PRIMARY HEALTH CENTRE ROOF-TOP SOLAR ENERGY SYSTEM PERFORMANCE ANALYSIS

Uwakwe Chikwado[1]
Department of Electrical/Electronic Engineering Imo State Polytechnic, Umuagwo, Owerri, Nigeria

Okafor Brian Okwuchukwu[2]
Department of Space Applications and Research, Advanced Space Technology Applications Laboratory, Uyo, Akwa Ibom, Nigeria
bokafor@astaluyo.gov.ng

Osuji Dennis Chiazor[3]
Department of Space Education and Training, Advanced Space Technology Applications Laboratory, Uyo, Akwa Ibom, Nigeria
dennischiazor@gmail.com

***Abstract*— A primary health centre roof-top solar energy system performance analysis is presented. Specifically, the photovoltaic (PV) energy yield is considered for six study sites selected from the six geopolitical regions in Nigeria. The basic analytical expressions for the determination of the rooftop energy yield of PV power system are presented along with the load demand of the health center. The global solar radiation data of the six selected study site are used to simulate and obtain the energy yield and losses due to temperature. The PV power system components and their sizes were selected using the PVSyst system dialogue box and the simulation was performed for each of the six study sites. The results of the annual average loss due to temperature show that Akwa Ibom has the lowest annual average temperature of 24.7°C while Gombe has the highest annual average temperature of 26.3°C. On the other hand, with a value of 695.87 kWh/year Akwa Ibom State has the lowest annual average energy loss due to temperature while Gombe has the highest annual average energy loss due to temperature with a value of 1115 kWh/year. In all, the results showed that solar energy are more abundant in the northern parts of Nigeria considered in the study, namely, Abuja, Gombe and Kano state. Also, the loss due to temperature is not dependent solely on temperature, but other parameters also affect its value.**

Keywords— Component Sizing , Energy Yield, Rooftop PV , Solar Ower, Ambient Temperature, Solar Radiation, Thermal Loss

1. INTRODUCTION

Across the globe, health centers of different categoeis have been found to be essential for meeting the health challenges of any nation [1,2,3,4,5,6,7,8]. In the developing countries, health centers at the rural communities are essential for inclusive health services to the disadvantaged rural populations [9,10,11,12,13]. However, one major problem of the health centers located in the rural communities is lack of access to power supply from the national grid [14,15,16,17,18,19,20,21,22,23]. In such case, solar power system has been advocated as a more environmentally friendly alternative power supply system [24,25,26,27,28,29,30,31].

In practice, photovoltaic (PV) power system energy yeild depends on different meteorological data which vary with location and time 32,33,34,35,36,37,38]. The spatio-temporal nature of the PV power energy yeild means that for a given set of PV system component configuration, the energy output will vary from one location to the other and from one particular time to another. Accordingly, in this paper, PV system component sizing and energy yield analysis is presented for a case study health center PV power installation located in different States in Nigeria, where one State is selected from each of the six geopolitical regions in Nigeria. The study seeks to evaluate how a model PV power system installation can be designed and employed for the health centers located invarious States in Nigeria.

2. METHODOLOGY

2.1 The daily energy yield expected from rooftop installed PV array

The required effective rooftop area (A_{pv}) for PV array installation that will supply the daily electric energy demand (E_L) with temperature and dc/ac de-rating factors (f_{temp} and $f_{dc/ac}$ respectively) is determined as follows;

$$A_{pv} = \frac{E_L}{(PSH * \eta_{pv} * f_{dc/ac} * f_{temp})} \quad (1)$$

Where η_{pv} denotes the PV module efficiency and PSH is the daily Peak Sun Hour.

On the other hand, when A_{pv} is given, then the daily energy yield expected from PV array occupying the given roof area, A_{pv} is denoted as E_{PV} and it is computed as follows;

$$E_{PV} = A_{pv} (G_d * \eta_{pv} * f_{de-rating}) \quad (2)$$

2.2 Electric Load Demand of the Case Study Health Centre and the Peak Sun Hour (PSH) Data of Selected Study Sites

The case study health facility is the Primary Health Centre West Itam Uyo, Akwa Ibom State Nigeria located at latitude of 5.050834 and longitude of 7.902476 (Figure 1).The daily electric load demand (E_L) of the case study health centre is taken from [39] which has E_L = 101. 808 KWh per day, as presented in Table 1. The equivalent daily energy demand can be expressed as a daily power demand of 12726 watts for an average of 8 hours a day which gives a daily energy demand of 101808 Wh /day.

The selected study sites from the Nigerian six geopolitical regions are shown in Table 2 and Figure 2.

The PVSyst software was used to extract the PSH data from the NASA solar radiation data web portal and the extracted solar radiation (PSH) data for the case study sites are given in Table 3 and Figure 3.

