Comparison Of Annually Fixed And Biannual Seasonal Fixed Tilt Standalone PV Power System For Microfinance Bank In UYO

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Abstract— **In this paper, comparison of annually fixed and biannual seasonally fixed tilt standalone solar photovoltaic (PV) power system is presented. The PV system component sizes are determined based on the daily load demand (of 51084 Wh/day) for a case study Microfinance bank located in Akwa Ibom State, at latitude of 5.076302 and longitude of 7.905607. The study was conducted for four different cases, namely; Case I : where yearly optimal irradiation yield is obtained at fixed PV array tilt angle of 8° ; Case II : where optimal tilt angle for Summer months (April to September) is obtained at PV tilt angle of 0° ; Case III: where optimal tilt angle for Winter months (October to December and January to March) is obtained at PV tilt angle of 24° ; and Case IV : which is a hybrid , where the PV tilt angle is adjusted once in a year, so that it is optimally fixed for both the Summer and the Winter months. The results showed that the hybrid (dual tilt angle) case IV with tilt angle at 0° for summer months and 24° for winter months has the highest annual average transposition factor of 1.028476745 with an annual solar radiation on the PV tilted plane of 1703.9 kWh/m².yr whereas the Case III with optimal tilt angle of 24° gave the lowest annual average transposition factor of 0.975047 1624.9 and the lowest annual solar radiation on the PV tilted plane of 1624.9 kWh/m².yr . Also, the results show that the Case IV with hybrid (dual) tilt angle at 0° for summer months and 24° for winter months has the highest annual energy yield is about 102.68% of the energy yield of the reference Case I which is the annually fixed optimal tilt angle of 8°. In all, the bi-annually fixed tilt angle gave the highest annual energy yield.**

Keywords— Tilt Angle, Energy Yield, PV Power System, Transposition Factor, Fixed Tilt Angle, Irradiation Yield, Biannual Seasonal Fixed Tilt Angle

1. INTRODUCTION

Over the years, there has been steady drop in the cost of PV power system components which gives rise to steady growth in the adoption of PV power system across the globe [1,2,3,4,5,6,7,8]. Besides, the urgent need for environmentally friendly technologies and green power supplies has also facilitated the growing adoption of PV power systems [9,10,11,12,13,14,15,16,17,18,19]. In any case, as the adoption grows, there is also need for efficient PV power system. Among other methods, proper selection of the tilt angle of the PV array is known to improve the average solar radiation captured on the plane of the PV array [20,21,22,23,24,25]. This in turn improves the energy yield of the array.

However, the optimal tilt angle varies with time and location. For a given location, the optimal tilt angle need to be adjusted with time. This requires the use of solar tracking system [26,27,28,29,30]. In any case, for cost effective solution, the tracking mechanism can be avoided. Rather, the optimal tilt angle can be manually adjusted at some times in the year. Particularly, in this paper, the case of annually fixed optimal tilt angle and the second case of biannual adjusted tilt angle. In the first case, the optimal tilt angle is select at design time and the PV arrays are installed at that fixed optimal tilt; the array tilt angle is never adjusted. In the second case, the optimal tilt angle for the winter season months and another optimal tilt angle for the summer months optimal tilt angle are determined. The PV array is installed at the optimal tilt angle based on the season at which the installation is performed. At the beginning of the other season, the PV array tilt angle is adjusted to align with the optimal tilt angle of the second season. In this way, the PV array assume two different optimal tilt angles in a year. The performance of the system under the yearly fixed tilt angle and the biannually adjusted tilt angle are compared. PVSYssyt software [31,32,33,34,35] was used to implement the performance analysis. The relevant key analytical expression for the performance analysis are presented along with the simulation input datasets, the simulation results and the discussion of the results.

2. METHODOLOGY

The PV system component sizes are determined based on the daily load demand (Table 1) of a case study Microfinance bank located in West Itam 1 Uyo Akwa Ibom State, at latitude of 5.076302 and longitude of 7.905607 (Figure 1). The monthly solar radiation on the horizontal plane for the case study site is given in Table 2.

