ENVIRONMENTAL LIFE CYCLE ASSESSMENT OF SMOKED FISH PRODUCTION: A CASE STUDY OF THE UNIVERSITY OF IBADAN FISH FARM

IGOMU BERNARD*, AREMU ADEMOLA, OMOBOWALE MOBOLAJI

Department of Agricultural and Environmental Engineering, University of Ibadan, P.M.B 5017, Ibadan, Nigeria

* Correspondence: igomuekoja@gmail.com

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Abstract: The study aimed to carry out a life cycle assessment (LCA) of the production and processing of smoked fish using the University of Ibadan Fish Farm as a case study to identify environmentally detrimental production and processing hotspots. The LCA used cradle-to-gate approach which involves the operations from breeding/hatching to the packaging of smoked fish. Four scenarios were drawn for assessing the impact by varying the energy and material resources. Six impact categories were measured for all four scenarios with Global Warming Potential (0.639 kg CO_2-Eqiv.) having the highest impact while Human Toxicity Cancer Effect recorded the least impact (3.463e-11 CTUh). At the end of this LCA study, it was recommended that renewable energy sources as well as energy from bio-waste should be explored for the smoking kilns to achieve cleaner production.

Keywords: life cycle assessment, global warming, acidification potential, smog air, smoked fish production and processing

1. INTRODUCTION

The supply and demand of fish and fish products worldwide have been well demonstrated in the last several years by the production and distribution of seafood. With an average yearly growth rate of 3.2%, the stated increase in the global supply of fish products for human consumption has surpassed population growth [1]. This figure essentially suggests that as the world's population grows, so will the demand for seafood and fish products on the international market, which will drive future supply growth. Fish production and processing business expansion is indirectly aided by the enormous market demand for fish products. Only 67 million tons of fish—that is, fresh, chilled, or alive fish—were available for direct human consumption in 2016, which accounts for 46% of the total fish consumed globally that year, according to the research found in [1].

Fish that had been preserved (19 million tons), cured (17 million tons), and frozen (44 million tons) comprised the remaining 54 percent of the processed fish. Fisheries and aquaculture, as with most other agricultural pursuits, involve environmental inputs or outputs that have an impact on the environment. The depletion of minerals and fossil fuels, smog, acidification, ozone layer depletion, global warming (greenhouse gases), eutrophication, and human toxicological pollutants are a few examples of these processes' impacts on the environment. Other processes include habitat destruction, deforestation or desertification, land use, and contamination [2]. In the production

* Corresponding author, email: igomuekoja@gmail.com
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pond, raising fish from breeding stock to smoke-worthy size typically takes four to five months. Additionally, processing and smoking the same fish results in a 48–72-hour turnaround time. Although research and knowledge gaps exist in understanding the environmental implications of such activities internationally, and notably in Nigeria, studies on the significance, prospects, and production processes of fish production have been done, with a specific focus on the smoking of fish.

The primary fish farmed in Nigeria is catfish (*Clarias gariepinus*), which is widely distributed throughout the nation, consumed by numerous tribes, resilient to challenging environmental conditions, reasonably priced, and capable of being preserved for several days during marketing. Over 253,898 metric tons of *Clarias gariepinus* are produced annually in the nation, according to estimates [3]. At these rates of production, it will be necessary to explore new catfish markets and value additions to eventually consume the entire production. There are no systematic scientific processing or value-adding enterprises that have been formed from catfish to fulfill the demands of global markets, except for smoking and drying.

On average, it takes about 4-5 months to produce fish starting from breeding to smoke-able size in the production pond. Also, it takes on average 48-72 hours to process and smoke the same fish which is a product. While studies have been conducted on the importance, prospect, and production processes of fish production with particular interest in the smoking of fish, there have been research and knowledge gaps in understanding the environmental impacts of such activities globally and particularly Nigeria. Fish is a nutritious source of food of high-quality protein often cheaper than meat though highly susceptible to deterioration without any preservative or processing measures [4]. [5] has reported that due to their chemical compositions, fish muscle is perishable and its flavor and texture changes rapidly after death and during storage. Harvesting, handling, processing and distribution provides livelihood for millions of people as well as providing foreign exchange to many countries.

Preservation and processing therefore become important parts of industrial fisheries. They are done in such a manner that the fish retain their freshness quality for a long time, with a minimum loss of flavor, taste, odor, and nutritive values [6]. Freshness of fish is usually judged entirely in trade by its appearance, odor and texture of the raw fish, and the assessment depends upon the senses, known as sensory or organoleptic evaluation [7].

Life Cycle Analysis (LCA) or Life Cycle Analysis is a quantitative method used to assess the environmental performance, throughout the entire life cycle of a product, process or activity in order to identify the best environmental option of waste treatment or handling [8]. The LCA should include the entire product life cycle, material and energy acquisition, input material and energy during manufacturing, product outputs, generation of wastes, use of end products and waste management. It is an ISO-standardized analytical tool developed to evaluate environmental performance of products and processes [9]. LCA, an analytical method standardized by ISO, was created to analyze how environmentally friendly activities and products are. It consists of an inventory and assessment of a product's inputs, outputs, and any environmental effects across the course of its life cycle; the word might apply to a particular research or a procedure. The inputs and outputs that are included in the study are defined by the system boundary in the assessment [10].

