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Performance Analysis of Sugar Cogeneration Plant By Method DEA

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Abstract: ***This study presents a feasibility of export electricity generation for a 7000 tons of Cane per day Crushing capacity factory which currently generates electricity for own consumption alone. The competitive sugar industry with high costs of production makes it necessary for diversification by sugar industry to increase its competitiveness. This will improve the sustainability of the cane sugar industry and the electricity grid by supply of green electricity. The factory and its cogeneration plant performances were examined for possible improvement and diversification into electricity export to the grid. 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 Months Oct 22, Nov 22, Dec 22, Jan 23, Feb 23, Mar 23 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: Sugar Cane Production; Cogeneration; Electricity Generation; Sugar Cane Milling. CCR Model, BCC Model, Sugar Mill, DEA, Potential Improvements.

I. INTRODUCTION

Bagasse from sugarcane milling has significant energy potential as a combustion fuel for power generation. Sugar cane is generally grown under a wide range of condition in tropical and sub tropical geographical reasons across the western Maharashtra region. It required rainfall between 1100-1500 mm/year sugar cane which is generally harvested every 10 to 18 months stage, which is depending upon planting time and crop time.

Sugar cane is grown in more districts in western Maharashtra. A typical sugar factory has average electricity demand of between 10 – 12 KW per Day of cane milled.by using bagasse as a fuel electricity generation efficiency increase, which gives the sugar cane industry a very important role in the sustainable energy transition.

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:

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

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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:

a) Gasification process for the combustion of heat for electricity generation.
b) Pyrolysis process for providing the liquid fuel .
c) 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.

M/s Shri Dnyaneshwar Shakari Sakhar karkhana Ltd. (DSSK) is registered under Maharashtra State Cooperative Societies Act 1960 and was established in the year 1973. DSSK is located in Bhenda village, District Ahmednagar, Maharashtra at 19°26'59.65"N and 75° 2'13.27"E. DSSK is one of the leading manufacturers of wide range of ago products like sugar, Distillery and thermal power production. Though efforts put on by Late Marotta Ghule Patil, the factory has efficiently improved their outstanding performance by ensuring higher yield productivity and by adopting energy saving, cost effective measures.DSSK is operating Sugar plant of sugar crushing capacity of 7000 TCD along with Cogeneration Plant of 31.5 MW.

Environment clearance granted by SEIAA; Maharashtra dated 23rd October 2017 for existing 7000 TCD along with Cogeneration Plant of 31.5 MW. As per EIA Notification 2006 and its amendment of the Ministry of Environment Forests and Climate Change, Govt. of India (MoEF&CC) the proposed project expansion is categorized in 5(j) group, prior environmental clearance is required for expansion of 7000 TCD to 9000 TCD.

Accordingly, the project proponent has submitted prescribed application along with pre-feasibility report to the SEAC -1 Mumbai. The project was considered in the 146th SEAC – I meeting dated 30th January 2018 and Terms of Reference has been approved by SEAC for expansion Based on the approved Tor and standard Tor, Environmental Impact Assessment studies are carried out. Draft EIA and EMP report were prepared and submitting to Maharashtra Pollution Control Board for public hearing.

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 498.29 degree Celsius and it can also produced surplus electricity about 82.19 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 cogeneration, 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

Sugarcane bagasse

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 field

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 $= \sum_{i=0}^{I} \mathbf{u}$ixi

Where ui is the weight assigned to xi .

Similarly, the virtual output of a firm is:

Virtual Output = Virtual Input $= \sum_{i=0}^{I} \mathbf{v}$iyi

Where vj is the weight assigned to yj .

As we know, Efficiency = Virtual Output/ Virtual Input

Virtual Input $= \sum_{i=0}^{I} \mathbf{u}$ixi / $\sum_{i=0}^{I} \mathbf{v}$iyi

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

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

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

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 :

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

$$\sum_{r=1}^{s} u_r y_{rj} - \sum_{i=1}^{m} v X_{ij} \leq 0 \qquad ,\forall r \& i$$

$$u'r ,v'i \geq 0$$

The above linear programming will be done for individual DMU in the firm.

A. Advantages of DEA

1) No need to explicitly specify a mathematical form for the production function.
2) The sources of inefficiency can be analysed and quantified for every evaluated unit.
3) Capability of handling multiple inputs and outputs.
4) Capable of being used with any input-output measurement.
5) The main advantage to this method is its ability to accommodate a multiplicity of inputs and outputs.
6) It is also useful because it takes into consideration returns to scale in calculating efficiency, allowing for the concept of increasing or decreasing efficiency based on size and output levels.

