Google Map-Based Rooftop Solar Energy Potential Analysis For University Of Uyo Main Campus

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Abstract— **In this paper, a study was carried out to analyse the Google map-based rooftop solar energy potential for University of Uyo main campus. First, the dimension of the individual rooftop and then the total rooftop areas in the University of Uyo main campus were obtained using Google Map imagery and ArcGIS tools. The PVSyst simulation software was used for the rooftop solar energy potential analysis. Particularly, the PVSyst software was used for the determination of the PV energy generation potential of the rooftop PV system along with its other techno-economic performance parameters. The meteorological data used for the simulation was obtained from NASA Website. The simulation was conducted for fully insulated PV arrays (close roof mounted) PV modules. The results shows that the system annual energy production was 7712 MWh/year with specific production of 1184 kWh/kWp/year, performance ratio of 68.4 % , total annual thermal loss of 1,649,831 kWh per year and unit energy cost of 82 Naira per kWh. Also, the results show that the thermal loss was the major loss component in the PV solar power system. Also, the operating PV efficiency of the PV module was 9.94 % which is much lower than the PV module efficiency of 13.45 % specified by the manufacturer.**

Keywords—Rooftop Solar Energy, Arcgis , Google Map, Solar Energy Potential, PV Modules, Fully Insulated PV Arrays, Free Standing PV Arrays

I. INTRODUCTION

Over the years, the need to tackle the problem of global warming has prompted growing quest for adoption of renewable energy power technologies [1,2,3,4,5,6]. Among the numerous options, photovoltaic (PV) solar power system is the most widely adopted renewable option [7,8,9]. However, the installation of PV panels occupies much spaces and this becomes a problem in the city where there is space constraint [10,11,12]. In view of this, the installation of PV panels on rooftops has become the option for spaced constrained PV project sites.

Accordingly, studies have shown that the energy potential of any given rooftop is determined by the available rooftop area, the tilt angle of the roof, the solar radiation, the ambient temperature, and other factors [13,14,15]. Importantly, in order to estimate the rooftop solar potential of large area, remote sensing technologies and Google maps can be used to capture requisite images of the area and then estimate the available rooftop areas from the images [16,17,18,19]. In this paper, Google map and ArcGIS software tools are used to estimate the rooftop areas of the buildings in the main campus of University of Uyo [20,21,22,23,24]. The rooftop areas are then summed up and used to estimate the rooftop potential of the rooftops in the University campus. Specifically, PVSyst software [25,26] was used to conduct the technical and economic analysis based on the estimated rooftop area. Also, some other parameters were also determined to assess the performance of the PV system.

II. METHODOLOGY

A. *Description of the Case Study Site*

The case study site is University of Uyo Main Campus located along Nwaniba Road. The enhanced Google Earth image of the case study site was acquired with the assistance of experts from the Advanced Space Technology Application Laboratory (ASTAL) Uyo. Particularly, the Area of Interest (AOI) was zoomed and allowed to settle in the Google Earth Application showing Uyo, Akwa Ibom State as at 11th January, 2019. The coordinate of the AOI, in this case the University of Uyo Main Campus were captured and the georeferenced image of the study area in is shown in Figure 1.

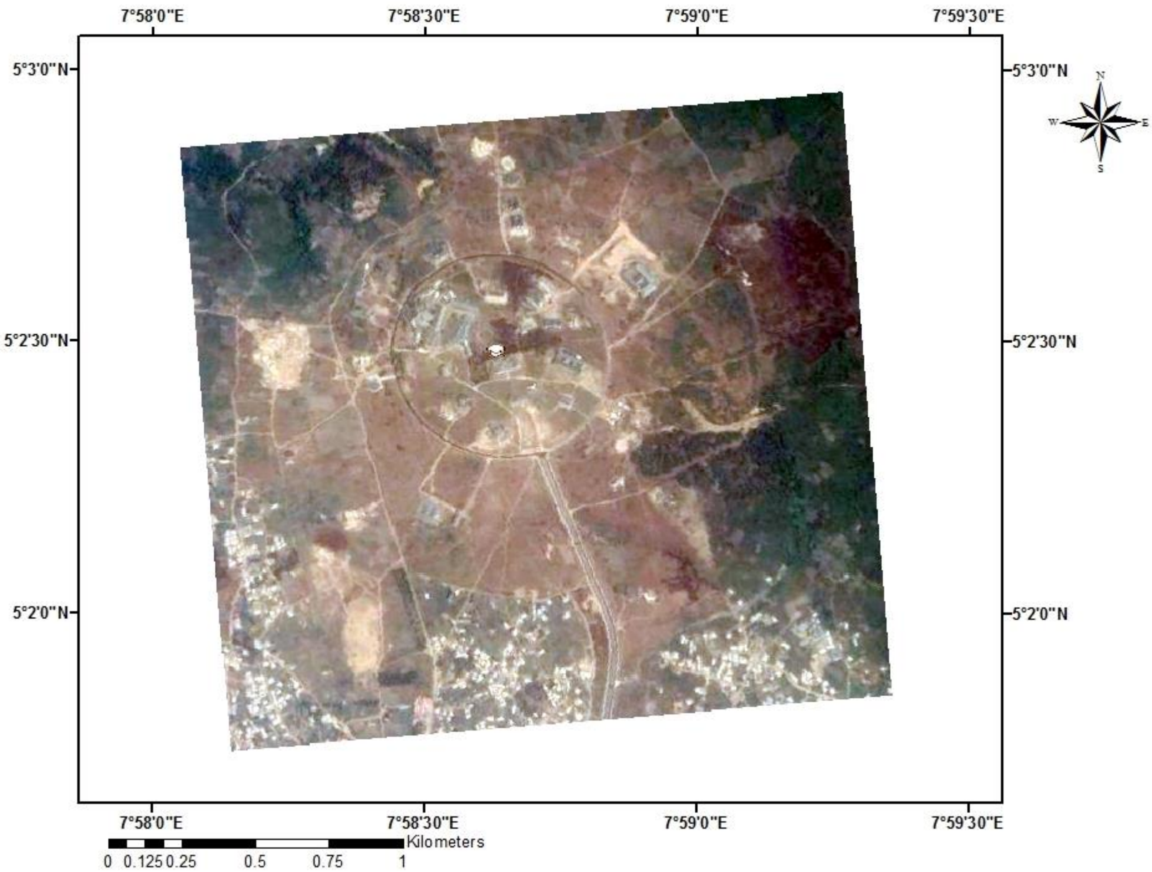


Figure 1: Georeferenced Google Earth Image of the Study Area.

B. Determination of the Building Rooftop Area using Google Maps and ArcGIS Tools

The building rooftop areas were obtained from the Enhanced Google Earth (EGE) image of AOI using ArcGIS. The image of the AOI was imported into the ArcGIS, georeferenced and the required features (rooftop area and road layout) were digitized out of the georeferenced image of the AOI. The features of interest such as buildings and roads were digitized out as showing in Figure 2.

