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(RESEARCH ARTICLE)

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Life cycle assessment of the environmental impacts of beer production process

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Abstract

In this study, significant environmental impacts of beer production process were established throughout its life cycle it is necessary to characterize all beer production operations; to carry out an inventory of inputs and outputs in every process; to evaluate possible human and ecological effects resulting from environmental emissions; and to define possible improvement potential. There are four major significant environmental impact categories; first ecotoxicity due to pollutants emitted with environmental score of 9.1762E-6 which was equivalent to 28.16%. It included impacts from marine aquatic which was the greater contributor to total ecotoxicity accounting for 74.12%, followed by terrestrial ecotoxicity with 23.5% and fresh water ecotoxicity which was least contributor with 2.3%, the major cause was burning fossil fuels for steam production and release of inadequately treated wastewater. Second was depletion of fossil fuels with environmental score of 6.8923E-6 equivalent to 21.15%. It was mainly due high consumption of natural gas, lubricating oils and diesels for machines and distribution trucks. Third major impact category was global warming with environmental score of 4.9001E-6 equivalent to 15.02% where the major flow contributor was carbon dioxide accounting 91% of total impact and the major causes were gaseous pollutants and heat released during energy production and transportation activities. The fourth significant impact category was human toxicity with environmental impact score of 4.6208E-6 which accounts for 14.18% of total environmental impacts. Its major flow contributor was dioxins making up 51%. The main causes were pollutant from burning fossil fuels in trucks and energy production and use of harmful chemicals.

Keywords: Life Cycle Assessment; Beer Production; Environmental Impacts; Ecotoxicity; Fossil Fuel Depletion; Global Warming; Human Toxicity; Particulate Matter

1. Introduction

Despite of the economic benefits of beer, the production process has environmental and health problems. The environmental impact included water shortage, global warming, Eco toxicity, acidification, human toxicity and depletion of abiotic resources. Beer production process requires large quantities of water. Also, in the same way effluent to beer ratio is correlated in beer production process. High water consumption can lead to insufficient water supply in the communities and also aquatic organism in water bodies. Effluent from brewery contain high Biochemical Oxygen Demand (BOD) of densities (7000 mg/l) and (15,000 mg/l) Chemical Oxygen Demand (COD), the organic content (example beer spills), nutrients (example $N\text{-}NH_3$) in effluent that could cause eutrophication potential, in water bodies causing death of aquatic species due to lack of dissolved oxygen. A simple act of brewery hygiene activities in effect could cause of environmental pollution fluctuations chemicals and pH in water bodies. Breweries have high energy consumption, example a well operated brewery can consume 8-12 kwh/hl of electricity to run machines and average of 158MJ /*hL* of natural gas Combustion of fossil fuels lead to greenhouse gas emissions hence global warming, depletion of natural resources and acidification of soil and water bodies. Also, industrial solid wastes produced like waste yeast

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and kieselguhr that if not properly managed can produce odors/nuisance also attract disease causing microbes and vectors that could cause health problems (Sjölander-Lindqvist et al., 2020; De Marco et.al. 2016; Abimbol, 2015).

The quantification of the contribution of beer industries to environmental impacts is a good approach to manage the environment. Life Cycle Assessment (LCA) is defined as an environmental management tool that can be used for the analysis of potential environmental impacts of a product system and offer measures towards the improvement of product system's environmental impacts. LCA tool gives a holistic picture of environmental impacts that may be associated with the product or process in question and offer a more realistic picture of the actual environmental balances in the choices of product and process. Many studies and reports done in Africa stating impacts of beer industries reflect only qualitative information. There is no study done in Tanzania which shows the extent in quantities of environmental performance on breweries, so one should be done to provide baseline information. Environmental impacts can be direct and some can be in direct, but all come from single activity or product. So, there was a need for a close follow up on the progress of our beer industries and other industries as well so as to ensure that development in a manner that considers sustainability of our ecosystem, people, resources for present and future generations (Benoît *et al.*, 2010).

In essence, beer production contributes a lot to economy through taxes and employment opportunities, but despite the benefits it provides, production of beer has been reported to contribute environmental problems. The environmental impacts associated with beer production process include global warming, ecotoxicity, human toxicity, photochemical smog, acidification, ozone layer depletion and depletion of fossil fuels. In many developed countries like Germany and Italy LCA tool is extensively used providing environmental pollution shares of breweries, (Olajire, 2020). But in Tanzania there was no research done to quantify environmental impacts emanated from beer production industries. Hence, in this this article a life cycle assessment tool is used to quantify the environmental impacts of beer production process, suggest potential mitigation measures and ultimately proving base line data future researches.

2. Literature Review

The framework for the stages involved in the beer production is presented in Figure 1. Beer production industry is noted to be among the largest consumers of water by the industrial sector. Despite numerous improvements that have taken place over the last two decades in technology, Olajire, (2020) confirms from his study that water and wastewater have remained some of the most critical environmental issues affecting the brewing industry elderly and energy consumption as well as solid wastes and by-products, and emission to air also remain other concerns of this industry. Energy consumption in the breweries is mainly two sources of energy thermal for fossil fuels and electrical from grid. Cooling system is commonly observed as the largest individual user of electricity, then brewing area and packing area. In case of thermal energy, it is applied in the production of steam in boilers primarily utilized in the process of wort boiling and water evaporation in the brew house and packaging hall. A standard operated brewery uses 8 to15 kWh of electricity and 150MJ of natural gas for one hectoliter of beer.

As a result of scarcity of fossil fuels, Amienyo, & Azapagic, (2016) affirm that the demand for energy rise in the world with its accumulation of greenhouse gases, photochemical oxidation and acidification lead to more harm in the environment. It is used largely due to its importance as one of the major constituents of beer and the fact that it constitutes 90 to 95% of beer by weight Water is used in the production of beer in almost every process, a proficient brewery shall use between 4 and 7 liters of water to produce one liter of beer. Thus, depending on the production and efficiency of water use, the amount of brewery wastewater will be affected. Pollutant load or composition of the brewery effluent, the organic content, the projected nutrient content including phosphorus, nitrate, and wear on machines especially conveyors on the packaging line, the nickel and chromium. Inefficient waste water may lead to eutrophication or even Eco toxicity. Brewery solid waste are those waste products produced by breweries in the brewing process and they include; spent brewing grains, spent hops, trub, solid sewage, waste yeast, diatomaceous earth slurry used in filtration process also known as Kieselguhr sludge and packing materials, (Amienyo, & Azapagic,. 2016). Most of the waste are organic, so if they are not treated before or recycled or disposed in a proper manner, they can cause methane emissions that contribute to greenhouse gases, when allowed to enter water bodies can cause eutrophication.

The key environmental impact of beer production stages can be described as shown in Fig. 2. It is worthwhile to know that these hazardous indicators contribute differently to the environment and they have several and varying impact on the environment depending on the deposition rate of effluents and other waste materials from the site of production.