Table 1 Case study health centre Daily Electric Load Demand (Source: [39])

S/N	Appliance Description	Qty.	Rated Power (Watts)	Number of Hours Operated	Total Power (Watts)	Total Wh per day	Total Kwh per day
1	Blood bank Fridge	2	50	24	100	2400	2.4
	Vaccine Fridge	2	80	12	160	1920	1.92
2	Microscope	2	15	6	30	180	0.18
3	Operating Lamp	1	125	4	125	500	0.5
4	Syringe Pumps	2	600	1	1200	1200	1.2
5	Air conditioners	2	746	6	1492	8952	8.952
6	Lighting	56	100	12	5600	67200	67.2
7	Hematology Mixer	1	28	4	28	112	0.112
8	Incubators	2	400	7	800	5600	5.6
9	Curing light	1	90	3	90	270	0.27
10	Microwave	1	700	3	700	2100	2.1
11	Medical Centrifuge	1	578	3	578	1734	1.734
12	Washing Machine	1	450	2	450	900	0.9
13	PC and Printer	2	120	6	240	1440	1.44
14	TV	2	50	10	100	1000	1
15	Drier	1	500	3	500	1500	1.5
16	Ceiling Fan	6	100	8	600	4800	4.8
Total					12793	101808	101.808
Average number of hours per day (hours)						7.958102	

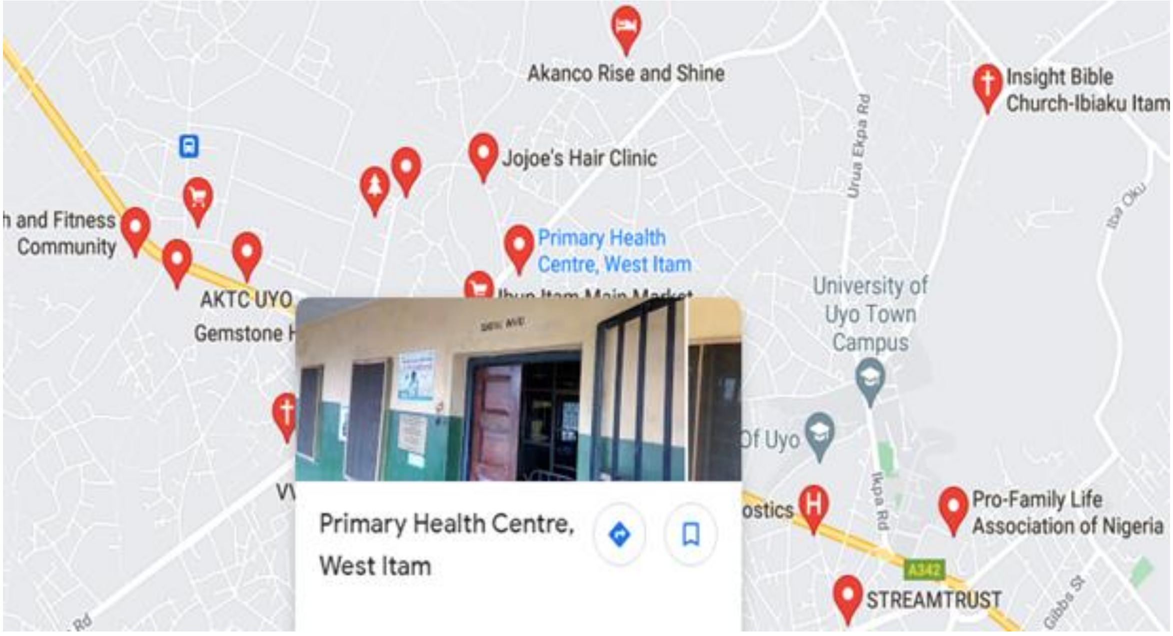


Figure 1 The case study is Primary Health Centre West Itam Uyo, Akwa Ibom State Nigeria located at latitude of 5.050834 and longitude of 7.902476

Table 2 The Selected Locations from the Nigerian Six Geopolitical Regions.

S/N	Geopolitical Region	State	Latitude	Longitude
1	North Central	Gwaska Abuja	9.010229	7.28928
2	North East	Bajoga Gombe State	10.907129	11.306798
3	North West	Sharada Kano State	11.952035	8.49841
4	South East	Awkunanaw Enugu State	6.393511	7.484218
5	South South	Primary Health Centre West Itam Uyo	5.050834	7.902476
6	South West	Sagamu Ogun State	6.828251	3.554311

