www.rericjournal.ait.ac.th

An Assessment of the Solar Photovoltaic Generation Yield in Malaysia using Satellite Derived Datasets

Tofael Ahmed*, +, 1, Saad Mekhilef*, Rakibuzzaman Shah#, and Nadarajah Mithulananthan^

***Abstract –** Precise and reliable estimation of energy yield for solar photovoltaic (PV) system is imperative for the accurate design of PV system components and power system planning studies with high penetration of renewables. A number of studies have conducted related to PV yield assessments in Europe and some parts of Asia. However, PV yield assessment for various locations in Malaysia is yet to be conducted. This work assesses the average annual PV yield (kWh/kWp/y) in Malaysia for the installed capacity in 2015. Meteorological data from Photovoltaic Geographic Information System (PVGIS) is utilized for yield evaluation. The comparative yield estimation based on PVGIS and yearlong-recorded data for installed PV system at the University of Malaya is conducted first. A little error is observed between the field measurements and the yield studies based on PVGIS data. Then, the expected average yield for the individual region in Malaysia is estimated from PVGIS. Finally, based on the obtained results the individual region in Malaysia is ranked for PV availability. This study could provide very useful information to the power utilities, PV industries, and policymakers regarding the planning of large-scale PV plant, network operation, and future PV system development in Malaysia.*

***Keywords –** azimuth angle, energy yield, PV generation estimation, solar photovoltaic (PV), tilt angle.*

1. INTRODUCTION

In recent years, growing needs for clean and green energy to reduce the reliance on fossil fuels and emissions have led to the worldwide integration of renewable energy generation [1]. To overcome the challenges associated with the large-scale deployment of renewable energy, countries around the world have changed their energy regulatory policies for renewable energy (RE). Malaysia has already implemented a feed-in tariff (FiT) policy to pay incentives and encourage RE penetration since 2011 [2]. According to the Malaysian Sustainable Energy Development Authority (SEDA), implementation of FiT has increased the RE integration significantly in Malaysia, especially PV [3]. Before FiT implementation, cumulative PV installed capacity was 9MW. Implementation of FiT has increased the PV installed capacity to 276.54 MW by 2016 [3],[4]. In addition to FiT, Malaysia has implemented a Net Energy Metering (NEM) from November 2016. Under NEM, excess energy produced from solar PV can be traded to distribution service providers like Tenaga Nasional Berhad (TNB) and Sabah Electricity Sdn Bhd (SESB) [3],[5]. Consequently, a new target has been set to install an additional 1.65 GW over 200,000 rooftops for the period 2016-2025 in Peninsular Malaysia and Sabah [6].

Solar PV has intermittent nature, and its power generation entirely depends on geographical location and weather conditions. Therefore, it is important to have a suitable and reliable monitoring system to estimate and predict the accurate yield for these installed PVs [7]. Energy yield is one of the key performance indicators for solar PV that can provide the correct performance indices of the installed capacity [8],[9]. Generally, annual energy yield is used as an index to estimate the energy generation from the PV system. An annual average yield (kWh/kWp/y) is the ratio of annual energy generation from PV and the total PV installed capacity. SEDA has used average yield as an index to evaluate the performance of the installed PV system. However, this value may not reflect the actual yield for the PV systems over various regions in Malaysia due to followings: i) All the installed PV systems are not registered under FiT or NEM policy, especially, those installed before implantation of FiT policy in 2011; ii) All the present and future installed solar PV might not be connected to the grid. Off-grid solar PV shares the significant portion of the PV capacity, (around 70% of total installed capacity) supplying power to schools, isolated islands, and remote community located in the rural area of Sabah and Sarawak [10]. Also, new installed capacity will not be registered uniformly throughout the year. Therefore, their generation contribution to the total annual generation cannot be represented by an average capacity value. Hence, it is important to calculate annual mean solar PV yield correctly to measure the contribution of solar PV to the energy mix. Precise and reliable solar PV yield can give a direct estimation of annual electricity generation from currently installed solar PV systems. Besides, this can reflect the actual scenario for emission reduction from

*Power Electronics and Renewable Energy Research Laboratory (PEARL), Electrical Engineering, Faculty of Engineering, University of Malaya, 50603, Kuala Lumpur, Malaysia.

+Department of Electrical and Electronic Engineering, Chittagong University of Engineering and Technology, Chittagong 4349, Bangladesh.

#School of Engineering and Technology, Central Queensland University (CQU), Perth, WA 6000, Australia.

^School of Information Technology and Electrical Engineering, The University of Queensland, St Lucia, QLD 4067, Australia.

1Corresponding author;
E-mail: tofaelcuet@gmail.com; and tofael@cuet.ac.bd.

solar PV in Malaysia. Measuring carbon footprint from solar PV is important for Malaysia as the government has set a target to reduce 45% GHG emission by 2030 with compared to 2005 levels [11].

Annual yield calculation requires both the appropriate information regarding annual solar PV power generation and installed capacity throughout its geographical area. It is also necessary to have the correct information about the tilt and orientation (azimuth) as well as the performance of PV plants. Various methods are presented for estimating solar PV generation such as analytical methods [12]–[14], a combination of numerical and analytical methods [15], a combination of physical approach and modern techniques like neural-network [16], and others. The web-based system has been developed for the estimation of solar PV generation for Europe and Asia by the European Commission Joint Research Centre (EC-JRC) [17].

To the best knowledge of authors, no research has been conducted regarding annual solar PV yield of Malaysia throughout the geographic region of Malaysia. Therefore, this paper aims to estimate the annual average solar PV yield of Malaysia by considering each state. Regional solar PV generation from the installed capacity is estimated by using the photovoltaic geographical information system (PVGIS) developed by EC-JRC. Calculated annual solar PV yield is compared with measurements obtained from yearlong-recorded data from the University of Malaya (UM) grid-connected PV systems. Then, various scenarios such as the variation of tilt angles, and orientations are considered for all the studied regions in Malaysia. Also, the uncertainty of the results and assumptions has been discussed for further verification of numerical results.

The rest of this paper is organized as follows: Section 2 presents the overview and comparison of calculated and measured PV yield in Malaysia. Section 3 discusses the scenarios used for yield calculations followed by numerical results in Section 4. Section 5 explains the discussion and policy implications. Section 6 summarizes the conclusions and contributions of this work.

2. OVERVIEW OF PV INTEGRATION IN MALAYSIA

2.1 Geographic Location and Solar Radiation Profile of Malaysia

Malaysia is located in between $0^o51'$ to $6^o43'$ in North latitude and $99^o38'$ to $119^o16'$ in east longitude [18]. Malaysia has two major parts; the Peninsular Malaysia (West Malaysia) and the Borneo Island (East Malaysia). West Malaysia has two federal territories, and eleven states, while East Malaysia has one federal territory, and two states. Malaysia is located within the equilateral hot zone and humid tropical monsoon weather. It receives abundant solar radiation (monthly average solar radiation of about 400-600 MJ/m^2 or 4-5 kWh/m^2/day [19]). Figure 1 illustrates the annual average solar radiation of Malaysia.

2.2 Experimental PV Plant Description

Power Electronics and Renewable Energy Research Laboratory (PEARL) located at the University of Malaya, Kuala Lumpur has installed a grid-connected PV system in October 2015 (see Figure 2). PEARL grid-connected PV systems mainly contain monocrystalline PV panels (Shell; SQ75), polycrystalline PV panels (Mitsubishi; PV-AE125MF5N) of 2.0kWp, and thin film (Sharp; NS-F135G5) PV panels of 2.7 kWp. These panels are connected to the utility grid through transformer-less inverters (Sunny Boy 1600TL and Sunny Boy 2500HF).

Grid-connected PV systems have been installed on the rooftop of the PEARL building (3°7'4" North, 101°39'18" East) in such a way that the entire glass surface is facing south (Azimuth 0 degree) with a tilt angle of 10 degrees. It should be noted that there is no tracking system installed in this PV system. Sunny Sensorbox with integrated irradiance sensor has been installed directly into the modules as shown in Figure 2. The data of solar irradiation, temperature, and each AC side inverter output are recorded in 5-min interval.

