EVALUATION OF COMPETITIVENESS OF POWER PLANTS: EVIDENCE FROM INDIA

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ABSTRACT

This study attempts to gauge the relative performance of a set of large size coal-based power stations of India. The primary data for the study were collected through survey questionnaires for relevant operating and performance parameters for India's 18 coal-based power stations including Mundra and Saasan Ultra-Mega Power Projects (UMPPs). Data Envelopment analysis (DEA) has been used in the study to gauge the relative performance of Mundra UMPP with Saasan UMPP and other large size coal-based power stations of the country. The classical DEA model has been used to distinguish the efficient coal power stations from rest of the large sized coal-based power stations of the country. Power stations with total installed generation capacity of 2000MW or more each were selected for the study. The study indicates the need and scope for improvement in the performance of power plants for sustainable industrialisation and urbanisation.

KEYWORDS

Coal-based power plant, Power plant, Competitiveness, Performance, Data envelopment analysis, India

INTRODUCTION

The aggregate installed power generation capacity of India as on the date of comparison for this study, i.e. 31st March 2016, was 3,02,087.84 Mega Watt (MW) (CEA Annual Report, 2016). Out of this, thermal power generation accounts for 2,10,675.04 MW (69.73%) and coal-based power alone constitutes for 1,85,172.88 MW (61.30%) of the total electricity produced in the country (CEA Report). Out of this 1,85,172.88 MW of total coal-based generation, Private sector accounts for the highest share of generation of 69,462.38 MW (37.58%) followed by State Sector with 64,320.50MW (34.84%) and Central sector with 51,390.00 MW (27.58%). Figure 1 displays the composition of coal-based power of the country based on ownership.

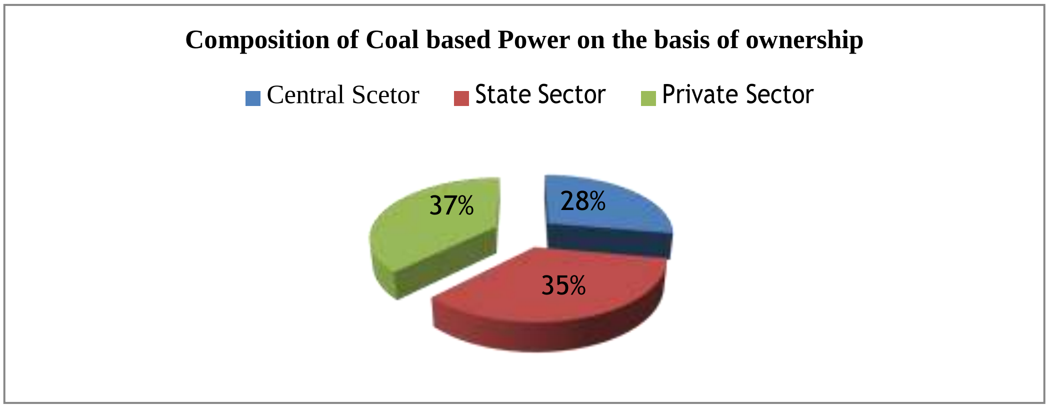

FIGURE 1
COMPOSITION OF COAL BASED POWER IN THE COUNTRY BASED ON OWNERSHIP

NTPC is the major constituent of Central sector whereas Tata Power, Adani Power and Reliance Power are the three largest private power producers of the country. Tata Power has the acclaim of installing India's first ultra-mega power project at Mundra in the state of Gujarat. Mundra UMPP with its total installed generation capacity of 4150 MW, alone constitutes 2.24% of India's total coal-based power generation and 5.97% of India's total coal-based power generation in private sector. Mundra UMPP was developed by Tata Power Company Ltd. through its special purpose vehicle Coastal Gujarat Power Ltd. (CGPL) under Built, Own and Operate (BOO) basis.

The coal-based power generating capacity in India has been built over the years and the sector has generating units of different capacities ranging from 20MW to 815MW. The highest total installed generation capacity of at a single location is as high as 4760MW. However, for the sake of parity, this study considers only the stations with total installed generation capacity of 2000 MW or above.

As the name signifies, coal-based power stations primarily utilise coal as a fuel to generate electricity. Pulverised coal is fired in large size furnaces to produce steam at high pressure and temperature. This steam at high pressure and temperature further works on a steam turbine and transfers its heat energy to mechanical energy by rotating the steam turbine. The alternator which remains coupled to this rotating steam turbine, thus, generates electricity which is further transmitted to load centres through high voltage transmission lines for further distribution to the end users.

Power generating stations consume a fraction of electricity generated to run the auxiliary drive units/equipment and is known as Auxiliary Power Consumption (APC). This is usually measured as a percentage of gross power generated.

Plant load factor (PLF) is a gauge of average capacity utilisation of any plant. In power generation industry, plant load factor is a measure of the output of a power plant as compared to the maximum rated output it could generate. The average PLF for coal based thermal power plants on an all-India basis has remained dismal at 62.3 per cent in FY 2015-16. Average PLF figure witnessed decline due to several factors like constraints of state-owned distribution companies (DISCOMS) in re-paying, improved generation contribution from the hydro and renewable energy segment and a substantial proliferation in power generation capacity in thermal field.