B. Disadvantages of DEA

1) Results are sensitive to the selection of inputs and outputs.
2) You can not test for the best specification.
3) The number of efficient firms on the frontier tends to increase with the number of inputs and outputs.
4) The results are potentially sensitive to the selection of inputs and outputs, so their relative importance needs to be analysed prior to the calculation.
5) DEA views each company as unique and fully efficient and efficient scores are very close to 1, which results in a loss of discriminatory power of the method

C. Application of DEA

1) Data envelopment analysis (DEA) is a nonparametric method in operations research and economics for the estimation of production frontiers.

2) DEA has been applied in a large range of fields including international banking, economic sustainability, police department operations, and logistical applications Additionally.

3) DEA has been used to assess the performance of natural language processing models, and it has found other applications within machine learning

V. PROCESS OF BAGASSE COGENERATION IN SUGAR MILL

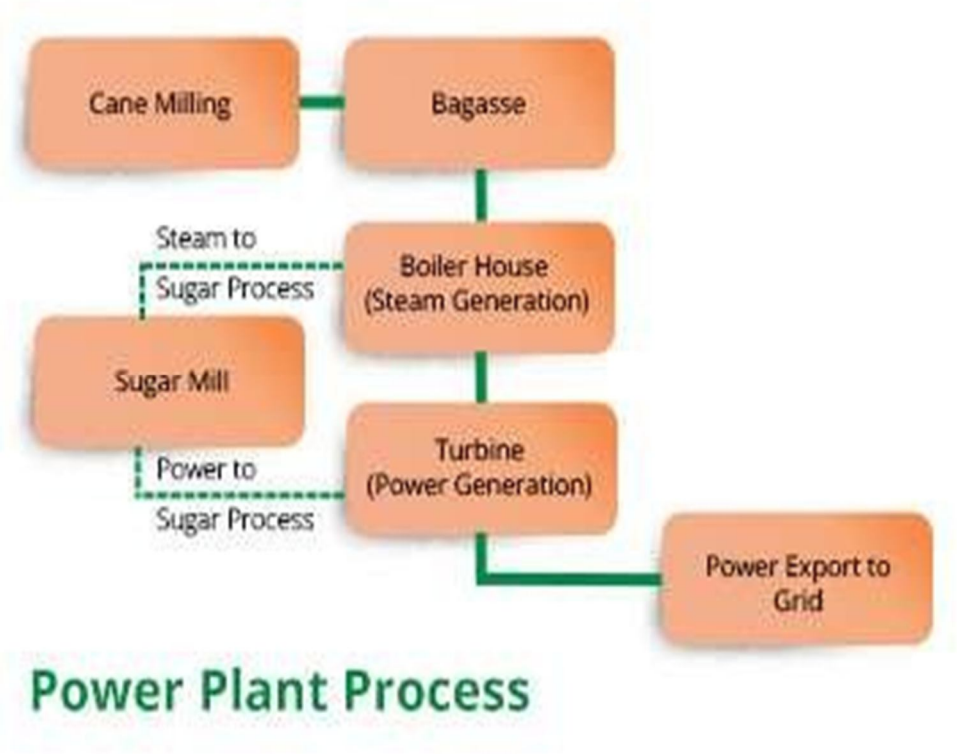

Figure 2. Bagasse Power Plant Process

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.

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 2-3 times.

INPUTS			OUTPUTS	
MONTH	TOTAL QUANTITY OF CANE CRUSHED	TOTAL HOME LOAD	TOTAL POWER GENERATED	TOTAL POWER EXPORT
OCT-22	14800	486840	618000	171960
NOV-22	223880	6315680	15287960	8977440
DEC-22	280540	7533480	18636000	11111400
JAN-23	262150	7085120	16961000	9924360
FEB-23	242470	6512227	16869400	10362120
MAR-23	153260	5128698	12242298	7274160

1) 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.

2) 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.

3) 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.

4) 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 MONTHS.

Table 1 shows the efficiency analysis within the various months for sugar mill by using CCR and BCC models for the months OCT 2022 to MAR 2023 with the range of 95.4 -100% respectively. The results come from the efficiency analysis gives the high level of correlation between CCR and BCC models by using Banxia frontier analysis the correlation coefficient which gives the value of 0.84-0.99.

