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A Comparative Life Cycle Assessment of Energy Use in Major Agro-processing Industries in Nigeria

Hammed Adeniyi Salami[1*]

[1]Department of Agricultural and Environmental Engineering, University of Ibadan, Nigeria.

Author's contribution

The sole author designed, analysed, interpreted and prepared the manuscript.

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ABSTRACT

A comparative assessment of environmental impacts associated with the use of energy in palm kernel oil production and cashew nut processing industries was carried out using life cycle assessment. One Kg of products from both industries was chosen as the functional unit. The gate – to – gate life cycle assessment results indicated that the total contribution per functional unit to global warming potential (GWP), abiotic depletion potential (ADP) and acidification potential (AP) were 50.2809 g of CO_2 equivalents, 0.1524 g antimony equivalents and 0.1280 g of SO_2 equivalents respectively for palm kernel oil production and 39.8350 g of CO_2 equivalents, 0.1209 g antimony equivalents and 0.0957 g of SO_2 equivalents respectively for cashew nut processing. The scenario-based results indicated substantial reductions for all the considered impact categories; approximately 18, 28 and 94% reductions were achieved for ADP, GWP and AP respectively for both industries when public power supply from the natural grid was the main energy source for agricultural production. Increasing the thermal efficiency of the nation's existing power architecture resulted into 62 and 56% reductions for GWP and ADP respectively for the two industries, while additional 6 and 7% reductions were achieved for both impact categories when the transmission and distribution loss was maintained at 5%. The

**Corresponding author: E-mail: salamihammed6@gmail.com;*

widespread adoption of clean and renewable energy sources, instead of over-reliance on electricity supply from diesel-powered generator, has been identified as a feasible alternative towards achieving sustainability in the agro-processing industry.

Keywords: Agro-processing industries; energy use; environmental impacts; life cycle assessment.

1. INTRODUCTION

Today, energy is a major component that is needed to effectively run our complex society and it is indeed an indispensable input in commercialized agriculture. Mechanized agriculture and food production rely heavily on energy to carry out the desired operations and obtain high processing efficiencies in the mechanization of crop handling, conveyance and thermal processing; to assure safe storage of agricultural products and conversion processes that create new forms of food [1]. Industrialized direct energy use in agricultural production is mostly in the form of fuel for transportation and electricity consumption from conventional thermal power plants, fuel-powered generator as well as from other sources [2]. However, the intensification of agricultural production processes has increasingly led to environmental burdens ranging from global warming to acidification, land use as well as depletion of natural resources [3].

Energy induced agricultural practices are known globally as major sources of gaseous emissions that are capable of degrading our natural environment. Emissions from on-farm energy use and production of fertilizers account for approximately 8 to 10% of global agricultural emissions; and in the absence of abatement measures, annual global emissions of GHG from agriculture are likely to increase by 30% by 2030 when compared to estimated levels in 2005 [4]. Also, emissions from agricultural processing plants have the huge potential of degrading air quality by contributing to acid rain and ozone depletion [5]. To combat these challenges, experts have iterated the need to adopt more sustainable forms of agriculture. Concerns about sustainability centre not only on the need to develop technologies and practices with low or zero adverse environmental impacts but also to achieve food security [6].

Traditionally, assessing the sustainability of energy use in agricultural production is best mirrored with the use of energy flow analysis. This tool focuses on the rational use of energy resources through increased energy efficiency without compromising the economics of agricultural production; this is reflected also in the environmental results since increased energy efficiency saves energy resources and reduces the potential generation of pollutants that are capable of having negative impacts on the environment [7]. Whereas, in recent times, life cycle assessment (LCA) has become a common environmental management tool and a good analytical methodology for assessing and optimizing the environmental quality of a system over its whole life cycle [8]. LCA has found widespread applications in various industrial sectors including major areas of agricultural production such as crop production, animal production and agro-processing.

