ASSESSMENT OF THE SUDANESES' SUGAR INDUSTRY LIFE CYCLE AND TECHNICAL FACTORS INFLUENCING THE PRODUCTIVITY

TS Ibrahim

Literature Review and Project Proposal

Submitted in partial fulfilment of the requirements for the degree of PhD

Supervisor: Prof. TS Workneh

Bioresources Engineering

School of Engineering

University of KwaZulu-Natal

Pietermaritzburg

October 2020

TABLE OF CONTENTS

LIST OF FIGURES

Page

LIST OF TABLES

Page

LIST OF ABBREVIATIONS

GHG	Greenhouse Gasses
LCA	Life Cycle Assessment
GIS	Global Information System
FAO	Food and Agriculture Organization
WNSF	White Nile Sugar Factory
TFP	Total Factor Productivity
SSC	Sudanese Sugar Company
A Sugar	First Grade Sugar
B sugar	Second Grade Sugar
C sugar	Third Grade Sugar
COMESA	Common Markets for the Eastern and Southern Africa
GDP	Gross Domestic Product
LCI	Life Cycle Inventory
LCIA	Life Cycle Impact Assessment
WRI	World Resources Institute
WBCSD	World Business Council for Sustainable Development

1. INTRODUCTION

For a long time, sugar is one of the essential components in the human diet (Contreras *et al*., 2009; Ramiro *et al*., 2019). Its importance is realized due to its contribution towards meeting the individual energy requirement. More than a hundred countries produce sugar, and approximately 70% of the sugar is produced from sugarcane stalk (Contreras *et al*., 2009). Evaluation of the environmental and economic aspects is of paramount importance to optimize the resource usage in sugarcane production and sugar processing and in reducing environmental impact (Contreras *et al*., 2009). In Sudan, the sugar industry contributes significantly to the national income, local consumer satisfaction, and exports (Abdalla, 2006; Adam *et al*., 2015). Sudanese sugar has a distinguished place among the African states. Sudan is the third-largest producer of sugar in Africa (Hassan, 2008; Nations, 2019). The country's estimated production is about 800 000 t, which is equivalent to 7.5 % of the African continent (Hassan, 2008). The industry is well established with a reasonable performance level on production efficiencies and technological advancements. The sector is considered one of the main strategic parts of the country (Bushara, 2016). The Guneid factory was the first sugar producer in the country. Later, the rest of the sugar factories came into operation during the period from 1965 to 2004. The six sugar factories are classified into two groups: The Kenana and White Nile are private limited companies, while the Guneid, Halfa, Sennar, and Assalaya, are publicly owned (Elzebair *et al*., 2015). The total cultivated area is about 173 000 ha, representing 5% of the arable land in the country (Adam *et al*., 2015). The harvested sugarcane area is between 69 600 and 74 672 ha over the period from 2013 to 2017 (Knoema, 2017). The harvesting of sugarcane is mechanically producing about 8 million tons of sugarcane per annum (Federal Ministry of Agriculture – [FMA], 2010).

However, due to severe problems, the industry has deteriorated. The most significant setback is declining sugar productivity due to unknown factors influencing sugarcane production. The amount of sugar produced in Sudan is fluctuating, as shown in Figure 3. The Kenana produces about 56% of sugar in the country and its production has declined by an average of 2.5% annually over the period from 2001 to 2016 (Abdalla, 2006; Elzebair *et al*., 2015; Kenana Sugar Company - [KSC], 2016).

Similarly, productivity has been declining in the Guneid, Halfa, Sennar, and Assalaya factories (Bushara, 2016). This has happened despite the fact that Sudan has the right growing conditions and the fact that there has been expansion in the planted area (Ibrahim, 2015). The recession has led to a decrease in sugar exports (Knoema, 2016). Reasons concluded for this problem were mediocre factories' designs and improper utilization of production inputs (Hassan, 2008; Ibrahim, 2015). Reforming the structure of the production process has positive effects on the performance level of the Kenana factory (Ibrahim, 2011). However, the study was limited to the investigation of one factory only (i.e., Kenana). The analyses made were found to be general and fallacious. The questions arise: what if the mass balance during the manufacturing process is insufficient. Are the systems of processing the sugarcane to crystals sugar working efficiently? There is no precise method implemented so far to test the technical efficiency of sugar processing supply chain for the Sudanese sugar industry, especially for the old factories. In addition to that, the production performance of sugar factories and proper sustainable solutions must be considered. Research to identify the technical factors influencing sugar productivity is required.

On the other hand, the sugar industry discharges the waste into open drains without treatment (El Hassan, 1998; Sanket, 2015). This situation could have polluted the freshwater and the surrounding environment. This problem needs to be solved sustainably to mitigate the environmental impact. In this respect, Ali *et al*. (2006) conducted a research to assess the pollution load of waste from Assalaya sugar factory on Nile water. The study found that the wastewater contaminates the water. Alim (2012) stated that the Kenana factory is on a process of construction waste recycling plants. Oboody (2016) conducted a study to produce biogas from the sugar industry waste using an anaerobic digestion technology in the Kenana. Some sugar factories have no sufficient base of data to attend to the issue of waste treatment. This trend could influence the surrounding environment and the community as well. The reason behind that is because the previous studies were limited to research conducted at some factories (i.e., the Kenana and Assalaya). The impact of the sugar industry waste on community health was not clear.

Also, the sugar production process consumes resources such as fossil energy (Nakhla, 2014). The utilization of fossil fuel releases harmful gases that cause global warming. Combusted bagasse releases ashes that affect human health (Cordiero *et al*., 2004; Mohamed and Samah, 2011; Le Blond *et al*., 2017). Nevertheless, sugar manufacture pollutants could be minimized and controlled (Abdeen, 2002; Sahu, 2018). There is no study in Sudan conducted to date to assess the impact of the sugar industry effluents and that has also attempted to identify the best practices for management. The assessment of greenhouse gasses emissions and energy consumption for the life cycle of the sugar industry has never been conducted in Sudan.

Many studies were conducted at a global level in different countries around the world (i.e., Brazil, South Africa, Egypt, and Mauritius) where the life cycle assessment (LCA) has become a tool to undertake a systematic environmental assessment of sugar production. Therefore, the questions arising are:

- What are the technical factors that influence the sugar productivity in Sudan in terms of factory efficiency of processing the cane into crystals sugar, mills performance and processing supply chains?
- What are the impacts of sugar industry waste disposals on the environment of the surrounding areas?
- What are the community health problems associated with these wastes?
- What is the quantity of greenhouse gasses emitted to the air?
- How much energy is used for the sugar industry in Sudan?

Therefore, a study to identify what are the factors influencing productivity is required. In addition, the effect of sugar waste disposal on the surrounding environment and community health is needed. This research will generate extensive empirical data that addresses the factors influencing the sugar industry's productivity in Sudan. It will analyse the current sugar processing supply chain of the mass balance and industry raw materials. Also, the study will determine the impact of sugar industry waste on the health community living in the vicinity of industries. Hence, it will identify opportunities to improve the environment of the surrounding areas. Also, this research will assess the energy use and greenhouse gasses (GHG) emissions for sugar production by applying the life cycle assessment methodology. It will identify possibilities to improve and develop a model to steer the decision-makers toward achieving sustainable production and services for the sugar industry in the country.

2. A REVIEW ON THE ASSESSMENT OF THE SUDANESE’ SUGAR INDUSTRY LIFE CYCLE, TECHNICAL FACTORS INFLUENCING THE PRODUCTIVITY AND IMPACT OF INDUSTRIAL WASTES ON THE ENVIRONMENT AND HEALTH

2.1 Introduction

The sugar industry plays a vital role in social and economic development in Sudan. It has created opportunities for jobs and increased production and productivity (Abid, 2008; Bushara, 2016). The government started by producing sugar to satisfy domestic consumption. The agro-climate and location of the country provide suitable conditions for sugarcane production, processing, and marketing (Obeid, 2013). Sudan started producing sugar in the early 1960s. In 1962, the first factory in Sudan was the Guneid, and the others came into operation between 1965 and 2012. There are six sugar mills in total: the Kenana, White Nile, Guneid, Halfa, Sinnar, and Assalaya (Abid, 2008; Adam *et al*., 2015). However, the sugar industry in the country is facing problems of productivity. Many factors have led to the current situation in the sugar industry.(Bushara,, 2016). In addition, the impact of sugar manufacture waste is problematic for the surrounding environment, especially community health (Oboody, 2016). Therefore, the significant challenges that need to be identified are rectifying the production performance, assessing gaseous and energy, and the impact of the sugar industry waste disposal in the country.

Accordingly, to solve the problems mentioned above, there are three aspects that will be reviewed in this report: (1) reasons behind the unsteady performance of sugar productivity and the factors affecting the growth of the industry in Sudan, (2) the waste disposal system practiced in the factories and the effect of the effluents on the community health and the surrounding areas and (3) assessment of the greenhouse gasses emission and energy use by applying the life cycle assessment for sugar production in the country.

2.2 Historical Background of Sudanese Sugar Factories

The agricultural sector in Sudan contributes 30 % to the national economy. The sugar industry was started earlier in the 1960s (Adam, *et al*., 2015; Bushara, 2016). Sugarcane grows mostly in tropical climate, in the central clay Plain between latitudes 16° and 10° N and longitudes 32° and 37° E because of the prevailing conditions in this area (Intisar, 2003; Ramiro, *et al*., 2019). Figure 1 shows the locations of the sugar industries in the country. The total arable land in Sudan is estimated to be 84 million hectares. Currently, the actual area under cultivation is about 15% of the arable land (Adam *et al*., 2015). The total cultivated area used for cane production was 173 300 ha in 2017 (Suliman, 2017). Sudan was the third highest sugar producing country with an estimated 800 000 t in 2007. This equal to 7.5 % of the whole production of the African continent sugar producing countries. The country came in second place with a share of 17.5% of the total sugar in the Northern Africa region (Table 1 and Figure 2). South Africa's sugar yield is generally triple that of Sudan due to the excellence of technologies used and higher hectares under production (SASA, 2015). It has been observed that Sudanese sugarcane productivity has not exceeded the average of 516 000 $t.year^{-1}$ over the period from 1980 to 2004 (Abdalla, 2006) although the potential is 855 000 t $year^{-1}$.

The country's annual sugar production over the past ten years was between 775 000 to 526 000 t and Figure 8 shows the total sugar productivity over the period. Accordingly, what factors led to this situation is a reasonable question that appears on the table and needs to be adequately answered.

The amount of sugar exports has declined (Knoema, 2016) due to declining productivity (Soltan, 2008). Sugarcane farms, namely Guneid, Halfa, Sinnar, and Assalaya, are publicly owned while Kenana and White Nile are private limited companies (Adam *et al*., 2015). Table 2 shows the sugar factories' production capacities and the highest actual productivity. Apart from the White Nile project, the largest producer is the Kenana factory, which produces 58% of the country's sugar. Sudan was on the process of constructing a new sugar factory under the umbrella of a project called the White Nile Sugar Project, and its estimated production capacity is 450 000 t per year (Tyler, 2004). However, the factory started producing the sugar in 2012, with low productivity which was less than one third of the expected production.

The production of the sugarcane in Sudan has dropped down and this may be attributable to the collapse of the rehabilitation program, carried out in 1988 (AlamEldin, 2008). Another rehabilitation program was done in 2000 renewing the boilers, power plants, and irrigation pumps for all publicly owned factories. However, despite this the annual production went down again in 2007, as it showed in Figure 8 (AlamEldin, 2008). Mohamed *et al*. (2016) conducted a study to measure the change in productivity by analysing the factory data from 2000 to 2007. The study concluded that the total variations of the factory's productivity remained negative and declining over time. However, productivity has been fluctuating over the past ten years.

Most of the factories in Sudan are located along the banks of the River Nile tributaries to ease the process and use the water for cooling and disposal of the wastewater. Therefore, most sewage released to the River Nile, which pollutes the water and affects diversity. These effluents could cause environmental problems (Ahmed, 2007; Mohamed *et al*., 2017). Table 1 shows the amount of wastewater and current practices of treatment in the Sudanese sugar industry. Therefore, empirical data collection is required to understand the impact of waste on the surrounding environment. Further, the productivity problem could be solved by evaluating the current practiced systems of the processing supply chain. Thus, opportunities for proper and sustainable solutions to these issues could be found.

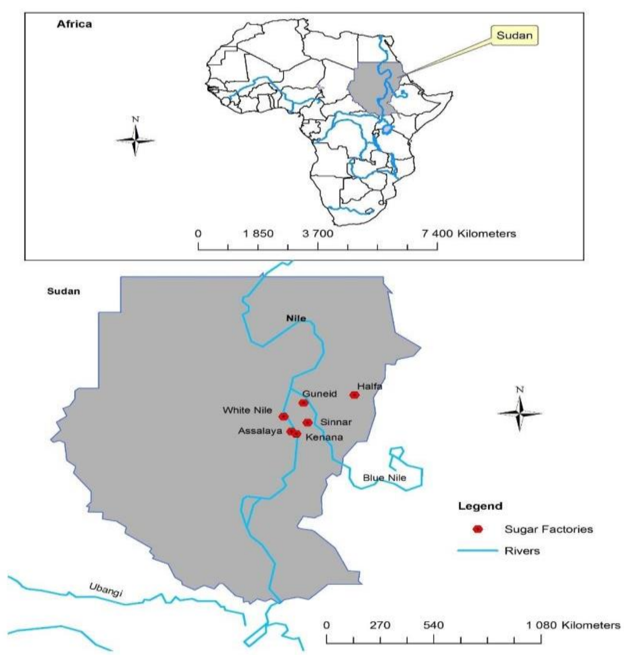

Figure 1 Sudanese sugar factories (GIS, 2016)

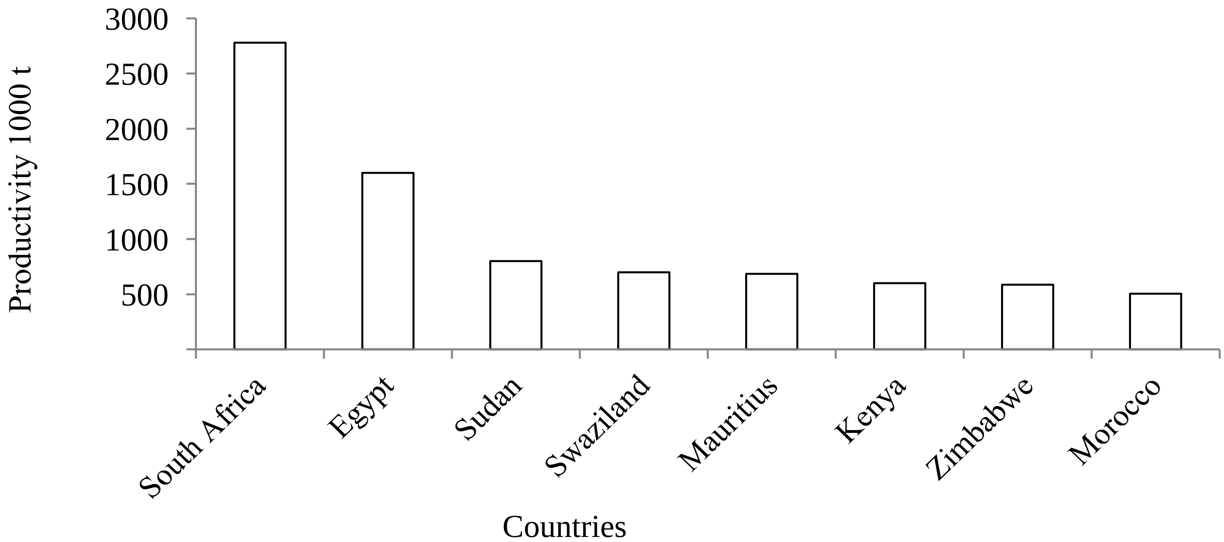

Figure 2 Main sugar producer countries in Africa (FAO, 2007; Knoema, 2019)

Table 1 Sugar factories waste and current practices of treatment (Ahmed, 2007; Mohmed, 2017)

Sugar factory	Waste water $m^3 .day^{-1}$	Waste treatment	Disposal site
Guneid	21 000	No treatment	Blue Nile
Halfa	20 300	No treatment	Atbara
Sennar	22 440	No treatment	Blue Nile
Assalaya	20 410	No treatment	White Nile
Kenana	40 000	No treatment	White Nile

2.3 Sugar Factories in Sudan

2.3.1 The Guneid sugar factory

The factory is located outside the plantation at the bank of the Blue Nile River. The total area under cultivation is 16 600 ha (Table 2). The factory is designed to produce a capacity of 60 000 t of sugar per year. However, the annual production began to decrease by 50% in 2013 (Elzebair, 2015). The low yields and high cost of agricultural operations at the Guneid mill are reportedly due to the tenant system. The poor management of the farms is attributed to the unsatisfactory water distribution caused by the uneven terrain and the lower water pumping capacity, cane diseases, and poor weed control. The low sucrose recovery rate is negatively affecting the factory productivity (Abdalla, 2006).

