Analysis Of Net Zero Solar Photovoltaic Energy Installation At Uniport's Africa Centre Of Excellence For Public Health And Toxicological Research

Ikrang, Elijah George[1]
Department of Agricultural and Food Engineering,
University of Uyo, Akwa Ibom, Nigeria

Olatunbosun Emmanuel Dapo[2]
Directorate Department, Advanced Space Technology Applications Laboratory, Uyo, Akwa Ibom, Nigeria
oladapobonty@yahoo.co.uk

Uwakwe Chikwado[3]
Department of Electrical/Electronic Engineering Imo State Polytechnic, Umuagwo, Owerri, Nigeria

***Abstract*—Basically, centre for public health and toxicological researches seek to develop educational and policy frameworks, as well as products and services that will promote safety, improve health and prolong the life of communities and their environment. Such centre relies on modern technologies that support extensive research collaborations. Importantly, effective power supply is paramount to achieving such objective. Notably, in situations of epileptic grid power supply, net zero photovoltaic power supply is an environmentally friendly power system that ensures energy sufficiency for its load. Consequently, in this paper, comparative analysis of net zero grid-connected solar photovoltaic energy power installation at University of Port (UNIPORT) Africa centre of excellence for public health and toxicological research is presented. The study site longitude and latitude are 4.77° and 7.02° respectively. The UNIPORT'S Africa centre of excellence for public health and toxicological research is expected to have a 10 kW PV power that can sustain its daily activities for 10.967 hours a day. This amounts to a daily load of 109.67 kWh/day and annual load of 40030 kWh/year. The analysis is simulated in PVSyst software for three different annual optimal tilt angle orientations of the PV panels, namely; yearly fixed optimal tilt angle of 8°, yearly fixed at Summer months optimal tilt angle of 0° and yearly fixed at Winter months optimal tilt angle of 28°. The results showed that for the yearly fixed tilt angle of 8° , the annual imported nergy and exported energy are both 23777 kWh/year resulting in a net energy of 0 kWh/year. Also, the annaul energy yield of the PV array is 40030 kWh/year which is also the same as the annual load demand. The self-consumed energy (which is 16253 kWh/year) and exported energy to the grid (which is 23777 kWh/year) sum up to 40030 kWh/year. The simulation results for the yearly fixed at Summer months optimal tilt angle of 0° showed that the annual imported energy is -23773 kWh/year and the exported energy is 23633 kWh/year, resulting in annual net energy deficit of -140 kWh/year. In all, the results showed that the simulation at yearly fixed installation at angle of 0° gave the best result with highest annaul energy yeild of 40030 kWh/year and net energy of 0 kWh/year. The yearly fixed installation at Winter months optimal tilt angle of 28° gave the worst result with the lowest annaul energy yeild of 38172 kWh/year and net energy of -1858 kWh/year. As such, the results showed that the PV tilt angle has significant influence on the energy yeild of the PV power installation at the case study site.**

Keywords— Net Zero Energy, Optimal Tilt Angle, Grid-Connected, Load Demand, Energy Yeild, Solar PV Power

1. INTRODUCTION

Public health is the application of education, policy and research to protect the safety, improve the health and prolong the life of communities or groups [1,2,3,4,5,6,7,8,9,10]. It involves analysis of the determinants of health of the community or group and the threats the community or group faces. On the other hand, toxicology is basically a 'science of safety', which applies scientific approaches to explain harmful effects of chemicals, substances and situations on human beings, animals and the environment [11,12,13,14,15,16,17,18,19]. It evaluates the probability that adverse effects can occur when human beings, animals or the environment are exposed to certain chemicals, substances or situations. The case study African center of excellence for public health and toxicological research is focused on such studies that address public health and toxicological issues. The center relies on multidisciplinary researches that their success depends on expertise located in different institutions across Africa and beyond. Such extensive collaboration requires modern research facilities and communication technologies that rely on effective power supply.

However, one of the major impediments to effective functioning of such centers across Nigeria is the epileptic power supply from the national grid [20,21,22,23,24,25,26,27]. The immediate alternative power source is the fossil fuel power generators. However, such power sources have been identified as hazardous to both human and the environment [28,29,30]. As such, photovoltaic (PV) power systems and other environmental friendly power supply systems have become the preferred alternative power supply for such center that seeks to promote public and environmental health.

In this paper, the PV power system that is designed for net-zero power supply to the world bank-funded University of Port Harcourt African center of excellence for public health and toxicological research (ACE-PUTOR UniPort) is presented. Furthermore, the effect of the PV module tilt angle on the PV system performance is also studied. In all, net-zero PV power system is a grid connected system where the PV array energy yield over the year is expected to satisfy the annual energy demand of the load without any deficit. In that case, the annual sum of energy exported to the grid is equal to the annual energy imported from the grid. Such PV power system for the ACE-PUTOR UniPort means that the center is self-sufficient in its annual energy generation from the PV power system.

2. METHODOLOGY

2.1 Analytical Expressions for Net Zero PV Power System

Let $\mathrm{E_{DAVAIL}}$ be the daily generated energy by the PV array and it is expressed in Wh.day, hence;

$$\mathrm{E_{DAVAIL}} = (N_{PV})(P_{Wp})(PSH)(f_{PV\_derat}) \quad (1)$$

Where the rated power of each PV panel is P_{Wp}, N_{PV} is the number of PV panels in the array, PSH is the peak sun hour per day and f_{PV_derat} is the PV de-rating factor. Now, let $\mathrm{E_{DL}}$ be the daily load demand in Wh/day, $\mathrm{E_{DSC}}$ be the daily self-consumed energy, $\mathrm{E_{DIMPT}}$ be the daily imported energy from the grid to make up for any deficit when $\mathrm{E_{DSC}} - \mathrm{E_{DL}} < 0$, and $\mathrm{E_{DEXPT}}$ be the daily exported energy to the grid to make up for any excess when $\mathrm{E_{DSC}} - \mathrm{E_{DAVAIL}} > 0$. When $\mathrm{E_{DSC}}$ and $\mathrm{E_{DL}}$ are given and $\mathrm{E_{DAVAIL}}$ is computed, then, the daily imported and exported energies are;

$$\mathrm{E_{DIMPT}} = MINIMUM(0, (\mathrm{E_{DSC}} - \mathrm{E_{DL}})) \quad (2)$$

$$\mathrm{E_{DEXPT}} = MAXIMUM(0, (\mathrm{E_{DAVAIL}} - \mathrm{E_{DSC}})) \quad (3)$$

