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LIFE CYCLE ASSESSMENT OF VEGETABLE OIL PRODUCTION: A CASE STUDY OF AN OIL MILL IN IBADAN, NIGERIA

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Abstract

The gate-to-gate study aimed to evaluate the potential environmental impacts associated with the production of vegetable oil and to proffer ways of improving and reducing some of the environmental impacts associated with the production system. This study compared the Life Cycle Impact Assessment (LCIA) of four scenarios; different transportation distances for palm kernel materials and different type of fuel used in the boiler. The LCIA was conducted using Gabi 6 and Tool for the Reduction and Assessment of Chemical and other Environmental Impacts (TRACI) methodology. Overall energy consumption in the crushing plant was 34,647.77 MJ and energy consumption in the refining plant was 23,371.65 MJ. Global Warming Potential (GWP) was from 0.0771 kg CO_2-equiv., to 0.0763 kg CO_2^- equiv. for all scenarios. Acidification Potential (AP) values for the four scenarios were: 0.0493 kg H^+, 0.0478 kg H^+, 0.0476 kg H^+ and 0.0492 kg H^+ moles-equiv. Eutrophication Potentials (EP), were 6.796E-5 kg N^-, 4.88E-5 N^-,6.726E-5 N^- and 4.905E-5 N^-equiv. for scenarios 1, 2, 3 and 4 respectively. Energy is consumed and expended more in the crushing plant than in the refinery plant. The best environment viable for vegetable oil production is to have a short distance as possible for raw materials and the use of diesel oil for firing boilers (scenario 2) as compared with Low Pour Fuel Oil (LPFO). It was recommended that study on environmental performance of vegetable oil production from different oil sources should be investigated in Nigeria, from cradle to grave.

Key Words: Vegetable oil production, life cycle assessment, energy consumption, global warming potential

1. Introduction

In our world today, there has been increased call for economic growth yet the environmental impacts are not properly addressed. Environmental sustainability is the way out for this economic advancement, which enhances the quality of human life, health of the biosphere and the efficient use of natural resources: air, water, land, flora and fauna (Chan, 2004). Vegetable oils are important to man as a source of nutrient (fat in the human diet) and industrial raw materials. According to Food and Agriculture Organization (FAO, 2003), per capita fat consumption has increased significantly, from an average of only 53 grams in 1967- 1969 over a decade to as much as 73 g/capita/day in 1997-1999 around the world and contributes 30% of total energy supply of mankind with projected continue growth. The increasing income in developing countries and the emergence of various health issues that eliminate previous doubt towards oil and fat products also contributed to this improvement (WHO, 2003).

They are derived from vegetable sources such as palm oil, soya bean, corn, cottonseed, which are processed for different uses. Crude vegetable oil obtained from various oil milling units is further refined before use for edible purposes. Vegetable oil in Nigeria comprised palm oil/palm kernel, soybean oil, and other oils contributing 70%, 25% and 5%, respectively, to total domestic vegetable oil supply. Others include: peanut, cottonseed, coconut/copra, sesame seeds, rapeseeds, castor seed, sunflower seed, linseed, etc. (Nzeka, 2014).

Concerns have been expressed about growing demand for vegetable oil, majorly because of their environmental effects. Wahid *et al.,* 2006 researched on the need to reduce greenhouse emissions, with reference to the role played by the oil industry. The study raised concerns over the increased climate change and recommendations were made for renewable energy, methane capture and substitute fossils fuel for safer environment. The influences on the environment are numerous which may vary from acidification, eutrophication to global warming. These impacts need to be researched and evaluated, economically and ecologically, and weighed in balance for sustainable environment. One of the ways in which production of vegetable oil can be assessed is to carry out life cycle assessments (LCA) on its raw materials and products. This will improve the knowledge of the environmental performance of products and their ingredients at every stage in the extended supply chain (Erich, 2013). The results will account for environmental assessment from cradle to grave of the products and effects to the environment.

Life Cycle Assessment (LCA) is a process tool to evaluate the environmental impact associated with a product, process or activity by identifying and quantifying energy and materials used as well as waste released into the environment.

