Performance Evaluation and Efficiency Analysis of the Coal Fired Thermal Power Plants in India

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Abstract

Power is the key input for most of the industrial, agricultural and social establishments. Indian economy, which till recently grew at a faster rate of above 9 per cent, faces power shortage. Several structural as well as institutional reforms have been undertaken by the Government of India to mitigate the perennial problem of power shortage. Despite the regular additions of power generating capacity, the gap between the generation of power and its demand has always been widening. This paper attempts to investigate whether this gap can be reduced through making the existing power plants more efficient. Efficient power generation is expected to make more power available at a lower cost for economic and other activities, which in turn shall make the country more competitive. The focus of the study is on the coal fired thermal power plants in the country. Thermal power in India accounts for about 64.6 per cent of the total power generation capacity. Out of which, the contribution of coal-fired plants has been 53.3 per cent. Data envelopment analysis (DEA) has been used to estimate the relative performance of the coal fired power-generating plants in India and explore the key determinants of the inefficient units.

Keywords: Data envelopment analysis (DEA), Performance evaluation, Power Generation, Coal fired thermal power plants.

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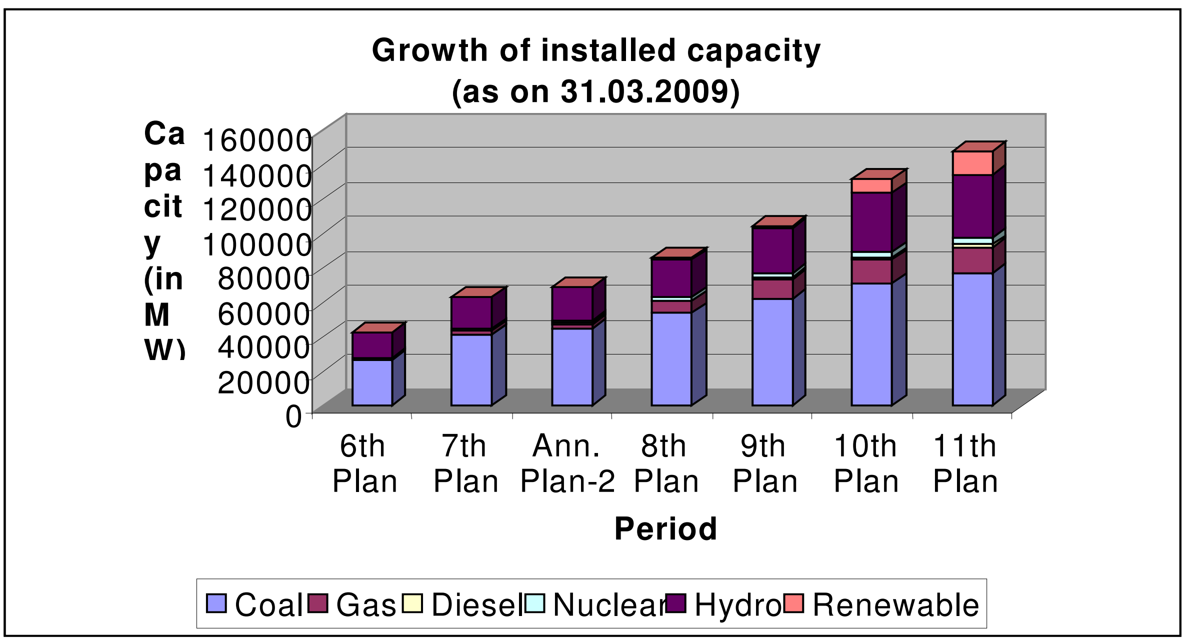
1. Introduction

India has an installed capacity to generate 1,47,965.41 MW of electricity along with the captive generation capacity of 19509.49 MW connected to the grid. Out of this, the thermal power contributes 93,725.24 MW (64.6%). Based on the type of primary fuel used, thermal power plants are of three types viz. coal based, gas based and diesel based. Currently the installed capacity of coal based, gas based and diesel fired thermal power plants is 77648.88MW, 14876.61MW and 1199.75MW, respectively (as on 31-03-2009, Source: Ministry of Power, Govt. of India Website, http://powermin.nic.in – last visited on 12-05-2009). The trend in the growth and composition of installed capacity is depicted in Figure-1. The coal based thermal power generating units dominate Indian power sector contributing to 53.3% of installed capacity and are managed in three sectors – state sector, comprising of the State Electricity Boards (SEBs) and their unbundled generation units; central sector, comprising of NTPC, Damodar Valley Corporation (DVC) and Neyveli Lignite; and private sector, comprising of Tata Power, Reliance Energy, CSES etc.



[Figure -1: Growth of Installed Capacity during the period 01-04-1980 to 31.03.2009]

The thermal power generation capacity is built over years and consists of units of different capacities ranging from 20MW to 500MW. The 660MW capacity units are being introduced in the central sector for the first time by NTPC. NTPC is the biggest operator in the country having an installed capacity of 30144MW from its 77 coal fired and 32 gas fired power generating units. The recent initiative of Government of India to enhance thermal capacity in the form of Ultra Mega Powers Projects (UMPP) are expected to have unit sizes of 800MW (http://powermin.nic.in – Last visited on 12-05-2009). Indian power generation sector is the fifth largest in the world and has generated 723.469 Billion Units with average cost of supply @Rs2.76 / unit during the year 2008-09.

