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Improved Brewery Wastes Management Using Life Cycle Analysis

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Abstract: Brewery is a major industrial activity in Nigeria from which wastes are generated. The present global attention on effective wastes management in the sector has compelled the country to embrace aggressive research methods on this essential subject matter. This has therefore been the impetus for this study to use the Cradle-to-Grave section of Life cycle analysis in the ISO 14040 for investigation of improved wastes management in a Nigerian brewery. In the study, emissions associated with brewery were identified and quantified to determine the releases into air, water and land. Materials use, use of energy, wastes and by-products generation as well as physical size from the sector were also determined for wastes management. The study shows that intensiveness of energy and water consumption in brewery industry during productions could cause large emissions that may have negative effects on the environment. Agreement of the material inputs and outputs in the study at about 99.6% level indicates that the adopted method can be of great help in solving wastes management problems in the brewery.

Keywords: Brewery; inventory; life cycle analysis; wastes; waste management.

I. Introduction

In the food industry, the brewing sector holds a strategic economic position with annual world beer production amounted to about 1.82 billion hectoliters in 2020, up from 1.3 billion hectoliters in 1998 [1]. Brewery processes are relatively intensive users of both electrical and thermal energy as well as large volumes of water. The process often generates air emissions as well as large amounts of wastewater effluent and solid wastes that must be disposed of or treated, even though, several technological advancements in the last 20 years have provided the brewing industry large savings by lowering generation of by-products in the process. However, the most significant environmental issues associated with the operation phase of breweries include water consumption, wastewater, solid waste and by-products, energy use and emissions to air [2]. Breweries are considered as food industries because brewery uses grains as one of the raw materials [3]. Roy et al. [4] reported that food industries strongly contribute to global warming potential (GWP) and total carbon dioxide emissions because food productions require large amounts of energy, and thus, several papers aimed at identifying and lowering environmental emissions due to food productions were published, using Life Cycle Assessment (LCA)

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analysis [5]. Life cycle analysis (LCA), a "cradle-to-grave" approach for assessing industrial systems, is an internationally recognized and ISO standardized accounting methodology to quantify the environmental impacts of a product, a process or a service throughout its life cycle, by identifying, quantifying and evaluating all the resources consumed and all the emissions and wastes released. Life Cycle Assessment (LCA) is useful as an information tool for the examination of alternative future scenarios for strategic planning [6]. In this study, Life Cycle Assessment (LCA) was carried out to identify wastes produced within the brewery and the processes through which they are generated; recommend methods of waste reduction for the substation; and identify/develop effective waste management practices.

A major source of pollution in developing countries is industrial activities and this has gradually increased the problem of waste disposal [7]. Increased industrial activities have led to pollutional stress on surface water both from industrial, agricultural and domestic sources [8]. However, the quantity of waste discharge from industries depends on the activities and usage of water. Breweries for example are known to consume water of about 4 to 8 cubic meters per cubic meter of beer produced [9]. Inefficient or unsatisfactory waste or effluent management has led to environmental pollution, depletion, global warming, deforestation, shoreline erosion or degradation of natural ecosystems and upon this, many potential pollutants have found their way into ground and surface waters causing harm to the environment, and also, to man, plants and animals. Industries such as breweries that uses large amount of water for processing have the potential to pollute waterways through the discharge of their effluents into streams and rivers or by run off's and seepage of stored wastes into nearby water resources [10]. Brewery plants have been known to cause pollution by discharging effluents into receiving stream, ground water and soil [9]. Brewery effluents comprise of waste water from washing bottles, water treatment plant, carbon dioxide generating plant, bottling and production hall and general waste water from domestic washing; they can be variable in quality and composition. The pollution discharge from brewery plants effluents come from the losses in beer production process and the cleaning-place (CIP) system located in the brewing house, cellar house and bottling house.

Ram and Sharma [11] reported that the environmental performance of products and processes are so important some companies are investigating ways to minimize their effects on the environment. Many companies have found it advantageous to explore ways of moving beyond compliance using pollution prevention strategies and environmental management systems to improve their environmental performance, such companies are breweries, and Life Cycle Analysis is a useful information tool amenable for the examination of alternative future scenarios for strategic planning to manage waste efficiently. This study was carried out to identify wastes produced within the brewery and the processes through which they are generated; recommend methods of waste reduction for the sector; and identify/develop effective waste management practices. This is to confirm the effectiveness of life cycle analysis or otherwise in wastes management of the brewery sector.

