

PERFORMANCE ANALYSIS OF A SUGARCANE BAGASSE COGENERATION POWER PLANT IN GRID ELECTRICITY GENERATION

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ABSTRACT

The overall objective of this study was to establish the feasibility of export-based cogeneration by a leading sugar factory in Kenya. It was established that the sugar factory invested in a 34 MW cogeneration power plant to export 26 MW excess electricity to the national grid. Reliance on bagasse alone as the fuel placed the plant at the mercy of the sugar factory operations and availability of cane. The study showed that after three years of profitable operation, the cogeneration power plant became unsustainable and export to the grid was stopped. The plant faced challenges like low load factor and capacity factors occasioned by unsustainable milling of cane. This meant irregular bagasse fuel supply to the power plant hence capacity underutilization and availability of the plant which attracted huge penalties from the utility company. The study recommends policy initiatives to encourage export of electricity from the sugar industry while development of multi-fuel plants will delink the co-generation from the challenges of sugar cane factory operation. These measures will improve the power plant availability, load factor, capacity factor and reliability ultimately making bagasse cogeneration suitable for base load grid electricity supply.

Key Words: Bagasse; sugarcane bagasse cogeneration; export cogeneration; challenges of bagasse cogeneration; electricity generation; combined heat and power.

1.0.INTRODUCTION

Up to six million Kenyans derive a livelihood from Kenyan sugar and hence the need for proper and competitive management of sugar factories (Jeremiah, 2018). Kenya saves anywhere from Sh40 billion to Sh55 billion a year in import costs by using locally produced sugar – which matters more as our trade deficit continues to grow and place downwards pressure on the value of the shilling (Kabeyi, 2020), yet to remedy the Government has drawn up new regulations that appear unjustified. The common market for Eastern and South African States (COMESA) warned the Kenyan government that there will be no further extensions in safeguards from imports by the trading block, yet Kenyan sugar currently costs \$870 a tonne to produce, compared with \$350 a tonne in Malawi and \$400 a ton in Egypt, countries which belong to the same trading block. COMESA has warned there will be no further extensions in protecting domestic sugar from imports, yet Kenyan sugar currently costs \$870 a tonne to produce, compared with \$350 a tonne in Malawi and \$400 a tonne in Egypt (Arum, 2019).

The sugar cane industry has significant potential of reducing greenhouse gas emissions and other energy related pollution. According to Naeem (2019), bagasse power plants reduce carbon emissions by replacing electricity produced from fossil fuels and avoiding disposal of unused bagasse which generates methane emissions on decomposition. In Kenya just like many other countries, electricity is the most preferred form of energy according to the Ministry of Planning and Development (MoPND) and the Ministry of Social Council (MoPND, 2007). According to the Energy Regulation Commission, ERC (2011), only 1.5% of Kenya's electricity generation comes from the bagasse cogeneration even though the country has a potential of generating up to 195MW out of its bagasse production capacity.

1.1 Background of Mumias Sugar Company Limited

In 1967, the Government of Kenya commissioned Booker Agriculture and Technical Services to do a feasibility study on the viability of growing sugarcane in Mumias and then initiate a pilot project. At the time, the Mumias area was underdeveloped, land utilization was poor as farmers grew food crops on small areas for subsistence only, while the rest of the land was purely for grazing. The relative remoteness of the area and poor communication prevented the development of an active market economy. The study showed that it was possible to establish a viable sugar scheme at Mumias where the factory is supplied with cane from both the Nucleus Estate and indigenous farmers. The Government accepted the findings and on July 1, 1971 incorporated Mumias Sugar Company as the body to implement the project. The Government was to hold majority shares (71%) and minority interests held by the Commonwealth Development Corporation (17%), Kenya Commercial Finance Company (5%), Booker McConnel (4%) and the East African Development Bank (3%). The company's original capacity of the factory was 45,000 tonnes of sugar per year when it was fully operational in 1973. The factory capacity has grown dramatically to 173,000 tonnes of sugar and 1.8 million tonnes of sugar cane crushed per year (Mumias, 2017).

In 1979, Mumias Sugar Company carried out an expansion of factory capacity to 3000 tons of cane per hour while in 1997 factory rationalization was completed and daily milling capacity increased further to 7,000 tons of cane per day and the efficiency of sucrose extraction was raised from 82% to the current 86% through factory modernization. With steady operations, and need to diversify the product base and expand the market visibility, in 2000 a nationwide distribution network for sales and marketing was established and an electricity sale agreement with Kenya Power and lighting Company to supply 10, 000MWh of electricity per annum to the national grid was concluded. These enabled Mumias to diversify into export cogeneration.

