5ER-O06: Performance Analysis and the Returns of Investment of Solar PV in Residential scale: Cases of the Installation in Thawiwatthana District, Bangkok.

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Abstract

Thailand is one of the top producers of renewable resources for electricity generation. the solar radiation potential in the central region has 18.1 MJ/m^2 per day. Thailand has great potential and a history of success to develop solar PV for electricity generation. Therefore, the government tries to encourage the installation of solar PV on a residential scale (solar rooftop). It also has carried out the objective of promoting solar energy investment for electricity generation on the residential scale. This study aims to investigate the performance analysis and the returns of investment of the selected solar PV installations in the residential scale in the selected region of Bangkok. Since the solar PV panel prices have been decreased rapidly, the motivations of solar PV installations on the residential scale are increased. In this study, the installations of solar PV on a rooftop scale in Thawiwatthana District are selected. The four-location installations of solar PV rooftops are selected in this district. The performance results of the solar PV installations are also compared with the simulation values obtained from PV-GIS software. The performance analysis includes The final yield of each solar PV installation, an annual performance ratio (PR), and an annual electricity generation (MW h/annum). The economic viability of investment in solar PV installation is in comparison by using the net present value (NPV), internal rate of return (IRR), and payback period (PB). These results can be used as a decision making for the investors in solar PV rooftop installations. The PR of the PV systems of solar PV rooftop installations in this study varies from 77% to 78% and their yearly energy yields range from 1,566.4 kWh/kW$_p$ to 1,566.6 kWh/kW$_p$. Equity %IRR is relatively between 10.3-13.5% and the payback periods are relatively less than 8 years. The return of investments are depending on the sizes of the household and the electricity consumptions.

Keywords: Solar PV, Solar PV rooftop, Performance analysis, Returns of investment, Solar-GIS and PV-GIS.

Introduction

The Ministry of Energy expected the proportion of renewable energy technology to be 20%, or higher than the former PDP2010 Revision 2 plan, using under consideration the long time Alternative Energy Development Plan 2015-2036 (DEDE, 2015). And then in 2015-2036, the increase of renewable electricity may be extended with the aid of following its ability and advanced generation development. Since power generation is projected to increase, renewable power and opportunity power are considered ability alternatives to the increasing electricity consumption. Solar energy is an important source for electricity generation as Thailand has a high potential for solar irradiation of all parts, including in Bangkok. The objective of this study is followed the government plan to promote the installation of solar PV rooftops on the residential scale. The results of this study can be used as the information for solar PV

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investment located in Thawiwatthana District. Thawiwatthana District was selected for this study because the author needs to investigate the possibility of solar PV rooftop investments in the residential scale in the areas located near Bangkokthonburi University.

Methodology

This paper investigates the electricity harvesting in the installations of solar PV on a rooftop scale in Thawiwatthana District, Bangkok with polycrystalline silicon (poly c-Si). Solar irradiation dataset in horizontal plan (in Figure 1), in optimal inclination angle, obtained from SolarGIS software. The Solar-GIS enables us to consider key characteristics of a PV system (Perez et al., 2002) as described in Figure 2. The technical assumptions in this research have followed the method in Solar-GIS software (Skoczek et al., 2008, 2009). The economic outputs such as the internal rate of return and the simple payback period of investment of electricity generation from solar PV power plants were computed for a range of inputs of capital cost, discount rate, loan terms, and interest rests, normalized annual electricity generation, and electricity feed-in tariffs.

