# Mechanised shea butter production in south-western Nigeria using Life Cycle Assessments (LCA) approach from gate-to-gate

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**Abstract:** Agriculture and food processing, industry are among the largest industrial sectors that uses large amount of energy. Thus, a larger amount of gases from their fuel combustion technologies are being released into the environment. The study was therefore designed to assess each unit production processes in order to identify hotspots using life cycle assessments (LCA) approach in South-western Nigeria. Data such as machine power rating, operations duration, inputs and outputs of shea butter materials for unit processes obtained at site were used to modelled Life Cycle Impact Analysis (LCIA) on GaBi6 (Holistic Balancing) software. Four scenarios were drawn for the impact assessments. Material sourcing from Kaiama, Scenarios 1, 3 and Minna Scenarios 2, 4 but different heat supply sources (Liquefied Petroleum Gas 'LPG' Scenarios 1, 2 and 10.8 kW Diesel Heater, scenarios 3, 4). Modelling of shea butter production on GaBi6 was for 1kg functional unit of shea butter produced and the tool for the Reduction and Assessment of Chemical and other Environmental Impacts (TRACI) midpoint assessment was tool used to analyse the life cycle inventories of the four scenarios. Eight categories in all four Scenarios were observed, out of which two impact categories; Global Warming Potential (GWP) (0.613, 0.751, 0.661, 0.799) kg CO2¬-Equiv., and Acidification Potential (AP) (0.112, 0.132, 0.129, 0.149) kg H+ moles-Equiv., had the greater impacts on the environment in Scenarios 1-4 respectively. Impacts from transportation activities were also seen to contribute more to these environmental impact categories due to large volume of petrol combusted leading to releases of gases such as CO2, CH4, N2O, SO2, and NOx into the environment during the transportation of raw shea kernel purchased. The ratio of transportation distance from Minna and Kaiama to production site was approximately 3.5. Shea butter unit processes with greater impacts in all categories was the packaging, milling and with the churning processes in ascending order of magnitude was identified as hotspots that may require attention. From the 1kg shea butter functional unit, it was inferred that locating production site at the shortest travelling distance to raw material sourcing and combustion of LPG for heating would reduce all the impact categories assessed in the environment.

**Keywords:** GaBi6, Life Cycle Assessment, shea butter production, global warming potential, acidification potential, South-western Nigeria

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## 1 Introduction

Agriculture and food processing industry around the world is one of the largest industrial sectors and hence, a larger user of energy leading to a significant proportion of carbon dioxide ($CO_2$), methane ($CH_4$,) and nitrous oxide ($N_2O$) gases being released into the atmosphere (Jekayinfa et al., 2013; IPCC, 2001a). Although, both $CH_4$ and $N_2O$ gases are released in much smaller quantities than $CO_2$, they have a much greater global warming potential. The contribution to the impact of greenhouse gases by emission of these gases from Africa is less than 4% and yet the most vulnerable to the impact of change because it has less or no adaptive strategy to cope with the climate change. While the industrialised nations such as the US; the largest emitter of $CO_2$, contribute more to global warming, they have the capacity to adapt to its effects (Nicholas et al., 2012; Olaniyi et al., 2013).

Shea tree exists in nineteen countries across the African continent according to FAO (1998) and covers a swath of the continent, some 5,000km long and

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400-750km wide; only in Ghana and Nigeria does it occur within 50km from the coast (Nikiema and Umali, 2007). For a matured shea tree, the height varies considerably with some trees attaining heights of over 14m to about 25m and girth of over 1.75m (Yidana, 1994). Shea butter industry is still a virgin industry in Nigeria but gaining an increasing awareness due to the interest of the Federal government on its importance as an industrial crop with potential for foreign exchange earnings. Upgrading of shea butter production technology is aimed at reducing the drudgery during production experienced by local people and also to make the shea butter of standard quality (Matanmi et al., 2011; Garba, et al., 2011).

Shea butter is an ivory or yellowish coloured natural fat extracted from dried kernels of the African shea tree. The shea butter tree (*Vitellariaparadoxa*) which belongs to the family *Sapotaceae*is native to sub-Saharan African; it flourishes best in the wild and it is not easily cultivated (Matanmi et al., 2011). Though it appears to be a rather obscure wild species, it is a widely known value and comprises of a unique resource for improving the livelihoods of the natives in areas where it occurs (Daniel et al., 2005). In an estimate of the population of shea tree given by Maranz and Wiesman (2003), it was seen that at least 500 million production trees are accessible in West Africa, and this equates to a total of 2.5 million tonnes of dry kernel per annum (based on 5 kg dry kernel per tree). In Africa, Nigeria is the leading producer of Shea nut with about 355,000 t (Metric Tonnes) produced in 1999, 58% of the production in Africa and 414,000 t in 2005. Other leading producers of shea nuts are Mali and Burkina Faso producing about 85,000 t and 70,000 t respectively as at 2005 (Garba, et al., 2011). There had not been proper estimate of the overall balance between the cost of input and economic output of Shea butter, as the processing is not only arduous, labour-intensive and time consuming, it also requires large amounts of water and energy. In an estimate made by Bonkoungou (2005) for the traditional processing of 1kg of Shea butter, it takes on an average of 20-30 hours for one person to process 1kg of shea butter from collection to final product. While studies have been conducted on the importance, prospect and production processes of shea butter, there have been knowledge gaps in understanding environmental impacts of such activities globally. Most agricultural activities have inputs from the environment or output into the environment which have effects they contribute to the environment. Influence on the environment may include acidification (soil and ocean) smog, ozone layer depletion, global warming (greenhouse gases), eutrophication, eco-toxicological and human toxicological pollutants, habitat destruction, desertification, land use as well as depletion of minerals and fossil fuels (Jekayinfa et al., 2013).

