Simulated Life Cycle Cost And Carbon Balance Analysis Of Grid-Connected Solar Photovoltaic Power System For A Hospital In Abuja, Nigeria

Okpura I. Nseobong
Department of Electrical/Electronic and Computer Engineering,
University of Uyo, AkwaIbom, Nigeria

Isaiah U. Imoh
Department of Electrical/Electronic and Computer Engineering,
University of Uyo, AkwaIbom, Nigeria

Nsikak Etim Udoh
Department of Electrical/Electronic and Computer Engineering,
University of Uyo, AkwaIbom, Nigeria

Abstract— **In this paper, simulated life cycle cost and carbon balance analysis of grid-connected solar photovoltaic (PV) power system is presented. The PV power was for a hospital that is located in Abuja, Nigeria with latitude of 9.01 and longitude of 7.29, as well as annual mean temperature of 24.7 °C and mean monthly global irradiance of 1988.9 kWh/m2.month. Also, the daily energy demand, of the hospital is 11.5 kWh/day. The life cycle cost analysis and the carbon balance analysis were conducted using PVSyst software. The results showed that the PV system performance ratio is 0.787 (that is 78.7%), total PV array nominal power is 8.93 kWp , annual energy yield is 14.42 MWh/year and solar fraction of 45.5%. The economic evaluation simulation results show that the gross investment cost (without taxes) of the PV power system is 33,424,990 Naira, the net investment cost (all taxes included) of the PV power system is 40,778,488 Naira, and the unit cost of the produced energy is 263 Naira/kWh.The carbon balance analysis simulation results show that the total savings or reduction in CO2 emissions is 112.469 tCO2, the annual savings or reduction in CO2 emissions is 4.499 tCO2/year, the savings or reduction in CO2 emissions per installed kWp power is 12.594 tCO2.kWp and the yearly savings of CO2 emissions per installed poweris0.504 tCO2/kWp/year.**

Keywords— Life Cycle Cost Analysis, Grid-Connected, Carbon Balance Analysis, Solar Photovoltaic Power System, Economic Evaluation

1. Introduction

In recent years, the demand for electric energy is increasing [1,2,3,4,5,6,7,8,9,10] as more people are drawn towards adoption of electric-powered technologies like cell phone, mobile devices, web-based solutions, Internet of Things, as well as wireless sensors, eLearning solution, and many more [11,12,13, 14,15,16, 17,18,19, 20,21,22, 23,24,25, 26,27,28, 29,30, 31, 32]. Many of these technologies are electronic and hence can be powered with batteries or relatively moderate capacity power supply systems. Moreover, in view of the lingering power shortage from the grid in many developing countries, alternative power supply options have been employed by many people to power their homes and office [33,34, 35,36, 37,38, 39,40, 41,42, 43,44, 45,46, 47,48, 49,50].

Notably, solar photovoltaic (PV) power supply has dominated the alternative green energy solution for the developing countries [51, 52, 53, 54, 55, 56, 57, 58, 59, 60, 61,62, 63, 64]. This has been attributed to the steady drop in the cost of the PV power components which makes it more affordable [65,66,67,68]. Also, the advancements in the PV and battery technologies have also improved on the efficiency of the PV power system. In addition, solar radiation is very much abundant in most of the developing countries in Africa [69,70,71,72,73].

In any case, despite the expected benefits, the solar PV power system is still more expensive to set up than the diesel generator counterpart. Particularly, the initial cost and the unit cost of energy produced by the system are usually required for the solar PV power system adoption decision making. Such costs components are provided in the life cycle cost analysis [74,75,76].

Moreover, nowadays, environmental impact assessment is required for power systems [77,78,79,80]. This is particularly importance for power system for such places like hospital and other health facilities. As such, in this paper, a simulated life cycle cost analysis and the carbon balance analysis of a grid-connected solar PV power system is presented for a case study hospital located in Abuja, the capital territory of Nigeria. The simulation was conducted with PVsyst software based on the daily energy demand of the case study hospital, the meteorological data of the hospital site, and the prevailing cost dataset for the various PV power system components.

2. Methodology

2.1 Power Output Of PV Array

The required PV array total power, P_{PvA} to deliver the daily energy demand, E_L is computed as follows [81,82,83];

$$P_{PvA} = \frac{E_L}{(PSI * \eta_{BO} * K_{loss} * G_d)} \quad (1)$$

Where PSI represents the peak solar intensity (1000 W/m^2), G_d represents the average solar radiation data at the installation site (in KWh/m^2/day), KLoss represents some loss factors that includes circuit losses, module temperature losses, dust, etc and η_{BO} represents the derating factors of the balance of system which is given as [81];

$$\eta_{BO} = (\eta_{inverterlosses})(\eta_{wiringlosses}) \quad (2)$$

Where $\eta_{inverterlosses}$, $\eta_{wiringlosses}$ and KLoss typical values are 15%, 10% and 90% respectively [83,84]. The daily energy demand, E_L is determined from the daily load demand profile of the hospital, which is taken from [81] and presented in Table 1. According to the data in Table 1, the daily energy demand, E_L is 11.5 kWh/day.

Table 1 The daily load demand profile of the case study hospital

	A	B	C=A(B)	D	E = C(D)	F=E/1000
Device Description	**Quantity**	**Power (Watts)**	**Total Watts**	**On-Time (watt hours/day)**	**Wattage (hours/ day)**	**kWh/day**
Vaccine Refrigerator/Freezer	1	60	60	6.0	360	3.6
Small Refrigerator (non-medical use)	1	300	300	5.0	1,500	1.5
Centrifuge	1	575	575	1.5	862.5	0.8625
Hematology Mixer	1	28	28	1.5	42	0.042
Microscope	2	15	30	3.0	90	0.09
Lighting	5	60	300	8.0	2400	2.4
Incubator	1	400	400	10	4,000	4.0
Water Bath	1	1,000	1,000	1.0	1,000	1.0
Communication via VHF Radio	1					
Stand-by		2	2	15	30	0.003
Transmitting		30	30	3	900	0.9
Total			2500		11500	11.500

2.2 Life cycle cost Analysis of the Grid-Connected PV Power System

The PV array total cost, C_{PvA} is expressed in terms of UC_{PvAPw} (the PV array cost per watt), N_{pvT} (the total number of PV modules in the array) and P_{Pv} (the rated power per PV module) as follows;

$$C_{PvA} = N_{pvT}(P_{Pv})(UC_{pvwp}) \quad (1)$$

The cost of installation (C_{inst}) is estimated as 12% of the cost of the PV array, hence,

$$C_{inst} = 0.12(C_{PvA}) \quad (2)$$

The charger controller cost (C_{chc}) is expressed in terms of per ampere unit cost of the charger controller (UC_{chc}) and total charger controller ampere rating (A_{chc}) as follows;

$$C_{chc} = A_{chc}(UC_{chc}) \quad (3)$$

The inverter cost (C_{Inv}) is expressed in terms of per watt unit cost of the inverter (UC_{Inv})and total inverter power rating in watt (P_{IvvWR}) as follows;

$$C_{Inv} = P_{IvvWR}(UC_{Inv}) \quad (4)$$

The battery bank initial cost (CC_{bat})is expressed in terms of Bat_{Ah} (the ampere-hour rating of the battery) and UC_{bat} (the battery unit cost per ampere-hour rating) as follows;

$$CC_{bat} = Bat_{Ah}(UC_{bat}) \quad (5)$$

The system life cycle time is assumed to be 25 years, the battery useful life time is 5 years, then the battery discount rate, $CC_{bat(n)}$ is computed as;

$$CC_{Bt(n)} = C_{bat}\left(\frac{1+i}{1+d}\right)^n \quad (7)$$

Where i is the inflation rate and d is the discount rate and n = 5, 10, 15, and 20. The initial annual cost of operation and maintenance ($C_{M\&O}$) is assumed to be 2.6 % of the cost of the PV array, then,

$$C_{M\&O} = 0.026(C_{PvA}) \quad (8)$$

The annual operation and maintenance cost ($C_{TM\&O}$) for the entire system lifetime of N years is computed as;

$$C_{TM\&O} = C_{M\&O}\left(\frac{1+i}{1+d}\right)\left(\frac{1-\left(\frac{1+i}{1+d}\right)^N}{1-\left(\frac{1+i}{1+d}\right)}\right) \quad (9)$$

