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Performance Analysis of Coal Operated Thermal Power Generation Companies

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Abstract; With ever-increasing demand for electricity due to economic and demographic expansion, the power industry has become highly vital. It is the sector responsible for converting diverse energy resources such as fossil fuels, coal, natural gas, and other unconventional resources into cleaner electric energy. Thermal power plants run on coal account for a significant portion of India's energy generation, with a remarkable cumulative yearly growth rate.

The purpose of this work is to examine the efficiency of coal-fired thermal power plants, both public and commercial, using a nonparametric Data Envelopment Analysis technique. It outlines the important criteria to consider while evaluating these firms' success. The investigation will aid in understanding of industry best practices for achieving peak performance. The study emphasizes aspects influencing the efficiencies of various units in order to assist in enhancing the efficiency of inefficient units. It also recommends regulatory measures to increase the efficiency of public-sector power producing businesses.

Keywords: CRS, VRS, Efficiency, Data Envelopment Analysis, Slack

Introduction:

After India got free from British rule, the national and state governments have operated and regulated the generation, distribution, and transmission of electric energy. There were several state and national players with vertical integration to deliver countrywide electricity. In 1991, India implemented liberalised laws and implemented several changes in the power industry in order to attract investment, revitalise the sector via restructuring, and foster market competition in order to increase productivity."

Since then, the electric energy industry has expanded at a remarkable pace. The Indian government's policy adjustments and restructuring measures have aided industry in its revitalization. Foreign direct investment rules have aided in bringing money and skills to the power industry. As of the end of February 2015, India's power industry has a rated capacity of 261.007 GW and produced around 961.778 BU from May"2020 to February"2021. In 2013, India surpassed Japan and Russia to become the world's third biggest generator of power, with a 4.8 percent worldwide share in electricity output. In spite of its expanding importance, experimental studies on the efficiency of India's power industry stand sparse, owing to a paucity of numbers on factor inputs utilized in the power sector.

This study demonstrates the use of DEA (a non-parametric rectilinear programming technique for assessing relative efficiency) to Indian Radiant Power Generation Companies over the years 2020–2021. Based on their performance and appropriate comparisons, the DEA provides different efficiency ratings to organizations. The goal of this research is to look at the efficiencies of various power generation companies, as well as the factors that lead to inefficiency in those companies.

Indian Power Sector:

After India's independence, the electrical supply act of 1948 brought power generation, delivery, and distribution in the urban and rural sectors under government control. At the national and state levels, the Central Power Authority (CEA) and State Electricity Boards (SEBs) stood formed to plan along with implementation of electricity planning. This also served as a basis for establishing and running central power plant benefits of public segment companies. Along with this it started providing certificates to produce along with dispense power certain specific areas established State Electricity Boards.

Energy production which is an important aspect in every nation's financial success and India is no exception. The emergence of new industries has resulted in widespread usage of electricity in all sectors, with development and improvement evident in consecutive five-year plans. Power utility rose 50 times in 48 years, from 1813 MW in 1951 to 89190 MW in 1999, while generation volume expanded 80 times, from 5.2 billion units to 421 billion units. With advancements in technical equipment that uses power, per capita use of electricity climbed from 15 kWh to 338 kWh. Since independence through the beginning of the twenty-first century, approximately 80% of the rural sector has been electrified. It has also reached the Northern Eastern sector.

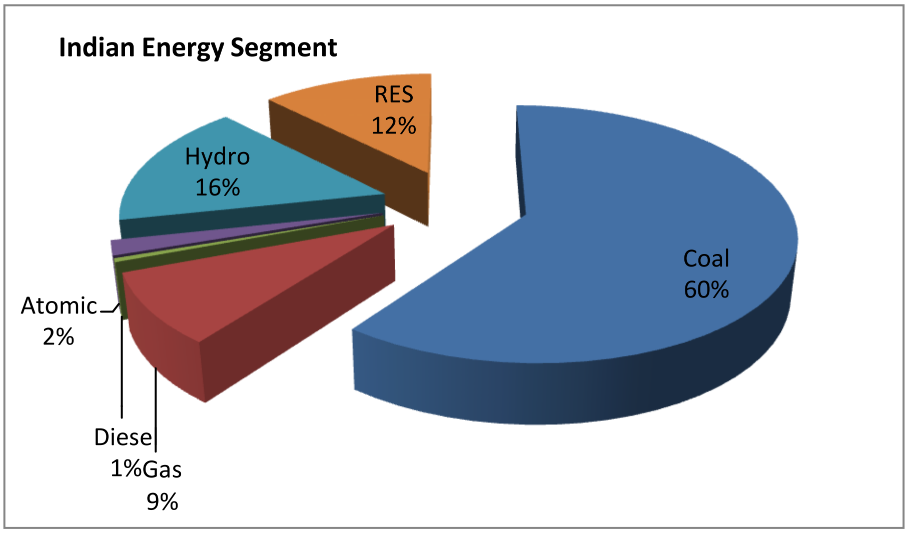


Figure 1 Percentage of different sectors in Power Generation

1. Literature Review:

In the past, researchers used a range of productivity evaluation methodologies to analyse the efficiency of energy-generating firms."Charnes (1978) and Banker et al. (1984) were the first to use empirical methodologies such as data envelopment analysis to measure the efficiency of production schemes with the help of various divisional statistics. Fare et al. (1985) were the first to compare the efficiency of private and public electric utilities using DEA method, discovering that public services were more productive. From 2005 to 2010, Alireza Fallahi, Reza Ebrahimi, and S.F. Ghaderi (September 2011) used DEA study to assess the enactment of thirty two power electric production company models for assessment of productivities of those companies. The many representations have contributed towards a better understanding of both pure technical and scale efficiency. The study's conclusions contributed in the improvement of many organizations' production, management practices, and policies. It also proved that technological advancements are not the major driver of increasing output; rather, low efficiency is the key reason of low output. Alexander Vaninsky employed DEA in May 2007 to evaluate the productivity of electric power generating enterprises in the United States. From 1991 to 2004, he evaluated the relative productivity of several businesses and estimated the goal input and production figures for those years. In 2010, he utilized auto-regression to estimate the output and input values required aimed at the optimal operation of various enterprises in order to achieve 100% efficiency.