The common categories of assessed damages or effect to the environment are global warming (greenhouse gases), acidification (soil and ocean), eutrophication, smog, eco-toxicological, ozone layer depletion, and human toxicological pollutants, habitat destruction, desertification, land use as well as depletion of minerals and fossil fuels (Jekayinfa *et al.,* 2013). Global warming results in increased temperature, acidification alters the pH of a receiving medium by causing damage to the organic and inorganic materials contained therein and eutrophication leads to change the composition of species living in the environment. LCA is a reliable and most advance tool in assessing the vegetable oil industry's environmental performance as the world is demanding for economic growth which comes with sustainability and quality of human life. LCA has been used to assess the production of different vegetable oil from many sources (Halimah *et al.,* 2012; Puah *et al.,* 2013; Tan *et al.,* 2010; Vijaya *et al.,* 2010; Choo *et al.,* 2011; Arvidsson *et al.,* 2013; Schmidt, 2010), then recent researches are yet to be reported as regards vegetable oil production (palm kernel oil) in Nigeria. The aim of this study was to assess environmental impacts associated with 1kg of vegetable oil production in Nigeria through the life cycle assessment tools.

Production processes and activities in the vegetable oil mills require high energy input especially in the extraction and refining of the oil resulting in heating and cooling at different stages. The energy consumption pattern was considered in small, medium and large palm kernel mills, with the main sources of energy input in the production of palm kernel oil. Results show that thermal energy input was mostly used in the small mill, electrical energy input in the medium mills while manual energy input is the lowest in large mills. Palm processing (nut cracking and oil expression) are the most energy intensive operation with which attempts should be made to modify or redesign machines used in operation (Bamgboye and Jekayinfa, 2006).

Sulaiman *et al.* (2012) studied on energy and exergy analysis for a vegetable oil refinery in the Southwest of Nigeria, the performance of the plant was evaluated by considering the energy losses in unit operation of the production process. The energy intensity for processing 100 tonnes of palm kennel oil into edible oil was estimated at 487.04 MJ/tonne with electrical energy accounting for 4.65%, thermal energy, 95.23% and manual energy, 0.12%. The most energy intensive group operation was the deodorizer accounting for 56.26% of the total net energy input. The gate-to-gate assessment of selected oil mill was considered to know the impacts of materials and processes on the environment, through life cycle assessment methodology. Therefore the objectives of this study were determination of potential impacts of vegetable oil production on the environment as a result of some inputs and outputs and emissions to and fro the system and assessment of various contributions of the system to environmental degradation.

2. Material and Methods

The methodological approach to this study employed the use of $Gabi_6$ software in Life Cycle Analysis for vegetable oil production designed to comply with ISO standards of LCA; ISO 14040: 2006 and ISO 14044: 2006 which describe the stages for an LCA study. The goal and scope was defined; the system boundary of vegetable oil was assigned; functional unit of the product was selected; data collection method was discussed; process flow sheet and the results were analyzed.

2.1 Measurement of Energy Consumption

2.1.1 Evaluation of Electrical Energy

The electrical energy input, *Ep*, in kW h was obtained by multiplying the rated power of the electric motor, *P*, in kW with the corresponding hours of operation, *t*. Motor efficiency, ŋ was assumed to be, 80% (Bamgboye; Jekayinfa, 2006).

$$E_p = \eta P t \tag{1}$$

2.1.2 Evaluation of Manual Energy

According to the Odigboh (1998) as reported by Bamgboye and Jekayinfa (2006) at maximum continuous energy consumption rate of 0.3kW and conversion efficiency of 25%, the physical power output of a normal human labourer in tropical climates is approximately 0.075kW sustained for 8-10 hours working day.

$$E_m = 0.075Nt \text{ (kWh)} \tag{2}$$

where: 0.075 is the average power of a normal human labour in kW, N is the number of persons involved in an operation and t is the useful time spent to accomplish a given task in hours.