On the other hand, the sugar manufacture wastewater is disposed into the Nile without treatment. The factory also produces pollutants (i.e., unburnt fibers, carbon particulates, pollutants particles, and suspended solids), which could affect the environment of the surrounding areas (Alim, 2012). Therefore, production and environmental performances need to be examined. Hence, opportunities could be identified to enhance factory productivity and mitigate the impact of waste.

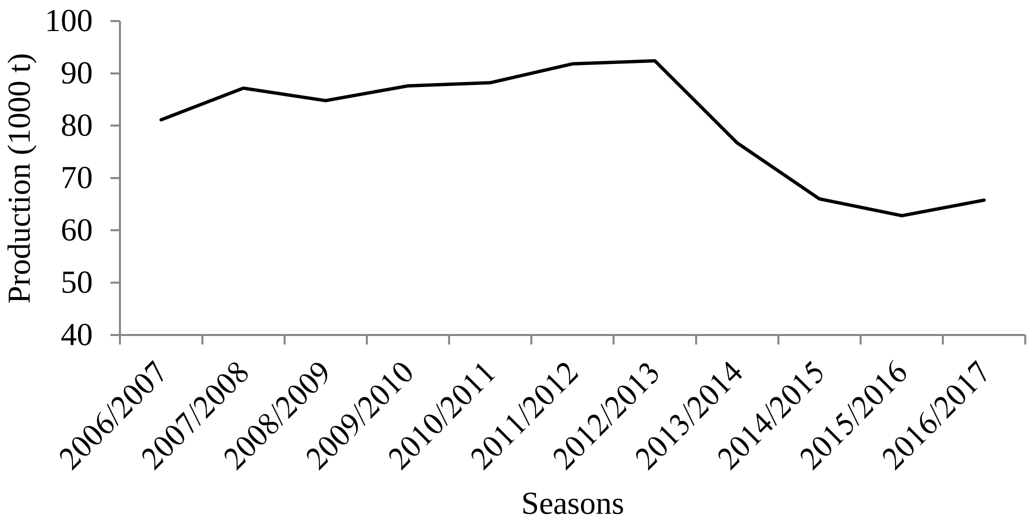

Figure 3 Sugar production of the Guneid sugar factory (GSF, 2016)

2.3.2 The Halfa sugar factory

The average cane transport distance of the factory is 11 km, which is less than the length to the Guneid (Farah, 2005). In this factory the production declined between 1999 and 2015, especially after 2012. Figure 4 shows the factory sugar productivity over the past ten years (HSF, 2016). The delay of cane handling to the mill is reportedly due to transportation problems (Farah, 2005). The plantation (15 540 ha) is irrigated using gravity from the Khashm El Giraba Dam (AbuZeid, 2015). The mill crushes 5 500 t of cane and processes 600 t of sugar per day (AbuZeid, 2015).

Most of the fields need proper land levelling to facilitate the application of water. Obtaining sufficient water for irrigation remains a challenge in this sugar-processing area. The main reason for the water shortage is the disagreement between the factory and the agricultural foundation which may has led to a meagre field’s yield (Arbab, 2009). Therefore, the current research aims to find factors that caused the decline in productivity and raw materials handling, thereby identifying opportunities for solutions.

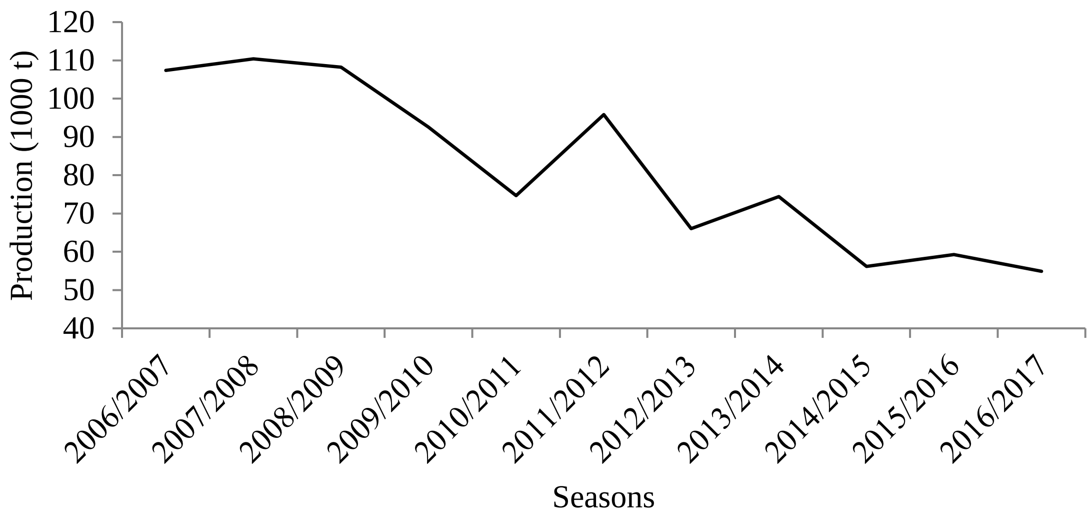

Figure 4 Production of sugar in the Halfa factory (HSF, 2016)

2.3.3 The Sennar sugar factory

The cane crushing capacity of the factory is 6 500 t. day^{-1} and it aims to produce 110 000 t.year^{-1} of sugar (Table 2). The total area used for cane production is approximately 16 000 ha. In earlier 1990s, the factory suffered technical problems (i.e., defection in boilers, steam control, and lubricating mechanism). The 1994 rehabilitation program was carried out to renew some factory equipment, which led to an average continuous increase of 5% in its annual production figures until 2007 (AlmEldin, 2008). However, since then, the mill's performance has started to decline by a yearly average of 6% (Figure 5). The factory extraction level of sugar is lower than that of

Guneid and Halfa. Table 1 indicates the sugar production and the harvested area for the past ten years. The sugar extraction of this mill is lower than that of Guneid and Halfa (Abdalla, 2006; AbuZeid, 2015). The factory has suffered from a lack of equipment and labour, which may have led to the inadequate land preparation of the cane plantations (Arbab, 2009.) Accordingly, many factors are affecting factory productivity that needs to be identified. This research work will examine the performance of the current production supply chain.

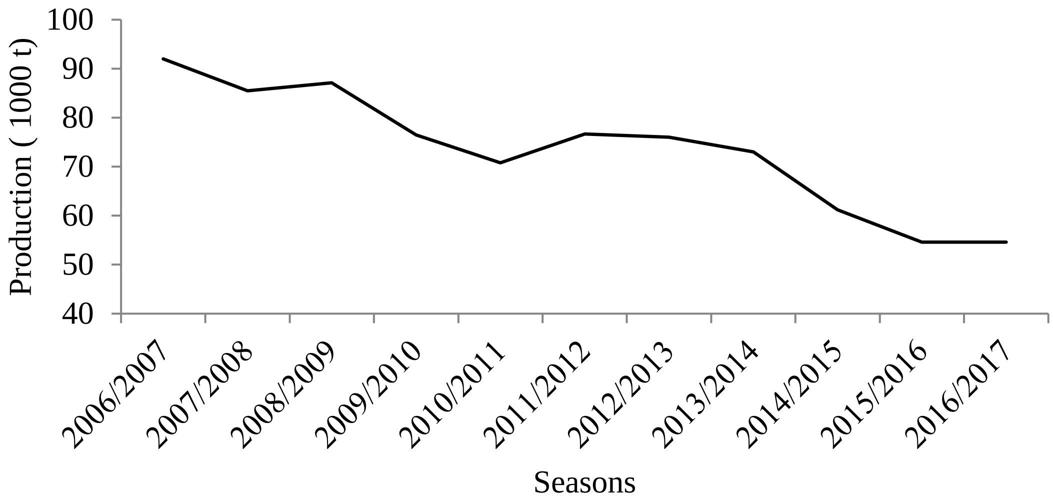

Figure 5 Production of sugar in Sennar (After AlmEldin, 2008; IPPS, 2009; SSF, 2016).

2.3.4 The Assalaya sugar factory

This factory is located at the eastern banks of the White Nile River, and it has suffered a severe technical failure in recent years. The factory boiler, power, and mill house have defected, leading to difficulties in sugar processing (Abdalla, 2006). Consequently, the milling capacity reduced by 41.5% from 2008 to 2016, which meant 3 800 t of cane was produced per day instead of 6 500 t (AbuZeid, 2015). Table 2 shows the designated crushing capacity of the mill. The problems (i.e., boiler, power, and mill house defections) have affected factory productivity. Besides the continuous failure of the irrigation pumps, the salinity of the farm soil and the uneven level of the land also plays an important role. The unavailability of proper agricultural machinery on this farm is the primary cause of its reduced production levels (Arbab, 2009 and Suliman, 2017). Figure 6 shows the factory production of sugar over the past ten years, from 2007 to 2016. However, research to examine the sugar processing supply chain is required to find opportunities to improve factory productivity.

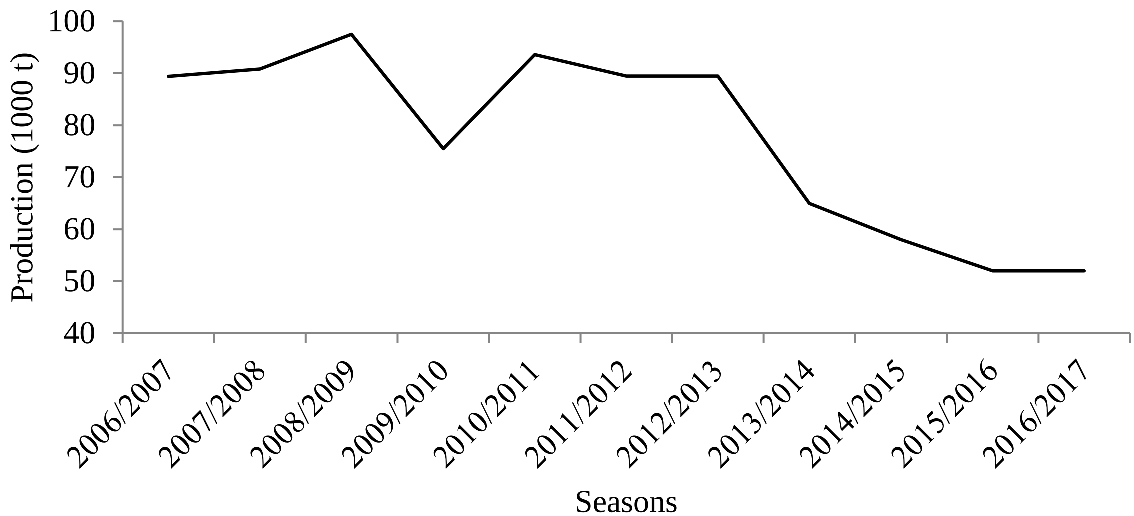

Figure 6 production of sugar in Assalaya factory (ASF. 2016)

2.3.5 The Kenana sugar factory

The Kenana factory, which is located in the White Nile state, started producing sugar in1981. It's designed to provide 300 000 t of sugar per year, while the factory crushing capacity is 17 000 t cane per day (Table 2) (KSC, 2016). The cane production area is around 40 000 ha, which produces four mn t of cane. The yield of sugar per hectare has reached 11.9 t (Abdalla, 2006). The crushing season lasts between 150 to 160 days, from November to mid-April (Ahmed, 2017). The factory produces sugar from both green cane and burnt cane, which is packed into 50 kg. Other plants work together with the sugar factory to produce ethanol, animal feed, and charcoal (AbuZeid, 2015). Figure 7 shows the sugar production of the factory over the period from 2006 to 2016. It shows that manufacturing has declined by 25.8%. However, the factory produces 50% of the country's sugar. Accordingly, factors that lead to low productivity need to identified. On the other hand, industrial wastewater is discharged without treatment. This could affect the surrounding environment and risk community health (Oboody, 2016). Therefore, the environmental impact of the waste needs to be empirically evaluated, and opportunities for sustainable solutions need to be identified

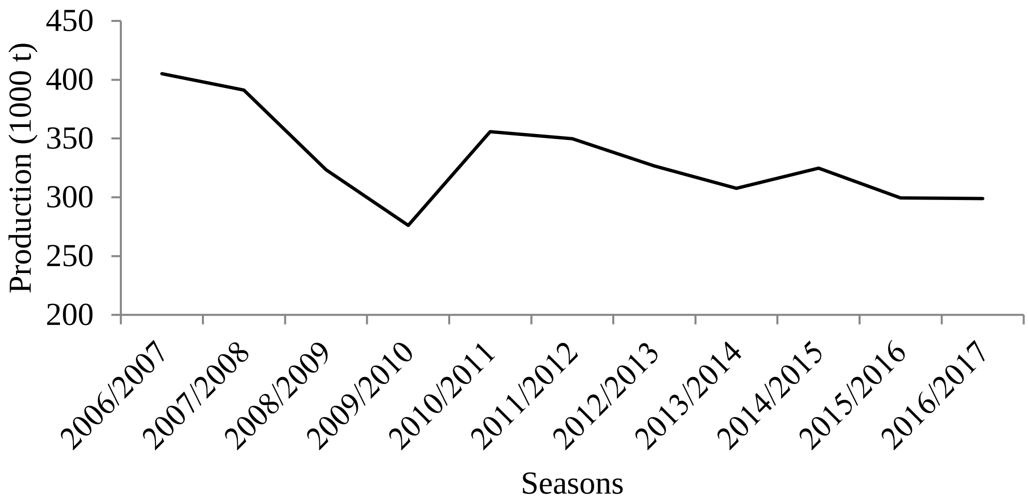

Figure 7Production of sugar in Kenana (KSC, 2016)

2.3.6 The White Nile sugar factory (WNSF)

The White Nile Sugar Factory (WNSF) was launched in 2012 and is the largest of the Sudanese factories. The Kenana Sugar Company owns 30% of this factory, while the remaining stake is between Egyptian investors and the Sudan government. The cane production area is about 66 000 ha (Table 2), and the crushing capacity of the mill is 30 000 t per day. The crushing capacity of the mills is 24 000 $t.day^{-1}$ (Table 2). Its sugar production capacity is 450 000 t per year. However, the cane fields are located on salty land, and hence reasonable cane yields are not expected (AbuZeid, 2015). Some proposed expansion projects are associated with the by-products of this factory, namely, ethanol production and animal feed plants (WNSF, 2012).