Agro-processing involves the transformation of primary agricultural produce into a useful product and it encompasses the development and use of appropriate machines, equipment and technologies to enhance sustainable agricultural production through time and drudgery reduction as well as achieving higher energy efficiency [9]. In line with the sustainable development goals, improving the energy-use efficiency of agro-processing is a key priority; leading to low production cost, reduce adverse environmental impacts and enhance efficient use of scarce natural resources [4]. In spite of the many advantages of energy efficiency, the use of LCA goes beyond the identification of areas where energy savings are most cost-effective; it also enhances the identification of various environmental impact categories that may be associated with energy use in the various agro-processing industries.

Though, there exist several studies that have documented energy use data to depicts sustainability in major agro-processing industries in Nigeria, the use of LCA in this sector is still a developing phenomenon. The LCAs of soy oil and vegetable oil production in Nigeria have been reported [3,10]. Nonetheless, considering the strategic importance of the agro-processing industry to the nation's economy and the need to protect the environment in line with best international practices, there is still much to be done in this regard. In a comparative life cycle assessment carried out by Schmidt [11], it was reported that one of the areas with the most significant contributions to global warming potential from palm oil production was the processing stage – palm oil mill and refinery – where anaerobic digestion of palm oil mill effluent causes significant methane emissions (87% methane, 11% CO_2 and 2% other).

Ntiamoah and Afrane [12] assessed the cradle-to-gate impacts associated with the production of cocoa products in Ghana, taking into consideration the production, transportation and processing stages. It was revealed that the industrial processing was the predominant stage and it accounted for 76.35 – 96.47% of the overall impacts for all the categories considered – photochemical ozone creation potential, global warming potential, atmospheric acidification potential and abiotic depletion potential. Combustion of fossil fuels in boilers and roasters was identified as the major cause of this anomaly and it was noted that ensuring high energy use efficiency in the energy-intensive equipment is a feasible mitigation approach. This study is therefore aimed at the comparative assessment of the potential environmental impacts associated with the use of energy in palm kernel oil production and cashew nut processing industries in Nigeria.

2. MATERIALS AND METHODS

Environmental impacts associated with the use of energy in agro-processing industries were evaluated using ISO-compliant Life Cycle Assessment (LCA) methodology. LCA was defined and standardized by the International Standards Organization within the procedural framework of ISO 14040–14043 series [12]. In this approach, the assessment of the potential environmental impacts of a product is achieved by quantifying and evaluating the resources consumed and the emissions to the environment at all stages of its life cycle [13]. This allows the identification of key leverage points for reducing environmental impacts within supply chains, as well as comparisons of the resource dependencies and emission intensities of competing production technologies [14]. The four major stages in LCA are goal and scope definition, life cycle inventory, life cycle impact assessment; and interpretation [15].

2.1 Goals and Scope Definition

The primary aim of this study is to comparably evaluate the LCA of two major agro-processing industries in Nigeria, namely: palm kernel oil (PKO) and Cashew nut processing (CNP). And also to investigate the effects of energy source and grid – mix indices on the total environmental impact. This attempt is limited to the large scale production of valuable products from these industries, whose main source of energy is from the use of diesel-powered generator (DPG); which is typical of a developing country like Nigeria. The functional unit was chosen to be 1 Kg of product – palm kernel oil and cashew kernel. Attention was focused on the gate-to-gate assessment of each production system as depicted in Fig. 1. Environmental impacts associated with the production and transportation of raw materials and fuel to the industry, as well as onsite waste treatment were excluded from this study.

Secondary data on materials and energy consumption and the detailed flow charts were sourced for from existing studies on energy use in agro-processing industries [1,2]. The unit operations for the two agro-processing industries are presented in Table 1. Average fuel consumption by the generating sets was determined through the use of diesel fuel consumption chart [16]. Environmental loads due to the use of manual energy were not considered since manpower is known to be a zero net contributor to adverse environmental impacts.