The various models have aided in gaining a better understanding of both clean practical and scale productivity. The study's findings aided a variety of organizations in improving their production, management methods, and policies. It also emphasized that technology developments are not the primary source of rising output; rather, low productivity is the result of inefficiency. In May 2007, Alexander Vaninsky made use of DEA to assess the productivity of electric power producing firms in the United States. Heexamined the relative efficiency of many firms over a five-year period, from 1991 to 2004, and calculated the objective input and output numbers for each year. He used auto-regression in 2010 to anticipate the input and output values needed for the optimal running of several businesses. The total enactment of private segment companies is superior to their public equivalents.

Tripta Thakura, S.G. Deshmukhb, and S.C. Kaushika (June 2005) made use of the non-parametric method DEA with an intention to compare the enactment for numerous public service corporations in the country. According to the findings, many public enterprises employ a huge quantity of workers to reduce their workforce in order to boost efficiency. Another difficulty that these firms had was a lack of competition, as well as encouragement and incentives to enhance performance. Many large utility companies were determined to be inefficient rather than improving efficiency with greater scale. They have also suggested other ways to improve the country's tariff and labour policies.

The input and output variables considered for calculating relative unit efficiency play an important role inthe entire study. It is critical to determine the major variables relating to the industry that will be used to evaluate performance. According to key investigations in the power business, yearly power production is one among the most significant yield parameters, but fuel costs along with labour expenses for generating are essential input components.

2. Methodology:

2.1 Data Envelopment Analysis

Data Envelopment Analysis is utilized for calculating the efficiency of coal-fired thermal power plants. The estimated productivity metric is comparative in nature, indicating how all of the power plants performed in comparison to all others in India over the same time frame. The DEA doesn't need a previous weighting of the significance of the Input and Output engaged into account. DEA method agrees us to compare the comparative efficiency of Decision Making Units used for multiple input - output scenarios. The DEA simply compares businesses to greatest generators in the business. It is an extreme technique that believes if one business will achieve a given stage of output using specified input levels, other organization's of equivalent scale should be able to do the identically.

2.1.1 Constant returns to scale:

Every Decision Making Units is considered to be utilized at optimal measure, with no limitations on inputs or outputs. The scale of operation is seen here. This model (CCR) suggests an isoquant reduction in inputs used to obtain the desired output (Farrell). When distinct DMUs function at different scales, this approach is inapplicable.

2.1.2 Variable returns to scale:

This representation can be utilized to get around a continuous return to scale model's constraint. The variablereturns to scale model (BCC), which can compute efficiency for rising, decreasing, or constant scales, as well as Farell and Fieldhouse's non diminishing returns model (1962). The notion of continuous returns to scale combines technological and scale efficiency. Variable Return to Scale representations divides the productivity in 2 parts 1. Pure technical efficiency 2. Scale efficiency

"The relationship can be explained as"

"Technical efficiency (CRS) = Scale efficiency * Technical efficiency (VRS)"

DEA Approach:

The technical productivities of various Decision Making Units are determined with the help of the Constant returns to scale (CRS) Data Envelopment Approach representation. The computation of DEA efficiency scores using mathematical formulae is detailed here. The rectilinear programming representation with specific restrictions for calculating the efficiency of associated DMUs for a certain output variables and a specific inputvariables are as follows.

DMU's: ***j = 1, 2 ....to n***

Output variables: ***yrj, r = 1,2 ....to sInput variables: xij, i = 1,2 . . . to***

Here the weightage for the outputs and inputs, are ur and vi respectively, where the input and output values, and all weightages, are considered to be positive. The weightages ur and vi for all Decision Making Units stay totally decided by the output and input data of all Decision Making Units in the cluster of data. As a result, the weightages assigned to every Decision Making Unit is those that optimize the productivity mark of the focal DMU.

$$Maximize\theta_0 = \sum_{r=1}^{s} u_r y_{r0} / \sum_{i=1}^{m} v_i x_{i0}$$

$$Subject\ to\ \frac{\sum_{r=1}^{s} u_r y_{rj}}{\sum_{i=1}^{s} v_i x_{ij}} \leq 1$$

$$u_{r,i} > 0\ for\ every\ r\ and\ i$$

3.1 Benchmarks:

The Decision Making Units that are on the proficient boundary serve as models of further Decision Making Units as well as aimed at the selves. Best practices remain claimed chosen to be followed by benchmark DMUs. Each inefficient DMU can be benchmarked by one or more DMUs. In this case, DMU must use a combination of all target Decision Making Units and shadow administration practices trailed by standard Decision Making Units. It must decrease input or grow the output in fraction to the standard Decision Making Units in order to become productive and touch the productivity boundary.

3.1.1 Input Variables:

Installed Power Generation Capacity:

Total installed capacity must be included in the input variable since it involves a considerable capital expenditure in equipment and apparatus.

Fuel/ Raw material Expenses:

Because fuel is the major supply used to generate electricity in thermal power plants, it is a critical input variable for productivity analysis.

Employees Expenses:

Another key component in power generating is the amount of labor used per unit produced.

3.1.2 Output Variables:

Power Generated:

PLF (%) = Energy generated During Period * 100 Total capacity
* Total hours under review

PLF is used to calculate a plant's volume operation. It is a amount for a plant's production in relation towards the highest output it will be attain. The PLF is constantly lesser compared to the one since it can certainly not generate more than its full capacity. A low load factor power plant is regarded to be less efficient than a high load factor power plant. As a result, a higher load factor produces more units of energy at a lesser expense for each unit of power.

Produced power will aid to gauge the productivity of power producing organizations. It will behelp us to gauge

Sales revenues:"

Because electricity production has such high prices, it's vital to figure out how much moneymay be made by recouping those costs through sales.