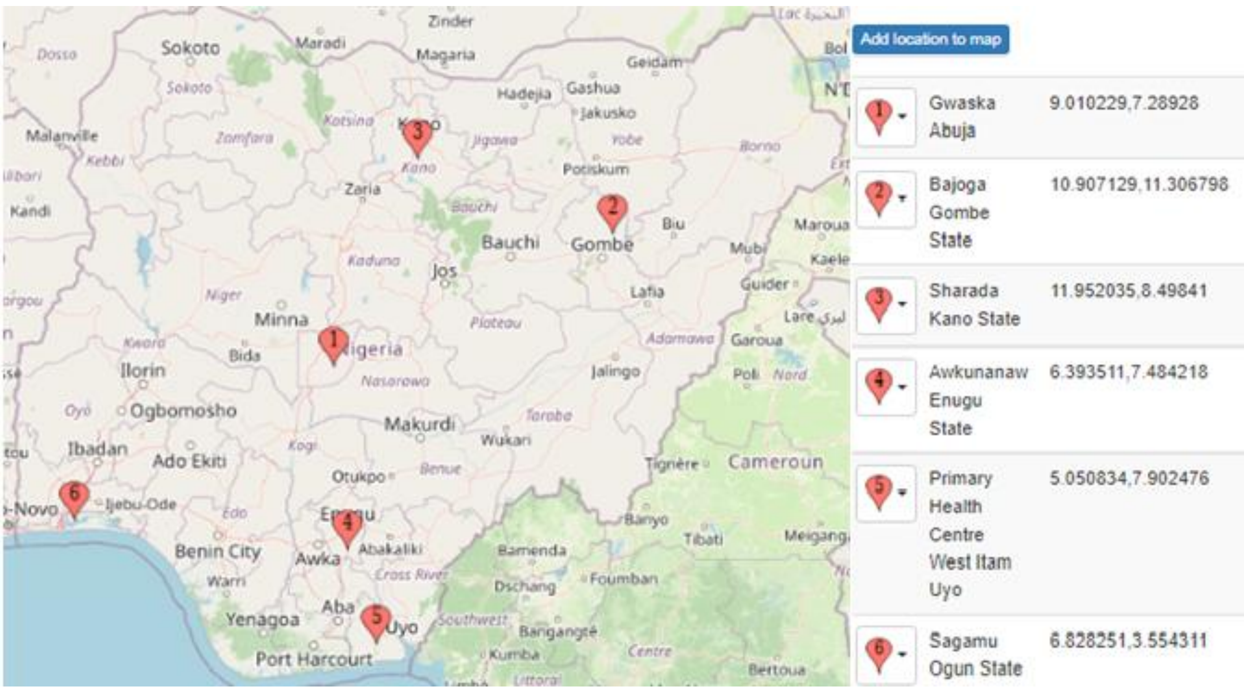


Figure 3 The Map Plot of the Selected Locations from the Nigerian Six Geopolitical Regions.

Table 3 The Solar Radiation data of the Selected Locations from the Nigerian Six Geopolitical Regions.

Month	Abuja GlobHor (kWh/m².mth)	Akwa Ibom State GlobHor (kWh/m².mth)	Enugu State GlobHor (kWh/m².mth)	Gombe StateGlobHor (kWh/m².mth)	Kano State GlobHor (kWh/m².mth)	Ogun State GlobHor (kWh/m².mth)
Jan	182.3	171.4	176.1	176.1	172	163.7
Feb	170.5	156.5	160.7	173.3	176.1	153.7
Mar	194.4	164.9	172.7	199.9	206.2	169.3
Apr	181.8	152.7	157.5	192.9	200.7	156.3
May	173	146.3	153.1	192.5	197.5	147.6
Jun	151.8	129.3	136.2	173.7	177.9	121.2
Jul	137.6	119.3	128.3	163.7	168.9	122.5
Aug	129.9	116.9	121.2	155	160	123.4
Sep	141.9	118.2	125.7	160.8	165.9	122.7
Oct	164.6	132.4	141.7	177.3	178.9	141.1
Nov	179.4	145.2	153.3	171	169.5	148.5
Dec	181.7	164	169.3	168.9	165.8	160.3
Year	1988.8	1717.2	1795.8	2105.2	2139.4	1730.1