2.1.3 Evaluation of Thermal Energy

Thermal energy input, E_t, was calculated based on quantity of fuel (diesel or oil-cake) used to generate steam in the boiler. The quantity of fuel, W, in kg used was converted to energy (MJ) by multiplying the quantity consumed by the corresponding calorific value, *Cf*, of fuel (J/kg)

$$E_t = C_f W \tag{3}$$

2.2 Environmental Impact Assessment

2.2.1 System Boundary

This included the stages of palm kernel seed entry until the final refined vegetable oil. This was from transportation of palm kernel into the mill, entering crushing and extraction plant, to the refinery for refined vegetable oil. In this approach only inputs (e.g. raw materials, energy) and outputs (e.g. emissions, waste) associated with the processes within the boundary are included. Agricultural production and downstream activities (e.g. distribution and use) are not part of this study. The system boundary for the vegetable oil production was illustrated in Figure 1.

The system boundaries involved in this study are in four scenarios: 1, 2, 3 and 4. The distance from the local farm in Delta State for the first scenario covers about 440 km for approximately travel time of 6 hours while that of the second scenario in Okitipupa, Ondo State covers about 220 km. Secondly, the deodorization process in the refinery generates emission that can be mitigated. In this process, the boiler was fired with low-pour-fuel-oil (LFPO) to generate heat (scenario 1). In the second scenario diesel fuel was used to power the boiler to generate heat for production. Table 1 gives the different scenarios that have been used in vegetable oil production.

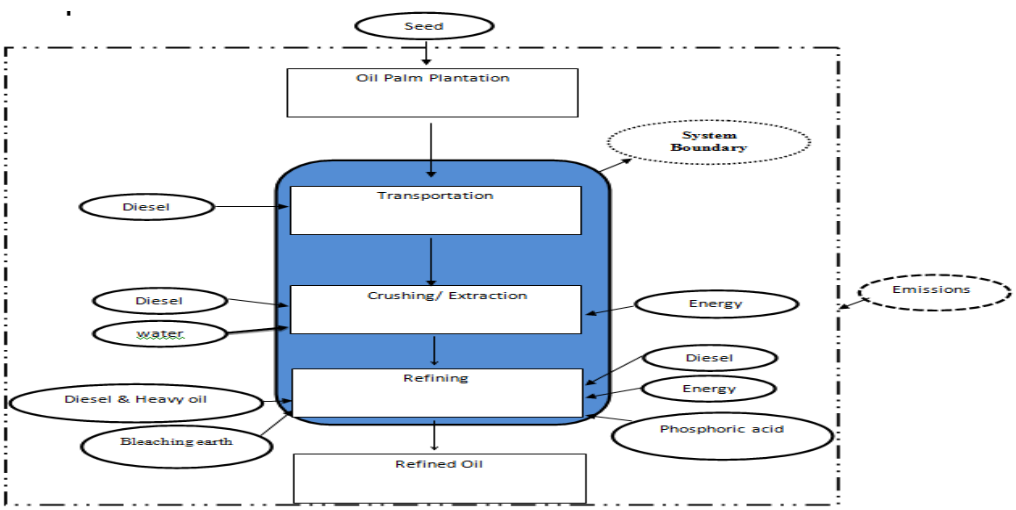

Figure 1: System boundary for Refined Vegetable Oil

2.2.2 Functional Unit

The functional unit (FU) for this study, towards which all the impacts were allocated, was defined as 1 kg of refined vegetable oil produced.

Table 1: Scenario definitions of vegetable oil production

Scenarios	Transportation distance (km)	Fuel
1	440	LPFO
2	220	Diesel
3	440	Diesel
4	220	LPFO

2.2.3 Life Cycle Inventory (LCI)

Process flow diagrams were used to outline the relationships between unit processes and flows across the system boundaries. The selected case study for this research is an oil and chemical company in Ibadan. Primary data sources were obtained by site visitation while information were collected through personal interview with the plant engineers, plant manager and the workers, observation of the power rating and efficiency of the electrical motors, and physical measurement of the mass flow in the plant.

2.2.4 Life Cycle Impact Assessment

Life Cycle Impact Assessment phase include classification (in which different inputs and outputs were assigned to different impact categories based on the expected types of impacts to the environment) and characterisation (relative contributions of each input and output to its assigned impact categories were assessed and the contributions were aggregated within the impact categories) which was based on the internationally accepted methods and data of the Tool for the Reduction and Assessment of Chemical and other Environmental Impacts (TRACI). The two main approaches used to classify and characterize environmental impacts are the problem-oriented approach (mid-point) and the damage-oriented approach (end point). TRACI is a problem-oriented method developed by the U.S. Environmental Protection Agency (EPA).