4 Results:

4.1.1 Constant Returns to Scale (CRS) Model:"

Original Data:

CategoricalStations	Employe esBenefit (mill INR)	Monitored Capacity (MW)	Raw Material(mill INR)	Generation (MWh)	Sales Revenues (mill INR)
APGENCO	7671.1	5189.6	82987.2	34883.36	138625
APL	1571.8	8600.1	61557.8	43782.39	107145
CGPL	3667.25	500.2	4556.38	1562.62	7716
DVC	10443.1	6291	75392	27849.79	116062
GSECL	5146.5	5658.61	37397.5	14590.74	61534
HPGCL	2093.4	3160.1	61630.1	13052.13	70372
JPL	610.2	1001	4831.3	8208.18	24569
JSWEL	890.1	2061	36779	14606.69	86888
KPCL	7358.2	2847.91	46361	15856.49	65487
MAHAGENCO	9100.37	9071	108221.1	40289.85	164238
MPL	319.8	1051	13307.6	6303.68	23381
MPPGCL	3981.07	3846	4328.26	16213.77	53047
NLC	22351	2991	923.2	19987.98	59674
NTPC Ltd	47675.5	37042.24	465104	233266.54	726441
RRVUNL	1858	4293.9	71792	24239.03	84015
TATA PCL	6210.2	2021.2	41442.9	9411.88	86905
UPRVUNL	5534.88	4924	54891.6	25874.49	79196
WBPDC	3984.87	4421	59549.7	20769.07	80213

The table depicts the original data from several DMUs used to calculate efficiencies, as well as the three inputvariables and two output variables used to calculate productivities.

Efficiencies:

Table 11 Constant Returns to Scale DEA method was used to calculate efficiencies.

DMU No.	DMU Name	CRS Efficiency
1	APGENCO	0.87596
2	APL	1.00000
3	CGPL	0.49615
4	DVC	0.57321
5	GSECL	0.40211
6	HPGCL	0.56758
7	JPL	1.00000

8	JSWEL	1.00000
9	KPCL	0.71945
10	MAHAGENCO	0.57233
11	MPL	0.98832
"12"	"MPPGCL"	01.000000
"13"	"NLC"	01.000000
14	NTPC Ltd.	0.77216
15	RRVUNL	0.79728
"16"	"TATA PCL"	01.000000
17	UPRVUNL	0.64264
18	WBPDC	0.59898

Desk shows that productivity marks for several Decision Making Units determined with the help of CRS Data Envelopment Approach method. The emphasized rows represent productive Decision Making Units that make the best with the help of specific inputs for chosen outputs. Decision Making Units with productivities not more than one are wasteful which implies they can cut their input consumption by a specific fraction for the identical output data in order to become productive and achieve productivity mark point equal to 1. With an efficiency score of 0.98832,

Slack table:

Table 12 Constant Returns to Scale DEA approach to calculate Slack values

		Input Slacks			**Output Slacks**	
DMU No.	**DMU Name**	***Employees Expenses (mill INR***	***Monitore dCapacity (MW)***	***Raw Material (mill INR)***	**Generation (MWh)**	**Sales Revenues (mill INR)**
1	APGENCO	4318.4341	0.00000	29693.353	0.00000	0.00000
2	APL	0.00000	0.00000	0.00000	0.00000	0.00000
3	CGPL	841.92947	0.00000	0.00000	156.30439	0.00000
4	DVC	4063.7015	0.00000	5483.3823	0.00000	0.00000
5	GSECL	0.00000	0.00000	0.00000	3541.7707	0.00000
6	HPGCL	361.91598	0.00000	6871.3653	0.00000	0.00000
7	JPL	0.00000	0.00000	0.00000	0.00000	0.00000
8	JSWEL	0.00000	0.00000	0.00000	0.00000	0.00000
9	KPCL	4202.7512	0.00000	12362.707	0.00000	0.00000
10	MAHAGENCO	2511.8677	0.00000	9729.4537	0.00000	0.00000
11	MPL	0.00000	0.00000	291.50231	0.00000	4641.54562
12	MPPGCL	0.00000	0.00000	0.00000	0.00000	0.00000
13	NLC	0.00000	0.00000	0.00000	0.00000	0.00000
14	NTPC Ltd.	19601.1131	0.00000	203401.171	0.00000	0.00000
15	RRVUNL	0.00000	0.00000	0.00000	0.00000	53201.5211
16	TATA PCL	0.00000	0.00000	0.00000	0.00000	0.00000
17	UPRVUNL	1639.97208	0.00000	18899.0551	0.00000	0.00000
18	WBPDC	919.63096	0.00000	11659.302	0.00000	0.00000

Above desk depicts various levels of several Decision Making Units with productivity scores not more than one. Slackvariable data for MAHAGENCO is as follows:

Input slack variables:

Employees Benefit = 2410.8679 Raw Material = 9729.4535
The value of Input slack variables suggests that MAHAGENCO can reduce its inputconsumption by thosemany units to make it efficiency score from 0.5417 to 1.

Output Slack variables:

The output slack variable of **MPL** is taken in to considerationSales Revenues (mill INR): 4638.54563
The figure indicates that in order to attain the efficient frontier, this MPL must lower input resource consumption of Raw Material expenditures by 289.5023 mill INR while also increasing output variable sales revenue by 4638.54563.

Target Data Table

Table: 13 Objective values measured with the help of CRS DEA method

	Efficient Input Target			**Efficient Output Target**	
DMU Name	***Employees Benefit (mill INR)***	***Monitore dCapacity (MW)***	***Raw material(mill INR)***	**Generation (MWh)**	**Sales Revenues (mill INR)**
APGENCO	2398.51561	4460.76881	43020.57265	34772.36000	138625.00000
APL	1618.91000	8580.10000	61557.91000	43782.37000	107144.40000
CGPL	981.63112	248.18175	2260.70451	1708.91439	7717.50000
DVC	1919.17623	3605.49793	37741.52486	27849.68000	116060.00000
GSECL	2071.46252	2275.44720	15037.68139	18122.52085	61533.30000
HPGCL	831.29409	1793.62461	28118.04044	13052.13000	70372.20000
JPL	609.31000	1001.00000	4831.41000	8208.18000	24568.80000
JSWEL	889.10000	2061.00000	36778.10000	14606.67000	86888.50000
KPCL	1101.20809	2049.90519	21100.49328	15856.49000	65487.04000
MAHAGENCO	2801.53738	5193.07423	52207.43640	40289.85000	164237.62000
MPL	321.25904	1038.72115	12862.37797	6303.68000	28021.54563
MPPGCL	3979.16000	3846.00000	4328.26000	16213.75000	53046.63000
NLC	22351.00000	2991.00000	923.20000	19987.98000	59673.67000
NTPC Ltd.	17216.75798	28601.3210	155746.0812	233266.54000	726441.20000
RRVUNL	1483.12700	3519.29947	57236.50040	24239.14000	137214.52126
TATA PCL	6211.40100	2032.31000	41442.90000	9411.88000	86904.80000
UPRVUNL	1916.88408	3265.65116	16372.81597	25874.47000	79196.31000
WBPDC	1463.28023	2651.54677	24006.56306	20769.16000	80213.00000

The goal desk shows input and output data that each decision-making unit should aim for in orderto achieve the productivity boundary. For MPL, it is clear that the data of the inputs are modified from their previous data.