As highlighted by [11], little has been done concerning LCA in Africa, where networks/research groups are notably limited. LCA is a useful technique to assess the environmental impacts of a product or service throughout its entire life cycle, i.e., from the extraction of raw material through to processing, transport, use, and finally recycling/disposal [12]. By considering several different impacts over the entire life cycle, it is possible to identify potential trade-offs from transitioning one stage to another or from one environmental problem to another. These are major differences with other assessment methods, such as the carbon/water footprint (focusing only on one environmental aspect) or the methods focusing only on the direct emissions of products during operation. Several global life cycle inventory databases [13] and life cycle impact assessment methods [14] exist that include African and especially Nigerian information, although the impact resolutions or data are quite limited. LCA is a methodology for assessing environmental impacts associated with all the stages of the life cycle of a commercial product, process, or service. In the case of a manufactured product, environmental impacts are assessed from raw material extraction and processing (cradle), through the product's manufacture, distribution, and use, to the recycling or final disposal of the materials composing it (grave) [15].

A LCA study involves a thorough inventory of the energy and materials that are required across the industry value chain of the product, process or service, and calculates the corresponding emissions to the environment [16]. LCA thus assesses cumulative potential environmental impacts. An LCA determines the associated emissions to the environment by taking a complete inventory of the energy and materials needed for the product, process, or service along the industry value chain [17]. As a result, LCA evaluates all possible environmental effects over time. The fish farming and processing sector also adds to the excessive use of electricity and other energy sources, as well as the production of a great deal of wastes, including heads, guts, and skins, as well as wastewater effluents [18]. Therefore, to develop ways to improve the industry's environmental performances, it is necessary to assess the effects that the fish production and processing sector has on the environment.

2. MATERIALS AND METHOD

2.1. Study location

The University of Ibadan is located in the city of Ibadan; the capital of Oyo state, Nigeria with coordinates 7.4433°N, 3.9003°E. The University fish farm is a research and training farm for the department of Aquaculture and Fisheries Management, but it has now been expanded to commercial fish products status because of the quality of the services provided.

2.2. Study approach

The LCA was developed to meet the requirements of ISO 14040 and ISO 14044 standards [17]. These standards offer a widely recognized approach to conducting LCAs and allow for considerable customization of project methodologies to meet specific energy and outcome requirements. In general, it entails a thorough measurement of the energy and materials used, the wastes discharged into the environment, the computation of the environmental consequences, the interpretation of the data, and the identification of opportunities for improving the whole production system and the life cycle of the product [9].

The methodology, suppositions, and findings of the cradle-to-gate LCA of the University of Ibadan, Nigeria Fish Farm are fully reported in this assessment. There are four steps in the LCA: The process of goal and scope definition involves defining the frameworks, objectives, goals, and boundaries. It also involves defining appropriate metrics, such as greenhouse gas emissions, water consumption, hazardous material generation, and/or waste quantity. Inventory analysis, on the other hand, entails gathering data that identifies the system's inputs, outputs, and environmental discharges. Life cycle impact assessment analysis, and interpretation of the results round out this process. The model's boundary system extended from the acquisition and conveyance of fish feed and brood stock to the packing of smoked fish (Figure 1). The Life Cycle Impact Assessment (LCIA) was for a function unit of 1kg of packaged smoked fish.

Modelling the smoked fish production unit processes at the University of Ibadan Fish Farm helped to outline the relationships between unit processes and flows across the system boundaries, describing the sources of emissions (Table 1). Four (4) scenarios for energy consumption were modelled on the $GaBi_9$ (holistic balancing) software for the purpose of this study (Table 2). This includes the variation in various energy sources and their estimated impacts on the environment.

Primary data were obtained from documented records of production and processing, interviews, and site visits to the University of Ibadan Fish Farm. Data obtained includes input and output of raw material from each unit processes, machine energy consumption and duration of each process. Fuel consumption for each unit process was calculated based on the machine power ratings and hours of operation. The total greenhouse gases derived from the combustion of fossil fuels used such as carbon dioxide (CO_2), carbon monoxide (CO), methane (CH_4), Nitrogen monoxide (N_2O) and fluorinated gases based on individual CO_2 equivalents were used to assess the global warming potential (GWP) of producing 1kg of smoked fish on GaBi9 software. Based on a 100-year time horizon, Intergovernmental Panel on Climate Change (IPCC) gave the CO_2 equivalent factors (kg CO_2-eq/kg) for GWP of these gases from the combustion of fossil fuels to be; CO_2 = 1, CO = 1.8, CH_4 = 25 and N_2O = 296 [19].

Emissions from transportation were calculated using the bottom-up approach method obtained from Climate Leaders GHG inventory Protocol. Gasoline (petrol) was the major fuel used in transportation of broodstock and feed materials, as well as for harvesting smoke-able sized fish. The emissions were calculated based on the distance travelled in kilometers and fuel economy factor (equation (1)). Emissions calculation procedure of pollutants from the combustion of diesel in stationary engines and burning of Premium Motor Spirit (PMS) were estimated using equation (2). For stationary combustion diesel engines and PMS combustion, the emission factors were based on data from [20] and [21] as shown in Table 3. The emission factors for petrol (Table 4) were obtained from [21] and [22]. The emission factors for grid electricity that was used were obtained from [23] while that of charcoal was obtained from the (IPCC) guidelines for national greenhouse gas inventory [19]. Also, emission factors for

Polyethylene (PE) self-adhesive plastic bags for individual packaging and Low-Density Polyethylene (LDPE) for bulk packaging plastic material were also obtained [24]. This is because, it has been reported that these materials emit heavy metals into the environment. The various heavy metal elements reported include: Pb, Cr, Cd, As, Cu and Zn and all is measured in mg/kg [25].

