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TECHNO-ECONOMIC ANALYSIS OF PV/DIESEL/BATTERY HYBRID RENEWABLE SYSTEM FOR REMOTE PRIMARY HEALTHCARE CENTER

Adedotun ADEYEYE[1], Jacob TSADO[2], Lanre OLATOMIWA[3]
Department of Electrical/Electronic Engineering, Federal University of Technology Minna, Niger State, Nigeria
email: adedotunadeyeye@gmail.com

Abstract: *This paper presents the techno-economic analysis of PV, diesel and battery hybrid renewable system for a remote healthcare facility using Hybrid Optimization Model for Electric Renewable (HOMER) software. Various system configurations that can meet an average daily energy consumption of 15.081kWh and 2.77kW peak demand of the healthcare center was optimized and compared. The optimum system configuration was determined based on electrical energy generated, life cycle cost and pollutant emission. The result obtained from the simulation study shows that, hybrid system architecture consisting twelve (12), 12V batteries connected in 3 strings, 4.65kW PV panels, 3.03kW converter and 3.4kW diesel generator is the best configuration to provide reliable electricity supply for the healthcare center at the lowest life-cycle cost. Furthermore, sensitivity analysis was carried out to know the effect of change in diesel fuel price on the optimal system configuration. Result shows that as the diesel price increases, the capacity of the solar panels and number of batteries needed to meet the load demand increases with associated decrease in generator running hours/fuel consumption. The study proved that off-grid hybrid power system is cost effective and environmentally friendly in providing energy to rural health clinic. Thus, paving way for the development of optimized off-grid energy map for remote health clinics in Nigeria.*

Keywords: *Healthcare, Hybrid Renewable, Off-grid and Techno-economic*

1. INTRODUCTION

Electricity is a driver of activities in almost every sector of the economy such as engineering, communication, medicine and transportation. The development and growth of any country is closely related to the availability of electricity supply [1]. Apart from economic growth and development of nations, access to electricity affects the health and well-being of any population [2]. Qualitative healthcare service delivery and coverage depends on access to sustainable and reliable electric power supply. Sterilization, illumination, refrigeration, scanning, diagnosis of patient, water supply and proper hygiene and many other services which are carried out in healthcare facilities require electricity [3].

Unreliable electricity supply in healthcare centers often lead to difficulty in the delivery of healthcare services. It often leads to loss of medicines, vaccines cold-chain systems, blood and organs due to reduced refrigerating capacity. The unavailability of electricity in remote areas (rural) has far more consequences on the delivery of healthcare services. Lack of motivation of healthcare personnel to work in rural areas, lack of needed medical electrical equipment and mortality prevalence in rural healthcare centers has been strongly linked to unavailability of continuous electricity supply [4].

Access to quality and continuous electricity supply in Nigeria is a major challenge despite the unbundling of the electricity industry through the passage of the Electric Power Sector Reform (EPSR) Act in 2005 and privatization in 2013. In Nigeria, 57.65% of the population has access to electricity of which, 60.69% of the rural populace does not have access to electricity [5]. Studies have shown that grid connected/off-grid Hybrid Renewable Energy System (HRES) is a feasible and economically viable option for providing electricity to remote areas where extension of transmission grid may be physically impossible and costly [6-10].

There are about 30,000 Primary Healthcare Centers (PHC) scattered across Nigeria [11]. Implementation of off-grid hybrid renewable electricity projects in these various locations would reduce dependency on conventional energy sources and ensure timely and quality health services are available to patients all year round as well as increasing renewable energy penetration in the country. In this study, Photovoltaic (PV), diesel and battery hybrid system is optimally sized using Hybrid Optimization of Multiple Energy Resources (HOMER) software so as to meet the electrical load profile of a Primary Healthcare center situated in Kalema village in Niger state, Nigeria.

