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Environmental Life Cycle Assessment of Sorghum (sorghum bicolor) Production, Storage and Disposal in Ilorin, Nigeria

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Abstract
Nigeria is one of the major producers of sorghum grains in the world. The production and storage of the crop consumed resources, both biotic and abiotic and this could lead to some environment burden in form of emissions and pollutions. Therefore, this study was carried out to assess the environmental life cycle of sorghum, from production to storage and packaging for market using life cycle assessment model (LCA).The life cycle inventory data was collected for production, and storage operations of three scenarios of sorghum namely: storage in jute bags and fumigation in Warehouse (FW), usage of Bio-pesticide (BP) and NSPRIDUST (ND) as protectant. The inventory data collected was based on a functional unit of one hectare of land for production, and one ton of grains for storage operations respectively. The data were analyzed using “Ganzheitliche Bilanz” (GaBi) 8.7 software. Environmental impact categories generated were Global Warming Potential (GWP), Acidification Potential (AP), Eutrophication Potential (EP), Ozone Depletion Potential (ODP) and Human Toxicity Potential (HTP).The GWP values obtained for sorghum scenario using FW, BP, and ND were 6.850, 7.930 and 6.890 kg CO_2, respectively. The AP values for FW, BP and ND were 0.009, 0.012 and 0.009 kg SO_2, respectively, while EP values obtained for FW, BP and ND were 2.180, 3.010 and 2.070 E-3 kg Phosphate, respectively. The ODP values using FW, BP and ND were 8.96, 8.96, and 8.96 E-13 kg R11 respectively, while the HTP values obtained using FW, BP and ND were 4.150, 4.150 and 4.150 kg DCB, respectively.The research showed that the impact values of FW, BP and NS for sorghum scenario had not much difference. The research finding is recommended for environmentalists, grain producers and handlers.
Keywords: Life Cycle Assessment, global warming, acidification, eutrophication, ozone layer depletion
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1. Introduction

Environment is the totality of everything that surrounds a living organism, including natural forces and other living things which provide conditions for development, growth, danger and damage, (Backsh and Fiksel, 2003). It comprises of many variables which are water, air, land and the interrelationships existing among and between human beings and other living creatures such as plants, animals and microorganisms (Cederberg and Stadig, 2003). The word ‘Environmental’ refers to being in connection with, or relating to the surroundings in which a person or animal lives. In recent years, scientists have been carefully examining the ways that people affect the environment and discovered that human actions caused damage either directly or indirectly to the environment. These anthropogenic activities can be industrial and manufacturing, agricultural and technological (Boadi, 2004). The effect of these activities had resulted into serious environmental damage and the most prominent is global warming, whereby the global temperature of the earth is increasing due to the release of specific gases into the environment. This temperature rise has led to extreme climate change and the eventual rise of the sea temperature, endangering thousands of species, including human beings (Eric *et al*, 2002).

All agricultural activities have impact on the environment, and the environment on the other hand also has impact on agricultural operations. Impact from agricultural activities on the environment involves a variety of factors ranging from the soil, soil diversity, people, plants, to water, the air, animal and the food.

The food and agriculture industry is a large user of energy and one of the world’s largest industrial sector. Greenhouse gas emission, which has increased remarkably due to immense energy use from food and agriculture industry, has resulted in global warming, acidification and eutrophication contributing to the festering problems that humankind faces today (Schmidt *et al*, 2015). Production of food, preservation and distribution will surely consume some amount of energy and release emissions in form of toxic loads to the environment (Boer, 2002). In order to reduce the environmental impacts, there is need to assess the entire food chain which are food production, storage and distribution. One of the well-known methodologies used for the evaluation of the environment is a Life Cycle Assessment (LCA) (John *et al*, 2005) for optimal environmental performance.

Life cycle assessment is a comprehensive environmental model to determine the energy, material, and waste flows of a product, and their impact on the environment. It systematically compiles and examines the inputs and outputs of materials, which is directly attributable to the functioning of a product or service system throughout its life cycle. The evaluation begins with the use of raw materials, manufacturing or processing with associated waste stream, storage, distribution and waste disposal (Roy *et al.*, 2007).

