Performance evaluation and the returns of investment of different solar PV panel types in the utility-scale: Cases of the installation in multi-region in Thailand

Prachuab Peerapong[1*]

Abstract

This research aimed to investigate the performance analysis and the returns of investment of solar PV installation of the selected power plants in the utility-scale of different Solar PV panel types in each region of Thailand. The performance results of the plant were also compared with the simulation values obtained from Solar-GIS software. The performance analysis included the final yield of each plant installation, an annual performance ratio (PR), and an annual electricity generation (MWh/annum). The economic viability of investment in solar PV installation was in comparison by using the usage of the net present value (NPV), internal rate of return (IRR), and payback period (PB). The PV system performance in this study varied from 71.1% to 84.50% and their energy yields per annum varied from 1,361 kWh/kW$_p$ to 1,467 kWh/kW$_p$ (poly c-Si); 1,492 kWh/kW$_p$ to 1,635 kWh/kW$_p$ (a-Si); 1,381 kWh/kW$_p$ to 1,495 kWh/kW$_p$ (CIS). The returns of investment namely: Equity %IRR is in the range of 9-11%, and the payback period is less than 10-11 years. The results from this research concluded that in the northern regions such as in Lampang province, polycrystalline technology of solar PV is preferable and recommended. While in other regions amorphous and polycrystalline solar PV technologies can be used. The solar PV installations can reduce emissions at a maximum rate of 773 tons of CO_2 per year of 1 MW installation in amorphous solar PV installation in Lop Buri province.

Keywords: solar PV, solar PV in the utility-scale, performance analysis, returns of investment, solar-GIS and PV-GIS

[1] Bangkokthonburi University

[*] Corresponding author. E-mail: bigman_thai@hotmail.com

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Introduction

The rationale of this study is to increase electricity generation from renewable energy resources under the power development plans both in 2015 and 2018, PDP 2015 and PDP 2018 respectively. For example, the target of solar PV installation for electricity generation of 6,000 MW from the start of power development plan 2015, PDP 2015, to the end of the plan; the new target of solar PV installation in the power development plan 2018 revision 1, PDP 2018 revision 1, has increased of new installation of 8,740 MW solar PV, during 2018 to 2037. The increase of electricity generation from renewables can decrease electricity imports from neighboring countries and also can decrease pollutant emissions. For example, the emission factor of CO_2 pollutant equivalent in the power generation sector has decreased from 0.507 kg/kWh in 2015 to 0.447 kg/kWh in 2019, while the imported electricity from neighboring countries has also decreased from 26,669.44 GWh in 2018, to 25,546.66 GWh in 2019, (EPPO, 2020). Although crystal-silicon cells dominate the current solar model marketplace, several thin-film technologies are beginning to receive considerable research and development and takes advantage of crystal silicon in terms of costs and temperature tolerance. Thin-film cells have their maximum efficiency lower than the crystalline silicon cells, for example in reviewed literature (Quansah, Adaramola, Appiah, & Edwin, 2017), solar panels including those made from amorphous silicon (a-Si, 6.90%) and copper indium selenide (CIS, 6.10%) have their efficiencies lower than that of the crystalline silicon (poly c-Si, 13.70%). Another type of solar panel is called the hybrid solar module type, obtained by combining crystalline silicon with non-crystalline silicon, normally adopting amorphous silicon with crystalline silicon. However, the solar module is called HIT, the technology based on this solar cell is an n-type silicon wafer that functions as a light absorber. Its efficiency can be as high as 18%.