On a monthly basis,

$$\mathrm{E_{MSC}} = \sum_{d=1}^{N_m} (\mathrm{E_{DSC(d)}}) \quad (4)$$

$$\mathrm{E_{MDL}} = \sum_{d=1}^{N_m} (\mathrm{E_{DL(d)}}) \quad (5)$$

$$\mathrm{E_{MAVAIL}} = \sum_{d=1}^{N_m} (\mathrm{E_{DAVAIL(d)}}) \quad (6)$$

Where the number of days in the month m is represented as N_m.

$$\mathrm{E_{MIMPT}} = \sum_{d=1}^{N_m} (MINIMUM(0, (\mathrm{E_{DSC}} - \mathrm{E_{DL}}))) \quad (7)$$

$$\mathrm{E_{MEXPT}} = \sum_{d=1}^{N_m} \left(MAXIMUM(0, (\mathrm{E_{DAVAIL}} - \mathrm{E_{DSC}}))\right) \quad (8)$$

On annual basis,

$$\mathrm{E_{ANSC}} = \sum_{d=1}^{365} (\mathrm{E_{DSC(d)}}) \quad (9)$$

$$\mathrm{E_{ANDL}} = \sum_{d=1}^{365} (\mathrm{E_{DL(d)}}) \quad (10)$$

$$\mathrm{E_{ANAVAIL}} = \sum_{d=1}^{365} (\mathrm{E_{DAVAIL(d)}}) \quad (11)$$

$$\mathrm{E_{ANIMPT}} = \sum_{d=1}^{365} (MINIMUM(0, (\mathrm{E_{DSC}} - \mathrm{E_{DL}}))) \quad (12)$$

$$\mathrm{E_{ANEXPT}} = \sum_{d=1}^{365} \left(MAXIMUM(0, (\mathrm{E_{DAVAIL}} - \mathrm{E_{DSC}}))\right) \quad (13)$$

2.2 The study site solar radiation data

The longitude and latitude of the PV installation site are 4.77° and 7.02° respectively (Figure 1). The Google map plot of the study site is shown in Figure 2 while the monthly and annual average meteorological data of the study site is presented in Figure 3. The UNIPORT'S Africa centre of excellence for public health and toxicological research is expected to have a 10 kW PV power that can sustain its daily activities for about 10.5 to 11 hours. In this paper, a 10 kW power supply that can supply energy to the center for 10.967 hours a day is selected. This system amounts to a daily load of 109.67 kWh/day and annual load of 40030 kWh/year.