2.2 Life Cycle Inventory

LCI is a tool used for the investigation of resource and material use, fuel and electricity consumption, and air pollutant emissions for each LCA stage, in which the data show corresponding quantities per functional unit [17]. The emission to the environment considered for this study are: carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), ammonia (NH_3), nitrogen oxide (NO_X) and sulfur dioxide (SO_2). The LCI assessment was done by the use of emission estimation methods specified in a similar research [3]. The inputs and outputs environmental loads associated with the use of energy in the chosen agro-processing industries are shown in Table 2.

2.3 Life Cycle Impact Assessment

Life cycle impact assessment (LCIA) involves calculating the contributions made by the material and energy inputs and outputs tabulated in the inventory phase to a specified suite of environmental impact categories [14], major impact categories include global warming, acidification, eutrophication, depletion of abiotic resources, human toxicity, ecotoxicity etc. Ntiamoah and Afrane [12] indicated that the mandatory phases of an LCIA are classification and characterization. Classification involves the assignment of LCI inputs and output to chosen impact categories while characterization involves the aggregation of the relative contributions of each LCI input and output to its assigned impact categories [10]. Global warming, acidification and depletion of abiotic resources were the impact categories selected for this study and all evaluations were determined using classical impact assessment methodology – midpoint approach.

The indicators chosen for the respective impact categories are global warming potential (GWP), acidification potential (AP) and abiotic depletion factor (ADP). GWP determines the climatic impact of a substance and it is the measure of the effect of the radiation of a particular quantity of the substance over time relative to that of the same quantity of CO_2 [23]. Also, AP measures the acidifying effects of pollutants. Acidifying pollutants have a wide variety of impacts on soil, groundwater, surface waters, biological organisms, materials (buildings) and ecosystems [13]. The CO_2- equivalence factors for determining GWP was chosen as CO_2: 1, CH_4: 23 and N_2O: 296 and the SO_2-equivalence factors for calculating AP was chosen as SO_2: 1, NO_X: 0.7 [15]. On the other hand, ADP was calculated adopting the approach developed by [24].

2.4 Scenario Analysis

The bane of economic development and industrial growth in Nigeria has always been

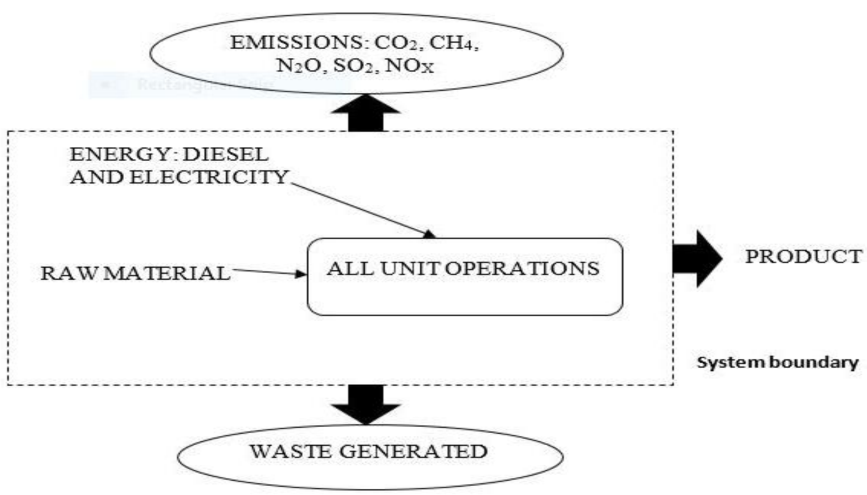

Fig. 1. System description for material and energy use in the agro-processing industry

Table 1. Unit operations in each agro-processing industry and the corresponding abbreviations