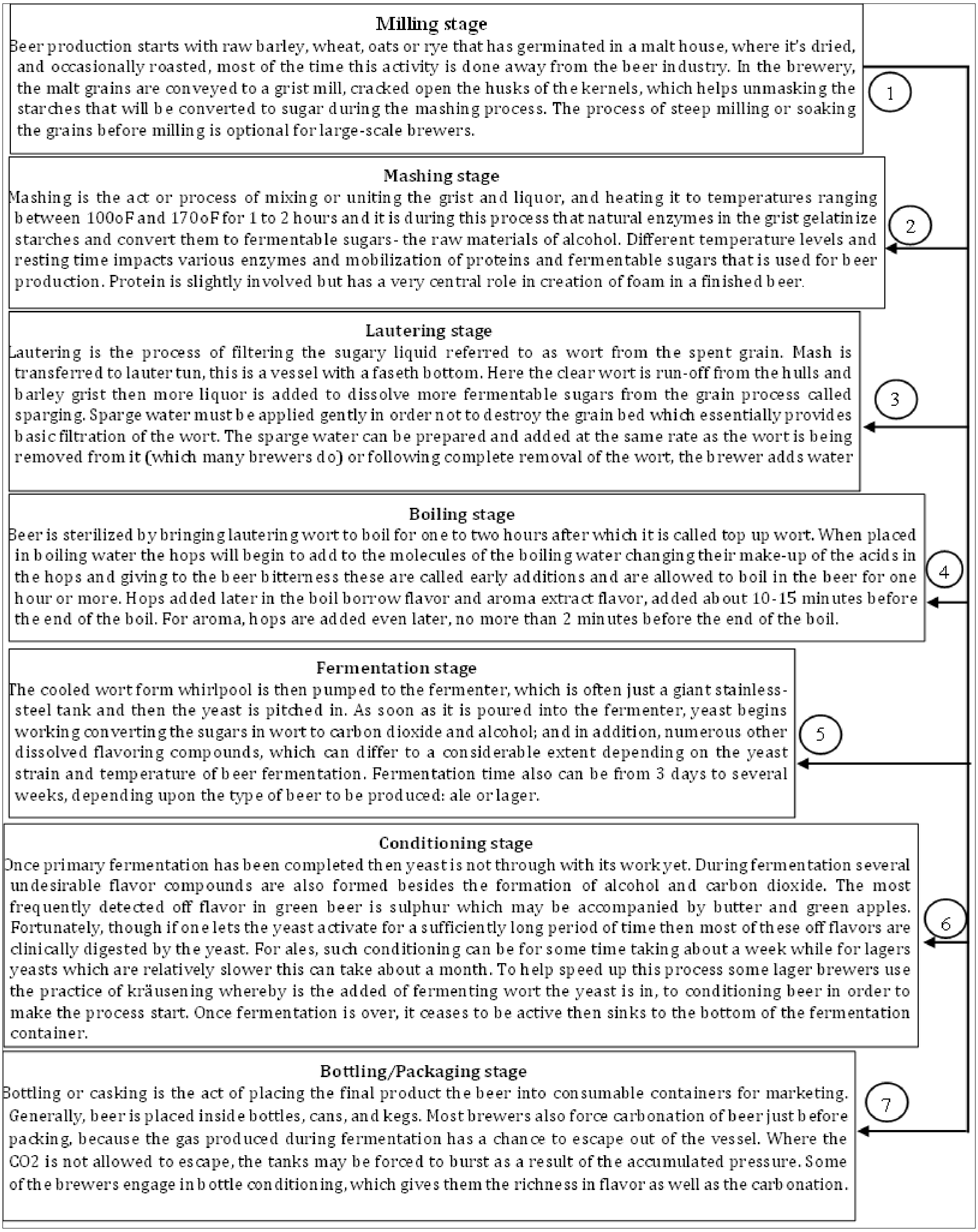

Figure 1 Beer Production process

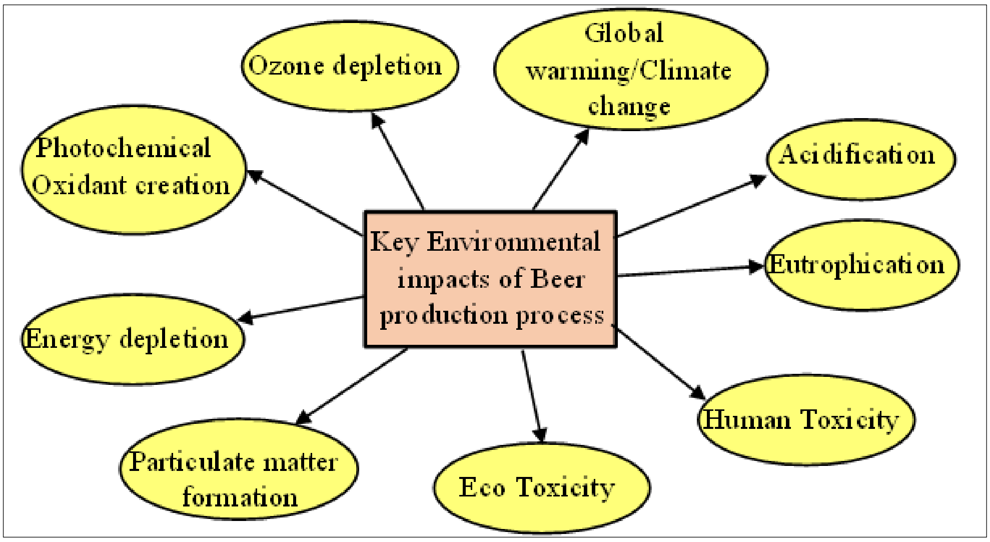

Figure 2 Environmental Impacts of beer production process

The global warming and climate change is the over exposure of the global surface temperature provoked by the heat trapped by the greenhouse effect through release of the greenhouse gases which include Carbon dioxide, Methane, carbon monoxide, Nitrogen dioxide and sulfur dioxide through human activities. This may lead to disruption of climate, increase in desertification, increase in sea levels and diseases prevalent in the region. The characterization of Environmental Profiles is based on factors created by Intergovernmental Panel on Climate Change of the UN (Aitor et al., 2016). Also, the acidification refers to acid deposition onto soil and into water depending on local conditions leading to changes in the degree of acidity affecting flora and fauna. Acidification Potentials (APs) represent the weighted measure of contribution acidification by the different environmental impacts. It's represented by kilograms of Sulphur equivalents per kilogram of emission of Sulphur oxides, nitrogen oxides and Ammonia gases that could form acids by release of H^+ ions and leaching of the corresponding anions from the concerned system. Acidification led to disruption of ecosystem function by enhancing unfavorable living conditions for organism in land and water.

Further, eutrophication refers to build-up concentration of chemical nutrients such as Nitrates and Phosphates (from to air, water and soil) leading to enrichment of an ecosystem that causes excessive plant growth like algae in freshwater bodies which causes severe reductions in water quality and animal populations. The nitrification potential (NP) is determined according to the stoichiometric of the following generic equation while the eutrophication Potential (EP) is expressed in terms of reference unit as kg PO43- and it is expressed as kg PO4 equivalents/ kg emission. Fate and exposure are not considered, timespans for these events are infinity, and geographical scale ranges from local to continental. The Human Toxicity Potential (HTP) is described as the toxicity exhibit by a chemical or substance in air, water or soil to adverse impact humans. It's an arithmetic index of risk, which quantifies the possible danger of one unit of the chemical to the human population. And it's the sum of the compound's toxicity and the quantity and dosage with the use of 1, 4-dichlorobenzene as a reference. Eco toxicity is divided further into Aquatic Eco toxicity and the terrestrial toxicity which is specialized for water and soil respectively. In fact, there is no definite method of measuring the aquatic Eco toxicity of a substance, as there are many diverse ways to do so. In effect, certain aquatic organisms are treated with a certain concentration of the chemical at different intervals. Example one is conducted with fish and a substance is exposed with the fish for 96 hours and an LC50 value is amounted – the concentration of the substance that kills 50 percent of the fish (LC=lethal concentration). Assessment of toxicological influence of substances on the ecosystem was done with the use of Maximum Tolerable Concentrations (Aitor *et al.*, 2016).

Photo-oxidant formation is the generation of chemical species, which are predicted to have negative impacts on the health of human beings, animals and crops besides affecting the ecosystem through the creation of injurious substances mainly ozone. This problem is also indicated with 'summer smog'. Winter smog is excluded from this category. POCP for emission of substances to air is determined with the help of the UNECE Trajectory model that takes into account the substances' fate, and is stated in kg of ethylene equivalent per kg of emitted substance. The time frame is 5 days while the areal extent ranges from local to continental. This refers to the reactions of NOx with volatile organic substances in the atmosphere under the influence of ultra violet light causing smog. Photochemical Oxidant Creation Potential (POCP) is defined and used to describe the photochemical oxidant creation of the different substances. Also, the ozone depletion is caused by ozone-depleting gases such as CFCs, halons and HCFCs which damage the ozone layer decreasing its ability to prevent ultraviolet (UV) light incoming the earth's atmosphere. This in turn raises the exposure received by the earth's surface to Ultra violet B rays which are carcinogenic. The characterization model has been developed by the World Meteorological Organization and states the ozone depletion potential in terms of a derived unit measuring the potential of a specific gas compared to the baseline gas chlorofluorocarbon-11 (CFC-11) in kilograms of CFC-11 equivalent.

Despite the fact that energy efficiency and an increased share of RE are considered as elements that can help limit climate changes, it is still impossible to mention definite proof that the transition to the bio-mass production has a positive mitigating effect. The global concern is that the available energy resources will soon be depleted While on the same note, the earth's atmosphere has a threshold limit of absorbing Greenhouse gases, anything beyond will push the effects of climate change beyond the manageable levels (IPCC, 2007). Due to this reason, the remaining energy resources should be carefully used and the blame of continuing with the development of new energy resources and also proper utilization of renewable sources of energy should be taken up. Particulate Matter therefore means the suspension in the air of particles that are very small in size. The ''Particulate matter formation (PM)'' estimate is expressed in PM10 equivalents, i. e. particles of 10 μm size. Particle pollution might be created of numerous constituents some of which include; acids including nitrates and sulphates, organic chemicals, metals and dust or soil particles. Particle pollution is associated with many practical health problems, particularly of the respiratory systems.

3. Methodology

In this article, Lifecycle assessment tool is applied to evaluate the environmental impact categories chosen for the beer production process at Tanzania breweries limited (Dar es Salaam plant). Model simulating beer production process was formulated in Open LCA 1.6 software obtained from green delta company website. The methodology for using LCA tool was described by ISO 14040 series (2006). It is important to note that the standard was released to the public by the International Organization for Standardization (ISO). ISO 14040: 2006 –Environmental management — Life cycle assessment — Principles and framework. The LCA analysis has been divided into four parts which includes; Goal and scope definition, Life cycle inventory analysis (LCI) Life cycle Impact assessment (LCIA), Interpretation of results.

The LCI involved data collection and calculations for sake of quantifying inputs and outputs used in beer production product system, they included things like energy and water consumption, raw material consumption and environmental releases like solid waste, liquid waste and gases in the whole system boundary specified prior to LCI. The outcome of LCI was the amounts of waste product released to the environment, were used as inputs to LCIA. Primary data collected were on inputs and outputs like energy, water consumption, malts, wastewater and solid waste etc. for processes considered in the product system processes that were in the system boundary from milling to distribution, outputs to the processes like waste water, spent grains and packaging materials. The methods used were interview, consultation and physical observation.