Table 1 The daily electric energy demand profile for the rural Microfinance bank in Akwa Ibom State (Source : [36])

Description of Item	Qty	Power (Watts)	Total load (Watts)	Daily Hour of Actual Utilization (hours)	Daily (Wh)
Wireless Access Point	2	12	24	24	576
Router	1	25	25	24	600
Server (plus accessories)	1	150	150	24	3600
Port fast Switch	1	15	15	24	360
Laptops (with security cables)	10	40	400	24	9600
HP Deskjet 5943	2	44	88	4	352
RF (Radio Communication)	1	40	40	24	960
Ceiling fans	4	60	240	24	5760
VOIP Phones	2	20	40	8	320
ATM Machine	2	1050	2100	12	24000
Laser Printer	1	100	100	3	300
Laptop (for miscellaneous uses)	1	40	40	12	480
Wireless Access Point	1	12	12	24	288
Lighting	4	15	60	24	1440
HP Deskjet (three-in-one)	1	44	44	12	528
Premises/Street Lightings	4	40	160	12	1920
Total			3538		51084

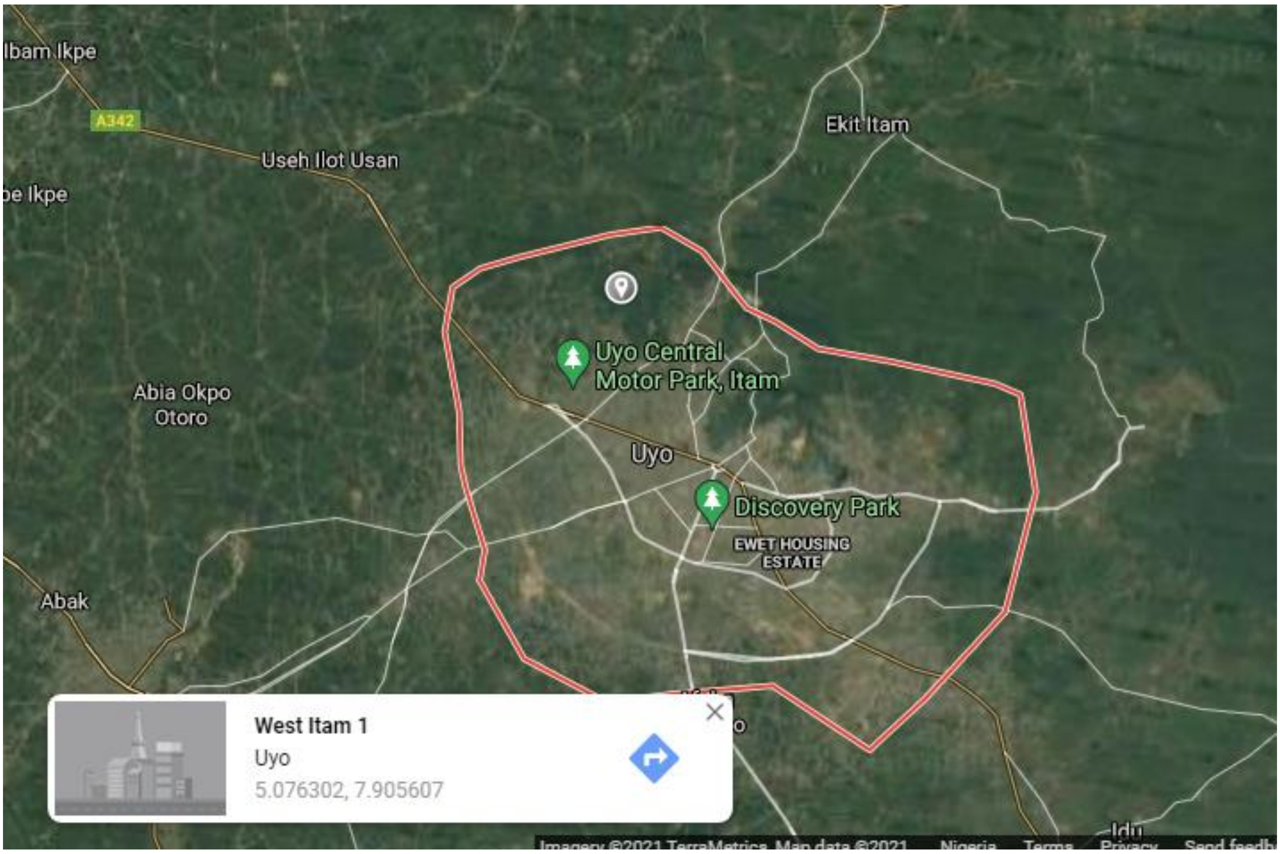

Figure 1 The Google map plot for the case study ICT Center in Akwa Ibom State

Table 2 Solar radiation on the horizontal plane for the case study site

Month	Monthly solar radiation on the horizontal plane kWh/m².mth
Jan	165.2
Feb	149.2
Mar	160.9
Apr	151.5
May	141.1
Jun	112.5
Jul	102.3
Aug	117.8
Sep	109.5
Oct	132.1
Nov	149.1
Dec	159
Annual	1650.2

