

# **A Comparative Life Cycle Assessment of Energy Use in Major Agro – processing Industries in Nigeria**

## **ABSTRACT**

A comparative assessment of environmental impacts associated with the energy use 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 50.2809g of CO<sub>2</sub> equivalents, 0.1524g antimony equivalents and 0.1280g of SO<sub>2</sub> equivalents respectively for palm kernel oil production and 39.8350 g of CO<sub>2</sub> equivalents, 0.1209g antimony equivalents and 0.0957g of SO<sub>2</sub> 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, then additional 6 and 7% reductions were achieved for both impact categories when the transmission and distribution loss was maintained at 5%. The widespread adoption of clean and renewable energy sources, in lieu of over reliance on electricity supply from diesel powered generator, has been identified as a feasible alternative towards achieving sustainability in 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 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 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 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].

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

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

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

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

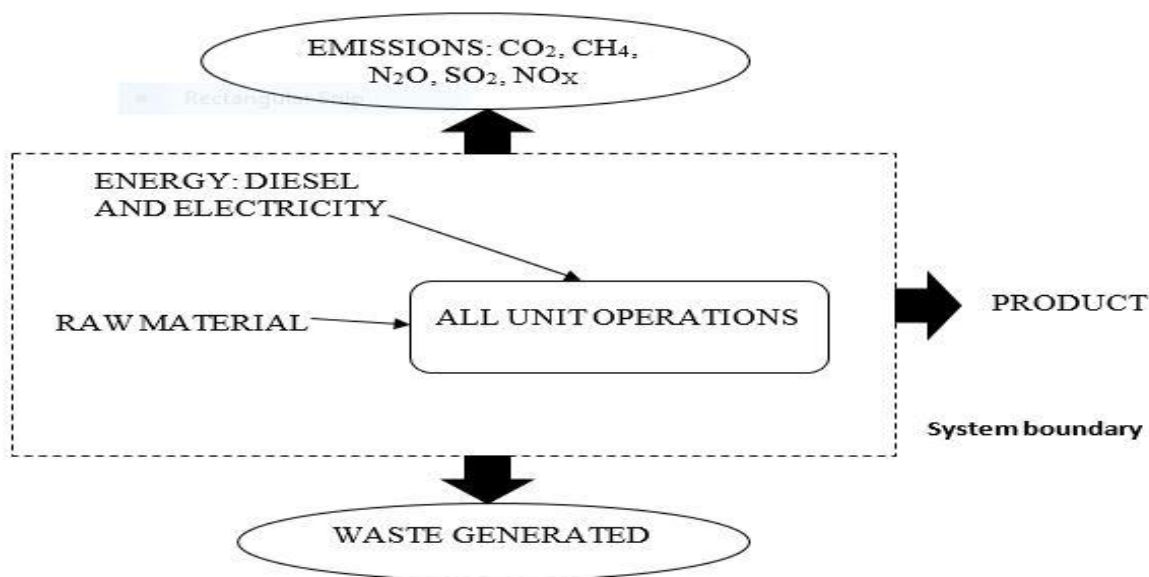
## 84 **2. MATERIAL AND METHODS**

85 Environmental impacts associated with the use of energy in agro – processing industries were evaluated  
86 using ISO – compliant Life Cycle Assessment (LCA) methodology. LCA was defined and standardized by  
87 the International Standards Organization within the procedural framework of ISO 14040 – 14043 series  
88 [12]. In this approach, the assessment of the potential environmental impacts of a product is achieved by  
89 quantifying and evaluating the resources consumed and the emissions to the environment at all stages of  
90 its life cycle [13]. This allows the identification of key leverage points for reducing environmental impacts  
91 within supply chains, as well as comparisons of the resource dependencies and emission intensities of  
92 competing production technologies [14]. The four major stages in LCA are: goal and scope definition, life  
93 cycle inventory, life cycle impact assessment; and interpretation [15].

