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Optimal Photovoltaic Resources Harvesting in Grid-connected Residential Rooftop and in Commercial Buildings: Cases of Thailand

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Abstract

Photovoltaic (PV) has recently undergone impressive growth and substantial cost decreases. A single-crystal silicon (mono-Si) or polycrystalline (poly-Si) have been dominant for solar rooftop and in commercial buildings installation in the past years. However until recently thin-film PV modules both amorphous silicon (a-Si) and other non-silicon thin films technology have been advance efficiency developments with low cost. The competition of crystalline and thin film solar panel technologies drives the cost significantly decreased and helps the solar investors for a good financial profit return for a shorter time. This study by satellite-derived data, Solar GIS pvPlanner software shows that the highest output is in a-Si, CdTe and followed by CIS, and c-Si PV modules for the locations considered in this study. The average energy output of amorphous panels in residential solar rooftop installed in Bangkok has the highest values of 1,503 kWh/kWp. The average energy output of amorphous panels in commercial building installed in Chonburi province has the highest values of 1,601 kWh/kWp. The optimal inclination angle is 15° south direction in both areas. Finally, the economic assessment of solar panels is also investigated for the feasibility investment by RETscreen model.

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Keywords: Photovoltaics resources, residentials, commercial buildings, economics, optimal solar harvesting

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1. Introduction

Solar energy potential in Thailand is significantly important. Geographical distribution of solar radiation was studied. It was found that 45% of the total areas of the country receive annual solar radiation in the range of 17-18 MJ/m^2.day, while there are only a few percentages of the areas with low solar radiation (less than 15 MJ/m^2.day) [1]. Under the Renewable and Alternative Energy Development Plan for 25 percent of final energy consumption in 10 years (AEDP 2012-2021), As of December 2014, the government of Thailand has planed that the electricity generated by solar power will be 2,000 MW[2]. Solar rooftop and solar PV installation in commercial buildings are promising because they will not consume large portions of land, such as in the utility solar installations or solar farms.

2. Material and Methods

In this study, the SolarGIS PvPlanner tool is used for analysis. The SolarGIS is based on using statistically aggregated solar and temperature data stored in with a time step of 15 minutes collected during 1994-2011 [3]. The simplified input parameters enable to consider key characteristics of a PV system, such as its position, geometry, type and mounting of modules, efficiency of inverter and losses in DC and AC sections. The model calculates reflectance losses at the surface of PV modules and losses due to irradiance and temperature characteristic operating performance of modules in a site-specific climate conditions. The other system losses, mainly at the DC and AC sections are to be set by a user. Solar rooftops and solar PV installation in commercial buildings are promising feasibility and the government has initiated the small residential solar rooftops and solar PV in commercial buildings by given highly incentive feed-in tariffs. This study optimized the highest electricity harvesting with its lowest energy production cost.

3. Results

3.1 *Sites meteorological and solar radiation data*

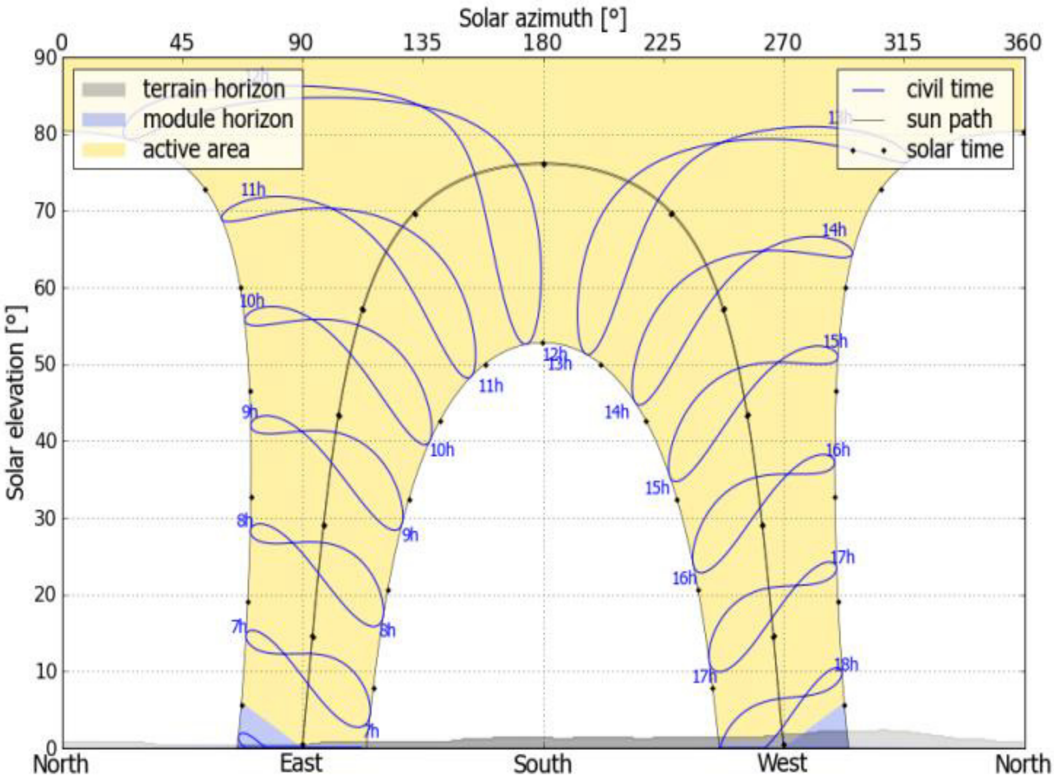
This study investigates the electricity output generated in different types of solar panels (crystalline-Si and thin film), and compared the results to the actual data collection by site visiting. The cases in this study divided into: 1.) Small scale solar rooftop 2.) Small scale solar PV installaton in the commercial buildings. The selected site are located at two specific areas: in Bangkok (13° 45' 49.15" N, 100° 32' 22.97" E), and in Chonburi province (13° 13' 30.83" N, 100° 56' 15.94" E).