The solar life cycle cost (LCC) is then computed as;

$$LCC = C_{PvA} + C_{chc} + CC_{Bt(5)} + CC_{Bt(10)} + CC_{Bt(15)} + CC_{Bt(20)} + C_{Inv} + C_{inst} + C_{TM\&O} \quad (10)$$

The annual life cycle cost (ALCC) is computed as;

$$ALCC = LCC\left(\frac{1-\left(\frac{1+i}{1+d}\right)^{N}}{1-\left(\frac{1+i}{1+d}\right)}\right) \quad (11)$$

The unit cost (UC) of the generated electrical energy expressed in cost per kWh is give in terms of ALCC and E_l (which is the daily electric energy demand) as follows;

$$UC = \frac{ALCC}{365(E_l)} \quad (12)$$

2.3 The Carbon Balance Analysis of the Grid-Connected PV Power System

Carbon balance is the reduction or the savings in the amount of CO2 emissions due to the PV system installation.

The carbon balance (t_{CO2e}) computation in PVSyst simulation software is conducted using the following parameters;

• The energy yield of the system (EGrid)

• The lifetime of the system (N =25 years)

• The Life Cycle *Energy* (*LCE*) of grid generated electricity (LCEGrid)

• The Life Cycle *Energy* (*LCE*) of PV system generated electricity (LCEPVSystem)

The carbon balance analysis tool in PVSyst gives four (4) values, namely;

i. The total savings or reduction in CO2 emissions (t_{CO2e}) expressed in tons of CO2 over the PV installation expected lifetime

ii. The annual savings or reduction in CO2 emissions (ty_{CO2e}) expressed in tCO2/year.

$$ty_{CO2e} = \frac{t_{CO2e}}{N} \quad (13)$$

iii. The savings or reduction in CO2 emissions per installed kWp power,($tPWp_{CO2e}$) expressed in tCO2/kWp

$$tPWp_{CO2e} = \frac{tPWp_{CO2e}}{\text{PnomTotal}} \quad (14)$$

Where PnomTotal is the array global power at STC , as presented in PVSyst simulation results.

iv. The yearly savings of CO2 emissions per installed power, ($tPWpPY_{CO2e}$) expressed in tCO2/kWp/year

$$tPWpPY_{CO2e} = \frac{tPWp_{CO2e}}{N} \quad (15)$$

The annual result values are average obtained over the entire PV system lifetime while taking into consideration the annual degradation, which is set at 1 %.

2.3 The simulation setup and data

The simulation of the grid-connected PV power system was conducted using PYSyst software. Specifically, the focus was on the life cycle cost analysis and the carbon balance analysis. The case study hospital is located in Abuja , Nigeria with latitude of 9.01 and longitude of 7.29, as well as annual mean monthly temperature of 24.7 °C and annual mean monthly global irradiance of 1988.9 kWh/m2.month. Also, the daily energy demand, E_L of the hospital (as shown in Table 1) is 11.5 kWh/day. The schematic diagram of the grid-connected PV power system is shown in Figure 1 while the PV array and inverter confirmations for the grid-connected PV power system are shown in Figure 2. Again, the screenshot of the PVSyst economic analysis input dialogue and the dataset used for the grid-connected PV power system shown in Figure 3.