Table 2 Sudanese sugar factories capacities (after FMA, 2010; WNSF, 2012; Adam *et al*., 2015)

Factory	Startup date	Production capacity (t.year^{-1})	Total area (ha)	Crushing capacity (t.day^{-1})	Highest actual production (t.year^{-1})
Guneid	1962	60.000	16.600	4.000	94171
Halfa	1964	75.000	16.600	5.000	87759
Sennar	1976	110.000	15.800	6.500	92038
Assalaya	1980	110.000	18.300	6.500	97500
Kenana	1981	330.000	40.000	17.000	427895
White Nile	2012	450.000	66.600	30.000	__
Total		1,135,000	173,900	69,000	799,363

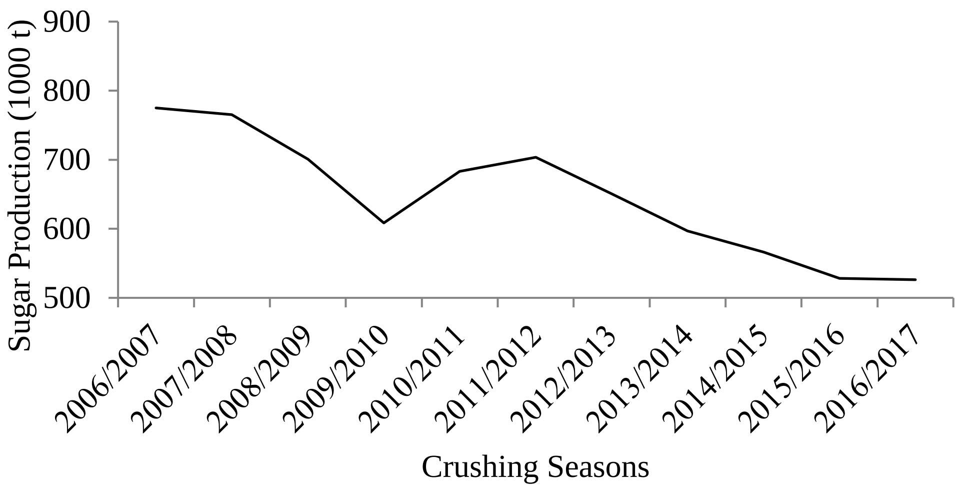

Figure 8 Sugar production of Sudanese Sugar Factories (KSC, 2016; SSF, 2016; ASF, 2016; HSF, 2016; GSF, 2016)

2.4 Factors Influencing the Growth of Sugarcane Processing Industry in Sudan

2.4.1 Input constrains

The productivity of some factories (i.e., Guneid, Sennar, and Assalaya) has been affected due to insufficient utilization of agricultural inputs and inadequate irrigation. The problem of sugarcane transporting from farms to the mills has also been identified. (Abdalla, 2006; Mohamed and Lubna, 2016). Figure 9 shows the declining efficiency of these factories over the period from 2009 to 2012. There is a problem with the sugar industry efficiency. Improvement is required to increase sugar factories' productivity. Therefore, a research work must be conducted to identify the technical factors that have led to delayed application agricultural inputs and frequent problems hindering cane handling.

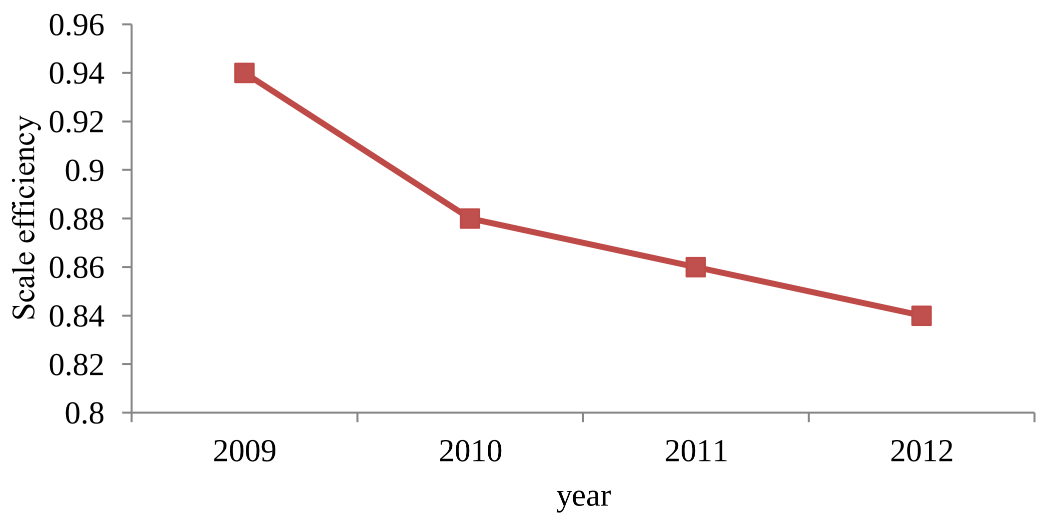

Figure 9 Scale efficiency of Sudanese Sugar Company (Ibrahim, 2015)

2.4.2 Technical manufacturing constrains

Many constraints hinder the sugar manufacturer in Sudan (i.e., technology deterioration, the increased cost per unit product, inefficient resource allocation, poor factory design and managements, total factors productivity and capital, and labour force).

It is reported (Bushara, 2016) that the Guneid, Halfa, Sennar, and Assalaya sugar industries have been suffering from fluctuation in their productivities over the period from 1999 to 2007. In 2007 the declining performance (i.e., 26%), was mainly due to the technology deterioration. The production is low despite the right growing conditions since 1981 due to poor management and poor designs (Soltan, 2008). It was reported by Abdalla (2006) that sugar output growth has fluctuated tremendously over the period from 1980 to 2004. The major contributor to the instability was the total factor productivity (TFP), the capital and labour force. As a result some sugar factories have been suffering from declining productivity over a recent period. Therefore, to improve the production performance of these factories, research is required to obtain empirical data to identify factors that influence productivity. Thus, analysing the mass balance of the current practiced sugar production and processing supply chain for all these factories is needed in Sudan.

2.4.3 Economic constrains

Sudan is one of the highest sugarcane producer countries in the Arab and African regions. The overwhelming contribution of the sugar industry to the national economy is losing ground to the new oil era, which creates economic problems. The problem can be avoided by creating strategic objectives with long-term planning to maintain viable agriculture with particular concentration to the sugar sector during and after the oil boom era (Ismail, 2006). It is reported (Adam *et al*., 2015) that the Sudan southern part secession has deprived 25% of the total area and 80% of oil income. This means about 75% of the vegetation cover and 30% of the potentially arable land, have been lost. Sudan stands to lose about 25% of its water resources. Besides, the financial aspect is one of the crucial factors that affect the availability of the necessary inputs. The lack of funding could constrain the sector, leading to poor infrastructure and poor services (Abdalla, 2006). In addition, the inflation rate in the national economy, price fluctuation, and increases of cane production costs are really factors beginning to have an impact of cane production (Bushara, 2016). Under these adverse economic conditions, the sugar industry in Sudan is suffering.

2.4.4 Energy constrains

The escalation of oil prices over the past decade have severly impacted the Sudanese economy. After the southern part secession in 2010, 80% of the oil income was lost (Adam *et al*., 2015). It is reported that the oil cost consumed more than 50 % of the income earnings (Abdeen, 2002). Sudan meets approximately 50.8% of its energy needs by use of biomass, while oil supplies 38.6%, and the remainder is produced by hydro and thermal power (Rabah *et al*., 2016). The total yearly energy consumed is approximately 9781 t oil equivalent. The Industrial sector, which is considered a significant power consumer, suffers from power shortages critical to the sugar industry. In 2012, the agricultural sector consumed 0.9% of the total energy produced as well as 1.1 % from petroleum products and 4.9% from electricity (Rabah *et al*., 2016). The sugar industry's design capacity is about 190 MW, which equals 60% of the national grid electric power. The available power is about 96 MW as the White Nile sugar factory works in low capacity. It is reported (Abdeen, 2002) that a shift to renewables (i.e., bagasse) would help solve the massive independence on fossil energy sources in the sugar industry in Sudan. Bagasse is sufficient to produce electric power for cane crushing season (i.e., 180 days/year) if a high technology of power generation installed.

2.5 Sugarcane Production

There are different cane varieties grown for the Sudanese sugar industry. The two main varieties are Co 997 and Co 6806. Other varieties, such as R 579, TUC 75-3, KnB 01-156, KnB 01-619, and KnB03-1184, are also grown but to a limited extent. The Kenana factory produces two or more different cane varieties on one plot. Some types, such as FR 9841, FR 9821, B 871294, and CP 881762, are still in their early stages of development and are not ready to be released for commercial production. The propagation of variety BR 81116 has started at the four Sudanese sugar estates (KSC, 2013; Obeid, 2013; AbuZeid, 2015; SSC, 2015; Oboody, 2018). Figure 10 shows the cane varieties and their plot sizes as percentages of the total planted area in 2015. The early stages varieties (i.e. FR 9841, FR 9821 and B 871294) appear in zero percentages in the diagram as they still under development.

Harvesting is a critical operation in sugarcane production. It begins with fields drying for at least one month. Then, cane burning, water banks breakage, and roads to make movements of harvesters and transportation machinery easy. The process includes different machinery and equipment such as tractors with trailers and Grab loader and trucks with mechanical harvesters (Adam *et al*., 2015). Sugarcane is harvested mechanically in Sudan. It is chopped into 12-14 inch billets by a combine harvester and hauled by wagons or trailers that run alongside the harvester, transporting them to the mills. The cane is transported by trailers in public-owned factories while in the Kenana, wagons are used (Adam *et al*., 2015).

However, mechanical harvesting operations use fossil fuel massively, resulting in excessive greenhouse emissions. Assessment of the gaseous emissions is as a matter of concern as it causes global warming. The energy usage and emissions from different sugar production stages have not been assessed for the sugar industry in Sudan. Therefore, quantifying the energy use and greenhouse gasses will be considered in this study to help achieve sustainable environmental performance of this industry.

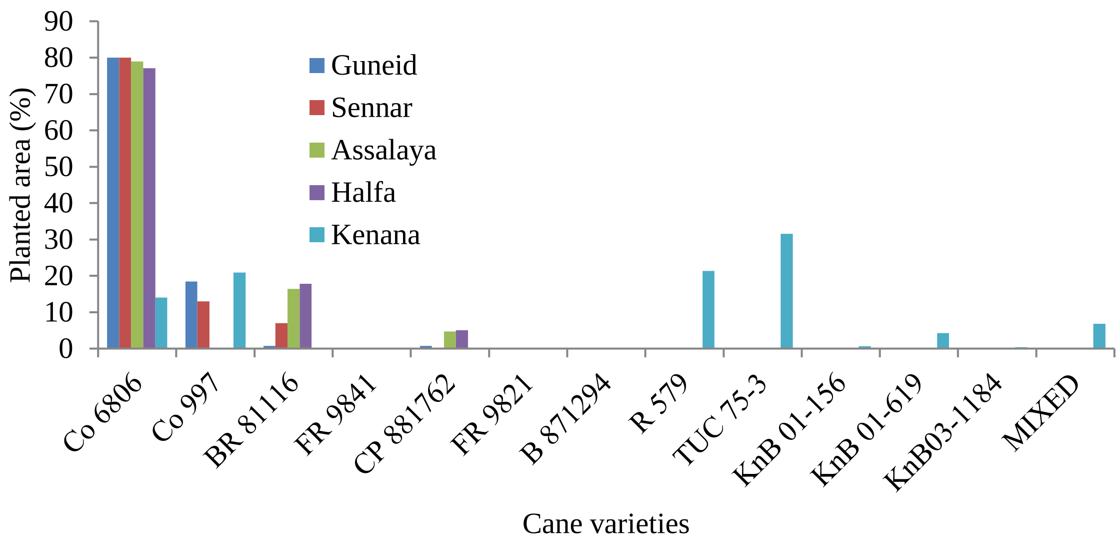

Figure 10 Sugarcane varieties grown in Sudan (KSC, 2013; Obeid, 2013; AbuZeid, 2015; SSC, 2015).

2.6 Sugar cane Processing and its By-Products

2.6.1 Process description

Sugarcane is received in the factory and prepared to extract the juice. Figure 7 shows the processing flow chart for sugar production. After the cane is weighted, it washed by spraying clean water then crushed by revolving knives driven by high-voltage electricity (Kouzi, 2008). The crushing capacity of all sugar factories in Sudan is about 69 000 t cane per day (FMA, 2010; WNSF, 2012). The crushed cane is then milled to separate the juice. The mill carrier transports the crushed cane by using the imbibition system to condensate the used water and separates the bagasse. In some countries (i.e., South Africa), a diffusion process is used for juice extraction, giving a higher extraction rate with lower energy consumption (Alim, 2012). The clarification phase is done by heating the juice to 30°C and liming using milk with phosphoric acid. Then, the juice temperature is raised up to 105°C. At this stage, the filter cake is precipitated and separated from the juice into two clarifiers at 98°C and 100°C. The clear juice is separated from the mud in a rotary vacuum filter. The clarified liquid is heated to 115°C and moved to the evaporator (Kouzi, 2008). Quadruple-effect evaporators are used to concentrate the juice from 16 to 60 %.

This process produces the syrup with about 65 % solids and 35 % water (Arbab, 2011). The sugar is then conveyed to the vacuum pans for the crystallization (Kouzi, 2008; Arbab, 2011).

The crystallization starts when the syrup reaches the saturation stage during the evaporation. The process begins with seeding, then the sugar' size increases by discharging the massecuite into the cooling crystallizer. Massecuite is transferred to high-speed batch centrifugal machines to separate heavy molasses from crystals A sugar. The crystals are washed with water and centrifuged again as light molasses. The heavy molasses is reboiled to yield B massecuite, which in turn yields B crystals. The B massecuite is transferred to the crystallizer and then to the B centrifuge to produce B sugar and B molasses which is lower in purity than A molasses. The B sugar is mixed with water to make the magma. It is re-boiled with A light molasses to form a low-grade massecuite, which goes to cooling crystallizers and then centrifuged to form C sugar. The sugar is dried in rotary driers cooled and transferred to bagging bins and storage (Kouzi, 2008). In some factories, further refining before bagging for shipment is carried out (Alim, 2012).

However, the current sugar production supply chain (i.e., milling efficiency) needs to be evaluated. Thus, identifying the factors that lead to the decline of sugar production and opportunities for proper solutions for the sugar industry in the country can be made.

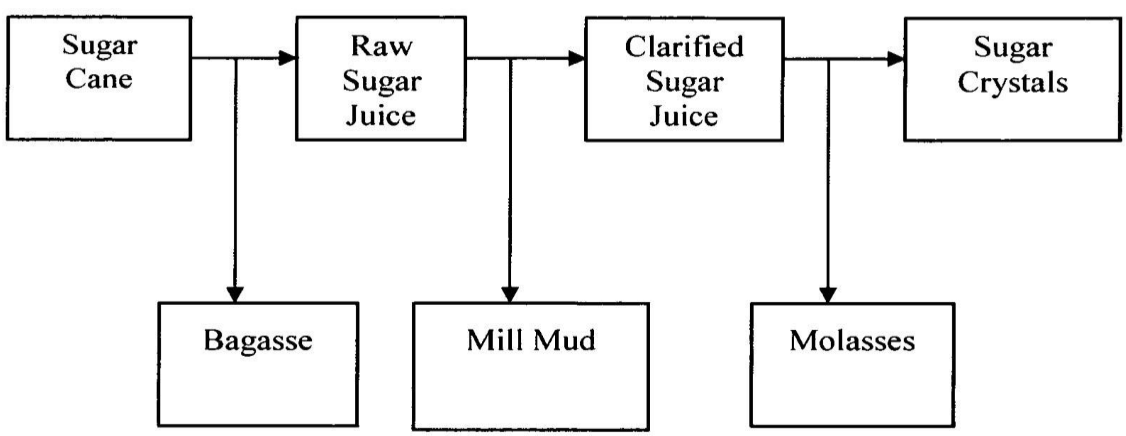

Figure 11 Processing flowcharts of sugarcane and by-products (David *et al.*, 2009)

2.6.2 Sugar cane by-products

The essential by-products of sugar manufacturing are bagasse, molasses, and filter mud (Solomon, 2011), which are used in many diverse fields in Sudan (Intisar, 2003).