Life Cycle Assessment (LCA) is a tool that can be used to evaluate the environmental impact of providing, using and disposing of a product or providing service throughout its life cycle (ISO, 2006), which is known as a ‘from cradle to grave’ analysis. LCAs have been used as a tool to identify “hot spots” in the production chain that may introduce effective mitigation measures for simultaneously lowering environmental impacts and improving efficiency and profitability (Hogass, 2002). This research was designed to investigate and quantify varieties of environmental impacts associated with mechanised shea butter of a production industry in Nigeria using the “cradle to gate” LCA methodology. This would help in compiling an inventory of relevant inputs and outputs of shea butter production from shea nut and also to help shea butter industry stakeholders identify and evaluate the scope for the improvement of their production system.

The LCA shall adopt a cradle-to-gate global impact assessment and carbon footprint (global warming potential) analysis. These will include full analyses of the upstream impacts of materials and energy consumed for processing of shea butter from a functional unit. Researchers such as (Olaniyan and Oje 2007; Garba et al., 2011; Ololade and Ibrahim, 2014; Obibuzor et al., 2014) have investigated the properties, production, contribution and potential industrial uses of Shea butter, no report has been on carbon foot print of such activities.

## 2 Materials and methods

This study employed the $GABI_6$ software in LCA of a mechanised shea butter production process in Nigeria. The LCA was designed to comply with ISO 14040 and ISO 14044 standards which provide an internationally accepted method of conducting LCAs, while leaving significant degree of flexibility in the customisation of individual projects methodology to suit the desired application and outcomes. The LCA consists of four stages: (1) goal and scope definition, in which the frameworks, goals, objectives and boundaries would be defined-including appropriate metrics (e.g. greenhouse gas emissions, water consumption, hazardous materials generated, and/or quantity of waste); (2) inventories analysis, which involves collection of data that identifies the system inputs and outputs and discharges to the environment, (3) impact assessment, and (4) analysis and interpret the results.

This life cycle assessment is a gate-to-gate (from shea kernel purchase at farm-gate to shea butter exit-gate) data collected was primarily from an industry in Ilorin. The system boundaries begin with shea nut transportation and end with the packaging of the product (Figure 1).Functional unit of this study is defined as one kilogram of shea butter produced. For convenience, analysis conducted in this study is for the 1kg of butter product category and does not take into consideration processing and packaging material for additional product sizes. All $GaBi_6$ model inputs are for 30% of shea butter produced from the raw materials, however, in the impact analysis we run for 1kg of shea butter produced. This is to enable the comparison of mechanised shea butter production with other methods of shea butter production.

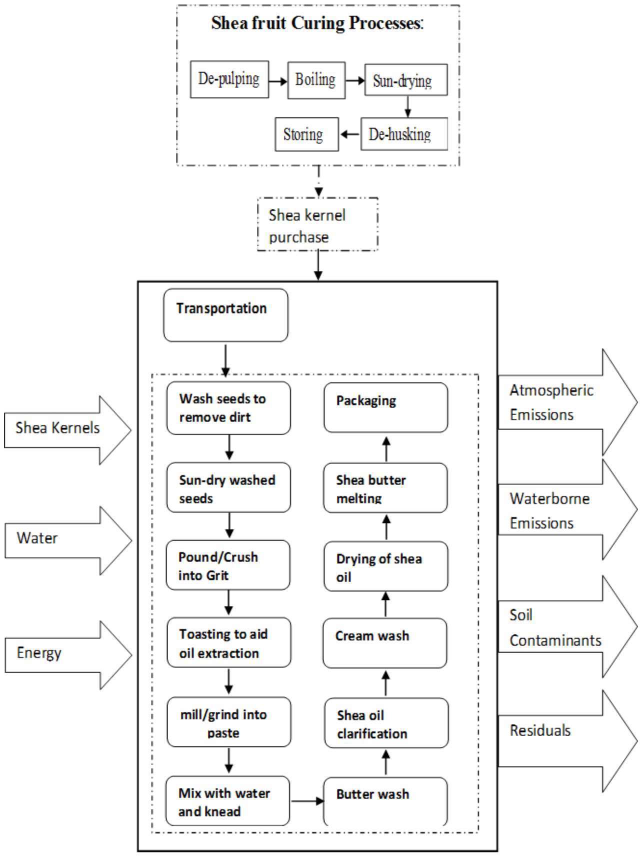


Figure 1 System boundary flow diagram for a mechanised shea butter production

Data for project Life Cycle Inventories (LCI) collected was based on all energy and material inputs for each unit processes as well as the quantity and type of waste generated. Modelling the shea butter unit processes helped to outline the relationships between unit processes and flows across the system boundaries, describing the sources of emissions (Table 1). Two scenarios of mechanised shea butter production were considered in terms of mode of heat supplied to some of the processes. Scenario 1 was for shea butter production using gas ($S.B_{gas}$) as a mode of heat supply in some processes, while scenario 2 was using 10.8 kw heaters ($S.B_{heater}$) (Table 2). Processes involving heat energy were; toasting, clarification, drying and melting processes. For both scenarios, distance for the transportation of shea kernels was varied based on two locations from which shea kernel were purchased.

**Table 1 Sources of primary greenhouse gas emissions (cold extraction method of shea butter production)**

| Item (input/output) considered | Processes included in assessment | Sources of GHG emissions for inputs and outputs |
|---|---|---|
| Harvesting of shea fruits | Harvesting and decomposition | $N_2O$ from post-harvest, crop residues left on fields, fuel combustion during transportation |
| Curing | De-pulping, Boiling, Sun-drying, De-husking, storing | $CO_2$ and $CH_4$ from decomposition of waste generated, $CO_2$ from wood combustion, electricity and fuel used for processing |
| Raw shea kernel purchase | Transportation of shea kernel from farm gate to processing site | Fuel combusted during transportation |
| Shea kernel washing | Water, energy used | Electricity, fuel, water pumping |
| Shea kernel crushing | Energy used | Fuel combusted, electricity used |
| Shea kernel toasting | Gas burner, heater, Energy used | gas, fuel and/or electricity used |
| Shea kernel grinding | Water pump, motor energy | Electricity, fuel combustion |
| Shea kernel churning | Water pump, motor energy | Electricity, fuel combustion |
| Butter wash | Water pump, motor energy | Electricity, fuel combustion |
| Shea butter clarifier | Water pump, motor energy | Electricity, fuel combustion |
| Shea oil dryer | Gas burner, heater | Gas, electricity and fuel |
| Shea butter melting | Gas burner, heater | Gas, electricity and fuel |
| Shea butter packaging | Electricity or fuel used | Fuel, electricity used |
| Shea kernel waste | Waste deposit on land | $CH_4$ from waste on land |

