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A COMPARATIVE LIFE CYCLE ASSESSMENT OF VARIOUS PRODUCT SYSTEMS IN A WATER PRODUCTION COMPANY

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Abstract

It is no news that man's activities usually have negative impacts on the environment. One major activity that man carries out that grossly affects the environment is the Production processes in general, especially those that are heavily industrialized. This paper presents a comprehensive Life Cycle Assessment (LCA) conducted on four different product systems in the University of Nigeria's LION water Company. The study makes use of the OpenLCA software to evaluate the environmental impacts associated with the life cycle of four selected product systems, including 50cl PET bottle water, 75cl PET bottle water, 60cl sachet water and 18l dispensary water. The aim is to provide insights into the environmental implications of the different water packaging options and identify potential areas for sustainability improvements. The LCA methodology encompasses the use of the 'ecoinvent_391_cutoff_upr_regionalized' database and the impact assessment was done using the 'openLCA - ReCiPe 2016 Midpoint (H)' method to analyse resource use, emissions, and other environmental indicators. Summarized results show that the 60cl sachet water production system has the least environmental impact, while the 50cl PET bottled water production system exhibits the highest environmental impact. The study recommends a reduction in 50cl PET bottle water production and an increase in 60cl sachet water production within University of Nigeria (UNN) Lion Water to minimize negative environmental footprints and promote sustainability in water production operations.

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1.0 INTRODUCTION

Life Cycle Assessment (LCA) is a methodology used to examine how products, processes, or systems affect the environment over the course of their entire life cycle[1], [2], [3]. It is a method for evaluating the environmental impacts related to each stage of the life cycle of a commercial good, process, or service. It considers every phase of a product's life, including the gathering of raw materials, production, use, and disposal. The necessity to quantify the effects of industrial activity and growing worries about environmental deterioration led to the development of the LCA concept in the 1960s and 1970s[4]. LCA's early development was influenced by packaging studies, which mostly focused on energy use and a few emissions. This led to an uncoordinated development approach in the US and Northern Europe. Energy requirements for the manufacturing of chemical intermediates and products were the subject of the (perhaps) first LCA-focused study, which was presented in 1963 [5].

There are four major stages involved in the LCA process (Figure 1). These stages include Goal and Scope Definition, Life Cycle Inventory (LCI), Life Cycle Impact Assessment (LCIA) and Interpretation[6], [7], [8].

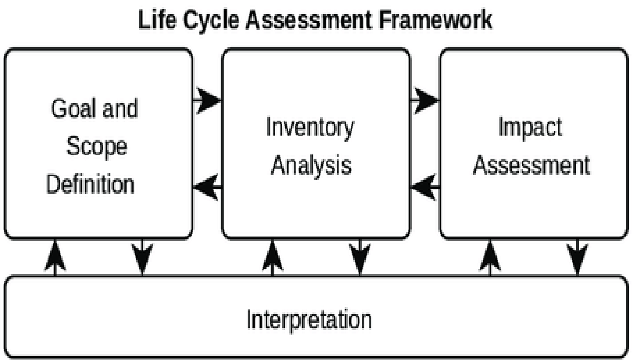

Figure 1: Steps of the LCA methodology [9]

The goal and scope definition step, which is the first stage of the LCA approach, entails defining the study's scope and purpose. Data on the energy and material inputs required for each stage of the life cycle of the product, including removal of raw material from the ground, production, distribution, consumption, and disposal, is gathered during the LCI stage [10], [11][10]. LCIA is the third step of the LCA approach, which entails evaluating the ecosystem effects associated with a products lifecycle. The environmental consequences are identified and quantified using the data gathered during the LCI stage, and they are then shown as impact categories and indicators. The fourth and last stage of the Life Cycle Assessment (LCA) technique is called Interpretation. It entails deriving conclusions about the ecosystem effect of the product under investigation from the findings of the Life Cycle Inventory (LCI) and Life Cycle Impact Assessment (LCIA) stages [12], [13], [14], [12]. LCA can be classified based on their system boundaries into gate to gate, cradle to gate, cradle to customer, cradle to grave, and cradle to cradle [15], [16], [17].