### 94 **2.1 Goals and scope definition**

95 The primary aim of this study is to comparably evaluate the LCA of two major agro – processing  
96 industries in Nigeria, namely: palm kernel oil (PKO) and Cashew nut processing (CNP). And also to

97 investigate the effects of energy source and grid – mix indices on the total environmental impact. This  
 98 attempt is limited to the large scale production of valuable products from these industries, whose main  
 99 source of energy is from the use of diesel powered generator (DPG); which is typical of a developing  
 100 country like Nigeria. The functional unit was chosen to be 1 Kg of product – palm kernel oil and cashew  
 101 kernel. Attention was focused on the gate-to-gate assessment of each production system as depicted in  
 102 figure 1. Environmental impacts associated with the production and transportation of raw materials and  
 103 fuel to the industry, as well as onsite waste treatment were excluded from this study.



104  
 105 Figure 1: System description for material and energy use in agro – processing industry.  
 106 Secondary data on materials and energy consumption, and the detailed flow charts was sourced for from  
 107 existing studies on energy use in agro – processing industries [1, 2]. The unit operations for the two agro  
 108 – processing industries are presented in table 1. Average fuel consumption by the generating sets was  
 109 determined through the use of diesel fuel consumption chart [16]. Environmental loads due to the use of  
 110 manual energy were not considered, since manpower is known to be a zero net contributor to adverse  
 111 environmental impacts.

112 **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)

113

## 114 2.2 Life cycle inventory

115 LCI is a tool used for the investigation of resource and material use, fuel and electricity consumption, and  
116 air pollutant emissions for each LCA stage, in which the data show corresponding quantities per  
117 functional unit [17]. The emission to the environment considered for this study are: carbon dioxide (CO<sub>2</sub>),  
118 methane (CH<sub>4</sub>), nitrous oxide (N<sub>2</sub>O), ammonia (NH<sub>3</sub>), nitrogen oxide (NO<sub>x</sub>) and sulfur dioxide (SO<sub>2</sub>). The  
119 LCI assessment was done by the use of emission estimation methods specified in a similar research [3].  
120 The inputs and outputs environmental loads associated with the use of energy in the chosen agro –  
121 processing industries are shown in table 2.

122 **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]

## 123 2.3 Life cycle impact assessment

124 Life cycle impact assessment (LCIA) involves calculating the contributions made by the material and  
125 energy inputs and outputs tabulated in the inventory phase to a specified suite of environmental impact  
126 categories [14], major impact categories include: global warming, acidification, eutrophication, depletion  
127 of abiotic resources, human toxicity, ecotoxicity etc. Ntiamoah and Afrane [12] indicated that the  
128 mandatory phases of an LCIA are classification and characterization. Classification involves the  
129 assignment of LCI inputs and output to chosen impact categories while characterization involves the  
130 aggregation of the relative contributions of each LCI input and output to its assigned impact categories  
131 [10]. Global warming, acidification and depletion of abiotic resources were the impact categories selected  
132 for this study and all evaluations were determined using classical impact assessment methodology –  
133 midpoint approach.

134 The indicators chosen for the respective impact categories are: global warming potential (GWP),  
135 acidification potential (AP) and abiotic depletion factor (ADP). GWP determines the climatic impact of a  
136 substance and it is the measure of the effect on radiation of a particular quantity of the substance over  
137 time relative to that of the same quantity of CO<sub>2</sub> [23]. Also, AP measures the acidifying effects of  
138 pollutants. Acidifying pollutants have a wide variety of impacts on soil, groundwater, surface waters,  
139 biological organisms, materials (buildings) and ecosystems [13]. The CO<sub>2</sub>- equivalence factors for  
140 determining GWP was chosen as: CO<sub>2</sub>: 1, CH<sub>4</sub>: 23 and N<sub>2</sub>O: 296 and the SO<sub>2</sub>-equivalence factors for  
141 calculating AP was chosen as: SO<sub>2</sub>: 1, NO<sub>x</sub>: 0.7 [15]. On the other hand, ADP was calculated adopting  
142 the approach developed by [24].