VII. EFFECTIVE ANALYSIS OF SUGAR MILL BY USING BCC

Table no.1- efficiency evaluation table

Units	Comparison 1		
Unit name	Score	Efficient	Condition
Dec-22	100.0%	✔	
Feb-23	100.0%	✔	
Jan-23	95.4%		
Mar-23	100.0%	✔	
Nov-22	96.1%		
Oct-22	100.0%	✔	

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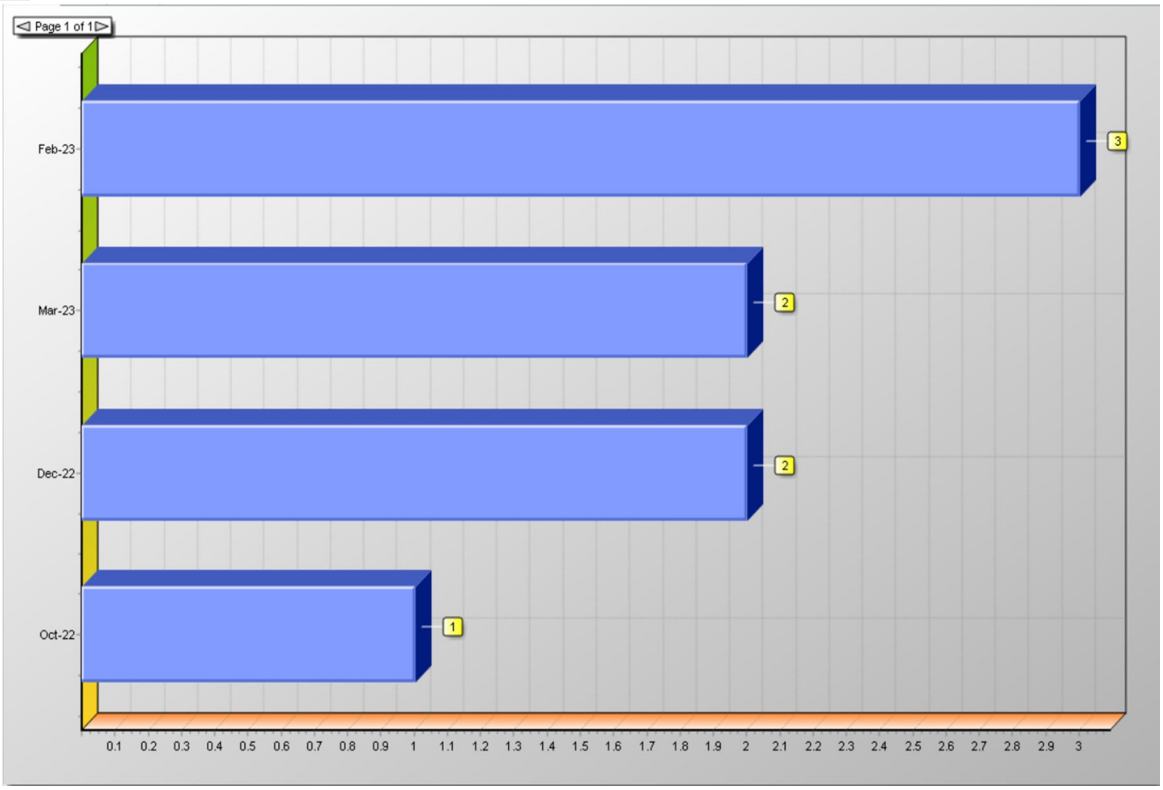
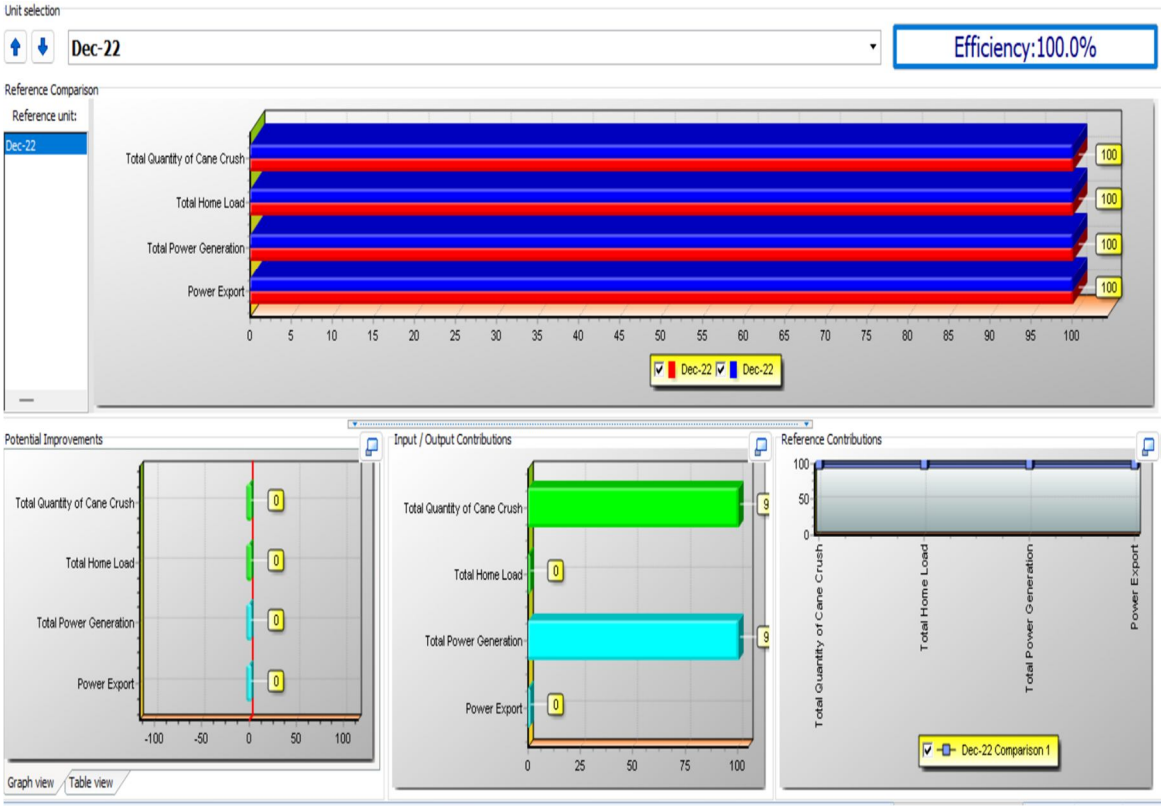
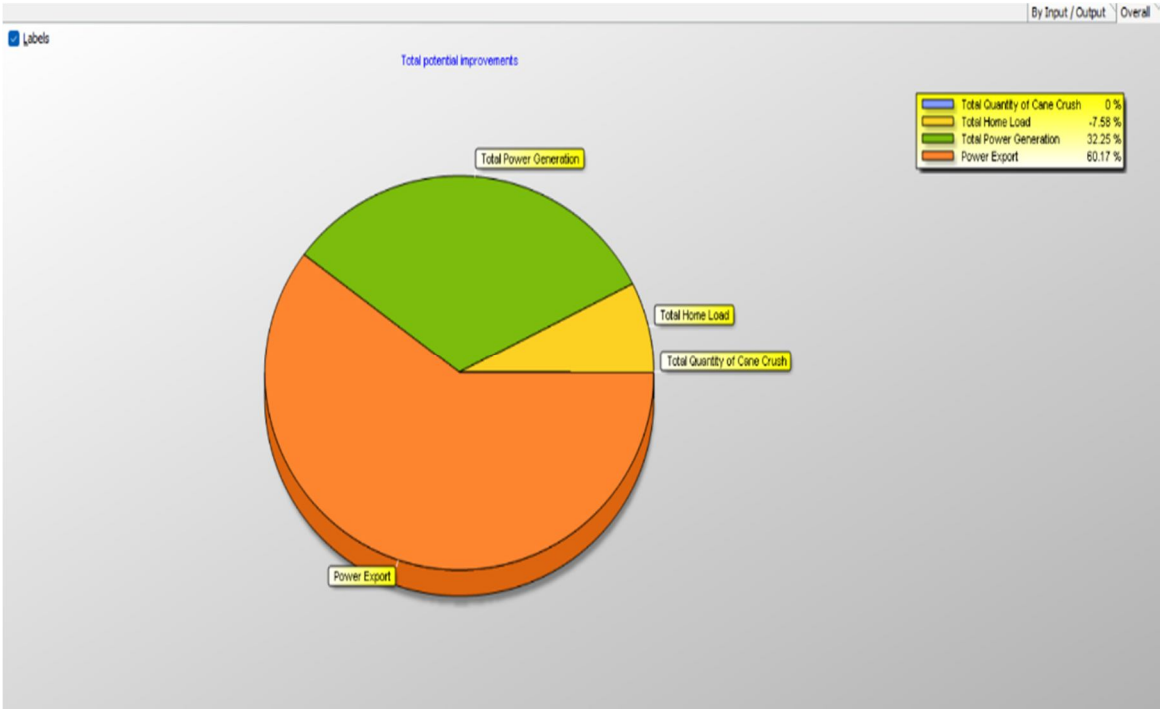