The thermal power generating units primarily consume scarce and non-renewable fossil fuels. Excess consumption by one plant has the cascading effect of increasing the production cost of that unit as well as depriving other remaining plants of this limited natural resource. Indian power sector faces acute shortage of coal and as a result several units are shutdown. During 2005-06, power stations lost generations of 1653.5 MUs due to shortage of coal which further aggravated during 2008-09 resulting loss of generation of 9 Billion Units (up to Dec'2008). Reduction in the consumption of coal/ oil by one unit shall make available is to other units thereby reducing cost of electricity which being an input to most industrial and social process shall provide more competitiveness to their products / services. Power stations consume a portion of electricity generated to power the auxiliary equipments called Auxiliary Power (APC). For the year 2005-06 this varied from 5.59% to 16.23% with average of 8.44%. Any reduction in APC shall make more power available to the grid for fuelling the national economy. In this context, estimation of the productive efficiency of the power generating units is important as this gives an idea of the current level of productivity of the power generation process, the consumption levels of various inputs and directions as well as quantum of possible improvement possible. In this paper, attempt was made to quantitatively estimate the relative performance level of the power generation units based on multiple inputs and analyse the determinants of less efficient units. The rest of the paper is organized as follows: section 2 reviews the literature on the productivity studies in the power sector, multi criteria quantitative techniques used for the productivity measurement, Data Envelopment Analysis (DEA) and its applications, section 3 reviews the performance parameters of the plants under study and current approaches to performance evaluation followed by section 4 which explains the concepts of DEA and section 5 which focuses on data analysis and discussion. The last section, Chapter 6 details conclusions and the limitations of the current study and scope for further research.

2 Review of Literature:

'When you can measure what you are speaking about and express it in numbers, you know something about it' says Kelvin. Sumanth (1998) lists Measurement, Evaluation, Planning and Improvement as the four phases of a productivity process. Productivity measurement thus holds the key to any productivity management exercise. Increased productivity enhances the competitive advantages of a firm in the form of decreased product cost, improved product quality leading to improved market share and profit. Key to the productivity enhancement lies in identifying areas of potential productivity improvement.

Several techniques have been used to quantitatively estimate the productivity levels of various processes. The classic measure of productivity as the ratio of output to input, which does very well for the single input and output processes, fares badly with the increasing complexity of the modern day business, processes which in reality consumes multiple inputs to produce a variety of outputs. A production function is defined as a relationship between the maximal technically feasible output and the inputs needed to produce that output – Shephard (1970). Mishra (http://ssrn.com/abstract=1020577 – last visited on 20-05-2009) traces the history of production functions, which has been formulated over the years to unravel the underlying relationship between the inputs and outputs. Technical efficiency (TE) of a firm reflects its ability to minimize usage of inputs to produce a given amount of output. The firm, which uses the least input, is called technically efficient and has a TE score of 100%. Over the years Stochastic Frontier Analysis (SFA) and Data Envelopment Analysis (DEA) has emerged as the preferred quantitative techniques for performance measurement based on multiple input and output criteria. SFA is the result of three independent models proposed around same time in 1977 by Meeusen and van den Broeck (MB), Aigner, Lovell and Schimdt (ALS) and Battese and Corra (BC). SFA is a parametric method and requires assumption of a functional form of the productivity process and capable of handling stochastic error. The story of DEA dates back to Rhodes's PhD thesis which led to the publication of the CCR model in Cooper (1978). DEA is a linear programming based non-parametric method used to measure the relative performance level of homogenous firms called Decision Making Units (DMU) like banks, hospitals, municipalities etc. The initial (CCR) model without taking scales of operation into account was subsequently modified by incorporating variable return to scale in the BCC model by Banker (1984).

The basic DEA models has been augmented by a) Additive Model – which combines input and output orientations, b) Slack Based Measure – making the additive model unit invariant, c) Hybrid Model – unifying radial and non radial measures, d) Free Disposal Hull (FDH) model, e) Super Efficiency Model – ranking of efficient units, f) Models with Restricted Multipliers – to incorporate subjective assessments by way of weight restrictions, g) Non-controllable, Non-discretionary and Bounded Variable models.

DEA has been used with other tools like Regression, Principal Component Analysis (PCA) – Adler (2001), Adler(2009), Stochastic Frontier Analysis (SFA) – Li (1998), Huan and Li (2002), Kuosmanen (2006), Fuzzy logic – Kao (2000) and Guo (2001), Artificial Neural Networks (ANN) - Wu (2004), Celebi (2008) and Emrouznejad (2009) over the years to take care of the diversities and complexities in the real world problems. The application of DEA from performance measurement has been expanded to other areas like policy studies - Gurgen(2006) , Iimi(2003), Delmas (2003) , Toba(2003) and Arocena (1999), Benchmarking , Checking a virtual merger, Comparison of business models, Site Selections etc. - Cooper (2007). Emrouznejad (2001) provides an extensive collection of DEA literature.

Several studies have been conducted world wide to estimate the performance level of electric power industry. Golany *et al.* (1994) studied the relative performance level of thermal power plants in Israel. Chitkara (1999) and Arocena (1999) attempted to measure the efficiency of power generation units in India and Spain respectively. Diewert and Nakamura (1999) examined 77 plants in 28 countries funded by World Bank for benchmarking and the measurement of best practice efficiency. Olatubi (2000), Lam (2001) and Sueyoshi (2001) studied the performance levels of electric utilities in US, China and Japan respectively.

Shanmugam (2005) analyzed the efficiency of 56 coal based thermal power generation stations in India during the period 1994-95 to 2001-02 using Stochastic Frontier Analysis (SFA). They have used the capital employed, specific coal consumption, specific secondary oil consumption, auxiliary power consumption and power generated as variables and found that the technical efficiency varies from 46% to 96% and is time invariant. They have also found that 22 out of 56 power stations analyzed have TE below 70%. Nag (2006) developed a framework to estimate the carbon base line for power generation in India till the end of 11th five-year plan period (2010-11) based on the Specific Coal Consumption (SCC) and APC. Dash, Behera and Rath (2008), while exploring alternative matrices for India's future power demand have observed that there is substantial scope for improvement of the performance of the thermal power plants and suggested for aggressive action plans for augmenting the current output levels.