Tata Group

The TATA Group is among one of the most efficacious and esteemed business groups in India. The TATA group brought together 96 independent companies across 7 sectors of industry: energy, consumer products, materials, information systems & communications, engineering, and chemicals. The largest and well-known TATA companies include Tata Steel, Tata Power, Tata Motors, Tata Consultancy Services (TCS), Tata Chemicals, Indian Hotels, Tata Tea and Tata Communications.

Tata Group's outstanding performance even during the 2008 economic recession, which wracked many stock exchanges and tumbled the stocks of many giants, drew the attention of investors across the globe. In December 2009, the Tata group was at the top of the economic value creation charts. Branzei (2010) had cited in one of his case studies that the Tata Group topped the economic value creation charts, despite the global recession of 2008-2009. In 2008- 2009, the Group had grossed US$70.8 billion in revenues.

Tata Power

Tata Power is one of the key components of the group and a pioneer in the field of private power generation. The foundation of Tata Power was laid with commissioning of India's first power plant at Khopoli in 1915. Tata Power is India's largest integrated power company with a substantial global presence. It has an installed generation capacity of 9432 MW in India and has a pan-sectoral presence in all the segments of the power sector such as generation (thermal, solar, hydro and wind), distribution & transmission and power trading.

Ultra-Mega Power Projects (UMPPs)

In tune with the objective of "Power to all by 2012", the Government of India initiated the ambitious programme of UMPPs in the year 2005. Under this UMPP mission, each project was envisaged to have an installed capacity of 4000 MW and energy efficient and environment friendly technology with the intent to utilize the economies of scale in order to make power available at the minimum possible cost. Public Private Partnership (PPP) model with competitive tariff-based bidding and on a build, own and operate (BOO) basis was adopted to develop these UMPPs. Power Finance Corporation (PFC) was appointed as the nodal agency by the Government of India for development of UMPPs which, in turn, established Special Purpose Vehicles (SPVs) for developing the UMPPs. SPVs were responsible for all key development work including obtaining the required land for the project, receiving clearances related to environment and other related clearances for the project. So far, a total of 16 UMPPs have been strategically planned in different locations of India, out of which two UMPPs are in the operational phase.

Bidding Process of UMPPs

In accordance with the provisions laid down in the competitive guidelines, a twin stage process of selection was adopted. Request for Qualification (RFQ) was the first stage of bidding and it involved qualifying criteria for selection of the interested bidders. The bidders were required to submit the RFQ documents which were evaluated to identify the eligible bidders. These eligible bidders could participate in the second stage of the bidding process.

In the second Stage of the bidding process, Request for Proposals (RFP) was invited from the qualified bidders. The successful bidder was identified after thorough evaluation of the RFP documents on the basis of the lowest levelized tariff.

Mundra Ultra Mega Power Project (Tata Mundra UMPP)

Tata power introduced Coastal Gujarat Power Limited (CGPL) as its wholly owned subsidiary to implement the 4,000 MW UMPP in the state of Gujarat near the port city of Mundra. The selected unit size was 830 MW. It was the first time in India that 830 MW units based on supercritical technology was being installed in the country. This was not the first time when Tata Power was venturing into adoption of new technology. Tata Power is known for being an early adopter and, hence, it has been first to commission: India’s first 150 MW thermal unit at Jamshedpur, India’s first 500 MW thermal unit at Trombay, Mumbai and India’s first 150 MW pumped storage hydro plant at Khopoli, Mumbai.

Being present in power generation for almost a century was considered a strength for the Tata Power as it led them to an efficient experience curve. The TATA Mundra UMPP project was scheduled to supply power to the five states that were facing acute deficit of electricity supply. These were Gujarat, Maharashtra, and Rajasthan in Western India; and Punjab and Haryana in Northern India. The Mundra UMPP is a coastal project located at Mundra Taluka of Kutch District in Gujarat. Being located in the coastal region, it is completely dependent on the imported coal.

Rationale of the Study

There is no dearth of literature in operations management when it comes to address operations area decision. However only a few studies have analysed these decisions in the process industry, especially in a coal-based power generating plant. The PFC as nodal agency for installing UMPPs in the country had a vision of adopting energy efficient and environment friendly technology for the proposed UMPPs. Now, since two UMPPs were operational for almost two years up to the date for which study was conducted, a need was felt to gauge the effectiveness for Mundra UMPP with other large size coal-based power plant of the country. Usually, during the process of evaluating the efficiency of a coal-based power station, an extremely generic approach of output-input ratio analysis is carried out where the electricity produced per energy input is analysed. This generic output-input ratio analysis fails to portray the factual portrait of the operational efficiency. This limitation can be eliminated by using Data Envelopment Analysis (DEA) for evaluation of efficiency parameters for the power plants. The study compares the operating and performance parameters of Mundra UMPP with other large coal-based power stations of the country through Data Envelopment Analysis.