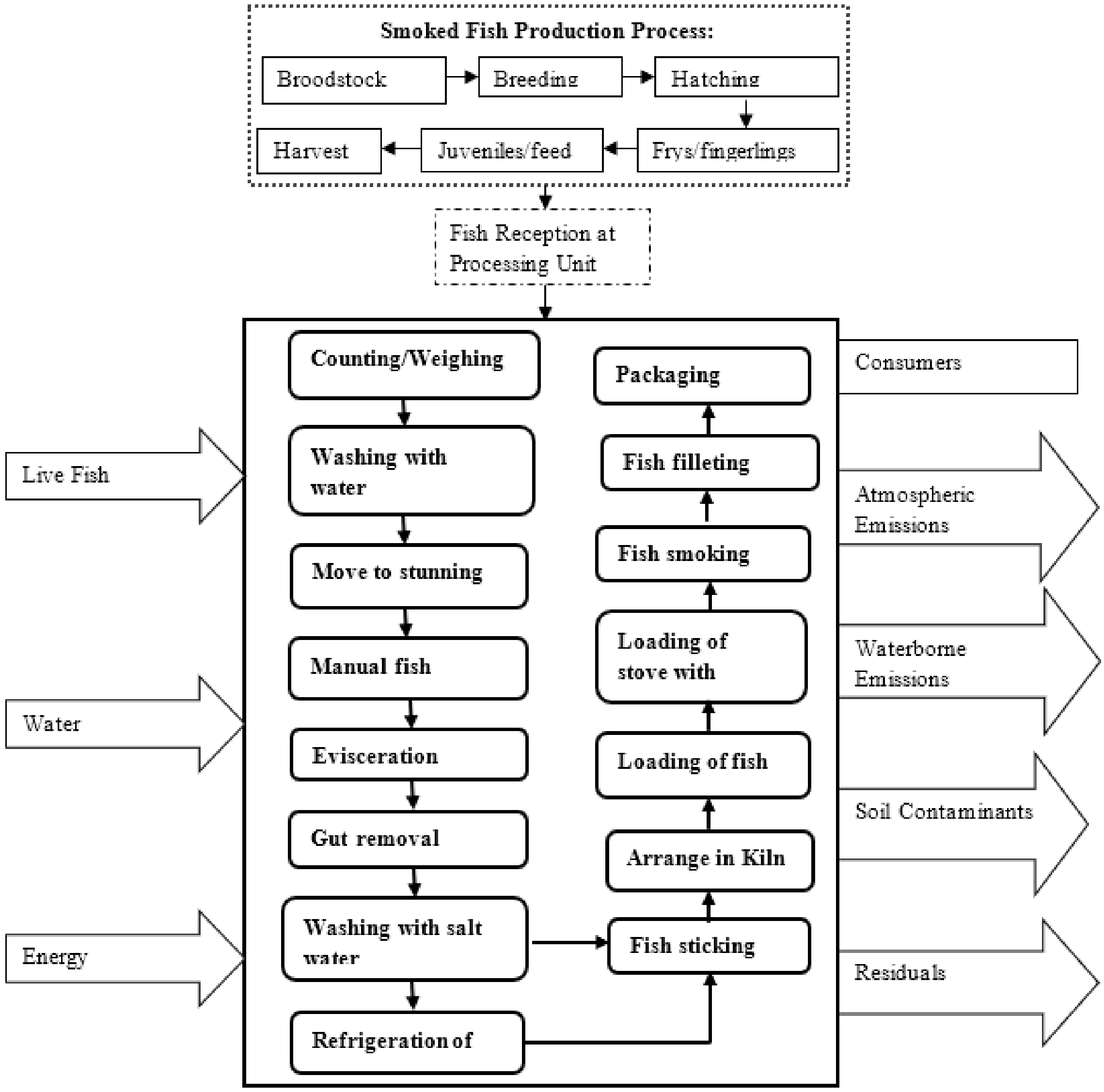

Fig. 1. System boundary flow diagram for smoked fish production process.

Table 1. Sources of primary greenhouse gas emissions in smoked fish processing.

Item considered (input/output)	Processes included in assessment	Sources of GHG emissions for inputs and outputs
Purchase/transportation	Transportation	Fuel combustion of broodstock
Fish Feed Production	Machine usage	Fuel combustion
Harvesting of Fish	Pond dragging, water expulsion, pond de-silting	Fuel combustion during water expulsion
Fish washing	Water and Energy	Electricity, fuel for water pumping
Fish Stunning and gutting	Stick, knife and energy	-
Fish slime removal/washing	Water pump and energy	Electricity, fuel for water pumping
Fish washing/ sticking	Water pump and energy	Electricity, fuel for water pumping
Fish loading into Kiln	Charcoal loaded stove lighting	CO_2 emission from charcoal burning during smoking

Fish Waste	Waste deposit on land/water	CH_4 from waste on land

Table 2. Description of scenarios.

Scenarios	Features of the scenarios
Scenario 1(Electricity and Charcoal)	Utilization of petrol for transportation, pond water pumping machine, electricity for feed production, and charcoal as source of energy for fish smoking
Scenario 2 (Electricity)	Utilization of petrol for transportation, pond water pumping machine and grid electricity as energy source for feed production and smoking of fish
Scenario 3 (Diesel and Charcoal)	Utilization of petrol for transportation, pond water pumping machine and diesel as source of energy for feed production, borehole water pumping and smoking of fish
Scenario 4 (Diesel)	Utilization of petrol for transportation, pond water pumping machine and diesel as source of energy for feed

2.2.1 Bottom-up approach to estimate fuel use

Emissions from fuel use is calculated thus:

$$Fuel\ use = DT \times FE \tag{1}$$

where *DT* are distance travelled activity factor; and *FE* is fuel economy factor.

Estimation method of pollutants from stationary combustion diesel engines and PMS.

$$Emissions(p, s) = As \times EFp\text{,s} \tag{2}$$

where *p* stands for pollutants (such as CO_2, CH_4, Cd…); *s* is Source category; *A* is activity level; *EF* is emission factor.

Environmental impact of fish waste was analyzed in GaBi9 software, based on the mean nutrient properties of fish waste values reported in [25]. The analyzed parameters included nitrogen (N), phosphorus (P), biochemical oxygen demand (BOD_5)), chemical oxygen demand (COD), pH, oil and grease, and total coliform bacteria.