**Table 2 Description of scenarios**

| Scenarios | Distance | Features of the scenarios |
|---|---|---|
| Scenario 1($S.B_{gasKaiama}$) | 103 | utilization of gas for the heating of some shea butter production processes |
| Scenario 2($S.B_{gasMinna}$) | 365 | utilization of gas for the heating of some shea butter production processes |
| Scenario 3($S.B_{heaterKaiama}$) | 103 | utilization of heaters (10.8kW) for the heating of some shea butter production processes. |
| Scenario 4($S.B_{heaterMinna}$) | 365 | utilization of heaters (10.8kW) for the heating of some shea butter production processes. |

Primary data were obtained from documented records of production, interview and site visits. Data obtained includes, input and output of raw material from each unit processes, machine energy consumption and also duration of each processes. Fuel consumption for each unit process was calculated based on the machine power ratings and hours of operation using diesel generator fuel consumption chart in litres. In this case a 30 kVA diesel generator was used to power the machines. For the purpose of this analysis, the same mode of transport (3.5 tons petrol bus, from EcoInvent data base in $GaBi_6$), but two different average distances from point of shea kernel purchase to the processing site were considered. Shea kernels were transported over 103km from kaiama local government in Ilorin, Kwara state and 365km from Minna, in Niger state to the processing site in Ilorin Kwara state.

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 of producing 1kg of shea butter on $GaBi_6$ software. Based on a 100-year time horizon, Intergovernmental Panel on Climate Change (IPCC, 2007) 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 = 1.9, $CH_4$ = 27.75 and $N_2O$ = 298.

Emissions from transportation were calculated using the bottom-up approach method obtained from 'Climate Leaders GHG inventory Protocol'. Petrol/gasoline was the major fuel used in transportation and the emissions were calculated based on the distance travelled in kilometres and fuel economy factor (Equation 1). Emissions calculation procedure of pollutants from the combustion of diesel in stationary engines and burning of Liquefied Petroleum Gas (LPG) were estimated using Equation 2. The emission factors for petrol (Table 3) were obtained from National Pollutant Inventory (NPI, 2002) and Spielmann et al. (2007). For stationary combustion diesel engines and LPG combustion, the emission factors were based on data from Environmental Protection Agency (EPA, 2008) and NPI (2002) as is shown in Table 4. Bottom-up approach to estimate fuel use

$$\text{Fuel use} = DT \times FE \quad (1)$$

Where: *DT* = Distance travelled activity factor; and *FE* = Fuel Economy Factor.

Estimation method of pollutants from stationary combustion diesel engines and LPG

$$\text{Emissions}_{p,s} = A_s \times EF_{p,s} \quad (2)$$

Where: *p* = Pollutant (such as $CO_2$, $CH_4$, Cd…); *s* = Source Category; *A* = Activity Level; *EF* = Emission Factor.

Environmental impact of shea waste were analysed in $GaBi_6$ based on the mean mineral properties of shea waste values obtained from a research project by Abdul-Mumeen et al. (2013). The minerals were nitrogen (N) 2.96 mg/kg, potassium (k) 4.05 mg/kg, magnesium (Mg) 1.43 mg/kg, phosphorus (P) 0.22 mg/kg, sodium (Na) 0.4, Calcium (Ca) 0.51 mg/kg, cupper (Cu) 0.09 mg/kg, mercury (Hg) 0.1 mg/kg, lead (Pb) 0.13 mg/kg.

**Table 3 Emission factors for petrol-road transport**

| 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 |
| 1,3,Butadiene | 1.78E-05[b] | kg/km |
| Benzene | 5.17E-05[b] | kg/km |
| CO | 1.18E-02[b] | kg/km |
| NOx | 1.50E-03[b] | kg/km |
| $PM_{10}$ | 3.10E-05[b] | kg/km |
| $SO_2$ | 5.58E-05[a] | kg/km |
| VOCs | 1.16E-03[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 |

Note: (a):Spielmann et al.(2007) (b): National pollutant inventory (2002)

**Table 4 Emission factor for diesel and LPG combustion**

| Diesel combustion in stationary engines | | | LPG combustion for cooking | | |
|---|---|---|---|---|---|
| Pollutant | Emission factor | Unit | Pollutant | Emission factor | Unit |
| $CO_2$ | 3.17E+00[c] | $kg/kg_{fuel}$ | $CO_2$ | 2.96E00[C] | $kg/kg_{fuel}$ |
| $CH_4$ | 4.50E-04[c] | $kg/kg_{fuel}$ | $CH_4$ | 2.40E-04[C] | kg/L |
| $N_2O$ | 8.12E-05[c] | $kg/m^3$-fuel | $N_2O$ | 1.08E-04[C] | kg/L |
| $NO_X$ | 7.25E+01[b] | $kg/m^3$-fuel | $NO_X$ | 1.56E-03[C] | kg/L |
| CO | 1.56E+01[b] | $kg/m^3$-fuel | CO | 9.00E-04[C] | kg/L |
| $SO_2$ | 4.77E+00[b] | $kg/m^3$-fuel | $SO_2$ | 1.20E-05[C] | kg/L |
| VOC | 5.30E+00[b] | $kg/m^3$-fuel | TOC | 1.20E-04[C] | kg/L |
| $PM_{10}$ | 5.10E+00[b] | $kg/m^3$-fuel | $PM_{total}$ | 2.40E-05[C] | kg/L |

Note: (b): National pollutant inventory (2002) (c): EPA (2008)

Tool for the Reduction and Assessment of Chemical and other Environmental Impacts (TRACI) impact assessment methodology was employed. TRACI midpoint is a problem-oriented approach and uses environmental themes such as in Table 5.

