EFFICIENCY EVALUATION OF BAGASSE COGENERATION PLANT BY USING DEA

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Abstract- Energy is one of the largest driver in our whole world growth and economy. It is one of the major source to increase the living standards of people and Bagasse is highly used fuel in Sugar mill and can be used as an alternative to Coal based generation. In this study, we have taken the Data from the mill 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 and BCC model in Data Envelopment Analysis. Results have been obtained by Banxia Frontier Analyst Software which reveal the fully efficient DMU's and the other years are potentially improved by reducing the inputs.

Keywords- CCR model, BCC model, Sugar mill, DEA, potential improvements.

I. INTRODUCTION

Energy consumption in India is very much based on the fossil fuels that are 60 percent is generated from coal and 40 percent from the primary energy supply. The energy demand is dependent on the increased consumption of fossil fuels that will not only increase the GHG emissions but also the various environmental problems for example health related problems and social problems. While reducing the fossil fuels, India goes through the tough tasks for increased energy demand. The rural people usually consume more energy supply and takes one third of the power generated. 90 percent of the rural and 40 percent of the urban requirements are mainly fulfilled by the biomass energy.

India is having the great potential for employing the power generation in agricultural sectors. The main reason for this is the worlwide interest in the renewable energy resources and it is due to the following factors:

- To decrease the GHG emissions in whole nation.
- To fulfill the energy demand in our country.
- To expand the market for renewable energy and saves the future time.

Renewable energy is of prime importance in fulfilling the environmental concerns and also decreased the GHG emissions. It can be used in different methods to provide the energy:

- Gasification process for the combustion of heat for electricity generation.
- Pyrolysis process for providing the liquid fuel .
- Direct combustion process to provide heat for steam production and auxilliary purposes.

Biomass energy is one of the most important renewable energy source which is rapidly using at a fast rate in India. It is available in the form of solid, gas and liquid. It is the second largest commercial source of renewable energy. Biomass energy can be converted into various forms of energy like electrical or thermal energy by using different thermochemical or bioconversion techniques. These methods are very cheap in cost and higher reliability.

Biomass, as a renewable energy source, is biological material from living, or recently living organisms. As an energy source, biomass can either be used directly, or converted into other energy products such as biofuel.

In the first sense, biomass is plant matter used to generate electricity with steam turbines & gasifiers or produce heat, usually by direct combustion. Examples include forest residues (such as dead trees, branches and tree stumps), yard clippings, wood chips and even municipal solid waste. In the second sense, biomass includes plant or animal matter that can be converted into fibers or other industrial chemicals, including biofuels.

II. COGENERATION IN SUGAR MILL

A. Bagasse Fuel

Bagasse as a fuel has been traditionally practicing by Sugar industry for cogeneration. With the consumption of steam at high pressure and temperature, sugar mills can produce electricity and steam for the auxiliary purposes. This mills uses Bagasse for the production of steam and sale of electricity to the grid. If the steam and temperature increases about 485 degree Celsius and 66 bar then it can also produced surplus electricity about 80 Kwh for every one ton of cane crushed. This export of electricity to the grid from Bagasse cogeneration adding a more power availability in the mill itself. Bagasse fuel gives us the best option for renewable based cogeneration. It explores the power generation

throughout the whole regions in our India. The various advantages of this type of cogeneration vary from social to environmental areas. By using this fuel, we can get the increased diversity of supply and also attains the sustainable development.

The fastest growing crop in India is sugarcane and it is grown in the cyclical variations from year to year. As sugar mills have always practice the co-generation, the emerging awareness in the sugar industry has led to setting up of 'high efficiency' Bagasse based co-generation system.
Hence, Bagasse and its other biofuel counterparts based co-generation offers great potential for electricity production in agricultural based economy of Punjab state.



FIGURE 1. Bagasse Fuel

B. Indian Sugar Industry

Sugar industry is one of the important organized industries in India. It is one of the agricultural based industries that provides generation, employment and environmental benefits also. India is the fourth major sugarcane producing country in the world. About 553 sugar factories have been registered and it annual production capacity is 180 lakh metric tones. Sugar industry is largely self adequate in energy requirements through consumption of bagasse for generating electricity and steam. In fact, sugar industry produces surplus exportable energy through cogeneration and helps in dropping the energy deficit that India is facing currently.

C. Cogeneration

Cogeneration is a process of making two different types of energy. In this process, firstly the fuel is burnt in the boiler then the steam produced from the boiler goes to the turbine which drives it to expand the steam and then generator is used to produce electric power which is used for the substation and the exhaust steam is used for the auxilliary purposes in the mill. Cogeneration is widely used in the sugar industries where both energies are generated or produced using Bagasse as a chief cogeneration fuel.

D. DEA (Data Envelopment Analysis)

This analysis is a new technique of data oriented approach which is used for knowing the performances of DMU's which converts the multiple inputs into outputs. It is mostly used for the firms and big organisations and defines its performance and respective improvements.

