Performance Analysis and Development of an Export Cogeneration Plant for A 3000 TCD Sugar Cane Factory

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ABSRACT

This study presents a feasibility of export electricity generation for a 3000 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 public grid. There is need to diversify operations by sugar industry which is facing a crisis as a result of sugar dumping and high costs of production. Other than diversification into ethanol production, export cogeneration has a potential to generate additional revenue streams for struggling industry. This study involves a performance analysis of an operating sugar factory to determine its electricity generation potential. Data was collected by observation, document analysis, interview, and questionnaire. The study showed that the cogeneration potential is significant and currently underutilized and can significantly contribute towards greenhouse gas emission mitigation from power generation and earn revenue for the struggling sugar factory making the factory more competitive. The plant uses old inefficient equipment of very low efficiency that contributes to the low performance. Steam generation is inefficient from 3 boilers all older than 30 years. Use of high-pressure high temperature boilers and an alternative fuel to bagasse as a secondary fuel will make export cogeneration more competitive and feasible. The study shows that at current design milling capacity and average performance, a continuous cogeneration plant with capacity of 15 MW is recommended.

Key words
Bagasse; cane sugar production; cogeneration; electricity generation; sugar cane milling; Nzoia Sugar Company.

1. Introduction

Bagasse from sugarcane milling has significant energy potential as a combustion fuel for power generation. Sugarcane is generally grown under a wide range of conditions, in tropical and sub-tropical geographical regions across 35°N in Spain to 35°S in South Africa. It requires rainfall between 1,200-1,600 mm/year, that is well distributed to grow without irrigation. Sugarcane is generally harvested every 9-24 months, based on variety and growing conditions(M J B Kabeyi, 2020b; Kabeyi & Oludolapo, 2021). The three largest sugarcane growers in terms of production are Brazil, India, and China. Sugarcane is grown in more than 100 countries around the world, although 10 countries account for about 80% of the global sugar production led by Brazil and India (Schlindwein et al., 2017). A typical sugar factory has average electricity demand of between 20 and 30 kwh/ton of cane milled. Low efficient sugar factories can produce 60 to 70 kWh/tc while more efficient mills with steam generation at a high pressure of 88 bars can generate 130 kWh/tc (Council, 2007). If the bagasse is dried and pelletized, and Cane tops and leaves used, electricity generation can increase to 100–110 kWh/tc. An evaluation of bagasse cogeneration shows that the cost of electricity generated within the sugar industry is as competitive as electricity from fossil fuels (Schlindwein et al., 2017; USDA, 2020). This gives the sugar cane industry a very important role in the sustainable energy transition.

Nzoia Sugar was incorporated on 1st August 1975 under the Companies Act as a limited liability company with the Government of Kenya owning 98% of shares while 2% was shared by Five Cail Babcock of France (FCB) and Industrial Development Bank (ADB). The company had initial cane milling capacity of 2000 tonnes of cane per day (TCD) which was increased in 1986 to 3000 TCD and optimum sugar production of 315 per day. The planned capacity is 7000 TCD and 735 tonnes of sugar per day(Nzoia Sugar Company Ltd., 2020). Kenya relies heavily on domestic production of sugar to cater for its sugar needs. There is hardly any sugar left for export as the production is average and cannot even fully satisfy domestic consumption leave alone exportation. The sugar industry in the recent past and even currently continues to struggle and is riddled with heavy losses and dwindling performance (M J B Kabeyi, 2020; Kabeyi & Olanrewaju, 2021a; Kabeyi & Olanrewaju, 2021b).

The development of bagasse cogeneration as a reliable source of grid electricity requires involvement of many actors, and massive investment in technology and capital in a facilitating policy and legislative environment as demonstrated by progress towards export based cogeneration in Mauritius, India and Brazil (M J B Kabeyi, 2020; To et al., 2018).With suitable conditions for sugarcane development in the lowland areas in western and the coastal regions of Kenya, the realization of the full potential by sugarcane plants is being hampered by the over-reliance on rain fed agriculture and the mismanagement of state owned sugar factories resulting in high cost of production. By design, all sugar factories have an in-built cogeneration plant, however, the firms in Kenya have for long operated relatively inefficient boilers due to the age of the equipment, poor maintenance, and inefficient processes of sugar production and lack of ready market for power.