**Table 5 Cause-effect chain selection**

| Impact category | Midpoint level selected | Level of site specificity selected | Possible endpoints |
|---|---|---|---|
| Ozone Depletion (kg CFC 11-Equiv) | Potential to destroy ozone based on chemical's reactivity and lifetime | Global | Skin cancer, cataracts, material damage, immune system suppression, crop damage |
| 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 (mol $H^+$ 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 | Plant, animal and ecosystem effects, odors and recreational effects, human health impacts |
| Fossil fuel | Potential to lead to reduction of availability of low cost/energy fossil fuel Supplies | Global | Fossil fuel shortages leading to use of other energy sources, which may lead to other environmental or economic effects |
| Land use | Proxy indicator expressing potential damage to threatened and endangered species | U.S., east or west of Mississippi River, U.S. census regions, county | Effects on threatened and endangered species (as defined by proxy indicator |
| Water use | Not characterized at this time | | Water shortages leading to agricultural, human, plant, and animal effects |

Source: Bare et al. (2003)

The modelling of mechanised shea butter production chain in $GaBi_6$ accounted for all units involved in the shea butter extraction chain starting from shea kernel purchasing distance to packaging. Each stage in the shea butter production chain was constructed as a unit process on $GaBi_6$, the input and output date (energy, volume of diesel, raw materials and emissions) were the flows. Flows are used to link processes up. Input flows were majorly, quantity of raw materials used such as volume of water, L; weight of shea kernel, kg; and volume of fuels, L. The output flows were the mass of processed shea kernels, kg; volume of waste water, L; volume of corresponding emissions to the Atmosphere (GHG), water (Eutrophication), and soils.

## 3 Results

In the processing of shea butter for this life cycle assessment report, it was observed that about 30% of the mass of raw shea kernel processed was obtained as shea butter while others were wastes (shea cake waste) obtained from four unit processes in the shea butter production chain. The unit processes are: clarification (8% shea cake waste), butter washing (3% shea cake waste), cream washing (2% shea cake waste), with the bulk of shea waste (57%) from churning process (Figure 2). The major material input in the mechanised shea butter production system was water. Volume water inputted is directly released as waste output into the environment after each unit process for which it was utilised.

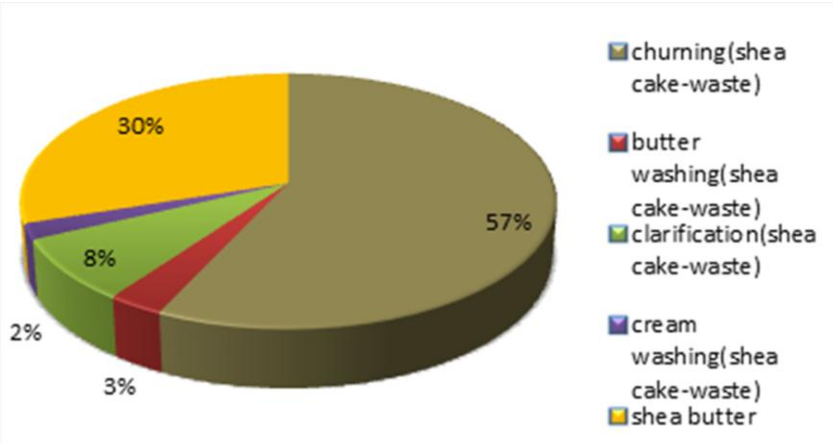


Figure 2 Percentage of shea kernel wastes and shear butter produced

### 3.1 Global warming potential

From Figure 3 to Figure 6 showed the gate-to-gate complete LCIA of all unit processes in shea butter production chain modelled on $GaBi_6$ for the four scenarios as analysed by the IPCC 2007 GWP impact method. Also included are the GWP for all transportation made based on individual distance from shea kernel purchase locations to the industry. Scenario 4 was seen to produce the greatest impact (0.799kg $CO_2$-eq) among other three scenarios due to higher $CO_2$ equivalent gases emitted from the combustion of diesel in four unit processes. Comparing Scenario 2 with Scenario 4, with both having the same distance, Scenario 2 was observed to have a lower emission of '0.048kg $CO_2$-eq'. Apparently, this was due to lower emission of carbon dioxide equivalent gases from the combustion process of LPG for heating. Among the unit processes having greater GWP, it was seen in all four scenarios that these unit processes; shea nut milling, churning, and shea butter packaging had the same GWP of 0.158 kg, 0.164 kg and 0.079 kg $CO_2$ equivalent respectively. This may be due to the fact that these three unit processes combusted diesel as the only major source of fuel during the unit operations. Each unit processes combusted equal volume of diesel in all scenarios and transportation distance of raw materials does not come to play here as all unit operations were within the processing factory.

