Benchmarking of Energy Efficiency in Coal Based Indian Thermal Power Plants

THESIS

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By

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CERTIFICATE

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This is to certify that the thesis entitled **"Benchmarking of Energy Efficiency in Coal Based Indian Thermal Power Plants"** and submitted by **Manojkumar Surajkaranji Soni** ID No **2002PHXF401** for award of Ph.D. Degree of the institute, embodies original work done by him under my supervision.

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Dedicated to

My Parents

and

My Spiritual Master

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In this world that we are passing through,
We sometimes forget to say thank you,
So before this moment slips away,
There is just one thing I would like to say,
Thanks a million.
I think that it's great,
For all you've done I appreciate!

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ABSTRACT

The gap between growing demand for electrical energy and its availability is ever increasing. In the context of increasing shortage on one hand and scarcity of resources on the other, the most cost effective option available to any country to bridge the gap between demand and supply of electrical energy is the energy management.

Thermal power plants, especially coal based, holds a lion's share in power generation in India. Improving the efficiency of these plants plays an important role in improving the performance of India's power sector. It allows enhancing energy security and helping to reduce local and global pollution through more efficient coal use.

Improvement in Energy Efficiency and harnessing Clean Development Mechanism potential are the important areas where attention is required to be focused. Looking into the poor performance of Coal Based Indian Thermal Power Plants (CBITPPs) it can be observed that there is an urgent need to evaluate the Energy Efficiency improvement and CO_2 emission reduction potential of these plants. This evaluation has been attempted in this study and observed that there is an enormous potential for improving the performance and reducing CO_2 emission in these plants.

In order to rate the performance of these plants, there is a need to first assess their performance and then identify the plant having `best' performance. The other plants can then follow the practices followed in the `best' plant and can improve their performance.

Benchmarking of power plant is a process in which the energy performance of an individual plant or an entire sector of similar plants is compared against a common metric that represents `standard' or `optimal' performance.

In order to evaluate the performance of plants under consideration, different models were tried and it is observed that Cobb-Douglas form of the Stochastic Frontier Production Function fits data the best. For this purpose the cross sectional data pertaining to about seventy seven thermal power plants, distributed in various geographical regions in India from 1999-2000 to 2005-2006 i.e. for seven year period has been collected.

The primary data was collected for plants from authentic sources and direct plant visits, and the remaining data was taken from the published reports. The consistency of the results of the analyses is verified using Data Envelopment Analysis models. The power plants are grouped capacity wise and the plant having best performance is benchmarked for that group.

During the seven year period from 1999 to 2006, it is observed that the mean Technical Efficiency of plants is varying from 80.84 percent to maximum of 87.08 percent, indicating that on an average, 13 to 20 percent of the technical potential of thermal power plants is not realized. Hence, there is substantial scope for raising thermal power production in the country, without employing additional resources. The findings can aid policy-makers and international agencies in adopting appropriate strategies to improve power generation in India.

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LIST OF ABBREVIATIONS AND ACRONYMS

A.E. CO.	Ahemdabad Electricity Company
$AbsCO_2$	Absolute CO_2 emission of the station
BEE	Bureau of Energy Efficiency
BEST	Benchmarking and Energy Savings Tool
BHEL	Bharat Heavy Electricals Ltd.
bn tonne	Billion Tonne
BoA	Braunkohlenkraftwerk mit Optimierter Anlagentechnik
BU	Billion Units
CAP.	Capacity
CDM	Clean Development Mechanism
CEA	Central Electricity Authority
CenPEEP	Centre for Power Efficiency and Environmental Protection
CEP	Condensate Extraction Pump
CES	Constant Elasticity of Substitution
C_f	Capacity in MW of the Unit on Forced Outage
CFL	Compact Fluorescent Lamp
CMIE	Centre for Monitoring Indian Economy
COLS	Corrected ordinary least square
C_p	Capacity in MW of Unit on Planned Shutdown
CRS	Constant Returns to Scale
CW	Circulating Water
D.P.L.	Durgapur Projects Limited
DEA	Data Envelopment Analysis
DMU	Decision Making Unit
DVC	Damodar Valley Corporation
ECEEE	European Council for Energy Efficient Economy

EE	Energy Efficiency
EEI	Energy Efficiency Index
EF	CO_2 Emission Factor
EGAT	Electricity Generating Authority of Thailand
EI	Energy Intensity
EII	Energy Intensity Index
EPS	Electric Power Survey
E_{tot}	Total Actual Energy Consumption
EU	European Union
EWI	Energy Wise India
EXT.	Extension
F()	Frontier Production Function
FO	Forced Outage
FuelCon	Amount of fuel consumed
GCV	Gross Calorific Value
GDP	Gross Domestic Product
GHG	Greenhouse Gas
GW	Giga Watt
GWh	Giga Watt hour
H_f	Duration of Outage in Hours
HHV	Higher Heating Value
HP	High Pressure
H_p	Duration of Shutdown in Hours
i.i.d.	independent and identically distributed
IEA	International Energy Agency
IEA CCC	International Energy Agency Clean Coal Centre
IEP	Iterative Estimation Procedure
IISI	International Iron and Steel Institute

IPCC	Intergovernmental Panel on Climate Change
IREDA	Indian Renewable Energy Development Agency
ITPP	Indian Thermal Power Plants
K	Input Variable
kcal	Kilo Calorie
kWh	kilo Watt hour
L	Input Variable
LLF	Log Likelihood Function
LRT	Likelihood Ratio Test
MJ	Mega Joule
ml	milliliter
MLE	Maximum Likelihood Estimates
MMOE	Million Metric Tons of Oil Equivalent
MMT	Million Metric Tons
MNES	Ministry of Non-Conventional Energy Sources
MOC	Ministry of Coal
MOEF	Ministry of Environment and Forests
MOP	Ministry of Power
MTOE	Million Tons of Oil Equivalent
MU	Million Units
MW	Mega Watt
NCV	Net Calorific Value
NO_x	Oxides of Nitrogen
NPC	National Productivity Council
NTPC	National Thermal Power Corporation
OAF	Operating Availability factor
OECD	Organization for Economic Co-operation and Development
OLS	Ordinary Least Square

Oxid	Oxidation Factor of the Fuel
PGEC	Pacific Gas and Electric Company
P_i	Production Quantity
PLF	Plant Load Factor
PM	Planned Maintenance
POWGEN	Power Generated
Q	Actual Power Generated or Output
R&M	Renovation and Modernization
ROR	Rate of Return Regulation
SEC	Specific Energy Consumption
SFA	Stochastic Frontier Analysis
SFC	Specific Fuel Consumption
SFE	Stochastic Frontier Estimation
SOEU	State Owned Electric Utilities
STPS	Super Thermal Power Station
T&D	Transmission and Distribution
TE	Technical Efficiency
TEDDY	TERI Energy Data Directory and Year book
TERI	The Energy and Resources Institute
TFP	Total Factor Productivity
TJ	Tera Joule
tn kWh	Trillion kilo Watt hour
Translog	Transcendental Logarithmic
TWh	Tera Watt hour
u	Error or Residual Term
UNFCCC	United Nations Framework Convention on Climate Change
v	Random Noise Term or Random Variable
VRS	Variable Returns to Scale

WEC	World Energy Council
X	Input Quantity
x	Amount of input by utilized a Decision Making Unit
y	Amount of output produced by a Decision Making Unit
z	Number of Utilities or Decision Making Units
μ	Mean of Variable u
β	Unknown Parameters or Coefficients Associated with Variables
η	Unknown Parameter
θ	Efficiency Score
λ	Dual Variable

CHAPTER I

INTRODUCTION

"India's power sector is a leaking bucket; the holes deliberately crafted and the leaks carefully collected as economic rents by various stakeholders that control the system. The logical thing to do would be to fix the bucket rather than to persistently emphasize shortages of power and forever make exaggerated estimates of future demands for power. Most initiatives in the power sector (Independent Power Producers and mega power projects) are nothing but ways of pouring more water into the bucket so that the consistency and quantity of leaks are assured..."

Deepak S. Parekh, (Ramakrishnan, 2001)

1.1 INTRODUCTION

Electricity is an essential input in various sectors of an economy such as industry, agriculture as well as commercial and domestic sectors. Despite the fact that India's per capita electricity consumption is very low, the demand for electricity in the country has been rising at a faster pace (exceeding 9%) than anywhere else in the world. In spite of sustained growth, the per capita electricity consumption which was 15.6 kWh during 1950 increased to 559 kWh during the year 2001-02, 592 kWh during the year 2003-04, and 606 kWh during the year 2004-05; far below the world average of 2,252 kWh (CEA, 2005a).

Growth of power generation in India, since its independence, has been noteworthy; making India the third largest producer of electricity in Asia. The generating capacity has grown several manifold, from 1362 MW in 1947 to 1,32,110.21 MW (as on 30.04.2007). The overall generation in India has increased from 301 Billion Units

(BUs) during 1992-93 to 659 BUs in 2006-07. However, the growth has not been able to meet the demand and substantial energy and peak shortages of 9.5% and 14.2% respectively exist (CEA, 2004a and MOP, 2007a).

Coal Based Indian Thermal Power Plants (CBITPPs) are the leading providers of electricity in India, followed by hydro, nuclear, gas and diesel-based power plants. The power generating capacity of the thermal power plants is 85,575.84 MW which is about 64.7% of the total power generating capacity of India. Coal based thermal power plants are the largest power producers having capacity of 70,682.38 MW. These power plants have a capacity ranging from 30 MW to 3,000 MW, comprising of units of 20 MW to 500 MW capacities. About thirty five percentage of the total power is produced in hydroelectric, nuclear and non conventional sectors (CEA, 2004a; MOP, 2007a).

Coal based thermal power plants have the largest share of installed electricity generation capacity in the country, while their share in actual power generation in India is even larger. However, in spite of the rapid advance in electricity generation in the country, peak deficits and energy shortages are still frequent. Moreover, the performance of CBITPPs remains very unsatisfactory, due to the poor quality of coal used, lack of facilities for processing coal, inadequacy of trained workforce and control equipment as well as aging of stations (TERI, 2001).

1.2 NEED FOR ENERGY EFFICIENCY IN CBITPPs

India currently has a peak demand shortage of around 13% and an energy requirement of 719 BUs. As per the 16th Electric Power Survey (EPS) projections, by the year 2012, India's peak demand would be 1,57,107 MW with energy requirement of 975 BUs (MOP, 2007a). Keeping this in view and to maintain a Gross Domestic Product (GDP) growth of 8% to 10%, the Government of India has very prudently set a target of 2,15,804 MW power generation capacity by March 2012. In order to deliver a sustained growth of 8% through 2031, India would, in the very least, need to grow its electricity supply by five to seven times of today's consumption. By 2031-32 the power generation capacity would have to increase to 7,78,095 MW, if no measures are taken to reduce requirement. Along with quantity, the quality of power supply would have to be improved. This challenge is of fundamental importance to India's economic growth imperatives (Planning Commission, 2005).

To meet the projected demand in 2011-12, additional capacity requirement of about 78,000 MW is required to be added in the 11th Plan (2007-12). Thermal power generation is expected to continue to dominate in the power generation scenario. The thermal power generation addition in the eleventh plan is 58,688 MW, out of which 54,355 MW is from CBITPPs (CEA, 2007a). Considering an investment need of Rs. 50 million per MW of generation and about 1.3 times this cost for T&D (transmission and distribution), the total funds required for generation and distribution of thermal power alone will be Rs. 62,50,825 million (Abbi, 2001). To meet the target of the capacity addition, massive resources would be required. According to the estimates of Government of India, investments of more than 100 billion dollars would be required in power generation in the next ten years. This is a huge investment for the developing country like India.

Apart from the huge investment for new plants, the major problems associated with existing CBITPPs are low Plant Load Factor (*PLF*) and low efficiencies. CEA report (CEA, 2006a) states that the average *PLF* of CBITPPs has been varying from 55 to 75% during year 1991-92 to 2005-06, and the overall thermal efficiency varying from 15 to 30%. The comparative sector-wise *PLF* of CBITPPs in percentage over the years is given in Table 1.1. The reason for low *PLF* values is the low operating availability of thermal power plants due to high *Forced Outage* rates while the low efficiencies are due to low calorific value of low grade coal available in India. Also such plants produce huge amount of ash, due to high ash contents in coal, and have very high poisonous emissions. These are of a major concern due to the degree of environmental damage involved.

Table 1.1: The Comparative Sector-Wise PLF of CBITPPs

Year /Sector	Central	State	Private	Overall
1990-91	58.1	51.3	58.4	53.8
1995-96	70.9	58.1	72.3	63.0
2000-01	74.3	65.6	73.1	69.0
2001-02	74.3	67.0	74.7	69.9
2002-03	77.1	68.7	78.9	72.1
2003-04	78.7	68.4	80.5	72.7
2004-05	81.7	69.6	85.1	74.8
2005-06	82.1	67.1	85.4	73.6
2006-07*	83.3	69.5	87.2	75.6

(*up to Jan. 07), Source: MOP, 2007b

In order to meet the growing power demand other options available are hydro electric power plants, nuclear power plants and non-conventional energy resources. Hydro electric power plants call for comparatively larger capital investments with low rate of return. At the same time, large hydro power plants need large catchment area, disturb the ecology of the area, by way of deforestation, destroying vegetation and uprooting people (MNES, 2005).

Nuclear power plants are at an economic disadvantage compared to CBITPPs for base load generation. Other problems like risk of major accidents like Chernobyl, nuclear waste disposal, security and above all reliable supply of fuel and technologies for such plants are of great concern.

Though the non-conventional energy resources of India are significant, various factors like seasonal variations, absence of proper technology, resources and huge costs involved make them unsuitable for large scale sustainable power production.

Significant technology and monetary inputs have to be made if non-conventional energy resources have to become a competent energy provider.

Following large-scale economic reforms in 1991 and as part of its overall strategy for reforms in the electricity sector, the government of India plans to expand the installed capacity of CBITPPs, given adequate coal reserves in the country. However, even though India has sufficient coal reserves; transport bottlenecks and environmental regulations may cause a decline in the supply of domestic coal. In this context, imported coal or multi-fuel options can be substituted for domestic coal to maintain electricity generation in the country (TERI, 2001). From the above discussion it is clear that with the amount share of coal in power generation and the amount of coal reserves, CBITPPs are likely to dominate the supply of electricity in India even in the future.

1.2.1 Role of Energy Efficiency as a Solution to Energy Problems

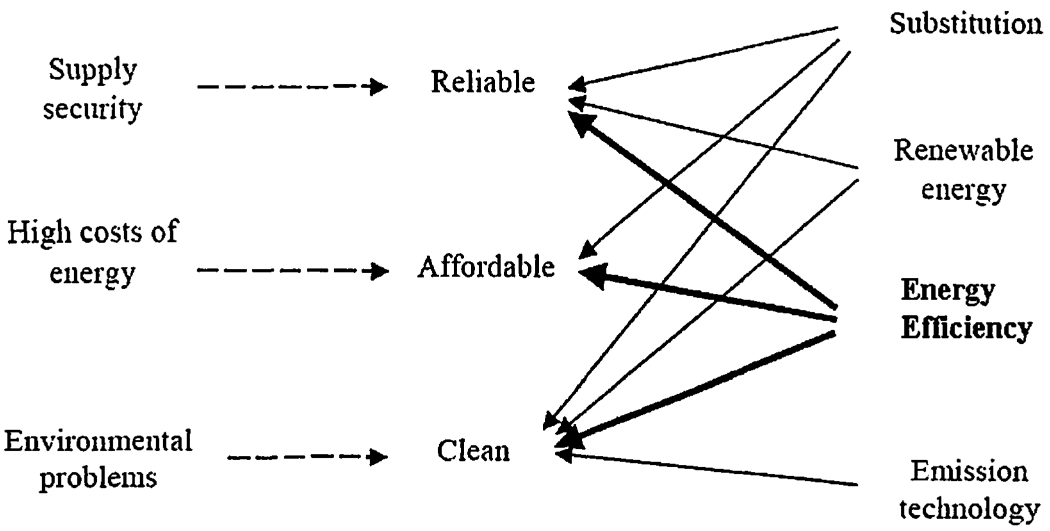
As mentioned earlier, major issues related to the power sector are security of energy supply, high cost of energy carriers and environmental problems (caused by power generation). Potential solutions to these problems are:

- Substitution with nuclear energy,
- Increased use of renewable energy sources,
- Enhanced savings on energy consumption,
- Improved Energy Efficiency on supply side, and
- Implementation of advanced technologies to reduce harmful emissions.

In the energy policy of many countries the problems mentioned about the energy supply system have been rendered into three policy goals: reliable, affordable and clean (see Fig. 1.1). Substitution with nuclear energy is one of the solutions but for

India there are various technical and political hurdles for this option. Renewable energy sources are clean and may be reliable but the cost of options like solar is very high. Advanced technology to reduce harmful emissions is very clean option but not the reliable and affordable. Energy Efficiency is the only option which is reliable, affordable and at the same time it is clean. It can contribute to each of the policy goal, in 'competition' with the other solutions.

Fig. 1.1: Role of Energy Efficiency as a Solution to Energy Problems



1.3 NEED FOR BENCHMARKING OF ENERGY EFFICIENCY OF CBITPPs

Benchmarking of CBITPPs, in the overall context of infrastructure management, is now perceived as an essential component of utility management. Such assessment is necessary not only to determine the efficiencies of existing power plants, but also from a viewpoint of establishing goals, formulating strategies to achieve goals. Introducing the concepts of efficiency and effectiveness in power plants has assumed growing importance in the recent times.

In this context, it becomes essential to assess the performance of coal based thermal power plants in India. A power plant is considered inefficient, or more precisely, technically inefficient if the plant's existing resources or inputs are utilized sub-optimally, as a consequence of which the plant's power generation is less than its potential or maximum possible generation given existing inputs/technology. In general, technical inefficiency, as defined above, is indicative of poor plant performance, while an improvement in plant efficiency, or Technical Efficiency (*TE*) leads to greater electricity generation given existing inputs and hence superior plant performance.

In order to access the performance of CBITPPs very few studies are seen in literature. Singh (1991) has studied the efficiency of thermal power plants in India during the pre-reform period, using cross-sectional data for 1986-87. While technical efficiency evaluation of sixty six thermal power plants in India for the period of 1987-88 to 1990-91 was done by Khanna *et al* (1999). A non-parametric approach to frontier analysis is applied in the work carried out by Chitkara (1999) to evaluate the operational inefficiencies of generating units. Shanmugam and Kulshreshtha (2002) have measured the technical efficiency of coal-based thermal power plants in India from 1994-95 to 1996-97.

More recently, Tripta Thakur (2005) and Tripta Thakur *et al* (2005) have assessed the comparative efficiencies of distribution of electricity by Indian State Owned Electric Utilities (SOEU), which have been mainly responsible for the generation, distribution and transmission of electricity in India. Shanmugam and Kulshreshtha (2005) measured the technical efficiency of Indian thermal power plants using panel data.

From the above discussion it is quite evident that for performance evaluation of Indian thermal power plants very few studies are done and of benchmarking only one study is done by Tripta Thakur *et al.* (2005), where benchmarking of electricity distribution by state owned electric utilities have been done.

As mentioned earlier India is facing power crisis and in the future the scenario is going to be bleak. The Indian power sector is going through reforms, improvement in Energy Efficiency and harnessing Clean Development Mechanism (CDM) potential are the important areas where attention is required to be focused. Looking into the present performance of CBITPPs, as discussed earlier, the plants are being operated at lower *PLF* and efficiency. In view of the above there is an urgent need to evaluate the Energy Efficiency improvement and simultaneous CO_2 emission reduction potential. In order to rate the performance of the CBITPPs, there is a need to first assess their performance and then identify the power plant having best performance, the 'best' plant can be considered as 'benchmarked'. The other plants can then follow the practices followed in the 'best' or 'benchmarked' plant and can improve their performance. In view of the above, the objectives of present research work are given below.

1.4 OBJECTIVES OF THE STUDY

Following are the main objectives of the study:

1. To study the scenario of Indian power plants in general and CBITPPs in particular.
2. To assess potential of Energy Efficiency improvements in CBITPPs.
3. To evaluate potential of CO_2 emissions reduction in CBITPPs as a part of Clean Development Mechanism.
4. To evaluate the performance of CBITPPs.
5. To benchmark the CBITPPs based on their performance.

1.5 SCOPE OF THE STUDY

In this study, for performance evaluation and benchmarking, various CBITPPs from all the sectors viz. central, state and private are considered. Apart from the primary data from authentic sources and direct plant visits, the secondary data which was available in reports of various agencies is also taken. The data pertains to about seventy seven CBITPPs, distributed in various geographical regions in India from 1999-2000 to 2005-06 i.e. for seven year period. For non-existent data due to missing information regression analysis is used.

The CDM and Energy Efficiency potential in CBITPPs have been assessed with the help of methods presented in empirical studies. The total Energy Efficiency improvement and CO_2 emission reduction potential has been evaluated.

The Stochastic Frontier Production function models are used for evaluating performance of CBITPPs. The consistency of the results of the analyses is verified using Data Envelopment Analysis models. The benchmarking of CBITPPs is done based on the evaluated performance.

1.6 PLAN OF THE THESIS

Chapter 1: In this chapter the background of the thesis covering the need for of Energy Efficiency in CBITPPs, role of Energy Efficiency as a solution to energy problem, and need for benchmarking are discussed. The chapter also states the objectives of the research followed by the scope of the study and organization of the thesis.

Chapter 2: This chapter gives the power scenario of world in general and India in particular with a special emphasis on coal based power generation.

Chapter 3: In this chapter essentials of Energy Efficiency with its advantages and barriers are disused. The CDM and Energy Efficiency potential in CBITPPs have been assessed with the help of methods presented in empirical studies. The total Energy Efficiency improvement and CO_2 emission reduction potential has been evaluated and presented here.

Chapter 4: This chapter tells about benchmarking, its process and methodologies. A thorough review of various empirical studies available in literature is presented. Based on the same, the methodology for benchmarking is identified for the present study and discussed.

Chapter 5: In this Chapter, the data sources for the present study, the model used for analysis and results of the analysis have been discussed. The input and output variables selected for the analysis have been presented. The interrelated input variables are clubbed and their computation method is also given. The Stochastic Frontier Production Function models used for the analysis are specified and the empirical analysis of the best model is discussed. Estimated Technical Efficiency of all CBITPPs are presented and after capacity wise grouping them benchmarking has been done and presented.

Chapter 6: In this chapter, summary of results and conclusions of the research work are presented. General conclusions are followed by specific contributions of the research work. Scope for further work is also presented.

There are six appendices included in the thesis. These include barriers to Energy Efficiency, energy saving measures in CBITPPs, sample data, parameters estimates of Translog model, Technical Efficiency scores by various models and capacity wise ranking of the plants. List of publications based on present investigations is also appended to the thesis.

CHAPTER II

POWER SCENARIO

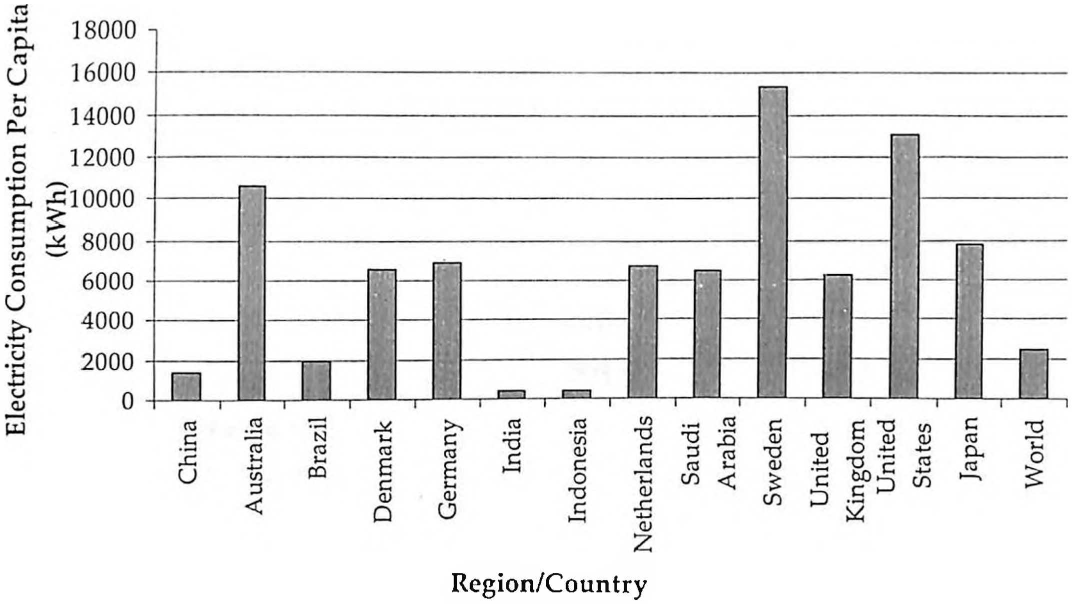
Diverse, secure, affordable and environmentally acceptable supplies of energy are essential for sustainable development of world societies. The issues related to meeting the energy requirements of both developing and mature economies vary over time and between regions of the world. In this chapter the power scenario of world in general and India in particular is discussed with a special emphasis on coal based power generation.

2.1 WORLD POWER SCENARIO

World's average per capita energy consumption for the year 2003, as per Planning Commission's report (Planning Commission, 2005), was 2,429 kWh, while India was one of the lowest in the world. India consumed only 435 kWh per person of electrical energy in 2003 compared to 1,379 kWh in China. The consumption in USA was 13,066 kWh per person, while in Sweden it was highest at 15,397 kWh per person (Kothari and Nagrath, 2008). Figure 2.1 gives per capita electricity consumption of different countries for the year 2003.

IEA World Energy Outlook 2004 (IEA, 2004a) projects world electricity demand to grow at an annual rate of 2.5%, nearly doubling from 16.1 trillion kilowatt-hour (tn kWh) in 2002 to 31.7 tn kWh in 2030. Strong growth in electricity consumption is expected in countries of the developing world, where electricity demand increases by an average of 3.5% per year. The global power sector will need 4,800 GW of new capacity between now and 2030 to meet the projected rise in electricity demand and to replace ageing infrastructure. The total installed capacity is expected to increase from 3,500 GW to more than 8,000 GW. The exact mix of fuel input to this new generating capacity will depend on a number of factors including fuel diversity, indigenous and international availability, cost and environmental acceptability; and will vary between different regions of the world. Gas and renewable energy sources will play increasing roles, particularly in the industrialized nations. However, coal's wide availability, supply security and competitiveness are recognized in the projections. They show coal retains a very important position in fuelling this electricity generating capacity.

Figure 2.1: World Per Capita Electricity Consumption



Source: Planning Commission, 2005

2.1.1 Power Generation

Total world electricity generation was 17,531 TWh in 2004. As per IEA (IEA, 2006), this is projected to rise to 31,657 TWh in 2030, growing at an average rate of 2.5% per year. The largest increase will be in China, which will raise production by 3,898 TWh from now to 2030, a quarter of the world's projected increase.

Table 2.1 shows the world's top electricity producers in 2004. The United States was by far the largest producer having a lion's share of 23.8% of the total power generation of the world in 2004 and could stay at the top of the list in 2030, but China will be nearly as large as it by that time. Though India was on the fifth position, it is likely to be third on this list i.e. ahead of Japan by 2030, with a market about a third of that of China.

Table 2.1: World's Top-Ten Electricity Producers in 2004

Producers of Electricity	TWh*	Share in world (%)
United States	4,148	23.8
People's Rep. of China	2,200	12.6
Japan	1,071	6.1
Russia	930	5.3
India	668	3.8
Germany	610	3.5
Canada	598	3.4
France	567	3.2
United Kingdom	393	2.3
Brazil	387	2.2
Rest of the World	5,878	33.8
World	17,450	100.0

* Gross production minus production from pumped storage plants.

Source: IEA, 2006.

Long term global economic growth cannot be achieved without adequate and affordable energy supplies, which will require continuing significant contributions from fossil fuels, including coal. Coal, the largest contributor for power generation in

2004, provided the fuel for 39.61% of electricity production globally generating 6,944.33 TWh of electricity. It will continue to make an important contribution to energy security because of its widespread geographic distribution, and the extent of available resources relative to anticipated energy needs. The electricity generated from various sources in the world is shown in Fig. 2.2.

Natural gas based electricity production was 19.5% in 2004 which is expected to triple between 2007 and 2030. While in developing countries, this share is expected to rise to 26% by 2030.

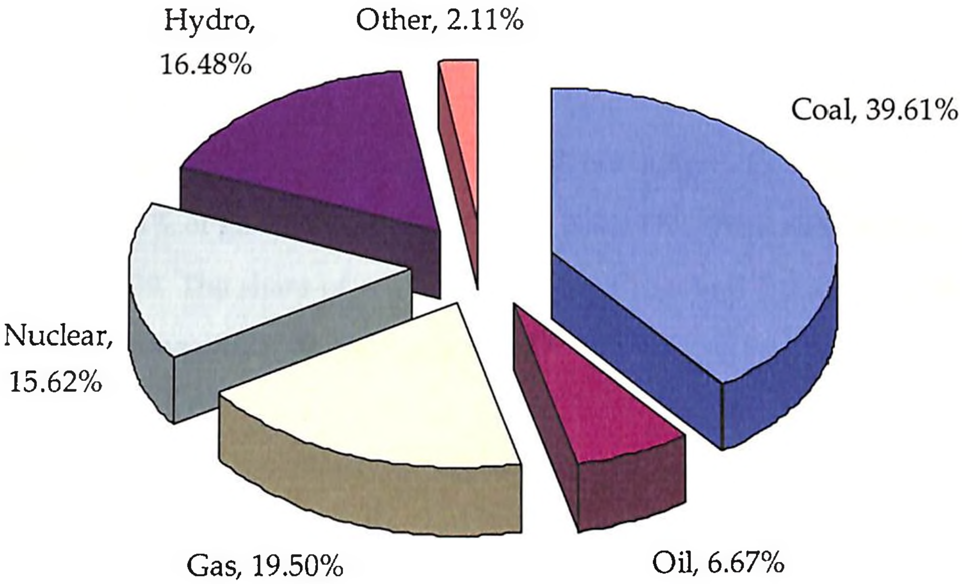
Hydropower based electricity generation was 16.48% globally in 2004 which is expected to increase to 4,248 TWh by 2030, but its share will fall to 13% in 2030. Hydropower could increase most in developing countries where its remaining potential is still high. However, there is much discussion about the environmental and social effects of building large dams and such issues could adversely affect the future of hydropower. Growth of hydro-electricity in the Organization for Economic Co-operation and Development (OECD) countries will be limited by the lack of available sites and by environmental regulations. Some OECD countries provide incentives for the development of small hydropower plants.

There are thirty one countries in the world operating nuclear power plants. These plants produced 15.62% of world's power in 2004 which was around 2,738 TWh of electricity. Over 85% of nuclear electricity is produced in seventeen countries that are members of the OECD.

Oil-fired electricity generation, which accounted for 7% of world power production in 2002, was reduced to 6.67% in 2004. This share is a third of what it was thirty years ago, because many countries reduced oil use in power generation after the first oil shock. The share of oil will continue to diminish in the future, falling to 4% in

2030. Future oil-fired generation will be concentrated in distributed-generation applications in industry and in remote areas.

Fig. 2.2: World Electricity Generation through Various Sources in 2004



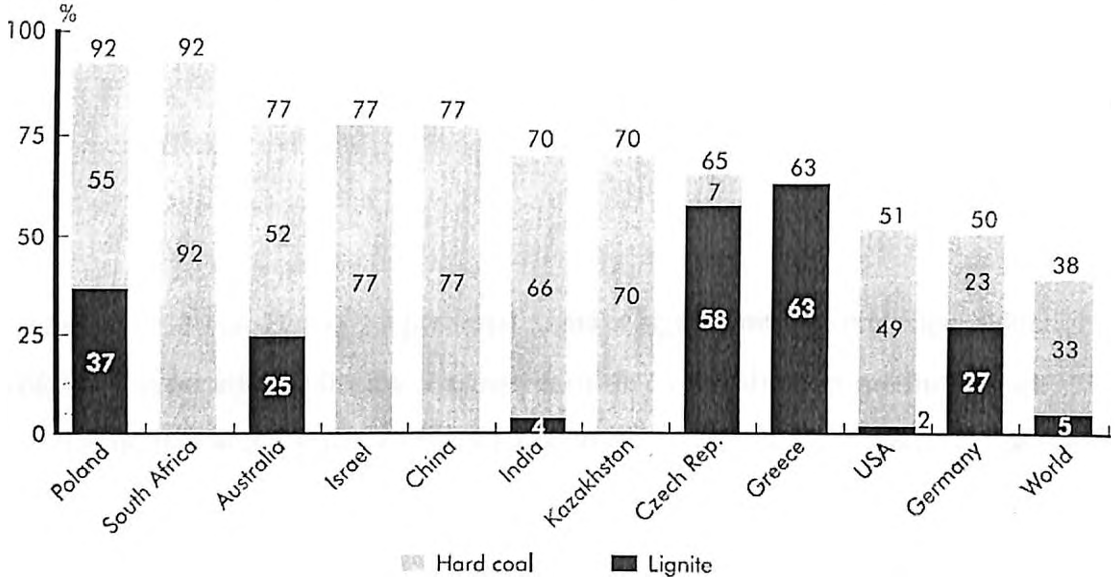
Source: IEA, 2004b

Electricity from other renewable energy sources i.e., other than hydropower amounted to 2.11% of world electricity production. These sources will substantially increase their contribution to electricity generation, growing nearly six fold between 2007 and 2030. Their contribution to electricity generation will increase to 6% by 2030. This increase will be largely driven by government action in OECD countries to reduce CO_2 emissions and dependence on fossil fuels. Several developing countries are also adopting policies to increase the use of renewable energy sources.

2.1.2 Coal Based Power Generation

Coming back to coal, as per IEA (IEA, 2005), currently two-thirds of the coal consumed worldwide is used for electricity generation. In many large developed as well as in the developing countries, coal occupies top slot as energy source in power generation. In almost every region, power generation accounts for most of the projected growth in coal consumption of 1.5% per annum. Coal-fired power plants provided 39.61% of global electricity needs in 2004. This share will fall only slightly, to 38% by 2030. The share of coal including hard coal and lignite in world power generation for the year 2002 is given in Fig. 2.3.

Fig. 2.3: Share of Coal in Power Generation, 2002



Source: IEA, 2005. Electricity Information 2004 - Tables 6 and 7.

Nearly 60% of the world's current coal-based electricity production is in OECD countries. Most new coal-fired power plants will be built in developing countries, especially in Asia. Coal will remain as the dominant fuel in power generation in those countries because of their large coal reserves and coal's low production costs. Developing countries are projected to account for almost 60% of world coal-based electricity in 2030. China and India together will account for 44% of worldwide coal-based electricity generation.

Over the period 2003-2030, nearly 1,400 GW of new coal-fired power capacity will be built worldwide. About two-thirds of these plants will be built in developing countries. They will be, in general, less efficient than coal plants in OECD countries, because of the technology used, the type of coal burnt, the mediocre maintenance of the plants and their size. In many developing countries the efficiency of coal use is still at the level reached by OECD countries over fifty years ago (IEA CCC, 2002). The average efficiency of coal-fired generation in the OECD was 36% in 2002, compared with just 30% in developing countries. This means that one unit of electricity produced in developing countries emits almost 20% more CO_2 than does a unit of electricity produced in an OECD coal plant. The efficiency gap between developed and developing countries will narrow, but not close. In 2030, the average conversion efficiency of coal plants in developing countries will reach 36%, while the OECD will have attained 50%.

Coal-based technology has the potential to make significant CO_2 emission reductions which are compatible with low emissions rules. In the short to medium term, this requires market and regulatory frameworks that encourage investments in the latest technologies that will improve the efficiency of coal-fired electricity generation and thus reduce CO_2 emissions. Collaborative action by governments and industry is also required now to encourage worldwide coordinated research, development and demonstration of clean coal technologies such as carbon capture and storage, which will in the longer term deliver near-zero CO_2 emissions from the use of coal.

2.1.3 Efficiency Improvement and CO_2 Emission Reduction Potential in Some Countries

There is considerable potential to reduce CO_2 emissions from coal use by applying existing state-of-the-art technology. Under ideal conditions, modern coal-fired power plants are capable of achieving efficiency levels of more than 40% on a Higher Heating Value (HHV) basis. This is about a 30% improvement on plants built in the 1950s and 1960s, with equivalent reductions in CO_2 emissions. Furthermore, modern installations emit less dust, sulphur and NO_x than older plants, and their reduced fuel usage contributes to management of increasingly scarce energy resources.

New power plants illustrate the current status of power plant technology. In Germany, the 965 MW BoA (German abbreviation: BoA stands for "Braunkohlenkraftwerk mit optimierter Anlagentechnik" i.e. lignite-fired power plant with optimized plant technology) lignite-fired power plant with supercritical steam conditions went fully on stream in 2003 at Niederaussem/Rhineland with an efficiency of more than 43% on a lower heating value basis. In Australia, the recently completed 860 MW Millmerran black coal power plant has an efficiency of around 40% on HHV basis, and in Japan, the 1,050 MW Tachibanawan-2 black coal power plant has an efficiency of around 42% on HHV basis. These are some of the best coal based power plants in the world.

Coal-fired generating capacity of about 1,000 GW is installed worldwide. Almost two-thirds of the international coal-fired power plant portfolios are older than twenty years and have an efficiency of 29%. These power plants emit some 3.9 bn tonnes CO_2 per year. If the normal life of these plants is assumed to be forty years, and they are replaced when they reach this age with modern, Ultra-Supercritical plant with efficiencies typically around 45%, the total greenhouse gas (GHG) emissions from this 1,000 GW of capacity will be reduced by 1.4 bn tonnes CO_2 per year, reflecting a 36% reduction in GHG emissions. This corresponds to some 6% of the 23.4 bn tonnes of global energy-related CO_2 emissions which are reported by the IEA for 2002 and is more than the targeted reductions under the Kyoto Protocol in 2008-2012. This is an important contribution, albeit it is recognized that even greater reductions are required.

Average efficiencies of coal-fired power plants in China, India and Russia are 30%, 30% and 27.9% respectively as shown in Table 2.2. These have average CO_2 emissions of 1,216 tonnes of CO_2 per MWh. If efficiency of these plants is increased to 33% would allow CO_2 emissions to be cut by 283 million tonnes per year. This is equivalent to one-third of total CO_2 emissions in Germany.

Table 2.2: CO_2 Reduction through Efficiency Increase Potential of Coal-based Power Generation in Some Countries

	Unit	China	India	Russia	Total
Coal-based power generation	TWh/year	1,139	435.8	544.6	2,119.4
Average efficiency	%	30	30	27.9	29.5
Average CO_2 emissions	t CO_2/MWh	1,202	1,120	1,325	1,216
CO_2 emissions for efficiency of 33%	t CO_2/MWh	1,090	1,020	1,120	1,083
CO_2 emissions reduction	Million tonnes/year	127.6	43.6	111.6	282.8

Source: IEA, 2005.

In a long-term view, after 2020, coal-fired generation technologies featuring efficiencies of some 50% can be available. A modern plant with an efficiency of 50% implies a 28% cut in CO_2 emissions compared to a typical plant of around 36% efficiency.

The replacement of older power generating plants with modern equipment would also yield numerous ancillary benefits, including greater coal-use efficiency, substantial reductions in conventional pollutant (SO_2, NO_x, particulate) emissions, a reduced cost to implement any new emission controls that may be required by future national legislation such as in the USA, and the potential to construct these plants to enable retrofitting with CO_2 capture technology, when it becomes commercially available.

Electricity generating companies are constantly making plant investment decisions, whether to meet new capacity requirements, to improve environmental performance of existing plant, or to reduce overall costs. It is essential that these decisions are made within policy frameworks that recognise the CO_2 reduction potential of increasing the efficiency of coal-fired electricity generation.

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2.2 INDIAN POWER SCENARIO

India is home to 16% of the world population, but its current energy use only represents around 3% of world consumption (EWI, 2005). With increasing urbanization and industrialization, it is inevitable that the demand for energy will grow rapidly. While new generation capacity is urgently needed, the focus cannot be entirely on improving energy supply. Equal attention must be given to minimizing demand by improving the efficiency of energy use. The Table 2.3 given below depicts Indian energy reserves as compared to the world.

Table 2.3: Indian Energy Resources (1% of World)

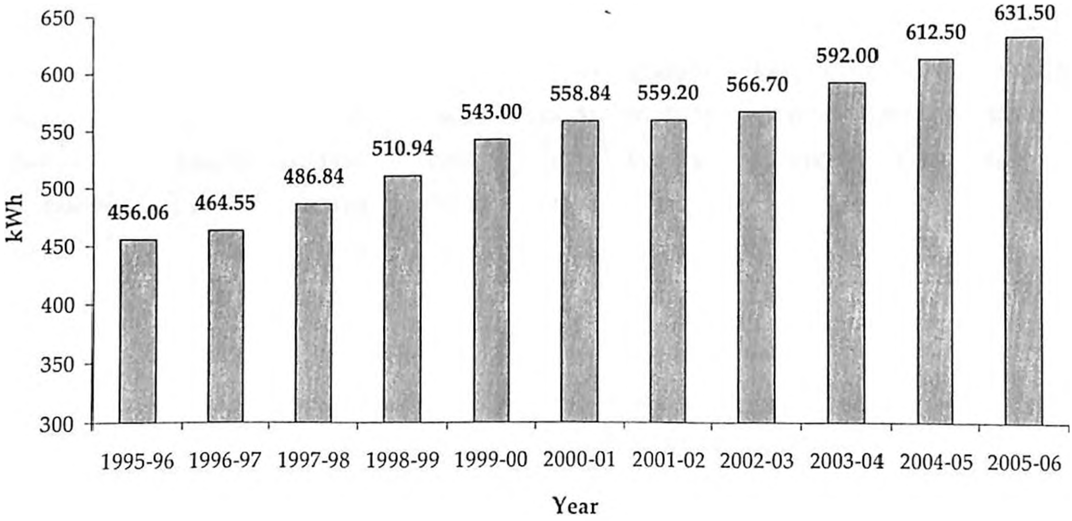
Fuel Type	World Reserves	Indian Reserves	As % of World Reserves
Oil (MMT)	1,38,300	800	0.58
Gas (MTOE)	1,39,700	700	0.30
Coal (MMT)	10,31,610	69,947	6.70
Hydro (MTOE)	218	30	13.76
Nuclear (MMOE)	596	2	0.34

Source: EWI, 2005

Since from the post independence era the power sector in India has registered significant progress after the process of planned development of economy began in 1950, hydro power and coal based thermal power have been the main sources of generating electricity. Nuclear power development is at slower pace, which was introduced, in late sixties. The concept of operating power systems on a regional basis crossing the political boundaries of states was introduced in the early sixties. In spite of the overall development that has taken place, the power supply industry has been under constant pressure to bridge the gap between supply and demand.

In India the electricity consumption has increased from 4,157 GWh as on 31-12-1950 to 3,22,459 GWh during the year 2001-02, the last year of the 9th Plan. It further increased to 3,60,937 GWh during the year 2003-04 i.e. the 2nd year of 10th Plan (CEA, 2005a). This increase is by an average of 7% per year since independence. Though the overall demand-supply gap decreased from an estimated 8.1% in 1997-98 to 5.9% in 1998-99, it rebounded to 6.2% in 1999-2000. Peak power shortages fell from 18% in 1996-97 to 12.6% in 2000-01 while it is around 13.9% in 2007. In spite of sustained growth, the per capita electricity consumption which was 15.6 kWh during 1950 increased to 559 kWh during the year 2001-02, 592 kWh during the year 2003-04, 612.5 kWh for the year 2004-05 and 631.5 kWh for the year 2005-06 far below the world average as shown in the Fig. 2.4 (IEA, 2002; CEA, 2006b; Kothari and Nagrath, 2008).

Fig. 2.4: Growth of Per Capita Electricity Consumption (kWh) 1995-96 to 2005-06



Source: CEA, 2006b

The installed power generation capacity which was only 1,713 MW as on 31-12-1950 rose to 1,32,110.21 MW as on as on 30-04-2007. Of the total power generating capacity, about 64.7% is thermal based. This will be around 85,575.84 MW, out of which 70,682.38 MW is produced by coal based thermal power plants. About thirty five percentage of the total power is produced in hydroelectric, nuclear and non conventional sectors. The region wise installed capacity is given in Table 2.4 (CEA, 2007). The total installed capacity by different sources and their percentage is given in Table 2.5 (MOP, 2007a).