With improved performance, in 2001 the company was converted from a parastatal to a public limited liability company and listed on the Nairobi Stock Exchange. However, Mumias continued to be managed under contract by Booker Tate until 2003 when the contract expired. In 2006, under new management, an agreement was signed with Avant Garde Engineers and Consultants (P) Ltd of India to develop US\$ 40 million power production unit, to increase generation capacity of the factory 38 MW of which 26 MW was for export to the National Grid and the balance for domestic or factory consumption (Jetro, 2009). This shows that, it is through prudent management and good company performance that Mumias Sugar Company Ltd. developed and grew in capacity and diversified into export power generation when the Government of Kenya liberalized power generation (Kabeyi, 2020). It also shows that the Government of Kenya played a crucial policy role in facilitating bagasse cogeneration in the Kenyan sugar industry (Abagu & Dayness, nd). Figure 1 shows leafy young can growing in the field. On maturity, it will supply mature cane for processing into sugar and a fibrous combustible biomass by product called bagasse(Kabeyi, 2020).



Figure 1. Sugarcane crop (Abagu & Dayness, nd).

Figure 1 shows sugarcane as a leafy fibrous crop which results to a solid fibrous waste called bagasse upon juice extraction in the factory.

The factory's cogeneration plant operated profitably but due to inability to get constant supply of cane for factory milling and hence bagasse for cogeneration, Mumias suffered huge penalties as per the power purchase agreement

with Kenya Power that finally led the utility company into switching off power supply to Mumias. This move triggered a crisis that saw the miller stop operations and was finally placed under receivership at the time of this study. The purpose of this study is to establish the performance of the cogeneration plant and identify the potential and challenges of bagasse cogeneration in supply of grid electricity.

1.2. Problem Statement

There is a global shift from reliance on fossil fuels to green sources of energy for grid electricity generation (Kabeyi, 2019; Kabeyi & Olenwaraju, 2021). In 2015, 2016 and in 2018, the Kenyan electricity utility company, Kenya Power disconnected electricity supply to Mumias Sugar Company triggering a serious operational crisis. The miller was reported to owe the utility firm, nearly ksh2 billion (US\$ 20, 000,000) in unpaid bills, yet coincidentally, the factory should generate own power and export up to 26 MW to the grid. (Business Daily, 2015; The Daily Nation, 2018). Challenges in cogeneration forced the company to stop export cogeneration, hence breach of contract as stipulated in the power purchase agreement (PPA) forcing a renegotiation of the power purchase agreement with utility company Kenya Power Plc. However, lack of sugar cane made it difficult to generate electricity for export to the grid (Business Daily, 2019). In 2018, the company stopped operations when the utility company switched off electricity supply to the factory over the unrecovered billions of shillings most of which are penalties for failure to deliver on its contractual obligations (Mumias, 2018). Of greatest concern is why a company that should be exporting electricity be disconnected from the grid and eventually collapse over failure to generate one of its own primary input and product as well, that a net exporter is a net importer of electricity.

2.0. BAGASSE AS A FUEL

2.1. Characteristics of bagasse

The bagasse that leaves the factory mills as residue is normally made up of fibrous outer part and the underlying pith which is the white, soft, smooth parenchymatous tissue which is highly hygroscopic. Pith mainly consists of sugars, cellulose, pentosans, hemicellulose and lignin. It also consists of wax and minerals. Properties of pith or bagasse generally depend on the type of cane, its age as well as the method of harvesting used. However, on average, it has been established that bagasse at the point of generation from the last mill 49-52% moisture content, 47.4% fiber content and 2.3% soluble materials. 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, 1986; Okomo, 2016). The average fiber 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 (Kabeyi, 2020; Hugot, 1986). Bone dried bagasse has a gross calorific value of 17,632kj/kg. At 50% moisture content it exhibits a net calorific value of 8816kj/kg (Okomo, 2016; Barroso, Barreras, Amaveda, & Lozano, 2003). The table 1 below shows a typical content composition of mill bagasse.

Table 1: Mill bagasse composition (Hugot, 1886; Kabeyi, 2020).

COMPOSITION	PERCENTAGE	AVERAGE COMPOSITION
Moisture	46-52	50
Fibre	43-52	47.7
Soluble solids	2-6	2.3

From table 1, it is noted that bagasse mainly consists of moisture and fiber and traces of soluble solids. Other physical features of bagasse also have the following physical properties are specified below.

- i.) It is odorless.
- ii.) Has specific weight of 250kg/m³

iii.) It is white and light green in color.

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.