The objectives of this study were to propose an alternative to solar system installation the three types of solar panels of namely: crystalline silicon (c-Si), amorphous silicon (a-Si), and copper indium selenide (CIS). The performance ratio and the financial return of investment have been investigated. The investigations of these objectives have been studied in multi-regions in Thailand. Many authors have studied the performances and financial payback of investments in solar PV installations. For example, in the installation of 110 kW_p in different technologies of grid-connected solar PV in a residential building in India, the study concluded that the energy output with the values of 1,483, 1,646, and 1,513 kWh/kW_p and the performance ratio of 71.60%, 79.50%, and 73.10% for Crystalline silicon (c-Si), amorphous silicon (a-Si), and copper indium selenide solar modules, respectively (Shukla, Sudhakar, & Baredar, 2016). Kumar, & Sudhakar (2015) studied the performance evaluation of 10 MW of grid-connected solar PV power plants in India. They used PV Syst and PV-GIS software in this study in the average solar radiation of 4.97 kWh/m^2/day with the annual average environmental temperature of 27.30 degrees centigrade. They found that the polycrystalline solar PV technology can get the final yield of the plant of annual power of 1,635 kWh/kW$_p$ and the performance ratio of 76.60%. The Solar-GIS used in this study is based on user input parameters that enable us to consider key characteristics of a PV system (Perez et al., 2002) as described in (Figure 2). Many authors have studied solar performances in different technologies. The technical assumptions in Solar-GIS software inputs are used by many authors, for example, (Skoczek, Sample, & Ossenbrink, 2008; Skoczek, Sample, & Dunlop, 2009). Humada, Hojabri, Hamada, Samsuri, & Ahmed (2016) studied the performance of 5 kWp of two solar PV technologies (c-Si and CIS) installed in the buildings on the tropical climate condition in Malaysia. They found that the capacity factors of CIS and c-Si in solar PV installation were 18.90% and 18%, respectively. The performance ratios of CIS and c-Si in solar PV installation were 77.50% and 73.50%, respectively. They concluded that the area requirement for 1 kW$_p$ installation in the CIS system was 10.50 m^2 while in the crystalline system was 7 m^2. Nour-eddine, Lahcen, Fahd, Amin, & Aziz (2020) studied the outdoor performances of three solar PV installations in comparison under the semi-arid climate in Morocco. They found that the system efficiencies were 14.94%, 14.91%, and 7.57%; the performance ratios were 85.51%, 85.37%, 76.66% and the capacity factors were 21.87%, 21.81%, 17.90% for mono-crystalline solar PV, poly-crystalline solar PV, and amorphous solar PV, respectively.

Methodology

This paper investigated the electricity harvesting of solar PV potential installations in diffident regions in Thailand with polycrystalline silicon (poly c-Si), amorphous silicon (a-Si), and copper indium selenide (CIS) PV modules. Solar irradiation dataset in Thailand in a horizontal plane (Figure 1) (solar irradiation potential in Thailand from Solar-GIS database), of optimal inclination angle, both of one-axis and two-axis solar irradiation and energy output prediction in optimal inclination installation obtained from Solar-GIS software. The outputs obtained from the Solar-GIS model were performance ratios and electricity yields both monthly and yearly. 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 described from the assumptions in this analysis was collected from many various resources. The system price cost was composed of the cost of modules and balance of system (BOS), the system prices such as the capital cost, discount rate, loan terms, and interest rest, normalized annual electricity generation, and electricity feed-in tariffs are the important required inputs.

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 1 MW installation on a ground-mounted utility scale. The optimal inclined fixed PV solar power plant in each region with polycrystalline, amorphous, and thin-film CIS solar modules has been investigated by Solar-GIS software (Solargis, 2021).

Solar irradiation

This study investigated five provinces in the north, northeast, central, and east of Thailand. The Solar-GIS dataset was chosen because it had the lowest mean bias errors (MBE) and root means square errors (RMSE). The MBE and RMSE of the Solar-GIS dataset were 2.50% and 7.90% when compared with MBE and RMSE of NASA dataset were 2.70% and 9.30%, respectively. The positive value of MBE means that it overestimates with a maximum deviation of 7.90% and the prediction of energy output used, is therefore reduced by 7.90%. Geographical position in main highly potential areas in Thailand has been studied. The global solar radiation in Thailand with an average value of 4.83 kWh/m^2/day. However, it varies in different regions. In the north, the highest value of solar radiation is 5.08 kWh/m^2/day (Uthai Thani province) while its average value in this region is 4.77 kWh/m^2/day. However, it varies in different regions.