S/N		Unit operations
	Palm kernel oil production	Cashew nut processing
1	Palm-nut – Cracking (PNC)	Cashew nut – Cleaning (CNC)
2	Palm kernel – Roasting (PKR)	Cashew nut – Soaking and conditioning (CNS)
3	Palm kernel – Crushing (PKC)	Cashew nut – Roasting (CNR)
4	Palm kernel – Oil expression (PKE)	Cashew nut – Shelling (CNSL)
5	Palm kernel – Oil sifting (PKS)	Cashew Kernel – Separation (CKS)
6	Palm kernel Oil – Pumping and bottling (PKB)	Cashew Kernel – Drying (CKD)
7		Cashew Kernel – Peeling and grading (CKG)
8		Cashew Kernel – Packaging (CKPK)

Table 2. Associated environmental loads and output coefficients

Source	Output coefficient	Reference
Diesel fuel combustion		
GWP related emission	See the text	[3]
AP related emission	See the text	[3]
Electricity generation: Grid mix		
Energy use and related emission	See the text	[18, 19, 20]
Natural gas combustion		
GWP related emission	See the text	[21]
AP related emission	See the text	[22]

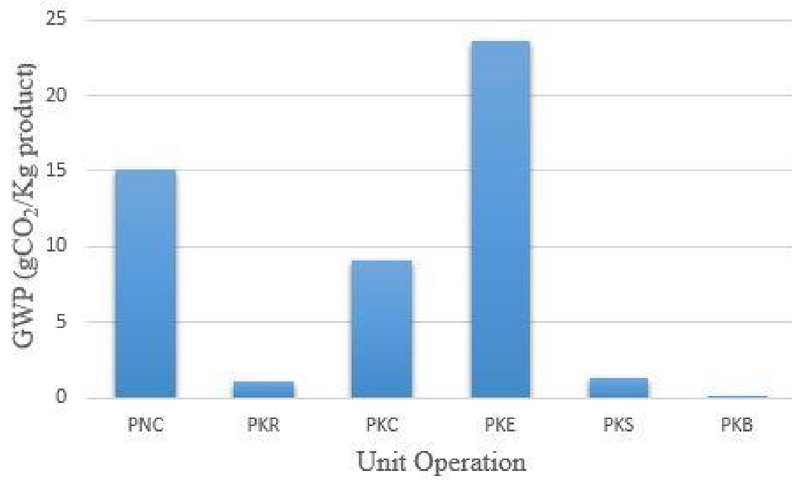

Fig. 2. Total contribution to GWP for each unit operation in Palm kernel oil production

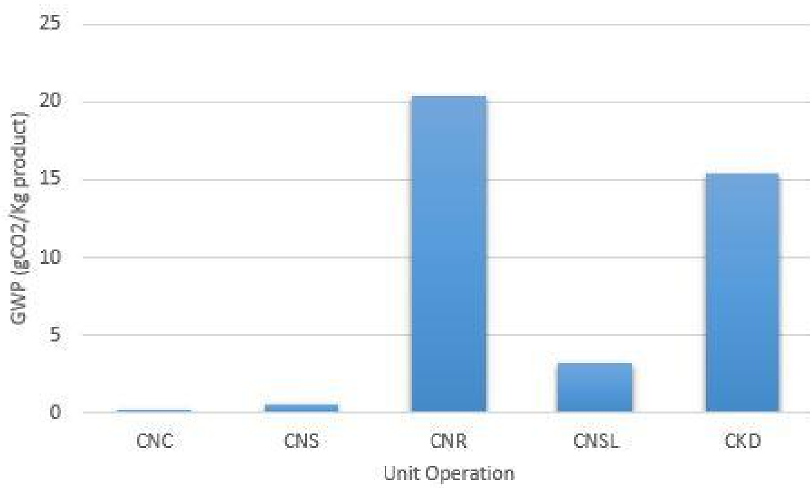

Fig. 3. Total contribution to GWP for each unit operation in Cashew nut processing

attributed to the nation's poor power sector. According to NESP [25], the nation was ranked 187 of 189 countries in the ease of getting electricity and this is mostly due to the dwindling investment in its power sector, reduction in maintenance budget and lack of additional viable capacity. The report further revealed that about 58% of the final available electricity in the nation is for residential usage while a meagre of about 16% is available for industrial use. This study, therefore, set to further investigate the environmental gains that can be accrued when agro-processing industries are less dependent on the direct combustion of fossil fuels for energy consumption. Hence, two scenarios were considered for the possible reduction of environmental impacts.

