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Assessing Sudan's potential energy from Bagasse cogeneration

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Contents

Summary

This brief assessment report looks into the availability of Bagasse in The Sudan and its potential utilization into the energy sector with particular emphasis on Co-generation. Due to the lack of both time and resources; various reports, case studies and papers were used and referred to in the assessment.

The assessment concludes to the huge energy potentials that Bagasse cogeneration can contribute to the country. It also identifies the significance of having other uses of Bagasse in terms of converting it to Bio-Ethanol. The assessment ends with recommendations for achieving optimum results.

Aim and Methodology of assessment

The aim of this assessment is to identify Sudan's energy potential from producing Sugar cane by-product Bagasse.
Due to the lack of both resources and time, the assessment entails utilizing existing results concluded from various case studies and reports. Results from one key feasibility study carried out by Cleaner Energy Fund for Agroindustry in Africa (CEFA) shall be extensively used.

Background

Sudan's energy consumption:

Sudan is one of the largest countries in Africa with a total land area of 1,882,000 km^2. Arable land area account for 200 million acres however, only 40 million acres have been cultivated. Total water resources are 30.8 billion m^3 for a population of approximately 33.5 million (with growth rate 2.84% per year). Agriculture is one of the most important sectors in the country that play big role in the country's economy. Main crops include maize, wheat, millet, cotton and peanuts. Other grown crops mainly are sugarcane, dates, sunflowers, sorghum and citrus.[1]

Sudan is not one of the energy consuming countries, in fact it lies at the bottom ranks of the global energy consumption list [2].
It was back in 2001, when the last major national study on Sudan's energy consumption was conducted. Since then however many events occurred in the country. Key energy related events include:

- The split of the country into two countries in 2011: presently named Sudan and South Sudan.
- Petroleum products becoming widely available from local refineries (especially up and till the countries were united), with their shares in the energy market increasing from 20% in 2001 to 36% in 2009.
- Liquefied Petroleum Gas (LPG) produced at the capital's refinery set aside for domestic consumption and power generation. This in effect led into the decrease of biomass share in the energy market (from 78% in 2001 to 63% in 2009).
- Considerable expansion in both Hydro and Thermal power generation. [3]

Although there has been a notable fall in the biomass contribution towards energy consumption between 1981 (83%) to 2009 (63%), biomass however remains the dominant source of energy in the country. According to Sudan's national energy balance data, 14,908 kilo tonnes of oil equivalent (ktoe) was the country's primary energy supply in 2008, while the energy consumption of the same year was 9,810 ktoe thus implying a high rate of energy loss. An energy loss, which has been attributed to poor levels of electricity generation-distribution, petroleum product refining and distribution as well as poor levels of biomass conversion.[3]

As of 2008, the households sector dominated the End-use sectors for energy consumption with percentages as high as 49%. Followed the households came the transport sector (26%), Commercial and Governmental Services (14%), Industry (10%) and lastly the Agriculture sector with only 1%.
Almost nearly all (95%) of the households energy consumption needs were secured by biomass energy (primarily through burning of firewood and charcoal).[3]

Sudan's overall biomass energy consumption:

The total consumption of biomass energy fell from being approximately 8 million toe in 1999 to about 6.5 million toe in 2008. Firewood fuel was the most contributor in biomass energy consumption, accounting for 63% of total biomass consumption. Charcoal (20%) and agriculture residues (17%) came in the 2nd and 3rd places. [3]
The main consuming sector from the total biomass energy was the households sector which reached up to 68%. Following the household sector came the medical/services (21%) and other industries with about 11% share.
Geographically, the major consumers of biomass energy came from the states of Khartoum (where the capital lies) and South Darfur with respectively 13% and 10% biomass energy consumptions shares.[3]

Looking closely into the household sector where as mentioned earlier firewood dominated its contribution as a biomass energy supply, there is also a geographical pattern within the country into the types of biomass used. While firewood is the dominant cooking fuel in the rural areas of the country (used by more than 81% of households), charcoal is the main cooking fuel in the urban households (used by more than 81% of households). For instance, Khartoum state has the lowest urban consumption of firewood per capita.[3]
This rather low-tech primitive use of biomass not only affects the environment in terms of deforestation but also results ultimately to the suffering of women.
Not only do women need to walk long distances to secure the growing scare wood fuel but even more worse is having them and their accompanied children inhale the smoke produced during the application (i.e. cooking).[4]

Sudan's Sugar production:

The sugar industry in Sudan goes back to 1960's when the government realized the importance of utilizing its natural resources. The first production season was in 1962 in El-Guneid Sugar Factory.[5]
Presently there are five sugar factories in the country with total design capacity of 755,000 tons (see table 1 in following page).