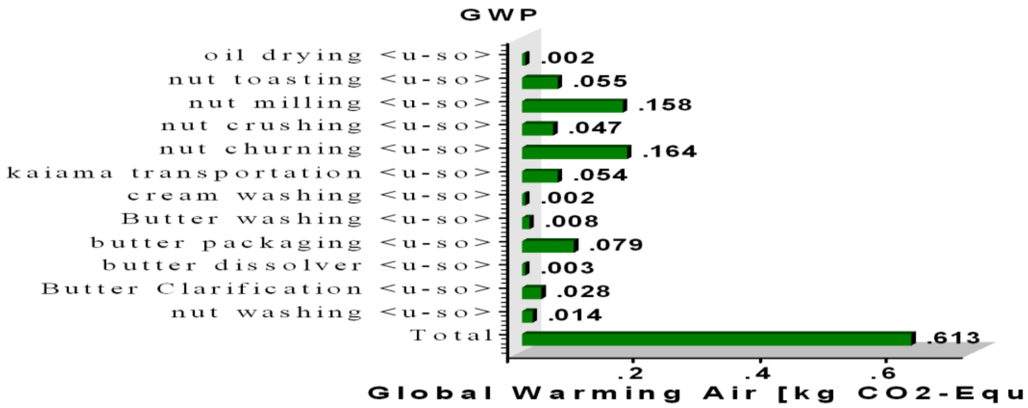


Figure 3 GWP for unit processes of 1 kg shea butter for scenario 1

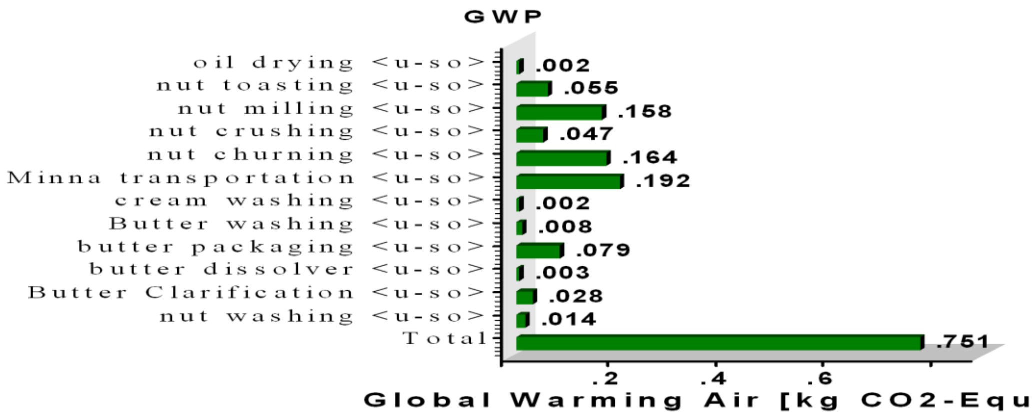


Figure 4 GWP for unit processes of 1 kg shea butter for scenario 2

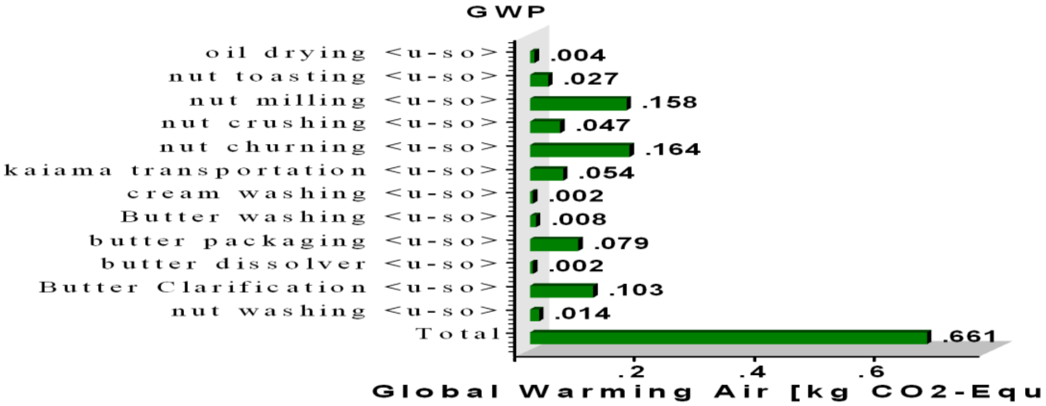


Figure 5 GWP for unit processes of 1 kg shea butter for scenario 3

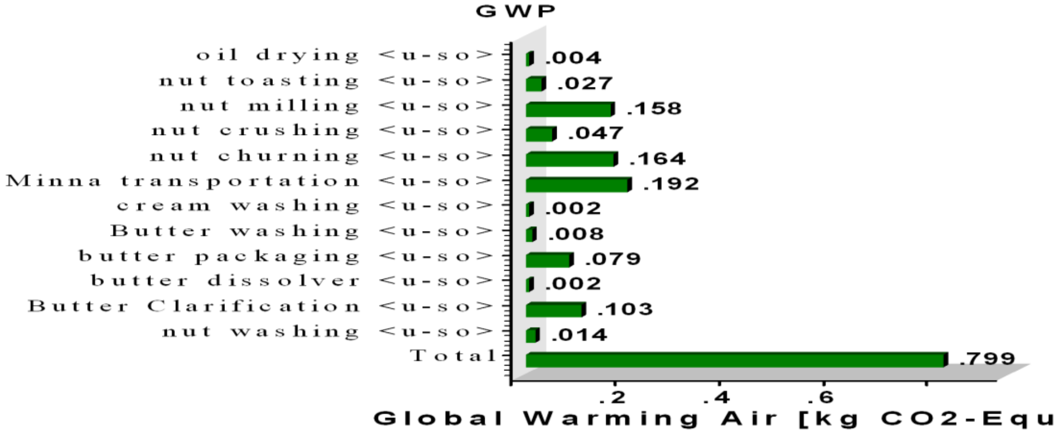


Figure 6 GWP for unit processes of 1 kg shea butter for scenario 4

Differences observed in the totals of scenarios 1 and 2, and scenarios 3 and 4 in the unit production processes of 1 kg shea butter for Global Warming Potentials was due to the impacts associated with raw materials transportation distance covered; from these it can be inferred that the least total impact GWP was observed for scenario 1. Hence, combusting liquefied petroleum gas (LPG) for heating in the unit production and travelling over a shortest distance (Kaiama) to sort for raw materials for the processing factory gave the least GWP impact.