3 Performance Parameters and Measurement Systems:

Coal based thermal power plants are capital intensive and takes almost 6 years from concept to commissioning. At the current level, the tentative cost of these units varies between Rs 40 to Rs 50 Million / MW (http://cea.nic.in – last visited on 20-05-2009). The key input in any performance measurement exercise of these plants should be the cost of capital. Since the capacities are built over years and cost of capital is not available for the many of the operational plants, installed capacity is taken as an indicator of capital. Shanmugam (2005) considered capacity as capital input. These plants primarily use coal and oil as fuels and electricity to power auxiliary equipments. The amount of coal and oil consumed to generate one unit (Kilo Watt Hour -KWH) of electricity are called Specific Coal Consumption (SCC) and Specific Fuel Oil Consumption (SFOC). APC is considered as a deemed input and is a part of the output. Other important inputs to the plants are maintenance expenditure, which includes employee costs, inventory costs and other costs. Since most of the power generating units are in the state sector, the employee costs, inventory costs, profit earned are either not computed separately or not available in the public domain.

The Operational Availability Factor (OAF) of a plant is the percentage of time a plant is available for generation during a period. OAF is arrived at by excluding the duration for which the plant is not available because of various outages. Cook (2005) categorized outages into 4 categories which are long duration planned maintenance – usually for major overhauls, short duration maintenance outage - for minor routine maintenance, unscheduled forced outage – due to equipment failure with some prior warning and sudden outages - forced outage without prior warning. In India the performance review by Central Electricity Authority (CEA - http://cea.nic.in) captures outages in two categories. While the Planned Maintenance (PM) includes planned outage and maintenance outage, the Forced Outage (FO) includes forced outage and sudden outage. FO ignites public opinion, interrupts business operations, and generally reflects negatively on the organization and should play a direct role in any measure of efficiency Cook (2005). In absence of explicit maintenance cost information, PM and FO figures can be considered as an indicator of the maintenance and opportunity costs. Since it is possible to reduce the APC, PM and FO figures by means appropriate managerial intervention in the form of improved operation and maintenance practices, and going by the argument of lower is the better for inputs, APC, PM and FO can be considered as deemed inputs like Capacity, SCC and SFOC.

The important output parameters of thermal power plants are the amount of electricity generated by a plant during a period in India this is usually measured in terms of Plant Load Factor (PLF) which is the ratio of actual generation to theoretical possible generation during a period which may be a day, month, quarter or a year.

Descriptive statistics of SCC, SFOC, APC, PM, FO and PLF is detailed in table-1.

a. Currently practice of performance evaluation of the thermal power units, is based on ratio analysis. In this method, ratio of an output to an input (PLF, OAF) or an input to an output (SCC, SFOC and APC) is computed and used as a performance indicator (PI). Various PIs like PLF, OAF, SCC, SFOC, APC, PM, FO etc are computed and indicated separately. While PIs provides useful information on the performance of a unit on individual pairs of inputs and outputs, they are problematic when used to gain an overall view of the unit's performance - Thanassoulis (1996). While ratios are easy to compute, which in part explains their wide appeal, their interpretation is problematic, especially when two or more ratios provide conflicting signals. Therefore ratio analysis is often criticized on the grounds of subjectivity, because an analyst must pick and choose ratios in order to assess the overall performance of a firm Malhotra (2008). To foster the competitive spirit amongst various power stations so as to encourage them to improve the operational performance, Govt. of India has introduced several award schemes for this sector formulated by CEA. Till 2003-04 separate award schemes were there for important operational parameters viz PLF, SFOC, and APC. From the year 2004-05, important operational parameters like specific fuel oil consumption, APC, peak PLF and SHR were included to calculate a composite score. In October 2008, CEA (2008) proposed to include design SHR in place of normative SHR in the performance calculation. The weight matrix decided are [0.50 0.15 0.15 0.20] for the performance parameter matrix [Peaking_PLF Station_Heat_Rate Specific_Fuel_Oil_Consumption Aux._Power_Consumption]. While this methodology of computing a unified performance index is quite simple and relatively easy, it raises a host of questions. Are the so-called efficient units truly efficient because of their performance parameters or purely because of favorable weight matrix? How much of the efficiency ratings are due to the weights and how much inefficiency is associated with the observations? Cooper [2007]. Should the weight matrix be decided a priori or it should be derived from the performance matrix.

4 **Data Envelopment Analysis (DEA):**

The primal version of DEA is called the multiplier version and involves discovering the optimal set of weights for the inputs and outputs that maximizes the efficiency of the DMU relative to other DMUs. The efficiency of a DMU which is defined as the ratio of the weighted sum of outputs to weighted sum of inputs is maximized such that, the efficiency of all other DMUs lie between 0 and 1. Maximizing the ratio involves fractional programming, which can either be achieved by maximizing the numerator or minimizing the denominator by setting the other to 1. For a set of N DMUs, consuming I inputs to produce J outputs, the multiplier version involving maximization of the weighted sum of outputs is represented as:

$$\max z = \sum_{j=1}^{J} v_{jm} y_{jm}$$

Subject to

$$\sum_{i=1}^{I} u_{im} x_{im} = 1$$

$$\sum_{j=1}^{J} v_{jm} y_{jn} - \sum_{i=1}^{I} u_{im} x_{in} \leq 0 \;;\; n = 1,2,K,N$$

$v_{jm}, u_{in} \geq \varepsilon$; i=1,2,K,I ; j= 1,2,K,J

Where

x_{im} and y_{jm} are the *i*th input is the *j*th output of the *m*th DMU

u_{im} and v_{jm} is the weight associated with x_{im} and y_{jm}

x_{in} and y_{jn} are the *i*th input and *j*th output of the *n*th DMU

The dual of the primal version is called the envelopment version and involves creating a hypothetical DMU from the linear combination of the existing real DMUs that either consumes less inputs to produce at least the same output (input oriented) or produces more output without requiring additional inputs (output oriented).