Figure 2 shows the various approaches through which the Life Cycle assessment of a product or product systems can be done. The product life cycle involves extraction, production, distribution, use, end of life and recycling as seen.

Since LCA focuses on determining and quantifying the environmental impact of human processes and activities, its application can be seen in a vast number of areas. LCA is widely recognized as a system analysis application whose main goal is to paint a picture of how an activity interacts with the environment, acting as a tool for environmental management. LCA therefore has two primary goals. The first step is to measure and assess a product's or a process's environmental performance in order to assist decision-makers in weighing their options. Providing a foundation for evaluating prospective advancements in the system's environmental performance is another goal of LCA [19]. Generally speaking, LCA application can be seen in marketing, process optimization, analysis of own product, analysis of own product, analysis of a person's business, resource evaluation, choice of supplier and materials among other human activities.

Figure 2: Different classification by Life Cycle Assessment [18]

[20] conducted an online literature review of articles published between 2000 and 2016 making use of words such as "life cycle assessment," "carbon footprinting," "water footprinting," and "environmental impact" to examine the availability of life cycle assessment (LCA) studies in Nigeria and Ghana. In total, thirty -one (31) LCA and environmental studies encompassing industries like energy, waste management, real estate, food, timber, and gold were discovered, the majority of which were academic in nature. The paucity of studies in these West African nations may be brought on by businesses not promoting quantitative environmental studies, internal retention of studies for internal use in alternative evaluation methods, or a dearth of cutting-edge research resources in university research institutions. More quantitative environmental studies, according to the authors, are required to better understand environmental implications, especially as more businesses ask for this data to support background operations. [21] carried out a study with the goal of providing an overview of approaches for identifying, characterizing, propagating, understanding, and

communicating uncertainty in LCA to be able to develop the accuracy and legitimacy of LCA results.

For a typical case study of the production of particleboard in Brazil, [22] compared the outcomes of four different Life Cycle Assessment (LCA) software tools: SimaPro, Gabi, Umberto, and OpenLCA. The study discovered that, particularly for effect categories like photochemical ozone generation and eco toxicity freshwater, using different software instruments can produce distinct results for equivalent product system. To lessen differences in LCA results between various software tools, the article suggests that LCIA methodologies be included in a node at the Global LCA Data network.

An overview of life cycle assessment (LCA) studies of polyethylene terephthalate (PET) packaging is given in the study by [23]. These studies primarily compare PET recycling with other disposal options and compare PET with other materials. The analysis emphasizes the need for more thorough LCA PET research, particularly when considering mechanical recycling systems and information from underdeveloped nations. Emerging challenges include the usage of alternative polymers for carbonated beverage bottles and post-consumer PET for chemical recycling must also be considered[23].

Globally, the usage of plastic materials for packaging and storage has expanded, raising questions about their effects on the environment. Although many nations have created systems for recycling and disposing of plastic garbage, Nigeria lacks information on how to control its usage of plastic, endangering the environment both now and in the future. The consumption of plastics, its trash generation, collection, and treatment in Nigeria and other chosen nations are highlighted in [24], with an emphasis on the issues related to insufficient waste management. The authors made proposals for viable research and investment opportunities as well as for sustainable regulatory measures to be taken by the government to address the issues.

Although LION water production company takes the necessary precautions and guidelines available to make sure their activities have less negative impact on the environment, the available information may just not be enough. Hence the need to look for the most optimal solution available to ensure that their activities are environmentally friendly. Understanding which of the four products have least and which has greatest impact on the environment will go a long way in improvement of the business' efficiency. And this will ultimately favour the environment and in turn, give room for suggestion and insight on how to improve the production systems for a more sustainable environment.