Environmental Impacts were assessed using the TRACI (Tool for the Reduction and Assessment of Chemical and Other Environmental Impacts) methodology. TRACI midpoint is a problem-oriented approach and uses environmental themes, as illustrated in Table 5.

Table 3. Emission factor for diesel and PMS combustion [21].

Diesel combustion in stationary engines			PMS Combustion in stationary engines		
Pollutant	**Emission factor**	**Unit**	**Pollutant**	**Emission factor**	**Unit**
CO_2	3.17E+00[c]	kg/kg_{fuel}	CO_2	2.32E-03	kg/kg_{fuel}
CH_4	4.50E-04[c]	kg/kg_{fuel}	CH_4	1.00E-04	Kg/L
N_2O	8.12E-05[c]	kg/m^3-fuel	N_2O	2.10E-05	Kg/L
NO_X	7.25E+01[b]	kg/m^3-fuel	NO_X	2.41E+01	Kg/L
CO	1.56E+01[b]	kg/m^3-fuel	CO	9.27E+02	Kg/L
SO_2	4.77E+00[b]	kg/m^3-fuel	SO_2	1.24E+00	Kg/L
VOC	5.30E+00[b]	kg/m^3-fuel	VOC	4.01E+01	Kg/L
PM_{10}	5.10E+00[b]	kg/m^3-fuel	PM_{total}	1.48E+00	Kg/L

Table 4. Emission factors for gasoline (petrol) - road transport [21, 22].

Pollutant	Emission factor per unit	Unit
CO_2	3.172[a]	$kgCO_2/kg$
N_2O	0.0313[a]	g/km
CH_4	0.0842[a]	g/km
CO	1.18E-02[b]	kg/km
NO_x	1.50E-03[b]	kg/km

PM_{10}	3.10E-05[b]	kg/km
VOCs	1.16E-03[b]	kg/km
SO_2	5.58E-05[a]	kg/km
1,3, Butadiene	1.78E-05[b]	kg/km
Benzene	5.17E-05[b]	kg/km
Cd	0.01[a]	mg/kg
Cu	1.7[a]	mg/kg
Cr	0.05[a]	mg/kg
Ni	0.07[a]	mg/kg
Se	0.01[a]	mg/kg
Zn	1[a]	mg/kg
Pb	2E-03[a]	mg/kg
Hg	7E-05[a]	mg/kg
Cr (VI)	1.0E-04[a]	mg/kg

Scientific notation is used in the manuscript, eg., 5.50E-06 represents 5.50 x 10^{-6} or 0.0000055

Table 5. LCA cause-effect chain selection [26].

Impact category	Midpoint level selected	Level of site specificity selected	Possible endpoints
Global warming (kg CO_2-Equiv.)	Potential global warming based on chemical's radiative forcing and lifetime	Global	Malaria, coastal area damage, agricultural effects, forest damage, plant, and animal effects
Acidification (moles of H^+ Equiv.)	Potential to cause wet or dry acid deposition	U.S., east or west of the Mississippi River, U.S. census regions, states	Plant, animal and ecosystem effects, damage to buildings
Eutrophication (Kg N-Equiv.)	Potential to cause eutrophication	U.S., east or west of the Mississippi River, U.S. census regions, states	Plants, animal and ecosystem effects, odors and recreational effects, human health impacts effects, plant effects
Smog (Kg NO_x-Equiv.)	Photochemical smog	Mississippi River, U.S. census regions, states	
Human health: cancer (Kg Benzene-Equiv.)	Potential of a chemical released into an evaluative environment to human cancer effects	U.S. A	Variety of specific human cancer effects
Land use	Proxy indicator expressing potential damage to threatened and endangered species	U.S., east or west of the Mississippi River, U.S. census regions, states	Effects on threatened and endangered species (as defined by proxy indicator)
Water use	Water shortages, proxy indicator expressing potential damage to threatened and endangered	Local	Water shortages leading to agricultural, human, plant and animal effects

3. RESULTS AND DISCUSSION

The cradle-to-gate complete LCA of all unit processes in the smoked fish production chain of the University of Ibadan Fish Farm estimated the impacts of the process modelled on $GaBi_9$ on the environment for the four scenarios as reported in Table 6. Each of these scenarios, as defined in Table 2, represents an original scenario and a simulation of three other possible scenarios of energy and material combinations and their level of potential impacts on the environment. GWP quantifies the potential for scenarios to contribute to global climate change.

Scenario 3 recorded the highest GWP at 0.639 kg CO_2-eq. attributed to increased emissions of greenhouse gases, particularly CO_2 and CO, resulting from the fish smoking and transportation of broodstock unit processes. Effectively making them the production and processing hotspots in the entire system. Scenario 1 has the lowest GWP at 0.429 kg CO_2-eqiv, suggesting a relatively lower impact on global warming. This is as a result of combining grid electricity supply with charcoal in the smoking process, thereby reducing reliance on fossil fuels. Acidification Potential (AP) measures the potential for scenarios to cause acid rain and harm ecosystems. Scenario 4 has the highest AP at 5.68e-04 kg SO_2-equiv, indicating it emits more SO_2, a major contributor to acid rain. This is because of the high level of emission recorded as diesel fuel is the only source of energy in scenario 4. Scenario 1 has the lowest AP at 2.19e-04 kg SO_2-equiv, implying lower emissions of SO_2 and a reduced potential for acidification as electricity and charcoal are the sources of energy for scenario 2. Eutrophication Potential (EP) assesses the potential for scenarios to lead to nutrient enrichment in aquatic ecosystems. Scenario 3 has the highest EP at 7.24e-04 kg N-equiv., indicating higher nitrogen emissions, which promotes eutrophication. This occurrence results majorly from the processing unit, which produces nutrient rich wastewater and guts from fish processing. Scenario 1's low EP at 2.19e-05 kg N-equiv. reflects minimal nitrogen emissions and a reduced level contribution to eutrophication.