If it not feasible to create a hypothetical DMU, then the DMU under evaluation is termed efficient and the loci of such efficient units define the efficiency frontier. Else the DMU under study is inefficient and the targets for the hypothetical DMU can be set for real DMU. The quantity of input contraction or output augmentation, which can be achieved to pull (input oriented) or push (output oriented) the inefficient units to the frontier, indicates the degree of inefficiency and the margin for improvement. The input oriented model aims to contract the input levels to produce at least the current output levels and is given by:

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

Subject to

$Y_\lambda \geq Y_m$; $X_\lambda \leq \theta_m X_m$; $\lambda \geq 0$; θ_m free

The output oriented version is:

$$\max_{\Phi,\mu} \varphi_m$$

Subject to

$Y\mu \geq \varphi_m Y_m ; X\mu \leq X_m ; \mu \geq 0; \varphi_m$ free

The strength of DEA lies in discovering the optimal set of weights for each DMU from the performance of the DMUs itself, eliminating the subjective bias involved in selecting them. DEA is capable of identifying the sources and amounts of inefficiency and thus possible improvements, set rational targets and pin point bench mark members which can be the sources of best practices for subsequent performance improvement initiatives. All this is possible based on the actual achievements of individual units and not on the theoretical estimates, without requiring assumption of a functional form for the production function.

5 Data Analysis and Discussion:

The performance data of various power generating units is being compiled by CEA in its Annual Thermal Performance Reviews. In this study the performance data for the year 2005-06, of 74 generating stations having an installed capacity of 62309MW out of the commissioned capacity of 67284MW (as on 31-03-2006) (92.60 %) is taken into account – CEA (2006). The review presents some of the unit level performance data like PLF, OAF, PM, FO etc and few other plant level data APC, SCC, SOC. Even though unit level analysis would have provided more focused results, to capture more parameters like APC, SCC and SOC in the study, we considered individual plants as DMUs. Performance data for some of the stations are not available in the report and attempt was made to collect the data from individual generating stations. The performance data for some of the parameters, which could not be collected from power stations, is interpolated from the historical published data. The descriptive statistics of important operational performance parameters is detailed in table-1.

Descriptive Statistics

	N	Range	Minimum	Maximum	Mean	Std. Deviation
APC	74	10.64	5.59	16.23	9.6572	2.28806
Capacity	74	2970.00	30.00	3000.00	842.0135	635.80318
FO	74	51.53	.00	51.53	10.5726	11.56606
OAF	74	94.23	4.71	98.94	79.2131	19.57541
PLF	74	96.80	2.82	99.62	68.4249	24.03707
PM	74	95.29	.00	95.29	10.2143	14.06498
SFOC	74	38.85	.10	38.95	3.1165	5.60780

	N	Range	Minimum	Maximum	Mean	Std. Deviation
SCC	74	.63	.46	1.08	.7415	.13459
Valid N (listwise)	74					

Table – 1: Descriptive Statistics of Performance Data for the year 2005-06

Considering the large variation in installed capacities of power plants ranging from 30 MW to 3000 MW, BCC- model to account for Variable Return to Scale is used so that the plants are compared among the comparables. To use BCC model, the ratio data (in which scale information is lost) is converted back to absolute values of the input and output parameters. The analysis was done using six inputs – Capacity in MW, Coal Consumed in MT, Oil Consumed in KL, APC in MU, PM and FO in deemed MUs and power generated in MUs.

DEA analysis for the 74 generating stations the performance parameter was performed using DEAP 2.1 with input oriented envelopment model under variable return to scale. With 6 inputs and 1 output, as a rule of thumb the DMUs should be more than max {6 X 1, 3(6+1)} i.e. 18 - Cooper (2007, page 284). The number of DMUs studied is 74, which are quite good. As such with 74 DMUs under study, the number of input and output parameters can be extended far beyond. The results are detailed below:

1. The CRS TE, VRS TE, scale efficiency, Peer Count, Return to scale (RTS) along with input targets for the 74 generating stations is listed in table-2. Henceforth VRS TE is indicated as efficiency unless otherwise specified.

DMU No	DMU	Capacity	CRS TE	VRS TE	RTS	Scale Efficiency	Peers
1	Ahemadabad	420	1	1	-	1	1
2	Amarkantak	60	0.53	1	IRS	0.53	2
3	Amarkantak Ext	240	0.563	0.631	IRS	0.891	68 , 41 ,52, 61
4	Anpara	1630	0.829	0.864	DRS	0.959	14, 73
5	Badarpur	720	0.866	0.873	DRS	0.992	73, 14
6	Bandel	540	0.827	0.829	IRS	0.998	1, 41, 19, 68
7	Barauni	320	0.448	0.479	IRS	0.935	68, 1, 41
8	Bakeshwar	630	0.957	0.957	-	1	53, 14, 19, 68, 41
9	Bhatinda	440	0.699	0.7	IRS	0.998	41, 19, 68, 1
10	BhatindaExt.	420	0.972	0.973	IRS	0.999	68, 14, 19, 1, 41
11	Bhusawal	483	0.821	0.828	IRS	0.992	59, 46, 19
12	Birasinghpur	840	0.703	0.703	-	1	73, 68, 59, 19