The first scenario examined the effect of energy source on the overall environmental impacts; factors considered are: 100% reliance on power supply from diesel-powered generator (DPG), 100% reliance on public power supply (PPS) from the national grid, and 50:50 % of electricity from national grid and diesel-powered generator (D-PPS). While the second scenario examined the effect of the grid – mix indices such as transmission and distribution loss (T&D), and thermal efficiency (TE).

3. RESULTS AND DISCUSSION

3.1 Global Warming Potential

The total contributions to global warming for the gate – to – gate life cycle assessment was 50.2809 and 39.8350 gCO_2/Kg product for palm kernel oil and cashew kernel production respectively. In both industries, CO_2 emission accounted for 99.57% of the total GWP and this is easily traceable to the chemical characteristics of the diesel fuel utilized for power generation. As expected, the contributions from N_2O and CH_4 emissions to the total GWP were significantly small with values of 0.35 and 0.08 gCO_2/Kg product respectively. Bamgbade et al. [10] also reported a similar but higher GWP value in the range 74.2 – 77.1 gCO_2/Kg product for the production of vegetable oil, taking into consideration factors that were not considered in this study such as transport distance and transport fuel type.

The contributions of the various unit operations in each industry are depicted in figs. 2 and 3. In palm kernel oil production, oil expression accounted for approximately 47% of the total GWP. Nut cracking and kernel crushing are major contributors to the total CO_2 equivalence and both accounted for 30.10% and 18.19% of the total GWP respectively. On the other hand, nut roasting accounted for more than half of the total GWP with a significant contribution to the overall CO_2 equivalence in the cashew nut processing industry. Whereas, cashew nut shelling and Kernel drying contributed more than 46% of the total GWP.

3.2 Abiotic Depletion Potential

Abiotic depletion potential is the characterization factor for describing the impact of depletion of abiotic resources, which is the decrease of availability of the total reserve of the potential functions of resources [24]. Table 3 shows the abiotic depletion potential of the industries in Kg antimony/Kg product. Palm kernel oil production has the higher impacts on the depletion of natural reserves, its ADP per unit product was 0.1524 g antimony/Kg product as compared to 0.1209 g antimony/Kg product estimated for cashew kernel production. In both industries, the unit operations that accounted for the least ADPs per unit product include: palm kernel cracking, pumping of palm kernel oil, cashew nut cleaning and, kernel peeling and grading. These unit operations are characterized by the massive use of manual energy, which is known to possess zero net environmental impact.

3.3 Acidification Potential

The calculated APs for the gate – to – gate life cycle assessment were 0.1280 and 0.0957 gSO_2/Kg product for palm kernel oil and cashew kernel production. Similarly, for the two industries, approximately 84% of the total contribution to AP was as a result of NO_x emission while SO_2 accounted for the balance. The AP result presented by Jekayinfa et al. [3] differs slightly from the result obtained in this study, this seems to be a result of the differences in energy use intensity. This assertion appears to agree with the AP value obtained by [12] in the LCA carried out for the production of cocoa products. Though the crop production and transportation stages were considered in their study; nevertheless, based on the specified technology, the energy use intensity in the cocoa processing stage also exceeds that obtainable in this study.

The detailed information on the total contribution of each unit operation is illustrated in figs. 4 and 5 for palm kernel oil and cashew kernel production respectively. Similarly, as compared to the result obtained for GWP in the palm kernel oil production industry, oil expression has the highest contribution to AP while oil pumping has the least contribution. Also, in the cashew nut processing industry, nut roasting accounted for the major contribution to AP while the least was obtained from the cleaning operation. Approximately 40% of the total contribution to AP was due to the high energy input in the cashew nut drying operation.