The study aims to carry out a comparative Life Cycle Assessment of four different product systems (50cl PET bottled water production system, 75cl PET bottled water production system, 60cl sachet water production system and 18 litres dispensary water system) of UNN Water Resources Management Laboratory (UNN Lion Water production company) using OpenLCA software for Life cycle Inventory (LCI) and Life cycle impact assessment (LCIA) to determine the environmental impacts of each.

2.0 METHODOLOGY

Data was sourced from some information gotten from the company on the processes involved in producing each of the four products, from measurements of some weights of samples of the products, from the database chosen and also, from literature.

There are six steps involved in the life cycle analysis of any product and these steps each correspond to the methodology involved in the life cycle analysis of the four different water product systems[25]. These steps or the methods for the analysis of water product systems are:

1. Definition of the goal and scope of the analysis
2. Collection of data
3. Creation of process model
4. Performing Life Cycle Impact Assessment
5. Interpret and analyse result.
6. Report and communicate.

The definition of goal was the first and most important step carried out in this project. The goal of the LCA study for the water production system was clearly defined and it is the comparative life cycle assessment of four product systems which are 50cl PET bottle water production system, 75cl PET bottle water production system, 60cl sachet water production system and 18 litres dispensary production system.

LCA can be classified based on their system boundaries into gate to gate, cradle to gate, cradle to customer, cradle to grave, and cradle to cradle[26]. For this project, the type that was selected is the cradle to customer approach and this system boundary deals with all the processes involved in the production of a product from its raw material extraction to the point of the consumers' use.

The data collection stage was the next important stage after the goal and scope definition stage. Primary data was sourced from the company on the processes involved in producing each of the four products, and from weight measurements of samples of the products, from the OPENLCA database chosen and also, from literature.

A functional unit of 9,000 litres of production of water was selected. This quantity of water translates to the following quantities for each of the product systems:

Table 1: The equivalent of the functional unit in each product system

60 cl Water Sachet	50 PET Bottles	75cl PET Bottles	18 litres Dispensary
15,000	18,000	12,000	500

A summary of the data collected and how they were put into the OpenLCA software in the modelling phrase is shown in Table 2.

Table 2: Product system data used for the study

Parameter	Description	Quantity	Product
D1	Distance from the point of production/purchase of the granulates (in Lagos) to the point of processing (in Oshodi, Lagos).	20km	All
D2	Distance from Oshodi, Lagos to UNN Water Resources Management Lab. Ltd. (UNN Lion Water)	610km	All
D3	Maximum Distance from UNN Lion Water to Consumer (within the University Community)	10km	All
WFB	Weight of Full Bottle/can	0.511kg/0.769kg/18.38kg	50cl/75cl/18l
WFS	Weight of Full Sachet	0.515kg	60cl
WHDPE	Weight of High-Density Polyethylene	0.0008kg/0.0008kg	50cl/75cl
WHDPE_can	Weight of Dispensary Can only (which is made up of High-Density Polyethylene)	0.684kg	18l
WHDPE_lid	Weight of Dispensary Lid only (which is made up of High Density Polyethylene)	0.0288kg	18l
WHDPEg	Weight of High-Density Polyethylene Granulates	0.0008kg/0.0008kg	50cl/75cl
WHDPEg_can	Weight of the High-Density Polyethylene granulates the Dispensary Can is made of.	0.747kg	18l
WHDPEg_lid	Weight of the High-Density Polyethylene granulates the Dispensary Lid is made of.	0.0288kg	18l
WLDPE	Weight of Low-Density Polyethylene	0.00005kg	60cl
WLDPEg	Weight of Low Density Polyethylene Granulates	0.00005kg	60cl
WPET	Weight of Polyethylene Terephthalate	0.019kg/0.02kg	50cl/75cl
WPETg	Weight of Polyethylene Terephthalate Granulates	0.02075kg/0.02184kg	50cl/75cl
WPETp	Weight of Polyethylene Terephthalate Preform	0.027kg	50cl
WPP	Weight of Polypropylene	0.0005kg/0.0006kg/0.002kg	50cl/75cl/18l
WPPg	Weight of Polypropylene Granulates	0.0005kg/0.0006kg/0.002kg	50cl/75cl/18l
WPW	Weight of Processed Water in bottle/sachet/can	0.4907kg/0.51495kg/0.7476kg/17.6652kg	50cl/60cl/75cl/18l