3.0. THE COGENERATION PLANT AT MUMIAS SUGAR

3.1. Cogeneration

An energy-focused environmental accounting method based on the embodied solar energy principle was used for evaluating biomass and coal-based combined heat and power (CHP) cogeneration processes. The energy method expresses all the resources needed (fuel, investment, labor etc.) as solar energy equivalents. The method looks at sustainability from the point of view of the biosphere. In fact, energy aims to be a 'memory' of how much work the biosphere has done to provide a product. Biomass and coal-based CHP alternatives were compared with independent production of heat & power. It was found that biomass-based cogeneration is 3.3 times more energy-efficient than coal-based independent production, i.e., the biosphere needed to work 77% less for biomass CHP produced heat & power compared to that produced independently from coal. Cogeneration from the same fuel was in all cases 0.3 times more energy-efficient than independent production. In general heat and power production from biomass is 2.3 times more energy-efficient than that from coal in a similar process. The energy sustainability index shows a similar trend, e.g., the sustainability index of a biomass CHP plant is 15 times higher than that of a coal CHP plant. The fuel, its transport, and the oxygen in air used for burning account for over 80% of the energy in biomass CHP, whereas in a coal-based process the share is over 90%. The share of capital is quite small in terms of total energy (Sha & Hurme, 2012).

3.2. Cogeneration Power plant capacity

The main objectives for establishing the 38 MW bagasse cogeneration plant by Mumias Sugar Company was to make use of excess bagasse fuel to generate extra power for sale to grid and hence earn extra revenue stream in addition to sugar sales. Selling surplus power to the national grid contributed to Kenya's efforts of achieving self-sufficiency in electricity generation and supply. The plant was also to help eliminate the cost of disposing off excess bagasse and its effects to the environment. The 38 MW cogeneration plant was commissioned in May 2009 which led to increased internal electricity demand from 10 MW to 12 MW but excess electricity for sale to the grid increased from 3 MW to 26 M at a cost of \$ 40 Million dollars' loan capital.

3.3. Cost of Cogenerated power

The unit cost of the cogenerated electricity based on both export and installed capacity of the power plant is computed below based on the power plant loan capital.

- i.) The unit cost of the export capacity is $\$40,000,000/26,000 \text{ kW} = \$1,538/\text{kW}$
- ii.) Based on the total capacity of the cogeneration plant, the unit cost is $40,000,000/34,000\text{kW} = \text{US } \$1,176 \text{ US\$/kW}$.

The assumption is that there is no other cost involved in the power plant development.

3.4. Environmental Impact

The installation of the new plant would reduce carbon emissions by up to 120,000 tons per year according to the CER ratings whose rates vary between \$6 and \$20 per ton, hence extra revenue and mitigation against carbon emissions and global warming. This was a great step aimed at increasing the power production in the factory. The project was registered by the UNFCCC Executive Board as a CDM project on 1st Sept, 2008 (Mumias Sugar, n.d; Omuoyoma, 2012).

3.5. Comparison of The Old and new Cogeneration Power plant

The comparison between the old plant and new plant is as illustrated in the tables 3 and 4 below.
Table 2: The characteristics of the old and new cogeneration plants (Omuoyoma, 2012).

	PARAMETERS	OLD PLANT	NEW POWERPLANT
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1	Daily bagasse production	140 tons/hr.	140 tons/hr
2	Bagasse Usage	110 mt/hr.	130 tons/hr
3	Excess Bagasse (Fuel accumulation)	30 mt/hr.	10 tons/hr
4	Boilers (number)	7	2
5	Steam	220 mt/hr.	170 tons/hr (New), 110 tons/hr (old boiler)
6	Steam quality	330°C, 45 bar	New boiler (87 bar, 550°C Old boiler(330°C, 45 Bar)
7	Installed capacity	13 mw	38 mw
8	Domestic Power consumption	10 mw	12 mw
9	Excess power for export	3 mw	26 mw

The following observations are made from table 3 above.

- i.) The new cogeneration plant did not require factory capacity expansion.
- ii.) Number of boilers were reduced from 7 to two by construction of a new boiler and retirement of 6 old smaller boilers
- iii.) Factory electricity demand increased from 10 MW to 12 MW due to increased auxiliary demand.
- iv.) Excess electricity generation increased from excess of 3 MW to 26 MW for export.
- v.) High pressure steam for factory use and medium pressure for the cogeneration plant were generated with room for modernization and expansion of medium pressure boiler.
- vi.) Excess bagasse generation and buildup reduced from 30 tonnes per hour to 10 tonnes per hour hence reduced fuel wastage.
- vii.) Steam generation increased from combined capacity of 220 tons/hr to 280 tons/hr.