Power in India is produced by three major sectors; they are: the central sector, the state sector and the private sector. The percentage of power produced by the different sectors is given in Table 2.6. The State sector contribute to 52.73% while the Central sector's contribution is 34.32% and only 12.95% of the total power is produced by the private sector but this is expected to go up in the coming years.

Table 2.4: Region Wise Installed Capacity (MW) as on 30-04-2007

Region	Hydro	Thermal				Nuclear	Wind/ RES $	Total
		Coal	Gas	Diesel	Total			
Northern	13,000.38	18,027.50	3,323.19	14.99	21,365.68	1,180.00	813.37	36,359.43
Western	6,918.83	22,002.50	5,820.72	17.48	27,840.70	1,840.00	1,874.76	38,474.29
Southern	11,011.71	16,172.50	3,586.30	939.32	20,698.12	1,100.00	4,971.55	37,781.38
Eastern	2,496.53	14,149.88	190.00	17.20	14,357.08	0.00	46.76	16,900.37
N. Eastern	1,221.07	330.00	771.50	142.74	1,244.24	0.00	48.91	2,514.22
Island	5.25	0.00	0.00	70.02	70.02	0.00	5.25	80.52
All India	34,653.77	70,682.38	13,691.71	1,201.75	85,575.84	4,120.00	7,760.60	1,32,110.21

Source: CEA, 2007. *Captive Generating capacity connected to the Grid (MW) = 14,636*

$R.E.S. =Renewable Energy Sources (RES) includes Small Hydro Project (SHP), Biomass Gas (BG), Biomass Power (BP), Urban & Industrial waste Power (U&I), and Wind Energy

Table 2.5: Breakup of Installed Capacity by Different Sources as on 30-04-2007

Sources	Fuel	Capacity (Mw)	Percentage
Total Thermal		85,575.84	64.78
	Coal	70,682.38	53.51
	Gas	13,691.71	10.36
	Oil	1,201.75	0.91
Hydro		34,653.77	26.23
Nuclear		4,120.00	3.12
Renewable		7760.60	5.87
Total		1,32,110.21	100.00

Source: MOP, 2007a

Table 2.6: Breakup of Installed Capacity under Different Sectors as on 30-04-2007

Sector	MW	Percentage
State sector	69,656.60	52.73
Central sector	45,340.99	34.32
Private sector	17,112.62	12.95
Total	1,32,110.21	100.00

Source: MOP, 2007a

As per Central Electricity Authority (CEA) report (CEA, 2004c), by the end of the 11th Plan i.e. 2011-12, it is estimated that the installed capacity requirement to fully meet the demand projected by the 16th EPS would be 2,12,000 MW. To provide availability of over 1,000 units of per capita electricity by year 2012 it had been estimated that need based capacity addition of more than 1,00,000 MW would be required during the period 2002-12.

2.2.1 Thermal Power

From the earlier discussion it is seen that out of the total thermal power generated about 82.6% is the power generated from coal based power plants. The major problem associated with such modes of power generation is low *PLF* and low efficiencies. CEA report (CEA, 2006a) states that the average *PLF* of Indian thermal power plants has been varying from 55% to 75% during year 1991-92 to 2005-06, and the overall thermal efficiency varying from 15% to 30%. The capacity wise *PLF* of these units is given in Table 2.7. As discussed in chapter I, the reason for low *PLF* values is the low operating availability of thermal power plants due to high *Forced Outage* rates in India. Due to high ash contents in coal, such plants produce huge amount of ash and high emissions.

As per CEA report (CEA, 2006b), the total numbers of thermal power plants ending March 2005 were ninety five having an aggregate installed capacity of 67,791 MW. Out of total ninety five, eighty nine were coal fired thermal power plants and five lignite fired and one multi fuel fired plant. These power plants are having a maximum capacity up to 3,000 MW, comprising of units of 20 MW to 500 MW capacities. The units of the size 200/210/250 MW and 500 MW together constitute about 60% of total thermal capacity. These units form the backbone of Indian power industry.

Table 2.7: Capacity Group Wise PLF of Coal Based Indian Thermal Power Plants

Capacity Group (MW)	97-98	98-99	99-00	00-01	01-02	02-03	03-04	04-05	05-06
500	73.69	71.91	77.62	77.59	80.80	82.45	82.36	84.32	82.73
250	81.87	75.25	81.18	81.54	83.89	87.36	86.48	90.19	87.74
200/210	71.13	71.43	74.00	75.28	75.51	78.31	79.44	79.76	79.22
140/150	51.38	44.69	45.32	44.66	46.73	40.41	42.21	55.76	50.52
120	44.07	42.30	41.23	43.35	39,19	43.18	34.86	42.89	44.46
110	44.10	42.91	42.51	43.46	49.00	52.69	53.64	55.92	52.84
100	41.04	54.78	51.77	54.47	56.33	57.42	52.01	50.21	51.27
70/85	34.67	39.63	38.38	33.94	42.70	46.71	49.58	45.62	54.23
62.5/67.5	61.64	57.22	62.94	61.01	59.10	53.83	61.79	66.90	59.41
60	44.64	43.83	45.03	47.04	46.58	45.52	44.00	46.32	42.27
50/57.5	44.62	39.99	44.95	44.06	38.96	39.01	38.99	42.70	35.62
20/40	35.85	33.93	33.14	39.01	37.12	40.62	37.63	39.90	44.65
Total	**64.86**	**64.56**	**67.47**	**68.74**	**69.97**	**72.34**	**72.96**	**74.82**	**73.71**

Source: CEA 2000, 2001, 2002, 2003, 2004b, 2005b, 2006

Out of total ninety five thermal power plants, twenty six power plants having aggregate installed capacity of 7,336.88 MW reported an overall thermal efficiency of less than 25% during 2004-05. These twenty six power plants produced 19,085.27 GWh i.e. 4.5% of the total electrical energy produced by the thermal power plants. Twenty power plants with an aggregate installed capacity of 13,490.00 MW reported an overall thermal efficiency ranging from 25% to 30% and generated 74,913.61 GWh. i.e. 17.66% of total electrical energy generation thermal power plants in the country during 2004-05. Forty nine power plants with an aggregate installed capacity of 46,964.00 MW had an overall thermal efficiency above 30% and produced

3,30,283.19 GWh representing 77.85% of total electrical energy produced during 2004-05 (CEA, 2006b).

From the above discussion and based on the data received from power plants and also energy audits carried out by CEA at various stations (CEA, 2004a) it is seen that large numbers of power plants are operating with *HEAT RATEs* significantly above their design values. The reasons for higher *HEAT RATEs* are mainly lack of adequate stress on efficient operation, part load operation of the units, outage of unit HP heaters, etc. The *auxiliary power consumption* in Indian thermal power plants has been observed to vary from 8% to 14% and in majority of cases; there is scope to reduce this to below 10%. The *auxiliary power consumption* depends on type of fuel, unit size, efficiency of auxiliaries, *PLF* etc. Low *PLF* increases percentage auxiliary consumption as the plant auxiliaries are optimized for full load operation in most of the power plants. The performance of thermal power plants including total installed capacity in MW, power generated in million units, *PLF, auxiliary power consumption, specific coal consumption* and *specific oil consumption* for the last ten years is given in Table 2.8.

A major problem associated with the usage of coal as a fuel is its impact on the environment notably, the greenhouse and other toxic components of the flue gases. A study carried out by Parikh and others (Parikh *et al.* 2004) at four Indian thermal power plants revels that if the system auxiliary consumption is restricted to 8% or less, the cost savings are Rs. 1,023 Million annually and there is a reduction in CO_2 emissions to the tune of 2,18,000 tonnes per year.

As far as Gas based power plants are concerned, in all there are thirty five plants operating under Central Sector, State Sector and Private Utilities as on 31-3-2006 comprising 147 units of total capacity 8211.9 MW. Use of combined cycle is being promoted for energy conservation because of higher efficiencies as compared to coal based power plants. In addition, economic aspects show a high return on investment with combined cycle gas based plants, twenty three combined cycle power projects are operating as on 31-3-2006 (CEA, 2006a).

Table 2.8: Performance of Coal Based Indian Thermal Power Plants (last 10 years)

Year	Cap. (MW)	Gen (MU)	PLF (%)	Aux. Power Cons (%)	Sp. Coal Cons. (kg/ kWh)	Sec. Fuel Oil Cons. (ml/ kWh)
96-97	51,103	2,84,886	64.55	8.91	0.73	4.36
97-98	52,848	2,97,601	64.86	8.86	0.73	3.45
98-99	54,853	3,06,000	64.56	8.79	0.72	3.50
99-00	56,154	3,29,431	67.47	8.81	0.71	3.59
00-01	57,923	3,49,281	68.95	9.01	0.71	2.75
01-02	59,902	3,65,253	69.97	8.72	0.70	2.70
02-03	61,152	3,83,379	72.34	9.55	0.71	0.68
03-04	62,727	3,98,412	72.96	9.91	0.70	2.30
04-05	64,646	4,15,484	74.82	8.57	0.71	1.37
05-06	66,449	4,26,138	73.71	8.44	0.70	1.77

Source: CEA, 2006a

2.2.2 Hydro Electric Power

In order to meet the growing power demand, one of the options is hydro electric power plants. With the installed capacity of 34,653.77 MW as on 30-04-2007, hydro electric power plants contribute to 26.23% of total installed capacity of India (MOP, 2007a). According to MNES report (MNES, 2005), the 50,000 MW hydro initiatives have already been launched in May 2003 for the development of 162 new hydro electric projects spread across sixteen states with an aggregate capacity of 48,000(47,930) MW.

Hydel projects call for comparatively larger capital investments. Therefore, debt financing of longer tenure would need to be made available for hydro projects. At the same time large hydro power plants involve severe ecological imbalance and displacement of human habitat for the land also creates more problems (Tehri and Sardar Sarovar projects are the best examples). Reports also suggest that these power plants are inducing seismic activity in the region. The intensity of these problems is increasing exponentially with increase in power requirement due to increasing population and development in technology (MNES, 2005).

2.2.3 Nuclear Power

Nuclear power is an established source of energy to meet base load demand. As on 30-04-2007, India's Nuclear power installed capacity is 4,120 MW. These reactors are operated by Nuclear Power Corporation of India which works under the Department of Atomic Energy. Share of nuclear power in the overall capacity profile will need to be increased significantly. India is vigorously pursuing an accelerated growth path to improve the share of nuclear energy in the overall power scenario.

Compared to coal, nuclear power is at an economic disadvantage for base load generation. Furthermore, the investment required to develop a competitive nuclear power industry would be high (Kakodkar, 2006).

2.2.4 Renewable Energy

India is blessed with abundant sources of renewable energy which can be perfectly suited to complement the conventional energy sources. Feasible potential of non-conventional energy resources, mainly small hydro, wind and bio-mass would also need to be exploited fully to create additional power generation capacity. The potential and currently installed capacities of various alternatives available to meet the growing demand mainly on renewable side are as given in Table 2.9.

Table 2.9: Cumulative Potential and Installed Capacity of Grid Interactive Renewable Power as on 31-12-2005

Source / Systems	Estimated Potential (MW)	Cumulative installed Capacity (MW)*
Wind Power	45,000	4,434.00
Biomass Power	16,000	376.00
Bagasse Co-generation	3,500	491.00
Small Hydro (up to 25 MW)	15,000	1,747.98
Waste to Energy	2,700	45.76
Solar photovoltaic	20 MW per sq. km.	2.80
	Total	**7,097.54**

(*as on 31-12- 2005) Source: MNES, 2005

The Indian Renewable Energy program is well established, having been constituted under the Department of Science and Technology before being transferred to the Department of Non-Conventional Energy Sources in 1982. The Department was upgraded to the Ministry of Non-Conventional Energy Sources (MNES) in 1992 and MNES has since worked with the Indian Renewable Energy Development Agency (IREDA), created in 1987, to accelerate the momentum of renewable energy development. The promotion has been achieved through R&D, demonstration projects, government subsidy programmes, programmes based on cost recovery supported by IREDA and also private sector projects (MNES, 2005). The potential of different renewable energy sources are discussed in the following paragraphs.

2.2.4.1 *Solar Power*

India receives a good level of solar radiation; as per TEDDY report (TEDDY, 2005), the solar radiation falling over India is about 5,000 trillion kWh/year. There are about 300 clear sunny days in a year in most parts of the country. The average insolation incident over India is about 5.5 kWh per square meter over a horizontal surface.

Solar thermal and solar photovoltaic technologies are both encompassed by the Solar Energy Program that is being implemented by the MNES. Solar photo voltaic technology is one of the fastest growing technologies among all non-conventional energy techniques. A program for demonstration and utilization of photovoltaic systems in India began in 1983. Since then numerous applications of the technology have been developed and demonstrated in the country.

A country wide solar photovoltaic programme is being implemented by the MNES for about last two decades. The programme is aimed at developing the cost effective photovoltaic technology and its applications for large scale diffusion in different sectors, especially in rural and remote areas.

2.2.4.2 *Wind Power*

Wind energy, is the most prominent of all the renewable energy resources. The country has a gross potential of over 45,000 MW, the technical potential estimated is about 13,000 MW. Out of which 4,434 MW is harnessed till the end of December 2005 (MNES, 2005).

Potential locations with abundant wind have been identified in the flat coastal terrain of southern Tamilnadu, Kerala, Gujarat, Lakshadweep, Andaman & Nicobar Islands, Orissa and Maharashtra. Other favorable sites have also been identified in some inland areas of Karnataka, Andhra Pradesh, Madhya Pradesh, West Bengal, Uttar Pradesh and Rajasthan. With the assumption of a 20% grid penetration, it has been estimated that 9,000 MW of potential is already available for exploitation in such states. Most of the Indian wind power generation capability has been developed in Tamil Nadu (53%), Maharashtra (22%), Gujarat (10%), Karnataka (7%) and Andhra Pradesh (5%).

The main advantages of wind power are short gestation period, zero fuel cost and employment generation. At good windy sites, it is competitive with traditional fossil fuel generation technologies including coal. The environmental benefits of installing wind farms are reduction in emissions of CO_2 (2100 MT/MW), SO_2 (2.5 MT/MW) and NO_x (1.7 MT/MW) and total suspended particulate (0.5 MT/MW) (Pohekar *et al*, 2004).

2.2.4.3 Small Hydro Power

After wind, the next easy option is small hydro power plants. India has a century old history of hydro power, and the beginning was from small hydro. The first hydro power plant (130 kW), set up in Darjeeling during 1897, and marked the development of hydro power in the country. With the advancement of technology, and increasing requirement of electricity, the thrust of electricity generation was shifted to large size hydro and thermal power stations. However, during the last ten to fifteen years there is a renewed interest in the development of small hydro power projects due to their benefits - particularly concerning the environment, and their ability to produce power in remote areas. Small hydro projects are economically viable and have a relatively short gestation period. The major constraints associated with large hydro projects are usually not encountered in small hydro projects (MNES, 2005).

Small hydro plants are the plants having capacity up to 25 MW. There is an estimated potential of 15,000 MW of small hydro in the country. Of this, 4,233 potential sites with an aggregate capacity of 10,477 MW have been identified. The potential is observed in all the states while the highest being from the Himachal Pradesh. A capacity addition of 600 MW during 2002–07 is being targeted through a mix of public and private sector projects (Saxena, 2005). Table 2.10 gives the scenario of small hydro power projects of the country.

Table 2.10: Small Hydro Plants (Up to 25 MW Scene)

Item	Capacity (MW)
Overall potential	15,000
Identified potential (4404 Sites)	10,477
Installed capacity (529 Projects)	1,729
Under construction (203 Projects)	602
Target capacity addition tenth plan (2002-2007)	600

Source: MNES, 2005

2.2.4.4 *Biomass*

The technology for generation of electricity from biomass materials is similar to conventional coal based thermal power generation. The technology for use of biomass for power generation is fairly well established in the country.

Various studies have indicated that at least 150 - 200 million tonnes of biomass materials, comprising agricultural and agro-industrial residues are produced every year. Such material does not have much productive use, and can be made available for alternative uses at an economical cost. This quantity of biomass has the potential to generate 16,000 MW of power as stated in Table 2.9. In addition, the biomass grown on wastelands, road, rail track - site plantation, etc., can used to generate electricity of the order of 70,000 MW (Sukumaran, 2005). The power generation potential by Bagasse cogeneration is estimated about 3500 MW.

2.3 REMARKS

The growth rate of Indian economy is one of the fastest in the world. The policy makers are planning to maintain and, if possible, increase this impressive growth rate. The prerequisite for a booming economy is the supply of high quality and affordable power, due to this reason in the coming years India along with China will be the largest consumers of electric power.

As of now the lion's share of India's power production is borne by thermal power stations in general and coal based thermal power plants in particular. India has significant amount of coal reserves so the fuel used in most of these power plants is coal, this trend is likely to continue since the prices of other fossil fuels are sky rocketing day by day. India stands eighth in the world with estimated coal reserves of 211 bn tonnes which is enough to meet India's power needs for at least another 100 years (MOC, 2000). It ranks the third largest coal-consuming country in the world, behind China and the United States (Choudhary, 1998). It accounts for about 8 per cent of the world's annual coal consumption and about 7.5 per cent of the world's annual coal production. Nearly three-quarters of India's electricity and two-thirds of its commercial energy comes from coal, and the demand for coal has been steadily increasing over the past decade. So, coal is likely to dominate as the reliable source for generation of electricity in India even in the future.

At the same time the growing power demand can be met more easily, only if available installed power generating capacity is effectively utilized adopting refined operating and maintenance practices. It has been analyzed that by improving and monitoring operating procedures lot of the energy could be saved. In many cases, outdated equipments and processes consume more power than required due to inefficient operations as compared to Western countries.

According to Soni *et al* (Soni *et al,* 2006a), improving efficiency of existing power plants is the easiest way to make rapid strides in electricity because at present, the efficiencies of thermal power plants are low. It is estimated that 1% reduction in plant efficiency (or 1% decrease in *HEAT RATE*) amounts to annual loss of the order of 40 million INR for a 210 MW unit or 100 million INR for 500 MW on fuel cost alone for a pit head station. Even at 0.5% increase in boiler efficiency can result in a substantial saving of 8 million INR per annum for a typical 500 MW boiler.

From the discussion up to this point it is certainly clear that coal based thermal power plants are going to dominate the future of power generation in India. At the same time these power plants have lot of potential for improvements in their performance as well as reduction in CO_2 emission in order to become energy efficient. So in order to get the exact picture it is necessary to evaluate the Energy Efficiency improvement and CO_2 emission reduction potential from these power plants. This has been attempted in the next chapter.

CHAPTER III

ENERGY EFFICIENCY AND CDM POTENTIAL IN COAL BASED INDIAN THERMAL POWER PLANTS

Efficient use of energy is the most important, economical, prompt, underused, overlooked, reliable, affordable and clean way to provide future energy services. Energy Efficiency can displace costly and disagreeable energy supplies, enhance security and prosperity, speed global development, and protect earth's climate by reducing CO_2 emissions, not at cost but at a profit. In this chapter essentials of Energy Efficiency with its advantages and barriers are disused. The CDM and Energy Efficiency potential in CBITPPs have been assessed with the help of methods presented in empirical studies. The total Energy Efficiency improvement and CO_2 emission reduction potential has been evaluated and presented here.

3.1 INTRODUCTION

As per discussion in previous chapter it is seen that the present Indian energy scenario is dismal. The present per capita power consumption in India corresponds to the consumption of USA a few decades back. It has been estimated that the need based capacity addition of more than 1,00,000 MW would be required during the period 2002-12 to meet the growing energy requirements (MOP, 2007a).

As per the CEA report (CEA, 2006c), the present supply-side picture in India is alarming. India has one of the highest transmission and distribution (T&D) losses in the world. It ranges from 15-35%, whereas, China which is economically comparable to India has their national T&D loss at 14%, and international losses are lower at 8-

12%. The *auxiliary power consumption* in the generating utilities is about 9% (about 7.81% in central sector, 7.27% in private sector and 9.4% in state sector) of total generation in our country, which has a lot of scope for reduction. In earlier discussion it has been observed that the *PLF* of the CBITPPs is one of the lowest. The state sector has *PLF* of about 67.3% while central sector has 81.91% and private sector 85.37% with a national average of 73.71%. So with more *auxiliary power consumption,* poor performance, low *PLF* and high T&D losses indicate that there is a huge potential for improvement in Energy Efficiency of Indian thermal power industry. World Energy Council's report (WEC, 2001) indicates that a 10 percent reduction in T&D losses in India would release enough power to wipe out power shortage. Equally, better utilization of coal in power plants, better thermal efficiency, high *PLF* and minimum *auxiliary power consumption* could help step up power generation further.

Efficient use of energy provides multiple advantages both to power industry and the economy. It helps to cut down costs of production and increase power generation. The economy benefits from being cost efficient. Energy savings on a national scale also go a long way in minimizing energy shortages and making the best possible use of fossil fuels. A reduction in ash content in the coal supplied (which is very high in Indian coal) could significantly improve the performance of the thermal power plants. In order to improve the performance of a plant, Khosla in his book (Khosla, 1994) suggested some of the measures as follows:

- Avoidance of wastage and wasteful uses such as good house keeping measures and regular maintenance;
- Substitution of costly and exhaustible sources of energy such as oil, by new and renewable energy sources and by relatively abundant energy sources like coal;

- Adoption of total energy systems such as integration of all thermal operations, etc.;
- Recycling of energy waste through various waste heat recovery systems;
- Retrofitting of old machinery to achieve optimal energy utilization;
- Improving efficiency of conversion of primary fuels into secondary forms of energy, ensuring quality of energy supplied and minimizing transmission and transport losses;
- Adoption of material conservation measures to reduce the consumption of energy intensive materials and products along with recycling of materials and reusing of components;
- Adoption of preventive maintenance techniques to cut down the energy and materials costs involved in routine overhauls and breakdowns;
- Instrumentations of industrial process to monitor energy use; and
- Intensive research on viable energy alternatives and less energy intensive techniques.

3.2 ESSENTIALS OF ENERGY EFFICIENCY

In the 1997 Kyoto Protocol, the European Union (EU) member states committed themselves to an 8% reduction in greenhouse gas emissions by 2012. This may not seem like much. However, given that emission trends have been pointing upwards for years, the challenge is formidable: in practice, the 8% reduction means that the EU has to reduce its emissions by 20-30% compared to a business-as-usual scenario (Soni *et al*, 2006b).

In order to fulfill the goals of the Kyoto Protocol, an increasing share of the energy supply must come from renewable energy sources such as solar, wind and biomass. However, if energy demand keeps increasing, it will be virtually impossible to satisfy our needs with renewable sources alone. Energy Efficiency is the cornerstone of a sustainable society. Also as shown in Fig. 1.1 in chapter I, it has been observed that Energy Efficiency is one of the best solutions to growing energy problems.

Guthrie and Mitchel in their paper (Guthrie and Mitchel, 2005) defined each watt saved by Energy Efficiency as "negawatts". With today's energy prices, a negawatt of energy saving costs about half of what it costs to produce the same amount of energy. It is the cheapest, most competitive, cleanest and most secure form of energy.

As per Paterson (Paterson, 1996), Energy Efficiency is a generic term, and there is no one unequivocal quantitative measure of Energy Efficiency. The term Energy Efficiency refers to using less energy to produce the same amount of services or useful output. Hence, Energy Efficiency is often broadly defined as the ratio of Useful output of a process to the energy input into a process. Here the 'useful output' of the process need not necessarily be an energy output. It could be a tonne of product or some other physically defined output, or it could be the output enumerated in terms of market prices.

Energy Efficiency as mentioned earlier is delivering the same (or more) services for less energy, also helps to protect the environment. When less energy is used, the less energy needs to generate at power plants, which reduces greenhouse gas emissions and improves the quality of the air. Energy Efficiency helps the economy too, by saving consumers and businesses millions of dollars in energy costs. Energy efficient solutions can reduce the energy bill for many homeowners and businesses by 20 to 30 percent (Energystar, 2007).

Energy Efficiency also contributes to economic and social prosperity. Energy is a costly production factor for India's economy. Increased Energy Efficiency contributes to energy security and will make India more competitive in an increasingly globalizes world.

3.3 ADVANTAGES OF ENERGY EFFICIENCY

Following are the prominent advantages of Energy Efficiency:

- It can reduce energy costs. Indian power plants have very high secondary fuel oil consumption, recorded as 10 ml/kWh for some power plants in the year 2004-05 (CEA, 2005b).
- It can help to improve quality of output. Controls, for example, often address both energy use and product characteristics and flows. Improved steam management can ensure that the steam at proper temperature and pressure will be available. Better energy management also means that one can ensure a more reliable supply of energy, which is critical to many production processes. Many plants, for example, can lose millions of dollars, in a moment if energy is shut off. Both Energy Efficiency and product quality are closely related to effective maintenance and attention to operational detail.
- It can help to improve overall reliability. Developing an Energy Efficiency program will help to prepare a plant-wide energy strategy with rationalized demand of energy. Reduced auxiliary power consumption or coal and secondary oil consumption will mean that there is a need to purchase less energy.
- It can have corollary benefits such as reduced maintenance costs and improved worker safety. Many energy efficient technologies are more reliable than their inefficient counterparts. Fluorescent lighting, for example, requires less maintenance and fewer replacements than incandescent lighting. Likewise, repairing steam leaks and insulating steam lines can make steam

system safer for the operators who work around it. This in turn can improve morale and productivity.

- It can help to reduce pollution. In addition to helping the environment, reducing pollution can reduce environmental fees and fine (Evans, 1999).

Ultimately, it can be said that Energy Efficiency is a starting point to improve business.

3.4 BARRIERS TO ENERGY EFFICIENCY

Some of the important barriers identified by Ramachandran (Ramachandran, 1998) for promoting Energy Efficiency in India are listed below. These are further discussed in the Appendix-A.

- High cost of energy efficient equipment
- Limited availability of energy efficient technologies
- Resource constraints
- Lack of information or awareness
- Energy labeling and standards
- Lack of expertise
- Quick payback requirements
- Small scale manufacturing market
- Simple solutions not undertaken
- Lack of expertise for transfer of technology
- Problem with quality of power supply.

3.5. ENERGY SAVING MEASURES IN COAL BASED INDIAN THERMAL POWER PLANTS

In order to understand and determine the potential of possible improvements in Energy Efficiency of CBITPPs, the study of various losses occurred and possible saving measures are studied. In this study especially different thermo-mechanical components have been included. Only those energy conservation measures which relate thermo-mechanical components are taken under consideration for the study. Boiler, turbine, condenser and cooling tower and their auxiliaries are the thermo-mechanical components which have been considered (Soni *et al,* 2006a). These measures are discussed in Appendix-B.

3.6 CLEAN DEVELOPMENT MECHANISM

The Kyoto protocol, signed by Japan, Russia and Europe, requires developed countries to reduce GHG emissions by 5% in 2010 compared to the emissions of 1990. Energy Efficiency and renewable energy have been highlighted for promotion to achieve this objective (EWI, 2005).

The CDM under the Kyoto Protocol to United Nations Framework Convention on Climate Change (UNFCCC) gives an opportunity to developing countries in achieving their sustainable development objective. Besides providing an additional opportunity to introduce new and efficient technologies and earn revenue in the form of selling Carbon Credits to developed countries.

The CDM provides an opportunity for the Indian power sector to earn revenue through the reduction of GHG, particularly carbon dioxide (CO_2). India has tremendous potential for CDM projects, particularly in the power sector.

Power generation based on higher efficiency technologies such as supercritical technology, integrated gasification combined cycle, and Renovation and Modernization (R&M) of old thermal power plants, co-generation along with renewable energy sources are some of potential candidates for CDM in the power sector. Energy Efficiency and conservation projects also present themselves as eligible CDM projects, as these would also result in energy savings and displace associated CO_2 emissions which otherwise would be produced by grid-connected power stations. (Soni *et al*, 2006b)

According to The Energy and Resources Institute (TERI) (TEDDY, 2002-03), about 30,000 MW of the total installed capacity of coal based thermal power plants is in need of some form of R&M in India. In fact, almost 15,000 MW worth of coal based thermal power plants are operating at *PLF* levels below 45%. Renovation and Modernization of these plants can yield, in the short-term, an output increase equivalent of 5,000 MW in new capacity.

From the earlier and above discussion it is clear that there is a great potential for improvement in the performance of coal based Indian thermal power plants. The potential for improvement in Energy Efficiency and CO_2 emission reduction has been determined in the subsequent sections.

3.7. AN OVERVIEW OF DETERMINING ENERGY EFFICIENCY IMPROVEMENT AND CO_2 EMISSION REDUCTION POTENTIAL

Within the power industry, Energy Efficiency comparisons can be used as a tool to assess a plant's performance relative to that of other plants and also it can help to make an estimate of the magnitude of the avoided energy consumption and emissions. Estimation of Energy Efficiency improvement potential in industries including power industry has been done by various authors as seen in the literature. These studies have been discussed below.

Phylipsen *et al* (Phylipsen *et al*, 2002) assessed the Dutch energy-intensive industry's relative Energy Efficiency performance. The Energy Efficiency of the Dutch industry is evaluated relative to the industries in countries worldwide. The assessment of the energy consumption and CO_2 emissions is done by comparing the current level of Energy Efficiency of the Dutch industry - including electricity production - to that of the most efficient countries and regions. The assessment of the avoided energy consumption and emissions is based on the difference between the current Energy Efficiency levels of Dutch Industry and the level of Energy Efficiency attained in the currently most efficient plant. As a result, the calculated energy savings and emission reductions represent an amount of energy and CO_2 emissions that would have been avoided in the hypothetical case that industry currently would have been required to be among the most efficient one.

The methodology used in the study done by Phylipsen *et al* to estimate the Energy Efficiency of the industry has been published in the 'Handbook on International Comparisons of Energy Efficiency in the Manufacturing Industry' (Phylipsen *et al*, 1998). Here, the actual Specific Energy Consumption (*SEC*) i.e. energy consumption per tonne of product output, is compared with a reference *SEC* that is based on the given sector structure. This means that both the actual *SEC* and the reference *SEC* are similarly affected by changes in sector structure. Here, the reference *SEC* is defined as the *SEC* of the best commercially operating plant observed worldwide (also referred to as 'best plant'). The selection of the best plant is based on an extensive survey of literature and exchange of information within the network during those years. Especially countries that are generally considered to be among the most efficient, such as Japan, South Korea, Germany and the Netherlands have been thoroughly analyzed. It cannot be guaranteed, however, that there is no single plant with a lower *SEC* than the ones which are used for comparison. The difference with the best plant as identified in the analysis, however, is not expected to be large, because generally the industries considered are mature industries, in which technological development (for Energy Efficiency purposes) occurs in small, incremental steps. Such a best plant is defined for each type of industry and the sectoral value is calculated as the weighted average, based on the shares of the various processes and products according to Eq. (3.1).

$$EEI_a = 100 \times \frac{SEC_a}{SEC_{ref,a}} \text{ --------- } (3.1)$$

In which EEI_a is the Energy Efficiency Index for sector *a*, SEC_a the Specific Energy Consumption for sector *a*, $SEC_{ref,a}$ the reference Specific Energy Consumption for sector *a*.

The difference between the actual and reference *SEC* is used as a measure of Energy Efficiency, because it shows which Energy Efficiency level would be achieved in a country with a particular sector structure in case only best plant technologies would be used. The smaller the difference, the better is the Energy Efficiency. The relative differences between actual and reference *SEC* can be compared between countries. Usually this is done by calculating an Energy Efficiency Index (*EEI*): the ratio between actual *SEC* and reference *SEC*. If only best plant technology is used within a sector, the *EEI* would equal 100. An *EEI* of 105 means that the *SEC* on average is 5% higher than the reference level, so that 5% of energy could by saved at the given sector structure by implementing the reference level technology.

In another study done by Birchfield (Birchfield, 2000) with Solomon Associates has offered Energy Efficiency evaluation capabilities to hydrocarbon industries (refineries and chemical plants). The tool covers many areas of production, including energy, which is the largest operating expense at many plants. Here Energy Efficiency has been evaluated using a metric called the Energy Intensity Index (EII). In this approach, standard energy consumption factors are developed for each process unit in the hydrocarbon industry. For each facility, the throughput of materials at each unit is multiplied by the consumption factor. These values are then summed across all units to give a standard energy consumption value for the plant. Actual plant energy use is divided by this value to yield a percentage called the EII. Solomon promotes its benchmarking tool as a source of information and as an incentive for process improvements. Their indices can, without revealing proprietary information, provide information on the state-of-the-art performance in an industry and tell an individual plant how it compares to other plants and to its own past performance. Knowledge that more efficient plants exist in an industry coupled with the desire for process improvements and cost savings can drive gains in Energy Efficiency. Several companies now offer benchmarking programs for other industries.

Worrell and Price (Worrell and Price, 2006) have done similar kind of evaluation for Iron and Steel Industry. They have developed an integrated benchmarking and Energy Efficiency evaluation tool, named Benchmarking and Energy Savings Tool (BEST).

In designing an evaluation tool that compensates for production differences, it is necessary to take a look inside the production processes and account for the various steps used. BEST has been developed to support two Chinese integrated iron and steel plants in designing a strategic energy management program. In this, the key process steps are identified and a benchmark performance is assigned to each step. The performance of a plant is then compared incorporating information about how each step is used by the plant.

In order to determine the technical energy-efficiency potential for an iron and steel plant, the plant process-step total production energy intensity is compared to the process-step energy intensity of a reference "state of the art" iron and steel plant. Such references can be constructed using either a hypothetical energy-efficient steel plant or selecting to an actual energy-efficient steel plant.

BEST uses data from a hypothetical best practice plant. Data for the construction of a hypothetical energy-efficient steel plant are available from the International Iron and Steel Institute (IISI). The IISI study provides data for both a hypothetical "All-Tech" plant that includes technologies that may not be currently economical but lead to significant energy savings and a hypothetical "Eco-Tech" plant that is based on the use of technologies and measures that are considered economic. These values can be used to construct a benchmark "All-Tech" or "Eco-Tech" comparable energy intensity. The difference between this benchmark value and the total production energy intensity values for each pilot plant can be considered to represent the technical energy-efficiency potential.

Once the actual energy intensity and reference energy intensity have been calculated for each plant, they can be used to construct an *EEI*. The *EEI* is a measurement of the total production energy intensity of a plant compared to the reference energy intensity. The *EEI* can be used to calculate the energy-efficiency potential at a plant and it can be used for evaluating plant progress in Energy Efficiency improvement, by eliminating the effects of a change in product mix.

The *EEI* can be used to calculate plant energy-efficiency potential by comparing actual plant energy intensity to the energy intensity that would result if the plant used "state of the art" technology for each process step. The difference between the actual energy intensity, which is the energy use per tonne of product produced, and that of the reference technology, is calculated for each of the key process steps of the plant and then aggregated for the entire plant. The aggregated *EEI* is calculated as follows (Eq. 3.2):

$$EEI = 100 * \frac{\sum_{i=1}^{n} P_i \cdot EI_i}{\sum_{i=1}^{n} P_i \cdot EI_{i,B}} = 100 * \frac{E_{tot}}{\sum_{i=1}^{n} P_i \cdot EI_{i,B}} \text{ -------- } (3.2)$$

Where:

EEI = Energy Efficiency Index
n = number of process steps to be aggregated
EI_i = actual energy intensity (EI) of process step i
$EI_{i,B}$ = Reference energy intensity (EI) of process step i
P_i = production quantity for process step i
E_{tot} = total actual energy consumption for all process steps

The *EEI* provides an indication of how the actual total production energy intensity of the plant compares to the reference energy intensity. By definition, a plant that uses the reference or "state of the art" technology will have an *EEI* of 100. In practice, all plants will have an *EEI* greater than 100. The gap between actual plant energy intensity at each process step and the reference level energy consumption can be viewed as the technical energy-efficiency potential of the plant. BEST is an initial screening tool that helps to identify which processes are most efficient and which are most inefficient compared to "state of the art" conditions and which are most likely to have a substantial potential for Energy Efficiency improvement.

3.8 METHODOLOGY ADOPTED TO DETERMINE ENERGY EFFICIENCY IMPROVEMENT AND CO_2 EMISSION REDUCTION POTENTIAL IN COAL BASED INDIAN THERMAL POWER PLANTS

3.8.1 Energy Efficiency Improvement Potential

In electricity generation, it is common to think of energy intensity in terms of energy used per kilowatt-hour of electricity generated. In order to determine Energy Efficiency potential in the CBITPPs the approach used by Phylipsen *et al* (Phylipsen *et al*, 2002) is followed. The performance of the power plant is evaluated relative to the reference power plant. The assessment of the energy consumption and CO_2 emissions is done by comparing the current level of Energy Efficiency of a coal based thermal power plant to that of the most efficient power plant. For the analysis the CBITPPs are grouped into the following groups:

A) Up to 250 MW,
B) 250-500 MW,
C) 500-750 MW,
D) 750-1000 MW and
E) 1000 MW and above.

The assessment of the avoided energy consumption and emissions is based on the difference between the current energy-efficiency levels of the power plant of each group with that of the Energy Efficiency attained in the currently most efficient plant. Here in the groups mentioned above, the power plant which is having the minimum Specific Fuel Consumption (*SFC*) is considered to be the reference plant or 'best plant' in that particular group. The actual *SFC* i.e., fuel consumption per unit of power output (kg/kWh), is compared with a reference *SFC* of that particular group.

The *EEI* for a group *a* is calculated using following Eq. 3.3

$$EEI_a = 100 \times \frac{SFC_a}{SFC_{ref.a}} \text{ ------ } (3.3)$$

In which EEI_a is the Energy Efficiency Index for power plant of the capacity up to 250 MW, SFC_a is the Specific Fuel Consumption i.e. amount of coal consumed in kg per kWh of plant output for plants having capacity up to 250 MW, $SFC_{ref,a}$ is the reference Specific Fuel Consumption for the same group.

The difference between the actual and reference *SFC* is used as a measure of Energy Efficiency, because it shows which Energy Efficiency level would be achieved in a particular group in case only best plant technologies would be used. The smaller the difference, the better is the Energy Efficiency.

As a result, the calculated energy savings and emission reductions represent an amount of energy and CO_2 emissions that would have been avoided in a particular case that plant currently would have been required to be among the most efficient one.

In this work the *EEI* is calculated for all the power plants as per the groups for the year 1999-2000, 2000-2001, 2001-2002, 2002-2003, 2003-2004, 2004-2005, and 2005-2006. After Calculating *EEI* for each group, the equivalent coal savings in tonnes is calculated.

3.8.2 CO_2 Emission Reduction Potential

In our earlier discussion it is seen that the installed capacity is predominantly coal based and therefore, is a major source of CO_2 emissions in India. Also it has been discussed that many plants are operating inefficiently. Hence, there exists scope for reducing the CO_2 emissions by improving the thermal efficiency of power generation.

CO_2 emissions of thermal stations are calculated using the Eq. 3.4 suggested by CEA (CEA, 2007b) with calculation approach being station level

$$AbsCO_2(station)_y = \sum_{i=1}^{2} FuelCon_{i,y} \times GCV_{i,y} \times EF_{i,y} \times Oxid_{i,y} \text{-------(3.4)}$$

Where:

$AbsCO_{2,y}$: Absolute CO_2 emission of the station in the given fiscal year y

$FuelCon_{i,y}$: Amount of fuel of type i consumed in the fiscal year y

$GCV_{i,y}$: Gross calorific value (GCV) of the fuel i in the fiscal year y

$EF_{i,y}$: CO_2 emission factor of the fuel i in the fiscal year y

$Oxid_{i,y}$: Oxidation factor of the fuel i in the fiscal year y

The emission factors for coal and lignite are based on the values provided in India's Initial National Communication under the UNFCCC (MOEF, 2004). The emission factor for coal is supported by the results of an analysis of approximately 120 coal samples collected from different Indian coal fields. Since the values in the National Communication are based on the Net Calorific Value (NCV), they were converted to *GCV* basis using a formula also furnished in the National Communication. For other fuels, default emission factors from Intergovernmental Panel on Climate Change

(IPCC) (also based on the respective fuel's NCV) were taken and converted to GCV basis using IEA default conversion factors (IPCC, 1996).

The oxidation factors are default values provided by IPCC. However, the oxidation factor for coal is supported by a cross-check performed with data on the unburnt carbon in ash from various Indian coal-fired power plants.

3.8.3 Data

During the period of study various CBITPPs across the India have been visited and primary data was collected and for remaining plants data is taken from the reports published by various government agencies, institutions and through personal contacts. The details about the data collection are explained in subsequent chapter. Some sample data from the published reports of CEA has been given in Appendix-C.

For the operation of CBITPPs coal is a primary fuel while oil is used as a secondary fuel. For analysis purpose the *specific oil consumption* has been converted to its coal equivalent and then added to *specific coal consumption*.

3.8.3.1 Conservativeness

The need to ensure conservativeness of calculations in situations of uncertainty is a fundamental principle in the CDM. Assumptions are conservative if they tend to reduce the number of emission reductions being credited to a CDM project activity. The following approaches and assumptions contribute to the conservativeness in calculation of CO_2 emissions of CBITPPs (CEA, 2007b):

- The fuel emission factors and oxidation factors used are generally consistent with IPCC defaults. For coal, the emission factor provided in India's Initial National Communication was used (95.8 t CO_2/TJ on NCV basis), being somewhat lower than the IPCC default for sub-bituminous coal (96.0 t CO_2/TJ).

- Fuel emission factor is considered as 92.5 gCO_2 /MJ for coal and 98.8 gCO_2/MJ for lignite on *GCV* basis.
- Oxidation Factor is considered to be 0.98 for coal and lignite.

Wherever the data is not available:

- *HEAT RATE* is calculated assuming *GCV* of coal as 15,721 kJ/kg (3,755 kcal/kg), while *GCV* of secondary oil is considered as 41,868 kJ/liter (10,000 kcal /liter). For lignite the *HEAT RATE* is assumed to be 12,619 kJ/kWh (3,014 kcal/kWh).
- *Specific Oil Consumption* is assumed as 2.0 and 3.0 ml /kWh for coal and lignite based plants respectively.
- The data is also projected using regression analysis from the available data.

3.9 SAVING ESTIMATES

The equivalent coal savings and CO_2 emissions reduction potential in thousand tonnes of CBITPPs for the year 1999-2000 to 2005-2006 have been calculated. Table 3.1, Table 3.2 and Fig. 3.1 to 3.5 give the equivalent Energy Efficiency (in terms of coal savings) improvement and CO_2 emissions reduction potential for CBITPPs having capacities varying from up to 250 MW, 250 to 500 MW, 500 to 750 MW, 750 to 1000 MW, and more than 1000 MW capacity respectively. While Fig. 3.6 gives the equivalent Energy Efficiency and CO_2 emissions reduction potential from all the CBITPPs. Table 3.3 gives the number of plants in each group under study.

It has been observed that on an average highest improvement in Energy Efficiency potential is in group E. This is on an average of 18 million tonnes of coal equivalent and CO_2 emission reduction potential to the tune of 25 million tonnes per annum. The reason for such a high potential being that these plants are of capacity ranging from 1,000 MW to 3,000 MW and power output is ranging from 7,700 MU to 21,000 MU. The numbers of power plants in this group are about eighteen to twenty four.

Amongst other groups, group B is having highest Energy Efficiency improvement potential. The reason for this is that the number of power plants in this group is highest i.e. ranging from nineteen to twenty four with a power output up to 4,400 MU. The Energy Efficiency improvement potential is on an average of 8.75 million tonnes of coal equivalent and CO_2 emission reduction potential to the tune of 12.28 million tonnes. In group A though the numbers of power plants are about twelve but saving potential is very low due to their small capacity hence output.

The total Energy Efficiency improvement and CO_2 emissions reduction potential for the period of 1999-2000 to 2005-2006 of CBITPPs is of the order of 288 million tonnes of coal equivalent and 406 million tonnes of CO_2 emissions reduction respectively. This would have been possible if all the plants were operated at par with the 'best plant' of their particular group. The cost of one tonne of CO_2 in the international market is about 22.9 Euros (Point Carbon, 2007) and the equivalent of one euro in INR is 57.8035 (ADVFN, 2007). So the CDM potential mentioned above, had this been realized, would have fetched total of 5,37,000 million INR in the international market as a carbon credit. Table 3.4 gives Equivalent CDM benefit in millions of INR for all the groups during over the period of study.

