Estimation of operational efficiency and its determinants of Thermal power plants by using DEA

R Sharma

School of Mechanical Engineering

Lovely Professional University, Phagwara, Punjab

Abstract: *Present research attempts to benchmark the performance of coal fired power plant (CFPPs) by estimating their operational efficiency and its determinants using Data Envelopment analysis (DEA). Data Envelopment Analysis (DEA), a comparative or relative method for calculating output that uses multiple variables to compare certain defined units with each other. This seeks no absolute efficiency metric, but offers a basis for recognizing good performance practices. It helps to create performance targets, optimal operating rates, role models that can mimic dysfunctional coal-fired power plants (CFPPs), and to what degree improvements can be made over time. This technique is applied to 2016-17 coal-fired power plant data (CFPPs) where CFPP performance is measured. The results suggest ways to improve the overall efficiency of many CFPPs. DEAP technologies is used for analytical purposes.*

Key words: *Operational efficiency, Thermal power plants, DEA*

1. History

Using a production function, a company's input and output combinations are represented in microeconomic development theory. The maximum efficiency that can be achieved with any possible combination of inputs can be demonstrated using a production function. DEA was founded about 30 years ago to answer the question of how to use this concept in practical applications when solving the problem that one can look for actual companies (or other DMUs)

Building on the concepts of Farrell (1957), Charnes, Cooper & Rhodes ' seminal work "Measuring the Efficiency of Decision-making Units" (1978) first uses linear programming to estimate quantitative output engineering limits. The method was historically used in Germany to estimate the average efficiency of R&D and other output factors (Brockhoff 1970). Since then, DEA has written several books and journal articles or applied DEA to various sets of issues. In addition to a company's assessment of performance across DMUs, DEA was also used to measure business efficiency. There are several types of DEA with the most common being CCR based on Charnes, Cooper & Rhodes, but DEA also tackles various scale returns, including CRS (constant scale returns, VRS (variable), non-increasing scale returns, or Ylvinger (2000) non-decreasing scale returns. Seiford & Thrall (1990) recorded the major developments of DEA in the 1970s and 1980s.

2. General Introduction

India faces a huge challenge in its power sector over the next few decades. The per capita energy consumption of India is actually much lower than that of China and other industrialized nations. However, the country is one of the five fastest growing economies in the world, and the only country of those five with a gross domestic product (GDP) of over $1 trillion, according to Nasdaq. Bloomberg estimates that 240 million Indians do not have access to affordable electricity. Thus, one challenge India faces is providing affordable electricity to a staggering number of people, while managing emissions. Improving steam power plant efficiency is one tool that will help the nation achieve this objective.

3. Energy Consumption Trends in India

The Economic Times projects that India's energy consumption is set to grow at an average annual rate of 4.2 percent through 2035. This is the fastest growth rate of any major economy in the world. The growth rate for renewables in India is expected to be much higher than for fossil fuels, but consumption of oil, gas, and coal are all expected to more than double by 2035.

With the rapid growth in fossil fuel consumption, India will be challenged to meet its climate commitments. On April 22, 2016, India became a signatory of a treaty negotiated by 195 countries in Paris. The goal of the Paris Accord is to arrest the rise of the world's carbon dioxide emissions. The agreement seeks to achieve "global peaking of greenhouse gas emissions as soon as possible," according to The New York Times. As part of the Paris Accord, the Indian government committed to reducing the country's emissions intensity by 33–35 percent below the 2005 level, per unit of GDP, by 2030.

India's commitment to renewable energy will help the country meet its climate goals. An expansion in the country's nuclear power—projected to grow by more than 300 percent by 2035—will further help India manage its emissions as energy consumption rises. However, nearly 71 percent of India's power capacity is based on fossil fuels, with over 62 percent from coal, according to India's Central Electricity Authority. India's coal consumption is projected to grow by 105 percent in the next 20 years, according to The Economic Times, so it will be critical that India's coal plants are operated as efficiently as possible.

In addition, as the country expands its renewable portfolio, it will need to incorporate more load-following power plants. These load-following plants are typically gas turbines that can be started up quickly to balance out the load from variable renewables. They require fast response times to handle transient loads.

4. Improving Steam Coal Plants

Conventional steam power plants have long supplied the largest share of the world's electricity, according to Power. However, coal has the highest carbon intensity of the primary sources of electricity. According to the EIA, the production of 1 kWh of power from coal generates over 80 percent more carbon dioxide than the same electricity production from natural gas. Also, coal contains certain impurities like mercury and sulfur that can enter the environment when coal is burned in a power plant.

Thus, it is crucial to use the best pollution-control technologies available at new and existing coal-fired power plants and to maximize steam power plant efficiency. In addition to reducing the carbon dioxide emissions per unit of power production, operating plants at higher efficiency also reduces the level of pollutants such as mercury, particulate emissions (PM), NOx, and SOx per unit of power production. Technologies are available to address each pollutant individually, but an integrated solution is the best option in most cases.

Finally, employing a carrot-and-stick approach often achieves the best results. While the Indian government has announced new pollution control limits for coal-fired power plants (the "stick"), it could also provide incentives (the "carrot") to allow power generation companies to keep more of the efficiency savings. Current regulations only allow the developer to retain 60 percent of the efficiency savings. This leads to longer payback times for these projects, which decreases the incentive for generating companies to invest in retrofitting older power plants with state-of-the-art technologies to manage emissions.

India is one of the world's largest power consumers, and the country's energy consumption is set to expand dramatically in the next two decades. As a result, the country faces the challenge of managing its emissions while providing affordable power for its citizens. The emissions issue is of worldwide concern, and India is a signatory of the Paris Accord—committed to controlling global greenhouse gas emissions. An integrated solution that addresses emissions, efficiency, and flexibility, especially as variable power grows, will go a long way to help India meet its goal of providing affordable energy.