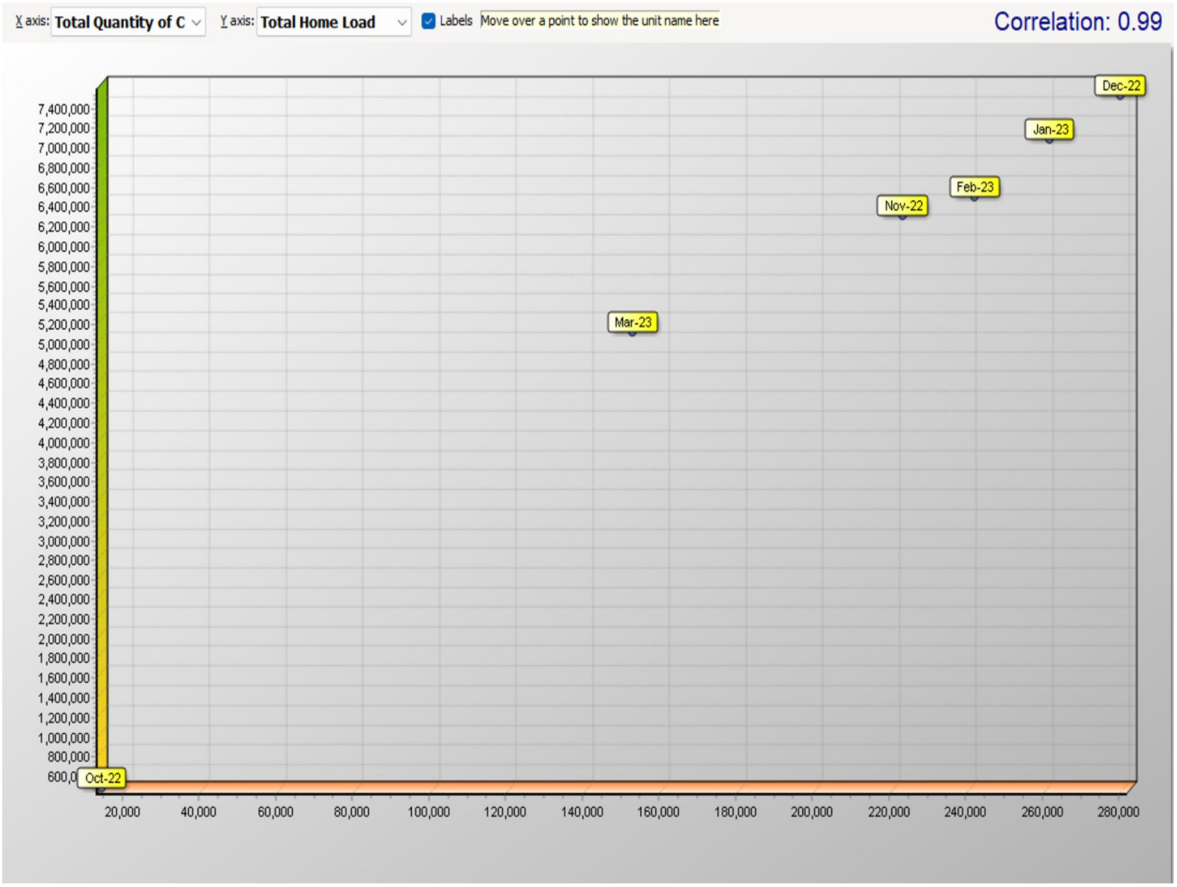
Graph 1: Effective Analysis Of Sugar Mill By Using BCC