Table 3. Abiotic depletion potential for the various unit operations in the selected agro-processing industries

S/N	Palm kernel oil production		Cashew nut processing	
	Unit operation	ADP (g antimony/Kg)	Unit operation	ADP (g antimony/Kg)
1	PNC	0.0459	CNC	0.0007
2	PKR	0.0034	CNS	0.0017
3	PKC	0.0277	CNR	0.0619
4	PKE	0.0714	CNSL	0.0097
5	PKS	0.0038	CKD	0.0469
6	PKB	0.0002		

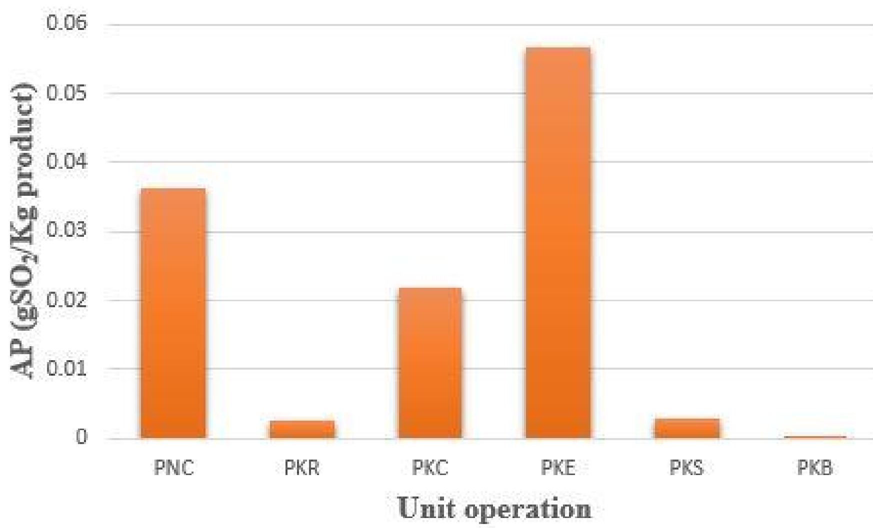

Fig. 4. Total contribution to AP for each unit operation in Palm kernel oil production

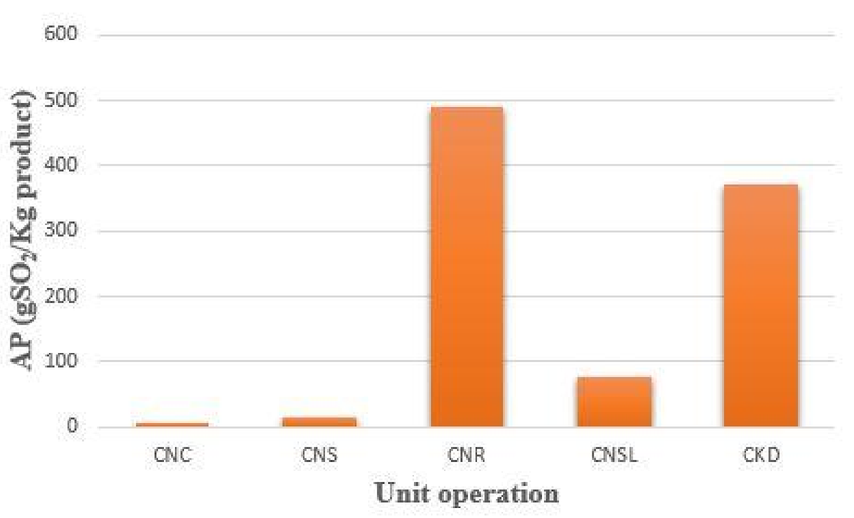

Fig. 5. Total contribution to AP for each unit operation in Cashew nut processing