Consider, for example, a situation with K DMUs, with M inputs and N outputs each. Let X i^kbe input level I in DMUk and let Y j^kbe output level j in DMU k. Without loss of generality, inputs and outputs are supposed to be described in a way that allows for better consideration of lower inputs and higher outputs. DMU k's relative efficiency, known as byw k, is calculated by the following linear equation being solved.

$$\text{Maximize } w_k = \sum_{j=1}^{N} \beta_j Y_j^k$$

Subject To:

$$\sum_{i=1}^{M} \alpha_i X_i^k = 1$$

$$\sum_{j=1}^{N} \beta_j Y_j^t - \sum_{i=1}^{M} \alpha_i X_i^t \leq 0 \quad \forall\, t = 1, 2, \ldots, \mathrm{K}$$

$$\alpha_i, \beta_j \geq 0$$

The basic idea in this approach is to transform input and output sets using αandβ weights into a single' virtual input' and a single' virtual output.' The performance associated with DMU is defined by the ratio of digital output to virtual input.

Over the past three years, India's power sector has undergone an unprecedented turnaround, marred by chronic shortages and lack of quality and reliable supply to homes and factories.

Today, the country boasts a situation in which 3000-4000 mw of surplus power is available in real time and at competitive power exchange rates to state and distribution companies at any time of the day.

The ease of gaining power at affordable rates is the product of targeted reforms initiated over the past three years by the central government in the power sector. Within three years, India's total power capacity increased by nearly one-third (31% or 76,577 MW) from 243 GW in March 2014 to 320 GW in March 2017 and traditional or coal power (i.e. 76,577 MW).

Fuel	MW	% of Total
Total Thermal	2,18,960	66.2%
Coal	1,92,972	58.3%
Gas	25,150	7.6%
Oil	838	0.3%
Hydro (Renewable)	44,963	13.6%
Nuclear	6,780	2.0%
RES* (MNRE)	60,158	18.2%
Total	**330,861**	

* Installed capacity in respect of RES (MNRE) as on 30.09.2017.

Figure 1: Percentage of Installed Capacity for Electricity based on Fuel type- http://www.powermin.nic.in

In 2014, fuel shortages amounted to 42.428 million units (4.2%), down to 7.459 MU in 2017 (0.7%). Likewise, the peak energy shortfall in 2014 was 6,103 MW (4.5%), which in 2017 dropped to 2,608 MW (1.6%).

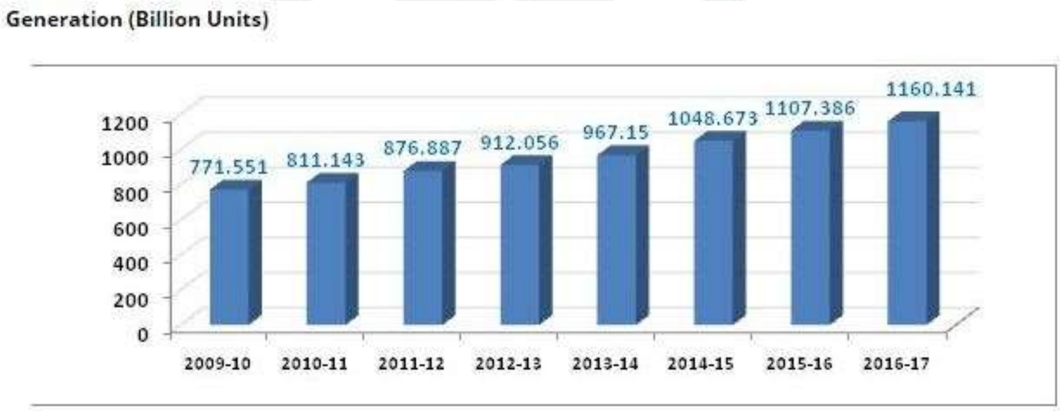


Figure 2: Electricity Generation over the year

Source- http://www.powermin.nic.in

The increase in power generation over the past three years is 6.4 percent (provisional) from 2014-2017. Generation growth would have increased more, but for Energy Efficiency programs such as UJALA, which our government has been concentrating on since 2014. Growth was 6.9% in 2014-16, and if we add the generation that was avoided due to energy efficiency activities, it was 9.5%

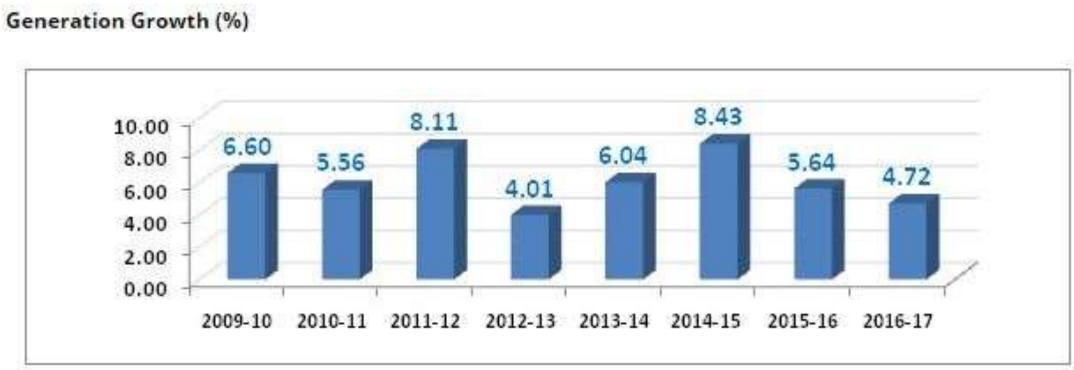


Figure 3: Electricity Generation growth in MUs over the year

Source- http://www.powermin.nic.in

Significantly, in 2017, India turned from a net importer of electricity to a net exporter of electricity exporting around 5,798 million units to Nepal, Bangladesh and Myanmar. We used the Data Envelopment Analysis (DEA) method in this research to determine the relative effectiveness of CFPPs. Using the DEA gives better insight into the asset management problems.

Project Objective

a) Identifies CFFPs which requires to be technically efficient
b) Identifies strength of individual power plant
c) It investigates the performance variables that emerge from it.
d) The study suggests a number of measures to improve efficiency.

5. LITERATURE REVIEW

Several studies have been conducted to evaluate the power generation and distribution sector's performance. Below are briefly mentioned several important studies:

Chitkara (1999) used the DEA approach to assess the inefficiencies in but also recognizing the triggers in different units of those inefficiencies.

Shrivastava et al. (2012) used the DEA test to measure the performance of thermal power plants (TPPs) and compared the size and ownership output.