Graph 2: Detailed Evaluation of December Month By Bcc Model



Graph 3: Total Power Analysis in plant



Graph 4: X Axis- Total Quantity of cane crush and Y axis- Total home load Plot

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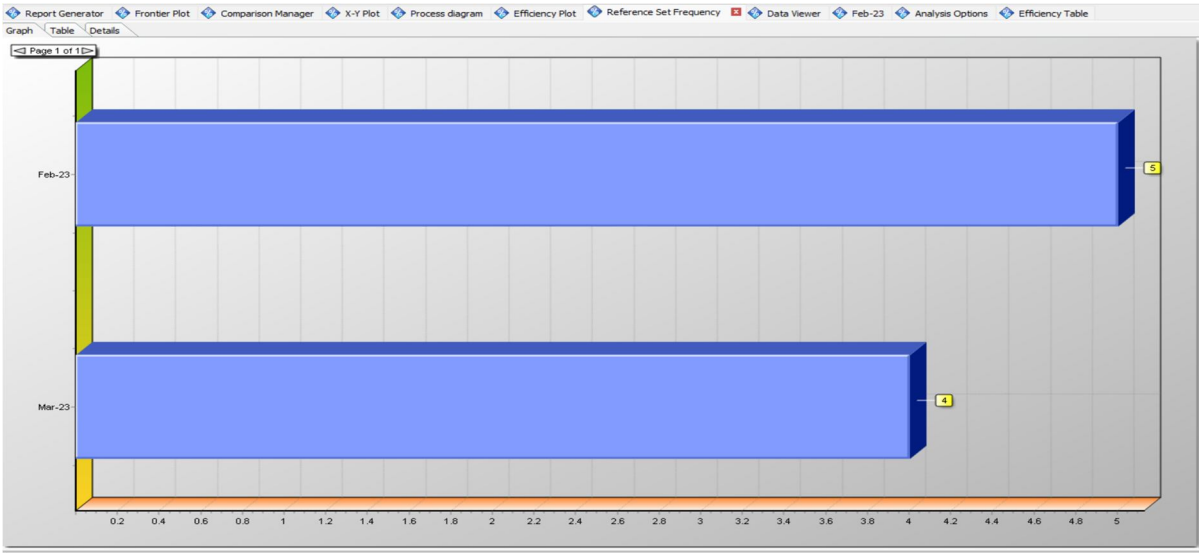
VIII. EFFECTIVE ANALYSIS OF SUGAR MILL BY USING CCR