From the above discussion it is clearly observed that there is enormous scope of improvement in Energy Efficiency in CBITPPs. These improvements will not only save the precious energy reserves but also will help in reducing the green house gas emissions to a very large extent and the benefits of CDM as carbon credits can be availed for the same. Here during calculations, it has been considered that the power plant which is having the lowest *SFC* is the best plant. But in order to declare a plant to be most energy efficient; apart from *SFC*, the effect of other parameters should also be considered like, *Capacity, HEAT RATE, Operational Availability Factor, Auxiliary Power Consumption* and *PLF* etc. After considering these factors the plant which is having the best performance should be considered as the best plant and other plants should then follow the practices of the best plant. So there is a need of benchmarking the CBITPPs and once the benchmarking is done (group wise) then the energy efficient practices which are followed in the best plant can be implemented in others and benefits may be reaped. The benchmarking procedure is explained and analysis is done in the next chapters.

Table 3.1: Equivalent Coal Savings in Thousand Tonnes

Capacity(MW)/ Year	1999-2000	2000-2001	2001-2002	2002-2003	2003-2004	2004-2005	2005-2006
A) Up to 250	1,449.73	1,724.35	1,701.07	1,892.68	1,464.96	1,152.09	1,470.47
B) 250-500	9,384.06	8,167.42	8,141.25	9,043.90	8,214.85	7,953.80	10,329.12
C) 500-750	4,353.89	4,606.90	4,769.49	4,338.87	4,424.55	3,882.76	3,670.26
D) 750-1000	7,820.00	7,791.08	8,519.85	10,941.78	9,676.99	9,559.53	5,299.71
E) 1000 onwards	18,171.32	14,154.30	14,091.43	13,919.22	20,290.11	21,526.05	23,481.94
Total	41,178.99	36,444.05	37,223.10	40,136.45	44,071.47	44,074.24	44,251.50

Table 3.2: Equivalent CO$_2$ Reduction in Thousand Tonnes

Capacity (MW) / Year	1999-2000	2000-2001	2001-2002	2002-2003	2003-2004	2004-2005	2005-2006
A) Up to 250	2,261.49	2,611.88	2,647.67	2,914.85	2,271.40	1,850.72	2,240.21
B) 250-500	13,197.11	11,483.98	11,363.07	12,843.39	11,498.10	11,118.09	14,432.88
C) 500-750	6,409.18	6,627.37	6,981.20	6,642.56	6,448.33	5,755.25	5,473.90
D) 750-1000	10,922.31	11,157.61	11,846.14	14,580.21	13,804.85	13,712.56	7,416.84
E) 1000 onwards	25,003.59	19,758.31	19,335.09	19,041.74	28,495.83	29,936.82	32,992.09
Total	57,793.68	51,639.13	52,173.18	56,022.76	62,518.52	62,373.44	62,555.93

Table 3.3: Number of Plants in Each Group under Study

Capacity /Year	1999-2000	2000-2001	2001-2002	2002-2003	2003-2004	2004-2005	2005-2006
A) Up to 250	14	14	15	14	14	11	12
B) 250-500	24	24	19	19	19	20	20
C) 500-750	8	7	10	9	9	8	8
D) 750-1000	12	14	15	17	14	15	13
E) 1000 onwards	18	18	18	18	21	21	24
Total	76	77	77	77	77	75	77

Table 3.4: Equivalent CDM Benefit in Millions of Indian Rupees

Capacity (MW) / Year	1999-2000	2000-2001	2001-2002	2002-2003	2003-2004	2004-2005	2005-2006
A) Up to 250	2,993.53	3,457.34	3,504.72	3,858.39	3,006.65	2,449.80	2,965.37
B) 250-500	17,469.02	15,201.34	15,041.30	17,000.80	15,220.04	14,717.02	19,104.81
C) 500-750	8,483.83	8,772.65	9,241.02	8,792.76	8,535.65	7,618.22	7,245.80
D) 750-1000	14,457.87	14,769.32	15,680.74	19,299.82	18,273.48	18,151.32	9,817.68
E) 1000 onwards	33,097.25	26,154.08	25,593.87	25,205.55	37,719.94	39,627.37	43,671.64
Total	76,501.50	68,354.73	69,061.64	74,157.33	82,755.77	82,563.73	82,805.29

Fig. 3.1: Equivalent Energy Efficiency Improvement and CO_2 Emissions Reduction Potential for CBITPPs (Group A) having Up to 250 MW Capacity

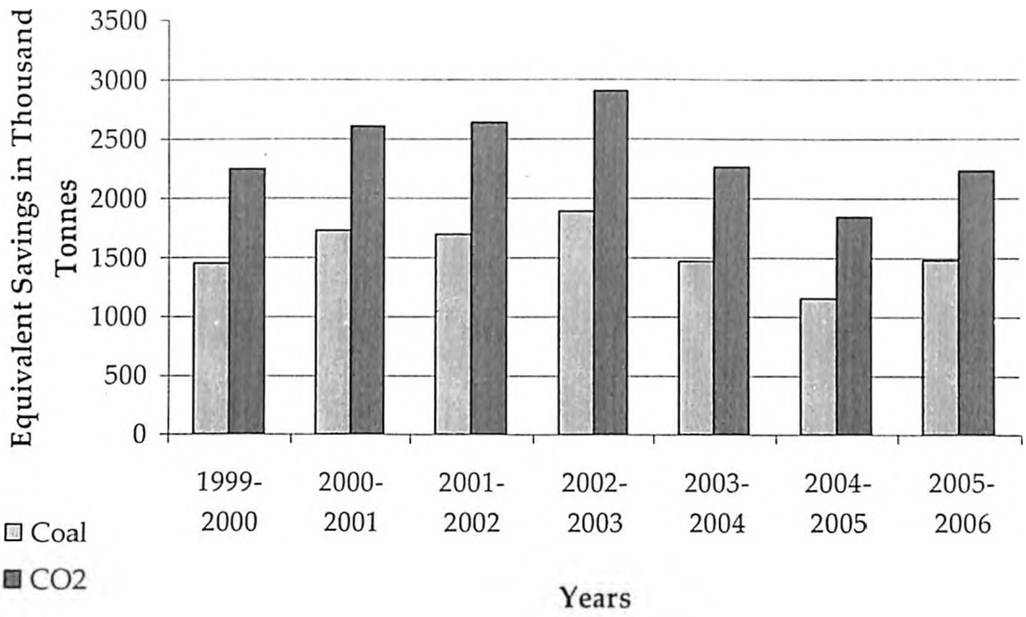


Fig. 3.2: Equivalent Energy Efficiency Improvement and CO_2 Emissions Reduction Potential for CBITPPs (Group B) having 250 to 500 MW Capacity

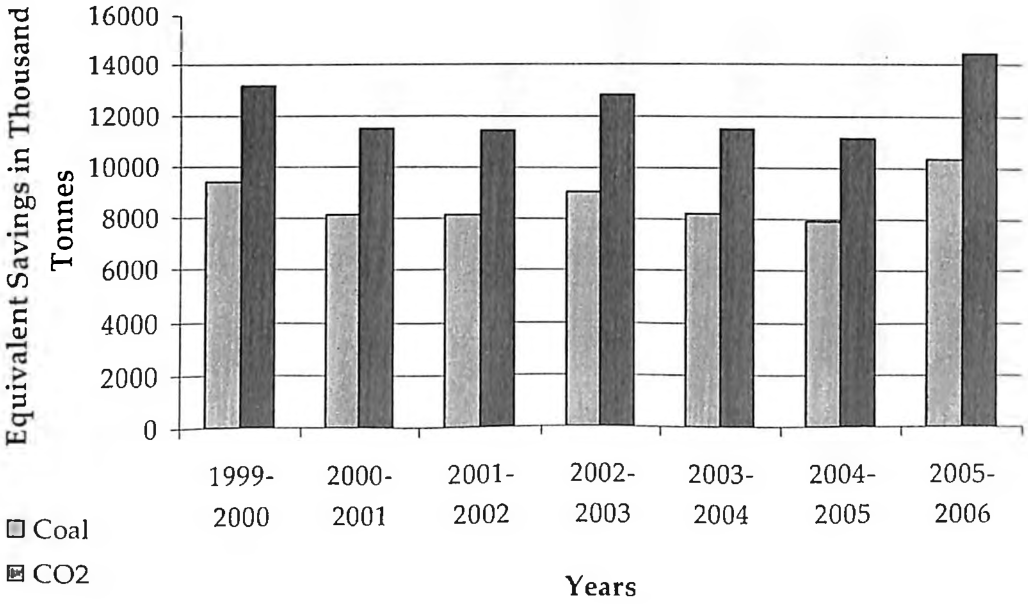


Fig. 3.3: Equivalent Energy Efficiency Improvement and CO_2 Emissions Reduction Potential for CBITPPs (Group C) having 500 to 750 MW Capacity

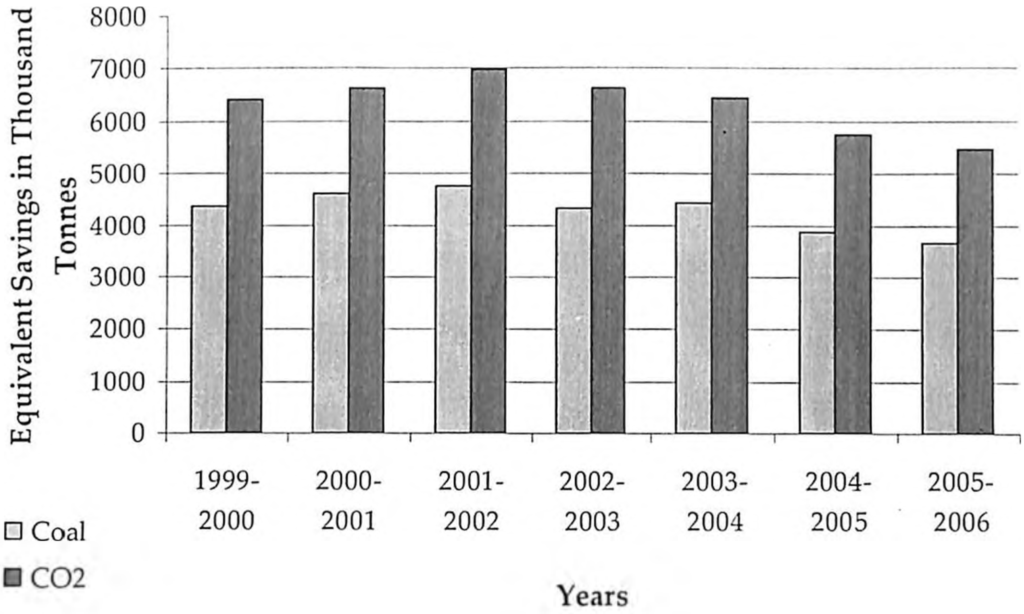


Fig. 3.4: Equivalent Energy Efficiency Improvement and CO_2 Emissions Reduction Potential for CBITPPs (Group D) having 750 to 1000 MW Capacity

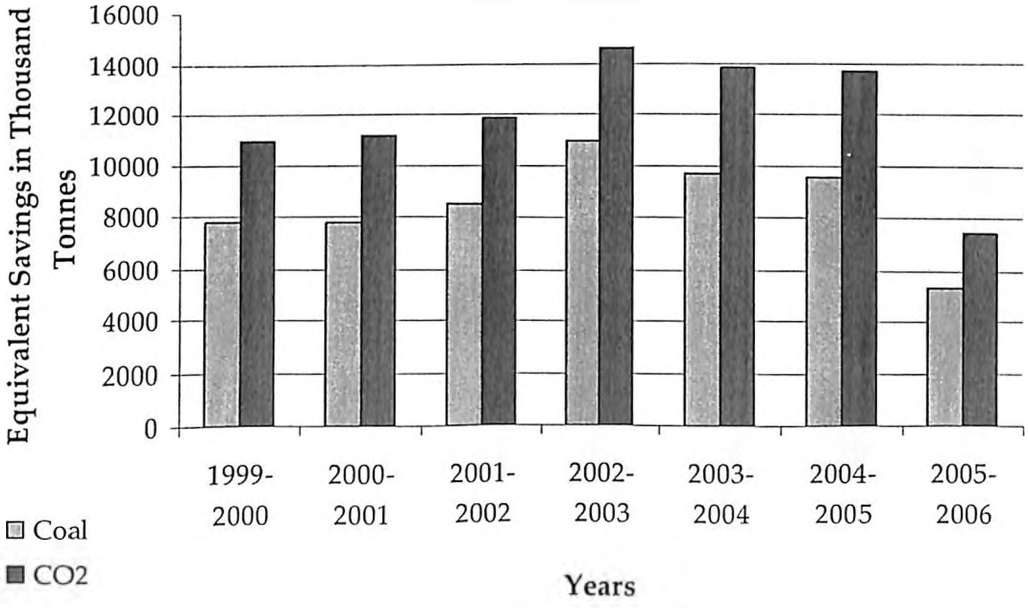


Fig. 3.5: Equivalent Energy Efficiency Improvement and CO_2 Emissions Reduction Potential for CBITPPs (Group E) having More Than 1000 MW Capacity

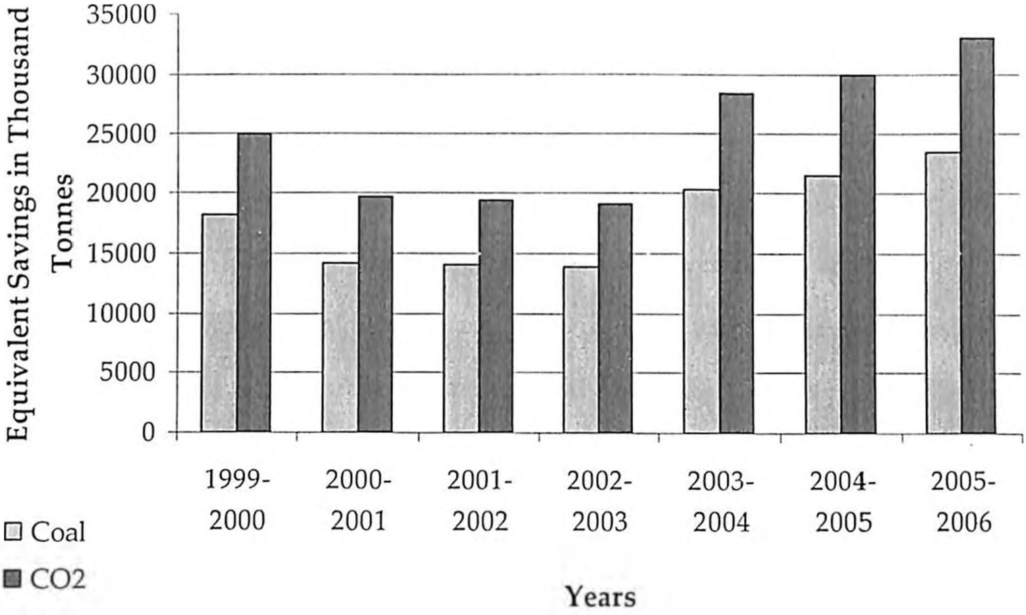
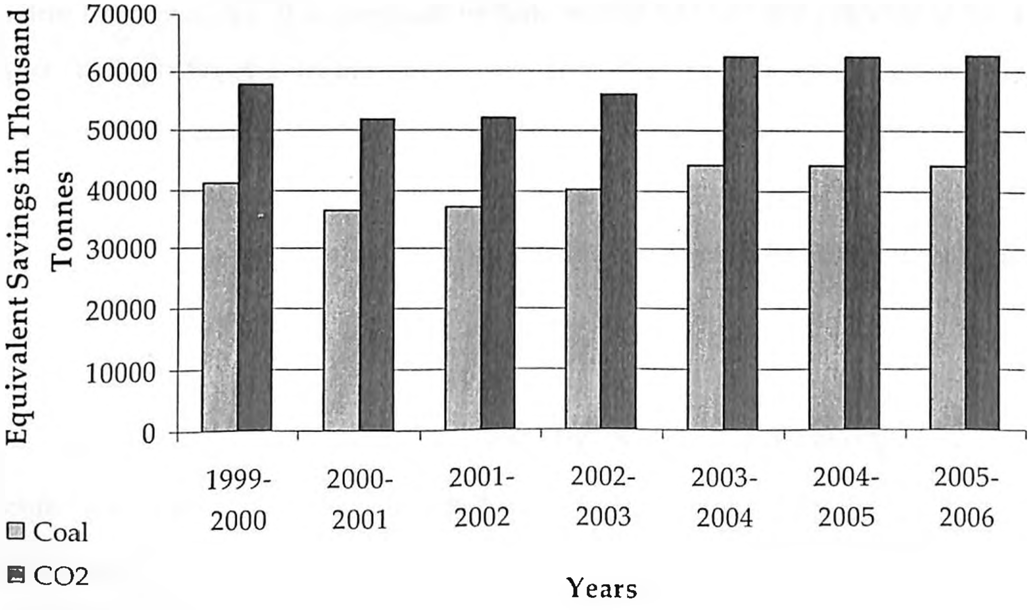


Fig. 3.6: Equivalent Energy Efficiency Improvement and CO_2 Emissions Reduction Potential from All CBITPPs



CHAPTER IV

BENCHMARKING

Benchmarking is a systematic comparison of organizational performance to create new standards. Benchmarking methods are used to determine how well a business organization or corporation is performing compared with other similar entities. In this chapter benchmarking, its process and methodologies are discussed. A thorough review of various empirical studies available in literature is presented. Based on the same, the methodologies for benchmarking are identified for the present study and discussed.

4.1 INTRODUCTION

Benchmarking is recognized as an essential tool for continuous improvement of quality. Decision makers are constantly on the look out for techniques to enable quality improvement. It is one such technique that has become popular in the recent times. Though benchmarking is not new, it has now found more subscribers, and occupies a prominent place, helping quality upgradation. Quite often, the benchmarking concept is understood to be an act of imitating or copying. But in reality this proves to be a concept that helps in innovation rather than imitation (Dattakumar and Jagadeesh, 2003).

Benchmarking is a systematic method by which organizations can measure themselves against the best industry practices. It promotes superior performance by providing an organized framework through which organizations learn how the "best in class" do things, understand how these best practices differ from their own, implement change to close the gap and using the information as the basis for goals, strategies and implementations (Pryor, 1989). The essence is the process of borrowing ideas and adapting them to gain competitive advantage.

Benchmarking is a method of performance monitoring that assesses the potential of efficiency improvements within organizations, by comparing operating efficiencies with their national and international counterparts. It is also possible to measure comparative improvements in the performance of an entity over time. This provides an indication of the rate of previous productivity gains and helps to establish the expected rate over the regulatory period. It helps entities to ensure gradual but continuous efficiency gains and better service delivery. Well designed benchmarking method assists entities to develop catch-up plan to deploy the best practices and performance as followed by the lead entity on respective parameters optimizing overall performance of the sector. It is a tool to achieve business and competitive objectives. It is powerful and extremely effective when used for the right reasons and aligned with organization strategy. In contrast to the traditional method of extrapolating next year's goal from previous year's performance, benchmarking allows goals to be set objectively, based on external information. When personnel are aware of the external information, they are usually much more motivated to attain the goals and objectives. Also it is hard to argue that an objective is impossible when it can be shown that another organization has already achieved it.

It is time and cost efficient. Because the process involves imitation and adaptation rather than pure invention, saves time and money. Benchmarking partners provide a working model of an improved process, which reduces some of planning, testing and prototyping effort (Besterfield *et al*, 1989).

4.2 BENCHMARKING OF COAL BASED INDIAN THERMAL POWER PLANTS

Benchmarking of power plants is now perceived as an essential component of utility management. Such an effort is necessary not only to gauge the efficiencies of existing plants but also from a viewpoint of establishing goals and for formulating strategies to achieve goals. The appraisal in itself is fairly attractive to all competitive utilities, the experience of companies in England and Wales has shown that as companies gradually exhaust simple measures of cost reductions such as staff reductions, the trend is to look for formal benchmarking since all evidence from other privatized industries indicates that cost reductions are achievable on a sustained basis (Tripta Thakur, 2005). Introducing the concepts of efficiency and effectiveness in power sector has, therefore, assumed growing importance in the recent times. Though regulation cannot completely replace competition and free electricity market, however benchmarking becomes a pertinent concept for regulators to ensure that the performance of electricity utilities is aligned to competitive forces.

Benchmarking can be a useful tool for understanding energy consumption patterns in an industrial facility and for designing policies to improve Energy Efficiency. Benchmarking for power industry is a process in which the energy performance of an individual plant or an entire sector of similar plants is compared against a common metric that represents 'standard' or 'optimal' performance. While benchmarking provides insights into the relative energy performance of the plant, it is also a good starting point for analysis of further improvement opportunities. It may also entail comparing the energy performance of a number of plants against each other (Worrell and Price, 2006).

Comparisons of Energy Efficiency of power plants can provide a benchmark against which a plant's performance can be measured to that of other plants. It can also aid in the evaluation of implemented policies (Phylipsen *et al*, 1998 and 2002).

Benchmarking studies can help to identify the scope for efficiency improvements. The variations arise because each power plant faces a particular set of circumstances (factors) these include, plant *Capacity, HEAT RATE, PLF, auxiliary power consumption* and grade of coal used etc. Associated with these differences are advantages and disadvantages that have an impact on the comparative performance of power plants. Benchmarking studies account for all of the above besides providing an indication of the levels of efficient operating, maintenance and capital expenditure. Benchmarking studies are essential to draw lessons that can greatly help in avoiding structural and contractual inefficiencies in the emerging power sector.

4.3 PROCESS OF BENCHMARKING

The number of steps in the benchmarking process may vary from organization to organization. It includes steps like deciding the aspects to benchmark, understanding current performance, planning, studying others, analyzing, recommending and use the findings (Besterfield *et al,* 1989).

Benchmarking of power plants is often a complicated exercise as it employs multiple inputs and output(s). One of the ways could be to compare performance in terms of certain key indicators on an indicator-to-indicator basis. But this exercise may not result in complete evaluation that may not convey policy-makers and the other not so technically specialized personnel a concrete idea about the overall performance of a utility vis-à-vis other utilities. For example, a utility might perform poorly in terms of certain indicators, but may perform outstandingly well in terms of other indicators as compared to another utility. In such cases, evaluating, comparing, and rating the overall performances has to be done carefully. Furthermore indicator-by-indicator comparisons do not yield concrete information on target allocation of resources. Hence most benchmarking studies in the developed countries employ advanced methodologies for benchmarking power utilities.

4.4 BENCHMARKING METHODOLOGIES

The benchmarking methodologies (Ajodhia *et al,* 2004; Tripta Thakur, 2005; Jamasb and Pollitt, 2001 and 2003) can be broadly classified into two groups: the Average Methods and the Frontier Methods. While the Average Methods compare the target utility to some measure of average performance, the Frontier Methods compare the target utility to the most efficient comparable utilities. The different Average Methods are Simple Comparisons, Ordinary Least Square (OLS) and Total Factor Productivity (TFP). While the different types Frontier methods are Corrected Ordinary Least Square (COLS), Stochastic Frontier Analysis (SFA), and Data Envelopment Analysis (DEA). The Frontier Methods are regarded as more scientific and precise as compared to the Average Methods. The Frontier Methods create an efficiency frontier from a sample of utilities; which is then used as the benchmark against which performance of the subject utility is measured. The inherent assumption behind the Frontier Methods is that all utilities in a selected sample should be able to operate at an efficiency level determined by the most efficient utilities in the sample. Frontier Methods compare ratios of inputs and outputs, and the utilities on the frontier are those that use the minimum inputs to produce a given level of output (input orientation) or produce maximum output from a given level of inputs (output orientation).

4.5 REVIEW OF EMPIRICAL STUDIES

The aim of this study is to provide an estimate of the technical efficiency of the power plants and then benchmark the power plant having best performance. Amongst the all power plants in India, coal based thermal power plants are analyzed.

In order to do the benchmarking, the performance of CBITPPs is to be evaluated on some common scale. The first law efficiency can not give the perfect picture of plant's performance for comparison as it is just the ratio of power output to the rate of heat supplied. Some other method is needed, where the other parameters such as *Capacity* of the power plant, *Forced Outages, Plant Availability, Specific Fuel Consumption, GCV* of the fuels used, etc. are also considered. In order to identify the techniques to access the performance of CBITPPs and benchmark them, a thorough literature survey was done which is as discussed below.

An increasing number of recent studies on efficiency of electricity generation in developed countries are using Frontier Methods such as Data Envelopment Analysis and Stochastic Frontier Analysis. These methods involve the estimation of both production and cost functions. Many studies where such techniques are used, have evaluated the Technical Efficiency (*TE*) of the plants. Technical Efficiency was first introduced by Farrel (1957) and it refers to the ratio of actual output that can be realized from a given input set to the potential output of the plant from the same amount of given input.

A comprehensive review of literature and past studies of the electricity sector is provided in Pollit (1995). He used Long Run Translog Shadow Cost Function (parametric approximation), which is estimated jointly with the factor cost share equations, following Zellner's method (1962). In his studies he used a sample of companies from different OECD countries for electricity generation from fossil fuel with 1986 data. In Chapter 5, the productive efficiency of the ninety five public and private electric utility firms form different countries like Australia, Japan, UK, France, Italy, Denmark, Canada, Ireland and USA, has been evaluated. In Chapter 6, technical efficiency of 768 thermal power plants situated in various countries like USA, UK, Japan, Australia, Canada, South Africa and remaining from other countries has been evaluated for the year 1989. It was found that the *PLF* is the major explanatory factor for inefficiency and there is no significant difference by the type of ownership. In Chapter 7, allocative efficiency of 164 base load thermal power plants from different countries was determined for the year 1989. It was found that allocative efficiency for private firms was implausibly high.

Pollitt (1996) used DEA to assess the efficiency of nuclear power generators in five countries: the UK, Canada, Japan, South Africa and USA. This study was followed by several other studies of international comparisons of electric utilities by various researchers, such as Zhang and Bartels (1998) on New Zealand, Australia and Sweden. Although efficiency studies of the generation sector of developed countries abound, analyses of smaller systems and of developing countries' generating systems are lacking. Jamasb and Pollitt (2001) assembled an extensive comparison of international efficiency studies for the electricity sector stressing the importance of the proper variable choice. In a subsequent paper, Jamasb and Pollitt (2003) performed an international benchmarking study of sixty three utilities from six European countries comparing several SFA and DEA specifications. Although they determined a high correlation among the models, the results for single utilities differed noticeably.

Olatubi and Dismukes (2000) attempted to measure cost efficiency opportunities for coal fired electric generation facilities by applying non-parametric measurement techniques to plant-specific information. They also partitioned cost efficiency into its component parts and considers the influence that fuel type, technology, vintage and size has on operating efficiency. It is observed that there are considerable opportunities for cost reduction in the industry that could result in price reductions to electricity consumers.

Mayer (2000) uses non-frontier regression analysis to study reliability problems of small islands in electricity generation. He concludes that the inability of most Caribbean and Pacific islands to tap power from an inter-continental transmission grid has meant that these islands have significantly larger capacity margins in order to meet a given reliability criterion.

Frontier applications for developing countries are also very few. Meibodi (1998) employs both DEA and SFA to estimate Technical Efficiency in electricity generation. He used Iranian data combined with data from World Bank. The conclusion reached was that a substantial proportion of the variation in efficiency within the electricity industry in developing countries was due to a factor related to the size of the plant. Most of the highly efficient power plants were found to be relatively large. The results also indicated that increasing returns to scale prevailed in the electricity generation of most developing countries. Whiteman (1995) used DEA in an attempt to benchmark electricity systems of developing countries using the World Bank data used by Meibodi (1998), but his study was flawed in two important ways, first it made use of only two inputs labour and capital, and secondly, it used four outputs. For a cross-section dataset, this meant that the final outcome was a large number of countries lying on the frontier (forty eight out of eighty five countries). Hawdon (1998) estimated Technical Efficiency of power plants from eighty two developing countries for the data of 1988 using DEA with gross electricity generated as output variable and installed capacity, number of employees in generation, number of employees in distribution, and fuel as input variables.

Coelli (2002) evaluated Total Factor Productivity of thirteen Australian power plants for the period of 1981-82 to 1990-91. He used Stochastic Frontier Production Function and DEA with output variable as electricity sent out and input variables as labour, capacity and fuel.

Ruangrong (1992) analyzed the prospects of improving the economic efficiency of electricity generation in Thailand by privatization. She investigated the economic efficiency of generating activities of Electricity Generating Authority of Thailand (EGAT). Her data set covered fourteen thermal and gas-turbine power plants of EGAT during period of 1973-1989. This study employed the generalized cost function to investigate the economic efficiency using the basic model developed by Atkinson and Halvorsen (1984).

In addition to the study using the plant-level data, there are several cross country studies regarding the relative Technical Efficiency of firms in Electricity Supply Industry in which data of Thailand was also included, which are studies by Yunus and Hawdon (1997), Meibodi (1998), Hawdon (1998) and Sirasoontorn (2004). These studies assess the relative Technical Efficiency of firms by either SFA or DEA or both. They found EGAT to be among the more efficient electricity producers. Moreover Yunus and Hawdon (1997) found that public firms performed almost same as private firms.

Azadeh *et al* (2007) proposed a non-parametric efficiency frontier analysis method based on the adaptive neural network technique for measuring efficiency of the power generation sector of Iran, and found that the neural network provide more robust results and identifies more efficient units than the conventional methods.

For benchmarking and efficiency analysis in the electricity sector DEA and SFA are the most commonly used methods. They have been particularly popular in the regulatory process in Great Britain, Switzerland, the Nordic States, USA and Austria. The vast majority of these studies are USA based.

Kopp and Smith (1980) estimated Stochastic Frontier Production Functions for forty three coal-fired electric power plants of USA. They consider three alternative functional forms; three estimation methods; and also divide their data into two capital vintage groups, finding that all three factors have an influence upon the measures of mean Technical Efficiency.

Nerlove (1963) has analyzed cross sectional sample of 145 privately-owned electric industry firms in USA for the year 1955. With output taken as kWh of electricity generation and input factors as capital, labor and fuel, he used Cobb-Douglas Ordinary Least Squared Method.

Atkinson and Halvorsen (1984 and 1986) with output taken as kWh of electricity generation and input factors as capital, labor and fuel, have done parametric efficiency test and evaluated relative efficiency of thirty publicly and 123 privately owned firms of USA for the year 1970. They used Long Run Translog Shadow Cost Function (parametric approximation) and Iterative Estimation Procedure (IEP) used by Zellner (1962). They found that there is price inefficiency on total cost and input demands, as well as no significant difference in allocative efficiency between publicly and privately owned firms.

Scale economies at plant level for the period of 1976-78 of USA's Nuclear Power plants with labor, fuel and fixed capital as input have been evaluated by Krautman and Solow (1988). With cross sectional sample of forty three observations of eleven bi-reactors using Short Run Translog with share equation IEP. They found that two reactors plants are more efficient for bigger output levels.

A comparison of costs in privately owned and publicly owned electric utilities with differences in efficiency in the Rate of Return (ROR) regulation framework for 121 privately owned firms and sixty one publicly owned firms of USA for the year 1986 was done by Koh *et al* (1996). It was found that the publicly owned firms are more efficient than the privately firms at low output levels and are less efficient at high output levels.

Kleit and Terrell (2001) measured potential efficiency gains of natural gas electric power generation from deregulation of using a Bayesian approach. Seventy eight power plants of USA using natural gas were evaluated for the year 1996. Level of capacity and cost utilization using cross sectional sample of 514 coal and 261 natural gas and oil plants, for 1995 and 1996, of USA was done by Maloney (2001). He found that capacity utilization is the most important determinant of cost especially in coal plants. Hiebert (2002) evaluated coal and gas based power generating plant's operating cost efficiency using stochastic frontier approach. He used unbalanced panel of 432 coal and 201 natural gas and oil plants over the period 1988-1997 of USA. It was observed that inefficiency decreases as plant capacity utilization rises and average efficiency of coal based power plants increased where retail competition had begun.

Comparative Technical Efficiency analysis of electricity generators in sixteen small islands and 121 investor-owned utilities of USA using panel data for the period of 1994-2000 was done by Domah (2002) using SFA and DEA with output variable as electricity generated and input variables as labour, installed capacity, fuel, per capita consumption, number of customers and capacity utilization factor. It was observed from both DEA and SFA generated Technical Efficiency scores that capacity utilization factor is unanimously the most important variable that explains efficiency differences between islands and non-islands.

Knittel (2002) has investigated the effect of incentive regulation and other alternative regulatory programs on the Technical Efficiency of a large set of investor-owned coal and natural gas generation units of USA for the period of 1981-1996. Within a stochastic frontier framework, to provide a greater incentive to reduce fuel costs, he found that those programs tied directly to generator performance and those that modify traditional fuel cost pass through programs, are associated with greater efficiency levels. Other programs have no statistical association with efficiency levels.

The performance evaluation and benchmarking of electricity distribution utilities of many countries has been done by many authors using SFA, DEA or both. Filippini (1998) and Filippini and Wild (2001) applied SFA for Swiss electricity distribution utilities. Hjalmarsson and Veiderpass (1992) analyzed Swedish electricity retail distributors and Norwegian electricity utilities respectively using panel data approach. Similar study was done by Forsund and Kittelsen (1998). Frontier Economics and Consentec (2003) assessed German energy consuming industry while Hirschhausen *et al* (2006) did efficiency analysis of German electricity distribution utilities using SFA and DEA.

As far as India is concerned there are only few studies done in this area. Singh (1991) has analyzed the Technical Efficiency of thermal power plants in India, using cross sectional data for 1986-87. While Technical Efficiency evaluation of sixty six power plants in India for the period of 1987-88 to 1990-91 was done by Khanna *et al* (1999). She did semi-parametric analysis using SFA. In this work, cost of electricity generated was taken as output variable and price of labour, price of fuel, net electricity generated, dummy variables for coal based plant, ownership, age of plant, and non-utilized capacity factor were taken as input variables. With this she also explored the sources and magnitude of energy-inefficiency in the electricity generating sector in India and its implications for carbon emissions from this sector.

She developed econometric methodology to disaggregate and quantify the contribution of technical and institutional factors to the inefficiency. The analysis demonstrated the potential for institutional and economic policy reforms that provided incentives for the adoption of efficiency-enhancing production practices to reduce carbon emissions while increasing net electricity generation, even with the existing capital equipment. A non-parametric approach to frontier analysis, DEA, is applied in the work carried out by Chitkara (1999) to evaluate the operational inefficiencies of generating units. In this work three parameters viz. generation per unit of coal consumed, generation per unit of oil consumed and generation per unit of auxiliary power consumed have been considered as indicators of performance.

Tripta Thakur (2005) and Tripta Thakur *et al* (2005) using DEA, have assessed the comparative efficiencies of distribution of electricity by Indian State Owned Electric Utilities (SOEU), which have been mainly responsible for the generation, distribution and transmission of electricity in India. The parameters taken here are cost, number of consumers, distribution line length and energy sold. It was found that the performance of several SOEUs was sub-optimal, suggesting the potential for significant cost reductions. Shanmugam and Kulshreshtha (2002 and 2005) employed SFA to measure the Technical Efficiency of Indian thermal power plants using panel data. They found that the efficiency varies widely across firms and regions and is time - variant.

From the above discussion it is quite evident that DEA and SFA are the most commonly used methods in the literature on benchmarking and efficiency analysis in the electricity sector all over the world. For efficiency analysis of CBITPPs very few studies have been done and for benchmarking only one study has been done by Tripta Thakur *et al.* (2005), where benchmarking of electricity distribution by State Owned Electric Utilities have been analyzed.

As Indian power sector is going through reforms and improvement in Energy Efficiency is the need of the hour. In the changing environment there is an urgent need for detailed analysis of CBITPPs' performance using standard benchmarking techniques; a process that can reveal finer mechanisms causing inefficiencies and can throw some light on structural reasons for inefficiencies.

4.6 METHODOLOGY ADOPTED FOR THE PRESENT STUDY

Frontiers have been estimated by applied economists and econometricians using many different techniques over the past forty years. Ordinary Least Squares and its variants provide simple averaged estimation. Other than these there are the two principal methods which provide some degree of 'best practice' are the following (Ajodhia *et al,* 2004):

1) Stochastic Frontier Estimation (SFE), also known in the regulatory practice as Stochastic Frontier Analysis (SFA); and
2) Data Envelopment Analysis (DEA), which is the focus of much regulatory practice in the field of electric utilities.

The two methodologies involve econometric and mathematical programming methods, respectively. The discussion in this section provides a brief introduction to modern efficiency measurement. A more detailed treatment is provided by Fare *et al.* (1985, 1994), and Fried *et al.* (1993). An interesting overview of DEA is in Seiford and Thrall (1990), whereas the two basic DEA models being developed in the late Seventies and early Eighties - to which most applied papers still refer - are those by Charnes *et al.* (1978) for Constant Returns to Scale (CRS) DEA, and by Banker *et al.* (1984) for Variable Returns to Scale (VRS) DEA.

4.6.1 Stochastic Frontier Analysis

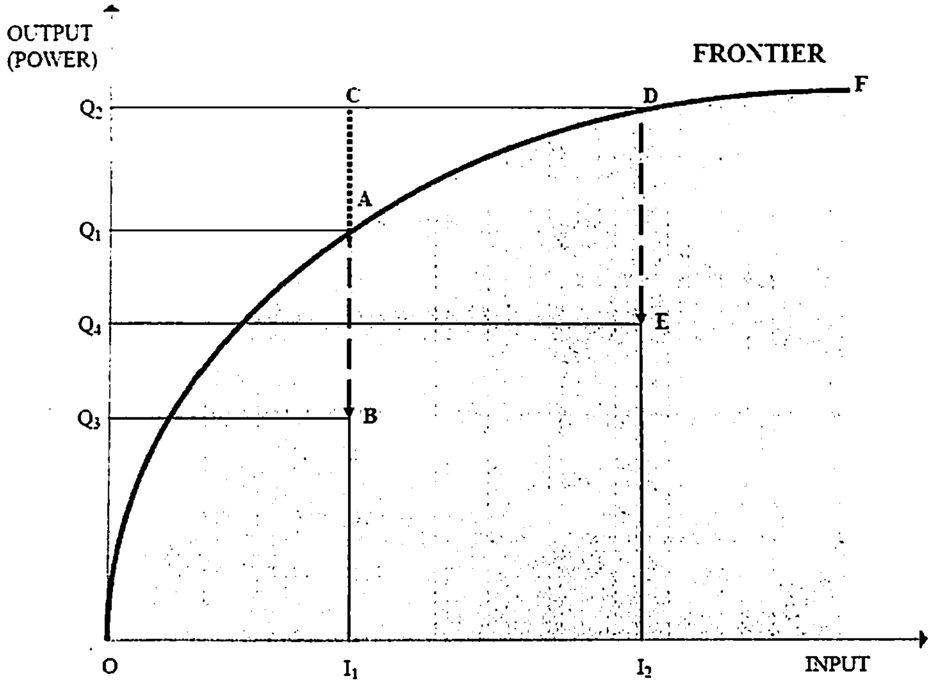
Stochastic Frontier Analysis is a method of economic modeling. It has its starting point in the Stochastic Production Frontier Models. This approach proposed by Farrell (1957) which came to prominence in the late 1970s as a result of the work of Aigner *et al.* (1977), Battese and Corra (1977) and Meeusen and Van Den Broeck (1977).

The SFA is a parametric method used to estimate the efficient frontier and efficiency scores. It uses statistical techniques to estimate a production function and to estimate efficiency relative to this frontier. The statistical nature of the method allows inclusion of stochastic errors in the analysis and testing of hypotheses. This method requires specification of a production function and also it recognizes the possibility of stochastic errors.

A Frontier Production Function or frontier refers to the potential or maximum feasible output (power) that can be achieved by a thermal power station from given quantities of inputs and currently available technology.

The concept of a Frontier Production Function is explained by Fig. 4.1. The curve OADF represents the frontier, which traces the maximum level of output (power) that a station can achieve at different levels of input, given the current technology. (For expositional convenience, it is assumed that the station employs only one input.) For instance, if the station uses I_1 units of the input, the maximum output that can be produced given the present technology is Q_1 units, which is represented by point A on the frontier. Similarly, if the plant uses I_2 units of the input, the potential or maximum feasible output is Q_2 units, given the current technology, as illustrated by point D on the frontier. If a station operates at any point on the frontier, such as point A or D, it is considered to be technically efficient or efficient, since it is able to employ the input efficiently to produce the maximum possible output, using the presently available technology.

Fig. 4.1: Frontier Production Function



However, a plant may operate at a point below the frontier, such as point B or E, so that its output is less than its potential or maximum feasible output, for the given level of input and technology. In this case, the plant is considered to be technically inefficient or inefficient. This may happen either because plant engineers may have incomplete knowledge regarding the best techniques of applying the input or may be because of various organizational constraints that prevent the plant from reaching the frontier (Kalirajan and Shand, 1994). For instance, at point B in Fig. 4.1, which lies inside or below the frontier, the plant uses I_1 units of input but is able to produce only Q_3 units of output, which is less than Q_1 units or the frontier output of the plant at I_1 units of input. In this case, the output loss due to technical inefficiency is (Q_1 – Q_3) units. Similarly, at point E, which also lies below the frontier, the plant uses I_2 units of input but produces only Q_4 units of output, which is less than the frontier output Q_2. Therefore, the output loss on account of Technical Efficiency is ($Q_2 - Q_4$) units. (Note: Although it is feasible for the plant to produce Q_2 units of output by employing I_2 units of input (point D in Figure 4.1), it is not possible for the plant to achieve Q_2 level of output by employing only I_1 units of input (point C in Figure 4.1), given the current technology. In other words, point C is infeasible under present technological conditions. However, with a technological advancement, the plant may be able to reach point C.)

The ratio of the actual output and potential or frontier output of a plant can be treated as a measure of the Technical Efficiency as given in Eq. 4.1, or *TE* of the plant. In other words,

$$TE \ of \ a \ Plant = \frac{Actual \ Output \ of \ the \ Plant}{Potential \ or \ Frontier \ Output \ of \ the \ Plant} \text{ ----- } \mathbf{(4.1)}$$

The following formulation (Eq. 4.2) of *TE* of a plant in a given period captures all key elements (factors and variables) associated with *TE*:

$$TE = \frac{Q_t}{F(X_t, \beta)} = Exp(-u_t) \text{ -------- } \mathbf{(4.2)}$$

where --

- Q_t is the actual power generated by the plant in period *t*.
- X_t is a vector that contains the quantities of all inputs employed by the plant in period *t*.
- β is a vector of unknown constants or parameters that can influence the production process of the plant.
- $F(X_t, \beta)$ represents the frontier production function of the plant. Here, *F* gives the potential or frontier output of the plant in period *t*, which depends on

input quantities X_t and parameters β. (Note: X_t and β are put under brackets next to *F* to indicate that the frontier output of the plant depends on the input quantities and parameters.)

- u_t is the error or residual term in period *t* (explained in detail below).
- *Exp* is the exponential function, and *Exp*$(-u_t)$ represents the value of the exponential function at $(-u_t)$. (Again, note that the error term u_t is put under brackets with a negative sign, next to the exponential function *Exp*, to indicate that the value of the exponential function depends on the residual term, with a negative sign.)

Rearranging terms in Eq. 4.2 above, the following relationship between the actual output of a plant and its frontier or potential output in a given period can be obtained (Eq. 4.3):

$$Q_t = F(X_t, \beta) \times Exp(-u_t) \text{ ------- } \mathbf{(4.3)}$$

Or, *Actual Plant Output = Frontier Output × TE*

According to the above relationship, a plant's actual output may be different from its frontier or potential output on account of *TE* of the plant.

According to the above formulation of *TE*, *Exp* $(-u_t)$, where u_t is the error or residual term, gives the technical efficiency of a plant in period *t*. The residual term u_t is the deviation of the actual value of an observation from the true regression line. It can either be zero or take a positive value. (Note: Since the residual term never takes negative values, it is often called a one-sided error term.) If u_t equals zero, then the exponential function *Exp* $(-u_t)$ equals one. Therefore, according to Eq. 4.2 above, *TE* equals 1 or the plant is technically efficient in period *t* (full *TE*). In this case, a plant's actual output in period *t* equals its potential or frontier output (which can also be verified by Eq. 4.3 above).

However, if the residual term u_t is greater than zero, the exponential function i.e. *Exp* $(-u_t)$ takes a value less than one. Hence, according to Eq. 4.2 above, *TE* is less than 1 or the plant is technically inefficient in period *t* (less than full *TE*). In this case, plant's actual output is less than the frontier output (as Eq. 4.3 also demonstrates). In general, there is an inverse relationship between the residual term u_t and a plant's *TE*: as u_t increases (respectively, decreases), the *TE* of a plant decreases (respectively, increases). The residual term u_t is also referred to as the *TE* effect of a plant in period *t*.

