Maximizing the penetration levels of hybrid renewable energy systems in rural areas with demand side management approaches in achieving SDGs

Lanre Olatomiwa[1,2 *], Richard Blanchard[1]

[1]Centre for Renewable Energy Systems Technology, Loughborough University, LE11 3TU, UK

[2]Department of Electrical & Electronics Engineering, Federal University of Technology, PMB 65, Minna. Nigeria

[*]Email: olatomiwa.l@futminna.edu.ng; r.e.blanchard@lboro.ac.uk

Abstracts

Access to quality healthcare services is an integral part of sustainable development goals (SDGs) and reliable electricity access is a pre-requisite for improving human lives, enhancing healthcare delivery, education as well as other developmental growth within local communities. However, many rural locations far away from the grid centres have difficulties in accessing electricity, due to distance and cost of extension of grid to such areas, and this has resulted in the inability to provide basic amenities. Rural healthcare centres located in such places are unable to deliver their intended mandate, thus hindering the realization of SDG 3. Therefore, the innovative idea of this study is increasing the penetration of renewable energy technology while minimizing the cost by integrating the users' perspective with demand side management (DSM) approaches, techno-economic analysis, and environmental impact assessment of hybrid energy system configuration, taking a health institution as the case study. To meet the considered rural healthcare facility's initial average load demand of 20.58kWh/day, an optimum PV-Gen-battery hybrid system was selected using HOMER with cost of energy (COE) of $0.224/kWh, net present cost (NPC) of $61,917.6 and initial capital cost of $16,046.5. After the DSM measures were applied to reduce the peak and average demand, an optimum hybrid system was obtained, producing a COE of $0.166/kWh, NPC of $18,614.7 and initial capital cost of $10,070.8. The cost saving realized for the considered rural healthcare facility is $0.057/kWh, representing a 25.8% reduction from the current COE and a 70% reduction in Total NPC. On the other hand, the optimal configurations gave around a 75% reduction in CO_2 emissions compare to a diesel-alone configuration. The work provides novel insights which may be applicable worldwide. It has the potential to significantly advance the development of high-quality and timely evidence to underpin current and future developments in the rural energy sector and contribute to the implementation of SDG3 and 7.

Keywords: Sustainable Development Goals, Demand side management, Energy Access, electricity demand, healthcare services, renewable energy, reliable supply,

1. Introduction

Reliable electricity access is a pre-requisite for improving human lives, enhancing healthcare delivery, providing education as well as other developmental growth within local communities. However, it has been reported that many rural locations far away from the grid centre have difficulties in accessing electricity, due to distance and cost of extending grid to such area, and this has resulted in the inability of rural healthcare facilities located in such places to deliver their intended mandate [1]. Furthermore, based on the survey data from the report; one (1) out of every four (4) remote healthcare centres in sub-Sahara African countries lack access to electricity, and where the electricity is available, the unreliability of grid supply is characteristic. This deficiency implies that medical equipment such as; ultrasound, autoclave, centrifuge and other portable medical equipment cannot be used in such places because of limited or unstable electricity access to power basic services, hence making operators of these rural healthcare facilities have reduced care capabilities potentially resulting in higher mortality rates. Air temperature is crucial in healthcare facilities, as patients require warmer air due to lower metabolic rates caused by physical inactivity [2]. Hot water is also required for sterilization, laundry, cleaning, washing purposes. These deficiencies have often led to poor quality of health in the rural communities and resulted in many other problems; including obstetric complications, which is one of the root causes of the high maternal mortality rates in the rural areas. Further, the lack of antenatal care, absences of skilled birth attendants and limited availability of emergency obstetrics procedures due to lack of electricity are other reasons for this situation [3].

In many of these remote locations, the traditional approach to providing electricity access should have been extension of central grid. However, the provision of electricity to the rural communities has not improved due to non-access to the grid, coupled with grid unreliability; other constraints include inaccessible terrain, and the high cost of grid extension to the communities. Power generation in rural villages through the use of diesel generators may seem reliable option, if there is proper operation and regular maintenance [4]. However, the noise and environmental pollution resulting from the emission of CO_2 and other harmful gasses could have negative effects on the environment, thus pose a serious drawback [5].