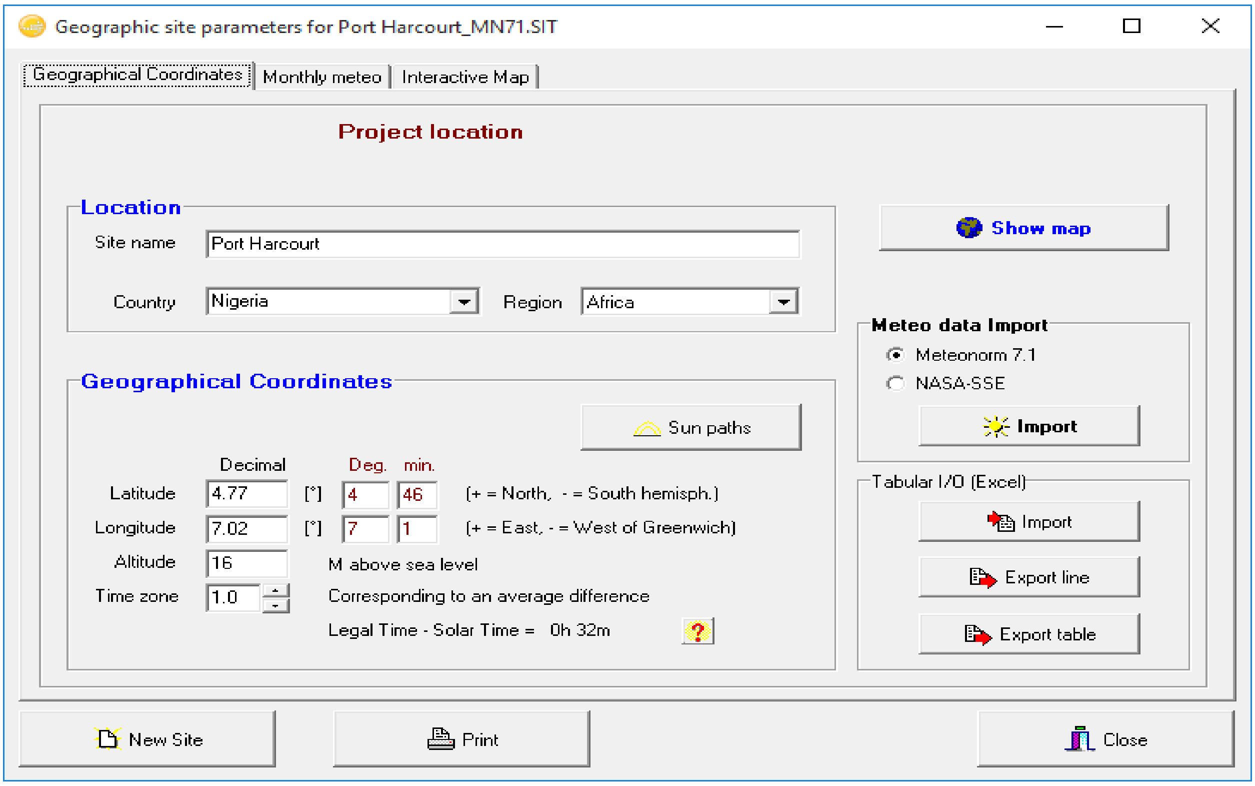


Figure 1 The longitude and latitude of the PV installation site

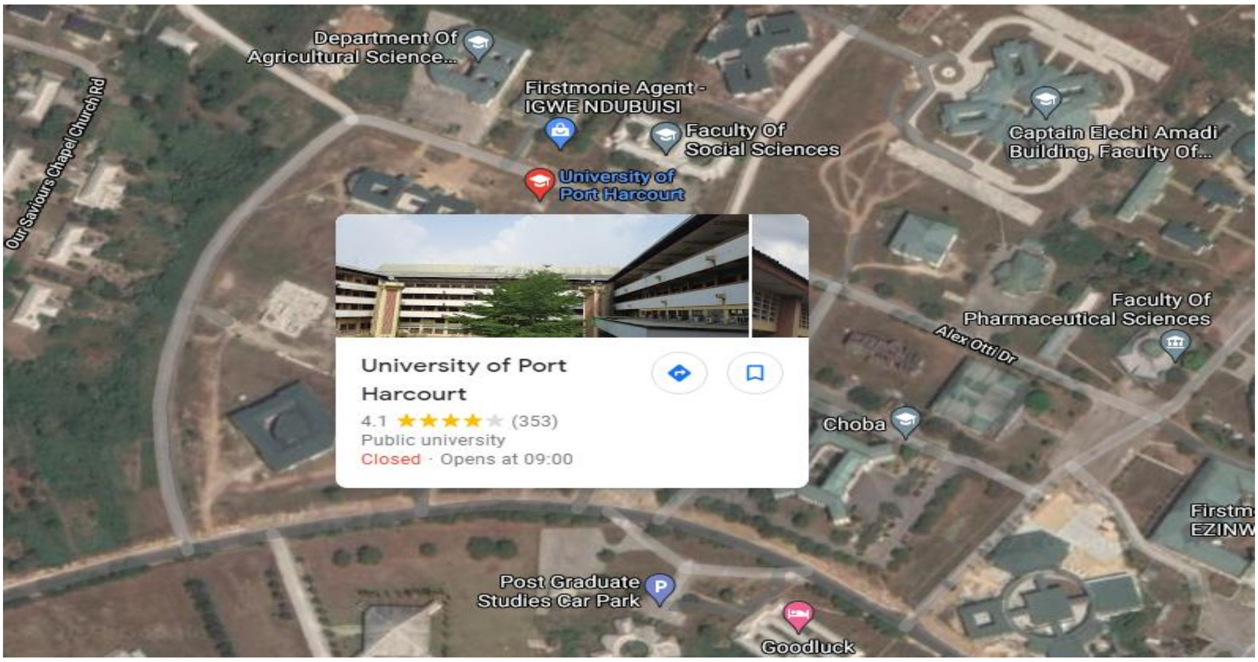


Figure 2 The Google map plot of the study site

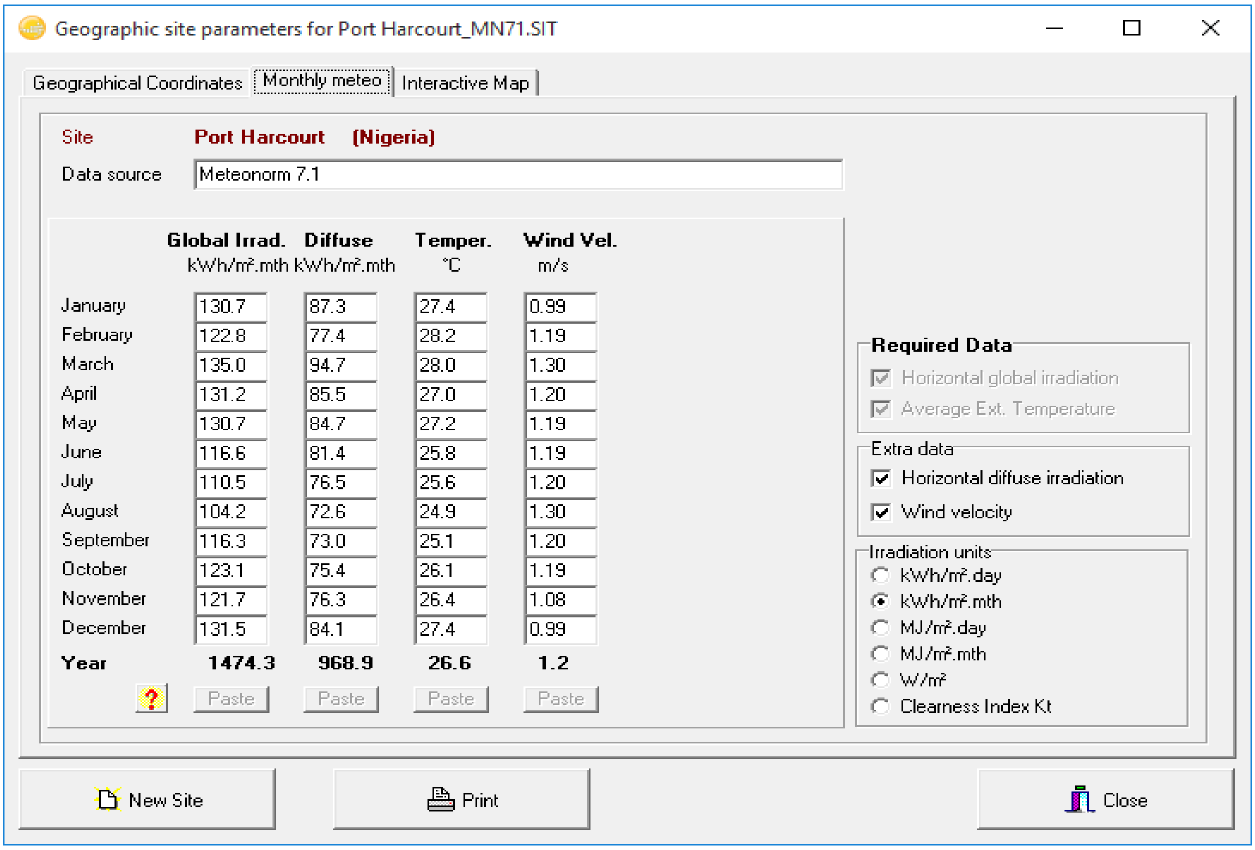


Figure 3 The monthly and meteorological data of the study site

3. Results and Discussion

PVSyst program was used to run the net zero analysis based on the estimated annual energy demand of 40030 kWh/year and for different optimal tilt angles. The first set of simulations were for a yearly fixed optimal tilt angle of 8° (Figure 4) and the simulation parameters are shown in Figure 5.

The silmulation results on the monthly and annual energy use , user's energy needs, imported energy, exported energy and net energy at yearly fixed tilt angle of 8° are shown in Table 1, Figure 6 and Figure 7. The results showed that annual imported energy and exported energy are both 23777 kWh/year resulting in a net energy of 0 kWh/year. Also, the annaul energy yield of the PV array is 40030 kWh/year which is also the same as the annual load demand. The self-consumed energy (which is 16253 kWh/year) and exported energy to the grid (which is 23777 kWh/year) sum up to 40030 kWh/year. Essentially, for the yearly fixed tilt angle of 8°, a net zero energy is achieved with the given set of simulation parameters; imported energy from the grid = exported energy to the grid).