2.3 Analysis of Data using the GABI Software

The computer program $Gabi_6$ was utilized for this assessment. Gabi software was developed in accordance with the ISO 14040 and ISO 14044 standards and allows for managing and storing the necessary data, as well as performing the calculations and required sensitivity tests. The software comes with the ecoinvent database, which covers a broad range of data available as unit operations and systems. It has characterisation (equivalent factors) for all the environmental interventions; indices of the magnitude of environmental impact of the associated substance. Moreover, Gabi has normal or reference values for individual impact categories such as global warming. These reference values are used for normalisation of impact categories.

The modelling of vegetable oil production in $Gabi_6$ application software was in accordance to the system boundaries (Figure 2) which accounted for all units involved starting from palm kernel transportation to the refined oil. Each stage was constructed as a unit process on $Gabi_6$ and the input and output data were the flow (Figure 2). Flows are used to link processes up. The input flows were majorly quantity of raw materials used such as volume of fuel, weight of palm kernel and volume of water used in operation. The output flows were the mass of processed vegetable oil, volume of waste water, volume of corresponding emissions to the atmosphere, water and water.

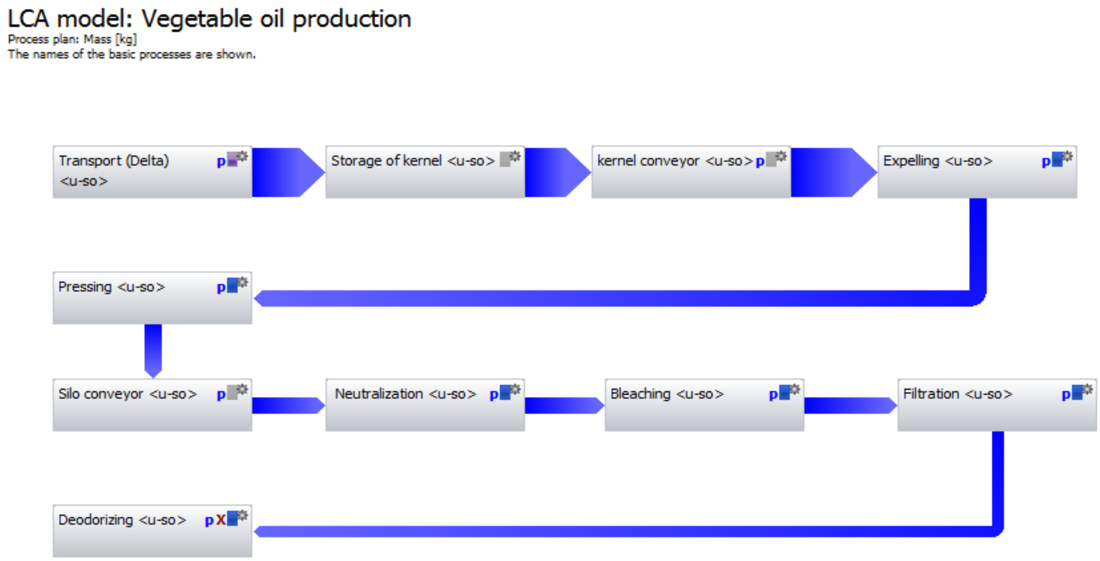

Figure 2: LCA of Vegetable Oil Production using $GaBi_6$ software

3. Results and Discussion

3.1 Energy Consumption

The primary sources of energy for production processes of vegetable oil in the oil mill are from electrical energy (generators) present in the industry, thermal energy for the production of steam from boiler and manual energy from human activities. Results of the energy consumption in the oil mill for palm kernel processing into refined vegetable oil based on 24 hours production, in which about 200 tonnes of palm kernel are processed and as shown in Tables 2 and 3. Palm kernel processing (crushing plant) were divided into unit operations to obtained crude palm kernel oil which are further refined in the refining plant. The unit operations in the refining plant are neutralization, bleaching, filtration and deodorizing.