A. Bagasse

Bagasse and cane trash provide a significant amount of renewable source for electricity production (Abdeen, 2002; Solomon, 2011). Most of the sugar factories produce about 15 to 30 kWh per ton of cane. About 400 to 800 kWh per ton of cane of electricity can be produced if biomass gasified-combined cycle systems supply the factories in Sudan. Figure11 shows the available quantity of bagasse in Sudan over the period from 2003 to 2011. On the other hand, bagasse residue ash could harm the surrounding environment. Therefore, this research will assess the environmental impact of the burnt bagasse on the surrounding community. It also will recommend proper solutions to mitigate the effects.

Figure 12 Bagasse available in Sudan (United Nations Statistics Division [UNSD], 2016)

B. Molasses

One of the possible alternatives to maximize the usage of molasses is to transform it into ethanol. However, the losses of sucrose from sugarcane in molasses affect the factory profit (Gasmalla *et al.*, 2012). The estimated quantity of molasses in sugar factories in Sudan in 2006 is around 285 000 t, as shown in Figure 13. This indicates that Sudan's potential for developing an industrial-scale biofuels supply is promising, which fits within the overall development of bioenergy in

Sudan (Abdelraheem, 2015). However, It is reported (Hajer, 2007) that some factories in Sudan export the molasses to the international markets, and others utilize it for animal feed.

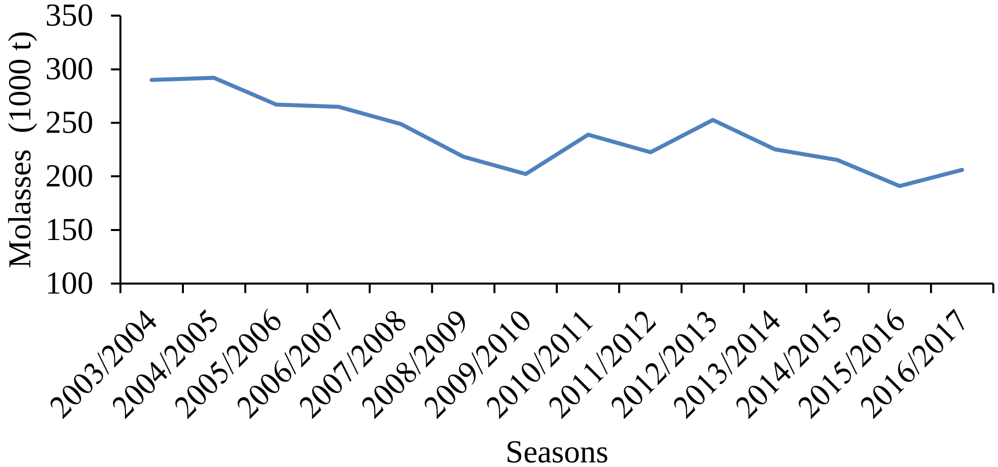

Figure 13 Sudan molasses production quantity (FAOSTAT, 2015; KSF, 2016; GSF, 2016; HSF, 2016; ASF, 2016; SSF, 2016)

C. Filter mud

The filter mud is the precipitate obtained in the clarification stage after adding lime and sulphur dioxide to the cane juice. The precipitate settles as sludge in a clarifier and is filtered by using a rotary vacuum filter. About 3 to 4% of the weight of the crushed cane is filter mud. Filter mud in Sudan is generally used for fertilizing cane in the field (Oboody, 2016).

2.6.3 Utilization options for sugarcane residues

The agricultural residues can be used as raw materials to generate steam and electricity in sugar mills (Solomon, 2011; Seng, 2018). It is possible to convert dry leaves and tops into briquettes or as mulches to improve the soil properties (Balakrishnan *et al*., 2011). In addition, it easy to ensilage it to produce animal feed or mix with molasses to produce livestock fodder (Cheeseman, 2005). However, none of the above mentioned processes have been applied for the agriculture resides in Sudan's sugar industries due to financial difficulties. Some sugar factories started to convert the leaves into animal fodder; however, it still at an early stage.

a. Bagasse

It is reported that the bagasse can be converted into solid fuel pellets or briquettes (Nemerow, 2007; León-Niño, 2013). This process increases the efficiency of combustion by 80%. Many countries produce charcoal from bagasse by carbonizing the bagasse. Also, the carbonized charcoal is mixed with molasses to produce briquettes (Paturau, 1982; Nadia, 2014). Bagasse can be used to produce ethanol because it contains a high percentage of carbohydrates and a relatively low lignin percentage (Nigam *et al*., 2009). Due to high content of fibres and sugar, bagasse can be used as animal feed. It could be treated by many methods to become suitable animal fodder (El-Hagar, 2007). Bagasse has a potential for use in producing chemical complexes such as furfural and xylitol, which are alternative sweeteners (Cheesman, 2005). In Sudan, bagasse ash is used as a mortar for local buildings. However, more detailed work is required to explore the environmental impacts of these materials to expand its applications (Suliman, 2011). Therefore, the current study will identify the environmental effects on the community residing around the industries where the availability of bagasse ash materials is high. Then, opportunities for best-reusing bagasse ash will also be found.

b. Filter mud (cake)

It can be used as fuel and chemicals. Biogas can be produced from filter mud through anaerobic digestion due to its high content of organic materials. An Indian sugar factory has set up a production unit of biogas to produces 160 Litter per kg pressed mud. Chemicals such as wax and protein can be extracted from sugarcane filter mud. In addition, it could be used as a substrate for the production of citric and lactic acids (Balakrishnan *et al*., 2011). This study will discuss the feasibility of adopting a convenient option from the above mentioned to address the waste from the selected sugar factories.

c. Furnace ash

Bagasse furnace ash contains high percentages of silica, aluminium, iron, alkalis, and alkaline earth oxides. Souza *et al*. (2011) proved the feasibility of using furnace ash to produce ceramic by mix 60 % of ash with clay. Faria *et al*. (2012) demonstrated the possibility of using ash as filler in clay bricks. However, these proposed usages of sugar by-products are benefiting the environment. Therefore, to adopt such a facility to reuse the by-products of sugar manufacturing in Sudan is possible. From this respect, a model of the framework to be proposed and developed is essential to achieve zero waste and excellent environmental performance for sugar factories in the country.

2.7 Sugar Industry Wastewater Disposal

Sugar factories dispose untreated wastewater through open drains to open fields of catchments. This creates swamps that can potentially affect the water, soil, and the surrounding environment (El Hassan, 1998; Qureshi *et al*., 2015). The Kenana factory discharges about 40 000 m3.day-1 of polluted wastewater. About 150 000 m3.day-1 of sewage is discharged from the whole sugar factories in Sudan. On the other hand, wastewater is being used for crop irrigation (Aisha, 2007; Kumar, 2014). However, releasing untreated sewage could affect the environment and the community around factories. Therefore, there is need to investigate the impact of sugar manufacturing waste on the community around these factories.

2.8 Sudanese Sugar Marketing

The sugar industry has effectively contributed to the income of the country (Farah, 2005). The domestic consumption of sugar is currently estimated between 1.2 and 1.3 mn t per year. However, this leaves a shortfall of about 600 000 t of sugar required to satisfy the annual local consumption (Obied, 2013). Sudan used to export about 400 000 t sugar to the common market for eastern and southern African countries and the European union. The declining sugar production has caused (ADBG, 2011) the sugar exports to drop to below 100 000 t per year since 2001 (Figure 12) (Obied, 2013).

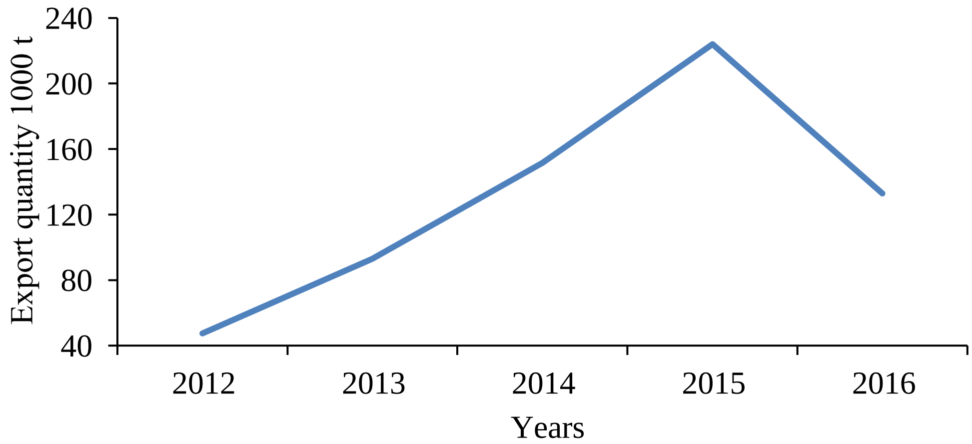

Figure 14 Sudan sugar exports to world markets (knoema, 2017)

2.9 Socio-economic Importance of Sudanese Sugar Industry

The sugar industry plays an essential role in developing the economy of Sudan by contributing more than 25% for the gross domestic product (GDP), which equals US$4.8 billion (Suzan, 2005; Adam, *et al*., 2015). The socio-economic significance of the sugar subsector comes through providing employment and job opportunities and improves skills and capacities through training. The Sudanese sugar factories employ more than 14 500 permanent workers and more than 19 000 seasonal workers (AbuZeid, 2015). The sugar sub-sector also provides health, education, and social services to the citizens (Suzan, 2005; Takalani, 2013). The economic situation of the villages has improved due to the interventions of these factories (Hind, 2015).

On the other hand, the intervention of sugar factories in Sudan has affected the livelihood of households in rural areas. Many people have been displaced by the schemes and resettled in groups (Suzan, 2005). However, the environmental impact of the industry on the community residing around these factories remains unknown.

2.10 Sugar Production and Environmental Issue

The environment is one of the main elements of individual and community health. In Sudan, pollution is rapidly increasing due to urbanization and industrialization (Alim, 2012). It has been reported that the sugar industry is one of the major contributors to pollution (Hassan *et al*., 2017). On the other hand, there are minimal control measures of the institutional and legislative frameworks to ensure compliance. The environmental governance of the industry was virtually non-existent until 2000. Significant challenges need to be considered in terms of impact assessment and improving the operation of older and government managed sugar factories (Alim, 2012). For instance, most of the sugar industries release untreated wastewater containing pollutants into the Nile resulting in poisoning of the water source. There is a reasonable amount of waste resulting from sugarcane processing (i.e., vinasse, sewage, and filter mud), which harm the human and ecosystem (Oboody, 2016). To achieve sustainable solutions for this problem, the Kenana factory is currently constructing plants for wastewater treatment (Alim, 2012). However, this issue needs to be addressed sustainably and collaboratively for all sugar factories in Sudan. Therefore, analyses of the environmental aspect must be carried out for the sugar factories through identifying the impacts of these untreated influents on the community around.

Besides, the combustion of bagasse produces ash, which affects human health (Mohamed *et al*., 2011; Le Blond *et al*., 2017). According to Sudan, Sugar Company bagasse represents 26% of sugarcane stalk. This means there is about 1.82 million tons of bagasse produced annually. Figure 12 shows the annual quantity of bagasse produced in the Sudanese sugar factories. Around 0.62% of burnt bagasse is residual ash (Cordiero *et al*., 2004). Theoretically, about 11 284 tons of remaining ash is produced annually from sugar factories in Sudan. However, the impacts of this pollutant need to be determined and appropriately solved.

On the other hand, sugar factories' authorities are concerned about the difficulty of recovering this waste problem and the high costs associated with treatment (Oboody, 2016). There is a lack of sufficient information background on waste treatment and its impact on the community residing around these sugar industries, which makes the procedures of identifying the adverse effects of these wastes more complicated (Abid, 2008). Therefore, research must be carried out to find sustainable solutions to treat this waste with effective and nun costly means.

Moreover, sugar factories release a large number of gases (carbon and others) and ashes that affect humans, animals, and plants. The harvesting process causes high dust storms, which affects the labour force and the surrounding households. The Intensive usage of chemicals (fertilizers, pesticides, fungicides, and herbicides) in sugar production is inevitable, while on the other hand, they negatively affect the soil and sugar produced. The intensive usages of machinery result in a spill-over of minerals oil, which pollutes land and water. Sugar factories are a source of noise due to the various operations and heavy machinery taking part during the production process (Abid, 2008; Takalane, 2013). However, the environmental performance of the sugar industry in Sudan must be evaluated. The assessment of greenhouse gasses emissions for the sugar production process should be carried out.

2.11 Global Warming and Greenhouse Gasses Effect of Sugar Cane Production

Fossil fuel utilization has been criticised because it releases harmful gases that cause global warming through trapping heat in the atmosphere. Industrialized countries have the highest levels of emissions and more contribution to global warming. Developing countries must mitigate emission levels that will happen in the future (Abdeen, 2002). Based on this, efforts to implement innovative programs to reduce emissions from the agricultural sectors are a top priority (Eduardo, 2010). Further, expanding biofuel production has led to indirect climate benefits by reducing greenhouse gasses emissions and carbon. Bio-fuel expansion is an essential solution in minimizing climate change (Scott *et al*., 2011). Zhao (2015) reported that expanding sugarcane into existing crop and pasture land has a direct local cooling effect. Sugarcane may be better than other field crops for environmental protection. However, in Sudan, there was no study so far that has been conducted neither to determine the greenhouse gasses nor to reduce the emissions for the sugar production sector.

2.12 Life Cycle Assessment of Sugarcane industries

Life cycle assessment for sugarcane production has been carried out in many countries around the world (i.e., South Africa, Mauritius, Brazil, Thailand, Australia, and Mexico). It has been reported by Palacios *et al*. (2019) that life cycle assessment was used in Mexico to analyse the environmental damage attributable to cane sugar production. It has been shown that sugarcane growing and harvesting stages are harmful to the environment, followed by electricity cogeneration, sugarcane transportation, and sugar processing. Mashoko *et al*. (2013) conducted a study identifying the environmental benefits of power produced from bagasse for the South African sugar industry through developing a model that produces 150 kWh per ton of bagasse. They concluded that bagasse has significant environmental benefits through releasing less GHG emissions compared to coal when burnt. Cane cultivation, transportation, and water use contributed significantly to CO_2 emissions. Minimizing the utilization of chemicals inputs and optimizing the irrigation water use will reduce the impacts of the cultivation phase.

Silva *et al*. (2012) conducted an LCA study to determine the main environmental impacts of bagasse's energy generation, transmission, and distribution in Brazil and to recommend opportunities for enhancement. The study concluded that cane burning before harvesting must be stopped in order to reduce emissions. It was also recommended using the cane straw as a soil conditioner improved nutrient enrichment potential instead of burning. In addition, an LCA study was carried out in Mauritius to assess the impacts of bagasse combustion for electricity generation compared to other sources. The study reported that emissions of CO_2 are equal to just 15% of all fossil fuel emissions on the island. The environmental impact of the agricultural inputs was five times the electricity generated in the power plants. The study also stressed on using effective means to control fly ash emissions from the boiler, optimizing the use of chemicals and effective irrigation methods to reduce the environmental impacts. The utilization of bagasse to produce electricity has its benefits in reducing greenhouse gasses emissions compared with fossil fuel-derived electricity. On the other hand, freshwater consumption and eutrophication are the drawbacks to bagasse derived electricity (Ramjeowon, 2008).