Smog Air values indicate the potential for scenarios to contribute to ground-level ozone formation, which can harm respiratory health. Scenario 3 with a value of 0.478 kg O_3-equiv has the highest potential for smog formation, mainly due to emissions of VOCs and NOx which directly comes from burning diesel and charcoal as energy source in the production process. Scenario 1, with a value of 0.0702 kg O_3-equiv, shows the lowest potential for smog formation, showing cleaner air quality with reduced emissions of VOCs and NOx.

Scenario 3 has the highest impact on human health criteria air at 1.503e-03 kg PM10-equiv. This signifies a significant potential health impact from fine particulate matter PM10, which can lead to respiratory and cardiovascular issues. Scenario 1 has the lowest impact at 4.173e-03 kg PM10-equiv, indicating relatively reduced health risks associated with PM10 exposure. The environmental profiles of human health criteria cancer show Scenario 4, with feed production and smoking as the production hotspots has the highest impact at 3.607e-10 CTUh, translating to the scenario having the highest potential cancer risk because of the release of carcinogenic substances into the atmosphere. Scenario 3 also has a notable cancer risk at 3.463e-10 CTUh, indicating potential exposure to carcinogens.

Table 6. Summary of results for all impact scenarios of smoked fish per kilogram.

Environmental Impacts/Units	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Global warming potential (GWP), kg CO_2-eqiv.	0.429	0.515	0.639	0.624
Acidification potential (AP), kg SO_2-equiv.	2.19e-04	2.88e-04	3.37e-04	5.68e-04
Eutrophication potential (EP), kg N-equiv.	2.19e-05	4.88e-05	7.24e-04	3.25e-04
Smog air, kg O_3-equiv.	0.0702	0.288	0.478	0.277
Human health criteria air, kg PM_{10}-equiv.	4.173e-03	3.502e-04	1.503e-03	3.443e-03
Human health criteria cancer, CTUh	1.738e-10	3.463e-11	3.463e-10	3.607e-10

3.1. Global warming potential

As analyzed by the IPCC GWP impact method [28], Figures, 2 and 3 shows the least and highest impact scenarios of GWP of the cradle-to-gate complete life cycle impact assessment of the unit processes associated with smoked fish production which was modelled on $GaBi_9$ for all the four different scenarios which was analyzed by the [27] GWP impact method. The total GWP for all the four scenarios (1, 2, 3 and 4) are 0.429, 0.515, 0.639 and 0.624 all measured in kg CO_2-Equiv. respectively.

The graph in Figure 3 represents scenario 3, which produced the greatest impact on GWP due to higher emission of CO_2 from the combustion of charcoal and diesel when smoking the fish in the kiln and producing feed. This is significantly less than the 3,670 kg CO_2-Equiv. reported by [28] using Sima Pro software to access fish production in three country countries. Consequently, the fish smoking/drying process emerged as the major contributor to

GWP. In contrast, Scenario 1 exhibited the lowest impact GWP impact, with broodstock transportation identified as its primary hotspot, as illustrated in Figure 2.

The differences observed among scenarios 1, 2, 3 and 4 for the production of 1kg of smoked fish at the University of Ibadan Fish Farm for GWP were primarily due to the impacts of fish smoking in the kiln and the duration required, as well as the impacts associated with transportation of the broodstock, feed production and fish harvesting. Among the unit processes having the greater GWP, the fish smoking/drying unit produced the highest GWP because that is the unit where CO_2-eq production activities happened the most. From these, it can be inferred that the least total impact GWP was observed for scenario 1.

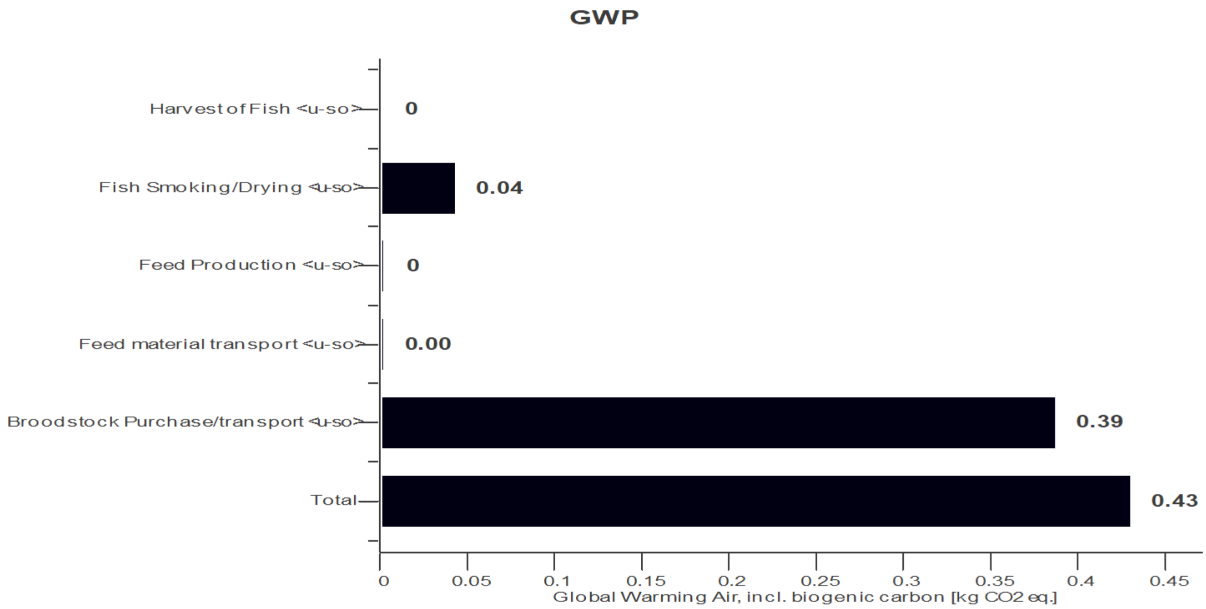

Fig. 2. Least global warming potential (Scenario 1).

