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Reduction of Greenhouse Gas Emissions through Adoption of Supercritical Technology in Coal Fired Thermal Power Plants in India

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Abstract

In India, emissions of greenhouse gases (GHGs) are increasing, due to the rise in energy demands to sustain economic growth. Coal is used as a dominant fuel in Indian thermal power plants, but the efficiency of these is low in comparison with prevailing international standards. As such, emissions of GHGs are much higher than is feasible to achieve. The adoption of Clean Coal Technologies (CCTs) – like the Supercritical (SC) steam cycle – for new capacity addition in Indian thermal power plants will increase the efficiency of the Indian grid. These technologies are more environmentally benign and would help meet increased energy demands. India has taken initiatives for the adoption of the technology, as explained in the 11th plan of the Planning Commission.

This thesis looks at the National Electricity Policy of India, and also reviews how coal power is useful for sustainable development. It further reviews technological growth of some of the CCTs which could be of relevance for the Indian power sector. Furthermore, it highlights the present status of Supercritical (SC) Technology in India. In addition, this study analysizes four hypothetical scenarios – in each five year plans until the 14th plan (2022-2027) – for Supercritical and Ultra Supercritical (USC) Technology penetration for coal based thermal power plants, and their impact on reducing GHGs emissions.

Finally, it is concluded from the study that SC and USC technology penetration would be helpful for reducing GHGs emissions. The hypothetical scenarios analyzed showed that up to 50% technology penetration for new capacity addition until 2027 would be helpful for reducing GHGs emissions. Although the results showed that there is reduction in GHGs emissions, India needs a greater percentage of technology penetration in order to reduce emissions of GHGs. This technology penetration depends upon policy support.

Keywords: Greenhouse gases (GHGs), Clean Coal Technologies (CCTs), India, Technology.

Executive Summary

Introduction

Along with an increase in energy demand for economic development and poverty reduction, there is an increase in greenhouse gas (GHGs) emissions from coal based thermal power plants in India. In order to sustain 8-10% economic growth, the supply of energy must increase. In India, coal is the dominant fuel, and the efficiency of Indian coal based thermal power plants is very low in comparison with international standards. By increasing energy efficiency, energy intensity (which is one of the virtual sources of energy) can be lowered. In order to increase the energy efficiency of Indian coal based thermal power plants, Clean Coal Technologies (CCTs) should be adopted. India has taken initiatives for the adoption of CCTs for increasing the efficiency of coal based thermal power plants through different policies.

Power Scenario and Clean Coal Technologies (CCTs) in India

The National Electricity Policy of India includes provision of "Power for all by 2012" at affordable cost. In order to fulfil the goals of the National Electricity Policy, a capacity addition programme for power plants is being proposed in the 11^{th} five year plan, as indicated in an Indian Planning Commission report.

Coal can also play an important role for sustainable development. As the demand for energy is increasing, coal will remain the main source of energy because of its affordability. It can be stored and transported easily.

There are ranges of CCTs which are suitable in an Indian context, such as Supercritical (SC), Ultra-Supercritical (USC), Pressurized Fluidized Bed Combustion (PFBC), Integrated Gasification Combined Cycle (IGCC) technology. However, India can not afford to have costly technology, and needs technologies which are mature. Supercritical (SC) Technology, one of the clean coal technologies, is mature and efficient.

In India, new plants are encouraged to adopt clean coal technologies, in order to increase the efficiency of the power plant and help achieve sustainable development. In India four new power plants based on Supercritical technology for power generation are under construction.

This study shows that adoption of supercritical technology would be beneficial for reducing GHGs emissions. In this study four hypothetical scenarios are analysed, starting from the 12^{th} plan until the 14^{th} plan. The results of the scenarios show that 50% technology penetration would achieve a reduction of 15.7% in the tonnes of CO_2 emitted.

Conclusion and Recommendations

This study focuses on Supercritical and Ultra-Supercritical technology penetration of up to 50% for new capacity additions. It can be concluded from the results that maximum reduction of the emissions would occur when the technology penetration is of 50%. Although a 15.7% reduction in GHG emissions until 2027 (with 50% technology penetration) does not have a large impact on climate change, there is nonetheless a reduction of greenhouse gas emissions with the adoption of clean coal technologies. With the increase in technology penetration, the environmental profile of the Indian power sector can be improved. Future technology penetration will depend on policy support and availability of finances.

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1 Introduction

1.1 Background

In India, Green House Gases (GHGs) emissions from coal fired thermal power plants increase with increasing energy demands for the economic growth. If the country is to eradicate poverty and to meet human development needs, India needs 8-10% economic growth over next 25 years. In order to sustain 8-10% economic growth, the demand for the energy must increase (GOI, 2006). So, one of the biggest challenge India is facing in terms of the quality of the conversion system for the energy production and how the energy produced could be provided to the users in a most sustainable way at reasonable cost (GOI, 2006). *The World Energy Outlook 2007: China and India Insights* is another report which reveals that the economic growth target of India between 2007-2012 is 9% in the 11th five year plan. For sustaining 8-9% economic growth, the corresponding growth of energy use is required, and coal is the key source of commercial energy. In India 70% of the electricity is produced from coal. Another sources of energy for meeting India's energy challenge and energy security is lowering of energy intensity of GDP growth by higher energy efficiency. India's energy intensity is about 0.16 kgoe. This energy intensity is lower than China (0.23 kgoe) and US (0.22 kgoe). By increasing energy efficiency to lower the energy intensity is equivalent to a virtual source of energy. The amount of energy saved by a user is greater than energy produced due to decrease in the energy losses due to production, transmission and distribution. The Planning Commission report of India reavled that by increasing energy efficiency and energy conservation it is possible to lower 25% of energy intensity (GOI**,** 2006).The level of economic growth of any country can be indicated by the level of per capita energy supply. In 2000, about 44.25% of total households (rural as well as urban) did not have access to electricity. India's commercial energy consumption in 2004-2005 was 348 Mtoe in 2004-2005. This demand of energy is very less in comparison to China (1100-1200 Mtoe) and U.S.A (2400-2500 Mtoe), .But this demand would be more than China's demand and one seventh of the U.S.A. (GOI, 2006).So, lowering energy intensity through increasing energy efficiency can be very useful for fulfilling the future energy needs of India.

In 2005, 39% of the primary energy demand of India was fulfilled by coal and it is projected that the share of the coal for electricity generation will increases by 71% by 2030. Indian power plants have low efficiency in comparison to the power plants in the world. Efficiency can be improved by constructing new power plants by adopting new technologies (IEA, 2007). Some Initiatives have been taken in India for the adoption of Clean Coal Technologies (CCTs) through different policies. The National Electricity Policy of India includes provision of adequate power supply at affordable cost to all the citizens by 2012. In order to fulfil the goals of the National Electricity Policy, a capacity addition programme of the power plants is being proposed in the 11^{th} five year plan as given in Indian Planning Commission report. One of the initiatives taken by the Ministry of Power for capacity addition programme is setting up of coal based Ultra Mega Power Projects, each with a capacity of 4000MW or above. The technology adopted by these projects is Supercritical Technology which is more benign environmentally (Ministry of Power,2007-2008).