The Kenyan sugar industry has been facing various challenges characterized by poor and delayed payments for farmers and workers, governance issues including corruption and low efficiency in production. The first sugar mill was established in Kenya in 1922 by British settlers and many other were developed over years. High sugar production costs have rendered Kenyan sugar internationally and locally uncompetitive hence the need to diversify into other products like ethanol and export power cogeneration to survive(M J B Kabeyi, 2020b). Figure 1 shows the relative cost of sugar production among the COMESA (common Market for East and Southern African).

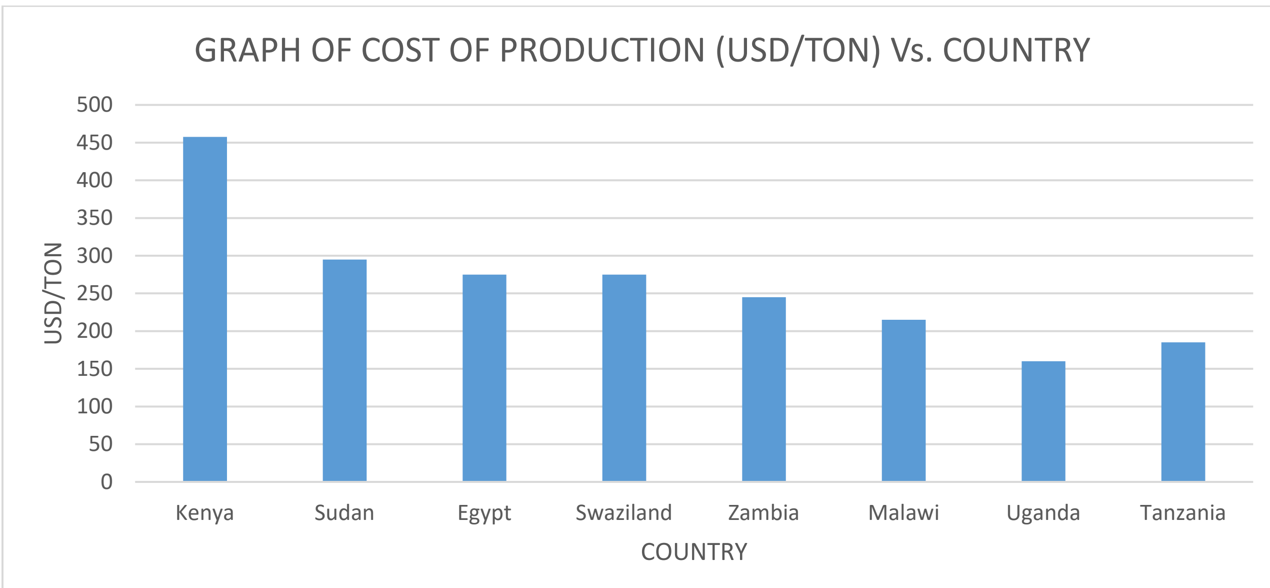

Figure 1: A graph of cost of production per ton in various selected countries

From figure 1, it is noted that Kenya's sugar industry is still characterized by the highest cost of production in the East and Central African region. In 2009, sugar production costs in Kenya were the highest in the region, these costs not only limit the industry's capacity to meet the national demand for sugar, but they also hinder its ability to compete with more efficient producers in the international market (M J B Kabeyi, 2020). Exploiting bagasse cogeneration potential is limited by the following factors:

i.) Generation of electricity using low pressure boilers and backpressure turbines is inefficient and therefore wasteful.
ii.) Only bagasse is usually used for power generation while sugar trash, which is significant is usually left in the fields, yet its use can increase combustible biomass by between 50 and 100%.
iii.) Generation of electricity from bagasse is limited to the milling season as no steam is required for out of crop and bagasse is only obtained from cane milling process (Rycroft, 2019).