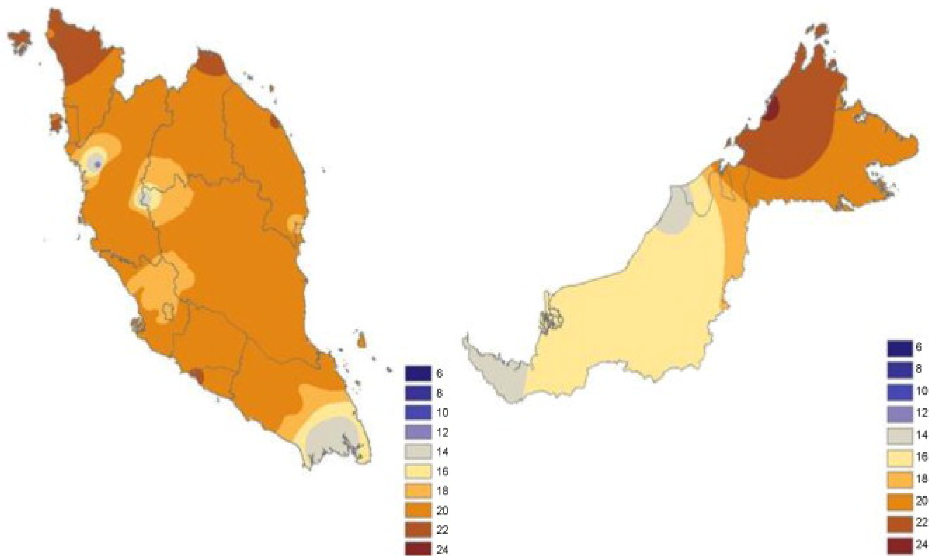


Fig. 1. Annual average solar radiation (MJ/m2/day) [18].

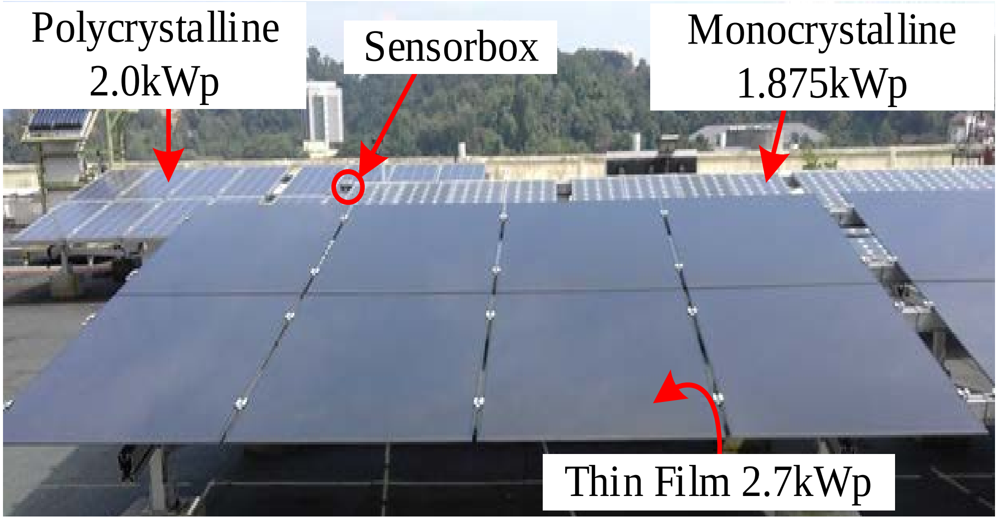


Fig. 2. PEARL PV system.

2.3 Photovoltaic Geographical Information System (PVGIS)

EC-JRC has produced a web-based system namely PVGIS to estimate the PV performances [17]. Climate Monitoring Satellite Application Facility (CM-SAF) stores the metrological data from both polar and geostationary orbiting satellite and PVGIS system utilizes CM-SAF data for estimating solar radiation [17]. Initially, the combination of PVGIS and CM-SAF radiation database was developed for estimating solar irradiance in Europe and Africa from 1998 to 2011. Later EC-JRC updated CM - SAF - PVGIS system which now covers solar irradiance measurements from 2005 to 2016 and could estimate the solar radiation for Asia up to 120^{0}E [20],[21].

Solar irradiance at surface level consists of direct radiation from solar, diffuse radiation that comes after reflecting or scattering by the atmosphere, and reflected radiation from the ground surface or nearby obstacles. However, reflected radiation from the ground surface has less effect, thereby, can be ignored. If there is no blocking due to cloud cover then direct radiation is available, while, the diffuse radiation is always available in the surface. Knowing the availability of the maximum surface solar irradiance at any location is only possible when the solar irradiance information under clear sky, clean and dry atmospheric conditions are known. The CM - SAF - PVGIS system aims to retrieve spectrally resolved surface irradiance in high accuracy. For this, CM - SAF - PVGIS system first estimate the cloud influence on solar irradiance by analyzing the pixel of the satellite image at the same time in a given period. After calculating an *effective cloud albedo*, PVGIS system calculates the solar irradiance at clear sky conditions. Finally, the PVGIS system calculates the total surface irradiance from cloud albedo and the clear-sky irradiance. Overall clear sky approach of calculating clear sky surface irradiance can be represented by Equation 1 [22].

$$I_{\Lambda} = (I^{LUT}_{\Lambda(aod,ssa,gg)} + I_{\Lambda,H_2Ocor} + I_{\Lambda,O3cor}) * SAL_{\Lambda,cor} \quad (1)$$

In Equation 1, I_{Λ} is the final spectrally resolved irradiance for cloud free skies, $I^{LUT}_{\Lambda(aod,ssa,gg)}$ is the spectrally resolved irradiance for a given aerosol state derived from the basis look-up table (LUT) for fixed water vapour, ozone and surface albedo, I_{Λ,H_2Ocor} and $I_{\Lambda,O3cor}$ are the correction of deviations in water vapour and ozone from the fixed values used in the LUT, respectively, and $SAL_{\Lambda,cor}$ is the scaling to the given surface albedo relative to 0.2, which has been used in all previous steps.

Another important part of PVGIS system is to calculate the PV power output. PV power efficiency mainly depends upon the irradiance and the module temperature. PVGIS calculates the output according to Equation 2 [23].

$$P(G',T') = G'(P_{STC,m} + k_1 \ln G' + k_2 \ln G'^2 + k_3 T' + k_4 T' \ln G' + k_5 T' \ln G'^2 + k_6 T'^2) \quad (2)$$

$$T' = T_{mod} - 25^0\mathrm{C} \quad (3)$$

In Equation 2 and 3, $P(G',T')$ is instantaneous module power (W), Standard Testing Conditions (STC), G' normalized irradiance G' = G/1000 (dimensionless), $P_{STC,m}$ is module power, maximum power point at STC (W), G_{STC} in-plane irradiance at STC, k_1 to k_6 coefficients of the module power model, T is temperature (^{0}C), T_{mod} is the module temperature, T' is module temperature relative to standard test conditions, T_{mod} is the module temperature..

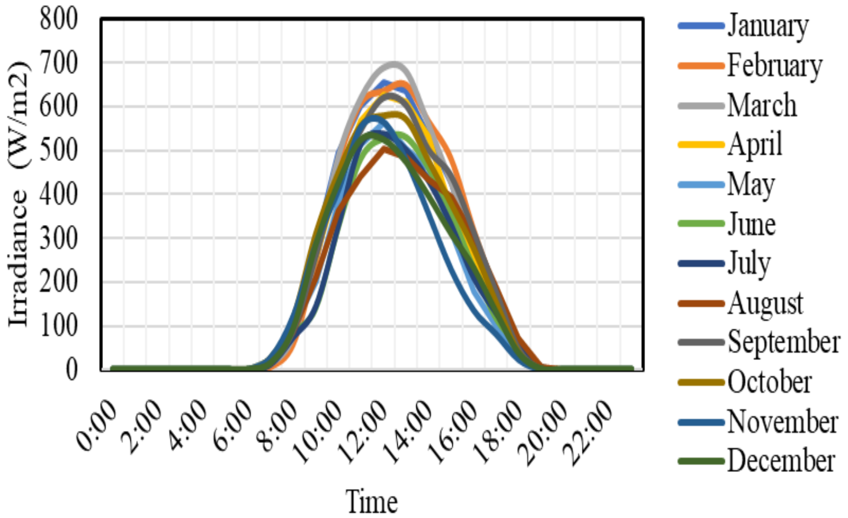
Module temperature is calculated based on Equation 3.