## 143 2.4 Scenario analysis

144 The bane of economic development and industrial growth in Nigeria has always been attributed to the  
145 nation's poor power sector. According to NESP [25], the nation was ranked 187of 189 countries in the  
146 ease of getting electricity and this is mostly due to the dwindling investment in its power sector, reduction

147 in maintenance budget and lack of additional viable capacity. The report further revealed that about 58%  
148 of the final available electricity in the nation is for residential usage while a meager of about 16% is  
149 available for industrial use. This study therefore set to further investigate the environmental gains that can  
150 be accrued when agro – processing industries are less dependent on direct combustion of fossil fuels for  
151 energy consumption. Hence, two scenarios were considered for possible reduction of environmental  
152 impacts.

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

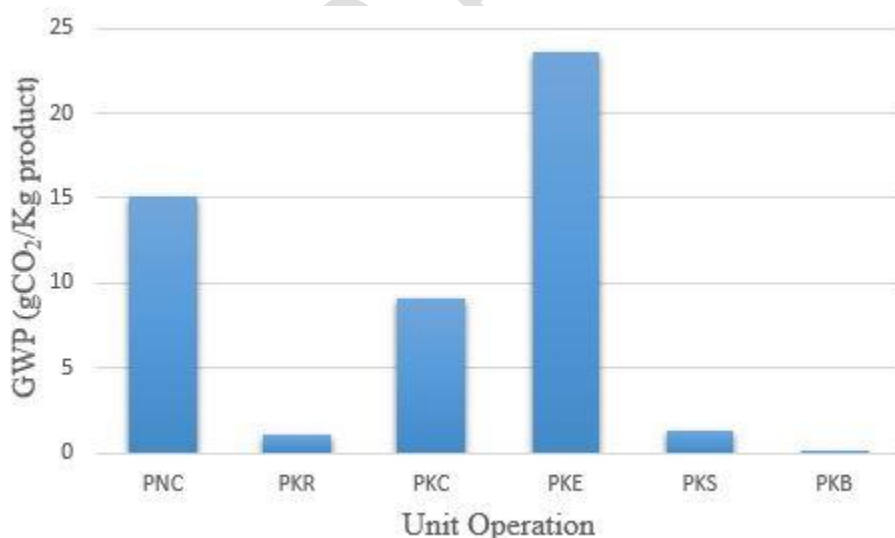
### 158 3 RESULTS AND DISCUSSION

#### 159 3.1 Global warming potential

160 The total contributions to global warming for the gate – to – gate life cycle assessment was 50.2809 and  
161 39.8350 gCO<sub>2</sub>/Kg product for palm kernel oil and cashew kernel production respectively. In both  
162 industries, CO<sub>2</sub> emission accounted for 99.57% of the total GWP and this is easily traceable to the  
163 chemical characteristics of the diesel fuel utilized for power generation. As expected, the contributions  
164 from N<sub>2</sub>O and CH<sub>4</sub> emissions to the total GWP were significantly small with values of 0.35 and 0.08  
165 gCO<sub>2</sub>/Kg product respectively. Bamgbade *et al.* [10] also reported a similar but higher GWP value in the  
166 range 74.2 – 77.1 gCO<sub>2</sub>/Kg product for the production of vegetable oil, taking into consideration factors  
167 that were not considered in this study such as transport distance and transport fuel type.

168 The contributions of the various unit operations in each industry are depicted in figures 2 and 3. In palm  
169 kernel oil production, oil expression accounted for approximately 47% of the total GWP. Nut cracking and  
170 kernel crushing are major contributors to the total CO<sub>2</sub> equivalence and both accounted for 30.10% and  
171 18.19% of the total GWP respectively. On the other hand, nut roasting accounted for more than half of the  
172 total GWP with a significant contribution to the overall CO<sub>2</sub> equivalence in the cashew nut processing  
173 industry. Whereas, cashew nut shelling and Kernel drying contributed more than 46% of the total GWP.