Table: 14 Comparison of original and target values for MPL

	DMU Name	*Employees Benefit (mill INR)*	*Monitored Capacity (MW)*	*Raw material (mill INR)*	**Generation (MWh)**	**Sales Revenues (mill INR)**
Originalvalues	MPL	320.8	1052	13407.6	6299.68	23381
Target Values	MPL	321.15903	1041.72116	12902.37788	6299.68000	27998.54564

To reach the efficient frontier, MPL must decrease input Workers profit to 321.15903 since its current value of 319.9, reduce Monitored capacity to 1041.72116 from its current value of 1050, and reduce Raw material expenses to 12862.377 from its current value of 13307.5, while maintaining the output value of Generation at 6303.69 and increasing Sales revenues to 28020.545 from its current value of 23382.

Optimum Lambda with Benchmark:

Table: 15 Optimal lambdas with targets measured with the help of CRS DEA method

DMU Name	**Sum of Lambdas**	**Optimal Lambdas with Benchmarks**					
APGENCO	3.613	2.813	JPL	0.810	JSWEL		
APL	1.000	1.000	APL				
CGPL	0.103	0.061	JSWEL	0.042	NLC		
DVC	2.801	2.046	JPL	0.759	JSWEL		
GSECL	2.025	1.818	JPL	0.168	JSWEL	0.036	NLC
HPGCL	1.026	0.310	JPL	0.726	JSWEL		
JPL	1.000	1.000	JPL				
JSWEL	1.000	1.000	JSWEL				
KPCL	1.607	1.188	JPL	0.419	JSWEL		
MAHAGENCO	4.121	3.108	JPL	1.012	JSWEL		
MPL	0.309	0.063	APL	0.247	JSWEL		
MPPGCL	1.000	1.000	MPPGCL				
NLC	1.000	1.000	NLC				
NTPC Ltd.	27.908	27.255	JPL	0.655	JSWEL		
RRVUNL	1.714	0.016	APL	0.195	JPL	1.506	JSWEL
TATA PCL	1.000	1.000	TATA PCL				
UPRVUNL	3.122	3.081	JPL	0.042	JSWEL		
WBPDC	2.205	1.787	JPL	0.419	JSWEL		

The efficiency scores with variable returns to scale (BCC model) are different from the constant returns to scale. This is called pure technical efficiency. Some companies with efficiency scoresless than one on CRS have been able to achieve VRS efficiency score one. If UPRVNL becomes able to reduce its input or increase output by the suggested value it will soon become benchmark for itself and will have efficiency score of one.

Variable Returns to Scale (VRS) model:
Efficiencies:

The efficiency scores with variable returns to scale (BCC model) differ from those with constant returns to scale. This is known as pure technical efficiency. Some organizations with CRS efficiency ratings less than one have been able to obtain VRS efficiency score one.

Table 16 Efficiencies calculated using Variable Returns to Scale DEA approach

Input-Oriented VRS			
DMU No.	*DMU Name*	*Efficiency*	*Returns to scale*
1	APGENCO	1.00000	Decreasing
2	APL	1.00000	Constant
3	BPSCL	1.00000	Increasing
4	DVC	0.69742	Decreasing
5	GSECL	0.47275	Decreasing
6	HPGCL	0.56947	Decreasing
7	JPL	1.00000	Constant
8	JSWEL	1.00000	Constant
9	KPCL	0.77092	Decreasing
10	MAHAGENCO	0.80578	Decreasing
11	MPL	1.00000	Increasing
12	MPPGCL	1.00000	Constant
13	NLC	1.00000	Constant
14	NTPC Ltd.	1.00000	Decreasing
15	RRVUNL	0.93299	Decreasing
16	TATA PCL	1.00000	Constant
17	UPRVUNL	0.77711	Decreasing
18	WBPDC	0.68461	Decreasing

Slack:

Table: 17 Slack values measured with the help of VRS DEA method

	"Input Slacks"			**Output Slacks**	
DMU Name	***Employees Benefit (millINR)***	***Monitored Capacity (MW)***	***Raw Material (mill INR)***	**Generation (MWH)**	**Sales Revenues (mill INR)**
APGENCO	0.00000	0.00000	0.00000	0.00000	0.00000
APL	0.00000	0.00000	0.00000	0.00000	0.00000
CGPL	0.00000	0.00000	0.00000	0.00000	0.00000

DVC	0.00000	0.00000	0.00000	321.80385	0.00000
GSECL	0.00000	0.00000	0.00000	0.00000	0.00000
HPGCL	314.05842	0.00000	6599.26243	0.00000	0.00000
JPL	0.00000	0.00000	0.00000	0.00000	0.00000
JSWEL	0.00000	0.00000	0.00000	0.00000	0.00000
KPCL	3359.53822	0.00000	5384.91437	0.00000	0.00000
MAHAGENCO	0.00000	506.74470	0.00000	2619.53	0.00000
MPL	0.00000	0.00000	0.00000	0.00000	0.00000
MPPGCL	0.00000	0.00000	0.00000	0.00000	0.00000
NLC	0.00000	0.00000	0.00000	0.00000	0.00000
NTPC Ltd.	0.00000	0.00000	0.00000	0.00000	0.00000
RRVUNL	0.00000	0.00000	18412.0146	0.00000	16817.6514
TATA PCL	0.00000	0.00000	0.00000	0.00000	0.00000
UPRVUNL	0.00000	0.00000	0.00000	0.00000	3561.55623
WBPDC	0.00000	0.00000	0.00000	0.00000	6033.30360