Shanmugam et al. (2005) used the stochastic frontier function approach to analyze the performance of 56 coal-based thermal power plants over the period 1994-1995 and 2001-2002.

Wu et al. (2010) analyzed the shift in efficiency and productivity in different settings in 30 Chinese CFPPs between 1999 and 2007.

Azadeh and Ghaderi (2007) used a DEA, PCA and numerical taxonomy (NT) to determine the productivity of 40 TPPs in Iran. Their study's unique feature was the use of a robust PCA-NT approach to verify and validate the DEA approach.

Tyagi et al. (2009) used sensitivity analysis to assess the relative performance of IIT Roorkee's academic departments.

Fallahi et al. (2011) measured the change in efficiency and productivity in Iran's power generation businesses. Their sensitivity results indicated that all parameters had consistent efficiency scores and the analysis selected the best model.

Lam and Shiu (2001, 2004), based on cross-sectional and panel data, calculated the technical efficiency of China's thermal power generation. The analysis showed that the influences of fuel efficiency and capability have a significant impact on the technical performance.

See and Coelli (2012) used stochastic frontier analysis to analyze the degree to which different factors affect output rates in Malaysian thermal power plants. The study of researchers revealed that ownership, plant size and type of fuel have a significant influence on the level of technical efficiency while plant age and type of peak production have no statistically significant impact on technical efficiencies.

Yang and Pollitt (2009) adopted a four-stage method to assess Chinese CFPP efficiency. Their results revealed relatively significant influence of uncontrollable variables.

Using the Tobit test, Fleishman et al. (2009) analyzed the effects of air quality legislation on U.S. power plant performance. Authors have shown that more stringent regulations on sulfur dioxide have a negative effect on the output of coal plants. On the other hand, NOx regulations do not seem to have any significant impact on the efficiency of coal plants.

Sirasoontorn (2005) analyzed Thailand's state-owned electricity generation business and the findings showed that the plant age had a significant positive effect on the level of technical inefficiency.

6. Study Design

6.1 Variables and data issues

There are two types of variables:

6.2 Controllable variables

The most critical step of carrying out the DEA analysis is to determine the input and output variables. There is no universal rule for variables choice. The inputs are commonly defined as the assets used by the decision-making units (DMUs), whereas the outputs are generated by the DMUs operation. The selected input variables were designed to build the DEA model for efficiency evaluation by considering the element of energy consumption.

Table 1: Reflects statistically summarized data for the year 2016-2017.

Variable	Net Electricity produced (MU)	Coal (thousand ton)	APC (Mus)	Oil (litre)	IC (MW)
Mean	1618.62	7694.5	5580.96	616.62	125603.86
Median	1452	6500	4018.8	520	112546.8
Maximum	4750	31867	23463.4	2550	334087.76
Minimum	340	100	918	10	25524.46
SD	886.4	5489.21	4636.33	519.37	67536.62

8.3 Uncontrollable variables and expectations

DEA performance rating can be determined by the number of uncontrollable variables. Because of data unavailability, variables between age are time-oriented parameter, performance of coal is related to the geographic characteristics of coal mines, and size and plant make are basic characteristics of plant generation produced in the design and construction process. By orienting a power plant's entire thermal environment, plant operators can not alter any of these variables. We can therefore assume that at this juncture these variables are beyond managerial control.

$$\min\theta - \varepsilon \left(\sum_{k=1}^{m} s_k^- + \sum_{i=1}^{r} s_i^+ \right)$$

Subject to

$$\theta x_{\mathrm{ko}} - \sum_{j=1}^{n} x_{\mathrm{kj}}\lambda_j - s_k^- = 0$$

$$\sum_{j=1}^{n} y_{\mathrm{ij}}\,\lambda_j - s_i^+ = y_{\mathrm{io}}$$

$$\lambda_j, s_k^-, s_i^+ \geq 0$$

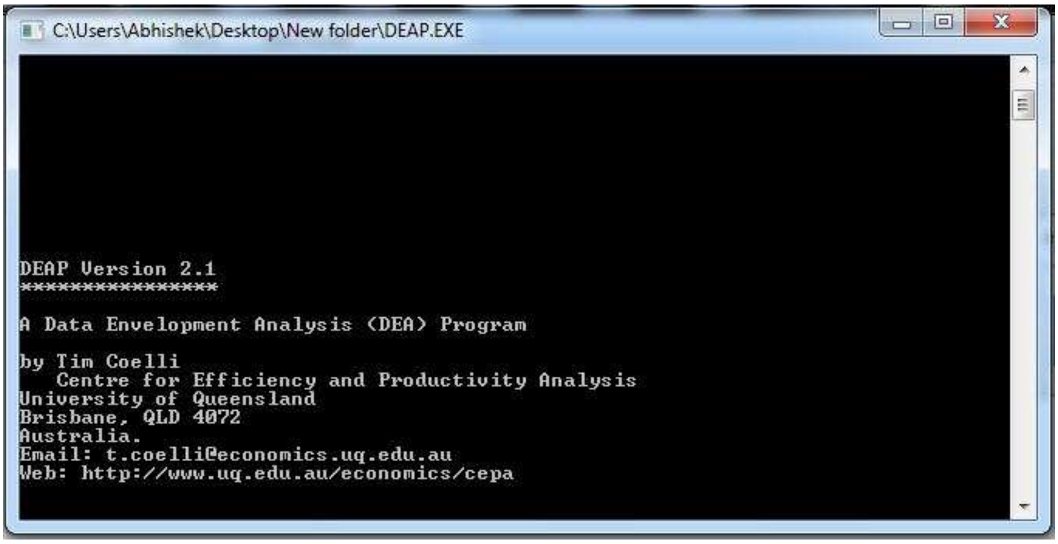
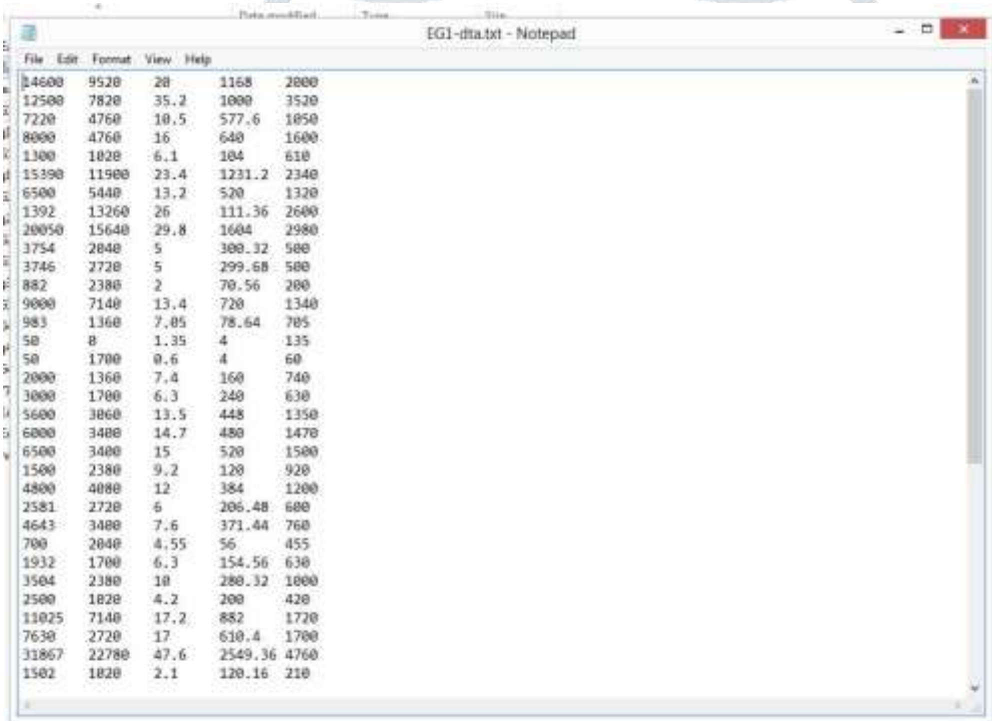