### 3.2 Acidification potential

Acidification shows important processes that increase the acidity (hydrogen ion concentration, $H^+$) of water and soil systems as seen in Figure 7 to Figure 10. Acidifying substances are often air emissions, which may travel for hundreds of miles prior to wet deposition as acid rain, fog, or snow or dry deposition as dust or smoke particulate matter on the soil or water. Sulphur dioxide ($SO_2$) and nitrogen oxides ($NO_x$) from fossil fuel combustion have been the largest contributors to acid rain. Acidification causing substances has deleterious effects on building materials, paints, and other human-built structures, lakes, streams, rivers, and various plants and animals. The use of TRACI midpoint assessment on $GaBi_6$ gives an acidification model which incorporates the increasing hydrogen ion potential with the environment without incorporation of site-specific characteristic such as the ability for certain environment to provide neutralization capability (USEPA, 2012). Each column in Figures 7 to 10 showed the total fuel-related acidification emissions for all four scenarios.

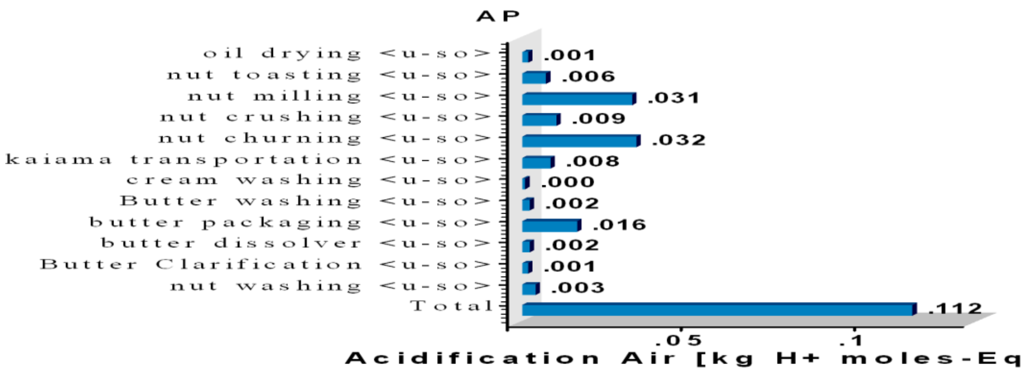


Figure 7: Acidification Air for unit processes of 1kg-shea butter for scenario 1

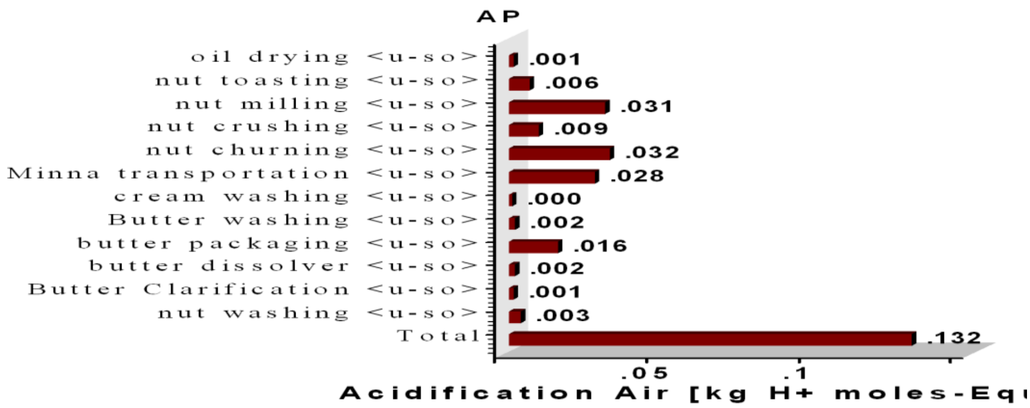


Figure 8 Acidification Air for unit process of 1 kg shea butter for scenario 2

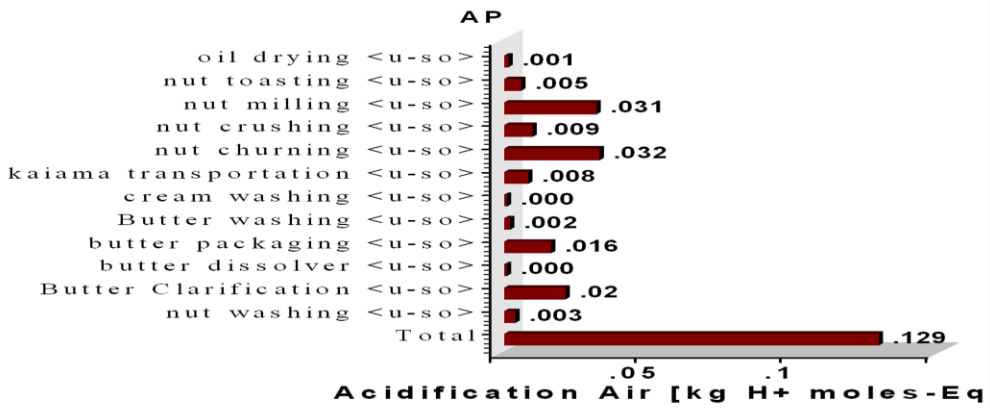


Figure 9 Acidification Air for unit process of 1 kg shea butter for scenario 3

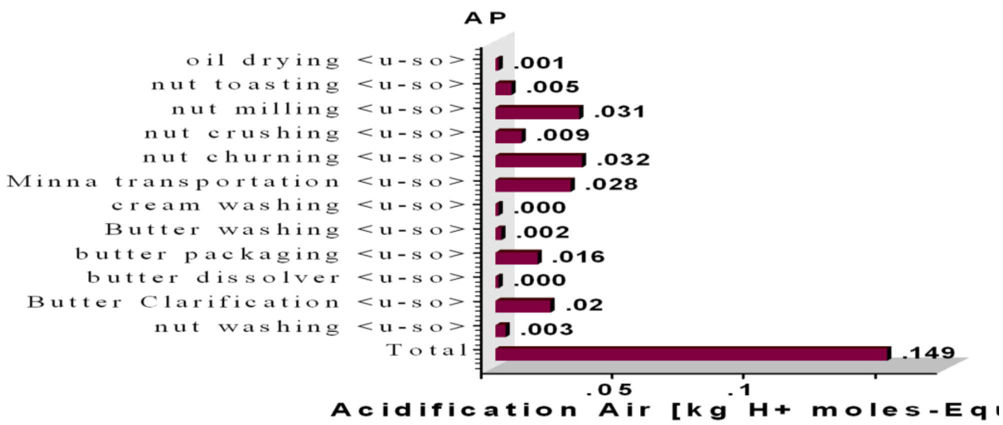


Figure 10: Acidification Air for unit process of 1kg shea butter for scenario 4