Sugar cane is the most appropriate biomass for use in bioelectricity generation compared to many other alternative globally (da Silva et al., 2017).Agriculture accounts for over 50% of the GDP of several countries in sub-Saharan Africa. The use of bagasse to generate heat and electricity through cogeneration is one of the most economically viable options for participation of agriculture in sustainable energy generation and sustainable development (To et al., 2018). Bagasse cogeneration will substitute fossil fuels in power generation hence reduced consumption of coal, diesel and natural gas in power besides improving the competitiveness of the sugar industry which is struggling with huge costs of production in Kenya and other developing countries (Mashoko et al., 2008). Bagasse cogeneration will also improve energy security and reduce overall environmental impact from power generation (Mashoko et al., 2013). Electricity from sugarcane bagasse can complement generation from fossil fuels and seasonal hydropower as well as variable renewables like solar and wind while increasing revenue for sugar factories, create employment and stabilize the grid through decentralized generation. Electricity from bagasse is cleaner than that from nuclear and fossil fuels (da Silva et al., 2017; Kabeyi, 2019; M J B Kabeyi, 2020b; Kabeyi & Oludolapo, 2020a, 2020b, 2020c).

The objective of this study is to determine the electricity export potential of the 3000 (TCD) tons of cane milled per day at Nzoia Sugar company in Kenya. The study started with the survey of the sugar industry and a performance analysis of the factory. The factory is located between Webuye and Bungoma Towns of Western Kenya. It was commissioned in 1978 with an initial rated capacity of 2,000 TCD, which was raised to 3,000 TCD. The factory gets 80% of the sugar cane from contracted farmers while 20% is supplied from the company owned nucleus estate(M J B Kabeyi, 2020b).

2. The Sugar Cane Industry

2.1. Sugar Production Process

Sugar cane is the is an important crop as is grown in over 100 countries even though 10 countries alone account for over 80% of global sugar production (da Silva et al., 2017; M J B Kabeyi, 2020b). Sugar cane manufacture involves two main energy intensive operations. These operations are processing of beets or sugar cane to raw sugar and refining of raw sugar. Cane and beet sugar extracts consists of mainly sucrose, polysaccharides, proteins lignin, gums, starches, waxes, and other colloidal impurities. The removal of the proteins and colloidal matter requires addition lime, heating, and clarification processes (Singh, 2015). Figure 2 shows the processes involved in sugar manufacture.

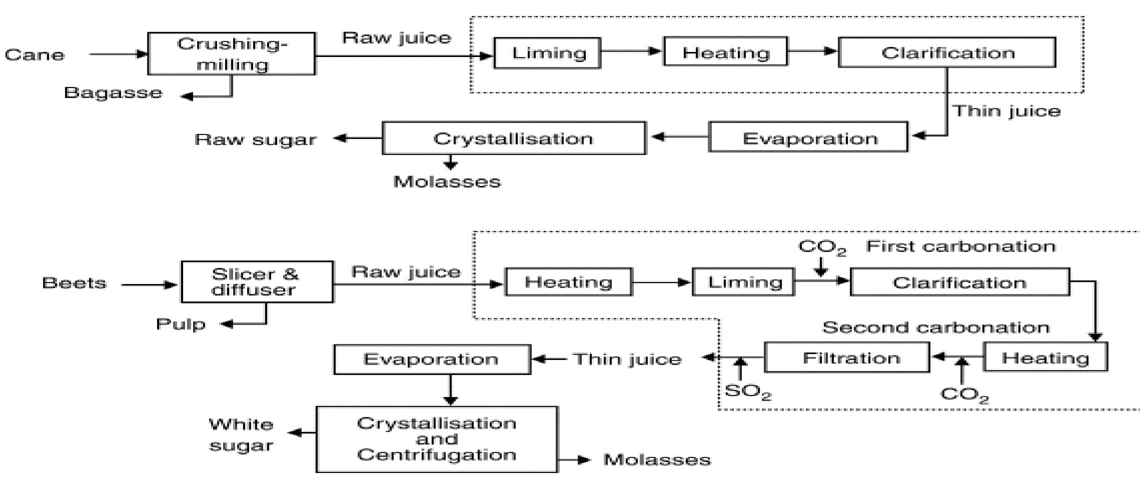

Figure 2: Sugar production process from cane and beets(Singh, 2015)