2. MATERIALS AND METHODOLOGY

HOMER software, developed by the United States National Renewable Energy Laboratory (NREL) was used for this study. It performs three major tasks: simulation, optimization, and sensitivity analysis [12]. It was used to evaluate different situations to determine the system configuration that would provide acceptable reliability at the lowest lifecycle cost. It allows power systems comparison options based on technical and economic merits [13].

The research method begins with establishment of the health center load profile, collection of solar energy resources data, definition of system economic parameters and components cost, modeling and simulation of the hybrid system, selection of optimum system based on simulation results and the techno-economic assessment of the selected systems. In addition, sensitivity analysis was carried out to know the effect of change in diesel fuel price on the optimal system configuration (Fig. 1).

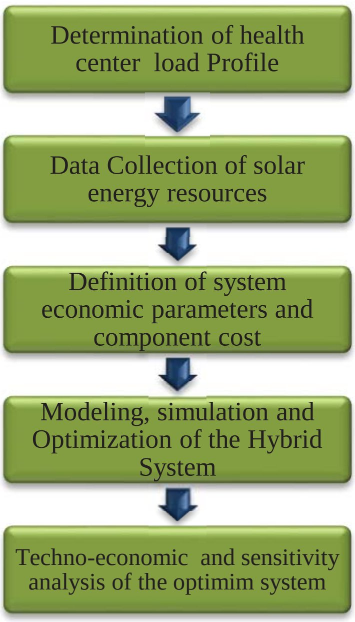

Fig.1. Block Diagram of Research Methodology

2.1. Description of Study site and Data Collection

In this study, a rural primary health center (PHC) in a village located at latitude 9°12.5'N and longitude 4°46.6'E has been selected for techno-economic evaluation of PV/diesel hybrid system. The PHC under study is located in Kalema village under Mokwa Local Government Area (LGA) of Niger State. The solar resource information used for selected clinic were obtained from National Aeronautics and Space Administration surface meteorology and Solar Energy (NASA/SSE) website using the latitude and longitude of the location (latitude 9°12.5'N and longitude 4°46.6'E). Solar radiation data of the study location confirms availability of solar radiation all year round (Fig. 2). The annual average solar radiation was found to be 5.48kWh/m^2/day and the average clearness index was found to be 0.559.

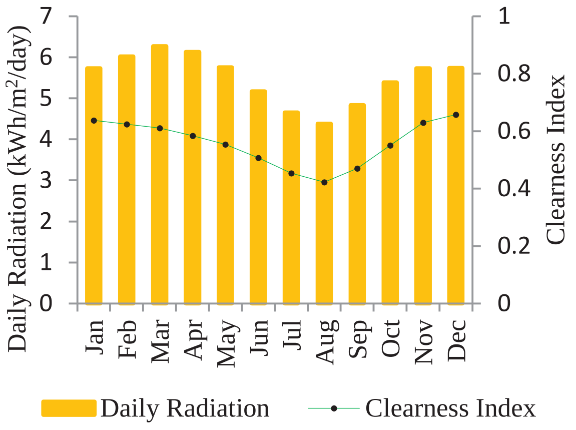

Fig.2. Plot of Monthly daily radiation and clearness index

2.2. Electrical Load Profile of the Health Center

The electrical load profile was obtained from the power ratings of the available equipment in the Primary Health Center and their hourly usage (Table 1). The daily load curve of the health center shows that electricity consumption is mainly around the mid-day when the clinic is most active and evening time for lighting and fans (Fig. 3). The maximum demand of the clinic is around 2.77kW and has an annual average load consumption of 15.081kWhr per day. To avoid underestimating the peak load demand, day-to-day random variation variability of 5% and hour-to-hour random variability of 10% was specified in HOMER simulation.