Other forms of data collected for the modelling in the software include information about the water treatment process carried out in the company, the PET bottle production processes, the sachet water production processes and finally, the dispensary water production processes.

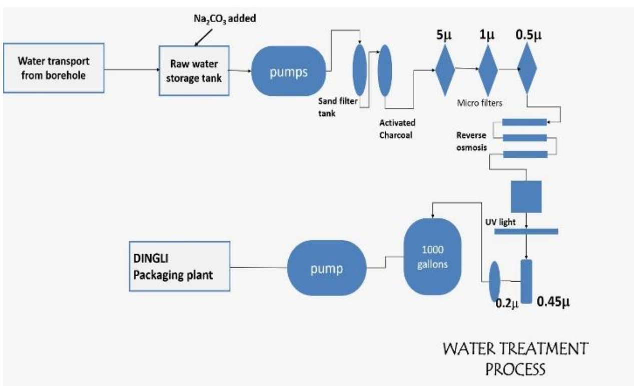

Figure 3: Water treatment process

Figure 3 shows the water treatment processes which the water resources laboratory in UNN undergo to purify the water used in the various packaging processes. This is done to ensure that the water is pure and safe for drinking by consumers. This is very essential as it is the first step taken before the water is fit to be packaged. As seen from the diagram above, the water is first transported from a borehole then, it is stored in a tank where Na_2CO_3 is added[27], [28]. This is done to increase the pH of the water thereby reducing acidity. The water is then passed through series of filters and purifiers all increasing in the order of purification (the unwanted particles filtered are more minute as the stages go on). For example, in the reverse osmosis stage, it removes ions, unwanted molecules and larger particles from the drinking water using a partially permeable membrane among other filters and micro-filters used. The water is then stored in a tank till it is ready to be moved to the packaging plant.

Figure 4 shows the process involved in the manufacture of a PET water bottle. First, the plastic granulate are produced. The plastic granulates for the polyethylene terephthalate, poly propylene and high density polyethylene are produced in Lagos. After this production, the granulates are transported to a new location in Lagos for a new production process. In this new location, the main plastic components are manufactured from the granulates. These components are the PET preforms made from PET (polyethylene), the lid made from the HDPE (high density propylene) and finally the label made from PP (polypropylene). These plastic components are then transported down to the water production facility in University of Nigeria Nsukka. In the water production facility, the PET preforms are blown to the final PET product and then the labels are attached to the body of the bottle. The already treated water is then poured into the bottle and the lid is used to close it. The final product is then transported to the retail customers.

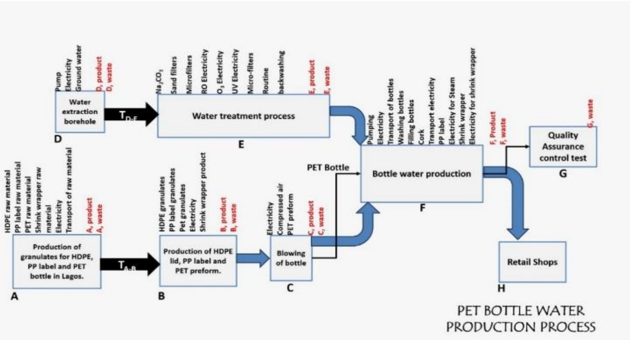

Figure 4: PET bottle water production process

It is important to note that the 50cl and 75cl PET bottle production process differ slightly in the UNN water resources management laboratory (UNN Lion Water). The difference is that unlike the 50cl bottle whose PET preform is blown in the UNN Lion water plant, that of 75cl is blown already before it is transported to the company. This means that for this case, the production process of the 50cl PET is quite longer and more detailed than that of 75cl.