3.2 *Solar modules under this study*

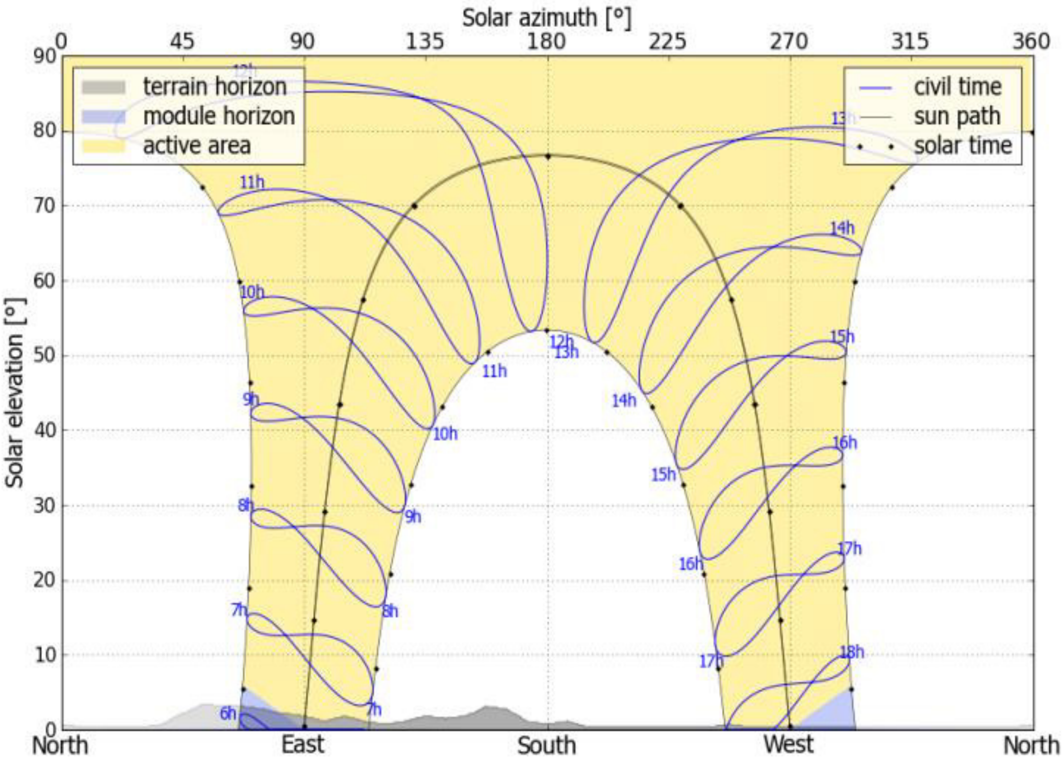
This paper uses data collected from monthly average daily global horizontal irradiation (GHI) of two locations against satellite-derived data from the commercially available software. The best dataset for locations in Thailand was selected as that with the lowest root mean square error. Energy output prediction from Solar GIS pvPlanner software [2]. The software was validated using measured performance data for a PV system. The software was then used to evaluate the energy generated by PV systems with optimally inclined PV modules. This paper therefore assesses the energy generation potential of PV systems with 275 Wp crystalline silicon (c-Si) module, 145 Wp amorphous silicon (a-Si) module, 85 Wp copper indium selenide module (CIS or CIGS) and 70 Wp cadmium telluride (CdTe).The details of solar module used in this study are shown in Table 1.The capacity installation in large residential rooftop in Bangkok is 11.0 kWp while the capacity installation in small commercial building in Chonburi province is 66.0 kWp. PV modules in both locations in Thailand shows satellite-derived annual average daily GHI available in Solar GIS for different locations in Thailand. Solar GIS pvPlanner software investigates the solar irradiation varies between 4.79 kWh/m^2 per day in Bangkok (central region) and 5.06 kWh/m^2 per day in Chonburi province (eastern region). The annual average ambient air temperature varies between 27.2°C in Chonburi and 27.5°C in Bangkok. The optimal inclination angle is 15° south direction in both areas, the solar azimuth in Bangkok and in Chonburi province as shown in Fig. 1.