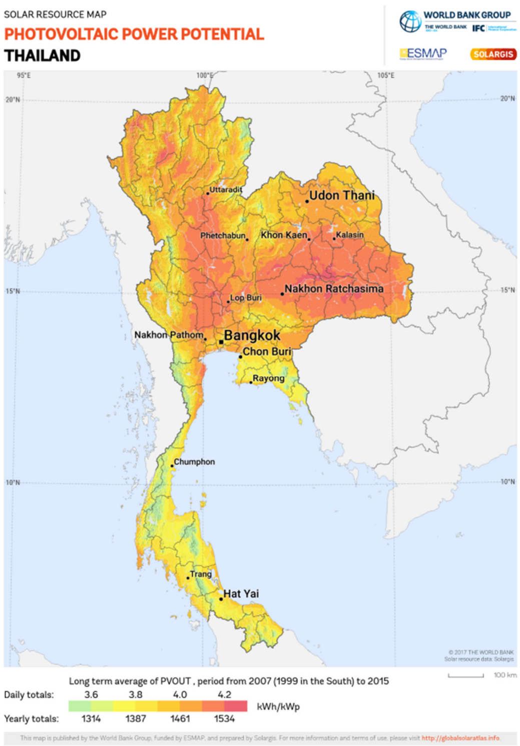

Figure 1 Photovoltaic power potential in Thailand.