4.6.1.1 Stochastic Frontier Production Function

The Frontier Production Function described in the previous section is deterministic in nature. It assumes that all thermal power plants have the same Frontier Production Function and plants may achieve different levels of performance, in terms of power generation in a given period, either because of different quantities of inputs employed, or because of differences in their Technical Efficiency. Note that the factors which influence Technical Efficiency of a plant, such as incomplete knowledge of best practices in applying inputs and organizational constraints (which were also discussed in the previous section), can be controlled by the plant.

However, a plant's performance or power generation in a given period can also be influenced by various factors that cannot be controlled by the plant, such as poorly functioning equipment, unsuitable weather conditions and non-availability of essential or imported inputs (Goldar, 1997). Such factors represent random shocks, which lead to statistical 'noise' or error in the measurement of a plant's frontier. In this case, the frontier production function of a plant is said to be stochastic since there are random fluctuations in the frontier output of plants. These fluctuations are captured by a random noise term v_t, which is assumed to follow a normal distribution, with mean 0 and variance σ_v^2. (Note: The random noise term is v_t is a two-sided error term since it can take both positive and negative values, unlike the one-sided residual term u_t, which never takes negative values.)

If a plant's frontier is stochastic, the relationship between the plant's actual output and its potential or frontier output can be expressed as:

$$Q_t = F(X_t, \beta) \times Exp(-u_t) \times Exp(v_t) \text{ ------ } (4.4)$$

Or, *Actual Plant Output = Frontier Output × TE × Exp* (v_t)

The above relationship (Eq. 4.4) indicates that if the Frontier Production Function is stochastic, a plant's actual output can differ from its frontier or potential output not only on account of the plant's Technical (in)Efficiency (*TE*), but also due to random fluctuations in the frontier output of the plant, which are measured by *Exp* (v_t) or the exponential function, evaluated at the random noise term v_t.

The Stochastic Frontier Production Function can be estimated by the Maximum Likelihood Method of estimation. According to Battese and Coelli (1992), the residual term u_t or the *TE* effect of a plant in period t can be expressed in terms of a random variable u and an unknown parameter η. The random variable u follows a truncated normal distribution, with mean μ and variance σ_u^2. Battese and Coelli have shown that a plant's *TE* increases, remains the same, or decreases over time (i.e. *TE* can be time dependent or time-variant), depending on whether parameter η is positive, zero, or negative.

Battese and Coelli (1992) also define a parameter γ, which captures the fraction of the deviation in a plant's actual output from its frontier output due to the technical inefficiency of the plant. If the residual term or *TE* effect of a plant in a given period is zero, then the plant is fully technically efficient. In this case, all deviations of plant output from the frontier output are due to the random noise variable v_t and parameter γ equals zero. Moreover, the Maximum Likelihood Estimates (MLE) of the Stochastic Frontier Production Function are identical to the estimates obtained by the OLS method of estimation. In contrast, if parameter γ equals one, all deviations in plant output from the frontier output arise because of technical inefficiency of the plant.

Restrictions on the various parameters of the Stochastic Frontier Production Function model lead to a number of interesting cases. Setting μ (mean of random variable u) equal to zero reduces the model to the half-normal distribution model. Similarly, setting parameter γ equal to zero gives rise to the case where the plant is fully technically efficient. If parameter η equals zero, then *TE* is time-invariant or the *TE* of power plants does not improve over time. One can test the hypothesis that all of the above three restrictions hold simultaneously, i.e. whether $\gamma=\mu=\eta=0$ (or the present model is a half-normal distribution model with full and time-invariant efficiency), by using a generalized likelihood-ratio test statistic which follows a mixed χ^2 (Chi-square) distribution, with three degrees of freedom.

4.6.2 Data Envelopment Analysis

Data Envelopment Analysis for benchmarking utilities is a multi-factor productivity analysis model for measuring the relative efficiencies of a homogenous set of Decision-Making Units (DMUs). It can be applied to analyze multiple outputs and multiple inputs without pre-assigned weights and without imposing any functional form on the relationships between variables. The technique was suggested by

Charnes *et al.* (1978), and is built on the idea of Farrell (1957). With time a number of models and modifications have also evolved. The following sections describe the models employed in the current study for analysis.

4.6.2.1 The Constant Returns to Scale Model

This model was suggested by Charnes *et al.* (1978). This model assumes Constant Returns to Scale assumption. The efficiency score in the presence of multiple input and output factors is defined as the ratio of weighted sum of outputs to the weighted sum of inputs.

Assuming that the chosen sample has z utilities (called Decision Making Units or DMUs in the popular DEA terminology); each with *m* inputs and *n* outputs, the relative efficiency score of a test DMU *p* is obtained by solving the following model proposed by Charnes *et al.* (1978):

$$max \ \frac{\sum_{k=1}^{n} v_k y_{kp}}{\sum_{j=1}^{m} u_j x_{jp}},$$

Subjected to

$$\left.\begin{array}{lll} \dfrac{\sum_{k=1}^{n} v_k y_{ki}}{\sum_{j=1}^{m} u_j x_{ji}} \le 1 & & \forall i \\ u_j v_k \ge 0 & & \forall j,k \end{array}\right\} \text{------ (4.5)}$$

where, i = 1 to z, j = 1 to m, k = 1 to n. y_{ki} is the amount of output k produced by DMU i, x_{ji} the amount of input j utilized by DMU i, v_k the weight given to output k, u_j the weight given to input j.

The fractional programme in Eq. 4.5 is subsequently converted to a linear programming format and a mathematical dual is employed as shown in Eq. 4.6, to solve the linear problem. The dual is required as it reduces the number of constraints from $z+m+n+1$ in the primal to $m+n$ in the dual; thereby rendering the linear problem easier to solve. Charnes *et al.* (1978) spell this model development and can be referred for greater details.

$$min_{\theta,\lambda}\,\theta,$$

Subjected to

$$\left.\begin{array}{ll}\theta x_{jp} - \sum\limits_{i=1}^{z} \lambda_i x_{ji} \geq 0 & \forall j \\ -y_{kp} + \sum\limits_{i=1}^{z} \lambda_i y_{ki} \geq 0 & \forall k \\ \lambda_i \geq 0 & \forall i \end{array}\right\} \text{------ (4.6)}$$

where θ is the efficiency score and λ_i the dual variables (weights in the dual model for the inputs and outputs of the z DMUs).

The above problem is run z times in identifying the relative efficiency scores of all the DMUs, and values of θ (efficiency score), and λ_i (weights in the dual model for the inputs and outputs) are computed. The weights obtained show the target utility in the most favorable mode. The linear programme is to be solved for each individual DMU in the sample. The method creates a frontier using information on the assumed most efficient utilities and measures the efficiency relative to the rest of the utilities. The DEA attempts to approximate the efficient frontier by a "piece-wise" linear approximation based on the sample. Efficiency scores are constructed by measuring how far a utility is from the frontier. A test DMU is considered inefficient if a composite DMU (defined as linear combination of units in the set) can be identified which utilizes less input than the test DMU while maintaining the same or greater output levels. In general, a DMU is efficient if it obtains a score of 1; while a score of less than 1 indicates that it is inefficient. Koopmans (1951) had provided a more comprehensive definition of efficiency: a DMU is efficient if it operates on the frontier and also has zero associated slacks, a description now widely accepted. The units involved in the construction of the composite DMU can then be utilized as benchmarks for the inefficient test DMU. The technique also computes the input and output refinements that would turn an inefficient unit into an efficient one.

4.6.2.2 The Variable Returns to Scale Model

When the utilities do not perform at optimal scales, this model can be modified to account for Variable Returns to Scale conditions as shown by Banker *et al.* (1984), by adding a convexity constraint. This VRS model relaxes the CRS assumption of the CRS model and makes it possible to investigate whether the performance of each DMU was conducted in region of increasing, constant or decreasing returns to scale in multiple outputs and multiple inputs situations. The VRS model helps decompose the CRS efficiency into the Technical Efficiency and Scale Efficiency components, thereby allowing investigating the scale effects.

This model employs the same equation as employed in the CRS model, with the modification that a convexity constraint is now added to Eq. 4.6 as shown in Eq. 4.7.

$min\ \theta,\lambda^{\theta},$

Subjected to

$$\left.\begin{array}{ll}
\theta x_{jp} - \sum_{i=1}^{z} \lambda_i x_{ji} \geq 0 & \forall j \\
- y_{kp} + \sum_{i=1}^{z} \lambda_i y_{ki} \geq 0 & \forall k \\
\sum_{i=1}^{z} \lambda_i = 1 & \\
\lambda_i \geq 0 & \forall i
\end{array}\right\} \text{------ (4.7)}$$

To further find out if a utility is operating in the area of increasing or decreasing returns to scale Eq. 4.6 is modified with the imposition of non-increasing returns to scale condition as shown in Eq. 4.8. The condition $\sum_{i=1}^{z} \lambda_i \leq 1$ ensures that any utility is benchmarked with only the utilities that are smaller than it.

$min\ \theta,\lambda^{\theta},$

Subjected to

$$\left.\begin{array}{ll}
\theta x_{jp} - \sum_{i=1}^{z} \lambda_i x_{ji} \geq 0 & \forall j \\
- y_{kp} + \sum_{i=1}^{z} \lambda_i y_{ki} \geq 0 & \forall k \\
\sum_{i=1}^{z} \lambda_i \leq 1 & \\
\lambda_i \geq 0 & \forall i
\end{array}\right\} \text{------ (4.8)}$$

CHAPTER V

DATA, MODEL AND RESULTS

In this chapter, the data sources for the present study, the model used for analysis and results of the analysis have been discussed. The input and output variables selected for the analysis have been presented. The interrelated input variables are clubbed and their computation method is also given. The Stochastic Frontier Production Function models used for the analysis are specified and the empirical analysis of the best model is discussed. Estimated Technical Efficiency of all CBITPPs is presented and after capacity wise grouping them, benchmarking has been done and presented.

5.1. DATA SOURCES

During the period of study the author visited various thermal power plants spread all over India, namely Badarpur (Delhi), Dadri (Uttar Pradesh), Farakka (West Bengal), Jhanor-Gandhar (Gujrat), Kahalgaon (Bihar), Kawas (Gujrat), Koradi (Maharashtra), Korba (Chhattisgarh), Ramagundem (Andhra Pradesh), Rihand (Uttar Pradesh), Singrauli (Uttar Pradesh), Simhadri (Andhra Pradesh), Unchahar (Uttar Pradesh), and Vindhyachal (Uttar Pradesh) etc. During these visits primary data had been collected. Later on for the consecutive years data were taken from authentic sources or contacts developed during visits.

For other plants secondary data has been taken from the reports published by CEA, Government of India. The data pertains to about seventy seven CBITPPs, distributed in various geographical regions in India from 1999-2000 to 2005-06 i.e. for seven year period. Some sample data from the published reports of CEA has been given in Appendix-C. In some cases data has been taken from the various other sources like published reports of other agencies or through personal contacts. The data collected was tested for reliability using appropriate methods for analysis.

Wherever the data is not available:

- *HEAT RATE* is calculated assuming *GCV* of coal as 15,721 kJ/kg (3,755 kcal/kg), while *GCV* of secondary oil is considered as 41,868 kJ/liter (10,000 kcal/liter). For lignite the *HEAT RATE* is assumed to be 12,619 kJ/kWh (3,014 kcal/kWh).
- *Specific Oil Consumption* is assumed as 2.0 and 3.0 ml/kWh for coal and lignite based plants respectively.
- The data is also projected using regression analysis from the available data.

5.1.1 Variables

Selection of input and output variables is one of the important tasks of performance analysis and the choice of variables depends on not just the choice of methodology and technical requirements of the chosen model, but also on data availability and its quality. No universally applicable rational template is available for selection of variables. However, in general, the inputs must reflect the resources used and the outputs must reflect the degree to which the utility is meeting its objective of generating electricity. The input/output selection for the present study was made in consideration of those parameters that directly affect the plant's performance and the choice of variables was also based on the study of available literature to sort out the right indicators from a potential group of parameters. The variables were finalized initially with the help and advice of experts from power sector (interviews with various officers and executives of thermal power plants visited), industries and educational institutes whose opinions were also considered. The different variables tried for analysis are like, *Specific Coal Consumption, Specific Oil Consumption, GCV* of coal, *PLF, Auxiliary Power Consumption, Capacity* of the plant, *Vintage, Forced Outage, Planned Maintenance, Operational Availability Factor* etc. as input, while power generated is taken as output. Later on during analysis, various combinations of these variables were tried and then the combination of input variables and output giving best results has been presented in this chapter.

The final output and input variables selected are: the plant output, which is measured as power-generated in Giga Watt Hour or GWh (denoted as *POWGEN*). While the plant inputs selected are:

(i) Capital employed (*CAPITAL*), and
(ii) Heat rate (*HEAT RATE*).

Both these input variables are formed by clubbing various other variables. The computation of these input variables is given below. Table 5.1 reports the mean and standard deviation of output factor i.e. *POWGEN* in Million Units (MU) and input factors used in the study i.e. *CAPITAL* and *HEAT RATE.* Also given is the *CAP* i.e. Capacity of power plant.

Table 5.1: Summary Statistics for Selected Variables

YEAR	1999-2000		2000-2001		2001-2002		2002-2003		2003-2004		2004-2005		2005-2006	
VARIABLES	Mean (S.D.)*	Min. (Max.)	Mean (S.D.)	Min. (Max.)	Mean (S.D.)	Min. (Max.)	Mean (S.D.)	Min. (Max.)	Mean (S.D.)	Min. (Max.)	Mean (S.D.)	Min. (Max.)	Mean (S.D.)	Min. (Max.)
CAP (MW)	715.52	30	722.72	30	752.63	30	765.75	30	778.02	30	821.13	30	836.79	30
	(521.73)	(2,340)	(516.72)	(2,340)	(540.85)	(2,340)	(538.98)	(2,340)	(547.74)	(2,340)	(594.85)	(2,600)	(616.38)	(3,000)
POWGEN (MU)	4,222.25	129	4,375.83	79	4,624.08	72	4,857.17	147	5,013.61	89	5352.97	153	5,461.41	7.4
	(3,996.39)	(16,642)	(4,041)	(16,418)	(4,191.82)	(16,576)	(4,248.44)	(16,978)	(4,255.07)	(16,377)	(4466.74)	(17,831)	(4,677.66)	(20,883.3)
HEAT RATE (kJ/kWh)	12,661	9,451	12,519	8,416	12,531	9,225	12,548	9454	12,454	8,684	12365	8512	12,175	8,962
	(2,653)	(21,039)	(2,573)	(20,942)	(2,460)	(21,579)	(2557)	(22,683)	(2,542)	(23,864)	(2495)	(23,681)	(2,306)	(22,249)
CAPITAL (MWh)	5,022.62	220.15	5,062.01	254.84	5,283.6	223.91	5,537.27	227.24	5,632.85	230.3	6022.31	252.45	6,070.99	12.38
	(4,222.61)	(18,373.92)	(4,231.99)	(17,919.7)	(4,343.32)	(18,491.61)	(4,399.92)	(17,590.17)	(4,426.76)	(18,212.83)	(4854.26)	(20,707.94)	(4,879.83)	(23,291.96)

*S.D. = Standard Deviation

5.1.1.1 Computation of the CAPITAL Variable

This variable is computed using the procedure suggested in Dhrymes and Kurz (1964) and Singh (1991). This variable is calculated using Eq. 5.1:

$$CAPITAL = \frac{CAP \times OAF \times TIME}{10^3} \; (MWh) \text{-------} \; \mathbf{(5.1)}$$

where *CAP* is the installed plant capacity in MW, *TIME* (= 8760 hrs) is the number of hours in a year and *OAF* is the *Operating Availability factor,* which is computed using Eq. 5.2.

$$\begin{aligned} &Operating\ Availability\ factor\ (OAF)\% \\ &\quad = 100 - Planned\ Maintenance\ (PM\%) - Forced\ outage\ (FO\%) \end{aligned} \text{-------} \mathbf{(5.2)}$$

Where the *Forced Outage (FO%)* and *Planned Maintenance (PM%)* are determined using Eq. 5.3 and 5.4 respectively.

$$Forced\ outage\ (FO\%) = \frac{Cf_1 \times Hf_1 + Cf_2 \times Hf_2 + \ldots\ldots\ldots + Cf_n \times Hf_n}{C \times H} x100 \text{-------} \mathbf{(5.3)}$$

Where Cf_1 ....Cf_n are the capacities in MW of the units on Forced Outage and Hf_1......... Hf_n are the duration of each outage in hours. C is the total capacity in MW and *H* is the total hours in the period under review.

$$Planned\ Maintenance(PM\%) = \frac{Cp_1 \times Hp_1 + Cp_2 \times Hp_2 + \ldots\ldots + Cp_n \times Hp_n}{C \times H} x100 \text{-----} \mathbf{(5.4)}$$

Where Cp_1 ....Cp_n are the capacities in MW of units on planned shutdown and Hp_1.......Hp_n are the duration of each shutdown in hours in the period under review.

5.1.1.2 *Computation of the HEAT RATE Variable*

HEAT RATE is an important index for assessing the efficiency of a thermal power station. It should be the endeavor of any station to improve the operating *HEAT RATE* and try to bring close to the design *HEAT RATE*. The improvement of *HEAT RATE* also helps in reducing pollution from thermal power plants. Thermal power plants analyzed in the current study are using coal as primary fuel and oil as secondary fuel.

HEAT RATE values are taken from data sources. For missing data, operating parameters such as gross generation, total coal consumption, average *GCV* of the coal and oil, *specific oil consumption* have been collected from thermal power plant authorities and also from various reports published by agencies. Thereafter, *HEAT RATE* for each year is calculated using Eq. 5.5 as given below:

$$\begin{aligned}\mathit{HEAT\ RATE} &= \mathit{Specific\ Coal\ Consumption\ (kg/kWh)} \times \mathit{GCV\ of\ Coal\ (kJ/kg)} \\ &+ \mathit{Specific\ Oil\ Consumption\ (litre/kWh)} \times \mathit{GCV\ of\ Oil\ (kJ/litre)}\end{aligned} \quad \text{-------(5.5)}$$

Where *Specific Coal Consumption* and *Specific Oil Consumption* are evaluated using Eq. 5.6 and 5.7 respectively.

$$\mathit{Specific\ Coal\ Consumption} = \frac{\mathit{Total\ coal\ consumption\ in\ a\ year\ (kg)}}{\mathit{Gross\ generation\ in\ the\ year\ (kWh)}} \quad \text{-------(5.6)}$$

and

$$\mathit{Specific\ Oil\ Consumption} = \frac{\mathit{Total\ oil\ consumption\ in\ a\ year\ (litre)}}{\mathit{Gross\ generation\ in\ the\ year\ (kWh)}} \quad \text{-------(5.7)}$$

5.2. THE MODELS

Economically speaking Technical Efficiency refers to the ability of a firm to minimize inputs proportionally to produce a given set of output. To measure Technical Efficiency, a production frontier must be constructed. As per our discussion in previous chapter, there are two approaches which are used to construct production frontier: nonparametric and parametric approach. These two approaches are:

- Stochastic Frontier Analysis, and
- Data Envelopment Analysis

Amongst the above two approaches, the parametric approach i.e. SFA is used for analysis in the present work, while the consistency of the results is checked with DEA. Both SFA and DEA are already discussed in the previous chapter. The SFA models used in the present work are discussed below in detail.

5.2.1 Stochastic Frontier Analysis

To estimate the Stochastic Frontier Production Function and plant-specific Technical Efficiency, two Stochastic Frontier Production Function models for cross sectional data developed by Battese and Coelli (Battese and Coelli, 1992; Coelli *et al*, 1997) have been employed and tested. These are

- A Cobb-Douglas Production Frontier, and
- A Translog (Transcendental Logarithmic) Production Frontier

5.2.1.1 Cobb-Douglas Production Frontier

The *stochastic* frontier production function in the Cobb-Douglas form, for any given plant i is given as in Eq. 5.8:

$$ln(Q_i) = \beta_0 + \beta_1 \times ln(K_i) + \beta_2 \times ln(L_i) + (v_i - u_i) \text{ -------(5.8)}$$

Where Q_i is output while K_i and L_i are inputs respectively. v_i are random variables which are assumed to be independent and identically distributed (i.i.d.) and have $N(0, \sigma_v^2)$ distribution, independent of the u_i; the u_i are non negative random variables which are assumed to account for technical inefficiency in the production and are often assumed to be i.i.d. $|N(0, \sigma_u^2)|$. v_i and u_i are assumed normal and half normal distributed respectively.

For the present study the Eq. 5.8 can be written as

$$ln(POWGEN_i) = \beta_0 + \beta_1 \times ln(CAPITAL_i) + \beta_2 \times ln(HEAT\_RATE_i) + (v_i - u_i) \text{ -------(5.9)}$$

In Eq. 5.9 above, $ln(\cdot)$ denotes the natural logarithmic transformation of a variable and suffixes i adjacent to every variable indicate that each variable value is associated with plant i. Moreover, β_0, β_1, and β_2 are unknown parameters or coefficients associated with variables, to be estimated for plant i. The last term of the above equation: $(v_i - u_i)$ is the error term of the model, where v_i is the random noise term associated with plant i in and u_i is the *TE* effect of plant i (one-sided residual term), as postulated by Battese and Coelli (1992). u_i is a random variable associated with plant i, which follows a truncated normal distribution, with mean μ and variance σ_u^2.

5.2.1.2 *Translog (Transcendental Logarithmic) Production Frontier*

Translog Production Function is a more general specification of a production function than other commonly used functional forms. It is a flexible form which imposes relatively few restrictions on the underlying production technology. It allows for variable elasticity of substitution between inputs and variable returns to scale. The Translog functional form in general can be written as (Eq. 5.10):

$$\begin{aligned} ln(Q_i) = \beta_0 + \beta_1 \times ln(K_i) + \beta_2 \times ln(L_i) + \beta_3 \times (ln(K_i))^2 + \beta_4 \times (ln(L_i))^2 \\ + \beta_5 \times (ln(K_i) \times ln(L_i)) + (v_i - u_i) \end{aligned} \qquad \text{-------(5.10)}$$

While for the present study it is

$$\begin{aligned} ln(POWGEN_i) = \beta_0 + \beta_1 \times ln(CAPITAL_i) + \beta_2 \times ln(HEAT\_RATE_i) + \beta_3 \times (ln(CAPITAL_i))^2 \\ + \beta_4 \times (ln(HEAT\_RATE_i))^2 + \beta_5 \times (ln(CAPITAL_i) \times ln(HEAT\_RATE_i)) + (v_i - u_i) \end{aligned} \qquad \text{-------(5.11)}$$

Note that the first three terms in Eq. 5.11 - which are the intercept and the terms involving capital and heat rate variables - make up the Cobb-Douglas production function, while the last three terms - which are the quadratic terms involving *CAPITAL* and *HEAT RATE,* and a *CAPITAL - HEAT RATE* interaction term - convey information regarding the curvature of the Translog Production Function.

Eq. 5.9 and 5.11 has been estimated using 'Frontier' computer package developed by Coelli (1996a).

5.3 EMPIRICAL ANALYSIS

In order to estimate the plant specific *TE*, as mentioned above, the two models have been tried viz. Cobb-Douglas Production Frontier and Translog (Transcendental Logarithmic) Production Frontier for the data collected.

It has been shown in the previous chapter that the actual output of the plants which is affected by the given quantities of inputs and parameters and also individual plant's efficiency which is related to the degree to which the plant fails to reach its frontier. Of the fitted available functional forms of a plant's frontier production function, like Cobb-Douglas form and Translog form, it has been observed that the Cobb-Douglas form fitted the available data best. Therefore, in the present study, Stochastic Frontier Production Function in the Cobb-Douglas form is used.

As per the literature survey, the work carried out by the various authors like Singh (1991), Khanna *et al* (1999), Chitkara (1999), Shanmugam and Kulshreshtha (2002 and 2005), the input parameters which were used in earlier studies are like coal consumption, oil consumption, or in some cases *Specific Coal Consumption* and *Specific Oil Consumption, GCV* of coal. In the present study all these variables are experimented and also as mentioned in various studies it is observed that these variables are correlated. Results of the logged models have shown that these variables are highly correlated. So, instead of using these variables individually, *HEAT RATE* is used as one of the input parameter for analysis. It is also a very important parameter based on theoretical observations. This had also been confirmed after brain storming sessions with academicians and authorities of various plants visited during the span of present study. In the conventional way the plant's performance is checked by its *HEAT RATE* value only. Lower its value better is its performance.

The sign of coefficients of the parameters i.e. β is positive for the *CAPITAL* and negative for *HEAT RATE*, which signifies that the higher value of *CAPITAL* and lower value of *HEAT RATE* is desirable.

The sign of the coefficients of the parameters i.e. β is found to be as expected in Cobb-Douglas model. The possible reason for negative sign associated with *HEAT RATE* is as the *HEAT RATE* improves i.e. decreases, the power plant's performance improves i.e. the plant is consuming less energy in order to produce the output. Lower the value of *HEAT RATE* better is the plants performance. This is the thumb rule followed in the power plants. Also the coefficient of *CAPITAL* variable is positive and is as per expectation. The positive value represents higher values of *Capacity* and higher values of operational availability of the power plant and lower value of *Forced Outage* i.e. better is the *PLF* and hence the performance.

The estimated parameters of the Cobb-Douglas' model which are obtained by OLS and MLE are presented in Table 5.2. These estimates provide a useful benchmark for present analysis.

The estimated parameters of the Translog model which are obtained by OLS and MLE are presented in Table D.1(a) and D.2(b) in Appendix-D.

The parameter associated with *CAPITAL* is positive and statistically significant at 5% level of significance, indicating that *CAPITAL* is an important determinant of thermal power generation in India.

The estimates of the frontier production function, which are obtained by the MLE technique, without imposing any restrictions on the parameters of the model. As in the OLS model, the coefficients of *CAPITAL* and *HEAT RATE* variables are positive and negative respectively. And both are statistically significant in the MLE estimation case.

The parameters obtained by OLS have some optimal properties and OLS is an essential component of most of the econometric techniques. The estimates obtained by OLS methods are Best, Linear and Unbiased Estimates which are also called as BLUEs.

It is also found that parameter σ^2, which equals the total variation in plant output due to variation in plant performance, is positive and statistically significant at 5% level of significance. The parameter γ, which is attributable to variation in plant-specific *TE*, is also positive and statistically significant.

The statistical significance of both parameters σ^2 and γ implies that a plant's actual output differs significantly from its frontier output. This is due to differences in plant performance or plant-specific *TE* (which is within the control of power stations), and due to random factors (which are beyond the control of power stations). More specifically, the estimated value of γ, which is the ratio of the variance of plant specific *TE* to the total variance of output, is varying from 0.9284 to 0.9981, which indicates that 92.84% to 99.81% of the difference between the actual and Cobb-Douglas output of thermal stations is attributable to factors which are under the control of the power stations. The γ values for similar studies, Shanmugam and Kulshreshtha (2002 and 2005), were 0.5355 and 0.7429 respectively. This indicates that the proposed model is a better model as compared to the models used in the studies carried out by Shanmugam and Kulshreshtha (2002 and 2005).

Table 5.2: Estimated Parameters of Cobb-Douglas Model by OLS and MLE

COBB-DOUGLAS	1999-2000		2000- 2001		2001-2002		2002-2003		2003-2004		2004-2005		2005-2006	
	OLS	MLE	OLS	MLE	OLS	MLE	OLS	MLE	OLS	MLE	OLS	MLE	OLS	MLE
Constant	4.0521	2.9632	3.8071	2.7135	2.8389	2.9884	4.7873	1.7090	5.0550	2.8736	6.1517	4.0037	6.4062	3.5114
	(3.3930)	(11.7605)	(3.7063)	(2.1747)	(2.6076)	(3.0407)	(4.2691)	(3.6105)	(5.3412)	(3.0918)	(6.9935)	(3.0468)	(6.5047)	(2.9120)
ln(CAPITAL)	1.0650	1.0105	1.0863	1.0599	1.0913	1.0501	1.0359	1.0298	1.0471	1.0191	1.0283	1.0297	1.0300	1.0182
	(40.0768)	(40.4477)	(47.9027)	(54.5854)	(49.2529)	(34.3326)	(42.9924)	(59.4254)	(53.4413)	(79.8990)	(54.6612)	(80.9076)	(60.6439)	(61.1712)
ln(HEAT RATE)	-0.6087	-0.3883	-0.5968	-0.4100	-0.4790	-0.4353	-0.6643	-0.2501	-0.7079	-0.3841	-0.8252	-0.5390	-0.8599	-0.4621
	(-4.6067)	(-9.8950)	(-5.1903)	(-2.6218)	(-3.9594)	(-4.6925)	(-5.3913)	(-5.5332)	(-6.7218)	(-3.2233)	(-8.4665)	(-3.2994)	(-7.6412)	(-2.9109)
sigma-squared	0.0331	0.0916	0.0274	0.0630	0.0227	0.0462	0.0245	0.0625	0.0187	0.0540	0.0153	0.0385	0.0186	0.0538
(σ^2)		(5.8288)		(3.8939)		(5.5751)		(6.3228)		(4.4561)		(3.8409)		(3.9480)
Gamma (γ)		0.9874		0.9284		0.9286		0.9981		0.9761		0.9510		0.9783
		(165.9130)		(12.1954)		(3.1890)		(262.9443)		(30.3676)		(16.0133)		(24.7197)
LLF	23.1639	29.8591	30.7830	36.2195	37.9903	44.1256	35.0575	48.6605	45.4019	48.3398	51.9222	56.0752	45.6236	48.8485
LRT		13.3903		10.8730		12.2708		27.2061		5.8758		8.3061		6.4499
Sample size	76	76	77	77	77	77	77	77	77	77	75	75	77	77

(Bracketed terms are *t ratios*)

The generalized likelihood ratio test ($\chi 2$ statistic), approximately equal to 12.8974, which exceeds the critical $\chi 2$ value and based on this, the hypothesis that proposed model is a traditional half-normal distribution model is rejected.

The parameter η is positive and statistically significant, which implies that the *TE* of CBITPPs is time-dependent and plant efficiency is varying over the time period of the study.

The goodness of fit of regression equation evaluated by the coefficient of determinants i.e. R^2 for the Least Square Method gives us the value 0.9387. This implies that about 94 percent explanation is there by the two explanatory variables. In addition the *F*-statistic of 267.38 shows that the relationship between variables exogenous and endogenous is significant at the 1% level.

5.3.1 Consistency of Results from SFA and DEA

In order to check the consistency of the results by SFA, the *TE* scores are determined using DEA also. These TE scores by DEA are estimated using Eq. 4.6 and 4.8 mentioned in chapter 4. These equations have been estimated using `DEAP' computer program developed by Coelli (1996b).

After comparing scores of technical efficiency over the period of study obtained from DEA CRS, DEA VRS and SFA of CBITPPs, the first impression is of hugely different scores of each plant obtained from different approaches. The *TE* scores obtained by all the models tried viz. Cobb-Douglas, Translog, DEA CRS, and DEA VRS for the years 1999-2000 to 2005-2006 are given in Table E.1 to Table E.7 in Appendix E. From these tables it is observed that the scores from DEA CRS are lower than those from DEA VRS and SFA. It is not surprising as this is owing to the scale effect. But under the same variable return to scale assumption, DEA VRS and SFA scores are also not consistent. Therefore, the consistency conditions in ranking and identification of the most and least efficient power plants are considered again.

Spearman Rank Correlation Coefficients between the different approach (DEA and SFA) in Table 5.3 are positive, quite high and statistically significant from zero at 1 per cent level of significance. Therefore the results of various techniques are consistent in terms of ranking.

In many cases the precise values of the variables considered for the analysis may not be available, so sometimes it is impossible to calculate the value of correlation coefficient with the formulas developed in the methodologies. For such cases it is possible to use another statistics, the Rank Correlation Coefficient. When applying Rank Correlation Coefficient, even in the present study, it doesn't matter whether observations are ranked in ascending or descending order. However in present work the same rule has been used for ranking all the variables. Wherever two or more observations have the same value the mean rank has been assigned to them.

Table 5.3: Spearman Rank-Order Correlations between Efficiency Scores Obtained from Different Models

	SFA (CD)	DEA CRS	DEA VRS
SFA (CD)	1	0.8622	0.5356
DEA CRS	-	1	0.7313
DEA VRS	-	-	1

5.3.2 Technical Efficiency Estimates

As per earlier discussion the analysis of yearly data shows that *TE* of CBITPPs is time-dependent or time-variant. The time-specific *TE* values for all seventy seven plants are given in Table 5.4 of the report. During the seven year period i.e. year 1999-2000 to 2005-2006, the mean *TE* of plants is varying from 80.84 percent to a maximum of 87.08 percent, indicating that on average, 13-20 percent of the technical potential of thermal power plants is not realized. Annual *TE* values for each plant during the study period have been presented in Table 5.4.

The overall average *TE* values for all the stations are given in column 9 of Table 5.4. The estimated (mean) *TE* values of stations vary from 40.70 percent in BONGAIGAON station (in Assam) to 97.97 percent in NEYVELI-I (Tamil Nadu). The estimated *TE* by the proposed model of BONGAIGAON plant is shown in Table 5.4, this plant was operated at estimated *TE* value of 39.78, 37.84 and 44.48 percent for the year 1999-2000, 2000-2001, and 2001-2002 respectively. This shows that as per the proposed model this power plant was highly technically inefficient during the period mentioned. This finding is supported by the fact that because of such a poor performance this plant was shut down in 2002. Furthermore, SIMHADRI plant started in 2002 with low *TE* of 43.93 percent because of starting hurdles but later on the *TE* improved to 94.54, 94.25 and 88.33 percent for the years 2003-2004, 2004-2005, and 2005-2006 respectively which is well above the annual average. As mentioned this plant is quite a new plant as compared to other plants and its higher *TE* estimates by the proposed model is validated by its performance.

Fig. 5.1 to Fig. 5.7 shows the distribution of number of CBITPPs by estimated *TE* values varying from below 60% to above 90% with an increment of five for the year 1999-2000 to 2005-2006, while Fig. 5.8 shows the distribution of number of CBITPPs by average estimated *TE* values for the same period. It can be seen here that the *TE* values of thirty five out of eighty plants fall below 84.66 percent or the average plant *TE* value.

Percentage wise distribution of number of plants by *TE* values is given in Table 5.5. Column 2 to 8 of this table give year wise distribution of percentage of total number of plants by *TE* values i.e. from 1999-2000 to 2005-2006, while ninth column gives distribution based on overall *TE* for the same period. It is seen from the Fig. 5.1 to 5.8 and Table 5.5 that large numbers of CBITPPs i.e. almost 45 percent are operating well below the average *TE* of about 85 percent. Thus, *TE* varies significantly across stations and still a lot remains to be accomplished to improve the *TE* of CBITPPs.

Table 5.4: Plant Specific Technical Efficiency Values in Percentage

YEAR STATION	1999-00	2000-01	2001-02	2002-03	2003-04	2004-05	2005-06	OVER ALL
A.E.CO. & SABARMATI	94.77	95.29	95.98	99.37	97.60	96.94	97.93	96.84
AMAR KANTAK	81.54	85.99	83.03	77.38	69.92	74.56	66.50	76.99
ANPARA	91.83	89.74	91.41	92.11	90.01	86.02	87.39	89.79
BADARPUR	90.30	92.90	94.30	93.24	90.57	91.13	91.83	92.04
BAKRESHWAR	-	75.65	86.51	84.68	76.70	75.97	78.94	79.74
BANDEL	63.70	66.41	65.16	65.00	66.06	70.35	60.93	65.37
BARAUNI	50.95	56.27	66.11	49.40	56.67	53.63	42.17	53.60
BHATINDA	88.54	91.69	94.19	90.87	90.57	91.69	87.07	90.66
BHATINDA EXT.	78.80	95.10	93.52	94.10	91.92	93.51	92.51	91.35
BHUSAWAL	86.87	86.68	87.84	84.89	90.45	90.64	92.05	88.49
BIRSINGHPUR	76.89	84.87	87.08	82.05	82.62	88.91	82.86	83.61
BOKARO	73.56	76.64	87.63	78.44	76.91	88.24	75.36	79.54
BONGAIGAON	39.78	37.84	44.48	-	-	-	-	40.70
BUDGE BUDGE	44.63	73.26	81.52	78.45	84.14	90.11	95.71	78.26
CHANDARPUR	82.53	78.97	83.00	81.72	82.89	85.34	85.09	82.79
CHANDRAPURA	67.85	68.01	78.86	60.61	68.51	80.30	73.13	71.04
DADRI	96.44	92.45	91.64	90.54	87.93	91.39	91.54	91.70
DHANU	86.31	87.35	91.37	97.11	95.79	94.29	94.53	92.39
DURGAPUR	75.45	74.69	85.22	81.84	80.17	82.92	74.31	79.23
DURGAPUR (D.P.L.)	66.58	73.63	76.99	73.37	82.67	89.26	84.89	78.20
ENNORE	71.12	83.91	73.11	77.43	76.34	77.07	69.60	75.51
FARAKKA STPS	79.00	72.80	83.26	84.31	88.92	93.34	94.66	85.18
FARIDABAD EXTN.	96.80	96.75	97.35	98.90	95.89	92.97	85.26	94.85
GANDHI NAGAR	71.35	71.49	81.44	88.26	78.20	75.28	73.15	77.02
HARDUAGANJ B	74.86	83.80	76.88	71.17	65.96	62.00	60.66	70.76
I.B. VALLEY	92.37	89.93	86.86	77.54	88.21	92.34	86.95	87.74

YEAR STATION	1999-00	2000-01	2001-02	2002-03	2003-04	2004-05	2005-06	OVER ALL
I.P. STATION	72.43	79.61	70.92	72.86	63.64	76.61	69.98	72.29
KAHALGAON	68.83	80.70	95.52	91.63	96.87	97.34	97.97	89.84
KHAPARKHEDA II	91.37	91.78	84.73	90.67	91.22	91.43	87.83	89.86
KOLAGHAT	76.71	73.97	74.87	73.77	83.36	83.18	79.19	77.86
KORADI	79.18	77.97	86.14	81.72	85.42	86.57	86.33	83.33
KORBA EAST	90.01	91.87	90.31	88.87	91.98	94.90	94.93	91.84
KORBA STPS	95.07	88.82	91.47	93.11	94.17	95.22	95.80	93.38
KORBA-WEST	89.67	89.50	90.45	94.83	91.23	87.33	87.35	90.05
KOTA	95.76	94.38	95.50	98.33	78.97	94.23	95.55	93.25
KOTHAGUDEM	88.74	92.39	93.34	93.37	93.11	94.98	86.64	91.80
KUTCH LIGNITE	84.08	85.60	92.61	77.89	75.03	78.22	98.45	84.55
MEJIA	48.79	68.33	82.36	77.98	87.76	89.45	85.84	77.22
METTUR	87.10	90.96	92.90	97.09	95.94	94.56	93.42	93.14
MUZAFFARPUR	48.04	62.84	59.45	45.96	46.88	-	-	52.63
NASIK	85.62	82.04	85.55	83.76	85.96	83.84	85.80	84.65
NELLORE	69.59	88.40	94.27	78.40	76.30	80.68	76.61	80.61
NEW COSSIPORE	79.95	76.57	66.84	63.12	80.09	-	-	73.31
NEYVELI FST EXT	-	-	-	-	-	-	93.89	93.89
NEYVELI-I	98.30	97.57	97.13	98.62	98.50	98.52	97.13	97.97
NEYVELI-II	92.06	90.34	92.81	92.70	94.76	92.08	88.21	91.85
NORTH MADRAS	86.47	88.84	89.93	90.26	88.73	90.82	90.28	89.33
OBRA THERMAL	75.16	74.41	75.66	73.88	74.55	72.32	67.94	73.42
PANIPAT	83.29	87.24	85.51	97.22	95.56	95.43	90.86	90.73
PANKI	64.65	88.10	83.39	83.56	83.03	76.79	69.87	78.48
PARAS	93.17	95.77	96.29	93.52	97.70	96.59	96.63	95.67
PARICHA	67.87	82.14	91.72	73.59	72.40	86.45	81.15	79.33
PARLI	83.09	86.88	86.87	87.27	87.39	94.56	91.30	88.19
PATRATU	70.89	82.13	79.59	55.79	49.25	63.47	60.12	65.89

YEAR STATION	1999-00	2000-01	2001-02	2002-03	2003-04	2004-05	2005-06	OVER ALL
RAICHUR	89.63	89.13	91.26	94.24	92.39	89.75	88.50	90.70
RAJGHAT	98.14	93.91	97.29	92.02	95.64	83.72	73.98	90.67
RAMAGUNDEM - B	96.62	96.68	96.95	96.37	97.31	96.89	86.60	95.35
RAMAGUNDEM STPS	86.43	89.26	90.21	93.75	91.72	75.38	86.39	87.59
RAYALSEEMA	95.46	92.94	95.17	97.89	92.16	91.18	83.37	92.60
RIHAND STPS	93.65	90.54	91.23	92.24	90.76	88.78	80.86	89.72
ROPAR	93.72	92.62	95.02	94.26	91.41	92.04	92.19	93.04
SANTALDIH	66.50	62.72	67.48	59.94	63.85	64.71	61.07	63.75
SATPURA	95.27	90.94	88.96	91.73	88.00	90.10	91.58	90.94
SIKKA REPL	83.03	90.68	91.69	94.06	74.27	88.33	87.83	87.13
SIMHADRI	-	-	-	43.93	94.54	94.25	88.33	80.26
SINGRAULI STPS	94.24	89.32	89.94	92.38	91.15	90.12	93.99	91.59
SOUTHERN REPL	69.44	80.14	74.14	89.89	89.28	94.97	94.59	84.64
SURATGARH	72.68	81.47	67.26	82.97	83.66	89.88	92.14	81.44
TALCHER	83.41	92.10	94.16	93.35	96.50	95.98	95.36	92.98
TALCHER STPS	69.29	85.93	81.40	87.07	84.91	72.70	83.76	80.72
TANDA	57.26	70.55	84.94	94.76	94.27	96.53	97.22	85.08
TENUGHAT	79.74	86.78	78.37	76.19	85.04	94.97	77.97	82.72
TITAGARH	84.42	88.87	89.51	92.00	91.59	95.63	95.42	91.06
TROMBAY	-	-	-	-	-	-	77.44	77.44
TUTICORIN	94.04	92.06	93.56	95.92	94.78	92.64	91.20	93.46
UKAI THERMAL	83.04	88.74	92.20	88.50	87.71	85.85	84.29	87.19
UNCHAHAR	95.89	94.09	93.71	94.16	94.00	94.78	95.23	94.55
VIJAYAWADA	94.75	90.57	93.15	94.85	92.43	90.35	86.85	91.85
VINDHYACHAL STPS	92.82	89.18	86.73	90.64	88.60	88.28	90.93	89.60
WANAKBORI	85.63	89.95	91.69	96.07	89.36	89.36	90.03	90.30
MEAN	**80.84**	**84.16**	**85.80**	**84.70**	**85.07**	**87.08**	**84.95**	**84.66**

Fig. 5.1: Distribution of Number of Plants by Technical Efficiency Values (1999-2000)

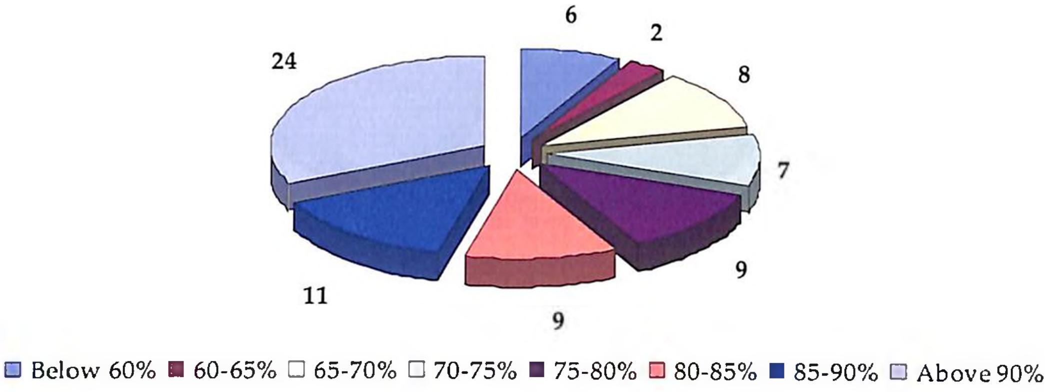


Fig. 5.2: Distribution of Number of Plants by Technical Efficiency Values (2000-2001)