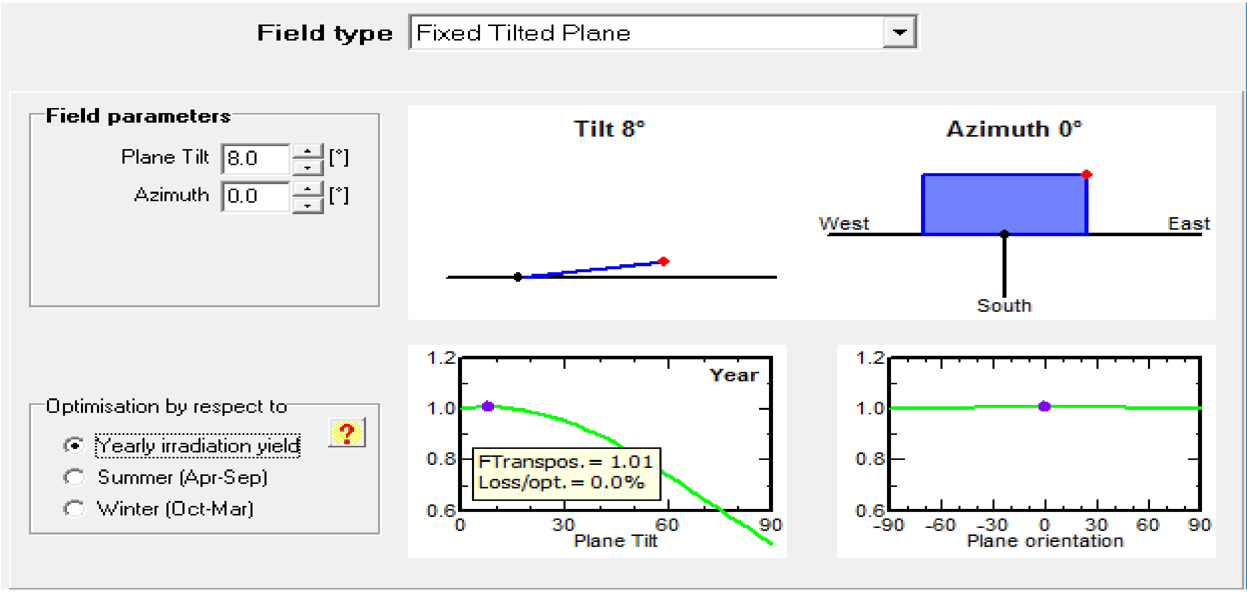
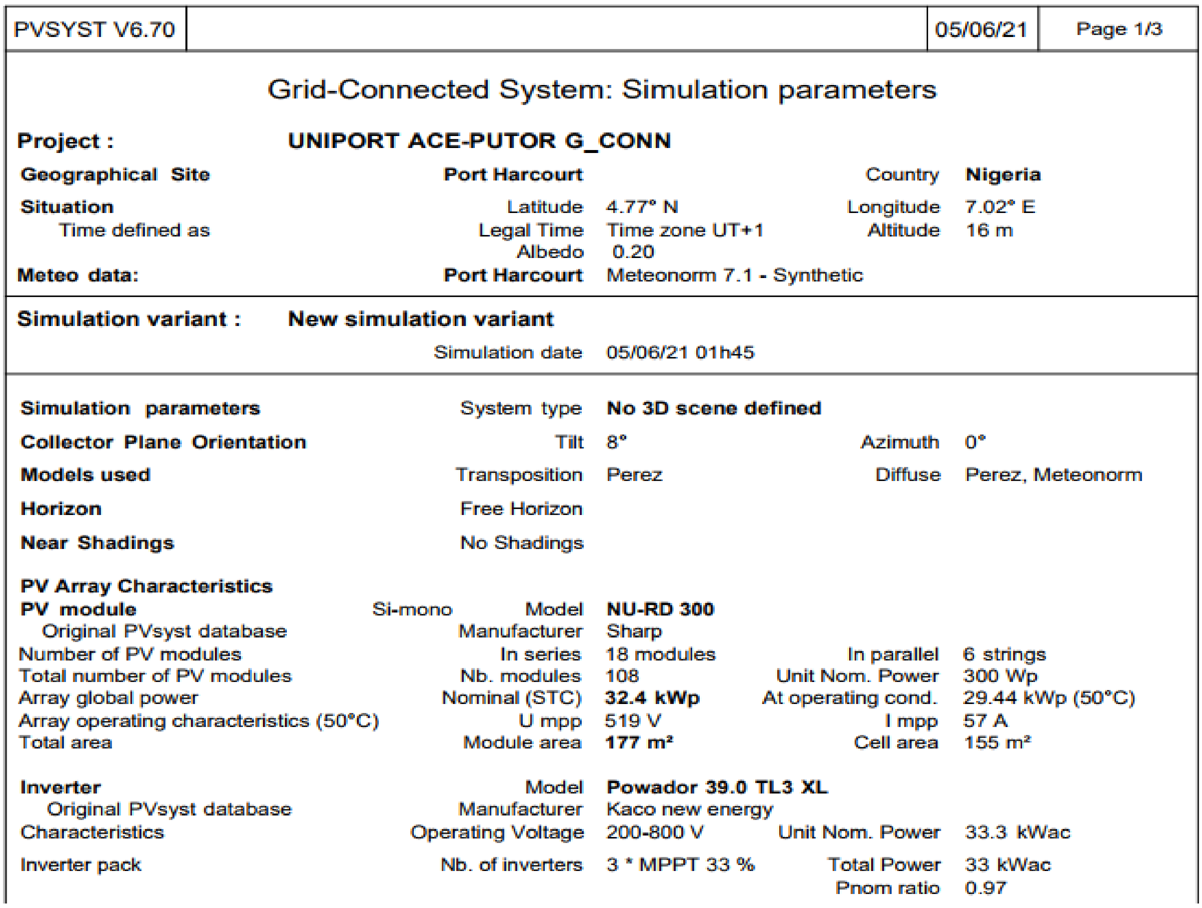


Figure 4 The Yearly Fixed Optimal Tilt Angle of 8°



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Grid-Connected System: Simulation parameters