$$T_{mod} = T + G/(U_0 + U_1 W) \quad (4)$$

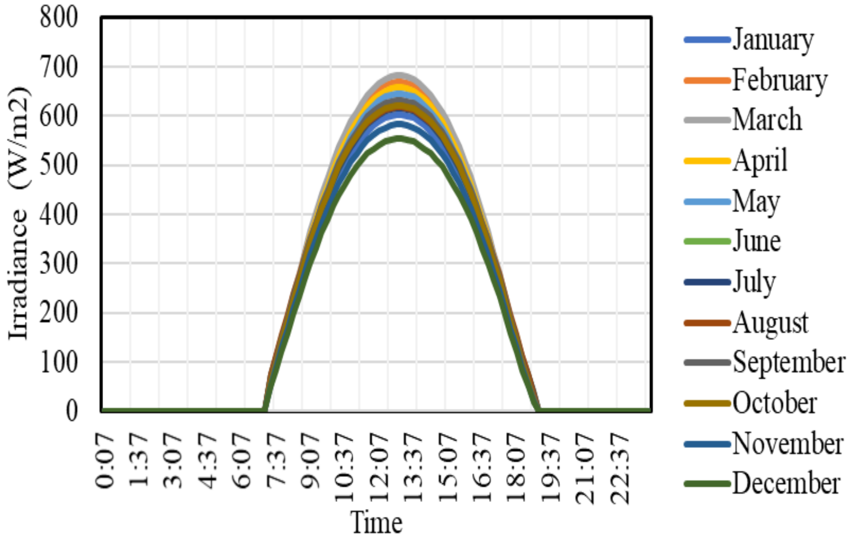
In Equation 4, T_{mod} is the module temperature, T is temperature (^{0}C) of air, G is in-plane irradiance (W/m^2), U_0 and U_1 are coefficients, W is the wind speed (m/s).
The CM-SAF-PVGIS system estimates the losses due to temperature and low irradiance as well as the losses due to angular reflectance effects. Other user-defined losses such as cable and inverter losses for grid-connected PV can be evaluated from the CM-SAF-PVGIS system also. Optimal tilt angle and azimuth for maximum PV yield can be obtained from CM - SAF – PVGIS. Details of the operation of PVGIS system can be found in [22]–[24]. It can be seen that by providing user-defined inputs for PV technology, installed peak power, system losses, module position, and module orientations (*i.e.* azimuth and tilt angle), the annual average solar PV yield for any specific location can be estimated.

2.4 Comparison between the Measured and Estimated Results

A comparison has been conducted between the estimated and yearlong measured results for the PEARL PV plant location for 2016. All the specifications of PEARL PV plant including various performance parameters and loss components have been considered during the estimation of the PV generation from the CM-SAF - PVGIS database. Losses are taken from the detailed PV system design guideline supplied by the supplier. These PV plants performance parameters and loss components include PV module mismatch factor, dirt factor, inverter losses, cable losses, and shading. These parameters result in a combined loss of 15% and 12%, respectively for polycrystalline and thin film solar PV plants of PEARL. Figures 3(a) shows the average hourly global horizontal irradiance (GHI) at PEARL solar PV plant for 2016 from plant integrated Sensor Box. Figures 3(b) gives the GHI for the same location from CM-SAF-PVGIS database. It can be seen from Figure 3(a) and (b) that both the measured and estimated average hourly GHI follow a similar pattern. It also observed that each month follows the same sequence of receiving monthly solar irradiation, *i.e.* both the measured and estimated GHI has a maximum in March and minimum in December.



(a)



(b)

Fig. 3. Average hourly global horizontal solar irradiance at PEARL PV plant, (a) measured, (b) estimated from CM-SAF - PVGIS database.

Results in Figures 4(a) and (b) show the recorder and estimated monthly electricity generation in 2016 for polycrystalline and thin film solar PV plants. User-defined loss of 15% for polycrystalline and 12% for thin-film solar PV plants are considered during the estimation of monthly electricity generation from CM-SAF-PVGIS database. It can be seen from Figure 4(a) that recorded energy generation for 2016 from PEARL polycrystalline PV plants and estimated energy generation for the same location from CM-SAF-PVGIS database has minimal differences. The recorded and estimated energy generation of polycrystalline silicon follows approximately the same pattern. On the other hand, it can be observed from Figure 4(b) that the recorded energy generation in 2016 for PEARL thin film PV plants and estimated energy generation from CM-SAF-PVGIS database are also very much close to each other and follow the similar pattern.

Percentage error of the recorded and estimated annual energy generation for both of the PEARL polycrystalline and thin film PV plants is presented in Table 1. It can be seen from Table 1 that the recorded and estimated monthly generation have a maximum error of 14.25% and 15.81%, respectively for November for both the polycrystalline silicon and thin film PV plant due to the heavy rainfall in November 2016. Conversely, recorded and estimated monthly generation has the minimum error of 0.16% and 0.42%, respectively for July and June for the polycrystalline silicon and thin film PV plant. However, the recorded and estimated total annual generation of polycrystalline silicon and thin film PV plants have an average annual error of 2% and 0.44%, respectively. Therefore, it can be concluded that the CM-SAF-PVGIS database can be used to estimate the PV yield for various locations in Malaysia.

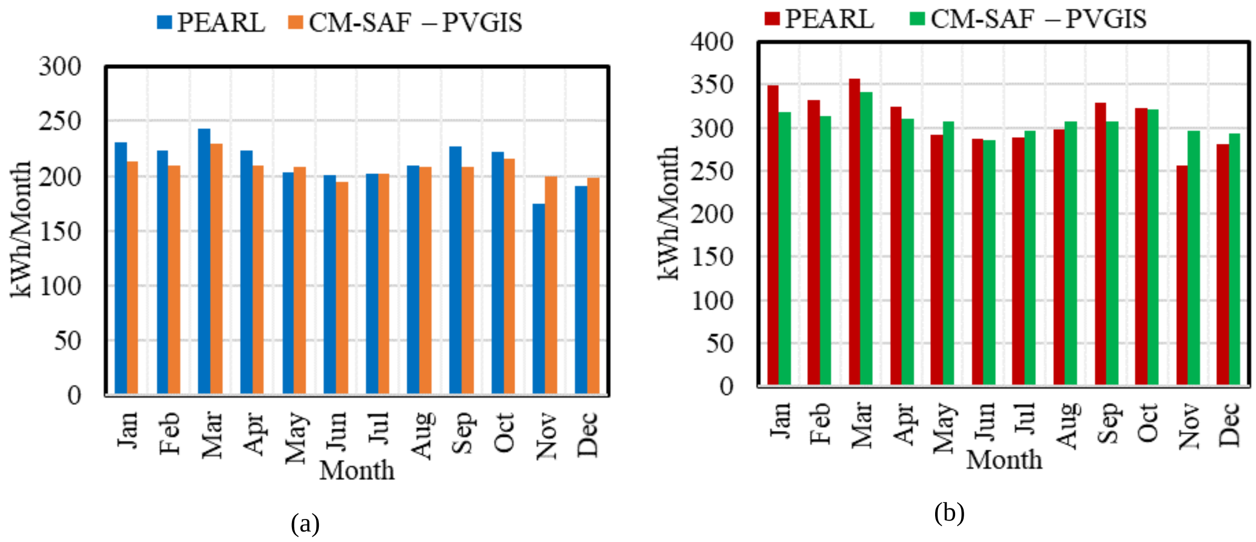


Fig. 4. Average monthly energy generation, (a) polycrystalline solar technology, (b) thin-film solar technology.

Table 1. Percentage error between the recorded and estimated monthly electricity generation.

Month	Error (%) for Polycrystalline	Error (%) for Thin Film
January	7.47	9.0
February	6.19	5.4
March	5.66	4.0
April	6.42	3.9
May	-2.52	-5.0
June	2.91	0.4
July	0.16	-2.6
August	0.89	-2.9
September	8.18	6.5
October	2.50	0.4
November	-14.25	-15.8
December	-3.90	-4.4
Total	2.11	0.4

3. SCENARIO GENERATION

Solar PV energy yield depends upon the solar azimuth and tilt angle [25],[26]. Solar panels in the northern hemisphere are faced with the true south orientation and vice versa for optimal power generation throughout the year [14],[27]. However, these general rules are more appropriate for the places with medium and high latitudes where the sun inclines to the north or south sky for a longer period of duration. On the contrary, a region like Malaysia (which is near to the equator) this optional orientation may not work because of the position of the sun throughout the year. The sun remains to the north sky for 168 days from March 30 to September 13, and the south sky for 197 days from September 14 to March 29 [18]. As a result, the stationary solar panel will be less sensitive related to its orientation towards true north or true south. Several researchers have analyzed the relationship between solar azimuth (south facing or north facing) and solar radiation for Malaysia. Work in [18] has reported that the solar panel would receive the approximately same amount of monthly average daily solar radiation at latitude 3^0 N for both north and south solar azimuth. Another study has been conducted at latitude 4.57^0 N and reports that solar azimuth direction should be north facing for the months between April to August and rest should be south facing [28]. Hence, it is evident that there is no rigid solution for the optimal orientation of solar PV in Malaysian climatic condition. Therefore, this study will consider both the solar azimuth directions for yield estimation.