Table 1.Health Clinic Electrical Energy requirement

Electrical Appliances	**Rated Capacity (W)**	**Qty**	**Run time (hrs/day)**	**Watt-hrs/day**
Vaccine Refrigerator	120	1	8	960
Autoclave	1500	1	3	4500
Ceiling Fan	75	5	14	5250
CFL bulbs	26	9	12	2808
Microscope	30	1	1	30
Centrifuge	70	1	1	70
Desktop Computer	150	1	8	1200
Printer	250	1	1	250
Total			48	15068

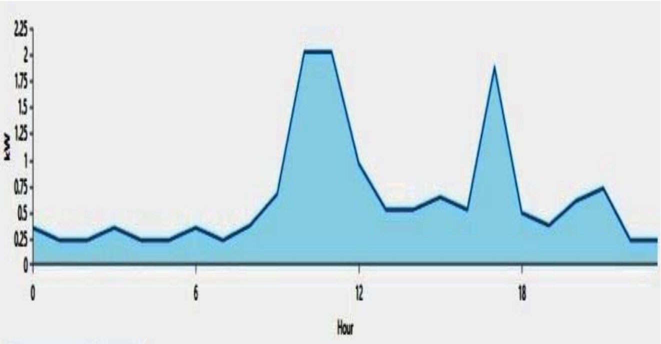

Fig.3. Daily Load curve of Kalema village PHC

2.3. System Modeling and Economic Parameters

HOMER simulates the operation of a system by making energy balance calculations in each time step (interval) of the year. For each time step, HOMER compares the electric demand in that time step to the energy that the system can supply in that time step, and calculates the flow of energy to and from each component of the system [13]. Fig. 4 shows the PV/diesel/battery system hybrid configuration schematics modeled in HOMER. Other input parameters such as economic costs, system constraints, dispatch strategy and technical specifications of the system components are illustrated in Table 2.

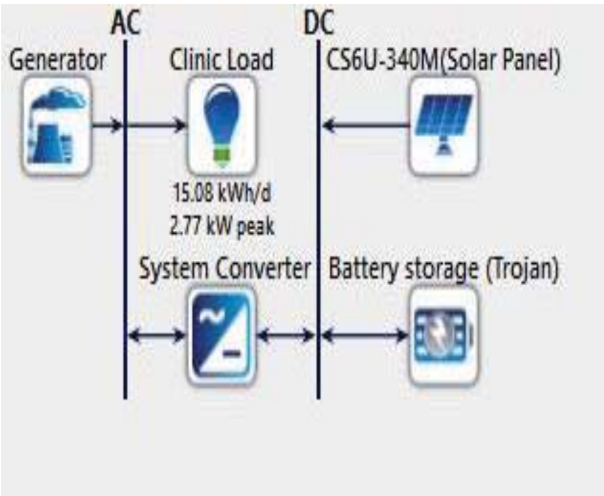

Fig.4. HOMER modeling schematics

Table 2.Economic and Technical Specifications of the hybrid system components

Components	Parameters	Values
PV	Model	Canadian Solar Max Power CS6U-340M
	Capital Cost	₦436,500/kW
	Replacement Cost	₦386,000/kW
	O&M Cost	₦12,000/year
	Lifetime	20 years
	Fixed slope	9.208deg
	De-rating Factor	90%
	Tracking	No Tracking
Converter	Capital Cost	₦249,000/5kW
	Replacement Cost	₦249,000/5kW
	O&M Cost	Nil
	Lifetime	10 years
	Inverter Efficiency	90%
	Rectifier Efficiency	90%
Battery	Model	Trojan SAGM 12 205
	Rating	2.63kWh, 219Ah
	String size	4
	Nominal voltage	12V
	Minimum state of charge	20%
	Round trip efficiency	85%
	Capital Cost	₦216,000/Unit
	Replacement Cost	185,000₦/Unit
	O&M Cost	Nil
Components	**Parameters**	**Values**
Diesel Generator	Type	Generic
	Minimum load Ratio	25%
	Fuel curve slope	0.2512 l/hr/kW
	Fuel curve intercept	0.0591 l/hr/kW
	Capital Cost	₦ 99,500/kW
	Replacement Cost	₦89,500/kW
	O&M Cost	₦ 41.37/op. hour
	Diesel Price	₦205.81/litre
Controller	Dispatch Strategy	Cycle Charging
System Economics	Project Lifetime	20 years
	Inflation Rate	15.37%
	Nominal Discount Rate	17.71%
System Constraints	Operating Reserve as a percentage of load	20%
	Operating Reserve as a percentage of Renewable output	50%