In food industries, LCA is used to identify the steps in the food chain that have the highest impact on the environment so that improvement efforts will be recommended (Ohlsson, 2006). Input resources in LCA refers to energy, fuels or the chemicals used for the activities involved in the food chain. LCA has four phases and they are; goal and scope definition, inventory analysis, life cycle impact assessment and interpretation (ISO14040, 2006). The aim of this study was to assess the environmental life cycle impacts of sorghum (*sorghum bicolor*), due to its high level of production and consumption pattern in Ilorin, Nigeria.

2. Materials and Methods

2.1 Study Locations

The study locations were chosen based on the institutional research mandate , and they were; the National Centre for Agricultural Mechanization (NCAM) Ilorin, Nigeria (for sorghum planting activities) and Nigerian Stored Products Research Institute (NSPRI) Ilorin, Nigeria (for the post-harvest activities of the grain; storage and disposal). The two locations are in the North- central of Nigeria which lies between latitude 8^0 22' 42" to 10^0 50' 42"N and longitude 4^0 41' 35" to 7^0 9'35" E. The two institutions are research institute whose mandate is in line with grains production and have available machineries and technologies in grain production and storage in Nigeria.

2.2 Grain Chosen for the Study

Grain selected for this study is sorghum (*Sorghum bicolor*). It was selected based on its high level of production and consumption pattern in Nigeria, Africa and the world. Nigeria is among the first five world leading producer of sorghum, and leading producer in West Africa. The consumption pattern of the crop by Nigerian populace is highly encouragingly which enhances more production, however the associated environmental burden were unaccounted for.

2.3 Study Procedure

The research was conducted in accordance with International Standard Organization (ISO) procedural framework for performing LCAs in the ISO 14044 series. The inventory data collected was analyzed using GABI 8.7 think step software, 2018 version.

2.3.1 System boundary

System boundary for sorghum

The system boundary for Sorghum grain production, storage and disposal chain was divided into 3 stages i.e. pre-planting, planting and post-harvest operations with input, output and associated emissions as shown in Fig 1. The system boundary covers land preparation using the following tractor mounted implements; disc plough, disc harrow and disc ridger. This operation was followed by planting, fertilizer application, weed control and crop protection using tractor mounted implement like seed planter, boom sprayer, and fertilizer applicator. After the sorghum is matured, manual labour was used for the harvesting. Threshing and grain cleaning was done using multi-crop thresher. The sorghum grains were later transported to NSPRI Ilorin for storage. After satisfying storage conditions that is, well cleaned with 12% moisture content dry basis, 1000 kg of sorghum grain was stored in warehouse. The storage maintenance in terms of fumigation was carried out. The second storage method scenario for the sorghum grain was the use of bio-pesticide (Mixing 1 kg of bio-pesticide (pepper fruit) to 1000 kg of sorghum and bagged into 20 units of 50 kg polypropylene bags. Also, the third storage method scenario for the sorghum grain was mixing 1000 kg of sorghum with 1 kg of "NSPRIDUST" thoroughly by a grain mixer and bagged into 20 units of 50 kg polyethylene bag. The grains were stored for six (6) months after which the grains were emptied into a bunker (large container). From the bunker the grains were weighed, bagged and sewn into 25 kg and 50 kg bags respectively using electric weighing balance and electric sewing machine. The bagged Sorghum grains were transported to Ago market in Ilorin using petrol engine double cabin truck for disposal to consumers.

2.3.2 The Scenarios created

In order to input inventory data into the GABI software, three scenarios was created for the grain. Scenario creation allows easy comparison to be made on the impact of different system configurations/conditions. Any number of parameters can be selected to create a scenario and this can be compared directly with other scenarios. Scenario for sorghum as shown in Plate 1 includes:

1. Sorghum production and storage in warehouse using jute bag with fumigation
2. Sorghum production and storage using Bio-pesticide inside polypropylene bag

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3. Sorghum production and storage using "NSPRIDUST" inside polypropylene bag