Another important issue regarding PV yield estimation is tilt angle since most of the installed solar PV is operated in a stationary condition with fixed azimuth and tilt angle [26],[29],[30]. Very few research works have been conducted for calculating optimal tilt angle in Malaysia. Yan, *et al.* [14] shows that non-tracking PV panels are placed at the tilt angle of local latitude. The results in [18] revealed that the solar panels located in low latitude region like Malaysia have a seasonal optimal monthly tilt angle of 14.43^0 for south facing and 14.84^0 for north facing. Also, it shows that the deviation of ± 5^0 tilt angle has very less impact on energy generation (less than 0.3%) for both the south and north solar azimuth. Finally, work in [18] mentioned that this low latitude region would receive high solar radiation for tilt angles within 10^0 to 20^0. Work in [31] has investigated the optimum tilt angle for solar PV for the five major cities in Malaysia. Table 2 shows the monthly and seasonal optimal tilt angles for the selected zones. From Table 2, it can be found that monthly and seasonal optimum tilt angles are approximately zero degrees for all the selected cities from April to September. While, from October to March, seasonal optimal tilt angles vary between 15^0 to 23^0. Work in [32] explored the optimal tilt angle by considering the dust effect for the low latitude (4.39^0N and 100.98^0E). From the analysis, it can be seen that PV panels will receive the highest solar radiation while the optimum annual tilt angle is equivalent to locational latitude. However, solar panels performances will be less due to dust accumulation for all the year. Finally, the authors concluded that the optimum tilt angle for the south facing surface should range between 10^0 to 15^0 for low latitude region like Malaysia. Research in [32] also reported that solar panels in Kuala Lumpur will receive maximum solar radiation and have less shading effect while the panels are tilted with an optimal tilt angle of 10^0. Hence, this study will analyze the solar PV performance for three different tilt angles of 5^0, 10^0 and 15^0 for the ground mounted system. However, from the abovementioned discussion, it is evident that the mid-point (10^0) can be considered as the optimal tilt angle for Malaysia as solar panels have less dust accumulation at this angle.

Building Integrated Photovoltaic (BIPV) has great potential (7.8 TWh of electricity) in Malaysia [33],[34]. The government of Malaysia has set a target to achieve 8.45 GW BIPV installation in between 2026-2035 (which will share 30% of the national peak demand [6]). Therefore, this study will also consider BIPV yield analysis along with ground-mounted PV systems in Malaysia.

Table 2. Optimal tilt angles for solar PV [31].

Zones	Monthly optimal tilt angles (^{0})												Seasonal optimal tilt angle (^{0})	
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Apr - Sep	Oct - Mar
Kuala Lumpur	29	19	5	0	0	0	0	0	0	14	24	24	0	19
Alor Setar	32	22	8	0	0	0	0	0	2	15	26	31	0	23
Johor Buhru	24	17	3	0	0	0	0	0	0	11	22	25	0	17
Ipoh	28	19	6	0	0	0	0	0	2	13	22	25	0	19
Kuching	19	16	3	0	0	0	0	0	0	11	21	22	0	15

Crystalline Silicon (Mono and Poly), CIS (Copper-Indium-Diselenide), and Thin-film Silicon (using Amorphous Silicon) technologies are the most popular in the Malaysian solar PV market [35],[36]. Among these technologies, the crystalline silicon-based solar panel has the best performance under the hot sunny weather [37]. Table 3 presents the available solar PV panel performances under the Malaysian climatic conditions, and it shows that crystalline silicone technology (both mono and poly) have the best performance under the hot sunny weather in Malaysia. Another study in [38] also shows that the poly-crystalline silicon technology based solar panel has the highest performance with compared to mono-crystalline and amorphous silicon technology based solar panel in the Malaysian hot and humid weather. Average output efficiency (%), average module efficiency (%), and performance ratio (%) are estimated from Equations 5 to 7 [37],[38].

$$\eta_p = P_{mea} / P_{\max} \; X100\% \tag{5}$$

$$\eta_{me} = \frac{P_{mea}}{PV_A.H} X100\% \tag{6}$$

$$PR = \frac{P_{mea}}{P_{\max}} / \frac{H}{G_{STC}} \tag{7}$$

In Equations 5 to 7, η_p is average output efficiency (%), P_{mea} is average power output (W) measured on site in a specific period, P_{max} is maximum power output (W) of the panel, η_{me} is average module efficiency (%), PV_A is the panel surface area (m^2), *H is a*verage incident radiation (W/m^2) on site in a specific period, *PR* is performance ratio, and G_{STC} is Irradiance at Standard Testing Conditions (STC) (W/m^2).

Based on the prior knowledge given earlier, this study considered crystalline PV technology for calculating the annual average solar PV yield in Malaysia. Furthermore, the additional losses of 15% have been considered to cover the cable, inverter, and other losses for grid-connected PV system. By considering all the losses stated earlier, the total losses for ground-mounted solar PV plants, and BIPV are between 28% - 29% and 32% - 33%, respectively.

Based on the discussions given earlier, total of nine scenarios (given in Table 4) will be used for this study.

Table 3. Solar PV panel performances under Malaysian climate conditions [37].

PV Technology	Average output efficiency (%)	Average module efficiency (%)	Performance ratio
Mono-crystalline	30.1	6.87	0.933
Poly-crystalline	30.34	5.14	0.941
CIS	35.31	3.99	1.094
Thin Film (amorphous silicon)	33.74	2.23	1.046

Table 4. Scenarios for analyzing the PV yield in Malaysia.

Scenarios	Considerations	Placement of PV power plant
Scenario I	azimuth = 0^0; tilt = 5^0	Ground mounted
Scenario II	azimuth = 180^0; tilt = 5^0	Ground mounted
Scenario III	azimuth = 0^0; tilt = 10^0	Ground mounted
Scenario IV	azimuth = 180^0; tilt = 10^0	Ground mounted
Scenario V	azimuth = 0^0; tilt = 15^0	Ground mounted
Scenario VI	azimuth = 180^0; tilt = 15^0	Ground mounted
Scenario VII	azimuth = 0^0; tilt = 10^0	BIPV
Scenario VIII	azimuth = 180^0; tilt = 10^0	BIPV
Scenario IX	azimuth = 0^0; tilt = 90^0	BIPV

The south facing panel have solar azimuth = 0^0; North facing panel have solar azimuth = 180^0

4. ANALYTICAL RESULTS

The solar PV yield of Malaysia is estimated for each of the individual states. Figure 5 shows the geographical area of Malaysia and locations individual yield calculation. Individual locations are selected in such a way that it could estimate the yield of the whole state from PVGIS system and typically representing a city or large town. Average PV yield of individual states has been estimated from the arithmetic mean of each selected location of that state.

Table 5 shows the installed capacity of individual states solar PV projects scenario for 2015 except Sabah and Sarawak, whereas, for Sabah and Sarawak, installation data are taken for 2014 [39],[40]. Additionally, Table 5 shows the calculated average solar PV yield of individual states of Malaysia and the capacity-weighted average solar PV yield of entire Malaysia for nine different scenarios as mentioned in Section 3. It can be seen that scenario I (azimuth 0^0, tilt 5^0) have the highest possible weighted average solar PV yield of 1,317.95 kWh/kWp/y and scenario IX (vertical installation, azimuth 0^0, tilt 90^0) have the lowest possible weighted average solar PV yield of 460.48 kWh/kWp/y. Furthermore, it can be seen that annual average solar PV yield of Malaysia decreased with the increment of tilt angle and south facing panels have more annual solar PV yield than north facing solar PV panels. Moreover, BIPV has very much appreciable annual average solar PV yield of 1,238.42 kWh/kWp/y for south-facing solar panels with 10^0 tilt. Although the annual average solar PV yield is decreasing with the increment of tilt and azimuth angle, but, the changes are less than 3% with respect to the highest annual solar PV yield (azimuth = 0^0; tilt = 5^0) to the lowest possible solar PV yield (azimuth = 180^0; tilt = 15^0) for the ground mounted system. Therefore, it can be seen that azimuth and tilt angle has less effect on annual average solar PV performances for the low latitude region like Malaysia. However, being a northern hemisphere country, true south facing solar PV systems have higher average annual average solar PV yield in Malaysia.