Target Table:

Table: 18 Target values measured with the help of VRS DEA method

	Efficient Input Target			**Efficient Output Target**	
DMU Name	***Employees Benefit(mill INR)***	***Monitored Capacity (MW)***	***Raw Material (mill INR)***	**Generation (MWH)**	**Sales Revenues (mill INR)**
APGENCO	7668.20000	5092.50000	82897.10000	34772.35000	138626.00000
APL	1568.90000	8580.00000	61557.90000	43782.38000	107144.30000
CGPL	3667.26000	500.00000	4556.37000	1562.61000	7717.40000
DVC	7283.13187	4386.75663	52580.40419	28171.49385	116061.00000
GSECL	2433.05831	2675.11608	17679.73835	14590.75000	61533.20000
HPGCL	878.13251	1799.53347	28497.33488	13052.12000	70371.20000
JPL	610.30000	1000.00000	4831.40000	8208.19000	24567.80000
JSWEL	890.00000	2060.00000	36778.00000	14606.68000	86888.60000
KPCL	2313.11295	2195.51482	30354.87723	15856.48000	65486.04000
MAHAGENCO	7332.90915	6803.31247	87202.56796	42909.36984	164238.6200
MPL	319.90000	1050.00000	13307.50000	6303.69000	23382.0000
MPPGCL	3981.06000	3845.00000	4328.25000	16213.76000	53045.6300
NLC	22350.00000	2990.00000	923.10000	19987.97000	59672.6700
NTPC Ltd.	47675.40000	37042.23000	465102.9000	233266.5300	726440.2000
RRVUNL	1734.42473	4006.06395	48568.12827	24239.04000	100831.6514
TATA PCL	6210.30000	2021.30000	41442.80000	9411.89000	86903.80000
UPRVUNL	4301.19272	3825.70354	42656.78877	25874.48000	82756.8662
WBPDC	2728.05768	3025.95698	40768.10912	20769.06000	86245.3036

Optimal Lambdas with Benchmarks:

Table: 19 Optimal lambdas with reference measured with CRS DEA method

DMU Name	**Optimal Lambdas with Benchmarks**									
APGENCO	1.000	APGENCO								
APL	1.000	APL								
CGPL	1.000	BPSCL								
DVC	0.688	JSWEL	0.095	MPPGCL	0.159	NLC	0.057	NTPC Ltd.		
GSECL	0.210	JPL	0.369	JSWEL	0.409	MPPGCL	0.010	NLC	0.003	NTPC Ltd.
HPGCL	0.010	APGENCO	0.273	JPL	0.718	JSWEL				
JPL	1.000	JPL								
JSWEL	1.000	JSWEL								
KPCL	0.232	APGENCO	0.536	JPL	0.232	JSWEL				
MAHAGENCO	0.731	JSWEL	0.141	MPPGCL	0.128	NTPC Ltd.				
MPL	1.000	MPL								
MPPGCL	1.000	MPPGCL								
NLC	1.000	NLC								
NTPC Ltd.	1.000	NTPC Ltd.								
RRVUNL	0.219	APL	0.766	JSWEL	0.015	NTPC Ltd.				
TATA PCL	1.000	TATA PCL								
UPRVUNL	0.032	APGENCO	0.845	JPL	0.049	JSWEL	0.073	NTPC Ltd.		
WBPDC	0.023	APGENCO	0.424	JPL	0.514	JSWEL	0.038	NTPC Ltd.		

Scale Efficiencies:
Efficiency table

Table: 20 Scales productivities measured from VRS productivity and CRS productivity marks

DMU No.	DMU Name	CRS Efficiency	VRS Efficiency	Scale Efficiency
1	**APGENCO**	0.87595	1.00000	0.875949
2	**APL**	1.00000	1.00000	1
3	**CGPL**	0.49616	1.00000	0.496164
4	**DVC**	0.57320	0.69742	0.821882
5	**GSECL**	0.40210	0.47275	0.85056
6	**HPGCL**	0.56757	0.56947	0.996661
7	**JPL**	1.00000	1.00000	1
8	**JSWEL**	1.00000	1.00000	1
9	**KPCL**	0.71944	0.77092	0.933223
10	**MAHAGEN CO**	0.57232	0.80578	0.710265
11	**MPL**	0.98831	1.00000	0.988306
12	**MPPGCL**	1.00000	1.00000	1
13	**NLC**	1.00000	1.00000	1
14	**NTPC Ltd.**	0.77215	1.00000	0.772154
15	**RRVUNL**	0.79727	0.93299	0.854529
16	**TATA PCL**	1.00000	1.00000	1
17	**UPRVUNL**	0.64263	0.77711	0.826946
18	**WBPDC**	0.59899	0.68461	0.874945

Firms with a Constant Return to Scale mark of not more than one and a Variable Return to Scale score ofone have a Constant Return to Scale mark of not more than one and a Variable Return to Scale mark of one because of scale productivity mark data not more than one.

5. Key Findings:

With little exceptions, the whole segment runs on an productivity mark greater than 0.5. The majority ofprivate segment firms are determined to be on the efficient envelop, with a productivity mark of one. The primary cause which increased productivities was shown to be productivity resource usage, such as staff expenditures and fuel costs for electricity generation. MPL is the only private sector company witha true efficiency score of 0.988.

When compared to comparable moderate capacity rivals, NTPC, one of India's major public sector companies, has an efficiency score of 0.77215, which is inefficient. The efficiency score of two public- sector businesses was judged to be one.

To increase their efficiency, most businesses must lower their personnel and fuel costs. In order to achieve the efficient frontier, certain organizations must simultaneously enhance their output while reducing their inputs.

The high cost of gasoline shows that the limited resource is not being used to its maximum potential,and that technology or manufacturing methods must be improved to increase productivity.

While we put various units on varied marks, organization with a huge number of installed capability get an productivity mark of one, indicating that they are capable of reaching pure technical efficiency of one.

The organizations are found to be deficient in attaining scale productivities which has pure technical productivity mark one (Variable Return to Scale) but does not have Constant Return to Scale productivity score one. (BPSCL, APGENCO, NTPC, MPPGL). All private sector companies have been able to achieve scale efficiency also equals to one.