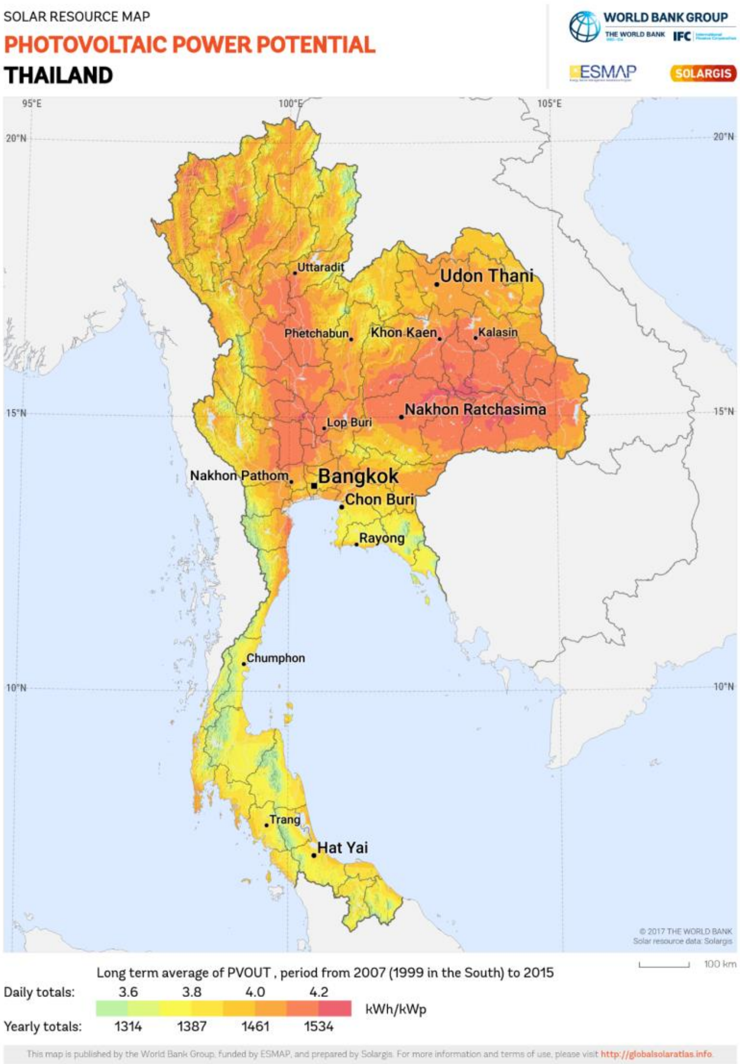

Figure 1 Photovoltaic power potential in Thailand.