### 3.3 Eutrophication potential

This LCA report on eutrophication potential is based solely on the impact of atmospheric emissions from combustion of fossil fuel-derived oxides of nitrogen. On $GaBi_6$, TRACI characterisation factor for eutrophication are the product of a nutrient factor and a transport factor. For each scenario, the weight of each pollutant emitted is calculated and inputted into the software. Each column in Figure 11 to Figure 14 shows the fuel-related eutrophication emissions of each unit process for scenarios 1-4 respectively. The unit processes seen to contribute higher eutrophication impacts among all other unit processes having constant value for all scenarios in order of increasing magnitude are; shea nut churning (1.956E-05 kg N-eq), shea nut milling (1.883E-05 kg N-eq), shea nut packaging (0.937E-05 kg N-eq) and shea nut crushing (0.557E-05 kg N-eq) for the four scenarios. This was due to the fact that all the four unit processes burned the same volume of diesel for their operations. Eutrophication potential form the combustion of petrol fuel in transportation for both Scenarios 2 and 4 (3.077E-05 kg N-eq) in Figures 12 and 14 were also of higher impacts. Scenario 4 gave the highest eutrophication potential of 1.04E-04 kg N-eq (Figure 14) while Scenario 1 had the least impact of 7.399E-05 kg N-eq (Figure 11).

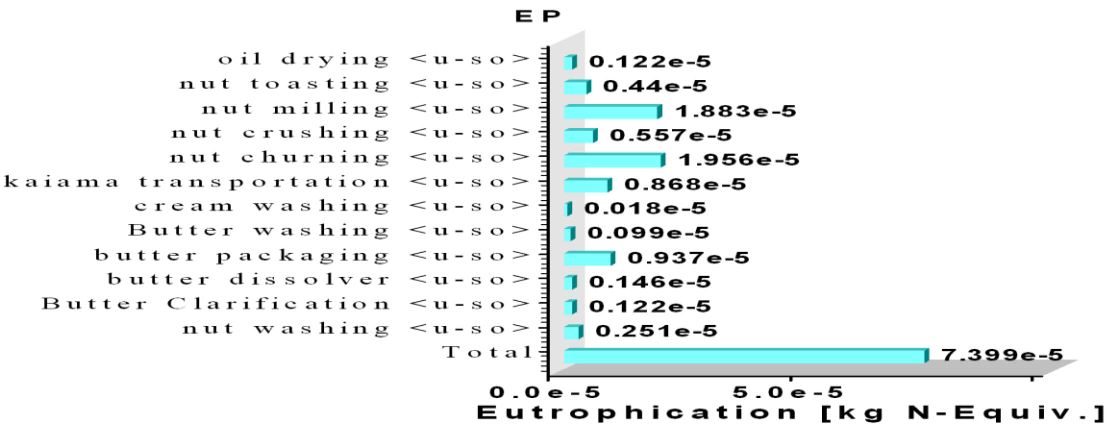


Figure 11 (EP) for unit process of 1 kg-shea butter for scenario 1

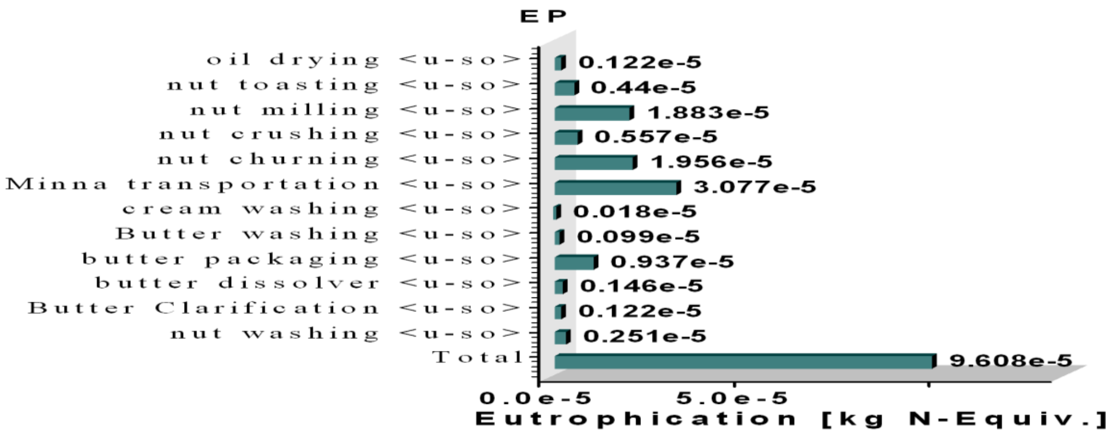


Figure 12 Eutrophication (EP) for unit process of 1kg-shea butter for scenario 2

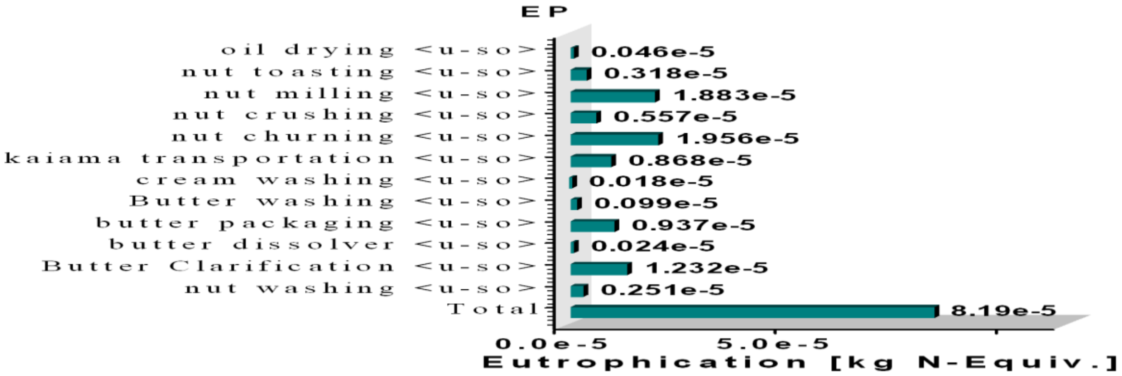


Figure 13 Eutrophication (EP) for unit process of 1 kg-shea butter for scenario 3