Figure 2 shows the sugar production process from both sugar cane and beet sugars. In cane sugar production, bagasse which is the important cogeneration fuel is produced after milling cane to remove the sucrose rich juice.

Sugarcane crop is used as a feedstock for efficient biofuel production and energy generation. Sugar cane and sugar and byproducts of sugar production have many industrial applications as raw materials including steam and power generation from bagasse combustion in boilers(Rabelo et al., 2020).

2.2. Bagasse Cogeneration Options

Bagasse cogeneration can be implemented based on three technologies. These are the back pressure steam turbine, condensing extraction turbine and the use of a biomass/Integrated Gasifier/Gas Turbine Combined Cycle.

i.) The Backpressure Stream Turbine (BPST)

This is the simplest cogeneration system making use of a back pressure steam turbine. A back pressure steam turbine exhausts steam at a pressure above atmospheric which is used for process heating and other thermal operations normally between 1.5 and 2 bars(M J B Kabeyi, 2020b).

ii.) The Condensing Extraction Steam Turbine (CEST)

These cogenerations set up uses a condensing turbine with steam extraction between the turbine expansion stages for process application. The remaining steam is exhausted at a pressure often below atmospheric into a condenser for condensation. This turbine is more efficient and hence will generate more power from the same steam(Hugot, 1986a).

iii.) 2.9.3 Biomass/Integrated Gasifier/Gas Turbine Combined Cycle.

This is a new technology for the sugar industry in which biomass like bagasse of other wastes like trash is partially oxidized at a temperature range of 800^{o}C to 1200^{o}C to produce combustible fuel gases. These gases are then used in a turbine for power generation. A Rankine cycle system can be installed to use the turbine exhaust gases which have significant amount of heat energy(Hugot, 1986a; M J B Kabeyi, 2020b).

3. Electricity Potential of Sugar Factories

Sugar cane bagasse accounts for 25 to 30% the weight of cane milled by a sugar factory with 50% moisture content (da Silva et al., 2017; M J B Kabeyi, 2020b). Different methods can be used to estimate the thermodynamic performance of cogeneration facilities relative to others. Very commonly used criteria include energy utilization factor, fuel saving ratio, heat-to-electricity ratio, exegetic efficiency, and electricity produced per ton of cane crushed (tc)(M J B Kabeyi, 2020a; Kabeyi & Olanrewaju, 2022). The existing high pressure, high efficiency, Rankine cycle steam turbine cogeneration plants generate 115–120 kWh/tc, while BIG-GT and BIG-STIG have a potential to generate 270–275 kWh/tc. Cogeneration with backpressure and condensing steam turbines perform with energy and exegetic efficiency of about 60–70 % and 22–25%, respectively. The steam consumption in sugar mills at present varies from 480–550 kg/tc. The electricity consumption varies between 16–22 kWh/tc for steam turbine driven mills and 32–40 kWh/tc for electrified mill drives (Kamate & Gangavati, 2009).

3.1. Bagasse as Composition

The bagasse that leaves the factory mills as residue is normally made up of fibrous outer part and the underlying prit which is the white, soft, smooth parenchymaton tissue which is highly hygroscopic. Prit mainly consists of sugars, cellulose, pentosans, hemicellulose and lignin. It also consists of wax and minerals. Properties of bagasse generally depend on the type of cane, its age as well as the method of harvesting used. On average one ton of bagasse in Brazilian conditions yields 280 kg of bagasse while in Nepal, one ton of sugarcane yields about 362 kg of bagasse. The difference is due to cane variety differences and hence the composition of sucrose and fiber in cane(Khatiwada et al., 2012). However, on average, it has been established that bagasse at the point of generation from the last mill contains 49-52% moisture content, 47.4% fiber content and 2.3% solute materials. The table 1 below shows a typical content composition of mill bagasse

Table 1: mill bagasse composition (Hugot, 1986b; M J B Kabeyi, 2020b).