The World Energy Outlook 2007: China and India Insights report describes the use of the coal as a primary source of energy in Indian thermal power plants. It also describes that due to inefficient thermal plants of India, the emissions of the CO_2 is increased. The major cause for the higher level of CO_2 emissions is due to the low efficiency of power stations as compared to international standards. According to the report, 943 grammes of CO_2 was emitted per kWh of electricity production in 2005 which is more than 50% higher than the average of the emissions of the CO_2 from the countries such as Australia, South Africa, Indonesia which depends on the coal for electricity production (IEA, 2007).

The coal Initiative report (Chikkatur,2008) explains that for Indian power sector advanced technologies are necessary for increasing the efficiency of the thermal power plants and increased efficiencies would be helpful for meeting the energy challenge of India at low cost and for the protection of the environment. These technologies would be helpful to reduce the emissions of the Green House Gases (GHGs).

1.2 Objective of the Study

This study would articulate that how the adoption of supercritical technology would be helpful in meeting the energy needs for economic growth as well as for reduction of Green House Gases (GHGs) emissions for improving the environmental profile of Indian power sector. Another, objective of this study is to analyze that how CCTs with special reference to Supercritical (SC) and Ultra-Supercritical (USC) technologies would be helpful for thermal power plants in Indian power sector for fulfilling the goal of sustainability in this sector.

1.3 Methodology

The literature for the reviewing was collected by accessing the websites of the Ministry of Power, Central Electricity Authority (CEA). The other sources for the collection of the literature was Electronic Library databases such as ELIN.Some of the information for the study was collected from the World Bank Database. The Energy and Resources Institute (TERI) intranet was also accessed for collecting data and research papers.

For total Installed capacity in 11th plan and capacity addition in 12th plan and beyond data was collected from National Electricity Plan published by Central Electricity Authority (CEA) from TERI library on 01.03.2009 and used in the third week of the February. This data is used for constructing hypothetical scenarios.

Data for Plant Load Factor (PLF) and data for Absolute Emissions and Net Generation for 500MW Units and less than 500MW was taken by accessing the CEA's website on 16.02.2009. PLF is used for calculating total emissions in each scenario. Absolute Emissions data and Net Generation data was used for calculating emission factor.

Some of the data such as Net Generation Efficiency for Supercritical technology, Ultra-Super Critical technology was provided by TERI.

All the documents, articles and research papers collected were reviewed to study the power scenario of India and technological growth of CCTs. Further, it is also reviewed that how coal power can contribute for sustainable development. This study also provides information about the status of Supercritical Technology in India.

Finally, three different technology penetration scenarios have been analyzed in comparison to scenario in the absence of Supercritical and Ultra-Supercritical technology penetration with scenarios for Supercritical (SC) and Ultra-Supercritical Technology penetration in each five year plans till 14th Plan (upto March 2027).

1.4 Limitations

The figures for the capacity addition in each five year plan were taken from National Electricity plan published from Central Electricity Authority (CEA), under the Ministry of Power, India. It is the agency which is responsible for power planning of the country. The figures are based on the demand projections for 8% GDP growth as planned by planning commission, Government of India.

One of the main limitations of this study is that figures for installed capacity vary in different sources and it also varies in this study wherever they are used. Other limitation of this study is that it does not cover the analysis of all the strategies which are helpful for achieving the goal for power for all by 2012. In this study, only analysis about technology upgradtion is done which is covered under power generation strategies and transmission strategies to achieve the target of power for all by 2012.

Another limitation of this study is that scenarios generated are hypothetical and the percentage of technology penetration is assumed according to the percentage given by working group for power, for 11^{th} plan report that supercritical technology penetration during 11^{th} plan is 18% and it is forseen that this technology penetration would increase to 50-60% in the coming future. These hypothetical scenarios are used to calculate the reduction of emissions of GHGs by Supercritical technology and Ultra Supercritical technology. The scenarios only include coal based generating capacity planned for introduction in India. These scenarios does not include large hydro and nuclear generating capacity addition planned for India.

2. Power Scenario of India

2.1 National Electricity Policy

Power is the key driver for rapid economic growth and poverty alleviation. India has a target to provide 'power for all' by 2012.National Electricity Act, 2001 provides framework for the efficient development of the Indian power sector. The act requires the formulation of the National Electricity Policy and National Electricity Plan. The National Electricity Policy has been formed by Central Government in consultation with Central Electricity Authority (CEA) and State Governments. Central Electricity Authority (CEA) was responsible for the formulation of National Electricity Plan (Central Electricity Authority,2007).

The National Electricity Policy seeks to fulfil the following objectives:

- Access to Electricity for all households.
- Demand of power to be fully met by 2012.
- Reliable and quality power supply in an efficient manner and at reasonable rates.
- Per capita availability of electricity to be increased to over 1000 kWh by 2012.
- Protection of Consumer's interests.

The National Electricity Policy also addresses some of the issues such as rural electrification, generation of electricity, technology development and research and development, energy conservation, environmental problems and protection of consumer's interests (CEA, 2007).

2.2 Power Scenario till 2027

The power scenario on all India basis at the end of the 10th Plan was is given in Table 2-1. Total Installed capacity for power production from different sources of power such as Hydro, Thermal; Nuclear Renewable was 70 172MW at State level. On the other hand, the total installed capacity for private and central sector was 17 036 MW and 45 121MW respectively. We can see from Table-2-2 the Total Installed Capacity on 28-02-2009 capacity addition for fulfilling the goal of the National Electricity Plan (CEA, 2009).

Table 2-1. Installed Capacity (At the end of 10th plan)(MW)

Sector	Hydro	Thermal				Nuclear	Renewable Energy Sources	Total
		Coal	Gas	Diesel	Total			
State	25862	39090	3640	8605	43334.4	0.0	976	70172
Private	1230	4242	4183	597	9022	0.0	6785	17036
Central	7562	27760	5899	0.0	33659	3900	0.0	45121
Total	34654	71091	13722	1202	86015	3900	7761	132329

Source: CEA, 2009

Table 2-2 Installed Capacity on 28.02.2009 (MW)

Sector	Hydro	Thermal				Nuclear	Renewable Energy Sources	Total
		Coal	Gas	Diesel	Total			
State	27056	42125	3945	603	46672	0.0	2248	75976
Private	1230	5241	4566	597	10404	0.0	10995	22629
Central	8592	29760	6639	0.0	36399	4120.0	0.0	49111
TOTAL	36878	77127	15149	1200	93475	4120.0	13242	147715

Source: CEA, 2009

In order to fulfil the goals of the National Electricity Policy, a capacity addition programme has been proposed in 11th five year plan (2007-2012) as described in Indian Planning Commission report. During 11th plan, coal based generation capacity addition would be 52 904MW. At the beginning of the 11th plan Total Installed capacity as on 31-03-2007 was 71 121MW. The share of the private sector out of the total addition capacity would be 5 460MW while capacity addition by central and state sector for coal based thermal plants would be 24 310MW and 23 135MW respectively (CEA,2007). So, it is projected that total installed capacity at the end of the 11th plan would be 124 025MW.

The total capacity addition projects for coal based thermal power plants during 12th plan would be 83 640MW. During 12th plan a large number of hydro and nuclear projects would be taken for fulfilling the energy needs of the country. The main cause for large number of hydro and nuclear plants is to reduce the green house gas emissions from thermal power plants. During 12th plan same capacity addition as given in 12th plan is recommended for 13th plan and 14th plan (CEA, 2007).

