Month wise Efficiency Evaluation of Bagasse Cogeneration plant by DEA Tool (CCR model)

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ABSTRACT

The aim of this work is to evaluate the efficiency of the Bagasse Cogeneration plant using the DEA (Data Envelopment Analysis). For this, Sugar mill of Punjab is selected. Bagasse is highly used fuel in Sugar mill and can be used as an alternative to conventional coal or bagasse based electricity generation. In this analysis, we have taken the Data from this mill (month-wise) that is power generation record from the Year 2012-2013, 2013-2014, 2014-2015 when mill was working. Two inputs (Total Quantity of Cane crushed, Total home load) and two outputs (Total power generation and Total power Export) are taken for evaluating the efficiencies in different months and years by using CCR in Data Envelopment Analysis. Results have been obtained by Banxia Frontier Analyst Software which reveal that the march 2012 and 2013 are fully efficient and the other months and years are potentially improved by reducing the inputs. This inputs can be improved by increasing the calorific value, decreasing the moisture content of the Bagasse fuel and various other methods also. Hence, biofuels based cogeneration could play a substantial role in bridging the ever widening gap between the electricity supply and demand.

Keywords: DEA (Data Envelopment Analysis), CCR model, Bagasse Cogeneration.

1. INTRODUCTION

Energy is the major driver of the world economy. Rising populations and hopes of improved standards of living of people are increasing the demand for energy. Scientists have recognized the positive or direct relationship between financial growth and Greenhouse gas (GHG) emissions. One of the important variables affecting this relationship is raised energy demand as a result of economic well being. For the last two years, India is one of the fastest growing countries in the world, with a GDP growth exceeding 8% time after time, and this trend is too much predictable to continue. In another 25 years, India's Energy demand is expected to be three to four times more compared to the past trends.

India is the fourth major sugar producing country in the world [6]. Sugar industry takes an important place amongst various organized industries in India. Sugar industry, one of the major agro based industries in India, has been instrumental in resource mobilization, employment generation, income and creation of social infrastructure in rural places. Sugar industry is majorly self sufficient in energy needs through utilization of Bagasse for generating electricity and steam. Sugar industry has been traditionally practicing cogeneration by using a Bagasse as a fuel. With the spread in the technology for generation and utilization of steam at high temperature and pressure, sugar industry can be produced electricity and steam for their own needs. By using the same quantity of Bagasse, it can also produce surplus electricity for sale to the grid. For example, if the temperature/pressure of steam generation increases from 400^oC/33 bar to 485^oC/66 bar, about 80 KWh of extra electricity can be produced for every ton of cane crushed. The export of surplus power generated through optimum cogeneration will help a sugar mill to advance its viability, apart from adding up to the power generation capacity of the country.

2. METHODOLOGY

A. DEA Tool

Data Envelopment Analysis was introduced by Charnes, Cooper and Rhodes (1978). DEA is a technique of mathematical programming that enables the determination of a unit's efficiency based on its inputs and outputs, and compares it to other units involved in the analysis. The efficiency of a Decision Making Unit (DMU) is measured relative to all other DMUs with the simple restriction that all DMUs lay on or below the extreme frontier. Charnes, Cooper, and Rhodes (1978) described DEA as a "mathematical programming model applied to observational data provides a new way of obtaining empirical estimates of relations - such as the production functions and/or efficient production possibility surfaces " that are cornerstones of modern economics.

B. Mathematical Programming Aspect of DEA Tool

The graphical methods cannot be used if we consider a greater no. of inputs and outputs. Hence, a general mathematical model is needed to evaluate the performance. The techniques of frontier analysis have been described by **Farrell** in 1957, but a mathematical framework to handle frontier analysis could be established after 20 years. This mathematical formulation was provided by **Charnes et al.** (1978). The authors coined the term '**Data Envelopment Analysis**'.

In DEA:

The virtual input of a firm is the linear weighted sum of all its inputs.

Virtual Input = $\sum_{i=0}^{I} u_i x_i$
Where u_i is the weight assigned to x_i during the aggregation.

Similarly, the virtual output of a firm is:
Virtual Output = $\sum_{j=0}^{J} v_j y_j$
Where *vj* is the weight assigned to output *yj* during the aggregation.

As we know, Efficiency = Virtual Output/ Virtual Input
$= \sum_{j=0}^{J} v_j y_j \,/\, \sum_{i=0}^{I} u_i x_i$

Here, *x* and *y* are inputs and outputs respectively.
Subscripts *i* and *j* to represent particular input and output respectively.
I and *J* are total no. of inputs and outputs respectively, where *I, J > 0*.