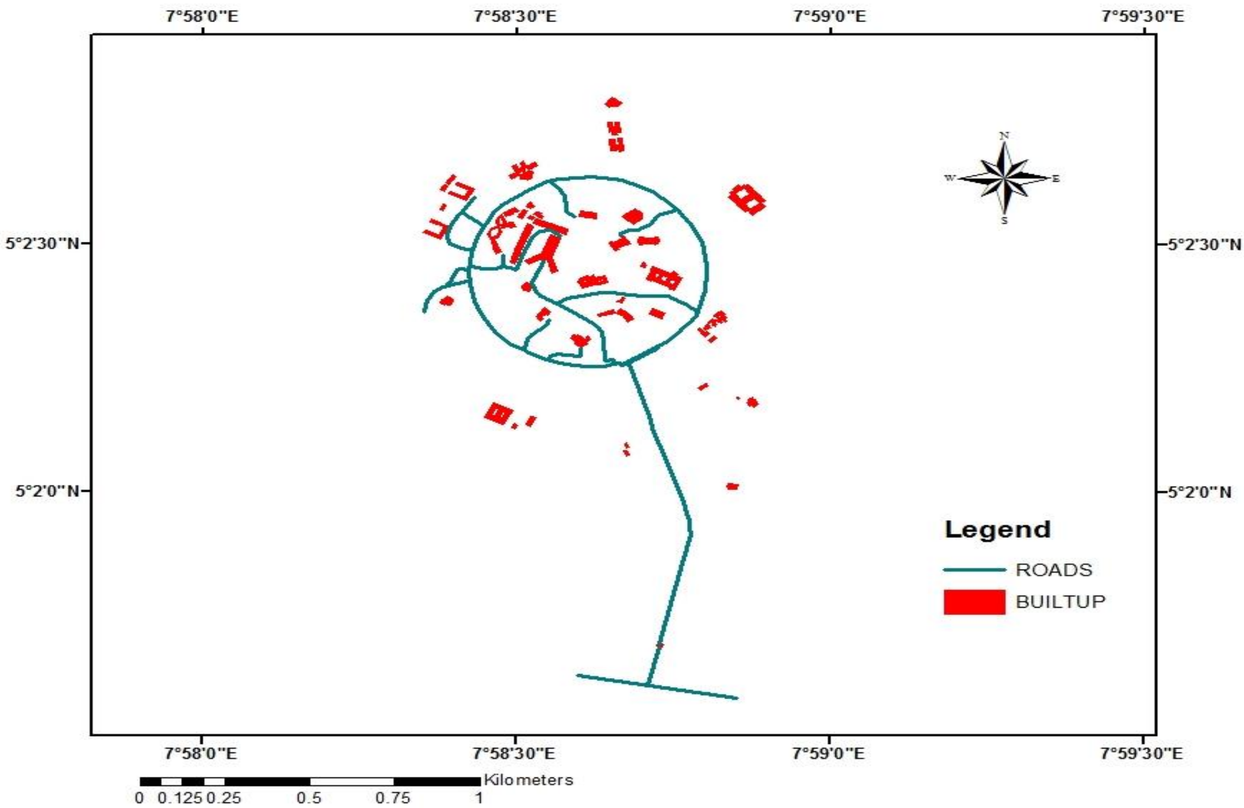


Figure 2: Map of University of Uyo showing the Solar Potential Facilities and Road Network

The digitized features thereby automatically showed the two dimensional polygon of the building rooftop in metre square (m^2). A handheld GPS (Garmin 12) was used to ensure positional accuracy of the buildings within the campus and the names assigned to them. Before the enhanced EGE image can be georeferenced, it needs to project the coordinate system from three-dimensional (3D) coordinate system to a two-dimensional (2D) coordinate system. The type of projected coordinate adopted in this study is the Universal Transverse Mercator (UTM), a system that assigned coordinate to location on the surface of the earth. Essentially, the UTM projected coordinate system was used during the georeferencing. The area of the building rooftops were automatically computed using the tools in ArcGIS. The complete list of the computed rooftop areas are given in Table 1. From Table 1, the total rooftop area of the building in the case study site is 57007.9481m^2.

Table 1: Detailed Georeferencing of Area, Latitude and Longitude Coordinate Value

1	Admin Building	1259.56956	5.038000107	7.977000237
2	Admin Building 1	226.9123094	5.039000034	7.977000237
3	ELF Thearter	785.7769614	5.039999962	7.981999874
4	Untitled Polygon	898.4765999	5.039000034	7.975999832
5	TetFund Building	4649.654217	5.040999889	7.975999832
6	Agric Lab	2002.803299	5.041999817	7.975999832
7	Computer Lab	1954.242217	5.041999817	7.974999905
8	ICT Building	713.292197	5.040999889	7.974999905
9	Workshop	416.8818734	5.040999889	7.973999977
10	Engr 1	797.8771038	5.041999817	7.974999905
11	Engr2	257.2010513	5.041999817	7.973999977
12	Engr 3	379.5915111	5.041999817	7.974999905
13	Engr 4	519.5493734	5.041999817	7.974999905
14	Engr 5	264.0372781	5.041999817	7.974999905
15	New Building	755.4098498	5.043000221	7.974999905
16	Workshop 2	439.1231524	5.043000221	7.974999905
17	University Canteen	349.5920371	5.043000221	7.974999905
18	Workshop 3	154.6513702	5.043000221	7.974999905
19	Workshop 4	143.1738482	5.043000221	7.975999832
20	Faculty of Engineering Lavatory	186.6616064	5.043000221	7.975999832
21	Female Hostel	1491.653765	5.041999817	7.97300005
22	Eka Sami Canteen	185.2252536	5.043000221	7.97300005
23	Male Hostel	1580.48013	5.043000221	7.973999977
24	Unknown 1	284.6137183	5.044000149	7.97300005
25	Unknown 2	437.5177658	5.044000149	7.97300005
29	Physical Planning	2541.373154	5.044000149	7.974999905
30	Lecture Thearter	859.9557874	5.039999962	7.97300005
31	Untitled Polygon	1442.037467	5.045000076	7.978000164
33	Untitled Polygon	1074.904883	5.046000004	7.978000164
34	Untitled Polygon	1062.226448	5.046000004	7.978000164
35	Untitled Polygon	993.1153179	5.043000221	7.977000237
36	Untitled Polygon	2051.624871	5.043000221	7.978000164
37	Untitled Polygon	1343.572157	5.041999817	7.979000092
41	Untitled Polygon	5502.439819	5.043000221	7.980999947
42	Untitled Polygon	484.4381865	5.039000034	7.977000237
43	Untitled Polygon	1063.507853	5.039000034	7.978000164
44	Untitled Polygon	153.7931379	5.039999962	7.978000164
45	Untitled Polygon	925.9726127	5.039000034	7.979000092
46	Untitled Polygon	2494.198424	5.039999962	7.977000237
49	Untitled Polygon	220.3220504	5.040999889	7.978000164
50	Untitled Polygon	4101.672108	5.039999962	7.979000092
55	PG School	3133.163802	5.035999775	7.974999905
56	Untitled Polygon	181.5561792	5.034999847	7.974999905
57	Health Center	548.4142087	5.035999775	7.974999905

58	Untitled Polygon	472.584911	5.039000034	7.980000019
59	Untitled Polygon	267.2910473	5.038000107	7.980000019
60	Untitled Polygon	277.548069	5.039000034	7.980000019
61	Science Faculty's Business Centers	948.671327	5.039000034	7.980000019
79	Untitled Polygon	173.0923034	5.034999847	7.978000164
80	Untitled Polygon	145.5831036	5.034999847	7.978000164
81	Untitled Polygon	553.4521102	5.032999992	7.980999947
82	Untitled Polygon	708.1577112	5.035999775	7.980999947
83	Untitled Polygon	38.8983095	5.035999775	7.980999947
84	Unknown	128.6470295	5.037000179	7.980999947
85	Unknown	108.8524521	5.037000179	7.980000019
86	Untitled Polygon	82.31936956	5.037000179	7.980000019
87	Concrustion Site	1602.689444	5.041999817	7.978000164
88	Untitled Polygon	187.9043917	5.027999878	7.979000092
	Total	57007.9481	5.040258621	7.976982774

C. *Analytical Determination of the Effective Rooftop Area that can be used for PV Panel Installation in the case study site*

Let the total actual area of the roof be denoted as A_{RFA} and the total effective area of the roof for PV panel installations be denoted as A_{PVT}, then;

$$A_{PVT} = (f_o)(f_s)(A_{TRF}) \quad (1)$$

Where,

$$f_o = (f_{flat})(r_{flat}) + (f_{peak})(r_{peak}) \quad (2)$$

f_o = Overall reduction factor for roof inclination with respect to optimal tilt angle

f_{flat} = Fraction of roof area that is flat roof

f_{peak} = Fraction of roof area that is peaked

r_{flat} = Reduction factor for roof area that is flat roof (usually, r_{flat} = 1)

r_{peak} = Reduction factor for roof area that is flat peaked (usually, r_{peak} = 0.5)

f_s = Reduction factor to account for roof area that has shading and others portion of the roof area that are used for other purposed and for panel servicing and installation (typical range of values are, $0.3 \le f_s \le 0.9$)

In this work, the reduction factors used for the calculations are: f_{flat}= 1; f_{peak} = 0, r_{flat} =0.95;r_{peak} = 1 and f_s = 0.9.