Let the daily electric energy consumption for the case study ICT center be denoted as E_{ld}, the daily peak sun hour at the PV array installation site be PSH, inverter efficiency be η_{inv}, wiring efficiency be η_{wir}, manufacturers tolerance be f_{man}, temperature de-rating factor be f_{tem} and de-rating factor for dust be f_{dirt}, then the required PV rated peak power (P_{pv}) that can supply the required daily load E_{ld} is determined as follows;

$$P_{pv}= \frac{E_{ld}}{[(\eta_{\mathrm{inv}})(\eta_{\mathrm{wir}})][(f_{\mathrm{man}})(f_{\mathrm{tem}})(f_{\mathrm{dirt}})](PSH)} \quad (1)$$

where

$$f_{\mathrm{tem}} = 1-\left[\gamma\left(T_{cell.eff}-T_{stc}\right)\right] \quad (2)$$

Again, γ denotes the PV array temperature coefficient in C, T_{stc} denotes the standard test conditions cell temperature which is 25 C and $T_{\mathrm{cell.eff}}$ denotes the daily average cell temperature in C which is given as

$$f_{\mathrm{tem}} = \mathrm{Ta.day} + 25 \quad (3)$$

Where $T_{\mathrm{a.day}}$ denotes the average daytime ambient temperature in C.

The PSH data is based on the solar radiation on tilted plane of the PV array which can be fixed or adjusted. In this paper, the focus is on two cases, namely; one, sizing of the PV power supply for annual fixed tilted plane and two, sizing of the PV power supply for bi-annual fixed tilted plane. In the second case, within a year, the tilt angle of the PV array is adjusted once whereas in the first case, the tilt angle of the PV array is never adjusted. In each case, the optimal tilt angle is selected based on the solar radiation parameter values for the PV array installation site.

The optimal PV tilt angle ($\theta_{OAnnFxd}$) for annually fixed tilted PV array is given in terms of the installation site latitude (Lat) as follows;

$$\theta_{OAnnFxd} = 0.69\,|\mathrm{Lat}| \quad (3)$$

If the solar radiation incident on the PV array on a horizontal plane is denoted as PSH_h where the tilt angle is zero (0°) and the solar radiation incident on the PV array on a titled plane is denoted as $\mathrm{PSH}_{\theta t}$, then the transposition factor , T_f is given as ;

$$\mathrm{T}_f = \frac{\mathrm{PSH}_{\theta t}}{\mathrm{PSH}_h} \quad (4)$$

The higher the value of T_f the better. When the optimal tilt angle is selected, the annual average of T_f is such that $\mathrm{T}_f \geq 1$. However, when the tilt angle is not optimal, the annual average of T_f is such that $\mathrm{T}_f \leq 1$.

Specifically, in this paper, PVSyst software is used to select the optimal tilt angle for the annual fixed tilt and for the bi-annual adjusted tilt angle of the PV array. In each case, the analysis is meant to compare the annual energy yield and other key parameters of the system.

3. RESULT AND DISCUSSION

The first simulation was performed for the case I where yearly optimal irradiation yield is obtained at fixed PV array tilt angle of 8° (Figure 2). The second set of simulations were performed for the case II where optimal tilt angle for Summer months (April to September) is obtained at PV tilt angle of 0° (Figure 3). The third set of simulations were performed for the case III where optimal tilt angle for Winter months (October to December and January to March) is obtained at PV tilt angle of 24° (Figure 4). The fourth set of simulation is for case IV , which is a hybrid , where the PV tilt angle is adjusted once in a year, so that it is optimally fixed for both the Summer and the Winter months.

The different tit angles give rise to different transposition factors and hence different solar radiation on the tilted PV plane, as shown in Table 3 , Table 4 and Figure 5. The results in Table 3and Table 4 showed that the hybrid case IV with tilt angle at 0° for summer months and 24° for winter months has the highest annual average transposition factor of 1.028476745 with an annual solar radiation on the PV tilted plane of 1703.9 kWh/m².yr whereas the Case III with optimal tilt angle of 24° gave the lowest annual average transposition factor of 0.975047 1624.9 and the lowest annual solar radiation on the PV tilted plane of 1624.9 kWh/m².yr , as shown in Figure 6.