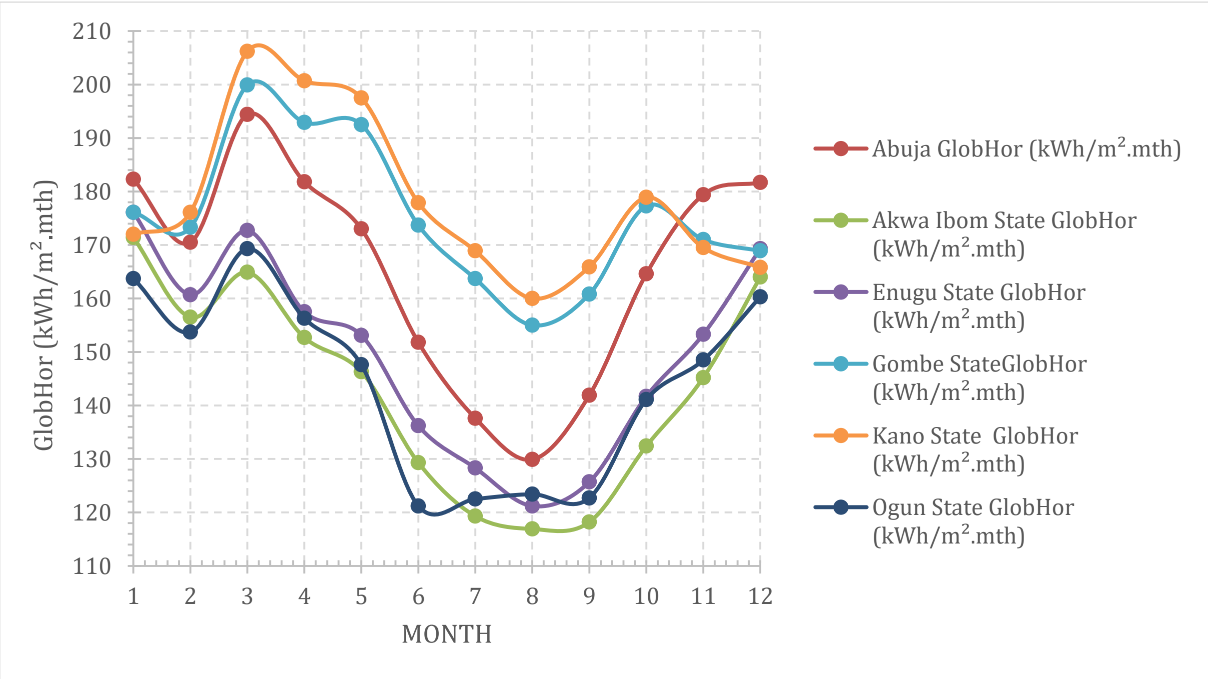


Figure 3 The Plot of the Solar Radiation data of the Selected Locations from the Nigerian Six Geopolitical Regions.

3. Results and discussions

The PV power system components and their sizes were selected using the PVSyst system dialogue box. The system simulation parameters used for the six selected sites are presented in Figure 4. The results of the monthly and annual available energy at the inverter output, EOutInv (kWh) for the selected six study sites are presented in Table 4 and Figure 5. The results showed that Kano State has the highest annual energy yield of 6654.4 kWh/year while Akwa Ibom State has the lowest annual energy yield of 5363.1 kWh/year, as shown in Table 4, Figure 5 and Figure 6. Also, Figure 7 shows that Kano State has 124% of annual energy when compared to that of Akwa Ibom State, which is the reference State with 100% annual energy yield.

The results of the annual average loss due to temperature and the annual average temperature for the selected six study sites are presented in Figure 6 and Figure 7. The results show that Akwa Abuja has the lowest annual average temperature of 24.7°C while Gombe has the highest annual average temperature of 26.3°C. On the other hand, with a value of 695.87 kWh/year, Akwa Ibom State has the lowest annual average energy loss due to temperature while Gombe has the highest annual average energy loss due to temperature with a value of 1115 kWh/year.

In all, the results showed that the loss due to temperature is not dependent solely on temperature, but other parameters also affect its value. That is why the site with the lowest temperature does not give the lowest energy loss due to temperature. Also, the energy yield results showed that solar energy are more abundant in the northern parts of Nigeria considered in the study, namely, Abuja, Gombe and Kano state.

PVSYST V6.70		29/05/21	Page 1/3

Grid-Connected System: Simulation parameters

Project : **HEALTH CENTER**

Geographical Site **AKWA IBOM STATE** Country **Nigeria**

Situation Latitude 5.05° N Longitude 7.90° E
Time defined as Legal Time Time zone UT Altitude 56 m
Albedo 0.20

Meteo data: **AKWA IBOM STATE** NASA-SSE satellite data, 1983-2005 - Synthetic

Simulation variant : **New simulation variant**
Simulation date 29/05/21 07h18

Simulation parameters System type **No 3D scene defined**

Collector Plane Orientation Tilt 14° Azimuth 0°

Models used Transposition Perez Diffuse Perez, Meteonorm

Horizon Free Horizon

Near Shadings No Shadings

PV Array Characteristics

PV module Si-poly Model **GES-6P50**
Original PVsyst database Manufacturer Sainty Solar
Number of PV modules In series 14 modules In parallel 5 strings
Total number of PV modules Nb. modules 70 Unit Nom. Power 50 Wp
Array global power Nominal (STC) **3500 Wp** At operating cond. 3417 Wp (50°C)
Array operating characteristics (50°C) U mpp 359 V I mpp 9.5 A
Total area Module area **31.1 m²** Cell area 25.6 m²

Inverter Model **AT 3600**
Original PVsyst database Manufacturer Sunways
Characteristics Operating Voltage 242-600 V Unit Nom. Power 3.60 kWac
Inverter pack Nb. of inverters 1 units Total Power 3.6 kWac
Pnom ratio 0.97

PV Array loss factors
Thermal Loss factor Uc (const) 20.0 W/m²K Uv (wind) 0.0 W/m²K / m/s
Wiring Ohmic Loss Global array res. 633 mOhm Loss Fraction 1.5 % at STC
Module Quality Loss Loss Fraction -0.8 %
Module Mismatch Losses Loss Fraction 1.0 % at MPP
Strings Mismatch loss Loss Fraction 0.10 %
Incidence effect, ASHRAE parametrization IAM = 1 - bo (1/cos i - 1) bo Param. 0.05