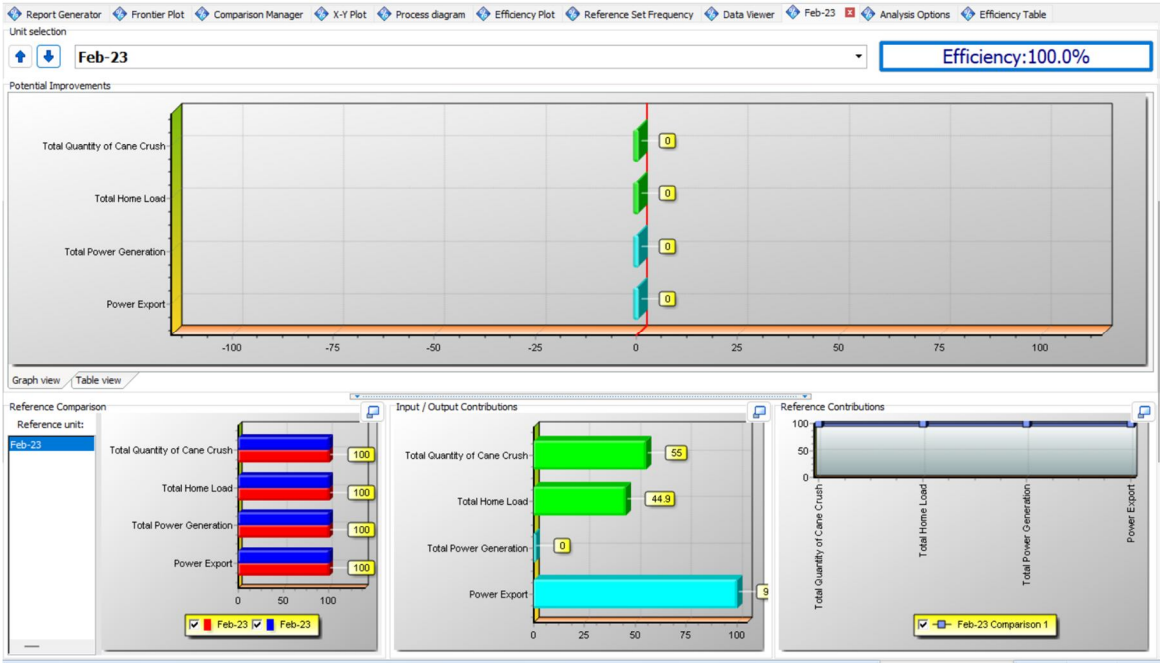
Table no.2 efficiency evaluation table

Efficiency scores | Summary graph | Distribution

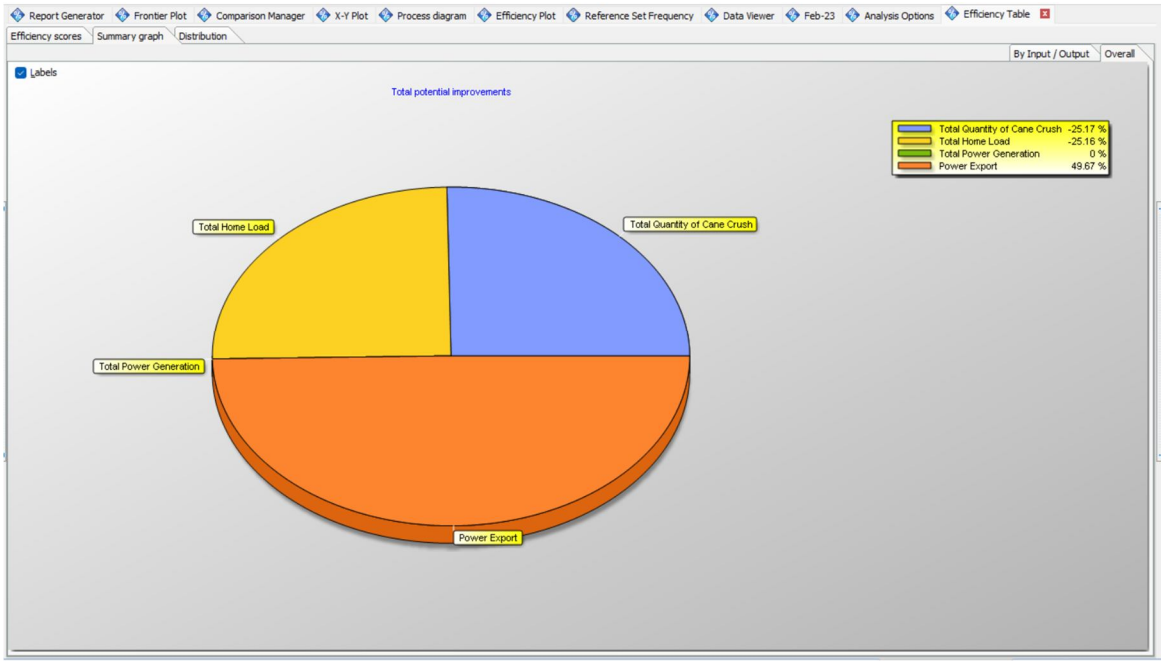
Units	Comparison 1		
Unit name	Score	Efficient	Condition
Dec-22	95.5%		
Feb-23	100.0%	✔	
Jan-23	92.6%		
Mar-23	100.0%	✔	
Nov-22	95.3%		
Oct-22	52.9%		



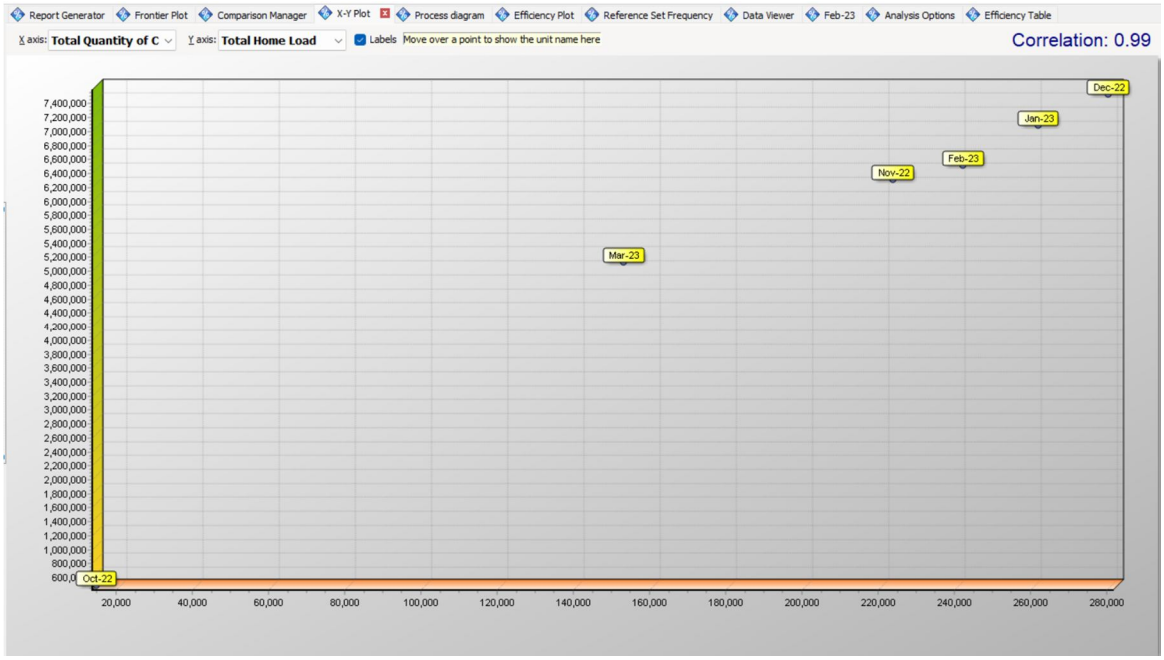
Graph 5: Effective Analysis of Sugar Mill By Using CCR