2.12.1 Life cycle assessment of the Sudanese sugar industry

The sugar industry produces waste streams and emissions. Cane transportation and milling are energy consuming (Palacios *et al*., 2019). Each wastes management option for residues has significant importance on the environment (Nakhla, 2014). The environmental performance connected with the different stages of sugarcane production can be assessed using the LCA technique. The environmental performance, combined with the various stages of sugarcane production in Sudan, has never been determined. Subsequently, research work is required to attain ecological sustainability for the sugarcane industry in Sudan. Life cycle assessment (LCA) should be applied to assess the energy use, greenhouse gas emissions, and environmental impacts for the selected Sudanese sugar factories. Different stages of sugar production will be chosen (i.e., cane farming, cane harvesting, transportation, and sugarcane processing).

2.12.2 Life cycle assessment

Life cycle assessment (LCA) is a technique used as a tool for managing environmental performance, auditing, and impact assessment (Nakhla, 2014). The International Organization for Standardization (ISO) defines life cycle assessment as "compilation and evaluation of the inputs, outputs, and the potential environmental impacts of a product system throughout its life cycle." LCA is a well-established constructed method that can be applied for industry research (Nakhla, 2014). It considers the life stages of the product (i.e., sugar), starting with extraction, processing the raw materials, manufacture, use, reuse, recycling, final disposal, transportation and distribution (Contreras *et al*., 2009). Life cycle assessment of sugar production is a method based on scientific procedures used to evaluate the environmental effects and energy consumption of all phases of the sugar production process from its raw materials to final disposal (Williams, 2009; Livison, 2010). The key benefit of conducting an LCA is getting the full image of the impacts of a product, process, or activity to find the proper solutions for their improvement. Life cycle assessment is the core topic in the field of environmental management and is considered essential for achieving sustainability goals (Curran, 2016).

2.12.3 Life cycle assessment phases

Life cycle assessment consists of four phases: (1) Goal definition, which defines the outline that all other LCA phases must comply with. It comprises the study purpose, data specificity and collection method, functional unit, impact assessment, and assumptions. (2) Life cycle inventory; it completed the diagram of the process, data collection, and evaluation of these data. (3) Life cycle impact assessment which includes the potential impacts of the process and selection of impact categories, grouping and weighting of these impacts (4) Life cycle interpretation which provides for identification of the significant effects and evaluation of LCA findings and final recommendations (Williams, 2009; Nakhla, 2014; Astuti *et al*., 2018).

2.12.4 Life cycle impact assessment methodology

Different methods have been developed by many specialists' organizations in various countries in the world (Table 3). Each method has its distinguished characterization models, factors, and weighting factors that differ from others. Selection of one of these methods depends on the goal set for the LCA study (Nakhla, 2014).

Table 3 Life cycle impact assessment methodology

No	Method	Factors considered to be measured	Reference
1	Eco-indicator 99	The damage to (1) the human health comprises indicators of carcinogenesis, respiratory effects, radiation, ozone depletion and climate change. (2) ecosystem quality expressed in (%) includes indicators of toxicity, acidification, eutrophication and land use and (3) fossil resources expressed in mega joules involves depletion of mineral and fossil fuels.	Azapagic and perdan, 2011; Nakhla, 2014; Rigon, *et al.*, 2019
2	IMPACT 2002+	It considers the previous three damage categories plus the climate change as fourth category.	Pre-Consultants, 2010; Rigon, *et al.*, 2019
3	CML 2 Method	The potential impacts of abiotic resource depletion,	Azapagic and
		global warming, photochemical oxidant formation, ozone depletion, acidification, eutrophocation, human toxicity and eco-toxicity.	perdan, 2011; Curran, 2012; Rigon, *et al.*, 2019

4	ReCiPe	This method integrates the CML2 and eco-indicator 99 so as it takes the advantage of both by implementing both strategies.	Pre-Consultants, 2010; Rigon, *et al.*, 2019
5	Ecological Footprint	It considers direct and indirect land occupation, energy use and CO_2 emissions. It does not normalize the impact since each impact has weighting factor.	Pre Consultants, 2010
6	Greenhouse Gas Protocol	It calculates carbon dioxide equivalents (CO_2e) of all non CO_2 gases (CH4, N2O, SF6, HFCs, CFCs) used and reports on the most recent 100- year global warming potentials (GWP)	Pre-Consultants, 2010
7	IPCC 2007	It registers the climate change factors of the Intergovernmental Panel on Climate Change (IPCC) based on timeframe of 20, 100 and 500 years. There is no normalization of weighting factors considered in this method.	Nakhla, 2014; Rigon, *et al.*, 2019

2.13 Industrial Waste Handling Framework

The waste management strategies are significantly different between countries so it remains to be a prominent issue to achieve specific objectives. A well-designed framework can steer managers to address the waste issue in a cost-effective and timely manner. It can spur the enhancements of existing plans or aid in designing new ones (Davidson, 2011; Singh, 2017). A variety of approaches have been developed to tackle the waste problem such as the Integrated waste management (IWM), which combines a range of techniques, technologies, and management practises to achieve specific objectives and goals. Systems analysis provides useful information to define, evaluate, and adapt waste management systems (Pires *et al.*, 2011). There are two central systems analysis techniques to waste management: (1) systems engineering models such as predicting models, simulation models, optimization models, and integrated modelling systems.

(2) system assessment tools such as management information systems, decision support systems, expert systems, scenario development, material flow analysis, life cycle assessment, risk assessment, environmental impact assessment, strategic environmental assessment and socio-economic assessment (Pires *et al*., 2011). Many concepts could help structure waste management plans, as shown in table (6).

Table 4 Key concepts to structure waste management plan

No	Concept	Focus	Reference
1	Zero Waste	Restructuring production and distribution systems to reduce waste and eliminating waste from the outset.	Young *et al*., 2010; Davidson, 2011
2	Cradle-to Cradle (C to C) / Cradleto-Grave	Designing industrial systems in a way that materials flow in closed loop cycles which minimize, recycle and reuse of the waste.	McDonough *et al*., 2003; Davidson, 2011
3	Eco-Efficiency	Integrating environmental with the economic aspects of certain developments processes.	Hellweg *et al*., 2005; Davidson, 2011
4	Industrial Ecology	Redesigning, integrating, and adapting technology to activities and processes to be more sustainable in a fashion similar to C to C.	Davidson, 2011 and Bhatnagar., *et al*., 2016

The prospective industrial waste handling framework, which will be developed in this study, it's key goals, objectives, indicators, targets, and strategies can be outlined in Table 5.

Table 5. Features of the industrial waste handling framework for the selected sugar factories

Goals / Objectives	Indicators / Targets	Strategy
Maximize reuse and recycling of waste resulting from sugarcane manufacturing	Use additional facilities to reduce the production impact.	Target specific materials such as surplus bagasse and waste water for reuse and recycling.

• Support decision makers toward achieving sustainable sugarcane production in Sudan. • Achieve zero waste for sugar industry in Sudan.	Substitute reusable items for disposable items in waste handling.	• Increase the effectiveness of existing and the on process recycling programs. • Develop facilities and systems to reuse the waste as raw materials to produce friendly environmental products such as paper from bagasse, biogas from waste water, ceramic from bagasse ash.

2.14 Discussion

Despite the importance of the sugar industry in Sudan and its contribution to the national economy there is minimal productivity (Abdalla, 2006; Soltan, 2008; Ibrahim, 2015). Studies have been conducted in this respect (Soltan, 2008; Ibrahim, 2015 and Bushara and AbuSin, 2016). The reasons for this were poor factory design, improper utilization of the mills' production inputs, and technology deterioration. However, some sugar industries processing systems in the country have a low extraction rate. The operations of converting cane to crystals sugar are insufficient in terms of milling performance and industrial efficiencies. No defined method identified the factors that led to a decline in sugar productivity over the past ten years, from 2008 to 2017. The reduction has also affected the largest sugar producer (i.e., the Kenana). Factories' cane yield has reached the highest level of production capacity. The previous studies have not examined the Sudanese sugar processing supply chain. Even if the majority of these industries are old, the question that arises is, what factors influence the efficiency of sugar processing factories in Sudan?

On the other hand, the untreated sugar production wastewater harms the environment and the surrounding community. Most sugar industries discharge the wastewater into open fields of catchments leading to Nile (El Hassan, 1998 and Qureshi *et al*., 2015). Using the wastewater for crop irrigation is unhealthy (Aisha, 2007; Kumar, 2014), while the treatment of sewage is costly (Oboody, 2016). Researches in the identification of determinants to solve this problem sustainably and adequately are required. However, one of the factories in this study is currently building plants for wastewater treatment (Alim, 2012). The previous studies were limited and conducted for one factory. Most of the sugar factories in Sudan have insufficient information background about the environmental issues associated with the sugar industry. The impact of sugar processing waste on the heath of the surrounding community remains one of a critical environmental issue. Although did has not concluded that, there is a lack of means for wastewater treatment in most of the factories, which makes the procedures of identifying the adverse effect of the waste difficult (Abid, 2008). The previous studies have never implemented a precise method on how to assess the direct impact of the waste disposal from sugar factories on the surrounding community of the selected sugar factories in Sudan.

Fossil energy has been heavily used at all sugar manufacturing factories (Palacius *et al*., 2019). Sugarcane is mechanically harvested which process emits large quantities of greenhouse gasses into the air. The process of sugar manufacture releases gasses and bagasse residual ashes to the atmosphere as well (Cordiero *et al*., 2004; Mohamed *et al*., 2011, Le Blond, *et al*., 2017). These pollutants affect human health, especially those who are living around factories. Exposure to these pollutants is inevitable as long as the sugar manufacturing process operates. The impact of sugar processing pollutants on human health has never been examined for the community surrounding the Sudanese sugar factories.

Nevertheless, emissions resulting from the different stages of sugar production life cycle could be minimized and controlled. It is reported by Abdeen (2002) that reducing the greenhouse gasses emissions is hugely demanded. However, this process needs efforts to be made firstly, determine the effluents, secondly, assess their impacts then, and identify opportunities to enhance the environmental performance. None of the previous procedures have been implemented or studied in Sudan. The assessment of energy use and the emissions associated with sugar production in the country need to considered.

The sugar industry in Sudan needs to be developed sustainably. From this respect, measures required to increase productivity and reduce the environmental impacts, which will provide benefits for community and mills. This provides an opportunity to reconcile environmental and production needs with the long-term development of the sugar industry in the country.

Therefore, this study will examine the production systems of the selected factories by analysing their milling and processing supply chain efficiencies. It will identify the impacts of untreated wastewater disposal on the community around these factories. The study will also determine energy use (i.e., fossil fuel and renewable resources) and greenhouse gasses emissions of the sugar production process for the selected sugar factories in Sudan. The study will also identify opportunities for sustainable solutions to improve the performance of this industry.

2.15 Summary

The sugar industry in Sudan was established with proven track records on production efficiencies and technological advancements. However, nowadays, the features of most sugar industries are deteriorated. The sector is phasing challenges form problems (i.e. a decline in sugar productivity, discharging the untreated wastewater, and gases emission), that need to be peremptorily resolved. The pollutants mentioned above could affect the environment and, thereby, the community residing around the factories. This study will contribute to solving these constraints sustainably and adequately by focusing on both the productivity and environmental aspects. The importance of the research comes through the fact that these issues have not been studied before for the Sudanese sugar industries. Therefore, using new precise methods such as examining the sugar processing supply chain to address the problem of lower productivity. Evaluating the impact of sugar manufacture waste on the community around the factories to solve the environmental issue will provide useful data/information to better management the effluents. Moreover, applying the life cycle assessment to the energy use and emissions for sugarcane industries in the country will be a baseline information to improve the environmental performance of sugar industry in Sudan Therefore, the study will add new knowledge towards a better understanding to finding solutions to the problems facing this sector which are the declining productivity, health risks and environmental impact of the industrial wastes. The study will identify factors influencing the low productivity through collection of empirical data from relevant sources such as interviews, annual reports, and yearly records of the selected factories and examining the current practices of the sugar production processes. The study will also determine the impacts of factories' effluents on the local community residing around by using a self-administrated questionnaire. Greenhouse gasses emissions and energy use for sugar production will be quantified by applying the life cycle assessment for the selected factories. Finally, a framework will be developed for proper waste handling to steer the decision-makers towards improving the environmental performance of the selected sugar factories in Sudan.

3. PROJECT PROPOSAL

3.1 Research Rationale

The sugarcane industry sector in Sudan has problems in many aspects that require research. The identified Sudanese sugar factories indicate the following:

1. A decline in sugar productivity over the past ten years. The problem is threatening the sustainability of the sector unless the unknown influencing factors are identified. Limited method developed so far to examine the efficiencies of the sugar processing supply chain for the industries, especially those that are old.
2. The sugar factory wastes disposal is causing environmental degradation, such as air pollution and other health problems that might affect the community residing around these factories. Due to the lack of reliable data, it has been challenging to quantify the impacts of the wastes and the exact problems that are leading to human health risk.
3. Sugar processing consumes energy and emits harmful gasses. Limited research has been conducted to assess the Sudanese factories' energy use and GHG emissions associated with the different stages of sugarcane production. Hence, it will be challenging to evaluate environmental performance and identify proper solutions for this industry unless that is conducted.

3.2 Research Questions

The research questions are:

1. What are the factors influencing the productivity of sugar industries in Sudan?
2. What affects factories’ efficiencies in converting cane to crystals sugar?
3. What affects mills’ performances and processing supply chain?

4. What are the impacts of sugar industry waste disposal on the community around the factories?
5. What are the health problems caused by wastes?
6. How much greenhouse gasses are emitted into the air and
7. How much energy is used for sugar production in Sudan?

3.3 Objectives

The main aim of this study is to evaluate the performances of sugar processing supply chains, to assess the life cycle of sugar production and to identify the impacts of wastes on the community around the selected sugar factories in Sudan.

The specific objectives of this study are:

1) To evaluate factors influencing the productivity of Sudanese sugar industry,
2) To analyse the efficiency of sugar processing steps in the factory,
3) To assess the energy use and GHGs emissions for the selected most crucial life cycle stages of sugar manufacturing in the Sudanese factories,
4) To identify the impacts of wastewater disposals, particle pollutants and toxic gases on the community residing around the sugar industries, and
5) To develop an integrated framework to improve the sugar processing sustainably and to properly handling the associated wastes for the selected sectors.

3.4 Materials and Methods

3.4.1 Study area

Depending on the literature reviewed and data analysed above, all the sugar factories in Sudan have problems of productivity and the environmental performance except the White Nile Factory as there was no sufficient data. Therefore, five sugar factories will be selected for this study (Guneid, Halfa, Sennar, Assalaya and Kenana). Kenana and Assalaya factories are from White Nile State. While Guneid is from Gazeira State, Sennar factory is from Sennar State and Halfa factory is from Kassala State. Guneid is located between latitude 13°17'20''N and longitude 32°46'52''E, Halfa is located roughly between latitude 15°28'20" N and longitude 35°34'32" E, Sennar lies between 13°49'38''N latitude and 33°27'35''E longitude, Assalaya is located between latitude 13°15'43" N and longitude 32°44'74" E, Kenana lies between 13°8'16" N latitude and 32°59'53" E longitude, and White-Nile locates between latitude 14°4'30" N and longitude 32°28'21" E.

3.4.2 Data collection

This study depends on both primary and secondary data sources. The primary data will be collected by a self-administrated semi-structured questionnaire constructed exclusively to cover the particular side of the study. The surveys will be developed and pretested by experts to avoid ambiguity (Mengistu *et al.*, 2016). The secondary data will be collected from the industries' annual reports, official records, dissertations, thesis, and related companies (i.e., Sudanese Sugar Company, and Kenana Sugar Company).