About 18% of the total coal based feasible capacity addition during 11th plan is Supercritical technology based plants. These projects are under planning stage during 11th plan and would yield results in 12th plan. According to the working group for power for 11th plan report it is envisaged that 50-60% of the capacity addition for coal based plants would be Supercritical technology (SC) (Ministry of Power, 2007).

For this study, Total Installed Capacity (MW) in scenario without supercritical and ultra supercritical technology penetration is taken as on the 31-03-2012 is 124 025MW. For 12th, 13th and 14th plan the capacity addition is 83 640MW in each five year plan. Table 2-3 presents the scenario taken without Supercritical and Ultra-Supercritical technology penetration for this study.

Table 2-3 Total Installed Capacity (MW) in the Scenario without Supercritical and Ultra-Supercritical Technology Penetration

	As on 31-03-2012	Beginning of 12th Plan (2012-2017)	Beginning of 13th Plan (2017-2022)	Beginning of 14th Plan (2022-2027)
Capacity addition in each five Year	Sub-Critical 124025 Nil	Sub Critical- 207665 Nil	Sub Critical- 291305 Nil	Sub Critical- 374945 Nil
Total Installed Capacity	124025	207665	291305	374945

Source: CEA, 2007

2.3 Plant Load Factor

2.3.1. Plant Load Factor

"The Plant Load Factor (PLF) is an important measure of the operational efficiency of thermal power plant" (Ministry of Power, 2005). It can be seen from Table 2-4, the Plant Load Factor (PLF) improvement from 2002 to 2007 (10th Plan). It can also be seen the improvement in PLF for the year 2007 to 2009 (11th plan). With the increase in the installed capacity and operational experience, Plant Load Factor (PLF) has reached 78% in 2007.It is expected to increase further with the increase in the capacity addition

Table 2-4 Plant Load Factor improvement from year 2002 to 2007

Year	Target (%)	Actual (%)
2002-2003	70	72
2003-04	72	73
2004-05	73	74
2005-06	74	74
2006-07	76	77
2007-08	77	78
2008-09	79	77

Source: http://www.powermin.nic.in/JSP_SERVLETS/internal.jsp#

The projected growth taken for this study is given in Table- 2-5

Table 2-5 Plant Load Factor (PLF) growth (%) till 2027

	As on 31-03-2012	12th Plan (2012-2017)	13th Plan (2017-2022)	14th Plan (2022-2027)
Plant Load Factor	79%	80%	81%	82%

2.4 Coal Power and Sustainable Development

The report *Coal: Delivering Sustainable Development* by World Coal Institute highlights about the role of the coal industry for sustainable development. The report explains about the increase in the energy demand in developing countries for economic growth and poverty allevation.It further explains that coal will play a major role for meeting the future energy needs. One of the main reason regarding the role of the coal for meeting future energy needs is its affordability. Coal is a cheaper per energy unit in comparison to other fuels. Some of the other reason's for it's use is stable price in comparison to oil and natural gas, it's widespread availability, easy and safe to transport (WCI, 2007).

The report also talks about the programmes that China and India has started to improve the performance of their coal fired thermal power plants by adopting clean coal technologies. Further, it also talks about a major rehabilitation programme for coal fired power in India funded by the Global Environment Facility. This programme allows India to obtain their energy demands for their development at the same time fewer GHGs (WCI, 2007).

A position paper by Coal Industry Advisory Board (CIAB) prepared for World Summit on Sustainable Development also describes about the role of the coal for sustainable development. This paper defines sustainable development as "development that meets the needs of the present generation without undermining the capacity of the future generations to meet their needs". This report describes about the use of the coal in consistent with sustainable development (IEA, 2003).

The paper explains that according to CIAB recommendations, "coal will play important role in energy systems that support sustainable development for foreseeable future" (IEA, 2003).

Coal Industry Advisory Board (CIAB) survey explains about the activities of the coal producers, electricity generators for sustainable development. For example, major coal producers like BHP Billiton has taken initiatives at national level as well as at international level for the coal industry to move in sustainable direction. Health, safety, environment and community management standards developed are being implemented in all the mineral production sites. BHPB is also involved with number of social responsibility programs in South Africa and other regions. HIV/AIDS prevention and remediation is one of the main programmes run by BHPB in South Africa (CIAB, 2002).

3 Technological Growth

3.1 Pulverised Technology in India

In India, first Pulverised Coal (PC) boilers was established in 1950. PC boilers were used at temperature and pressures lower than the critical point of water for producing steam and electricity generation. This technology is known as Sub critical Pulverised Coal Technology. The larger units of different sizes were imported from the U.S. and U.S.S.R in late 1960s and early 1970s. In 1960s indigenous manufacturing industry for heavy electrical equipment was established in India. Bharat Heavy Electrical Limited (BHEL) was established for the management of manufacturing industry for the coordinator of the manufacturing of power plant equipment in 1973. BHEL is the main indigenous manufacturer of power plants in India. Approxmatiely 60% of the new power plants in India were manufactured by BHEL between 1970 and 1980. Approximately, all the power plants were BHEL manufactured during 1981-1991. BHEL 500MW Sub Critical PC units are the existing standard for coal power technologies in India (Chikkatur, 2008). Table-3-1 shows that size and vintage of the coal based power plants in India

Table 3-1Size and Vintage of coal based units in India

Age	Installed Capacity (up to end of 2005)					Installation year
Unit Size	< 100	100/110/120/ 140/150 (MW)	200/210/250 (MW)	500 (MW)	Total	
< 5 years		490	3165	4500	8155	2001-2005
5-10 years	75	740	5280	2000	8095	1996-2000
10-14 years	205	120	8060	3500	11885	1991- 1995
15-19 years	332	890	8370	5500	15092	1986-1990
20-24 years	540	1670	8270	500	10980	1981-1985
25-29 years	120	2670	3290		6050	1976-1980
30-34 years	460	2710			3170	1971-1975
35-39 years	2210	720			2930	1966-1970
40+ years	1466	430			1896	< 1965
Total	5408	10410	36435	16000	68253	

Source: Chikkatur and Sagar, 2007

In India," the average net efficiency of the entire fleet of coal power plants" in India is approximately 29%. The units which are less than capacity of 200MW is having very worst efficiencies and low Plant Load Factor. The 500MW Subcritical units which are considered to be the best plants are operating with a net efficiency of approximately 33%. On the other hand, if we compare it with the 50 U.S. most efficient coal based plants, the average net efficiency is 36 %(Chikkatur, 2008). Some of the main causes for the poor efficiency of India's power plants are poor quality of coal, low PLF, degradation of the power plants due to age and awful conditions of grid. Other main causes for the poor efficiency of Indian power plants are lack of "proper operation and maintence of the plants, ineffective regulations, and lack of incentives for efficiency improvements" (Khanna and Zilberman, 1999).

3.1.1 Environmental Impacts of coal power plants

Direct impacts are produced due to construction of the coal power plants. These impacts include flu gas emissions of particulates; nitrous oxide (NO_X), sulphur oxides (SO_X). Other impact includes water pollution of the local streams, rivers and groundwater. Noise pollution produced during operation and degradation of land which is used for storing fly ash is some of the impacts to the environment. Emissions of Green House Gases (GHGs) such as CO_2 are also one of the important challenges for Indian coal power plants (Chikkatur, 2008). Coal based CO_2 emissions were 70% in 2005 in India (Maryland *et al.,* 2007)

Indirect impacts are produced mainly due to coal mining. Some of the indirect effects associated with coal power plants are degradation and destruction of land, water, forests and habitats. Due to mining operation, resettlement and rehabilitation is also one of the main impact due to coal power plants. For increasing the efficiency of Indian power plants advanced technologies are required which would be useful for reducing the environmental impacts and CO_2 emissions from coal based power plants. Indian power plants are based on sub critical PC technology. There is improvement in the coal utilization technologies worldwide for the need for higher efficiency and improving local environment. Today range of advanced technologies is present which are cleaner and efficient than conventional PC technology (Chikkatur, 2008).