DMU No	DMU	Capacity	CRS TE	VRS TE	RTS	Scale Efficiency	Peers
13	Bokaro B	630	0.667	0.668	IRS	0.999	1, 41, 19, 68
14	Budge Budge	500	1	1	-	1	14
15	Calcutta	160	0.671	0.945	IRS	0.71	41, 52, 61
16	Chandrapur	2340	0.8	0.802	DRS	0.997	59, 53, 64, 68
17	Chandrapura	780	0.73	0.731	IRS	0.998	19, 41, 53, 68
18	Dadri	840	1	1	-	1	18
19	Dahanu	500	1	1	-	1	19
20	Durgapur	350	0.719	0.737	IRS	0.975	1, 41, 19, 68, 52
21	Durgapur (DPL)	395	0.687	0.707	IRS	0.971	68, 41, 67, 19, 61
22	Ennore	450	0.524	0.53	IRS	0.989	1, 41, 19, 68
23	Farakka STPS	1600	0.896	0.902	DRS	0.993	19, 59, 73
24	Faridabad	180	0.559	0.636	IRS	0.88	19, 52, 68, 41, 61
25	Gandhinagar	660	0.829	0.83	-	1	41, 19, 1, 68
26	Harduaganj	450	0.46	0.466	IRS	0.987	41, 1, 68
27	I.P.Stn.	248	0.52	0.571	IRS	0.911	1, 52, 41, 19, 68
28	IB Valley	420	0.86	0.868	IRS	0.991	46, 59, 19, 14
29	Kahalgaon	840	0.927	0.936	DRS	0.991	71, 73, 59, 14
30	Khaperkheda	840	0.796	0.801	DRS	0.994	14, 19, 73
31	Kolaghat	1260	0.737	0.789	DRS	0.935	53, 19, 68
32	Koradi	1100	0.721	0.731	DRS	0.987	19, 1, 68, 53
33	Korba East	440	0.839	0.844	IRS	0.994	46, 14, 19
34	Korba STPS	2100	1	1	-	1	34
35	KorbaWest	840	0.796	0.806	DRS	0.987	19, 14, 73
36	Kota	1045	0.916	0.973	DRS	0.942	53, 71, 73, 14
37	Kothagudem	1180	0.813	0.836	DRS	0.972	14, 73
38	Mejia	840	0.82	0.864	DRS	0.949	53, 73, 1
39	Mettur	840	0.939	0.942	DRS	0.997	59, 19, 73
40	Nasik	910	0.788	0.803	DRS	0.982	53, 19, 68, 1
41	Nellore	30	1	1	-	1	41
42	North Chennai	630	0.827	0.827	-	1	68, 41, 1, 19
43	Obra	1550	0.589	0.595	DRS	0.991	19, 68, 1
44	Panipat	1360	0.743	0.781	DRS	0.952	53, 73, 68, 1
45	Panki	220	0.614	0.719	IRS	0.854	52, 41, 61, 68
46	Paras	63	1	1	-	1	46
47	Paricha	430	0.543	0.55	IRS	0.986	1, 41, 68, 19
48	Parli	690	0.858	0.871	DRS	0.985	73, 14
49	Patratu	840	0.505	0.509	IRS	0.992	41, 1, 68
50	Raichur	1470	0.826	0.869	DRS	0.95	19, 53, 68
51	Rajghat	135	0.562	0.652	IRS	0.861	19, 41, 1, 68, 52
52	Ramagundam	62	0.792	1	IRS	0.792	52
53	Ramagundam STPS	2600	1	1	-	1	53
54	Rihand	2000	0.963	0.982	DRS	0.981	53, 73, 68, 19
55	Ropar	1260	0.86	0.906	DRS	0.949	19, 73, 1, 53
56	Santaldih	480	0.714	0.756	IRS	0.944	1, 41, 52, 68, 2
57	Satpura	1143	0.798	0.803	DRS	0.994	59, 19, 73
58	Sikka	240	0.772	0.776	IRS	0.995	19, 41, 1, 68

DMU No	DMU	Capacity	CRS TE	VRS TE	RTS	Scale Efficiency	Peers
59	Simhadri	1000	1	1	-	1	59
60	Singrauli	2000	0.946	0.957	DRS	0.989	59, 73, 19
61	Southern Repl	135	1	1	-	1	61
62	Suratgarh	1250	0.926	0.991	DRS	0.935	14, 53, 71, 73
63	Talcher	470	0.861	0.864	IRS	0.996	14, 19, 46
64	TALCHER-Kaniha	3000	1	1	-	1	64
65	Tanda	440	0.867	0.872	IRS	0.995	14, 46
66	Tenughat	420	0.704	0.706	IRS	0.997	41, 19, 1
67	Titagarh	240	0.964	1	IRS	0.964	67
68	Trombay	1150	1	1	-	1	68
69	Tuticorin	1050	0.87	0.878	DRS	0.992	19 ,14, 73
70	Ukai	850	0.816	0.816	-	1	41, 68, 53, 19
71	Unchahar	840	0.981	1	DRS	0.981	71
72	Vijayawada	1260	0.898	0.989	DRS	0.907	73, 53, 71
73	Vindhyachal	2260	1	1	-	1	73
74	Wanakbori	1260	0.809	0.849	DRS	0.953	19, 53, 73, 1

Table 2: Technical Efficiency, Scale Efficiency and Return to Scale

2. While the efficiency frontier defined by the operational parameters consisting of Generation, installed capacity, capacity unutilized because of PM and FO, coal and oil consumption, without relaxing for scales of operation (CRS frontier) is occupied by 11 power plants, after relaxing for the unique scales of operation 4 more power plants move to the VRS efficiency frontier. The list of efficient plants is detailed in table 3.

Sector	Operator	Plants
Private – 5 Plants [Total -]	Reliance Energy	Dahanu
	Tata Power	Trombay
	CESC	Budge Budge, **Titagarh***, SouthGen.
Central – 7 Plants [Total -]	NTPC	Vindhyachal, **Unchahar***, Ramagundam, Talcher – Kaniha, Simhadri, Dadri, Korba
State – 5 Plants [Total -]	GSECL	Ahmedabad
	APGenco	**Ramagundam***, Nellore
	MahaGenco	Paras
	MPGenco	**Amarkantak***

Table - 3: Power plants defining the efficiency frontier (* occupy only the VRS frontier)

3. These plants have VRS technical efficiency of 100%. It can be seen that even though four plants have CRS Technical Efficncy as low as 53.0% (Amarkantak) , 79.2%

(Ramagundam, 96.4% (Titagarh) and 98.1% (Unchahar), these plants occupy the efficiency frontier because there are no other plants of comparable size with whom their performance could be compared. It is found that 450MW Harduaganj plant has the lowest efficiency of 46.6% followed by 320MW Barauni 47.9% and the efficiency of only these two plants are below 50%. The efficiency of other remaining plants varies in the range of 50.9% to 100% with mean value of 83.9%. Dahanu, which is an efficient plant, has the highest peer count of 38 i.e. 38 other power stations see best practices in Dahanu compared to 32 of Trombay. The peer count of other efficient DMUs is shown in figure-2.

