International Journal of Mechatronics, Electrical and Computer Technology (IJMEC)
ISSN: 2305-0543 (Online), ISSN: 2411-6173 (Print)
Vol. 11(40), Apr. 2021, PP. 4983-4988

Design and Evaluation of a Hybridized Energy System for Remote Palm Oil Mill and Community

Ernest O. Ezugwu*[1]
Department of Electrical and Electronic Engineering,
Federal University of Technology Owerri, Imo State, Nigeria.
ernest.ezugwu@futo.edu.ng

Chinedu E. Aniagu[2]
Department of Electrical and Electronic Engineering,
Federal University of Technology Owerri, Imo, Nigeria.
aniaguchinedue@gmail.com

Samuel O. Okozi[3]
Department of Electrical and Electronic Engineering,
Federal University of Technology Owerri, Imo ,Nigeria
samuel.okozi@futo.edu.ng

Kufre Esenowo Jack[4]
Department of Mechatronic Engineering,
Federal University of Technology Minna, Nigeria.
kufre@futminna.edu.ng

Lazarus. O. Uzoechi[5]
Department of Electrical and Electronic Engineering
Federal University of Technology Owerri, Nigeria
lazarus.uzoechi@futo.edu.ng

***Abstract*—This study centered on the design and evaluation of a solar-biomass energy system for a remote oil mill and host community. The renewable energy sources considered in this research are solar energy and biomass energy from the oil-palm wastes at Ada Palm Oil Mill, Etekwuru-Egbema in Imo State Nigeria. Ada Palm has an oil mill with capacity of 30tons FFB/hr with an average output of 121.5 tons/day biomass fuel. The total load demand for both the oil mill and host community was calculated using the point load and area survey methods. The area has a daily solar radiation average of4.53kWh/m^2/day. HOMER PRO was used for the simulation to obtain an optimal system. The design is a hybrid configuration consisting of solar PV, biogas generator, storage battery and a system converter. The optimal system obtained has a net present cost (NPC) of $519,942, an initial capital cost of $190,983 and a COE of $0.01709 which is slightly higher than the COE for the existing power supply system to the mill alone. The optimal system obtained consisted of a 400kW biogas generator and a 176kW PV with the PV producing 185,604kWh/yr. amounting to 7.6% of total system power output**

Keywords*— *Biomass, Hybridized energy system, Optimization, Renewable energy, Rural electrification

I. INTRODUCTION

Exploring alternative renewable energy sources like biodiesels [1] and solar PVs for electric power generation has become a global focus in recent times [2]. This is because of the obvious environmental challenges of using fossil fuel; which have become big threat and topic of discussion for the whole wide world [3]. Aside the fact that the use of diesel from fossil fuel to power industrial machineries are expensive, there are also issues of environmental pollution as highlighted by the trending phenomena of global warming and climate change [4]. It is in view of these that green energy sources are being explored for electricity generation, among which are the solar and biomass energy resources. Furthermore, power generation in Nigeria is largely dependent on gas thermal plants which are grossly not enough to serve the entire population of Nigeria especially those remote villages. Nigeria's current generating capacity is about 12,522 MW with available capacity of about 400MW [5][6], this is far less than the required capacity. Consequently, businesses have been clampdown and majority of those living in the rural communities are left in complete blackout [7]. The little available capacity is supply cities and major industries, leaving remote villages mostly out of supply. Palm oil plantation and mills are majorly sited in the villages where there are enough hectares of land, and as a result of non-availability of electricity, these palm oil mills depend mostly on diesel powered generators to meet their daily energy demand. This method is quite expensive and leave them with minimal gain at the end of the process. Finding alternatives – utilizing the huge biomass wastes generated in from the mills and hybridizing it with the abundant solar energy would save them lots of costs in powering oil mill equipment and goes a longer way in providing supply the host community.

A. Profile of the Pilot Palm Oil Mill

The pilot site for this project is Ada palm. Ada palm oil mill is a 30 ton/hr capacity mill for the processing of palm fruits. It is located at (5º18.8'N, 6º52.7'E), a distance of about 65km from Owerri, the capital city of Imo state Nigeria. The mill and its plantation occupy a total 4310 hectares of land, out of which 3800 hectares is covered with matured palm plantation. The remaining portion is taken up by the mill and the residential quarters for the workers. Fig. 1.1 shows the location of the location of the mill.

Ada palm oil mill runs on a twin 500kVA gas powered generator operated alternately. From data collected 500kVA generator cannot power all their equipment once rather the machines are run in turn during operation, therefore the need for this alternative.