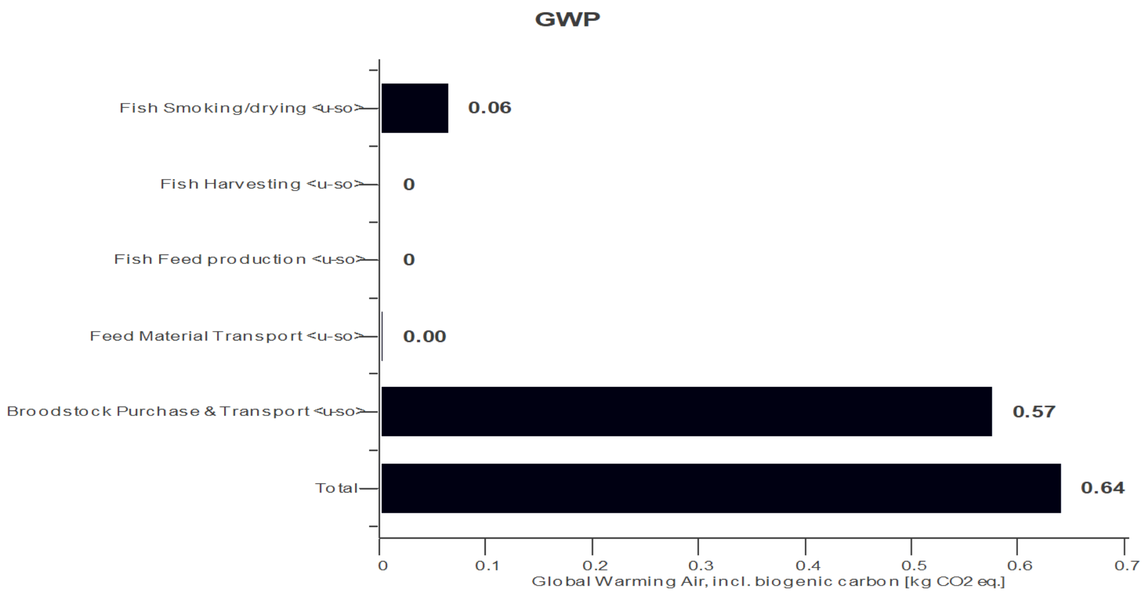

Fig. 3. Highest global warming potential (Scenario 3).

3.2 Acidification potential

This occurs because of pollutants finding its way into the water which then goes into the soil thereby increasing the acidity (hydrogen H^+). Acidifying substances are mostly emissions through air, which might travel for several hundreds of miles preceding its deposition as acid rain, fog, drying deposition as dust or smoke particulate matter on the soil or water, snow, etc. Majorly, acids of Sulphur dioxide (SO_2) and Nitrogen oxides (NO_x) from fossil fuel combustion are the largest contributors to acid rain [29].

Acidification results in the alteration of the pH of the receiving system which in turn damages the organic and inorganic nutrients and materials found in the medium. Substances that cause acidification have a high detrimental effect on lakes, streams, structures built by humans, paints, building materials, plants, and animals [30].

The AP of emissions from the unit processes of smoked fish production at the University of Ibadan Fish Farm is shown in Figures 4 and 5 for scenarios 1 and 4 respectively. The AP of scenario 4 was the highest (5.617e-04kg SO_2-Equiv.) from the process. Scenario 4 has the largest impact because of the emissions from AP gases of combusting large volume of fuel in the smoking/drying unit process. This is low compared to what was reported by [28] (25.12kg CO_2-Equiv.). This also makes the fish smoking unit process the production hotspot. Scenario 3 has the next highest impact on the environment due to the combination of charcoal and diesel in the smoking/drying unit process.

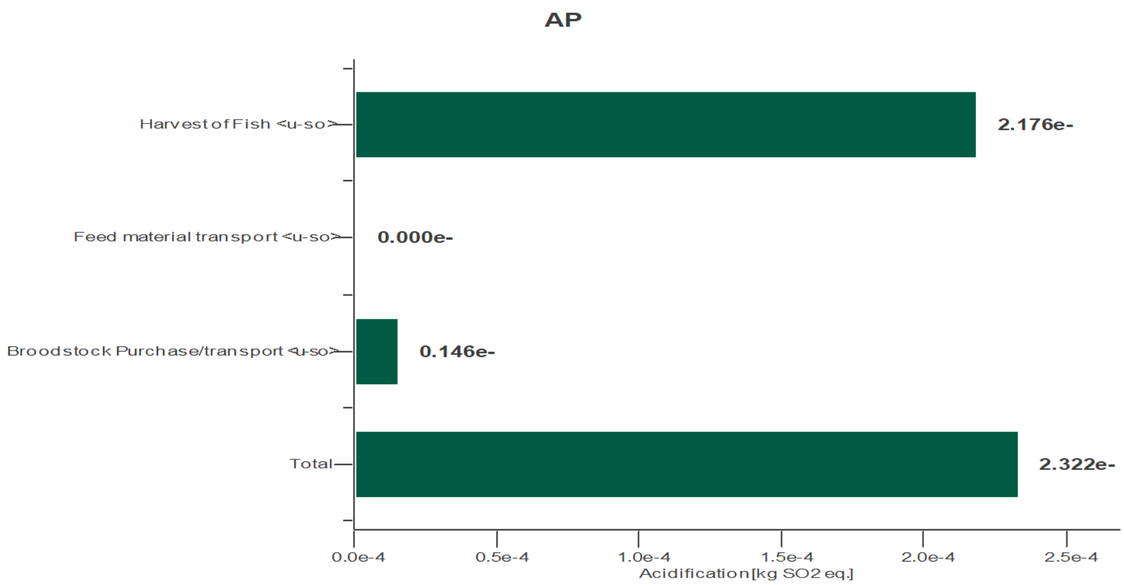

Fig. 4. Least acidification potential (Scenario 1).