Given the fact that improvement of rural accessibility to electricity via connection to the national grid in many rural locations in sub-Sahara African countries seems impracticable at the moment, and the use of diesel generators is not sustainable, the establishment of a system that is autonomous and off-grid in such locations becomes imperative. In fact, the International Energy Agency predicts that achieving universal electricity access within the 2030 target timeframe of SE4ALL and SDG7 will require 60% of new connections to be delivered via off-grid, renewable-based solutions, with the remaining 40% delivered via main grid extension [6]. Therefore, a solution based on renewable energy (RE) technologies, would be a viable option due to the availability of the certain resources, coupled with the associated environmental friendliness, cost effectiveness in operation as well as sustainability. In the case of rural health facilities, the provision of portable hybrid renewable power supply will enable certain medical equipment, critical lighting and mobile communication devices to be powered in an off-grid area for timely delivery of critical medical care for the rural dwellers.

2. Literature Review

To achieve this, there is need for analysis of various renewable energy configuration options to deliver the most cost efficient and environment benefit choices. Solar, wind, small hydro and biomass make up the different renewable resources in many developing countries, especially in Nigeria. These sources have been assessed in order to establish their potential and viability for electricity generation in the country [7]. Out of the various renewable energy resources in the country, wind and solar are the most favored for electricity generation. However, the investigation of wind power potential at different location in the country shows viable wind speeds are not evenly distributed, as such wind energy is not applicable at all locations in the country. Conversely, solar irradiation data indicates suitable solar energy potentials at almost every location within the country [8]. Moreover, photovoltaic (PV) modules which convert solar energy into electricity also have the advantage of being more suitable for residential buildings on small scale because of its modular structure, zero operating noise, ease of maintenance as well as the environmental friendliness [9].

The potential for solar energy utilization for various activities in the country have been established by different authors in various studies [3], [10-14]. Some of these areas of applications have been identified include; agricultural, industrial, building (commercial and residential), operating pumping machines for water supply and purification, rural electrification, and heating applications [10]. A feasibility assessment of solar energy utilization for electricity generation in buildings has been conducted in Nigeria [13]. A hypothetical remotely located off-grid base transceiver station sites at different geographical regions in Nigeria for solar PV application has been considered [14]. Another key area of application of solar and other renewable sources is in rural health clinics [15]. The optimal configurations of hybrid renewable systems for rural health clinic application in three grid-independent rural villages in Nigeria have also been assessed [3].

However, the major drawback of the utilization of solar PV system is its affordability, due to high initial cost of purchase and installation since there is no obvious or popular national policy that encourages increased renewable energy penetration in Nigeria at present [9].

Government intervention in the form of subsidy on the importation of Renewable Energy Technologies (RET), especially solar PV to bring down high costs, and encourages private individuals and groups to invest in solar technologies would help tap this potential in the country [16]. Therefore, the aim of the innovative idea of this study is increasing the penetration of RET (Solar PV in a hybrid system). The objectives are to model the power requirements of a rural health clinic and how these can be met using solar energy, minimize costs by integrating the users' perspective with demand side management (DSM) approaches, and perform techno-economic analysis, and environmental impact assessment of the hybrid energy system configuration.

3. Material and Methods

3.1 Case study description

A rural health clinic in Nasarawa State, Nigeria having similar characteristics of many rural healthcare centres in Nigeria and other sub-Sahara Africa countries has been considered as a case study. The coordinates of Karu Local Government Area is latitude 90 08'N and longitude 70 51'E; and covers an approximate land area of 704 sq. km. The rural community has two distinct seasons (wet and dry), typical of north-central Nigeria.

The health centre consists of two blocks of building housing a consulting room, injection room, card room, a pharmacy, male ward, female ward, a delivery room, and a laboratory. The entire community is off-grid. Therefore, the clinic depends on two gasoline generators for its power supply. Table 1 present the description of the generators, and their operation and maintenance (O&M) cost. Oral interviews with the facility maintenance personnel, physical inspection and observation of energy consumption pattern were carried out to ascertain the level of electricity availability and consumption in the clinic.

Table 1. Current Power Source for the Clinic

Code	Name	Name Plate Details	Target Load	kWh/Day Supplied	O & M Cost
GEN.1	Tiger (TG 2700) Gasoline Generator	50Hz, 230V, Single Phase Rated Output: 2KVA	Submersible Pumping Machine	2.2	₦0.86/day ₦0.39/kWh
GEN.2	SANDING (SD 3000) Gasoline Generator	50Hz, 230V, Single Phase Rated Output: 2.2KVA Maximum Output: 2.5KVA	Lighting, Medical Equipment, T.V, Phone Charging and Refrigeration	3.55	₦0.86k/day ₦0.24/kWh
TOTAL				5.75	₦1.73/day ₦0.64/kWh

To achieve the objective of designing a low-cost hybrid power system that uses a mix of Solar PV, diesel generator and battery power bank that meets the rural healthcare clinic need, the methodology employed is shown Figure 1.