3.6 Power Purchase agreement (PPA)

A power purchase agreement (PPA) is legally binding agreement between the utility company and electricity producer and contains targets and obligations for all parties in the contract (Kabeyi, 2020). In this case the Mumias Sugar Company has a binding agreement with Kenya Power to supply electricity. The PPA has the following provisions shown in table 2.

Table 3: PPA specifications (Author's summary of information)

	CONTRACT ITEM/PARAMETER	SPECIFICATIONS
1	Contract period	10 years
2	Rate/price of power	Capacity (US cents 2.6)+ Energy (US cents 3.4)=US cents 6 per kWhr
3	Plant export capacity	26 MW
4	Availability	85% of the capacity
5	Operating days (Target)	275 Days per annum
6	Guaranteed Min Dispatch	90 Million KWh/year 40% capacity/year

7	Amount surcharged as penalties	US \$20 cents per kWh
8	Total amount surcharged	KShs. 1.1 billion

Table 3 shows that the company is paid for exported power based on both available capacity of the powerplant and total electricity supplied to the grid and combined total of 6 US cents per KWhr but with a penalty at the rate of 20 US cents for failure to supply power as per the PPA which is about 3.3 times more than the total unit price. This shows that the power purchase agreement heavily punishes failure to supply power by the sugar company.

4.0. PERFORMANCE ANALYSIS OF THE COGENERATION PLANT

4.1. Generation, Revenue and penalties

Table 4. Annual power export (GWh) by Mumias Sugar Company between 2009-2015

Years	Bagasse Production (tons)	Bagasse Used (tons)	Export in GWhrs	Surcharge (GWhrs)	Annual Revenue(\$)	Surcharge (US \$)	Net Revenue (Dollars)
2009-2010	731,000	650,000	99	10.2	5,940,000	2,040,000	3,900,000
2010- 2011	731,000	650,000	87	22.2	5,220,000	4,440,000	780,000
2011- 2012	731,000	650,000	100	9.2	6,000,000	1,840,000	4,160,000
2012-2013	520,000	520,000	71	38.2	4,260,000	7,640,000	(3,380,000)
2013-2014	420,000	410,000	57	52.2	3,420,000	10,440,000	(7,020,000)
2014-2015	90,000	90,000	14	95.2	840,000	19,040,000	(18,200,000)
TOTAL	3,223,000	2,970,000	428	227.2	25,680,000	45, 440,000	(19,700, 000)

Table 4 shows the financial performance of the cogeneration plant between 2009 and 2015. It shows the total electricity exported was 428 GWhrs, units surcharged or penalized for failure to supply to the utility amounted to 227.2 GWhrs, cumulative revenue earned was US\$ 25,680, 000, penalties for poor performance earned the company a surcharge of US\$ 45, 440,000 and net financial loss was US\$ 19,700,000. Continued fluctuations in the plant output made it difficult for the plant to meet the terms of agreement in the PPA. At some point the company could not export any power to the national grid at all. For the first 3 years of the power plant operation, the technical performance based on 21.5 effective capacity and 26 MW installed capacity was follows.

- i.) Total generation was 286 GWhrs
- ii.) Average load based on agreed 285 days of operation annually is 10.8 MW
- iii.) Load factor was 0.5
- iv.) Capacity factor was 0.4

4.3. Bagasse Supply and Electricity Generation

A bar graph showing the total amount of bagasse supplied to the plant annually.