Tables 2 and 3 shows the energy use in palm kernel processing to obtain refined vegetable oil with Figures 3 and 4 with their corresponding percentages. The total energy requirement for processing palm kernel seed into refined vegetable oil was estimated to be 58.02×10^3 MJ as compared to 48.70×10^3 MJ that was stated by Sulaiman *et al*., (2012). The electrical and thermal proportions in percentage are 99.3 and 0.7% respectively in the crushing plant. The electrical, thermal, manual energy consumption in the refining plant is 4.77, 95.07 and 0.16% respectively. As shown in the table, the manual energy is minimal in both the crushing and refining plants, while thermal energy was not consumed in the crushing plant. Automation in the crushing and refining plant caused the minimal manual energy input for the oil production.

As observed from Table 2, the operations involved in the use of electrical energy has the highest energy consumption, with expelling unit process with the highest energy consumed 21,153.15 MJ (61.05 %) followed by pressing 12,088.44 MJ (34.9 %). Other unit operations (storage of kernel, kernel conveyor and silo conveyor) account for 1,406.14 MJ (4.05 %) of the electrical use in the crushing plant. High energy consumed in expelling unit process was due to the number of expellers with high electric motor ratings used for production operation. The manual energy obtained from the crushing plant was 235.17 MJ with silo conveying with the most energy consumption, about 87.69 % (235.17 MJ).

Table 3 shows the energy consumption in the refining plant with estimate of 23, 371.65 MJ. Deodorizing has the highest energy consumed accounting for 56.23 % of the total energy, with bleaching operation having 39.64 %, neutralization with 3.49 % and filtration accounting for the lowest (0.64%). Thermal energy has the highest energy consumption in the refining plant which was from the fuel burned in the boiler 22,220.46 (95.07%), electrical energy consumption with 4.77 % (1,114.47 MJ) and manual energy with 0.16% (36.72MJ). The results were higher in crushing plant than in the refining plant which indicated that palm kernel oil refining is less energy intensive.

Table 2: Energy Consumption in the Crushing Plant

Operations	**Electrical Energy (MJ)**	**Thermal Energy (MJ)**	**Manual Energy (MJ)**	**Total Energy (MJ)**	**% of Total Energy**
Storage of kernel	-	-	21.6	21.6	0.06
Kernel conveyor	241.7	-	-	241.7	0.7
Expelling	21,149.10	-	4.05	21,153.15	61.05
Pressing	12,085.20	-	3.24	12,088.44	34.9
Silo conveying	936.6	-	206.24	1142.84	3.29
Total	34,412.60	-	235.17	34,647.73	100

Table 3: Energy Consumption in the Refining plant

Operations	Electrical Energy (MJ)	Thermal Energy (MJ)	Manual Energy (MJ)	Total Energy (MJ)	% of Total Energy
Neutralization	447.15	361	861	1669.15	6.89
Bleaching	132.9	9,118.23	12.96	9,264.09	38.24
Filtration	145.02	-	4.86	149.88	0.62
Deodorizing	389.4	12,741.23	10.8	13,141.43	54.25
Total	1,114.47	22,220.46	36.72	24,224.55	100