Composition	Percentage	Average Composition
Moisture	46-52	50
Fibre	43-52	47.7

Soluble solids/impurities	2-6	2.3

From table 1, it is noted that bagasse consists of three main constituents, namely moisture, fiber, and soluble solids. The specific composition is influenced by the cane quality and process conditions like quality of juice extraction and imbibition use.

Compared to other conventional fuels, bagasse has a relatively lower energy value. However, its availability at the factory and the reduced transport costs involved in ferrying it make bagasse a more suitable source of fuel or energy in sugar factories especially at a lower moisture content level.

3.2. Calorific Value of Bagasse

At 50% moisture content, bagasse has a calorific value (GCV) of 9600Kj/Kg and 7600 Kj/Kg net calorific value. Dry ash free bagasse has GCV of 19400kj/kg(Hugot, 1986a; M J B Kabeyi, 2020b). The average fibers content of cane is close to 10- 17% by mass, but it generally lies in the region of 12-15% while the quantity of the bagasse varies between 24 and 30% by weight of sugarcane or approximately one quarter. Bone dried bagasse has a gross calorific value of 17,632kj/kg. At 50% moisture content it exhibits a net calorific value of 8,816kj/kg(Becharry, 1996; Bressanin et al., 2021). Table 2 below show the calorific value of the constituents of bagasse fuel. Table 2 shows the energy value of the bagasse constituents.

Table 2: Composition and calorific value of bagasse constituents(Hugot, 1986a; M J B Kabeyi, 2020b)

Item	Constituent	Calorific Value (Kj/Kg)
1	Fibre	19,320
2	Sugar	16,611
3	Impurities	17,220
4	Water	0

From table 2, it is noted that fiber, sucrose/sugar, water, and impurities make up the combustible and noncombustible elements of bagasse fuel.

Studies have shown that there is considerable difference in appearance between different sugar cane, but the gross calorific value of dry bagasse is almost constant for all varieties and countries(M J B Kabeyi, 2020b; Kabeyi & Olanrewaju, 2021b). The estimated gross calorific values for bagasse from different countries/states are as is shown in table 3 below

Table 3: GCV of bagasse by state/Country(Hugot, 1986a; M J B Kabeyi, 2020b)

COUNTRY	GCV OF DRY BAGASSE (Kj/kg)
Australia	19,076
South Africa	19,257
Hawaii	19,412

Cuba	19,702
Puerto Rica	19,295
AVERAGE	19,488

From table 3, it can be established that the average universal gross calorific value of dry bagasse is (GCV) is about 19,488 kJ/kg of dry bagasse. Given that dry bagasse has 6-7% moisture content, a working average of 6.5% moisture gives net calorific value of N.C.V = 17,850kj/kg.

3.3. Electricity Potential

Bagasse cogeneration provides a potential avenue for diversification of the sugar industry into export power cogeneration. Through promotion of cogeneration, the sugar industry can diversify its revenue portfolio and stabilize the industry and create jobs as well as more revenue to the sugar cane farmers(Kabeyi & Olanrewaju 2021). Cogeneration experience from successful countries in bagasse cogeneration like India, Réunion, Mauritius, Brazil and Cuba have demonstrated significant production of excess electricity by sugar industries for export to the grids. There are three main cogeneration options that can be adopted by sugar factories. They are intermittent, continuous and generation firm power plants with bagasse as cogeneration fuel or other energy sources like biomass or agricultural wastes(M J B Kabeyi, 2020b; Kabeyi & Olanrewaju, 2021a; Kabeyi & Olanrewaju, 2021b).