The LCIA was done in order to quantify environmental themes. This was done by using calculations based on the methodology developed by IPCC (2007). The impact factors used were obtained from IPCC (2007), IEA (2009), Ecoinvent (2010), and Climate Registry (2009) that were in Open LCA 1.5.6 life cycle impact assessment method pack. In the study the characterization methods used to calculate the environmental impacts categories where Zelm (2009) used to calculate fossils depletion , eco-toxicity impact categories that used World Re Zelm (2009) as a normalization and weighting factors, CML (non-baseline) was used to calculate acidification, human toxicity that used World, 2000 as a normalization and weighting factors , CML (baseline) used to calculate photochemical oxidation impact category toxicity that used World, 2000 as a normalization and weighting factors and IPCC, 2001 was used to calculate climate change over a 100 year global warming potential. The environmental impacts chosen were major significant with relation to the beer production process study and their characterization models are described as follows;

1. Global warming can thus be defined as the progressive rise in the earth's climate system average surface temperature over time. The characterization model of the Environmental Profiles was derived from factors formulated by the Intergovernmental Panel on Climate Change of the United Nations. The global warming effect is expressed as Global Warming Potential over the time horizon of 100 years (GWP100), measured in the reference unit, kg CO_2 equivalent (IPCC, 2013; Aitor *et al*., 2016).

$$Global\ warming\ effect\ (kg)\ =\ \Sigma GWPii \times\ emission\ to\ the\ air\ (kg) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ 1$$

The Acidification potential (AP) was indicated using the reference unit, kg SO2 equivalent, refers to deposition either on to the soil and into water where possible/according to the local conditions thereby altering the degree of acidity for flora and fauna. The model does not consider regional differentiation in the sense of which regions are more or less likely to experience changes in the acidity level. It accounts only for acidification caused by SO_2 and NO_2.

$$Acidification\ (kg)\ =\ \Sigma APii \times\ emission\ to\ the\ air\ (kg) \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots\ 2$$

This means exposure of man to toxic materials making him develop some health complications. Replacement models used include Human Toxicity Potentials (HTP) estimated to be 1. As for toxic impacts, the calculated 4-dichlorobenzene equivalents per kg emission were determined for an infinite time horizon with the USES-LCA model, which performs the fate, exposure, and effects of toxic substances. Potential health risks of exposure are excluded while is the working environment;

$$Human\ toxicity\ (kg) = \Sigma HCAii\ \times\ emission\ to\ the\ air\ (kg)\ +\ HCWi \times emission\ to\ the\ water\ (kg)\ +\ HCWi \times emission\ to\ the\ soil\ (kg) \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots .3$$

Photochemical oxidant creation: these are reactions of NOx with volatile organic substances in the atmosphere under the influence of ultra violet light causing smog. Table 3.4 shows a list of some of the flows and their POCP factors used to calculate the photochemical oxidant creation of this study (Aitor *et al*., 2016).

$$Oxidant\ creation\ (kg)\ =\ \Sigma POCPii \times\ emission\ to\ the\ air\ (kg) \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots .4$$

Eco-toxicity refers to the exposure of flora and fauna to toxic substances leading to health problems. EPA has defined two groups of eco-toxicological classification factors; ECA for aquatic ecosystems and ECT for terrestrial ecosystems are determined from equations 5 and 6 (Aitor *et al*., 2016).

$$Aquatic\ Eco\ toxicity\ (m3)\ = \Sigma ECAii(m3mg-1)\ \times\ emission\ to\ the\ water\ (mg) \ldots \ldots \ldots \ldots \ldots \ldots 5$$

$$Terrestrial\ eco-toxicity\ (kg)\ = \Sigma ECTii(kg\ mg-1)\ \times\ emission\ to\ the\ soil\ (mg) \ldots \ldots \ldots \ldots .6$$

Any emission to the air or water of ammonia, nitrates, nitrogen and phosphorous will contribute to the phenomenon of eutrophication The process of eutrophication. Computed by using the IPCC method of assessment of emissions to water that can lead to eutrophication. The nutrient enrichment capability was normalized and calculated in terms of Eutrophication Potential (EP) in reference units, which is kg PO43- equivalents (Aitor et al., 2016).

$$Eutrophication\ =\ \Sigma EPii \times\ emission\ to\ the\ air/water/soil\ (kg). \ldots \ldots \ldots \ldots \ldots \ldots \ldots ...7$$

In the beer production process considered in this research, specific environmental aspects of the production system are now elaborated upon to generate the life cycle assessment (LCA) inventory. Figures 3 and 4 shows the inventory of material and energy flows that were applied in the brewing production process. As stated earlier, beer production process includes the following modelled processes namely; milling of barley, wort production, fermentation, filtration, bottling/packaging and lastly distribution of beer. Process flow chart and develop system boundary were developed so as aid input and output data collection and finally obtain sensible scientific results that can be used for analysis.

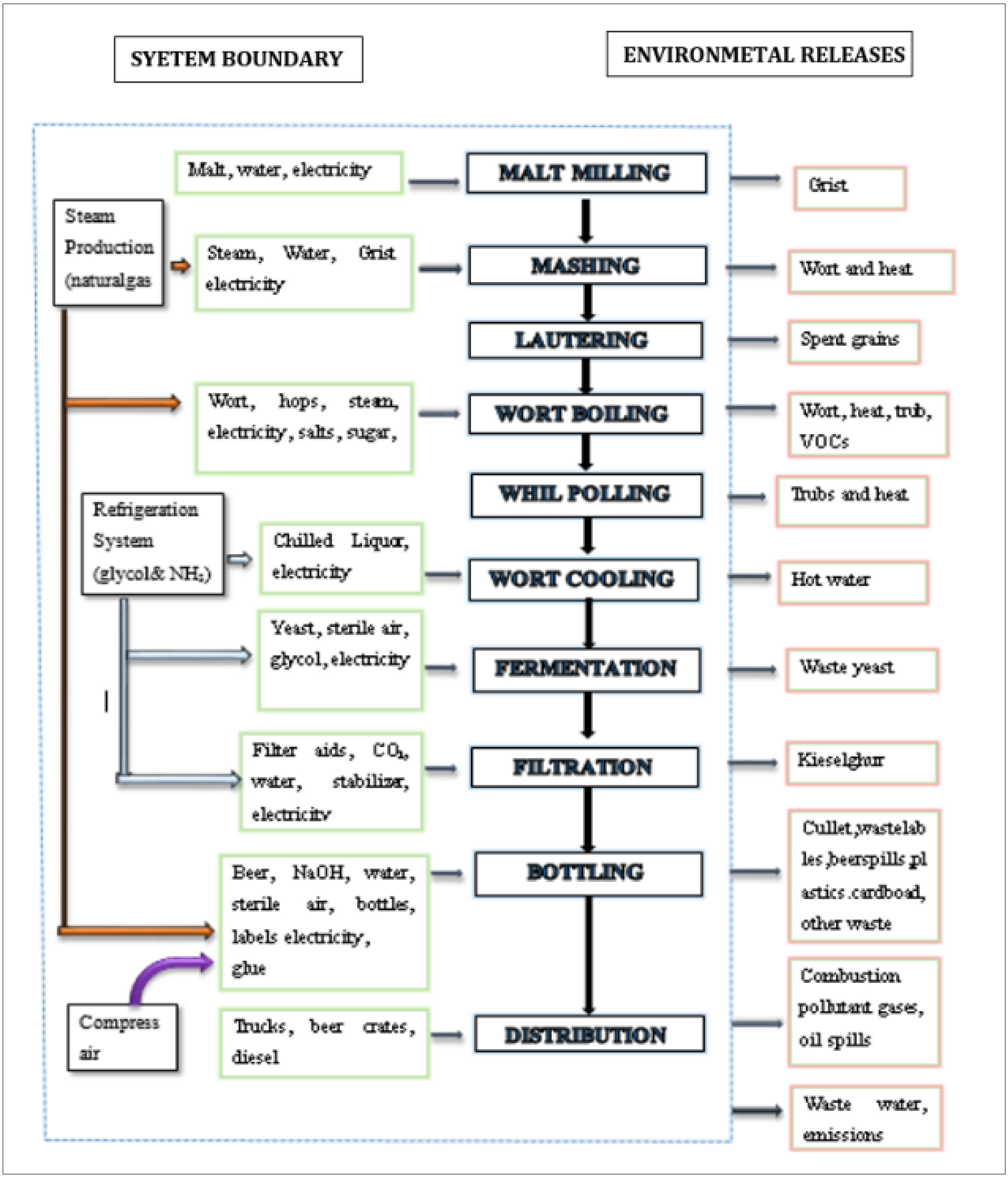

Figure 3 Process flow chart for beer production process showing inputs and outputs