II. Materials and Methods

Two steps employed in this study were a preliminary interview with the staff and the brewery visit for information collection on the size, layout, location, processes, and current waste management practices. This was to evaluate the operation, verify the information collected in the interview, and identify waste reduction opportunities. Questionnaire was purposely administered to gather some sensitive consumption data required in the preparation of a material balance to determine the level of agreement between the inputs and outputs so as to confirm the effectiveness of this cradle-to-grave in wastes management. The ISO 14040 [12], a basic requirements of ISO 14000 [13] on the principles and framework of life cycle assessment was used in the Life Cycle Analysis of the brewery. Though four steps are required in a comprehensive life cycle assessment (Figure 1), step two i.e. the life cycle inventory analysis which is required for materials movement monitoring was the focus. It involves identifying and quantifying emissions to air, releases to water, releases to land, use of materials, use of energy, wastes and by-products generation, and physical size. The basic steps recommended in ISO 14049 [14] in goal and scope definition and inventory analysis of the research (Figure 2) were strictly followed in strategy development for the study.

For inventory analysis, the major inputs and outputs of each of the unit operations involved need to be determined as recommended in ISO 14049 (Figure 3). The method involves identification of unit operations, construction of process flow diagrams of essential parts, determination of material inputs, quantification of process outputs, accounting for wastes (solids, liquid, and gas), assembling input and output information for unit operations, and drawing of material balance. This is an approved strategy supported in studies of this nature [15, 16].