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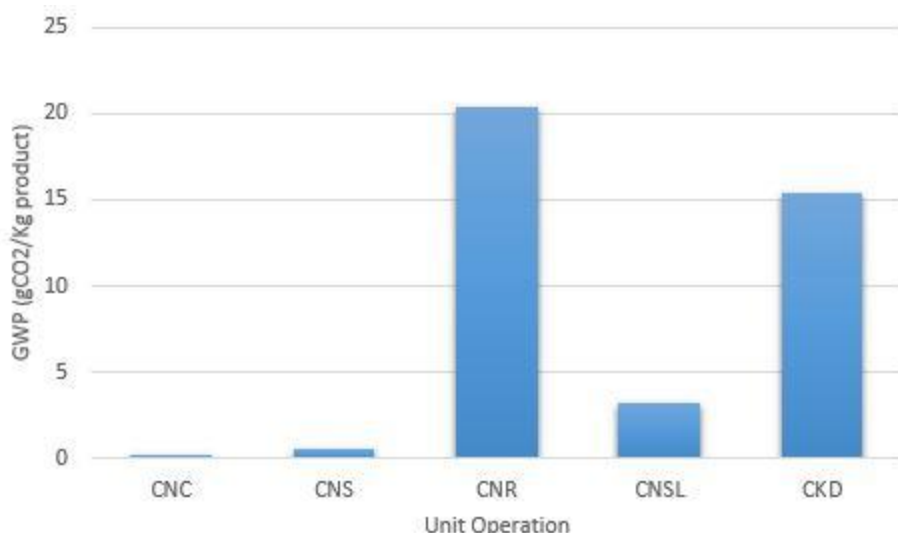


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176 Figure 2: Total contribution to GWP for each unit operation in Palm kernel oil production.

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182 Figure 3: Total contribution to GWP for each unit operation in Cashew nut processing.

183 **3.2 Abiotic depletion potential**

184 Abiotic depletion potential is the characterization factor for describing the impact of depletion of abiotic  
 185 resources, which is the decrease of availability of the total reserve of the potential functions of resources  
 186 [24]. Table 3 shows the abiotic depletion potential of the industries in Kg antimony/Kg product. Palm  
 187 kernel oil production has the higher impacts on the depletion of natural reserves, its ADP per unit product  
 188 was 0.1524g antimony/Kg product as compared to 0.1209g antimony/Kg product estimated for cashew  
 189 kernel production. In both industries the unit operations that accounted for the least ADPs per unit product  
 190 include: palm kernel cracking, pumping of palm kernel oil, cashew nut cleaning and, kernel peeling and  
 191 grading. These unit operations are characterized by the massive use of manual energy, which is known to  
 192 possess zero net environmental impact.

193 **Table 3: Abiotic depletion potential for the various unit operations in the selected agro –**  
 194 **processing industries.**