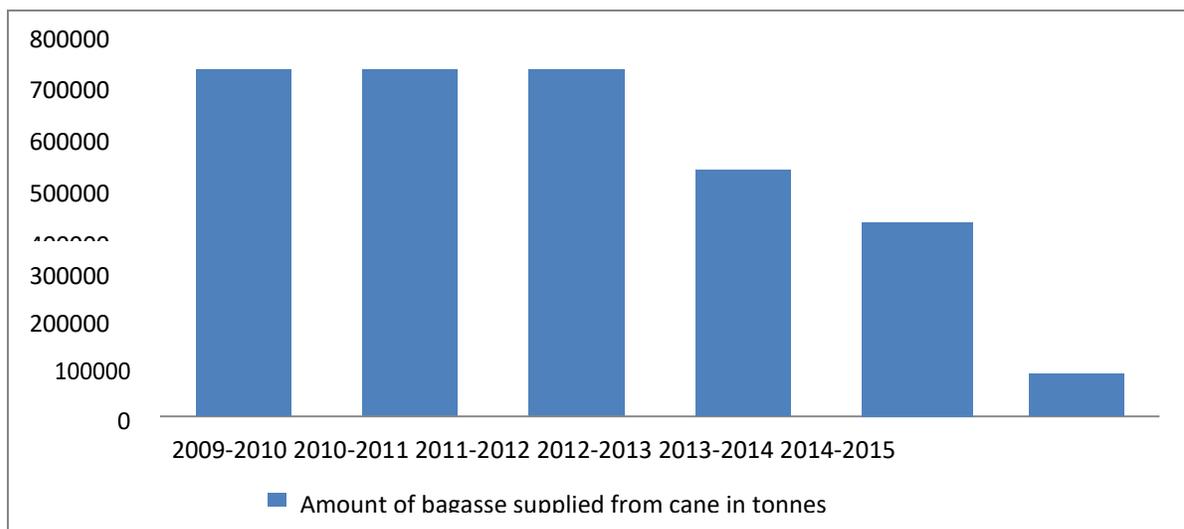


Figure 2. Bagasse supply between 2009 and 2015 (Kabeyi, 2020).

From figure 1, it is noted that enough bagasse was supplied to the plant during the first three years after which the supply began to reduce significantly. The reduction in the amount of bagasse supplied continued to reduce from 2012 until 2015 as indicated when only less than 100,000 tons of bagasse was supplied during the whole year. The plant was designed to burn more than 100 metric tons of bagasse per hour at its optimum performance. However, due to insufficient supply of bagasse, it could not run at its optimum anymore. Reduced power output led to reduced power exported to the national grid and hence reduced revenue generation from power export to the Company.

The bagasse cogeneration plant is also designed such that it operates on just one, but high-volume boiler that runs on a single-high-capacity furnace. The generated steam is used to drive a single turbine. The turbine is large enough and can generate as high as 34 MW of power. The fact that the massive plant runs on a single furnace, single boiler and a single prime mover makes it very difficult to control the costs involved in its operation. For example, the costs involved in generating 10 MW and 34 MW are no different since at both low and high output levels the plant operates at constant conditions. It is, therefore, uneconomical running the plant at lower output considering the heavy initial investment involved in setting it up. Whenever there occurs a break down or damage of part, however minor, the entire plant must be shut down for repairs to be done unlike other power plants that are made up of several units. This means that the plant cannot generate power at all during both repair and maintenance periods. The plant is, therefore, unavailable during such times and hence unreliable in supplying power to the national grid. Figure 3 below shows the gross revenue from sold electricity.