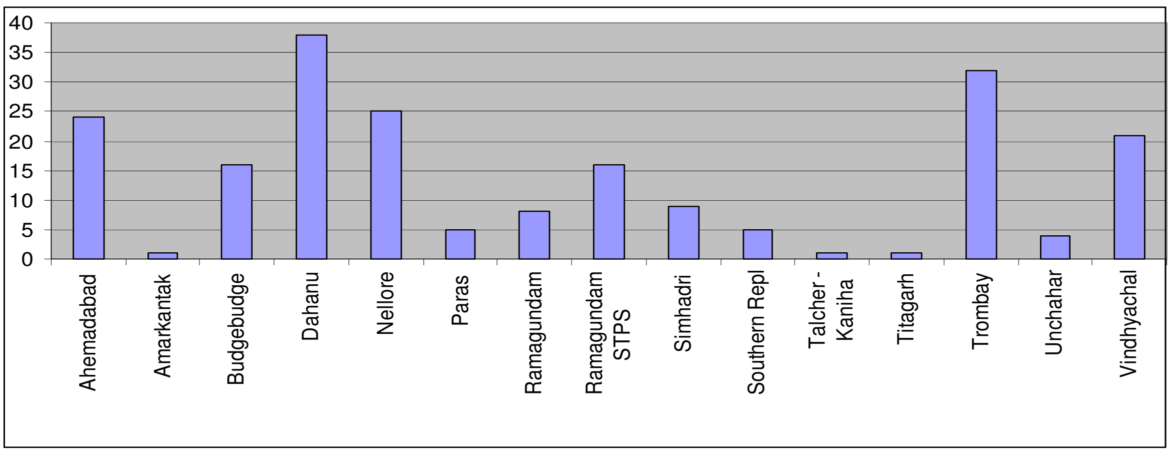


Figure-2: Peer Count of Efficient DMUs

4. It is observed that 18 plants have constant return to scale, 27 plants have decreasing return to scale and 29 plants have increasing return to scale.

5. Operator wise analysis of the efficiency scores reveal that while Reliance Energy and Tata Power have an average efficiency of 100%, the average efficiency level of 4 other operators – CESC, RRVUNL , APGenCo and NTPC is above 95%. The average efficiency of BSEB is lowest at 47.9% followed by JSEB at 50.9%. The average efficiency of as many as 13 operators is below the national average. Operator wise average efficiency is detailed in figure-3.

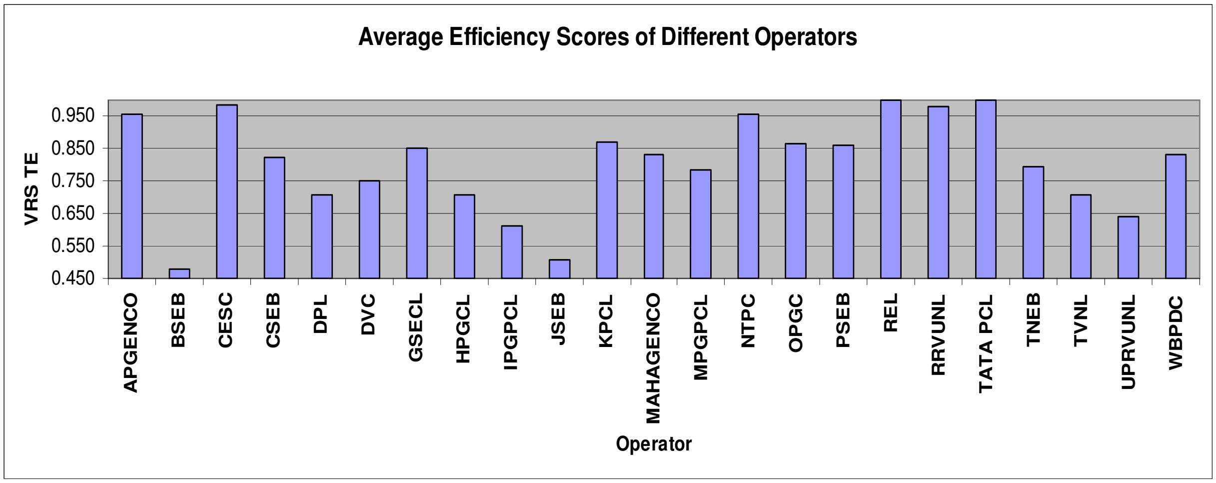


Figure-3: Average Efficiency Score of different Operators

6. The variation of average efficiency based on plant size is shown in figure-4.

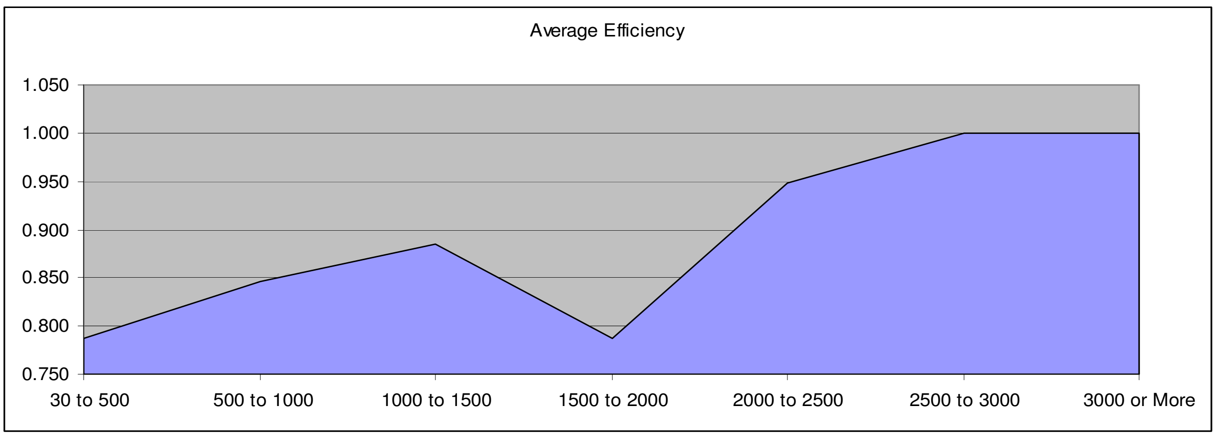


Figure-4: Variation of Average Efficiency with Plant Capacity

It can be seen that barring plant capacities in the 1500 to 2000 MW band, the average efficiency increases with plant size. There are 3 plants in the 1500MW to 2000MW band namely Obra – 1550MW, Farakka STPS – 1600 MW and Anpara – 1630 MW and the efficiency scores are 59.5%, 90.2% and 86.4% respectively. The average efficiency of plants of size 2500MW or higher is 100%. As such there are 2 plants Ramagundam STPS – 2600MW and Talcher Kaniha – 3000MW and both lie on the CRS efficient frontier. The smallest and oldest plant the 30 MW Nellore plant has peer count of 25 and turns out to be efficient in both the CRS as well as VRS frontiers. This is inline with the findings of Golany (1994) and Diewert and Nakamura (1999).