Figure 4: Screen shot of DEAP Software


EG1-dta.txt - Notepad

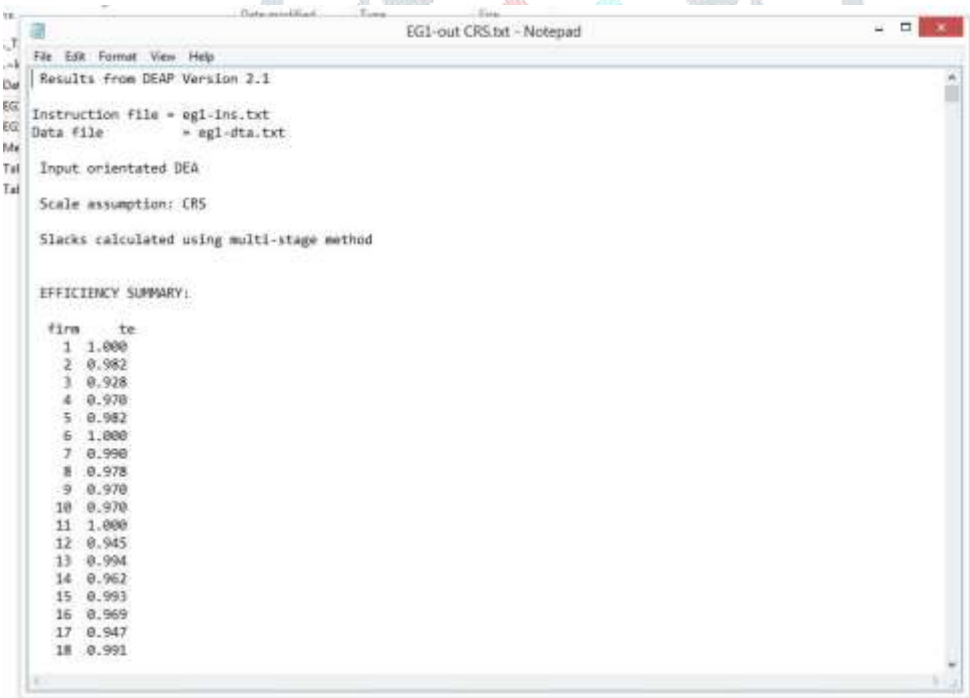
File Edit Format View Help

14600	9520	20	1168	2000
12500	7820	35.2	1000	3520
7220	4760	10.5	577.6	1050
8000	4760	16	640	1600
1300	1020	6.1	104	610
15390	11900	23.4	1231.2	2340
6500	5440	13.2	520	1320
1392	13260	26	111.36	2600
20050	15640	29.8	1604	2980
3754	2040	5	300.32	500
3746	2720	5	299.68	500
882	2380	2	70.56	200
9000	7140	13.4	720	1340
983	1360	7.05	78.64	705
50	8	1.35	4	135
50	1700	0.6	4	60
2000	1360	7.4	160	740
3000	1700	6.3	240	630
5600	3060	13.5	448	1350
6000	3400	14.7	480	1470
6500	3400	15	520	1500
1500	2380	9.2	120	920
4800	4080	12	384	1200
2581	2720	6	206.48	600
4643	3400	7.6	371.44	760
700	2040	4.55	56	455
1932	1700	6.3	154.56	630
3504	2380	10	280.32	1000
2500	1020	4.2	200	420
11025	7140	17.2	882	1720
7630	2720	17	610.4	1700
31867	22780	47.6	2549.36	4760
1502	1020	2.1	120.16	210