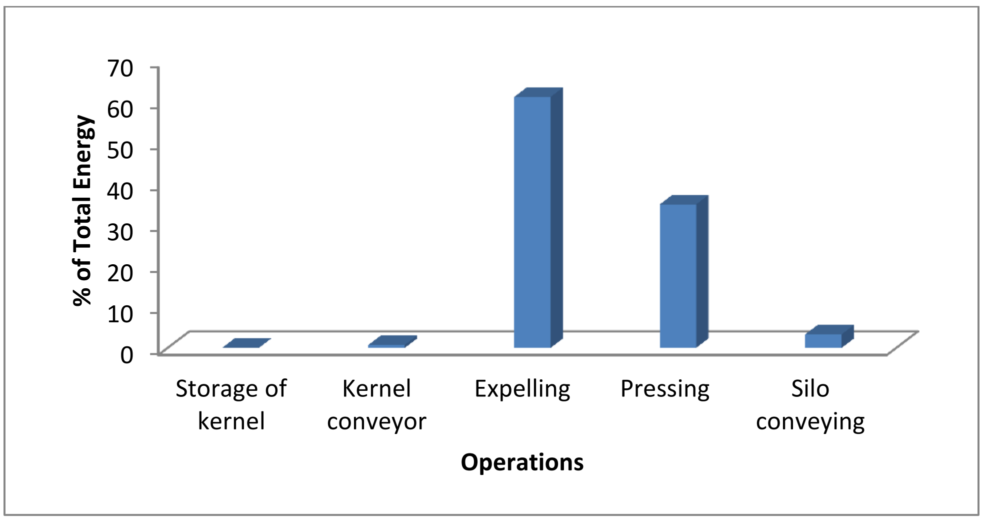

Figure 3: Percentage Energy Consumption in the Crushing plant

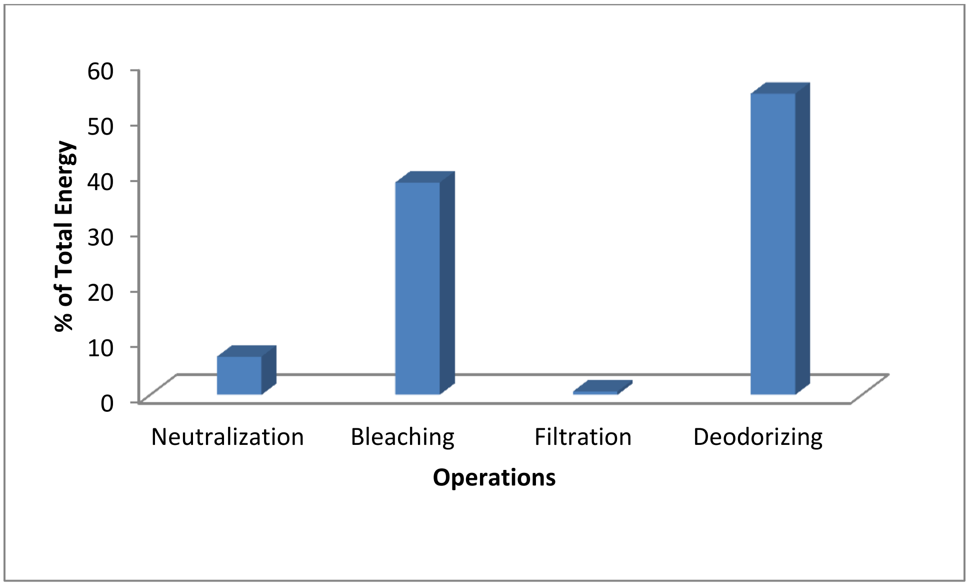

Figure 4: Percentage Energy Consumption in the Refining plant

3.2 Environmental Impact

The emissions of the system boundary have been grouped into impact categories with the use of TRACI. The impact indices determined from the scenarios were: Global Warming Potential (GWP), Acidification Potential (AP), Eutrophication Potential (EP) and Smog air (Erich, 2013). The global warming potential is calculated in carbon dioxide equivalents (CO_2-Eq.) which is given in relation to CO_2 usually within a period of 100 years. Sulphur dioxide and nitrogen oxide and their respective acids (H_2SO_4 und HNO_3) produce relevant contributions in acidification. The acidification potential is given in sulphur dioxide equivalents (SO_2-Eq.). The eutrophication potential is calculated in phosphate equivalents (PO_4-Eq) which contains nitrogen or phosphorus with consequences of increased nutrient enrichment and decreased biodiversity.

The summary of total environmental impacts associated with the production of 1 kg of refined vegetable oil is shown in Table 4. The comparisons of different scenarios for the total environmental impacts were shown in Figures 5 – 8 respectively.

Table 4: Environmental Impacts of Vegetable Oil Production per kg

Environmental Impacts and Units	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Global Warming Potential (GWP) , kgCO_2-equiv	0.0771	0.0742	0.0763	0.0746
Acidification Potential (AP), kg H^+ moles- equiv.	0.0493	0.0478	0.0476	0.0492
Eutrophication Potential (AP), kg N-equiv.	6.796E-5	4.88E-5	6.726E-5	4.905E-5