While we limit ourselves to a more credible analysis of the performance of power plants, the context could not be starker. Therefore, it is important to underline that while the rationale of industrialisation and the world becoming urban is well-understood, the climate crisis is forcing the ‘invisible hand’ away from the fossil fuels and towards the sources of renewable energy. There is a call to “protect the environment, prevent pandemics, ‘nature is sending us a clear message’” (U.N., 2020b). There is a prediction of growing discontent with the quality of growth amid a global slowdown during the current pandemic (U.N., 2020a). This situation where improvement in the efficiency and performance of the thermal power plants have a huge importance both for environment and economic growth. Under these circumstances, the efficiency of the power plants becomes a litmus test not only of the efficiency and sustainability of industrialisation and urbanisation but also that of commitment to environment. This is a rationale for the study from the macro point of view.

LITERATURE REVIEW

"What gets measured gets done" says Tom Peters (1987), Sumanth (1984) identified four stages of productivity process namely Measurement, Evaluation, Planning and Improvement. The success to productivity management exercise lies in productivity measurement. With an increase in productivity, an organization is able to successfully decrease its cost of production and hence increased market share and profit. The exercise of productivity improvement starts with identification of key potential improvement areas. There are several techniques in vogue to quantitatively estimate the productivity levels of different processes. Output to input ratio analysis has been quite popular classically for the single input and output process. This classic technique of output to input ratio analysis suffers the drawback of incompatibility with increased quantity and variety of inputs and outputs in the modern world of increasing complexity.

Farrell (1957) initially developed the idea of quantifying relative efficiencies of different utilities and establishments. Later, Banker et al. (1984) & Charnes et al. (1978) further developed the concept and proposed Data Envelopment Analysis (DEA) for use in making comparative analysis of various types of decision-making units (DMUs) such as hospitals, schools, utility power plants, etc. In the modern world, it has matured to become an inevitable tool in the field of operation research and in economic and management studies. The DEA has versatile applications in a wide range of management and economics related problems both in private and public sectors. Li & Reeves (1999). The DEA has importance much beyond the field of performance measurement and it has been widely used in different areas (Gurgen, 2006; Zhou et al., 2008; Emrouznejad et al., 2008).

The DEA approach has been practised to gauge the productivity of electrical utilities under various ownership structures since early 1980s. Using DEA for the productivity study has two-pronged advantages. Firstly, it helps in comparison of individual organisations with the best operating organisation within a homogenous category. Secondly, it helps to identify the various sources of inefficiencies which can further be used to provide crucial inputs for formulating policies by the regulators.

Researchers have conducted various studies worldwide to estimate the performance level of utility power producers. Golany et al. (1984) evaluated the relative performance level of thermal power plants operating in Israel. Olatubi & Dismukes (2000) & Lam & Shiu (2001) extended the use of DEA to gauge relative performance levels of power utilities in US and China, respectively.

DEA is a non-parametric linear programming technique which is extensively used to gauge the productivity and efficiency of different decision-making units in a fraternity. DEA is recognised as a versatile tool worldwide due to dyadic reasons: (i) Multiple inputs and outputs can be used concurrently to come out with a single efficiency score to establish ranking of various decision making units (DMUs) under consideration and (ii) DEA is free from biases arising out of subjectively assigned weights since it does not have an assumption of a functional form for the frontier. Due to this, DEA has found worldwide application in a variety of industries from software development Banker, et al. (1991) to textile (Zhu, 2003). In DEA analysis, relative performance of DMUs is calculated as the ratio of the weighted sum of the output to the weighted sum of input.

These weightages are allocated by the model and are not pre-determined.

METHODOLOGY AND DATA

Methodology

The study involved collection of primary data from the 18 large sized coal-based power stations of India each with a total installed generation capacity of 2000 MW or above. The primary data collected through survey questionnaire are on the performance and operating parameters of the coal-based power plants for the financial year 2015-16. Since the data for the power plant- the Tata Mundra UMPP could be procured only for the year 2015-16, we decided to do the analysis for all the 18 power plants for this particular financial year.

The selected parameters for study are further analysed through regression to verify strong dependence of dependent variable, i.e., Total gross generation in Million Units (MU) on independent variables [Total installed generation capacity in Mega Watts (MW), Total coal consumed in metric tonnes (MT), Total auxiliary power consumed in MUs and Total forced outage in terms of deemed generation lost in Mus].

The study further evaluates Mundra UMPP in comparison with the other 17 largest coal-based power stations of India on various operating and performance parameters through Data Envelopment Analysis (DEA). The inputs in the study are Total installed generation capacity in MW, Total coal consumed in MT, Total auxiliary power consumed in MUs and Total forced outage in terms of deemed generation loss in MUs. Total gross generation has been considered as output.