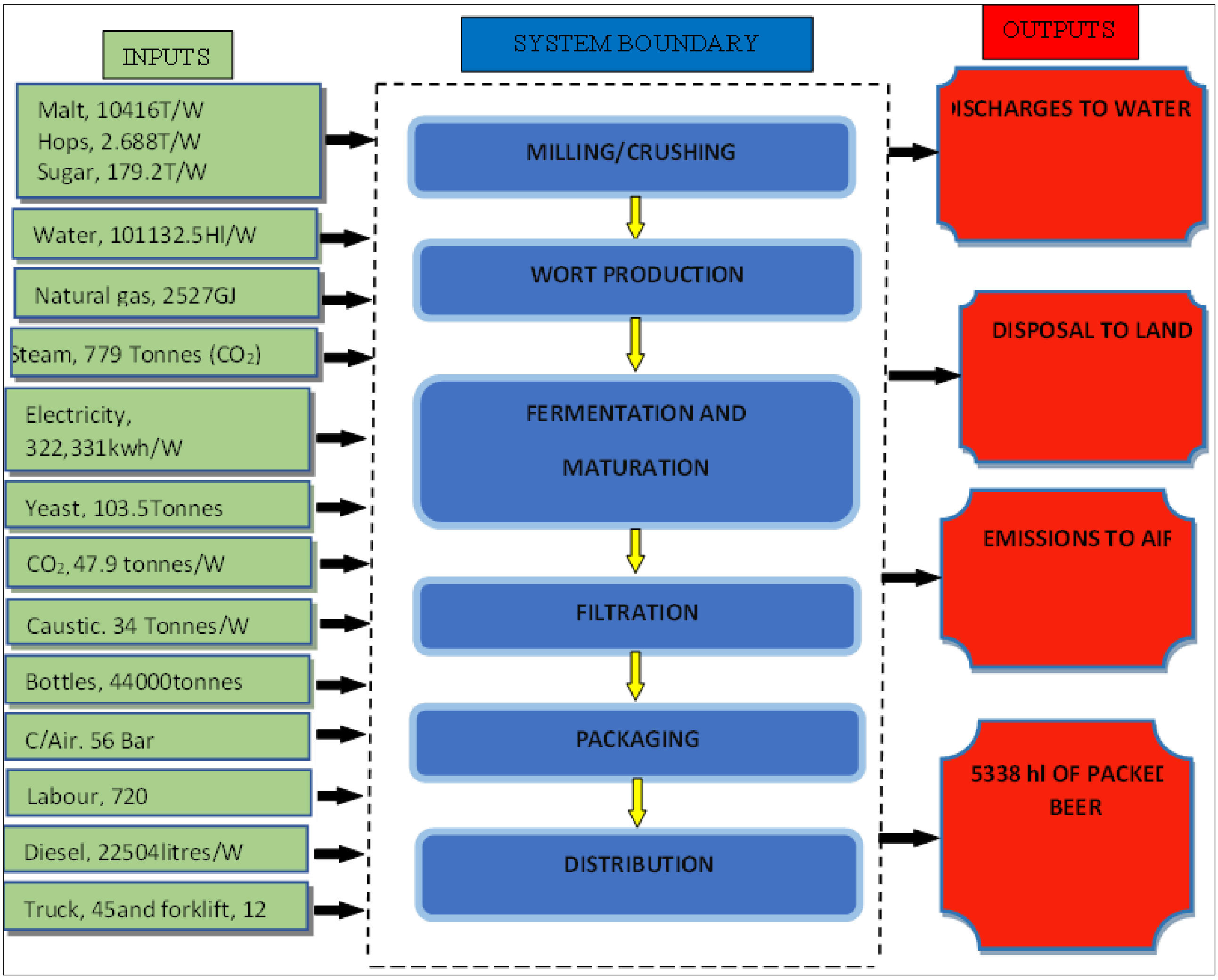

Figure 4 System boundary of all important process in beer production processes

4. Results

The data in Table 1 comprise of major inputs of beer production process from brewing to distribution. The inputs are quantified according to weekly bases as used in the brewery. Each brew consumes about 660 Hectolitres of brew liquor (water), 2.55 Tonnes of sugar, 9.1 Tonnes of malt, 3.2 Tonnes of corn starch, 1.9 bar of steam and 7 bars of compressed air and 30 kilograms of hops. In fermentation process 1.9 Tonnes of yeast were needed at constant temperature of 15 $°C$ for 3 to 4 days and maturation depends on the recipe and market demand but doesn't exceed 21 days, 49,000 Tonnes of carbon dioxide were captured and used in future packaging processes. During all this stages condition and quality assessments were done throughout to ensure quality of final product.

After maturation green beer was filtered in cellars were 7 kilograms of CO_2, 730 hectoliters of dilution water and 108 kilograms of beer stabilizer were added to produce bright beer. After filtration the beer was transferred to packaging hall were 288000bottles of 0.5 liters at required for bottling and 14,400 crates and 225 pallets were needed for packing and storage to the ware house. Final 113 trips were supposed to be made by trucks with capacity of carrying 22 pallets per trip that each truck has ratio of seven liter per kilometer. The total electric energy used per week is 318,118kWh and 2194 GJ of natural gas, hence as seen above beer production was resource and energy consuming process. Table 1 shows a summary of the inputs used in LCI of beer production done at TBL (Dar plant) as seen below.

Table 1 Inputs for beer production process

Flow	Category	Processes	Unit	Amount
Malt	Raw material	Mashing	Tonnes	509.6
Sugar	Raw material	Mashing	Tonnes	179.2
Hops	Raw material	Wort boiling	Tonnes	1.680
Water	Fluid	Wort production, filtration, Packaging	Hectolitres	101,663
Steam	Energy	Wort production, filtration, packaging	Tonnes	1,274
Yeast	Raw material	Fermentation	Kilograms	51,744
CO_2	Raw material	Packaging	Tonnes	0.0479
Filter aids	Filtration aid	Filtration	Tonnes	1.4
Bottles	Packaging material	Packaging	Tonnes	44000.0
Labels	Packaging material	Packaging	Tonnes	1.14021
Beer	Packaging material	Filtration and packaging	Hectolitres	25338
Electricity	Energy	Wort-making, fermentation, filtration and packaging	kWh	318118
Diesel	Energy	Electricity production and distribution	Litres	91,217
Natural Gas	Energy	Wort production	Giga joule	2,396
Biogas	Energy	Wort production	Giga joule	231.87
Caustic	CIP	Wort production, fermentation, filtration, packaging	Tonnes	34.0
Trucks	Transport	Distribution	Number of items	46
Workers	Labourers	Wort-making, fermentation, filtration, Packaging and distribution.	Number of people	720

Beer manufacturing is a wet process which produces a huge amount of wastewater and effluent from processing activities (Olajire, 2020). Major type of liquid waste generated by the plant includes process wastewater from bottle washing, equipment cleaning and hygienic activities. About 9000HL of wastewater was produced per day. The wastewater does not conform to Tanzanian standards as the chemical oxygen demand (COD), pH and TSS average concentrations were above standard, and this was due to low efficiency of the wastewater treatment plant as seen from in figure 4.3, 4.4 and 4.5. Other liquid waste generated were sanitary waste and domestic that were directed to the sea or municipal sewerage system, liquid hazardous waste such as fuels/oils and used chemicals. pH refers to either acidic/basic characteristic of water. As seen in Figure 5 below, five sample measured they showed that final effluent for discharged from TBL wastewater treatment plant had basic pH range of average 8.9 and do not conform to TBS standards of effluent discharge (6.5-8.5). This indicated that there was inefficient treatment of the WTP. Hence the effluent will increase alkalinity in fresh water bodies leading to destruction of aquatic ecosystem because of disruption of optimal conditions for growth and metabolism of the aquatic organisms.

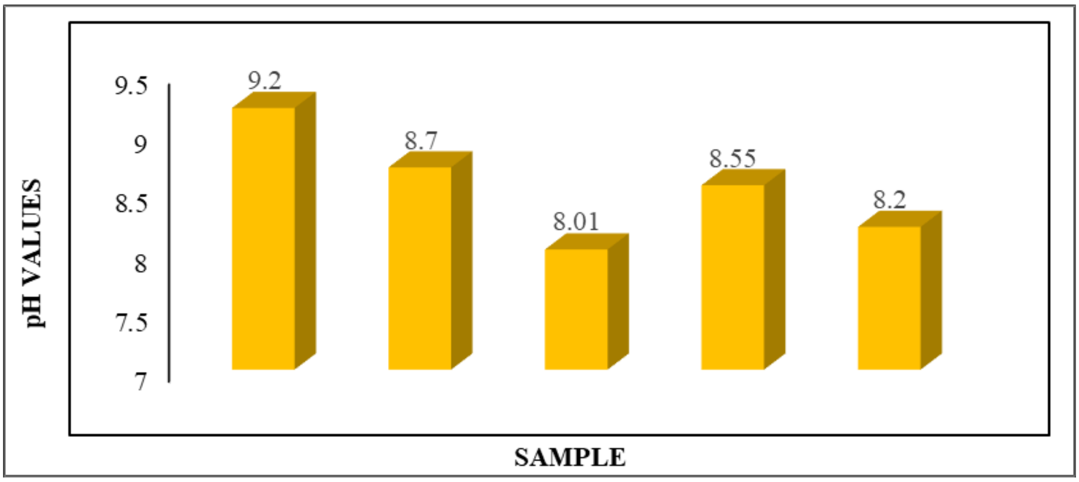

Figure 5 pH ranges on waste water samples at TBL, Dar plant

COD refers to the indicative measure used to quantify the amount of oxidizable organic pollutants found wastewater. As shown in Figure 4.4 below average COD concentration of effluent was 159mg/l that did not conform to TBS standards effluent discharge (100mg/l). These organic pollutants come mainly from brew house, fermentation and filtration where there was beer, spent grains, kieselguhr spills. As the waste water was allowed to be discharged into the river Msimbazi it adds the organic pollutant load that can caused death and even extinction of aquatic organism due to lack of dissolved oxygen in water caused by microbial decomposition activities.

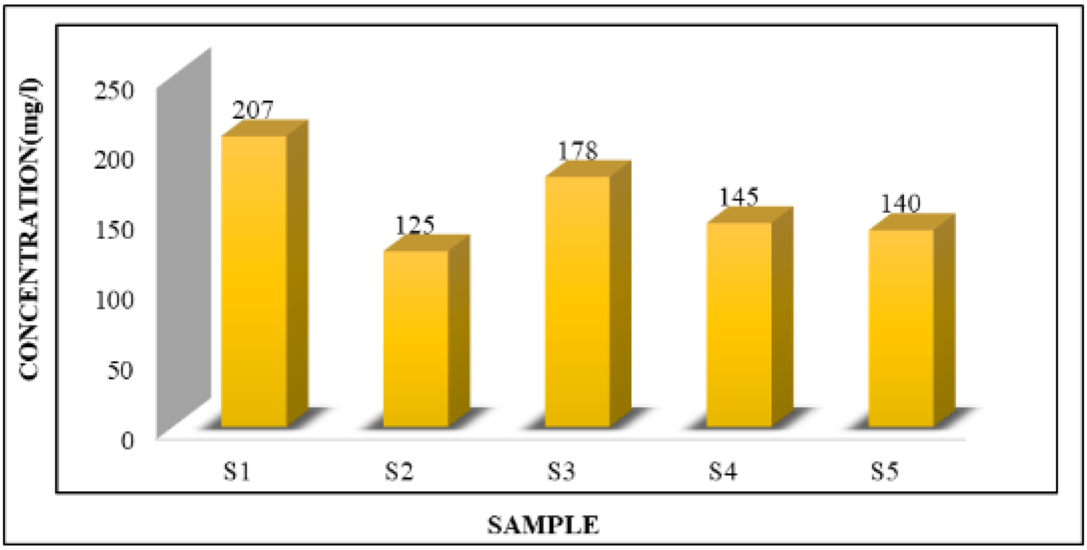

Figure 6 COD concentrations of waste water samples at TBL, Dar es Salaam

TSS refers to solids in water that can be locked in by a filter. For the case of TBL the average TSS concentration of final effluent sample was 270mg/l, it was relatively high compared to the TBS standards of effluent discharge (100mg/l) as presented in Fig. 7 below. The sources of were the particle from bottle labels, spent grain, kieselguhr, culets and wear and tear of machines. Effluent with high TSS can result to death of aquatic organism. This because TSS reduce light passing through water causing reduced photosynthesis with reduced dissolved oxygen in water, hence cause death of aquatic plants and animals. Microbial decomposition of dead matter result to even more depletion of dissolved oxygen. Also, TSS can clog fish gills, reduce their ability to catch prey due to increased turbidity, when TSS settle at bottom can suffocate new hatched organisms and provide adhering surfaces for pesticides, metals bacteria and nutrients (Mitchell et al., 1994).