3.2 Clean Coal Technologies

According to Chikkatur (2008), some of the clean coal technologies relevant in Indian Context are:

- Supercritical Technology(SC)
- Ultra-Supercritical Technology (USC)
- Pressurized Fluidized Bed Combustion(PFBC)
- Integrated Gasification Combined Cycle(IGCC)

3.2.1 Supercritical Technology

"Supercritical is a thermodynamic expression describing the state of a substance where there is no clear distinction between the liquid and the gaseous phase (i.e. they are a homogenous fluid). Water reaches this state at a pressure above 22.1 M Pa. The efficiency of the thermodynamic process of a coal-fired power describes how much of the energy that is fed into the cycle is converted into electrical energy. The greater the output of electrical energy for a given amount of energy input, the higher is the efficiency. If the energy input to the cycle is kept constant, the output can be increased by selecting elevated pressures and temperatures for the water-steam cycle" (Sharma,"n.d.").

"The steam cycle operating at steam pressure above 22.1 M Pa or 225.36 ate (atmosphere absolute) is called supercritical steam cycle". The density of water and steam is same at this pressure. Therefore, due to same density of water and steam; there is no need for a boiler drum that separates steam from water. The once through boiler is required and it is helpful for increasing the efficiency of the steam cycle (TERI, 2006). Supercritical plants require less coal per MWh. Due to less use of coal per mega watt-hour, there are less emissions of carbon dioxide per mega watt hour. This would result into higher efficiency and lower fuel cost per megawatt hour of electricity.

Although this technology is useful for Indian context but due to some technical and operator experience, there were some problems associated such as boiler tube leaks and corrosion due to high temperature (Chikkatur and Sagar, 2007).

3.2.2 Ultra Supercritical Technology

In Ultra-Supercritical Technology, the temperature and pressure is higher than supercritical technology. Temperature and pressure parameters used for USC technology is 1050°F and 4500psi (311bar/593°c) (IEA, 1998). Maintenance of equipment reliability and operational flexibility are some of the challenges for USC technology (Ghosh,2005). The efficiency range of the plants using Ultra-Supercritical technology are supposed to be in the range of 46-48 % (Batoo, 2007).

3.2.3 Pressurised Fluidized Bed Combustion

In Pressurized fluidized bed combustion (PFBC) technology, PFB combustor and hot gas clean-up system is used instead of the conventional combustion chamber of the gas turbine. The products of the combustion pass "through gas turbine and the heat recovery steam generator. The system is called combined cycle". This system is capable of giving generation efficiency 5%-6% higher than sub-critical steam cycle plants. This system is a strong competitor for Ultra-super critical system (TERI and Office of the Principal Scientific Adviser, 2006). The combustion temperature in PFBC is between 800°c to 900°c.The main advantage of this temperature is that Kn_{ox} formation is less than Pulverised Coal Combustion (PC) technology. One of the main disadvantages of PFBC is that it produces more waste in comparison to a PC plant with Flue Gas Desulphurisation (FGD) (NRC, 1995).

3.2.4 Integrated Gasification Combined Cycle

In Integrated Gasification Combined Cycle (IGCC),"the hot raw gas from the gasifier is cooled by generating steam through heat recovery steam generation (HRSG). This steam is integrated in the combined cycle with the steam produced from HRSG downstream of the gas turbine. Part of the steam produced is used in the gratifier. This cycle is known as IGCC". Currently, the plants using coal- fired IGCC exists in Europe and United States. In 1993, in Netherlands, Beggenum, one of the first IGCC plant with an electrical output 250 megawatts was commissioned. Some other plants using this technology are in Spain and United States. Presently, this technology coupled with Carbon Capture and Sequestration (CCS) is considered to be the most promising for eliminating coal-plant CO_2 emissions (Batoo, 2007). According to Choker and Sager (2007), before the deployment of the CCS technology in developing countries, it would be first explored in industrialised countries. Many industrialised countries, Australia, United States (U.S.) and European Union are exploring various aspects of CCS (Chikkatur and Sagar, 2007).

In IGCC process, the sulphur present in coal can be captured as hydrogen sulphide and concentrated hydrogen sulphide can be recovered as sulphuric acid. This acid can be sold as commercial by product. The ash of the gasifier is recovered as glassy slag. This slag can be used as construction material (NCC, 2001). Higher fuel conversion efficiency in IGCC is helpful for reducing CO_2 emissions (Ghosh, 2005). Some of the other disadvantages of this technology is high capital cost. This technology is not yet matured. The plant of the IGCC is more complex than a chemical plant (Chikkatur and Sagar, 2007).

3.3 Status of the Clean Coal Technologies relevant in Indian context

The present status of some of the CCTs in India and worldwide is given in Table -3-2.It also shows the level of the maturity of the technology. The comparison of the net efficiency of the technology in India and worldwide can also be seen in the table. The value of the Net Efficiency is less in India in comparison to other countries because in India efficiency is based on High heating value (HHV) of the Input fuel. Efficiencies based on High heating value are less than based on Low heating value (Chikkatur and Ambuj, 2007).

Table 3-2 Status of the clean coal technologies relevent in Indian context

Technology	Supercritical Technology	Advanced Ultra supercritical technology	Circulating FBC	Pressurized Fluidized-bed FBC (PFBC)	Integrated Gasification Combined Cycle IGCC
Status in India	Sipat and Barh plants under construction	None	Surat Lignite and Akrimota Lignite power Stations	R&D, pilot scale plant.	R&D, pilot scale plant. Plans for demonstration plant.
Worldwide	Europe (Denmark, Netherlands, Germany); Japan, U.S., China, Canada	Netherlands, Denmark, Japan	U.S., Europe, Japan, China, Canada	Japan, Demo plants in Europe, U.S.	A 6 MW unit in Europe, 100 MW demo plant in U.S. Widespread use for chemicals production and poly generation
Level of Maturity	Commercial	Commercial/demonstration	Commercial	Demonstration	Gasifier – commercial; IGCC – demonstration
Net Efficiency in India	35.00%		30-33%	38.00%	40%
Net Efficiency Worldwide	39-41%	40-44%	34-40%	40.00%	44-48%

Source: Chikkatur and Ambuj, 2007

3.4 Present status of supercritical technology implementation in India

The report *clean coal technology transfer to India and China (2007*) explains that India cannot afford to invest in new inventions of clean coal technologies which need time and money. India needs CCTs that are proven and supercritical technology is one of the mature and cheaper technologies than other technologies like Integrated Gasification Combined Cycle (IGCC), Fluidized Bed Technology (FBC) and Ultra-Supercritical (USC) Technology. This technology is more efficient and would be helpful for the reduction of the pollution. Finally; the report concluded that supercritical technology is cleaner technology than Pulverised Coal technology. It is cheaper than the IGCC and FBC. Although it is less efficient than IGCC and FBC technology. It is also explained in the report; India cannot afford to have costly technologies like IGCC and FBC (Batoo, 2007).