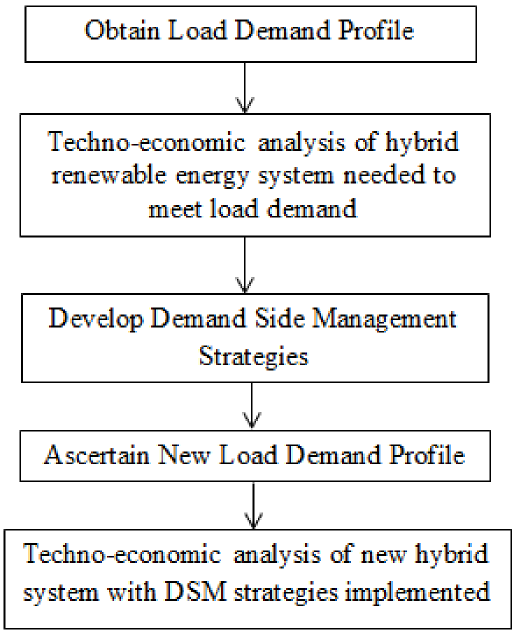

Figure 1. Block Diagram of Methodology

3.2 Current Load Profile at the health centre

The current electricity load profile of the centre supplied by the two generators is shown in Figure 2. The total connected load is 3.2kW, with peak load of 1.5kW and average daily demand of 4.75kWh/day. As observed from figure 2, electricity consumption is shifted towards evening hours when the generators are used mainly for lighting purpose. Other uses of power were shifted to the same hours except during emergency situations. Immunization in the clinic is usually carried out once a month due to lack of power supply to maintain cold chain for vaccines. The lack of an electric centrifuge also slows the process of laboratory tests, as blood samples separation are done manually. The laboratory technician manually operates the microscope in the daytime as there is no power supply required. The lack of reliable power supply has hindered the clinic from providing effective healthcare services to the dwellers.

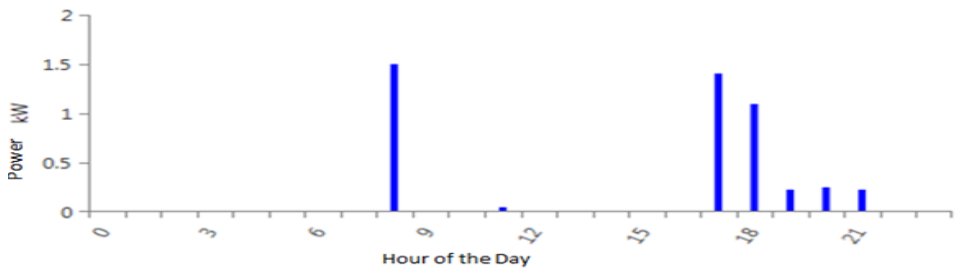

Figure 2. Current Load Profile of the Clinic

However, in order to enhance the service delivery of the health centre, there is need for increasing the number of hours electricity is supplied to the centre. The energy load requirements to allow appliances at the clinic to be fully utilized is shown in Table 2. This new load serves as the input to the optimization software, HOMER with day-to-day and hourly variability of 5% and 10% respectively, to avoid underestimating the peak load.

Table 2. A new load description with all the basic medical appliances functioning

Application	Detail	Quantity	Capacity (watts)	Run time (hours/day)	Peak load(W)
Lighting	Bulb (Incand.)	2	100	12	200
	Bulb(Fluorc.)	10	40	8	160
	Bulb (CFL)	15	18	12	270

	Bulb (CFL)	17	11	8	187
Ventilation	Ceiling fan	8	75	8	600
Medical Equipment	Sterilizer	1	1,500	1	1500
	Microscope	1	20	1	20
ICT and Audio Visual	LCD T.V	1	45	1	45
	Mobile Phones	5	3.68	2	18.4
Water Supply	Submersible Pump	1	1,100	1	1100
Other	Refrigerator(Non-Med)	1	300	1	300

Figure 3 shows the new load profile with 4.64kW connected load, 2.67kW peak load, and 20.58kWh/day average daily demand.