Graph 6: Detailed Evaluation Of February-2023 Month By CCR Model



Graph7:-Total Power Utilization in plant Feb - 2023



Graph 8: X Axis- Total Quantity of cane crush and Y axis- Total home load Plot

IX. CONCLUSION

This study concludes that M/s Shri Dnyaneshwar Shakari Sakhar Karkhana Ltd. (DSSK) with design cane crushing capacity of 7000 tons of cane per day (TCD) has significant electricity potential of about 31.5 MW. The plant should increase its availability to about 95% for steady milling and electricity generation. We have done the performance of the factory to increase the efficiency compared to the existing efficiency. We concluded that we can achieve 40% efficiency using VFD and AC drives. For Different 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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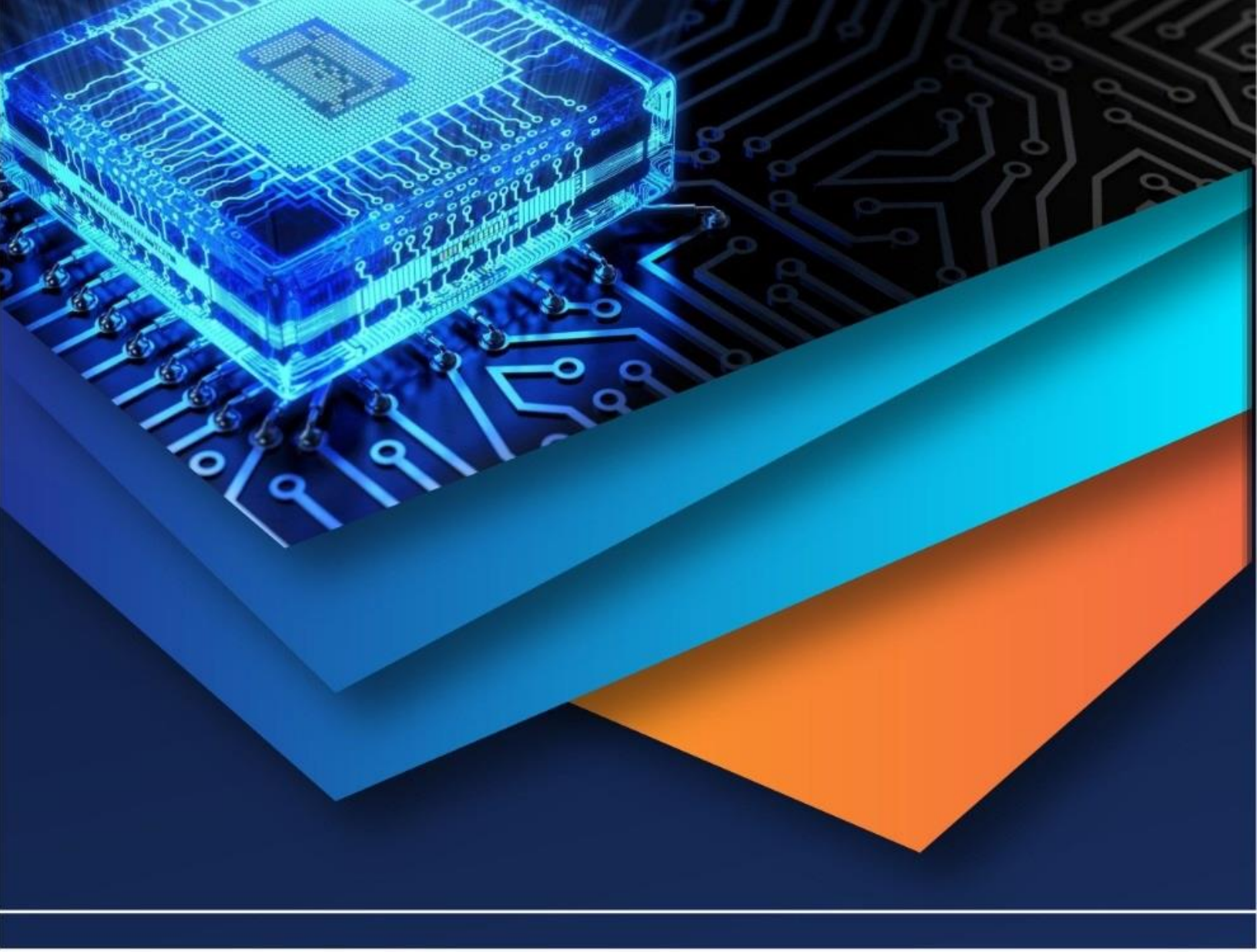

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