C. General forms of CCR DEA model

Output maximization model:

$$max\theta_{0=} \sum_{r=1}^{s} u_r y_{rj}$$

Subjected to: $\sum_{i=0}^{m} v_i x_{ij} = 1, \;\; \sum_{r=1}^{s} u_r y_{rj} - \sum_{i=0}^{m} v_i x_{ij} \le 0$
$\forall\, r \,\&\, i$
Where *i* is set of inputs *i = 1, 2… m*
r is set of output *r = 1, 2 … s*
j is set of DMU's *j = 1, 2 …n*
u_r is the weighting variable for the *rth* output, *yrj* is the *rth* output of the *jth* DMU, *xij* is the *ith* input of the *jth* DMU, and *vi* is the weighting variable for the *ith* input.

Input minimization model:

$$min\theta_{0=} \sum_{i=1}^{m} v'_i x_{ij}$$

Subjected to: $\sum_{r=1}^{s} u'_r y_{rj} = 1, \;\; \sum_{r=1}^{s} u_r y_{rj} - \sum_{i=0}^{m} v_i x_{ij} \le 0$
$\forall\, r \,\&\, i$

The above linear programming should be solved for each individual DMU in the sample. So instead of solving above equation, general efficiencies are calculated based on its dual problem.

3. PROCESS OF BAGASSE COGENERATION IN SUGAR MILL

When burned by a sugar mill, Bagasse, the fibrous material leftover after juice is extracted from sugarcane, usually produces enough electricity to power all of the mill's operations and then some. For every 10 metric tons of sugarcane crushed, a sugar factory produces nearly 3 metric tons of wet Bagasse. Many mills across the globe that take advantage of bagasse for power are making improvements to their plants to make the whole process more efficient.

Co-generation is the concept of producing two forms of energy from one fuel. One of the forms of energy must always be heat and the other may be electrical or mechanical energy. In a conventional power plant, fuel is burnt in a boiler to generate high-pressure steam which is used to drive a turbine, which in turn drives an alternator through a steam turbine to produce electrical power. The exhaust steam is generally condensed to water which goes back to the boiler. As the low-pressure steam has a large quantum of heat which is lost in the process of condensing, the efficiency of conventional power plants is only around 35%. In a cogeneration plant, very high efficiency levels, in the range of 75%–90%, can be reached. This is so, because the low-pressure exhaust steam coming out of the turbine is not condensed, but used for heating purposes in houses. Since, the sugar mills in India consume their own bagasse to run their mills during the season and generate steam to run the boilers and turbines; they generate power to run their plants.

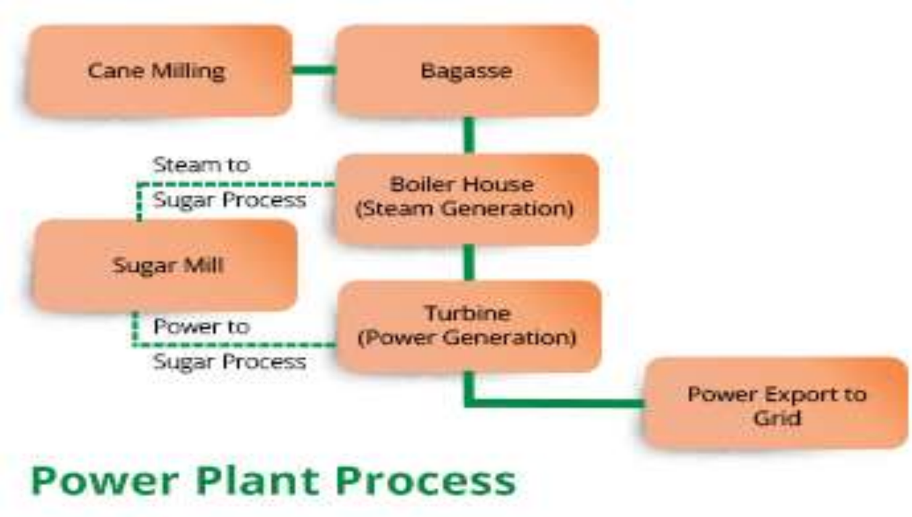

Fig 1: Bagasse Cogeneration Power Plant Process

4. DATA ANALYSIS

D. Inputs and Outputs Performance Indicators

INPUT 1 : Total Quantity of Cane Crushed. One of important input for the sugar mills is the total Quantity of Cane crushed and this input is very much useful for generating power and Steam for the sugar process in the mill which is further exported to the Grid for Auxilliary purposes.