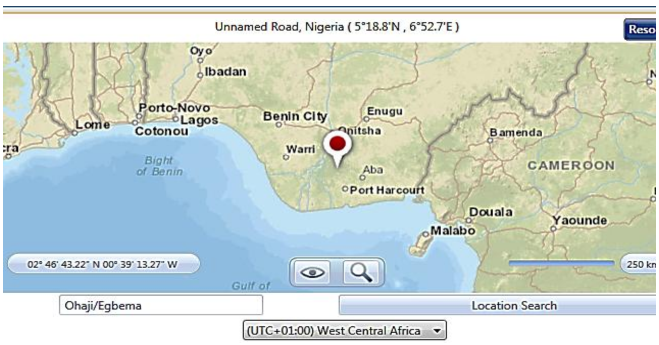


Figure 1: Location of Ada Palm Mill

Article History:
Received Date: Jan. 23, 2021, Accepted Date: Mar. 10, 2021, Available Online: Apr. 01, 2021

B. Oil Palm Waste Biomass

Biomass is any organic matter that can be utilized as a source of energy [8]. The stored energy in biomass can be utilized in many ways to generate electricity using appropriate technologies [8]. Studies have shown that palm oil mills only produce 25 to 30% of main product, while about 70 to 75% of outputs are by-products [9]. They include Empty Fruit Bunch (EFB), Palm Fibre, Palm Kernel Shell, Palm Kernel Cake (PKC), Palm Oil Mill Effluent (POME), and Sterilizer Condensate [9] EFB at a moisture content of 50% has a heat value of 1950kCal/kg [10]. Also, Biogas from anaerobic digestion of POME generated from 1ton of Fresh Fruit Bunch (FFB) is estimated at 19.6m^3with a calorific value of 22.9MJ/m^3[10]. Palm Fibre and Palm Kernel Shell have the highest calorific value of all the by-products. Their respective calorific values are given as 18.6GJ/ton and 20.8GJ/ton. Thus, the total energy from the shell and fibre of a palm tree is about 14GJ [9]. All of these present viable sources from which electricity can be generated.

C. Nigeria Solar Energy Potential

Solar energy is the radiant light and heat from the sun. Studies have shown that Nigeria being situated in the tropical region has enormous solar potentials. With a land mass of 923.768sqkm, annual total solar radiation on average varies from about 12.6MJ/m^2/day (3.5kwh/m^2/day)[11] in the coastal latitudes to about 25.2MJ/m^2/day (7.0kwh/m^2/day) [11]in the far North. This translates to an annual average solar energy intensity of 1934.5kwh/m^2/year [12]. Thus, applying appropriate conversion methods will result in substantial amount of electrical power generation.

II. MATERIALS AND METHODS

In undertaking this study, the material resources used included: a laptop computer, HOMER PRO software, MATLAB software and Microsoft office tools. The steps listed below summarises the methodology of the study:

a. Obtain the load, biomass and solar resources data.
b. Analyse the data to obtain input profiles for the simulation.
c. Build the schematic by selecting appropriate system components.
d. Specify the component sizes, quantities, costs and other properties.
e. Check for errors in the selected system components.
f. Run the simulation to obtain the optimization results.
g. Input sensitivity variables
h. Run sensitivity simulation and obtain results.
i. Analyse the results to arrive at the most optimal design.
j. Perform economic comparability analysis of the obtained model with the existing power supply system.

TABLE 1 . AVERAGE MONTHLY CLEARANCE INDEX, IRRADIANCE AND TEMPERATURE OHAJI/EGBEMA

Month	**Clearness Index**	**Daily Radiation** kWh/m²/day	**Temperature (°C)**
January	0.571	5.410	25.650
February	0.539	5.390	26.030
March	0.496	5.160	25.940
April	0.481	5.000	26.000
May	0.456	4.600	25.870
June	0.416	4.100	25.030
July	0.353	3.510	24.290
August	0.349	3.570	24.100
September	0.353	3.650	24.360
October	0.409	4.110	24.680
November	0.494	4.710	24.950
December	0.555	5.140	25.050
Average	0.456	4.53	25.16