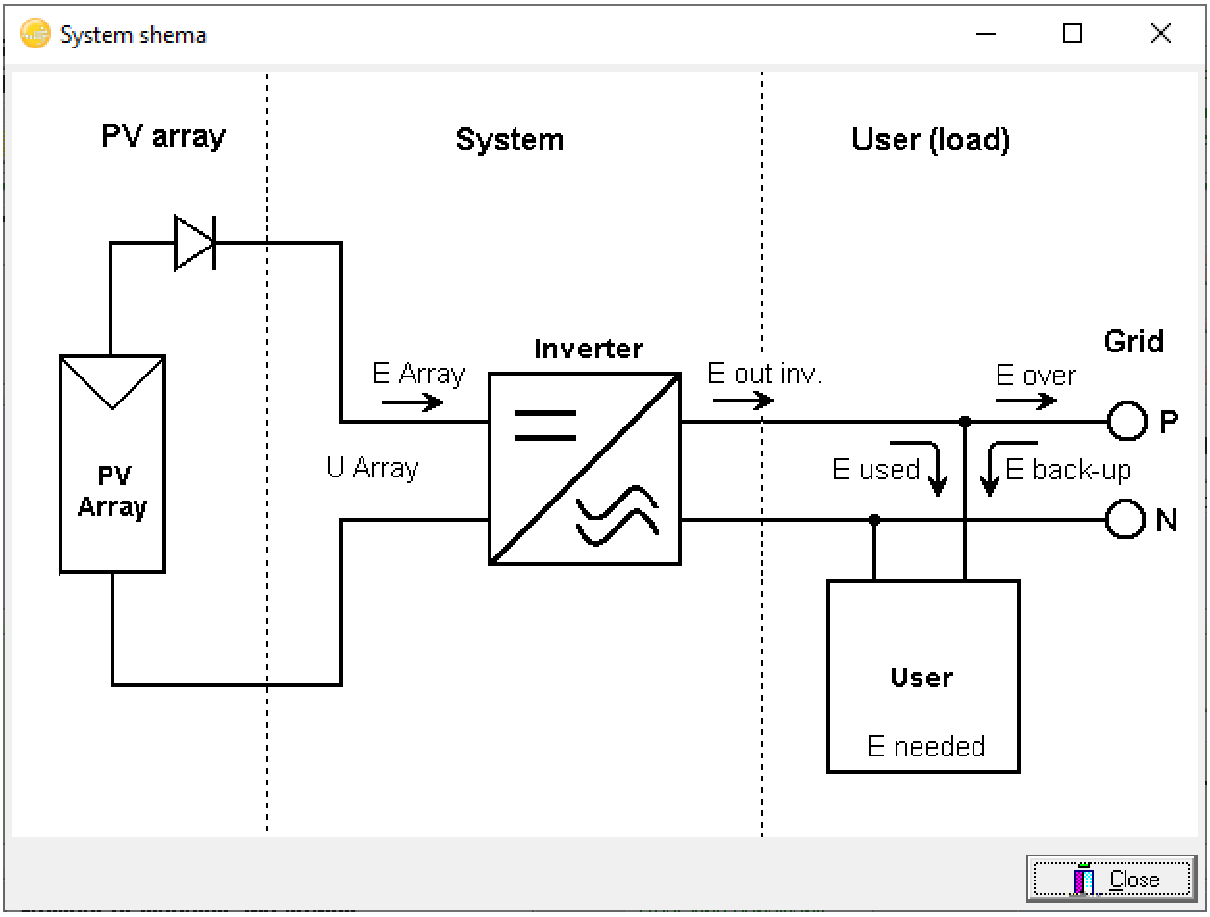


Figure 1 The schematic diagram of the grid-connected PV power system

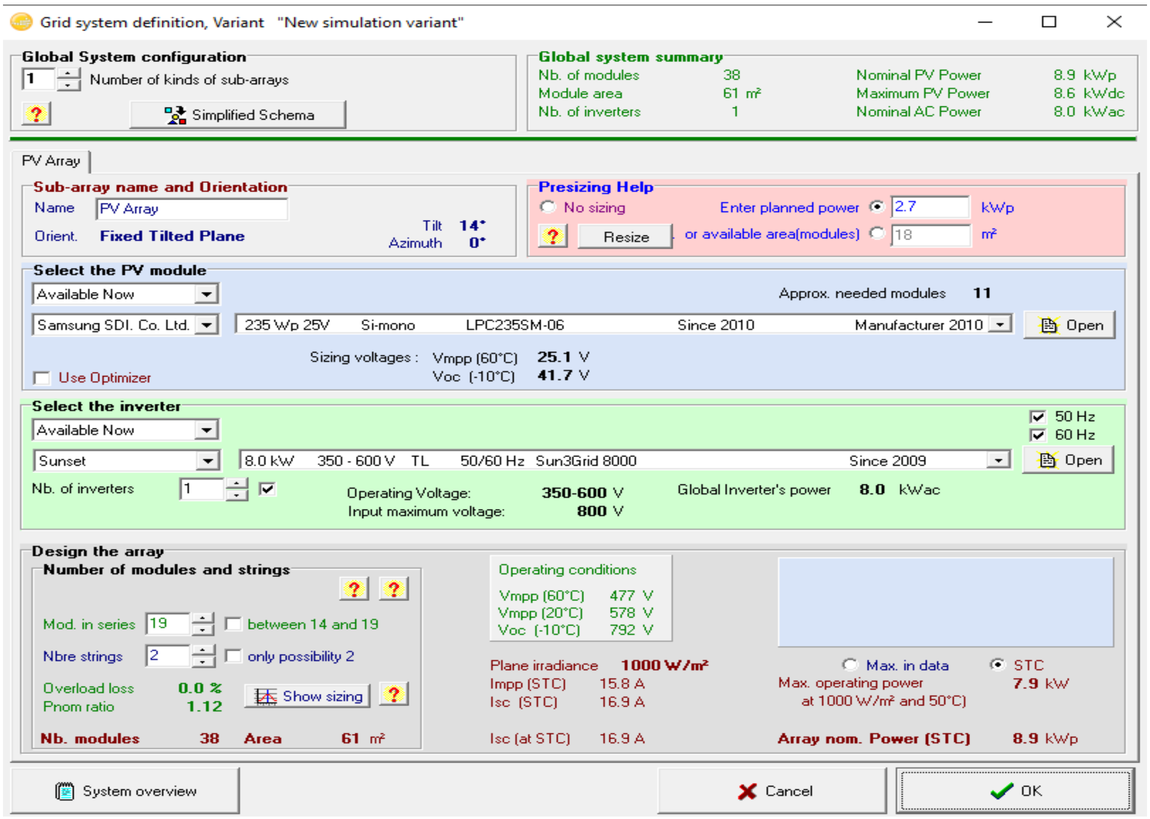


Figure 2 The PV array and inverter confirmations for the grid-connected PV power system

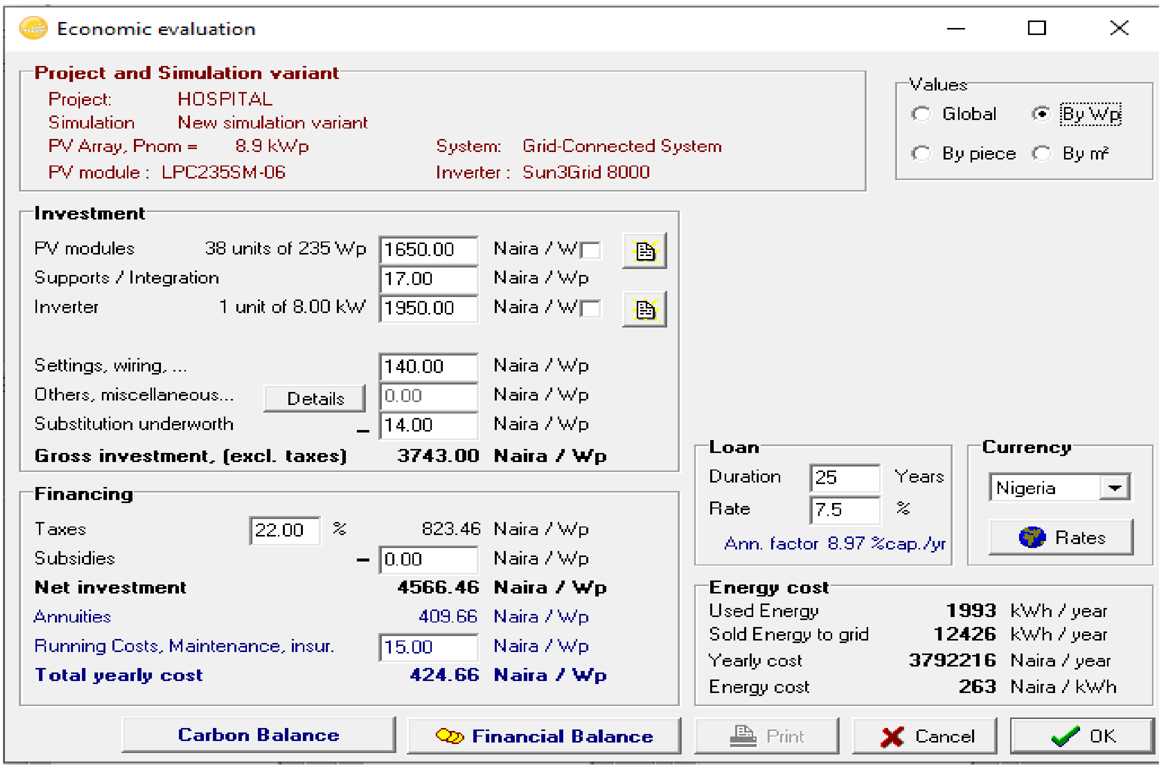


Figure 3 The screenshot of the PVSyst economic analysis input dialogue and the dataset used for the grid-connected PV power system

3. Results and Discussion

With the daily energy demand (presented in Table 1), the PVSyst was used to select the specific PV module and inverter for the solar power system, as well as the required number of PV modules in the PV array, as shown in Figure 2. The screenshot of the results showing the PV system performance ratio of 0.787 (that is 78.7%), total PV array nominal power of 8.93 kWp and annual energy yield of 14.42 MWh/year is presented in Figure 4. The results in Figure 4 also shows the unit cost of energy as 263 Naira/kWh and solar fraction of 45.5%.