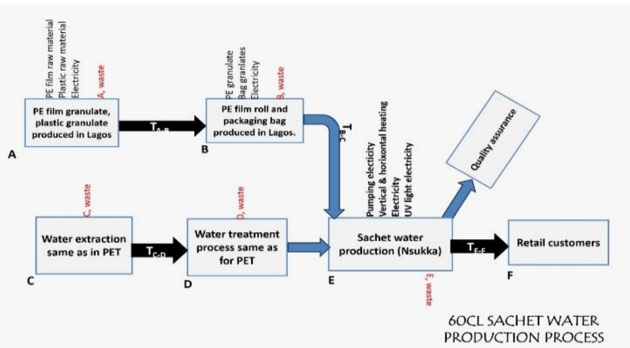

Figure 5: Sachet water production process

Figure 5 gives a pictorial description of the process of production of sachet water. First, PE film granulates are produced in Lagos and then transported to a new location in Lagos. In this new location, PE film rolls and packaging bags are produced in Lagos and then transported down to the water production facility in UNN. In this production facility, the already treated water is used to fill the sachet and the final sachet water is then transported to the retail customers.

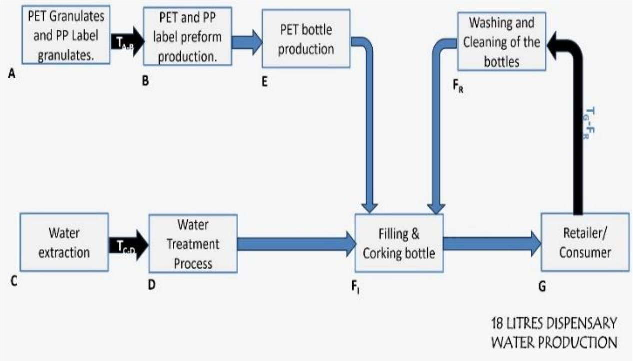

Figure 1: Dispensary water production process

Figure 6 shows a detailed description of the process. This process also happens to be very similar to the process for the production of PET water bottle. The PET granulate and PP label granulate are produced in Lagos and moved to a new location in Lagos for further production. In this new location, PET preform and PP label production are made and then transported down to UNN. In the water production facility in UNN, the PET bottles are produced and treated water is used to fill up the bottle and the bottle is then sealed/corked. The water is then finally transported to the retailer/customers. There is a kind of recycling process that goes on after this. After use, the customer delivers the bottle to a washing and cleaning section where the bottle is washed and then transported back to the production facility for refill.

The Cradle to Customer approach which focuses on the extraction of raw materials to the production, to the distribution stage and then, to the consumer use without considering the end of life and recycling stages was the type of life cycle approach adopted in this study [29].

To make the modelling of the data gotten from the various sources into the OpenLCA software possible, choices had to be made on the exact type of database to be used and the type of impact assessment method to be used while also noting that the use of the OpenLCA software was also a choice as there are other software available that can also conduct the analysis. For this study, the database used is *Ecoinvent*

3.9.1 cutoff_upr_n3_20230629 while the impact assessment method used is *openLCA - ReCiPe 2016 Midpoint (H)* [27]. These were chosen among the many others available due to some qualities they possess for example, the former for its high level of detail and global relevance and the latter for its comprehensive coverage and its comparison capability among other considerations.

3.0 RESULTS AND DISCUSSION

The impact categories whose results satisfy this flow chart moving from the highest impact to the lowest impact are Fine Particulate Matter Formation (Figure 7), Ozone Formation, Human Health (Figure 8), Global Warming, Water Consumption, Freshwater Eutrophication, Ozone Formation, Terrestrial Ecosystems and Land Use. They are seven in number. Two examples are shown below.