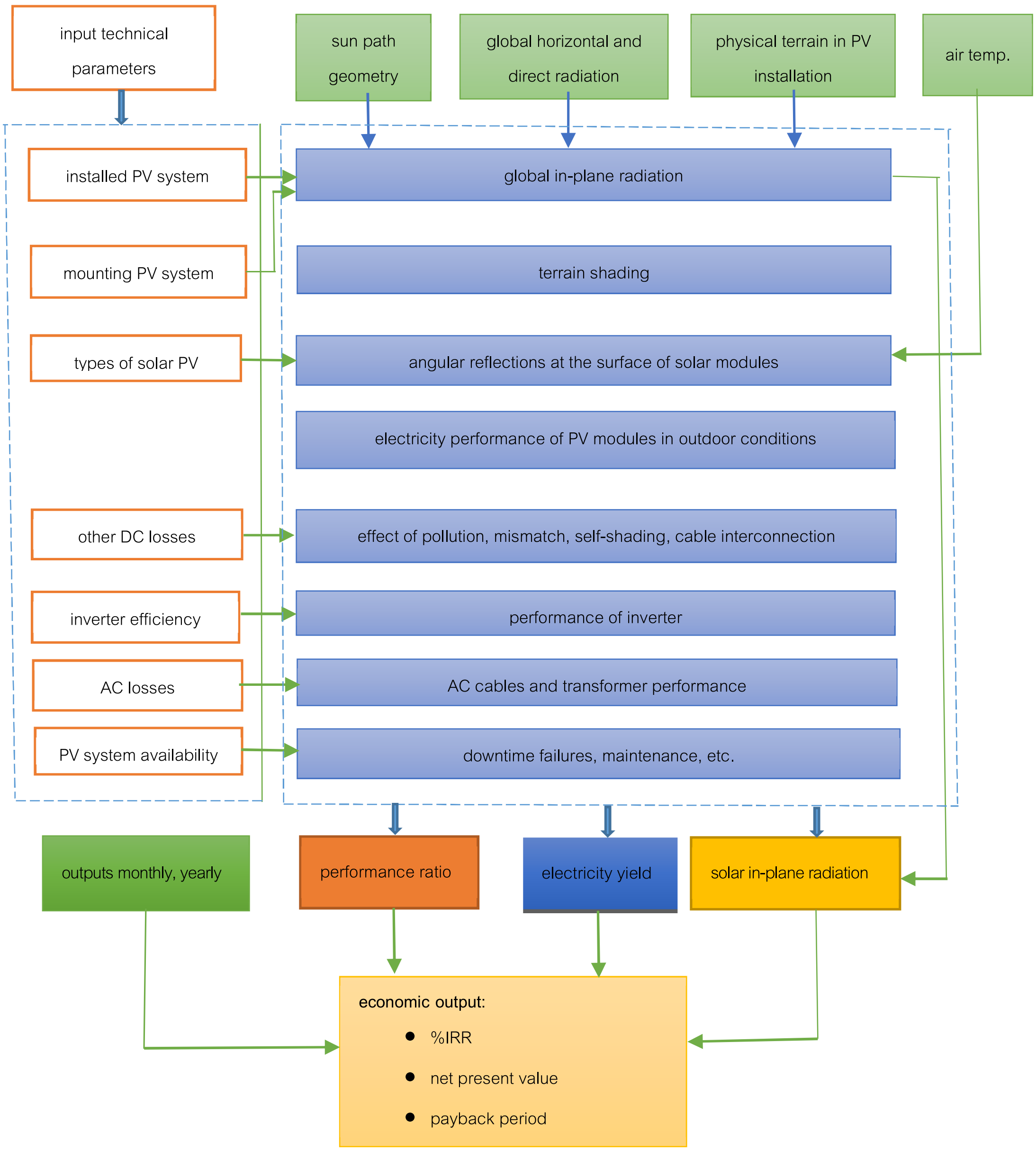

Figure 2 Simulation methodology.

Solar radiation in the north, the highest value of solar radiation is 5.08 kWh/m^2/day (Uthai Thani province) while its average value in this region is 4.77 kWh/m^2/day. In the northeast, the highest value of solar radiation is 4.97 kWh/m^2/day (Burirum province) while its average value in this region of 4.77 kWh/m^2/day. And in central and west regions are also high solar radiation, the highest value is 5.14 kWh/m^2/day (Supan Buri province) with its average in this region of 4.97 kWh/m^2/day. In the south, the value of solar radiation is 5.17 kWh/m^2/day (Pattani province) with its average value in this region of 4.83 kWh/m^2/day. In this conclusion, Thailand has a high solar potential for electricity generation. The distribution of average daily solar radiation in Thailand is 45.06% of the total areas of the country receive annual solar radiation in the range of 4.72-5.00 kWh/m^2/day, 28.47% of the total areas in the range of 4.44-4.71, 23.33% of the total areas in the range of 5.01-5.27, and the others 3.14% of total areas receive solar radiation of less than 4.43 or above 5.28 kWh/m^2/day.

Table 1 Physical position and yearly average solar radiation in horizontal, optimal inclination, one-axis, and two-axis tracking of selected locations in Thailand.

provinces	latitude, longitude	optimal angle	solar irradiation (kWh/m^2), yearly			
			horizontal plane	in optimal inclination	1-axis tracking	2-axis tracking
Ayutthaya	14° 16' 12.0" N, 100° 35' 24.0" E	16^o	1851	1910	2191	2262
Lampang	18° 18' 0.0" N, 99° 30' 0.0" E	19^o	1824	1918	2221	2294
Nakhon Ratchasima	14° 58' 12.0" N, 102° 04' 48.0" E	17^o	1853	1921	2211	2285
Lop Buri	14° 49' 12.0" N, 100° 37' 48.0" E	16^o	1876	1938	2230	2303
Prachuap Khiri Khan	11° 34' 48.0" N, 99° 32' 24.0" E	15^o	1719	1777	2050	2107

Results and discussion

Site selection and electricity generation

In this study, sites in five provinces had been selected. The site's selection with the high potentials of solar radiation, available grids connection, the experience of an existing solar power plant in utility-scale (equals or larger than 1 MW installation), and planning of installation in a few years. The selected provinces in the north region was Lampang, in the northeast was Nakhon Ratchasima, in the central region were Ayutthaya and Lop Buri provinces and in the south region was Prachuap Khiri Khan. The results (Table 1) showed the yearly average solar radiation in horizontal, optimal inclination, one-axis, and two-axis tracking of selected provinces. The solar radiation: 1) in horizontal plane ranged from 1719 kWh/m^2 to 1876 kWh/m^2, 2) in optimal inclination plane ranged from 1777 kWh/m^2 to 1938 kWh/m^2, 3) in one-axis ranged from 2050 kWh/m^2 to 2230 kWh/m^2, 4) in dual-axis ranged from 2107 kWh/m^2 to 2303 kWh/m^2, respectively. The lowest value occurred in Prachuap Khiri Khan while the highest value occurred in Lop Buri province. The optimal inclination angle in each province obtained from SolarGIS software was varied: 1) between 17-20^o in the north area, 2) between 17-20^o in the northeast area, 3) with 16^o in the central area, 4) between 15-18^o in the south area, respectively.