The contribution of scenario 3 to the AP on the environment was recorded to be 3.37e-04kg SO_2-Equiv., while scenario 1 (2.322e-04kg SO_2-Equiv.) contributed the least impact AP. Scenario 1 has the least value of AP because of the lower emissions from the unit process thereby involving smaller amount of fuel being combusted. The activities in scenario 2 (2.808e-04kg SO_2-Equiv.) contributed the second lowest to AP due to low emissions from the use of electricity in the entire process.

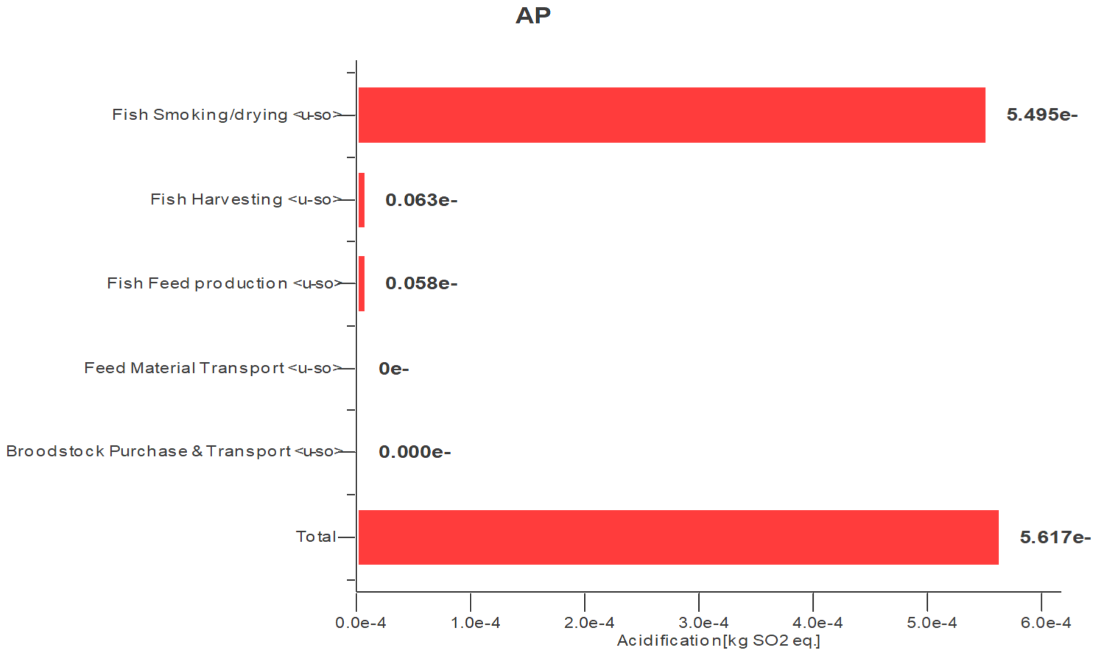

Fig. 5. Highest acidification potential for (Scenario 4).

3.3. Smog air

Smog airs are ozone (O_3) created at the ground-level by various chemical reactions between Nitrogen oxides (NOx) and volatile organic compounds (VOCs) in sunlight and which appears often as a haze in the air. Methane (CH_4) and carbon monoxide (CO) gases also play a role in the formation of ozone. Prolonged exposure of the environment to the ozone through smog has been identified as a contributing factor to adverse effects on structures, visibility, pre-mature deaths, effects on vegetation etc. human adverse health effects includes: permanent lung damage, increasing symptoms of asthma, emphysema, bronchitis, etc. [31].

Smog characterization analysis was done for VOCs and NO_x on $GaBi_9$ to determine the impact of the unit processes on the environment using TRACI midpoint model. The graph in Figure 6 represents scenario 1 which recorded the value 0.0702kg O_3-Equiv. with fish harvesting process the smog air emission hotspot, while the other unit processes recorded significantly lesser values. Scenario 2 reported smog air potential value of 0.288kg O_3-Equiv. Figure 7 represents scenario 3 with the value for smog air potential recorded to be 0.478kg O_3-Equiv. The graph of this scenario showed a better distribution of emissions between unit processes than the other three scenarios with fish harvesting taking 0.28kg O_3-Equiv. while feed production unit with 0.19kg O_3-Equiv. is the next smog air hotspot. Scenario 4 recorded the value of 0.277kg O_3-Equiv. Among all the procedures in the processes involved in the production of smoked fish at the University of Ibadan Fish Farm, scenario 3 contributed the greatest amount of smog air to the environment. The unit process which contributed the highest amount to smog air is the smoking/drying process because of the higher energy consumption compared to the rest of the other processes. Furthermore, the fish harvesting unit process showed the next highest values in terms of smog air hotspot because of the combustion of fossil fuel during the process. Scenario 1 contributed the least amount of smog air impact followed by scenario 4. This value is also lower compared to the 2.92kg CO_2-equivalent reported by [32]. This is because scenario 3 combusted a higher amount of fossil fuel in addition to the charcoal being used for smoking the fish. Meanwhile, scenario 1 has the least impact on eutrophication because the process requires less energy consumption.