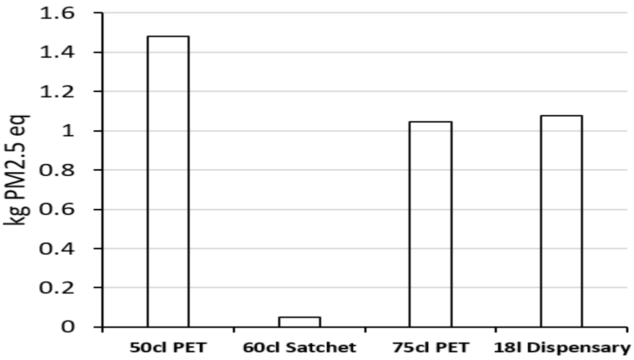

Figure 7: Fine particulate matter formation

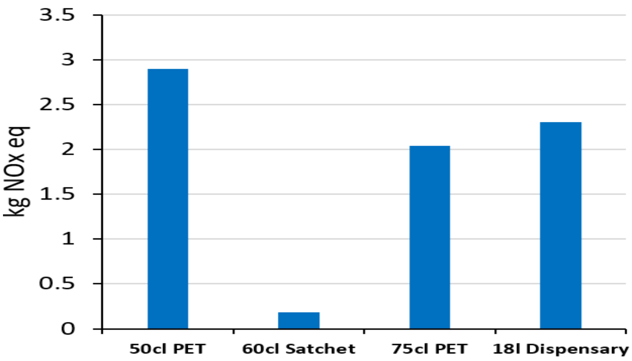

Figure 8: Ozone formation, human health

The impact categories whose results satisfy this flow chart moving from the highest impact to the lowest impact are Ionizing Radiation (Figure 9), Stratospheric Ozone Depletion (Figure 10), Human Carcinogenic Toxicity, Human Non-Carcinogenic Toxicity, Freshwater Ecotoxicity, Terrestrial Ecotoxicity, Terrestrial Acidification, Marine Ecotoxicity, Marine Eutrophication and Mineral Resource Scarcity. These are ten in number hence the highest number of impact categories follow this flowchart in their results display. Because of this information, it is possible to see how the overall result may look like as it has the highest number of impact categories following the pattern. This will be confirmed in the subsequent section where a full comparison is done with all the 18 categories considered to give an overall result. Two examples of graphs that follow this pattern are shown below.