Table 1: Sudanese Sugar plants' sugar production and capacity [5]

S. No.	Factory	Operating since	Total Area, Feddan	Design Capacity, Ton Sugar/y	Highest Production, Ton Sugar/y
1	El-Guneid	1962	40,000	60,000	94,171
2	New Halfa	1964	40,000	75,000	87,759
3	Sinnar	1976	38,000	110,000	92,038
4	Assalaya	1979	44,000	110,000	97,500
5	Kenana	1980	87,000	400,000	427,895
			TOTAL:	755,000	799,363

In the last decade sugar production in Sudan witnessed a steady increase and to date the trend seems to be still on rise.
Continuous development and expansion projects are being deployed into the industry with renovations and upgrading of existing factories and construction of new ones.[5]
The first phase expansion program aims to achieve 1 million tons/y production. New sugar factories have been proposed to be built in different parts of the country [5].
With huge amounts of sugar being produced, sugar by-products too were on the rise. Key by product, Bagasse, will be the one of concern in this brief assessment.

Bagasse

Bagasse composition

Bagasse is the fibrous leftover after sugarcane stalks are crushed to extract their juice[6]. Composition of bagasse varies with harvesting methods, maturity and variety of sugar canes. Chemically, it contains about 50% α-cellulose, 30% pentosans and 2.4% ash [7]. Since Bagasse is a by-product of the sugar cane industry, the quantity of production in a country is in line with the quantity of sugar cane produced. Typically an approximate of 250 kg of bagasse can be produced out of one ton [5]. These residues provide significant amount of biomass for electricity production especially with advanced cogeneration technologies.
The Bagasse has a gross calorific value of 19,250 KJ/kg at zero moisture content and 9,950 KJ/kg at 48% moisture content. Net calorific value at 48% moisture content is 8,000 KJ/kg. As indicated the moisture content is a vital parameter in identifying the magnitude of the calorific value in a given amount of Bagasse. Poor milling processes would result in Bagasse with 52% moisture content; however factories with good milling processes can produce Bagasse with 48% moisture content.

Cogeneration:

When Bagasse is burnt in quantity, it produces sufficient heat energy to supply all the needs of a typical sugar mill, with enough energy to spare. The secondary use of Bagasse comes into the cogeneration process, where the Bagasse is used as a fuel to provide both heat energy used in the mill and electricity to be typically sold on to consumers through power grids (see Fig.1 below). [8]

Power produced through co-generation not only substitutes the conventional thermal alternative but also helps in reducing greenhouse gas emissions. It is perceived as an attractive technology both in terms of its potential to produce carbon neutral electricity as well as its economic benefits to the sugar sector. [8]

Components forming the cogeneartion system include a prime mover, generator, heat recovery and electrical interconnection. It is the prime mover which ultimately identifies cogeneration system. Following are typical combinations making up a cogeneration setup:

- Steam turbine and fired Boiler based cogeneration system
- Gas turbine based cogeneration system
- Combined steam/gas turbine based cogeneration system
- Reciprocating engine based cogeneration system.[5]

Table 2: Typical cogeneration performance parameters [5]

Cogeneration System	Heat to Power kW_{th}/kW_e	Power Output (as% of fuel input)	Overall Efficiency
Back pressure Steam turbine	4–14.3	14–28	84–92
Condensing Extraction Steam Turbine	2–10	22–40	60–80
Gas Turbine	1.3 – 2	24–35	70–85
Combined Cycle (Gas+Steam)	1–1.7	34–40	69–83
Reciprocating engine	1.1–2.5	33–53	75–85

Typical cogeneration systems in the sugar industry are based on steam turbine and Bagasse fired Boilers