The results on the energy use and the user's energy need are shown in Table 2 where is observed that the annual available energy is 14419 kWh, the annual energy demand of the user is 4380.0 kWh, the annual energy supplied to the load from the PV system is 1992.9 kWh and the annual energy injected into the grid is 12426 kWh. Again, the solar fraction is 0.455 (that is 45.5%).

The screenshot of PVSyst economic evaluation simulation results is shown in Figure 5. The economic evaluation results (in Figure 5) show that the gross investment cost (without taxes) of the PV power system is 33,424,990 Naira, the net investment cost (all taxes included) of the PV power system is 40,778,488 Naira, and the unit cost of the produced energy is 263 Naira/kWh.

Grid-Connected System: Main results

Project : **HOSPITAL**

Simulation variant : **New simulation variant**

Main system parameters	System type	**Grid-Connected**		
PV Field Orientation	tilt	14°	azimuth	0°
PV modules	Model	LPC235SM-06	Pnom	235 Wp
PV Array	Nb. of modules	38	Pnom total	**8.93 kWp**
Inverter	Model	Sun3Grid 8000	Pnom	8.00 kW ac
User's needs	daily profile	Constant over the year	Global	4380 kWh/year

Main simulation results				
System Production	**Produced Energy**	**14.42 MWh/year**	Specific prod.	1615 kWh/kWp/year
	Performance Ratio PR	78.68 %	Solar Fraction SF	45.50 %
Investment	Global incl. taxes	40778488 Naira	Specific	4566 Naira/Wp
Yearly cost	Annuities (Loan 7.5%, 25 years)	3658266 Naira/yr	Running Costs	133950 Naira/yr
Energy cost		**263 Naira/kWh**		

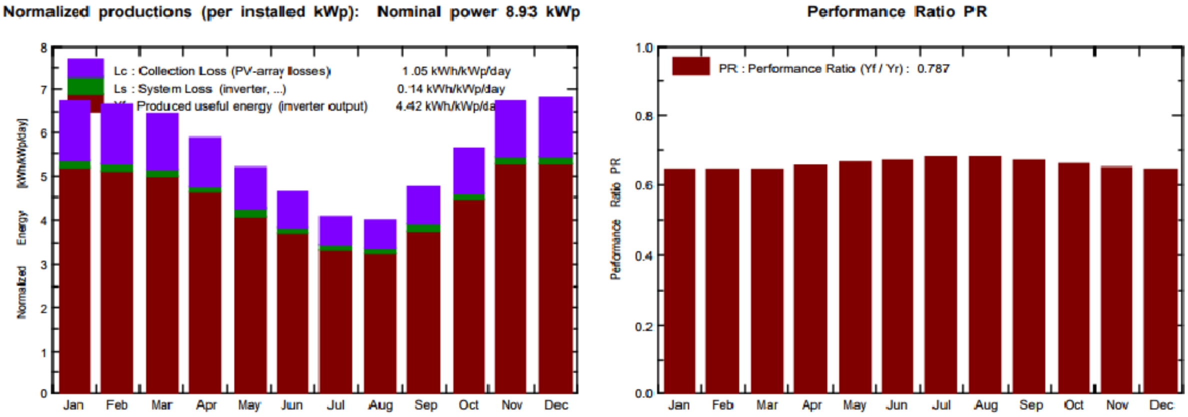


Figure 4 The screenshot of PVSyst simulation result showing the main system parameters, man simulation results, performance ratio and the normalized production of the grid-connected PV power system

Table 2 The results on the energy use and the user's energy need

Energy use and User's needs

	E Avail kWh	E Load kWh	E User kWh	E_Grid kWh	SolFrac
January	1440	372.0	170.5	1269	0.458
February	1277	336.0	154.5	1123	0.460
March	1384	372.0	170.5	1213	0.458
April	1235	360.0	164.7	1071	0.458
May	1139	372.0	167.9	971	0.451
June	996	360.0	163.4	833	0.454
July	925	372.0	169.3	756	0.455
August	904	372.0	167.8	736	0.451
September	1017	360.0	162.4	855	0.451
October	1234	372.0	166.5	1067	0.448
November	1407	360.0	165.0	1242	0.458
December	1460	372.0	170.5	1289	0.458
Year	14419	4380.0	1992.9	12426	0.455

PVSYST V6.70		12/11/22	Page 5/6

Grid-Connected System: Economic evaluation

Project : **HOSPITAL**
Simulation variant : **New simulation variant**

Main system parameters	System type	**Grid-Connected**		
PV Field Orientation	tilt	14°	azimuth	0°
PV modules	Model	LPC235SM-06	Pnom	235 Wp
PV Array	Nb. of modules	38	Pnom total	**8.93 kWp**
Inverter	Model	Sun3Grid 8000	Pnom	8.00 kW ac
User's needs	daily profile	Constant over the year	Global	4380 kWh/year

Investment

PV modules (Pnom = 235 Wp)	38 units	387750 Naira / unit	14734500 Naira
Supports / Integration		3995 Naira / module	151810 Naira
Inverter (Pnom = 8.0 kW ac)	1 units	17413500 Naira / unit	17413500 Naira
Settings, wiring, ...			1250200 Naira
Substitution underworth			-125020 Naira
Gross investment (without taxes)			**33424990 Naira**

Financing

Gross investment (without taxes)		33424990 Naira
Taxes on investment (VAT)	Rate 22.0 %	7353498 Naira
Gross investment (including VAT)		40778488 Naira
Subsidies		0 Naira
Net investment (all taxes included)		**40778488 Naira**
Annuities	(Loan 7.5 % over 25 years)	3658266 Naira/year
Annual running costs: maintenance, insurances ...		133950 Naira/year
Total yearly cost		**3792216 Naira/year**

Energy cost

Used Energy	1993 kWh / year
Energy sold to the grid	12426 kWh / year
Cost of produced energy	263 Naira / kWh

Figure 5 The screenshot of PVSyst economic evaluation simulation results

The screenshot of PVSyst carbon balance analysis simulation results is shown in Figure 6. The carbon balance analysis results (in Figure 5) show that the total savings or reduction in CO2 emissions (t_{CO2e}) is 112.469 tCO2, the annual savings or reduction in CO2 emissions (ty_{CO2e}) is 4.499 tCO2/year, the savings or reduction in CO2 emissions per installed kWp power,($tPWp_{CO2e}$) is 12.594 tCO2.kWp and the yearly savings of CO2 emissions per installed power, ($tPWpPY_{CO2e}$) is0.504 tCO2/kWp/year.