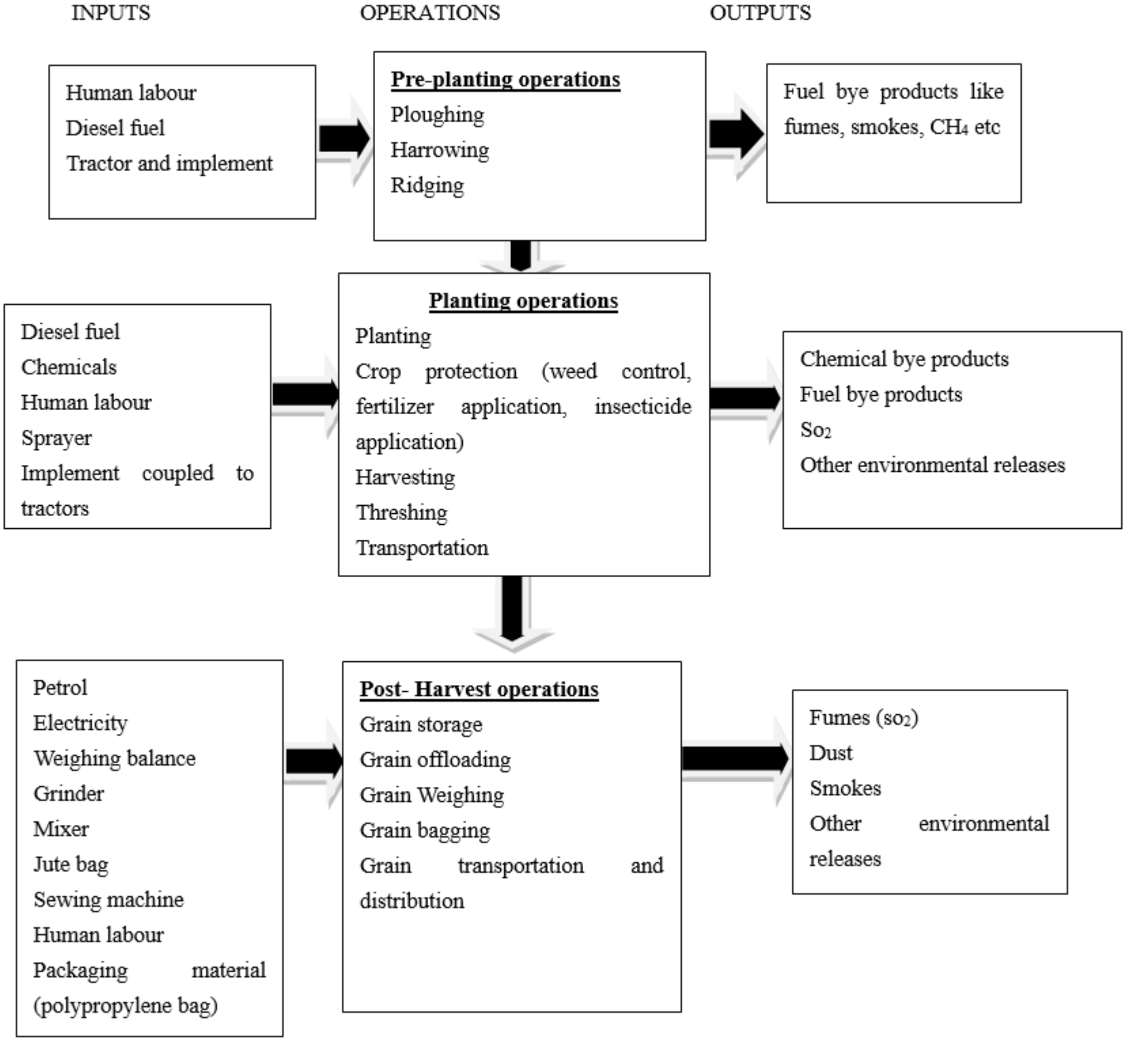

Plate 1: Sorghum Scenario created

2.3.3 Environmental impact assessment methods of the grain production, storage and disposal processes

There are different methods that could be used to perform a Life Cycle Impact Assessment. These methods are continuously researched and developed by different scientific groups based on different methodologies. The method used in this research project was Centre of Environmental Science, University of Leiden, Netherlands (CML).

There are different impact categories in life cycle project, but for this research work, five impact categories were selected which includes: global warming potential (GWP), acidification potential (AP), eutrophication potential (EP), ozone layer depletion potential (ODP), and human toxicological potential.

2.3.4 Life cycle inventory of sorghum production, storage and disposal

The inventory sum of resources consumption in the production, storage and disposal of the sorghum grain system of study is presented in Table 1, all the basic grain production operations involved the use of some sources of energy from land preparation to harvesting to storage and disposal. The use of direct energy in form of fossil fuel (diesel) was involved in land preparation stage which include ploughing, harrowing, and planting; for ploughing operation 10 L/ha was used, harrowing 9 L/ha and ridging 10 L/ha , attached to a 4-wheeled tractor for land preparation operations. Crop protection operations involved the use of synthetic fertilizer (25 kg NPK fertilizer 15-15-15) to boost the yield of grain. Sorghum grain was planted with a spacing of 75 cm by 50 cm, 1-3 grains per stand and population density of 80,000 ha, 25 kg of grains is required to plant 1 hectare of land to give a yield of 1– 3 tons/ha (Adeboye et al, 2006).