The first introduction of DEA was given by Charnes, Cooper and Rhodes in the year 1978. It is a method of finding the unit's efficiencies for firms and compare it to the other units to know their relative performances. It is a mathematical programming approach. CCR defines DEA as the programming model which is used for finding the empirical estimates of relations such as production functions that are the chief stones of today's economics by applying the observational data.
DEA had also been used to provide new insight to the various activities of the industries that are already evaluated by the other methods. This benchmarking practices of DEA had given a new criterion for finding the inefficiency of firms or industries and this has been a good approach for applied studies also. This analysis is basically needed for evaluating relative efficiency of the decision making units. DEA is one of the most popular fields in operation research.

III. MATHEMATICAL PROGRAMMING ASPECT OF DEA

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. An analysis method called as frontier is developed by farrell in 1957 but a framework 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 any firm is defined as the weighted sum of all the inputs.
Virtual Input = $\sum_{i=0}^{I} u_i x_i$
Where ui is the weight assigned to xi .
Similarly, the virtual output of a firm is:
Virtual Output = $\sum_{j=0}^{I} v_j y_j$

Where vj is the weight assigned to yj .
As we know, Efficiency = Virtual Output/ Virtual Input

$$= \sum_{j=0}^{I} v_j y_j \,/\, \sum_{i=0}^{I} u_i x_i$$

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

IV. GENERAL CCR MODEL

Output Maximization model :

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

Subjected to

$$\sum_{i=0}^{m} v_i x_{ij} = 1$$

$$\sum_{r=1}^{s} u_r y_{rj} - \sum_{i=0}^{m} v_i x_{ij} \leq 0 \quad , \forall r \& i$$

Where i is the set of inputs i = 1, 2… m
r is the respective set of outputs r = 1, 2 … s
j is the respective set of DMU's j = 1, 2 …n
ur 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 :

$$\sum_{r=1}^{s} u'_r y_{rj} = 1$$

$$\sum_{r=1}^{s} u_r y_{rj} - \sum_{i=0}^{m} v_i x_{ij} \leq 0$$

$\forall r \& i$

$u'_r, v'_i \geq 0$ The above linear programming will be done for individual DMU in the firm.

V. PROCESS OF BAGASSE COGENERATION IN SUGAR MILL

Bagasse, the fibrous form of material taken after the juice after crushing the sugar cane in this sugar mill and when it is burned it produces the enough electricity for powering the whole industry. It produces 3 metric tones wet bagasse for around 10 metric tones of crushed sugarcane in this plant.

Most of the mills in the world are taking very well benefits of Bagasse for generating power for doing well improvements to their plants for making the system wholly efficient.

Co-generation is the method of generating two different types of energy from single fuel. In the coal used power plants, fuel is burnt to produce a steam in the boiler which is further used to drive a steam turbine to drive a generator for producing electricity. Then the steam wasted is condensed in the condenser to water which is again used in the boiler. The efficiency of the power plant is 35% because the steam used in condensing is at low pressure and has a large quantity of heat. And in the cogeneration plant, the efficiency is in range of 75-90 % because in this, the steam at low pressure is not used for condensing process but further used for other heating purposes. So the mills of sugarcane had taken their own Bagasse for producing electricity in the running season and also generates steam to run the boilers to drive the turbines. Extra energy could also be exported to the distribution grid. The CERC is the central body which taken care of the generation system of various aspects at national level. Irrespective of CERC, there are SRC in every State to concern with the parts of tariff and system of regulation for supply and distribution of various forms of energy.

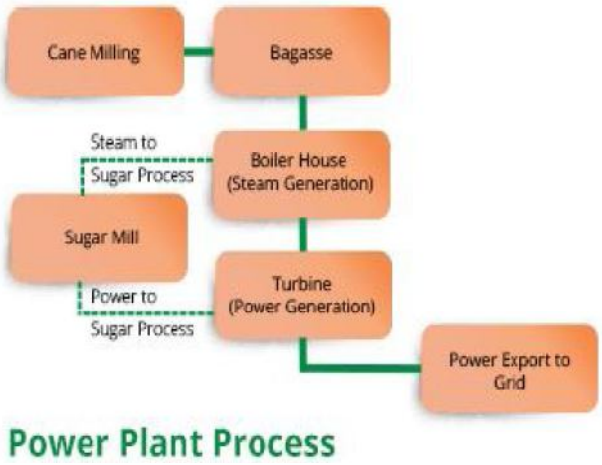

FIGURE 2. Bagasse Cogeneration Power Plant Process

A. Power generation Record

The efficiency evaluation as described in the methodology using DEA tool started with the selection of proper inputs and outputs that are combined into a group for overall performance. Inputs are defined as different aspects for the industries for consuming its operation and evaluating its performance well and Outputs are given as the quantitative measures of the results which are expecting from the industries. In this study, all had chosen from the proper facility of Data taken from the mill by visiting it 2 times.