The results of the monthly and annual energy yield for the four different fixed tilt angles are given in table 5 and

Figure 7. The results show that the Case IV with hybrid tilt angle at 0° for summer months and 24° for winter months has the highest annual energy yield of 25450 kWh/yr which is about 102.68% of the energy yield of the reference Case I whereas the Case III with optimal tilt angle of 24° gave the lowest annual energy yield of 724093 kWh/yr which is about 97.2% of the energy yield of the reference Case I. In all, the dual annual fixed tilt angle gave the highest annual energy yield.

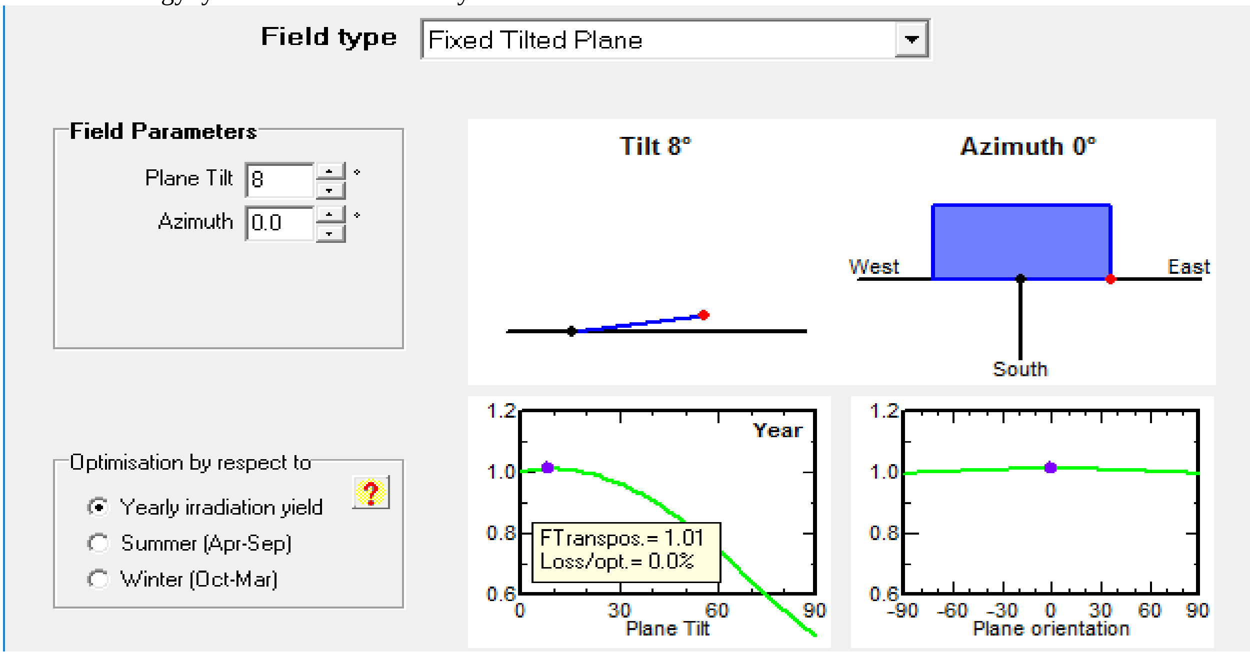

Figure 2 Yearly optimal irradiation yield fixed angle of 8°

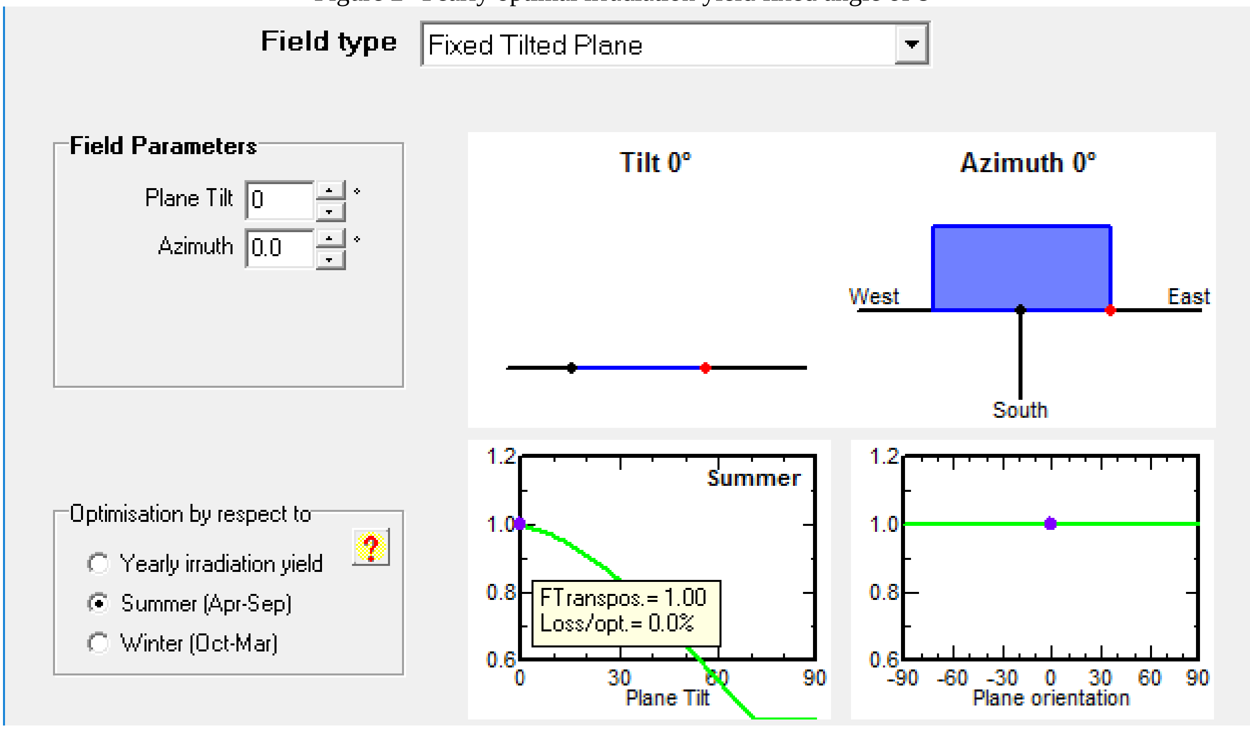

Figure 3 Optimal tilt angle for Summer months (April to September) fixed tilt angle