Figures 2A and 2B show the solar data of the pilot site

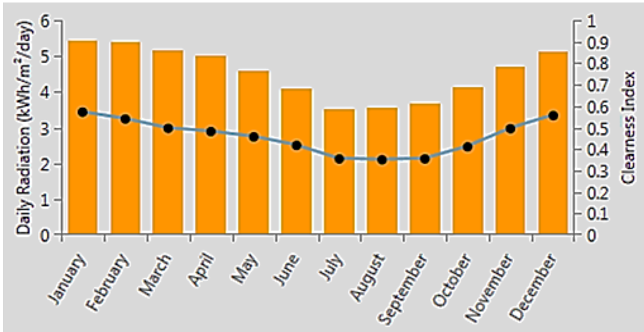


Figure 2A: Chart of average monthly irradiance and clearness index

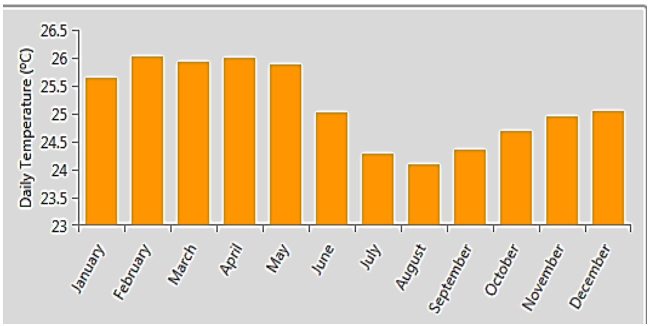


Figure 2B: Chart of Average Monthly Temperature

A. Biomass Resources

Ada Palm mill has a milling capacity of 30tons FFB/hr. The following assumptions were made based on literature [9]: that the mill produces 22% EFB, 13% Fibre and 5.5% Shell for every FFB produced. This amounts to 40.5% of biomass fuel for every FFB processed.

The 8hrs operation period occurs during the dry season from October to March. Available biomass was calculated as shown:

$$Total\ FFB\ processed\ =\ 30\ \times =\ 240ton$$

Total biomass fuel available = $\frac{40.5}{100} \times 240 = 97.2ton$

IEEE Office - SEET Complex, Federal University of Technology, Owerri, Nigeria, https://aeuso.org
EISSN: 2305-0543, PISSN: 2411-6173

The 12hrs operation period occurs during the Rainy season between April and September. The available biomass fuel was calculated as shown:

$$Total\ FFB\ processed\ = 30 \times 12 = 360ton/day$$

Total biomass fuel available = $\frac{40.5}{100} \times \ 360 = 145.8ton$/day

B. Electrical Load Data

The load data for the mill was obtained by conducting a field visit to the mill. The mill manager was consulted, who led the investigation round the mill pointing to the different machines and their power ratings, the lightings, offices and residential quarters. The mill consists of 8 major machines with varying power ratings, two 40hp water pumps, an office building and the lighting loads. There are two junior quarters made up of a total of 48 apartments, and a management quarter of 22 apartments.

The remote village consists of approximately 300 households; ten of which are storey buildings. There are 20 shops, 1 civic centre, 3 water pumps and a health centre. For the simulation, load demands for the mill, residential quarters and the village safe water pump loads were taken as primary load while the water pump loads were considered as deferrable load.

Tables 2, 3 and 4 show the load data of the mill, residential quarters and village respectively.

TABLE 2. LOAD DATA FOR ADA PALM MILL

S/N	ITEM	Power (HP)	Wattage (watts)	Number of Units	Total power (kW)
1	Fluorescent Lamp	-	40	66	2.64
2	Fan	-	80	3	0.24
3	Desktop Computer	-	150	3	0.45
4	Air Conditioner	-	1800	3	5.4
5	Water pump	40	29840	2	59.68
6	Capstan Machine	55	41030	1	41.03
7	Bunch Feeder	50	37300	1	37.3
8	Digester	30	22380	2	44.76
9	Elevator	40	29840	1	29.84
10	Cake Breaker	45	33570	1	33.57
11	Cracker	50	37300	1	37.3
12	Boiler	45	33570	2	67.4
13	Presser	35	261102	2	52.22
	Total				411.57

TABLE 3. RESIDENTIAL QUARTERS LOAD DATA

S/N	Items	Wattage (watts)	Number of Units	Total power (Kw)
Junior Quarter				
1	Light Bulb	40	672	26.88
2	Fan	80	192	15.36
3	Television	120	96	11.52
4	Phone	7	96	0.672
5	DVD Player	60	96	5.76
	Total			60.192
Management Quarter				
1	Light Bulb	40	196	7.92
2	Fan	80	66	5.28
3	Fridge	200	22	4.40
4	Television (LED)	60	22	1.32
5	Air Conditioner	1800	10	18.00
6	Washing Machine	1000	10	10.00
7	Cooker unit	2000	10	20.00
8	Decoder	30	22	0.66
9	Electric Iron	1000	22	22.00
	Total			89.58