Table 2 shows the result of the environmental impact of the sorghum grain process studied and the result is represented using CML (2015) methods from GABI.

Total electricity consumed in grain weighing, operating grain mixer, and grain packaging bag sewing was 25 kw/hr. ,1.5 ltr pendelin herbicide was used for weed control, 2 tablets of phostoxin was used in fumigating the bagged sorghum in warehouse, packaging materials include 10 units of 100 kg jute bag, and 20 units of 50 kg polypropylene bags. 1 unit of 40"x 48"x 6" wooden pallets was used for grain bag seat and this was covered by 15 yards of fumigating sheet, fastened to the ground by 12 units of 1 m sand-snake. 1 kg of black pepper and 'NSPRIDUST' was used respectively as grain protectant.

Table 1: Life cycle inventory data sum in the sorghum production, storage and disposal

S/No	Total items used	Quantity Total	Comment
1	Diesel Fuel	51.5 L	Fuel used for ploughing, harrowing, ridging, planting, spraying 1 hectare of land.
2	Human labour	53-man hr.	Human labour used in operating mobile and stationery machines and implement used, manual harvesting, grain bagging, grain weighing, chemical mixing, purging of silo etc
3	Petrol Fuel	40 L	Fuel used for threshing operation, for pickup van transportation, for stationery operations to power grain conveyor for 1,000kg (1 ton) of grain.
4	Electricity	25 kw/h	Electric power consumed in grain weighing, sewing of bag, operating grinder and mixer.
5	Grains (sorghum)	25 kg	Grain input for planting 1 hectare of land.to give a yield of 2.5 tons.
6	Chemicals		
	Herbicide (pendelin)	1.5 L	Chemicals for weed control and fumigation
	Phostoxin tablet	2 tablets	For fumigation
7	Packaging Materials		
	Jute bag	100 kg (10 pcs)	For storage and packaging to market
	Polypropylene bag	50 kg (20pcs)	
8	Wooden Pallets	1 unit of 40''x 48"x 6"	For grain bag seat
9	Fumigation sheet	15 yards	For fumigation in warehouse
	Sand snake	12 pieces of 1 m	to fasten fumigation sheet to the floor (gas leakage prevention)
10	Bio-pesticide (pepper fruit)	1 kg	For grain storage
	"NSPRIDUST"	1 kg	For grain storage

Table 2: Sorghum Environmental Impact results using CML Method

Impact categories	Characterization factor Grain warehouse	Bio-pesticide	"NSPRIDUST"	Grain warehouse	Bio-pesticide	"NSPRI DUST"
Global Warming Potentials (100 years)	Kg CO_2 Eq. 6.85	7.93	6.89	6.85	7.93	6.89
Acidification Potential	Kg SO_2 Eq. 0.00897	0.0121	0.0086	0.00897	0.0121	0.0086
Eutrophication Potential	E-3 kg Phosphate 2.18	3.01	2.07	2.18	3.01	2.07
Ozone Depletion Potential (Steady State)	E-13 kgR11 Eq. 8.69	8.69	8.69	8.69	8.69	8.69
Human Toxicity Potential (Cancer)	Kg DCB Eq. 4.15	4.15	4.15	4.15	4.15	4.15

3. Results and Discussion

3.1 Global Warming Potential (GWP)

From Table 2, the characterization factor for the CML method of assessment is kg CO_2 Eq. for global warming. The impact value obtained for sorghum scenario from the grain warehouse storage was 6.85, Bio pesticide was 7.93 and NSPRIDUST was 6.89 respectively. In Fig.2, Bio pesticide had the largest contribution to global warming potential with 7.93 kg CO_2 eq. impact value, because of various fuel usage in pre-planting and planting operations and materials used in packaging the grains. This was supported by the report from Jekayinfa *et al*. (2013) that global warming had the highest environmental impact as a result of high fuel combustion associated with the system studied, and also in accordance with what Olaniran, (2015) reported that global warming also had the highest impact value in cassava production and processing system he studied.