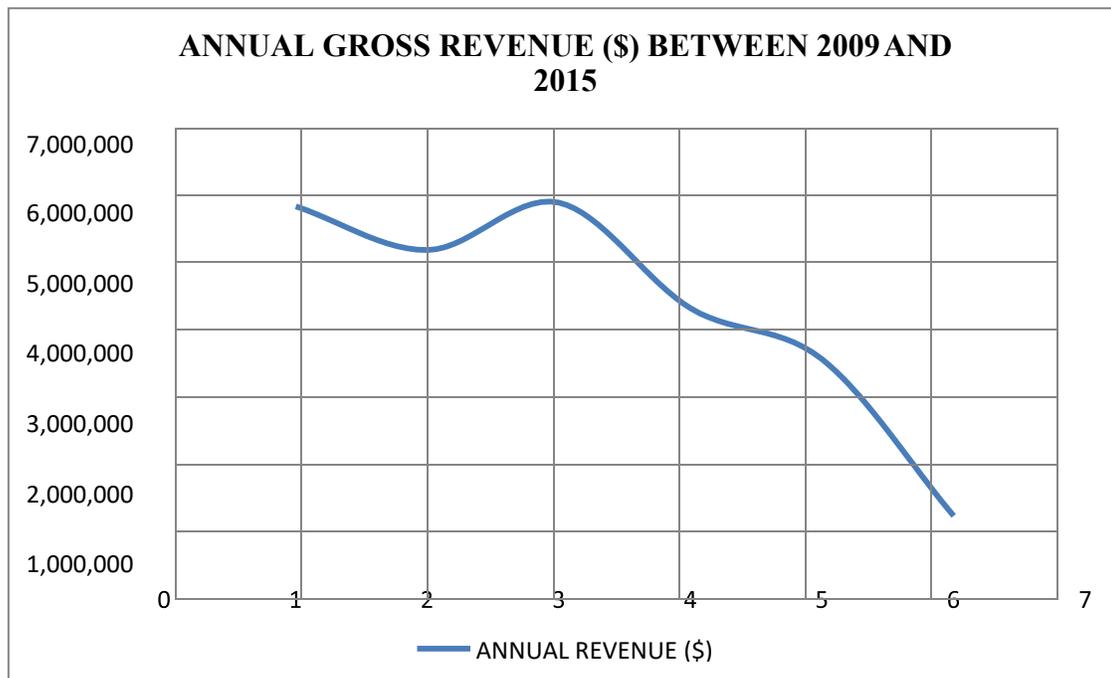


Fig 3. A Graph of Annual Net Revenue between 2009 and 2015

Figure 3 shows the annual gross revenue for 2009-2015. It is noted that in the first three years, between 2009 and 2011, the Company recorded annual revenue of \$5-\$ 6 million. However, beginning 2012 the annual revenues began decreasing drastically and consistently until 2015 when the lowest amount was recorded. In the first three years of operation, the Company made profit out of the generated and exported power. Later, beginning 2012, the Company began making losses. The amount of losses made increased significantly down to 2015 when it made a loss of more than \$ 18 million. The cogeneration plant is currently experiencing a financial crisis as there is no revenue collected since no power is being exported to the national grid (Mumias, 2010).

5.0. CONTRIBUTION TO THE NATIONAL ELECTRICITY GRID

The Kenyan electricity grid receives power from various generating power stations with most of the power received from the Government controlled Kenya Electricity Generating Company. Most Independent Power producers own and generate diesel power plants while Mumias is the only company that supplied power from sugar industry cogenerations. Other sources of grid electricity are geothermal, hydro power stations, and wind energy (Ministry of Planning and Development (MoPND), 2007; Omuyma, 2012; Riley et al., 2020). Table 5 below shows the various sources of grid power between 2009 and 2015.

Table 5: Electricity generation in Kenya from different sources between 2009 and 2015 (ERC, 2016).

Company	Capacity (MW) as at 30.06.2015		Energy Purchased in GWh					
	Installed	Effective	2009/10	2010/11	2011/12	2012/13	2013/14	2014/15
KenGen								
Olkaria I 4 & 5	140	140						744
Geothermal Total	488	480	939	1,081	1,106	1,096	1,156	3,104
Wind:								
Ngong	25.5	25.5	16.3	17.7	14.6	13.9	17.6	37.7
KenGen Total	1,596	1,534	3,606	5,040	5,409	5,968	5,931	6,943
Government of Kenya (Rural Electrification Programme)								
Thermal	18	14.5	19	21	23	26	29.8	35.1
Solar	0.569	0.569			0.3	1	0.8	0.9
Wind	0.55	0.2			0.1	0.7	0.4	0.003
Total Offgrid	19	15	19	21	23	27	31	36
Independent Power Producers (IPPs) - Thermal & Geothermal								
Iberafrica I&II	108.5	108.5	621	722	705	592	550	198
Tsavo	74	74	495	368	283	178	152	83
Thika Power	87	87					454	233
Mumias - Cogeneration	26	21.5	99	87	100	71	57	14
OrPower 4 - Geothermal I, II & III	110	110	400	372	392	503	851	955
Rabai Power	90	90	318	394	338	443	633	609
Imenti Tea Factory (Feed-in Plant)	0.3	0.3	0.3	0.4	0.8	0.7	0.1	0.5
Gikira small hydro	0.514	0.514					0.4	1.6
Triumph Diesel	77	77						5
Gulf Power	80.32	80.32						60
IPP Total	654	649	1,933	1,945	1,820	1,788	2,698	2,160
Emergency Power Producers (EPP)								
Aggreko Power	30	30	1096	267	381	261	93.8	62.7
EPP Total	30	30	1,096	267	381	261	94	63
Imports								
UETCL			37	30	36	41	83	76
TANESCO			1.1	1	1.1	1.2	1.3	0.6
EEPCO							2.1	2.8
Total Imports			38	31	37	42	87	79
System Total	2,299	2,228	6,692	7,303	7,670	8,087	8,839	9,280

From table 5, it is noted that KenGen has the largest installed capacity in 2016 with 1596 MW installed capacity and effective capacity of 1534 MW (96.1%) from various energy sources out of total installed capacity of 2299 MW and effective capacity of 2228 MW of which Mumias cogeneration plant had installed capacity of 26 MW and effective capacity of 21.5 MW (82.7%).

Mumias Sugar Company has electricity export installed capacity of 26 MW with effective capacity of 21.5 MW. Its electricity exports as shown in figure were 99 GWhrs, 87, 100, 71, 57 and 14 GWhrs between 2009 and 2015 averaging 73.3 GWhr per annum. This amounts to load factor of 39.2%. The average contribution to the grid power for the same period was 1.5%, 1.2%, 1.3%, 0.9%, 0.6% and 0.2% which results to average contribution of 0.7% to the national electricity grid. The contribution kept on reducing due to annual increase in electricity demand while the capacity of the cogeneration plant kept reducing mainly because of deterioration in sugarcane Production and hence fuel supply to the power plant.