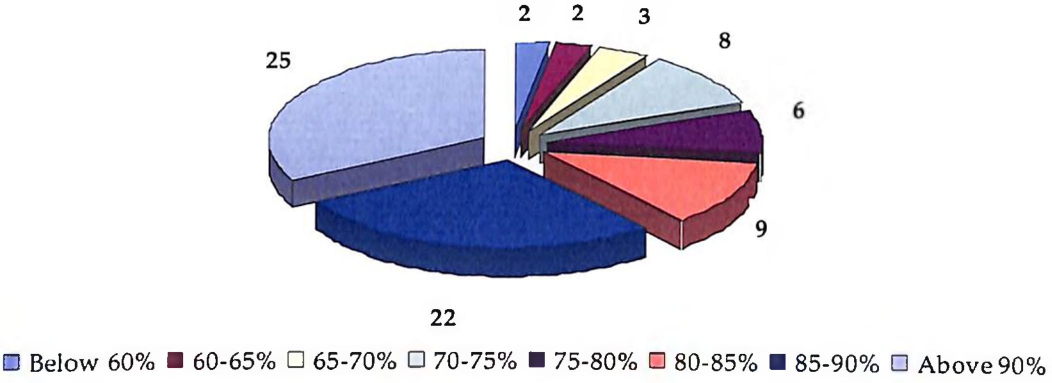


Fig. 5.3: Distribution of Number of Plants by Technical Efficiency Values (2001-2002)

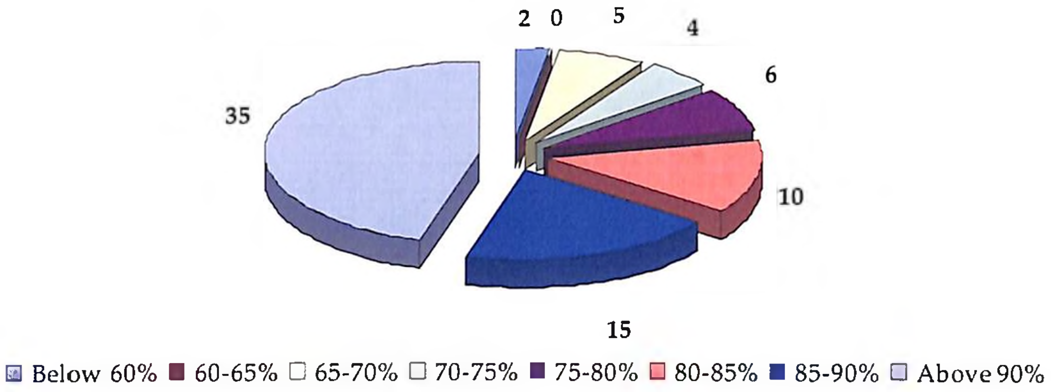


Fig. 5.4: Distribution of Number of Plants by Technical Efficiency Values (2002-2003)

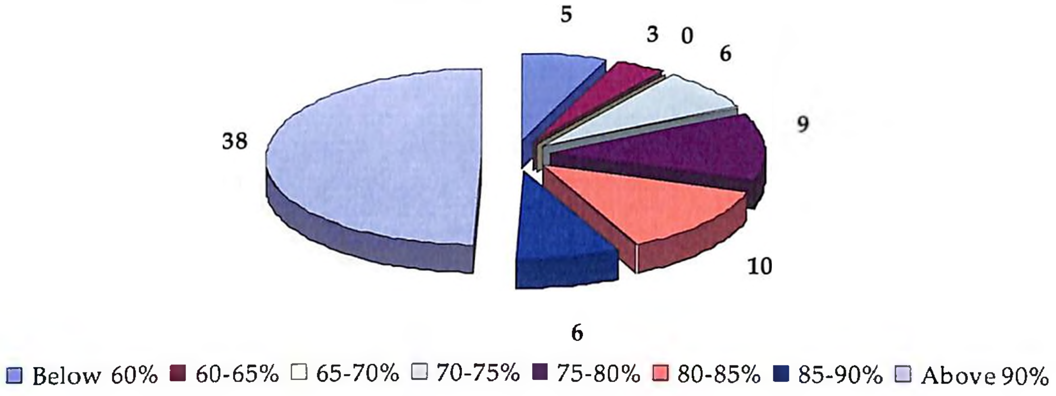


Fig. 5.5: Distribution of Number of Plants by Technical Efficiency Values (2003-2004)

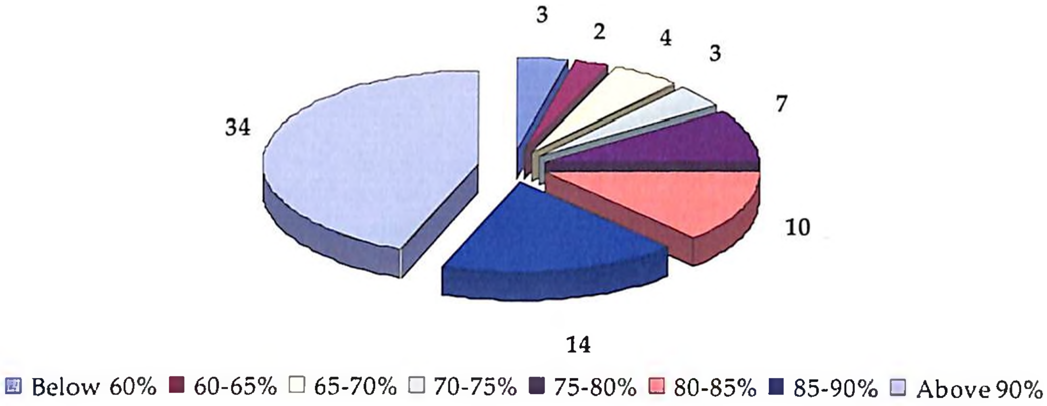


Fig. 5.6: Distribution of Number of Plants by Technical Efficiency Values (2004-2005)

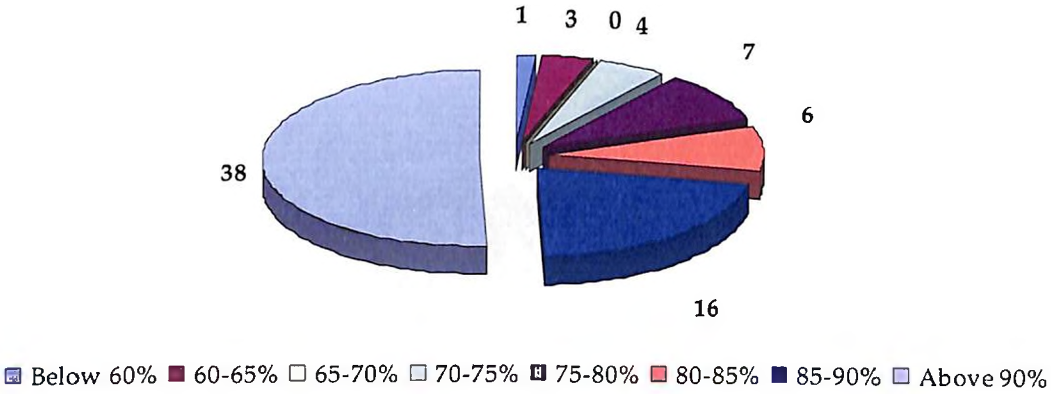


Fig. 5.7: Distribution of Number of Plants by Technical Efficiency Values (2005-2006)

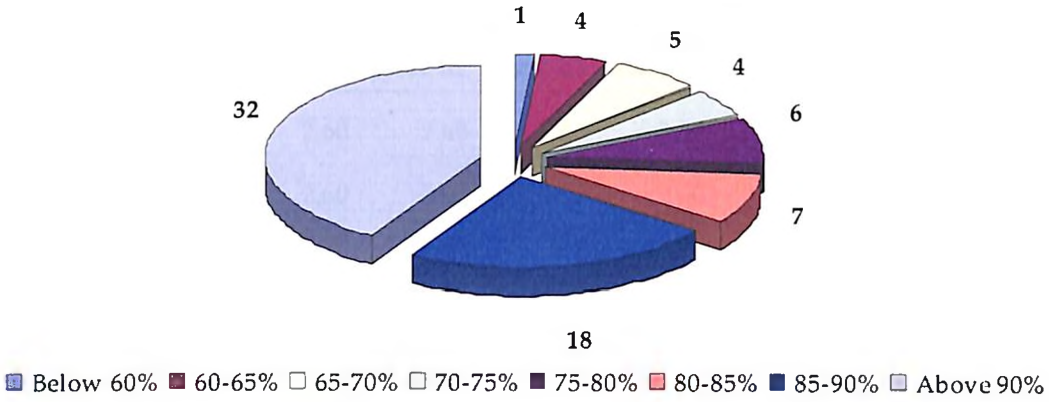


Fig. 5.8: Distribution of Number of Plants by Technical Efficiency Values (Over All)

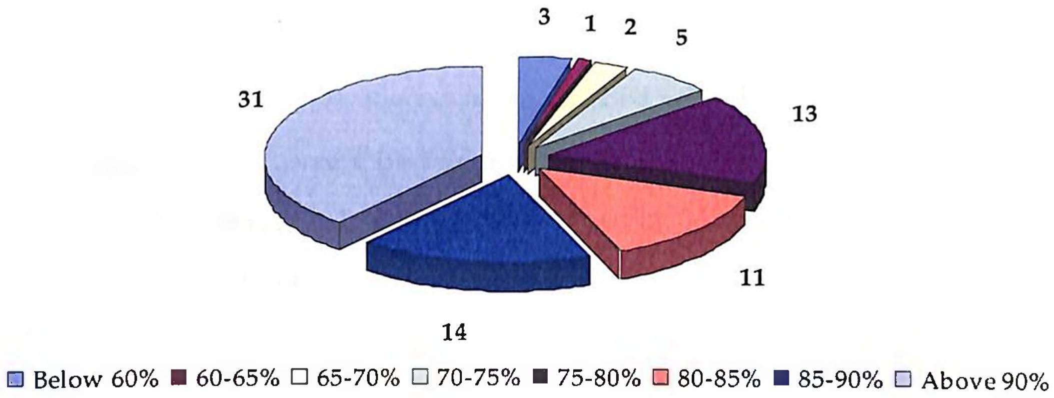


Table 5.5: Percentage Wise Distribution of Number of Plants by Technical Efficiency Values (%)

TE (%)	1999-2000	2000-01	2001-02	2002-03	2003-04	2004-05	2005-06	OVERALL
Below 60	7.89	2.60	2.60	6.49	3.90	1.33	1.30	3.75
60-65	2.63	2.60	0.00	3.90	2.60	4.00	5.19	1.25
65-70	10.53	3.90	6.49	0.00	5.19	0.00	6.49	2.50
70-75	9.21	10.39	5.19	7.79	3.90	5.33	5.19	6.25
75-80	11.84	7.79	7.79	11.69	9.09	9.33	7.79	16.25
80-85	11.84	11.69	12.99	12.99	12.99	8.00	9.09	13.75
85-90	14.47	28.57	19.48	7.79	18.18	21.33	23.38	17.50
Above 90	31.58	32.47	45.45	49.35	44.16	50.67	41.56	38.75
Total	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00

The numbers of CBITPPs are basically divided into five regions: Southern, Western, Eastern, Northern and North Eastern region. In North Eastern region there is only one power plant that too is shut down since 2002. Hence, mainly four regions are selected, the North Eastern Region being clubbed with Eastern Region. Region wise distribution of number of CBITPPs studied for the year 1999-2000 to 2005-2006 is given in Fig. 5.9. It is clearly observed from the Fig. 5.9 that the CBITPPs selected for the study are spread all across the country and almost equal in numbers except the Southern Region where numbers of CBITPPs are less.

Mean *TE* of CBITPPs in different regions during the period of study is reported in Fig. 5.10. Here it is observed that the Eastern and North Eastern Region CBITPPs are operating with lowest mean *TE* values while Southern Region CBITPPs are operating with highest mean *TE* values.

Region wise and state wise mean *TE* values of CBITPPs are given in Table 5.6. Southern (90.01%), Northern (88.25%) and Western region (87.80%) plants have mean *TE* values above all-India mean *TE* value (84.66%) while Eastern (76.26%) and North Eastern region (40.70%) have lower mean *TE* values. Southern region plants have highest mean *TE* value followed by Northern, Western then Eastern and North Eastern Region.

State wise, Haryana (92.79%) has got highest over all mean *TE* while Assam (40.70%) has the lowest overall mean *TE*. The states like West Bengal, Jharkhand including DVC, Bihar and Assam have over all mean *TE* values less than all-India mean *TE* value (84.66%). These states thus have enormous potential for improving their plant performances. One possible reason for variation in *TE* across regions may be excess usage of inputs such as coal that are in abundant supply. This may result in an inefficient use of resources, higher production costs and lower profits.

Fig. 5.9: Region Wise Distribution of CBITPPs

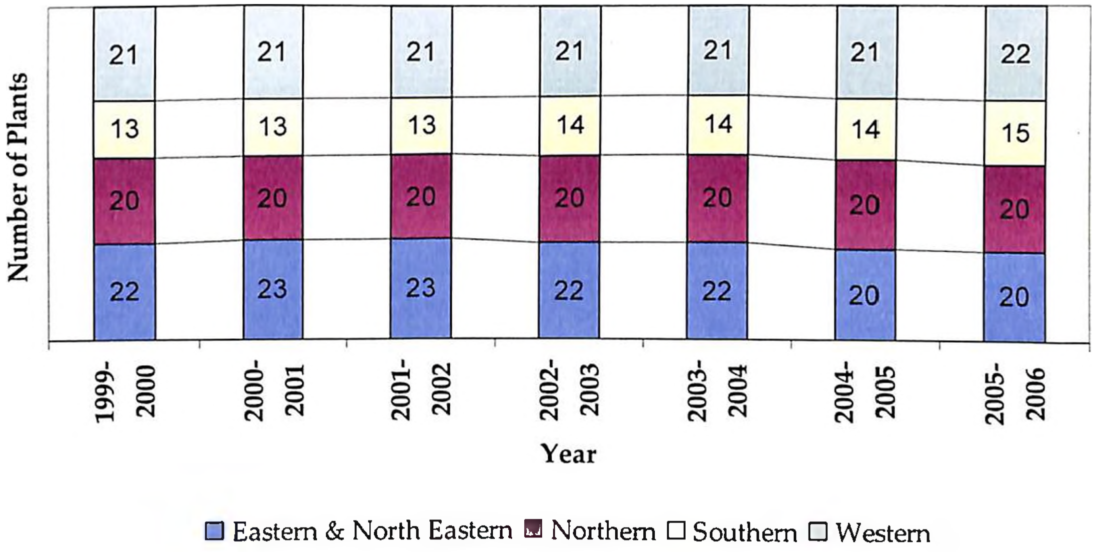


Fig. 5.10: Region Wise Mean Technical Efficiencies of CBITPPs

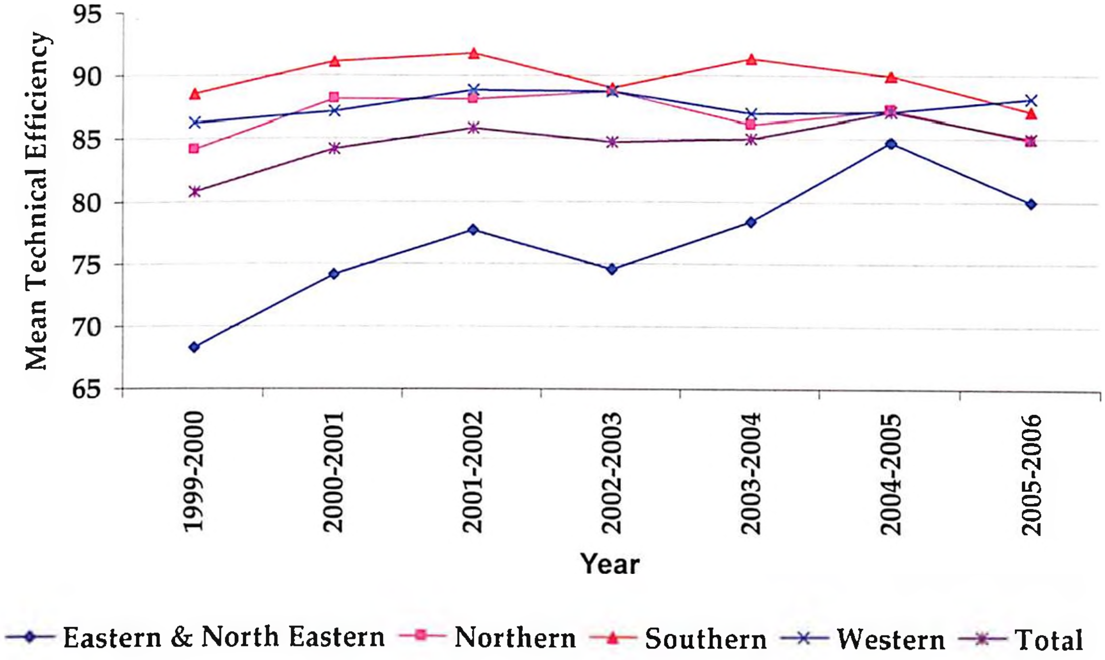


Table 5.6: Mean Technical Efficiency (in Percentage) Region Wise and State Wise

Region State (No. of plants)	1999-00	2000-01	2001-02	2002-03	2003-04	2004-05	2005-06	OVER ALL
Eastern Region								
BIHAR (3)	55.94	66.60	73.69	62.33	66.81	75.49	70.07	65.36
DVC (4)	66.41	71.92	83.52	74.72	78.34	85.23	77.16	76.76
JHARKHAND (2)	75.32	84.46	78.98	65.99	67.15	79.22	69.05	74.31
ORISSA (3)	81.69	89.32	87.47	85.99	89.87	87.01	88.69	87.15
WEST BENGAL (10)	70.10	74.40	76.63	76.45	80.67	84.17	82.82	77.74
Eastern Region (22)	**69.53**	**75.84**	**79.17**	**74.56**	**78.38**	**83.44**	**79.92**	**76.84**
North Eastern Region								
ASSAM (1)	39.78	37.84	44.48	0.00	0.00	0.00	0.00	40.70
North Eastern Region (1)	**39.78**	**37.84**	**44.48**	**0.00**	**0.00**	**0.00**	**0.00**	**40.70**
Northern Region								
DELHI (3)	86.96	88.81	87.50	86.04	83.28	83.82	78.60	85.00
HARYANA (2)	90.05	92.00	91.43	98.06	95.73	94.20	88.06	92.79
PUNJAB (3)	87.02	93.14	94.24	93.08	91.30	92.41	90.59	91.68
RAJASTHAN (2)	84.22	87.93	81.38	90.65	81.32	92.06	93.85	87.34
UTTAR PRADESH (10)	81.19	85.51	87.05	85.84	84.41	84.52	82.59	84.44
Northern Region (20)	**84.12**	**88.04**	**88.07**	**88.66**	**86.09**	**87.32**	**84.86**	**86.74**
Southern Region								
ANDHRA PRADESH (7)	88.60	91.71	93.85	85.51	91.08	89.10	84.97	88.58
KARNATAKA (1)	89.63	89.13	91.26	94.24	92.39	89.75	88.50	90.70
TAMIL NADU (7)	88.18	90.61	89.91	92.00	91.51	90.95	89.10	90.74
Southern Region (15)	**88.49**	**91.00**	**91.83**	**88.92**	**91.36**	**89.94**	**87.13**	**89.73**
Western Region								
CHATTISGARH (3)	91.58	90.06	90.74	92.27	92.46	92.48	92.69	91.76
GUJARAT (6)	83.65	86.96	90.94	90.69	83.70	85.66	88.61	87.17
MADHYA PRADESH (4)	86.63	87.75	86.45	85.45	82.29	85.46	82.97	85.28
MAHARASHTRA (9)	86.02	85.93	87.72	87.58	89.60	90.41	88.56	86.98
Western Region (22)	**86.25**	**87.16**	**88.83**	**88.73**	**86.93**	**88.41**	**88.12**	**87.38**
ALL India	**80.84**	**84.16**	**85.80**	**84.70**	**85.07**	**87.08**	**84.95**	**84.66**

5.3.3 Benchmarking

Benchmarking is recognized as an essential tool for continuous improvement of quality. It is a systematic method by which organizations can measure themselves against the best industry practices.

Benchmarking for power industry is a process in which the energy performance of an individual plant or an entire sector of similar plants is compared against a common metric that represents "best in class" performance. Comparisons of Energy Efficiency of power plants can provide a benchmark against which a plant's performance can be measured to that of other plants. It can also aid in the evaluation of implemented policies.

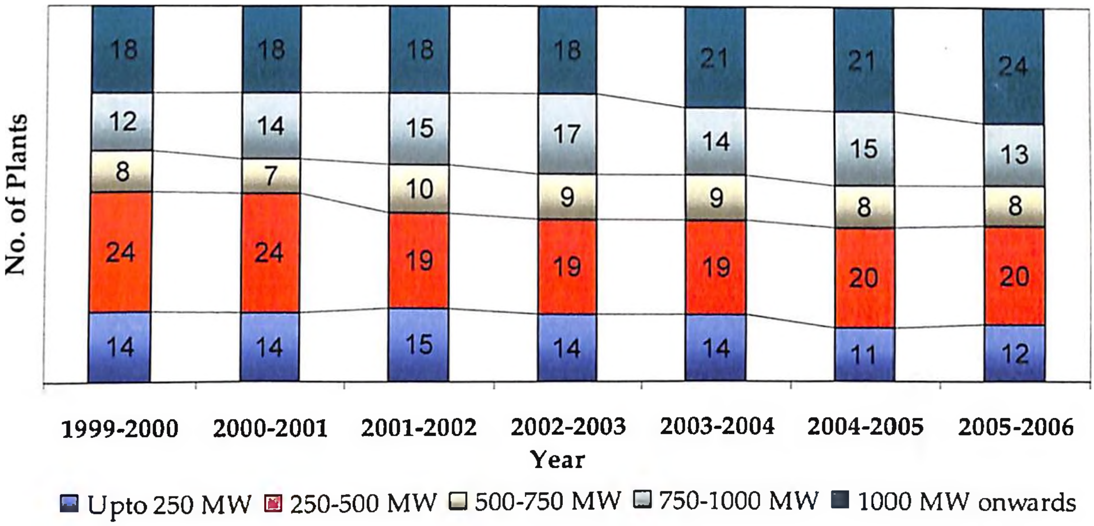
In the present study total seventy five to seventy seven plants are studied and their performance in terms of *TE* has been evaluated for the year 1999-2000 to 2005-2006. But here the practices followed for plants of different sizes like of lower range i.e. below 250 MW is different from the plants having capacities more than 1000 MW. So it is proposed that in order to benchmark, all the thermal power plants under study are divided into five groups as done in section 3.8.1

A) Up to 250 MW,
B) 250-500 MW,
C) 500-750 MW,
D) 750-1000 MW and
E) 1000 MW and above.

Now the performance of the plants in Group A i.e Up to 250 MW can be accessed on the basis of their *TE*. The plant having highest *TE* can be considered as the most efficient plant, while the other plants in the same group can follow the practices used in the benchmarked plant and may improve their performance. The same procedure can be followed for other groups i.e. in B, C, D, and E.

The group wise distribution of number of CBITPPs considered for analysis for the year 1999-2000 to 2005-2006 is given Fig 5.11. Here it is seen that the Group B and Group E i.e. having capacity 250-500 MW and above 1000 MW shares the maximum number of plants, while Group C has smallest share.

Fig. 5.11: Groupwise Number of CBITPPs



The best plants according to the capacity wise and year wise grouping are shown in Table 5.7. Overall performance wise grouping over the study period i.e. 1999-2000 to 2005-2006, it is seen from the Table 5.7 that the most efficient plant in group A is PARAS with *TE* of 95.67%; in group B, A.E.CO. & SABARMATI with *TE* of 96.84%; in group C, NEYVELI-I with *TE* of 97.97%; in group D, UNCHAHAR with *TE* of 94.55% and in group E, TUTICORIN with *TE* of 93.46%. These are the Benchmarked Plants and are given in Table 5.8.

Table 5.7: Best Plants - Capacity and Year Wise Grouping

Year/ Capacity (MW)	1999-00	2000-01	2001-02	2002-03	2003-04	2004-05	2005-06	Overall
A) Up to 250	RAJGHAT (98.14%)	FARIDABAD EXTN. (96.75%)	FARIDABAD EXTN. (97.35%)	FARIDABAD EXTN. (98.90%)	PARAS (97.70%)	RAMAGUNDEM (96.89%)	KUTCH LIG. (98.45%)	PARAS (95.67%)
B) 250-500	UNCHAHAR (95.89%)	A.E.CO. & SABARMATI (95.29%)	A.E.CO. & SABARMATI (95.98%)	A.E.CO. & SABARMATI (99.37%)	AECO.& SABARMATI (97.60%)	A.E.CO. & SABARMATI (96.94%)	A.E.CO. & SABARMATI (97.93%)	A.E.CO. & SABARMATI (96.84%)
C) 500-750	NEYVELI-I (98.30%)	NEYVELI-I (97.57%)	NEYVELI-I (97.13%)	NEYVELI-I (98.62%)	NEYVELI-I (98.50%)	NEYVELI-I (98.52%)	NEYVELI-I (97.13%)	NEYVELI-I (97.97%)
D) 750-1000	DADRI (96.44%)	KOTA (94.38%)	KAHALGAON (95.52%)	KOTA (98.33%)	KAHALGAON (96.87%)	KAHALGAON (97.34%)	KAHALGAON (97.97%)	UNCHAHAR (94.55%)
E) 1000 & above	SATPURA (95.27%)	ROPAR (92.62%)	ROPAR (95.02%)	WANAKBORI (96.07%)	TUTICORIN (94.78%)	KORBA STPS (95.22%)	KORBA STPS (95.80%)	TUTICORIN (93.46%)

Figures in parentheses refer to *TE*

Table 5.8: Benchmarked Plants Based on Overall Performance for the Period 1999-2000 to 2005-2006

Capacity (MW)	Benchmarked Plants	*TE* (%)
A) Up to 250	PARAS	95.67
B) 250-500	A.E.CO. & SABARMATI	96.84
C) 500-750	NEYVELI ST I	97.97
D) 750-1000	UNCHAHAR	94.55
E) 1000 & above	TUTICORIN	93.46

Group wise best *TE* and mean *TE* values on yearly basis are given in Fig. 5.12 to 5.16. Fig. 5.17 shows Capacity wise best *TE* on yearly basis and over all bases.

Tables F.1 to F.7 in Appendix-F give capacity wise rankings of the plants for the year 1999-2000 to 2005-2006 respectively and Table F.8 gives rankings of the plants for over all performance. These tables also give capacities, *TE* values, ranks in respective group and overall ranks of the plants for the respective year.

In the present study, for the year 1999-2000, under Group A, out of total fourteen power plants, RAJGHAT power plant of Delhi is the best plant having highest *TE* of 98.14%, while FARIDABAD-EXTN. of Haryana is the second best having *TE* of 96.80%. If we compare these two plants, RAJGHAT having a *HEAT RATE* of 14,272.8 kJ/kWh (3,409 kcal/kWh), *PLF* of 79.44% and *OAF* of 97.47% with FARIDABAD-EXTN which is having a *HEAT RATE* of 16,646.72 kJ/kWh (3,976 kcal/kWh), *PLF* 65.91% and *OAF* of 80.32%, then it is seen that former is having lower *HEAT RATE* and higher *PLF* and *OAF* and hence better performance. In the same group lowest is the BONGAIGAON of ASSAM having *TE* of 39.78%. The mean *TE* being 77.40% so in this group a potential improvement of about 20% is possible.

For the year 1999-200 in group A, the RAJGHAT plant operated with an *OAF* of 87.47%, *PLF* of 79.44%, and *HEAT RATE* of 14,272.8 kJ/kWh (3,409 kcal/kWh) while SOUTHERN REPL. plant operated with an *OAF* of 96.67%, *PLF* of 63.28%, and *HEAT RATE* of 11,924 kJ/kWh (2,848 kcal/kWh). The estimated *TE*s of these two plants suggested by the model used are 98.14% and 69.44% respectively. If these two plants are compared in a conventional way then since the latter is operated with lower *HEAT RATE* it is considered as the better plant. But the model used in the present study tells that the former is a better one even though its *HEAT RATE* is higher. Though the former is operated at higher *HEAT RATE* but have lower *OAF* and higher *PLF* as compared to latter. At the same time the power output *POWGEN* of former is 942 MU as compared to 750 MU of the latter. That means the former plant is giving higher output, so it is giving output closer to its potential power output hence higher *TE*. And the latter having lower *HEAT RATE* is not utilizing its complete potential of which it was capable of and hence technically less efficient.

From the above discussion it is clear that the suggested model is a better way of evaluating the performance of CBITPPs as compared to, the Average Method discussed in chapter III where in only *Specific Fuel Consumption* is considered, and Conventional Method where only *HEAT RATE* is considered, as the only parameter for assessing the performance of CBITPPs. So here it can be concluded that the model used is a better model for benchmarking of the CBITPPs.

Fig. 5.12: Best Technical Efficiencies of Upto 250MW CBITPPs

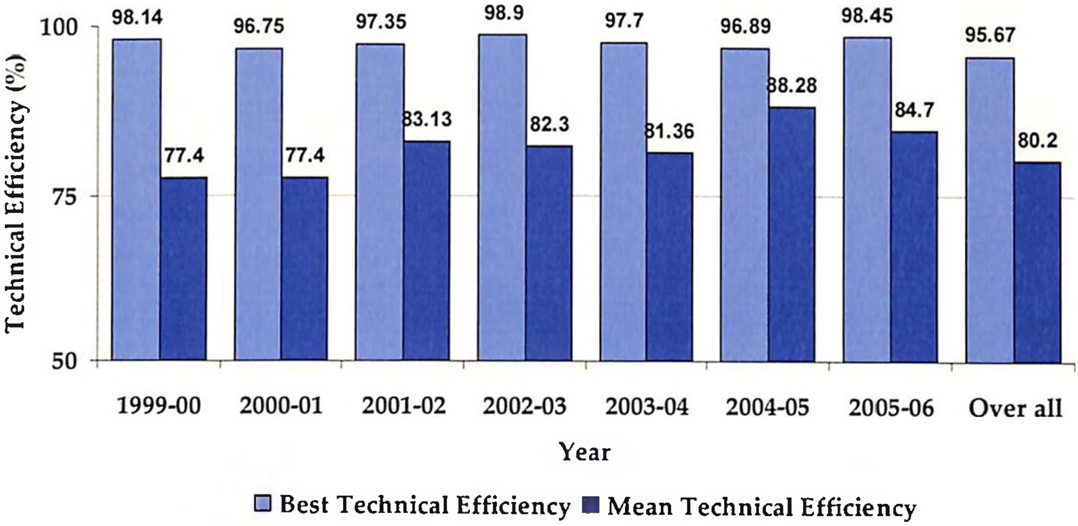


Fig. 5.13: Best Technical Efficiencies of 250 - 500 MW CBITPPs

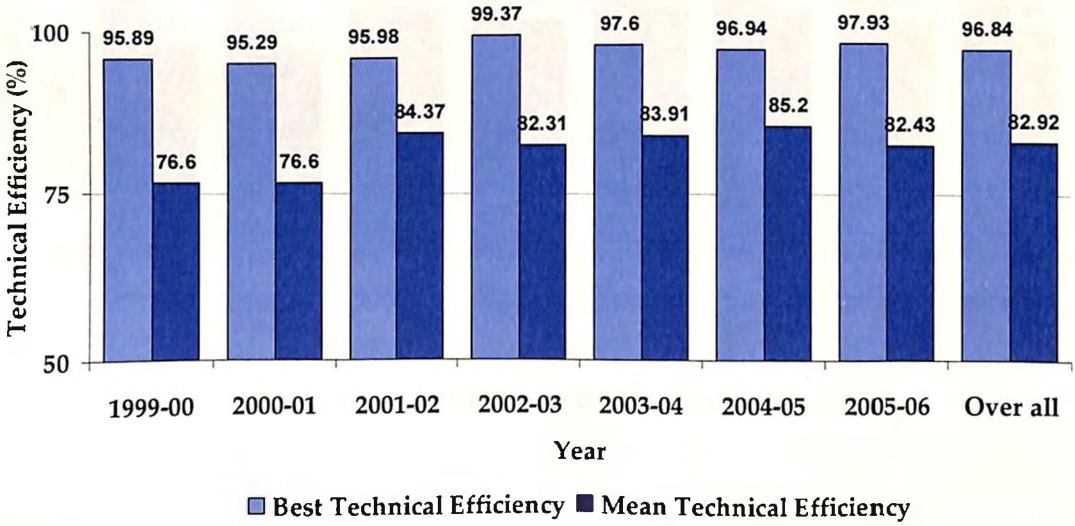


Fig. 5.14: Best Technical Efficiencies of 500 - 750 MW CBITPPs

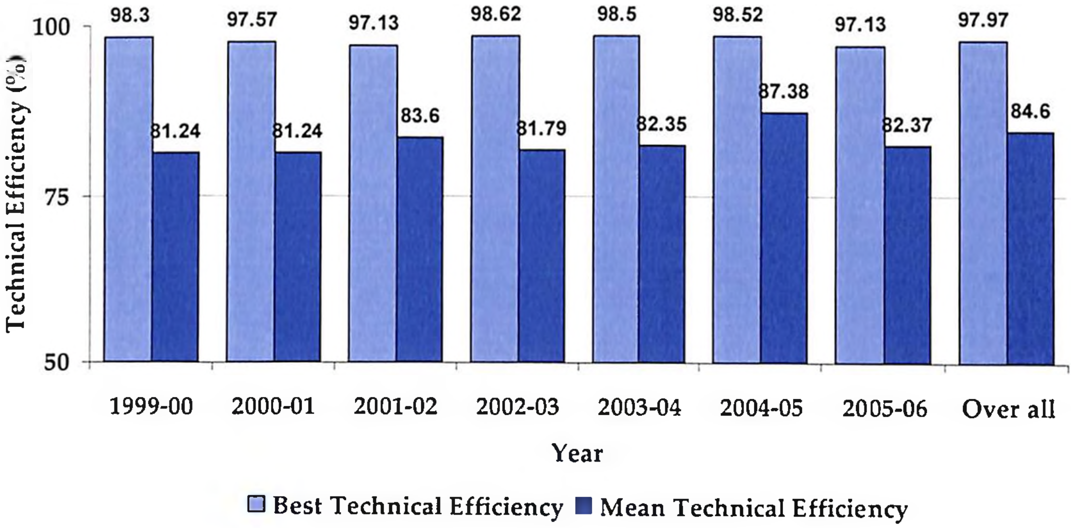


Fig. 5.15: Best Technical Efficiencies of 750 - 1000 MW CBITPPs

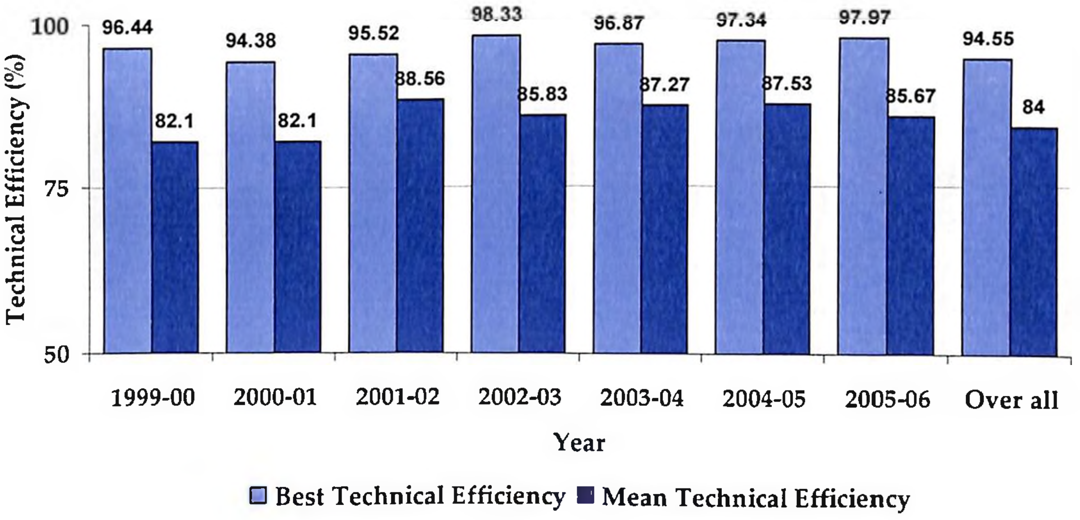


Fig. 5.16: Best Technical Efficiencies of 1000 MW and above CBITPPs

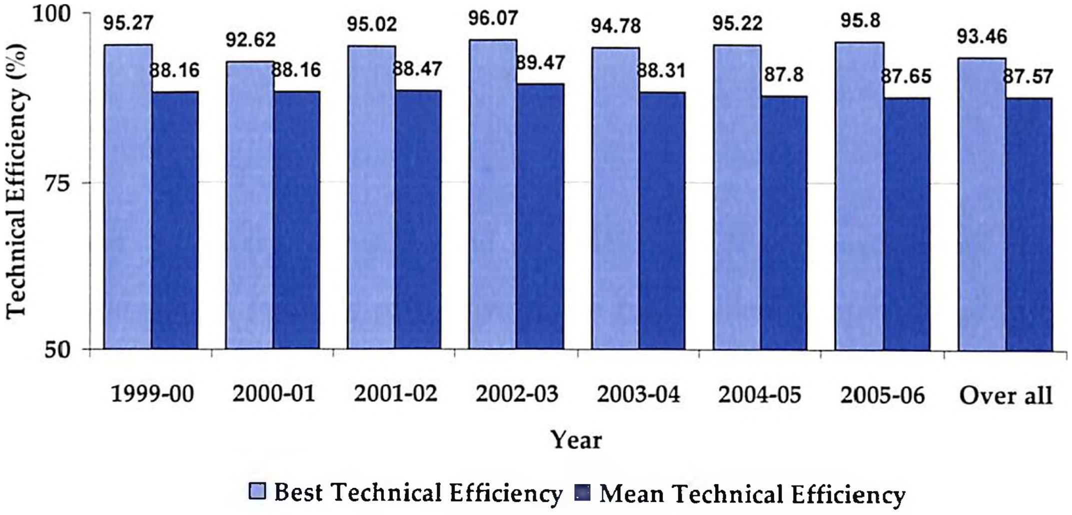
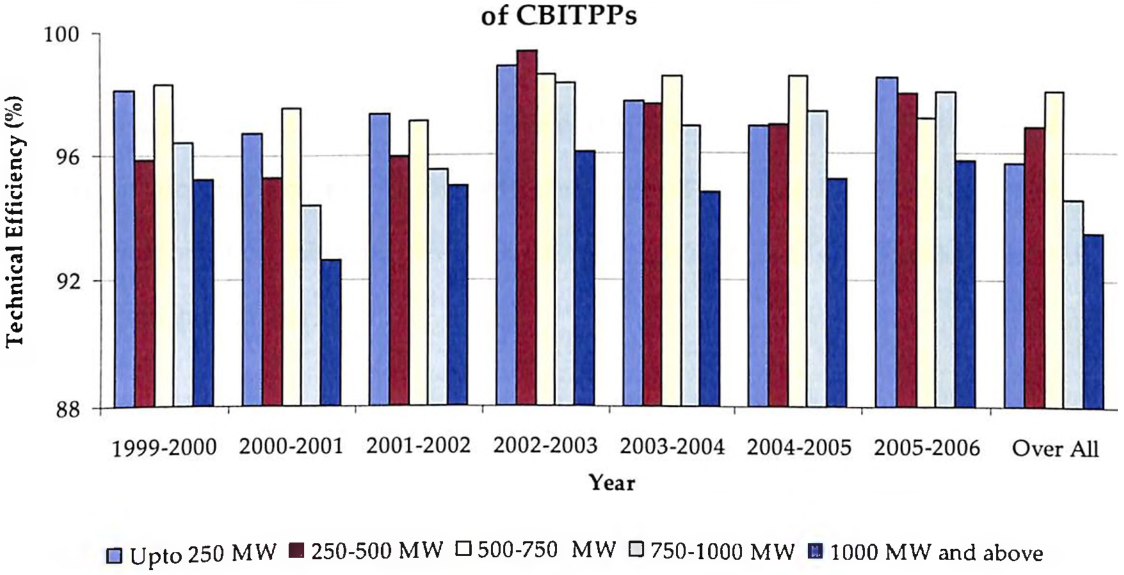


Fig. 5.17: Capacity Wise (Yearly Basis) Best Technical Efficiencies of CBITPPs



CHAPTER VI

SUMMARY AND CONCLUSIONS

In this chapter, summary of results and conclusions of the research work are presented. The salient features of the work are highlighted. Scope for further work is also presented.

6.1 SUMMARY

The growth rate of Indian economy is one of the fastest in the world. The policy makers are planning to maintain and, if possible, increase this impressive growth rate. The prerequisite for a booming economy is the supply of high quality and affordable power, due to this reason in the coming years India will be the largest consumers of electric power. As of now the biggest slice of the cake of India's power production is of thermal power stations in general and coal based thermal power plants in particular.

The broad objectives of the work started with reviewing the power scenario of India and its position in the power map of world. It is observed that the CBITPPs are dominating the Indian power sector and this trend will continue in future also.

In order to assess the Energy Efficiency improvement (equivalent coal savings) and CO_2 emissions reduction potential of CBITPPs, a through literature survey was done. The methods proposed in the literature are studied and then average method is selected. This assessment has been done for the year 1999-2000 to 2005-2006.

For this appraisal, the CBITPPs are grouped in to A, B, C, D, and E groups according to their capacities as given in chapter III. The power plant which is having minimum *SFC* is considered to be the reference plant or 'best plant' in that particular group.

From Table 3.1 and 3.2, it has been observed that 28,73,79,790.47 tonnes of coal and 40,50,76,627.81 tonnes of CO_2 emissions reduction would have been possible if all the plants were operated at *SFC* at par with the 'best plant' in that particular group for the study period. After considering the cost of one tonne of CO_2 in the international market, the CDM potential mentioned above, had this been realized, (Table 3.4) would have fetched about 5,37,000 million INR in the international market as a carbon credit. This proves that there is enormous scope of improvements in the Energy Efficiency in CBITPPs.

In order to realize the aforementioned potential there is a need to identify a plant which is having best performance. But in order to declare a plant to be most energy efficient; apart from *SFC*, the effect of other parameters like, *Capacity, HEAT RATE, Operational Availability Factor, Auxiliary Power Consumption* and *PLF* etc. should also be considered. After considering these factors the plant which is having the best performance should be considered as the best plant. Then the other plants may follow the practices of the best plant. So there is a need of benchmarking the CBITPPs and once the benchmarking is done (group wise) then the energy efficient practices which are followed in the benchmarked plant can be implemented in other plants and benefits may be reaped.

Benchmarking the Energy Efficiency of CBITPPs is a process in which the energy performance of an individual plant or an entire sector of similar plants is compared against a common metric that represents 'standard' or 'optimal' performance.

Exhaustive literature survey has been carried out in order to evaluate the performance and to "Benchmark" the CBITPPs. In the literature survey it has been observed that parametric and non parametric approaches in functional form are used for such appraisal.

In this study, in order to benchmark the Energy Efficiency of CBITPPs, two Stochastic Frontier Production Function models developed by Battese and Coelli i.e. Cobb-Douglas Production Frontier, and Translog (Transcendental Logarithmic) Production Frontier, have been employed and tested for cross sectional data for the year 1999-2000 to 2005-2006.

From the analysis of the results of the models it has been observed that the Cobb-Douglas form fitted the available data best. At the same time, after comparing results of the present study with the similar type of studies done by Shanmugam and Kulshreshtha (2002 and 2005), it is seen that the proposed model is a better model (Sec. 5.3).

The consistency of the results obtained by Cobb-Douglas Production Frontier has been checked with the DEA CRS and DEA VRS models using Spearman Ranking of Correlation Coefficients (Table 5.3). It is observed that the Spearman Rank Correlation Coefficients are positive and statistically significant.

The performance of the plant has been expressed in terms of its Technical Efficiency. The plant-specific *TE* of the CBITPPs from 1999-2000 to 2005-2006 has been evaluated.