Project : **UNIPORT ACE-PUTOR G_CONN**

Geographical Site — **Port Harcourt** — Country **Nigeria**

Situation — Latitude 4.77° N — Longitude 7.02° E

Time defined as — Legal Time: Time zone UT+1 — Altitude 16 m

Albedo 0.20

Meteo data: **Port Harcourt** — Meteonorm 7.1 - Synthetic

Simulation variant : **New simulation variant**

Simulation date 05/06/21 01h45

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

Collector Plane Orientation — Tilt 8° — Azimuth 0°

Models used — Transposition Perez — Diffuse Perez, Meteonorm

Horizon — Free Horizon

Near Shadings — No Shadings

PV Array Characteristics

PV module Si-mono — Model **NU-RD 300**

Original PVsyst database — Manufacturer Sharp

Number of PV modules — In series 18 modules — In parallel 6 strings

Total number of PV modules — Nb. modules 108 — Unit Nom. Power 300 Wp

Array global power — Nominal (STC) **32.4 kWp** — At operating cond. 29.44 kWp (50°C)

Array operating characteristics (50°C) — U mpp 519 V — I mpp 57 A

Total area — Module area **177 m²** — Cell area 155 m²

Inverter — Model **Powador 39.0 TL3 XL**

Original PVsyst database — Manufacturer Kaco new energy

Characteristics — Operating Voltage 200-800 V — Unit Nom. Power 33.3 kWac

Inverter pack — Nb. of inverters 3 * MPPT 33 % — Total Power 33 kWac

Pnom ratio 0.97

Figure 5 The PV power system simulation parameters

Table 1 PVSyst Result on Monthly and Annual Energy Use , User's Energy Needs, Energy yield of the PV Array, Imported Energy , Exported Energy and Net Energy at Yearly Fixed Tilt Angle of 8°

	E Avail (kWh)	E Load or Load Demand (kWh)	E User or Self Consumed Energy (kWh)	E_Grid (kWh)	SolFrac (kWh)	Deficit or *Imported Energy (kWh)*	Excess or Exported Energy (kWh)	Net Energy from and to The Grid (kWh)
Jan	3665	3400	1391	2274	0.409	-2009	2274	265
Feb	3363	3070	1252	2111	0.408	-1818	2111	293

Mar	3649	3400	1415	2234	0.416	-1985	2234	249
April	3482	3290	1381	2101	0.420	-1909	2101	192
May	3420	3400	1428	1992	0.420	-1972	1992	20
June	3073	3290	1359	1714	0.413	-1931	1714	-217
July	2923	3400	1359	1564	0.400	-2041	1564	-477
Aug	2796	3400	1294	1502	0.381	-2106	1502	-604
Sept	3150	3290	1285	1865	0.391	-2005	1865	-140
Oct	3373	3400	1335	2038	0.393	-2065	2038	-27
Nov	3418	3290	1346	2072	0.409	-1944	2072	128
Dec	3718	3400	1408	2310	0.414	-1992	2310	318
Year	**40030**	**40030**	**16253**	**23777**	**0.406**	**-23777**	**23777**	**0**

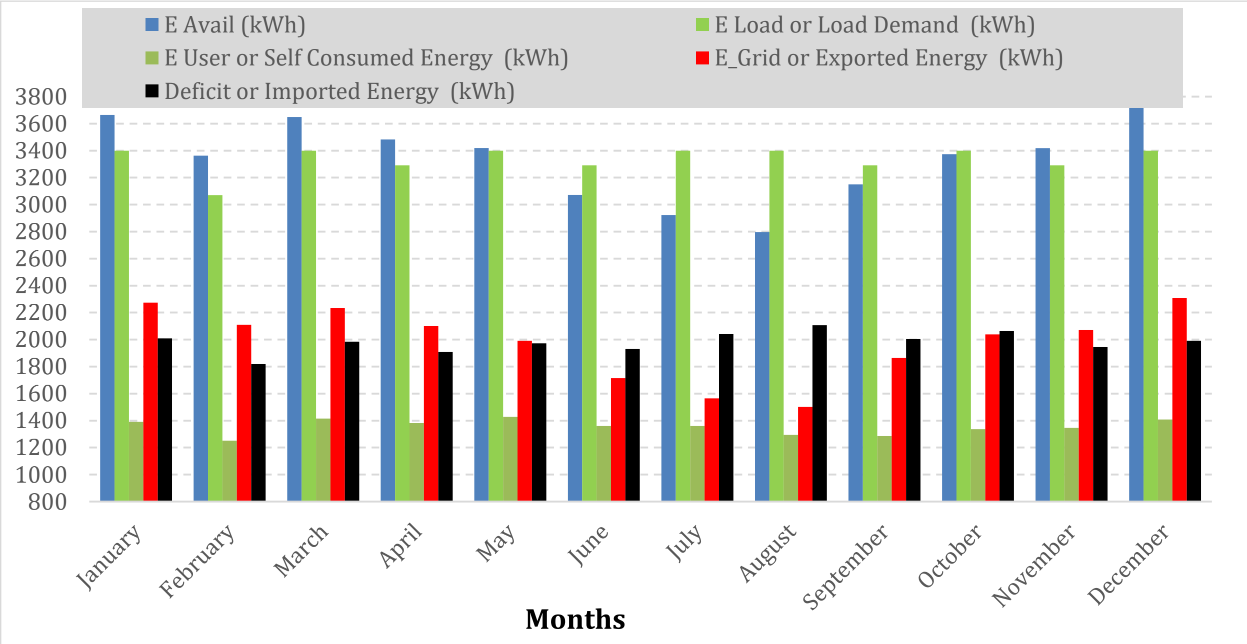

Figure 6 The Bar Chart of Results on Available Energy at the output of the PV Array, Load Demand, Self-Consumed Energy, Imported Energy and Exported Energy at Yearly Fixed Tilt Angle of 8°