INPUT 2 : Total Home Load. This is one of the another major input for the Cogeneration process in the mill. When the power is generated from the cane crushed it is further given or exported to the substation nearby or grid and also given to the load running by the mill so it is taken as the input for the process .While when home load is reduced then the efficiency increases or vice-versa.

OUTPUT 1 : Total Power Generated. This is one of the most important output as cogeneration process is totally based upon the power generation from the industry. When the cane is crushed it gives Bagasse as by-product which is given to the boiler for generating steam and then further given to the Turbine for generating Power and efficiency is purely based upon this.

OUTPUT 2 : Total power export. Power exported to the Grid is also one of the major output for the mill. Power generated from the cogeneration process is exported to the grid or substation and if this will be increased then efficiency will also affect greatly.

To reach the conclusion, Spearman rank correlation coefficient (rs) has been used to correlate the results shown by CCR and BCC Models as per the formulae below:

$R_s = 1- (6\sum d^2 / n(n^2-1))$

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TABLE 2: Tables showing Performance indicators (Inputs and Outputs) for Different seasons in Sugar Mill, Punjab

SEASON 2014-2015

INPUTS			OUTPUTS	
MONTHS	**TOTAL QUANTITY OF CANE CRUSHED**	**TOTAL HOME LOAD**	**TOTAL POWER GENERATED**	**TOTAL POWER EXPORT**
DECEMBER	107422.50	4093.4	6592.38	3010.30
JANUARY	108995.00	4203.7	7245.50	3041.80
FEBRURAY	101055.00	3834.9	6532.06	2697.10
MARCH	89570.00	3465	5980.80	2515.30

SEASON 2013-2014

INPUTS			OUTPUTS	
MONTHS	**TOTAL QUANTITY OF CANE CRUSHED**	**TOTAL HOME LOAD**	**TOTAL POWER GENERATED**	**TOTAL POWER EXPORT**
DECEMBER	112141.2	4241.4	7695.44	3454.042
JANUARY	123646.1	4383.49	8042.93	3659.942
FEBRURAY	110721.5	4000.8	7267.5	3266.7
MARCH	61011.02	2435.7	4392	1956.3

SEASON 2012-2013

INPUTS			OUTPUTS	
MONTHS	**TOTAL QUANTITY OF CANE CRUSHED**	**TOTAL HOME LOAD**	**TOTAL POWER GENERATED**	**TOTAL POWER EXPORT**
DECEMBER	129608	4344.47	6994.11	2649.99
JANUARY	119560	3892.92	6860.84	2967.92
FEBRURAY	106430	3384.22	6077.7	2693.48
MARCH	79699	2848.90	5374.63	2525.73

E. Software used: Banxia Frontier Analyst

This analyst helps to improve and measure the performance of the organization or industries. It is for greater efficiency which is never ending process as managers of the industries are always under pressure to improve the performance of their industries. This analysis uses a powerful technique called Data envelopment analysis which compares relative efficiency of a decision making units where units perform similar tasks. These units utilize similar resources, referred to as inputs to generate similar outputs.

It allows us to take account of all the important factors that affects a units performance to provide a complete and comprehensive assessment of efficiency. This analysis does this by converting the multiple inputs and outputs into a single measure of productive efficiency. By doing so it identifies those units which are operating relatively efficient and those which are not. The efficient units those making best use of resources are rated as being 100% efficient whilst the inefficient ones obtain lower resources.

5. RESULTS AND DISCUSSION

F. Performance Evaluation within Bagasse Cogeneration plant for different months by CCR Model

Table 3 shows the efficiency analysis within the various months for sugar mill by CCR for the months DEC 2012 to MAR 2015 with fluctuation of 85.30-100. The revelation through efficiency analysis using CCR reflected high level of correlation between them with spearman rank correlation coefficient (r_s) = 0.96.

Table 3: **Efficiency Analysis within Different months by CCR model**

Months (when mill is working)	Efficiency (CCR model) in %	Ranking by DEA (CCR model)
DEC-2012	85.30	1
JAN-2013	93.40	4
FEB-2013	95.20	7
MAR-2013	100	11.5
DEC-2013	98.50	10
JAN-2014	97.30	9
FEB-2014	96.70	8
MAR-2014	100	11.5
DEC-2014	87.80	2
JAN-2015	94.30	5
FEB-2015	92.60	3
MAR-2015	94.50	6

Table 4 expresses the Potential Improvements for performance indicators which indicate by how much and in what areas an inefficient unit needs to improve in order to become efficient. The negative percentage in the improvements gives the amount of decrease needed for showing the specific variables in order to increase the efficiency.