3. RESULTS AND DISCUSSION

3.1. Optimization Result

The optimum hybrid system is the system type that can supply electricity at the lowest total Net Present Cost (NPC) and supplying electricity at the required level of availability. Table 3 shows the categorized result of the simulation of the hybrid configuration of Fig. 4 considering the technical inputs of various components, economic costs and system constraints in Table 2.

3.1.1. Economic Cost Analysis

The result of the simulation and optimization presented five (5) feasible configurations (PV/Diesel/Battery, PV/Battery, Diesel/Battery, PV/Diesel and Diesel only configuration). The result reveals that the initial capital investment required for a diesel only configuration is about 87.43%, 84.96%, 91.93% and 88.20% lower from the initial capital required for PV/Diesel, Diesel/battery, PV/Battery and PV/Diesel/Battery configuration respectively (Table 3). Meanwhile, as a result of high operating and maintenance cost, diesel only configuration has the highest NPC (₦39,700,000). The results also shows that the average cost per kWh of useful electrical energy known as levelised Cost of Energy (COE) of diesel only configuration is about 19.11%, 84.77%, 234.81%, 246.64% higher than PV/Diesel, Diesel/battery, PV/Battery and PV/Diesel/Battery configuration respectively.

According to the simulation result, the hybrid of PV/Diesel/Battery which has the lowest COE (127.69₦/kWh) and NPC (₦11,461,610) was ranked first. Therefore, from an economic perspective, off-grid renewable hybrid system consisting PV, storage battery bank and a diesel generator is relatively cost effective than other system configurations and diesel generators only configuration.

Table 3.Categorized optimization results

System Configuration	PV (kW)	Gen (kW)	Battery	Converter (kW)	COE ₦/kWh	Total NPC (₦)	Initial capital (₦)	Gen Hours	Total Fuel (L/yr)
PV/Diesel/Battery	4.65	3.4	12	3.03	127.69	11,500,000	5,410,898	91	93.25
PV/Battery	5.19		24	3.19	132.20	11,900,000	7,907,325		
Diesel/Battery		3.4	16	3.02	239.55	21,500,000	4,244,738	1,998	2107.68
PV/Diesel	9.83	3.4		3.03	371.62	33,400,000	5,079,373	5,694	2545.65
Diesel Only		3.4			442.62	39,700,000	638,300	8,759	3951.92

3.1.2. Electrical Performance of the Optimum System

The solar panel generates 96.3% of the total of 8,155kWh of energy generated in a year. The optimum system relies majorly on the PV panel for electrical power production. The PV panel runs for 4,253 hours yearly, on an average of 11 to 12 hours daily. Thus, a higher renewable fraction of 94.6% was obtained. On the other hand, the diesel generator operates for about 91.0 hours per year with 18 starts. It generates the remaining 3.66% of total power produced. The annual energy generation from the different energy sources and other relevant performance indicators of the hybrid system is summarized in Table 4.

Table 4.Electrical performance of the optimum hybrid system

Quantity	Value
PV array energy production	7,856kWh/yr (96.3%)
Diesel Generator energy production	298 kWh/yr (3.66%)
AC Primary load	5,504 kWh/yr (100%)
Excess Electricity	1,582kWh/yr
Capacity Shortage	0
Renewable Fraction	1,582 kWh/yr
Dispatch strategy	Cycle charging
Hours of operation of diesel generator	91.0 hrs/yr

3.1.3. The Emissions

The diesel generator is the only component that is capable of producing emission. An average of 93.3L of fuel is consumed in a year for the optimal system configuration as compared to diesel only system configuration that consumed 3,952L of diesel fuel. Table 5 shows the emission results of all possible system configurations. The diesel-only system emits 10,345kg/yr of CO_2 while the optimal hybrid renewable system configurations emitted 244kg/year of CO_2. This represents 97.64% cut in CO_2 emission to the environment.