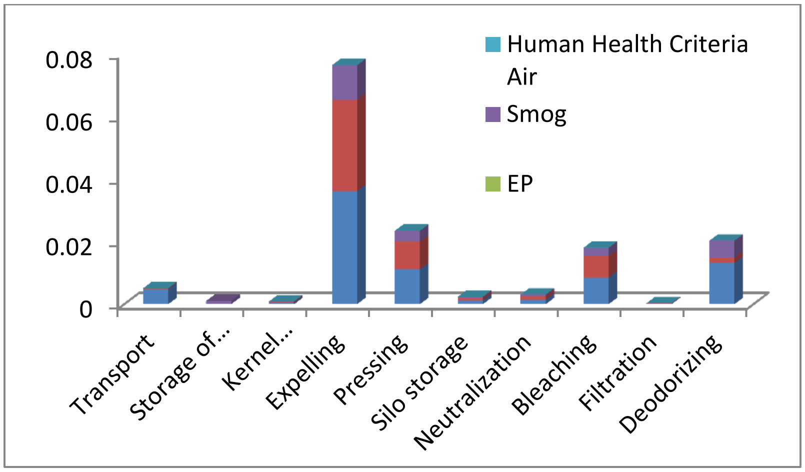

Figure 5: Comparison of Total Impacts for scenario 1

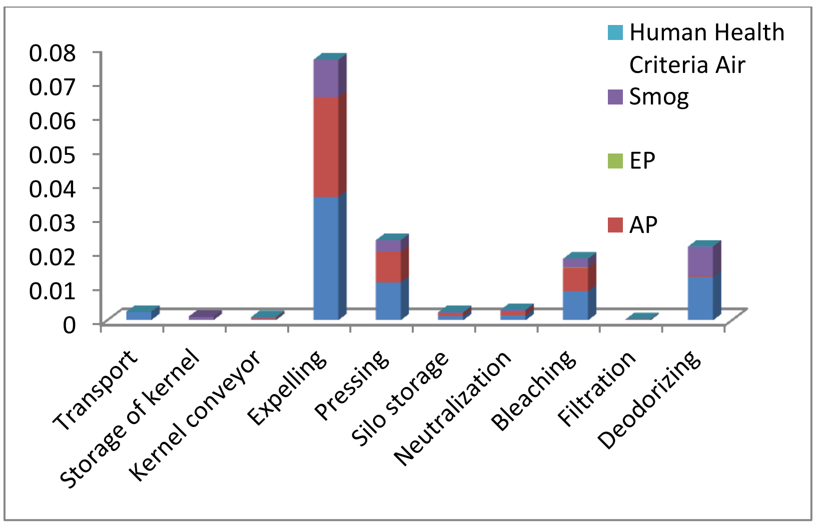

Figure 6: Comparison of Total Impacts for scenario 2

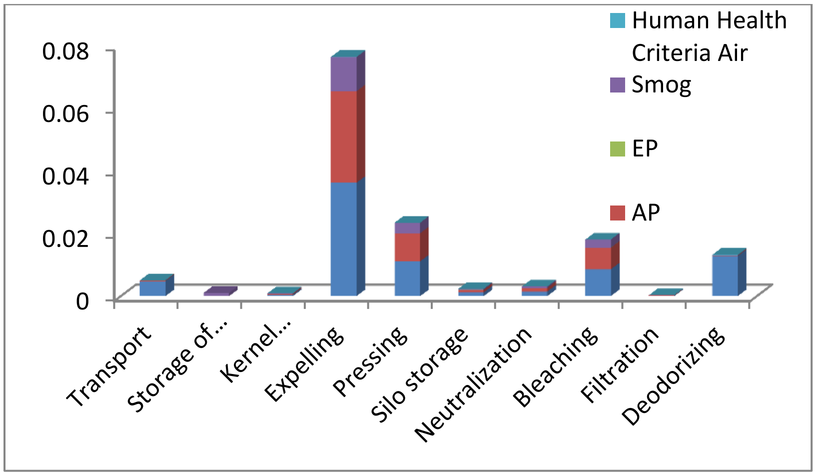

Figure 7: Comparison of Total Impacts for scenario 3

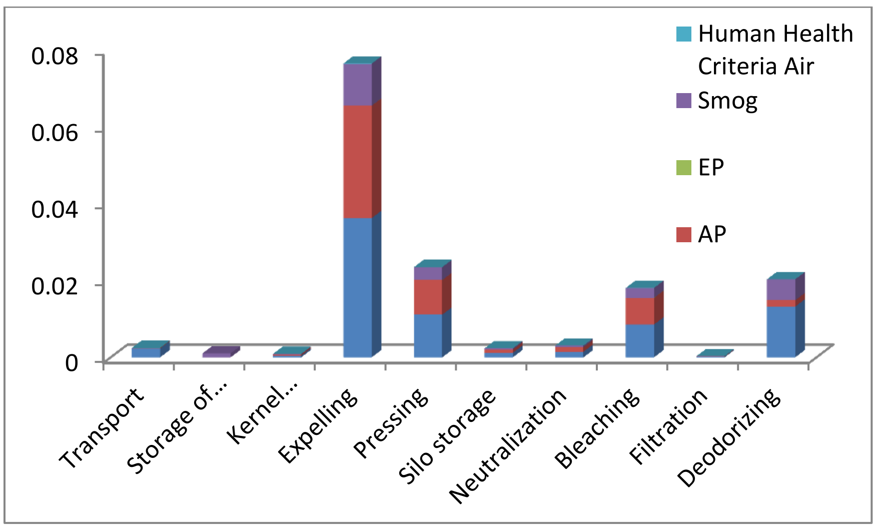

Figure 8: Comparison of Total Impacts for scenario 4

Global Warming Potential (GWP), Acidification Potential (AP), Eutrophication and Smog Air are the assessed environmental impacts from TRACI. These impacts were modelled with different scenarios to give different instances and case studies.

Global Warming Potential (GWP) compares the ability of each greenhouse gas to trap heat in the atmosphere relative to another gas. The impact during expelling process of kernel is largely due to the emissions from diesel fuels used to power the expellers, which carbon dioxide (CO_2) contributed to the high impact score of global warming using carbon cycle equivalent as observed in scenario 1 (incomplete combustion of the high carbon fuel). The combustion of fossil fuel releases greenhouse gases (such as carbon dioxide and nitrogen oxide) and toxic substances (such as heavy metal and carbon monoxide) (IPCC, 2007). The impacts from the transportation mainly come from the consumption of fuel and emission from the exhaust. The emission of carbon dioxide from fuel combustion contributes to global warming and emission of toxic substances cause harms to human health (Fuglestvedt *et al*., 2008).

Gases from acidification; sulphur dioxide and nitrogen oxide and their respective acids (H_2SO_4 and HNO_3) produce relevant contributions to acidification from scenario 1 to scenario 4 which affects and damages ecosystems. Acidification has direct and indirect damaging effects, such as nutrients being washed out of soils or an increased solubility of metals into soils.