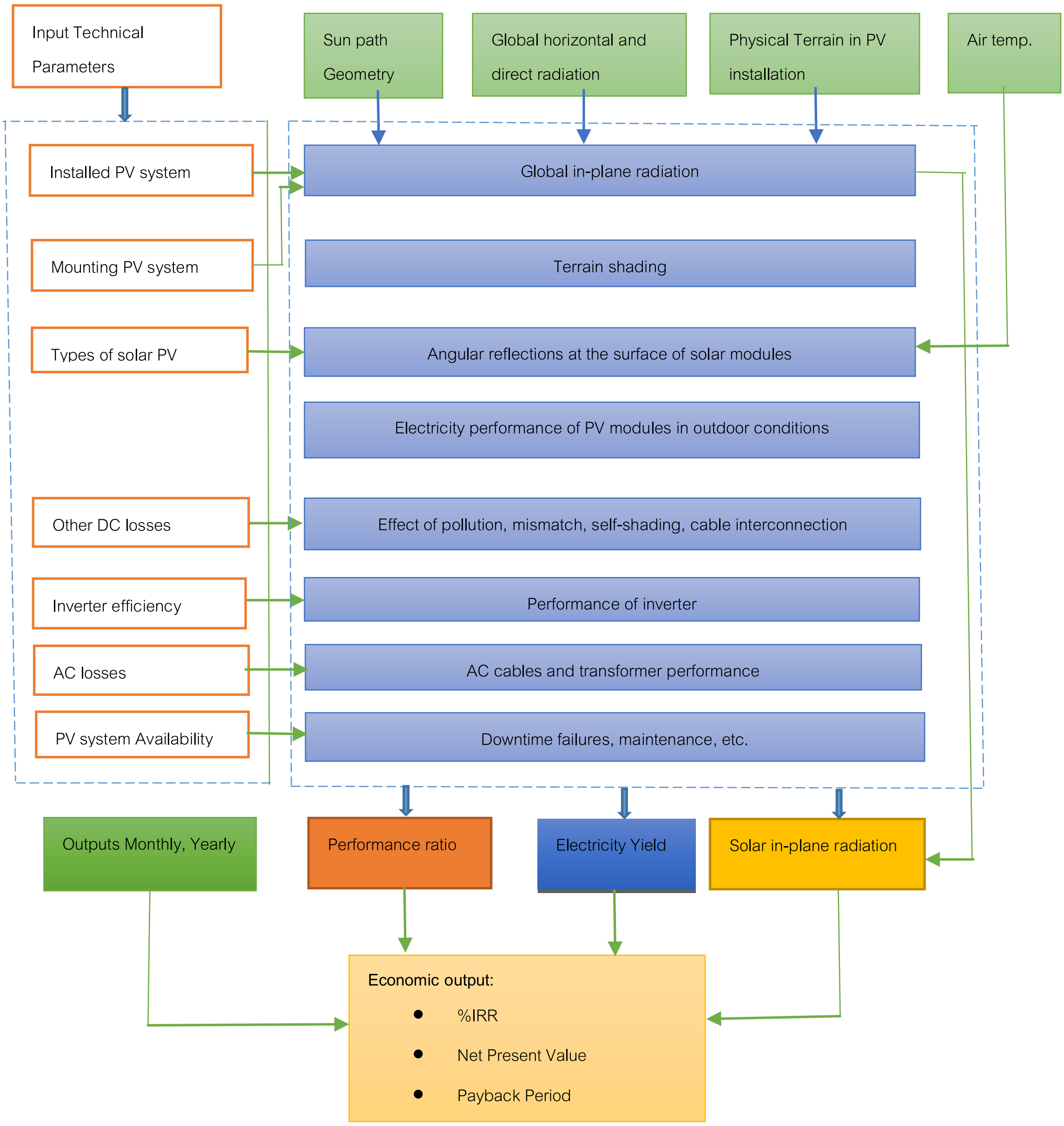

Figure 2 Simulation methodology.

Results and discussion

Most of the areas in Thailand have a high potential for solar irradiance. This study is aimed to obtain solar irradiation and electricity generation of 3-4.5 kW installation of solar rooftop in the residential scale. The optimal inclined fixed PV solar power plant in each region with polycrystalline solar module has been investigated by SolarGIS software.

Solar irradiation

This study investigates four locations in Bangkok, Thawiwatthana District. The SolarGIS dataset is chosen because it had the lowest mean bias errors (MBE) and root means square errors (RMSE). The MBE and RMSE of SolarGIS dataset were 2.5% and 7.9% when compared with MBE and RMSE of NASA dataset were 2.7% and 9.3%, respectively. The positive value of MBE means that it overestimates with a maximum deviation of 7.9% and the prediction of energy output used is therefore reduced by 7.9%. Geographical position in main highly potential areas in Bangkok has been studied.

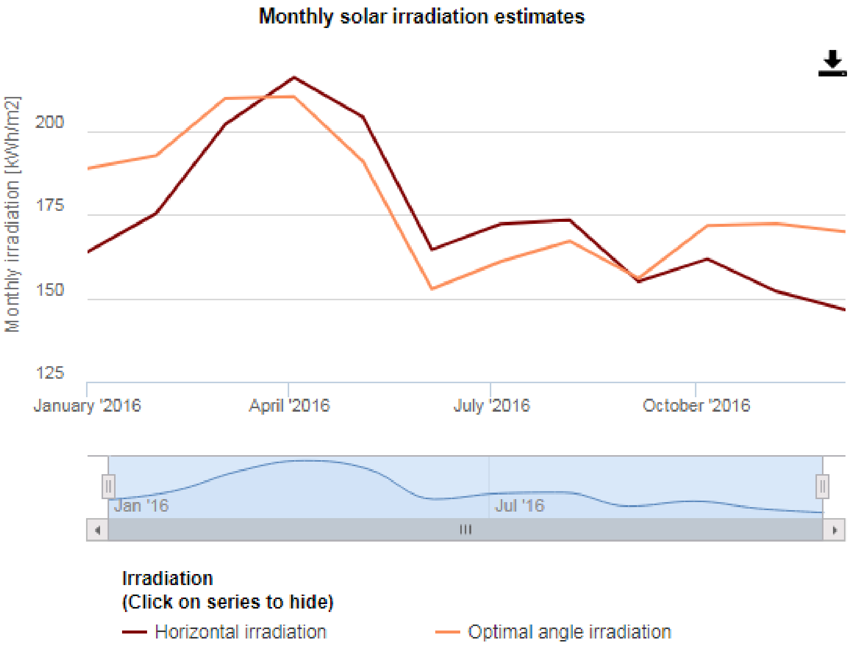

Figure 3 Monthly solar irradiation of irradiation data, in 2016, obtained from site A

Table 1 Physical position and yearly average solar radiation in horizontal, optimal inclination, of the selected locations in Bangkok, Thawiwatthana District.