DEA Model

DEA is a model for relative analysis of input-output based productivity for multiple units. DEA analyses relative technical efficiencies of a homogenous set of multiple decision-making units. DEA is a non-parametric linear programming technique which is extensively used to gauge the productivity and technical efficiency of different decision-making units in a fraternity. The primary version of data envelopment analysis is known as envelopment version. It involves creation of a hypothetical DMU with the linear combination of existing real DMUs which either consumes lesser input for production of at least the same output (input oriented) or produces more output without further requirement of any additional input (output oriented).

In case it is not possible to create a hypothetical DMU, the DMU under evaluation is termed to be efficient and the locus points of all such efficient DMUs define the efficient frontier. Otherwise, the DMU under study is considered to be inefficient and the targets for the hypothetical DMU may be then set for real DMU. This study uses input-oriented model and it aims to contract the input level parameters to produce the same level of current output and is represented by:

Min θm

θ, λ

Subject to

$Y \lambda \geq Ym\ ;\ X\lambda \leq \theta m\ Xm;\ \lambda \geq 0;\ \theta m$ free

Target Respondents

This study identifies 17 other largest coal-based power plants of the country and compares them with Mundra UMPP on several operating and performance parameters.

Table 1 displays the unit sizes and total installed generation capacity along with ownership details and the state they are situated in.

Table 1
DETAILS OF COAL-BASED POWER PLANTS COVERED UNDER THIS STUDY

SI. No.	Thermal Power Station Name	State	Owner	Total Installed Capacity (MW)	Design HR	Configuration of Unit Size (MW)							
						200	210	250	330	500	600	660	830
1.	Vindhyachal Thermal Power Station	MP	NTPC	4760	2408		6			7			
2.	Mundra Thermal Power Station	Gujarat	Adani Power	4620	2258				4			5	
3.	Mundra Ultra Mega Power Plant	Gujarat	Tata Power	4150	2012								5
4.	Saasan Ultra Mega Power Plant	MP	Reliance Power	3960	2112							6	
5.	Jindal Super Thermal Power Station	Chhattisgarh	Jindal Power	3400	2350			4			4		
6.	Tiroda Thermal Power Station	Maharashtra	Adani Power	3300	2112							5	
7.	Talcher Super Thermal Power Station	Odisha	NTPC	3000	2380					6			
8.	Rihand Thermal Power Station	UP	NTPC	3000	2380					6			
9.	Sipat Thermal Power Plant	Chhattisgarh	NTPC	2980	2219					2		3	
10.	Ramagundam Thermal Power Station	AP	NTPC	2600	2419	3				4			
11.	Korba Thermal Power Station	Chhattisgarh	NTPC	2600	2419	3				4			
12.	Jharsuguda Thermal Power Station	Odisha	Sterlite Energy Ltd.	2400	2260					0	4		
13.	Kahalgaon Super Thermal Power Station	Bihar	NTPC	2340	2414		4			3			

14.	Chandrapur Super Thermal Power Station	Maharashtra	Mahagenco	2340	2414		4			3			
15.	Mejia Thermal Power Station	West Bengal	DVC	2340	2425		4	2		2			
16.	Farakka Super Thermal Power Station	West Bengal	NTPC	2100	2425	3				3			
17.	Singrauli Super Thermal Power Station	UP	NTPC	2050	2423		5			2			
18.	Simhadri Super Thermal Power Station	Andhra Pradesh	NTPC	2000	2380					4			

Sampling Procedure

The study uses Purposive Sampling for selecting the coal-based power plants for consideration under the study. For the study, all the coal-based power plants of the country with total installed generation capacity of 2000MW or more were selected for the study.

PERFORMANCE PARAMETER AND MEASUREMENT SYSTEMS

Coal based power plants require capital intensive and take almost 4 to 5 years from concept to commissioning. The fixed cost per MW capacity installed varies from 40 to 50 million rupees (http://cea.nic.in – last visited on 12-11-2016). The principal input in any performance evaluation exercise of power plants should be its cost of capital. But, unfortunately the data on cost of capital is not available as many of these power plants were built over the years. Alternatively, total installed generation capacity in Mega Watt (MW) is considered as an input parameter as an implicit indicator of the cost of capital.