User's needs : Unlimited load (grid)

Figure 4 The PVSyst simulation parameters for the PV Power SYstem

Table 4 The monthly and Annual Available Energy at the Inverter Output, EOutInv (kWh) for of the Selected Six Locations

Month	Month	AKWA IBOM STATE EOutInv (kWh)	ENUGU STATE EOutInv (kWh)	OGUN STATE EOutInv (kWh)	ABUJA EOutInv (kWh)	GOMBE STATE EOutInv (kWh)	KANO STATE EOutInv (kWh)
Jan	1	582.6	616.8	573.1	652.4	631.6	629.4
Feb	2	508.5	530	508.3	566.7	574.9	591.5

Mar	3	511.3	529	519	597.1	605.2	630.1
Apr	4	449.3	449.6	449.2	515.5	543.3	568.4
May	5	416.1	413.5	400	461.9	511.3	530.7
Jun	6	362.2	361.5	325.3	398.7	456.1	473.1
Jul	7	342.6	350.3	333	373.7	444.1	463
Aug	8	351.2	349.9	352.8	373.3	442.9	460.6
Sep	9	363.5	382.3	374.8	432.2	484.2	509.6
Oct	10	417.6	457.7	456.4	540	576.4	587.6
Nov	11	489.2	530.3	511.6	634	588.1	593.8
Dec	12	569	609	576.8	666.3	611.3	616.6
Year		5363.1	5579.8	5380.3	6211.8	6469.4	6654.4

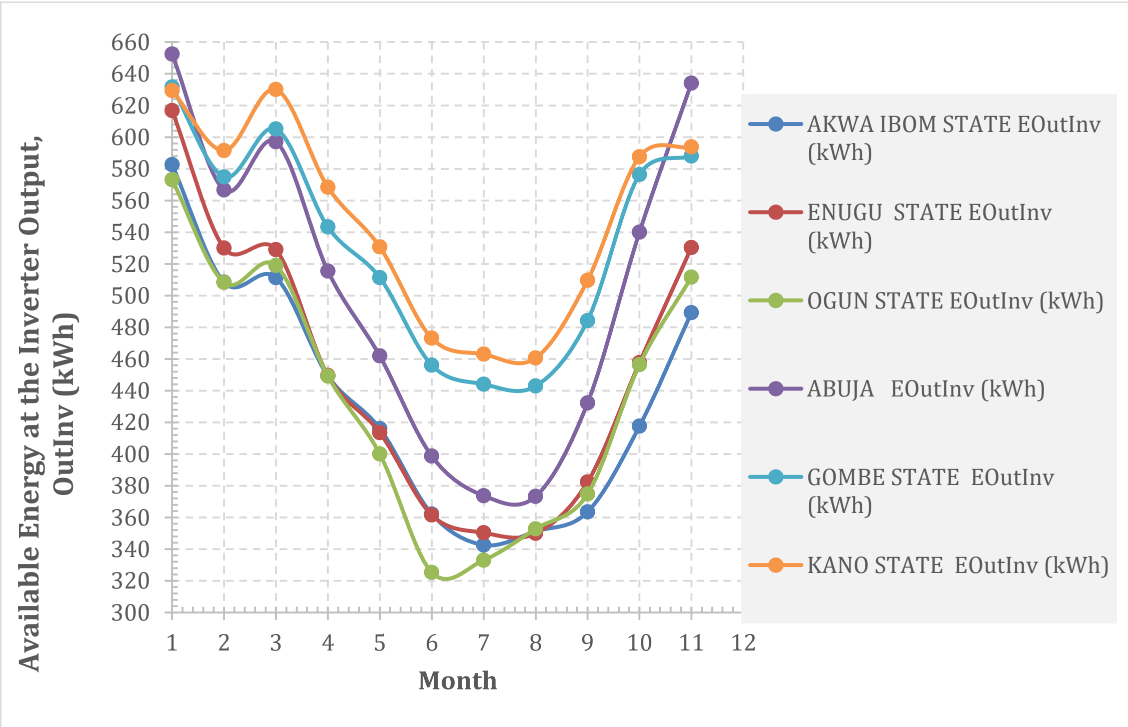
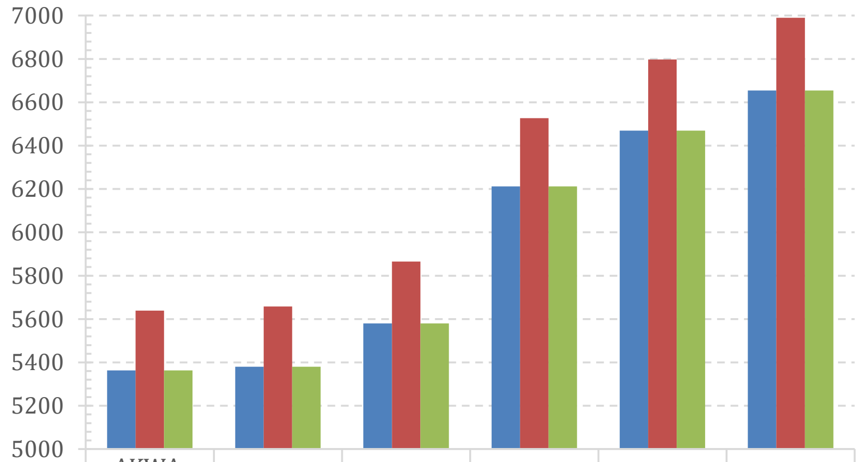
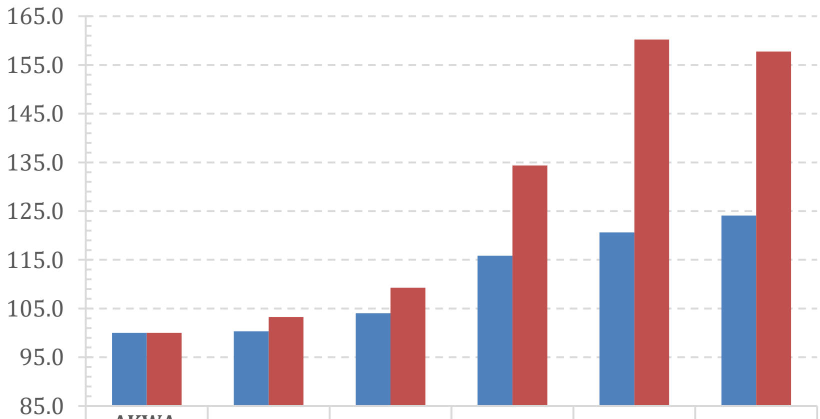