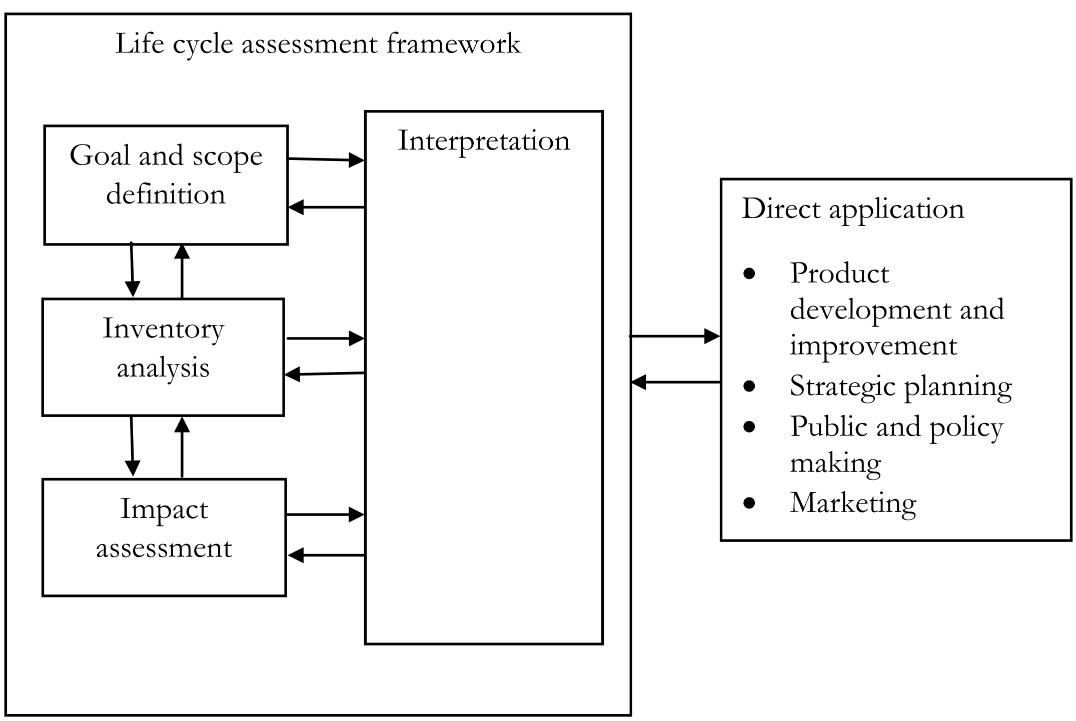

Figure 1: Generic Steps of Life Cycle Assessment

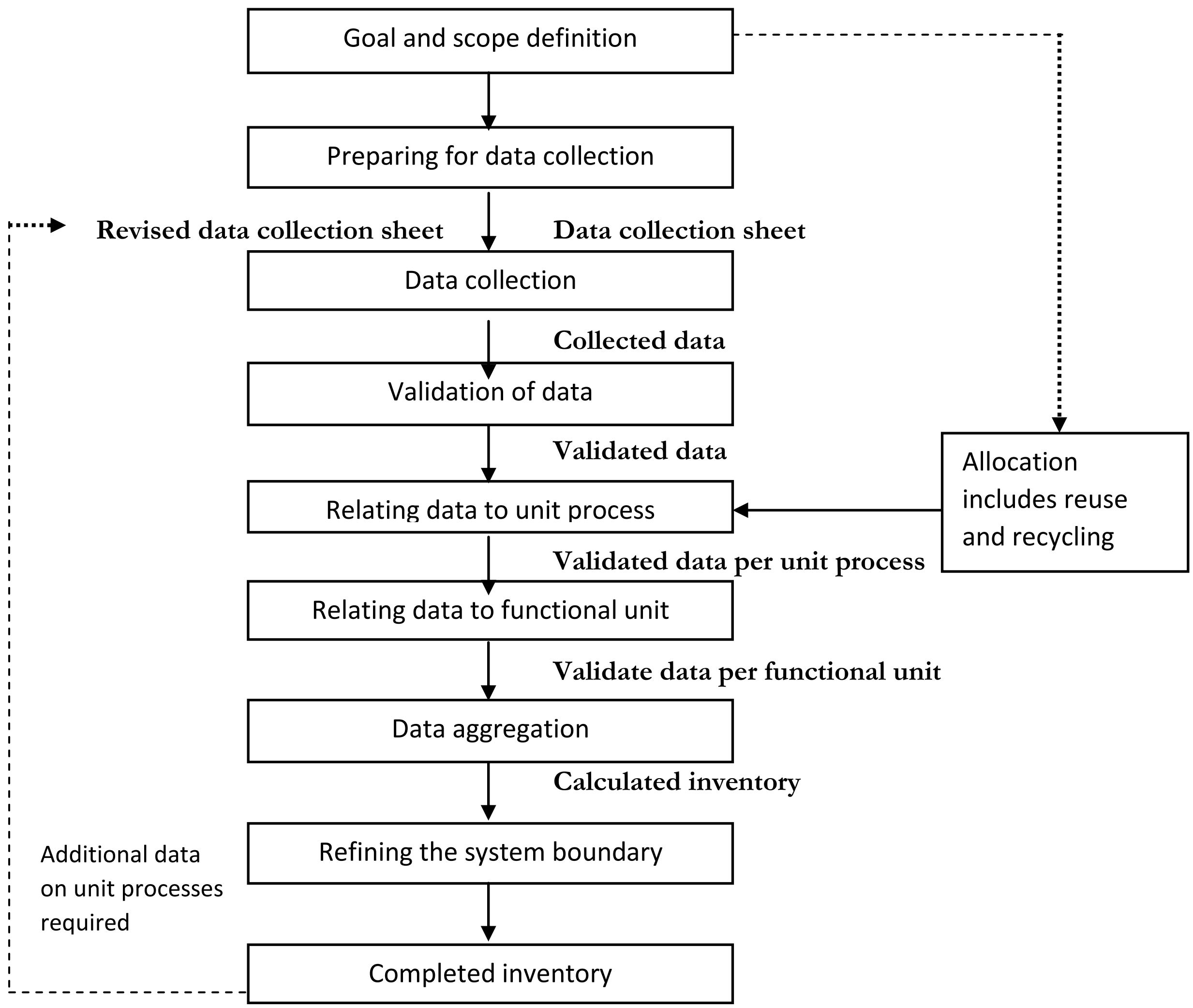

Figure 2: Simplified Procedures for Inventory Analysis – ISO

III. Results and Discussion

To achieve easy tracking to realize the main objective of this study, the results are presented for consideration in form of inputs and outputs.

A. Inputs Determination

Raw materials of different forms are required in addition to large volume of water and huge amount of energy demanded by brewing operations. Each of these was identified and quantified in this study for the purpose of material balance development of the brewery activities.

Water Supply and Usage: Water is obtained from different sources in the brewery and it is consumed at different points. It is made available in the brewery through four boreholes located within the brewery premises. Since the product nature requires water of high quality especially in production, water is treated to expected standard either as process liquor or de-aerated liquor. There are water reservoirs which are made of two surface tanks from which raw water is sent to the various consumption points after treatment. Each of these tanks is of 750,000 litres.