3.2 Acidification Potential (AP)

The characterization factor as shown in Table 2 under CML for acidification potential in the sorghum scenario is kg SO_2 equivalent, according to Mutegi *et al*, 2010. The impact value obtained from the grain warehouse storage scenario was 0.00897, Bio pesticide 0.0121 and NSPRIDUST was 0.00859. This was as a result of emission from fuel usage in pre-planting operations as reported by Baksh and Fiskel in 2003, they discovered that emission of sulphur oxides from diesel fuel has more impact on the environment than biofuels. In Fig.3, Bio pesticide scenario has the largest contribution to acidification potential with 0.0121kg SO_2 eq. impact value. This was as a result of fuels used for various operations in the sorghum scenario.

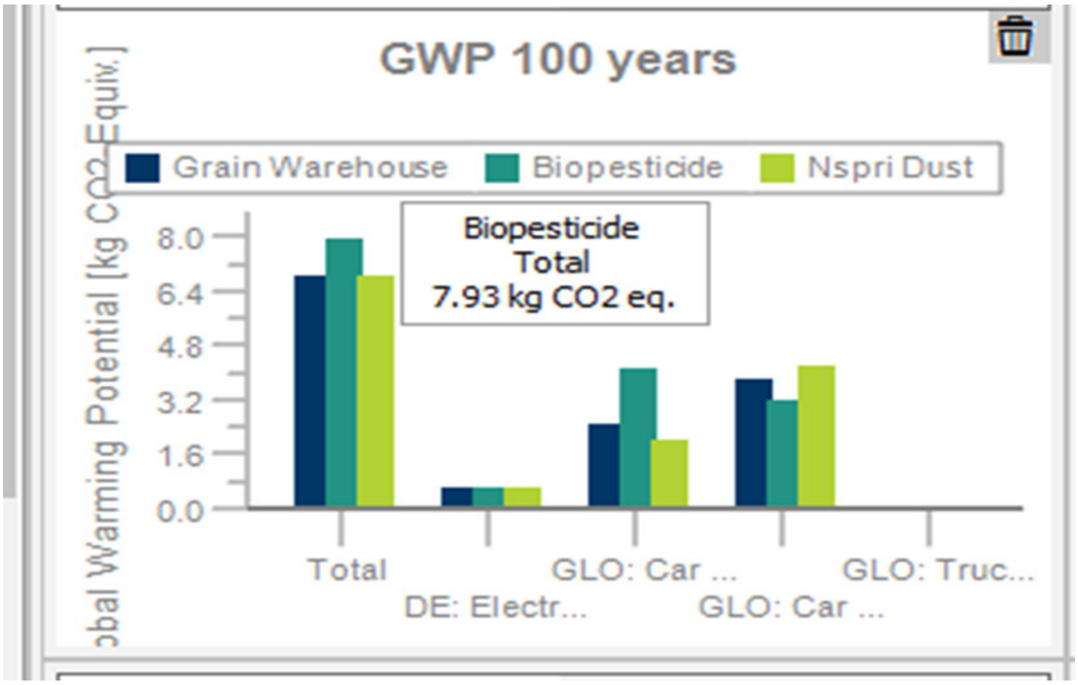

Figure 2: Global warming potential for sorghum scenario

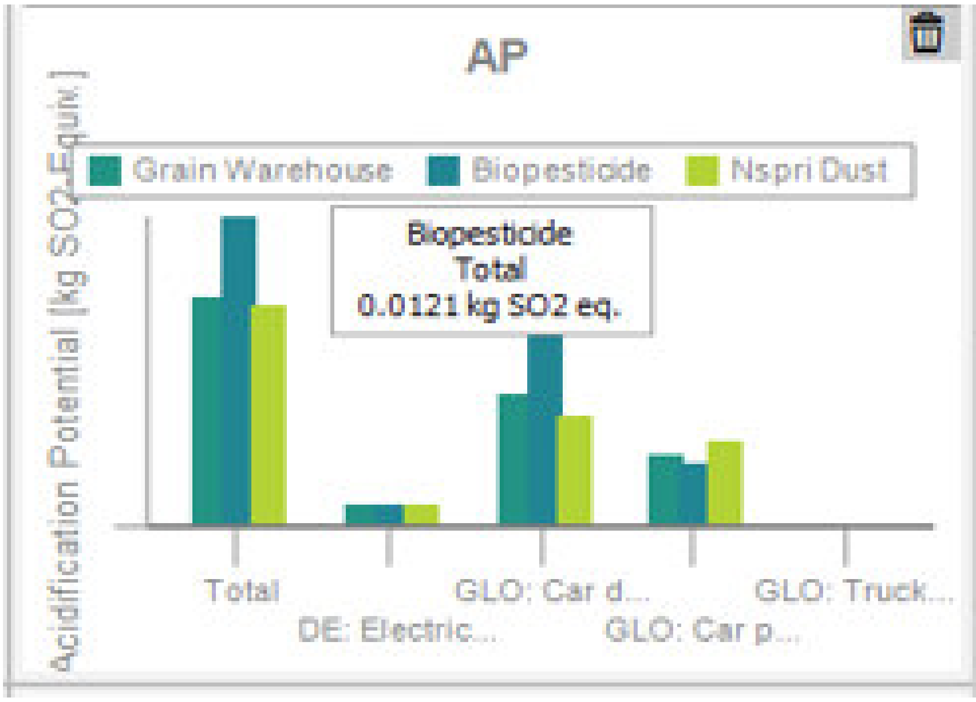

Figure 3: Acidification potential for sorghum scenario

3.3 Eutrophication Potential (EP)

The characterization factor in CML method for Eutrophication potential in the sorghum scenario was E-3 kg phosphate equivalent. The impact value obtained from sorghum scenario from the grain warehouse storage was 2.18, Bio pesticide was 3.01 and NSPRIDUST was 2.07 E-3 kg. The impact resulted from contributions from fuel usage and packaging materials (polypropylene and polyethylene) usage. In Fig.4, Bio pesticide has the largest contribution to eutrophication potential with 3.01 E-3kg phosphate equivalent impact value. This was as a result of fuel combusted during tillage operations and transportation activities. This can be buttressed by the findings from Biswas *et al.* (2008) in transporting one ton of wheat grain to Freemantle Port in Western Australia and found out that pre-planting, planting and post-harvest stage accounted for 75% of the greenhouse gas total emission.