Energy output assessment

The electricity generation of 1 MW in ground-mounted utility-scale installation in different solar modules was also investigated by Solar-GIS software. The loss in this power plant was therefore to model the energy output from various module types in the PV systems assuming: 97.50% inverter efficiency, 5.50% DC losses, 1.50% AC losses, and 99% electricity availability generation. However, the loss in each module type is described in detail due to its solar panel specification characteristic (Table 2) and it varies in different regions. The results (Table 3) showed annual electricity production. The electricity obtained from 1 MW; 1) polycrystalline solar module installation varied from 1361 MWh/year in Prachuap Khiri Khan to 1467 MWh/year in Lop Buri and Lampang provinces, 2) amorphous solar module installation varied from 1492 MWh/year in Prachuap Khiri Khan to 1635 MWh/year in Lop Buri province, 3) thin-film CIS solar module installation varied from 1381 MWh/year in Prachuap Khiri Khan to 1495 MWh/year in Lop Buri province.

Table 2 Specification of PV module in this study.

solar panel type	amorphous PV	polycrystalline PV	thin-film CIS PV
manufacturer	Sun Well	Suntech	Solar Frontier K.K.
PV model	WD-A-CC-087A	STP275-24/Vd	SF150-L
maximum power at STC (Pmax)	100 Wp	275 Wp	150 Wp
module efficiency	7%	14.20%	12.20%
maximum power voltage (Vpm)	104 V	35.10 V	74.50 V
maximum power current (Ipm)	0.99 A	7.84 A	1.47 A
open circuit voltage (Voc)	139 V	44.70 V	100 V
short circuit current (Isc)	1.18 A	8.26 A	2.10 A
temperature coefficient (Pmax)	-0.22%/°C	-0.47%/°C	-0.31%/K
temperature coefficient (Voc)	-0.34%/°C	-0.34%/°C	-0.30%/K
temperature coefficient (Isc)	0.04%/°C	0.045%/°C	0.01%/K

Performance ratio

The performance ratio (PR) indicates how close it approaches ideal performance during real operation and allows comparison of PV systems independent of location, tilted angle, orientation, and their nominal rated power capacity. The performance ratio is defined by the following equation (Ma, Yang, & Lu, 2013)

$$PR = \frac{E_{AC}}{G_m \eta_{STC}} \quad (1)$$

where E_{AC} is the yearly 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°C.

The performance ratio of each solar module to solar irradiation is also different, but it has a few variations in each region in this study. The performance ratio for polycrystalline solar module is between 75.50-76.70%, for the amorphous solar module, is between 83.80-84.60%, and for thin film, CIS solar module is between 77-78%, respectively. From this study, the highest electricity generation in comparison with polycrystalline and thin-film CIS solar module types, and the highest values were in Chaiyaphum and Surin provinces in the northeast part and the lowest value was in Prachuap Khiri Khan province, in the Southern part of Thailand.