Figure 5 The plot of the monthly Available Energy at the Inverter Output, EOutInv (kWh) for of the Selected Six Locations



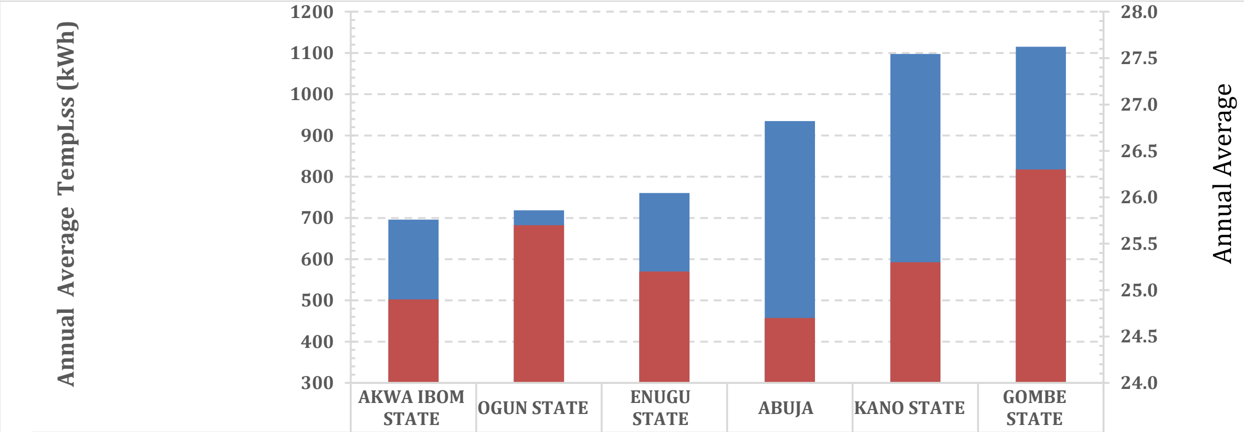
	AKWA IBOM STATE	OGUN STATE	ENUGU STATE	ABUJA	GOMBE STATE	KANO STATE
Annual EOutInv (kWh)	5363.1	5380.3	5579.8	6211.8	6469.4	6654.4
Annual Earray (kWh)	5638.8	5657.9	5865.5	6527.1	6797.8	6989.7
Annual E_Grid (kWh)	5363.1	5380.3	5579.8	6211.8	6469.4	6654.4

Figure 6 The plot of the Annual Available Energy at the Inverter Output, EOutInv (kWh) for of the Selected Six Locations



	AKWA IBOM STATE	OGUN STATE	ENUGU STATE	ABUJA	GOMBE STATE	KANO STATE
Normalized Annual Average EOutInv with respect to Akwa Ibom State (%)	**100.0**	**100.3**	**104.0**	**115.8**	**120.6**	**124.1**
Normalized Annual Average TempLss with respect to Akwa Ibom State (%)	**100.0**	**103.3**	**109.3**	**134.3**	**160.2**	**157.7**

Figure 7 The plot of the Normalized Annual Available Energy at the Inverter Output, EOutInv (kWh) for of the Selected Six Locations