3.4 Scenario-based Impacts

The scenario-based results showed considerable reduction in the environmental loads for all the impact categories that were considered, and these are aptly depicted in Figs. 6 and 7 for palm kernel oil and cashew kernel production respectively. The GWP and ADP values in the palm kernel oil production industry dropped to 43.2440 gCO_2/Kg and 0.1391 g antimony/Kg product respectively when power consumption was based on a 50:50 ratio of electricity supply from the diesel-powered generator and the national grid. For the scenario based on 100% public power supply from the national grid, the GWP and ADP values further dropped to 36.1841 gCO_2/Kg and 0.1256 g antimony/Kg product respectively. A similar trend occurred for cashew kernel production, in which the GWP and ADP values dropped to 34.2520 gCO_2/Kg and 0.1102 g antimony/Kg product respectively for a 50:50 ratio of electricity consumption, and to 26.6632 gCO_2/Kg and 0.0995 g antimony/Kg product for 100% public power supply from the national grid.

In both industries, the results also revealed that 100% public power supply from the national grid as compared to the overall supply of electricity from the diesel-powered generator led to a massive 94% reduction in AP. A notable reason for this significant reduction is traceable to the fact that natural gas accounted for 80% of the nation's power sector and it is also known to be sulphur-free. Hydro, which is the other components of the nation's grid mix, is widely recognized as a clean source of energy with consequential low environmental impact. This phenomenon affirmed that a gradual shift from energy consumption solely on fossil fuel combustion to renewable energy will go a long way in achieving a significant reduction in the overall environmental loads for all the impact categories.

However, as illustrated in Figs. 6 and 7, the consumption of 100% public power supply from the national grid as compared to diesel-powered generator only achieved 28% and 18% reduction for GWP and ADP respectively in the two industries. This is likely to be as a result of the major losses that are peculiar to the nation's power architecture. The distribution grid suffers technical and non – technical losses, having only a meagre thermal efficiency of about 40.10% while the transmission network also experiences losses up to 25% and more due to system overload [18,20]. The more these losses are, the more the consumption of fuel for power generation thereby leading to higher environmental loads.

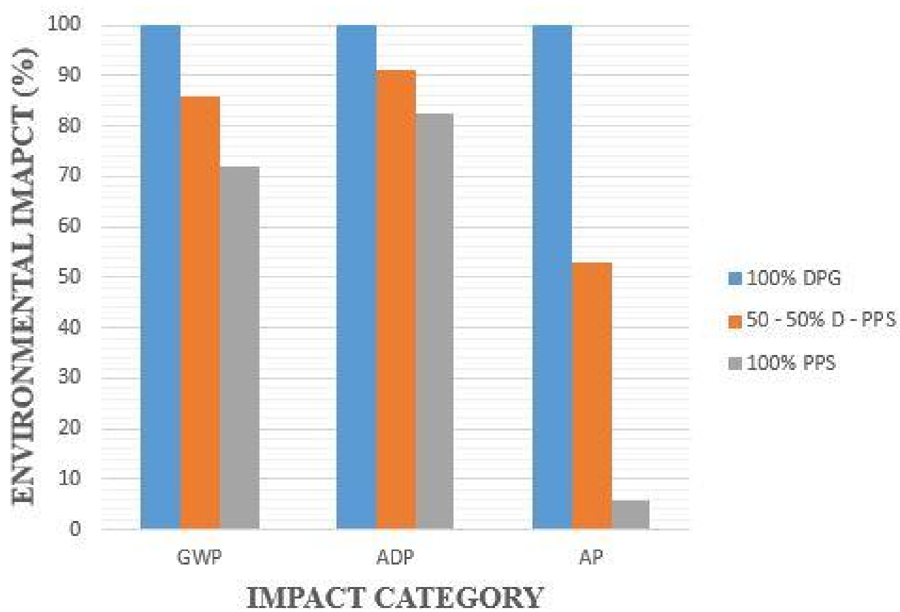

Fig. 6. Effect of energy source on environmental impact indicators for Palm kernel oil production