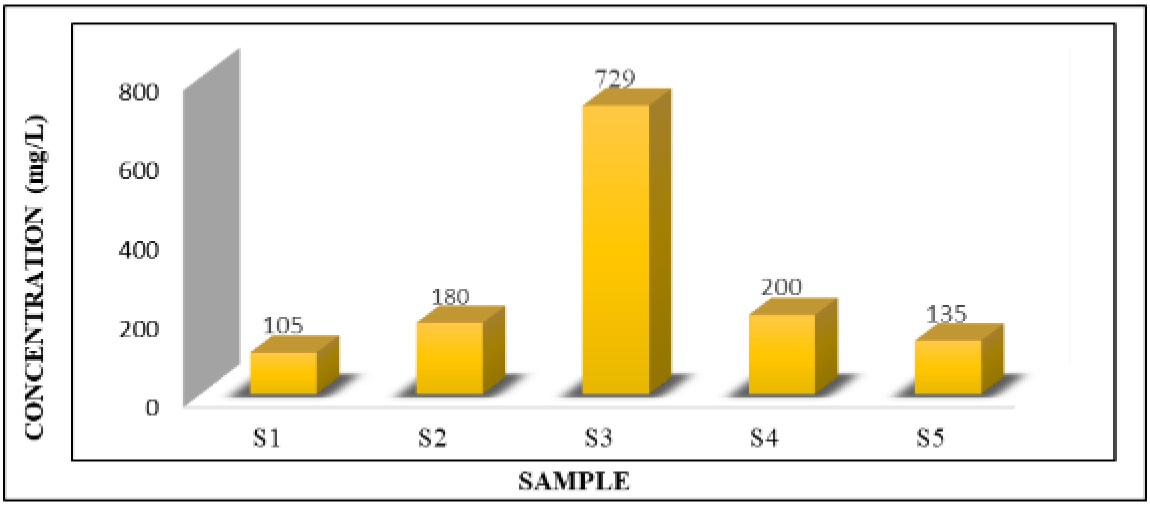

Figure 7 Concentration of TSS in water samples of TBL, Dar es Salaam

The evaluated results of major impact categories of all the processes of beer production at the breweries used as a case study were shown in Figure 8. The environmental impact category scores were as follows; the greatest was Eco toxicity which contributed 28.16% of total impact, second was fossil fuel depletion which contributed to 21.15%, third was climate change calculated based on the global warming potential of 100 years which contributed 15.04%, it was followed by human toxicity which contributed 14.18% , then photochemical oxidation which contributed 7.82%, followed by acidification which contributed 7.15% and lastly was particulate matter formation which was 6.51%.According to study done by Koroneos *et al.*(2003) ,showed that ecotoxicity Normalization impact categories score was largest impact (88%) for beer production process followed by smog formation.

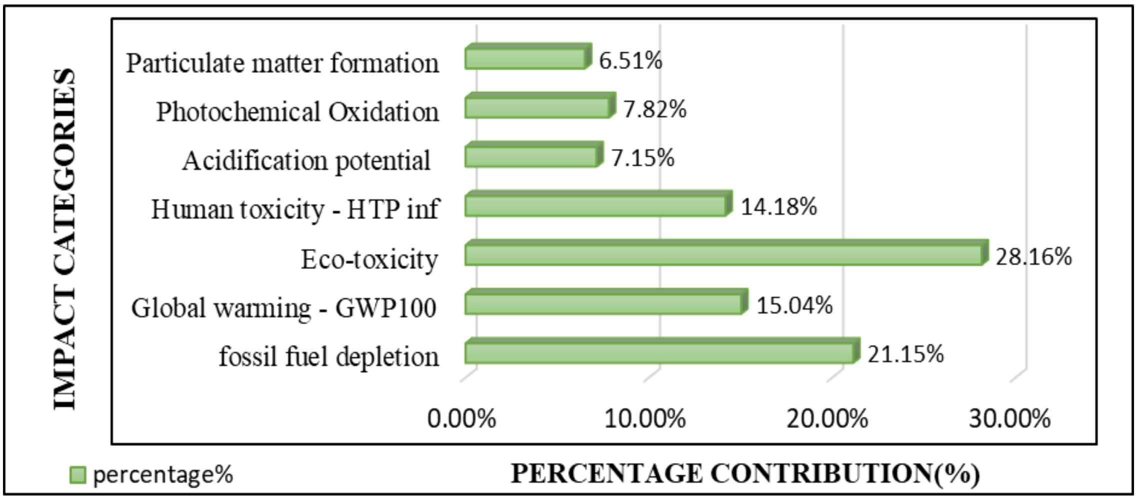

Figure 8 Results of Environmental impacts beer production process

4.1.1. Eco toxicity

It includes environmental impacts due exposure of marine aquatic, freshwater and terrestrial ecosystems to toxic compounds they come in contact with in the environment. It ranks as the first quantified environmental theme with great contribution to the total environmental impacts, with impact score of 7.7295E-6 which accounts 28.16% of total environmental impacts. Main flow contributors to ecotoxicity were Hydrogen fluoride gas, Nickel, Vanadium, Selenium, Mercury and Zinc. The results relate to the results of Life cycle assessment study done in Aristotle University in Greece evidenced where ecotoxicity also was the major impact category in beer production that was highly contributed by bottle production & packaging subsystem, followed by beer production and transportation subsystems (Koroneos et al., 2005)

4.1.2. Marine aquatic ecotoxicity

It refers to impacts caused by marine ecosystem interactions with harmful/toxic chemicals. Environmental impact score for marine aquatic ecotoxicity at TBL (Dar plant) activities was 6.801E-6 which was about 74.12% of ecotoxicity impact category. Flow contributor to marine aquatic ecotoxicity were presented in figure 9, were hydrogen fluoride with contributed 99% that came from processes including, discharge of wastewater from cleaning activities and energy consuming processes like wort production that require steam produced by combustion of natural gas which release hydrogen fluoride as waste gas. But also, from indirect processes like electricity, bottle production and packaging materials but also diesel use. Nickel contributed 0.52 %, which was output of diesel combustion in generators, forklifts and trucks used for distribution of beer and lastly Vanadium 0.48% that came from bottle washing in bottling process because it's used as glass coating for the bottles used for packaging. Illustrated in the figure 9. Marine ecotoxicity is the major contributor to ecotoxicity because it's the ultimate receiver of all pollutants from terrestrial and fresh water ecosystems. The results were not compared with other studies due to lack of data on marine ecotoxicity from beer production process.

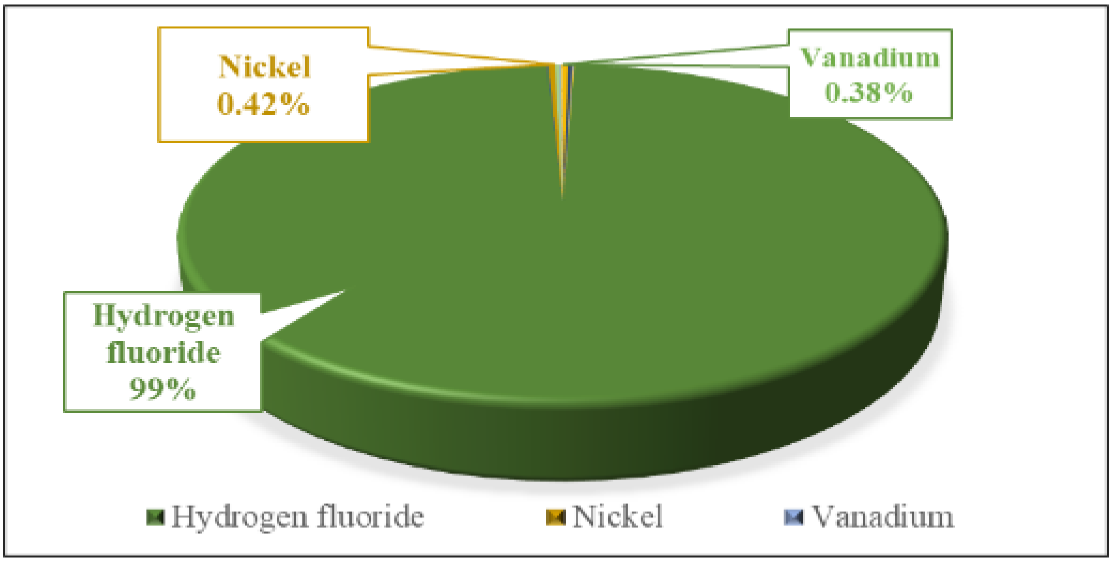

Figure 9 Flow contribution to marine aquatic eco toxicity

4.1.3. Fresh water ecotoxicity

The total amount of fresh water ecotoxicity as result of brewery processes for TBL (Dar plant) activities was 2.155E-7 which accounted for 2.38% of total ecotoxicity impact category. A seen in figure 4.5 below, flow contributors to fresh water ecotoxicity were vanadium with 29% and characterized value of 633 kg 1, 4-dichlorobenzene eq, Selenium with 28%and characterized value of 611 kg 1, 4-dichlorobenzene eq and nickel with 43% and characterization value of 941 kg 1, 4-dichlorobenzene eq. Main process contributor of the impact at TBL (Dar plant) were brewing, bottling, fermentation, filtration and hygiene, which all produced wastewater. About 9000HL of effluent was produced every day and only about 40% was recycled back to plant, this means 60% was disposed to public drainage systems that eventually pours into river Msimbazi. As seen from Figures 8 and 9 shows that final effluent composition does not conform to Tanzanian effluent discharge standards which was the main source pollutant chemicals entering the fresh water ecosystems.