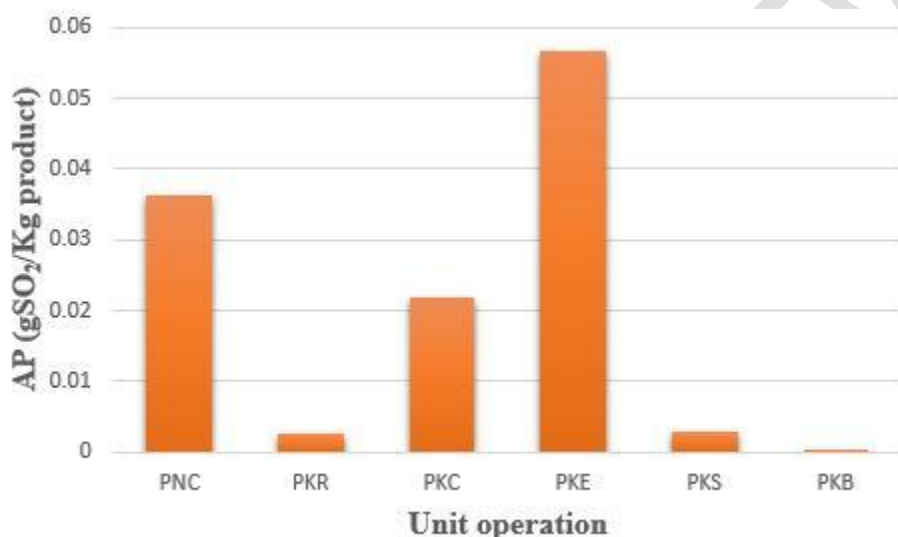
S/N	Palm kernel oil production		Cashew nut processing	
	Unit operation	ADP (g antimony/Kg)	Unit operation	ADP (g antimony/Kg)
1	PNC	0.0459	CNC	0.0007
2	PKR	0.0034	CNS	0.0017
3	PKC	0.0277	CNR	0.0619
4	PKE	0.0714	CNSL	0.0097
5	PKS	0.0038	CKD	0.0469
6	PKB	0.0002		

195 **3.3 Acidification potential**

196 The calculated APs for the gate – to – gate life cycle assessment was 0.1280 and 0.0957 gSO<sub>2</sub>/Kg  
197 product for palm kernel oil and cashew kernel production respectively. Similarly, for the two industries,  
198 approximately 84% of the total contribution to AP was as a result of NO<sub>x</sub> emission while SO<sub>2</sub> accounted for  
199 the balance. The AP result presented by Jekayinfa *et al.* [3] differs slightly from the result obtained in this  
200 study, this seems to be as result of the differences in energy use intensity. This assertion appears to be in  
201 agreement with the AP value obtained by [12] in the LCA carried out for the production of cocoa products.  
202 Though the crop production and transportation stages were considered in their study; nevertheless,  
203 based on the specified technology, the energy use intensity in the cocoa processing stage also exceeds  
204 that obtainable in this study.

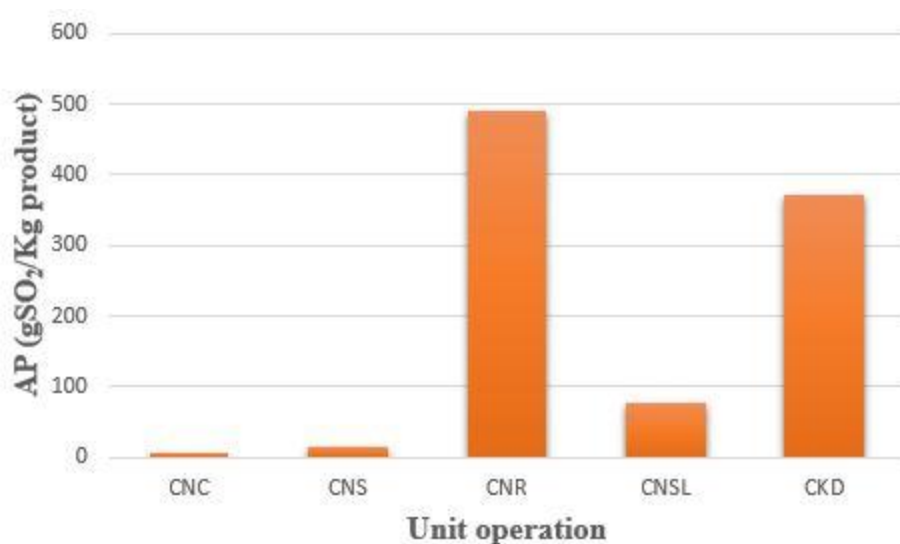
205 The detailed information on the total contribution of each unit operation is illustrated in figures 4 and 5 for  
206 palm kernel oil and cashew kernel production respectively. Similarly, as compared to the result obtained  
207 for GWP in the palm kernel oil production industry, oil expression has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

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214 Figure 4: Total contribution to AP for each unit operation in Palm kernel oil production.