For the evaluation of performance of CBITPPs, initially different variables and their combinations were tried. These variables are *Specific Coal Consumption, Specific Oil Consumption, GCV* of coal, *PLF, Auxiliary Power Consumption, Capacity* of the plant, *Vintage* (age of the plant), *Forced Outage, Planned Maintenance, Operational Availability Factor* etc. as input, while power generated (*POWGEN*) is taken as output. Finally, the inputs selected are *CAPITAL* (Sec. 5.1.1.1) and *HEAT RATE* (Sec. 5.1.1.2). Both these inputs are the combinations of various variables. These input variables are found to be significant determinants of power generation. While other parameters such as *Auxiliary Power Consumption, Vintage* of the plant etc. were found out to be statistically insignificant. The *POWGEN* is considered as the plant output in GWh.

The results of analysis reveal that during the period of study, the overall performance wise the most efficient plant or benchmark plant in group A is PARAS with *TE* of 95.67%; in group B, A.E.CO. & SABARMATI with *TE* of 96.84%; in group C, NEYVELI-I with *TE* of 97.97%; in group D, UNCHAHAR with *TE* of 94.55% and in group E, TUTICORIN with *TE* of 93.46% (Table 5.7).

Coal based thermal power plants located in Southern Region are found to be most technically efficient while Eastern and North Eastern Region plants are found to have lowest mean *TE* values. These plants can improve their performance by following the practices used in the benchmarked plants of their respective groups.

The above facts provide useful analytic information regarding the performance of coal based thermal power stations in India. The results of the study highlight the need for strengthening the technical know-how of CBITPPs which have low levels of *TE*, so that these plants can exploit the full potential of the existing technology.

This study will prove useful to the development agencies and policy-makers in evaluating and enhancing the performance of the present coal based thermal power stations in India. At the same time it will be an aid to establishment of new coal based thermal power plants, where the new plants can be designed by taking benchmarked plant as the reference plant.

6.2 CONCLUSIONS

Following are the specific conclusions of the present research work:

1. In this study, in order to benchmark the Energy Efficiency of CBITPPs various models were tried and it is observed that Cobb-Douglas form of the Stochastic Frontier Production Function fits data the best.

2. For the analysis, different input variables and their combinations were tried. It is observed that the *CAPITAL* employed and the *HEAT RATE* of the plant emerged as the dominant input factors in determining the level of plant output. While the actual Power Generated (*POWGEN*) of each plant, is taken as the output variable.

3. During the period under study, the mean *TE* of plants varies from 80.84 percent to a maximum of 87.08 percent, indicating that on an average, 13 to 20 percent of the technical potential of CBITPPs is not realized. So on an average, the thermal power production in the country can still be raised by about 13 to 20 percent through better application of existing technology, without employing additional inputs.

4. There are considerable variations in the efficiency levels of CBITPPs in the country. The estimated mean *TE* values of plants vary from 40.70 percent in BONGAIGAON plant (in Assam) to 97.97 percent in NEYVELI-I (Tamil Nadu).

5. The analysis reveals that actual output is less than the potential or frontier output for all CBITPPs. In particular, approximately 50 to 60 per cent of the difference between the actual and frontier output of BONGAIGAON, BARAUNI and MUZAFFARPUR power plants is due to the technically inefficient performance of these stations.

6. The *TE* values of thirty five out of eighty plants fall below 84.66 percent of the all-India mean *TE* value.

7. During the period under review, the benchmarked plant in group A is PARAS with *TE* of 95.67%; in group B, A.E.CO. & SABARMATI with *TE* of 96.84%; in group C, NEYVELI-I with *TE* of 97.97%; in group D, UNCHAHAR with *TE* of 94.55% and in group E, TUTICORIN with *TE* of 93.46%.

8. Mean *TE* of thermal power plants in Southern (90.01%), Northern (88.25%) and Western Region (87.80%) plants are above all-India mean *TE* value (84.66%) while Eastern (76.26 %) and North Eastern Region (40.70%) plants have lower mean *TE* values.

9. State wise, Haryana (92.79%) has got highest over all mean *TE* while Assam (40.70%) has the lowest overall mean *TE*. The states like West Bengal, Jharkhand including DVC, Bihar and Assam have over all mean *TE* values less than all-India mean *TE* value (84.66%). That means these states have enormous potential for improving their plants performance. Therefore, these plants deserve policy-makers' attention and can follow the practices available in benchmarked plants of their (capacity wise) group to increase their production, without employing additional resources.

6.3 SPECIFIC CONTRIBUTIONS

The following are the specific contributions of the present research work:

1. The thesis is a maiden attempt to assess Energy Efficiency improvements and CO_2 emissions reduction potential of CBITPPs.
2. This thesis is an attempt where CBITPPs have been grouped capacity wise and then benchmarked in Indian context.
3. The primary data was collected through field visits while the remaining data was taken from published reports.
4. The key variables for analysis were identified with the help and advice of experts from power sector, industries and educational institutes.
5. The present research work evaluates performance of CBITPPs in terms of their *TE* using Cobb-Douglas form of the Stochastic Frontier Production Function which was the best suited model and the results have been validated using DEA VRS and DEA CRS models.
6. The statistical analysis of the results shows that it is a better model as compared to the model proposed by Shanmugam and Kulshreshtha (2002 and 2005).

6.4 SCOPE OF FURTHER WORK

The scope for further work is as given below:

1. A power plant consists of small units of sizes varying from 20 MW to 500 MW. In the present study overall plant is considered for analysis as compared to its units. There is a need to evaluate performance on unit basis. This will help further reaching closer to the bull's eye.

2. Labour and cost are the inputs of the thermal power stations which have been excluded due to non-availability of data. Here it is suggested that in the analysis effect of these variables may also be tested.

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APPENDIX-A

BARRIERS TO ENERGY EFFICIENCY

Some of the important barriers identified by Ramachandran (Ramachandran, 1998) for promoting Energy Efficiency in India are discussed below:

A.1 High Cost of Energy Efficient Equipment

The cost of energy efficient equipment is invariably higher than standard equipment normally purchased and the end-user's decision is largely based on the initial capital outlay (eg. cost of CFL is much higher as compared to bulbs used). Consumers often seek to minimize the initial cost of equipment even though this may result in higher operating costs. This also applies to energy efficient equipment procured from outside the country. Further, government policies on taxes and duties can help in bringing down the cost of energy efficient equipment. There is a need to identify innovative financing options to reduce the initial cost of energy efficient equipment and also to share the risk of trying out new technologies.

A.2 Limited Availability of Energy Efficient Technologies

Most of the major equipments used in power plants are imported from developed nations. But now a days some of them are manufactured by BHEL, and the power plants which are operating with latest technology in the world with efficiency above 45% are not available in India.

A.3 Resource Constraints

Due to limited resources most industries, with the exception of energy intensive industries, find it more attractive to invest scarce resources in expanding production facilities and marketing channels. Energy Efficiency is generally given low priority by the industries where the share of energy costs is fairly low (say, around 10 percent).

A.4 Lack of Information or Awareness

One of the major constraints to promote Energy Efficiency programs is the information gap. Consumers are not completely aware of the opportunities to improve Energy Efficiency. Often information on Energy Efficiency equipment is not available, and if available is rather general in nature.

A.5 Energy Labeling and Standards

One important tool to increase consumer awareness is energy labeling. Labeling provides the consumer with more information on energy consumption and is expected to encourage manufacturers to move towards products that are energy efficient, and consumers to purchase such products.

A.6 Lack of Expertise

Shortage of skilled manpower to provide technical assistance and training in identifying, installing and maintaining energy efficient equipment has hindered efficiency improvement efforts in India. Technical assistance capabilities need to be developed through training programs, setting up energy conservation cells at the state utilities, state energy development agencies, etc.

A.7 Quick Payback Requirements

Studies of consumer behavior reveal a fairly high private discount rate. If the energy saving device does not pay for itself in two years, consumers are not likely to invest in that equipment.

A.8 Small Scale Manufacturing Market

Small scale industries play a dominant role in the Indian manufacturing industry. While appliances produced in the small scale sector are available at relatively low prices due to manual assembly, lower overheads, special protection from the government etc., there are concerns regarding the quality of these products. To ensure the quality and reliability of the equipment manufactured in the county, it is perhaps necessary to: (a) increase consumer awareness on Energy Efficiency and quality which would require the small industries to produce quality products; and (b) encourage small industries to have their products certified by the Bureau of Indian Standards.

A.9 Simple Solutions Not Undertaken

Energy savings do not necessarily require the use of advanced technologies, or entire process changes. There are several solutions that can be undertaken by consumers which need either marginal investments or, in several cases, none at all. Initiating house keeping measures or improving operation and maintenance practices can bring about a 10-15 percent savings at the unit level.

A.10 Lack of Expertise for Transfer of Technology

It is, not just enough to import energy efficient equipment; what is required is a transfer process which would enable design, manufacturing, and maintenance of this equipment in India. It is thus important that there is a larger plan to transfer the technology by collaborating with private research institutions, engineering colleges and universities in the area of Energy Efficiency. The need to be self-reliant must be accepted.

A.11 Problem with Quality of Power Supply

Poor quality of power supply obligates manufacturers to produce and end-users to use equipment that can withstand large voltage fluctuations. However, such equipment is often less efficient than equipment designed to operate in a narrower voltage range.

APPENDIX-B

ENERGY SAVING MEASURES IN COAL BASED INDIAN THERMAL POWER PLANTS

B.1 BOILER SIDE

B.1.1 Furnace Oil Consumption

Fuel oil is used as secondary fuel in thermal power plants. It represents considerably in terms of operating cost associated with electric power production. Among the various costs involved in generation of electricity, furnace oil consumption/ optimization is the only on whose control, significant impact on generation cost can be felt.

Optimization of furnace oil consumption can be achieved by concentrating on following measures:

a. Minimizing cold / hot start up time.
b. Quick low load stabilization.
c. Avoiding unit tripping.
d. Keeping mining system healthy.
e. Redefining and fine-tuning of operation practices.

Amongst oil consumption heads, those areas, which are major contributor to total specific oil consumption of the station, are being short listed and actions are taken by prioritizing the heads, to optimize oil consumption.

Causes due to which oil consumption was considerable and optimization realized are:

a. Coal quality.
b. Unit start ups.
c. Bunker chocking.
d. Safety valve setting/floating.
e. Combustion tuning.

B.1.2 Boiler Blow-down Heat Recovery Measure Reduces Steam System Energy Losses

Typical blow-down flow range from 3 to 15 percent of a boiler's steam generating capacity. Any boiler with continuous surface blow-down exceeding 5 percent of the steam generation rate is a good candidate for blow-down waste heat recovery. In boiler with intermittent or periodic blow down could also equipped with blow-down waste heat recovery.

The boiler blow-down process involves the periodic or continuous removal of water from a boiler to remove accumulated dissolved solids and/or sludge. During the process, water is discharged from the boiler to avoid the negative impacts of dissolved solids or impurities on boiler efficiency and maintenance. However, boiler blow-down wastes energy because the blown down liquid is at about the same temperature as the steam produced. Much of this heat can be recovered by routing the blown down liquid through a heat exchanger that preheats the boiler's makeup water. A boiler blow-down heat recovery will save annually certain fuel costs.

B.1.3 Boiler Feed Blower

For running the blower, three phase induction motor, Star/Delta starter for air-blower motor operation is used. Airflow is controlled by damper. Problems observed with this are high starting current kicks and energy loss due to flow control through damper (all time full speed of operation of motor). It is suggested to remove the damper-plates of air blower (Damper 100% opened). Air flow controls by varying the speed of motors through AC Variable frequency drive potentiometer with gear arrangement in correspondence to modulation system.

B.1.4 Restoration of Draught Margin

- Loss of draught margins adversely affects boiler efficiency, reliability and availability.
- Restoration of draught margins resulted in reduction in auxiliary power consumption.
- In coal-fired boilers loss of draught margin is the main cause of boiler operation at less than optimum efficiency. Loss of draught margin is invariable due to increase in pressure drop on account of increased flue gas volume. Air ingress from eroded ducts, openings, expansion joints and air heater leakage are the major reasons for increase in flue gas volume.
- Twin objective of sustaining optimum boiler efficiency and reducing environmental emissions can be achieved by boiler operation at optimum level of excess air (CenPEEP, 2004). High air leakage from air heaters, air ingress from pent house refractory, eroded ducts, expansion joints, ash evacuation system are some of the causes of overloading of induced draft (ID) fans. This leads to boiler operation at less than optimum combustion regime.

B.1.5 Induced Draft Fans

- ID design deficiency in maintaining lower pressure causing high power consumption.
- Disturbance of the fan performance due to a bend or other system component located too close to the fan inlet.
- High stack temperature causing an additional consumption.
- Loss of chimney draught capability shall also be reflected by loadings on ID fans.

B.1.6 Forced Draft (FD) Fans

- Increased power consumption is due to FD fans running at lower percentage of rated capacity.
- Power electronic controlled motor also can be explored which may give additional saving even at part loads.

B.1.7 Primary Air (PA) Fans

- PA fans efficiency deteriorated due to reduced header capacity running of FD fans. Detailed study is required on this account.
- Leakage, re-circulation or other defects in the system may affect the performance of the fans.

B.1.8 Heat Losses Measures

More than 90% losses comprises of Dry gas loss, Unburnt loss and Moisture and Hydrogen loss (Mukherjee and Verkey, 1993).

B.1.8.1 Dry Gas Loss

It is the amount of sensible heat carried away by the flue gases excluding the heat carried by water vapor. Dry gas depends mainly on the flue gas exit temperature and quantity. Higher the excess air, higher is the flue gas quantity and hence higher the loss. This brings out the need for maintaining optimum oxygen in the flue gas.

Other factor affecting the dry gas loss is the flue gas temperature. The factors leading to higher exit gas temperature are due to fouling of heat exchanger surface, choking of air pre-heater heating elements.

- A close regular monitoring of soot blowing is a must for high cycle efficiency. Soot-blowing operation is often not given its due weightage. It is very important from energy conservation point of view.
- Air pre-heater elements need regular steam blowing to get rid of choking materials. Regular inspection and chemical cleaning is required during overhaul.

B.1.8.2 Unburnt Loss

The presence of combustibles in the bottom ash and fly ash contribute to this effect. It depends on the percentage of unburnt particles present in ash.

- Pulverization quality should be properly checked in order to reduce unburnt carbon.
- By maintaining the proper combustion regime, the unburnt losses can be reduced.

B.1.8.3 Moisture and Hydrogen Loss

It is the sensible heat carried away by water vapor generated from moisture and hydrogen in the coal.

- This loss depends on the amount of moisture and hydrogen in the fuel.

- This loss contributes to 40% of the total boiler losses. However the boiler engineer does not have much control over this.

B.1.9 Top Ten Recommendations from the 2006 Energy Savings Assessments (ESAs)

B1.9.1 Improve Boiler Efficiency (Steam)

- Improve boiler's combustion efficiency
- Insulate steam distribution and condensate return lines
- Minimize boiler blow down
- Return condensate to the boiler
- Upgrade boilers with energy-efficient burners

B.1.9.2 Reduce Steam Demand by Changing Process Steam Requirements (Steam)

- Install an automatic blow down control system
- Minimize boiler blow down

B.1.9.3 Improve Insulation (Steam)

- Install removable insulation on valves and fittings
- Insulate steam distribution and condensate return lines

B.1.9.4 Reduce the Oxygen Content of Flue (Exhaust) Gases (Process Heating)

- Check burner air to fuel ratios
- Improve boiler's combustion efficiency
- Oxygen-enriched combustion
- Upgrade boilers with energy-efficient burners

B.1.9.5 Implement a Steam Trap Maintenance Program (Steam)

- Inspect and repair steam traps

B.1.9.6 Change Condensate Recovery Rates (Steam)

- Insulate steam distribution and condensate return lines
- Return condensate to the boiler

B.1.9.7 Modify the Feed Water Heat Recovery Exchanger Using Boiler Blow Down (Steam)

- Install an automatic blow down control system
- Recover heat from boiler blow down

B.1.9.8 Properly Insulate and Maintain Furnace Structure or Parts (Process Heating)

- Check heat transfer surfaces
- Reduce air infiltration in furnaces
- Reduce radiation losses from heating equipment

B.1.9.9 Add or Modify Operation of Backpressure Steam Turbine (Steam)

- Consider installing high-pressure boilers with backpressure turbine-generators
- Replace pressure-reducing valves with backpressure turbo-generators

B.1.9.10 Implement a Steam Leak Maintenance Program (Steam)

- Install removable insulation on valves and fittings
- Insulate steam distribution and condensate return lines (Energy Matters, 2007)

B.2 TURBINE SIDE

B.2.1 Optimization of Auxiliary Power Consumption in Circulating Water (CW) System

The auxiliary power consumption in a large station could be the order of 6 % to 8 % of the gross power generation and circulating water pumps may count for 25 % to 30 % of overall power consumption. Therefore it is important to ensure that it is kept as near to optimum as possible. For example, let us assume the CW inlet temperature is low enough the back pressure can be reduced by putting more CW through the condenser tubes. However, this will require more and more CW pumping power and gain from improved back pressure must offset against the extra power absorbed by the pumps. Therefore CW pumps should be run only when the running cost is outweighed by benefit derived by extra output from the main unit. In other words the pump operation should be optimized.

Running hours of CW pumps in winter season has been reduced by stoppage of one or more pumps for three months, without sacrificing the condenser vacuum by taking the advantage of low CW inlet water temperature during winter.

B.2.2 Condensate Extraction Pump (CEP)

CEP extracts condensate from the hot well and pumped up to deaerator through main ejector, gland steam coolers and low pressure (LP) heaters. For reducing the auxiliary power consumption in CEP

- Running the pump at low load condition.

- The condenser level in the hot well should be maintained at designed level. This may cause optimum Net Positive Suction Head (NPSH) available to the pump.
- Disturbance to the flow due to a bend or other located too close to the pump inlet

B.2.3 Heat Recovery from Turbine Lubricating Oil

Steam turbine lubricating oil is circulated through bearings and collected in main oil tank at 60-65 °C. From tank it is sucked by main oil pump and cooled to 45 °C by circulating through oil cooler and supplied to bearings. The heat transferred to cooling water in oil cooler is rejected in cooling tower. If heat pipe heat exchanger is installed with property of fluid evaporation at 55 °C, it would cool oil to 55 °C and can be used to preheat condensate collected in condenser from 45 °C to 53 °C. This would not only recover energy directly but also help reduce cooling load on cooling tower.

Steam turbine lubricating oil serves two functions –

1) Lubrication,

2) Dissipation of excess heat from journal bearings (heat is generated due to shear forces in oil as well as conducted along turbine rotor).

In this process, its temperature increases from 45 °C to 65 °C across the bearings. The oil at 65 °C is cooled to 45 °C in oil cooler and re-circulated. In oil cooler, water circulated at 35 °C from cooling tower picks up heat from oil and gains temperature rise of approx. 4 °C. The heat picked up by water is dissipated to atmosphere through cooling tower.

In the heat pipe heat exchanger system, approx. 50% of heat in oil would be picked up by turbine condensate (and not cooling water) thereby raising condensate temperature from 48 °C to say 55 °C (before going to regenerative heater). After heat pipe heat exchanger, Lubricating oil would be further cooled to 45 °C in oil cooler in existing system. The net effects of interposing heat pipe heat exchanger would be:

1) Condensate preheating by recovering some heat from lubricating oil,
2) Reduction in cooling load on cooling tower which translates to blower power saving/ circulating water pump power saving, lower water evaporation rate leading to saving of treatment chemicals & lower blow down rate from cooling tower.

B.2.4 Boiler Feed Pump (BFP)

Main problem related to BFP is discharging less flow than designed flow.

- The common reason for this is chockage of booster pump and main pump suction strainer.
- The second reason, reduction in pump's rpm.
- Error in estimation of flow resistance could affect the performance of pump.

B.2.5 General Measures

- To keep condenser vacuum at lowest. This will increase net work done by steam.
- Regenerative heating should be properly done. This will bring Rankine cycle closer to Carnot cycle which in turn leads to higher efficiency (Bandopadhyay, and Pradhan, 1992).

B.3 CONDENSER AND COOLING TOWER SIDE

Improving the performance of condenser in a power plant certainly draws attention towards controlling the back pressure or exhaust pressure of steam after it does work on LP turbine. Condenser, in this sense, plays a vital role in decreasing the back pressure or exhaust pressure of steam by condensing exhaust steam from LP turbine or Drive turbine of BFP. High vacuum or low absolute pressure in a condenser ensures higher range of expansion of steam providing maximum work per unit mass of steam, hence finally improving the efficiency of the unit. The hot well section of the condenser recovers condensed steam as condensate and provides short term storage of condensate. It also serves as low pressure collection points for drains from other system.

The following factors affect the condenser performance:

- Fouling / scaling of condenser tube.
- Cooling water inlet temperature.
- Quantity of cooling water.

B.3.1 Condenser Performance Improvement by Condenser Tube Cleaning

In a condenser, there are many factors which become responsible for low vacuum. One of the most important reason is fouling of inner wall of condenser tubes due to deposition of salts and due to bacterial growth i.e. formation of algae restricting heat transfer between steam and circulating water. High circulating water temperature in summer and rainy season is one of the major limitations which badly affect the condenser back-pressure. The fouling depends on the quality of the cooling water. The silt layer and hard scale formation on inner side of the tube-wall.

Different practices are being followed for optimizing the performance of condenser. Application of high pressure water jet has been found most effective in removing silt layer. For removing the hard layer acid cleaning is required. The high pressure jet has been required in a range of 10 mm to 15 mm of Hg column. One useful tool has been suggested in this context, which could find application in power plant.

B.3.1.1 Condenser Tube Cleaning-Removes both Soft and Hard Deposits

With assistance from U.S. Department of Energy Inventions and Innovation Program, Superior I.D. Tube Cleaners (SIDTEC) Inc. invented the SIDTEC mechanical on-line condenser maintenance service program for thermal power plants.

The SIDTEC program incorporates a two-part tube cleaner and a recovery system. The cleaning elements, or Rockets, are injected into the condenser cooling water system, conveyed through the condenser tubes with the normal flow of water, and recovered in the discharge. The cleaning element contacts the tube surfaces, wiping away mud, silt, and bio-fouling deposits. Near-neutral buoyancy ensures even distribution throughout all condenser tubes. The product replaces conventional cleaning systems, such as automatic tube-cleaning systems or sponge balls; chemicals used to clean the condensers; and off-line mechanical tube-cleaning, which is costly in manpower and lost generation while the unit is off-line.

B.3.1.2 Benefits

- Potential savings for one 500-MW plant are $250,000 annually.
- Rocket tube cleaners do not impact circulating water pump performance
- Reduces the accumulation of bacterial slime, mud, dirt, and silt on heat transfer surfaces without the use of biocides such as chlorine and bromine.

B.3.1.3 Applications

Maintaining waterside tube cleanliness in the main steam condenser in thermal power plants (Choudhary, 1998).

B.3.2 Cooling Tower (CT) Fan

Leakage, re-circulation or other defects in the system, inaccurate estimation of flow resistance, and excessive loss in a system component located too close to the fan outlet, disturbance of the fan performance due to a bend or other system component located too close to the fan inlet, inaccurate estimation of flow resistance are the factors that could affect performance of fans.

- CW inlet temperature affects the condenser vacuum. Continuous monitoring of working cooling tower is important. Optimum blade angle plays vital role in this context.
- Correct excessive and/or uneven fan blade tip clearance and poor fan balance.

B.3.3 General Measures in Cooling Tower

- Follow manufacturer's recommended clearances around cooling towers and relocate or modify structures that interfere with the air intake or exhaust.
- On old counter-flow cooling towers, replace old spray type nozzles with new square spray ABS practically non-clogging nozzles.
- Install new nozzles to obtain a more uniform water pattern.
- Periodically clean plugged cooling tower distribution nozzles.
- Replace splash bars with self-extinguishing PVC cellular film fill.
- Balance flow to cooling tower hot water basins.
- Cover hot water basins to minimize algae growth that contributes to fouling.

- Control cooling tower fans based on leaving water temperatures especially in case of small units.
- Cooling tower performance degrades over time from the following effects; corrective action regarding this should be taken to optimize the performance.

  -Fouling of the fill from debris and precipitation of dissolved solids
  -Slippage of fan belts and dirt or wear of the bearings
  -Dirt in the fan wheels (centrifugal tower fans)
  -Fouling in the nozzles (PGEC, 2002)

B.4 RECOMMENDATIONS

1. Operate furnaces and boilers at or close to design capacity
2. Use reduce excess air for combustion
3. Regular cleaning of heat transfer surfaces
4. Minimize radiation losses from openings
5. Proper insulation of furnace or boiler wall to reduce heat losses
6. Insulate air or water-cooled surfaces exposed to the furnace environment and steam lines leaving the boiler.
7. Install heat recovery equipment such as air preheat
8. Minimize boiler blow down by improving water treatment
9. Optimize deaerator vent rate
10. Explore the steam lines for leaks and repair
11. Minimize vented steam
12. Follow an effective steam trap maintenance program
13. Use high-pressure condensate to make low-pressure steam
14. Optimize condensate recovery
15. Reduce air leakages into the furnace by sealing openings

16. Maintain optimum positive furnace pressure
17. Modify the furnace system or use a separate heating system to recover furnace exhaust gas heat
18. Recover part of the furnace exhaust heat for use in lower-temperature processes.

APPENDIX-C

SAMPLE DATA FROM CEA REPORT, PERFORMANCE REVIEW OF THERMAL POWER STATIONS 2000-01

C.1 Station-wise Specific Secondary Oil Consumption

STATIONWISE SPECIFIC SECONDARY OIL CONSUMPTION
PERIOD 1994-95 TO 2000-01

S.NO.	STATION	Specific sec. Oil Consumption (ML/Kwh)					
		95-96	96-97	97-98	98-99	99-00	2000-01
II. PRIVATE SECTOR							
	1 SABARMATI (AE. CO.)	3.6	4.19	6.76	3.9	1.78	N.A
	2 BSES Ltd./DAHANU	6.91	1.86	0.53	0.62	0.17	0.28
	3 TITAGARH	3.23	4.59	5.63	1.64	3.32	N.A
	4 BUDGE BUDGE	——	——	43.66	4.85	2.86	N.A
	5 SOUTHERN	1.92	3.48	3.01	4.96	5.74	N.A
CESC TOTAL		**2.74**	**4.24**	**N/A**	**3.6**	**3.48**	N.A
P.SEC. TOTAL		**3.94**	**3.29**	**4.76**	**2.7**	**1.94**	**0.28**
III STATE ELECTRICITY BOARDS							
	1 I.P. STN.	16.95	24.65	15.59	23.25	16.47	10.02
	2 RAJGHAT	19.25	23	27.73	17.8	6.24	6.47
D.V.B. TOTAL		**17.88**	**23.89**	**19.41**	**20.81**	**11.01**	**8.32**
	1 FARIDABAD	10.97	16.23	9.95	8.03	4.61	5.39
	2 PANIPAT	20.1	19.16	14.09	14.42	7.91	5.58
HGPC TOTAL		**17.72**	**18.6**	**13.33**	**12.84**	**7.08**	**5.54**
	1 BHATINDA	3.46	1.86	2.11	7.71	2.07	2.82
	2 BHATINDA EXTN.	——	——	——	——	4.01	1.54
	3 ROPAR	5.93	4.11	1.61	1.23	2.74	2.01
PSEB. TOTAL		**5.31**	**3.51**	**1.73**	**3.12**	**2.84**	**2.06**
	1 KOTA	3.01	2.79	1.73	1.3	1.15	0.68
	2 SURATGARH	——	——	——	——	——	3.34
RSEB. TOTAL		**3.01**	**2.79**	**1.73**	**1.3**	**1.15**	**1.56**
	1 OBRA	7.01	7.09	5.98	7	6.75	4.81
	2 HARDUAGANJ B & C	19.39	10.69	17	25.62	20.36	7.37
	3 PANKI	15.62	13.73	8.2	8.12	7.36	7.23
	4 PARICHA	27.66	20.11	27.04	17.67	34.96	13.78
	5 ANPARA	1.26	0.7	0.98	1.26	11.6	7.69
	6 TANDA	14.16	7.55	15.69	24.97	——	N.A
UPSEB TOTAL		**5.3**	**3.86**	**4.7**	**5.84**	**11.12**	**6.97**
	1 UKAI	13.17	14.21	10.35	4.31	4.69	2.41
	2 GANDHI NAGAR	3.91	8.16	9.53	9.26	8.59	4.77
	3 WANAKBORI	10.02	11.97	1.36	1.76	1.01	1.02
	4 SIKKA	8.04	3.22	6.58	6.64	5.21	4.64
	5 KUTCH LIGNITE	16.03	16.63	23.96	12.96	10.2	9.82
GEB. TOTAL		**9.17**	**11.03**	**6.47**	**4.93**	**4.02**	**2.68**

C.2.Overall Performance 2000-01

NAME OF UNIT / SYSTEM	CAP (MW)	GEN (GWH)	P.M. (%)	F.O. (%)
KOTA 1	110	837	7.82	1.79
KOTA 2	110	856	6.01	3.04
KOTA 3	210	1742	4.73	0.16
KOTA 4	210	1375	22.51	2.49
KOTA 5	210	1630	0.00	10.71
KOTA	**850**	**6439**	**8.52**	**3.93**
SURATGARH 1	250	1724	8.12	7.54
SURATGARH 2	250	1471	9.75	3.06
SURATGARH	**500**	**3195**	**8.82**	**5.62**
TOT. RSEB	**1350**	**9634**	**8.62**	**4.50**
TOT.RAJASTHAN	**1350**	**9634**	**8.62**	**4.50**
OBRA THERMAL 2	40	80	28.90	38.23
OBRA THERMAL 3	40	184	7.11	22.55
OBRA THERMAL 4	40	186	5.95	23.80
OBRA THERMAL 5	40	0	65.69	34.23
OBRA THERMAL 6	94	183	16.99	42.12
OBRA THERMAL 7	94	360	0.00	30.51
OBRA THERMAL 8	94	0	100.00	0.00
OBRA THERMAL 9	200	1083	5.68	12.99
OBRA THERMAL 10	200	1015	0.13	10.76
OBRA THERMAL 11	200	1140	0.00	9.11
OBRA THERMAL 12	200	666	0.47	49.44
OBRA THERMAL 13	200	1015	0.00	9.41
OBRA THERMAL	**1442**	**5914**	**11.48**	**20.75**
PANKI 1	32	0	100.00	0.00
PANKI 2	32	0	100.00	0.00
PANKI 3	105	316	33.84	16.43
PANKI 4	105	545	0.00	11.63
PANKI	274	861	36.33	10.75

C.3. Specific Coal Consumption for the Year 1999-2000 and 2000-01

S.NO.	NAME OF TPS	CAP. IN MW AS ON 1.3.2001	SPCC KG/KWH 99-2000	SPCC KG/KWH 2000-01
NORTHERN REGION				
DELHI				
1	Badarpur	705	0.68	0.73
2	I.P.Station	248	0.81	0.8
3	Rajghat	135	0.77	0.77
HARAYNA				
4	Faridabad	165	0.87	0.94
5	Panipat	650	0.79	0.8
PUNJAB				
6	Bhatinda	440	0.72	0.73
7	Bhatinda Ext.	420	0.72	0.69
8	Ropar	1260	0.67	0.69
RAJASTHAN				
9	Kota	850	0.58	0.6
10	Suratgarh	500	0.64	0.56
UTTAR PRADESH				
11	Anpara	1630	0.71	0.69
12	Harduaganj	385	1.04	1.09
13	Obra	1442	0.93	0.84
14	Panki	274	0.83	0.83
15	Paricha	220	0.89	0.9

C.4. Heat Rate for the Year 1999-2000 and 2000-01

Sl. NO.	Name of Stn-units & cap MW	Cap (MW)	Design H.R Kcal/Kwh	1997-98		1998-99		1999-2000		2000-01	
				Oprtg H.R	% Eff.	Oprtg H.R	% Eff.	Oprtg H.R	% Eff.	Oprtg H.R	% Eff.
	NORTHERN REGION										
	DELHI										
1.	IP Stn—1*36.6+3*62.5+1*60	284.1	2667.39	3597	23.91	3883	22.15	3403	22.27	3246	26.49
2.	Rajghat—2*67.5	135	2580.35	3129	27.48	3572	24.08	3409	25.23	3243	26.52
	HARAYANA STATE										
3.	Faridabad—3*55	165	2811.25	4226	20.35	4058	21.19	3976	21.63	4469	19.24
4.	Panipat—4*110+1*210	650	2425.00	3342	25.73	3359	25.60	3108	27.67	3257	26.40
	Punjab STATE										
5.	G.N.Bhatinda—4*110	440	2510.19	3056	28.14	3076	27.96	3053	28.17	3056	28.14
6.	GGS Ropar—6*210	1260	2259.43	2754	31.23	2760	31.16	2810	30.60	2821	30.49
7.	Kota—2*110+3*210	850	2353.55	2669	32.22	2596	33.13	2489	34.55	2657	32.37
8.	Obra A—5*50+3*100	550	2818.61	3443	24.98	3410	25.22	3396	25.32	3090	27.83
9.	Obra B—5*200	100	2636.00	2900	29.66	3201	26.87	3446	24.96	3213	26.77
10.	Anpara—3*210+2*500	1630	2358.18	2739	31.40	2644	32.53	2662	32.31	2676	32.14
11.	Panki—2*110+2*32	284	2528.47	3870	22.22	4051	21.23	4206	20.45	3962	21.71
12.	H"Ganj—2*50+2*55+2*60+1*11	440	2830.66	4492	19.15	4689	18.34	5025	17.11	5002	17.19
13.	Parichha—2*110	220	2479.34	4445	19.35	4590	18.74	4261	20.18	3646	23.59
	WESTERN REGION										
	Gujarat STATE										
14.	Dhuvaran—4*63.5+2*140	534	2527.61	2924	29.41						
15.	Ukai—2*120+2*200+1*210	850	2358.27	2665	32.27	2764	31.11	2554	33.67	2591	33.19
16.	G.Nagar	660	2341.77	2506	34.32						
	w.e.f. 4/98—2*120+3*210	870	2336.00			2441	35.23	2450	35.10	2494	34.48
17.	Sikka Rpl—2*120+3*210	870	2336.00			2441	35.23	2450	35.10	2494	34.48
18.	Kutch Lignite—2*70+1*75	215	2744.71	3617	23.78	3362	25.58	3398	25.31	3411	25.21
19.	Wanakbori—6*210	1260	2350.81	2506	34.32	2502	34.37	2521	34.11		
	Wanakbori-7*210 wef 4/2000	1470	2344.75							2477	34.72
20.	Sabarmati (A.E)—2*30+3*110	390	2553.34	2941	29.44	2918	29.47	2812	30.58	2932	29.33

APPENDIX - D

ESTIMATED PARAMETERS OF TRANSLOG MODEL BY OLS AND MLE

Table D.1(a): Estimated Parameters of Translog Model by OLS and MLE

TRANSLOG	1999-2000		2000-01		2001-02	
	OLS	MLE	OLS	MLE	OLS	MLE
Constant	35.5425 (0.5996)	31.0716 (0.7165)	-1.5204 (-0.0380)	-1.3943 (-1.4154)	3.8313 (0.0662)	3.9674 (3.9871)
ln(CAPITAL)	-1.3758 (-0.6620)	-0.9178 (-0.6757)	-0.0825 (-0.0502)	-0.1651 (-0.2211)	1.1317 (0.5826)	1.1379 (1.2726)
ln(HEAT RATE)	-6.0967 (-0.4642)	-5.4268 (-0.5549)	1.8692 (0.2105)	1.7845 (2.4647)	-0.7558 (-0.0589)	-0.7293 (-0.7999)
SQ(ln(capital)	0.0258 (1.0305)	0.0183 (0.9846)	-0.0096 (-0.4424)	0.0055 (0.2436)	-0.0117 (-0.5494)	0.0021 (0.0686)
SQ(ln(heat rate)	0.2186 (0.2980)	0.2057 (0.3697)	-0.2339 (-0.4659)	-0.2069 (-2.5249)	0.0081 (0.0114)	0.0235 (0.1987)
ln(CAPITAL)*ln(HEATRATE)	0.2546 (1.1375)	0.2072 (1.4070)	0.1651 (0.9384)	0.1444 (1.3853)	0.0178 (0.0846)	-0.0152 (-0.2012)
sigma-squared	0.0336	0.0770 (4.4289)	0.0271	0.0511 (0.9085)	0.0234	0.0451 (1.8917)
gamma		0.9556 (21.4888)		0.8868 (0.9091)		0.9362 (1.5168)
LLF	24.1915	30.9626	32.7906	36.7282	38.4741	43.4688
LRT		13.5421				9.9894
Sample size	76	76	77	77	77	77

(Bracketed terms are "t ratios")

Table D.2(a): Estimated Parameters of Translog Model by OLS and MLE

TRANSLOG	2002-03		2003-04		2004-05		2005-06	
	OLS	MLE	OLS	MLE	OLS	MLE	OLS	MLE
Constant	30.8913 (0.5722)	30.3693 (30.8332)	37.4150 (0.8788)	37.5367 (35.6119)	33.8208 (0.8750)	33.9165 (34.2872)	26.3172 (0.5246)	26.4064 (26.8097)
ln(CAPITAL)	-2.7490 (-1.3816)	0.3393 (0.4436)	-1.8201 (-1.1319)	-1.9995 (-2.4504)	-2.1152 (-1.5130)	-2.2068 (-2.7425)	-2.3816 (-1.5567)	-2.4367 (-3.4160)
ln(HEAT RATE)	-3.4800 (-0.2954)	-6.6569 (-9.0908)	-5.9144 (-0.6421)	-5.8718 (-7.1256)	-4.6288 (-0.5486)	-4.7182 (-5.8638)	-2.5419 (-0.2273)	-2.5920 (-3.6191)
SQ(ln(capital)	0.0402 (1.7789)	-0.0110 (-1.0093)	0.0162 (0.9224)	0.0187 (1.4049)	0.0167 (1.0686)	0.0157 (1.2382)	0.0198 (2.1702)	0.0168 (2.1810)
SQ(ln(heat rate)	-0.0163 (-0.0251)	0.3434 (4.2032)	0.1621 (0.3238)	0.1612 (1.6837)	0.0604 (0.1307)	0.0699 (0.7472)	-0.0825 (-0.1324)	-0.0776 (-0.9227)
ln(CAPITAL)* ln(HEATRATE)	0.3934 (1.8430)	0.1071 (1.3512)	0.3255 (1.8706)	0.3413 (4.0077)	0.3594 (2.3639)	0.3738 (4.4287)	0.3886 (2.2052)	0.4007 (4.9017)
sigma-squared	0.0227	0.0600 (9.7129)	0.0176	0.0370 (3.4734)	0.0129	0.0241 (0.7865)	0.0156	0.0293 (1.9543)
gamma	39.5767	1.0000 (3546.6704)		0.8918 (8.0140)		0.9014 (1.0647)		0.8597 (1.6751)
LLF		51.7097	49.3789	53.1939	59.9363	65.9088	53.9442	55.7843
LRT		24.2660		7.6300		11.9449		3.6802
Sample size	77	77	77	77	75	75	77	77

(Bracketed terms are "t ratios")

APPENDIX – E

TECHNICAL EFFICIENCY SCORES BY VARIOUS MODELS

Table E.1: Technical Efficiency Scores by Various Models for Year 1999-2000

SNO.	STATION (UPTO 250 MW)	CAP (MW)	COBB-DOUGLAS	TRANSLOG	DEA CRS	DEA VRS
1	NELLORE	30	69.59%	76.26%	58.60%	100.00%
2	PARAS	58	93.17%	93.80%	84.20%	95.80%
3	RAMAGUNDEM - B	62.5	96.62%	93.74%	93.00%	100.00%
4	NEW COSSIPORE	130	79.95%	91.58%	62.10%	65.80%
5	RAJGHAT	135	98.14%	97.64%	91.00%	93.90%
6	SOUTHERN REPL	135	69.44%	71.59%	65.60%	86.70%
7	FARIDABAD EXTN.	165	96.80%	97.45%	82.20%	84.80%
8	KUTCH LIGNITE	215	84.08%	89.61%	74.40%	78.40%
9	MUZAFFARPUR	220	48.04%	55.41%	38.40%	63.30%
10	PARICHA	220	67.87%	76.87%	54.70%	63.00%
11	BONGAIGAON	240	39.78%	44.83%	33.50%	87.20%
12	SIKKA REPL	240	83.03%	80.22%	84.20%	100.00%
13	TITAGARH	240	84.42%	86.69%	80.70%	86.90%
14	SURATGARH	250	72.68%	72.95%	73.60%	97.40%
		Mean	77.40%	80.62%	69.73%	85.94%

SNO.	STATION (250-500 MW)	CAP (MW)	COBB-DOUGLAS	TRANSLOG	DEA CRS	DEA VRS
15	PANKI	274	64.65%	71.31%	52.60%	60.20%
16	I.P. STATION	277.5	72.43%	77.89%	63.90%	73.70%
17	AMAR KANTAK	290	81.54%	85.57%	74.80%	80.40%
18	BARAUNI	310	50.95%	59.63%	39.70%	60.50%
19	DURGAPUR	350	75.45%	79.59%	67.80%	73.30%
20	HARDUAGANJ B	385	74.86%	85.94%	56.70%	59.70%
21	A.E.CO. & SABARMATI	390	94.77%	94.53%	91.70%	92.40%
22	DURGAPUR (D.P.L.)	390	66.58%	68.64%	63.30%	85.00%
23	KORBA EAST	400	90.01%	92.27%	82.20%	83.00%
24	BHATINDA EXT.	420	78.80%	80.77%	76.50%	85.30%
25	I.B. VALLEY	420	92.37%	91.92%	94.40%	97.20%
26	KHAPARKHEDA II	420	91.37%	91.85%	90.20%	92.30%
27	MEJIA	420	48.79%	49.87%	49.40%	97.40%
28	RAYALSEEMA	420	95.46%	93.97%	99.50%	100.00%
29	TENUGHAT	420	79.74%	82.66%	75.00%	83.90%
30	UNCHAHAR	420	95.89%	94.92%	95.80%	96.40%
31	BHATINDA	440	88.54%	90.71%	82.50%	83.20%
32	TANDA	440	57.26%	62.19%	49.80%	69.30%

33	ENNORE	450	71.12%	75.31%	64.10%	72.70%
34	TALCHER	460	83.41%	86.63%	74.10%	74.80%
35	BHUSAWAL	478	86.87%	87.86%	87.60%	93.40%
36	SANTALDIH	480	66.50%	70.65%	58.30%	67.50%
37	BUDGE BUDGE	500	44.63%	45.97%	45.70%	98.10%
38	DHANU	500	86.31%	86.74%	89.80%	100.00%
		Mean	76.60%	79.47%	71.89%	82.49%

SNO.	STATION (500-750 MW)	CAP (MW)	COBB-DOUGLAS	TRANSLOG	DEA CRS	DEA VRS
39	BANDEL	530	63.70%	66.16%	58.80%	75.40%
40	NEYVELI-I	600	98.30%	96.58%	62.80%	64.60%
41	BIRSINGHPUR	630	76.89%	78.87%	71.30%	75.70%
42	NORTH MADRAS	630	86.47%	87.57%	86.70%	90.80%
43	PANIPAT	650	83.29%	85.71%	77.10%	78.00%
44	PARLI	690	83.09%	84.50%	81.50%	86.00%
45	BADARPUR	705	90.30%	90.75%	90.60%	91.20%
46	CHANDRAPURA	750	67.85%	70.91%	56.10%	59.40%
		Mean	81.24%	82.63%	73.11%	77.64%

SNO.	STATION (750-1000 MW)	CAP (MW)	COBB-DOUGLAS	TRANSLOG	DEA CRS	DEA VRS
47	PATRATU	770	70.89%	75.04%	60.60%	64.90%
48	BOKARO	805	73.56%	76.40%	65.70%	69.80%
49	DADRI	840	96.44%	94.95%	99.80%	100.00%
50	KAHALGAON	840	68.83%	69.08%	63.30%	72.10%
51	KORBA-WEST	840	89.67%	90.01%	85.30%	85.50%
52	METTUR	840	87.10%	87.84%	88.00%	91.20%
53	KOTA	850	95.76%	94.50%	98.40%	98.60%
54	UKAI THERMAL	850	83.04%	84.26%	83.30%	90.40%
55	GANDHI NAGAR	870	71.35%	72.61%	72.70%	93.90%
56	NASIK	910	85.62%	86.43%	86.50%	91.00%
57	RIHAND STPS	1000	93.65%	92.91%	97.30%	97.60%
58	TALCHER STPS	1000	69.29%	69.94%	67.70%	83.30%
		Mean	82.10%	82.83%	80.72%	86.53%