The report by Ministry of Environment and Forest, Ministry of Power and Bureau of Energy Efficiency (GOI, 2007) also explains that new plants in India are encouraged to adopt CCTs technologies for increasing the efficiency of the power plant for sustainable development. It reveals that four new plants based on the Super Critical Technology for power generation are under construction (GOI, 2007). Table- 3-3 shows the list of the proposed thermal projects based on supercritical technology in India.

Table: 3-3 Proposed Supercritical Projects in India

S.no.	Project	Implementing Agency	State	Capacity (MW)	Status
1	Sipat Stage I	NTPC	Chhattisgarh	3χ660	Main Plant order placed with Korea's Doosan Heavy Industries
2	Barh Stage I	NTPC	Bihar	3χ660	Main Plant order placed with Russia's Techno Prom Export
3	Barh Stage II	NTPC	Bihar	2χ660	BHEL sole bidder for equipment order
4	North Karapura	NTPC	Jharkand	3χ660	Bidding for boiler and turbines under way
5	Lara	NTPC	Chhattisgarh	5χ800	Planning and investigation stage
6	Darlipalli	NTPC	Orissa	4χ800	Planning and investigation stage
7	Mundra UMPP	Tata Power Company	Gujarat	4000	Order for equipment placed with Japan-based Toshiba
8	Susan UMPP	Reliance Power	Madhya Pradesh	4000	Selection process for

S.no.	Project	Implementing Agency	State	Capacity (MW)	Status
					equipment provider yet to begin
9	Krishnapatnam	Reliance Power	Andhra Pradesh	4000	Selection process for equipment provider yet to begin
10	Tilaiya UMPP	SPV	Jharkhand	4000	Bidding process for developer initiated
11	Tadri UMPP	SPV	Karnataka	4000	Alternative location (Bhavnagar in Gujrat) under construction
12	Girye UMPP	SPV	Maharashtra	4000	Alternative location (Dighe in Maharastra)
13	Sundergrah UMPP	SPV	Orissa	4000	Project site yet to be finilised
14	Akaltara UMPP	SPV	Chhatisgarh	4000	Progress stalled with state government demanding 12 percent free power
15	Cheyyur UMPP	SPV	Tamil Nadu	4000	Alternative location suggested ; CEA to evaluate site and submit report
16	Udangundi	TNEB-BHEL JV	Tamil Nadu	2χ800	MOU signed for JV between TNEB and BHEL
17	Krishnapatnam	AP Genco	Andhra Pradesh	2χ800	Rebidding for boilers and turbines under way
18	Meja	UPRVUNL-NTPC JV	Uttar Pradesh	2χ660	MOU signed for JV between UPRVUNL and NTPC

Source: Dewal, 2008

4. Supercritical Technology Penetration Scenarios for Green House Gases (GHGs) Emissions Reduction in Coal Based Thermal Power Plants

Scenarios assumed for this thesis work are hypothetical. According to working group report, for 11th five year plan, 18% of the total coal based capacity addition is Supercritical Technology Units. It is envisaged by the working group that capacity addition for 12th plan would increase to 50-60% based on Supercritical Technology (Ministry of Power, 2007).

So, it was assumed for this study that there would be increase in the capacity addition in next five year plans as the number of design and manufacturing facilities are being set up in India.

This is a simple calculation exercise for calculating that how much Green House Gases (GHGs) emissions reduction are possible through penetration of advanced clean coal technologies (CCTs) such as Supercritical (SC) and Ultra Supercritical Technologies (USC) for coal based thermal power plants for each hypothetical scenario.

4.1 Method used for Calculating the Emissions Reduction

The steps involved for the calculations are as follows:

- First step involves the calculation of the emission factors for Sub-critical, Super-Critical and Ultra-Super Critical Technology.
- For each period and scenario, weighted average emission factor is calculated.
- Total emissions for each period and scenario is calculated based on weighted average emission factor and the total generation of electricity.
- Total emissions for each period and scenario is calculated based on weighted average emission factor and the total generation of electricity.
- Emission reduction is the difference of emissions between a particular scenario and the scenario without Supercritical and Ultra –Supercritical Technology Penetration (with sub critical technology only).

4.2 Four Scenarios:

- Scenario- I (Absence of Supercritical and Ultra Supercritical Capacity)
- Scenario- II (Supercritical and Ultra Supercritical Technology Penetration)
- Scenario- III (Supercritical and Ultra Supercritical Technology Penetration)
- Scenario- IV (Supercritical and Ultra Supercritical Technology Penetration)

4.2.1 Scenario – I (Absence of Supercritical and Ultra Supercritical Capacity)

In this scenario, there is no major supercritical technology penetration for improving environmental and social profile of coal based thermal power plants. This scenario incorporates the existing government plans and policies. In this scenario the installed capacity is based on sub-critical technology. However, it is expected that all future capacity additions would be based on plants having efficiency equal to that for present 500MW plants. In India the standard coal based plant is 500MW with Sub-Critical Technology (Chikkatur, 2008).

In this scenario, the total coal based power generation capacity is 124 025MW as on 31-03-2012. The projected total capacity addition projects for coal based thermal power plants during 12th plan would be 83 640MW.Same capacity addition as for 12th plan, is recommended for 13th plan and 14th plan. Table- 4-1 shows the Total Installed Capacity in Scenario-I (CEA, 2007). Under this scenario – I, it was assumed that there is no supercritical additions. The main reason for this assumption is that most of the supercritical plants which are planned in India in the 11th five year plan, their outcome would be seen in the 12th plan .So, it was assumed that Supercritical and Ultra-Supercritical Technology Penetration would be seen for the 12th Plan and further five year plans.

Table 4-1 Total Installed Capacities (MW) in Scenario- I

	As on 31-03-2012	Beginning of 12th Plan (2012-2017)	Beginning of 13th Plan (2017-2022)	Beginning of 14th Plan (2022-2027)
Capacity addition in each five Year	Sub-Critical 124 025 Nil	Sub Critical- 207 665 Nil	Sub Critical- 291 305 Nil	Sub Critical- 374 945 Nil
Total Installed Capacity	124 025	207 665	291 305	374 945

4.2.2 Scenario - II

In this scenario there is very less penetration of supercritical and ultra-super critical technology for increasing the environmental profile of Indian thermal power plants. This scenario assumes that 70% of the capacity addition would be sub-critical whereas, for supercritical technology, the capacity addition would be 20% and 10% for ultra-supercritical technology for each five year plan till 14th plan (2022-2027) respectively. Table- 4-2 presents the level of the technology penetration in each five year plan in scenario-II.

Table 4-2 Technology Penetration Level (MW) in Each Five Year Plan in Scenario- II

	As on 31-03-2012	12th Plan (2012-2017)	13th Plan (2017-2022)	14th Plan (2022-2027)
Capacity addition in each five Year	Sub-Critical 124 025 Super-Critical Nil Ultra Supercritical Nil	Sub-Critical 58 548 Super-Critical 16 728 Ultra Supercritical 8 364	Sub Critical 58 548 Super Critical 16 728 Ultra Supercritical 8 364	Sub Critical 58 548 Super- Critical 16 728 Ultra Supercritical 8 364
Total Installed Capacity	124 025	207 665	291 305	374 945

4.2.3 Scenario- III

This scenario assumes a higher supercritical and ultra-super critical technology penetration in comparison to scenario-III. In this scenario, 60% of the technology would be sub-critical in each five year plan. On the other hand, for supercritical and ultra supercritical for each five year plan the technology penetration is 25% and 15% respectively. The technology penetration level in this scenario in each five year plan till 14th plan is shown in Table- 4-3.