The Eutrophication Potential shows the potential effects of vegetable oil production on biomass formation, by comparing it to the effect of phosphate $PO4^{3-}$. Pollutants of nitrogen, phosphorus and both in the transportation system (scenario 1) causes the most impact for eutrophication in all scenarios considered while in the deodorization unit process, the formation of eutrophication is more in scenario 1 and scenario 4. This is to the high percentage of nitrogen and phosphorus in the composition of low fuel pour oil which is used to fire the boilers.

Transport distance of 440 km and low-pour-fuel-oil (scenario 1) has the highest impact for all input category modelled while transport distance of 220 km and diesel fuel (scenario 2) was with the least impact on the environment.

4. Conclusion

Energy consumption analysis of the gate-to-gate assessment of vegetable oil production showed that more energy was expended in the crushing plant than in the refining plant. The expellers in the crushing plant accounted for the high energy, thereby generating more green-house gases emission. Vegetable oil refining, transportation and expelling have been identified as the crucial unit processes that pose considerable environmental threats due to the combustion of residual fuel oil boilers; combustion of diesel fuel for machine operations; and combustion of diesel in transporting trucks from farm to the mill. The diesel fuels for palm kernel transportation and electricity generation (generators) from farm to mill contributed most to global warming. From this work, it was deduced that scenario 1 have the most impact on the environment, followed by scenario 4, scenario 3 and scenario 2 had the least. The best environmental viable production for vegetable oil is to have a short distance as possible for raw materials and the use of diesel oil in fire boilers (scenario 2) may be a viable option of all scenarios studied. The combustion of fuels either in the transport or for boiler contributed to the greenhouse gases which causes global warming thereby leading to climate change.

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