3.4.3 The methodology of evaluation of the sugar processing performance

3.4.3.1 Data collection

A comprehensive country-wide database for the sugar industry sector will be established by reforming a survey work for the selected sugar mills. An introductory letter seeking permission and staff assistance in data collection will be written to the selected sugar factories' directorate. For the past ten years (i.e. from 2007 to 2016), empirical data will be collected from the annual reports, official records, and related companies of the selected sugar factories (i.e., SSC and

KSC). Data will also be gathered from relevant dissertations and thesis. The cane quality, milling efficiency, the overall factories performance of converting cane to crystals sugar and chemical inputs used for sugar manufacturing, will be calculated. The three factors are considered as the core of sugar processing and affect productivity. Table 6 and Figure 13 provide the final parameters that will be considered for the evaluation of sugar processing performance over the last ten years.

* Cane quality identification: Cane quality analysis comprises determining the percentages of water, fibre, sucrose, and soluble impurities of the cane. The estimations will be calculated from the relevant laboratory records of the sugar manufacture departments of the selected industries.

* Milling performance: the factory milling performance can be calculated in percentages (%) by using Equation 1 as follow:

$Mill\ Extraction\ x\ 100$

$$\text{Milling performance (\%)} = \frac{Mill\ Extraction\ x\ 100}{100 - 0.20\ F} \qquad (1)$$

Where: 0.20 = extraction ratio and F = actual fiber of the cane (Fourmond, 2016).

* The factory performance: the total factory performance can be quantified (%) by using equations 2 and 3 as follows:

$$FP\ (\%) = 100\left[\frac{Tx}{Tc}\left(\frac{100}{ERC\%\ Cane}\right)\right] \qquad (2)$$

Where: Tx = crystal actually produced (ton), Tc = cane crushed (ton)
ERC = estimated recoverable crystal of sugar which can be calculated using Equation 3

$$ERC\ (\%)\ Cane = a.S - b.N - c.F \qquad (3)$$

Where:

ERC (%) Cane = the estimated quantity of crystal which can be recovered from the incoming cane supply (expressed in terms of crystal (%) cane). S = the sucrose (%) cane. N = the non-sucrose (%) cane (calculated as Brix (%) cane minus sucrose (%) cane). F = the fiber (%) cane.

a, b, and c = constant parameters related to the sucrose losses within the factory. The constant "a" represents the fraction of the sucrose losses in filter cake. The constant "b" represents the loss of sucrose in final molasses. The constant "c" represents the loss of sucrose in bagasse (Peacock and Schorn, 2002).

3.4.3.2 Data analysis

The cause and effect analysis (Hekmatpanah, 2011; Suripto *et al*., 2018) will be used to identify the factors affecting the problem of the decline of sugar productivity. A fishbone diagram (Hekmatpanah, 2011) will be built to identify all the potential causes that could possibly contribute to the main problem. The intensity relations matrix analysis will be conducted using the linked thinking techniques. The third step corresponds to the factors in a dot plot diagram to be displayed in the active, critical, sluggish, and passive field. Factors of interest are those that fall into active and critical fields. Interactions expected between factors in the active field and in the critical field among each other.

Table 6 Sugarcane processing parameters over the period from 2007 to 2016

Parameter	Value
Total cane productivity	$t.ha^{-1}$
Total cane stalk	$t.year^{-1}$
Cane crushed	$t.day^{-1}$
Milling efficiency	%
Sucrose % cane	%
Bagasse % cane	%
Sucrose % bagasse	%
Total sugar produced	$t.day^{-1}$
Factory performance	%
Total sugar	$t.year^{-1}$
Molasses produced	$kg.t^{-1}$ sugar
Energy efficiency index	%
Bagasse burnt / total produced	%
Inputs (Chemicals)	Value

Lime	$kg.t^{-1}$ sugar
Sulfur	$kg.t^{-1}$ sugar
Soda	$kg.t^{-1}$ sugar
Residues	
Filter cake	$kg.t^{-1}$ sugar
Boiler ashes	$kg.t^{-1}$ sugar
Waste water	$m^3.day^{-1}$

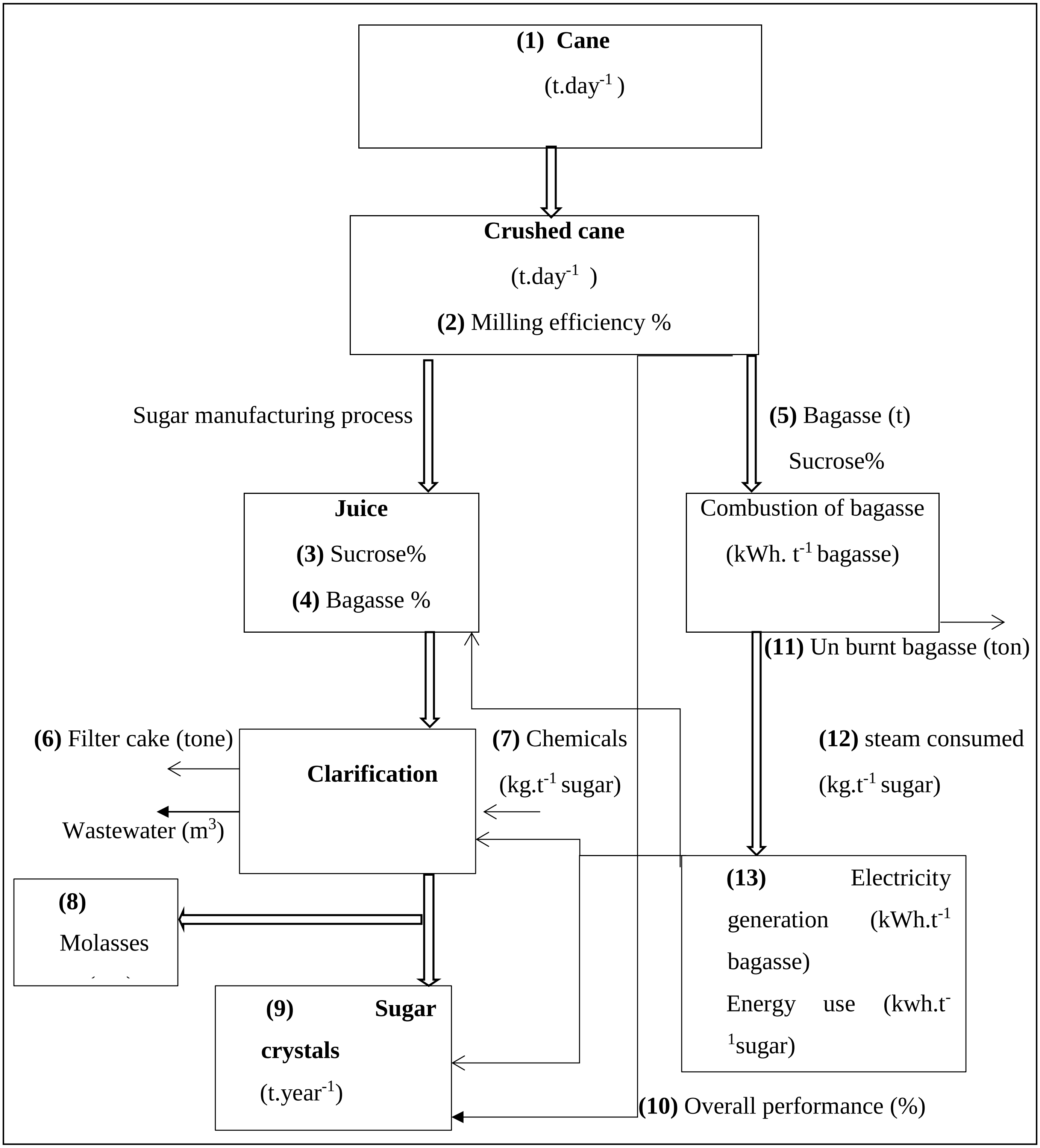

Figure 15 Sugar processing parameters

3.4.4 The methodology of quantifications the energy and greenhouse gasses

3.4.4.1 Data collection

Data will be collected from the relevant reports and annual records of the selected industries and energy companies. The past ten years' collected data will be used for the calculations of fossil energy consumption and GHGs emissions (objective 4). Fossil energy consumption will be calculated per Mega-Jules per one ton produced sugar ($MJ.t^{-1}$) by summing up the quantities of the consumed fuel during cane farming, burning, harvesting, transportation, and sugar processing as shown in Figure 15. The life cycle assessment will be applied based on International Organization for Standardization (ISO) standard 14044 in which LCA will be divided into four phases: goal definition, inventory analysis, impact assessment, and interpretation using (Sima Pro) software (Livison *et al.*, 2010). The average tons of cane used to produce one ton of sugar will be determined. Then the total energy required for cane farming will be calculated per $MJ.ton^{-1}$ sugar produced.

3.4.4.2 Fossil fuel energy consumption

Fossil fuel energy for cane transportation to produce one ton of sugar will be calculated per MJ. The fuel consumption for a truck will be determined per $L.tkm^{-1}$, and the energy content for diesel will be taken as MJ. $Liter^{-1}$ energy consumption for the truck in Sudan will be determined per $MJ.tkm^{-1}$. Energy used during sugar manufacture ($MJ.t^{-1}$ sugar) will be calculated by quantifying the amount of diesel consumed in kilograms to produce one ton of sugar. The net calorific value (NCV) of diesel per $MJ.kg^{-1}$ will be determined according to Livison *et al*. (2010).

3.4.4.3 Renewable energy consumption

Survey work to power departments of the selected factories will be carried out to collect the relevant data from the records sheets and conducting personal contacts with specialists. The parameters that will be considered consist of bagasse combusted per ton a day, the net calorific value (NCV) of bagasse assumed to be 7.8 MJ/kg (Livison *et al*., 2010; Rakesh *et al*., 2016), electricity ($kW.day^{-1}$) generated to supply sugar processing, the renewable energy required to produce one ton of sugar, the total renewable energy consumption for the system per $kWh.t^{-1}$ sugar produced and energy efficiency index which will be calculated using Equation 4

$$EI = (Et - E_D)/S_J \qquad (4)$$

Where: EI = energy efficiency Index, ET = total energy, ED = Diffuser energy usage, and SJ = volume of sugar in all final products (Hocking *et al*., 2015).

The calculation methods of GHGs are based on fuel used in the selected life cycle of sugar manufacturing in Sudan. Data on the consumed fuel will be collected, and the emissions estimated by using Equation 5 (IPCC, 2006). The three most important GHG are calculated for the selected stages of the sugar life cycle. These gases are, namely CO_2, CH_4, and N_2O. The global warming potentials (GWPs) are used to quantify the GHG, which is expressed as CO_2 – equivalents. The global warming potentials developed by the intergovernmental panel on climate change (IPCC) are quantified for a horizon of 100 years. Accordingly, equivalent factors for the three essential gases are defined as fellows; 1g CO_2 = 1 g CO_2-eq, 1 g CH_4 = 23 CO_2 – eq and 1 g N_2O = 296 g CO_2 – eq

$$Emissions_{GHG,\ fuel} = Fuel\ Consumption_{fuel} \bullet Emission\ Factor_{GHG,\ fuel} \qquad (5)$$

Where:

$Emissions_{GHG,\ fuel}$ = emissions of a given GHG by type of fuel (kg GHG)

$Fuel\ Consumption_{fuel}$ = amount of fuel combusted (TJ)

$Emission\ Factor_{GHG,\ fuel}$ = default emission factor of a given GHG by type of fuel (kg gas/TJ).

The amount of fuel of a particular kind combusted per one ton of sugar expressed in tera joule (TJ) can be estimated by using Equation 6.

$$Fuel_{a,f} = litters_{fuel\ a,f} * Density_{fuel\ a} * NCV_{fuel} \div 10^6 \qquad (6)$$

Where:

$Fuel_{a,t}$ = Amount of fuel type a consumed in TJ

$Litters_{Fuel\ a,\ t}$ = Quantity of fuel of type a consumed (litre)

$Density_{Fuel\ a}$ = Density of fuel type (kg/litre)
$NCV_{Fuel\ a}$ = Net calorific value of fuel type (TJ/Gg)

Calculation of the total emissions by gas from the Equation1 will be done by summing up the overall fuels using Equation 7 (IPCC, 2006).

$$Emissions_{GHG} = \sum_{fuels} Emissions_{GHG,\ fuel} \quad (7)$$

The approach that will be used for this methodology is summarized in five steps as follows:

- Determine the amount of fuel consumed at all the sugar factories, measured in terms of mass or volume.
- Convert the amount of fuel consumed into energy flow by using the heating value of the fuel type.
- Determine the emission factor of a given GHG by the type of fuel expressed as kg gas/TJ. For CO_2, it includes the carbon oxidation factor, assumed to be 1.
- GHG emitted calculation expressed as kg CO_2 equivalent.
- Sum-up the total GHG emission according to fuel type.

The GWP of fossil energy can be then estimated by quantifying the total GHG emissions along the selected sugar production stages. Hence, they multiply the GHG emissions by their respective equivalence factors and sum up the results (Francesco, 2010). The GHG emissions calculated below are related to the defined functional unit, one ton of sugar.

The sub-systems that will be included in this study for objective three are shown in Table 7 and Figure 15.

Table 7 Fossil energy use and GHGs emissions from sugar production (2016)

Operation	**Fossil energy use**	**GHG emissions**
Sugarcane farming	$MJ.t^{-1}$ sugar	kg $CO_2eq.t^{-1}$
Trash burning	$MJ.t^{-1}$ sugar	kg $CO_2eq.t^{-1}$
Field emissions	$MJ.t^{-1}$ sugar	kg $CO_2eq.t^{-1}$
Sugarcane transportation	$MJ.t^{-1}$ sugar	kg $CO_2eq.t^{-1}$

Sugar manufacture	MJ.t^{-1} sugar	kg CO_2eq.t^{-1}
Energy from bagasse (Displacement of fuel fired boilers)	- MJ.t^{-1}sugar	kg CO_2eq.t^{-1}
Total	MJ.t^{-1} sugar	kg CO_2eq.t^{-1}