Based on the given roof dimensions and roof area reduction factors,

$$f_o = (f_{flat})(r_{flat}) + (f_{peak})(r_{peak}) = (1)(0.95) + (0)(0.5) = 0.95$$

$$A_{PVT} = (f_o)(f_s)(A_{TRF}) = (0.95)(0.9)(A_{TRF})$$

$$A_{PVT} = (0.855)(57007.85) = 48741.71m^2 \approx 48742\ m^2$$

Therefore, the effective roof area (A_{PVT}) for PV installation is $A_{PVT} = \approx 48742\ m^2$

D. *Use of PVSyst and the Geo-coordinates of the Case Study Site*

The geo-coordinates of the case study site (at University of Uyo main campus also known as UNIUYO Main Campus) is given as latitude: 5.03, longitude: 7.98 and altitude: 49. The PVSyst meteorological data dialogue box was uses for downloading 22-years monthly average values of the solar radiation on the horizontal plane along with the 22-years monthly average values of ambient temperature of the site.

E. *Determination the Optimal Tilt Angle for PV Panel Installation in the Case Study Site*

The optimal tilt angle, β_{opt} for the PV module is computed as;

$$\beta_{opt} = 3.7 + 0.69|\varphi| \quad (3)$$

Where φ is the latitude of the site with latitude of 5.03, then $\beta_{opt} = 3.7 + 0.69|5.03| = 7.1707 \approx 8$.

F. *Selection of the Appropriate PVSyst Thermal Loss Factor Setting for the Rooftop PV Panel Installation*

PVsyst software uses the thermal loss factor model given by Kaldellis et al., (2014) as;

$$U\,(T_{cell} - T_a) = \alpha(G)\,(1 - \eta_{PVSTC}) \quad (4)$$

$$U = \left(\frac{\alpha(G)\,(1 - \eta_{PVSTC})}{T_{cell} - T_a}\right) \quad (5)$$

Where U is the thermal loss factor; α is the absorption coefficient of solar irradiation. The default value for the absorption coefficient (α) is 0.9; T_{cell} and T_a are the module and the ambient temperatures (in °C) respectively; G is the irradiance incident on the plane of the module or array (W/m^2) and η_{PVSTC} is the module efficiency at standard test condition (STC).

Based on the thermal loss factor model, PVsyst determines the cell temperature based on the Faiman module temperature model given by Copper et al., (2013) as;

$$T_{cell} = T_a + \left(\frac{\alpha(G)(1-\eta_{PVSTC})}{U_0 + U_1\,(V_{wind})}\right) \quad (6)$$

PVsyst published thermal loss factor settings for U_0 and U_1 for fully insulated arrays (close roof mount) is Uo =15, U1= 0 PVsyst (2012). Accordingly, in this paper, the thermal loss factor setting of Uo =15, U1= 0 was adopted.

G. *Sizing of the PV Power System Components in PVSyst*

For grid connected solar power systems, the PVSyst-based system sizing can be done based on two criteria, namely; the load demand or the available area for the PV modules. Specifically, for any given daily load demand (E_L) in Kwh/day with de-rating factors $f_{dc/ac}$ and f_{temp}, the PV size in terms of area (A_{PVT}) required to meet the daily load demand is given as;

$$A_{PVT} = \frac{E_L}{(G_d * \eta_{pv} * f_{dc/ac} * f_{temp})} \quad (7)$$

Conversely, for any given PV size in terms of area, A_{PVT}, the daily load demand (E_L) the PV can satisfy is given as;

$$E_L = A_{pv}\,(G_d * \eta_{pv} * f_{dc/ac} * f_{temp}) \quad (8)$$

Where: A_{PVT} is the PV area in m^2; E_L is the daily load demandin Kwh/day; G_d is the average daily solar global irradiation based on the global air-mass 1.5 spectrum of 1000 w/m^2. G_d is also called the Peak Sun Hour (PSH); η_{pv} is the module efficiency; $f_{dc/ac}$ is the DC to AC de-rating factor (%); f_{temp} is the temperature de-rating factor. The temperature de-rating factor, f_{temp} is given as:

$$f_{temp} = 1 - (\gamma_{pv} * (T_c - T_{STC})) \quad (9)$$

Where: f_{temp} is the temperature de-rating factor, dimensionless; γ_{pv} is the temperature coefficient of power, that is, the absolute value of power temperature co-efficient per degree Celsius ; T_c is the average daily cell temperature; T_{STC} is the cell temperature at Standard Test Conditions, in degrees Celsius. Let $f_{dc/ac}$ be the overall DC to AC de-rate factor, the $f_{dc/ac}$ is calculated by multiplying the component de-rate factors as follows;

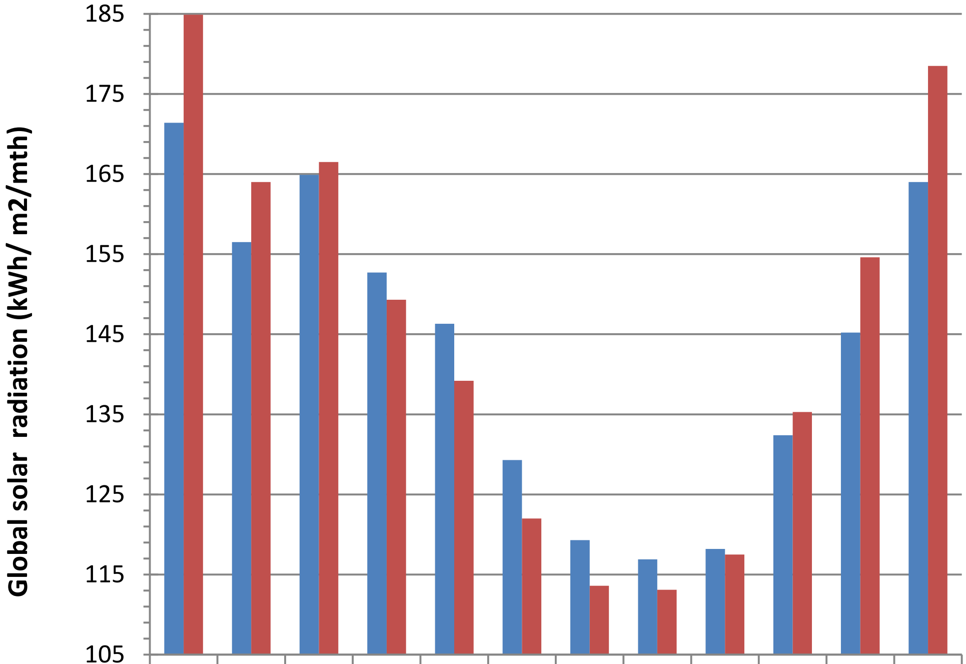
$$f_{dc/ac} = f_{pvtol} * f_{mism} * f_{diode} * f_{dcwiring} * f_{pacwiring} * f_{soiling} * f_{sysavail} * f_{shading} * f_{suntrack} * f_{aging} \quad (10)$$

Where the various derate factors are: f_{pvtol} is the de-rating factor due to PV module nameplate tolerance DC rating ; f_{inv} is the de-rating factor due to Inverter and Transformer ; f_{mism} is the de-rating factor due to Mismatch f_{diode} is the de-rating factor due to Diodes and connections ; $f_{dcwiring}$ is the de-rating factor due to DC wiring ; $f_{pacwiring}$ is the de-rating factor due to AC wiring ; $f_{soiling}$ is the de-rating factor due to Soiling ; $f_{sysavail}$ is the de-rating factor due to System availability ; $f_{shading}$ is the de-rating factor due to Shading ; $f_{suntrack}$ is the de-rating factor due to Sun – tracking ; f_{aging} is the de-rating factor due to Age ; The value of each derate factor is greater than zero but less or equal to 1. Consequently, $0 < f_{dc/ac} \leq 1$.