3.2. Sensitivity Result

In this study, sensitivity analysis was carried out by varying the price of diesel price was varied from ₦150 to ₦350 in steps of ₦25.

The result of sensitivity analysis presented in Table 6 shows that the optimal system configuration (4.65kW solar panel, twelve (12) 12V batteries, 3.40kW diesel generator and 3.03kW converter) is optimal for three of the ten sensitivity cases. As the diesel price is increased from the present price of ₦205.81/L to ₦250/L, the optimal system configuration capacity and generator fuel consumption is unchanged while, there is no significant change in the total NPC and COE. Similarly, Fig. 3 shows a decline in fuel consumption as diesel fuel price increases from ₦150/L to ₦200/L. Notably, for the sensitivity case of ₦205.81/L, ₦225/L and ₦250/L, their fuel consumption remains unchanged (91hrs/yr). Also, a sharp decline in fuel consumption was observed as the fuel price increases from ₦275 to ₦350. Thus, effectively lowering the operating cost at higher diesel price

The result of the sensitivity analysis also shows that as the diesel price increases, the capacity of the solar panels and number of batteries needed to meet the load demand increases with associated decrease in generator running hours/fuel consumption. Thus, increasing the initial capital cost and lowering the operating cost. The result shows that the optimal system operating cost is significantly lower for the sensitivity case of ₦325/L (13.24% lower) and ₦350/L (13.04% lower) compared to the optimal operating cost of the present price of diesel (₦205.81/L). Also, the optimal system initial capital cost was found to be 15.81% and 15.77% higher for the sensitivity case of ₦325/L and ₦350/L respectively as compared to the optimal system initial capital cost of the present diesel price. This is as a result of increase in solar panels, battery and converter capacity.

Table 5.Emission result of various system configurations

Pollutant	PV/Diesel/Battery	Diesel/ Battery	Diesel/PV	PV/Battery	Diesel only
Carbon Dioxide	244.00	5517.00	6664.00	0.00	10345.00
Carbon Monoxide	1.54	34.80	42.00	0.00	65.20
Unburned Hydrocarbons	0.07	1.52	1.83	0.00	2.85
Particulate Matter	0.01	0.21	0.26	0.00	0.40
Sulfur Dioxide	0.60	13.50	16.30	0.00	25.30
Nitrogen Oxides	1.45	32.70	39.50	0.00	61.30

Table 6.Result of optimal system configuration changing with fuel price

Diesel Fuel Price (₦ /L)	Solar Panel (kW)	Generator (kW)	Battery Storage Unit	Converter (kW)	COE (₦)	NPC (₦)	Operating cost (₦ /yr)	Generator (Hours)	Fuel (L)
150.00	4.41	3.40	12.00	3.05	126.70	11,373,010	372,055.00	110.00	113.08
175.00	4.43	3.40	12.00	3.03	127.16	11,413,650	374,049.20	109.00	111.69
200.00	4.64	3.40	12.00	3.02	127.73	11,465,350	371,447.80	94.00	96.09
205.81	4.65	3.40	12.00	3.03	127.69	11,461,610	371,051.40	91.00	93.25
225.00	4.65	3.40	12.00	3.03	128.01	11,490,790	372,840.90	91.00	93.25
250.00	4.65	3.40	12.00	3.03	128.44	11,528,810	375,172.20	91.00	93.25
275.00	4.63	3.40	12.00	3.46	129.19	11,596,190	378,473.00	89.00	92.45
300.00	4.66	3.40	12.00	3.10	129.37	11,612,350	379,796.70	90.00	92.80
325.00	4.94	3.40	16.00	3.50	130.08	11,676,430	321,909.20	29.00	30.60
350.00	4.94	3.40	16.00	3.50	130.19	11,685,820	322,654.80	29.00	30.60