Sugar production requires relatively energy in form of steam/heat and electricity. This energy is met by either conventional cogeneration which uses a back pressure steam turbine which generates electricity, and the exhaust steam supplies process steam and heat required. or use a condensing extraction turbine which is more efficient as it generates more electricity while process steam is extracted or bled off from between the turbine expansion stages. Major equipment in a sugar factory like the cane knives and mills have either electric drives of steam turbine drives(Hugot, 1986a; Kabeyi & Olanrewaju 2021). Conversion of steam turbine driven systems to electric driven systems will avail more steam for electricity generation and hence greater powerplant capacity.

Conventional conversion systems System achieve efficiency of about 25% with bagasse for steam pressures of 45-66 bars, which can allow export potential of about 100 kWh per ton of cane crushed. Generation capacity of about 110 kWh at 82 bar has been achieved per ton of cane crushed from operations in Reunion, Mauritius, India and Brazil(Hugot, 1986a; Kabeyi & Olanrewaju 2021). There are their basic cogeneration configurations based on plant design and capacity. These are intermittent generation where electricity generation is not continuous and is based on sugar production needs. This is followed by continuous powerplants which are expected to operate continuously during the sugarcane crop season. The firm power plants are designed to operate throughout the year for average of 300 days except for 65 to 66 days during which the powerplant is under maintenance. Table 4 below shows that characteristics of the three bagasse cogeneration setups.

Table 4: comparison of the three cogeneration setups that can be adopted by sugar mills.

	Parameter	Intermittent Generation	Continuous Generation	Firm power Generation
1	Electricity generation per ton of cane milled	10 kWh/ton	60 kWh/ton	110 kWh/ton
2	Cane crushing rate	10 TCH or 240 TCD	150 TCH or 3,600 TCD	230 TCH or 5600 TCD
3	Load factor and availability	Intermittence allowed	90% load factor	90% load factor, 300 milling days or 7200 hours a year and 65-66 days for maintenance.

4	Steam: bagasse ratio	1.8:2.2	2.5	2.5
5	Steam specifications	25 to 30 bars	30-40 bars	82 bars
6	Turbine type	Back pressure or condensing	Condensing	Condensing type
7	Boiler capacity	40 tons/hr	120 tons/hr	140-150 tons/hr
8	Steam consumption	500-600 kg/ton of cane crushed	400 kg/ton of cane milled	400 kg/ton of cane milled
9	Electricity consumption	25 kWh/ton of cane crushed	30% internal consumption	Not more than 30% internal consumption
10	Turbine capacity	0.5-1.5 MWe	15 MW	At least 30 MW

From table 4, it is observed that firm power plants have the highest generation potential while the intermittent generation has the list generation and export potential. Condensing turbines are common turbines for firm and continues cogeneration power plants.

3.4. Investment Costs for Bagasse Cogeneration

For cogeneration plants, the investment costs vary with net export capacity, from $1.4 million/MW at the lower pressures, through $1.8 million/MW mid-range to $3.1 million/MW at the top end. This compares with $1.1 million/MW for heavy fuel plants, $2.25 million/MW for geothermal and $2.5 million/MW for hydro power plants. Thermal power plants have significant fuel costs that are passed directly to the consumers under current tariffs(M J B Kabeyi, 2020b; Kabeyi & Olanrewaju, 2021b).

3.5. Investment options for Bagasse cogeneration

Experience based on the various bagasse cogeneration projects globally proposed the following guidelines to sue in sizing of a bagasse cogeneration plant(M J B Kabeyi, 2020b).