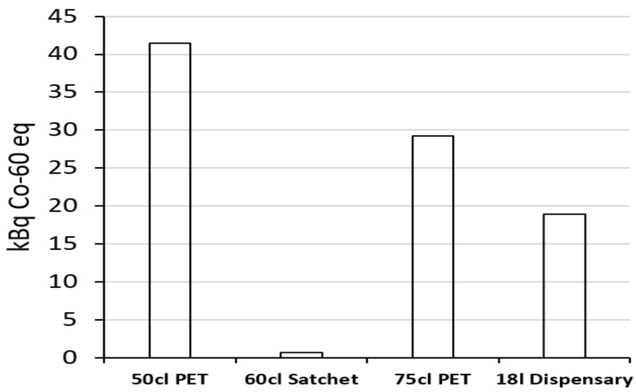

Figure 9: Ionizing radiation

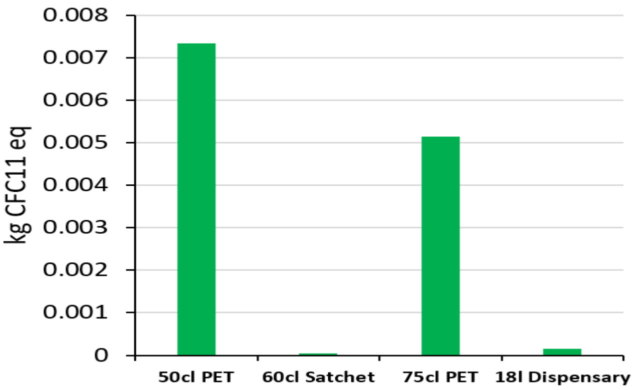

Figure 10: Stratospheric ozone depletion

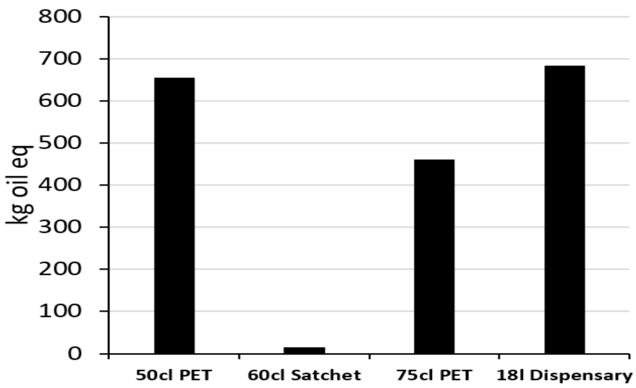

Figure 11: Fossil resource scarcity

There is only one impact category whose result is represented by this flowchart and it is the result of Fossil Resource Scarcity (Figure 11). Hence, this might have little to no impact on the overall results and conclusions.

A summary of these results, showing the effects of all the eighteen impact categories is shown in the radar chart as described below.

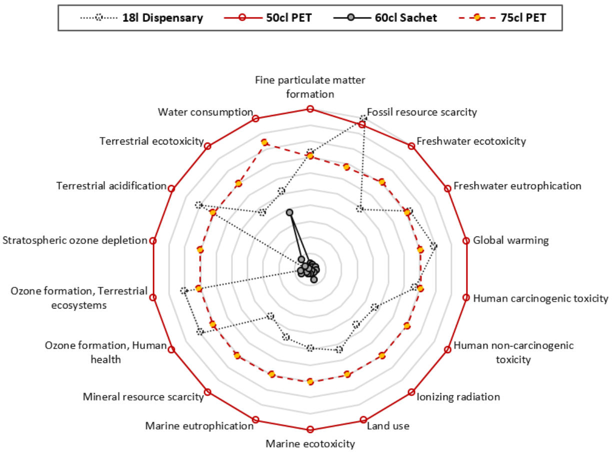

Figure 12: Effect of the four product systems on all the impact categories

From Figure 12, it is evident that the 50cl PET bottle water production system has the highest environmental impact. This is because it has the largest area in the radar chart, and it also has the most rounded shape. The production system with the second largest area is the 75cl PET bottle water production system. This is followed by the 18 liters dispensary production system. The production system with the smallest area coverage in the radar chart is the 60cl Sachet water production system. Hence the 60cl Sachet water production system releases the least environmental impacts among the four product systems. These findings underline the significance of packaging materials and volumes in influencing the overall environmental footprint of these product systems.

4.0 CONCLUSION

This paper presents a comprehensive Life Cycle Assessment (LCA) conducted on four different product systems in the University of Nigeria's LION water Company. The study makes use of the OpenLCA software to evaluate the environmental impacts associated with the life cycle of four selected product systems, including 50cl PET bottle water, 75cl PET bottle water, 60cl sachet water and 18l dispensary water. The aim is to provide insights into the environmental implications of the different water packaging options and identify potential areas for sustainability improvements. The LCA methodology encompasses the use of the 'ecoinvent_391_cut-off_upr_regionalized' database and the impact assessment was done using the 'openLCA - ReCiPe 2016 Midpoint (H)' method to analyse resource use, emissions, and other environmental indicators. Summarized results show that the 60cl sachet water production system has the least environmental impact, while the 50cl PET bottled water production system exhibits the highest environmental impact. The study recommends a reduction in 50cl PET bottle water production and an increase in 60cl sachet water production within UNN Lion Water to minimize adverse environmental footprints and promote sustainability in water production operations.

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