Table 4-3 Technology Penetration Level (MW) in Each Five Year Plan in Scenario-III

	As on 31-03-2012	12th Plan (2012-2017)	13th Plan (2017-2022)	14th Plan (2022-2027)
Capacity addition in each five Year	Sub-Critical 124 025 Super-Critical Nil Ultra Supercritical Nil	Sub-Critical 50 184 Super-Critical 20 910 Ultra Supercritical 12 546	Sub Critical 50 184 Super Critical 20 910 Ultra Supercritical 12 546	Sub Critical 50 184 Super- Critical 20 910 Ultra Supercritical 12 546
Total Installed Capacity	124 025	207 665	291 305	374 945

4.2.4 Scenario- IV

This scenario involves higher supercritical and ultra-supercritical technology penetration in comparison to scenario-I. In this scenario, supercritical technology penetration is 30% and ultra-supercritical technology penetration is 20%.The sub critical technology assumed in this scenario is 50%. The technology penetration in each five year plans for scenario-IV is given in Table 4-4.

Table 4-4 Technology Penetration Level (MW) in Each Five Year Plan in Scenario- IV

	As on 31-03-2012	12th Plan (2012-2017)	13th Plan (2017-2022)	14th Plan (2022-2017)
Capacity addition in each five Year	Sub-Critical 124 025 Super-Critical Nil Ultra Supercritical Nil	Sub-Critical 41 820 Super-Critical 25 092 Ultra Supercritical 8 364	Sub Critical- 41 820 Super Critical 25 092 Ultra Supercritical 8 364	Sub Critical- 41 820 Super- Critical 25 092 Ultra Supercritical 8 364
Total Installed Capacity	124 025	207 665	291 305	374 945

5. Calculation of total emissions and emission reduction under different scenarios till 2027

Table 5-1 and Table 5-2 present Net generation and Absolute emission for 500MW units and less than 500MW units for year 2006-2007 (www.cea.nic.in).

Table 5-1 Net Generation (GWh) and Absolute Emissions (t CO2) for 500MW units (2006-2007)

S.No.	Plant Name	Net Generation (GWh)	Absolute Emissions(tCO2)
1.	Talcher	22356	21238394
2.	Rihand	15055	14343401
3.	Vindh chal	9289	9044126
4.	Trombay	3828	3,788,003
5.	R-gundem	3224	3102701
6.	Simhadri	7620	7204544
	Total	61372	58721169.5

Source: http://www.cea.nic.in/planning/c%20and%20e/Government%20of%20India%20website.htm

Emission Factor = Absolute Emissions / Net Generation

= 58721169.5/61372000

= 0.9568 tCO2/MWh for Sub-Critical 500MW units

Table 5-2 Net Generation (GWh) and Absolute Emissions (tCO2) for all power stations (2006-2007)

S.No	Plant Name	Net Generation (GWh)	Absolute Emissions (t CO_2)
1	PATRATU	526	971 969
2	BARAUNI	27	62 108
3	KAHALGAON	6031	6072998
4	TENUGHAT	2389	3173861
5	JOJOBERA IMP.	2443	2663902
6	CHANDRAPURA	1876	2562831
7	DURGAPUR	1827	2474807
S.No	Plant Name	Net Generation	Absolute Emissions

S.No	Plant Name	Net Generation (GWh)	Absolute Emissions ($t\ CO_2$)
8	BOKARO B	2957	4117232
9	MEJIA	5610	5984607
10	TALCHER	3189	3909082
11	I.B.VALLEY	2976	3047575
12	BANDEL	1380	1845340
13	SANTALDIH	1245	1986454
14	KOLAGHAT	6794	9851395
15	BAKRESWAR	4470	5549057
16	D.P.L.	1594	2316074
17	NEWCOSSIPORE	439	895270
18	TITAGARH	1676	2056613
19	SOUTHERN REPL.	919	1100299
20	BUDGE BUDGE	4015	3993139
21	FARAKKA STPS	10638	10479538
22	MUZAFFARPUR	0	0
23	BOKARO A	0	0
24	MULAJORE	0	0
25	SAGARDIGHI TPP	0	0
26	BONGAIGAON	0	0
27	BADARPUR	4879	5534896
28	I.P.STATION	805	1364390
29	RAJGHAT	558	769221
30	F_BAD EXTN.	523	1005556
31	PANIPAT	8963	10536475
32	GNDTP(BHATINDA)	1966	2527157
33	GHTP (LEH.MOH.)	3140	3185309
34	ROPAR	8952	9967825
35	KOTA	7398	8061323
36	SURATGARH	9270	9553928
37	OBRA-A	4646	6765032

		(GWh)	(t CO_2)
38	PANKI	804	1190519
39	H_GANJ B	644	989669
40	PARICHA	1906	3045717
41	ANPARA	11288	11622726
42	SINGRAULI STPS	13627	13366504
43	UNCHAHAR	6942	6918063
44	DADRI (NCTPP)	6517	6407235
45	TANDA	3114	3661485
46	YAMUNANAGAR TPP	0	0
47	UKAI_Coal	4383	5070801
48	GANDHI NAGAR	4276	5354254
49	WANAKBORI	10050	10687365
50	SIKKA REP.	1407	1819937
51	TORR POWER SAB.	2965	3745552
52	SATPURA	6687	8977281
53	KORBA-EAST	2978	3487324
54	KORBA-WEST	5387	6266451
55	AMAR KANTAK	1100	1822273
56	SANJAY GANDHI	4874	6183373
57	KORBA STPS	15472	14839026
58	VINDH_CHAL STPS	9549	9296292
59	NASIK	5936	7610198
60	KORADI	6123	7704177
61	K_KHEDA II	5989	6508214
62	PARAS	382	525693
63	BHUSAWAL	2885	3201514
64	PARLI	4142	4637269
65	CHANDRAPUR_Coal	12094	12340356
66	DHANU	4118	3852319
67	RAIGARH TPP	0	0
S.No	Plant Name	Net Generation	Absolute Emissions

		(GWh)	(t CO_2)
68	K_GUDEM	4361	4955127
69	K_GUDEM NEW	3337	3299153
70	VIJAYWADA	9074	8954414
71	R_GUNDEM – B	298	346321
72	RAYAL SEEMA	2961	2908440
73	R_GUNDEM STPS	18989	18271968
74	RAICHUR	10540	11177703
75	TORANGALLU IMP	1913	1389202
76	ENNORE	1230	1744354
77	TUTICORIN	7446	7647325
78	METTUR	6253	6519863
79	NORTH CHENNAI	4468	4559359
80	NELLORE	0	0
	Total	340628	377290081

Source: http://www.cea.nic.in/planning/c%20and%20e/Government%20of%20India%20website.htm

Emission Factor (Sub-critical) = Absolute Emissions (t CO_2) / Net Generation (MWh)

= 377,290,081/ 340,628,000

= 1.1076 (t CO2)/ MWh

It can be seen from Table- 5-2, emission factor for Sub-Critical plant, Supercritical and Ultra -Supercritical Technology based units of 500MW and above for year 2006-2007.