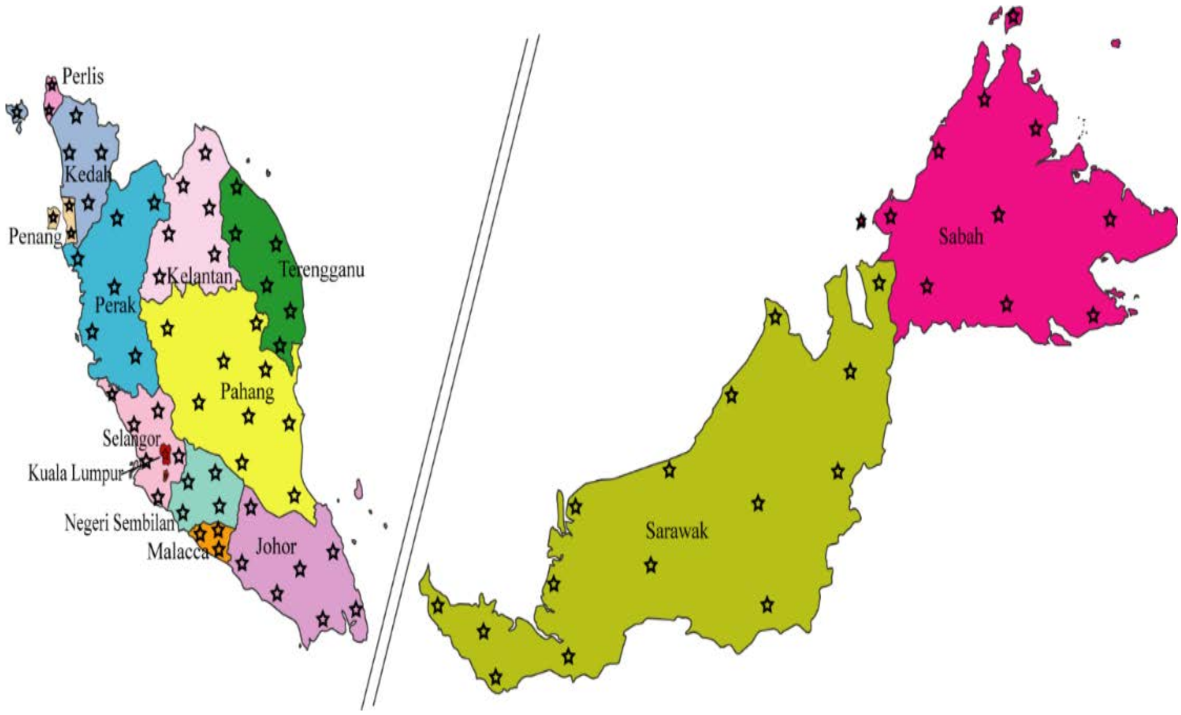


Fig. 5. Geographical area of Malaysia and PV yield calculation locations.

Table 5. Solar PV yields of individual states and weighted average of solar PV yield in Malaysia.

The states of Malaysia	Installed capacity (MW)	PV yield, kWh/kW/y								
		Scenario I	Scenario II	Scenario III	Scenario IV	Scenario V	Scenario VI	Scenario VII	Scenario VIII	Scenario IX
Perlis	13.58	1375.00	1355.00	1375.00	1340.00	1365.00	1315.00	1295.00	1265.00	507.00
Kedah	5.41	1356.00	1338.00	1354.00	1324.00	1346.00	1298.00	1278.00	1250.00	501.80
P. Pinang	3.95	1376.67	1363.33	1373.33	1346.67	1363.33	1323.33	1293.33	1273.33	502.67
Perak	9.77	1346.67	1338.33	1340.00	1321.67	1330.00	1303.33	1265.00	1251.67	479.50
Selangor	52.62	1328.33	1325.00	1320.00	1313.33	1308.33	1293.33	1248.33	1243.33	457.00
Kuala Lumpur	1.34	1270.00	1265.00	1265.00	1255.00	1255.00	1240.00	1195.00	1185.00	447.50
Negari Sembilan	34.41	1305.00	1300.00	1295.00	1290.00	1280.00	1275.00	1225.00	1220.00	455.25
Melaka	15.57	1320.00	1320.00	1313.33	1310.00	1296.67	1293.33	1240.00	1240.00	454.67
Johor	10.40	1250.00	1250.00	1242.86	1241.43	1230.00	1231.43	1175.71	1177.14	431.43
Pahang	7.31	1282.22	1281.11	1272.22	1271.11	1258.89	1256.67	1204.44	1202.22	443.56
Terengganu	7.31	1250.00	1250.00	1240.00	1240.00	1228.33	1223.33	1171.67	1171.67	430.83
Kelantan	5.62	1303.33	1300.00	1295.00	1288.33	1281.67	1271.67	1223.33	1216.67	443.50
Labuan		1400.00	1380.00	1390.00	1370.00	1380.00	1340.00	1320.00	1290.00	495.00
Sabah	1.737	1276.00	1269.00	1270.00	1256.00	1259.00	1238.00	1199.00	1189.00	457.00
Sarawak		1252.00	1251.33	1243.33	1243.33	1228.00	1230.00	1174.67	1176.67	430.60
Capacity weighted average yield		1317.95	1312.62	1310.47	1301.06	1297.86	1282.96	1238.42	1230.86	460.48

The installed capacity of grid-connected PV systems and a number of grid-connected PV system sites in Malaysia from 2012 to 2015 are shown in Table 6 (taken from [40],[41]). It can be seen from Table 6 that grid-connected PV systems are dominated by individual installation which will mostly be installed in domestic rooftops and will operate in nearly optimum orientation (Scenario VII). Data given in [29] shows that non-individuals (>500kW) are dominating among the approved solar PV applications under FiT until September 2015 with the installed capacity of 196.94 MW. Nevertheless, these will mostly operate in optimum or nearly optimum orientation (Scenario III). Based on the above discussion it can be stated that most of the solar PV applications in Malaysia will operate fixed system either ground-mounted or BIPV with optimum orientation. As a result, this paper considered mid-point of scenario III and scenario VII for the annual weighted average solar PV yield of Malaysia which gives solar PV yield of 1,274.45 kWh/kWp/y.

Table 6. Number of PV systems in operation [40],[41].

Year	Number of sites			Grid-connected PV installed capacity (MWp)
	Individuals	Non-individuals	Community	
2012	-	-	-	31.58
2013	1326	86	-	107.01
2014	1447	109	-	65.06
2015	1752	37	45	26.83
Cumulative	4525	232	45	230.48

- *Data not available*

Table 7. Installed capacity and power generation of commissioned solar PV installations under FiT system [3].

Year	Installed Capacity (MW)	Annual Power Generation (MWh)	Yield (kWh/kWp/y)
2012	31.56	4,714.01	149.37
2013	106.93	48,612.07	351.02
2014	64.88	178,329.6	876.87
2015	60.11	250,249	949.78
2016	30.66	188,110.78	639.53

5. DISCUSSIONS

Estimated annual average solar PV yield of Malaysia is 1,274.45 kWh/kWp/y, (an estimation from the CM-SAF-PVGIS database). This paper considered the orientation of Scenario III (azimuth = 0^0 and tilt = 10^0) for yield calculation. It can be seen that optimum oriented solar plants have less annual average solar PV yield comparing to Scenario I (azimuth = 0^0 and tilt = 5^0). However, the difference is very negligible(less than ± 1%). Thus, the optimum orientation considered in this paper has appreciable performance in the Malaysian climate. Solar power plants that are oriented toward optimum or near optimum in ground-mounted should have an annual yield of 1,310.47 kWh/kWp/y. In contrast, optimum or near optimum oriented BIPV power plants should have an annual yield of 1,238.42 kWh/kWp/y under Malaysian climate. The average yield of these two scenarios gives the estimation of annual average solar PV yield of 1,274.45 kWh/kWp/y. This estimated value can give the energy generation scenario from solar PV in Malaysia.

The losses in a grid-connected PV system are evaluated during solar PV yield estimation. These PV losses give the equivalent system performance ratio (PR) of 71 to 72% for ground-mounted solar PV power plants and 67 to 68% of BIPV power plant.

5.1 Calculated and Published Yield

SEDA publishes yearly installed capacity and generation from various renewable sources under FiT [3]. Table 7 shows the installed capacity and yearly generations of commissioned solar PV installations under FiT for the period of 2012 to 2016. The annual yield is evaluated in this paper by dividing the yearly generation and cumulative installed capacity of that year. It can be seen from Table 7 that annual solar PV yield of Malaysia changes year to year and the maximum value of annual yield is 949.78 kWh/kWp/y for 2015. Calculated solar PV yield of Malaysia by using the data of SEDA would not represent the correct annual solar PV yield of Malaysia. It can be seen that the annual yield for 2012 and 2013 are 149.37 kWh/kWp/y and 351.02 kWh/kWp/y, respectively which are significantly lower with compared with the installed capacity of the respective years. Nevertheless, yield values for 2012 and 2013 have a large difference from the yield values for the year 2014 and 2015. Moreover, the yield for the year 2016 reduces from the year 2015. There is no explanation in SEDA for these large variations of the yield of 2012 to 2016. Furthermore, the procedures for generation data collection have not mentioned here. As a result, these values may not represent the actual annual solar PV yield of Malaysia and underestimate the overall PV generation of Malaysia. On the other hand, National Survey Report of PV Power Applications in Malaysia for 2014 and 2015 [40],[41] reported no change for PV yield for 2014 and 2015 (1,200 kWh/kWp). This yield value is close to the calculated value of this paper of 1,274.45kWh/kWp/y. However, this average value does not consider weighted regional average value during yield calculation. Additionally, there is some mismatch in yield results given in these reports. Hence, the yield data given in [40], [41] underestimate the annual solar PV generation of Malaysia.