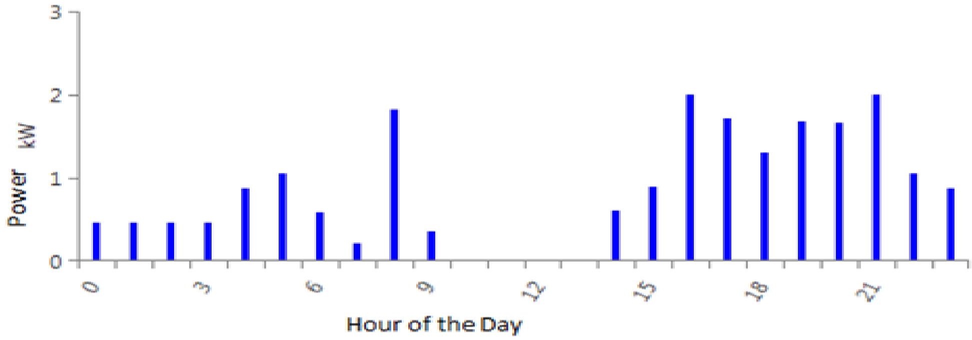

Figure 3. Proposed Clinic Load Profile without DSM

3.3 Hybrid energy system optimal sizing

Hybrid Optimization of Multiple Electric Renewables (HOMER) software designed by US's National Renewable Energy Laboratory (NREL) was used to design and optimally size the hybrid power supply that meets the clinic load demand. It is an optimization model for micro-power [17]. The inbuilt algorithm HOMER uses for its optimization and sensitivity analysis allows the user to gauge the technical and economic possibility of a variety of electricity generation technology options that can serve a particular load. Different types of data are required by HOMER for simulation and optimization. These include energy resources meteorological data, load profile, equipment characteristics, search-space, economic and technical data.

3.3.1 Resources Data

The monthly average daily solar irradiance data used for the study site is presented in Table 3. These data were obtained from Nigeria Meteorological Agency (NiMET).

Table 3. Monthly average global solar radiation and clearness index for the study site

Month	Solar Insolation	Clearness Index
Jan	5.88	0.65
Feb	6.09	0.63
Mar	6.27	0.61
Apr	6.06	0.58
May	5.58	0.54
Jun	5.06	0.49
Jul	4.42	0.43
Aug	4.18	0.40
Sep	4.73	0.46
Oct	5.30	0.54
Nov	5.97	0.66
Dec	5.87	0.67
Annual	5.45	0.56

3.3.2 System components data

The information regarding components pricing and sizing as adopted in the proposed hybrid system, are presented in Table 4. Present market values were used for the prices of each component per kW [18].

3.4 Demand Side Management

Demand side management (DSM) is a process of managing energy consumption to optimize available and planned resources for power generation [19]. With DSM, it is possible to increase renewable energy penetration, optimize energy costs and reduces carbon emissions. DSM incorporates all activities that influence consumer use of electricity and results in the reduction of the electricity demand. There are two primary indices used in assessing both the economic and technical benefits of DSM. They are the demand side management quality index (DSMQI) for measuring the technical effects, and the demand side management appreciation index (DSMAI) for weighing economic results. These indices help to appreciate the justification for any adopted DSM program.

3.4.1 DSM Quality Index (DSMQI)

Demand side management quality index (DSMQI) evaluates the technical gains of a particular DSM program [19].

$$DSMQI = \frac{KW_{WODSM}}{KW_{WDSM}} \quad (1)$$

kW_{WDSM} and kW_{WODSM} are the kW rating with and without DSM, respectively. A DSMQ1>1 is good; the higher the ratio, the higher the benefit of the DSM program.

3.4.2 DSM Appreciation Index (DSMAI)

Demand side management appreciation index (DSMAI) is an index that reveals the economic benefits of DSM programs DSMAI is expressed as[19]:

$$DSMAI = \frac{CKWh_{WODSM}}{CKWh_{WDSM}} \quad (2)$$

$CkWh_{WDSM}$ and $CkWh_{WODSM}$ are the cost of electricity per kWh with and without DSM, respectively.