III. RESULTS AND DISCUSSION

Based on the latitude of 5.03° for the case study site, the optimal tilt angle was computed as $\beta_{opt} = 3.7 + 0.69|5.03| = 7.1707° \approx 8°$. The monthly average of global solar radiation on the horizontal plane and the monthly average of global solar radiation on the tilted plane are given in Figure 3.

The simulations in PVSyst Software was carried out for the technical and economic analysis of the rooftop PV energy potential of the case study site using thermal loss factor settings for fully insulated arrays (close roof mount) PV modules with Uo =15, U1= 0 (PVsyst, 2012). The screenshot of the PVSyst software system sizing dialogue box setting of the PV power system for the fully insulated arrays (close roof mount) PV modules is shown in Figure 4. The results show that a total of 26048 PV modules with a total area of 48729 m^2 are required. The screenshot of the PVSyst software economic analysis input dialogue box setting of the PV power system is shown in Figure 5.



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Global solar radiation on the horizontal plane (kWh/ m2/mth)	171.4	156.5	164.9	152.7	146.3	129.3	119.3	116.9	118.2	132.4	145.2	164
Global solar radiation on the tilted plane (kWh/ m2/mth)	184.9	164	166.5	149.3	139.2	122	113.6	113.1	117.5	135.3	154.6	178.5

Figure 3: The bar chart of the global solar radiation on the horizontal plane and the global solar radiation on the tilted plane

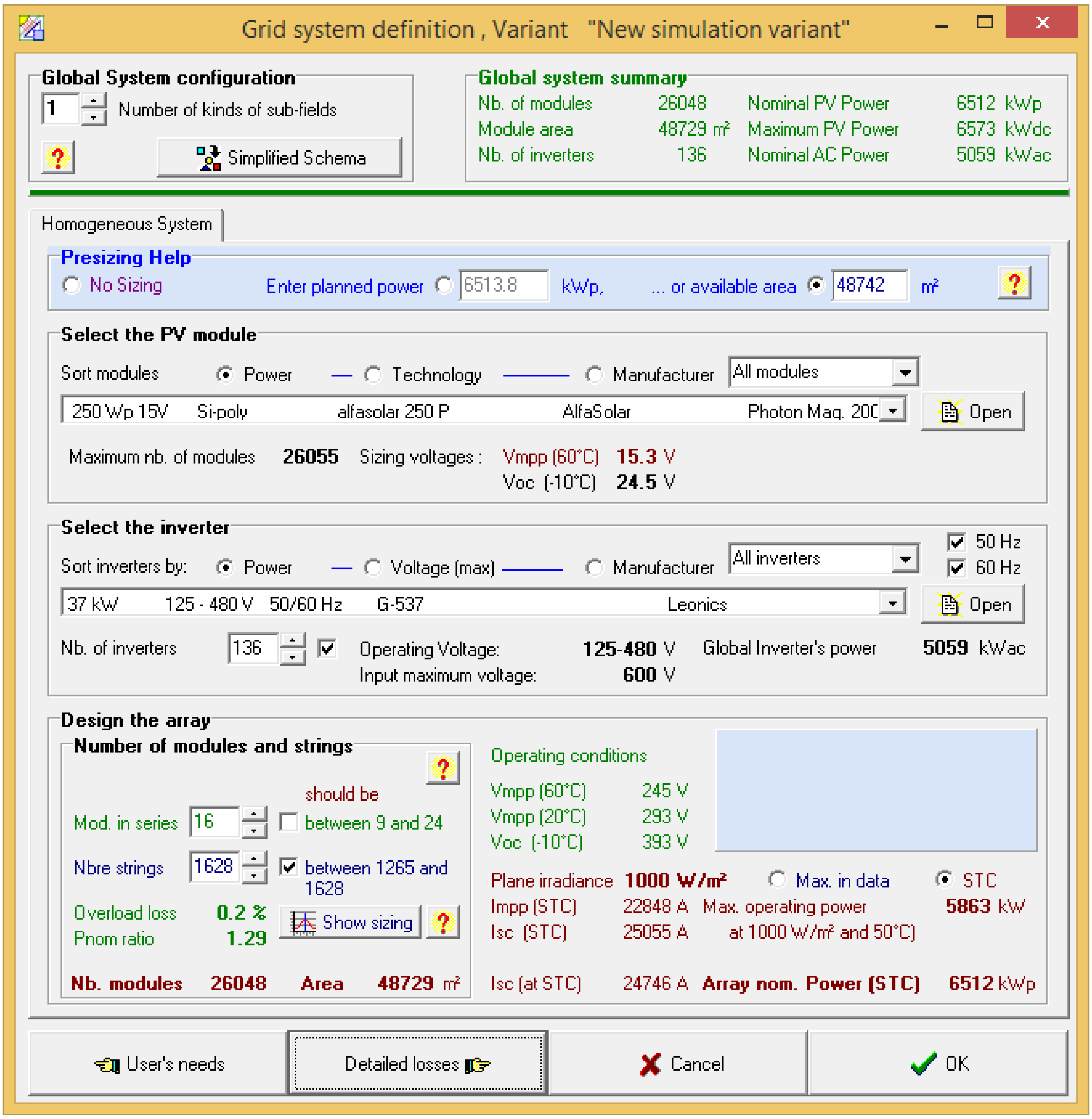


Figure 4: The screenshot of the PVSyst software system sizing dialogue box setting of the PV power system for the fully insulated arrays (close roof mount) PV modules