	INPUTS		OUTPUTS	
YEAR	TOTAL QUANTITY OF CANE CRUSHED	TOTAL HOME LOAD	TOTAL POWER GENERATED	TOTAL POWER EXPORT
2012-2013	435297	14470.51	25307.28	10837.11
2013-2014	407519.8	15061.38	27397.87	12336.98
2014-2015	407042.5	15597.06	26350.74	11264.5

TABLE 1. YEAR WISE RECORD

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.

For making the conclusion exact, spearman rank coefficient is used by relating the results obtained from the CCR and BCC model as per given formula:

$Rs = 1- (6 \sum d^2 / n(n2-1))$

VI. PERFORMANCE EVALUATION OF BAGASSE COGENERATION PLANT FOR DIFFERENT YEARS

Table 1 shows the efficiency anaylsis within the various months for sugar mill by using CCR and BCC models for the months DEC 2012 to MAR 2015 with the range of 96.1-100 and 100 % respectively. The results come from the efficiency analysis gives the high level of correlation between CCR and BCC models by using the Spearman's correlation coefficient which gives the value of 0.56.

Respective Years (when mill is working)	Efficiency (model CCR) in %	Ranking by DEA (model CCR)	Efficiency (model BCC) in %	Ranking by DEA (model BCC)
YEAR 2012-2013	96.1	1	100	2
YEAR 2013-2014	100	3	100	2
YEAR 2014-2015	96.3	2	100	2

TABLE 2: Efficiency Analysis within Different Years by using DEA models

	YEAR 2012-2013	YEAR 2013-2014	YEAR 2014-2015
Total Quantity of Cane crushed	-13.52	0.00	-3.71
Total home Load	-3.86	0.00	-7.13
Total Power Generated	0.00	0.00	0.00
Total Power Export	5.15	0.00	5.34

TABLE 3: Performance Evaluator wise Potential Improvements within different Years by CCR model (in percent)

The CCR model analysis in the table 2 concludes from the different inefficient years, it was shown that total quantity of cane crushed and total Home load had shown the largest requirements of potential improvement with range varying in between the -3.71 to -13.52 percent and -3.86 to -7.13 percent respectively.

Figures 3 and 4 shows the Efficiency scores within Bagasse Cogeneration plant for different years or seasons when working by CCR and BCC models respectively.

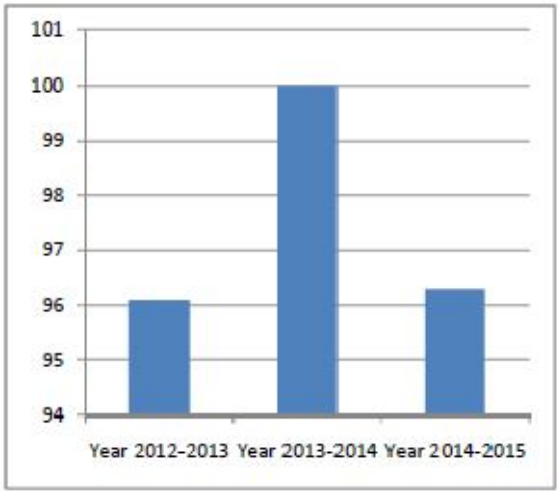

FIGURE 3. Efficiency Scores within Bagasse Cogeneration Plant for Different Years by CCR model

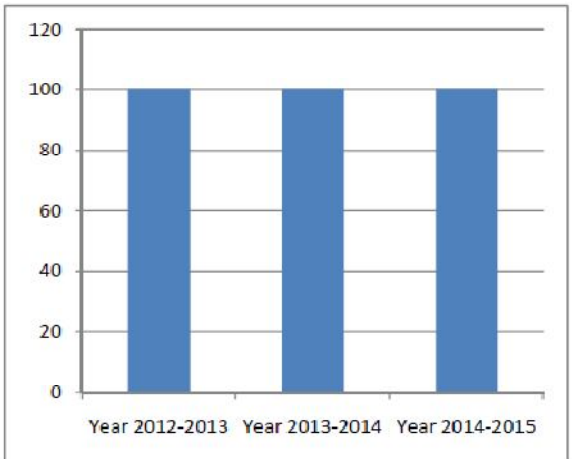

FIGURE 4. Efficiency Scores within Bagasse Cogeneration Plant within Different Years by BCC model

CONCLUSION

For 3 Different years or seasons when plant was running, by using DEA analysis i.e CCR model (minimizing inputs to seek the same outputs) we can reduce the inputs that is Total Quantity of cane crushed(TCC) and Total Home Load(THL) at an average of 8.615 and 5.495% respectively for better efficiency scores or full 100% efficient system and there is no potential improvements by using BCC model.

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