Table 1. Solar modules used in this study

Technology	Module	Efficiency (%)	Frame Area (m^2)	Modules required for rooftops, 11 kW	Modules required for Commercial buildings, 66 kW
Poly c-Si	STP275-24/Vd	14.2	1.94	40	240
a-Si	Q-Cells SN2–145 W	8.2	1.78	76	456
CIS	Q-Cells SL1–85 W	11.3	0.75	130	780
CdTe	Abound AB1–70 W	9.7	0.72	158	948



(a)



(b)

Fig. 1. Solar azimuth (°) (a) in Bangkok; (b) in Chonburi province

3.3 *Energy output assessment*

Predicting the energy output from a PV system is a matter of combining the characteristics of the major components, that is, the PV array and the inverter with local irradiation and temperature data. Energy output prediction using Solar GIS's pvPlanner tool was validated using measured data reported. The pvPlanner tool was therefore used to model the energy output from the PV systems assuming: 97.5% inverter efficiency, 5.5% DC losses, 1.5% AC losses and 99% availability. The energy outputs in the optimal cases in solar rooftop, solar PV in commercial buildings are comparable. The highest output is in a-Si, CdTe and followed by CIS, and c-Si PV modules for two locations considered in this study. The average energy output has the lowest values of 1,341, for c-Si in Bangkok area and 1,440 kWh/kWp in Chonburi province and highest values of 1,503 and 1,601 kWh/kWp in Bangkok and Chonburi respectively for a-Si PV modules. Considering that the Solar GIS dataset can also estimate average energy outputs and average annual electricity production as the same as data collected from site visiting.

3.4 *Data input and economics*

To determine the potential of PV power installations in Thailand, this study uses climate data database by GeoModel solar colleted from 1994-2011 in Solar GIS's pvPlanner tool, to predict the estimated rooftop surface areas available and energy harvesting from two selected areas. The NASA climate database, which uses the RETScreen model of its the long-term monthly average meteorological data from the meteorological website [4], is also used to measure the irradiation of sunlight at national level. The difference of two sources of solar irradiation is less significant. This study includes income taxes in the calculation of the deployment costs of PV equipment; it uses the discounted rate through the whole life costing method. The RETScreen model is therefore calculating, the cost of PV power generation (US$/kWh) is mainly comprised of investment and operation costs, and other financial investment indicators. The financing input data for the base case are: 1) the project lifetime of 25 years, 2) inflation rate of 2.5%, 3) real discount rate of 9%, 4) debt fraction of 50%, 5) loan term of 7 years, 6) loan interest rate of 7.25%, 7) operation and maintenance cost of 0.86% of PV capital cost, and 8) income tax rate of 30% after 8 years of exemption. The PV capital cost is 2,015 US$/ kWp for 3.0 kW, 2,008 US$/ kWp for 11.0 kW, and 2,003 US$/ kWp for 66.0 kW installation. The Projection cost of PV modules used as the reference is shown in Fig.2. The exchange rate used in this study is 32.5 Baht/US$ [8].

3.5 *Solar feed-in tariffs in Thailand*

A policy scheme to support the deployment of rooftop PV in Thailand is a new initiated scheme. According to the Ministry of Energy in AEDP 2012-2021 target, the electricity generated by solar power will reach 2,000 MW within 2021. Thailand's Energy Regulatory Commission (ERC) published target of rooftop package since September 2013. It has target of a total of 200 MW solar rooftops, which the updated feed-in tariffs as shown in the Table 2. below.