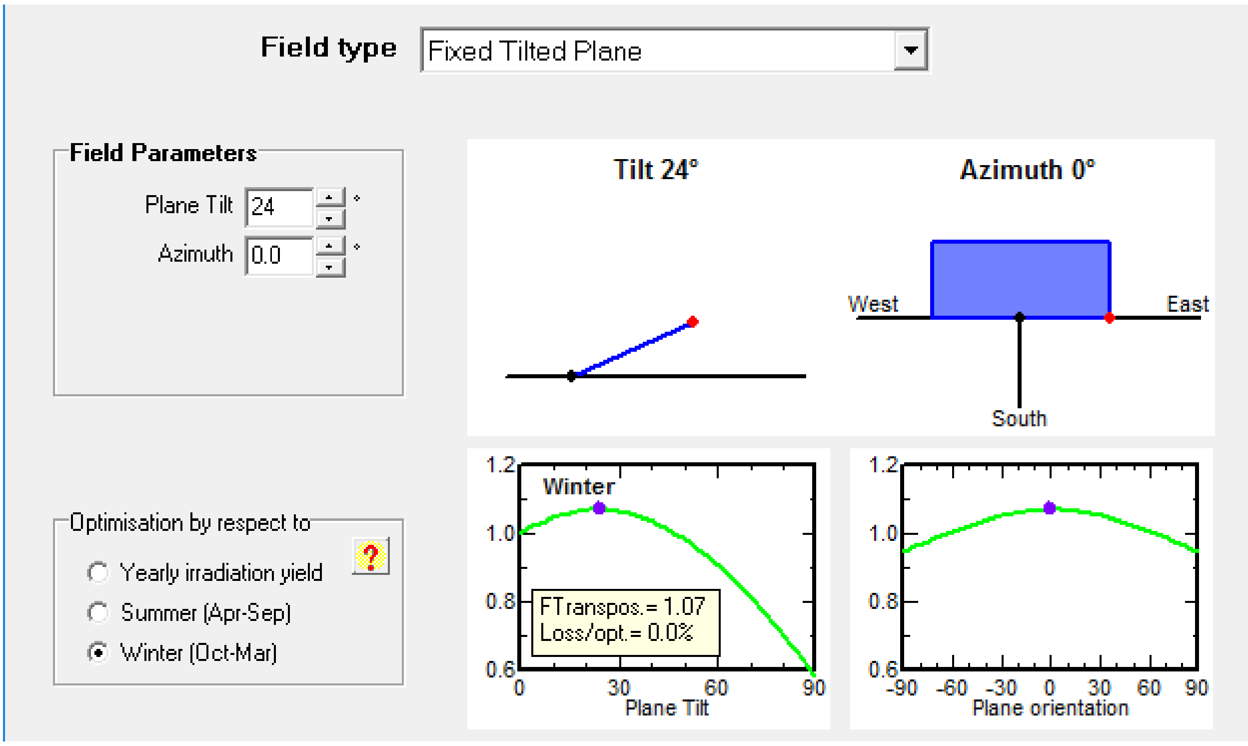

Figure 4

Optimal tilt angle for Winter months (October to December and January to March) fixed tilt angle

Table 3 Solar radiation on the tilted plane for the different fixed tilt angle

	kWh/m².mth	Case II: kWh/m².mth at 0°	Case I: kWh/m².mth at 8°	Case III: kWh/m².mth at 24°	Case IV: kWh/m².mth for the hybrid tilt at 0° for summer months and 24° for winter months
Jan	165.2	165.2	174.1	184	184
Feb	149.2	149.2	153.5	155.4	155.4
Mar	160.9	160.9	161.6	156.2	156.2
Apr	151.5	151.5	149	138.1	151.5
May	141.1	141.1	135.7	119.7	141.1
Jun	112.5	112.5	109	98.4	112.5
Jul	102.3	102.3	99.1	89.4	102.3
Aug	117.8	117.8	115.3	106.2	117.8
Sep	109.5	109.5	108.9	103.9	109.5
Oct	132.1	132.1	133.8	132.1	132.1
Nov	149.1	149.1	155.8	162.3	162.3
Dec	159	159	168.2	179.2	179.2
Annual Average	1650.2	1650.2	1664	1624.9	1703.9

Table 4 The Transposition factor for the different fixed tilt angles

Months	Transposition factor at 0° alone	Transposition factor at 8° alone	Transposition factor at 24° alone	Transposition factor for the hybrid tilt at 0° for summer months and 24° for winter months
1	1	1.053874	1.113801	1.113801453
2	1	1.02882	1.041555	1.04155496
3	1	1.004351	0.970789	0.97078931

4	1	0.983498	0.911551	1
5	1	0.961729	0.848335	1
6	1	0.968889	0.874667	1
7	1	0.968719	0.8739	1
8	1	0.978778	0.901528	1
9	1	0.994521	0.948858	1
10	1	1.012869	1	1
11	1	1.044936	1.088531	1.088531187
12	1	1.057862	1.127044	1.127044025
Annual Average	1	1.004904	0.975047	1.028476745