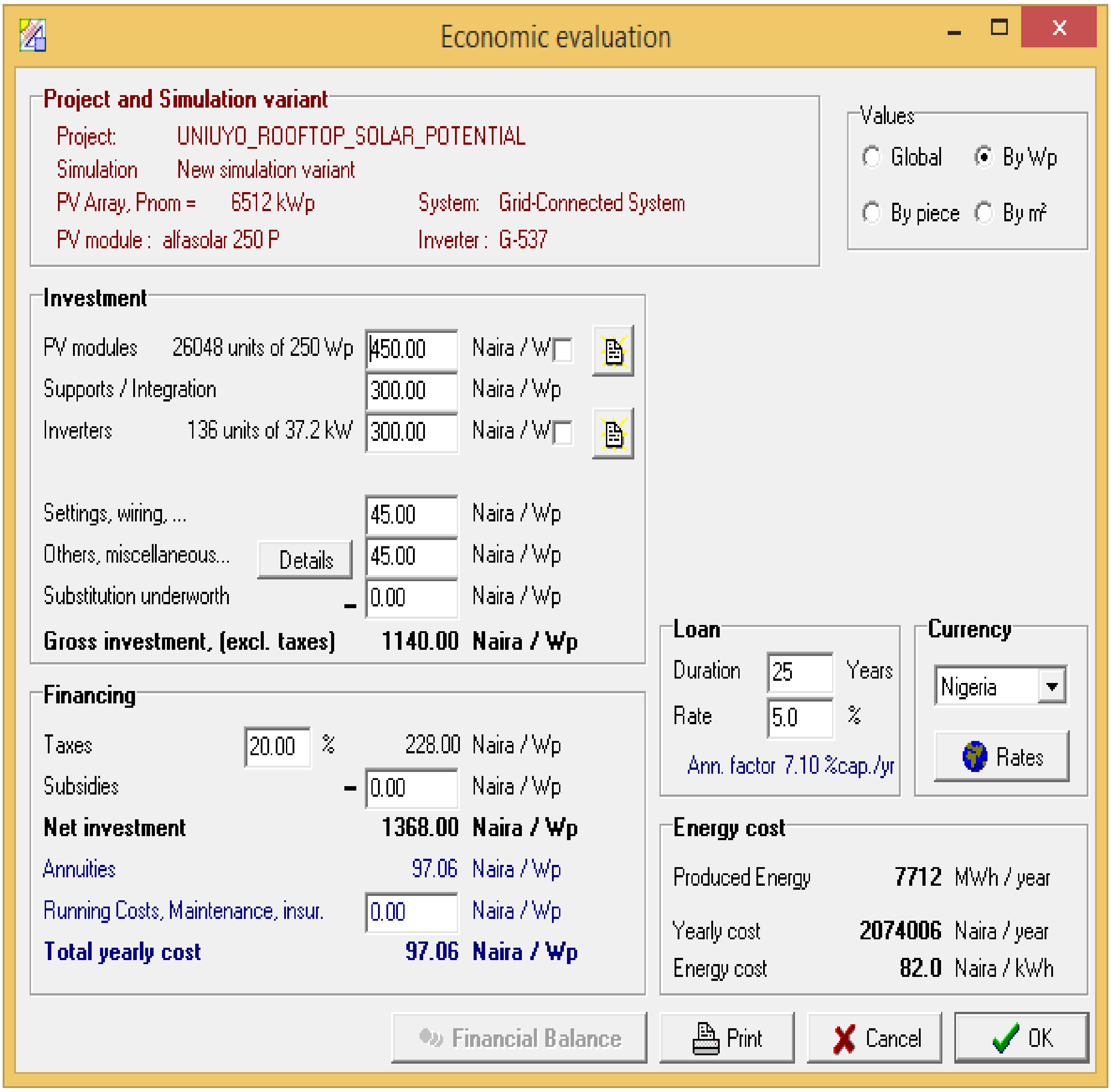


Figure 5: The screenshot of the PVSyst software economic analysis input dialogue box setting of the PV power system for the fully insulated arrays (close roof mount) PV modules

According to the results, the selected PV is the 250 Wp Si-poly manufactured by AlfaSolar. The total number of PV modules required is 26048 with 16 modules in series and 1628 strings in parallel. The results in Figure 6 and Figure 7 show that the system annual energy production is 7712MWh/year with specific production of 1184 kWh/kWp/year and performance ratio of 68.4 %. According to the results in Figure 5, the unit cost of energy for the fully insulated arrays (close roof mount) PV modules is 82 Naira per kWh.

The system loss diagram for the fully insulated arrays (close roof mount) PV modules is given in Figure 8. Among other losses, the thermal loss due to module cell temperature is about 15.6 % of the total energy. When the various losses in the system are considered, the energy at the inverter output is 7711651 kWh per annum which is approximately 7712 MWh per annum.

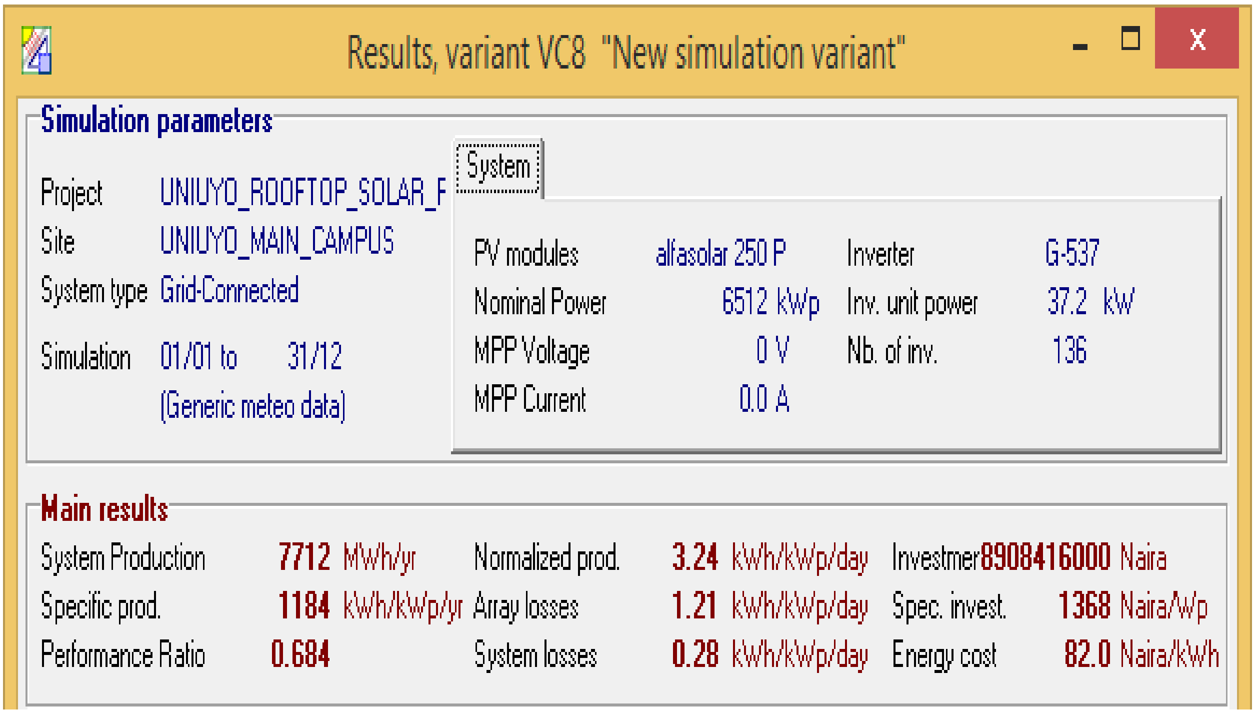
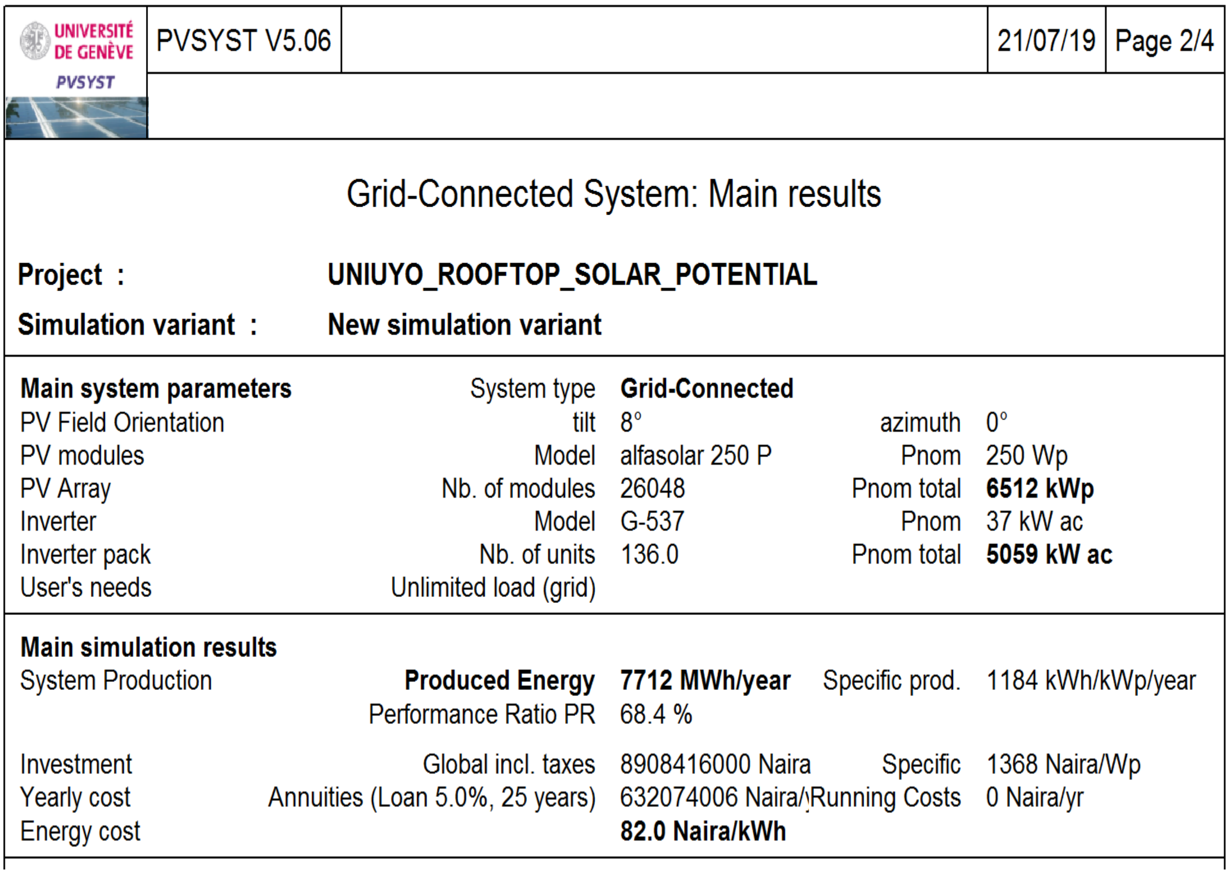