7. The variation of average efficiency with average unit size is shown in figure-5.

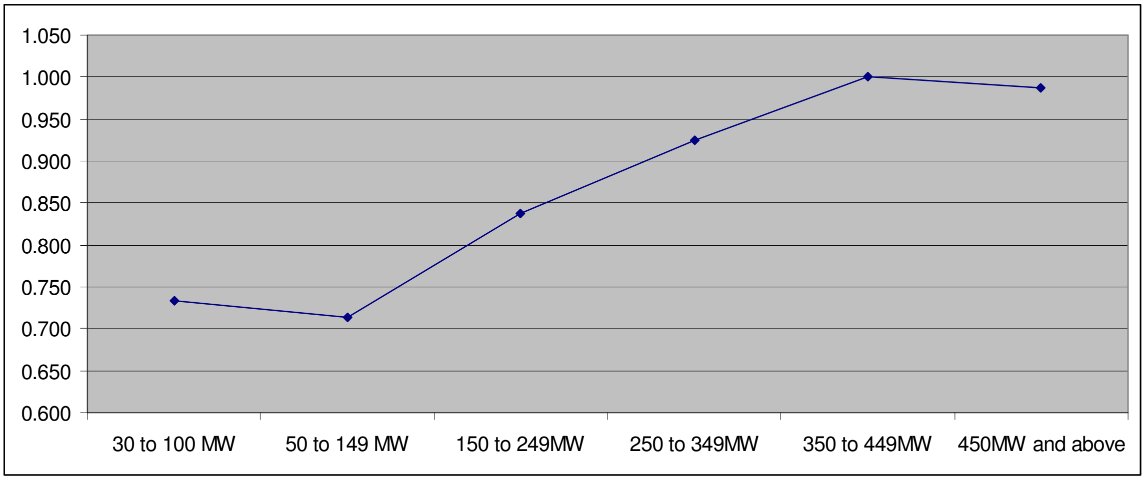


Figure-5: Variation of Average Efficiency with Average Unit Size

It is seen that barring plants with average unit size in the 50-149 MW band, the CRS efficiency increases with unit size.

8. Sector wise performance analysis of the power plants reveal, average efficiency of the plants in Private Sector has the highest average efficiency of 99.08% followed by plants in Central Sector and State Sector at 91.03% and 79.48% respectively. The findings are in line with the observations "the private plants have higher technical and scale efficiencies which hint at better managerial skills of the private sector" - Sarica (2006), and "the average efficiencies for the private plants are higher for the two developing country groupings (Caribbean and Tanzania)..." - Diewert and Nakamura (1999).

9. Region wise analysis of average efficiency scores indicate that the plants in Southern Region have the highest average efficiency of 89.73% followed by Western Region at 85.88% and Eastern Region at 82.12%. Plants in the Northern Region have the lowest average efficiency of 80.30%. The state wise plot of average efficiency is shown in figure-6. It is seen that the plants in Rajasthan highest average efficiency score of 98.2% followed by those in Andhra Pradesh at 97.1% and Orissa at 91.1%. The plants in Jharkhand, Delhi and Bihar are least efficient.

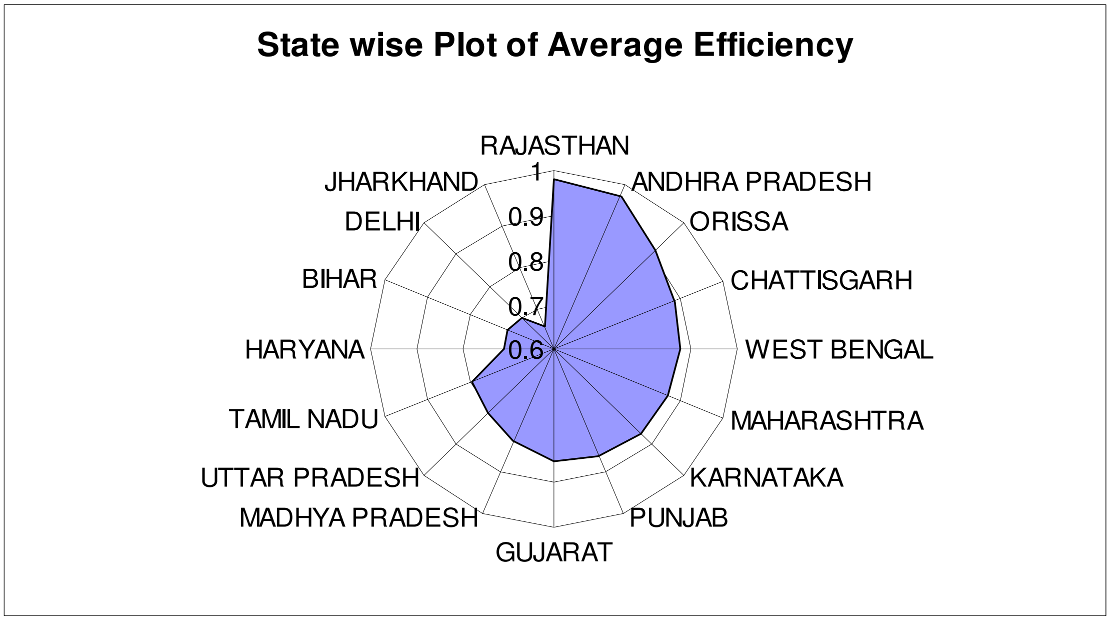


Figure-6: State wise variation of average Efficiency

10. Efficiency plot of different plants is shown in figure-7 and summary distribution of generation capacity and number of plants in different efficiency bands is shown in table-4.