Table 4: Potential improvements performance indicator wise within Bagasse Cogeneration plant for different months by CCR model (in percent)

	Dec12	Jan 13	Feb13	Mar 13	Dec 13	Jan 14	Feb 14	Mar 14	Dec 14	Jan 15	Feb 15	Mar 15
Total Quantity of cane crushed	-19.98	-14.91	-15.32	0.00	-1.54	-3.54	-3.27	0.00	-12.16	-5.72	-7.44	-5.47
Total home Load	-14.67	-6.58	-4.81	0.00	-1.54	-2.74	-3.27	0.00	-12.16	-5.72	-7.44	-5.47
Total power generated	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total power Export	24.03	8.63	6.04	0.00	1.90	3.27	4.01	0.00	0.21	7.91	10.5	7.56

The CCR model analysis in the table 4 concludes throughout the different inefficient months, it was evident that total quantity of cane crushed and total Home load have consistently shown the highest requirements of potential improvement with percentage fluctutation varying in between the -1.54 to -19.98 percent and -1.54 to -14.67 percent respectively.

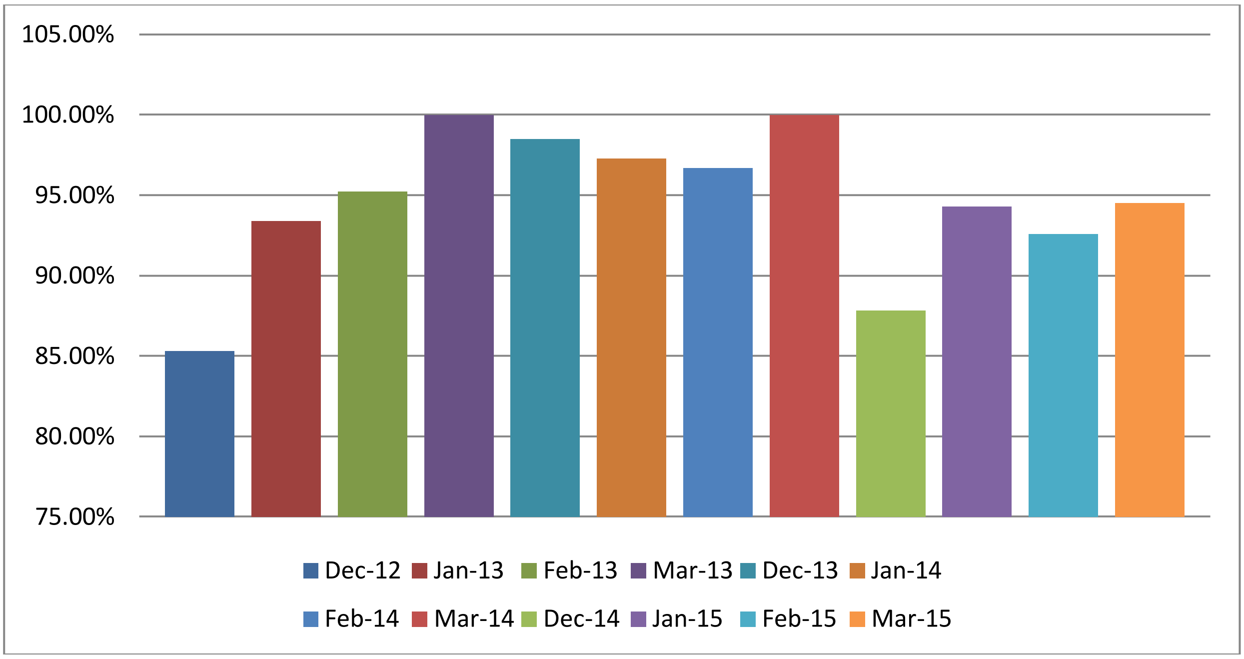

FIGURE 2: Efficiency Scores within Bagasse Cogeneration plant for Different Months by CCR model

6. CONCLUSION

After Doing this Analysis, For the various months during this three different years or seasons when mill was working, by using DEA analysis, CCR model we can reduce the inputs (TCC and THL) at an average of 7.446 and 5.367 % respectively for 100% efficient system and this shows that March 2013 and March 2014 are given as fully efficient and various other months are potentially improved by taking their efficiency scores accordingly. This analysis shows that efficiency must be increased by minimizing inputs and maximizing outputs. And this can be done by following measures:

- Bagasse fuel can be improved by reducing its moisture content.
- The calorific value of the fuel must be increased for obtaining the better output.
- Home Load can be reduced by using Power saving Appliances in the mill like CFL and energy efficient motors etc.

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