Figure 6: The simulation parameters along with the summary of the main results output window for the fully insulated arrays (close roof mount) PV modules



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Grid-Connected System: Main results

Project : **UNIUYO_ROOFTOP_SOLAR_POTENTIAL**

Simulation variant : **New simulation variant**

Main system parameters	System type	**Grid-Connected**		
PV Field Orientation	tilt	8°	azimuth	0°
PV modules	Model	alfasolar 250 P	Pnom	250 Wp
PV Array	Nb. of modules	26048	Pnom total	**6512 kWp**
Inverter	Model	G-537	Pnom	37 kW ac
Inverter pack	Nb. of units	136.0	Pnom total	**5059 kW ac**
User's needs	Unlimited load (grid)			

Main simulation results				
System Production	**Produced Energy**	**7712 MWh/year**	Specific prod.	1184 kWh/kWp/year
	Performance Ratio PR	68.4 %		
Investment	Global incl. taxes	8908416000 Naira	Specific	1368 Naira/Wp
Yearly cost	Annuities (Loan 5.0%, 25 years)	632074006 Naira/	Running Costs	0 Naira/yr
Energy cost		**82.0 Naira/kWh**		

Figure 7: The simulation main results and the summary of economic analysis output window for the fully insulated arrays (close roof mount) PV modules

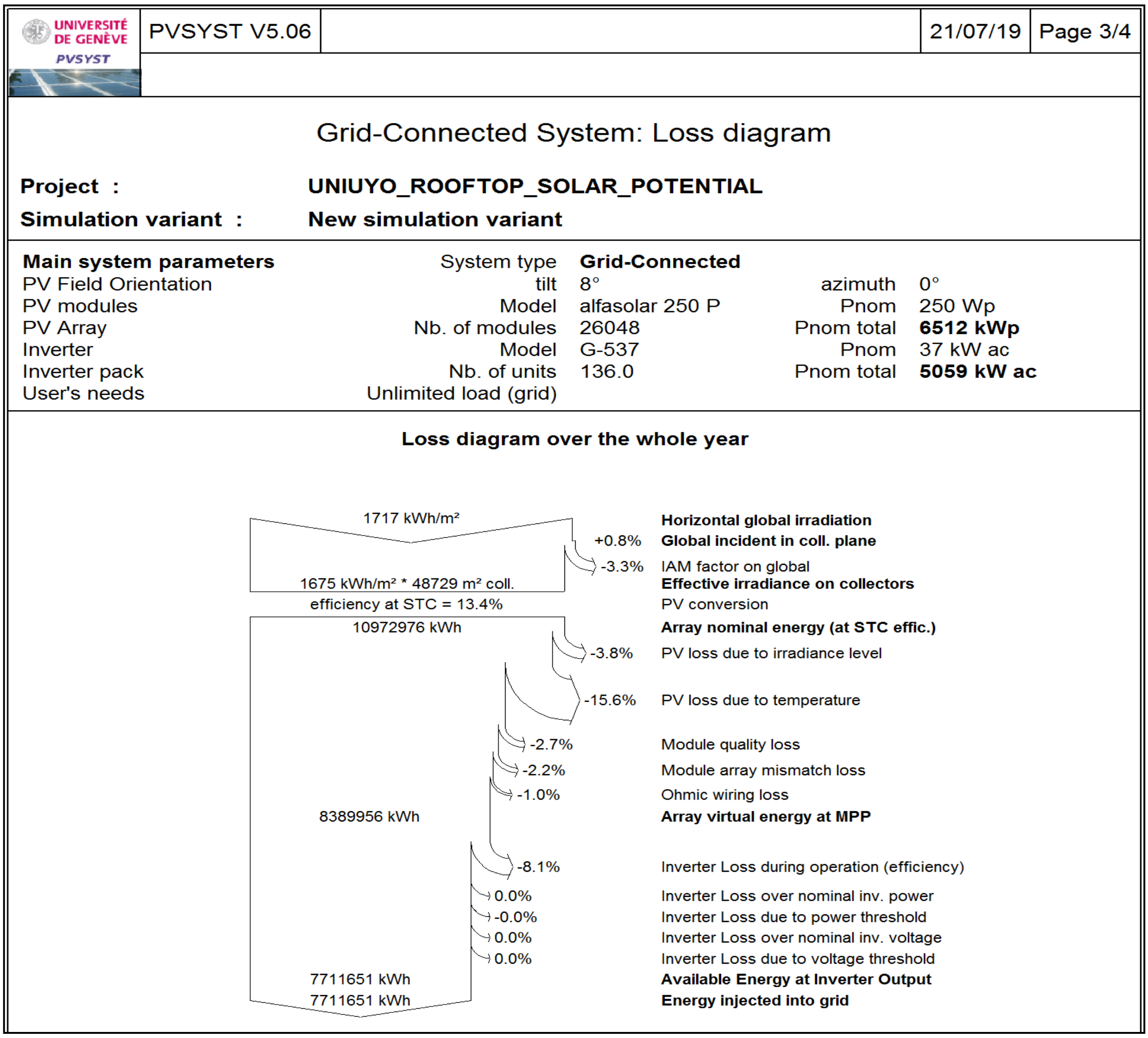

Figure 8: The system loss diagram for the fully insulated arrays (close roof mount) PV modules

The operating efficiency of the PV is computed from Figure 9 as follows:

$$\eta_{pv} = \left\{\frac{(14550\ Kwh/day)}{(3Kwh/m^2/day)(48742m^2)}\right\} x\ 100\% = 9.95\ \% \quad (11)$$

From the daily energy output diagram of Figure 9, the operating efficiency of the PV under its operating conditions is computed to be 9.95 % as against 13.45 % module efficiency at Standard Test Condition (STC) as shown in Figure 10. The computed operating module efficiency of 9.95 % corresponds to the yearly average array efficiency of 9.94 % as shown in Table 2 with yearly average EffArrR = 9.94 %.

Among other parameters, the results in Table 2 show the values of the thermal loss (TempLss), PV array temperature (Tarray) and the global solar radiation on the PV inclined plane (GlobInc) while the results in Table 3 show the correlation among thermal loss (TempLss), PV array temperature (Tarray) and the global solar radiation on the PV inclined plane (GlobInc). According to the results, the thermal loss (TempLss) has higher correlation value with PV array temperature (Tarray) than it has with the global solar radiation on the PV inclined plane (GlobInc). Essentially, the array temperature has more influence on the thermal loss of a PV array than the solar radiation. According to the results in Table 4, the total annual thermal loss (TempLss) is 1,649,831 kWh.