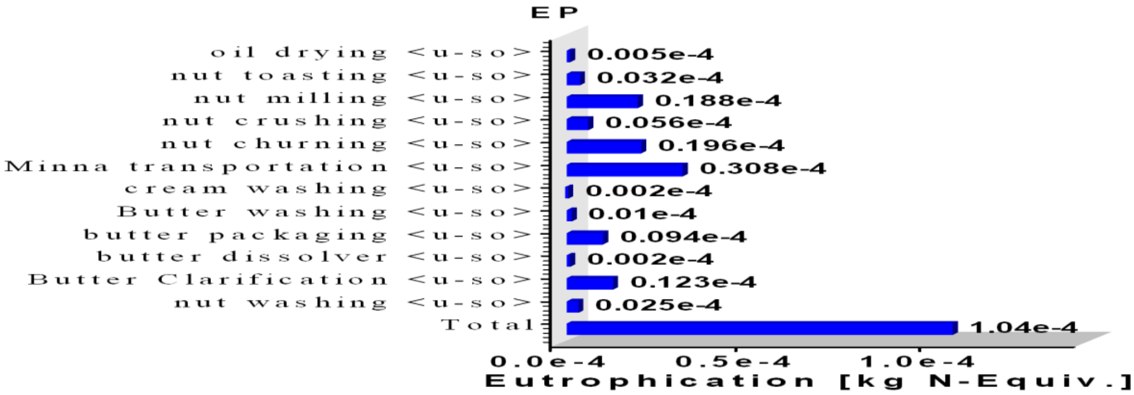


Figure 14 Eutrophication (EP) for unit process of 1 kg-shea butter for scenario 4

A general comparison of all the impact category of 1kg shea butter production showed that the highest impact categories among others from shea butter production for all scenarios were Global Warming Potential (GWP) and Acidification Potential (AP) categories (Figure 15). Among the contributors to these two categories with higher impacts was the transportation activity. A comparison among the four scenarios indicated that scenario 4 ($S.B_{HeaterMinna}$) gave the greatest impact on the environment for all TRACI midpoint impact categorisation while Scenario 1 ($S.B_{GasKaiama}$) showed the least impact (Figure 15). The LCIA for the unit processes showed that the greatest impact from shea butter production chain were from the milling, churning and packaging processes for Scenarios 1 and 2.

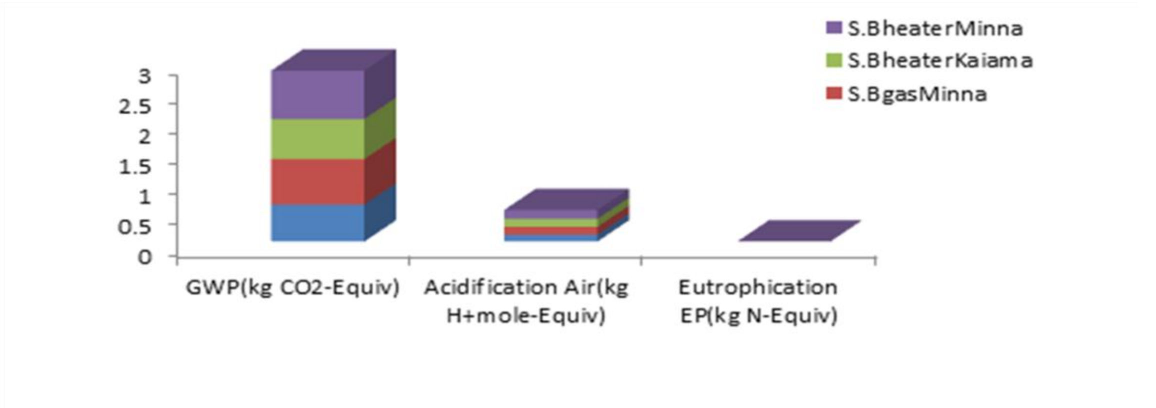


Figure 15 Comparing TRACI midpoint impact characterisation categories analysis for all scenarios

## 4 Conclusion

Hence for policy makers in decision making, to reduce environmental loads due to mechanised shea butter production in south-western Nigeria where the assessment was carried out, alternative fuel sources and least impact machine designs could be developed for the milling, churning and packaging processes that have been identified as hotspots in the production of 1kg functional unit of shea butter.

Main processes affecting GWP, AP and EP were the milling, churning and packaging unit processes and with the inclusion of clarification process in Scenarios 3 and 4. Diesel fuel was predominantly the major fuel used in operating all machines except in some cases when liquefied petroleum gas was used.

A comparison among the four scenarios indicated that scenario 4 ($S.B_{HeaterMinna}$) gave the greatest impact on the environment for all TRACI midpoint impact categorisation while Scenario 1 ($S.B_{GasKaiama}$) showed the lowest impact. In comparison of gate-to-gate impact of producing 1kg shea butter, a highest impact category among others in shea butter production was GWP. Since petrol was the major fuel used in transportation of raw shea kernels purchased, Minna transportation distances about 3.5 times Kaiama distances showed a great effect of shea kernel purchasing distance to production site.

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