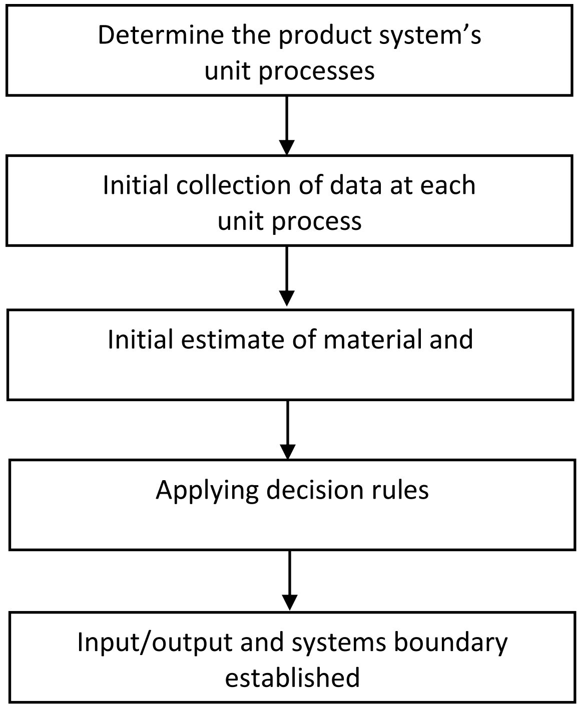

Figure 3: Inputs, Outputs and System Boundaries – ISO 14049

The identified water consumption points in the brewery include: toilets and bathrooms for domestic purposes; laboratory; production halls for brewing; packaging halls for washing and pasteurizing; boiler for steam generation and usually for make-up; fire/safety purpose and cooling system of the generators and steam boilers; and for gardening. On the average, the water consumption rate in the brewery is about 101,250 m^3/month (Table 1) which is equivalent of 101,250 tons/month. Brewing and packaging processes consume

Table 1: Typical Monthly Water Consumption Rate in the Brewery

Month	Consumption (m^3)
January	88000
February	81000
March	99000
April	100000
May	123000
June	110000
July	101000
August	133000
September	57000
October	82000
November	141000
December	100000

than any process in brewery industry. The higher the production, the more the water consumed.

Process Raw Materials Inputs: The other ingredients required in addition to water in the brewery depend on the targeted products and this is a function of the adopted standard recipe. They may include maize, sorghum, sugar, malt extract, sorghum extract, enzymes, hops and some additives. As summarized in Table 2, the average monthly consumption rate of these in the brewery for a typical month is about 1960.49 tons.

Packaging Materials: In the brewery, the packaging materials in use include bottles which come in different forms according to the various brands of the finished products, cans, labels, crowns, crates and glues. In addition to these are Acid Tolerance Response (ATR) acid and caustic soda (used for cleaning purposes) with an average monthly consumption rates of about 1.5 tons, 2.5 tons, and 33.7 tons respectively.

Table 2: Typical Materials Consumption Rates in Brewery (Source: This study)

S/No	Materials	Consumption (ton/month)
1.	Raw Sorghum	49.74
2.	Maize	171.94
3.	Barley Malt	1032.78
4.	Malted Sorghum	322.79
5.	Sugar	368.38
6.	Hops	2.27
7.	CDM	12.59

Compressed Air: Compressed air is supplied from about four compressors with an average supplying rate of about 18.3 m^3/min. Its major points of consumption in the brewery include the brewing section, packaging hall and the engineering section where it is used for the control of hydraulic valves and other allied functions. Using a 20-working days per month with the density of air taken to be 1.293 kg/m^3 at standard temperature and pressure, the compressed air consumption on the average in the brewery would be about 681.5 ton/month.

Lubricating Oil: For effective performance of the electric power generators, lubricating oil is required. The monthly lubricating oil consumption for this purpose is about 35 litres of lubricating oil which is 34.7 kg/month using 991 kg/m^3 lubricating oil density.