3.6 *Financial results*

This study used module cost taken from [2].The solar model decreases significantly and now the cost per watt of poly-crystalline module is less than 1 US$ [2,6]. The poly-crystalline solar module was used in this study with its efficiency of 14.2%. The project is located in Bangkok area with its solar irradiation of 4.79 $kWh/m^2 \cdot day$. Each inverter has its nominal output of 3.5 kW and its efficiency of 97.5%. Energy generated by this project is 14.8 MWh/annual at its 11.0 kW installation. The total capital cost of project is US$22,088 (2,008 US$/kWp) with its annual O&M of 0.86% of the capital cost. The output calculated the return of investment to equity IRR of 11.1% with its feed-in tariff of $0.2015/kWh. However, for the 3.0 kW installation in residential rooftop the project can get its feed-in tariff of $0.2108/kWh. The total capital cost of project will be US$ 6,045 (2,015 US$/ kWp) with its annual O&M of 0.86% of the capital cost, and the return of investment to equity IRR of 11.0%. The solar project in small building is located in Chonburi province with its solar irradiation of 5.06 $kWh/m^2 \cdot day$. Energy generated by this project is 93.5 MWh/annual from 66.0 kW installation. The total capital cost of project will be US$ 132,330 (2,005 US$/ kWp) with its annual O&M of 0.86% of the capital cost, and the return of investment to equity IRR of 11.4%. The payback period of the investment from three cases are; 8.2 years for 3 kW rooftop in

Bangkok, 7.9 years for 11 kW rooftop in Bangkok, and 7.8 years for 66 kW in commercial rooftop in Chonburi. The Energy production cost from solar PV rooftops in various installations is shown in Fig.3.

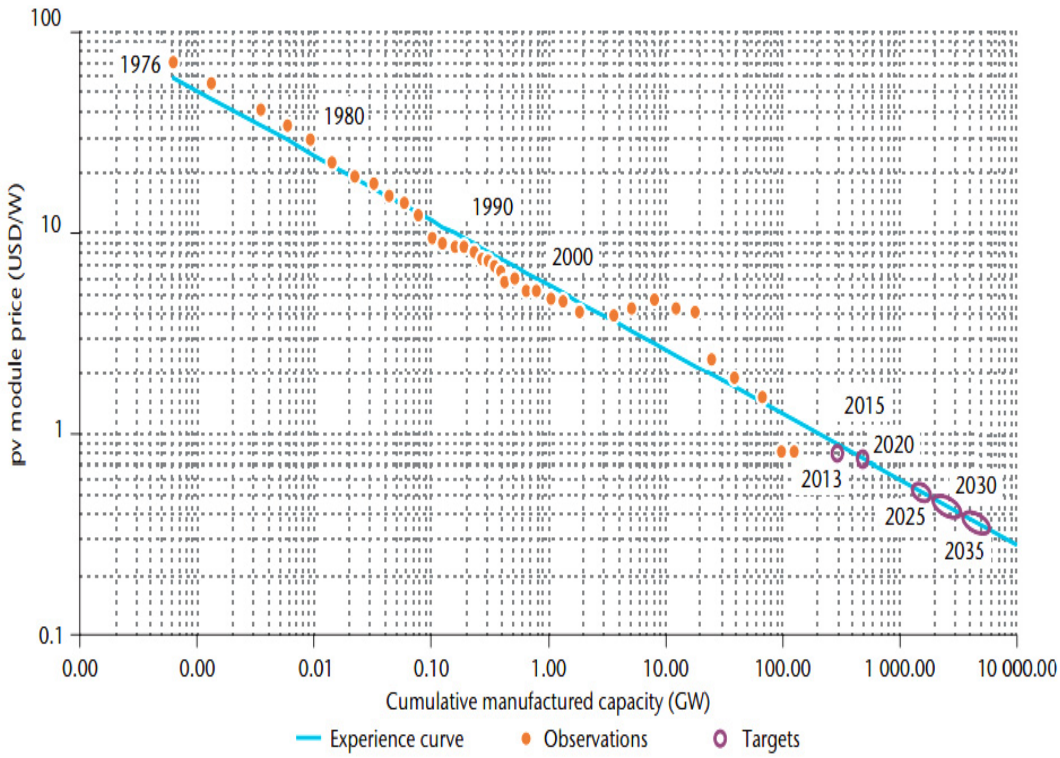


Fig. 2. Projection of solar PV module prices [6]