The data shows that in 2018 solar PV have a cumulative installed capacity of 297.69MW and generation of 399.93GWh under FiT scheme [29]. This would be equivalent to a yield of 1,343.44 kWh/kWp/y. This is very close to calculated ground mounted yield of 1,310.47 kWh/kWp/y and a little higher than the calculated yield of 1,274.45kWh/kWp/y which is the average of ground mounted and BIPV yield in this paper. Therefore, it can be concluded that calculated solar PV yield has some differences with the equivalent yield in [23] due to the scenario considered during the yield calculation. Figure 6 illustrates the percentages of solar PV power plants distribution which gives the yield value of 1,274.45kWh/kWp/y for the year 2015. It can be seen from Figure 6 that the Selangor and Negeri Sembilan states have the highest solar PV plants installed capacity which is 31.1% and 20.4%, respectively. Any changes in the installed solar PV power plants distribution will change the annual average yield value of Malaysia because the different region has different annual average solar PV yield as mentioned in Table 5. Presently, FiT and NEM accelerating a large amount of ground mounted and BIPV power plants installed capacity across Malaysia. This acceleration of solar PV installation in turns changing the annual average solar PV yield of Malaysia. Particularly, the annual average yield increased with the increment of PV installation in the high yield region. In 2018, solar PV power plants might be installed in ground-mounted rather than BIPV in the highest yield regions that in turns give the high annual average yield for Malaysia in 2018. The equivalent yield 1,343.44kWh/kWp/y value might have some uncertainty because of the calculation method for estimating the 2018 values. However, this yield 1,343.44 kWh/kWp/y value is in line with the calculated yield 1,274.44kWh/kWp/y value in this paper.

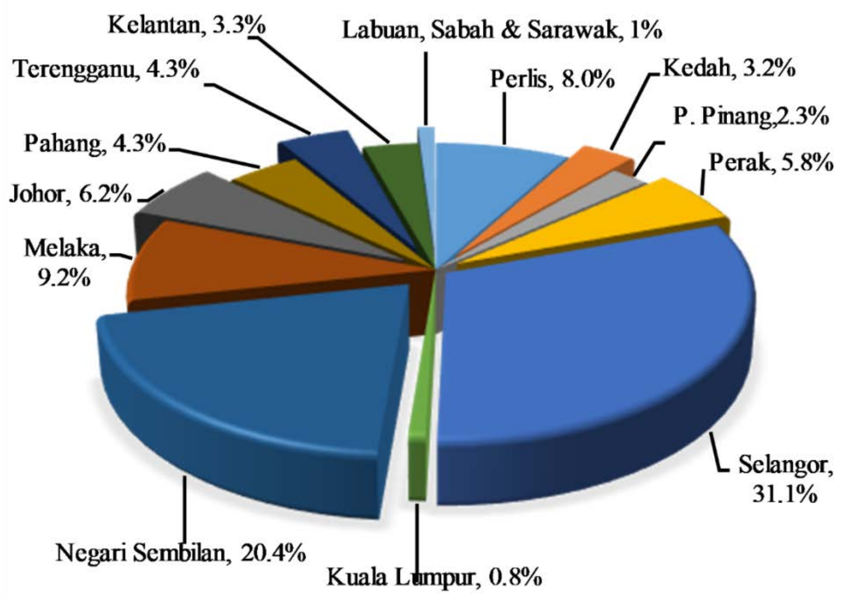


Fig. 6. Percentage of installed solar PV distribution in Malaysia.

5.2 Uncertainty in Calculated Yield

Losses due to temperature de-rating factor of individual locations, dirt factor, shading effect, and electrical losses are considered in calculating solar PV yield. However, losses related to the long-term aging effect of the solar PV have not considered here for yield calculation. A typical value of the aging factor of 0.5% per year is considered here for the analysis [42]. However, this has a very negligible effect on the annual calculated yield because of 90% solar PV installed within the last three years. Nevertheless, the calculation of weighted average solar PV yield could be carried out precisely. This high precision yield calculation depends on the detailed information about the regional distribution of installed PV capacity by year, the technology of the installed PV power plants, orientations of the installed PV power plants, the proportion of ground mounted, roof mounted, and BIPV power plants of individual regions. However, annual average solar PV yield calculated here in this paper might have ± 5% uncertainty due to the variations of solar irradiance of selected 85 different locations of Malaysia. Work in [21] shows that CM-SAF-PVGIS database has overall mean bias deviation (MBD) of +1.63 W/m^2 or +0.73% for GHI for Asia. The study in this paper considers the mean of the yield of ground mounted and building integrated PV systems as the overall annual average solar PV yield of Malaysia. However, tolerance between these two scenarios is ± 5.5%. This could be another source of error. Also, the capacity-weighted yield is calculated here in this paper, and this gives capacity-weighted average PR of 72% for Malaysia. PR of individual solar PV may vary widely from this value because of constant losses for the shading effect during calculation. Shading effect losses are mainly related to individual locations and climate conditions (cloud). Geographical background and climate conditions change year to year for individual locations and for this reason shading losses also change for different locations. Nevertheless, the average value should not change much, and the uncertainty of PR value should not exceed ± 2%. Additionally, annual average solar PV yield has been estimated by using annual average solar irradiance from CM-SAF-PVGIS database. However, the literature shows that mean annual solar irradiance level changes every year for the tropical country like Malaysia [43] and this could add uncertainty while estimating the value for any individual year. Considering these errors, the average estimated solar PV yield of Malaysia might have the uncertainty of less than ±5 % to the overall calculation which is much acceptable to estimate the yield.

5.3 Importance of Efficient Yield Estimation

The accurate estimation of generating solar PV yield is important for the operations planning of the entire electrical power system [16]. A misleading estimation may jeopardize the operation of the power system. One of the most import factors of power system planning is the capacity factor (CF). CF of a PV plant is the ratio of the real power generation from PV plant over a specific period and the PV power that would be generated if the PV plant could be operated with a total maximum installed capacity over that period. CF of solar PV can be calculated from the annual average yield according to the method given in [44]. Calculated annual solar PV yield of this study shows that CF in Malaysian solar PV for the year 2015 is 14.52%. This calculated CF for 2015 is similar to the CF in [45]. In addition, inter-provinces PV yield variability assessment is also important for power system planning. Figure 7 shows the inter-provinces PV yield variation for optimum oriented PV systems in terms of the weighted average energy value. The results in Figure 7 depicts that most of the provinces of Malaysia experience a higher deviation from the weighted average PV energy yield. It could be seen from Figure 7 that the ground-mounted and BIPV systems could experience annual energy output variation of as high as 116 kWh/kWp/y and 103 kWh/kWp/y, respectively from the calculated weighted average PV yield.

Individual providences of Malaysia can be ranked regarding annual solar energy yield. Figure 8 shows the ranking of the individual provinces of Malaysia. It can be seen that among the provinces of Malaysia, Labuan and Terengganu have the maximum and minimum solar energy yield, respectively. Additionally, it is possible to perform the instantaneous calculation of yearly generation from solar PV for the specific region from the current installed capacity.

The cumulative installed capacity of solar PV under FiT in 2014 of Malaysia was 155.65 MWp [3]. This installed capacity generates approximately 198 GWh of electricity from solar PV for the year 2014 which is nearly 0.14% of Malaysia's 145 TWh electricity generation in 2014 [45]. Besides, estimating regional PV generation can be possible by knowing the regional installed capacity, which in turns could be used as a benchmark for assessing the regional generation performance.