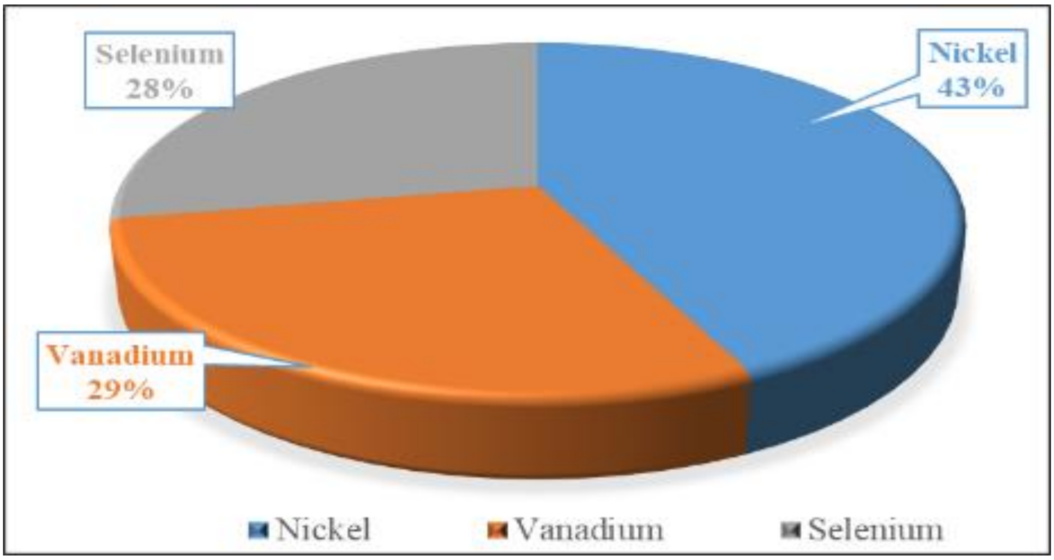

Figure 10 Flow contribution to fresh water ecotoxicity

As TBL wastewater was discharged with high COD (159 mg/l), it means that there were a lot of chemicals and organics that require treatment in wastewater. Apart from wastewater other contributing process was wort production that required natural gas combustion to produce steam. Also, indirect emission from bottle production other packaging materials can lead to emission of harmful gases, compounds and metals that later being washed out from soils by running water to fresh water bodies. Results were not compared to other studies due lack of information of fresh water ecotoxicity specifically for beer production process

4.1.4. Terrestrial ecotoxicity

The total terrestrial ecotoxicity impact score for TBL (Dar plant) activities was 2.159E-6 which accounted for 23.5% of total ecotoxicity impact category. Flow contributors to terrestrial ecotoxicity were presented in figure 4.6 below, were mercury with 68% and characterization value of 1,78E4 kg 1, 4-dichlorobenzene eq and zinc with 32% and characterization value of 8223.6 kg 1, 4-dichlorobenzene eq. The process flow contributors were, combustion processes in boilers, generators and automobiles, services of trucks, and forklifts, pest control activities due to use of fungicides, laboratory chemical waste for quality control activities and use of caustic soda for cleaning activities. Also, other indirect emission was from production of packaging materials like plastic and rubbers, clinical waste, machinery equipment wears and tear, thermostats probe in gas fired equipment like boilers and transformers in power generation. The results were not compared to other studies due to lack of information on terrestrial ecotoxicity, specifically in beer production process.

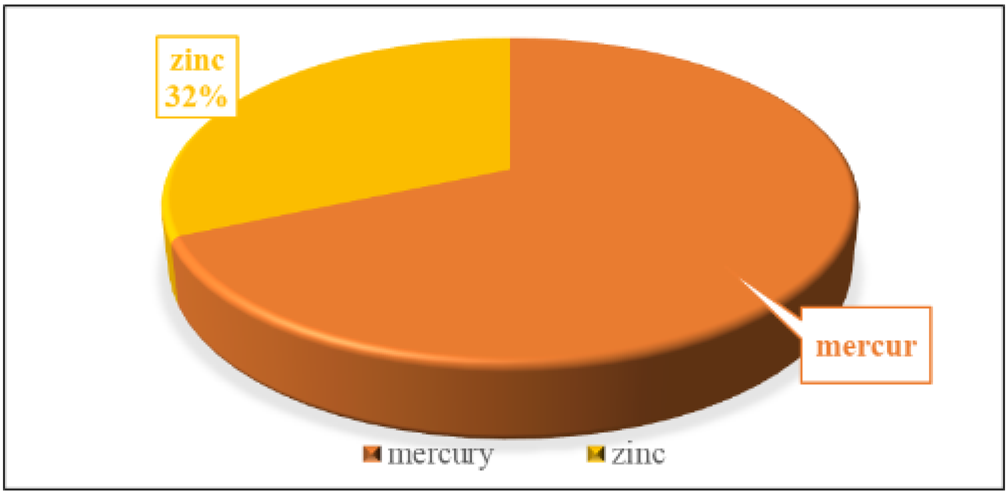

Figure 11 Flow contribution to Terrestrial ecotoxicity

4.1.5. Fossil fuels depletion

Fossil fuels are source of energy that is formed by the remains living organisms buried underground for millions of years. The environmental score for total fossil depletion was 6.89234E-6, which was equivalent to 21.15% ranking it second highest impact category contributing to total environmental impacts. The flow contributions to fossil depletion were presented in figure 12, were crude oil with characterization value of 4.45E7 Kg oil eq which was 76% and natural gas with characterization value of 8.49E6 Kg oil eq which was 24 %. Thermal energy sources make up about 70% of the energy consumed in the breweries and they include natural gas, crude oil and coal. Breweries use fossil fuels for steam and hot water production used for wort production, cleanliness in different brewery departments, but also diesel was the major source of energy used bottle production which most energy consuming sub process, powering different machines.

For the case study, they usually used natural gas (55.74MJ almost 69.5%) to power boilers to produce steam that use in wort production, filtration and packaging but in some rare cases heavy furnace oil was used. They also used diesel to power generation in cases of blackout and to power forklifts and trucks for distribution activities, without forgetting oil for lubrication of machines. Due to this extensive usage of fossil fuels for beer production process depletion of fossil fuels is inevitable. The results were not compared to other studies because of lack of information on the impact category specifically to beer production process.

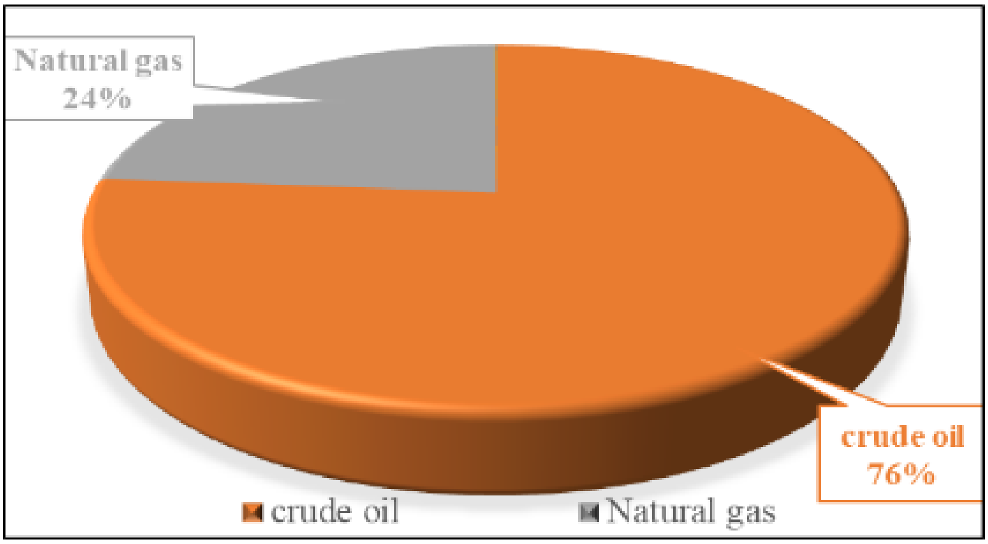

Figure 12 Flow contribution to depletion of abiotic resources (fossil fuels)

4.1.6. Global warming (GHG emissions)

Environmental impact score of global warming potential for TBL (Dar plant) was 4.90016E-6 which accounted for 15.02% of total environmental impacts. In which flows to global warming were presented in figure 13, were carbon dioxide that contributed by 91% with characterization value 1.865E8 kg CO_2eq, Methane contributes to 6%, Carbon monoxide contribute to 2%, Dinitrogen monoxide contribute 1 %. From literatures, the major causes of global warming effect area pollutant gas from combustion processes example in energy production activities and heat generation either from human activities.