Table 5: Investment guidelines for bagasse cogeneration projects(M J B Kabeyi, 2020b)

Component	Possible plant options		
Boiler pressure (bar)	45	60	82
Recommended plant capacity (tonnes of cane per day)	5000	5000	5000
Boiler capacity (tonnes of steam per hour)	140	140	140
Bagasse feed rate (tonnes per hour)	58	62	70
Turbine capacity (MW)	25	30	50
Daily power generation, gross (MWh)	420	550	820
Equivalent capacity (MW)	18	24	40

Daily export power, net (MWh)	260	330	550
Equivalent export capacity (MW)	12.5	14	24
Total capital investment ($ million)	18	25	75
Estimated local component ($ million)	4	5	12
Estimated annual revenue from electricity ($ million)	4	5	8.3
Simple payback period (years)	4.5	5	8.8

From table 5, it is noted that, based on factory size and choice of technology, there are types of boilers that can be selected for generation of steam based on a 5,000 TCD sugar factory. The steam pressure ranges from 35 to 82 bars or closer denominations.

4. Performance Analysis of the Factory

This study involved a study of operations at Nzoia sugar factory based in Western Kenya by analysis of current and historical data and physical verification of current state of the factory and the cogeneration plant. Data was collected with the help of questionnaires, interviews, and observation of the general plant.

4.1. Power House parameters

The performance parameter for the power house i.e. boilers and turbines are summarized below in table 5.

Table 6: Current condition of power generation in Nzoia Sugar Company (Nzoia Sugar Company Ltd., 2020)

Parameter	Rate/Value
Daily bagasse production	1040 tones
Usage (bagasse)	800 tones
Current availability of bagasse	Available
Daily cane availability	Available
1Watertube fixed grate boiler 25bar 330◦C	54 tones/hr.
2 FCB water tube boiler 23bar 320◦C	27 tones/hr. each
Number of boilers	3
Average age of the boilers	39 years old
Efficiency of the boiler	60%
Optimum capacity Operating capacity	3 MW
Domestic Consumption	2.8 MW
Export to the grid	0
Steam Pressure Range	20 -25 bars

Current operation of the plant	Operational

The table 6 shows the current condition of power generation in Nzoia Sugar Company. It is noted that the factor has got 3 boilers of capacity 108 tons/hr aged over 39 years with average bagasse consumption rate of 54 tons per hour and thermal efficiency of 60%. The plant consumes 76.9 % of bagasse produced during steady continuous milling hence a bagasse buildup of 24.1% indicating excess bagasse and wastage of useful energy resource for power generation.

4.2. Steam and Bagasse Production Data

Bagasse is produced as a solid remnant of sugar cane milling process. The quantity of bagasse produced is directly proportional to the amount of cane milled. The bagasse and steam production rates are summarized in table 7.

Table 7: Operational conditions Quantity and Units

Operational conditions	**Quantity**	**Units**
Sugar cane crushed/year	402740.89	TC
Sugar cane crushed/hr.	46	TC/H
Amount of bagasse produced (Average)	13.8	t/h
Steam produced	108	t/h
Steam pressure (Average)	22	Bar(g)
Steam temperature (average)	300	°C
Steam at pressure-reducing valve	10-15	t/h
Power consumed by plant	2.8	Mw
Effective operation days in one year	275	Days

The table 7 shows quantities and units for various inputs including steam produced and steam pressure, steam temperature, power consumed by the plant, among others. The data shows that process operations take 10 to 15 tons/hr of steam from boilers which is up to 14% of steam generation.

4.3. Turbines

The factory has got four powerhouse and 3 mill drive turbines which use steam from boilers. The specifications of the power house turbines are shown in table 8.

Table 8: Turbine technical data

	Parameter	Dresser Rand	Kessel (Multistage)	FCB turbine Not operational
1	Output	3MW	4MW	0
2	Normal Speed	5400/1135rpm	6480/1135 rpm	-

3	Trip Speed	5400-5300rpm	6480-6000 rpm	-
4	Steam Pressure	23Kg/cm^{2}g	25Kg/cm^{2}g	23Kg/cm^{2}g
5	Steam Temperature	300-330^{o}C	300-360^{o}C	300-330^{o}C
6	Exhaust Pressure	1.5Kg/ cm^{2}g	1.5Kg/ cm^{2}g	1.5Kg/ cm^{2}g

Table 8 shows specific characteristics of turbines including output power, normal speed and temperature, power rating and specific steam consumption, among others. The two operational turbines have installed capacity of 7 MW against effective capacity of 2.8 MW (40% of installed capacity) and excess capacity is 5.2 MW (60%).

