM emission limits:** Improving the efficiency of plants will lead to a decrease in emissions by about 13%. However, further emission reductions are feasible based on the available technologies (as identified in the report). Deployment of advanced ESPs having higher removal efficiency would be one of the key means for implementing lower SPM emission levels. Use of washed coal, apart from yielding efficiency improvement and reduction in forced outages also has an additional benefit of reducing SPM emissions. For regulating fugitive emission which does not get captured in SPM limits, installation and operation of dust suppression systems (in coal handling and ash handling plant) should be made mandatory by MoEF as a part of environmental clearance process.

- **Notification of emission norms for NOx, SOx and Mercury:** Emission standards should be introduced for several currently unregulated critical pollutants, namely NOx, SOx and Hg. However, adequate emission monitoring data for these pollutants is presently unavailable. Therefore, the MoEF/CPCB should initiate a COINDS study to gather baseline emission data for these pollutants and evaluate available emission control technologies, based on which emission norms can be developed.

- **Installation of Continuous Emission Monitoring System:** MoEF should mandate submission of online emission data for pollutants such as SPM, SOx, NOx and Hg from all coal plants. This would require all plants to install continuous emission monitoring devices. In February 2014, CPCB issued a notification mandating power plants and 16 other "highly polluting industries" to install Continuous Stack Emission Monitoring Systems (CSEMS) and all State Pollution Control Boards/Pollution Control Committees to install necessary systems for online emission monitoring data collection by March 2015. Effective compliance with this notification should be ensured by responsible agencies.

- **Ensuring Availability of Emission Control Technologies:** Implementing the proposed emission norms will require availability of control technologies in India. Emission control technologies would need to be optimized, and if required, redesigned as per Indian conditions, and require focussed R&D, international collaboration to replicate global best practices. Indigenous manufacturing will be required to make such globally successful technologies available to India at reasonable cost. Other types of challenges associated with these technologies will also need to be dealt with. For example, Wet FGD is a promising emission control technology. However, it would require additional water of about 20–30%. Wet FGD technology would also require additional waste treatment systems to deal with the wastewater generated. Focus on water conservation and recycling will be the key to adopt this technology. Installation of Wet FGD system would require additional space. This may be a constraint in the existing plants.

- **Availability of Washed Coal –** The assessed economic feasibility of emission control technologies relies on the abundant availability of washed coal. It is important to take view of the fact that without washed coal, most of the emission control technologies may result in increasing the cost burden on a utility. Ensuring availability of washed coal to the power plants is thus a major step to ensure effective implementation of emission control technologies.

3. Harmonization of the inter-ministerial functioning

- CERC tariff norms for central generating plants should be synchronised with BEE specified efficiency target; same harmonization by SERC's to be done for state owned plants; tariff to be structured in such a way that incentives are available if beyond BEE specified limit. Efficiency based tariff setting.

- Relaxation in net efficiency norms (of BEE and CERC) can be given to plants considering necessary deployment of emission control measures owing to decrease in net efficiency on complying with new norms. The relaxation would depend on the type of additional control measures deployed. Exhibit 28 illustrates impact on net efficiency from a baseline of 27.3% (in the form of multiplication factor):

- MoP, MoEF and Ministry of Coal should jointly evaluate the possibilities of following:

    i. Issue of washed coal availability to the sector

    ii. Plan for retirement of plants and coal linkage rearrangement

    iii. Plan to discourage setting up of new plants with less than 300 MW capacity

    iv. Means of financing the incremental investments. For energy efficiency measures alone, existing plants would require capital investment to the tune of 10 billion USD. National mission on clean coal or National Clean Energy Fund can play an active role to provide such incremental investments. A possible option through global carbon finance mechanisms can also be explored for feasibility such as taking support from International Climate Finance (of UK government) or World Bank's Partnership on Market Readiness program.

Exhibit 32: Relaxation in Net Efficiency Due to Emission Control Technologies

Emission control technology	Impact on net efficiency (Multiplication Factor)
Activated Carbon Injection	0.999
Upgrade to High Removal Efficiency (99.7%) ESP	0.988
Replacement of Existing ESP with Bag Filters	0.979
Semi Dry Flue Gas Desulphurization	0.987
Sea Water FGD	0.981
Low NOx burners	0.980
Selective Non Catalytic Reduction	0.996
Wet Flue Gas Desulphurization	0.983
Selective Catalytic Reduction	0.994
ROFA ROTAMIX	0.995
SO2 Sorbents	0.995
Electro Catalytic Oxidation	0.958

ACRONYMS

APC	Auxillary Power Consumption
ÀPH	Air Pre-Heater
BEE	Bureau of Energy Efficiency
BFP	Boiler Feed Pump
CEA	Central Electricity Authority
CEP	Condensate Extraction Pump
CERC	Central Electricity Regulatory Commission
CHP	Coal Handling Plant
CIL	Coal India Limited
COC	Cycles of Concentration
CO_2	Carbon Di-oxide
CPCB	Central Pollution Control Board
CSE	Centre for Science and Environment
DM	Di-mineralized
DGHR	Design Gross Heat Rate
DVC	Damodar Valley Corporation
EE	Energy Efficient
ESP	Electro Static Precipitator
FGD	Flue Gas De-sulphurization
FD	Forced Draft
GCV	Gross Calorific Value
GHR	Gross Heat Rate
GW	Giga Watts
gm/kWh	Grams per Kilo Watt Hour
Hg	Mercury
HHV	Higher Heating Value
HPH	High Pressure Heaters
HPT	High Pressure Turbine
ID	Induced Draft
IGEN	Indo German Energy Programme
IEA	International Energy Efficiency
IPT	Intermediate Pressure Turbine
GHG	Green House Gas
IPP	Independent Power Producers
KWh	Kilo Watts Hour
Kcal	Kilocalorie
kcal/kWh	Kilocalories per Kilo Watt Hour
Kg	Kilogram
LE	Life Extension
LHV	Lower Heating Value
LPH	Low Pressure Heaters
LPT	Low Pressure Turbine
L/G	Liquid to Gas Ratio

MDBFP	Motor Driven Boiler Feed Pump
MoP	Ministry of Power
MWhr	Mega Watts Hour
MT	Million Tonnes
MW	Mega Watts
NCV	Net Calorific Value
NPC	National Productivity Council
NHR	Net Heat Rate
NLC	Neyveli Lignite Corporation
NMEEE	National Mission for Enhanced Energy Efficiency
NTPC	National Thermal Power Corporation
OEM	Original Equipment Manufacturer
O&M	Operation & Maintenance
PA	Primary Air
PLF	Plant Load Factor
RLA	Residual Life Assessment
R&M	Renovation & Modernization
SCCL	Singareni Collieries Company Limited
SCR	Selective Catalytic Reduction
SDGHR	Station Design Gross Heat Rate
SDNHR	Station Design Net Heat Rate
SEC	Specific Energy Consumption
SH	Super- heater
SNCR	Selective Non - Catalytic Reduction
SONHR	Station Operating Net Heat Rate
SOGHR	Station Operating Gross Heat Rate
SPM	Suspended Particulate Matter
T	Tonnes
TDBFP	Turbine Driven Boiler Feed Pump
TSV	Turbine Stop Valve
VFD	Variable Frequency Drive
VSD	Variable Speed Drive

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