Table 2
DATA COLLECTED FROM COAL-BASED POWER STATION

SI. No.	Coal Based Power Station	Design Heat Rate Kcal/ KWh	Operating Heat Rate Kcal/ KWh	Deviation in HR from design (%)	PAF (%)	APC (%)	FO (%)	SCC (Kg/ KWh)	SOC (ml/ KWh)	Installed Capacity (MW)	Total Gross Gen. (MU)	Total Coal Consumed (MT)	Total Oil Consumed (KL)	Auxiliary Power Consumed (MU)	Forced Outage (Deemed MUs)
1.	NTPC Vindhyanagar	2408	2494	3.58	85.86	6.86	3.68	0.32	0.26	4760.00	34609	11074883	9.00	2374	175
2.	Adani Mundra	2258	2394	6.03	82.16	7.24	7.84	0.42	0.28	4620.00	27520	11448493	7.60	1992	362
3.	Mundra UMPP	2020	2080	2.97	93.83	7.80	1.19	0.19	0.12	4150.00	31686	5956996	3.87	2472	49
4.	Saasan UMPP	2112	2226	5.40	85.62	6.86	8.38	0.70	0.29	3960.00	28508	20012555	8.15	1956	332
5.	Jindal Super Thermal Power Station	2350	2487	5.83	50.04	7.57	11.78	0.77	0.35	3400.00	12882	9899494	4.57	974	401
6.	Adani Tiroda	2112	2216	4.92	87.86	6.72	4.68	0.68	0.28	3300.00	18518	12592556	5.19	1244	154
7.	NTPC Talcher	2380	2498	4.96	86.68	6.08	3.32	0.72	0.19	3000.00	23902	17209195	4.54	1453	100
8.	NTPC Rihand	2380	2497	4.92	89.84	6.78	4.78	0.51	0.19	3000.00	18964	9671460	3.53	1286	143
9.	NTPC Sipat	2219	2323	4.68	88.99	5.69	2.24	0.63	0.25	2980.00	22223	13978277	5.56	1264	67
10.	NTPC Ramagundam	2419	2511	3.82	87.66	5.94	3.34	0.24	0.18	2600.00	19993	4798265	3.56	1188	87
11.	NTPC Korba	2419	2498	3.28	88.64	6.42	5.36	0.31	0.21	2600.00	19633	6125469	4.12	1260	139
12.	Vedanta Jharsuguda	2260	2412	6.73	83.34	7.02	7.66	0.73	0.32	2400.00	12375	9033550	3.96	869	184
13.	NTPC Kahalgaon	2414	2536	5.04	86.68	7.98	4.32	0.78	0.21	2340.000	14796	11540681	3.11	1181	101
14.	Chandrapur, Mahagenco	2414	2539	5.17	82.16	7.99	8.84	0.81	0.36	2340.00	11618	9410979	4.18	928	207
15.	Mejia Thermal Power Station	2425	2542	4.82	81.86	8.20	9.14	0.82	0.39	2340.00	12885	10565941	5.03	1057	214
16.	NTPC Farakka	2425	2542	4.82	86.24	6.89	4.76	0.66	0.22	2100.00	11899	7853032	2.62	820	100
17.	NTPC Singrauli	2423	2532	4.50	82.68	7.36	6.32	0.21	0.23	2050.00	14154	2972444	3.26	1042	130
18.	NTPC Simhadri	2380	2488	4.54	87.24	6.26	3.76	0.42	0.27	2000.00	14538	610600	3.93	910	75

The other parameters considered as input are as below:

1. Total coal consumed in Metric Tonnes (MT): Total coal consumed is the amount of coal a power station consumes to generate electricity in a given period of time. It is usually measured in in Metric Tonnes (MT)
2. Total Auxiliary Power Consumption in MUs: Auxiliary Power Consumption (APC) is the fraction of energy that a power plant consumes in running its auxiliary equipment. This also includes excitation and transformer losses

within the premises of the generating station. It is usually measured as a percentage of the sum of aggregate energy generated at the generator outlet terminals of all the units of a power generating station.

3. Forced Outages in terms of deemed generation lost in MU: Forced Outage is the shutdown time of a power station when the generating units are unavailable to generate electricity due to unexpected breakdown. It is usually measured as % of total declared capacity or as loss in deemed generation in MUs.

Oil is used as a secondary fuel in coal-based power stations, but its consumption is limited to start-ups only and is marginal as compared to other input costs. Being miniscule in quantity, oil consumption has not been considered as an input parameter for the study. Other input parameters to the plant such as maintenance expenditure including cost of spares & consumables, employee cost and other costs are not available in public domain and the plants are not willing to share these data. Hence, the maintenance cost has not been considered as an input parameter for the study. In the absence of maintenance cost available explicitly, forced outage figures can be considered as an indicator of maintenance and opportunity cost. Since APC and forced outages can be reduced with adequate technological and managerial intervention, it is

Imperative to consider APC and forced outage as deemed inputs like capacity and coal consumption.

Total Million Units (MUs) of electricity generated in a year is considered to be the output parameter. Total Million Units of electricity generated are the total units of electricity that any power station generated electricity in a given period of time. It is usually measured in Million Units (MUs).

Table 2 displays the raw data received for this study from these above-mentioned coal-based power stations.

The operating and performance data for all the 18 selected power plants were collected through survey questionnaires for the year 2015-16. Plants having total installed generation capacity of 2000 MW or more were considered for the study. The selected 18 coal-based power stations considered for the study have the total installed generation capacity of 53,940 MW which is almost 30% of India's total coal-based generation of 1,85,172.88 MW.