A general comparison of all the six-impact category that was modelled in $GaBi_9$ for 1kg Smoked Fish production at the University of Ibadan Fish Farm showed that the highest impact categories among others from Smoked Fish production for all the four scenarios were GWP, Smog Air, Human Health Criteria Air and AP categories [33]. Among the contributors to these four categories with higher impacts was the fish smoking and transportation activity. A comparison among the four scenarios of GWP which is the greatest impact category indicated that scenario 4 (Diesel) gave the greatest impact on the environment for all TRACI midpoint impact categorization while Scenario 2 (Electricity) showed the least impact. Life Cycle Impact Assessment (LCIA) of the unit processes indicated that the highest environmental impacts across all scenarios were associated with fish smoking, transportation of broodstock and feed materials, fish harvesting and feed production.

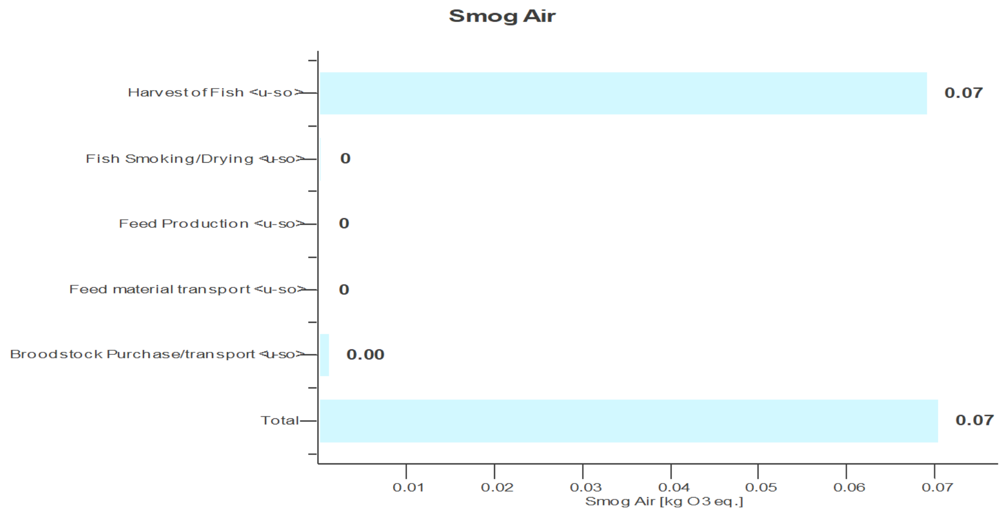

Fig. 6. Lowest smog formation potential (Scenario 1).

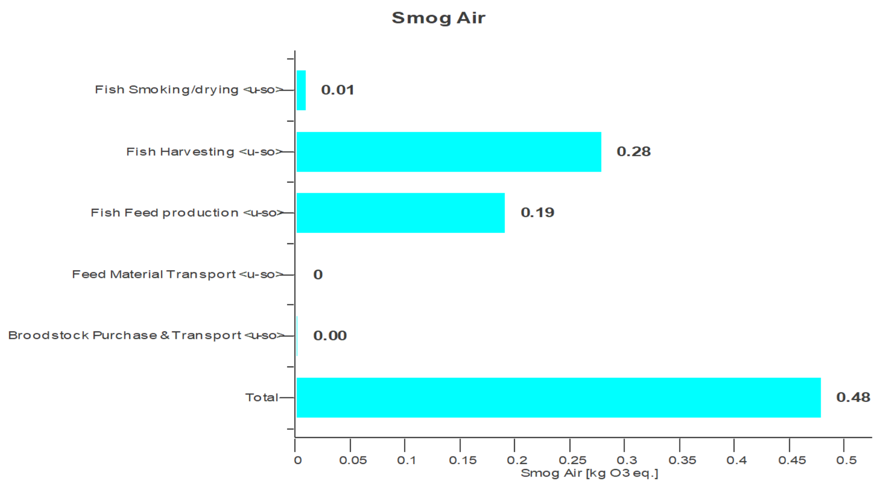

Fig. 7. Highest smog formation potential (Scenario 3).

4. CONCLUSION

In this work, the 'cradle-to-gate' method (from purchasing of broodstock to packaging) of the LCA of smoked fish products, and the University of Ibadan Fish Farm was used as a case study with particular focus on the production and processing of fresh fish into smoked/dried fish.

The impact categories characterized and analyzed for this LCA study include: GWP, AP, EP, Smog Air, Human Health Criteria Air and Human Toxicity Cancer Effect. Results from the analysis on $GaBi_9$ showed that the highest impact categories among others, from smoked fish production process, for all the scenarios, was the GWP at 0.639 kg CO_2-equivalent with the highest smog formation in scenario 4; the main process affecting it is the smoking of fish in the kiln which requires combustion of charcoal, diesel, and use of electricity for the various scenarios. Moreover, the human toxicity (cancer effect) impact category recorded the lowest impact, with a value of 3.463e-11 CTUh in Scenario 2. All four scenarios studied demonstrated adverse environmental impacts. Combustion of charcoal as an energy source releases into the environment greenhouse gases such as CO_2, CH_4,

N_2O, etc. In addition, the combustion of Premium Motor Spirit (PMS) and diesel released gases such as CO, NO_x, SO_2, VOC, $PM_{10\&2.5}$ etc. The disposal of the wastewater from the process into the open drains poses a risk of contaminating nearby water sources (particularly the Awba Dam) and the surrounding soil.

Therefore, for industry practitioners and policy makers in Fisheries and Aquaculture, during decision making, in order to reduce environmentally detrimental effects and impacts due to the production and processing of smoked fish in the University of Ibadan Fish Farm where this life cycle assessment was carried out, alternative fuel sources such as renewable energy, along with environmentally friendly machines should be designed and developed for the smoking process which was identified as the biggest hotspot in the production of 1kg functional unit of smoked fish at the University of Ibadan Fish Farm.

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