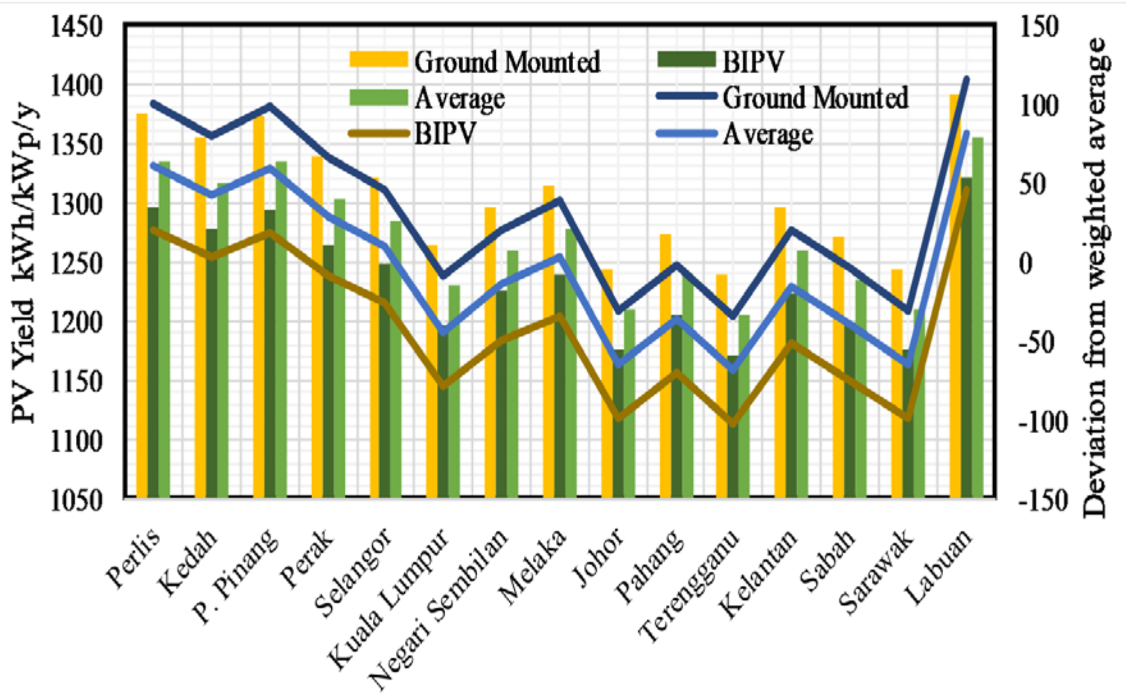


Fig. 7. Individual provinces yearly PV energy yield and deviation from the weighted average.

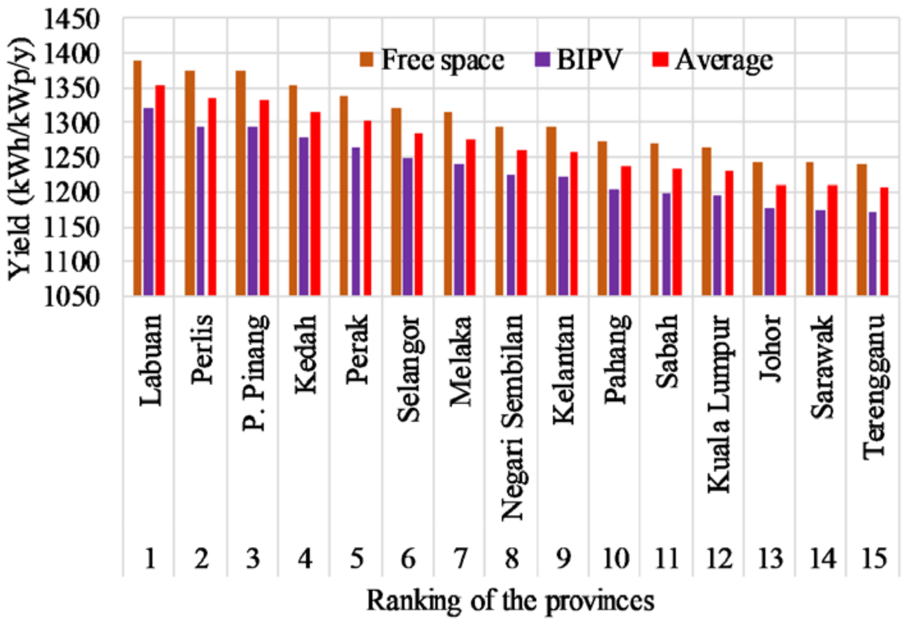


Fig. 8. Individual provinces yearly PV energy yield and deviation from weighted average.

Table 8. Regional solar PV electricity generation of Malaysia for the installed capacity in 2015.

The states of Malaysia	Installed capacity (MW)	Yield (kWh/kWp)	Annual Generation (GWh)
Perlis	13.58	1335.00	18.13
Kedah	5.41	1316.00	7.12
P. Pinang	3.95	1333.33	5.27
Perak	9.77	1302.50	12.73
Selangor	52.62	1284.17	67.57
Kuala Lumpur	1.34	1230.00	1.65
Negari Sembilan	34.41	1260.00	43.36
Melaka	15.57	1276.67	19.88
Johor	10.40	1209.29	12.58
Pahang	7.31	1238.33	9.05
Terengganu	7.31	1205.83	8.81
Kelantan	5.62	1259.17	7.08
Labuan Sabah Sarawak	1.737	1266.17	2.20
Total	169.03		215.42

Therefore, it will be possible to identify regional solar PV power plants which are underperforming by using the regional generation benchmark data. Table 8 shows the estimated annual solar PV electricity generation for each region of Malaysia, where, regional installed capacity for the year 2015 was taken from [39], [40]. It can be seen that the total solar PV electricity generation in the year 2015 is around 215.42 GWh, which is roughly 0.14% of the total electricity generation of 153 TWh in 2015 [45]. Percentages of regional electricity generation are shown in Figure 9. It can be seen that Selangor and Negeri Sembilan states are contributing more than half of generated solar PV electricity with the installed capacity of 2015. Furthermore, annual average PV yield is also important for evaluating the environmental impact of electricity generation, particularly, CO_2 emissions from electricity sector because 1 MWh of RE electricity generation could avoid 0.63 tonnes of CO_2 [46]. Malaysia had approximately 92.50 million tonnes (Mt) of CO_2 emissions from electricity generation in 2015 [45]. However, Malaysia has a specific target of reducing 42 Mt of CO_2 in the power sector in 2020 by generating 60,584 GWh of electricity from renewable energy [46]. As a result, it is essential to calculate solar PV generation appropriately to evaluate the environmental footprint from solar PV. Any misleading calculation will significantly exaggerate the solar PV contribution to the environment as well as mislead the calculation of the government target of reducing GHG. According to the calculated generation of 215.42 GWh in this paper, solar PV could contribute avoiding of 0.136 Mt of CO_2 for the year 2015.

It can be concluded from the prior results and discussions that the calculated annual average solar PV yield by weighted is more suitable to analyze the performances of distributed installed capacity of solar PV throughout the Malaysian jurisdiction. The conducted study of this paper could be considered as a benchmark for calculating the annual average solar PV of Malaysia. The work presented in this paper will provide not only invaluable information and tools for Malaysian PV industries and electricity utilities but also offer helpful methodologies to the renewable energy policymakers.

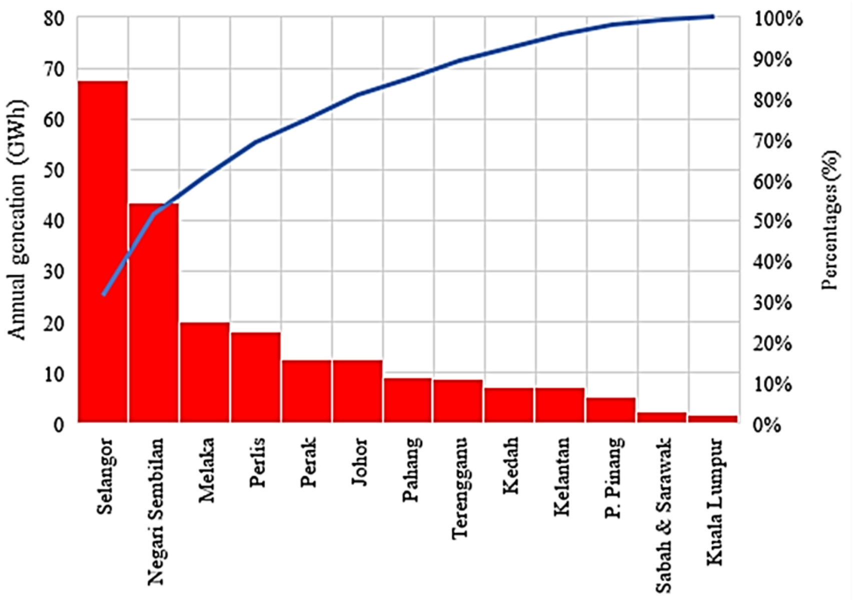


Fig. 9. Individual provinces yearly PV energy yield and deviation from weighted average.