SNO.	STATION (1000 MW and above)	CAP (MW)	COBB-DOUGLAS	TRANSLOG	DEA CRS	DEA VRS
59	RAICHUR	1050	89.63%	89.70%	90.70%	91.30%
60	TUTICORIN	1050	94.04%	93.10%	95.60%	95.80%
61	KORADI	1080	79.18%	79.68%	76.90%	82.00%
62	SATPURA	1142.5	95.27%	93.71%	94.70%	94.90%
63	KOTHAGUDEM	1170	88.74%	87.28%	66.60%	66.70%
64	KOLAGHAT	1260	76.71%	75.50%	71.10%	72.70%

65	ROPAR	1260	93.72%	92.09%	91.50%	91.60%
66	VIJAYAWADA	1260	94.75%	93.32%	97.30%	97.30%
67	VINDHYACHAL STPS	1260	92.82%	92.29%	98.60%	100.00%
68	OBRA THERMAL	1442	75.16%	74.26%	67.40%	68.00%
69	NEYVELI-II	1470	92.06%	89.54%	88.30%	88.40%
70	WANAKBORI	1470	85.63%	85.37%	87.10%	89.50%
71	FARAKKA STPS	1600	79.00%	76.76%	72.20%	72.30%
72	ANPARA	1630	91.83%	89.91%	91.60%	91.70%
73	SINGRAULI STPS	2000	94.24%	92.58%	100.00%	100.00%
74	KORBA STPS	2100	95.07%	92.05%	96.70%	96.70%
75	RAMAGUNDEM STPS	2100	86.43%	85.36%	98.60%	100.00%
76	CHANDARPUR	2340	82.53%	81.84%	94.70%	98.30%
		Mean	**88.16%**	**86.91%**	**87.76%**	**88.73%**

Table E.2: Technical Efficiency Scores by Various Models for Year 2000-2001

SNO.	STATION (UPTO 250 MW)	CAP (MW)	COBB-DOUGLAS	TRANSLOG	DEA CRS	DEA VRS
1	NELLORE	30	88.40%	90.93%	67.50%	100.00%
2	PARAS	58	95.77%	95.90%	82.80%	96.40%
3	RAMAGUNDEM - B	62.5	96.68%	96.43%	88.80%	100.00%
4	NEW COSSIPORE	130	76.57%	80.99%	59.30%	79.00%
5	RAJGHAT	135	93.91%	94.38%	81.00%	87.80%
6	SOUTHERN REPL	135	80.14%	81.69%	68.90%	93.10%
7	FARIDABAD EXTN.	165	96.75%	97.44%	78.90%	84.10%
8	KUTCH LIGNITE	215	85.60%	87.82%	70.40%	78.40%
9	MUZAFFARPUR	220	62.84%	69.08%	45.40%	69.90%
10	PARICHA	220	82.14%	86.31%	64.00%	76.50%
11	BONGAIGAON	240	37.84%	43.12%	25.50%	84.80%
12	SIKKA REPL	240	90.68%	90.87%	86.70%	100.00%
13	TITAGARH	240	88.87%	89.49%	81.60%	87.90%
14	I.P. STATION	247.5	79.61%	81.98%	66.20%	78.90%
		Mean	82.56%	84.74%	69.07%	86.91%

SNO.	STATION (250-500 MW)	CAP (MW)	COBB-DOUGLAS	TRANSLOG	DEA CRS	DEA VRS
15	PANKI	274	88.10%	91.39%	68.20%	72.80%
16	AMAR KANTAK	290	85.99%	87.70%	72.20%	79.10%
17	BARAUNI	310	56.27%	63.77%	38.70%	65.30%
18	DURGAPUR	350	74.69%	76.45%	61.70%	68.00%
19	HARDUAGANJ B	385	83.80%	91.43%	58.50%	62.80%

20	A.E.CO. & SABARMATI	390	95.29%	94.85%	93.70%	95.30%
21	DURGAPUR D.P.L.	390	73.63%	75.23%	63.40%	94.50%
22	KORBA EAST	400	91.87%	91.84%	82.70%	84.80%
23	BAKRESHWAR	420	75.65%	78.29%	77.20%	100.00%
24	BHATINDA EXT.	420	95.10%	94.92%	98.30%	99.90%
25	I.B. VALLEY	420	89.93%	91.26%	91.80%	95.50%
26	KHAPARKHEDA II	420	91.78%	92.21%	91.40%	93.70%
27	MEJIA	420	68.33%	70.06%	62.50%	75.60%
28	RAYALSEEMA	420	92.94%	93.76%	98.20%	100.00%
29	TENUGHAT	420	86.78%	87.70%	79.00%	88.10%
30	BHATINDA	440	91.69%	91.46%	85.00%	86.60%
31	TANDA	440	70.55%	72.73%	57.80%	67.30%
32	ENNORE	450	83.91%	87.02%	67.30%	77.20%
33	TALCHER	460	92.10%	91.85%	81.90%	83.50%
34	BHUSAWAL	478	86.68%	88.28%	86.30%	90.60%
35	SANTALDIH	480	62.72%	65.05%	50.60%	63.80%
36	BUDGE BUDGE	500	73.26%	77.23%	76.30%	93.90%
37	DHANU	500	87.35%	89.56%	90.20%	94.70%
38	SURATGARH	500	81.47%	85.41%	85.80%	96.30%
		Mean	82.49%	84.56%	75.78%	84.55%

SNO.	STATION (500-750 MW)	CAP (MW)	COBB-DOUGLAS	TRANSLOG	DEA CRS	DEA VRS
39	BANDEL	530	66.41%	67.53%	59.30%	67.80%
40	NEYVELI-I	600	97.57%	96.90%	95.30%	96.30%
41	NORTH MADRAS	630	88.84%	89.92%	89.80%	91.10%
42	PANIPAT	650	87.24%	87.24%	77.70%	79.30%
43	PARLI	690	86.88%	87.63%	85.90%	86.90%
44	BADARPUR	705	92.90%	92.63%	93.80%	94.50%
45	CHANDRAPURA	750	68.01%	70.46%	52.10%	57.00%
		Mean	83.98%	84.62%	79.13%	81.84%

SNO.	STATION (750-1000 MW)	CAP (MW)	COBB-DOUGLAS	TRANSLOG	DEA CRS	DEA VRS
46	PATRATU	770	82.13%	84.33%	66.30%	70.30%
47	BOKARO B	805	76.64%	77.28%	63.40%	65.80%
48	BIRSINGHPUR	840	84.87%	84.58%	80.90%	81.70%
49	DADRI	840	92.45%	93.33%	99.50%	100.00%
50	KAHALGAON	840	80.70%	79.14%	72.30%	73.00%
51	KORBA-WEST	840	89.50%	89.22%	88.00%	88.70%
52	METTUR	840	90.96%	91.70%	94.90%	95.50%
53	UNCHAHAR	840	94.09%	94.04%	98.60%	99.30%
54	KOTA	850	94.38%	94.11%	99.40%	100.00%
55	UKAI THERMAL	850	88.74%	89.55%	89.90%	90.80%

56	GANDHI NAGAR	870	71.49%	73.86%	72.30%	83.80%
57	NASIK	910	82.04%	83.88%	83.80%	86.40%
58	RIHAND STPS	1000	90.54%	91.91%	96.90%	97.50%
59	TALCHER STPS	1000	85.93%	86.50%	85.00%	85.90%
		Mean	**86.03%**	**86.67%**	**85.09%**	**87.05%**

SNO.	STATION (1000 MW AND ABOVE)	CAP (MW)	COBB-DOUGLAS	TRANSLOG	DEA CRS	DEA VRS
60	RAICHUR	1050	89.13%	90.23%	93.40%	93.80%
61	TUTICORIN	1050	92.06%	92.66%	98.20%	98.60%
62	KORADI	1080	77.97%	78.72%	77.20%	79.70%
63	SATPURA	1142.5	90.94%	90.32%	91.40%	91.80%
64	KOTHAGUDEM	1170	92.39%	90.83%	91.20%	91.50%
65	KOLAGHAT	1260	73.97%	73.89%	71.80%	74.30%
66	ROPAR	1260	92.62%	91.77%	94.90%	95.20%
67	VIJAYAWADA	1260	90.57%	91.91%	98.50%	98.70%
68	VINDHYACHAL STPS	1260	89.18%	91.34%	97.20%	98.00%
69	OBRA THERMAL	1442	74.41%	73.26%	69.50%	70.90%
70	NEYVELI-II	1470	90.34%	88.77%	91.30%	91.50%
71	WANAKBORI	1470	89.95%	91.02%	96.70%	96.90%
72	FARAKKA STPS	1600	72.80%	70.53%	68.60%	69.50%
73	ANPARA	1630	89.74%	89.49%	94.00%	94.20%
74	SINGRAULI STPS	2000	89.32%	91.23%	100.00%	100.00%
75	KORBA STPS	2100	88.82%	89.56%	96.90%	96.90%
76	RAMAGUNDEM STPS	2100	89.26%	90.87%	99.30%	100.00%
77	CHANDARPUR	2340	78.97%	82.21%	95.00%	99.30%
		Mean	**86.25%**	**86.59%**	**90.28%**	**91.16%**

Table E.3: Technical Efficiency Scores by Various Models for Year 2001-2002

SNO.	STATION (UPTO 250 MW)	CAP (MW)	COBB-DOUGLAS	TRANSLOG	DEA CRS	DEA VRS
1	NELLORE	30	94.27%	93.78%	65.10%	100.00%
2	PARAS	58	96.29%	96.46%	80.00%	93.10%
3	RAMAGUNDEM - B	62.5	96.95%	97.11%	89.30%	100.00%
4	NEW COSSIPORE	130	66.84%	66.80%	50.40%	75.10%
5	RAJGHAT	135	97.29%	97.54%	88.80%	94.60%
6	SOUTHERN REPL	135	74.14%	73.96%	63.90%	94.40%
7	FARIDABAD EXTN.	165	97.35%	97.68%	78.40%	82.70%
8	KUTCH LIGNITE	215	92.61%	92.99%	77.80%	82.70%
9	MUZAFFARPUR	220	59.45%	59.38%	42.60%	69.00%

10	PARICHA	220	91.72%	92.35%	71.40%	74.20%
11	BONGAIGAON	240	44.48%	43.70%	32.10%	100.00%
12	SIKKA REPL	240	91.69%	91.68%	84.60%	100.00%
13	TITAGARH	240	89.51%	89.59%	81.20%	91.30%
14	PANKI	242	83.39%	83.54%	69.70%	84.00%
15	I.P. STATION	247.5	70.92%	70.92%	59.10%	85.50%
		Mean	83.13%	83.16%	68.96%	88.44%

SNO.	STATION (250-500 MW)	CAP (MW)	COBB-DOUGLAS	TRANSLOG	DEA CRS	DEA VRS
16	AMAR KANTAK	290	83.03%	83.40%	66.50%	75.70%
17	BARAUNI	310	66.11%	65.98%	42.80%	56.40%
18	DURGAPUR	350	85.22%	85.75%	67.10%	71.90%
19	HARDUAGANJ B	385	76.88%	77.16%	58.00%	70.10%
20	A.E.CO. & SABARMATI	390	95.98%	96.31%	93.20%	93.60%
21	DURGAPUR (D.P.L.)	390	76.99%	76.73%	69.50%	98.20%
22	KORBA EAST	400	90.31%	90.77%	79.30%	80.00%
23	BHATINDA EXT.	420	93.52%	93.50%	93.20%	94.50%
24	I.B. VALLEY	420	86.86%	86.30%	85.90%	98.80%
25	RAYALSEEMA	420	95.17%	95.12%	100.00%	100.00%
26	TENUGHAT	420	78.37%	78.19%	70.30%	95.10%
27	BHATINDA	440	94.19%	94.66%	85.90%	86.30%
28	TANDA	440	84.94%	85.50%	71.60%	73.80%
29	ENNORE	450	73.11%	73.44%	58.90%	74.40%
30	TALCHER	460	94.16%	94.74%	82.90%	83.40%
31	BHUSAWAL	478	87.84%	87.47%	86.10%	90.70%
32	SANTALDIH	480	67.48%	67.81%	53.50%	72.00%
33	BUDGE BUDGE	500	81.52%	80.48%	84.50%	100.00%
34	DHANU	500	91.37%	90.84%	94.30%	98.80%
		Mean	84.37%	84.43%	75.97%	84.93%

SNO.	STATION (500-750 MW)	CAP (MW)	COBB-DOUGLAS	TRANSLOG	DEA CRS	DEA VRS
35	BANDEL	530	65.16%	65.24%	56.60%	77.30%
36	NEYVELI-I	600	97.13%	97.62%	87.20%	87.50%
37	BAKRESHWAR	630	86.51%	86.71%	78.80%	79.20%
38	BOKARO	630	87.63%	88.29%	73.70%	74.30%
39	MEJIA	630	82.36%	82.32%	75.80%	84.10%
40	NORTH CHENNAI	630	89.93%	89.53%	90.40%	92.10%
41	PARLI	690	86.87%	86.53%	85.20%	87.80%
42	BADARPUR	705	94.30%	94.43%	94.80%	94.90%
43	CHANDRAPURA	750	78.86%	79.64%	60.80%	63.80%
44	SURATGARH	750	67.26%	66.31%	69.10%	95.90%
		Mean	83.60%	83.66%	77.24%	83.69%

SNO.	STATION (750-1000 MW)	CAP (MW)	COBB-DOUGLAS	TRANSLOG	DEA CRS	DEA VRS
45	PATRATU	770	79.59%	79.95%	65.70%	76.70%
46	BIRSINGHPUR	840	87.08%	87.49%	78.50%	78.60%
47	DADRI	840	91.64%	91.05%	96.40%	97.00%
48	KAHALGAON	840	95.52%	96.14%	85.60%	86.00%
49	KHAPARKHEDA II	840	84.73%	84.13%	85.30%	89.50%
50	KORBA-WEST	840	90.45%	90.18%	90.60%	90.70%
51	METTUR	840	92.90%	92.68%	96.00%	96.00%
52	UNCHAHAR	840	93.71%	93.54%	97.80%	97.80%
53	KOTA	850	95.50%	95.62%	99.50%	99.60%
54	UKAI THERMAL	850	92.20%	92.11%	91.90%	91.90%
55	PANIPAT	860	85.51%	85.95%	76.30%	76.40%
56	GANDHI NAGAR	870	81.44%	80.77%	82.20%	89.00%
57	NASIK	910	85.55%	84.98%	86.10%	89.50%
58	RIHAND STPS	1000	91.23%	90.46%	97.30%	98.20%
59	TALCHER STPS	1000	81.40%	80.82%	81.70%	86.60%
		Mean	88.56%	88.39%	87.39%	89.57%

SNO.	STATION (1000 MW AND ABOVE)	CAP (MW)	COBB-DOUGLAS	TRANSLOG	DEA CRS	DEA VRS
60	TUTICORIN	1050	93.56%	93.22%	99.60%	99.60%
61	KORADI	1080	86.14%	86.06%	82.90%	82.90%
62	SATPURA	1142.5	88.96%	88.99%	86.00%	86.10%
63	KOTHAGUDEM	1170	93.34%	93.56%	92.10%	92.20%
64	KOLAGHAT	1260	74.87%	74.49%	73.10%	80.70%
65	RAICHUR	1260	91.26%	90.65%	96.00%	96.10%
66	ROPAR	1260	95.02%	95.23%	96.90%	97.00%
67	VIJAYAWADA	1260	93.15%	92.67%	100.00%	100.00%
68	OBRA THERMAL	1442	75.66%	75.61%	71.10%	75.50%
69	NEYVELI-II	1470	92.81%	92.93%	92.40%	92.50%
70	WANAKBORI	1470	91.69%	90.96%	98.40%	98.40%
71	FARAKKA STPS	1600	83.26%	83.28%	79.40%	79.40%
72	ANPARA	1630	91.41%	90.90%	95.80%	95.80%
73	SINGRAULI STPS	2000	89.94%	88.51%	100.00%	100.00%
74	KORBA STPS	2100	91.47%	90.58%	99.20%	100.00%
75	RAMAGUNDEM STPS	2100	90.21%	89.05%	98.50%	98.70%
76	VINDHYACHAL STPS	2260	86.73%	85.12%	100.00%	100.00%
77	CHANDARPUR	2340	83.00%	81.72%	96.70%	97.50%
		Mean	88.47%	87.97%	92.12%	92.91%

Table E.4: Technical Efficiency Scores by Various Models for Year 2002-2003

SNO.	STATION (UPTO 250 MW)	CAP (MW)	COBB-DOUGLAS	TRANSLOG	DEA CRS	DEA VRS
1	NELLORE	30	78.40%	86.66%	64.90%	100.00%
2	PARAS	58	93.52%	98.55%	80.60%	97.80%
3	RAMAGUNDEM - B	62.5	96.37%	96.07%	87.90%	100.00%
4	NEW COSSIPORE	130	63.12%	64.52%	55.00%	74.70%
5	RAJGHAT	135	92.02%	93.25%	80.90%	85.30%
6	SOUTHERN REPL	135	89.89%	88.73%	83.60%	92.20%
7	FARIDABAD EXTN.	165	98.90%	99.86%	84.00%	87.70%
8	KUTCH LIGNITE	215	77.89%	78.06%	68.90%	72.70%
9	MUZAFFARPUR	220	45.96%	47.46%	38.60%	68.10%
10	PARICHA	220	73.59%	73.23%	63.10%	66.00%
11	SIKKA REPL	240	94.06%	91.81%	89.20%	95.30%
12	TITAGARH	240	92.00%	90.52%	87.40%	90.20%
13	PANKI	242	83.56%	83.85%	75.10%	79.00%
14	I.P. STATION	247.5	72.86%	73.87%	64.40%	75.50%
		Mean	82.30%	83.32%	73.11%	84.61%

SNO.	STATION (250-500 MW)	CAP (MW)	COBB-DOUGLAS	TRANSLOG	DEA CRS	DEA VRS
15	AMAR KANTAK	290	77.38%	77.06%	69.70%	72.70%
16	BARAUNI	310	49.40%	49.59%	38.70%	56.40%
17	DURGAPUR	350	81.84%	81.89%	71.80%	74.50%
18	HARDUAGANJ B	385	71.17%	71.73%	62.90%	72.10%
19	A.E.CO. & SABARMATI	390	99.37%	99.87%	96.90%	97.20%
20	DURGAPUR (D.P.L.)	390	73.37%	72.54%	69.10%	78.00%
21	KORBA EAST	400	88.87%	88.27%	83.10%	84.20%
22	BHATINDA EXT.	420	94.10%	91.59%	93.70%	94.40%
23	I.B. VALLEY	420	77.54%	75.27%	77.90%	83.40%
24	RAYALSEEMA	420	97.89%	94.16%	100.00%	100.00%
25	TENUGHAT	420	76.19%	74.10%	73.60%	84.60%
26	BHATINDA	440	90.87%	90.37%	84.80%	85.40%
27	TANDA	440	94.76%	94.27%	87.00%	87.90%
28	ENNORE	450	77.43%	76.99%	70.70%	73.10%
29	TALCHER	460	93.35%	92.85%	86.50%	87.40%
30	BHUSAWAL	478	84.89%	82.36%	84.80%	88.70%
31	SANTALDIH	480	59.94%	59.44%	53.70%	62.10%
32	BUDGE BUDGE	500	78.45%	75.97%	80.60%	84.30%
33	DHANU	500	97.11%	94.15%	99.40%	99.40%
		Mean	82.31%	81.18%	78.15%	82.41%

SNO.	STATION (500-750 MW)	CAP (MW)	COBB-DOUGLAS	TRANSLOG	DEA CRS	DEA VRS
34	BANDEL	530	65.00%	64.61%	61.40%	67.70%
35	NEYVELI-I	600	98.62%	96.52%	89.20%	89.50%
36	BAKRESHWAR	630	84.68%	84.69%	100.00%	100.00%
37	BOKARO	630	78.44%	77.39%	71.70%	71.80%
38	MEJIA	630	77.98%	77.04%	77.80%	80.10%
39	NORTH CHENNAI	630	90.26%	89.44%	90.90%	90.90%
40	PARLI	690	87.27%	87.45%	84.40%	84.50%
41	BADARPUR	705	93.24%	92.82%	94.70%	94.80%
42	CHANDRAPURA	750	60.61%	58.96%	51.80%	57.10%
		Mean	81.79%	80.99%	80.21%	81.82%

SNO.	STATION (750-1000 MW)	CAP (MW)	COBB-DOUGLAS	TRANSLOG	DEA CRS	DEA VRS
43	PATRATU	770	55.79%	55.26%	49.90%	59.50%
44	BIRSINGHPUR	840	82.05%	82.59%	79.90%	80.00%
45	DADRI	840	90.54%	90.62%	92.90%	93.00%
46	KAHALGAON	840	91.63%	90.71%	85.10%	85.40%
47	KHAPARKHEDA II	840	90.67%	90.82%	93.10%	93.20%
48	KORBA WEST	840	94.83%	95.27%	93.90%	94.10%
49	METTUR	840	97.09%	97.61%	99.20%	99.30%
50	UNCHAHAR	840	94.16%	94.31%	96.20%	96.20%
51	KOTA	850	98.33%	99.11%	99.60%	99.70%
52	UKAI THERMAL	850	88.50%	88.19%	90.40%	90.70%
53	PANIPAT	860	97.22%	97.26%	92.70%	93.00%
54	GANDHI NAGAR	870	88.26%	88.41%	90.30%	90.50%
55	NASIK	910	83.76%	83.87%	85.20%	85.90%
56	RIHAND STPS	1000	92.24%	92.50%	97.40%	97.80%
57	SIMHADRI	1000	43.93%	44.44%	44.70%	49.60%
58	SURATGARH	1000	82.97%	83.00%	87.90%	89.30%
59	TALCHER STPS	1000	87.07%	87.81%	88.90%	89.10%
		Mean	85.83%	85.99%	86.31%	87.43%

SNO.	STATION (1000 MW AND ABOVE)	CAP (MW)	COBB-DOUGLAS	TRANSLOG	DEA CRS	DEA VRS
60	TUTICORIN	1050	95.92%	97.09%	99.50%	99.60%
61	KORADI	1080	81.72%	82.77%	81.60%	81.70%
62	SATPURA	1142.5	91.73%	93.31%	91.30%	91.40%
63	KOTHAGUDEM	1170	93.37%	95.38%	94.70%	94.80%
64	KOLAGHAT	1260	73.77%	75.19%	74.70%	75.80%
65	RAICHUR	1260	94.24%	96.57%	98.30%	98.30%
66	ROPAR	1260	94.26%	95.92%	96.30%	96.40%

67	VIJAYAWADA	1260	94.85%	97.20%	99.50%	99.50%
68	OBRA THERMAL	1442	73.88%	75.02%	72.80%	73.20%
69	NEYVELI-II	1470	92.70%	95.28%	93.10%	93.20%
70	WANAKBORI	1470	96.07%	98.84%	97.20%	97.20%
71	FARAKKA STPS	1600	84.31%	85.79%	82.80%	82.80%
72	ANPARA	1630	92.11%	95.48%	95.50%	95.50%
73	SINGRAULI STPS	2000	92.38%	97.43%	99.20%	99.30%
74	KORBA STPS	2100	93.11%	98.39%	97.80%	97.80%
75	RAMAGUNDEM STPS	2100	93.75%	99.22%	100.00%	100.00%
76	VINDHYACHAL STPS	2260	90.64%	95.98%	98.80%	100.00%
77	CHANDARPUR	2340	81.72%	86.51%	88.80%	89.00%
		Mean	**89.47%**	**92.30%**	**92.33%**	**92.53%**

Table E.5: Technical Efficiency Scores by Various Models for Year 2003-2004

SNO.	STATION (UPTO 250 MW)	CAP (MW)	COBB-DOUGLAS	TRANSLOG	DEA CRS	DEA VRS
1	NELLORE	30	76.30%	90.63%	61.10%	100.00%
2	PARAS	58	97.70%	96.23%	89.50%	100.00%
3	RAMAGUNDAM B	62.5	97.31%	93.78%	91.40%	100.00%
4	NEWCOSSIPORE	130	80.09%	89.20%	67.70%	81.90%
5	RAJGHAT	135	95.64%	96.47%	83.90%	88.30%
6	SOUTHERN REPL.	135	89.28%	89.66%	82.20%	96.00%
7	FARIDABAD	165	95.89%	98.07%	76.80%	80.70%
8	KUTCH LIGNITE	215	75.03%	83.66%	63.70%	77.00%
9	MUZAFFARPUR	220	46.88%	56.94%	37.60%	100.00%
10	PARICHA	220	72.40%	87.47%	57.50%	68.10%
11	SIKKA	240	74.27%	76.43%	68.70%	95.20%
12	TITAGARH	240	91.59%	92.17%	85.60%	91.60%
13	PANKI	242	83.03%	89.40%	72.50%	82.00%
14	I.P.STATION	247.5	63.64%	71.62%	54.20%	79.10%
		Mean	**81.36%**	**86.55%**	**70.89%**	**88.56%**

SNO.	STATION (250-500 MW)	CAP (MW)	COBB-DOUGLAS	TRANSLOG	DEA CRS	DEA VRS
15	AMARKANTAK	290	69.92%	78.66%	58.10%	70.70%
16	BARAUNI	310	56.67%	83.32%	39.30%	56.20%
17	DURGAPUR	350	80.17%	86.96%	68.40%	72.90%
18	HARDUAGANJ	385	65.96%	72.04%	57.80%	85.60%
19	AECO.& SABARMATI	390	97.60%	96.20%	95.40%	95.90%
20	DURGAPUR (DPL)	390	82.67%	86.80%	74.90%	82.80%
21	KORBA EAST	400	91.98%	93.26%	84.50%	87.10%

22	BHATINDA EXT.	420	91.92%	91.15%	92.50%	96.60%
23	I.B. VALLEY	420	88.21%	88.29%	88.30%	95.90%
24	RAYALSEEMA	420	92.16%	90.65%	94.60%	100.00%
25	TENUGHAT	420	85.04%	88.65%	77.10%	87.90%
26	BHATINDA	440	90.57%	92.57%	82.50%	83.20%
27	TANDA	440	94.27%	94.36%	87.40%	87.90%
28	ENNORE	450	76.34%	82.66%	66.90%	80.60%
29	TALCHER	460	96.50%	95.74%	90.20%	90.90%
30	BHUSAWAL	478	90.45%	90.69%	89.20%	92.70%
31	SANTALDIH	480	63.85%	71.15%	54.00%	73.20%
32	BUDGE BUDGE	500	84.14%	85.20%	84.80%	93.90%
33	DHANU	500	95.79%	94.00%	100.00%	100.00%
		Mean	**83.91%**	**87.49%**	**78.21%**	**86.00%**

SNO.	STATION (500-750 MW)	CAP (MW)	COBB-DOUGLAS	TRANSLOG	DEA CRS	DEA VRS
34	BANDEL	530	66.06%	70.72%	59.60%	81.70%
35	NEYVELI ST I	600	98.50%	96.91%	89.20%	89.20%
36	BAKRESHWAR	630	76.70%	78.18%	83.30%	100.00%
37	BOKARO	630	76.91%	80.52%	70.40%	78.30%
38	MEJIA(DVC)	630	87.76%	89.13%	86.50%	89.00%
39	NORTH CHENNAI	630	88.73%	89.82%	88.80%	91.00%
40	PARLI	690	87.39%	89.07%	85.30%	86.20%
41	BADARPUR	705	90.57%	91.48%	92.20%	92.50%
42	CHANDRAPUR(DVC)	750	68.51%	77.31%	54.30%	61.50%
		Mean	**82.35%**	**84.79%**	**78.84%**	**85.49%**

SNO.	STATION (750-1000 MW)	CAP (MW)	COBB-DOUGLAS	TRANSLOG	DEA CRS	DEA VRS
43	PATRATU	770	49.25%	56.18%	40.20%	66.90%
44	BIRSINGPUR	840	82.62%	84.60%	78.80%	78.90%
45	DADRI	840	87.93%	89.75%	89.70%	90.60%
46	KAHALGAON	840	96.87%	94.45%	87.30%	88.70%
47	KHAPERKHEDA	840	91.22%	92.02%	92.90%	93.00%
48	KORBA WEST	840	91.23%	91.71%	87.80%	88.20%
49	METTUR	840	95.94%	94.84%	97.20%	97.70%
50	UNCHAHAR	840	94.00%	93.73%	95.70%	96.00%
51	UKAI	850	87.71%	89.36%	85.70%	85.80%
52	PANIPAT	860	95.56%	94.02%	89.10%	90.00%
53	GANDHINAGAR	870	78.20%	80.99%	79.00%	86.10%
54	NASIK	910	85.96%	88.07%	86.90%	88.80%
55	RIHAND STPS	1000	90.76%	92.44%	98.10%	100.00%
56	SIMHADRI	1000	94.54%	94.07%	97.20%	97.40%
		Mean	**87.27%**	**88.30%**	**86.11%**	**89.15%**

SNO.	STATION (1000 MW AND ABOVE)	CAP (MW)	COBB-DOUGLAS	TRANSLOG	DEA CRS	DEA VRS
57	KOTA	1045	78.97%	81.63%	79.90%	84.20%
58	TUTICORIN	1050	94.78%	94.39%	99.30%	99.50%
59	KORADI	1080	85.42%	86.74%	82.70%	82.80%
60	SATPURA	1142.5	88.00%	88.17%	85.40%	85.70%
61	KOTHAGUDEM	1170	93.11%	92.77%	93.50%	93.80%
62	SURATGARH	1250	83.66%	86.71%	87.90%	91.10%
63	KOLAGHAT	1260	83.36%	81.66%	75.80%	76.20%
64	ROPAR	1260	91.41%	92.24%	94.40%	94.50%
65	VIJAYWADA	1260	92.43%	93.06%	97.10%	97.30%
66	WANAKBORI	1260	89.36%	91.00%	93.10%	93.20%
67	OBRA	1442	74.55%	74.96%	69.70%	71.10%
68	NEYVELI ST II	1470	94.76%	92.75%	93.70%	94.20%
69	RAICHUR	1470	92.39%	93.02%	97.60%	97.70%
70	TALCHER STPS	1500	84.91%	86.43%	86.60%	86.60%
71	FARAKKA STPS	1600	88.92%	84.00%	81.30%	81.90%
72	ANPARA	1630	90.01%	90.88%	93.80%	93.90%
73	SINGRAULI STPS	2000	91.15%	93.27%	100.00%	100.00%
74	KORBA STPS	2100	94.17%	92.49%	98.00%	99.20%
75	RAMAGUNDAM STPS	2100	91.72%	92.85%	99.10%	100.00%
76	VINDHYACHAL	2260	88.60%	92.32%	100.00%	100.00%
77	CHANDRAPUR	2340	82.89%	86.67%	93.60%	94.60%
		Mean	**88.31%**	**88.95%**	**90.60%**	**91.31%**

Table E.6: Technical Efficiency Scores by Various Models for Year 2004-2005

SNO.	STATION (UPTO 250 MW)	CAP (MW)	COBB-DOUGLAS	TRANSLOG	DEA CRS	DEA VRS
1	NELLORE	30	80.68%	92.81%	58.80%	100.00%
2	PARAS	62.5	96.59%	97.57%	79.70%	94.00%
3	RAMAGUNDEM - B	62.5	96.89%	92.07%	90.10%	100.00%
4	RAJGHAT	135	83.72%	84.19%	71.90%	89.50%
5	SOUTH. REPL.	135	94.97%	93.99%	85.50%	92.20%
6	FARIDABAD EXTN.	180	92.97%	97.72%	67.80%	71.60%
7	KUTCH LIGNITE	215	78.22%	86.25%	58.80%	68.70%
8	PARICHA	220	86.45%	94.49%	63.30%	66.50%
9	SIKKA REP.	240	88.33%	89.82%	76.90%	85.00%
10	TITAGARH	240	95.63%	95.49%	87.90%	89.70%
11	I.P.STATION	247.5	76.61%	82.75%	59.60%	72.20%
		Mean	88.28%	91.56%	72.75%	84.49%

SNO.	STATION (250-500 MW)	CAP (MW)	COBB-DOUGLAS	TRANSLOG	DEA CRS	DEA VRS
12	PANKI	252	76.79%	80.57%	63.10%	78.90%
13	AMAR KANTAK	300	74.56%	80.19%	55.80%	65.10%
14	BARAUNI	310	53.63%	81.17%	31.20%	63.20%
15	DURGAPUR	350	82.92%	86.93%	66.50%	72.60%
16	A.E.CO. & SABARMATI	390	96.94%	96.84%	92.80%	93.40%
17	DURGAPUR (D.P.L.)	395	89.26%	91.05%	76.90%	79.80%
18	HARDUAGANJ B	400	62.00%	65.27%	50.90%	83.00%
19	BHATINDA EXT.	420	93.51%	93.63%	94.50%	97.10%
20	I.B.VALLEY	420	92.34%	92.53%	92.50%	96.30%
21	RAYALSEEMA	420	91.18%	91.43%	94.50%	100.00%
22	TENUGHAT	420	94.97%	95.84%	82.10%	84.80%
23	BHATINDA	440	91.69%	92.32%	82.70%	86.70%
24	KORBA EAST	440	94.90%	95.15%	86.90%	87.90%
25	TANDA	440	96.53%	96.51%	90.50%	90.90%
26	ENNORE	450	77.07%	80.26%	64.30%	79.30%
27	TALCHER	470	95.98%	96.07%	87.50%	87.90%
28	SANTALDIH	480	64.71%	68.10%	51.70%	71.70%
29	BHUSAWAL	482.5	90.64%	91.59%	86.50%	88.50%
30	BUDGE BUDGE	500	90.11%	91.46%	89.90%	92.40%
31	DHANU	500	94.29%	95.15%	100.00%	100.00%
		Mean	**85.20%**	**88.10%**	**77.04%**	**84.98%**

SNO.	STATION (500-750 MW)	CAP (MW)	COBB-DOUGLAS	TRANSLOG	DEA CRS	DEA VRS
32	BANDEL	540	70.35%	72.31%	61.00%	77.00%
33	NEYVELI ST I	600	98.52%	97.83%	85.80%	85.90%
34	BAKRESWAR	630	75.97%	79.59%	84.80%	100.00%
35	BOKARO B	630	88.24%	89.57%	69.80%	70.60%
36	MEJIA	630	89.45%	91.47%	89.20%	90.00%
37	NORTH CHENNAI	630	90.82%	92.17%	91.00%	92.90%
38	PARLI	690	94.56%	95.29%	92.80%	93.20%
39	BADARPUR	720	91.13%	93.15%	91.20%	91.40%
		Mean	**87.38%**	**88.92%**	**83.20%**	**87.63%**

SNO.	STATION (750-1000 MW)	CAP (MW)	COBB-DOUGLAS	TRANSLOG	DEA CRS	DEA VRS
40	CHANDRAPURA	780	80.30%	83.08%	63.70%	68.40%
41	BIRSINGHPUR	840	88.91%	89.74%	83.30%	83.50%
42	DADRI (NCTPP)	840	91.39%	94.25%	95.30%	95.40%
43	KAHALGAON	840	97.34%	95.87%	87.50%	88.70%

44	KHAPARKHEDA II	840	91.43%	93.22%	90.90%	91.10%
45	KORBA-WEST	840	87.33%	89.32%	84.90%	84.90%
46	METTUR	840	94.56%	95.60%	95.60%	96.00%
47	PATRATU	840	63.47%	70.72%	46.60%	66.20%
48	UNCHAHAR	840	94.78%	95.95%	97.30%	97.70%
49	UKAI	850	85.85%	87.96%	83.30%	83.90%
50	PANIPAT	860	95.43%	94.60%	85.80%	86.70%
51	GANDHI NAGAR	870	75.28%	78.52%	75.30%	83.00%
52	NASIK	910	83.84%	86.73%	83.70%	85.90%
53	RIHAND	1000	88.78%	93.98%	97.50%	99.00%
54	SIMHADRI	1000	94.25%	95.86%	98.10%	98.40%
		Mean	87.53%	89.69%	84.59%	87.25%

SNO.	STATION (1000 MW AND ABOVE)	CAP (MW)	COBB-DOUGLAS	TRANSLOG	DEA CRS	DEA VRS
55	KOTA	1045	94.23%	95.42%	95.80%	96.20%
56	TUTICORIN	1050	92.64%	95.10%	96.80%	97.00%
57	KORADI	1100	86.57%	86.73%	81.10%	81.30%
58	SATPURA	1143	90.10%	89.56%	85.10%	85.50%
59	KOTHAGUDEM	1170	94.98%	96.15%	99.00%	99.30%
60	SURATGARH	1250	89.88%	94.37%	96.90%	96.90%
61	KOLAGHAT	1260	83.18%	82.29%	77.50%	77.60%
62	ROPAR	1260	92.04%	94.55%	95.70%	95.80%
63	VIJAYWADA	1260	90.35%	94.32%	96.40%	96.50%
64	NEYVELI ST II	1470	92.08%	91.92%	89.80%	90.10%
65	RAICHUR	1470	89.75%	93.25%	94.30%	94.40%
66	WANAKBORI	1470	89.36%	92.84%	93.70%	93.80%
67	OBRA	1500	72.32%	71.76%	65.10%	69.00%
68	FARAKKA STPS	1600	93.34%	86.54%	82.60%	83.20%
69	ANPARA	1630	86.02%	89.59%	89.70%	89.80%
70	SINGRAULI STPS	2000	90.12%	94.66%	98.20%	98.30%
71	KORBA STPS	2100	95.22%	95.11%	99.50%	99.70%
72	VINDHYACHAL STPS	2260	88.28%	95.38%	100.00%	100.00%
73	CHANDRAPUR	2340	85.34%	88.49%	89.90%	90.00%
74	TALCHER STPS	2500	72.70%	73.03%	73.50%	80.10%
75	RAMAGUNDEM STPS	2600	75.38%	81.77%	89.90%	93.90%
		Mean	87.80%	89.66%	90.02%	90.88%

Table E.7: Technical Efficiency Scores by Various Models for Year 2005-2006

SNO.	STATION (UPTO 250 MW)	CAP (MW)	COBB-DOUGLAS	TRANSLOG	DEA CRS	DEA VRS
1	NELLORE	30	76.61%	89.91%	57.90%	100.00%
2	PARAS	62.5	96.63%	96.74%	85.70%	96.90%
3	RAMAGUNDAM	62.5	86.60%	85.27%	79.60%	100.00%
4	RAJGHAT	135	73.98%	86.97%	61.60%	77.90%
5	SOUTH GEN.	135	94.59%	93.99%	88.10%	95.70%
6	FARIDABAD	180	85.26%	96.94%	66.10%	71.30%
7	KUTCH LIG.	215	98.45%	98.02%	89.60%	95.20%
8	PANKI	220	69.87%	77.27%	61.70%	83.10%
9	PARICHA	220	81.15%	96.11%	62.30%	68.20%
10	SIKKA	240	87.83%	90.75%	81.20%	90.00%
11	TITAGARH	240	95.42%	95.03%	89.50%	92.30%
12	I.P. STATION	247.5	69.98%	81.87%	57.40%	71.10%
		Mean	84.70%	90.74%	73.39%	86.81%

SNO.	STATION (250-500 MW)	CAP (MW)	COBB-DOUGLAS	TRANSLOG	DEA CRS	DEA VRS
13	AMARKANTAK	300	66.50%	78.25%	53.60%	67.10%
14	BARAUNI	320	42.17%	77.39%	28.40%	61.30%
15	DURGAPUR	350	74.31%	76.80%	73.40%	94.90%
16	A.E.CO. & SABARMATI	390	97.93%	96.46%	97.00%	97.00%
17	DURGAPUR (D.P.L.)	395	84.89%	90.08%	74.70%	77.40%
18	HARDUAGANJ	400	60.66%	74.28%	49.50%	74.60%
19	BHATINDA EXT.	420	92.51%	92.35%	94.90%	99.00%
20	I.B. VALLEY	420	86.95%	88.70%	88.80%	95.50%
21	NEYVELI FST EXT	420	93.89%	93.90%	90.50%	91.30%
22	RAYALSEEMA	420	83.37%	84.13%	86.30%	100.00%
23	TENUGHAT	420	77.97%	80.11%	75.70%	95.10%
24	BHATINDA	440	87.07%	90.08%	81.50%	86.00%
25	KORBA EAST	440	94.93%	94.74%	88.80%	88.80%
26	TANDA	440	97.22%	95.97%	93.80%	93.90%
27	ENNORE	450	69.60%	79.06%	59.90%	83.10%
28	TALCHER	470	95.36%	94.91%	88.80%	88.80%
29	SANTALDIH	480	61.07%	69.13%	52.40%	74.60%
30	BHUSAWAL	482.5	92.05%	92.73%	90.80%	91.70%
31	BUDGE BUDGE	500	95.71%	94.91%	98.70%	98.70%
32	DAHANU	500	94.53%	94.23%	100.00%	100.00%
		Mean	82.43%	86.91%	78.38%	87.94%

SNO.	STATION (500-750 MW)	CAP (MW)	COBB-DOUGLAS	TRANSLOG	DEA CRS	DEA VRS
33	BANDEL	540	60.93%	66.19%	56.00%	76.90%
34	NEYVELI ST I	600	97.13%	95.74%	81.40%	81.40%
35	BAKRESWAR	630	78.94%	83.85%	86.60%	100.00%
36	BOKARO	630	75.36%	80.21%	66.10%	71.40%
37	NORTH CHENNAI	630	90.28%	91.81%	92.40%	94.20%
38	GANDHINAGAR	660	73.15%	77.55%	73.10%	85.70%
39	PARLI	690	91.30%	92.58%	90.70%	90.80%
40	BADARPUR	720	91.83%	92.93%	91.70%	91.80%
		Mean	82.37%	85.11%	79.75%	86.53%

SNO.	STATION (750-1000 MW)	CAP (MW)	COBB-DOUGLAS	TRANSLOG	DEA CRS	DEA VRS
41	CHANDRAPURA	780	73.13%	79.08%	64.50%	73.90%
42	BIRSINGPUR	840	82.86%	85.83%	79.90%	80.90%
43	DADRI	840	91.54%	93.66%	96.70%	97.00%
44	KAHALGAON	840	97.97%	95.52%	91.90%	92.70%
45	KHAPERKHEDA	840	87.83%	90.57%	88.80%	89.00%
46	KORBA WEST	840	87.35%	90.04%	87.50%	87.60%
47	MEJIA	840	85.84%	89.95%	90.40%	94.40%
48	METTUR	840	93.42%	94.12%	96.10%	96.20%
49	PATRATU	840	60.12%	70.74%	50.00%	73.60%
50	UNCHAHAR	840	95.23%	95.01%	98.60%	98.80%
51	UKAI	850	84.29%	87.26%	82.90%	83.70%
52	NASIK	910	85.80%	88.86%	86.00%	86.80%
53	SIMHADRI	1000	88.33%	91.62%	92.20%	92.90%
		Mean	85.67%	88.64%	85.04%	88.27%

SNO.	STATION (1000 MW AND ABOVE)	CAP (MW)	COBB-DOUGLAS	TRANSLOG	DEA CRS	DEA VRS
54	KOTA	1045	95.55%	95.00%	98.50%	98.70%
55	TUTICORIN	1050	91.20%	93.25%	95.00%	95.00%
56	KORADI	1100	86.33%	87.49%	82.30%	82.40%
57	SATPURA	1142.5	91.58%	89.34%	83.90%	84.30%
58	TROMBAY	1150	77.44%	83.74%	82.80%	92.20%
59	KOTHAGUDEM	1180	86.64%	90.43%	90.40%	91.90%
60	SURATGARH	1250	92.14%	93.94%	97.20%	97.20%
61	KOLAGHAT	1260	79.19%	80.09%	75.50%	76.40%
62	ROPAR	1260	92.19%	93.66%	96.10%	96.20%
63	VIJAYAWADA	1260	86.85%	91.62%	93.10%	95.60%
64	WANAKBORI	1260	90.03%	92.34%	93.20%	93.20%
65	PANIPAT	1360	90.86%	90.71%	88.00%	88.20%