Figure 5: Screen shot of Input data of DEAP Software

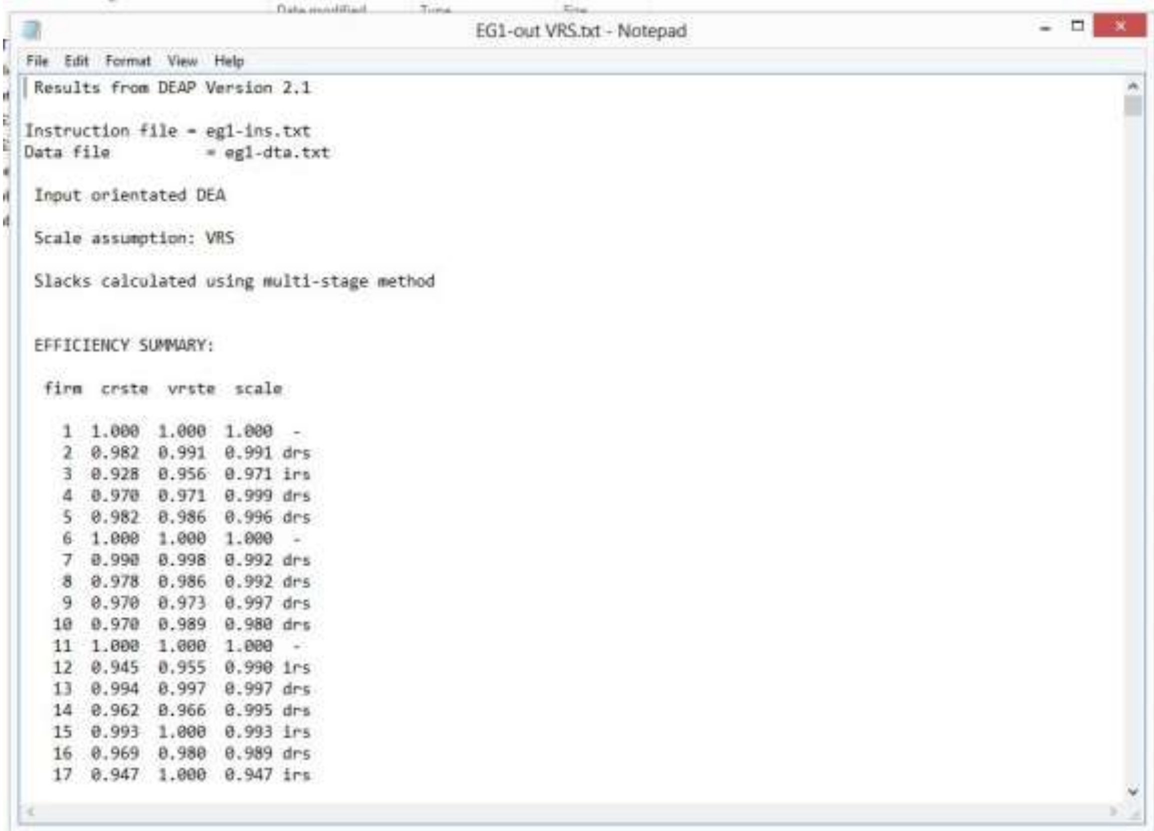
```
eg1-dta.txt        DATA FILE NAME
eg1-out.txt        OUTPUT FILE NAME
50                 NUMBER OF FIRMS
1                  NUMBER OF TIME PERIODS
1                  NUMBER OF OUTPUTS
4                  NUMBER OF INPUTS
0                  0=INPUT AND 1=OUTPUT ORIENTATED
0                  0=CRS AND 1=VRS
0                  0=DEA(MULTI-STAGE), 1=COST-DEA, 2=MALMQUIST-DEA, 3=DEA(1-STAGE), 4=DEA(2-STAGE)
```

Figure 6: Screen shot of Input Instruction File of DEAP Software



```
Results from DEAP Version 2.1

Instruction file = eg1-ins.txt
Data file        = eg1-dta.txt

Input orientated DEA

Scale assumption: CRS

Slacks calculated using multi-stage method


EFFICIENCY SUMMARY:

 firm   te
   1  1.000
   2  0.982
   3  0.928
   4  0.970
   5  0.982
   6  1.000
   7  0.990
   8  0.978
   9  0.970
  10  0.970
  11  1.000
  12  0.945
  13  0.994
  14  0.962
  15  0.993
  16  0.969
  17  0.947
  18  0.991
```

Figure 7: Screen shot of Output File- CRS of DEAP Software




```
Results from DEAP Version 2.1

Instruction file = eg1-ins.txt
Data file        = eg1-dta.txt

 Input orientated DEA

 Scale assumption: VRS

 Slacks calculated using multi-stage method


 EFFICIENCY SUMMARY:

  firm  crste  vrste  scale

    1  1.000  1.000  1.000  -
    2  0.982  0.991  0.991 drs
    3  0.928  0.956  0.971 irs
    4  0.970  0.971  0.999 drs
    5  0.982  0.986  0.996 drs
    6  1.000  1.000  1.000  -
    7  0.990  0.998  0.992 drs
    8  0.978  0.986  0.992 drs
    9  0.970  0.973  0.997 drs
   10  0.970  0.989  0.980 drs
   11  1.000  1.000  1.000  -
   12  0.945  0.955  0.990 irs
   13  0.994  0.997  0.997 drs
   14  0.962  0.966  0.995 drs
   15  0.993  1.000  0.993 irs
   16  0.969  0.980  0.989 drs
   17  0.947  1.000  0.947 irs
```

Figure 8: Screen shot of Output File- VRS of DEAP Software

Table:2- Data used for calculation of efficiency is as per collected data is as per table given below:

S.No	REGION	STATION_NAME	IC (MW)	Net Electricity produced (MU)	Coal (thousand ton)	APC (Mus)	Oil (litre)
1	EASTERN	MUZAFFARPUR TPS	610	1300	918	100	48780.48
2	EASTERN	KAHALGAON TPS	2340	15390	11305	1235	173759.04
3	EASTERN	PATRATU TPS	455	700	2040	58	34157.76
4	EASTERN	BOKARO `B` TPS	630	1932	1445	155	50893.92
5	EASTERN	KODARMA TPP	1000	3504	2142	280	71808
6	EASTERN	TALCHER STPS	3000	22400	18564	1798	212976
7	EASTERN	MEJIA TPS	2340	12588	6528	1008	177577.92
8	EASTERN	FARAKKA STPS	2100	13400	9662.8	1080	162792
9	EASTERN	BAKRESWAR TPS	1050	6500	4039.2	530	80539.2
10	EASTERN	SAGARDIGHI TPS	1600	3000	2475.2	238	121420.8
11	EASTERN	SANTALDIH TPS	500	3500	2366.4	276	33456
12	NORTHERN	BADARPUR TPS	705	983	1264.8	80	49474.08
13	NORTHERN	INDIRA GANDHI STPP	1500	6500	2652	520	122400
14	NORTHERN	PANIPAT TPS	920	1500	2618	120	71318.4
15	NORTHERN	GH TPS (LEH.MOH.)	920	3800	1462	305	75072
16	NORTHERN	ROPAR TPS	1260	4200	3121.2	338	107956.8
17	NORTHERN	GND TPS(BHATINDA)	440	1100	1122	90	38058.24
18	NORTHERN	SURATGARH TPS	1500	6500	2937.6	520	132192
19	NORTHERN	CHHABRA TPP	3320	4500	3998.4	360	279039.36
20	NORTHERN	RIHAND STPS	3000	21060	12597	1685	242352
21	NORTHERN	SINGRAULI STPS	2000	15770	10444.8	1263	159936
22	NORTHERN	UNCHAHAR TPS	1550	7020	4474.4	564	123950.4
23	NORTHERN	ANPARA TPS	2630	8500	12331.8	680	199585.44
24	NORTHERN	PARICHHA TPS	1140	7239	2475.2	580	85582.08
25	NORTHERN	OBRA TPS	1278	5102	3291.2	410	102199.1
26	SOUTHERN	SIMHADRI	2000	14600	9520	1160	163200
27	SOUTHERN	RAYALASEEMA TPS	1050	7220	4760	580	80539.2
28	SOUTHERN	DAMODARAM SANJEEV/	1600	8000	4807.6	640	127948.8
29	SOUTHERN	RAICHUR TPS	1720	11025	6640.2	880	136141.44
30	SOUTHERN	BELLARY TPS	1700	7630	2692.8	610	133171.2
31	SOUTHERN	VALLUR TPP	1500	8500	6330.8	680	113832
32	SOUTHERN	ENNORE TPS	340	400	1615	33	25524.48
33	SOUTHERN	METTUR TPS	1440	9500	6392	765	106928.64
34	SOUTHERN	NORTH CHENNAI TPS	1830	10700	4066.4	860	134395.2
35	SOUTHERN	TUTICORIN TPS	1050	750	2723.4	60	77112
36	SOUTHERN	RAMAGUNDEM STPS	2663	300	11628	25	195570.72
37	SOUTHERN	KAKATIYA TPS	1100	6000	4420	480	87964.8
38	WESTERN	SIPAT STPS	2980	20050	14545.2	1600	243168
39	WESTERN	UKAI TPS	1350	5600	2539.8	450	111261.6
40	WESTERN	WANAKBORI TPS	1470	6000	3298	480	99560.16
41	WESTERN	VINDHYACHAL STPS	4760	31867	23463.4	2550	334037.76
42	WESTERN	SATPURA TPS	1330	5500	3702.6	450	100931.04
43	WESTERN	SHRI SINGHAJI TPP	1200	6500	3029.4	520	93024
44	WESTERN	MAUDA TPS	2320	3000	4569.6	240	183632.64
45	WESTERN	DAHANU TPS	500	4000	1938	320	39984
46	WESTERN	BHUSAWAL TPS	1420	8300	5606.6	665	114713.28
47	WESTERN	CHANDRAPUR(MAHARAS	2920	15000	9424.8	1205	238272
48	WESTERN	KHAPARKHEDA TPS	1340	7200	5878.6	575	107157.12
49	WESTERN	KORADI TPS	2400	9000	5664.4	720	186048
50	WESTERN	PARLI TPS	1170	100	3515.6	10	88788.96

7. Results and discussions

Table 3: The results of CCR and BCC efficiency model are give in below Table.

S. No	STATION_NAME	MAKE	CCR Efficiency	BCC Efficiency	Scale efficiency	∑λ*	RTS	Peers
1	MUZAFFARPUR TPS	BHEL	1.000	1.000	1.000	1.000	-	1
2	KAHALGAON TPS	BHEL	0.982	0.981	0.991	4.545	drs	41 26
3	PATRATU TPS	Mixed	0.928	0.956	0.971	0.538	irs	11 1 32
4	BOKARO `B` TPS	BHEL	0.970	0.971	0.999	1.049	drs	26 1 11
5	KODARMA TPP	BHEL	0.982	0.986	0.996	1.473	drs	30 1 26
6	TALCHER STPS	BHEL	1.000	1.000	1.000	1.000	-	6
7	MEJIA TPS	BHEL	0.990	0.998	0.992	3.308	drs	30 20 26
8	FARAKKA STPS	BHEL	0.978	0.986	0.992	4.034	drs	1 26
9	BAKRESWAR TPS	BHEL	0.970	0.973	0.997	1.745	drs	30 26 1 11
10	SAGARDIGHI TPS	BHEL	0.970	0.989	0.980	2.308	drs	26 1
11	SANTALDIH TPS	Mixed	1.000	1.000	1.000	1.000	-	11
12	BADARPUR TPS	BHEL	0.945	0.955	0.990	0.756	irs	50 1 32
13	INDIRA GANDHI STPP	Mixed	0.994	0.997	0.997	1.563	drs	30 26 1
14	PANIPAT TPS	BHEL	0.962	0.966	0.995	1.154	drs	26 1
15	GH TPS (LEH.MOH.)	Mixed	0.993	1.000	0.993	0.681	irs	15
16	ROPAR TPS	BHEL	0.969	0.980	0.989	2.119	drs	26 1
17	GND TPS (BHATINDA)	Mixed	0.947	1.000	0.947	0.698	irs	17
18	SURATGARH TPS	BHEL	0.991	0.995	0.996	1.910	drs	26 30 1
19	CHHABRA TPP	Mixed	0.962	0.986	0.975	3.462	drs	26 1
20	RIHAND STPS	BHEL	0.991	1.000	0.991	5.451	drs	20
21	SINGRAULI STPS	BHEL	0.998	1.000	0.998	3.990	drs	21
22	UNCHAHAR TPS	BHEL	0.979	0.986	0.992	2.560	drs	1 30 26
23	ANPARA TPS	BHEL	0.974	0.991	0.983	4.385	drs	26 1
24	PARICHHA TPS	BHEL	1.000	1.000	1.000	1.000	-	24
25	OBRA TPS	Mixed	0.977	0.984	0.993	2.085	drs	1 30 26
26	SIMHADRI	BHEL	0.998	1.000	0.998	3.990	drs	26
27	RAYALASEEMA	BHEL	0.983	0.987	0.996	1.989	drs	1 30 26 11