The screenshot of PVSyst simulation results showing the produced and the replaced carbon emissions is presented in Figure 7. Again, Figure 7 shows that the carbon balance is 112.469 tCO2,

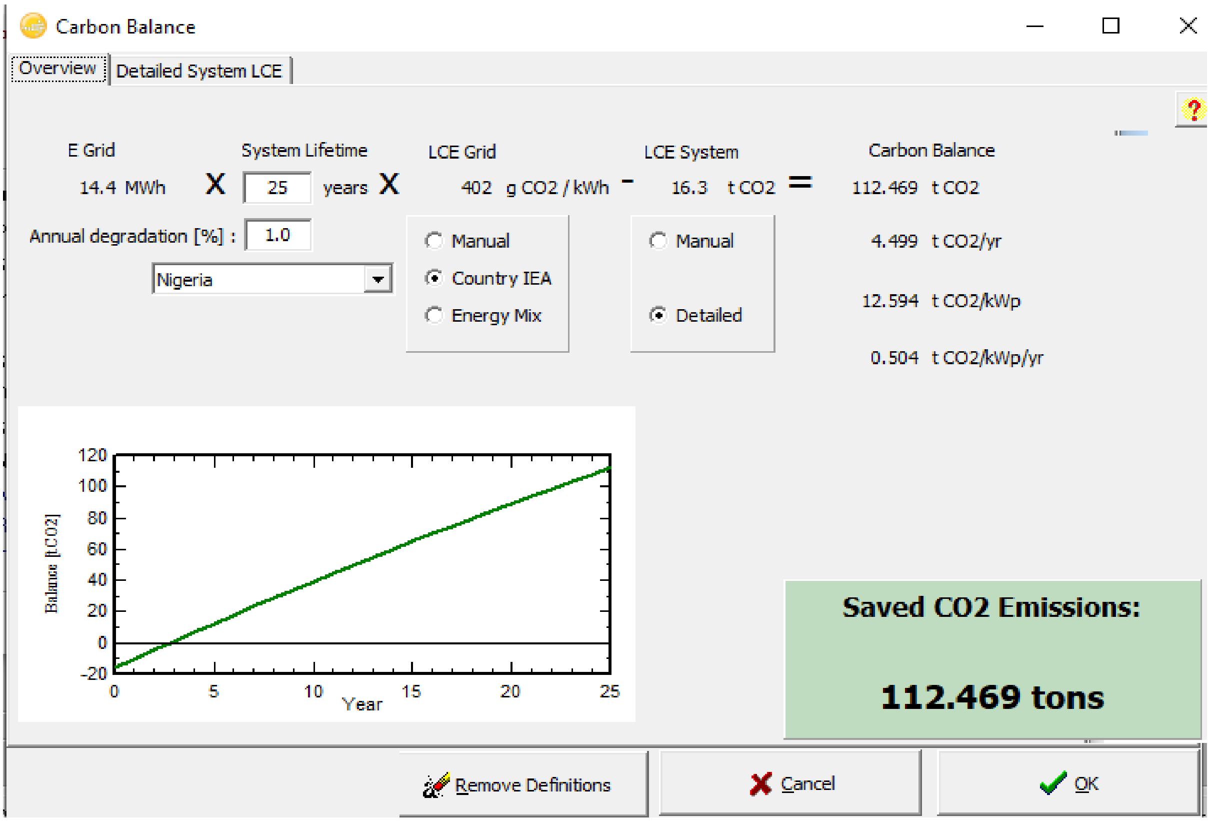
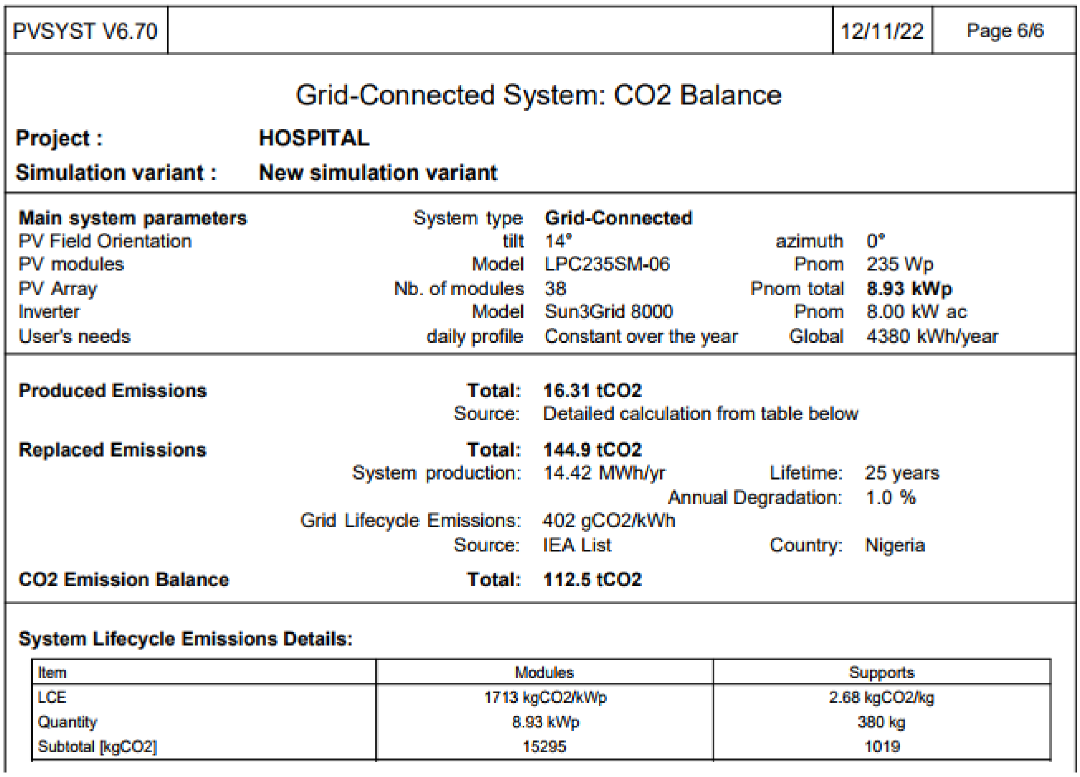


Figure 6 The screenshot of PVSyst carbon balance analysis simulation results



PVSYST V6.70		12/11/22	Page 6/6

Grid-Connected System: CO2 Balance

Project : **HOSPITAL**

Simulation variant : **New simulation variant**

Main system parameters	System type	**Grid-Connected**		
PV Field Orientation	tilt	14°	azimuth	0°
PV modules	Model	LPC235SM-06	Pnom	235 Wp
PV Array	Nb. of modules	38	Pnom total	**8.93 kWp**
Inverter	Model	Sun3Grid 8000	Pnom	8.00 kW ac
User's needs	daily profile	Constant over the year	Global	4380 kWh/year

Produced Emissions	**Total:**	**16.31 tCO2**		
	Source:	Detailed calculation from table below		
Replaced Emissions	**Total:**	**144.9 tCO2**		
	System production:	14.42 MWh/yr	Lifetime:	25 years
			Annual Degradation:	1.0 %
	Grid Lifecycle Emissions:	402 gCO2/kWh		
	Source:	IEA List	Country:	Nigeria
CO2 Emission Balance	**Total:**	**112.5 tCO2**		

System Lifecycle Emissions Details:

Item	Modules	Supports
LCE	1713 kgCO2/kWp	2.68 kgCO2/kg
Quantity	8.93 kWp	380 kg
Subtotal [kgCO2]	15295	1019

Figure 7 The screenshot of PVSyst simulation results showing the produced and the replaced carbon emissions

4. Conclusion

The life cycle cost analysis and the carbon balance analysis of a grid-connected PV power system is presented. Analysis is conducted using PVSyst software. The daily energy demand of a case study hospital was used for the sizing of the PV system components, including the PV array and the inverter. The life cycle cost analysis are based on the simulated energy yield of the PV system and some cost input dataset of the PV system components, their installation cost and maintenance cost.
Furthermore, the carbon balance analysis was also simulated using the PVSyst. The simulation results show the produced and the replaced carbon emissions along with the carbon balance figure for the PV system.