	AKWA IBOM STATE	OGUN STATE	ENUGU STATE	ABUJA	KANO STATE	GOMBE STATE
Annual Average TempLss (kWh)	695.87	718.58	760.4	934.9	1097.7	1115
Annual Average Temperature (°C)	24.9	25.7	25.2	24.7	25.3	26.3

Figure 8 The bar chart of the Annual Average Loss Due to Temperature and the Annual Average Temperature for of the Selected Six Locations

4. Conclusion

The component sizing and energy yield of a rooftop PV power installation for a health center is presented. The PV energy yield is considered for six study sites selected from the six geopolitical regions in Nigeria. The basic analytical expressions for the determination of the rooftop energy yield of PV power system are presented along with the load demand of the health center. The global solar radiation data of the six selected study site used to simulate and obtain the energy yield and losses due to temperature. In all, the northern part of Nigeria gave higher annual energy yield than the southern study sites.

References

1. Hogan, D. R., Stevens, G. A., Hosseinpoor, A. R., & Boerma, T. (2018). Monitoring universal health coverage within the Sustainable Development Goals: development and baseline data for an index of essential health services. *The Lancet Global Health*, *6*(2), e152-e168.
2. World Health Organization. (2006). *The world health report 2006: working together for health*. World Health Organization.
3. Theobald, S., Brandes, N., Gyapong, M., El-Saharty, S., Proctor, E., Diaz, T., ... & Peters, D. H. (2018). Implementation research: new imperatives and opportunities in global health. *The Lancet*, *392*(10160), 2214-2228.
4. Stephan, A., Bieber, A., Hopper, L., Joyce, R., Irving, K., Zanetti, O., ... & Meyer, G. (2018). Barriers and facilitators to the access to and use of formal dementia care: findings of a focus group study with people with dementia, informal carers and health and social care professionals in eight European countries. *BMC geriatrics*, *18*(1), 1-16.
5. Long, P., Abrams, M., Milstein, A., Anderson, G., Apton, K. L., & Dahlberg, M. (2017). Effective care for high-need patients. *Washington, DC: National Academy of Medicine*.
6. Langarizadeh, M., Tabatabaei, M. S., Tavakol, K., Naghipour, M., Rostami, A., & Moghbeli, F. (2017). Telemental health care, an effective alternative to conventional mental care: a systematic review. *Acta Informatica Medica*, *25*(4), 240.
7. Myers, G. L., Miller, W. G., Coresh, J., Fleming, J., Greenberg, N., Greene, T., ... & National Kidney Disease Education Program Laboratory Working Group. (2006). Recommendations for improving serum creatinine measurement: a report from the Laboratory Working Group of the National Kidney Disease Education Program. *Clinical chemistry*, *52*(1), 5-18.
8. Liu, Q., Luo, D., Haase, J. E., Guo, Q., Wang, X. Q., Liu, S., ... & Yang, B. X. (2020). The experiences of health-care providers during the COVID-19 crisis in China: a qualitative study. *The Lancet Global Health*, *8*(6), e790-e798.
9. Hashemi, G., Kuper, H., & Wickenden, M. (2017). SDGs, Inclusive Health and the path to Universal Health Coverage. Disability and The Global South. *Disability and the Global South*, *4*(1), 1088-1111.
10. Yeravdekar, R., Yeravdekar, V. R., Tutakne, M. A., Bhatia, N. P., & Tambe, M. (2013). Strengthening of primary health care: Key to deliver inclusive health care. *Indian journal of public health*, *57*(2), 59.
11. Wang, H., & Ramana, G. N. V. (2014). Universal Health Coverage for Inclusive and Sustainable Development.