TABLE 4. LOAD DATA FOR ETEKWURU-EGBEMA COMMUNITY

S/N	Items	Wattage (Watts)	Number of Units	Total Power (kW)
1	Light Bulb(incandescent)	60	910	54.6
2	Light Bulb (fluorescent)	40	56	2.24
3	Television (CRT)	120	116	13.92
4	Television (LED)	60	10	0.6
5	Fan	80	119	9.52
6	Phones	7	290	2.03
7	Air Conditioner	1800	10	18.00
8	Electric Iron	1000	10	10.00
9	Fridge	150	10	1.5
10	Socket Outlets	1500	24	36.00
11	Water pump	7460	3	22.38
	Total			170.79

C. Design And Simulation

The design and simulation were done using HOMER PRO so as to obtain an optimal configuration. Solar, biomass and load profiles were the inputs. System components selected includes: biogas generator, PV panels, converter and storage batteries. Sensitivity variables were added to analyse the effect of varying inflation rate on the optimal design obtained using 2% as base value. For the PV array, Homer calculates its output using equation 1:

$$P_{PV} = Y_{PV} f_{PV} \left(\frac{\bar{G}_T}{\bar{G}_{T,STC}}\right) [1 + \alpha_P (T_C - T_{C,STC}] \qquad (1)$$

Where,
Y_{PV} = PV rated capacity (kW)
f_{PV}= PV derating factor(%)
$\bar{G}_T$ = PV incident solar radiation (kW/m2)
$\bar{G}_{T,STC}$ = incident radiation at standard test conditions(1kW/m2)
α_P = temperature coefficient of power(%/°C)
T_C = PV cell temperature in the current time step (°C)
$T_{C,STC}$ = PV cell temperature under standard test conditions (25°C)

Table 5 shows the details of selected components.

TABLE 5. COMPONENT DETAILS

Component	Parameters	Value
	Size	500kW
	Capital Cost	$100,000
	Replacement Cost	$100,500
	O &M Cost	$0.03/op. hr
	Optimization Range	0 to 600kW
	Lifetime	20,000hrs
	Size	200kW
	Capital Cost	$50,000
	Replacement Cost	$45,000
	O&M Cost	$5/year
	Optimization Range	Homer Optimizer
	Efficiency	13%
	Derating Factor	70%
	Size	100kW
	Capital Cost	$10,000
	Replacement Cost	$9,500
	Inverter/Rectifier Efficiency	95/ 90%
	Lifetime	15years
	Size	4200Ah, 202kWh
	Capital Cost	$10,000
	Replacement Cost	$10,000
	Nominal Voltage	48V
	Optimization Range	Homer Optimizer
	Throughput	686,448kWh

Figure 3 shows the design system schematic

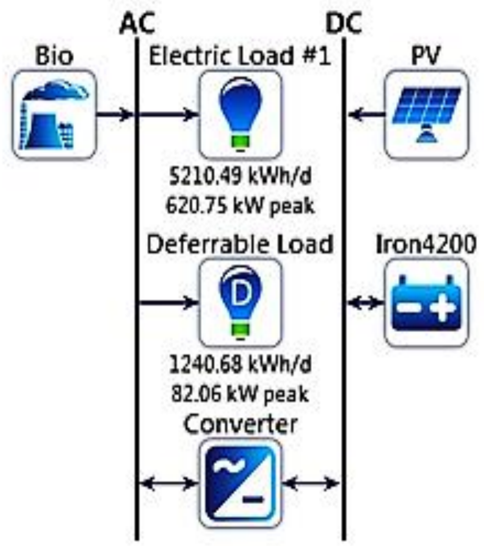
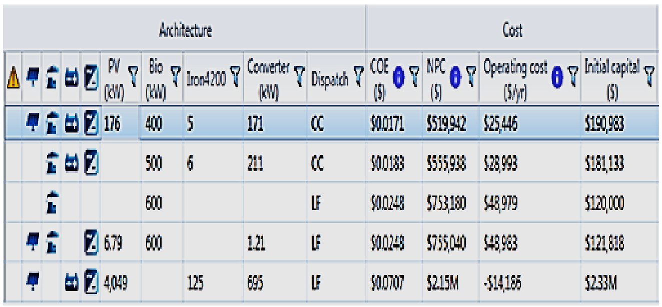


Figure 3: Design Schematics

III. RESULT AND DISCUSSSION

The result of optimization simulation is arranged in an ascending order of Net present Cost. The configuration with the least net present cost is considered the most feasible. Figure 4 shows the optimization results while table 6 the system architecture for the optimal design.