References

1. Albadi, M. H., & El-Saadany, E. F. (2008). A summary of demand response in electricity markets. *Electric power systems research*, *78*(11), 1989-1996.
2. Uko, Sampson Sampson, Ozuomba Simeon, and Ikpe Joseph Daniel (2019). Adaptive neuro-fuzzy inference system (ANFIS) model for forecasting and predicting industrial electricity consumption in Nigeria. *Advances in Energy and Power,* 6(3), 23-36.
3. Lund, H., & Mathiesen, B. V. (2009). Energy system analysis of 100% renewable energy systems—The case of Denmark in years 2030 and 2050. *Energy*, *34*(5), 524-531.
4. Effiong, Clement, Simeon Ozuomba, and Udeme John Edet (2016). Long-Term Peak Load Estimate and Forecast: A Case Study of Uyo Transmission Substation, Akwa Ibom State, Nigeria. *Science Journal of Energy Engineering 4(6), 85-89.*
5. Richardson, I., Thomson, M., Infield, D., & Clifford, C. (2010). Domestic electricity use: A high-resolution energy demand model. *Energy and buildings*, *42*(10), 1878-1887.
6. Stephen, Bliss Utibe-Abasi, Ozuomba Simeon, and Sam Bassey Asuquo. (2018) "Statistical Modeling Of The Yearly Residential Energy Demand In Nigeria." *Journal of Multidisciplinary Engineering Science Studies* (JMESS) Vol. 4 Issue 6, June – 2018
7. Suganthi, L., & Samuel, A. A. (2012). Energy models for demand forecasting—A review. *Renewable and sustainable energy reviews*, *16*(2), 1223-1240.
8. Effiong, Clement, Ozuomba Simeon, and Fina Otosi Faithpraise (2020). "Modelling And Forecasting Peak Load Demand In Uyo Metropolis Using Artificial Neural Network Technique." *Journal of Multidisciplinary Engineering Science and Technology (JMEST) Vol. 7 Issue 3, March – 2020*
9. Parag, Y., & Sovacool, B. K. (2016). Electricity market design for the prosumer era. *Nature energy*, *1*(4), 1-6.
10. Kalu, C., Ezenugu, I. A. & Ozuomba, Simeon. (2015). Development of matlab-based software for peak load estimation and forecasting: a case study of faculty of engineering, Imo State University Owerri, Imo state, Nigeria. *European Journal of Engineering and Technology, 3 (8)*, 20-29.
11. Perwej, Y., AbouGhaly, M. A., Kerim, B., & Harb, H. A. M. (2019). An extended review on internet of things (iot) and its promising applications. *Communications on Applied Electronics (CAE), ISSN*, 2394-4714.
12. Chikezie, Aneke, Ezenkwu Chinedu Pascal, and Ozuomba Simeon. (2014). "Design and Implementation Of A Microcontroller-Based Keycard." *International Journal of Computational Engineering Research (IJCER) Vol, 04 Issue, 5 May – 2014*
13. Ogbonna Chima Otumdi , Ozuomba Simeon, Philip M. Asuquo (2020) Device Hardware Capacity And Rssi-Based Self Organizing Map Clustering Of 928 Mhz Lorawan Nodes Located In Flat Terrain With Light Tree Densities *Science and Technology Publishing (SCI & TECH) Vol. 4 Issue 9, September - 2020*
14. Simeon, Ozuomba. (2018) "Sliding Mode Control Synthesis For Autonomous Underwater Vehicles" *Science and Technology Publishing (SCI & TECH*
15. Samuel, Wali, Simeon Ozuomba, and Philip M. Asuquo (2019). EVALUATION OF WIRELESS SENSOR NETWORK CLUSTER HEAD SELECTION FOR DIFFERENT PROPAGATION ENVIRONMENTS BASED ON LEE PATH LOSS MODEL AND K-MEANS ALGORITHM. EVALUATION, 3(11). *Science and Technology Publishing (SCI & TECH) Vol. 3 Issue 11, November - 2019*
16. Otumdi, Ogbonna Chima, Kalu Constance, and Ozuomba Simeon (2018). "Design of the Microcontroller Based Fish Dryer." *Journal of Multidisciplinary Engineering Science Studies (JMESS) Vol. 4 Issue 11, November - 201*
17. Ozuomba, Simeon, and Etinamabasiyaka Edet Ekott. (2020). "Design And Implementation Of Microcontroller And Internet Of Things-Based Device Circuit And Programs For Revenue Collection From Commercial Tricycle Operators." *Science and Technology Publishing* (SCI & TECH) Vol. 4 Issue 8, August – 2020
18. Idio, Uduak, Constance Kalu, Akaninyene Obot, and Simeon Ozuomba. (2013) "An improved scheme for minimizing handoff failure due to poor signal quality." In *2013 IEEE International Conference on Emerging & Sustainable Technologies for Power & ICT in a Developing Society (NIGERCON)*, pp. 38-43. IEEE, 2013.
19. Ozuomba, Simeon, Ekaette Ifiok Archibong, and Etinamabasiyaka Edet Ekott (2020). Development Of Microcontroller-Based Tricycle Tracking Using Gps And Gsm Modules. *Journal of Multidisciplinary Engineering Science and*