Table 4. Economic and Technical Specifications

Component Parameter	Values
PV Module	
Capital Cost ($/kW):	2,500
Replacement Cost ($/kW):	2,500
O&M Cost ($/year):	10
Lifetime (years):	25
De-rating Factor (%):	80
Search Space (kW):	0,1,2,3 & 4
Converter	
Capital Cost ($/kW):	250
Replacement Cost ($/kW):	250
O&M Cost ($/year):	10
Lifetime (years):	15
Efficiency (%):	9
Search Space(kW):	0,1,2,3 & 4
Battery	
Model:	Trojan J200-RE
Rating:	2.71kWh, 226Ah
Capital Cost ($/Unit):	167
Replacement Cost ($/Unit):	167
O&M Cost (₦/year):	10
Lifetime (years):	7
Search Space (Unit):	0, 8, 16, 24 & 32
Battery String:	1
Generator	
Type:	Generic Auto-size

Capital Cost ($/kW):	418
Replacement Cost ($/kW):	418
O&M Cost ($/hr):	8
Diesel Price ($ /liter):	0.54
System/Economic Constraints	
Maximum Capacity Shortage	20%
Minimum Renewable Fraction	55%
*Inflation Rate:	17.26%
*Interest Rate:	14.00%

3.4.3 Proposed Demand Side Strategies

In order to reduce energy consumption of the considered healthcare facility, some DSM strategies were considered based on the energy audit conducted. Smart appliance, energy efficiency programs and load partitioning are considered to achieve consumption reduction, thereby reducing the cost of the hybrid renewable energy system in the rural clinic.

3.4.3.1 Smart appliance

From the list of appliances listed in Table 2, the following appliances were observed to be inefficient and high energy consuming: (i) 2 No. 100W incandescent light bulbs(ii) 10 No. 40W fluorescent tubes fittings and (iii) non-medical refrigerator used for preserving vaccines. Therefore, it is proposed that the incandescent bulbs and fluorescent fitting be changed to Compact Fluorescent Lamps (CFLs). A solar vaccine refrigerator will also reduce energy consumption and improve the healthcare service delivery. To ensure each room in the centre is lighted according to standard, calculations were also done for the number of fixtures required for internal lighting.

3.4.3.2 Energy Efficient Water pumping

To ensure efficient use of water pumping machine, the water requirement of the centre was estimated. According to World Health Organization standard, water required a person, per day is 20 litres [20]. For In-patient (admitted patients) and Out-patient (non-admitted patients), it is 60litres and 5litres respectively. Laboratory water requirement is estimated at 75litres per day. A 20% miscellaneous is added for other use. The healthcare center usually has an average of five (5) staff on duty daily, with a total of seven (7) bed spaces for admitted patients.

3.4.3.3 Load partitioning

Loads in the healthcare centre were classified in order of priority as primary (critical) and deferrable (non-critical). The load classification is shown in Table 5.

Table 5. Classification of loads

Category	Detail	Priority
Lighting	All Light Fixtures	Primary
Ventilation	Ceiling fan	Primary
Medical Equipment	Sterilizer	Deferrable
	Microscope	Primary
ICT and Audio Visual	LCD T.V	Primary
	Mobile Phones	Deferrable
Water Supply	Submersible Pump	Deferrable
Other	Refrigerator (Non-Med)	Primary

Deferrable loads are electrical load that must be met within certain period, but the exact timing is not important. The deferrable loads identified, and their analysis, are as follows:

(1) Submersible pump: The clinic pumps water for two (2) hours daily. The pump has a pumping rate of 2000litres/hr. The water requirement of the centre is 714litres per

day (approximately 1000litres per day). It would take pump 0.5hours to pump the daily water required.

- Peak power (pump rated power) = 1.1kW
- Storage capacity = 2 (hours) × 1.1 (kW) = 2.2kWh
- Average deferrable load = 0.5×1.1=0.55kWh/day

(2) *Medical equipment Sterilization:* It takes between 25 to 30 minutes to complete one sterilization cycle.

- Sterilizer peak power = 1.5kW
- Storage capacity = 1 (hour) × 1.5 (kW) = 1.5kWh
- Average deferrable load = 0.5 × 1.5 = 0.75kWh/day

(3) *Mobile phones charging:* It takes on average 2hours to fully charge a mobile phone. However, to reduce power consumption, 1 hour has been allotted per staff on duty to charge their mobile phones when necessary.

- Peak power = 0.0184kW
- Storage capacity = 0.0184 × 2 = 0.0368kWh
- Average deferrable load = 1×0.0184= 0.0184kWh/day

(4) *De-lamping fixtures:* Some lighting loads that were cut down to reduce energy consumption these include: (i) External lighting: reduced to eight (8) points (4 for each block of building). (ii) Ceiling fan: reduced to four (4) points for entrance/card room, labour recovery ward, male and female wards.