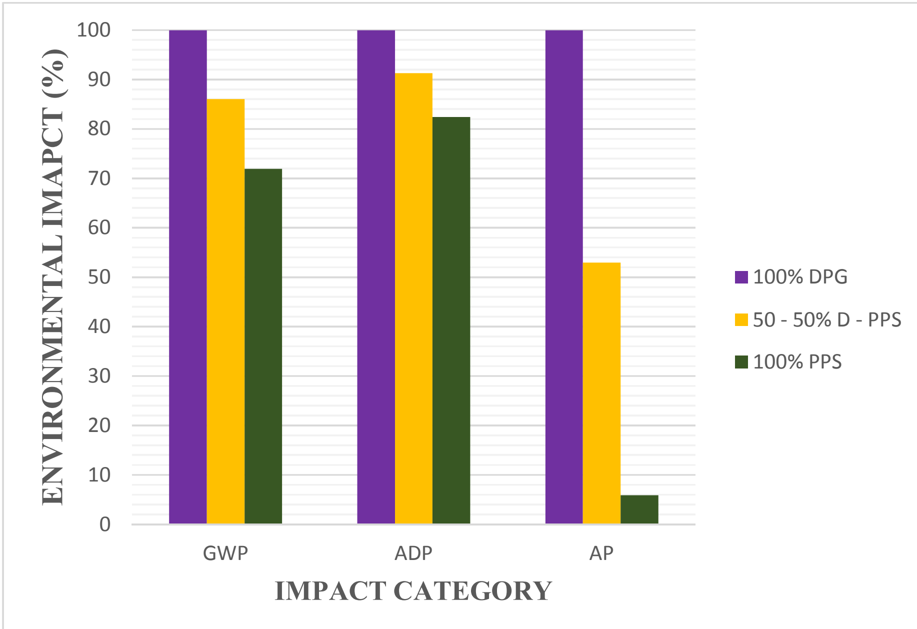

Fig. 7. Effect of energy source on environmental impact indicators for Cashew nut processing

Table 4. Effects of grid mix indices on overall environmental impact categories for the industries

Impact categories	Grid mix indices	
	Thermal efficiency (75%)	Additional T&D* loss (5%)
Palm kernel oil production		
GWP (gCO_2/Kg)	19.3051	16.2162
ADP (g antimony/Kg)	0.0670	0.0563
AP (gSO_2/Kg)	n.a	1.7108†
Cashew nut processing		
GWP (gCO_2/Kg)	15.2925	12.8457
ADP (g antimony/Kg)	0.0531	0.0446
AP (gSO_2/Kg)	n.a	1.4823†

**T&D loss was considered after thermal efficiency of 75%, † only T&D loss was considered, n.a = not applicable*

Table 4 presents the result of the effect of grid mix indices on the total environmental impact. When the thermal efficiency was increased to 75%, GWPs for both industries reduced by 62% and an additional 6% reduction was achieved when the transmission and distribution loss was reduced to 5%. In a similar trend, there was an approximately 56% reduction in ADPs when the thermal efficiency was increased to 75% while an extra 7% reduction was established also through the reduction of the transmission and distribution loss to 5%. Adoption of technologies with higher thermal efficiency coupled with a further reduction in the transmission and distribution loss is thus a sure alternative towards reducing the overall impact due to electricity consumption from the national grid.

4. CONCLUSION

Based on the scope of this study, palm kernel oil production shows a greater negative impact on the depletion of natural reserves as compared with cashew kernel production. This negative trend is associated with simultaneous higher global warming and acidification potentials, which is traceable to the over-reliance on the diesel-powered generator for the supply of electricity in the considered agro-processing industries. Contrarily, public power supply from the national grid shows a better but marginal environmental benefit in terms of GWP and ADP; mainly due to the several inadequacies in the country's power architecture. Hence, If the existing infrastructures in the nation's power sector are to be maintained, the environmental impacts associated with energy consumption can be considerably reduced through the maintenance of high thermal efficiency and low transmission and distribution loss. However, the widespread adoption of renewable energy and its subsequent integration into the national grid seems the most viable alternative towards achieving a truly sustainable environment.

COMPETING INTERESTS

Author has declared that no competing interests exist.

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