3.4 Ozone Layer Depletion Potential (ODP)

The characterization factor in CML method for Ozone layer depletion potential in the sorghum scenario is E-13 kg R11 equivalent. The impact value obtained for the ozone layer depletion potential from sorghum scenario from the grain warehouse storage, Bio pesticide and NSPRIDUST was the same value and it was 8.69 E-13 kg R11 equivalent respectively. Electricity usage and gas emission from freezer compressor usage contributed mostly to the emission as shown in Fig. 5, also diesel and petrol usage contributed mostly to the emission.

3.5 Human Toxicology Potential (HTP)

The characterization factor in CML method for Human toxicology potential in the sorghum scenario is kg DCB (dichlorobenzene) equivalent. The impact value obtained from CML for the human toxicology potential from the grain warehouse storage, Bio pesticide and NSPRIDUST was the same with equal value of 4.15 kg DCB equivalent respectively. These contributions to human toxicology potential from the three scenarios as shown in Fig. 6 was as a result of dust inhaled causing nasal and trachea blockage, and electricity usage and fuel combusted for various activities. This was in accordance with what Ntiamoah reported in 2008, who worked on environmental impact of cocoa production and processing and discovered that human toxicity impact on the system studied was high as a result of fertilizer and pesticide inhalation during application by human.