3.4.4 New Load Profile with DSM Implemented

Figure 4 shows the schematic of the new hybrid system designed with DSM strategies in place. The schematic contained the two classes of loads (primary and deferrable). The new primary load profile is shown in Figure 5 with total connected load of 1.15kW, peak load of 1.08kW and a daily average load of 7.01kW/day.

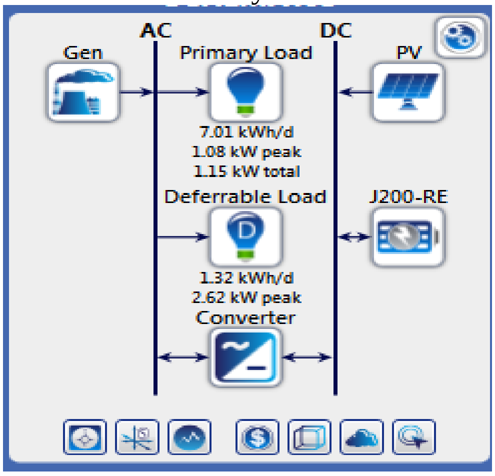

Figure 4. Schematic hybrid energy system with proposed DSM strategies

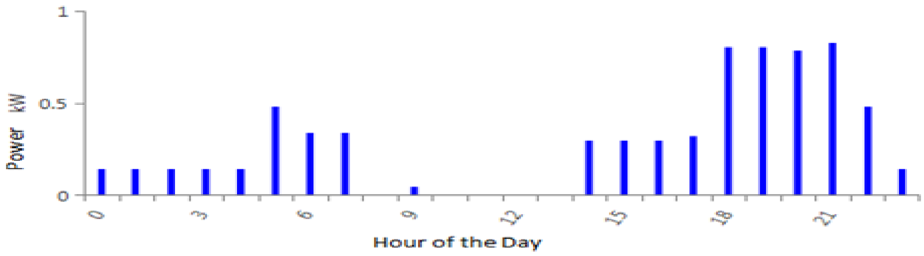

Figure 5. Primary load profile with proposed DSM strategies

4. Results and Discussion

The details optimization results for the selected hybrid system configuration for the considered primary healthcare centre are presented in this section. Input variables were introduced into HOMER to carry out the optimization and give the feasible and optimum system configuration. Results are displayed in categorized form showing the most feasible power system architecture which meets the load and the input constraints.

4.1 Optimization before DSM Strategies

With the load profile shown in Figure 3 and system constraints (Table 4), an optimum hybrid system configuration was obtained for the centre. The optimization result for various system configurations are shown in Table 6. Based on the total net present cost (NPC), the optimum configuration is found to be PV/Gen/Battery system. The configuration consists of a 4kW PV 3kW generator, 24 units (12V) batteries and a 3kW converter. The total NPC and cost of energy (COE) is presented in Table 6. Meeting the facility's energy need with generator alone will cost $1,253.6 as initial capital but a total lifetime cost (NPC) of $114,940 as presented in Table 6. It is worth noting that a PV-Battery system is not feasible with a 20% maximum annual capacity shortage constraint indicated in Table 4. The PV-Battery configuration is only feasible when the maximum annual capacity shortage is increased to 34%.

4.2 Optimization for Hybrid System with proposed DSM Strategies

The result of the optimization for the power system that meet the centre energy needs, with proposed DSM strategies is shown in Table 7. The optimization result shows that with DSM strategies in place, the optimum configuration to meet the electrical energy need of the healthcare centre is also a PV/Gen/battery system, but with 3kW PV, 1.7kW generator, 8 units 12V batteries and a 1kW converter. The Total net present cost (NPC) is $18,614.7 while cost of energy (COE) is $0.166/kWh. Meeting the facility's energy needs with generator alone system after implementing DSM strategies will costs $710.30 as initial capital and a total lifetime cost (NPC) of $57.972.90.

Table 6. Optimization result for hybrid power system before DSM strategies

System Configuration	PV (kW)	DG (kW)	Bat. (Units)	Con. (kW)	COE ($/kWh)	NPC ($)	Capital Cost ($)
PV-DG-Bat	4	3	24	3	0.224	61,917.60	16,046.50
DG-Bat	-	3	8	1	0.310	85,687.30	2,841.60
Gen. Only	-	3	-	-	0.415	114,940.30	1,253.60
*PV-Bat	4	-	32	3	0.266	70,501.60	18,046.50

*Maximum Capacity Shortage =34% (Not feasible for Maximum Capacity Shortage < 34%)