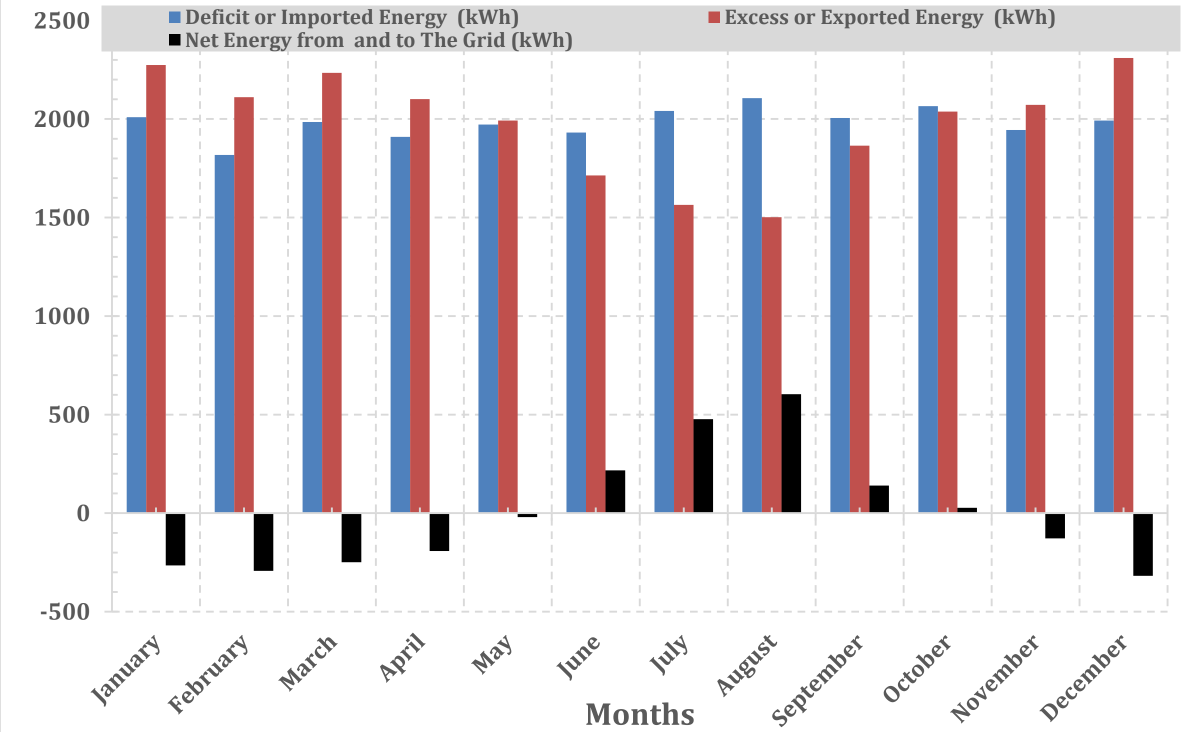

Figure 7 The Bar Chart of Results on Imported Energy , Exported Energy and Net Energy at Yearly Fixed Tilt Angle of 8°

The simulation was repeated for the two other cases, namely, the yearly fixed at Summer months optimal tilt angle of 0° and yearly fixed at Winter months optimal tilt angle of 28°. The silmulation results on the monthly and annual energy use , user's energy needs, imported energy , exported energy and net energy at yearly fixed at Summer months optimal tilt angle of 0° (Figure 8) are shown in Table 2. The results showed that annual imported energy is -23773 kWh/year and exported energy is 23633 kWh/year resulting in a net energy of -140 kWh/year.

Similarly, the silmulation results on the monthly and annual energy use , user's energy needs, imported energy , exported energy and net energy at yearly fixed at Winter months optimal tilt angle of 28° (Figure 9) are shown in Table 3. The results showed that annual imported energy is -23997 kWh/year and exported energy is 22139 kWh/year resulting in a net energy of -1858 kWh/year.

In all, the results shown in Table 3 and Figure 10 showed that the simulation at yearly fixed installation at angle of 0° gave the best result with highest annaul energy yeild of 40030 kWh/year and net energy of 0 kWh/year. The yearly fixed installation at Winter months optimal tilt angle of 28° gave the worst result with the lowest annaul energy yeild of 38172 kWh/year and net energy of -1858 kWh/year.

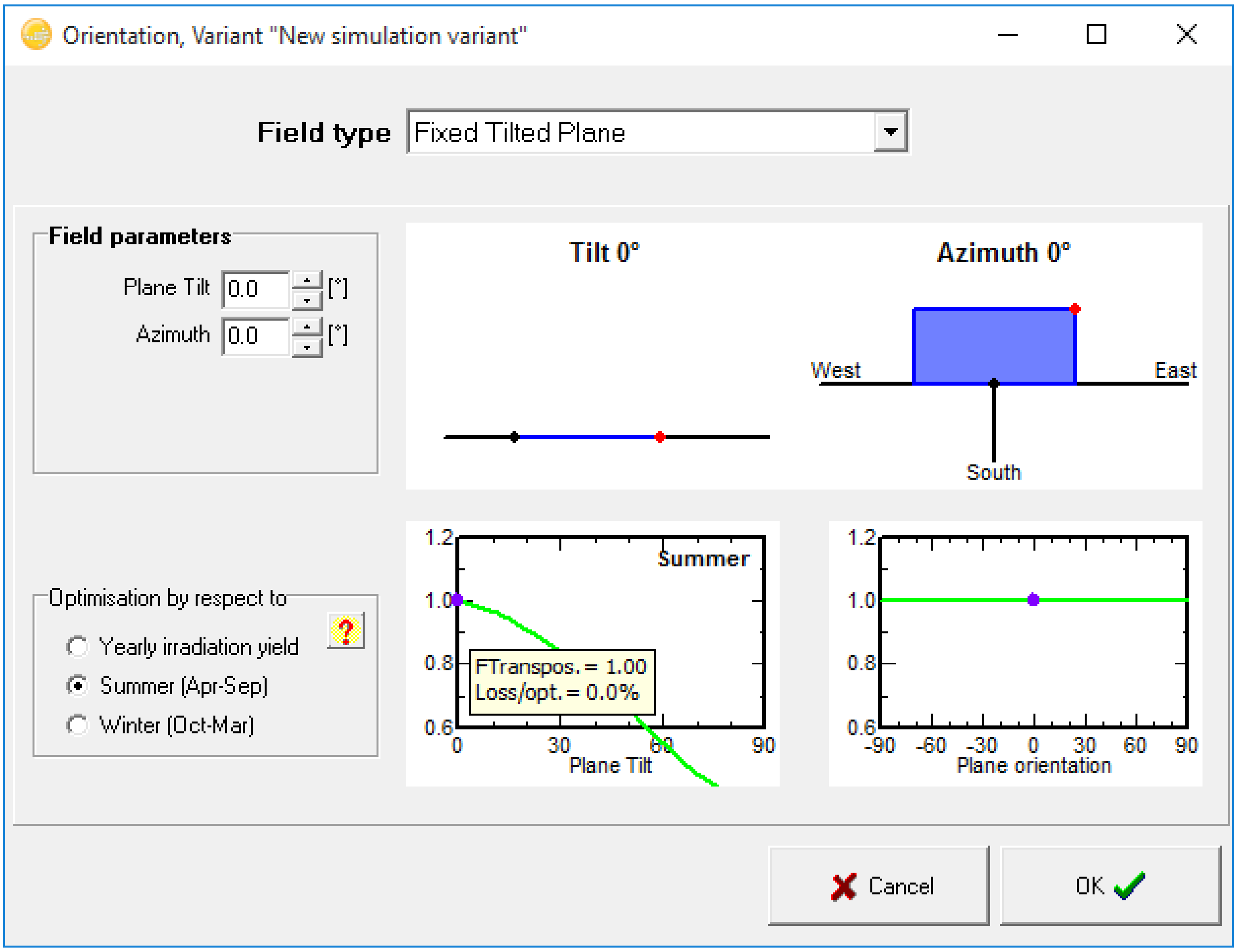

Figure 8 The Yearly Fixed Summer Months optimal tilt angle of 0°

Table 2 PVSyst Result on Monthly and Annual Energy Use , User's Energy Needs, Energy yield of the PV Array, Imported Energy , Exported Energy and Net Energy at Yearly Fixed at Summer months optimal tilt angle of 0°