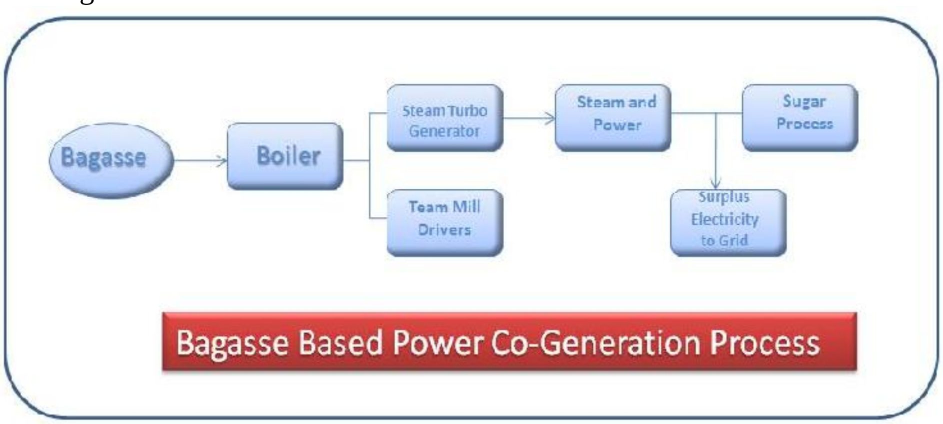

Figure 1: Bagasse cogeneration process [9]

Assessing Sudan's potential from Bagasse co-generation:

Various reports and case studies have been conducted to assess Sudan's energy potential from Bagasse cogeneration, however for this assessment we shall mostly be referring to results obtained from a feasibility study carried out by Cleaner Energy Fund for Agroindustry in Africa (CEFA) issued on Mar 2006. The study that included various sugar industries in Africa, covered four of the five Sudanese sugar factories mentioned earlier. Prior to the presentation of the obtained energy that have been concluded from the study, the following section presents the availability of Bagasse in the five Sudanese factories.

Results:

Sudan's Bagasse availability:

The following table (Table 3 – see below) shows the average annual Bagasse capacity and actual production between years 1995 to 2001 in five sugar factories in The Sudan.

Table 3: Sudanese Sugar plants Bagasse production and capacity [5]

S.No.	Factory	Design Capacity, Ton Bagasse/y	Yearly, Ton Bagasse,
1	El-Guneid	60,000	53,000
2	New Halfa	75,000	65,000
3	Sinnar	100,000	58,000
4	Assalaya	100,000	60,000
5	Kenana	300,000	266,000
	Total	635,000	502,000

According to the statistics in 2005- 2011, Sudan production of raw bagasse ranges from 2 to 2.5 million tons per year and presently lies around the eighteenth place worldwide in terms of Bagasse production. [10]

Potential of electricity Generation in Sudanese Sugar Industry:

The following table (Table 4) summarizes the results of a feasibility study carried out by Cleaner Energy Fund for Agroindustry (CEFA) in Africa. The study covers the potential of four Sugar industries in generating energy using Bagasse. The following assumptions were part of the study:

(i) Three scenarios used to estimate electricity generation with improved boiler efficiencies starting with 44Bars at 90kWh/TC, 65Bars at 115kWh/TC and 65Bars at 150 kWh/TC.
(ii) Energy outputs from The actual Installed electrical Capacity of the Sugar factory
(iii) Using 35% Bagasse to Cane ratio at 50% moisture content.

(iv) Additional Power: The difference between the Installed Capacity power outputs and other three scenarios having the three boiler efficiencies (i.e. 44Bar-93, 65Bar-115 and 82Bar-150 KWh/TC).

(v) kWh to MW assumes plants operating 270 days, 24hours a day and a capacity utilization of 85%. [5]

Table 4: Sudanese Sugar plants potential energy with various scenarios and installed capacity [5]

Sugar Factory	Cane crush	44Bar-93 KWh/TC		65Bar-115 KWh/TC		82Bar-150 KWh/TC		IC(2)	Additional Power(3)		
	$X10^3$ Ton	$X10^3$ KWh	MW (a)	$X10^3$ KWh	MW (b)	$X10^3$ KWh	MW (c)	MW (d)	MW (a) – (d)	MW (b) – (d)	MW (c) – (d)
Kenana	3,281	295,290	53.6	377,315	68.5	492,150	92.8	40.0	13.6	28.5	52.8
El-Guneid	825	74,250	13.5	94,875	17.2	123,750	23.3	3.0	10.5	14.2	20.3
New Halfa	835	75,150	13.6	96,025	17.4	125,250	23.6	6.0	7.6	11.4	17.6
Sinnar	880	79,200	14.4	101,200	18.4	132,000	24.9	6.5	7.9	11.9	18.4
Total	5,821	523,890	95.1	669,415	121.5	873,150	164.6	55.5	39.6	66.0	109.1

In addition to the above table, it is worth noting that sugar plants Kenana, El Guneid, Sinnar and Assalaya are located near electric grids while others have their own grids.