Table 7. Optimization result for hybrid power system after DSM strategies

System Configuration	PV (kW)	DG (kW)	Bat. (Units)	Con. (kW)	COE ($/kWh)	NPC ($)	Capital Cost ($)
PV-Gen-Bat	3	1.7	8	2	0.166	18,614,70	10, 070.80

PV-Bat	4	-	16	2	0.202	22,628.90	13,204.90
Gen-Bat	-	1.7	8	2	0.364	40,629.30	2,549.10
Gen. Only	-	1.7	-	-	0.518	57,972.90	710.30

4.2.1 *Initial Capital Cost comparison:* The initial cost of the optimum system configuration before DSM is $16,046.5 as compared to $10,070.8 after DSM as shown in Table 6 and 7, representing 37.3% reduction in cost.

4.2.2 *Total NPC comparison:* For the optimum configuration before applying DSM measures, the total net present cost is $61,917.6, while the NPC for optimum system configuration with DSM measures is $18,614.7, representing a percentage reduction of 70%.

4.2.3 *Cost of Energy (COE) comparison:* The Cost of Energy (COE), measured in $/kWh, is a convenient metric to measure the cost effective of the systems, even though HOMER does not rank systems based on COE. Table 6 and 7 compares the cost of energy in both load scenarios, representing 25.8% reduction

4.2.4 *Environmental Friendliness comparison:* The optimization results shows optimum system configurations after implementation of DSM measures are more environmentally-friendly, with lower CO_2 emissions than without DSM measure representing 96.6 % reduction as presented in Table 8. In both load scenarios, generator only systems also give the highest CO_2 emissions when compared with other system configuration.

Table 8. Comparison of emission for optimum system configuration after and before DSM strategies

Quantity	**Before DSM (kg/year)**	**After DSM (kg/year)**
Carbon Dioxide	2,579	88.22
Carbon Monoxide	10.05	0.56
Unburned Hydrocarbons	0.50	0.02
Particulate Matter	0.05	0.00
Sulfur Dioxide	0.80	0.22
Nitrogen Oxide	1.05	0.52

4.3 Evaluation of DSM Measures

The DSM strategies applied was tested using two indices- the Demand Side Management Quality Index (DSMQI) which give the value of 1.23 and the Demand Side Management Appreciation Index (DSMAI), which gives1.35 based on computation with equations (1) and (2) respectively. It can be observed that both DSMQI and DSMAI are above one (1), which is desirable to show that the DSM measures applied were productive in reducing connected load and the cost per kWh of electricity. DSMQI is only a little bit above 1, because the connected load after DSM is almost the same except for the load reduction measures in de-lamping external lighting points and taking out some ceiling fan loads. DSMAI on the other hand is little bit higher because of the demand response measures applied, leading to load partitioning namely primary and deferrable.

5. Conclusions

The study identified the lack of modern electricity supply as a major impediment to proper functioning of the healthcare centres in the rural areas thereby hindering effective realization of SDG3. The study has been able to model a PV hybrid microgrid to meet the energy needs of a rural health clinic. It has shown that DSM strategies are an effective means to reduce capital and operation costs through economic analysis. Furthermore, the environmental impacts of providing power are also reduced through cuts in air pollution. This work provides novel insights into renewable energy penetration which may be applicable worldwide. It has the potential to significantly advance the development of high-quality and timely evidence to underpin current and future developments in the rural energy sector and contribute to the implementation of SDG7.

An energy audit was conducted at a case study rural clinic located in Nigeria with the aim of proposing DSM measures to increase renewable energy penetration at the healthcare centre. The baseline load profile generated showed power supply shortages at the healthcare clinic. To improve healthcare service delivery, a new load profile was designed to meet the expected energy need. This resulted in peak load, total connected load and average daily demand of 2.67kW, 4.64kW and 20.58kWh/day respectively. The optimum system to meet the present load was found to be PV/Gen/Battery system with NPC of $61,917.6. The COE, initial capital cost and CO_2 emissions of the system were $0.224/kWh, $16,046 and 2,579kg/year respectively.

To reduce both NPC and initial capital cost, DSM measures were proposed. The DSM measures including de-lamping external lighting fixtures, reduction of ceiling fan points and load partitioning into primary and deferrable loads. With the proposed DSM, the new load profile was simulated with the required energy resource. The optimum system configuration was also found to be PV/Gen/Battery system, but with reduced initial capital cost of $10,070.8, NPC of $18,614.7, total COE of $0.166/kWh and a renewable fraction of 98%. With DSM strategies implemented at the healthcare centre, a cost savings of $0.06kWh was achieved, representing a 25.8% cost reduction from the present cost of energy per kWh, and 70% reduction in the total net present cost. The optimum system also has around a 96% reduction in CO_2 emissions.