Technology (JMEST) Vol. 7 Issue 1, January - 2020

20. Anietie Bassey, Simeon Ozuomba & Kufre Udofia (2015). An Effective Adaptive Media Play-out Algorithm For Real-time Video Streaming Over Packet Networks. European. *Journal of Basic and Applied Sciences Vol, 2(4).*
21. Kalu, C., Ozuomba, Simeon. & Udofia, K. (2015). Web-based map mashup application for participatory wireless network signal strength mapping and customer support services. *European Journal of Engineering and Technology, 3 (8),* 30-43.
22. Johnson, Enyenihi Henry, Simeon Ozuomba, and Ifiok Okon Asuquo. (2019). Determination of Wireless Communication Links Optimal Transmission Range Using Improved Bisection Algorithm. *Universal Journal of Communications and Network, 7(1), 9-20.*
23. Njoku, Felix A., Ozuomba Simeon, and Fina Otosi Faithpraise (2019). Development Of Fuzzy Inference System (FIS) For Detection Of Outliers In Data Streams Of Wireless Sensor Networks. *International Multilingual Journal of Science and Technology (IMJST) Vol. 4 Issue 10, October - 2019*
24. Samuel, W., Ozuomba, Simeon, & Constance, K. (2019). SELF-ORGANIZING MAP (SOM) CLUSTERING OF 868 MHZ WIRELESS SENSOR NETWORK NODES BASED ON EGLI PATHLOSS MODEL COMPUTED RECEIVED SIGNAL STRENGTH. *Journal of Multidisciplinary Engineering Science and Technology (JMEST) Vol. 6 Issue 12, December - 2019*
25. Simeon, Ozuomba. (2020). "APPLICATION OF KMEANS CLUSTERING ALGORITHM FOR SELECTION OF RELAY NODES IN WIRELESS SENSOR NETWORK." *International Multilingual Journal of Science and Technology (IMJST) Vol. 5 Issue 6, June - 2020*
26. Maduka, N. C., Simeon Ozuomba, and E. E. Ekott. . (2020) "Internet of Things-Based Revenue Collection System for Tricycle Vehicle Operators." *2020 International Conference in Mathematics, Computer Engineering and Computer Science (ICMCECS).* IEEE, 2020.
27. Thompson, E., Simeon, O., & Olusakin, A. (2020). A survey of electronic heartbeat electronics body temperature and blood pressure monitoring system. Journal of Multidisciplinary Engineering Science Studies (JMESS) Vol. 6 Issue 8, August – 2020
28. Simeon, Ozuomba. (2020). "Analysis Of Effective Transmission Range Based On Hata Model For Wireless Sensor Networks In The C-Band And Ku-Band." *Journal of Multidisciplinary Engineering Science and Technology (JMEST) Vol. 7 Issue 12, December - 2020*
29. Ogbonna Chima Otumdi , Ozuomba Simeon, Kalu Constance (2020). Clustering Of 2100 Mhz Cellular Network Devices With Som Algorithm Using Device Hardware Capacity And Rssi Parameters *Science and Technology Publishing (SCI & TECH) Vol. 4 Issue 2, February – 2020*
30. Atakpo, F. K., Simeon, O., & Utibe-Abasi, S. B. (2021) A COMPARATIVE ANALYSIS OF SELFORGANIZING MAP AND K-MEANS MODELS FOR SELECTION OF CLUSTER HEADS IN OUT-OF-BAND DEVICE-TO-DEVICE COMMUNICATION. *Journal of Multidisciplinary Engineering Science Studies (JMESS).*
31. Uduak Idio Akpan, Constance Kalu, Simeon Ozuomba, Akaninyene Obot (2013). Development of improved scheme for minimising handoff failure due to poor signal quality. *International Journal of Engineering Research & Technology (IJERT), 2(10), 2764-2771*
32. Akpan, Itoro J., Ozuomba Simeon, and Kalu Constance (2020). "Development Of A Guard Channel-Based Prioritized Handoff Scheme With Channel Borrowing Mechanism For Cellular Networks." *Journal of Multidisciplinary Engineering Science and Technology (JMEST) Vol. 7 Issue 2, February - 2020*
33. Oyedepo, S. O. (2012). Energy and sustainable development in Nigeria: the way forward. *Energy, Sustainability and Society*, *2*(1), 1-17.
34. Archibong, Ekaette Ifiok, Ozuomba, Simeon, Etinamabasiyaka Edet Ekott (2020) "Sizing Of Stand-Alone Solar Power For A Smart Street Light System With Vandalisation Monitoring And Tracking Mechanism." *Journal of Multidisciplinary Engineering Science and Technology (JMEST) Vol. 7 Issue 7, July - 2020*
35. Aliyu, A. S., Ramli, A. T., & Saleh, M. A. (2013). Nigeria electricity crisis: Power generation capacity expansion and environmental ramifications. *Energy*, *61*, 354-367.
36. Usah, Emmamuel Okon, Simeon Ozuomba, Enobong Joseph Oduobuk, and Etinamabasiyaka Edet Ekott. (2020). "Development Of Analytical Model For Characterizing A 2500 W Wind Turbine Power Plant Under Varying Climate Conditions In Nigeria." *Science and Technology Publishing (SCI & TECH) Vol. 4 Issue 6, June - 2020*
37. Olugbenga, T. K., Jumah, A. G. A., & Phillips, D. A. (2013). The current and future challenges of electricity market in Nigeria in the face of deregulation process. *African Journal of Engineering Research*, *1*(2), 33-39.
38. Archibong, E. I., Ozuomba, Simeon, & Ekott, E. E. (2020). Life Cycle Cost And Carbon Credit Analysis For Solar Photovoltaic Powered Internet Of Things-Based Smart Street Light In Uyo. *International Multilingual Journal of Science and Technology (IMJST) Vol. 5 Issue 1, January - 2020*
39. Oyedepo, S. O. (2014). Towards achieving energy for sustainable development in Nigeria. *Renewable and sustainable energy reviews*, *34*, 255-272.

40. Simeon, Ozuomba, Kalu Constance, and Okon Smart Essang (2020). Assessment Of The Effect Of The Water Pump Connection Configuration On The Electric Power Demand For A Solar Powered Groundnut Farm Furrow Irrigation System *International Multilingual Journal of Science and Technology (IMJST) Vol. 5 Issue 9, September - 2020*
41. Babawale, G. K., & Awosanya, O. A. (2014). Estimating household willingness to pay for improved electricity supply in Lagos metropolis. *British Journal of Economics, Management & Trade*, *4*(5), 672-93.
42. Archibong, Ekaette Ifiok, Simeon Ozuomba, and Etinamabasiyaka Edet Ekott. (2020). "Design And Construction Of The Circuits For An Iot-Based, Stand-Alone, Solar Powered Street Light With Vandalisation Monitoring And Tracking Mechanism." *Science and Technology Publishing (SCI & TECH) Vol. 4 Issue 7, July - 2020*
43. Lemene B. Deele, Ozuomba, Simeon, Nseobong Okpura (2020). Comparative Life Cycle Cost Analysis Of Off-Grid 200 KW Solar-Hydro Power Plant With Pumped Water Storage And Solar Power Plant With Battery Storage Mechanism *International Multilingual Journal of Science and Technology (IMJST) Vol. 5 Issue 8, August - 2020*
44. Giwa, A., Alabi, A., Yusuf, A., & Olukan, T. (2017). A comprehensive review on biomass and solar energy for sustainable energy generation in Nigeria. *Renewable and Sustainable Energy Reviews*, *69*, 620-641.
45. Archibong, Ekaette Ifiok, Simeon Ozuomba, and Etinamabasiyaka Ekott. (2020) "Internet of things (IoT)-based, solar powered street light system with anti-vandalisation mechanism." *2020 International Conference in Mathematics, Computer Engineering and Computer Science (ICMCECS)*. IEEE, 2020.
46. Idorenyin Markson, Simeon Ozuomba, Iniobong Edifon Abasi-Obot (2019) Sizing of Solar Water Pumping System for Irrigation of Oil Palm Plantation in Abia State. *Universal Journal of Engineering Science* 7(1): 8-19, 2019
47. Usah, Emmanuel Okon, Simeon Ozuomba, and Etinamabasiyaka Edet Ekott. (2020). "Design And Construction Of Circuits For An Integrated Solar-Wind Energy *System With Remote Monitoring And Control Mechanism." Journal of Multidisciplinary Engineering Science and Technology (JMEST) Vol. 7 Issue 6, June - 2020*
48. Dioha, M. O., & Kumar, A. (2020). Exploring sustainable energy transitions in sub-Saharan Africa residential sector: The case of Nigeria. *Renewable and Sustainable Energy Reviews*, *117*, 109510.
49. Simeon, Ozuomba.(2019) "An assessment of solar-powered soybean farm basin irrigation water supply system." *Science and Technology Publishing (SCI & TECH) Vol. 3 Issue 4, April - 2019*
50. Deele, L. B., Ozuomba, Simeon, & Okpura, N. (2019). Design and Parametric Analysis of a Stand-Alone Solar-Hydro Power Plant with Pumped Water Storage Technology. *International Journal of Engineering & Technology, 4(1), 9-23.*
51. Szabo, S., Bódis, K., Huld, T., & Moner-Girona, M. (2011). Energy solutions in rural Africa: mapping electrification costs of distributed solar and diesel generation versus grid extension. *Environmental Research Letters*, *6*(3), 034002.
52. Usah, Emmamuel Okon, Simeon Ozuomba, Enobong Joseph Oduobuk (2020). "Pvsyst Software-Based Comparative Techno-Economic Analysis Of PV Power Plant For Two Installation Sites With Different Climatic Conditions." *International Multilingual Journal of Science and Technology (IMJST) Vol. 5 Issue 7, July - 2020*
53. Arndt, C., Arent, D., Hartley, F., Merven, B., & Mondal, A. H. (2019). Faster than you think: Renewable energy and developing countries. *Annual Review of Resource Economics*, *11*, 149-168.
54. Victor Etop Sunday, Ozuomba Simeon and Umoren Mfonobong Anthony (2016). Multiple Linear Regression Photovoltaic Cell Temperature Model for PVSyst Simulation Software, International Journal of Theoretical and Applied Mathematics, 2(2): pp. 140-143
55. Kumar, R., & Singh, S. K. (2018). Solar photovoltaic modeling and simulation: As a renewable energy solution. *Energy Reports*, *4*, 701-712.
56. Lemene B. Deele, Ozuomba, Simeon, Okon Smart Essang (2020) SIZING OF AN OFF-GRID PHOTOVOLTAIC POWER SUPPLY SYSTEM WITH BATTERY STORAGE *Journal of Multidisciplinary Engineering Science and Technology (JMEST) Vol. 7 Issue 8, August - 2020*
57. Mekhilef, S., Saidur, R., & Safari, A. (2011). A review on solar energy use in industries. *Renewable and sustainable energy reviews*, *15*(4), 1777-1790.
58. Thiam, D. R. (2010). Renewable decentralized in developing countries: Appraisal from microgrids project in Senegal. *Renewable Energy*, *35*(8), 1615-1623.
59. Ikpe Joseph Daniel, Ozuomba Simeon, Udofia Kufre (2019) Google Map-Based Rooftop Solar Energy Potential Analysis For University Of Uyo Main Campus . *Science and Technology Publishing (SCI & TECH) Vol. 3 Issue 7, July - 2019*
60. Dincer, F. (2011). The analysis on photovoltaic electricity generation status, potential and policies of the leading countries in solar energy. *Renewable and sustainable energy reviews*, *15*(1), 713-720.
61. Ozuomba, Simeon, Edifon, Iniobong, and Idorenyin Markson (2019). Impact of the optimal tilt angle on the solar photovoltaic array size and cost for A 100 Kwh solar power system In Imo