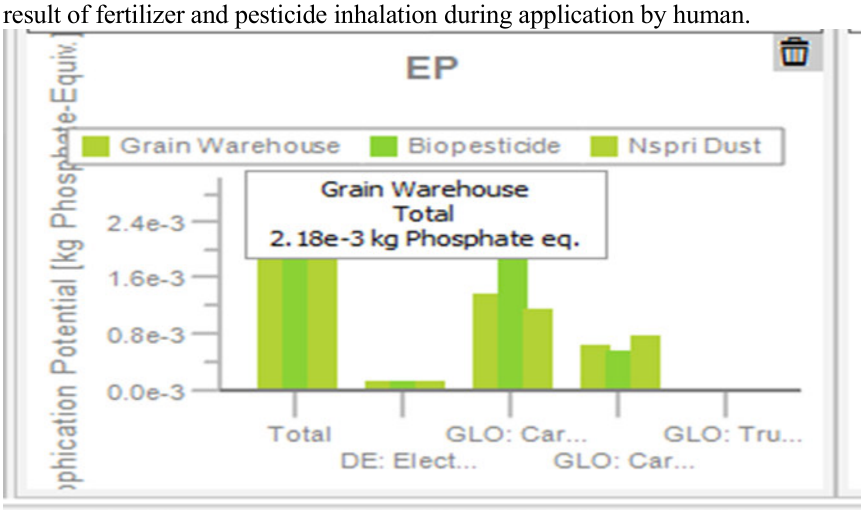

Figure 4: Eutrophication potential for sorghum scenario

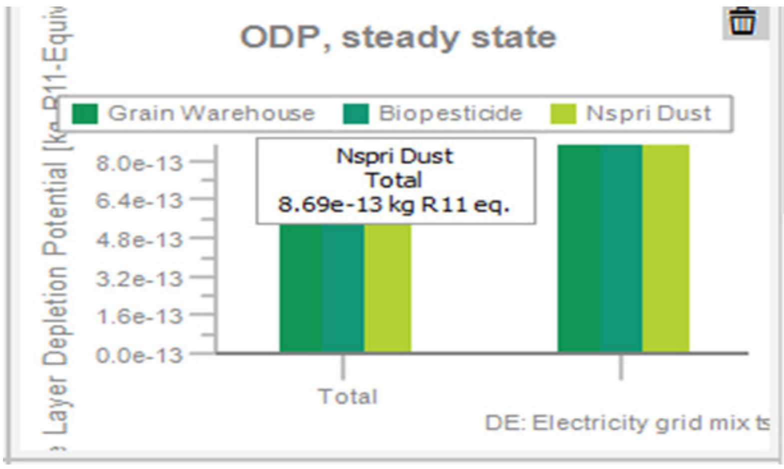

Figure 5: Ozone depletion potential for sorghum scenario

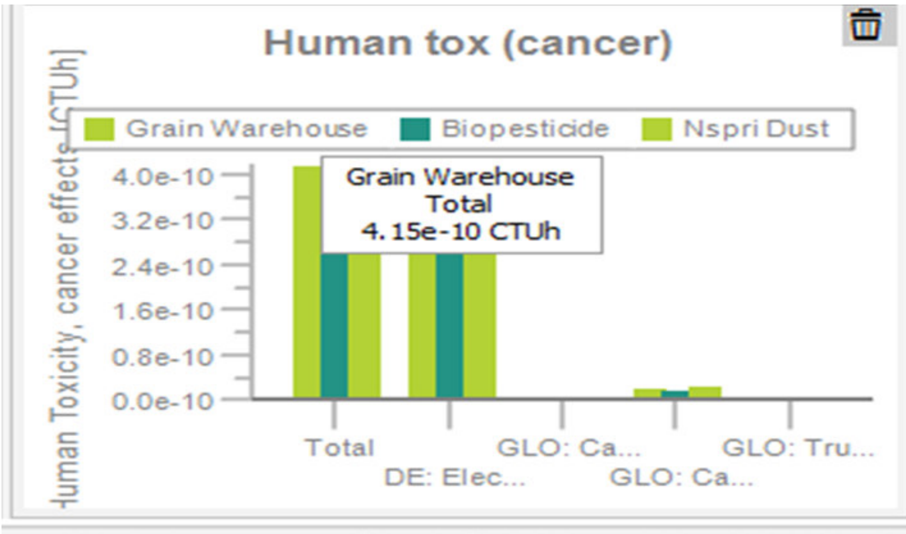

Figure 6: Human toxicity potential for sorghum scenario

4. Conclusions

The study has shown contributions of different environmental impacts in terms of global warming, acidification, eutrophication, ozone layer depletion and human toxicology from the sorghum production, storage and disposal in Ilorin, Nigeria. Although, the emission values from each scenario and characterization factors were within safe limits as recommended by standard tool in GaBi software, the use of diesel and petrol fuel for unit operations such as land preparation, planting operation and post-harvest operations were major hotspots which contributed significantly to emission of greenhouse gases to the environment. Also, the use of different chemicals for crop protection and during storage is another major hotspots that should be monitored.

However, all the storage methods (fumigation in ware house, Bio-pesticide in polypropylene bag and ''NSPRIDUST'' inside polypropylene bag) are environmental friendly and therefore are recommended for continuous use. Also, biofuel resources and organic agriculture could be explored to reduce the harmful emissions from conventional fuel to the environment. Life cycle assessment (LCA) tool has been found suitable for environment impact assessment in this study and is recommended for policy makers and stakeholders in environmental sector to monitor and ensure cleaner environment.

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