Energy/Fuel Supply and Consumption: Energy consumption in the brewery is in form of electricity and fuel. While electricity is generated by the generators, fuel is used for this purpose. In addition to this is steam being generated in the steam boiler where fuel is also used for this purpose. Private generation through electric power generators is the only source of power to the brewery since the brewery is not connected to the national grid. It is used for compressed air generation, steam generation, water generation, and refrigeration, among others. Typical monthly consumption is about 1,504,022 kw/hr of electricity (Table 3). For the private electric power generation in the brewery, there are eight electric generators and these all use diesel (AGO). The monthly rate of AGO consumption by the generators is a function of the hour of operation. On the average, it is about 776,496.5 litres per month (Table 4). This is equivalent to 694.18 tons per month using the AGO density of 894 kg/m^3.

Table 3: Monthly Electricity Consumption Rate in the Brewery

Month	Consumption (kwhr)
January	1402000
February	1300000
March	1400000
April	1455000
May	1590000
June	1300000
July	1400000
August	1480000
September	666700
October	1550000
November	1800000
December	1850000

Steam Generation in Steam Boilers: There are four Natural Gas and AGO (Automobile gas oil) fuel-fired burners boilers for steam generation in the brewery with two being used at a time, depending on steam requirements. The points of steam consumption include packaging halls where it is required for washing and pasteurizing and in the brewing house for heating purposes. From the steam supply rate of about 10 tons/hr in the brewery, a 480 working-hour per month gave estimated average steam consumption from the boilers to be about 9,600 tons/month while about 564125.6 Nm^3 and 2201 litres of natural gas and AGO respectively were the typical monthly fuel consumption (Table 5).

Table 4: Monthly AGO Consumption for Electricity Generation in the Brewery

Month	Consumption (kwhr)
January	762018
February	790383
March	824739
April	806115
May	896398
June	721986
July	722456
August	696054
Septemebr	744917
October	752154
November	756217
December	844521

Table 5: Typical Fuel Consumption in the Brewery by Boilers for Steam Generation

Months	Consumption	
	Natural Gas (Nm^3)	AGO (Litres)
Jan	592211.24	0
Feb	628932.5	0
Mar	662446	0
Apr	613970.64	0
May	755966.11	0
Jun	539966	0
Jul	423212.79	10216
Aug	501557.72	6765
Sep	541104.14	0
Oct	502400.49	0
Nov	502400.49	7550
Dec	505339.62	1881
Mean	592211.24	0

This average fuel consumption is equivalent to about 379.6 tons/month and 1.97 tons/month using the fuel density of 0.673 kg/m^3 and 894 kg/m^3 for natural gas and AGO respectively.

B. Determination of Outputs

Both the finished products and waste materials outputs from the brewery are solid, liquid and gaseous emissions (Figure 4). Using the data obtained during the study, the outputs for the period under considerations are presented for consideration in this subsection.

Solid Wastes: Solid wastes generated in the brewery are mainly from the various solid raw materials used in brewing and packaging. The silos dust solid wastes in the brewery is about 0.03 tons/month (Table 6). From the mash filter, spent grains monthly generation is 2.99 tons. However, these are not allowed into the drain but sold out to buyers who take them out of the brewery just like the kiesselguhr generated from products clarification which is about 0.56 tons/month. The surplus yeast in form of solid wastes is 0.89 tons/month. In the