State. International *Journal of Sustainable Energy and Environmental Research, 8(1), 29-35.*

62. Kuang, Y., Zhang, Y., Zhou, B., Li, C., Cao, Y., Li, L., & Zeng, L. (2016). A review of renewable energy utilization in islands. *Renewable and Sustainable Energy Reviews*, *59*, 504-513.
63. Umoette, A. T., Ozuomba, Simeon, & Okpura, N. I. (2017). Comparative Analysis of the Solar Potential of Offshore and Onshore Photovoltaic Power System. *Mathematical and Software Engineering*, *3*(1), 124-138
64. Usah, Emmamuel Okon, Simeon Ozuomba, and Etinamabasiyaka Edet Ekott. (2020). "Spatial Regression Models For Characterizing The Distribution Of Peak Sun Hours, PV Daily Energy Yield And Storage Battery Capacity For Standalone Photovoltaic (PV) Installations Across Nigeria." Delta 5, no. 5.808841: 4-53. *Journal of Multidisciplinary Engineering Science Studies (JMESS) Vol. 6 Issue 7, July – 2020*
65. Reichelstein, S., & Yorston, M. (2013). The prospects for cost competitive solar PV power. *Energy Policy*, *55*, 117-127.
66. Kollimalla, S. K., Mishra, M. K., & Narasamma, N. L. (2014). Design and analysis of novel control strategy for battery and supercapacitor storage system. *IEEE Transactions on Sustainable Energy*, *5*(4), 1137-1144.
67. Brenna, M., Faranda, R., & Leva, S. (2010, July). Dynamic analysis of a new network topology for high power grid connected PV systems. In *IEEE PES general meeting* (pp. 1-7). IEEE.
68. Krishna, K. S., & Kumar, K. S. (2015). A review on hybrid renewable energy systems. *Renewable and Sustainable Energy Reviews*, *52*, 907-916.
69. Shahsavari, A., & Akbari, M. (2018). Potential of solar energy in developing countries for reducing energy-related emissions. *Renewable and Sustainable Energy Reviews*, *90*, 275-291.
70. Shatat, M., Worall, M., & Riffat, S. (2013). Opportunities for solar water desalination worldwide. *Sustainable cities and society*, *9*, 67-80.
71. Mekhilef, S., Saidur, R., & Safari, A. (2011). A review on solar energy use in industries. *Renewable and sustainable energy reviews*, *15*(4), 1777-1790.
72. Kaygusuz, K. (2012a). Energy for sustainable development: A case of developing countries. *Renewable and Sustainable Energy Reviews*, *16*(2), 1116-1126.
73. Ondraczek, J. (2014). Are we there yet? Improving solar PV economics and power planning in developing countries: The case of Kenya. *Renewable and Sustainable Energy Reviews*, *30*, 604-615.
74. Leckner, M., & Zmeureanu, R. (2011). Life cycle cost and energy analysis of a Net Zero Energy House with solar combisystem. *Applied Energy*, *88*(1), 232-241.
75. Al-Karaghouli, A., & Kazmerski, L. L. (2010). Optimization and life-cycle cost of health clinic PV system for a rural area in southern Iraq using HOMER software. *Solar Energy*, *84*(4), 710-714.
76. Marszal, A. J., & Heiselberg, P. (2011). Life cycle cost analysis of a multi-storey residential Net Zero Energy Building in Denmark. *Energy*, *36*(9), 5600-5609.
77. Hosenuzzaman, M., Rahim, N. A., Selvaraj, J., Hasanuzzaman, M., Malek, A. A., & Nahar, A. (2015). Global prospects, progress, policies, and environmental impact of solar photovoltaic power generation. *Renewable and Sustainable Energy Reviews*, *41*, 284-297.
78. Laleman, R., Albrecht, J., & Dewulf, J. (2011). Life cycle analysis to estimate the environmental impact of residential photovoltaic systems in regions with a low solar irradiation. *Renewable and Sustainable Energy Reviews*, *15*(1), 267-281.
79. Sherwani, A. F., & Usmani, J. A. (2010). Life cycle assessment of solar PV based electricity generation systems: A review. *Renewable and Sustainable Energy Reviews*, *14*(1), 540-544.
80. Roy, B., Basu, A. K., & Paul, S. (2014, February). Techno-economic feasibility analysis of a grid connected solar photovoltaic power system for a residential load. In *2014 First international conference on automation, control, energy and systems (ACES)* (pp. 1-5). IEEE.
81. Ezenugu, I. A., Umoren, A. M., & Okpura, N. I. (2016). Performance Analysis of Stand-Alone Photovoltaic (SAPV) System for Category I Health Clinic in Orlu, Imo State, Nigeria. *Mathematical and Software Engineering*, *2*(1), 35-47.
82. Ahmad, G. E. (2002). Photovoltaic-powered rural zone family house in Egypt. *Renewable Energy*, *26*(3), 379-390.
83. Hassan, A. A., Nafeh, A. A., Fahmy, F. H., & El-Sayed, M. A. (2010, March). Stand-alone photovoltaic system for an emergency health clinic. In *Proc. International Conference on Renewable Energies and Power Quality (ICREPQ'10)*.
84. Sick, F., & Erge, T. (1996). *Photovoltaics in buildings: a design handbook for architects and engineers*. Earthscan.