28	DAMODARAM SANJEEVAIAH	BHEL	0.986	0.992	0.994	2.572	drs	30 1 26
29	RAICHUR TPS	BHEL	0.991	0.996	0.995	2.896	drs	30 1 26 11
30	BELLARY TPS	BHEL	1.000	1.000	1.000	1.000	-	30
31	VALLUR TPP	BHEL	0.983	0.991	0.992	2.815	drs	26 1
32	ENNORE TPS	Mixed	0.932	1.000	0.932	0.308	irs	32
33	METTUR TPS	BHEL	0.980	0.985	0.994	2.710	drs	1 26 11
34	NORTH CHENNAI TPS	BHEL	0.994	1.000	0.994	1.810	drs	34
35	TUTICORIN TPS	Mixed	0.962	0.979	0.982	0.577	irs	50 1
36	RAMAGUNDEM STPS	BHEL	0.923	1.000	0.923	0.231	irs	50 1
37	KAKATIYA TPS	BHEL	0.983	0.989	0.994	2.046	drs	26 1 11
38	SIPAT STPS	BHEL	0.988	0.999	0.989	5.847	drs	26 41
39	UKAI TPS	BHEL	0.986	0.990	0.996	1.717	drs	30 26 1
40	WANAKBORI TPS	BHEL	0.987	0.992	0.995	1.954	drs	1 30 26
41	VINDHYACHAL STPS	BHEL	0.985	1.000	0.985	9.308	drs	41
42	SATPURA TPS	BHEL	0.959	0.966	0.993	2.190	drs	1 30 26
43	SHRI SINGHAJI TPP	BHEL	0.994	0.996	0.998	1.537	drs	11 30 24 26
44	MAUDA TPS	BHEL	0.962	0.981	0.980	2.308	drs	1 26
45	DAHANU TPS	BHEL	1.000	1.000	1.000	1.000	-	45
46	BHUSAWAL TPS	Mixed	0.983	0.989	0.994	2.622	drs	26 1
47	CHANDRAPUR (MAHARASHTRA) STPS	BHEL	0.981	0.991	0.990	4.872	drs	20 30 26
48	KHAPARKHEDA TPS	BHEL	0.984	0.992	0.993	2.488	drs	26 1
49	KORADI TPS	Mixed	0.980	0.992	0.988	3.835	drs	30 1 26
50	PARLI TPS	Mixed	0.769	1.000	0.769	0.077	irs	50
		Overall Mean	0.975	0.990	0.984			
		BHEL Mean	0.982	0.990	0.992			
		Mixed Mean	0.95	0.99	0.96			

S.	REGION	STATE_NA	STATION_NAME	MAKE	CCR Efficier	BCC Efficier	Scale efficien
1	EASTERN	BIHAR	MUZAFFARPUR TPS	BHEL	1.000	1.000	1.000
2	EASTERN	BIHAR	KAHALGAON TPS	BHEL	0.982	0.981	0.991
3	EASTERN	JHARKHAND	PATRATU TPS	Mixed	0.928	0.956	0.971
4	EASTERN	JHARKHAND	BOKARO `B` TPS	BHEL	0.970	0.971	0.999
5	EASTERN	JHARKHAND	KODARMA TPP	BHEL	0.982	0.986	0.996
6	EASTERN	ORISSA	TALCHER STPS	BHEL	1.000	1.000	1.000
7	EASTERN	WEST BENGA	MEJIA TPS	BHEL	0.990	0.998	0.992
8	EASTERN	WEST BENGA	FARAKKA STPS	BHEL	0.978	0.986	0.992
9	EASTERN	WEST BENGA	BAKRESWAR TPS	BHEL	0.970	0.973	0.997
10	EASTERN	WEST BENGA	SAGARDIGHI TPS	BHEL	0.970	0.989	0.980
11	EASTERN	WEST BENGA	SANTALDIH TPS	Mixed	1.000	1.000	1.000
12	NORTHERN	DELHI	BADARPUR TPS	BHEL	0.945	0.955	0.990
13	NORTHERN	HARYANA	INDIRA GANDHI STPP	Mixed	0.994	0.997	0.997
14	NORTHERN	HARYANA	PANIPAT TPS	BHEL	0.962	0.966	0.995
15	NORTHERN	PUNJAB	GH TPS (LEH.MOH.)	Mixed	0.993	1.000	0.993
16	NORTHERN	PUNJAB	ROPAR TPS	BHEL	0.969	0.980	0.989
17	NORTHERN	PUNJAB	GND TPS(BHATINDA)	Mixed	0.947	1.000	0.947
18	NORTHERN	RAJASTHAN	SURATGARH TPS	BHEL	0.991	0.995	0.996
19	NORTHERN	RAJASTHAN	CHHABRA TPP	Mixed	0.962	0.986	0.975
20	NORTHERN	UTTAR PRADE	RIHAND STPS	BHEL	0.991	1.000	0.991
21	NORTHERN	UTTAR PRADE	SINGRAULI STPS	BHEL	0.998	1.000	0.998
22	NORTHERN	UTTAR PRADE	UNCHAHAR TPS	BHEL	0.979	0.986	0.992
23	NORTHERN	UTTAR PRADE	ANPARA TPS	BHEL	0.974	0.991	0.983
24	NORTHERN	UTTAR PRADE	PARICHHA TPS	BHEL	1.000	1.000	1.000
25	NORTHERN	UTTAR PRADE	OBRA TPS	Mixed	0.977	0.984	0.993
26	SOUTHERN	ANDHRA PRA	SIMHADRI	BHEL	0.998	1.000	0.998
27	SOUTHERN	ANDHRA PRA	RAYALASEEMA TPS	BHEL	0.983	0.987	0.996
28	SOUTHERN	ANDHRA PRA	DAMODARAM SANJEEV	BHEL	0.986	0.992	0.994
29	SOUTHERN	KARNATAKA	RAICHUR TPS	BHEL	0.991	0.996	0.995
30	SOUTHERN	KARNATAKA	BELLARY TPS	BHEL	1.000	1.000	1.000
31	SOUTHERN	TAMIL NADU	VALLUR TPP	BHEL	0.983	0.991	0.992
32	SOUTHERN	TAMIL NADU	ENNORE TPS	Mixed	0.932	1.000	0.932
33	SOUTHERN	TAMIL NADU	METTUR TPS	BHEL	0.980	0.985	0.994
34	SOUTHERN	TAMIL NADU	NORTH CHENNAI TPS	BHEL	0.994	1.000	0.994
35	SOUTHERN	TAMIL NADU	TUTICORIN TPS	Mixed	0.962	0.979	0.982
36	SOUTHERN	TELANGANA	RAMAGUNDEM STPS	BHEL	0.923	1.000	0.923
37	SOUTHERN	TELANGANA	KAKATIYA TPS	BHEL	0.983	0.989	0.994
38	WESTERN	CHHATTISGA	SIPAT STPS	BHEL	0.988	0.999	0.989
39	WESTERN	GUJARAT	UKAI TPS	BHEL	0.986	0.990	0.996
40	WESTERN	GUJARAT	WANAKBORI TPS	BHEL	0.987	0.992	0.995
41	WESTERN	MADHYA PRA	VINDHYACHAL STPS	BHEL	0.985	1.000	0.985
42	WESTERN	MADHYA PRA	SATPURA TPS	BHEL	0.959	0.966	0.993
43	WESTERN	MADHYA PRA	SHRI SINGHAJI TPP	BHEL	0.994	0.996	0.998
44	WESTERN	MAHARASHT	MAUDA TPS	BHEL	0.962	0.981	0.980
45	WESTERN	MAHARASHT	DAHANU TPS	BHEL	1.000	1.000	1.000
46	WESTERN	MAHARASHT	BHUSAWAL TPS	Mixed	0.983	0.989	0.994
47	WESTERN	MAHARASHT	CHANDRAPUR(MAHARA	BHEL	0.981	0.991	0.990
48	WESTERN	MAHARASHT	KHAPARKHEDA TPS	BHEL	0.984	0.992	0.993
49	WESTERN	MAHARASHT	KORADI TPS	Mixed	0.980	0.992	0.988
50	WESTERN	MAHARASHT	PARLI TPS	Mixed	0.769	1.000	0.769