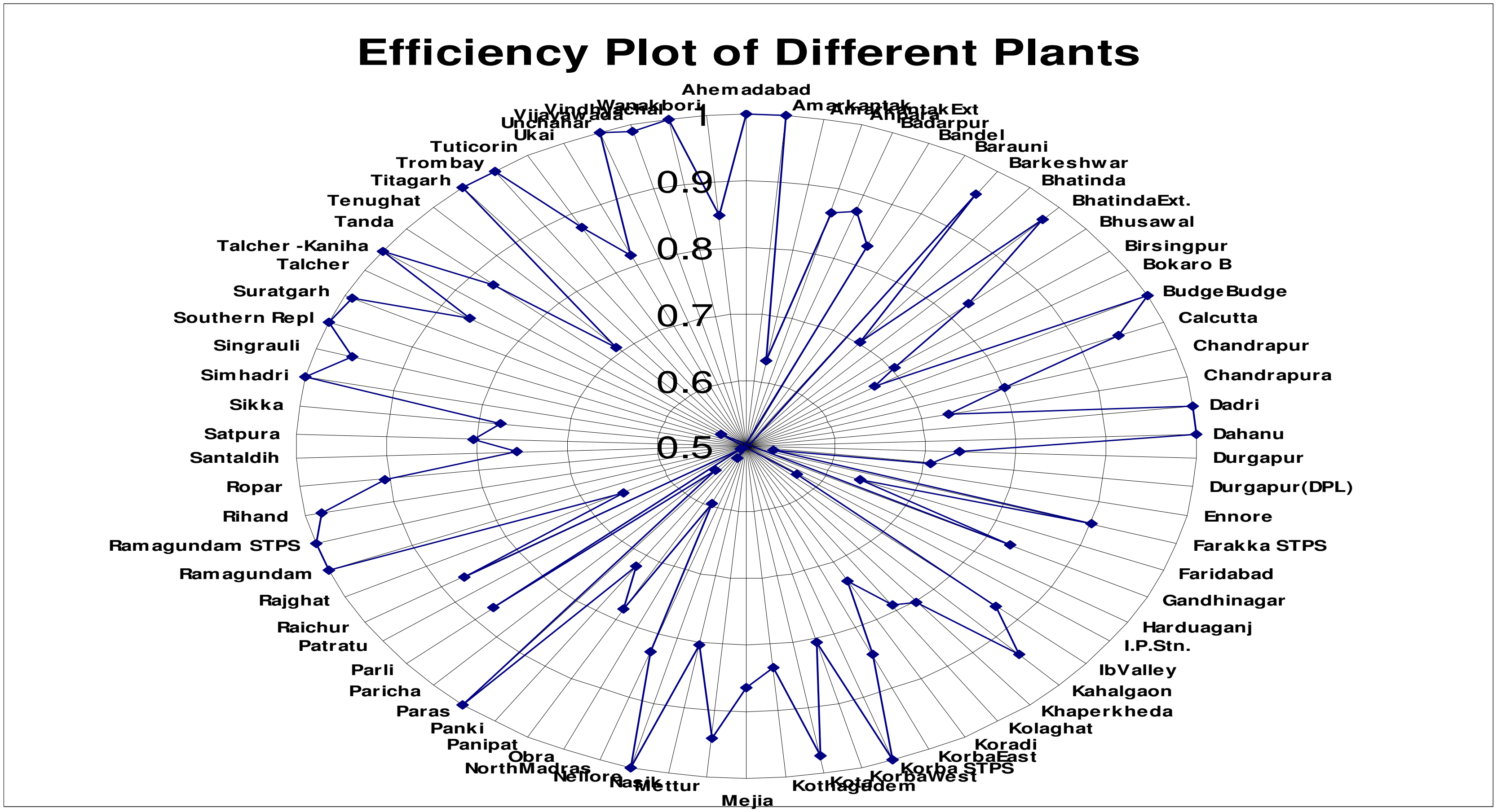


Figure-7: Efficiency plot of Different Plants

Efficiency Band (%)	Plants		Generation Capacity	
	Number	% age	MW	% age
Below 60	7	9.46	4288	6.88
60 – 70	4	5.41	1185	1.90
70 – 80	12	16.22	7885	12.65
80 – 90	22	29.73	19846	31.85
90 – 95	5	6.76	4700	7.54
Above 95	24	32.43	24405	39.17

Table-4: Distribution of Plants and Installed Capacity in Different Efficiency Bands

6 Conclusions:

We have attempted to model the relative performance level of coal fired thermal power plants in India during 2005-06 based on as many as 6 inputs and one output. The TE of plants varies from 46.6% to 100%. It is seen that the mean TE with CRS auumptions is 80.9% and with VRS is 83.9%. Out of the 74 power plants, the technical efficiency (VRS) of as many as 34 plants having aggregate capacity of 23,774MW is below the mean TE of 83.9%. This indicates substantial scope for contraction of the current input levels without deteriorating the output levels. Lesser consumption of inputs will not only reduce the cost of electricity generation there by enhancing the competitiveness but also make available the scarce inputs to generate more and more electricity. State wise analysis of the average TE indicates power plants in Rajasthan are most efficient followed by Andhra Pradesh and Orissa. The plants in Jharkhand, Delhi and Bihar are least efficient. Plants in the Southern Region are most efficient followed by those in Western and Eastern Region. The plants in the Northern Region are least efficient.

Considering the size and importance of the sector, it warrants more detailed productivity studies like analyzing the productivity trend over a 5-10 years horizon, extension of the study to unit level by capturing more and more parameters and validation of the findings with the field professionals. More and more real life constraints could be incorporated to model as close as to the real world business environment.

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