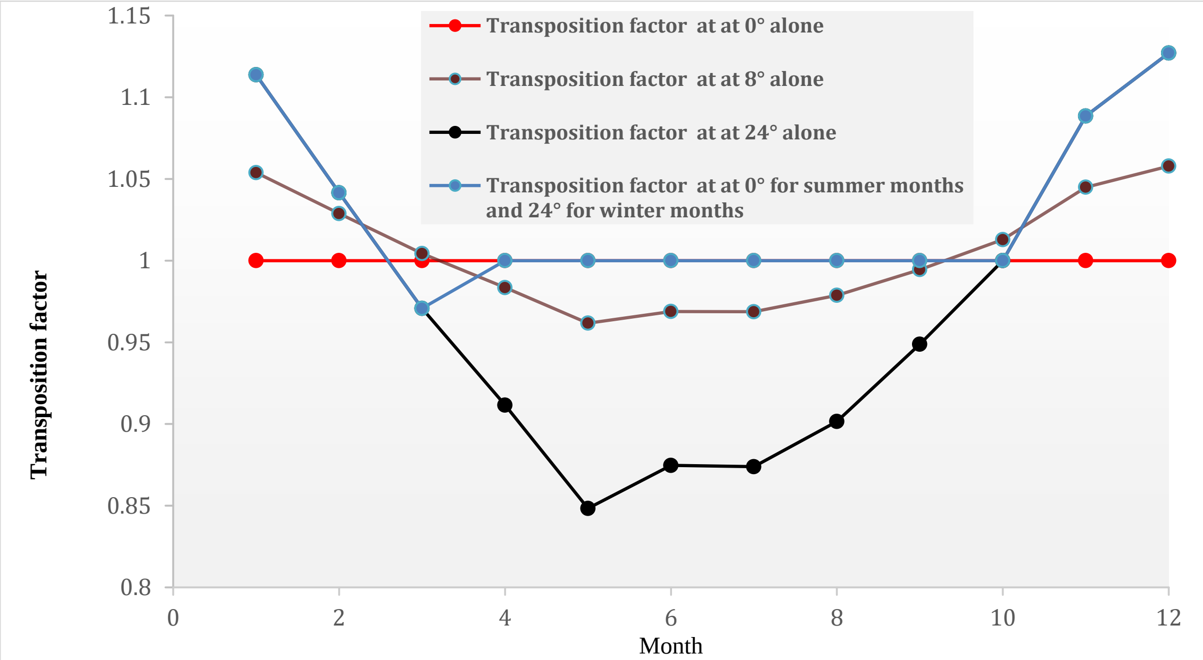

Figure 5 **Transposition factor for the different fixed tilt angles**

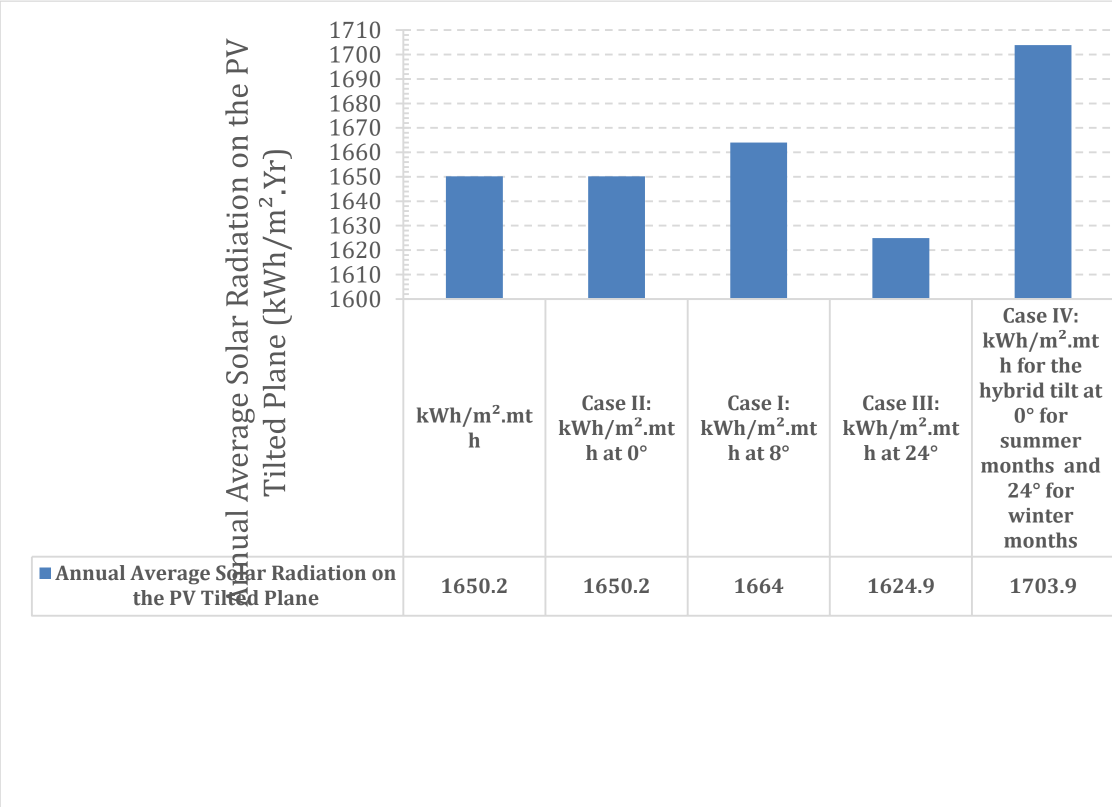

Figure 6 Annual Average Solar Radiation on the PV Tilted Plane (kWh/m².Yr)

Table 5 The monthly and annual energy yield for the four different fixed tilt angles

Month	Case I: E Avail 8° in kWh	Case II: E Avail 0° in kWh	Case III: E Avail 24° in kWh	Case IV: E Avail 0° and 24° in kWh
January	2565	2427	2723	2723
February	2312	2249	2331	2331
March	2493	2467	2395	2395
April	2277	2313	2094	2313
May	2025	2129	1709	2129
June	1565	1629	1396	1629
July	1388	1431	1255	1431
August	1700	1739	1522	1739
September	1560	1566	1474	1566
October	1930	1899	1923	1923
November	2340	2231	2465	2465
December	2629	2477	2806	2806
Year	24784	24557	24093	25450
Normalized E Avail	100	99.08409	97.21191	102.6872