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216 Figure 5: Total contribution to AP for each unit operation in Cashew nut processing.

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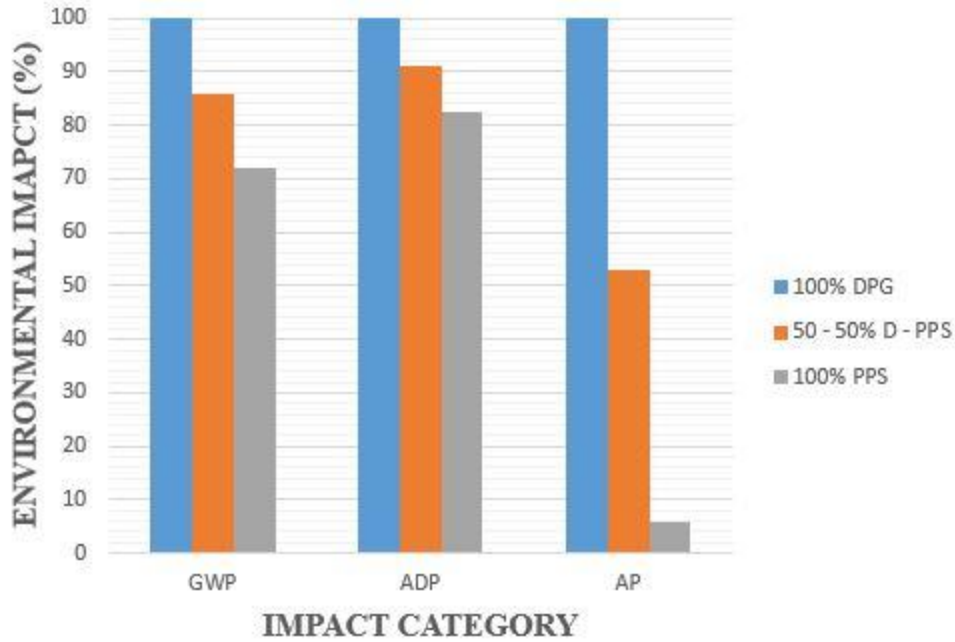
### 218 3.4 Scenario based impacts

219 The scenario based results showed considerable reduction in the environmental loads for all the impact  
 220 categories that are considered, and these are aptly depicted in figures 6 and 7 for palm kernel oil and  
 221 cashew kernel production respectively. The GWP and ADP values in the palm kernel oil production  
 222 industry dropped to 43.2440 gCO<sub>2</sub>/Kg and 0.1391g antimony/Kg product respectively when power  
 223 consumption was based on a 50:50 ratio of electricity supply from diesel powered generator and the  
 224 national grid. For the scenario based on 100% public power supply from the national grid, the GWP and  
 225 ADP values further dropped to 36.1841 gCO<sub>2</sub>/Kg and 0.1256g antimony/Kg product respectively. Similar  
 226 trend occurred for cashew kernel production, in which the GWP and ADP values dropped to 34.2520  
 227 gCO<sub>2</sub>/Kg and 0.1102g antimony/Kg product respectively for a 50:50 ratio of electricity consumption, and  
 228 to 26.6632 gCO<sub>2</sub>/Kg and 0.0995g antimony/Kg product for 100% public power supply from the national  
 229 grid.

230 In both industries, the results also revealed that 100% public power supply from the national grid as  
 231 compared to overall supply of electricity from diesel powered generator led to a massive 94% reduction in  
 232 AP. Notable reason for this significant reduction is traceable to the fact that natural gas accounted for  
 233 80% of the nation's power sector and it is also known to be sulphur free. Hydro, which is the other  
 234 components of the nation's grid mix, is widely recognized as a clean source of energy with consequential  
 235 low environmental impact. This phenomenon affirmed that a gradual shift from energy consumption solely  
 236 on fossil fuel combustion to renewable energy will go a long way in achieving a significant reduction in the  
 237 overall environmental loads for all the impact categories.