Discussion of results:

Looking at above data, it is quite indicative that Sudan represented by these five factories, does actually have a significant potential of biomass for electricity.

From Table 4, it can be noted how by having implemented improvements in boilers' efficiencies can have huge potentials for energy production in these factories. With improvements, energies exceed 500 GWh, 650 GWh, 850 GWh. In fact according to one report, if all five factories were to be fitted with biomass gasifier combined cycle systems, between 400 kWh to 800kWh of electricity could be produced per ton of cane, this which could be enough to satisfy all of Sudan's electricity demand.[11]

Though in order to have comprehensive assessments, more analytical depth shall be invested in analyzing and identifying the following parameters within each factory:

- Quality of the Sugar cane with fibre content, brix of juice and syrup along the crop season

- Sugar cane production (average and range)
- Exact steam requirements for the process
- Energy consumption of prime movers and process equipment during both normal operating conditions and transient stoppages and startup as a consequence of breakdowns or planned shutdowns.
- The moisture content of Bagasse.[5]

Additional use of Bagasse (Bio-Ethanol):

Apart from the electricity generation through cogeneration, Bagasse could also be used in producing second-generation Ethanol.

Lignocellulosic (2nd Generation) ethanol involves the conversion of cellulose and hemicelluloses. This is much more difficult than the conversion of starch and simple sugars however Ethanol produced from lignocellulosic feedstocks is seen as a viable option to decrease any perceived competition between the production of foods and bioenergy [12].

This production of Ethanol from Bagasse, through hydrolysis and fermentation, could yield about 280-330 L per ton of dry Bagasse considering a cellulose content of 40% in the Bagasse [13].

Sudan's potential in seeking 2nd Generation Ethanol :

Leading Sudanese Sugar company, Kenana, could play a key role in exploring the mechanism and feasibility of commercially producing second-generation Ethanol in the Sudan.

Presently the company produces first-generation Ethanol (from Molasses fermentation). Annual production is approximated to be 65 million L, where 10% is consumed locally and 90% is being exported. Expansions are underway to have this figure raised to 200 million L per annum[14].

Researches for ethanol production from sweet sorghum has already started and blending of 10% Ethanol with gasoline has already been launched. An ultimate target is to increase the Ethanol blending ratio and use these blends for agriculture planes. [14]

Benefits from Ethanol production from Bagasse:

There are numerous benefits of using second-generation Ethanol. In fact it has advantages over first generation Ethanol. Few of these entail:

- That Lignocellulose and cellulose are abundant and less expensive than agricultural food feedstocks
- That their growth potential is huge
- That some cellulosic crops can be grown in marginal lands that often require less fertilizer and water inputs [12]

In addition to the above, generally and in expanding the production and use of Bio-Ethanol we then:

- Contribute to the reduction of negative environmental impacts (e.g. green house gas emissions) generated by the worldwide utilization of the fossil fuels. [15]

- Promote renewable energy
- Promote domestically-produced energy resources (i.e. benefits energy security for the concerned country)
- Expand available resources to secure growing energy demands

Conclusion:

It is without doubt that the Sugar cane Bagasse in The Sudan provides a huge amount of biomass for electricity production; however the potential is much higher with advanced cogeneration technologies. Upgrading the cogeneration systems in the five Sugar plants (Kenana, El Guneid, Sinnar, Assalaya and New Halfa) will have a significant positive impact in terms of the magnitude of produced energy. With all these plants being either located near power grids or even having their own, it appears that considerable part of Sudan's electricity demands may well be secured by Bagasse cogeneration.
Key alternative use of Bagasse in producing Bio-Ethanol is also worth exploring in The Sudan. Leading Sugar company Kenana could set an example to remaining Sudanese firms if it succeeds in commercially producing Bio-Ethanol from Bagasse.