Site locations	Latitude, longitude	Optimal angle	Solar irradiation (kWh/m^2), yearly	
			Horizontal Plane	In optimal inclination
Site A	13.769048 N, 100.343586 E	17°	2027.47	2017.00
Site B	13.768793 N, 100.342326 E	17°	2027.47	2017.00
Site C	13.768629 N, 100.341497 E	17°	2027.47	2017.00
Site D	13.768779 N, 100.341021 E	17°	2027.47	2017.00

Table 2 Average monthly sum of irradiation in-plane per square meter received by the modules of the given system [kWh/m²].

Month	Site A, 3kW	Site B, 3.5 kW	Site C, 4.0 kW	Site D, 4.5 kW
January	188,3	188,3	188.3	188.3
February	183.5	183.5	183.5	183.5
March	197.7	197.7	197.7	197.7
April	188.3	188.3	188.3	188.3
May	169.0	169.0	169.0	169.0
June	144.4	144.4	144.4	144.4
July	145.4	145.4	145.4	145.4
August	152.5	152.5	152.5	152.5
September	149.9	149.9	149.9	149.9
October	151.1	151.1	151.1	151.1
November	166.0	166.0	166.0	166.0
December	181.6	181.6	181.6	181.5
Year	2017.61	2017.62	2017.62	2017.60

Table 3 Average monthly electricity production from the given system [kWh].

Month	Site A, 3kW	Site B, 3.5 kW	Site C, 4.0 kW	Site D, 4.5 kW
January	441.5	515.0	588.6	662.1
February	425.6	496.5	567.5	638.4
March	452.1	527.4	602.7	678.0
April	429.0	500.5	572.0	643.5
May	386.6	451.1	515.5	579.9
June	337.4	393.6	449.9	506.1
July	341.8	398.7	455.7	512.6
August	357.6	417.1	476.8	536.3
September	351.5	410.1	468.7	527.2
October	354.7	413.7	472.9	531.9
November	391.8	457.1	522.4	587.6
December	430.1	501.8	573.5	645.1
Year	4699.7	5482.48	6266.09	7048.78

Site selection and electricity generation

In this study, four site locations in Bangkok, Thawiwatthana District, have been selected. The site selection with the high potentials of solar radiation. The capacity installation of solar PV rooftop in the residential scale in the range of 3.0 kW-4.5 kW installations. The meteorological data and some physical data of the yearly average solar radiation in horizontal, and in the optimal inclination, in all selected sites. Table 2 shows the solar irradiation of in-plane per square meter in all site locations in this study. Table 3 shows an average of monthly electricity production from the solar PV rooftop system on the residential scale, with the optimal angle of 17o in Bangkok, Thawiwatthana District.

Detailed solar assessment

Solar irradiation data represent some of the most important inputs for a solar energy assessment of energy yield. This analysis was obtained from site-specific meteorological data, including temperature and humidity values in the selected regions in Bangkok, Thawiwatthana District. The one selected site A, used for example is the site location at the latitude 13.769048 N, longitude 100.343586 E is shown in Figure 3 (solar irradiation data in 2016) and Table 1. The daily global solar irradiation shows the highest value of 215.84 kWh/m2 in April and the lowest value of 155.94 kWh/m2 in September. Also, the solar irradiation in-plane of optimal tilted angle installation shows the highest value of 210.11 kWh/m2in April, and the lowest value of 155.89 kWh/m2 in September, correspondingly.

Energy output assessment

The electricity generation of installation with the range of 3.0 kW-4.5 kW in the solar rooftop in the residential scale installation in different solar modules is investigated by SolarGIS software. The loss in the solar PV systems including 97.5% inverter efficiency, 5.5% DC losses, 1.5% AC losses, and 99% electricity availability generation. The loss in the module type is described in detail due to its specific characteristic in Table 2, and Figure 4. The energy loss varies in different regions due to the effect of the temperatures in each site location.

Performance ratio

The PR of a PV system indicates how close it approaches ideal performance on the location, tilt angle, orientation, and nominal rated power capacity. The performance ratio is defined by the following equation.

$$PR = \frac{E_{AC}}{G_m \eta_{STC}} \tag{1}$$

where E_{AC} is yearly of power of the installed PV array of its efficient (η_{STC}) at standard test conditions (STC) of solar irradiance of 1 kW/m^2 G_m and cell temperature 25^{o}C

The performance ratios in solar PV resident rooftop in this study are shown in Table 3, in all site locations have the same value at 77.64%