Table 5-2 Emission factor for Sub-Critical, Super-Critical and Ultra Super Critical technology based units of 500MW and above for year 2006-2007

S.No.	Unit Rating(MW)	Net Generation Efficiency (Excluding Auxiliary Power Consumption)	Emission Factor (Ef) (t CO_2 /MWh)
1	Sub-Critical (All as on March, 2007)	-	Eve - 1.1076
2	Sub-Critical (500MW)	34.58%	Esc- 0.9568
3	Super-Critical (660MW)	35.51%	Esc- 0.9317
4.	Ultra Super-Critical(800MW)	36.59%	E_{USC}- 0.8978

5.1 Weighted Average Emission Factor at end of each plan year

Table 5-3 presents the weighted average emission factor for four scenarios.

Table 5-3 Weighted Average Emission Factor for four scenarios

	As on March 2012	March, 2017	March, 2012	March, 2027
With Sub-Critical	1.1076	1.0468	1.0209	1.0066
Scenario-I	1.1076	1.0424	1.0134	0.9983
Scenario- II	1.1076	1.0407	1.0122	0.9964
Scenario- III	1.1076	1.0029	0.9583	0.9336

5.2 Total Emissions of Green House Gases (GHGs)

Table 5-4 represents the total emission of Green House Gases in each five year plan. The formula used for calculating total emissions of green house gases (GHGs) is given in appendix- 1.

Table 5-4 Total emissions of Green House Gases (GHGs) (tCO_2)

	At the end of 11th Plan (March, 2012)	At the beginning of 12th Plan (March, 2017)	At the beginning of 13th Plan (March, 2022)	At the beginning of 14th Plan (March, 2027)
Scenario- I Sub-Critical- 100% Supercritical- Nil Ultra-Supercritical- Nil	950 655 971	1 611 908 356	2 289 391 210	2 983 104 534
Scenario- II Sub-Critical- 70% Supercritical -20% Ultra-Supercritical- 10%	950 655 971	1 517 021 732	2 094 681 340	2 688 726 306
Scenario-III Sub-Critical-60% Supercritical-25% Ultra-Supercritical- 15%	950 655 971	1 514 547 694	2 092 200 960	2 683 609 026
Scenario-IV Sub-Critical-50% Supercritical-30% Ultra-Supercritical- 20%	950 655 971	1 459 536 737	1 980 790 535	2 514 469 477

It can be seen from Figure 5-1, the total installed capacity till 2027 in India during five year plans.

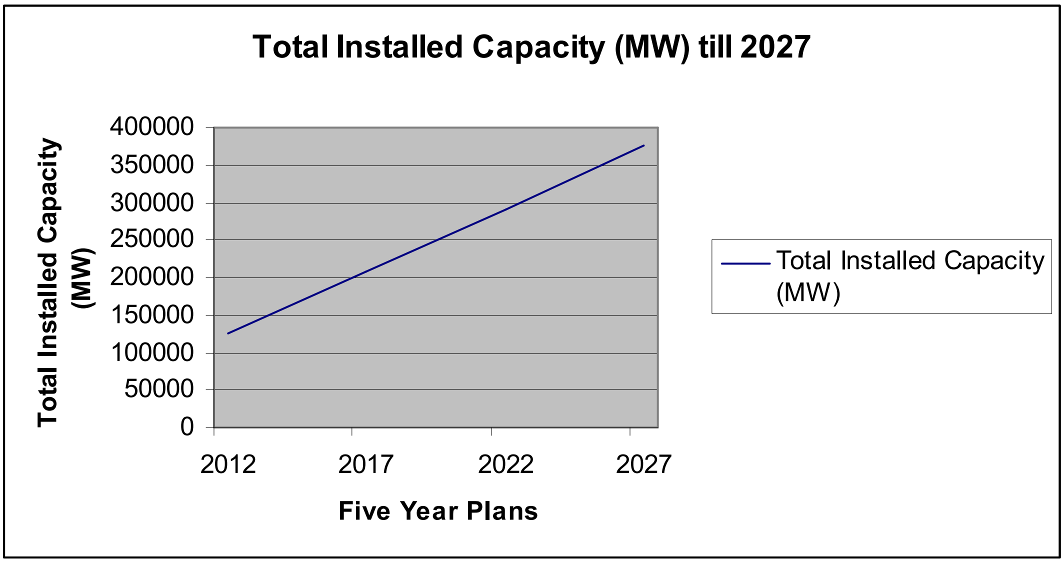

Figure 5-1 Total Installed Capacity till 2027

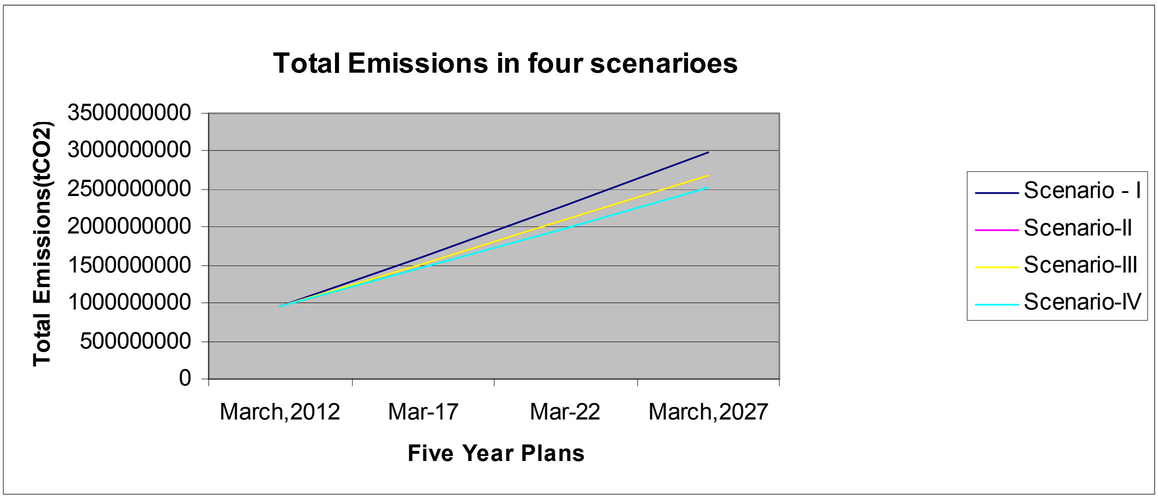

Figure 5-2 Graph showing Total Emissions (tCO2) in four scenarios

Figure 5-2 shows total emissions in four scenarios with the increase in installed capacity of coal based thermal power plant in each five year plan starting from 12th plan till 14th plan. It can be seen from the graph that there is increase in the CO_2 emissions with the increase in the installed capacity in each five year within each scenario. There is reduction in emissions as the percentage of technology penetration increases from Scenario - I to technology penetration scenarios. Further, it is projected in the graph that there is very less total emissions reduction from Scenario- I to technology penetration scenario-II (30%).It can be seen form the Graph that projections for the Scenario-I and Scenario- II is overlapping and it is not very clear in the graph but as the penetration of the technology increases from Scenario –III (40%) to Scenario – IV (50%) .There is more reduction in total emissions from Scenario-II to technology penetration scenario-IV.