The cogeneration plant performance can be summarized as follows based on agreed 285 days per year

- i.) Average load factor for the 6 years of operation is $\text{Generation} / \text{Expected maximum generation based on effective load capacity of 21.5 MW} = 428/883 = 0.48$
- ii.) Average capacity factor is 0.46 for the six years based on 26 MW capacity

6.0 CHALLENGES FACING MUMIAS SUGAR COMPANY

The deteriorating operations and inefficiencies at the Mumias Sugar Company led to the Company into incurring a huge debt adding to about Kshs12 billion. This rendered the company unable to fund its operations and purchases. The debt has exponentially increased to unmanageable levels discouraging investors and scaring away stakeholders who play a very important role of funding its businesses.

The Company was unable to pay farmers who supply it with cane because of lack of money. This has discouraged

farmers who then opted to abandon the whole idea of growing cane and embarked on subsistence farming. Others have ended up diverting and selling their cane to other local buyers who actually run small sugar factories within the same region. The coming in of other players in sugar milling within the same region led to stiff competition for the already financially weak Mumias Sugar Company. This competition made it even more complicated to find solutions to the predicaments of the crippling Mumias Sugar Company. The operations were paralyzed even more, and this significantly reduced its revenues and increased penalties for undelivered power by the utility. Finally, the sugar producer was placed under receivership hence collapse of the cogeneration powerplant too.

5.0. HIGHLIGHTS FROM THE STUDY

The following are major findings from this study.

- i.) The boiler efficiency is 60%, these provides room for further improvement through design and operations. To efficiencies greater than 70%
- ii.) One boiler is operating at 45 bar 330°C compared to the new boiler at 87 bars. Need to redesign the sugar factor to use high pressure boilers.
- iii.) The performance of the cogeneration plant is dependent on the performance and operation of the sugar plant hence need to improve the cane sugar supply chain and factory efficiency.
- iv.) A 34 MW turbine generator is too big and does not provide desired flexibility in generation with varying supply of bagasse and maintenance requirements.
- v.) Equipment inherited from the old power plant are old with most of them being older than 10 years which affects reliability and performance of the power plant availability and performance.
- vi.) The factory and hence power plant has planned maintenance of 90 days per year hence 275 days for generation. This provides an opportunity to apply modern maintenance techniques to reduce the downtime and supply more power.
- vii.) After three years of operation, the cash flow from the cogeneration plant seriously diminished due to low milling and hence low bagasse fuel supply for electricity generation leading to higher penalties than revenue. These made operation and plant maintenance impossible.
- viii.) The average load factor is 0.46 while capacity was 0.48.
- ix.) The power purchase agreement between the sugar factory and the utility company heavily penalized the powerplant unavailability regardless of the sources which was unsustainable with challenges in cane supply and milling.

6.0.CONCLUSION

Bagasse is a cogeneration is a feasible investment technical and financially, but its operation is loosely related. The bagasse cogeneration project in Mumias Sugar Company has ever since suffered a number of challenges that have seen the company close operations when Kenya Power disconnected electricity supply due to huge electricity bills arising from penalties accrued to the cogeneration plant failure to deliver the terms of the power purchase agreement. Cogeneration has been seriously affected by shortage of fuel due to supply interruptions caused by strikes and cane shortage leading to long forced outages of the sugar mills and the cogeneration plant. The amount of bagasse produced out of the crushed cane could not sustain the running of the boiler to ensure continuous power generation. It is therefore important that by all means the cane suppliers be motivated to remain on board and continue with cane farming to supply the factory that will guarantee adequate bagasse supply for the operation of the cogeneration plant.

The design of the cogeneration plant to use single fuel is a serious challenge to sustainable cogeneration. Multi-fuel boilers running on more than one fuel could guarantee continuous power generation since can faming and supply to the factory has deteriorated and is no longer sustainable. The cogeneration plant has capacity of 34 MW and was designed to run on a single high-capacity boiler with a single turbine prime mover. This is causes serious challenge in operation and maintenance in terms ensure consistency in power generation as the whole plant must be shut down altogether whenever there is need to carry out repair or maintenance. The single boiler also requires a lot of fuel to run and whenever there was little bagasse, the entire plant is stopped ultimately affecting cogeneration and sugar production in the factory.