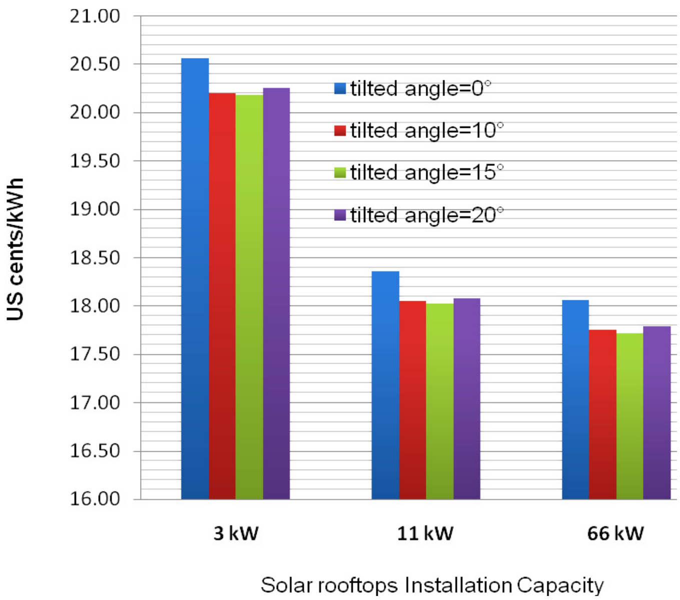


Fig. 3. Energy production cost from solar PV rooftops in various installations

Table 2. Feed-in tariff rates of solar rooftops in Thailand

Solar project classification	Scale	Quota/Target	Feed-in rate
Residential	1-10 kW	100 MW	6.85 Baht/kWh
Small and medium in commercial buildings	>10 -250 kW	100 MW	6.55 Baht/kWh
Medium and large in commercial/industrial	>250kW- 1 MW		6.16 Baht/kWh

Note: Exchange rate, 32.5 Baht/US$ [8]

4. Discussion

For this study the amorphous silicon PV modules had the highest energy output and performance ratio followed by cadmium telluride, copper indium selenide, and crystalline silicon. This study shows that thin film PV modules can be competitive with crystalline silicon PV modules. The thin film PV modules are favorable because of the less effects of high ambient temperature, such as in Thailand, on PV panels' efficiency in comparison with in crystalline silicon PV modules. Energy yield in terms of kWh per kW installation of amorphous silicon PV modules is highest even though it has lowest panel efficiency. It is mainly because of its lowest temperature coefficient loss. The power temperature coefficients of thin film modules is typically at -0.20%/°C for a-Si, -0.25%/°C for CdTe, -0.36%/°C for CIS while temperature coefficient of crystalline silicon modules is -0.47 %/°C [7]. Thailand is located in tropical country so the efficiency loss for solar PV modules due to ambient temperature is high while the name-plated efficiency of solar PV modules tested at standard condition (STD) of 25 °C with irradiance of 1,000 W/m^2 and air mass of 1.5 (AM 1.5) spectrums [7].

5. Conclusion

The thin-film modules are not appropriate for rooftops installation because they require more areas. Under the present scheme, at the feed-in rate of $0.2108/kWh for residential rooftop with installation of 10 kW or less, for 25 years subsidization in electricity generation investment from solar energy, and at rate of $0.2015/kWh in commercial rooftop with installation of 250 kW or less, is the financial feasibility. The study used various scales of investment from data collected in 2015. Since the solar modules decrease significantly, the capital costs of investment are reasonable for investment and make the equity investor feasibly profitable for the whole lifetime of the projects. The return of investment to equity is above 11.0% and the simple pay back of investment is about 7.5-8.5 years. However, with the rapidly and continuously decreasing of solar modules make the feed-in tariffs of solar PV power plants remarkably decreased in the near future. It is recommended that the feed-in tariffs would be revised every 2-3 years due to the decreasing solar modules prices.

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References

[1] Department of Energy Development and Promotion (DEDE), Alterative Energy Target in 2021.
[2] pvXchange. Available at: http://www.pvxchange.com/priceindex/Default aspx?langTag=en-GB. Accessed April 16, 2015.
[3] Department of Energy Development and Promotion (DEDE), Solar Radiation Maps from Satellite Data for Thailand, 2010
[4] Solargis. info/pvplanner 2013. Available on http://www.solargis.info/pvplanner. [5] RETScreen International. Renewable energy project analysis software.
[6] Technology roadmap, Solar Photovoltaic Energy. International Energy Agency, 2014.
[7] S.Kesler S. Kivrak, F. Dincer S. Rustemli M. Karasslan E. Unal U. Erdiven, The analysis of PV power potential and system installation in Manavgat, Tukey - A case study in winter season, Renewable and Sustainable Energy Reviews 31(2014) 671-80.
[8] Bank of Thailand, 2015. Available on https://www.bot.or.th/Thai/Pages/default.aspx. Accessed April 23, 2015.