Table 4: Showing Region wise efficiency

10.2 BCC efficiency

The efficacy of such plants as GH (Lehra Mohabbat), Rihand, Singrauli, Simadhri, Ennore, North Chennai, Ramagudenem, Vindhyachal and Parli increased to one. It indicates that the inefficiencies allocated to these nine plants are strictly scaled-based inefficiencies with respect to the presumption of CRS. Under both hypotheses, the output of the power plants in Muzarffpur, Talcher, Santaldidh, Pariccha, Bellary and

Dhanau remains the same. This reliability indicates that these plants run at the most competitive size of scale and are running efficiently. Efficient operations can therefore be due to good plant preventive and regular maintenance and better management and employee attitude towards energy saving. The plants in Patratru and Badarpur have a lower BCC efficiency while the output value of the plant level in Badarpur is about one. This result shows that the inefficient power plants have a significant practical value.

10.3 Slack analysis

The analysis shows that there is no slack in a productive factory. The slack analysis indicates that due to excessive oil use, most plants are inefficient can become effective. For example, by increasing 65,972 thousand liters of oil, 915 MT of Coal Consumption, the Koradi plant could increase its output. Excessive use of projected inputs reflects the energy consumption savings that result in energy savings.

The explanation IC is a slack factor may be due to overvalue of unit power and limited use of units.

Table 5: Below Mentioned Table showing Slack Analysis of Power Plants

Plant No.	IC	Net Elect	Oil	Coal
1	0.000	0.000	0.000	0.000
2	1042.664	0.000	1138.277	192.116
3	539.902	0.000	0.000	11.599
4	71.416	0.000	1682.267	0.000
5	0.000	0.000	117.925	103.517
6	0.000	0.000	0.000	0.000
7	0.000	0.000	6389.183	192.578
8	778.997	0.000	7558.232	195.004
9	0.000	0.000	218.478	0.000
10	431.579	0.000	56734.086	795.448
11	0.000	0.000	0.000	0.000
12	0.000	0.000	4770.018	133.896
13	0.000	0.000	7351.209	39.154
14	1482.068	0.000	18404.297	257.970

15	0.000	0.000	0.000	0.000
16	264.116	0.000	32032.737	321.299
17	0.000	0.000	0.000	0.000
18	0.000	0.000	20567.841	89.126
19	955.630	0.000	198882.964	2329.799
20	0.000	0.000	0.000	0.000
21	0.000	0.000	0.000	0.000
22	0.000	0.000	21653.530	283.578
23	6645.268	0.000	87053.968	1243.673
24	0.000	0.000	0.000	0.000
25	0.000	0.000	17254.921	224.192
26	0.000	0.000	0.000	0.000
27	0.000	0.000	0.000	4.575
28	0.000	0.000	14353.875	188.848
29	0.000	0.000	0.000	21.699
30	0.000	0.000	0.000	0.000
31	698.678	0.000	2078.035	123.919
32	0.000	0.000	0.000	0.000
33	66.559	0.000	0.000	90.490
34	0.000	0.000	0.000	0.000
35	558.096	0.000	8387.800	161.458
36	8545.333	0.000	113449.840	1586.333
37	411.079	0.000	0.000	8.659
38	612.659	0.000	25852.849	106.488
39	0.000	0.000	9090.825	58.319
40	0.000	0.000	708.713	230.508

41	0.000	0.000	0.000	0.000
42	0.000	0.000	11897.916	225.935
43	0.000	0.000	1206.525	0.000
44	2466.202	0.000	116775.367	1488.722
45	0.000	0.000	0.000	0.000
46	101.327	0.000	4486.334	63.249
47	0.000	0.000	62204.376	749.866
48	1095.863	0.000	6729.344	102.257
49	0.000	0.000	65972.572	915.018
50	0.000	0.000	0.000	0.000
Mean	535.349	0.000	18500.086	250.786

8. **Summary**

Most plants work in the IRS area (64 percent). BHEL MAKE plant's average efficiency is higher than mixed MAKE's average efficiency and overall mean performance. The slack analysis results provide the various modes for enhancing deficient plant performance and illustrating resource usage savings. The results explicitly reveal that to reduce oil consumption. The performance scores across various criteria, based on the consistency test, indicate that our findings are consistent across all criteria.