Capacity factor

The capacity factor (CF) is defined as the ratio of actual annual energy output to the amount of energy the PV system would generate if it operated at full rated (PPV rated) power for 24 hours per day for one year, the capacity factor is given in the following equation:

$$CF = \frac{E_{AC}}{P_{PVrated} \times 8760} \qquad (2)$$

The capacity factors in this study are shown in Table 3, in all site locations have the same value at 17.88%

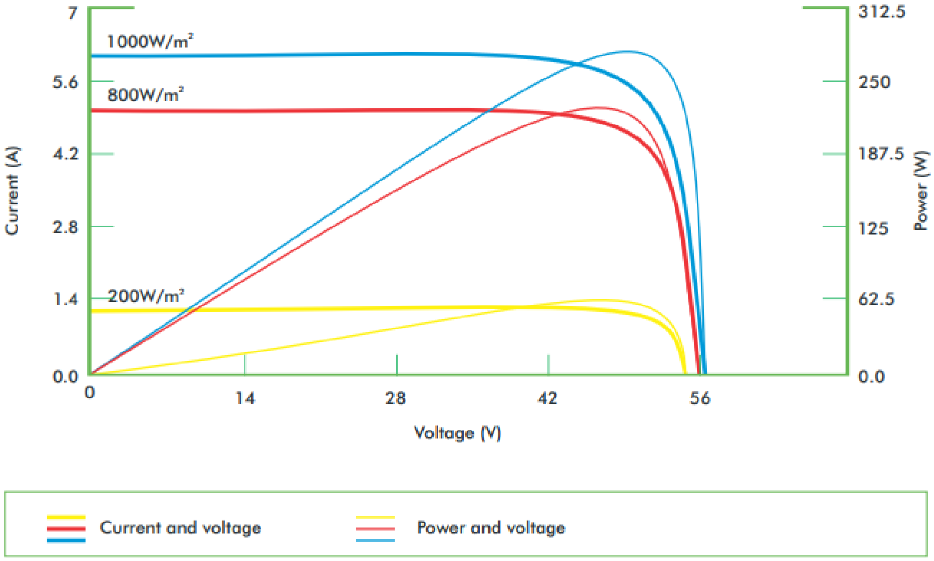

Figure 4 Solar module voltage and current relation characteristic

Table 4 Specification of PV module in this study

Solar panel type	Polycrystalline PV
Manufacturer	SENTSYS
PV model	SENTSYS-250W
Maximum Power at STC (Pmax)	250 Wp
Module efficiency	15.3%
Maximum Power Voltage (Vpm)	35.1 V
Maximum Power Current (Ipm)	7.94 A
Temperature Coefficient (Pmax)	-0.47 %/°C
Temperature Coefficient (Voc)	-0.34 %/°C
Temperature Coefficient (Isc)	+0.06%/°C

Table 5 Annual electricity production of PV modules of the installation in optimal inclination in selected locations in Thailand

Site locations and installed capacity	Electricity production kWh	PF (%)	PR (%)
Site A, 3.0 kW	4699.70	17.88	77.64
Site B, 3.5 kW	5482.48	17.88	77.64
Site C, 4.0 kW	6266.27	17.88	77.64
Site D, 4.5 kW	7048.78	17.88	77.64

Table 6 The result of returns in investment in each site location

Sites and installed capacity	Estimated Energy consumption (kWh/year)	Electricity cost (Baht/kWh)	Net Present Value (Thai Baht)	Equity IRR (%)	Payback (years)
Site A, 3.0 kW	3,200	3.346	39,525	10.3	7.4
Site B, 3.5 kW	4,900	3.160	56,191	11.4	7.0
Site C, 4.0 kW	5,600	2.951	77,111	12.6	6.5
Site D, 4.5 kW	6,300	2.811	96,520	13.5	6.2