The research showed that initial availability of the plant was established to be about 75%. This value is low compared to the recommended availability that should range between 98% and 99%. It also implies that for about 24.7% of the year the plant is not in operation and hence unproductive in terms of revenue generation. It therefore goes without saying that for any hope to be restored in the bagasse cogeneration sector, effort should be made to raise the plants availability to the recommended range of 98-99%. The idle time of the bagasse cogeneration plant stood at about 90 days per annum or 24.7% for the period under investigation. This is extremely high considering the fact that every minute lost is money lost. It is therefore important that the amount of the plant's idle time be scaled down to manageable levels. This will help raise the bagasse cogeneration plant availability and consequently raising the revenue returns.

On quality of bagasse fuel, the study showed that the moisture content of bagasse used is relatively high at an average of 52%, 2-4% higher than the recommended values of 48-50%. It is therefore important that a more effective method of drying bagasse before using it in the boilers be established to help reduce the moisture content further thereby raising the calorific value per unit mass of the fuel. Alternatively, mill setting in sugar processing should reduce moisture content to recommended range of 48-50%. It was also noted that technical personnel had challenges in operating and handling of the plant leading to longer downtimes and penalties from the utility company. The plant automation systems were not fully adopted because of lack of required skill while a number of tasks like what should be simple repairs and maintenance subcontracted or outsourced hence higher costs.

The government of Kenya has not given full support to encourage bagasse cogeneration through policy and legal initiatives like high the feed-in-tariff for sugar factories, promotion of intermittent electricity supply to the grid and motivating power purchase agreements. Lack of this initiatives led to huge penalties and losses from the Mumias Sugar cogeneration plant leading to total shutdown of operations and eventual liquidation of the entire Sugar Company. This shocked the entire sugar industry and all sugar factories that were pursuing export cogeneration suspended their plans.

7.0.RECOMMENDATIONS

- i.) The original design of the plant should be reviewed to allow the use of other alternative types of fuel e.g. coal to help to supplement the main fuel i.e. bagasse when it runs out for any reason like breakdown in the sugar mills or disruption in sugar cane supply for mill. This will help to maintain the cogeneration plant running and generating power during times of both availability and unavailability of bagasse in the factory.
- ii.) The company should invest in the training of the employees working in the cogeneration plant to equip them with the necessary skills to enhance performance and efficiency in the running of the plant activities. This will minimize forced outage of the cogeneration plant.
- iii.) The government should formulate and implement favorable policies that govern cogeneration to encourage investors to venture in the bagasse cogeneration industry. The existing Power Purchase Agreements (PPAs) should be reviewed to accommodate the dynamics and challenges that cogeneration plants like sugar factories face and minimize the imposition of penalties which have crippled the entire sugar factory through disconnection from the grid. This includes supplying electricity only when milling is going on with less or no penalties from the utility company.
- iv.) The farmers, who are the major stakeholders in sugar industries, should be motivated and encouraged to grow and supply cane to the sugar factories. This can be done through giving of incentives, good pay per tonnage as well as timely making of payments upon cane delivery. The farmers should also be paid for the fiber in cane which gives bagasse fuel. This will prove their revenue and encourage them to grow sugarcane.
- v.) The bagasse cogeneration plants should set up their own water treatment units to avoid incurring costs on buying the large volumes of demineralized water and lower the costs involved in the running of the plants and hence cost of electricity
- vi.) More efficient methods of drying bagasse fuel before use should be employed to lower the moisture content to the recommended high energy levels.
- vii.) Modernization of the sugar factory with installation of high efficiency machines with longer time to failure and shorter times to repair. This will ensure higher plant availability and lower plant idle time of the sugar mills and hence maximum supply of bagasse to the cogeneration plant. This will help to maximize electricity generation and power plant availability and capacity factor hence cheaper electricity and more sales revenue.
- viii.) The single unit, high capacity plant design should be reviewed and future expansion should consist of many smaller units of the same total capacity to enhance plant flexibility hence repair and maintenance as well as operations without interrupting the entire process of power generation in plant. This will help to realize a scenario where one unit

can be shut down for maintenance or repair as others continue running to generate power without interrupting the required output.

For optimum performance of the sugar industry in export based bagasse cogeneration, Mumias and other sugar companies should put in place the following measures;

- i.) modular capacity, high-efficiency boilers to be installed in phases.
- ii.) ample storage capacity for bagasse to cover autonomy.
- iii.) factory efficiency optimization
- iv.) improved scheduled maintenance.
- v.) harvesting cane trash as a possible extra boiler fuel (potential additional fuel capacity of up to 20%), which will require substantial investment.

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