Architecture					Cost			
PV (kW)	Bio (kW)	Iron4200	Converter (kW)	Dispatch	COE ($)	NPC ($)	Operating cost ($/yr)	Initial capital ($)
176	400	5	171	CC	$0.0171	$519,942	$25,446	$190,983
	500	6	211	CC	$0.0183	$555,938	$28,993	$181,133
	600			LF	$0.0248	$753,180	$48,979	$120,000
6.79	600		1.21	LF	$0.0248	$755,040	$48,983	$121,818
4,049		125	695	LF	$0.0707	$2.15M	-$14,186	$2.33M

Figure 4: Optimization Results

TABLE 6. OPTIMAL SYSTEM ARCHITECTURE

Component		Name	Size	Unit
Generator		Generic Biogas Genset (size your own)	400	kW
PV		Generic Flat Plate PV	176	kW
Storage		Iron Edison LFP 4200Ah	5	strings
System Converter		System Converter	171	Kw
Dispatch strategy		HOMER Cycle Charging		

A. *Cost Summary*

The most feasible system is the configuration with the least Net Present Cost of $519,942. It has a capital cost of $190,983, an operating and maintenance cost of $2,064, a replacement cost of $338,817 and the Cost of Energy (COE) of $0.0171. Figure 5 shows the cost summary of the system.

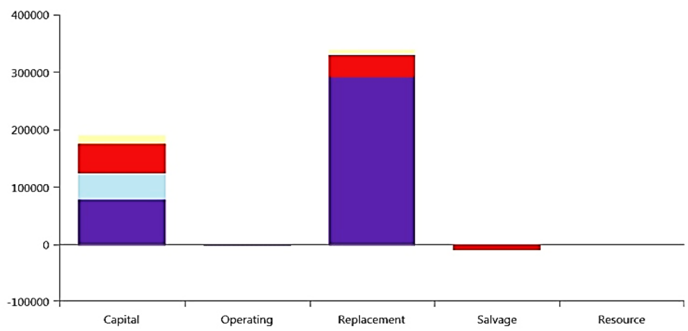


Figure 5: Cost Summary of Optimal System

As shown in figure 5, the biogas generator has the highest capital cost of $80,000, followed by the PV with $43,879. The biogas generator also has the highest operation and maintenance cost as well as replacement cost. This is due to the need to periodically maintain it and also replace it after every 20,000hours of operation.

IEEE Office - SEET Complex, Federal University of Technology, Owerri, Nigeria, https://aeuso.org
EISSN: 2305-0543, PISSN: 2411-6173

B. Electrical Summary

A total of 2,444,445kWh/yr of electricity is produced by the system. The biogas generator produces 2,258,841kWh/yr amounting to 92.4% of the total output while the solar PV generates the remaining 7.6%.

C. Sensitivity Analysis Results

The result of the sensitivity analysis indicates that inflation rate and Net Present Cost have a direct proportionality relationship. This implies that as inflation rate increase, NPC also increases. Figures 6 shows chart of the inflation rate against NPC.

D. Economic Comparability Analysis

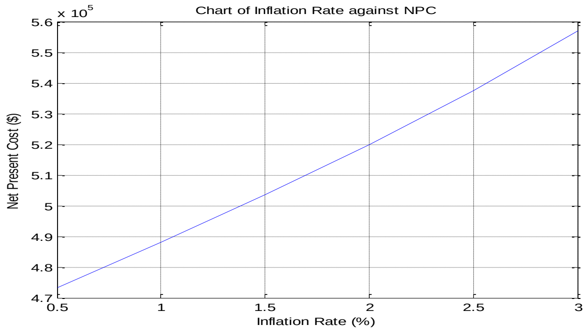


Figure 7: Chart of Inflation Rate against NPC

The optimal system and existing system were compared on the basis of their respective Cost of Energy (COE). The COE for the existing power supply of the mill was calculated as shown by equation 2

$$COE = \frac{C_{tac}}{E_{served}} \quad (2)$$

Where:

$$E_{served} = Energy\ Served$$

C_{tac} = Total Annual Cost and is given by equation 3

$$C_{tac} = C_{fuel} + C_{o\&m} + C_{acc} \quad (3)$$

$$C_{o\&m} = Operation\ and\ Maintenance\ Cost$$

$$C_{fuel} = Cost\ of\ Fuel$$

$$C_{acc} = Annual\ Capital\ Cost$$

The mill utilises an average of 200Litre of gas daily. The cost of gas was taken to be N250/Litre. Thus, the annual fuel costC_{fuel} is $52,142.86 at the exchange rate of 350Naira to one US Dollar. Where the operation and Maintenance cost (O&M) is of $0.6/hr, the annual operation and maintenance cost $C_{o\&m}$ is $5,256. At the Capital cost of $100,000, the annualised capital cost for the 500kVA diesel generator was obtained as $5,120 using equation 4

$$C_{acc} = \left[\frac{i(1+i)^n}{(1+i)^n - 1}\right] \times C_{pcc} \quad (4)$$

Where n = 25years and $C_{pcc} = Present\ Capital\ Cost$

Therefore, C_{tac} = 52,142.86 + 5,256 + 5,120 = $62,518.86

The mill runs on a 500kVA generator per time which gives an output of 625kW. Hence, the energy served annually E_{served} is 5475000kWh/year

Therefore, applying equation 2, the COE for the existing system is obtained thus:

$$COE_{existing} = \frac{62518.86}{5475000} = 0.01142$$

From the result of the simulation, COE of the optimal system is $0.01709 which is slightly higher than the COE of the existing system by $0.00567. However, the optimal system is still economical since the extra energy served the host community was not considered in calculating the COE of the existing system.

IV. CONCLUSIONS

Results obtained show that there are sufficient solar and biomass resources available to supply the needed electrical energy for the mill and community. The optimal system obtained comprises of 400kW biogas generator, 176kW PV, storage batteries and a system converter. A total of 2,444,445kWh/yr. of electricity is produced which was sufficient to serve the load of both the mill and village. Economic comparability analysis carried out showed that the optimal system is economical when both the mill and village are considered.

REFERENCES

[1] K. A. Zahan and M. Kano, “Biodiesel production from palm oil, its by-products, and mill effluent: A review,” Energies, vol. 11, no. 8, pp. 1–25, 2018.

[2] PwC Nigeria, “Powering Nigeria for the Future,” 2016.

[3] R. Mal, R. Prasad, and V. K. Vijay, “Design and testing of thermoelectric generator embedded clean forced draft biomass cookstove,” 2015 IEEE 15th Int. Conf. Environ. Electr. Eng. EEEIC 2015 - Conf. Proc., pp. 95–100, 2015.

[4] W. Tushar et al., “A motivational game-theoretic approach for peer-to-peer energy trading in the smart grid,” Appl. Energy, vol. 243, no. November 2018, pp. 10–20, 2019.

[5] “Nigeria Electricity Production [2005 - 2019],” CEIC, 2019. .

[6] Power Advisory Team, “Nigeria Power Baseline Report,” 2015.

[7] E. O. Ezugwu, D. O. Dike, S. O. Okozi, M. Olubiwe, and C. F. Paulinus-nwammuo, “Design of Power Pool Scheme for Demand-Side Management of Co-Located Banks To cite this article :,” vol. 8, no. 4, pp. 86–94, 2019.

[8] A. Freiberg, J. Scharfe, V. C. Murta, and A. Seidler, “The use of biomass for electricity generation: A scoping review of health effects on humans in

residential and occupational settings," Int. J. Environ. Res. Public Health, vol. 15, no. 2, 2018.

[9] S. Yusoff, "Renewable energy from palm oil - innovation on effective utilization of waste," vol. 14, pp. 87–93, 2014.

[10] K. E. Anyaoha, R. Sakrabani, K. Patchigolla, and A. M. Mouazen, "Evaluating oil palm fresh fruit bunch processing in Nigeria," Waste Manag. Res., vol. 36, no. 3, pp. 236–246, 2018.

[11] O. Bamisile, A. Babatunde, and O. Ayodele, "A review of renewable energy potential in Nigeria ; Solar power development over the years," Eng. Appl. Sci. Res., no. November, pp. 0–7, 2017.

[12] P. A. Nwofe, "Utilization of Solar and Biomass Energy- A Panacea to Energy Sustainability in a Deeloping Economy," vol. 2, no. 3, pp. 10–19, 2019.