4.4. Performance Analysis

The factory experiences variable performance based on the state of the mill and availability of sugar cane for milling and hence availability of bagasse for electricity generation.

Table 9: Table of sugar produced and cane crushed over years at Nzoia Sugar Company (M J B Kabeyi, 2020)

Year	Sugar Produced (TS)	Cane Milled (TC)
2009	68254	679568
2010	65859	645591
2011	61886	652170
2012	64669	690996
2013	55535	680364
2014	49648	596186
2015	86821	924721
2016	59218	706173
2017	46724	580868
	Average value	684, 071

From table 9, it is noted that milling generally varies from 580,868 tons of cane per year to 924, 721 tons of cane per year with 9-year average of 684,070.

5. Results and Discussion

A performance analysis of the current cogeneration plant at Nzoia Sugar factory indicates wasteful use of energy and hence the need to optimize the use and develop a more efficient power plant for export of power to the grid while meeting domestic factory operations electricity demand. Any maintenance or failure of the turbine means disrupting power production process since the optimum capacity is just 4 MW which is hardly sufficient to meet the entire factory electricity needs. The current power plant design is meant to maximize combustion of bagasse as a disposal method while generating just enough steam and electricity for factory operations. With high ratio of cane crushed (TC)/TS (Sugar made) means the bagasse has significantly high sugar content which causes undesirable clinkers in the boiler furnace during combustion of bagasse which diminishes boiler performance and efficiency. Old and obsolete boilers and turbines also call for replacement with more efficient equipment for steam and power generation while the prime movers like cane knife and mill turbines ought to be replaced with electric drives to reduce factory steam use and concentrate on power generation. Use of variable drives and right sizing of electric drives will also reduce factory electricity demand to avail more electricity for grid export. The bagasse moisture content is also relatively high which affects the fuel heating value and hence boiler as well as power plant efficiency hence to need to overhaul the milling process to reduce bagasse moisture content to the level of 48 to 50% moisture content from the current average of 52%.

As a fuel, bagasse has got that the average universal gross calorific value of dry bagasse is (GCV) is about 19,488 kJ/kg of dry bagasse. Given that dry bagasse has 6-7% moisture content, a working average of 6.5% moisture gives net calorific value of N.C.V = 17,850kj/kg. Conversion of steam turbine driven systems to electric driven systems will avail more steam for electricity generation and hence greater powerplant capacity. There are their basic cogeneration configurations based on plant design and capacity. These are intermittent generation where electricity generation is not continuous and is based on sugar production needs. This is followed by continuous powerplants which are expected to operate continuously during the sugarcane crop season. The firm power plants are designed to operate throughout the year for average of 300 days except for 65 to 66 days during which the powerplant is under maintenance.

With milling capacity of 580,868 tons of cane per year to 924, 721 tons of cane per year, the factory can develop a continuous power plant with electricity generation potential of 60kWh per ton of cane milled. It should however invest in boilers of pressure 30 bars to 40 bars and capacity average of 120 tons/hr. For maximum electricity export, the mill turbine and cane knife drives should be converted to electric drives to avail more steam for power generation reduce internal electricity consumption to below 30% of total generation, install condensing extraction turbines of capacity 15 MW on average and improve plant availability and load factor to about 90%.

6. Conclusion

This study concludes that Nzoia Sugar factory with design cane crushing capacity of 3000 tons of cane per day (TCD) has significant electricity potential of about 15 MW, but this may not be realized because of poor plant availability mainly due to breakdowns and shortage of sugarcane for milling. The plant should increase its availability to about 90% for steady milling and electricity generation. Investment in efficient electric drives as opposed to steam turbine drives and new efficient boilers of greater pressure and efficiency will position Nzoia Sugar company for export electricity generation.

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