	E Avail (kWh)	E Load or Load Demand (kWh)	E User or Self Consumed Energy (kWh)	E_Grid (kWh)	SolFrac (kWh)	Deficit or *Imported Energy (kWh)*	Excess or Exported Energy (kWh)	Net Energy from and to The Grid (kWh)
January	3526	3400	1381	2145	0.406	-2019	2145	126
February	3283	3070	1249	2034	0.407	-1821	2034	213
March	3629	3400	1415	2214	0.416	-1985	2214	229
April	3533	3290	1386	2147	0.421	-1904	2147	243
May	3526	3400	1436	2090	0.422	-1964	2090	126
June	3189	3290	1369	1820	0.416	-1921	1820	-101
July	3025	3400	1369	1656	0.403	-2031	1656	-375
August	2856	3400	1301	1555	0.383	-2099	1555	-544
September	3158	3290	1288	1870	0.391	-2002	1870	-132
October	3318	3400	1332	1986	0.392	-2068	1986	-82
November	3293	3290	1337	1956	0.406	-1953	1956	3
December	3554	3400	1394	2160	0.410	-2006	2160	154
Year	39890	40030	16257	23633	0.406	-23773	23633	-140

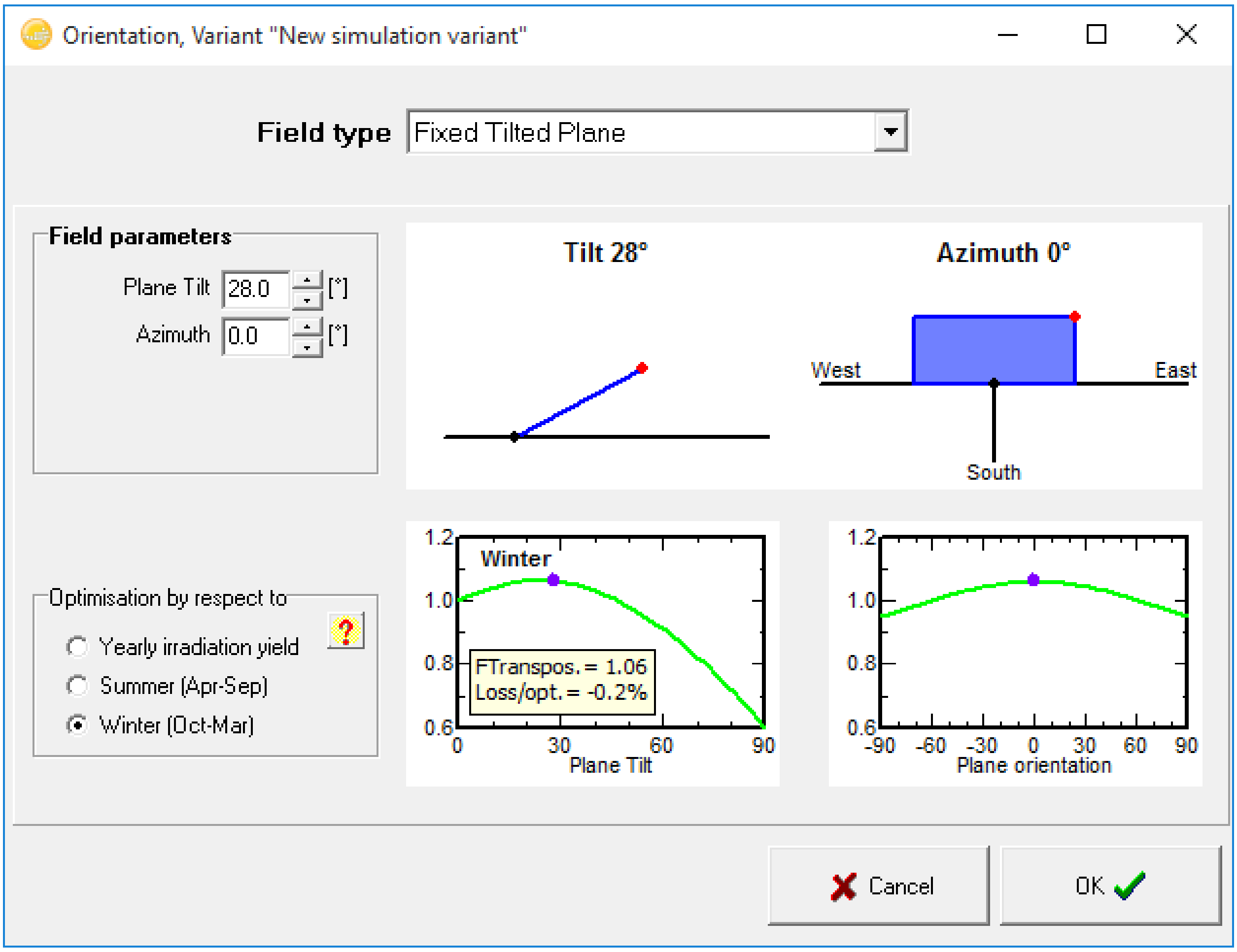

Figure 9 The Yearly Fixed Winter months optimal tilt angle of 28°

Table 3 PVSyst Result on Monthly and Annual Energy Use , User's Energy Needs, Energy yield of the PV Array, Imported Energy , Exported Energy and Net Energy at Yearly Fixed at Winter months optimal tilt angle of 28°