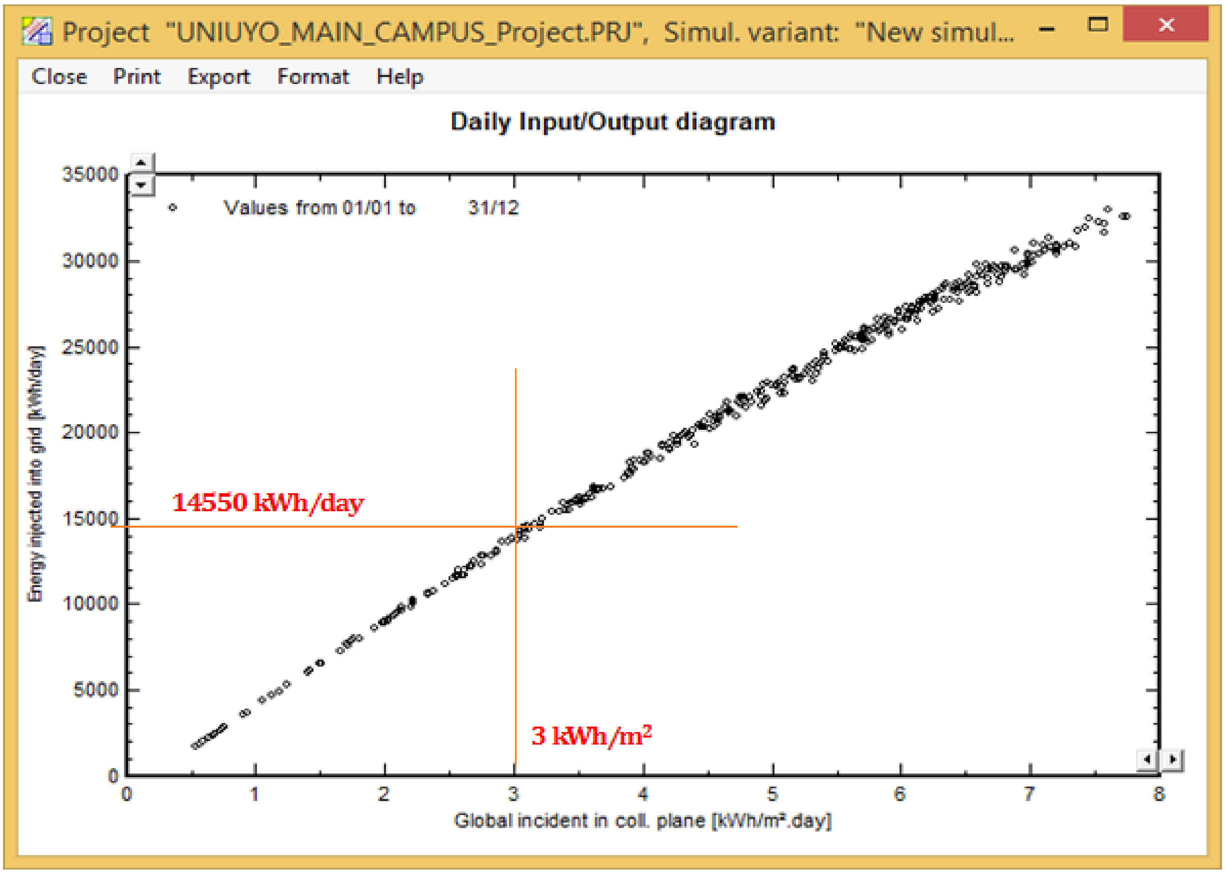

Figure 9: The daily energy output diagram for the fully insulated arrays (close roof mount) PV modules

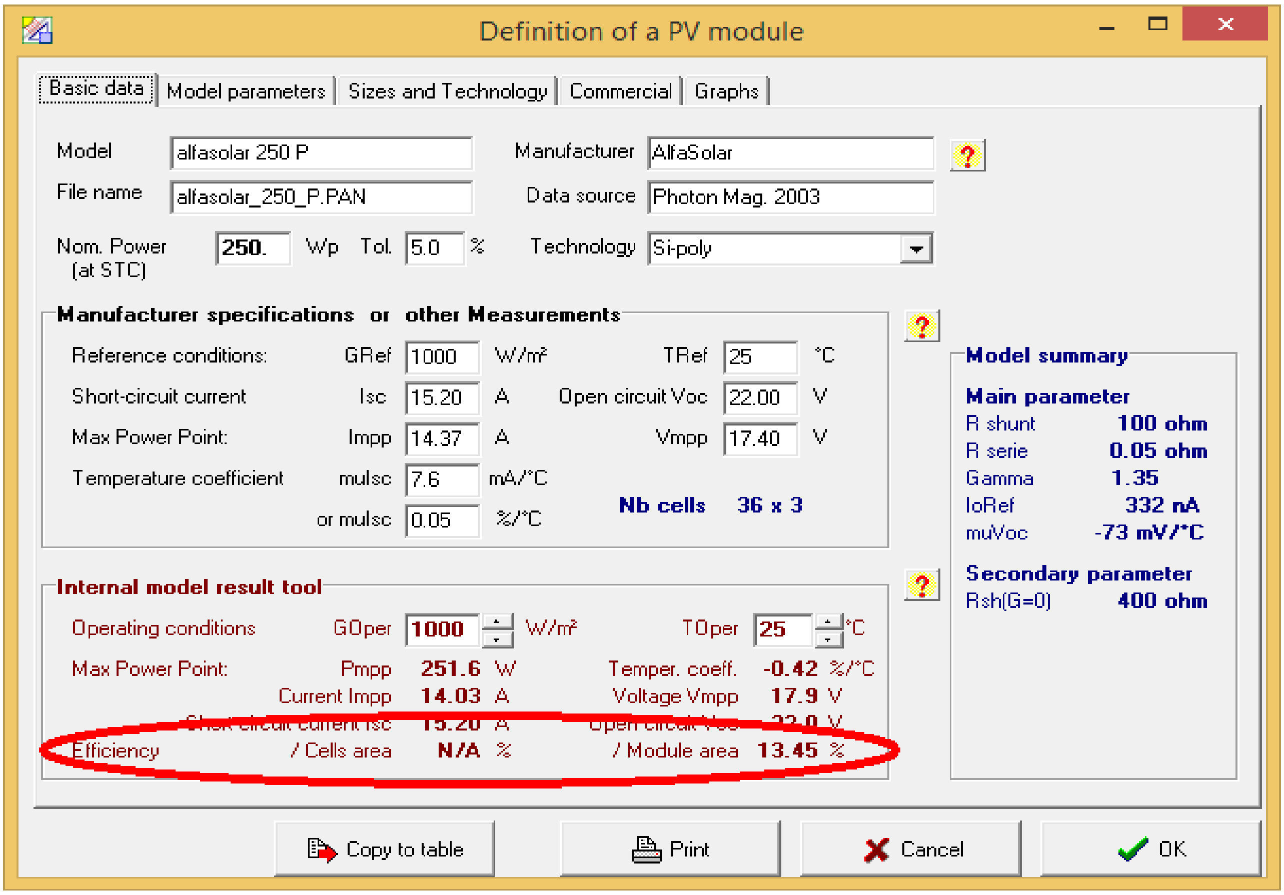

Figure 10: The efficiency of the PV modules at standard test condition (STC)

Table 2: The balances and main results table for the case of fully insulated arrays (close roof mount) PV modules

Balances and main results

	GlobHor kWh/m²	T Amb °C	GlobInc kWh/m²	GlobEff kWh/m²	EArray kWh	E_Grid kWh	EffArrR %	EffSysR %
January	171.4	25.40	181.0	175.7	864180	797660	9.80	9.04
February	156.5	25.80	161.8	157.0	763000	702946	9.68	8.92
March	164.9	25.70	165.6	160.6	797885	735191	9.89	9.11
April	152.7	25.80	150.0	145.3	727661	670369	9.95	9.17
May	146.3	25.60	140.5	135.6	683712	627831	9.98	9.17
June	129.3	24.80	124.4	119.7	616090	566043	10.16	9.33
July	119.4	24.10	115.6	111.1	574625	526408	10.20	9.34
August	116.9	23.90	114.3	110.0	563173	515122	10.12	9.25
September	118.2	24.10	117.5	113.6	574343	525128	10.03	9.17
October	132.4	24.40	134.5	130.0	657010	602037	10.03	9.19
November	145.2	24.70	151.8	147.0	728771	669595	9.85	9.05
December	164.0	24.70	174.1	168.8	837978	773321	9.88	9.12
Year	1717.1	24.91	1731.2	1674.5	8388426	7711651	9.94	9.14