Capacity factor

The capacity factor (CF) is defined to represent the energy delivered by electricity power. If the system is delivered with a full rate of power continuously, its capacity factor is unity. The capacity factor 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 ($P_{PV\ rated}$) power for 24 hours per day for one year, the capacity factor is given in the following equation:

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

Table 3 Annual electricity production of PV modules of 1 MW installation in optimal inclination in selected provinces in Thailand.

selected provinces	annual electricity production of different types of PV module, capacity factor, and performance ratio								
	polycrystalline PV			amorphous PV			thin-film CIS PV		
	MWh	CF (%)	PR (%)	MWh	CF (%)	PR (%)	MWh	CF (%)	PR (%)
Ayutthaya	1446	16.50	75.60	1612	18.40	84.30	1473	16.81	77.10
Lampang	1467	16.70	76.40	1619	18.50	84.30	1493	17.00	77.70
Nakhon Ratchasima	1464	16.70	76.10	1625	18.60	84.50	1491	17.00	77.50
Lop Buri	1467	16.70	76.60	1635	18.70	84.30	1495	17.00	77.00
Prachuap Khiri Khan	1361	15.50	76.50	1492	17.00	83.80	1381	15.80	77.60

From (Table 3) shows the results of capacity factors for the polycrystalline solar module (c-Si), amorphous module (a-Si), and thin-film CIS module in different regions of Thailand. The lowest values were in Prachuap Khiri Khan province with 15.50%, 17%, 15.80% for c-Si, a-Si, and thin-film CIS, and the highest values was in Lopburi province with 16.70%, 18.70%, and 17%, respectively. The capacity factors were also high in other provinces in the north, northeast, and central regions. The capacity of the solar system of the c-Si panel is relatively higher than other types of solar panels installation. The economic analysis was investigated in this study consists of the results of the equity interest of return (equity IRR), and the simple payback period. The results of solar resources harvesting by three types of solar modules from the previous description showed that Thailand has high potential solar irradiation, especially in the north, the northeast, and central regions. The economic analysis is investigated in the 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/Wp and the cost of the module of amorphous and thin-film CIS is set to $0.8-0.95/Wp, respectively. The balance of system (BOS) cost including land cost, labor cost, electricity grid extension cost, inverters, transformer, and other costs. The BOS cost is set to $1.0/Wp for the polycrystalline module, and $1.15/Wp for other thin-film modules (both amorphous and CIS modules). The PV project is set for 25 years lifetime with its warranty of all modules. The operation and maintenance cost as minimal as 1% of its capital cost. The loan term of this assumption is set to 10 years with an interest rate of 7.25%. The discount rate of this economic calculation is set to 6.50%. The electricity price, selling energy to the national grid with the incentive of the flatted price feed-in tariffs of $0.1742/kWh (money value exchange rate in 2020) for the whole project lifetime of 25 years.

Table 4 The return of investment from PV electricity production of different PV modules installation with the optimal inclination in selected provinces in Thailand.

provinces	polycrystalline PV		amorphous PV		thin-film CIS PV	
	equity IRR (%)	PBP(yrs)	equity IRR (%)	PBP (yrs)	equity IRR (%)	PBP (yrs)
Ayutthaya	9.90	8.80	13.30	7.70	10.80	8.60
Lampang	10.10	8.70	13.70	7.40	11.00	8.40
Nakhon Ratchasima	10.10	8.70	13.80	7.40	11.00	8.30
Lop Buri	10.10	8.70	13.90	7.40	11.10	8.30
Prachuap Khiri Khan	8.50	9.50	11.60	8.10	9.40	9.10

The results in (Table 4) showed that the equity interest return of a 1 MW solar power plant varied between 8.50-10.20% for polycrystalline module installation, 11.60-13.90% for amorphous module installation, and 9.40-11.10% for thin-film CIS module installation. Also, the highest of the equity interest of return occurred in Lop Buri province in the central region and its lowest value occurred in Prachuap Khiri Khan, in the south region, of three types of solar module installation. The simple payback period was defined that the period required for the profit from an investment to equal the cost of the project. Correspondingly, the simple payback period varied between 8.70-9.50 years for polycrystalline module installation, 7.40-8.10 years for amorphous module installation, and 8.40-9.10 years for thin film CIS module installation. It is evident, the investment of solar photovoltaic in northeast parts of Thailand, especially in Nakhon Ratchasima province, has the most profit in terms of the equity interest of return and the simple payback period. However, the results in (Table 4) showed that the investment in the north parts such as in Lampang, the investment in the central parts such as in Lopburi and Ayutthaya provinces, and the investment in the northeast parts such as Nakhorn Ratchasima, are also promisingly profitable. The result of the study is related to reviewed paper. For example, Mohammadi, Naderi, & Saghafifar (2018) studied the financial feasibility of growing grid-connected photovoltaic power, putting in 5 MW of capability in the 8 selected towns in many areas at the southern coast of Iran. However, the solar panel's cost has been decreasing rapidly, therefore the investment in solar PV system installation will be more profitable. The standard test conditions are assumed for the performance assessment of all solar PV types in this research. It can be discussed and assumed that the solar PV panels have linear annual degradation within 25 years lifetime, the level of annual degradation is assumed with the rate of 0.50%-1.00%, the temperature coefficient losses in different solar PV technologies are due to the solar panel specification, and the fixed tilts of optimal angles are varied in areas of solar PV installations in Thailand.