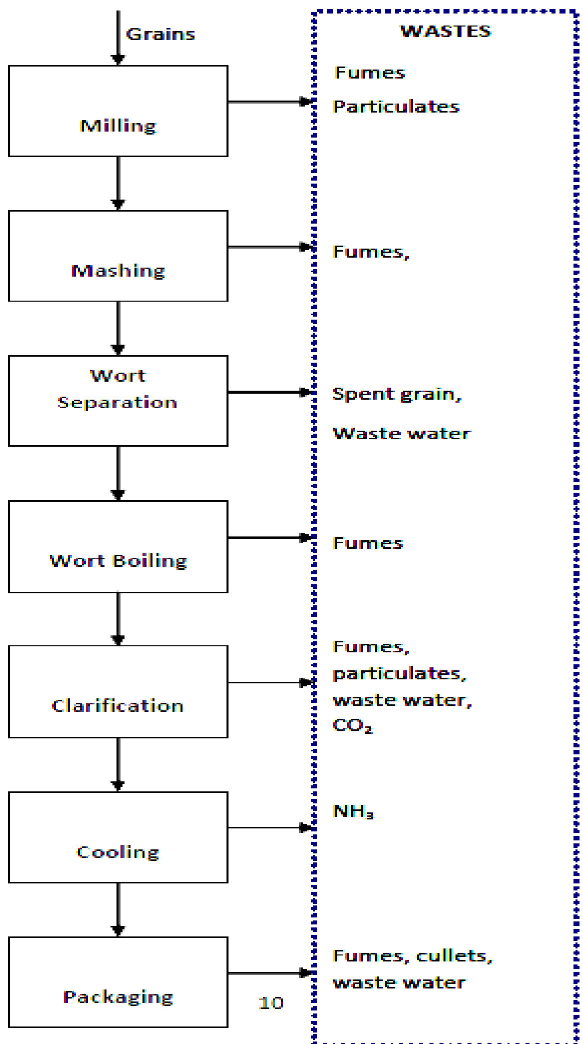

Figure 4: Unit Operations Involved in Brewing Process.

Table 6: Typical Monthly Process Solid Wastes Generation in the Brewery

Month	Generation (tons/month)			
	Silos Dust	Spent Grains	Surplus Yeast	Waste Kieselguhr
January	0.05	2.55	1.47	0.02
February	0.03	3.03	1.45	0.00
March	0.04	3.65	1.82	0.00
April	0.03	3.36	1.48	0.00
May	0.04	3.33	1.71	0.00
June	0.02	2.43	0.15	0.84
July	0.04	2.76	0.12	0.89
August	0.04	2.57	0.27	0.90
September	0.04	2.54	0.37	0.83
October	0.02	3.06	0.44	1.01
November	0.02	3.03	0.68	0.91
December	0.02	3.56	0.69	1.31

packaging section, broken bottles (culets) are generated as solid wastes. It occurs during bottles' movement on the conveyor in palletizing, de-palletizing, crating and de-crating. The packaging section has proper record of these broken bottles and their movement outside the brewery. They are being sold to contractors who take them out possibly for recycling by glass manufacturing industries thus making them to be by-products. During the research exercise available record showed that the average monthly generation culets in the brewery is 1.29 tons which come in green, mixed or amber (Table 6). Other solid wastes in the brewery include: crown cork, cartons, paper trays, glue buckets, lubricant drums, oxonia keg, acid keg, empty caustic sacks, damaged and foreign pallets. While the bailed cartons are about 0.02 tons/month, the damaged crates are about 0.09 tons/month with the damaged pallets and metal scraps monthly generation rates in the brewery being 0.28 tons and 0.03 tons respectively (Table 7).

Liquid Wastes: Liquid wastes in the brewery include: water, used oil, beer and malt drink. The wastewater comes from domestic, brewing and packaging operations. In brewing, one of the major sources of waste water is line sterilizing. During this process, about 15 hl/brew is used and this is discharged into the drain through the effluent treatment plant (ETP). In the packaging section, a lot of water is used for washing and this is finally sent to the drain after the recovery of used chemicals in the

ETP. The brewery has effluent treatment plant thus only pre-treated water is discharged. Using an absorbed water in spent grain of about 0.84 l/kg [17], about 1664.2 m^3/month (1664.2 ton equivalent) of water was estimated to be trapped in the spent grains. Used oil is generated both in the boiler and electric generators with a rate of about 0.03 tons/month which is usually sent as boiler fuel supplement. Lastly, due to breakage of filled bottles in the packaging section, there are liquid wastes in form of beer and malt drink but the quantity could not be ascertained.

Table 7: Monthly Packaging Solid Wastes Generation in the Brewery for the Period

Month	Generation (tons/month)						
	Paper and Cardboard (Bailed Cartons)	Plastic (Damaged Crates and others)	Damaged Pallets (wood)	Metal Scraps	Glass Culets		
					Green	Mixed	Amber
January	0.00	0.01	0.17	0.01	0.16	0.00	0.00
February	0.00	0.00	0.15	0.03	0.00	0.28	0.00
March	0.01	0.00	0.11	0.00	0.00	0.11	0.00
April	0.01	0.00	0.08	0.00	0.00	0.32	0.00
May	0.01	0.00	0.12	0.02	0.00	0.33	0.00
June	0.00	0.00	0.15	0.04	0.00	0.21	0.00
July	0.01	0.00	0.17	0.02	0.00	0.00	0.28
August	0.01	0.01	0.18	0.02	0.00	0.25	0.00
September	0.01	0.01	0.22	0.01	0.00	0.31	0.00
October	0.01	0.00	0.14	0.01	0.00	0.26	0.00
November	0.01	0.14	0.16	0.02	1.39	0.34	0.00
December	0.01	0.22	0.21	0.01	0.59	0.35	0.00

Liquid Products: Products from the brewery come out in liquid. About 109333.3 hl of these products are produced in the brewery per month (Table 8). Using the average beer density of about 1020 kg/m^3, the average monthly production in the brewery translates to about 11,152 tons.