Table 3
OUTPUT OF REGRESSION ANALYSIS

SUMMARY OUTPUT								
Regression Statistics								
Multiple R	0.976							
R Square	0.953							
Adjusted R Square	0.938							
Standard Error	1.793							
Observations	18							
ANOVA								
	df	*SS*	*MS*	*F*	*Significance F*			
Regression	4	842.305	210.576	65.494	1.75E-08			
Residual	13	41.798	3.215					
Total	17	884.1023						
	Coefficients	Standard Error	t Stat	P-value	Lower 95%	Upper 95%	Lower 95.0%	Upper 95.0%
Intercept	-0.604	1.678	-0.360	0.0072	-4.231	3.021	-4.230	3.021

APC (BU)	9.114	2.587	3.523	0.0037	3.526	14.702	3.526	14.702
FO (BU)	-16.158	6.435	-2.511	0.0261	-30.060	-2.255	-30.060	-2.255
Total Coal Consumed (TT)	0.179	0.115	1.565	0.0014	-0.068	0.427	-0.068	0.427
Installed Capacity (GW)	2.908	1.680	1.732	0.1070	-0.720	6.5367	-0.720	6.537

Table 3 displays summary output of regression analysis. The interpretation of this result is as below:

- Multiple R: This is a correlation coefficient. It indicates how strong the linear relationship is. Here the value of 0.976 means there is a strong relationship between the dependent variable (Total Gross Generation) and the independent variables (Installed Capacity, Total Coal Consumed, Auxiliary Power consumed and Forced outage).
- R Square: R Square equals 0.952, which is a very good fit. 95.2% of the variation in Total Gross Generation is explained by the 4 independent variables (Installed Capacity, Total Coal Consumed, Auxiliary Power consumed and Forced outage).
- Significance F and P-values: The results are reliable (statistically significant) Significance F (1.74E-8) is less than 0.05. All P-values are below 0.05
- Coefficients and Linear Regression Equation: The regression equation is

y = Total Gross Generation = – 0.6 + 9.11*APC – 16.157*Forced Outage + 0.18*Coal Consumption + 2.9*Installed Capacity in MW

DEA Analysis: According to Raab & Lichty (2002), in any DEA analysis, the minimum number of decision-making units (DMUs) must be greater than thrice the number of total inputs and outputs. This requirement gets satisfied in the study since we have 18 DMUs and this number is greater than the minimum requirement of 15, i.e. [3*(4+1)]. The descriptive statistics are displayed in Table 4.

Table 4
DESCRIPTIVE STATISTICS FOR COAL-BASED POWER PLANTS

Parameters	**N**	**Minimum**	**Maximum**	**Range**	**Mean**	**Std. Deviation**
Input Parameters						
Installed Capacity (MW)	18	2000	4760	2760	2997	871.63
Total Coal Consumed (MT)	18	2972444	20012555	17040111	10013904	4268144.56
Auxiliary Power Consumed	18	820	2472	1652	1348	508.10
Forced Outage (Deemed MUs)	18	49	401	351	168	102.59
Output Parameters						
Total Gross Generation (MU)	18	11618	34609	22991	19483	7211.5
Other Parameters						
Design Heat Rate (Kcal/KWh)	18	2020	2425	405	2323	129.07
Operating Heat Rate (Kcal/KWh)	18	2080	2539	459	2423	134.12
Deviation in HR from design	18	60	152	92	99	22.89
PAF (%)	18	50	94	44	84	9.11
APC (%)	18	6	8	3	7	0.74
FO (%)	18	1	12	11	6	2.77

PLF (%)	18	43	91	48	74	13.29
SCC (Kg/KWh)	18	0	1	1	1	0.22
SOC (ml/KWh)	18	0	0	0	0	0.07
Total Oil Consumed (KL)	18	3	9	6	5	1.78

The CRS TE and VRS TE along with scale efficiency are listed in Table 5. Henceforth, VRS TE is indicated as efficiency unless otherwise specified.

Table 5
DEA OUTPUT; CRS TE VS VRS TE

DMU No.	DMU Name	Capacity	CRS TE	VRS TE	RTS
1	NTPC Vindhyanagar	4760	0.941	1.000	Decreasing
2	Adani Mundra	4620	0.812	0.889	Decreasing
3	Mundra UMPP	4150	1.000	1.000	Constant
4	Saasan UMPP	3960	0.909	0.948	Decreasing
5	Jindal Super Thermal Power Station	3400	0.756	0.876	Increasing
6	Adani Tiroda	3300	0.852	0.879	Increasing
7	NTPC Talcher	3000	1.000	1.000	Constant
8	NTPC Rihand	3000	0.857	0.873	Increasing
9	NTPC Sipat	2980	1.000	1.000	Constant
10	NTPC Ramagundam	2600	1.000	1.000	Constant
11	NTPC Korba	2600	0.977	0.984	Increasing
12	Vedanta Jharsuguda	2400	0.814	0.962	Increasing
13	NTPC Kahalgaon	2340	0.799	0.866	Increasing
14	Chandrapur, Mahagenco	2340	0.716	0.893	Increasing
15	Mejia Thermal Power Station	2340	0.717	0.857	Increasing
16	NTPC Farakka	2100	0.833	1.000	Increasing
17	NTPC Singrauli	2050	0.977	1.000	Increasing
18	NTPC Simhadri	2000	0.945	1.000	Increasing

As such, the DEA results for all the 18 DMUs under study are as below:

- The plants having VRS technical efficiency of 100% are Mundra UMPP, NTPC Vindhyanagar, NTPC Talchar, NTPC Sipat, NTPC Ramagundam, NTPC Farakka, NTPC Singrauli and NTPC Simhadri.
- Tata Mundra along with above mentioned 7 power stations owned by NTPC do not have any slack and hence these are utilizing their available resources to the best extent.
- It is found that Mejia Thermal power Station has the lowest efficiency of 85.7% followed by NTPC Rihand 87.3%. The efficiency of other remaining coal-based power plants varies from 87.9 to 100 percent, with the mean value of 90.3%.
- It is observed that 4 plants have constant return to scale, 3 plants have decreasing return to scale and 11 plants have increasing return to scale.
- Saasan UMPP has slack in total installed capacity and forced outages percentage. This indicates that Saasan UMPP is not utilizing its full capacity and needs to focus on reducing forced outages of its units. Table 6 provides the slack analysis for all 18 power plants covered under the study.

Table 6
SLACK ANALYSIS

Inputs Installed Capacity (MW) Total Coal Consumed (MT) Auxiliary Power Consumed Forced Outage (Deemed MUs)			Outputs Total Gross Generation (MU)			
Input-Oriented VRS Model Slacks						
DMU No.	DMU Name	Input Slacks				Output Slacks
		Installed Capacity (MW)	Total Coal Consumed (MT)	Auxiliary Power Consumed	Forced Outage (Deemed MUs)	Total Gross Generation (MU)
1.	NTPC Vindhyanagar	0.000	0.000	0.000	0.000	0.000
2.	Adani Mundra	381.983	0.000	0.000	198.473	0.000
3.	Mundra UMPP	0.000	0.000	0.000	0.000	0.000
4.	Saasan UMPP	0.000	45071.179	0.000	184.122	0.000
5.	Jindal Super Thermal Power Station	914.860	14672.891	0.000	260.025	0.000
6.	Adani Tiroda	392.540	88325.785	0.000	64.902	0.000
7.	NTPC Talcher	0.000	0.000	0.000	0.000	0.000
8.	NTPC Rihand	85.070	0.000	0.000	49.235	0.000
9.	NTPC Sipat	0.000	0.000	0.000	0.000	0.000
10.	NTPC Ramagundam	0.000	0.000	0.000	0.000	0.000
11.	NTPC Korba	0.000	0.000	65.024	50.651	0.000
12.	Vedanta Jharsuguda	227.946	11565.814	0.000	81.446	0.000
13.	NTPC Kahalgaon	0.000	35880.200	98.000	11.717	0 000
14.	Chandrapur, Mahagenco	0.000	73032.850	0.000	87.309	550.128
15.	Mejia Thermal Power Station	0.000	28576.345	0.000	106.791	1516.118
16.	NTPC Farakka	0.000	0.000	0.000	0.000	0.000
17.	NTPC Singrauli	0.000	0.000	0.000	0.000	0.000
18.	NTPC Simhadri	0.000	0.000	0.000	0.000	0.000

It is observed that four plants have constant return to scale, three plants have decreasing return to scale and 11 plants have increasing return to scale.

- Figure 2 and Table 7 display the relative efficiency of all the 18 power stations on a radar plot.