	E Avail (kWh)	E Load or Load Demand (kWh)	E User or Self Consumed Energy (kWh)	E_Grid (kWh)	SolFrac (kWh)	Deficit or *Imported Energy (kWh)*	Excess or Exported Energy (kWh)	Net Energy from and to The Grid (kWh)
January	3805	3400	1401	2404	0.412	-1999	2404	405
February	3372	3070	1247	2125	0.406	-1823	2125	302
March	3507	3400	1404	2103	0.413	-1996	2103	107
April	3163	3290	1352	1811	0.411	-1938	1811	-127
May	2965	3400	1380	1585	0.406	-2020	1585	-435
June	2617	3290	1309	1308	0.398	-1981	1308	-673
July	2512	3400	1310	1202	0.385	-2090	1202	-888
August	2500	3400	1260	1240	0.371	-2140	1240	-900
September	2958	3290	1264	1694	0.384	-2026	1694	-332
October	3325	3400	1327	1998	0.390	-2073	1998	-75
November	3536	3290	1356	2180	0.412	-1934	2180	246
December	3912	3400	1423	2489	0.419	-1977	2489	512
Year	**38172**	**40030**	**16033**	**22139**	**0.401**	**-23997**	**22139**	**-1858**

Table 4 Comparison of the Net Energy for the three cases; Yearly Fixed optimal tilt angle of 8°, Yearly Fixed at Summer months optimal tilt angle of 0° and Yearly Fixed at Winter months optimal tilt angle of 28°

	E Avail (kWh)	E Load or Load Demand (kWh)	E User or Self Consumed Energy (kWh)	E_Grid (kWh)	Deficit or *Imported Energy (kWh)*	Net Energy from and to The Grid (kWh)
Fixed at Optimal Tilt Angle of 8°	**40030**	**40030**	**16253**	**23777**	**23777**	**0**
Fixed at Summer Months Optimal Tilt Angle of 0°	**39890**	**40030**	**16257**	**23633**	**23773**	**-140**
Fixed at Winter Months Optimal Tilt Angle of 28°	**38172**	**40030**	**16033**	**22139**	**23997**	**-1858**

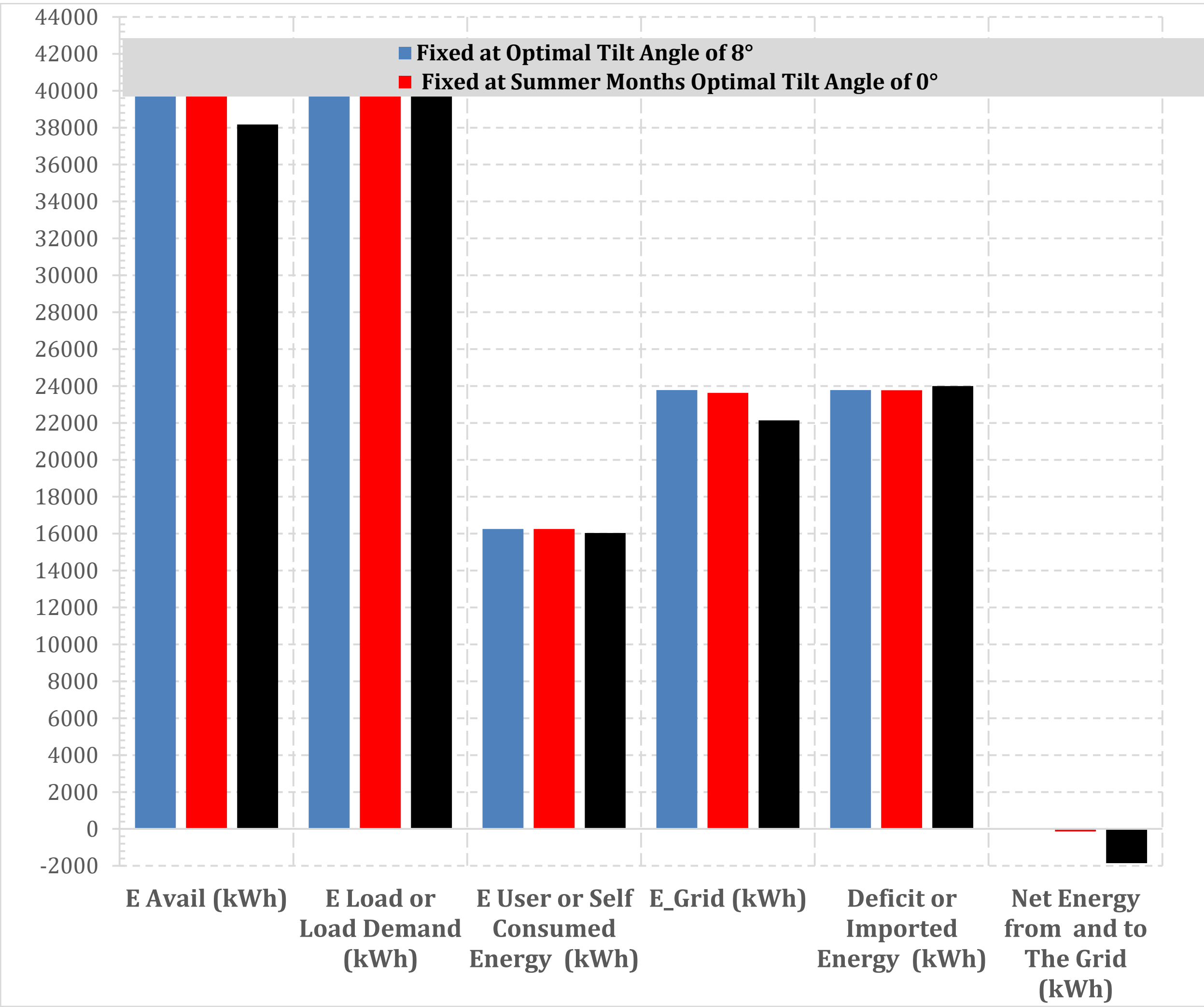

Figure 10 Comparison of the Net Energy for the three cases; Yearly Fixed optimal tilt angle of 8°, Yearly Fixed at Summer months optimal tilt angle of 0° and Yearly Fixed at Winter months optimal tilt angle of 28°

4. CONCLUSION

A grid-connected PV power system at University of Port, Rivers State Nigeria is analyzed for net zero operation based on three different annual optimal tilt angle orientations of the PV panels. The optimal tilt angles are obtained from PVSyst orientation dialogue box which gave yearly fixed optimal tilt angle of 8°, yearly fixed at Summer months optimal tilt angle of 0° and yearly fixed at Winter months optimal tilt angle of 28°. The results showed that the simulation at yearly fixed installation at angle of 0° gave the best result with highest annaul energy yeild and net zero energy while the yearly fixed installation at Winter months optimal tilt angle of 28° gave the worst result with the lowest annaul energy yeild and highest energy deficit (imported energy) per year. In all, the results showed that the PV tilt angle has significant influence on the energy yeild of the PV power system.

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