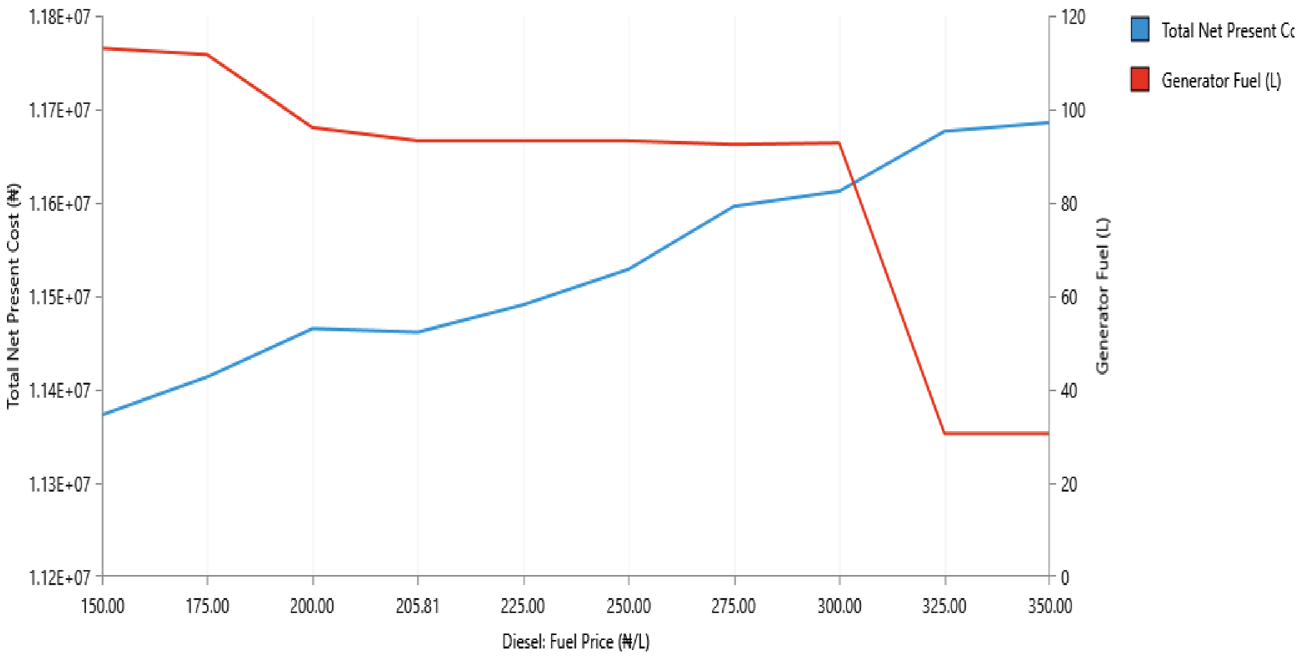

Fig. 3. Line plot of diesel fuel price against Total NPC and fuel consumption

4. CONCLUSION

The simulation result shows that hybrid system architecture of twelve (12), 12V batteries connected in 3 strings, 4.65kW PV panels, 3.03kW converter and 3.4kW diesel generator is the optimum system and best configuration for the PHC compare to PV-Battery, Generator-Battery, PV-Generator and Generator only configuration. Although, Generator only configuration has the least initial capital cost (₦638,300) among other system configurations, it was observed to be the worst configuration. It has a NPC of ₦39,700,000 which is four times the optimal system configuration (PV/Diesel/Battery). This is as a result of higher fuel consumption due to longer hours of operation (8,759hrs) of the generator and its associated maintenance cost. This shows that the configuration with the lowest capital cost may not necessarily be the configuration with the lowest cost of energy.