Table 3: The correlation among Thermal loss (TempLss), PV array temperature (Tarray) an the global solar radiation on the PV inclined plane (GlobInc)

	TempLss	*Tarray*	*GlobInc*
TempLss	1		
Tarray	0.985	1	
GlobInc	0.978	0.972	1

Table 4: Thermal loss (TempLss), PV array temperature (Tarray) an the global solar radiation on the PV inclined plane (GlobInc)

	TempLss kWh	TArray °C	GlobInc kWh/m²	E User kWh	EArray kWh	EffArrR %	EffSysR %
January	200669	56.39	181.0	797660	864180	9.80	9.04
February	188350	55.83	161.8	702946	763000	9.68	8.92
March	169628	52.21	165.6	735191	797885	9.89	9.11
April	145068	50.88	150.0	670369	727661	9.95	9.17
May	126670	47.05	140.5	627831	683712	9.98	9.17
June	91651	44.52	124.4	566043	616090	10.16	9.33
July	78996	42.11	115.6	526408	574625	10.20	9.34
August	87546	42.18	114.3	515122	563173	10.12	9.25
September	101460	43.52	117.5	525128	574343	10.03	9.17
October	119663	45.12	134.5	602037	657010	10.03	9.19
November	156866	49.84	151.8	669595	728771	9.85	9.05
December	183264	54.68	174.1	773321	837978	9.88	9.12
Year	1649831	48.61	1731.2	7711651	8388426	9.94	9.14

V. CONCLUSION

The solar potential of the rooftop of the buildings in the main campus of University of Uyo is presented. The Google Earth was used to acquire enhanced image of the case study site. The building rooftop areas were obtained from the Enhanced Google Earth (EGE) image of Area of Interest (AOI) using ArcGIS. Based on the building rooftop area, PVSyst software was used to determine the solar energy potential of the rooftops and the unit cost of the energy from the building rooftops in the case study site. The analysis was done for fully insulated PV arrays (close roof mount PV) and the results show that the thermal loss was the major loss component in the PV solar power system. Also, the operating PV efficiency is much lower than the PV module efficiency specified by the manufacturer.

REFERENCES

1. Lin, Boqiang, and Junpeng Zhu. "Determinants of renewable energy technological innovation in China under CO2 emissions constraint." *Journal of environmental management* 247 (2019): 662-671.
2. Olah, George A., et al. "Difference and significance of regenerative versus renewable carbon fuels and products." *Topics in Catalysis* 61.7-8 (2018): 522-529.
3. Cherp, Aleh, et al. "Integrating techno-economic, socio-technical and political perspectives on national energy transitions: A meta-theoretical framework." *Energy Research & Social Science* 37 (2018): 175-190.
4. Burke, Matthew J., and Jennie C. Stephens. "Political power and renewable energy futures: A critical review." *Energy research & social science* 35 (2018): 78-93.
5. Elum, ZA and, and A. S. Momodu. "Climate change mitigation and renewable energy for sustainable development in Nigeria: A discourse approach." *Renewable and Sustainable Energy Reviews* 76 (2017): 72-80.
6. Merrill, Laura. *Tackling fossil fuel subsidies and climate change: Levelling the energy playing field*. Nordic Council of Ministers, 2015.
7. Yushchenko, Alisa, et al. "GIS-based assessment of photovoltaic (PV) and concentrated solar power (CSP) generation potential in West Africa." *Renewable and Sustainable Energy Reviews* 81 (2018): 2088-2103.
8. Kemausuor, Francis, Morkporkpor Delight Sedzro, and Isaac Osei. "Decentralised Energy Systems in Africa: Coordination and Integration of Off-Grid and Grid Power Systems—Review of Planning Tools to Identify Renewable Energy Deployment Options for Rural Electrification in Africa." *Current Sustainable/Renewable Energy Reports* 5.4 (2018): 214-223.
9. Moon, Yongma, and Mesut Baran. "Economic analysis of a residential PV system from the timing perspective: A real option model." *Renewable energy* 125 (2018): 783-795.
10. Ntsoane, Moroasereme. *Rooftop solar PV potential assessment in the city of Johannesburg*. Diss. Stellenbosch: Stellenbosch University, 2017.
11. Bridge, Gavin, et al. "Geographies of energy transition: Space, place and the low-carbon economy." *Energy policy* 53 (2013): 331-340.
12. Tatari, Mohamed, et al. "The Roof Space Battle: PV vs Skylights and Other Technologies in Net-Zero Energy Capable Facilities." (2014).
13. Dioha, Michael O., and Atul Kumar. "Rooftop solar PV for urban residential buildings of Nigeria: A preliminary attempt towards potential estimation." *AIMS ENERGY* 6.5 (2018): 710-734.
14. Madessa, Habtamu B. "Performance analysis of roof-mounted photovoltaic systems–The case of a Norwegian residential building." *Energy Procedia* 83 (2015): 474-483.
15. Carl, Caroline. *Calculating solar photovoltaic potential on residential rooftops in Kailua Kona, Hawaii*. University of Southern California, 2014.
16. Andoni, Merlinda, et al. "Blockchain technology in the energy sector: A systematic review of challenges and opportunities." *Renewable and Sustainable Energy Reviews* 100 (2019): 143-174.
17. Choi, Yosoon, Jangwon Suh, and Sung-Min Kim. "GIS-Based Solar Radiation Mapping, Site Evaluation, and Potential Assessment: A Review." *Applied Sciences* 9.9 (2019): 1960.
18. Effat, Hala Adel. "Mapping Solar Energy Potential Zones, using SRTM and Spatial Analysis, Application in Lake Nasser Region, Egypt." *International Journal of Sustainable Land Use and Urban Planning* 3.1 (2016).
19. Palmer, Diane, et al. "Assessment of potential for photovoltaic roof installations by extraction of roof tilt from light detection and ranging data and aggregation to census geography." *IET Renewable Power Generation* 10.4 (2016): 467-473.
20. Aboushal, E. A. "Applying GIS Technology for optimum selection of Photovoltaic Panels "Spatially at Defined Urban Area in Alexandria, Egypt"." *Alexandria engineering journal* 57.4 (2018): 4167-4176.
21. Melius, J., R. Margolis, and Sean Ong. *Estimating rooftop suitability for PV: a review of methods, patents, and validation techniques*. No. NREL/TP-6A20-60593.

National Renewable Energy Lab.(NREL), Golden, CO (United States), 2013.
22. Chow, Annie, Alan Fung, and Songnian Li. "GIS modeling of solar neighborhood potential at a fine spatiotemporal resolution." *Buildings* 4.2 (2014): 195-206.
23. Palmer, Diane, et al. "A GIS-based method for identification of wide area rooftop suitability for minimum size PV systems using LiDAR data and photogrammetry." *Energies* 11.12 (2018): 3506.
24. Boz, Mesude Bayrakci, Kirby Calvert, and Jeffrey RS Brownson. "An automated model for rooftop PV systems assessment in ArcGIS using LIDAR." *AIMS Energy* 3.3 (2015): 401-420.
25. Kandasamy, C. P., P. Prabu, and K. Niruba. "Solar potential assessment using PVSYST software." *2013 International Conference on Green Computing, Communication and Conservation of Energy (ICGCE)*. IEEE, 2013.
26. Irwan, Y. M., et al. "Stand-alone photovoltaic (SAPV) system assessment using PVSYST software." *Energy Procedia* 79 (2015): 596-603.