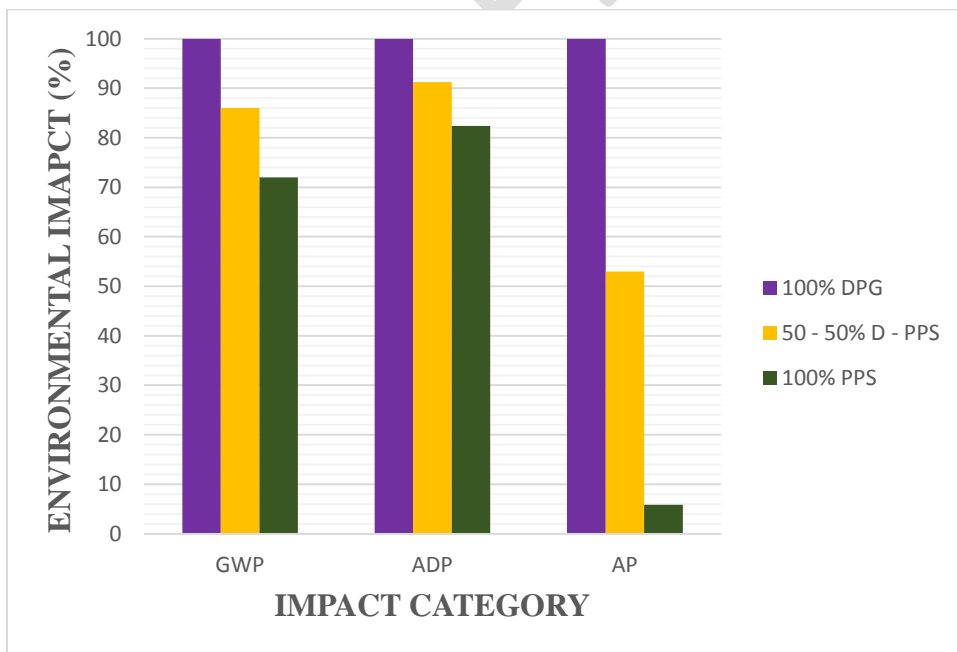
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 240 Figure 6: Effect of energy source on environmental impact indicators for Palm kernel oil production.  
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246  
 247 Figure 7: Effect of energy source on environmental impact indicators for Cashew nut processing.

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

255 Table 4 presents the result of the effect of grid mix indices on the total environmental impact. When the  
 256 thermal efficiency was increased to 75%, GWPs for both industries reduced by 62% and an additional 6%  
 257 reduction was achieved when the transmission and distribution loss was reduced to 5%. In a similar  
 258 trend, there was an approximately 56% reduction in ADPs when the thermal efficiency was increased to  
 259 75% while an extra 7% reduction was established also through the reduction of the transmission and  
 260 distribution loss to 5%. Adoption of technologies with higher thermal efficiency coupled with a further  
 261 reduction in the transmission and distribution loss is thus a sure alternative towards reducing the overall  
 262 impact due to electricity consumption from the national grid.

263

264 **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 <sub>2</sub> /Kg)	19.3051	16.2162
ADP (g antimony/Kg)	0.0670	0.0563
AP (gSO <sub>2</sub> /Kg)	n.a	1.7108 <sup>†</sup>
Cashew nut processing		
GWP (gCO <sub>2</sub> /Kg)	15.2925	12.8457
ADP (g antimony/Kg)	0.0531	0.0446
AP (gSO <sub>2</sub> /Kg)	n.a	1.4823 <sup>†</sup>

265 \*T&D loss was considered after thermal efficiency of 75%, <sup>†</sup> only T&D loss was considered, n.a = not  
 266 applicable.

267 **4. CONCLUSION**

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

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