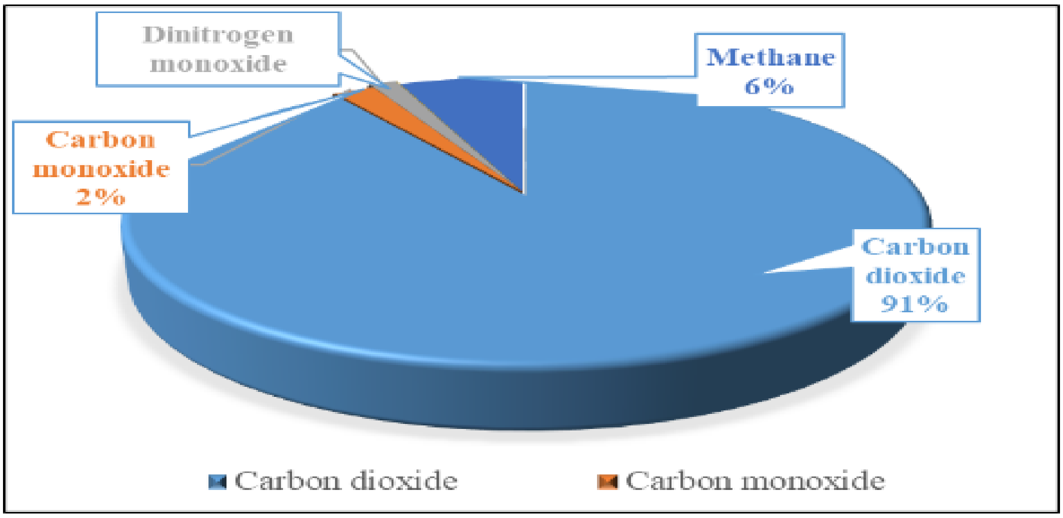

Figure 13 Flow contribution to global warming

Process contributors included, use of natural gas (28000GJ/Wk) and for steam production used brew house for wort production, cellars, utilities and packaging, natural gas is used for heating system to produce water vapour were 45% was used by brew house, 25% was used packaging and 20% in utilities thermal energy accounts for 69.8% of total brewery energy. Also, diesel is used as fuel to power up generators and trucks for beer distribution to the market and transportation within site, above 91,217L per week of diesel used generators in cases of blackouts and also in trucks for distribution of packed beer to customers. Indirect emissions from electricity production and bottle production where diesel is major energy source. Wastewater in to the environment also added to global warming through anaerobic digestion that produce methane. Comparing to the results of study done in university of Salerno, Italy, evidenced that wort boiling and hopping (1.35E-02) process was the largest contributor to global warming followed by mashing, fermentation, milling and lastly was filtration due to emission of pollutant gases produced from burning fossil fuels (Dawodu & Ajanaku, 2008)).

4.1.7. Human Toxicity

Human toxicity was ranked the fourth in its contribution to the total environmental impact categories with impact score of 4.62084E-6 which accounted for 14.18% of total environmental impacts. . Human toxicity was contributed by flow of dioxins 51%, Nickel by 24%, nitrogen dioxide by 13%, leads by 5%, Cobalt by 2%, Mercury by 2%, Sulphur dioxide 1% as presented in figure 14.

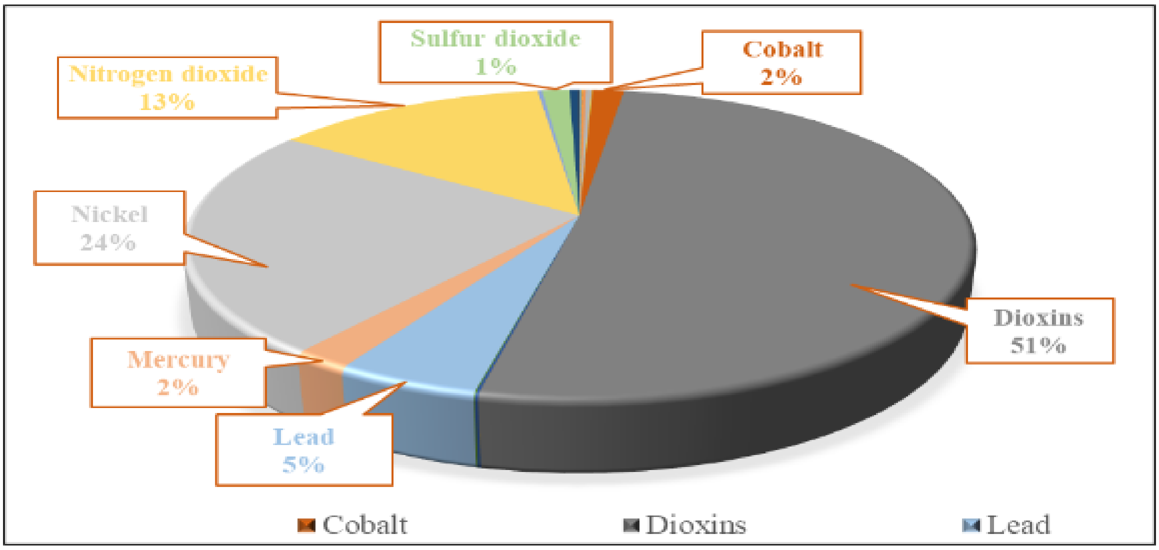

Figure 14 Flow contribution to marine Human toxicity.

Process contributors were, emission of dust from feed and storing of raw materials (malt and corn starch), use of chemical for cleaning and process, volatilization of organic compounds while brewing, fermentation, filtration and packaging, ammonia leaks, emission from waste and waste water, transportation activities and steam production. Due to lack of information on human toxicity of specifically for beer production process the results were not compared with other studies due to lack of information in impact category

4.1.8. Photochemical oxidation

Total photochemical oxidation impact category for beer production process had impact score of 2.54819E-6 which accounted to 7.8% of the total environmental impacts. As presented in figure 15, the flow contributors were Carbon monoxide (CO) with characterization value of 6.4824E4 and Sulphur dioxide with characterization value of 1.5899E4 which accounted for 80% and 20% respectively. The process contribution was from combustion of diesel in generator and distribution trucks also brewing, packaging due to due to consumption of steam generated from natural gas combustion. Also, indirect emissions from bottle and packaging material production, oil refining, and raw material production, processes emitted SO_2 and CO as outputs. The results were not compared to other studies due to lack of information of photochemical oxidation specifically for beer production processes.

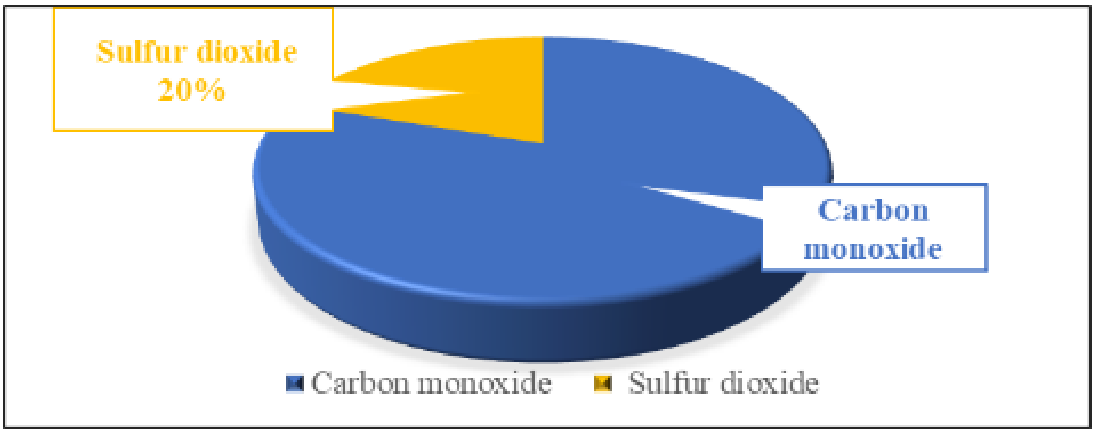

Figure 15 Flow contribution to photochemical oxidation

4.1.9. Acidification

The impact score for acidification for TBL (Dar plant) was 2.32944E-6 which accounts for 7.15% of the total environmental impacts. Acidification flow contributors were emissions Sulphur dioxide with characterization value of 3.312E4 kg SO2 eq and Nitrogen dioxide with characterization value of 2.188E5 kg SO2 eq, which accounts for 60% and 40% of the acidification impact category respectively. They were presented in figure 16.