Table 5 The benefit of emission reduction of a 1 MW solar PV installation in selected provinces in Thailand.

selected provinces	annual electricity production of different types of PV module, and emission reduction potentials					
	polycrystalline PV		amorphous PV		thin-film CIS PV	
	MWh	emission reduction (tons)	MWh	emission reduction (tons)	MWh	emission reduction (tons)
Ayutthaya	1446	683.96	1612	762.48	1473	696.73
Lampang	1467	693.90	1619	765.79	1493	706.19
Nakhon Ratchasima	1464	692.47	1625	768.63	1491	705.25
Lop Buri	1467	693.90	1635	773.34	1495	707.14
Prachuap Khiri Khan	1361	643.75	1492	705.72	1381	653.21

The benefit of emission reduction of 1 MW solar PV installation in selected provinces in Thailand in this research described in (Table 5). The avoided CO_2 emissions of 1 MW solar PV installation can reach 684-694 tons in polycrystalline PV, 653-707 tons in CIS PV, and 705-773 tons in amorphous PV, respectively.

Conclusion

This paper evaluated the technical performance of a 1000 kWp grid-connected solar PV system in utility-scale installation. Three types of solar PV panels were used in this study. The simulation with Solar-GIS to determine the performance ratio (PR) and the energy yield can be concluded:

1) The Performance ratio of the PV system performance in this study varies from 71.1% to 84.5% and their energy yields per annual vary from 1,361 kWh/kW$_p$ to 1,467 kWh/kW$_p$ (poly c-Si); 1,492 kWh/kW$_p$ to 1,635 kWh/kW$_p$ (a-Si); 1,381 kWh/kW$_p$ to 1,495 kWh/kW$_p$ (CIS).

2) From the three types of PV systems considered in this study in solar PV systems of all installations have their PRs higher than 70% and can reach 84.5% in an amorphous solar PV system.

3) The benefit of solar PV installations can reduce emissions as can the maximum of annual 773 tons of CO_2 reduction per MW installation in an amorphous solar PV technology.

In the hot temperature environments in the northeast regions such as in Nakon Ratchasima province, the amorphous technology is recommended. It is because, the polycrystalline is more sensitive to power loss in high-temperature environments than the amorphous technology (-0.47%/°C for polycrystalline PV, -0.22%/°C for amorphous PV). So in the northern regions such as in Lampang province, polycrystalline technology is preferable and recommended. It can be concluded that the performance ratio can obtain as high as or more than 80% in amorphous solar PV technology. It is because the amorphous solar panel is less sensitive to high temperatures with its lower temperature coefficient in tropical weather in all areas in Thailand. It is also in amorphous solar PV technology can obtain higher annual average electricity production and a higher return in financial terms of investment than other solar PV technologies. While other regions' solar PV installations can use both amorphous and polycrystalline technologies, especially in the central areas of Thailand. Normally, polycrystalline technology has an efficiency higher than that of amorphous technology. However, all solar PV installations are satisfied with the criteria of returns of investment namely: Equity %IRR is relatively between 9-11%, and the payback period is relatively less than 10-11 years. The results from this research are useful for renewable energy investors for solar PV investment in the utility scale in Thailand.

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