An investigation into the overall sensitivity result shows that as the diesel price increases, the capacity of the solar panels and number of batteries needed to meet the load demand increases with associated decrease in generator running hours/fuel consumption. Thus, increasing the initial capital cost and lowering the operating cost.

REFERENCES

[1] Bazmi, A. A., & Zahedi, G. (2011). Sustainable energy systems: Role of optimization modeling techniques in power generation and supply - A review. *Renewable and Sustainable Energy Reviews*, Vol.15, No.8, (October 2011), pp. 3480-3500, ISSN: 1364-0321

[2] Franco, A., Shaker, M., Kalubi, D., & Hostettler, S. (2017). A review of sustainable energy access and technologies for healthcare facilities in the Global South. *Sustainable Energy Technologies and Assessments*, Vol.22, (August 2017), pp. 92-105, ISSN: 2213-1388

[3] Adair-Rohani, H., Zukor, K., Bonjour, S., Wilburn, S., Kuesel, A. C., Hebert, R., & Fletcher, E. R. (2013). Limited electricity access in health facilities of sub-Saharan Africa: a systematic review of data on electricity access, sources, and reliability. *Global Health: Science and Practice*, Vol.1, No.2, (August 2014), pp. 249–261, ISSN: 2169-575X

[4] Welland, A. (2017). Electrification of health clinics in rural areas: Challenges and opportunities, *Available from:* http://sun-connect-news.org/fileadmin/DATEIEN/Dateien/New/TR12-Electrification-of-health-clinics-in-rural-areas-Challenges-and-opportunities_web.pdf *Accessed:* 2018-03-10

[5] World Bank Group (2017). Access to electricity, rural (% of rural population) Data. *Available from* https://data.worldbank.org/indicator/EG.ELC.ACCS.RU.ZS *Accessed*: 2017-10-29

[6] Bhattacharyya, S. C. (2013). *Rural electrification through decentralised off-grid systems in developing countries*, Springer-Verlag, ISBN: 978-1-4471-5985-8, London

[7] Dawoud, S. M., Lin, X., & Okba, M. I. (2018). Hybrid renewable microgrid optimization techniques: A review. *Renewable and*

Sustainable Energy Reviews, Vol.82, (February 2018), pp. 2039-2052, ISSN: 1364-0321

[8] Olatomiwa, L. (2016). Optimal configuration assessments of hybrid renewable power supply for rural healthcare facilities. *Energy Reports*, Vol.2, (November 2016), pp. 141–146, ISSN: 2352-4847

[9] Amutha, W. M., & Rajini, V. (2016). Cost benefit and technical analysis of rural electrification alternatives in southern India using HOMER. *Renewable and Sustainable Energy Reviews,* Vol.62, (September 2016), pp. 236-246, ISSN: 1364-0321

[10] Olatomiwa, L., Mekhilef, S., Huda, A. S. N., & Ohunakin, O. S. (2015). Economic evaluation of hybrid energy systems for rural electrification in six geo-political zones of Nigeria. *Renewable Energy*, Vol.83, (November 2015), pp. 435–446, ISSN: 0960-1481

[11] Aregbeshola, B. S., & Khan, S. M. (2017). Primary Health Care in Nigeria: 24 Years after Olikoye Ransome-Kuti's Leadership. *Front. Public Health,* Vol.5, (March 2017) pg.48, ISSN: 2296-2565

[12] Lambert, T., Gilman, P., & Lilienthal, P. (2006). Micropower system modeling with HOMER, In: *Integration of alternative sources of energy*, Farret, A. F., & Simoes, M. G., (Ed.), pp. 379-385, John Wiley & Sons Inc, ISBN: 978-0-471-71232-9, New Jersey, USA

[13] Lilienthal, P., & Lambert, T. (2004). HOMER: The Micropower Optimization Model. National Renewable Energy Laboratory (NREL) Innovation for Our Energy Future (Fact sheet). Available from https://www.nrel.gov/docs/fy04osti/35406.pdf *Accessed:* 2018-03-10