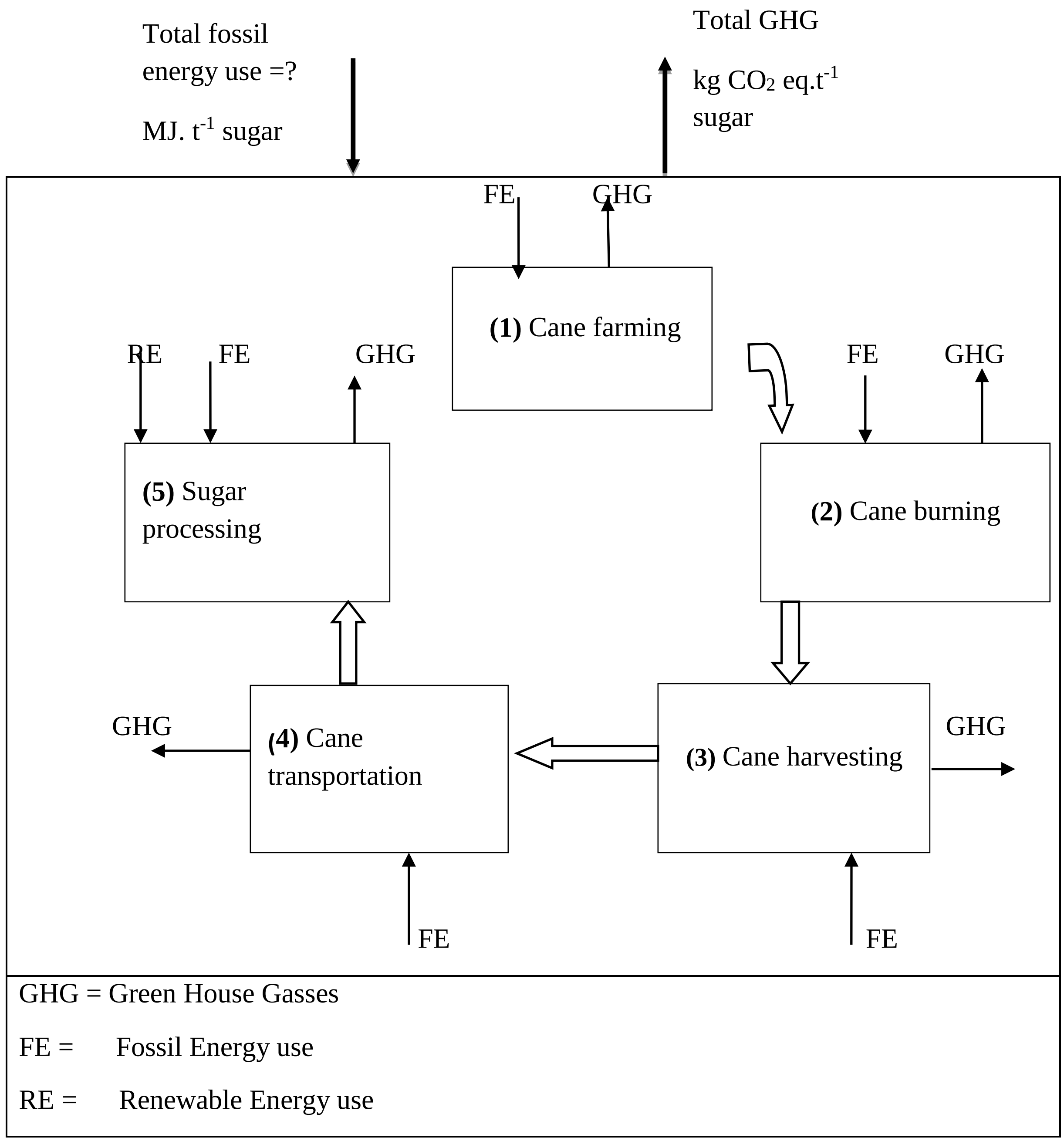

Figure 16 Energy use and GHGs emissions

3.4.4.3 Life cycle assessment

SimaPro Software and Eco-indicator 99 methodology will be used to analyse data obtained from objective four i.e., energy and greenhouse gasses quantifications (Livison *et al*., 2010). The software program will show the results in figures, charts, and tables. Hence, the sugar life cycle stage that has the most significant impacts on the environment will be identified. The environmental impacts include Global warming (i.e., based on 100-year global warming potential), fossil fuel use, ozone depletion, acidification, and ecotoxicity.

3.4.5 The environmental impact of the sugar processing waste

3.4.5.1 Data collection

Data will be collected from people living around the selected factories by using self-administered semi-structured questionnaire to achieve objective 5 (Mengistu *et al*., 2016). The questionnaire contains close-ended questions that will be evaluated and pretested through questioning 5 to 10 respondents from not targeted respondents. The investigation will provide detailed insights such as type of pollutants and their contributions in contaminating the environment and the kind of various diseases caused by them. In addition, the health challenges presented by the factories to the surrounding community will be considered (Hind, 2015). The overall number of samples for the six factories will be 540 questionnaires. There will be three targeted locations around each industry to be covered by 30 inquiries for each village. The questionnaire's structure that will be used is shown in the appendices.

3.4.5.2 Data analysis

The statistical package for social science (SPSS) version 19 will be used for data analysis. The descriptive statistics (i.e. frequencies standard deviation and standard error) well be included. Nonparametric analysis or cross-tabulation (i.e. Chi-Square test) will be used to calculate P values to identify the significant differences. Diseases caused by the pollutants will be identified and the relation between other parameters (i.e. risk to animals and crop production) will be determined by using the correlation coefficient test. The multinomial logistic regression approach will be used to find the significant factors influencing the surrounding environment. Multinomial logistic regression technique is a probability estimation model used when the dependent variable is more than two categories (i.e. agree disagree and neutral) and the independent variable is categorical or continuous (John, *et al.*, 2017).

The output will be discussed and interpreted.

3.6 Proposed Chapters in Thesis

A. An evaluation of the current status of the production performance of the sugar industry in Sudan: an overview.
B. Identification the technical factors influencing the sugar productivity in Sudan.
C. The environmental impact of the sugar industry waste in Sudan.
D. Data for understanding the health risks of the Sudanese sugar industrial wastes: wastewater and suspending Particulates.
E. Life cycle assessment of sugar production in Sudan: green-house gases emissions and energy usage.

3.7 Project Budget

Table 8 The preliminary breakdown for the budget of the study

Item	Cost US$
Traveling costs to Sudan	1500
Traveling costs to the factories and other areas	1000
Data collection and questionnaires (distribution, collection, fulfillments and other assistances)	500
Unforeseen expenses	500
Total	**3500**

3.8 Project Plan

	Years	2016							2017							2018							2019							2020			
Activity	Months	J	J	A	S	O	N	D	J	M	M	J	S	V	D	J	M	M	J	S	N	D	J	M	M	J	S	N	D	J	M	M	J
Literature review research and project proposal write-up																																	
Submission of literature review and proposal and presentation																																	
Publication of review																																	
Field survey and data collection																																	
Data analysis																																	
Publications of the objectives 1, 4 and 5																																	
Thesis writing up																																	
Submission the first draft of thesis																																	
Final draft submission																																	

4. REFERENCES

Astuti, A, Astuti, R and Hadiyanto, H. 2018. Application of life cycle assessment (LCA) in sugar industries. E3S Web of Conferences 31, 04011 (2018), Diponegoro University, Semarang, Indonesia.

Ahmed, EH. 2017. Personal communication. Agricultural department / Assalaya sugar industry, Assalaya, Sudan, 14 June 2017.

AbuZeid, MO. 2015. *Sugar Cane Growing and Processing with Special Reference to The Sudan.* IBDAA for printing, Khartoum, Sudan.

Adam, EA, Amna, OM, Alam-Eldin, AO. 2015. An assessment of mechanical vs. manual harvesting of the sugarcane in Sudan – the case of Sennar sugar factory. Journal of the Saudi Society of Agricultural Sciences 14(2): 160–166

Ahmed, HA. 2015. *Vinasse determination*. Report No 520:50, Ethanol plant, Kenana Sugar Company, Kenana, Sudan.

Abd El Raheem, HF and Lang, A. 2015. Production of transport biofuels in Sudan for replacement of petroleum fuels: the fundamental issues. Unpublished MScEng Dissertation, School of Mechanical Engineering, Sudan University of Science and Technology, Khartoum, Sudan.

Assalaya Sugar Factory (ASF). 2016. *Sugar production statistics*. Annual Report, Report for the year 2015, Halfa, Sudan.

Abbass, HM and Elhag, AH. 2013. Crop assessment and monitoring for sugar cane crop, Sudan, (new Halfa case study) using remote sensing and GIS techniques. *International Journal of Scientific and Research Publications* 3 (3) ISSN 2250-3153.

Alim, EE. 2012. Assessment the liquid and solid wastes from Guneid sugar factory. Unpublished MScEng Dissertation, University of Khartoum, Khartoum, Sudan.

African development Bank Group (ADBG). 2011. African Development Bank, Food Security, [Internet] available online: http://www.afdb.org/en/. [Accessed December 2011].

Azapagic, A and Perdan, S. 2011. Sustainable Development in Practice: Case Studies for Engineers and Scientists, United Kingdom: Wiley-Blackwell (an imprint of John Wiley and Sons Ltd).

Arbab, SH. 2011. Improvement of the sugar purification efficiency at new Halfa sugar factory. Unpublished MScEng dissertation, Sudan Academy for Science, Khartoum, Sudan.

Arbab, ZS. 2009. Economic - agricultural performance for the Sudanese sugar company. Case study Gunied sugar factory. Unpublished MScEng Dissertation. Faculty of economic and political science, Omdurman Islamic university, Khartoum, Sudan.

Abid, AA. 2008. Economic impact of air pollution by sugar industry in the White Nile State, Sudan, Unpublished MScEng Dissertation, University of Khartoum, Khartoum, Sudan.

Alam-Eldin, A. O. 2008. Economic evaluation of sugarcane harvesting systems in Sennar Sugar Factory- Sudan, Unpublished MScEng Dissertation, University of Khartoum, Khartoum, Sudan.

Aisha, MA. 2007. Impact of sugar industry waste water on some vegetable crops production. Unpublished MScEng Dissertation, Department of Agricultural Economics, Faculty of Agriculture, University of Khartoum, Khartoum, Sudan.

Abdalla, AA. 2006. Determinants of growth in sugar production in Sudan 1980 – 2004. Unpublished MScEng Dissertation, University of Khartoum, Khartoum, Sudan.

Ali, RA, Abdelmagid, IM and Baddour, EM. 2006. Environmental impacts of a wastewater from Assalaya sugar factory on the White Nile (Al- Jassir area). Unpublished PhD Eng Dissertation, Sudan Academy of Sciences, Khartoum, Sudan.

Abdeen, MO. 2002. Energy supply potentials and needs and the environmental impact of their use in Sudan. *The Environmentalist* 22: 353–365.

Bushara, MO and Abu Sin, AM. 2016. Evaluation of total factor productivity of Sudanese sugar company farms: a non-parametric analysis 1999-2007. *Arabian Journal of Business and Management* 6(3): 2223-5833.

Bhatnagar, A, Kesari, K and Shurpali, N. 2016. Multidisciplinary approaches to handling waste in sugar industries. *Water Air Soil Pollut* (2016) 227:11.

Balakrishnan, M and Batra, VS. 2011. Valorization of solid waste in sugar factories with possible applications in India: A review. *Journal of Environmental Management* 92(11): 2886-2891.

Contreras, AM., Rosa, E, Perez, M, van Langenhove, H and Dewulf, J. 2009. Comparative Life Cycle Assessment of four alternatives for using by-products of cane sugar production. Journal of Cleaner Production 17(8): 772-779.

Cheesman, O. 2005. Environmental Impacts of Sugar Production: The Cultivation and Processing of Sugarcane and Sugar Beet, United Kingdom: CAB International North America.

Cordiero, GC, Romildo, F, Eduardo, F, Cristiano, O, Tavares, S. 2004. Influence of Mechanical grinding on the pozzolanic activity of residual sugarcane bagasse ash. *International RILEM Conference on the Use of Recycled Materials in Buildings and Structures, Barcelona, Spain*, 731-740.

Davidson, G. 2011. *Waste Management Practices: Literature Review*. Dalhousie University - Office of Sustainability, Nova Scotia, Canada.

David, K and Barry, JK. 2009. Extracts Derived from Sugar cane and a Process for Their Manufacture. EP 2064352 A1.

Elzebair, SA, Ahmed, MA and Elamin, AE. 2015. Economic performance of private and public sugar estates, Sudan, 1990-2008. *Gezira Journal of Agricultural Science* 13 (2): 145-154.

Eduardo B, Alan, RP, Rangel, R and Newton, L. 2010. Greenhouse gas emission associated with sugar production in southern Brazil. Carbon Balance and Management, Available from: http://www.cbmjournal.com/content/5/1/3.

El Haggar, SE, 2007. *Sustainable Industrial Design and Waste Management: Cradle-to-Cradle for Sustainable Development*. Elsevier Academic Press, United States

El Hassan, BM. 1998. Sugar industry in the Sudan Status and environment. Environment Magazine NO 1, Sudan.

Fourmond, TH. 2016. How to measure' and express sugar mills efficiencies. *Proceedings of the South African Sugar Technologists' Association -March 1966 149,* 1-3. South Africa.

FAOSTAT. 2015. Production-statistics-crops-crops-processed. Sudan molasses production quantity. [Internet], Available from: http://knoema.com, [Accessed March 2016].

Faria, KC, Gurgel, RF and Holanda, JN. 2012. Recycling of sugarcane bagasse ash waste in the production of clay bricks. *Journal of Environmental Management* 101: 7-12. doi: 10.1016/j.jenvman.2012.01.032.

Fransisco, C. 2010. GHG balances of bioenergy systems – overview of key steps in the production chain and methodological concerns. *Renewable energy* 35: 1565-1573.

Federal Ministry of Agriculture (FMA). Investment Development Agency. 2010. Industry investment opportunity, report for sugar factory projects. Sudan. Available from in: www.aaaid.org.

FAOSTAT. 2007. Dams and Agriculture in Africa Prepared by the Aqua state Program, [Internet] Available from: http://www.fao.org/nr/water/aquastat/damsafrica/Aquastat. [Accessed 25 July 2008].

Farah, HS. 2005. The role of industry in local development: a case study of kenana sugar company. MSc Thesis, University of Khartoum, Khartoum, Sudan

Guneid Sugar Factory (GSF). 2016. *Operational Results*. Annual Report, Report No 54. Guneid, Sudan.

Gasmalla, MA, Yang, R, Nikoo, M, Su, M. 2012. Production of ethanol from Sudanese sugar cane molasses and evaluation of its quality. Journal of Food and Process Technology 3:7 doi:10.4172/2157-7110.1000163.

Goedkoop, M, Spriensma, R. 2001. *The eco-indicator 99. A Damage-Oriented Method for Life Cycle Impact Assessment.* Methodology Report Annex. PRé Consultants B.V. Amersfoort, Netherlands.

Hassan, M, Bashir, N and Assad, Y. 2017. Sugar industry as a source of pollution: a case study, Guneid sugar factory, Gezira state, Sudan. *EC Pharmacology and Toxicology* 4(5): 202-212.

Halfa Sugar Factory (HSF). 2016. *Sugar Production Statistics, Annual Report*. Report for the year 2015, Halfa, Sudan.

Hind, BA. 2015. The effect of Kenana sugar company on community livelihood: a case of Altogaba village, White Nile State, Sudan. *International Journal of Research in Humanities and Social Studies* 2 (3): 19-29.

Hocking, G, Gibson, E and Mitchell, S. 2015. An energy efficiency index for the south African sugar industry. Industry Representative, South Africa.

Hekmatpanah, M. 2011. The application of cause and effect diagram in the oil industry in Iran: The case of four-liter oil canning process of Sepahan Oil Company. *African Journal of Business Management* 5(26): 10900-10907.

Hassan, SF. 2008. Development of sugar industry in Africa, review article. *Sugar Tech* 10 (3): 197-203.

Hajer, ME. 2007. The feeding value of sugar cane molasses in broiler diets. MSc Thesis, University of Khartoum, Khartoum, Sudan.

Hellweg, S, Doka, G, Finnveden, G and Hungerbühler, K. 2005. Assessing the eco-efficiency of end-of-pipe technologies with the environmental cost efficiency indicator. *Journal of Industrial Ecology* 9(4): 189-203.

Ibrahim A. Onour. 2015. Efficiency of sugar industry in Sudan: data envelopment analysis. *SSRN Electronic Journal*. doi: 10.2139/ssrn.3049045.

Ibrahim, AE. 2011. Long term positive impact of structural reforms on cane production processes at Kenana sugar company, Sudan. *Proceedings of South African Sugar Technologists' Association* 84: 133-156. Kenana, Sudan.

Industrial and Petroleum Production of Sudan (IPPS). 2009. Production of sugar. [Internet], Available from: Central Bureau of Statistics, Sudan. [Accessed 15 April 2013].

Ismail, EA. 2006. Developments in sugar industry in Sudan: An analysis of the factors affecting sugar production, marketing and consumption. *Food d Processing Research Centre* (1): 75-92.

Intisar, YM. 2003. A Study on physicochemical attributes of sugar cane bagasse produced from four Sudanese factories. Unpublished M Sc. dissertation, University of Khartoum, Khartoum, Sudan.

John J, Soko, S, Yu, C and Aurelia, K. 2017. STEM Aspiration: The influence of social capital and chilly climate on female community college students. *Community College Journal of Research and Practice* 41(4): 253-266.