6. Conclusion:

Private enterprises use cutting-edge technology and invest in expanding their production skills, and they have built a high-performance culture. Profit is the driving force behind these businesses, and they strivefor ongoing progress. Because of all of these variables, these businesses have been able to attain extremely high efficiency when compared to government-run enterprises.

Because of the great efficiency of the private sector, the government should encourage private investment in electricity generation and create incentive measures to attract it. To attract international investors, the government must make significant efforts to enhance the business environment and minimise bureaucratic red tape. The promotion of FDI will also aid in technology transfer, which will not only increase production and overall system efficiency, but will also assist to minimise overall environmental degradation caused by poor productivity and subpar technologies.

To attain targeted efficiency, the majority of public sector enterprises must minimise labour costs. Because of labour restrictions in the public sector, it is extremely difficult for the government to terminate low-performing staff. This industry needs to encourage voluntary retirement plans for downsizing and embrace the high-performance culture that exists in the private sector. Some governments, like as China, are using the divestiture option to help make decisions that are not influenced by other government issues.

In this case, the government must encourage competition among diverse public-sector firms. They have little motivation to outperform others, thus the government must devise policies that encourage competition among diverse public sector enterprises.

The primary goal of public-sector companies is to provide services, but this can only be accomplished through investment in better technology and capability development; therefore, in addition to providing services, these companies should also be profit-driven in order to bring new advanced technologies to market.

These organisations with significant installed capacities were able to obtain pure technical economies but not scale efficiencies, implying that greater decentralisation and reorganisation of these companies will aid in better management.

As the government has proposed ultra-mega power plants, it will be preferable to develop them through public-private partnerships because private sector engagement helps to introduce high-performance culture and managerial skills, which improves production capacities.

Public sector enterprises can adopt best practices used by private sector companies or bring technology and experience from other nations via various treaties. Because of the increased focus on climate change and environmental preservation, all countries are eager to transfer clean energy production technology. As this involves large initial capital inputs, it should be supported through different incentives such as double taxation avoidance or tax breaks for the first few years.

References:

Farrell, M. J. (1957). The measurement of productive efficiency. *Journal of the Royal Statistical Society.Series A (General)*, 253-290.

Charnes, A., Cooper, W. W., & Rhodes, E. (1978). Measuring the efficiency of decision makingunits. *European journal of operational research*, *2*(6), 429-444.

Charnes, A., Cooper, W. W., Golany, B., Seiford, L., & Stutz, J. (1985). Foundations of data envelopment analysis for Pareto-Koopmans efficient empirical production functions. *Journal of econometrics*, *30*(1), 91-107.

Golany, B., Roll, Y., & Rybak, D. (1994). Measuring efficiency of power plants in Israel by data envelopment analysis. *Engineering Management, IEEE Transactions on*, *41*(3), 291-301.

Lam, P. L., & Shiu, A. (2004). Efficiency and productivity of China's thermal power generation. *Review of Industrial Organization*, *24*(1), 73-93.

Thakur, T., Deshmukh, S. G., & Kaushik, S. C. (2006). Efficiency evaluation of the state owned electric utilities in India. *Energy Policy*, *34*(17), 2788-2804.

Vaninsky, A. (2006). Efficiency of electric power generation in the United States: analysis and forecast based on data envelopment analysis. *Energy Economics*, *28*(3), 326-338.

Sarıca, K., & Or, I. (2007). Efficiency assessment of Turkish power plants using data envelopment analysis. *Energy*, *32*(8), 1484-1499.

Tone, K., & Tsutsui, M. (2007). Decomposition of cost efficiency and its application to Japanese-US electric utility comparisons. *Socio-Economic Planning Sciences*, *41*(2), 91-106.

Shafali, J., Tripta, T., & Arun, S. (2010). Cost Benchmarking of Generation Utilities Using DEA: A Case Study of India. *Technology and Investment*, *2010*.

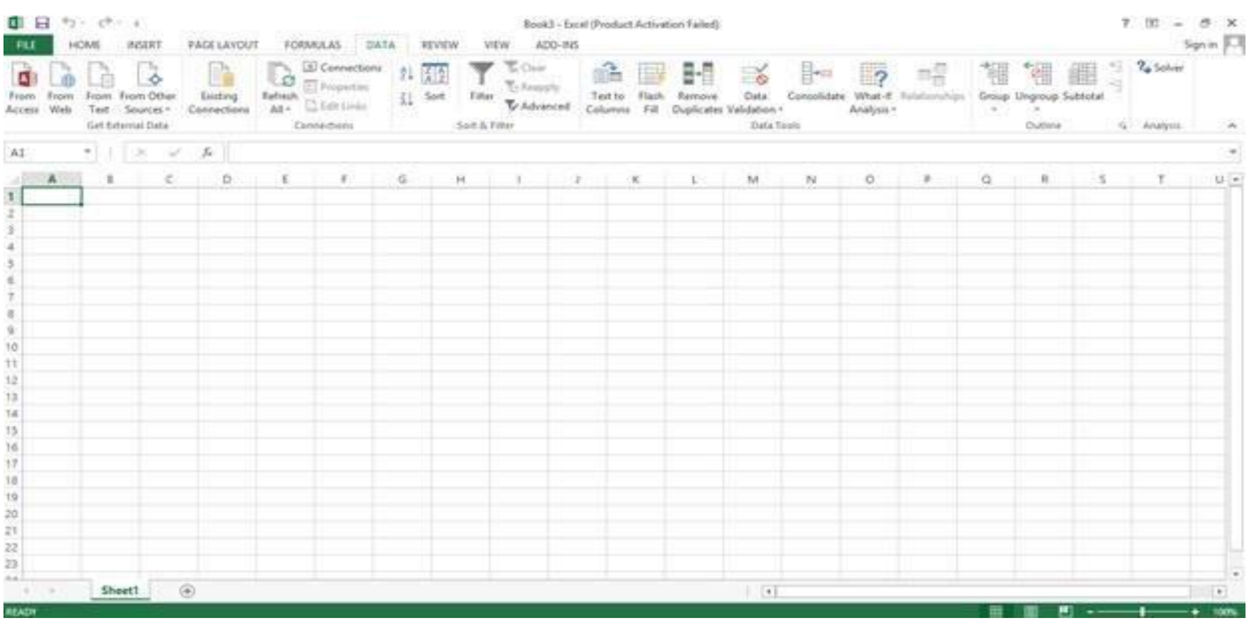
Fallahi, A., Ebrahimi, R., & Ghaderi, S. F. (2011). Measuring efficiency and productivity change in power electric generation management companies by using data envelopment analysis: A case
study. *Energy*, *36*(11), 6398-6405.