Air Emissions: Air emissions analyzed from the brewery were generated from the fermentation process, bottling line and fuel combustion in the boiler for steam generation, electric power generators, and forklifts driven around in the brewery for movements of raw materials, finished products, and wastes. Operations of electric power plants, boilers and forklifts are known to result in emissions of gaseous pollutants which include nitrogen oxides (NO_X), sulphur dioxide (SO_2), carbon

Table 8: Monthly Production in the Brewery for the Period Under Consideration

Month	Production (hl)
January	115000
February	91000
March	110000
April	121000
May	148000
June	101000
July	112000
August	122000
Septemebr	43000
October	108000
November	122000
December	119000

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dioxide (CO_2), carbon monoxide (CO), volatile organic compounds (VOCs) and particulates [18]. The particulates may contain mercury, Hg and carbon among other elements, depending on the type of fuel (natural gas, diesel, etc.) employed in firing the equipment. Emissions from the electric power plants and boilers go directly into the immediate environment through their stacks and are transported through plumes in the atmosphere to several kilometers away from the point of generation. Thus, apart from emission monitoring from stack of these equipment, it is always being recommended that emission modeling be carried out [19]. While the measurements will allow combustion efficiency determination, emission modeling will assist in recommending mitigation measures for perceived environmental problems. From the average monthly consumption of 379.6 tons/month of natural gas in the brewery, about 3.67 tons/month of air pollutants and 974.71 tons/month of CO_2 are anticipated. Similarly, from the monthly 694.18 tons AGO consumption in the electric power generators and its 1.97 tons consumption in the steam boilers, about 1012.58 tons/month of air pollutants and 26441.04 tons/month of CO_2 are anticipated (Table 9). These were arrived at using the AP-42 Emission Factors [20] for natural gas and AGO. Proper maintenance of equipment and operation at manufacturer's condition could help to reduce air pollution levels from these sources in the brewery. Though there is a high possibility of NH_3 emission from the brewery, the necessary control measures put in place are good enough to prevent such.

Table 9: Estimated Emissions from Fuel Consumption in the Brewery

Parameters	Emission (tons/month)	
	From Natural Gas	From AGO
NO_X	2.84	708.81
CO	0.03	151.89
SO_2	0.72	44.30
PM_{10}	0.06	50.63
CO_2	974.71	26441.04
VOCs	0.02	56.96
Total	**978.38**	**27453.62**

C. Life Cycle Inventory Analysis Material Balance Summary

Table 10 summarizes the Life cycle inventory main material, water, and energy consumption, yields, as well as waste production, relative to the operation of the brewery under study. Analysing the table 9, we may notice that in terms of raw material used, barley malt is the most consumed, 1032.8 ton/month followed by Kiesselguhr, 378.9 ton/month. The least consumed raw material is hops, 2.3 ton/month. This is understandable as hops is not a major raw material needed in the brewery, it is just being used to add characteristic bitterness to the beer. Beer and malt, 11152 ton/month are the major products of the brewery analysed. In the inventory analysis of air emissions, carbon dioxide CO_2, 27415.75 ton/month is the largest component, followed by oxides of nitrogen, NO_x, 711.65 ton/month. The least in the emitted air is sulphur dioxide SO_2, 45.02 ton/month. The result obtained in this work is not in agreement with [21] where they obtained 12,363.09 ton/month of CO_2 in one of the breweries they studied. Although.[21] only quantifying CO_2 emissions from the fermentation process of brewing beer and CO_2 emissions from breweries' coal-based electricity usage but in this study, air emissions from the brewery's fermentation process, bottling line and fuel combustion in the boiler for steam generation, electric power generators, and forklifts were considered. The result of CO_2 emissions shows that the Green House Gas emissions associated to brewery are significantly contributing to the Earth global warming.