The impact of this study is shown in the fact that SDG 7(affordable and clean energy) offers a series of interlinkages with other goals, such as SDG13 (reduce GHG emission) and SDG3 (access to quality healthcare services). Thus, it is expected that the results of the analysis in the study will be useful for planning stand-alone or mini-grid energy generation systems for off-grid remote healthcare centres locations around the world for effective realization of SDG3.

References

[1] 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, 1(2), 249-261

[2] Fischer, A. W., Cannon, B., & Nedergaard, J. (2018). Optimal housing temperatures for mice to mimic the thermal environment of humans: an experimental study. Molecular metabolism, 7, 161-170.

[3] Olatomiwa, L., & Mekhilef, S. (2015). Techno-economic Feasibility of Hybrid Renewable Energy System for Rural Health Centre (RHC): The Wayward for Quality Health Delivery. Paper presented at the IEEE Conference on Energy Conversion (CENCON).

[4] Ayodele, T., Ogunjuyigbe, A., & Akinola, O. (2017). n-split generator model: An approach to reducing fuel consumption, LCC, CO2 emission and dump energy in a captive power environment. Sustainable Production and Consumption, 12, 193-205

[5] Olatomiwa, L. (2016). Optimal configuration assessments of hybrid renewable power supply for rural healthcare facilities. Energy Reports, 2, 141-146

[6] IEA. (2017). World Energy Outlook. From http://www.iea.org/Textbase/npsum/weo2017SUM.pdf

[7] Diemuodeke, E., Hamilton, S., & Addo, A. (2016). Multi-criteria assessment of hybrid renewable energy systems for Nigeria’s coastline communities. Energy, Sustainability and Society, 6(1), 26.

[8] Ozoegwu, C. G. (2018). The solar energy assessment methods for Nigeria: The current status, the future directions and a neural time series method. Renewable and Sustainable Energy Reviews, 92, 146-159.

[9] Ayodele, T., & Ogunjuyigbe, A. (2015). Increasing household solar energy penetration through load partitioning based on quality of life: The case study of Nigeria. Sustainable Cities and Society, 18, 21-31

[10] Akinyele, D. O., & Rayudu, R. K. (2016). Comprehensive techno-economic and environmental impact study of a localised photovoltaic power system (PPS) for off-grid communities. Energy Conversion and Management, 124, 266-279.
[11] Nwofe, P. A. (2014). Utilization of solar and biomass energy: A panacea to energy sustainability in a developing economy. International Journal of Energy and Environmental Research, 2, 10–19.
[12] Ohunakin, O. S., Adaramola, M. S., Oyewola, O. M., & Fagbenle, R. O. (2014). Solar energy applications and development in Nigeria: drivers and barriers. Renewable and Sustainable Energy Reviews, 32, 294-301.
[13] Oji, J. O., Idusuyi, N., Aliu, T. O., Petinrin, M. O., Odejobi, O. A., & Adetunji, A. R. (2012). Utilization of solar energy for power generation in Nigeria. International Journal of Energy Engineering, 2, 54–59.
[14] Olatomiwa, L., Mekhilef, S., Huda, A., & Sanusi, K. (2015). Techno-economic analysis of hybrid PV–diesel–battery and PV–wind–diesel–battery power systems for mobile BTS: the way forward for rural development. Energy Science & Engineering.
[15] 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, 22, 92-105.
[16] Akinyele, D., Belikov, J., & Levron, Y. (2018). Challenges of Microgrids in Remote Communities: A STEEP Model Application. Energies, 11(2), 432.
[17] NREL. (2015). HOMER PRO Index. Retrieved from http://www.homerenergy.com/HOMER_pro.html
[18] Olatomiwa, L., Blanchard, R., Mekhilef, S. & Akinyele, D, 2018. Hybrid renewable energy supply for rural healthcare facilities: An approach to quality healthcare delivery. Sustainable Energy Technologies and Assessments, 30, 121-138.
[19] Eze, C. U., Agwu, D. D., & Uzoechi, L. O. (2016). A new proposed demand side management technique. International Journal of Engineering Sciences & Emerging Technologies, 8(6), 271–281.
[20] Reed, B. J. (2005). Minimum water quantity needed for domestic uses (Technical Notes for Emergencies No. 9).