Successfully utilization of Bagasse to secure either electricity and/or bio-fuels in The Sudan shall inevitably directly and indirectly promote many parameters. Key ones include:

- Alleviating pressure from the country's environment (i.e. reduce deforestation and green house gas emissions)
- Contributing to the country's energy sector
- Providing a sustainable and relatively clean source of energy
- Minimize the suffering of the most vulnerable sector of the society (i.e. poor women and children).

Recommendations:

Conducting a complete energy analysis and performance measurements for the cogeneration process and other processes (i.e. Bagasse-Ethanol covnversion) in all five sugar plants would provide a clear guideline to help improve the amount of potential energy being produced from Bagasse altogether. The analysis shall at least try to address and advise on the following:

- Improving the Bagasse quality and reduction in moisture content
- Better means of storing any excess Bagasse
- Improving the management and operation efficiency in boilers
- Possibility of installing additional new boilers
- Cost effective means of connecting to the national grid
- Exploring the requirements to include other processes (i.e. fermentation) within the existing facilities

References

[1] H. F. Abdelraheem & A. Lang, Production of Transport Biofuels in Sudan for replacement of petroleum fuels: The fundamentals issues, Sudan University of Science & Technology and World Bioenergy Association, No Date.

[2] A.G. Bakhiet, Investigation of Agricultural Residues Gasification for Electricity Production in Sudan as an Example for Biomass Energy Utlization under Arid Climate Conditions in Developing Countries, Technical University of Dresden, May, 2008, pp. 01-168.

[3] A. H. Hood, The use of liquified Petroleum Gas (LPG) in Sudan, United Nations Environment Programme, Dec., 2010, pp. 01-53.

[4] National Center for Biotechnology Information, Environmental crisis and its impact on women. The case of the Sudan, US National Library of Medicine National Institutes of Health, Jun., 1992. Available from: https://www.ncbi.nlm.nih.gov/pubmed/12318291[Accessed: 20th December 2016].

[5] W. I. Hussein, Performance Analysis of co-generation plant in White Nile sugar factor-Sudan, University of Khartoum, Sep., 2013, pp. 01-102

[6] M.E. Suliman & S.M. Fudl Almola, The use of sugarcane bagasse ash as an alternative local pozzolanic material: study of chemical composition, Juba University and COMSATS – SCIENCE VISION, Vol.16 and Vol. 17 (Jan. 2010 to Dec. 2011), pp. 65-69.

[7] B. Parameswaran, Sugarcane Bagasse, Bioenergy Research Centre and Korea Institute of Energy Research (KIER),2009, pp.239-248.

[8] Birla Sugar, Bagasse & Co-generation of Renewable Energy, KK Birla Group of Sugar companies, No Date.

[9] Maharashtra Shetkari Sugar Ltd., Make your farm profitable, Maharashtra Shetkari Sugar Ltd , No Date.

[10] NationMaster, Energy>Bagasse>Production: Countries Compared, NationMaster, 2003-2016.

[11] A. M. Omer & E. Braima, Renewable Energy Potential in Sudan, International Energy Journal, Vol.2, No.1, Jun 2001, pp.15-35

[12] G.Eggleston & I. Lima, Sustainability Issues and Opportunities in the Sugar and Sugar-Biproduct Industries, Sustainability Journal, ISSN 2071-1050 2015, 7, 12209-12235; doi:10.3390/su70912209, 2015, pp. 12209-12235

[13] SciFlow Brazil, Pretreatment Strategies for delignification of sugarcane bagasse: a review, Brazilian Archives of Biology and Technology, Jul/Aug., 2013. Available from: http://www.scielo.br/scielo.php?script=sci_arttext&pid=S1516-89132013000400019 [Accessed: 20th December 2016].

[14] BioEnergy 2013, Biofuels Production Potential in Sudan, Bio Bioenergy Exhibition & Conference , 4 to 6 Sep., 2013. Available from: http://www.sustech.edu/files/workshop/20140323064258732.pdf [Accessed: 20th December 2016].

[15] M.A. Gasmalla et al., Production of Ethanol from Sudanese Sugar Cane Molasses and Evaluation of its Quality, Food Processing & Technology, Vol.3 Issue 7, 1000163, 2012, pp. 01-03.