Knoema. 2017. Sudan - Sugar cane area harvested. [Internet]. Available from: https://knoema.com. [accessed 25 April 2019].

Knoema. 2016. Sudan - Sugar & sweeteners exports. [Internet]. Available from: https://knoema.com. [Accessed July 2016].

Knoema. 2019. Sugar production in Sudan. [Internet]. Available from: https://knoema.com. [Accessed July 2014].

Kenana Sugar Company (KSC), 2016. Operational Results. [Internet], Available from: www.kenana.com and www.ide.go.jp. Sudan [Acceded December 2016].

Kumar, V. 2014. Sugar mill effluent utilization in the cultivation of maize (Zea mays L.) in two seasons. *Journal of Waste Management*1-12 doi: 10.1155/2014/408509.

Kenana Sugar Company Manual, 3rd ED. (2013): Sugarcane production manual, KSC, Kenana, Sudan.

Kouzi, AI. 2008. Presence of dextran and it's negative effects on cane sugar production in Sudan. Unpublished PhD dissertation, University of Khartoum, Sudan.

Le Blond, JS, Woskie, S, Horwell, CJ and Williamson, BJ. 2017. Particulate matter produced during commercial sugarcane harvesting and processing: a respiratory health hazard. *Atmospheric Environment* 149 (2017): 34 – 46.

León-Niño, AD, Camargo, JM, Neto, AP, Toneli, JT and Nebra, SA. 2013. Sugarcane residual biomass briquetting aiming energetic use. *WASTES: Solutions, Treatments and Opportunities, 2nd International Conference*, Braga, Portugal

Livison, M, Charles, M and Valerie, MT. 2010. LCA of the South African sugar industry. *Journal of Environmental Planning and Management* 53(6): 793-807.

Mohamed, YA, Wahab, HA, Khalifa, SA, Yahia, D and Mansour, F. 2017. Wastewater analysis of Assalaya sugar factory. *International Journal of Trend in Research and Development* 4(6): 21-24

Mohamed, OA and Lubna, MA. 2016. Decomposing total factor productivity of Sudanese sugarcane factories (2000-2007). *International Journal of Economics and Management Sciences* 5(3): doi:10.4172/2162-6359.1000327

Mengistu, MG, Simane, B, Eshete, G and Workneh, TS. 2016. The environmental benefits of domestic biogas technology in rural Ethiopia. *Biomass and Bioenergy* 90 (2016):131–138.

Mashoko, L, Mbohwa, C and Thomas, VM. 2013. Life cycle inventory of electricity cogeneration from bagasse in the South African sugar industry. *Journal of Cleaner Production* 39: 42-49.

Mohamed, ES and Samah, MF. 2011. The use of sugarcane bagasse ash as an alternative local pozzolanic material: Study of chemical composition. *Science Vision* 46(1): 65-70.

McDonough, W, Braungart, M, Anastas, PT and Zimmerman, JB. 2003. Peer reviewed: Applying the principles of green engineering to cradle-to-cradle design. *Environmental Science and Technology* 37(23): 434-441.

Nations Encyclopedia. 2019. Sudan Industry. [Internet]. Available from: https://www.nationsencyclopedia.com/economies/Africa/Sudan-INDUSTRY.html. [Accessed 15 May 2019]

Nakhla, DA. 2014. Achieving environmental sustainability of sugarcane industry in egypt: an application of life cycle assessment. PhD Thesis, the American University in Cairo. Eygpt.

Nigam PS and Pandey, A, 2009. Biotechnology for agro-industrial residues utilization: utilization of agro-residues. Springer-Verlag, New York, United States.

Nemerow, NL, 2007. Industrial waste treatment [contemporary practice and vision for the future]. Elsevier, Butterworth-Heinemann. United States.

Oboody, FH. 2018. Personal communication. Cane Quality / Research Center / Kenana sugar factory, Kenana. Sudan, 14 November 2018.

Oboody, FH. 2016. Evaluation of biogas productivity from vinasse, waste water and Filter mud in Kenana sugar scheme. *International Journal of Current Microbiology and Applied Science* 5(4): 117-126.

Obeid, A. 2013. *An Overview of the Sugar Industry in the Sudan*. Annual Report. 2012 / 2013. Sugarcane Research Center, Guneid, Sudan.

Palacios, RM, Lasserre, A, Mendoza,L, Gallardo, J, Contreras, J and Lassman, A. 2019. Life cycle assessment of cane sugar production: the environmental contribution to human health, climate change, ecosystem quality and resources in México. *Journal of Environmental Science and Health, Part A*. doi: 10.1080/10934529.2019.1579537.

Pires, A, Martinho, G and Chang, N. 2011. Solid waste management in European countries: a review of systems analysis techniques. *Journal of environmental management* 92(4): 1033-1050.

PRe-Consultants, 2010. SimaPro 7 Database Manua. Methods library. Netherlands.

Peacock, SD and Schorn, PM. 2002. Crystal recovery efficiency as an overall measure of sugar mill performance. *Proceedings of the South African Sugar Technologists' Association, 76*. Tongaat-Hulett Sugar Limited, Glenashley, South Africa.

Paturau, JM. 1982. *By Products of the Cane Sugar Industry: An Introduction to Their Industrial Utilization*. 3rd edition. Elsevier Science, Amsterdam, Netherlands.

Qureshi, A, Mahessar, A, Leghari, M, Lashari, B and Mari, F. 2015. Impact of releasing wastewater of sugar industries into drainage system of LBOD, Sindh, Pakistan. *International Journal of Environmental Science and Development* 6(5): 381-386.

Ramiro, MP, Alberto, AA, Luis, FM, Jorge, R, Jose, O and Alejandro, A. 2019. Life cycle assessment of cane sugar production: the environmental contribution to human health, climate change, ecosystem quality and resources in Mexico. *Journal of Environmental Science and Health, Part A.* doi: 10.1080/10934529.2019.1579537.

Rigon, M, Zortea, R, Moraes, C and Modolo, R. 2019. Suggestion of life cycle impact assessment methodology: selection criteria for environmental impact categories. In: ed. Petrillo, A and De Felice, F. *New Frontiers on Life Cycle Assessment - Theory and Application*, Ch. 1-11. IntechOpen, São Leopoldo, Brazil. doi: 10.5772/intechopen.83454.

Suripto, M, Romli M and Rosidi, AH. 2018. Risk analysis and mitigation strategy for sugar cane production processes (Case study: X sugar cane factory –West Java). *IOP Conference. Series: Earth and Environmental Science*, 209, 012042. doi:10.1088/1755-1315/209/1/012042.

Rakesh, K, Mahesh, K and Amit. 2016. An experimental study to evaluate the calorific values of bagasse after solar cabinet drying. *International Journal on Recent and Innovation Trends in Computing and Communication* 4(6): 239–241.

Rabah, AA, Nimer, HB, Doud, KR and Ahmed, QA. 2016. Modelling of Sudan's energy supply, transformation and demand. *Journal of Energy*. http://dx.doi.org/10.1155/2016/5082678.

Ramjeawon, T. 2008. Life cycle assessment of electricity generation from bagasse in Mauritius. *Journal of Cleaner Production* 16: 1727–1734.

Sahu, O. 2018. Assessment of sugarcane industry: suitability for production, consumption and utilization. *Annals of Agrarian Science* 16: 389–395.

Seng, TL, Seebaluck, V and Leach, M. 2018. Future energy transitions for bagasse cogeneration: Lessons from multi-level and policy innovations in Mauritius. *Energy Research and Social Science* 35: 68-77.

Singh, A and Sushil. 2017. Developing a conceptual framework of waste management in the organizational context. *Management of Environmental Quality: An International Journal* 28 (6): 786-806.

Suliman, SA. 2017. Personal communication. Technical department / Sudanese sugar company, Khartoum, Sudan, 04 April 2017.

Sennar Sugar Factory (SSF). 2016. *Operational Results*. Annual Report, Report No 40, Sennar, Sudan.

Sudanese Sugar Company (SSC). 2015. *Agricultural Manual*. Sugar Research Centre. Guneid, Sudan.

Sanket, DA, Harshavardhan, UB and Nita, PC. 2015. Effluent treatment plant of sugar wastewater –a review. *Themed Section: Science and Technology* 1 (5). ISSN: 2395-6011

Silva, DA, Delai, I, de Miranda, MM, Montes, ML and Ometto, AR. 2012. LCA application: the case of sugar cane bagasse electricity generation in Brazil. *19th CIRP International Conference on Life Cycle Engineering*. Berkeley. USA.

Souza, AE,, Teixeira, SR, Santos, GA, Costa, FB and Longo, E. 2011. Reuse of sugarcane bagasse ash to produce ceramic materials. *Journal of Environmental Management* 92 (10): 2774-2780.

Scott, R, Loarie, DB, Lobell, GP, Asner, QM and Christopher, BF. 2011. Direct impacts on local climate of sugar-cane expansion in Brazil. *Nature Climate Change*. doi: 10.1038/NCLIMATE1067.

Solomon, S. 2011. Sugarcane by-products based industries in India. *Sugar Tech* 13(4): 408– 416.

SimaPro 9.0.0.49. SimaPro Faculty Temporary license. PRé Consultants bv. https://support.simapro.com/articles/Article/SimaPro-Installation/. Amersfoort, The Netherlands

Takalani, MN. 2013. Social impact assessment of sugar production operations in South Africa: a social life cycle assessment perspective. Unpublished MScEng Dissertation, Faculty of Engineering and Build Environment, The University of Johannesburg, Johannesburg, RSA.

Tyler G. 2004. *The African Sugar Industry A frustrated Success Story*. Background Report. All-Africa Review of Experiences with Commercial Agriculture. Competitive Commercial Agriculture in Sub–Saharan Africa (CCAA) Study. Centre for Environmental Policy, Imperial College London, UK.

United Nation Statistics Division Energy Statistics Database, 2016. Bagasse available in Sudan, [Internet], Available from: http://knoema.com, [Acceded March 2016].

Williams, AS. 2009. *Life Cycle Analysis: A Step by Step Approach*. ISTC Report. Illinois Sustainable Technology Centre, University of Illinois at Urbana-Champaign. USA.

White Nile sugar factory (WNSF). 2012. White Nile project, [Internet], Available from: www.foodprocessing technology.com /projects/white-Nile. Sudan, [Acceded 24 June 2017].

Wang, M, Wu, M, Huo, H and Liu, J. 2008. Life cycle energy analysis and greenhouse gas emission implications of Brazilian sugar cane production. *International Sugar Journal* 110 (1317): 527–545.

Young, CY, Ni, SP and Fan, KS. 2010. Working towards a zero-waste environment in Taiwan. *The Journal of the International Solid Wastes and Public Cleansing Association, ISWA* 28(3): 236-44.

Zhao, D and Rui Li, Y. 2015. Climate change and sugarcane production: potential impact and mitigation strategies. *International Journal of Agronomy*. http://dx.doi.org/10.1155/2015/547386.

5. APPENDICES

QUESTIONNAIRE

Dear Respondent, I am a PhD student at the *Department of Bioresources Engineering*, *University of KwaZulu-Natal*, *South Africa*. My research project is entitled as evaluation the production and environmental performances of Sudanese sugar industry. The aim of the research is to carry out a research on evaluation the impacts of waste disposals, particle pollutants and toxic gases on the community residing around the six sugar industries in Sudan. I kindly request you to response the questionnaire below. The information you provide contributes to important environment measures for Sudan. All responses will be handled confidentially only for research purposes.

Background information

(1) Gender: Male ( ) Female ( )

(2) Age: ………………………….

(3) Location……………………………………………………………………………….

(4) Education: Primary school ( ) Secondary school ( ) University ( ) Postgraduate ( )

(4) Period of residing: 0- 10 years ( ) 10-30 years ( ) 30- 50 years ( ) more than 50 years ( )

1. Family information					
No	Gender	Age	Education	occupation	Annual income (1US$ = 17,5 SDG)
1					
2					
3					
4					

5					

2. Effects of wastewater disposals resulting from sugarcane manufacturing on the populations living around the selected Factory			
	Disagree	Agree	Neutral
(a) The wastewater stream is close to where I live			
(b) The wastewater stream in running all the year			
(c) The wastewater is disposed to water body (Nile)			
(d) Wastewater contaminates water sources			
(e) The drinking water we use is crystal clear			
(f) The drinking water we use is normal tasted			
(g) The drinking water we use has no a distinctive unpleasant smell			
(h) The wastewater disposal creates swamps nearby where we live which inhabits the insects			
(i) Wastewater creates off-odors			
(j) Wastewater creates mosquitos			
(k) Wastewater creates flies			
(l) Ive experienced malaria disease several times because of the mosquitos			

3. Degree of family complaining towards:				
	High	Medium	Low	No complain
The odors of wastewater				
Mosquito				
Fly				

Suspending particles resulted from cane burning				
Suspending particles resulted from bagasse burning				

4. Effects of wastewater disposals resulting from sugarcane manufacturing on animal production		
	Yes	No
(a) Do you have a farm or work in a farm		
(b) Is there any livestock in your farm (cattle, sheep, poultry, horses)		
(c) What is the source of water for your livestock? choice from options bellow: i. Cane Irrigation canal ii. Cane drainage canal iii. Wastewater stream from the industry iv. River Nile v. Overhead tank vi. Ground water (well) vii. Natural trenches		
(d) Are there any illness cases among the animals because of water source (if it's the wastewater)?		
(e) Are there any death cases among the animals because of water source (if it's the wastewater)?		

5. Effects of wastewater disposals resulting from sugarcane manufacturing on crop production		
	Yes	No

(a) Do you have any crop plantation activity in your farm		
(b) If yes, what type of crop you used to planting 1. Vegetables 2. Cereal crop 3. Fruit trees		
(c) Do you use any kind of pre-treatment to the wastewater before you use it such as sedimentation tank?		
(d) Why did you choose to use the wastewater for irrigation? Because a) There is no other option b) It enriched with nutrients c) Low cost d) Other reasons ………………………….		
(e) According to your knowledge and experience, do you know the health risks of using the industrial wastewater for crop plantations		
(f) Were there any health problems coming from customers because of your products		
(g) If **<u>yes,</u>** what kind of health problems did you informed by them 1) Stomach ache 2) Vomiting 3) Diarrhea 4) Other reasons ………………………….		

6. Environmental effects of organic and particulate pollutants resulted from cane burning and processing on the community residing around the factory			
	Disagree	Agree	Neutral

(a) Particulates contaminate the air we breathe			
(b) Pollutants dirt the flours and clothes			
(c) There are huge smoke clouds covering the sky during the harvesting season which contaminate the air we breathing			
(d) The off-odors contaminate the air we breathe			
(e) Loud sounds coming from the factory side roil the mood			
(f) These problems were existing since the factory established but it became worth by aging of the industry			

7. Health effects of the pollutants resulted from cane burning and processing operation on the residences around the selected Factories									
Infested members in the family				The infection					
No	Gender		Age	Eye disease	Heart attach	Respiratory disease	Asthma	Chronic bronchitis	Irregular heartbeat
	Male	female							

8. Health services presented by the industry towards the community around		
	Yes	No
(a) There are rotational prevention procedures (pesticides spray) conducted by specialists' health team		
(b) There is a hospital nearby where I live		
(c) The are available medical aids in our hospital		

(d) There is enough medical team in our hospital		
(e) The available doctors are well qualified to assist		

9. Important issues should be considered			
	Disagree	Agree	Neutral
(a) Protecting the residences from endangered sugar factory's influences			
(c) Developing innovative technologies to improve the surrounding air quality such as stopping cane burning			
(d) Developing innovative technologies to enhance water quality for domestic usage such as establishing wastewater treatment plant			
(b) sufficient control to the sugar by-products and its recycling techniques			