66	NEYVELI ST II	1470	88.21%	88.61%	86.80%	86.80%
67	RAICHUR	1470	88.50%	91.60%	92.30%	92.80%
68	OBRA	1500	67.94%	70.21%	63.80%	70.70%
69	RIHAND	1500	80.86%	87.12%	86.90%	93.40%
70	FARAKKA STPS	1600	94.66%	90.90%	90.80%	91.10%
71	ANPARA	1630	87.39%	90.64%	91.60%	92.30%
72	SINGRAULI	2000	93.99%	94.52%	100.00%	100.00%
73	KORBA STPS	2100	95.80%	94.29%	99.80%	100.00%
74	VINDHYACHAL	2260	90.93%	94.13%	100.00%	100.00%
75	CHANDRAPUR	2340	85.09%	88.00%	88.80%	90.20%
76	RAMAGUNDAM STP	2600	86.39%	91.79%	100.00%	100.00%
77	TALCHER STPS	3000	83.76%	87.53%	100.00%	100.00%
		Mean	**87.65%**	**89.62%**	**90.70%**	**92.03%**

APPENDIX – F

CAPACITY WISE RANKING OF THE COAL BASED INDIAN THERMAL POWER PLANTS

Table F.1. Capacity Wise Ranking of the Plants for the Year 1999-2000

Sno.	STATION (UPTO 250 MW)	CAP (MW)	Tech Eff.	Rank (Overall Rank)
1	NELLORE	30	69.59%	10(61)
2	PARAS	58	93.17%	4(17)
3	RAMAGUNDEM - B	62.5	96.62%	3(4)
4	NEW COSSIPORE	130	79.95%	8(45)
5	RAJGHAT	135	98.14%	1(2)
6	SOUTHERN REPL	135	69.44%	11(62)
7	FARIDABAD EXTN.	165	96.80%	2(3)
8	KUTCH LIGNITE	215	84.08%	6(37)
9	MUZAFFARPUR	220	48.04%	13(74)
10	PARICHA	220	67.87%	12(65)
11	BONGAIGAON	240	39.78%	14(76)
12	SIKKA REPL	240	83.03%	7(42)
13	TITAGARH	240	84.42%	5(36)
14	SURATGARH	250	72.68%	9(56)
		Mean	77.40%	

Sno.	STATION (250 – 500 MW)	CAP (MW)	Tech Eff.	Rank(Overall Rank)
1	PANKI	274	64.65%	20(69)
2	I.P. STATION	277.5	72.43%	16(57)
3	AMAR KANTAK	290	81.54%	11(44)
4	BARAUNI	310	50.95%	22(72)
5	DURGAPUR	350	75.45%	14(52)
6	HARDUAGANJ B	385	74.86%	15(54)
7	A.E.CO. & SABARMATI	390	94.77%	3(11)
8	DURGAPUR (D.P.L.)	390	66.58%	18(67)
9	KORBA EAST	400	90.01%	6(24)

10	BHATINDA EXT.	420	78.80%	13(49)
11	I.B. VALLEY	420	92.37%	4(19)
12	KHAPARKHEDA II	420	91.37%	5(22)
13	MEJIA	420	48.79%	23(73)
14	RAYALSEEMA	420	95.46%	2(8)
15	TENUGHAT	420	79.74%	12(46)
16	**UNCHAHAR**	**420**	**95.89%**	**1(6)**
17	BHATINDA	440	88.54%	7(28)
18	TANDA	440	57.26%	21(71)
19	ENNORE	450	71.12%	17(59)
20	TALCHER	460	83.41%	10(38)
21	BHUSAWAL	478	86.87%	8(30)
22	SANTALDIH	480	66.50%	19(68)
23	BUDGE BUDGE	500	44.63%	24(75)
24	DHANU	500	86.31%	9(33)
		Mean	**76.60%**	

Sno.	STATION (500-750 MW)	CAP (MW)	Tech Eff.	Rank (Overall Rank)
1	BANDEL	530	63.70%	8(70)
2	**NEYVELI-I**	**600**	**98.30%**	**1(1)**
3	BIRSINGHPUR	630.0	76.89%	6(50)
4	NORTH MADRAS	630	86.47%	3(31)
5	PANIPAT	650	83.29%	4(39)
6	PARLI	690	83.09%	5(40)
7	BADARPUR	705	90.30%	2(23)
8	CHANDRAPURA	750	67.85%	7(66)
		Mean	**81.24%**	

Sno.	STATION (750-1000 MW)	CAP (MW)	Tech Eff.	Rank (Overall Rank)
1	PATRATU	770	70.89%	10(60)
2	BOKARO	805	73.56%	8(55)
3	**DADRI**	**840**	**96.44%**	**1(5)**
4	KAHALGAON	840	68.83%	12(64)
5	KORBA-WEST	840	89.67%	4(25)

6	METTUR	840	87.10%	5(29)
7	KOTA	850	95.76%	2(7)
8	UKAI THERMAL	850	83.04%	7(41)
9	GANDHI NAGAR	870	71.35%	9(58)
10	NASIK	910	85.62%	6(35)
11	RIHAND STPS	1000	93.65%	3(16)
12	TALCHER STPS	1000	69.29%	11(63)
		Mean	82.10%	

Sno.	STATION (1000MW & above)	CAP (MW)	Tech Eff.	Rank (Overall Rank)
1	RAICHUR	1050	89.63%	10(26)
2	TUTICORIN	1050	94.04%	5(14)
3	KORADI	1080	79.18%	15(47)
4	SATPURA	1142.5	95.27%	1(9)
5	KOTHAGUDEM	1170	88.74%	11(27)
6	KOLAGHAT	1260	76.71%	17(51)
7	ROPAR	1260	93.72%	6(15)
8	VIJAYAWADA	1260	94.75%	3(12)
9	VINDHYACHAL STPS	1260	92.82%	7(18)
10	OBRA THERMAL	1442	75.16%	18(53)
11	NEYVELI-II	1470	92.06%	8(20)
12	WANAKBORI	1470	85.63%	13(34)
13	FARAKKA STPS	1600	79.00%	16(48)
14	ANPARA	1630	91.83%	9(21)
15	SINGRAULI STPS	2000	94.24%	4(13)
16	KORBA STPS	2100	95.07%	2(10)
17	RAMAGUNDEM STPS	2100	86.43%	12(32)
18	CHANDARPUR	2340	82.53%	14(43)
		Mean	88.16%	
		Mean all	80.84%	

Table F.2. Capacity Wise Ranking of the Plants for the Year 2000-01

Sno.	STATION (UPTO 250 MW)	CAP (MW)	Tech Eff.	Rank (Overall Rank)
1	NELLORE	30	88.40%	7(38)
2	PARAS	58	95.77%	3(4)
3	RAMAGUNDEM - B	62.5	96.68%	2(3)
4	NEW COSSIPORE	130	76.57%	12(61)
5	RAJGHAT	135	93.91%	4(9)
6	SOUTHERN REPL	135	80.14%	10(56)
7	**FARIDABAD EXTN.**	**165**	**96.75%**	**1(2)**
8	KUTCH LIGNITE	215	85.60%	8(47)
9	MUZAFFARPUR	220	62.84%	13(74)
10	PARICHA	220	82.14%	9(51)
11	BONGAIGAON	240	37.84%	14(77)
12	SIKKA REPL	240	90.68%	5(22)
13	TITAGARH	240	88.87%	6(34)
14	I.P. STATION	247.5	79.61%	11(57)
		Mean	**82.56%**	

Sno.	STATION (250 – 500 MW)	CAP (MW)	Tech Eff.	Rank (Overall Rank)
1	PANKI	274	88.10%	9(39)
2	AMAR KANTAK	290	85.99%	13(45)
3	BARAUNI	310	56.27%	24(76)
4	DURGAPUR	350	74.69%	18(63)
5	HARDUAGANJ B	385	83.80%	15(50)
6	**A.E.CO. & SABARMATI**	**390**	**95.29%**	**1(5)**
7	DURGAPUR D.P.L.	390	73.63%	19(66)
8	KORBA EAST	400	91.87%	5(17)
9	BAKRESHWAR	420	75.65%	17(62)
10	BHATINDA EXT.	420	95.10%	2(6)
11	I.B. VALLEY	420	89.93%	8(27)
12	KHAPARKHEDA II	420	91.78%	6(18)
13	MEJIA	420	68.33%	22(71)
14	RAYALSEEMA	420	92.94%	3(10)
15	TENUGHAT	420	86.78%	11(43)

16	BHATINDA	440	91.69%	7(19)
17	TANDA	440	70.55%	21(70)
18	ENNORE	450	83.91%	14(49)
19	TALCHER	460	92.10%	4(15)
20	BHUSAWAL	478	86.68%	12(44)
21	SANTALDIH	480	62.72%	23(75)
22	BUDGE BUDGE	500	73.26%	20(67)
23	DHANU	500	87.35%	10(40)
24	SURATGARH	500	81.47%	16(54)
		Mean	82.49%	

Sno.	STATION (500-750 MW)	CAP (MW)	Tech Eff.	Rank(Overall Rank)
1	BANDEL	530	66.41%	7(73)
2	NEYVELI-I	600	97.57%	1(1)
3	NORTH MADRAS	630	88.84%	3(35)
4	PANIPAT	650	87.24%	4(41)
5	PARLI	690	86.88%	5(42)
6	BADARPUR	705	92.90%	2(11)
7	CHANDRAPURA	750	68.01%	6(72)
		Mean	83.98%	

Sno.	STATION (750-1000 MW)	CAP (MW)	Tech Eff.	Rank(Overall Rank)
1	PATRATU	770	82.13%	10(52)
2	BOKARO B	805	76.64%	13(60)
3	BIRSINGHPUR	840	84.87%	9(48)
4	DADRI	840	92.45%	3(13)
5	KAHALGAON	840	80.70%	12(55)
6	KORBA-WEST	840	89.50%	6(29)
7	METTUR	840	90.96%	4(20)
8	UNCHAHAR	840	94.09%	2(8)
9	KOTA	850	94.38%	1(7)
10	UKAI THERMAL	850	88.74%	7(37)
11	GANDHI NAGAR	870	71.49%	14(69)
12	NASIK	910	82.04%	11(53)

13	RIHAND STPS	1000	90.54%	5(24)
14	TALCHER STPS	1000	85.93%	8(46)
		Mean	86.03%	

Sno.	STATION (1000 MW & above)	CAP (MW)	Tech Eff.	Rank(Overall Rank)
1	RAICHUR	1050	89.13%	12(33)
2	TUTICORIN	1050	92.06%	3(16)
3	KORADI	1080	77.97%	15(59)
4	SATPURA	1142.5	90.94%	4(21)
5	KOTHAGUDEM	1170	92.39%	2(14)
6	KOLAGHAT	1260	73.97%	17(65)
7	ROPAR	1260	92.62%	1(12)
8	VIJAYAWADA	1260	90.57%	5(23)
9	VINDHYACHAL STPS	1260	89.18%	11(32)
10	OBRA THERMAL	1442	74.41%	16(64)
11	NEYVELI-II	1470	90.34%	6(25)
12	WANAKBORI	1470	89.95%	7(26)
13	FARAKKA STPS	1600	72.80%	18(68)
14	ANPARA	1630	89.74%	8(28)
15	SINGRAULI STPS	2000	89.32%	9(30)
16	KORBA STPS	2100	88.82%	13(36)
17	RAMAGUNDEM STPS	2100	89.26%	10(31)
18	CHANDARPUR	2340	78.97%	14(58)
		Mean	86.25%	
		Mean all	84.16%	

Table F.3. Capacity Wise Ranking of the Plants for the Year 2001-02

Sno.	STATION (UPTO 250 MW)	CAP (MW)	Tech Eff.	Rank(Overall Rank)
1	NELLORE	30	94.27%	5(12)
2	PARAS	58	96.29%	4(5)
3	RAMAGUNDEM - B	62.5	96.95%	3(4)
4	NEW COSSIPORE	130	66.84%	13(73)
5	RAJGHAT	135	97.29%	2(2)
6	SOUTHERN REPL	135	74.14%	11(68)
7	FARIDABAD EXTN.	165	97.35%	1(1)
8	KUTCH LIGNITE	215	92.61%	6(22)
9	MUZAFFARPUR	220	59.45%	14(76)
10	PARICHA	220	91.72%	7(24)
11	BONGAIGAON	240	44.48%	15(77)
12	SIKKA REPL	240	91.69%	8(26)
13	TITAGARH	240	89.51%	9(38)
14	PANKI	242	83.39%	10(53)
15	I.P. STATION	247.5	70.92%	12(70)
		Mean	83.13%	

Sno.	STATION (250 – 500 MW)	CAP (MW)	Tech Eff.	Rank (Overall Rank)
1	AMAR KANTAK	290	83.03%	12(55)
2	BARAUNI	310	66.11%	19(74)
3	DURGAPUR	350	85.22%	10(50)
4	HARDUAGANJ B	385	76.88%	16(65)
5	A.E.CO. & SABARMATI	390	95.98%	1(6)
6	DURGAPUR (D.P.L.)	390	76.99%	15(64)
7	KORBA EAST	400	90.31%	7(34)
8	BHATINDA EXT.	420	93.52%	5(17)
9	I.B. VALLEY	420	86.86%	9(44)
10	RAYALSEEMA	420	95.17%	2(9)
11	TENUGHAT	420	78.37%	14(63)
12	BHATINDA	440	94.19%	3(13)
13	TANDA	440	84.94%	11(51)
14	ENNORE	450	73.11%	17(69)

15	TALCHER	460	94.16%	4(14)
16	BHUSAWAL	478	87.84%	8(40)
17	SANTALDIH	480	67.48%	18(71)
18	BUDGE BUDGE	500	81.52%	13(58)
19	DHANU	500	91.37%	6(30)
		Mean	**84.37%**	

Sno.	STATION (500-750 MW)	CAP (MW)	Tech Eff.	Rank(Overall Rank)
1	BANDEL	530	65.16%	10(75)
2	**NEYVELI-I**	**600**	**97.13%**	**1(3)**
3	BAKRESHWAR	630	86.51%	6(46)
4	BOKARO	630	87.63%	4(41)
5	MEJIA	630	82.36%	7(57)
6	NORTH CHENNAI	630	89.93%	3(37)
7	PARLI	690	86.87%	5(43)
8	BADARPUR	705	94.30%	2(11)
9	CHANDRAPURA	750	78.86%	8(62)
10	SURATGARH	750	67.26%	9(72)
		Mean	**83.60%**	

Sno.	STATION (750-1000 MW)	CAP (MW)	Tech Eff.	Rank(Overall Rank)
1	PATRATU	770	79.59%	15(61)
2	BIRSINGHPUR	840	87.08%	9(42)
3	DADRI	840	91.64%	6(27)
4	**KAHALGAON**	**840**	**95.52%**	**1(7)**
5	KHAPARKHEDA II	840	84.73%	12(52)
6	KORBA-WEST	840	90.45%	8(33)
7	METTUR	840	92.90%	4(20)
8	UNCHAHAR	840	93.71%	3(15)
9	KOTA	850	95.50%	2(8)
10	UKAI THERMAL	850	92.20%	5(23)
11	PANIPAT	860	85.51%	11(49)
12	GANDHI NAGAR	870	81.44%	13(59)
13	NASIK	910	85.55%	10(48)

14	RIHAND STPS	1000	91.23%	7(32)
15	TALCHER STPS	1000	81.40%	14(60)
		Mean	88.56%	

Sno.	STATION (1000 MW & above)	CAP (MW)	Tech Eff.	Rank(Overall Rank)
1	TUTICORIN	1050	93.56%	2(16)
2	KORADI	1080	86.14%	14(47)
3	SATPURA	1142.5	88.96%	12(39)
4	KOTHAGUDEM	1170	93.34%	3(18)
5	KOLAGHAT	1260	74.87%	18(67)
6	RAICHUR	1260	91.26%	9(31)
7	ROPAR	1260	95.02%	1(10)
8	VIJAYAWADA	1260	93.15%	4(19)
9	OBRA THERMAL	1442	75.66%	17(66)
10	NEYVELI-II	1470	92.81%	5(21)
11	WANAKBORI	1470	91.69%	6(25)
12	FARAKKA STPS	1600	83.26%	15(54)
13	ANPARA	1630	91.41%	8(29)
14	SINGRAULI STPS	2000	89.94%	11(36)
15	KORBA STPS	2100	91.47%	7(28)
16	RAMAGUNDEM STPS	2100	90.21%	10(35)
17	VINDHYACHAL STPS	2260	86.73%	13(45)
18	CHANDARPUR	2340	83.00%	16(56)
		Mean	88.47%	
		Mean all	85.80%	

Table F.4. Capacity Wise Ranking of the Plants for the Year 2002-03

Sno.	STATION (UPTO 250 MW)	CAP (MW)	Tech Eff.	Rank(Overall Rank)
1	NELLORE	30	78.40%	9(57)
2	PARAS	58	93.52%	4(21)
3	RAMAGUNDEM - B	62.5	96.37%	2(9)
4	NEW COSSIPORE	130	63.12%	13(71)
5	RAJGHAT	135	92.02%	5(30)
6	SOUTHERN REPL	135	89.89%	7(39)
7	**FARIDABAD EXTN.**	**165**	**98.90%**	**1(2)**
8	KUTCH LIGNITE	215	77.89%	10(59)
9	MUZAFFARPUR	220	45.96%	14(76)
10	PARICHA	220	73.59%	11(66)
11	SIKKA REPL	240	94.06%	3(19)
12	TITAGARH	240	92.00%	6(31)
13	PANKI	242	83.56%	8(49)
14	I.P. STATION	247.5	72.86%	12(68)
		Mean	82.30%	

Sno.	STATION (250 – 500 MW)	CAP (MW)	Tech Eff.	Rank(Overall Rank)
1	AMAR KANTAK	290	77.38%	14(62)
2	BARAUNI	310	49.40%	19(75)
3	DURGAPUR	350	81.84%	10(52)
4	HARDUAGANJ B	385	71.17%	17(69)
5	**A.E.CO. & SABARMATI**	**390**	**99.37%**	**1(1)**
6	DURGAPUR (D.P.L.)	390	73.37%	16(67)
7	KORBA EAST	400	88.87%	8(40)
8	BHATINDA EXT.	420	94.10%	5(18)
9	I.B. VALLEY	420	77.54%	12(60)
10	RAYALSEEMA	420	97.89%	2(5)
11	TENUGHAT	420	76.19%	15(63)
12	BHATINDA	440	90.87%	7(34)
13	TANDA	440	94.76%	4(14)
14	ENNORE	450	77.43%	13(61)
15	TALCHER	460	93.35%	6(23)

16	BHUSAWAL	478	84.89%	9(45)
17	SANTALDIH	480	59.94%	18(73)
18	BUDGE BUDGE	500	78.45%	11(55)
19	DHANU	500	97.11%	3(7)
		Mean	82.31%	

Sno.	STATION (500-750 MW)	CAP (MW)	Tech Eff.	Rank(Overall Rank)
1	BANDEL	530	65.00%	8(70)
2	NEYVELI-I	600	98.62%	1(3)
3	BAKRESHWAR	630	84.68%	5(46)
4	BOKARO	630	78.44%	6(56)
5	MEJIA	630	77.98%	7(58)
6	NORTH CHENNAI	630	90.26%	3(38)
7	PARLI	690	87.27%	4(43)
8	BADARPUR	705	93.24%	2(24)
9	CHANDRAPURA	750	60.61%	9(72)
		Mean	81.79%	

Sno.	STATION (750-1000 MW)	CAP (MW)	Tech Eff.	Rank (Overall Rank)
1	PATRATU	770	55.79%	16(74)
2	BIRSINGHPUR	840	82.05%	15(51)
3	DADRI	840	90.54%	9(37)
4	KAHALGAON	840	91.63%	7(33)
5	KHAPARKHEDA II	840	90.67%	8(35)
6	KORBA WEST	840	94.83%	4(13)
7	METTUR	840	97.09%	3(8)
8	UNCHAHAR	840	94.16%	5(17)
9	KOTA	850	98.33%	1(4)
10	UKAI THERMAL	850	88.50%	10(41)
11	PANIPAT	860	97.22%	2(6)
12	GANDHI NAGAR	870	88.26%	11(42)
13	NASIK	910	83.76%	13(48)
14	RIHAND STPS	1000	92.24%	6(28)
15	SIMHADRI	1000	43.93%	17(77)

16	SURATGARH	1000	82.97%	14(50)
17	TALCHER STPS	1000	87.07%	12(44)
		Mean	85.83%	

Sno.	STATION (1000 MW & above)	CAP (MW)	Tech Eff.	Rank(Overall Rank)
1	TUTICORIN	1050	95.92%	2(11)
2	KORADI	1080	81.72%	16(54)
3	SATPURA	1142.5	91.73%	12(32)
4	KOTHAGUDEM	1170	93.37%	7(22)
5	KOLAGHAT	1260	73.77%	18(65)
6	RAICHUR	1260	94.24%	5(16)
7	ROPAR	1260	94.26%	4(15)
8	VIJAYAWADA	1260	94.85%	3(12)
9	OBRA THERMAL	1442	73.88%	17(64)
10	NEYVELI-II	1470	92.70%	9(26)
11	WANAKBORI	1470	96.07%	1(10)
12	FARAKKA STPS	1600	84.31%	14(47)
13	ANPARA	1630	92.11%	11(29)
14	SINGRAULI STPS	2000	92.38%	10(27)
15	KORBA STPS	2100	93.11%	8(25)
16	RAMAGUNDEM STPS	2100	93.75%	6(20)
17	VINDHYACHAL STPS	2260	90.64%	13(36)
18	CHANDARPUR	2340	81.72%	15(53)
		Mean	89.47%	
		Mean all	84.70%	

Table F.5. Capacity Wise Ranking of the Plants for the Year 2003-04

Sno.	STATION (UPTO 250 MW)	CAP (MW)	Tech Eff.	Rank(Overall Rank)
1	NELLORE	30	76.30%	9(64)
2	PARAS	58	97.70%	1(2)
3	RAMAGUNDAM B	62.5	97.31%	2(4)
4	NEWCOSSIPORE	130	80.09%	8(58)
5	RAJGHAT	135	95.64%	4(10)
6	SOUTHERN REPL.	135	89.28%	6(36)
7	FARIDABAD	165	95.89%	3(8)
8	KUTCH LIGNITE	215	75.03%	10(65)
9	MUZAFFARPUR	220	46.88%	14(77)
10	PARICHA	220	72.40%	12(68)
11	SIKKA	240	74.27%	11(67)
12	TITAGARH	240	91.59%	5(25)
13	PANKI	242	83.03%	7(53)
14	I.P.STATION	247.5	63.64%	13(74)
		Mean	**81.36%**	

Sno.	STATION (250 – 500 MW)	CAP (MW)	Tech Eff.	Rank(Overall Rank)
1	AMARKANTAK	290	69.92%	16(69)
2	BARAUNI	310	56.67%	19(75)
3	DURGAPUR	350	80.17%	14(57)
4	HARDUAGANJ	385	65.96%	17(72)
5	**AECO.& SABARMATI**	**390**	**97.60%**	**1(3)**
6	DURGAPUR (DPL)	390	82.67%	13(55)
7	KORBA EAST	400	91.98%	6(22)
8	BHATINDA EXT.	420	91.92%	7(23)
9	I.B. VALLEY	420	88.21%	10(40)
10	RAYALSEEMA	420	92.16%	5(21)
11	TENUGHAT	420	85.04%	11(48)
12	BHATINDA	440	90.57%	8(32)
13	TANDA	440	94.27%	4(15)
14	ENNORE	450	76.34%	15(63)
15	TALCHER	460	96.50%	2(6)

16	BHUSAWAL	478	90.45%	9(33)
17	SANTALDIH	480	63.85%	18(73)
18	BUDGE BUDGE	500	84.14%	12(50)
19	DHANU	500	95.79%	3(9)
		Mean	83.91%	

Sno.	STATION (500-750 MW)	CAP (MW)	Tech Eff.	Rank (Overall Rank)
1	BANDEL	530	66.06%	9(71)
2	**NEYVELI-I**	**600**	**98.50%**	**1(1)**
3	BAKRESHWAR	630	76.70%	7(62)
4	BOKARO	630	76.91%	6(61)
5	MEJIA(DVC)	630	87.76%	4(43)
6	NORTH CHENNAI	630	88.73%	3(38)
7	PARLI	690	87.39%	5(45)
8	BADARPUR	705	90.57%	2(31)
9	CHANDRAPUR(DVC)	750	68.51%	8(70)
		Mean	82.35%	

Sno.	STATION (750-1000 MW)	CAP (MW)	Tech Eff.	Rank(Overall Rank)
1	PATRATU	770	49.25%	14(76)
2	BIRSINGPUR	840	82.62%	12(56)
3	DADRI	840	87.93%	9(42)
4	**KAHALGAON**	**840**	**96.87%**	**1(5)**
5	KHAPERKHEDA	840	91.22%	7(28)
6	KORBA WEST	840	91.23%	6(27)
7	METTUR	840	95.94%	2(7)
8	UNCHAHAR	840	94.00%	5(17)
9	UKAI	850	87.71%	10(44)
10	PANIPAT	860	95.56%	3(11)
11	GANDHINAGAR	870	78.20%	13(60)
12	NASIK	910	85.96%	11(46)
13	RIHAND STPS	1000	90.76%	8(30)
14	SIMHADRI	1000	94.54%	4(14)
		Mean	87.27%	

Sno.	STATION (1000MW & above)	CAP (MW)	Tech Eff.	Rank (Overall Rank)
1	KOTA	1045	78.97%	20(59)
2	TUTICORIN	1050	94.78%	1(12)
3	KORADI	1080	85.42%	15(47)
4	SATPURA	1142.5	88.00%	14(41)
5	KOTHAGUDEM	1170	93.11%	4(18)
6	SURATGARH	1250	83.66%	17(51)
7	KOLAGHAT	1260	83.36%	18(52)
8	ROPAR	1260	91.41%	8(26)
9	VIJAYWADA	1260	92.43%	5(19)
10	WANAKBORI	1260	89.36%	11(35)
11	OBRA	1442	74.55%	21(66)
12	NEYVELI ST II	1470	94.76%	2(13)
13	RAICHUR	1470	92.39%	6(20)
14	TALCHER STPS	1500	84.91%	16(49)
15	FARAKKA STPS	1600	88.92%	12(37)
16	ANPARA	1630	90.01%	10(34)
17	SINGRAULI STPS	2000	91.15%	9(29)
18	KORBA STPS	2100	94.17%	3(16)
19	RAMAGUNDAM STPS	2100	91.72%	7(24)
20	VINDHYACHAL	2260	88.60%	13(39)
21	CHANDRAPUR	2340	82.89%	19(54)
		Mean	**88.31%**	
		Mean all	**85.07%**	

Table F.6. Capacity Wise Ranking of the Plants for the Year 2004-05

Sno.	STATION (UPTO 250 MW)	CAP (MW)	Tech Eff.	Rank(Overall Rank)
1	NELLORE	30	80.68%	9(59)
2	PARAS	62.5	96.59%	2(5)
3	RAMAGUNDEM - B	62.5	96.89%	1(4)
4	RAJGHAT	135	83.72%	8(56)
5	SOUTH. REPL.	135	94.97%	4(13)
6	FARIDABAD EXTN.	180	92.97%	5(23)
7	KUTCH LIGNITE	215	78.22%	10(61)
8	PARICHA	220	86.45%	7(51)
9	SIKKA REP.	240	88.33%	6(46)
10	TITAGARH	240	95.63%	3(8)
11	I.P.STATION	247.5	76.61%	11(64)
		Mean	88.28%	

Sno.	STATION (250 – 500 MW)	CAP (MW)	Tech Eff.	Rank(Overall Rank)
1	PANKI	252	76.79%	16(63)
2	AMAR KANTAK	300	74.56%	17(68)
3	BARAUNI	310	53.63%	20(75)
4	DURGAPUR	350	82.92%	14(58)
5	A.E.CO. & SABARMATI	390	96.94%	1(3)
6	DURGAPUR (D.P.L.)	395	89.26%	13(43)
7	HARDUAGANJ B	400	62.00%	19(74)
8	BHATINDA EXT.	420	93.51%	7(21)
9	I.B.VALLEY	420	92.34%	8(25)
10	RAYALSEEMA	420	91.18%	10(31)
11	TENUGHAT	420	94.97%	4(12)
12	BHATINDA	440	91.69%	9(28)
13	KORBA EAST	440	94.90%	5(14)
14	TANDA	440	96.53%	2(6)
15	ENNORE	450	77.07%	15(62)
16	TALCHER	470	95.98%	3(7)
17	SANTALDIH	480	64.71%	18(72)
18	BHUSAWAL	482.5	90.64%	11(34)

19	BUDGE BUDGE	500	90.11%	12(37)
20	DHANU	500	94.29%	6(18)
		Mean	85.20%	

Sno.	STATION (500-750 MW)	CAP (MW)	Tech Eff.	Rank(Overall Rank)
1	BANDEL	540	70.35%	8(71)
2	**NEYVELI-I**	**600**	**98.52%**	**1(1)**
3	BAKRESWAR	630	75.97%	7(65)
4	BOKARO B	630	88.24%	6(48)
5	MEJIA	630	89.45%	5(41)
6	NORTH CHENNAI	630	90.82%	4(33)
7	PARLI	690	94.56%	2(16)
8	BADARPUR	720	91.13%	3(32)
		Mean	87.38%	

Sno.	STATION (750-1000 MW)	CAP (MW)	Tech Eff.	Rank(Overall Rank)
1	CHANDRAPURA	780	80.30%	13(60)
2	BIRSINGHPUR	840	88.91%	8(44)
3	DADRI (NCTPP)	840	91.39%	7(30)
4	**KAHALGAON**	**840**	**97.34%**	**1(2)**
5	KHAPARKHEDA II	840	91.43%	6(29)
6	KORBA-WEST	840	87.33%	10(49)
7	METTUR	840	94.56%	4(17)
8	PATRATU	840	63.47%	15(73)
9	UNCHAHAR	840	94.78%	3(15)
10	UKAI	850	85.85%	11(53)
11	PANIPAT	860	95.43%	2(9)
12	GANDHI NAGAR	870	75.28%	14(67)
13	NASIK	910	83.84%	12(55)
14	RIHAND	1000	88.78%	9(45)
15	SIMHADRI	1000	94.25%	5(19)
		Mean	87.53%	

Sno.	STATION (1000 MW & above)	CAP (MW)	Tech Eff.	Rank(Overall Rank)
1	KOTA	1045	94.23%	3(20)
2	TUTICORIN	1050	92.64%	5(24)
3	KORADI	1100	86.57%	15(50)
4	SATPURA	1143	90.10%	10(38)
5	KOTHAGUDEM	1170	94.98%	2(11)
6	SURATGARH	1250	89.88%	11(39)
7	KOLAGHAT	1260	83.18%	18(57)
8	ROPAR	1260	92.04%	7(27)
9	VIJAYWADA	1260	90.35%	8(35)
10	NEYVELI ST II	1470	92.08%	6(26)
11	RAICHUR	1470	89.75%	12(40)
12	WANAKBORI	1470	89.36%	13(42)
13	OBRA	1500	72.32%	21(70)
14	FARAKKA STPS	1600	93.34%	4(22)
15	ANPARA	1630	86.02%	16(52)
16	SINGRAULI STPS	2000	90.12%	9(36)
17	**KORBA STPS**	**2100**	**95.22%**	**1(10)**
18	VINDHYACHAL STPS	2260	88.28%	14(47)
19	CHANDRAPUR	2340	85.34%	17(54)
20	TALCHER STPS	2500	72.70%	20(69)
21	RAMAGUNDEM STPS	2600	75.38%	19(66)
		Mean	**87.80%**	
		Mean all	**87.08%**	

Table F.7. Capacity Wise Ranking of the Plants for the Year 2005-06

Sno.	STATION (UPTO 250 MW)	CAP (MW)	Tech Eff.	Rank (Overall Rank)
1	NELLORE	30	76.61%	9(62)
2	PARAS	62.5	96.63%	2(6)
3	RAMAGUNDAM	62.5	86.60%	6(44)
4	RAJGHAT	135	73.98%	10(65)
5	SOUTH GEN.	135	94.59%	4(15)
6	FARIDABAD	180	85.26%	7(49)
7	KUTCH LIG.	215	98.45%	1(1)
8	PANKI	220	69.87%	12(69)
9	PARICHA	220	81.15%	8(56)
10	SIKKA	240	87.83%	5(37)
11	TITAGARH	240	95.42%	3(10)
12	I.P. STATION	247.5	69.98%	11(68)
		Mean	84.70%	

Sno.	STATION (250 - 500 MW)	CAP (MW)	Tech Eff.	Rank (Overall Rank)
1	AMARKANTAK	300	66.50%	17(72)
2	BARAUNI	320	42.17%	20(77)
3	DURGAPUR	350	74.31%	15(64)
4	A.E.CO. & SABARMATI	390	97.93%	1(3)
5	DURGAPUR (D.P.L.)	395	84.89%	12(51)
6	HARDUAGANJ*	400	60.66%	19(75)
7	BHATINDA EXT.	420	92.51%	8(20)
8	I.B. VALLEY	420	86.95%	11(41)
9	NEYVELI FST EXT	420	93.89%	7(18)
10	RAYALSEEMA	420	83.37%	13(54)
11	TENUGHAT	420	77.97%	14(60)
12	BHATINDA	440	87.07%	10(40)
13	KORBA EAST	440	94.93%	5(13)
14	TANDA	440	97.22%	2(4)
15	ENNORE	450	69.60%	16(70)
16	TALCHER	470	95.36%	4(11)
17	SANTALDIH	480	61.07%	18(73)

18	BHUSAWAL	482.5	92.05%	9(23)
19	BUDGE BUDGE	500	95.71%	3(8)
20	DAHANU	500	94.53%	6(16)
		Mean	82.43%	

Sno.	STATION (500-750 MW)	CAP (MW)	Tech Eff.	Rank(Overall Rank)
1	BANDEL	540	60.93%	8(74)
2	NEYVELI-I	600	97.13%	1(5)
3	BAKRESWAR	630	78.94%	5(59)
4	BOKARO	630	75.36%	6(63)
5	NORTH CHENNAI	630	90.28%	4(31)
6	GANDHINAGAR	660	73.15%	7(66)
7	PARLI	690	91.30%	3(27)
8	BADARPUR	720	91.83%	2(24)
		Mean	82.37%	

Sno.	STATION (750-1000 MW)	CAP (MW)	Tech Eff.	Rank(Overall Rank)
1	CHANDRAPURA	780	73.13%	12(67)
2	BIRSINGPUR	840	82.86%	11(55)
3	DADRI	840	91.54%	4(26)
4	KAHALGAON	840	97.97%	1(2)
5	KHAPERKHEDA	840	87.83%	6(36)
6	KORBA WEST	840	87.35%	7(39)
7	MEJIA	840	85.84%	8(47)
8	METTUR	840	93.42%	3(19)
9	PATRATU	840	60.12%	13(76)
10	UNCHAHAR	840	95.23%	2(12)
11	UKAI	850	84.29%	10(52)
12	NASIK	910	85.80%	9(48)
13	SIMHADRI	1000	88.33%	5(34)
		Mean	85.67%	

Sno.	STATION (1000 MW & above)	CAP (MW)	Tech Eff.	Rank(Overall Rank)
1	KOTA	1045	95.55%	2(9)
2	TUTICORIN	1050	91.20%	8(28)
3	KORADI	1100	86.33%	18(46)
4	SATPURA	1142.5	91.58%	7(25)
5	TROMBAY	1150	77.44%	23(61)
6	KOTHAGUDEM	1180	86.64%	16(43)
7	SURATGARH	1250	92.14%	6(22)
8	KOLAGHAT	1260	79.19%	22(58)
9	ROPAR	1260	92.19%	5(21)
10	VIJAYAWADA	1260	86.85%	15(42)
11	WANAKBORI	1260	90.03%	11(32)
12	PANIPAT	1360	90.86%	10(30)
13	NEYVELI ST II	1470	88.21%	13(35)
14	RAICHUR	1470	88.50%	12(33)
15	OBRA	1500	67.94%	24(71)
16	RIHAND	1500	80.86%	21(57)
17	FARAKKA STPS	1600	94.66%	3(14)
18	ANPARA	1630	87.39%	14(38)
19	SINGRAULI	2000	93.99%	4(17)
20	KORBA STPS	2100	95.80%	1(7)
21	VINDHYACHAL	2260	90.93%	9(29)
22	CHANDRAPUR	2340	85.09%	19(50)
23	RAMAGUNDAM STP	2600	86.39%	17(45)
24	TALCHER STPS	3000	83.76%	20(53)
		Mean	**87.65%**	
		Mean all	**84.95%**	

Table F.8. Capacity Wise Ranking of the Plants for the Over All Performance

Sno.	STATION (UPTO 250 MW)	CAP (MW)	Over all TE	Rank(Overall Rank)
1	NELLORE	30	80.61%	9 (55)
2	PARAS	62.5	95.67%	1 (3)
3	RAMAGUNDEM - B	62.5	95.35%	2 (4)
4	RAJGHAT	135	90.67%	5 (28)
5	SOUTHERN REPL.	135	84.64%	7 (47)
6	NEWCOSSIPORE	160	73.31%	11 (71)
7	FARIDABAD EXTN.	180	94.85%	3 (5)
8	KUTCH LIGNITE	215	84.55%	8 (48)
9	MUZAFFARPUR	220	52.63%	13 (79)
10	PARICHA	220	79.33%	10 (59)
11	BONGAIGAON	240	40.70%	14 (80)
12	SIKKA REP.	240	87.13%	6 (43)
13	TITAGARH	240	91.06%	4 (24)
14	I.P.STATION	247.5	72.29%	12 (72)
		Mean	**80.20%**	

Sno.	STATION (250 - 500 MW)	CAP (MW)	Tech Eff.	Rank(Overall Rank)
1	PANKI	252	78.48%	14 (61)
2	AMAR KANTAK	300	76.99%	17 (68)
3	BARAUNI	320	53.60%	21 (78)
4	DURGAPUR	350	79.23%	13 (60)
5	A.E.CO. & SABARMATI	390	96.84%	1 (2)
6	DURGAPUR (D.P.L.)	395	78.20%	16 (63)
7	BHATINDA EXT.	420	91.35%	7 (23)
8	I.B.VALLEY	420	87.74%	10 (40)
9	NEYVELI FST EXT	420	93.89%	2 (7)
10	RAYALSEEMA	420	92.60%	4 (14)
11	TENUGHAT	420	82.72%	12 (52)
12	BHATINDA	440	90.66%	8 (29)
13	KORBA EAST	440	91.84%	6 (19)
14	TANDA	440	85.08%	11 (45)
15	ENNORE	450	75.51%	18 (69)

16	HARDUAGANJ B	450	70.76%	19 (74)
17	TALCHER	470	92.98%	3 (13)
18	SANTALDIH	480	63.75%	20 (77)
19	BHUSAWAL	482.5	88.49%	9 (38)
20	BUDGE BUDGE	500	78.26%	15 (62)
21	DHANU	500	92.39%	5 (15)
		Mean	82.92%	

Sno.	STATION (500 - 750 MW)	CAP (MW)	Tech Eff.	Rank(Overall Rank)
1	BANDEL	540	65.37%	7 (76)
2	NEYVELI-I	600	97.97%	1 (1)
3	BAKRESWAR	630	79.74%	5 (57)
4	BOKARO	630	79.54%	6 (58)
5	NORTH CHENNAI	630	89.33%	3 (37)
6	PARLI	690	88.19%	4 (39)
7	BADARPUR	720	92.04%	2 (16)
		Mean	84.60%	

Sno.	STATION (750 - 1000 MW)	CAP (MW)	Tech Eff.	Rank(Overall Rank)
1	CHANDRAPURA	780	71.04%	13 (73)
2	BIRSINGHPUR	840	83.61%	9 (49)
3	DADRI	840	91.70%	3 (21)
4	KAHALGAON	840	89.84%	6 (33)
5	KHAPARKHEDA II	840	89.86%	5 (32)
6	KORBA WEST	840	90.05%	4 (31)
7	MEJIA	840	77.22%	11 (66)
8	METTUR	840	93.14%	2 (11)
9	PATRATU	840	65.89%	14 (75)
10	UNCHAHAR	840	94.55%	1 (6)
11	UKAI THERMAL	850	87.19%	7 (42)
12	GANDHI NAGAR	870	77.02%	12 (67)
13	NASIK	910	84.65%	8 (46)
14	SIMHADRI	1000	80.26%	10 (56)
		Mean	84.00%	

Sno.	STATION (1000 MW & above)	CAP (MW)	Tech Eff.	Rank(Overall Rank)
1	KOTA	1045	93.25%	3 (10)
2	TUTICORIN	1050	93.46%	1 (8)
3	KORADI	1100	83.33%	18 (50)
4	SATPURA	1142.5	90.94%	9 (25)
5	TROMBAY	1150	77.44%	23 (65)
6	KOTHAGUDEM	1180	91.80%	7 (20)
7	SURATGARH	1250	81.44%	20 (53)
8	KOLAGHAT	1260	77.86%	22 (64)
9	ROPAR	1260	93.04%	4 (12)
10	VIJAYWADA	1260	91.85%	6 (18)
11	PANIPAT	1360	90.73%	10 (26)
12	NEYVELI ST II	1470	91.85%	5 (17)
13	RAICHUR	1470	90.70%	11 (27)
14	WANAKBORI	1470	90.30%	12 (30)
15	RIHAND STPS	1500	89.72%	14 (35)
16	OBRA THERMAL	1550	73.42%	24 (70)
17	FARAKKA STPS	1600	85.18%	17 (44)
18	ANPARA	1630	89.79%	13 (34)
19	SINGRAULI STPS	2000	91.59%	8 (22)
20	KORBA STPS	2100	93.38%	2 (9)
21	VINDHYACHAL STPS	2260	89.60%	15 (36)
22	CHANDRAPUR	2340	82.79%	19 (51)
23	RAMAGUNDEM STPS	2600	87.59%	16 (41)
24	TALCHER STPS	3000	80.72%	21 (54)
		Mean	**87.57%**	
		ALL Mean	**84.66%**	

LIST OF PUBLICATIONS

- Soni, M.,S., Avinash and Ramachandran, M., 2006. Study of Opportunities for India as a CDM Player, Energy and Fuel Users' Journal, Vol. LVI, pp. 7-14.
- Soni, M.,S., Kadam, S.,M., and Ramachandran, M., 2006. Energy Saving Measures for Thermo-Mechanical Components in Thermal Power Plants, Energy and Fuel Users' Journal, Vol. LV, pp. 19-28.
- Soni, M.,S., Susruthan., K. and Ramachandran, M., 2006. An Overview of Indian Power Scenario and Potential of Greenhouse Gas Mitigation Technologies, National Conference on Energy and Environment (NCEE-06), 25th -26th November 2006, Jaipur Engineering College, Jaipur, India.

BRIEF BIOGRAPHY OF THE CANDIDATE

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Manojkumar Surajkaranji Soni is B.E. in Mechanical Engineering and M.E. in Thermal Power Engineering from Amravati University, Maharashtra. He rendered his services as a Lecturer in Mechanical Engineering Department of Visvesvaraya National Institute of Technology, Nagpur, Maharashtra for seven years. He took up teaching and research in Energy Efficiency from 2002 at Birla Institute of Technology and Science (BITS), Pilani. He has also taught various courses in on campus and off campus programmes of BITS, Pilani in the area of Energy Management and Mechanical Engineering. He is the Coordinator of BS Power Engineering program which is the collaborative programme of BITS Pilani with five power majors of India. He is also involved in conducting a number of training programmes to professionals at BITS, Pilani in the area of energy planning, energy conservations and energy management.

BRIEF BIOGRAPHY OF THE SUPERVISOR

Prof. Dr. M. Ramachandran

Prof. Dr. M. Ramachandran, did his Ph.D. in Renewable Energy Management from the Indian Institute of Science, Bangalore. He served the Renewable Energy field in India in various capacities for the past two decades. He set up the Centre for Renewable Energy and Environment Development (CREED) at BITS, Pilani for implementing sponsored projects in Renewable Energy and also developed courses in Renewable Energy, Energy Efficiency and Technology Management and supervised several student projects in these areas. He has published extensively on Energy Efficiency, Renewable Energy Planning, and Demand Side Management. He is actively engaged in energy education, resource development and training activities in the field of renewable energy. His areas of research are integrated renewable energy systems, energy planning and policy, energy efficiency, energy technology and demand side management.

Presently, he is the Director of the BITS, Pilani-Dubai Campus at Dubai, UAE.