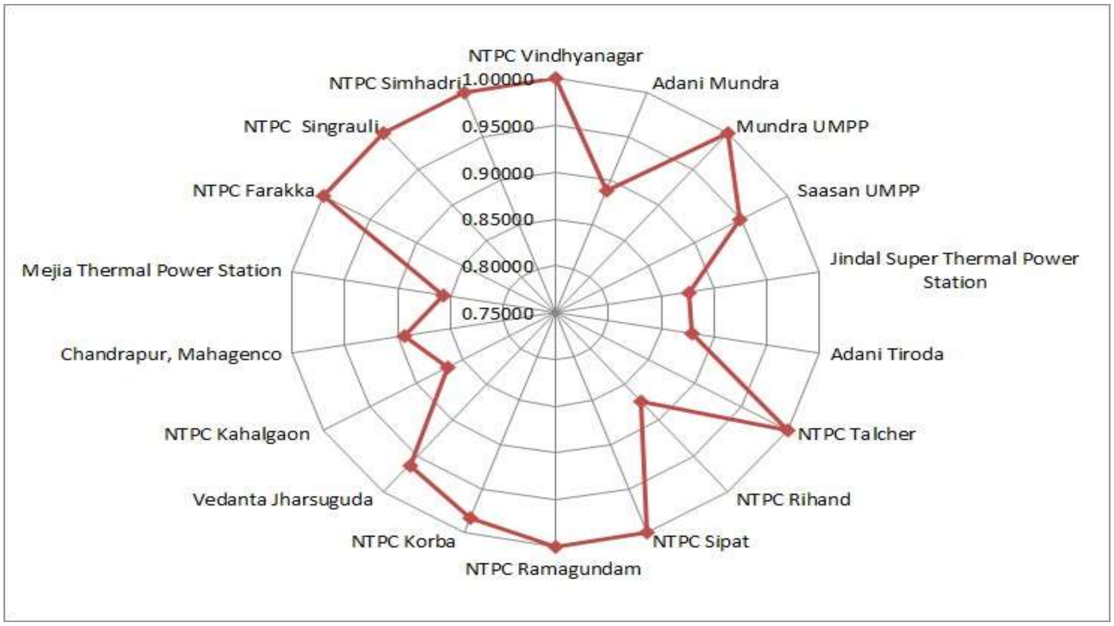

Table 7
DEA OUTPUT VRS TE

Inputs Installed Capacity (MW) Total Coal Consumed (MT) Auxiliary Power Consumed Forced Outage (Deemed MUs)		Outputs Total Gross Generation (MU)						
DMU No.	DMU Name	Input-Oriented VRS Efficiency	Optimal Lambdas with Benchmarks					
1.	NTPC Vindhyanagar	1.000	1.000	NTPC Vindhyanagar				
2.	Adani Mundra	0.889	0.475	NTPC Vindhyanagar	0.261	NTPC Sipat	0.264	NTPC Ramagundam
3.	Mundra UMPP	1.000	1.000	Mundra UMPP				
4.	Saasan UMPP	0.948	0.420	NTPC Vindhyanagar	0.015	Mundra UMPP	0.566	NTPC Talcher
5.	Jindal Super Thermal Power Station	0.876	0.628	NTPC Farakka	0.372	NTPC Simhadri		
6.	Adani Tiroda	0.879	0.518	NTPC Sipat	0.482	NTPC Simhadri		
7.	NTPC Talcher	1.000	1.000	NTPC Talcher				
8.	NTPC Rihand	0.873	0.350	NTPC Sipat	0.319	NTPC Ramagundam	0.332	NTPC Simhadri
9.	NTPC Sipat	1.000	1.000	NTPC Sipat				

10.	NTPC Ramagundam	1.000	1.000	NTPC Ramagundam				
11.	NTPC Korba	0.984	0.086	NTPO Talcher	0.787	NTPC Ramagundam	0.127	NTPC Simhadri
12.	Vedanta Jharsuguda	0.962	0.820	NTPC Farakka	0.180	NTPC Simhadri		
13.	NTPC Kahalgaon	0.866	0.028	NTPC Talcher	0.972	NTPC Simhadri		
14.	Chandrapur Mahagenco	0.893	0.898	NTPC Farakka	0.102	NTPC Simhadri		
15.	Mejia Thermal Power Station	0.857	0.052	NTPC Farakka	0.948	NTPC Simhadri		
16.	NTPC Farakka	1.000	1.000	NTPC Farakka				
17.	NTPC Singrauli	1.000	1.000	NTPC Singrauli				
18.	NTPC Simhadri	1.000	1.000	NTPC Simhadri				

CONCLUSION

With application of DEA, this study attempted to model the relative performance level of Mundra UMPP and other 17 large size coal based thermal power plants in India during 2015-16 based on as many as 4 inputs and one output. In order to have pragmatic and accurate outcomes from the analysis, only large size coal-based power plants on the basis of total installed generation capacity were selected for the study.

Regression analysis was done to check the significant relationship between dependent and independent variables. 6 out of 10 stations of NTPC were found to have zero slack and 100% efficiency. Saasan UMPP has slack in total installed capacity and forced outages percentage. This indicates that Saasan UMPP is not utilizing its full capacity and needs to focus on reducing forced outages of its units.

Out of the 18 power plants, the technical efficiency (VRS) of as many as seven plants with an aggregate capacity of 18,340 MW is below the mean TE of 94.6%. 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 in these plants by enhancing the competitiveness but will also thus free the scarce inputs to generate more and more electricity.

The 11 out of 18 power stations are not performing at their intended level of efficiency and may emulate the technological and managerial practices of 7 most efficient performing stations.

The slack analysis identified and quantified the input factors required for increasing performance of relatively less efficient power stations. On an average, low performing power stations can trim down their coal consumption by approximately 89,000 MT to bolster their productivity.

This has huge policy implications for the cost, prices, and production of power as well as for sustainable industrialisation and urbanisation and quality of environment. In this context, an overview of the current Indian thermal energy situation is imperative in order to recognise the challenges and opportunities in realising its potential for increasing the efficiency of power production and reducing the adverse environmental consequences.

Limitations and Scope for Future Work

The data availability beyond 2015-16 was not possible at the time of analysis. A study for later years can give an idea of change in the situation. The sample size of this study was18, however, more samples would have further provided increased accuracy in deriving the findings. While performing DEA analysis a greater number of inputs could not be taken due to smaller sample size. Analyzing DEA with increased DMUs would have brought more accuracy to the results. Considering the size and importance of the sector, it requires more detailed productivity studies such as 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. Super-critical units and sub-critical units to be studied separately as the operating pressure is different for both the systems.

The performance parameters for the power plants need to be explicitly built into policies for sustainable industrialization and urbanisation as well as promotion of environment and health, the importance of which has come to be highlighted with the dramatic appearance of the covid-19 pandemic.

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