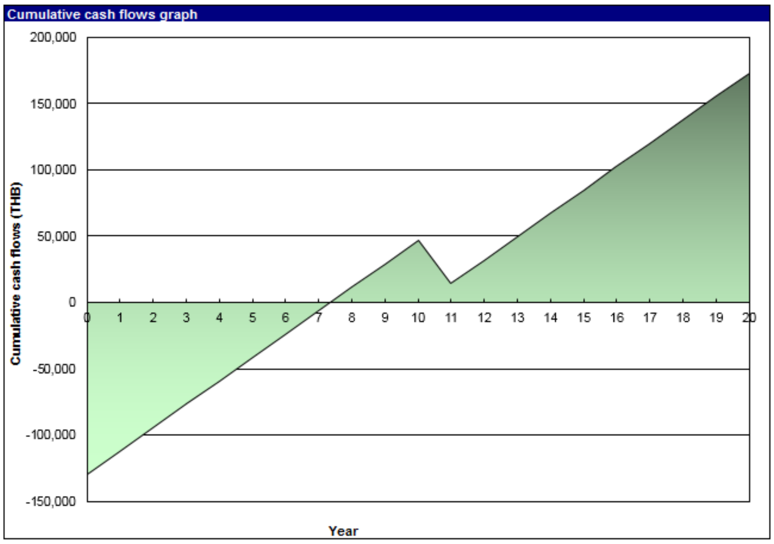

Figure 5 Cash flow analysis of solar PV system for residential rooftop in site A in this study

The economic analysis is investigated in this study consists of the results of equity internal rate of return (equity IRR), and the simple payback period. The results of solar resources harvesting by solar PV module of the polycrystalline type described in Table 4. The economic analysis is based on the assumption in and economic analysis is investigated in optimal inclination orientation of its installation.

The PV solar panel prices are continuously decreased significantly in recent years. The assumption for this analysis is collected from many various resources. The system price cost is composed of the cost of modules and balance of system (BOS) cost. For this study, the cost of the module of polycrystalline is set to $1.05/$W_p$. The balance of system (BOS) cost including land cost, labor cost, grid extension cost, inverters, transformer, and other costs. The BOS cost is set to $1.0/$W_p$ for a polycrystalline solar module. For overall cost per kilowatt peak installation of solar rooftop excluding the installation labor cost in this study, can be approximated at $2.48/$W_p$ (as the money exchange rate at 30.3 Baht per US dollar).

The PV project is set for 20 years lifetime with its warranty of all modules, but inverter in solar PV generation system needs to be changed at the 11th year. The operation and maintenance cost as minimal as 1.0% of its capital cost. The loan term of this assumption is set to 10 years with its interest rate of 7.25%. The discount rate of this economic calculation is set to 6.5%. The electricity price, replacing electricity bills in each month for purchasing electricity energy at the residential rate from the national grid with the rate of 3.96 Baht/kWh (MEA, 2020), and including other service charges making the average of the electricity bill 4.20 Baht/kWh. The results in Table 5 show the return of investment depending on the sizes of residential household and electricity consumptions in each month. The equity internal rate of return of 10.3-13.5%, the payback period of 6.2-7.4 years, and net present values of 39,525 Baht for 3.0 kW; 56,191 Baht for 3.5 kW; 77,111 Baht for 4.0 kW, and 69,520 Baht for 4.5 kW, obtained from the installation of solar PV rooftops in the residential scale for the whole project lifetime of 20 years with the installed capacity in the range between 3.0 kW and 4.5 kW, respectively. Also, Figure 5 shows the cash flow analysis of solar PV system installation for residential rooftops in the location at site A in this study.

Conclusion

This paper has evaluated the technical performance of the installed capacity of a 3-5 kWp grid-connected solar PV system in the utility-scale installation. Four site locations of the solar PV installations used in this study. The simulation with PV-GIS to determine the performance ratio (PR) and the energy yield can be concluded:

1. The PR of the PV systems of solar PV rooftop installations in this study varies from 77% to 78% and their yearly energy yields range from 1566.4 kWh/kW_p to 1566.6 kWh/kW_p.

2. Among the four site locations of PV systems considered in this study, four solar PV systems of c-Si installations have their PRs as high as 77.64 %

3. The capacity factor in all site locations is in the same value of 17.88%.

4. The benefit of the installation of solar PV rooftops on a residential scale is that it can reduce emission pollutants. For example, the avoided CO_2 emissions are 1.513 tons/year at site A; 2.318 tons/year at site B; 2.648 tons/year at site C; 2.980 tons/year at site D. The electricity generation by solar PV rooftop at a residential scale can replace electricity imports from neighboring countries and use for incomes if selling the excess electricity to grid.

From the annual energy yield of all PV systems, it is observed that the poly c-Si technology performs satisfactorily the condition in tropical weather for solar PV rooftop on the residential scale in Bangkok.

It is included in the economic consideration of solar PV installation in Thailand. All solar PV installations are satisfied the criteria of returns of investment namely: Equity %IRR is relatively between 10.3-13.5% and the payback periods are relatively less than 8 years. The return of investments are depending on the sizes of the household and the electricity consumptions.

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