Jain, S., & Thakur, T. Efficiency assessment of state owned electricity generation companies in India using data envelopment analysis.

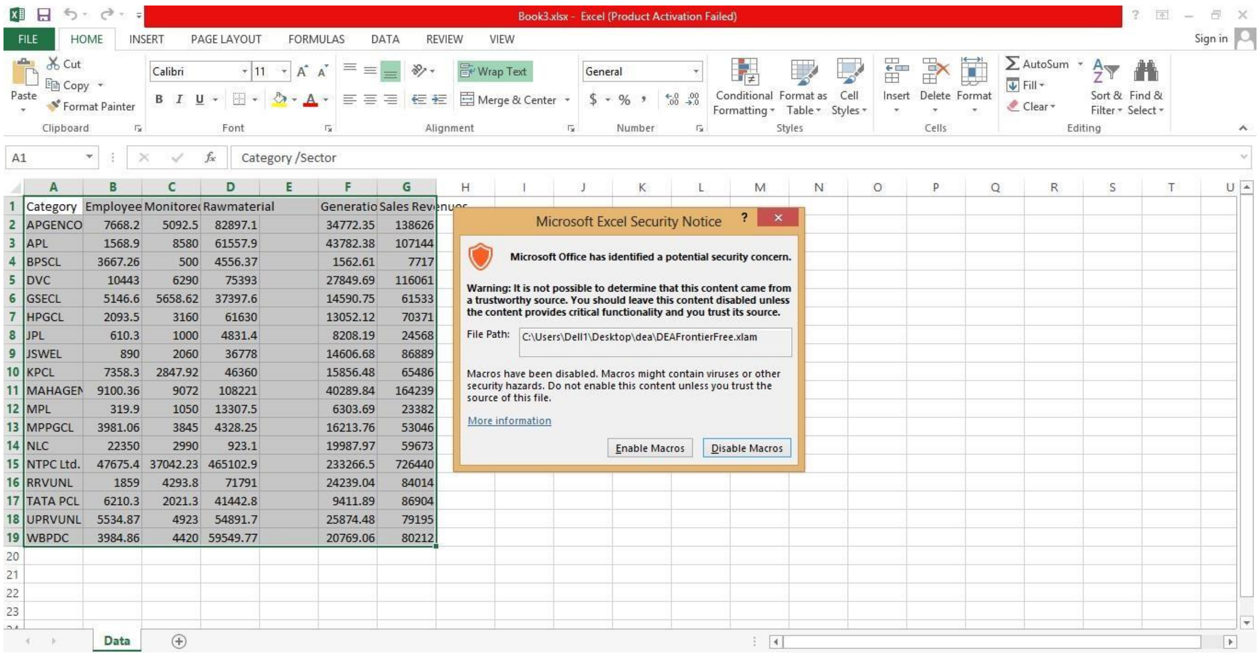
Appendix

Usage of Tool:

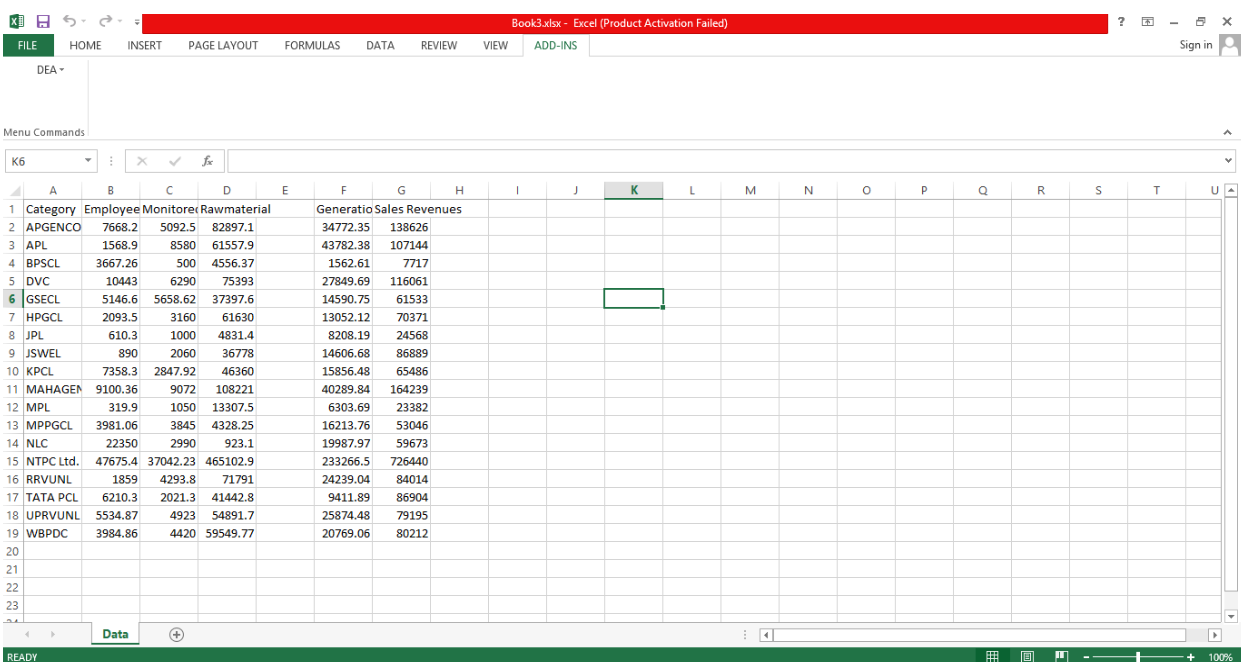
Make sure that Excel solver is available in the Data menu