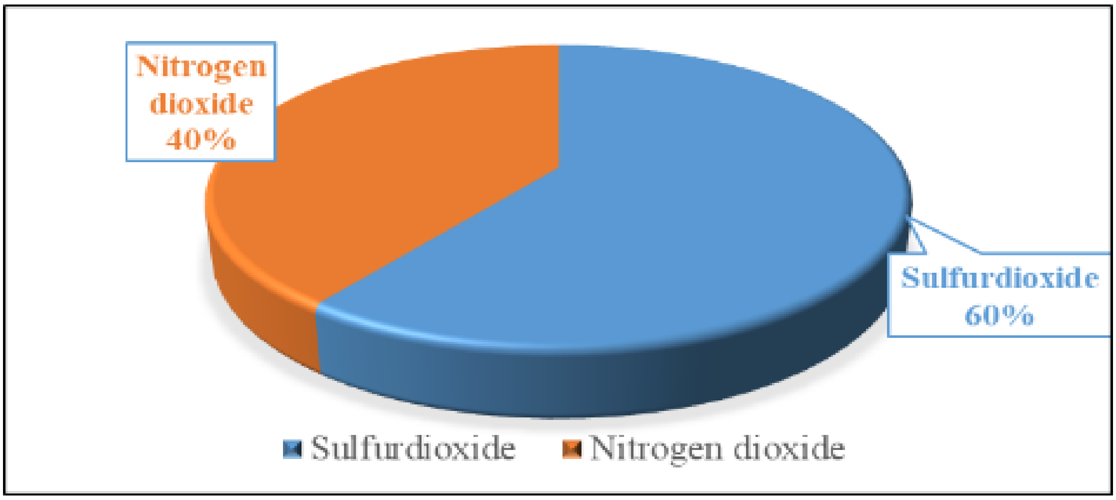

Figure 16 Flow contribution to Acidification

Core process contributors to the impact category were wort production process and bottling process due emissions from boilers for steam, electricity production from generators production and the beer distribution to customer at different area. Also, there were indirect emissions of Sulphur dioxide and nitrogen dioxides are from oil refinery, bottle production, raw material production and transportation, packaging materials production. The results were not compared to other studies due to lack of information of acidification specifically for beer production processes.

4.1.10. Particulate matter formation (PMF)

Particulate matter formation at TBL (Dar plant) ranked 7th in contribution to the total environmental impacts of beer production process. Its environmental impact score was 1.92276E-6 which accounts for 6.15%. The flow contributors were presented in figure 4.12 below to the impact were Particulate matter (<2.5um to <10um) with characterization value of 1.347E5 kg PM10 eq, Sulfur dioxide with characterization value of 6.625E4 kg PM10 eq and Nitrogen dioxide with characterization value of 6.877E4 kg PM10 eq. Which account for 50%, 25% and 25% to total impact category respectively. Process contributors to impact category include burning of natural gas for steam formation, combustion of diesel for electricity production, combustion of diesel to power forklifts and distribution trucks, bottle washing and packaging activities and solvent from cleaning chemicals and volatile organic compounds from brewing, fermentation filtration activities. The results were not compared to other studies, due lack of information on the impact category specifically on beer production process.

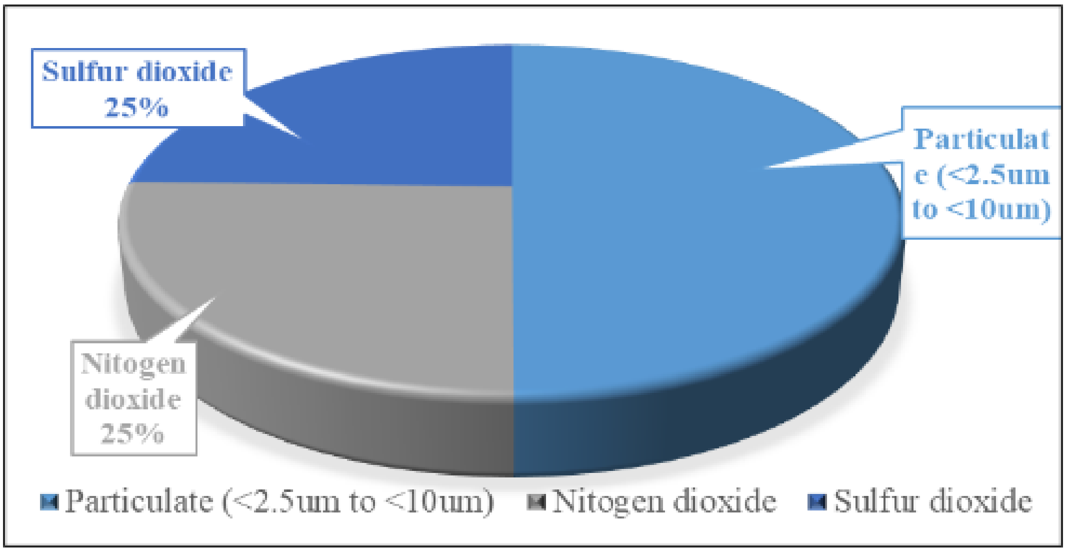

Figure 17 Flow contribution to particulate matter formation.

4.2. Discussion of The Results

Ecotoxicity was the largest impact category with impact score of 9.1762E-6, which include marine, fresh water and terrestrial ecotoxicity. Marine ecotoxicity was the leading contributor to total ecotoxicity (74.12%), because it the final receiver of all pollutants emitted from all other ecosystems. The major flow to marine aquatic ecotoxicity as Hydrogen fluoride gas, the gas is very toxicity and soluble to aquatic organisms as it forms strong hydrofluoric acid that when it interacts with some marine species example caddisfly species it kills them(www.greenfacts.org). Other contributors to impact were nickel from diesel combustions in trucks and for power generation and vanadium from bottle washing activities, which when dissolved in water disturb the ecosystem balances. Fresh water ecotoxicity flow contributors were Nickel, vanadium and selenium. It had less percentage contribution (2.38%) to ecotoxicity because most of the pollutant's concentration had endpoint effects in marine ecotoxicity. The main process contributor of fresh water ecotoxicity was due to discharge of inefficient treated wastewater with relative high COD (159mg/l), pH (8.9) and TSS (270mg/l) that were all above TBS standards, hence added organic load and chemicals in river Msimbazi causing disruption of habitats, which could lead to decrease of dissolved oxygen and contamination hence death of aquatic species (Mitchell et al., 1994; Abimbola et al., 2015). In case of terrestrial ecotoxicity, it contributed 23.5% to the total ecotoxicity impact, were flows where mercury and zinc. Terrestrial ecotoxicity implicate the impacts of soil ecosystem pollution due exposure to toxic chemicals. Soil pollution with inhibit the development of plants and animals and microbe that depend on soil habitat and food, hence lead to death or contamination those animals and plants ultimately, they will extinct (Koroneos et al., 2005).

Fossil fuel depletion was the second major impact category of beer production process with environmental score of 6.89234E-6 which was about 21.15% of total environmental impacts. The main flow contributors where crude oil and natural gas. Both of the fuel sources are non-renewable in nature but despite of that their consumption is higher than the rejuvenation rate. Hence depletion of fossil fuels will force people to return to the use of biomass (charcoal) as source of energy so causing desertification which will lead to decrease in rainfall leading ton hunger and finally death of (people and destruction of ecosystem and world climate (Olajide, 2012). Global warming was the third largest impact category with environmental score of 4.9001E-6 which was about 15.04% of total environmental impacts. Combustion of fuel and decomposition of waste used in beer production process produces greenhouse gases as out puts, which include CO, CO2, SO_2 , CH4 and NOx and other GHGs which were major contributors global warming (IPCC, 2013). Because their existence in the atmosphere reflects the infrared radiation preventing them to be released to the outer space, so eventually causing increase in earth surface temperature (global warming effect) hence disruption of climatic system (Aitor et al., 2016).

Human toxicity was the fourth major impact category of beer production process with environmental score of 4.62084E-6 which was about 14.18% of total environmental impacts. The flow contributors were cobalt, dioxins, Lead, Mercury, nickel, Nitrogen dioxide and Sulphur dioxide. The human toxicity effect depends on route of exposure and dose taken. The impact through inhalation route for toxic heavy metal air emissions will be low because of the low concentrations of these substances vaporized in air. But it's different for ingestion route because the toxic chemicals will be accumulated plants that can be easily eaten by humans and transfer them to their bodies, hence biomagnification of heavy metals within the food chains. Usually, they lead to cancer diseases to man. Also, gases will produce acids that may affect humans depending on nature of exposure. Hence significant environmental impact for beer production process (Dawodu & Ajanaku, 2008).

5. Conclusion

In conclusion, this LCA study has revealed the main aspects of beer production process as well as the main environmental impacts of this process at every stage in beer production, determine all beer production processes, the inventory analysis of inputs and outputs in the processes, define the potential human and ecological impacts of the environmental emissions, and propose possible means of improvement. The scope of the study is limited to environmental impact that would be associated in the production process of beer at local level. The intended users of the findings of this study include all stakeholders in the beer industry, researchers, non-governmental organizations (NGO), Government institution's etc. The functional unit was defined as 25,338 hectoliters of packed beer volume delivered to the final consumer per week. Beer production had six major processes which are milling, wort production, fermentation and maturation, filtration, packaging and distribution supported by utilities department by providing energy and fluids and they all used utilities that included the sub processes of steam production from natural gas, production of compressed air, refrigeration system that uses ammonia as primary refrigerant and glycol as secondary refrigerant and lastly the water treatment plant for process water. Beer production consume a lot of energy: natural gas 55.7MJ and electricity 24 MJ, water 14,523HL, chemicals: caustic solution 4tonnes and raw material: malt 72.8 Tonnes, corn starch 25.6 Tonnes, sugar 20.8tonnes yeast 240 Tonnes and yeast 14.4 Tonnes per day. Brewery also produce liquid waste above 9000HL/day (Ex brewery and cleaning chemicals), solid (spent grain, waste yeast and packaging waste) and gaseous waste (e.g.; NO_2, SO_3 and carbon dioxide). The most energy and water consuming processes were wort production, fermentation and packaging.

Compliance with ethical standards

Disclosure of conflict of interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this manuscript.

Authors contribution

Yvonne Laurent Mganga has received funding from Ardhi university, which supported all aspects of the research. Peter Makinde was an employee of Federal University of Technology, Akure, Nigeria, which provided final editing and review. However, these affiliations did not influence the study design, data collection, analysis, or interpretation of the results. All authors have approved the final version of the manuscript and agree to be accountable for all aspects of the work.

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