12. Martos, A. J., Wilson, P. A., & Meyer, I. H. (2017). Lesbian, gay, bisexual, and transgender (LGBT) health services in the United States: Origins, evolution, and contemporary landscape. *PloS one*, *12*(7), e0180544.
13. Gibbs, H., Like, R. C., & South-Paul, J. E. (2008). Building Diverse and Inclusive Communities in Academic Health Centers. In *Forum on Emerging Issues, Hedwig van Ameringen Executive Leadership in Academic Medicine (ELAM), Drexel University College of Medicine*.
14. Elusakin Julius, E., Olufemi, A. O., & Chuks, D. J. (2014). Challenges of sustaining off-grid power generation in Nigeria rural communities. *Afr. J. Eng. Res*, *2*, 51-57.
15. Ahlborg, H., & Hammar, L. (2014). Drivers and barriers to rural electrification in Tanzania and Mozambique–Grid-extension, off-grid, and renewable energy technologies. *Renewable Energy*, *61*, 117-124.
16. Olatomiwa, L. (2016). Optimal configuration assessments of hybrid renewable power supply for rural healthcare facilities. *Energy Reports*, *2*, 141-146.
17. Parshall, L., Pillai, D., Mohan, S., Sanoh, A., & Modi, V. (2009). National electricity planning in settings with low pre-existing grid coverage: Development of a spatial model and case study of Kenya. *Energy Policy*, *37*(6), 2395-2410.
18. Chaurey, A., Ranganathan, M., & Mohanty, P. (2004). Electricity access for geographically disadvantaged rural communities—technology and policy insights. *Energy policy*, *32*(15), 1693-1705.
19. Ahlborg, H., & Hammar, L. (2011, November). Drivers and Barriers to Rural Electrification in Tanzania and Mozambique-Grid Extension; Off-Grid and Renewable Energy Sources. In *World Renewable Energy Congress-Sweden; 8-13 May; 2011; Linköping; Sweden* (No. 057, pp. 2493-2500). Linköping University Electronic Press.
20. Kirubi, C., Jacobson, A., Kammen, D. M., & Mills, A. (2009). Community-based electric micro-grids can contribute to rural development: evidence from Kenya. *World development*, *37*(7), 1208-1221.
21. Safari, B. (2010). A review of energy in Rwanda. *Renewable and Sustainable Energy Reviews*, *14*(1), 524-529.
22. Palit, D., & Chaurey, A. (2011). Off-grid rural electrification experiences from South Asia: Status and best practices. *Energy for Sustainable Development*, *15*(3), 266-276.
23. Neto, M. B., Carvalho, P. C. M., Carioca, J. O. B., & Canafístula, F. J. F. (2010). Biogas/photovoltaic hybrid power system for decentralized energy supply of rural areas. *Energy Policy*, *38*(8), 4497-4506.
24. Ghenai, C., Merabet, A., Salameh, T., & Pigem, E. C. (2018). Grid-tied and stand-alone hybrid solar power system for desalination plant. *Desalination*, *435*, 172-180.
25. Chedid, R., & Rahman, S. (1997). Unit sizing and control of hybrid wind-solar power systems. *IEEE Transactions on energy conversion*, *12*(1), 79-85.
26. Ekanem, E. E., Fajola, A. O., Ogbimi, R., & Ogieva, J. I. (2017). Use of solar energy for the provision of cost effective and environmentally friendly power supply in health facilities in the developing world–Leasons from a community cottage hospital in southern Nigeria. *Int J Res Sci Mgt*, *4*, 32-7.
27. Adejuyigbe, S. B., Bolaji, B. O., Olanipekun, M. U., & Adu, M. R. (2013). Development of a solar photovoltaic power system to generate electricity for office appliances.
28. Alsharif, M. H., & Kim, J. (2016). Optimal solar power system for remote telecommunication base stations: A case study based on the characteristics of South Korea's solar radiation exposure. *Sustainability*, *8*(9), 942.
29. Totani, T., Kodama, T., Nagata, H., & Kudo, I. (2005). Thermal design of liquid droplet radiator for space solar-power system. *Journal of spacecraft and rockets*, *42*(3), 493-499.
30. Chen, K. K. (2014). Assessing the effects of customer innovativeness, environmental value and ecological lifestyles on residential solar power systems install intention. *Energy Policy*, *67*, 951-961.
31. Lauka, D., Pakere, I., & Blumberga, D. (2018). First solar power plant in Latvia. Analysis of operational data. *Energy Procedia*, *147*, 162-165.
32. Huld, T., Gottschalg, R., Beyer, H. G., & Topič, M. (2010). Mapping the performance of PV modules, effects of module type and data averaging. *Solar Energy*, *84*(2), 324-338.
33. Huld, T., Gottschalg, R., Beyer, H. G., & Topič, M. (2010). Mapping the performance of PV modules, effects of module type and data averaging. *Solar Energy*, *84*(2), 324-338.
34. Sayyah, A., Horenstein, M. N., & Mazumder, M. K. (2014). Energy yield loss caused by dust deposition on photovoltaic panels. *Solar Energy*, *107*, 576-604.
35. Pašičko, R., Branković, Č., & Šimić, Z. (2012). Assessment of climate change impacts on

energy generation from renewable sources in Croatia. *Renewable Energy*, *46*, 224-231.

36. Giraud, F., & Salameh, Z. M. (2001). Steady-state performance of a grid-connected rooftop hybrid wind-photovoltaic power system with battery storage. *IEEE transactions on energy conversion*, *16*(1), 1-7.
37. Diaf, S., Notton, G., Belhamel, M., Haddadi, M., & Louche, A. (2008). Design and techno-economical optimization for hybrid PV/wind system under various meteorological conditions. *Applied Energy*, *85*(10), 968-987.
38. Ismail, M. S., Moghavvemi, M., & Mahlia, T. M. I. (2013). Techno-economic analysis of an optimized photovoltaic and diesel generator hybrid power system for remote houses in a tropical climate. *Energy conversion and management*, *69*, 163-173.
39. Usman, R., & BarivureSigalo, M. (2917) Analysis and Simulation of Electrical Load in aHospital Using Hybrid (Diesel/Solar) System as aBack Up. *Journal of Electronics and Communication Engineering Research Volume 3 ~ Issue 9 (2017) pp: 01-14*