One of the most significant waste products of brewery operations is Wastewater [2]. Even though substantial technological improvements have been made in the past, [22] estimated that approximately 3-10 L of waste effluent is generated per liter of beer produced in breweries, mostly for the brewing, rinsing, and cooling processes. During the investigation,

Table 10: Life Cycle Inventory Analysis Summary for Nigerian Brweries Plc., Lagos Brewery

Input			**Output**		
Item	Quantity	Unit	Item	Quantity	Unit
Raw Materials			**Products**		
Maize	171.9	ton/month	Beer + Malt	11152.00	ton/month
Raw Sorghum	49.7	ton/month	Bottles	5100.87	ton/month
Hops	2.3	ton/month	Labels	15.90	ton/month
Sugar	368.4	ton/month	Crown	65.7	ton/month
Barley Malt	1032.8	ton/month	Cans	2164.4	ton/month
Malted Sorghum	322.8	ton/month	Sub Total	**18498.87**	**ton/month**
Kiesselguhr	379.8	ton/month			
Enzyme	89.0	ton/month	**Air Emissions**		
Additives	12.6		Oxides of nitrogen(NO_X)	711.65	ton/month
Sub Total	**2429.3**	**ton/month**	Carbon monoxide (CO)	151.92	ton/month
			Sulphur dioxide (SO_2)	45.02	ton/month
Packaging Materials			Particulate matter (PM)	50.69	ton/month
Chemicals	37.7	ton/month	Carbon dioxide (CO_2)	27415.75	ton/month
Bottles	5101.3	ton/month	Vol org compds. (VOCs)	56.98	ton/month
Labels	16.10	ton/month	**Sub Total**	**28432.01**	
Glue	7.59	ton/month			
Cans	2186.26	ton/month	**Liquid Wastes**		
Crown	66.39	ton/month			
Sub Total	**7415.34**	**ton/month**	Waste Water	65812.50	ton/month
			Used Oil	0.03	ton/month
Water. Fuel and Air			**Sub Total**	**65812.53**	**ton/month**
Water	101250.0	ton/month			
Air	681.5	ton/month	**Solid Wastes**		
Lubric oil	0.03	ton/month	Silos Dust	0.03	ton/month
Natural Gas	694.18	ton/month	Spent Grains	2.99	ton/month
AGO	696.15	ton/month	Surplus Yeast	0.89	ton/month
CO_2	16.60	ton/month	Kieselguhr	0.56	ton/month
Sub Total	**103338.46**	**ton/month**	Bailed Cartons	0.01	ton/month
			Damaged Crates	0.03	ton/month
			Damaged Pallets	0.16	ton/month
			Metal Scraps	0.02	ton/month
			Culets	0.43	ton/month
			Sub Total	**5.12**	**ton/month**
Total	**113183.1**	**ton/month**	**Total**	**112748.5**	**ton/month**

all the waste flows from all the units were investigated. From table 9, it is shown that 65,812.50 ton/month of waste water is generated. Amount of waste oil is insignificantly small, 0.03 ton/month. Brewery is one of the major industries with the highest water consumption. [23] reported that the rate of consumption of water during the brewing process is correlated to the effluent ratio, which is the amount of wastewater generated per production. This is evidenced in the result obtained with large amount of waste water generated. According to [2], solid waste from brewery consists of organic material residuals from the process including spent grains and hops, trub, sludge, surplus yeast, diatomaceous earth slurry from filtration (Kieselguhr sludge), and packing materials. However, Priest and Stewart [24] observed that this solid waste is inherent to beer production and hardly had their quantities formed reduced. In Lima [25], it was reported that spent grain accounts for 85% of the total waste generated from brewing process. Spent grains have the largest amount of 2.99 ton/month as shown in table 9. This value accounts for about 69.0% of the process waste, not in total agreement with the report of Lima [25]. From the breakdown of both inputs and outputs in the operation of Brewery, the material balance obtained is as summarized in Table 10. Agreement of materials input of **113183.1** ton/month and output of **112748.5** ton/month to about 99.6% indicates a very good material record keeping in the brewery.

IV. Conclusion

Information obtained from the brewery during the assessment exercise showed that there is a proper record keeping of chemical and material usage. The 99.8% level of agreement between these inputs materials and outputs materials supports this assertion. It also shows an improvement on the last research level of 97.8% agreement. It is however recommended that the brewery should work towards converting its AGO electric power generators to natural gas electric power generators to reduce air emissions into its operating environment.

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