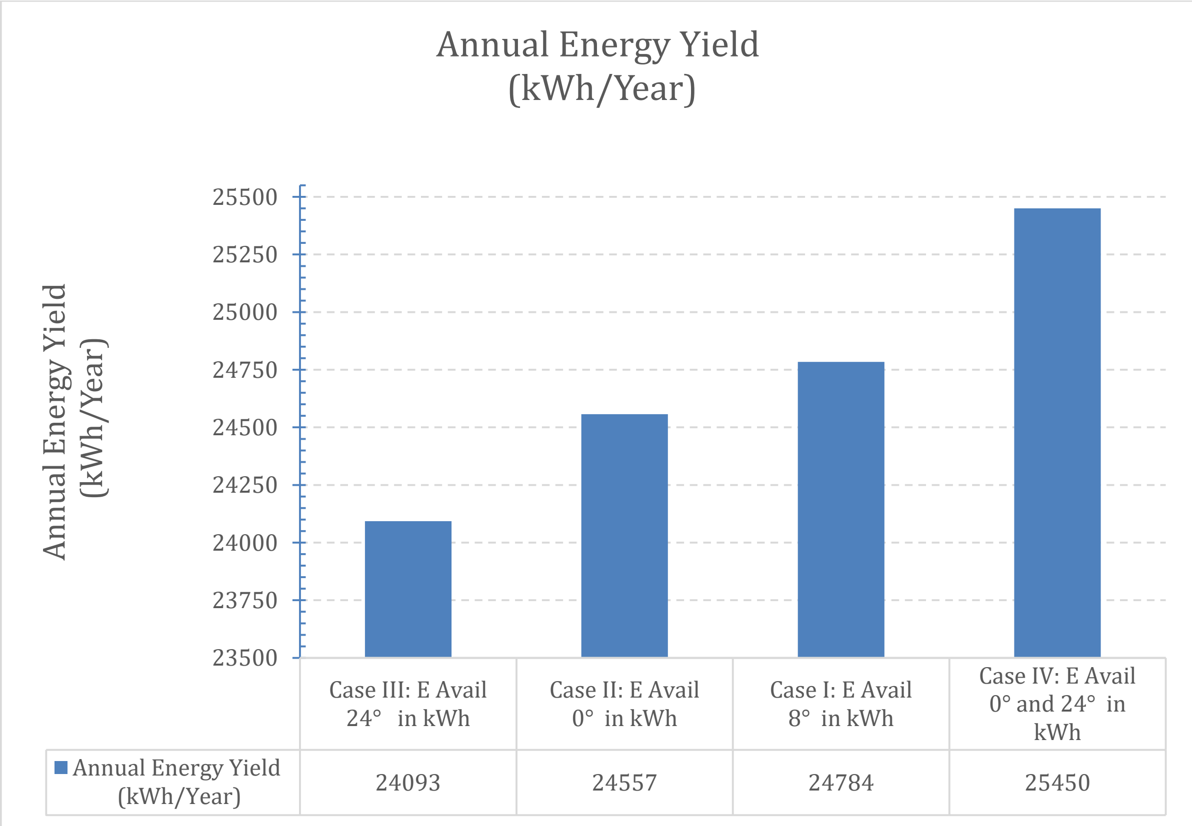

Figure 7 The annual energy yield for the four different fixed tilt angles

4. CONCLUSION

The effect of PV tilt angle on the effective solar radiation and the energy output from the PV array is presented. The study used a case study microfinance bank and simulated the energy output of the PV for four different cases, namely;

- Case I : where yearly optimal irradiation yield is obtained at fixed PV array tilt angle of 8° ;
- Case II : where optimal tilt angle for Summer months (April to September) is obtained at PV tilt angle of 0° ;
- Case III: where optimal tilt angle for Winter months (October to December and January to March) is obtained at PV tilt angle of 24° ;
- Case IV : which is a hybrid , where the PV tilt angle is adjusted once in a year, so that it is optimally fixed for both the Summer and the Winter months.

The results show that the Case IV with hybrid tilt angle at 0° for summer months and 24° for winter months has the highest annual energy yield is about 102.68% of the energy yield of the reference Case I. in all, the dual annual fixed tilt angle gave the highest annual energy yield.

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