5.3 Emissions Reductions

The emissions reduction with the increase in the technology penetration in each five year plan till March 2027 can be seen in Table - 5-5 & 5-6 and Figure - 5-3

Table 5-5 Emission Reduction of Green House Gases (GHGs) (tCO_2)

	March 2012	March 2017	March 2022	March 2027
Scenario -I	0	9,488,6624	1,947,09870	2,943,782,28
Scenario – II	0	9,736,0662	1,971,90250	3,086,006,75
Scenario – III	0	1,523,71619	3,086,00675	4,686,350,57

Table 5-6 Emissions Reduction of Green House Gases (GHGs) (%)

	March 2012 (%)	March 2017 (%)	March 2022 (%)	March 2027 (%)
Scenario -I	0	5.9	8.5	9.9
Scenario – II	0	6.0	8.6	10.3
Scenario – III	0	9.4	13.5	15.7

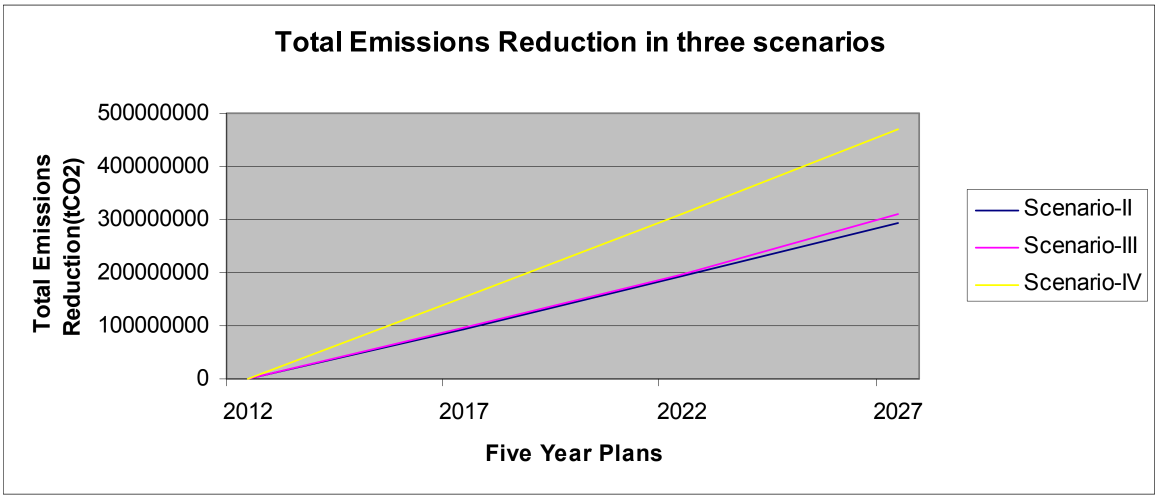

Figure 5-3 Graph showing reduction of emissions (tCO2) in three scenarios

6. Discussion

From the literature review, it is reavled that coal will remain a dominant fuel for producing electricity in India till 2031. The environmental impacts associated with the coal based thermal power plants are emissions of CO_2, NOx, particulates and SOx. Conventional Sub-Critical technology is presently used for coal based electricity generation. Adoption of the CCTs could be helpful for the reduction of the environmental impacts of the thermal power plants in Indian power sector.

There is range of CCTs available such as Supercritical (SC) Technology, Ultra-Supercritical (USC) Technology, Pressurised Fluidized Bed Combustion (PFBC) and Integrated Gasification Combustion Cycle (IGCC). But, India can not afford to have expensive clean coal technologies. India needs technologies which are mature. Supercritical technology is one of the clean coal technologies which are mature and commercialized. Ultra-Supercritical Technology penetration would also be helpful in reducing Green House Gases (GHGs) Emissions.

From the results of the technology penetration scenarios, it can be seen that there is increase in the reduction in Green House Gases (GHGs) emissions in each five year plan. Although, there is very less difference for the percentage of reduction of emissions of Green House Gases (GHGs) from Scenario-I to Scenario-II, there is huge difference between Scenario- III and Scenario –IV, as the percentage of the technology penetration increases from 40% to 50%.

7. Conclusion

It can be concluded that adoption of clean coal technologies would be helpful for reducing Green House Gases (GHGs), poverty reduction as well as development of India. The main key components of the national development strategy are enhancing energy access and supply. Indian economic development is increased due to increase in the energy growth. Increase in energy growth is also helpful for poverty reduction. The main reason for the growth of the energy is due to the adoption of the policies which favour enhancing energy efficiency of power plants by adopting clean coal technologies (Ministry of Power, Ministry of Environment and Forests and Bureau of Energy Efficiency, 2007).

It can be concluded that increase in Supercritical and Ultra Supercritical Technology penetration in India would be helpful for reducing the emissions of Green House Gases (GHGs), Poverty reduction and development of India.

Use of Cleaner coal and clean coal technologies in India would be helpful for energy security and also provide environmental benefits. The quality of the Indian Coal is very poor and the ash content of the coal is 30-50%. High ash content of the coal is harmful for power stations. A low- quality of the coal produces problems like erosion in "parts and materials, difficulty in pulverisation, poor emissivity". Clean Coal would be helpful for increasing efficiency and reduction in CO_2 emissions. The use of the clean coal for IGCC and Supercritical Technology would be helpful for increasing thermal efficiencies. Clean Coal Technologies (CCTs) would also be helpful for reducing the production cost of the electricity. Increased efficiency of the power plants would be helpful for reducing the air pollution (Zamuda and Sharpe, 2007).

This study is for Supercritical and Ultra-Super critical technology penetration upto 50% for new capacity additions. It can be concluded from the results that 15.7% emissions reduction of Green House Gases (GHGs) would occur with maximum of 50% technology penetration till 2027. The percentage of emission reduction is relatively minor emission reductions achieved in the larger span of time. One of the main reason could be capacity development towards clean coal technologies. For higher reduction of the emissions by fossil fuels, next level of technologies such as Integrated Gasification Combined Cycle (IGCC) combined with Carbon Capture and Strorage (CCS) could play an important role. The studies related to CCS are limited to entrained flow gasifier. For fluidized bed or moving bed gasifier for capture there is not any detailed studies available for India (Chikkatur and Abuja, 2007).

Increasing the penetration will definitely increase the Green House Gases (GHGs) reductions. India has already proposed setting up supercritical and ultra-supercritical technology projects (Table- 3-3).

7.1 Recommendations

These recommendations are based on the case data collected and analysis.

To summarize, recommendations are as follows:

- In India, the technology penetration will depend on the policy support.So; policies which support better technology penetration would be implemented.
- Government should play important role for making proper policies for technology penetration and implementation of those policies.
- Coordination at International level for funding and transferring of the technology should be done.

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Abbreviations

BHEL: Bharat Heavy Electrical Limited

CCTs: Clean Coal Technologies

CEA: Central Electricity Authority

CIAB: Coal Industry Advisory Board

FGD: Flue Gas Desulphurisation

GHGs: Green House Gases

HHV: High Heating Value

IEA : International Energy Agency

IGCC: Integrated Gasification Combined Cycle

PC : Sub- critical Pulverised Coal Technology

PLF: Plant Load Factor

PFBC: Pressurized fluidized bed combustion

SC : Supercritical Technology

TERI: The Energy and Resources Institute

USC: Ultra Supercritical Technology

Appendix - I

Total Emissions of Green House Gases (GHGs) = Plant Load Factor (PLF) × Weighted Average Emission Factor × 24 × 365 × Total Installed Capacity