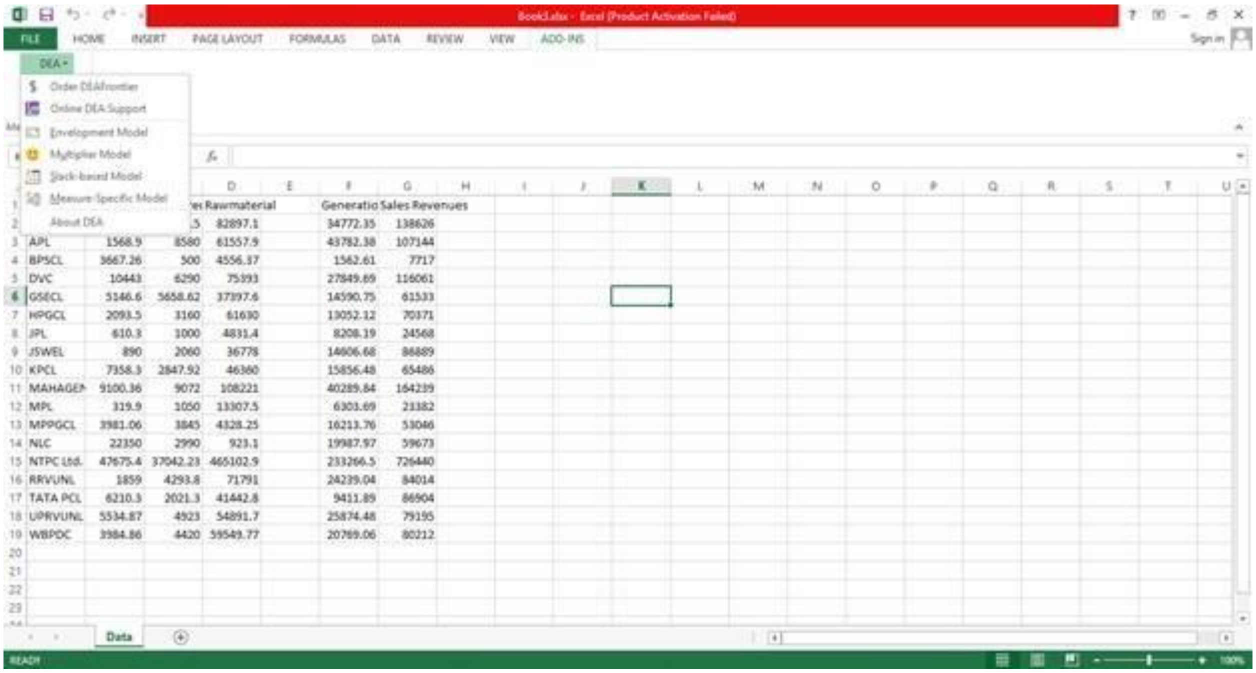
Now, Open DEAfrontier.xla file in to excel where Data file is also open, which will ask to enable macros



After enabling macros, you will be able to find DEA ad in in the menu bar

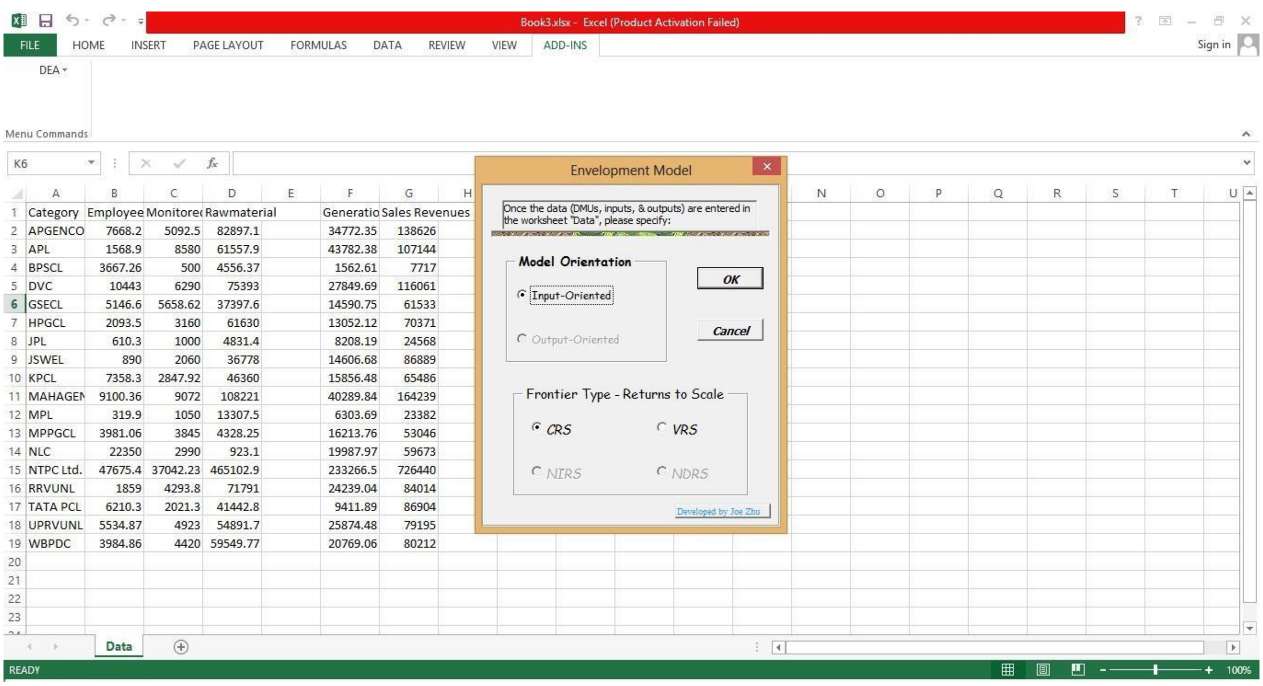


By moving cursor to the DEA add in, it will show the following Add in Menu,



We can run different models based on our need to analyse various efficiencies.

For example, to run CRS input oriented envelopment model just need to click the ok to the following tabafter choosing the needed option



It will give final results in different sheets named efficiency, slack and target for respective measures.