6. CONCLUSIONS

This paper estimates the annual average solar PV yield for Malaysia by using the PVGIS metrological database. This work first verified the effectiveness of the CM-SAF-PVGIS database by comparing the estimated results with yearlong-recorded data from 2.00 kWp polycrystalline and 2.7 kWp thin film technology based solar PV power plants. The mismatches between the estimated and measured results are 2.11% for polycrystalline and 0.44% for the thin film power plant, which in turns validates the effectiveness of CM-SAF-PVGIS database for annual average PV yield estimation.

The calculated annual average solar PV yield of Malaysia is 1,274.44kWh/kWp/y, which is the average value of nearly optimum orientation of the ground-mounted solar PV plants (1,310.47kWh/kWp/y) and BIPV plants (1,238.42kWh/kWp/y). This annual average solar PV yield is equivalent to the CF of 14.52%. The calculated yield might have an uncertainty of ± 5%. Installed capacity of 169.03 MW of solar PV in the year 2015 should generate 215.42GWh of electricity which is 0.14% of the total generation of the typical year and should avoid 0.136 Mt of CO_2 for the year 2015. The results and discussions given in this paper could provide useful information to industries and utilities for future PV planning.

ACKNOWLEDGEMENT

The authors would like to acknowledge the financial support received from the University of Malaya, Malaysia, though FRGS Grant No. FRGS/1/2018/TK07/UM/01/3, and Frontier Research Grant No. FG007-17AFR.

REFERENCES

[1] Mekhilef S., Saidur R., and Safari A., 2011. A review on solar energy use in industries. *Renewable and Sustainable Energy Reviews, 15*(4): 1777-1790.

[2] Renewable Energy Act. 2011. Renewable Energy Act 2011, Malaysia. Retrieved December 11, 2016 from the World Wide Web: https://efit.seda.gov.my/?omaneg=00010100000001010101000100001000000010100001000110&id=1722

[3] SEDA. 2016. Sustainable Energy Development Authority Malaysia. Retrieved December 12, 2016 from the World Wide Web: www.seda.gov.my

[4] KeTTHA, Malaysia. 2011. Handbook on the Malaysian Feed-in-Tariff for the Promotion of Renewable Energy, KeTTHA (Kementerian Tenaga Teknologi Hijau dan Air), Ministry of Energy, Green Technology and Water.

[5] Pacudan R., 2018. The economics of net metering policy in the Philippines. *International Energy Journal 18*(3): 283-296.

[6] MPIA. 2015. Solar PV – The Game Changer in Malaysian Electricity Supply Industry. *Malaysian Photovoltaic Industry Association (MPIA).* Retrieved December 12, 2017 from the World Wide Web: http://www.st.gov.my/index.php/en/download-page/category/121-workshop-on-solar-pv-net-energy-metering-nem-self-consumption-selco-and-large-scale?download=523:solar-pv-the-game-changer-in-malaysian-electricity-supply-industry.

[7] Shah R., Mithulananthan N., Bansal R.C., and Ramachandaramurthy V.K., 2015. A review of key power system stability challenges for large-scale PV integration. *Renewable and Sustainable Energy Reviews* 41: 1423-1436.

[8] Mason N.B., 2016. Solar PV yield and electricity generation in the UK. *IET Renewable Power Generation* 10(4): 456-459.

[9] Mirzaei M. and M.Z. Mohiabadi 2018. Comparative analysis of energy yield of different tracking modes of PV systems in semiarid climate

conditions: The case of Iran. *Renewable Energy* 119: 400-409.

[10] MBIPV. 2008. PV Industry handbook. *Malaysian Building Integrated Photovoltaic (MBIPV) Project.* Retrieved December 19, 2017 from the World Wide Web: http://www.mbipv.net.my/dload/FIF-PV%20Ind%20Final.pdf

[11] Carbon Brief. 2016. *Paris 2015: Tracking country climate pledges.* Retrieved December 15, 2017 from the World Wide Web: https://www.carbonbrief.org/paris-2015-tracking-country-climate-pledges

[12] Omar A., Hussin M., Shaari S., and Sopian K., 2014. Energy yield calculation of the grid connected photovoltaic power system. *8th International Conference on Renewable Energy Sources (RES)*: 162-167.

[13] Torres-Ramírez M., Nofuentes G., Silva J.P., Silvestre S., and Muñoz J.V., 2014. Study on analytical modelling approaches to the performance of thin film PV modules in sunny inland climates. *Energy* 73: 731-740.

[14] Yan R., Saha T.K., Meredith P., and Goodwin S., 2013. Analysis of yearlong performance of differently tilted photovoltaic systems in Brisbane, Australia. *Energy Conversion and Management* 74: 102-108.

[15] Navabi R., Abedi S., Hosseinian S.H., and Pal R., 2015. On the fast convergence modeling and accurate calculation of PV output energy for operation and planning studies. *Energy Conversion and Management* 89: 497-506.

[16] Graditi G., Ferlito S., Adinolfi G., Tina G.M., and Ventura C., 2016. Energy yield estimation of thin-film photovoltaic plants by using physical approach and artificial neural networks. *Solar Energy* 130: 232-243.

[17] Huld T., Müller R., and Gambardella A., 2012. A new solar radiation database for estimating PV performance in Europe and Africa. *Solar Energy,* 86(6): 1803-1815.

[18] Ng K.M., Adam N.M., Inayatullah O., and Kadir M.Z.A.A., 2014. Assessment of solar radiation on diversely oriented surfaces and optimum tilts for solar absorbers in Malaysian tropical latitude. *International Journal of Energy and Environmental Engineering* 5(1): 1-13.

[19] Mekhilef S., Safari A., Mustaffa W.E.S., Saidur R., Omar R., and Younis M.A.A., 2012. Solar energy in Malaysia: Current state and prospects. *Renewable and Sustainable Energy Reviews,* 16(1): 386-396.

[20] JRC. 2016. *Photovoltaic Geographical Information System.* Retrieved April 09, 2019 from the World Wide Web: http://re.jrc.ec.europa.eu/pvg_tools/en/tools.html#PVP

[21] Amillo A.G., Huld T., and Muller R., 2014. A new database of global and direct solar radiation using the eastern meteosat satellite, models and validation. *Remote Sensing* 6(9): 8165-8189.

[22] Mueller R., Behrendt T., Hammer A., and Kemper A., 2012. A new algorithm for the satellite-based retrieval of solar surface irradiance in spectral bands. *Remote Sensing* 4(3): 622-647.

[23] Huld T., Friesen G., Skoczek A., Kenny R.P., Sample T., Field M., and Dunlop E.D., 2011. A power-rating model for crystalline silicon PV modules. *Solar Energy Materials and Solar Cells* 95(12): 3359-3369. doi:https://doi.org/10.1016/j.solmat.2011.07.026

[24] JRC. 2019. *Overview of PVGIS data sources and calculation methods.* Retrieved April 04, 2019 from the World Wide Web: http://re.jrc.ec.europa.eu/pvg_static/methods.html#!

[25] Mohammadi K. and H. Khorasanizadeh. 2015. A review of solar radiation on vertically mounted solar surfaces and proper azimuth angles in six Iranian major cities. *Renewable and Sustainable Energy Reviews* 47: 504-518.

[26] Yadav A.K. and S.S. Chandel. 2013. Tilt angle optimization to maximize incident solar radiation: A review. *Renewable and Sustainable Energy Reviews* 23: 503-513.

[27] Hashim A.M., Ali M.A.M., Ahmad B., Shafie R.M., Rusli R., Aziz M.A., Hassan J., and Wanik M.Z.C., 2013. A preliminary analysis of solar irradiance measurements at TNB solar research centre for optimal orientation of fixed solar panels installed in selangor Malaysia. *IOP Conference Series: Earth and Environmental Science* 16: 012001.

[28] Sunderan P., Ismail A.M., Singh B., and Mohamed N.M., 2011. Optimum tilt angle and orientation of stand-alone photovoltaic electricity generation systems for rural electrification. *Journal of Applied Sciences* 11: 1219-1224.

[29] Chen W.-N., 2015. Status of feed-in tariff in Malaysia. *Sustainable Energy Development Authority (SEDA), Malaysia.* Retrieved December 20, 2016 from the World Wide Web: http://mys.mofa.go.kr/webmodule/common/download.jsp?boardid=1591&tablename=TYPE_LEGATION&seqno=ffafc8f8cff5fb3007fce06f&fileseq=fed017ff0ff5f88051fe7ffe

[30] Nijegorodov N., Devan K.R.S., Jain P.K., and Carlsson S., 1994. Atmospheric transmittance models and an analytical method to predict the optimum slope of an absorber plate, variously oriented at any latitude. *Renewable Energy* 4(5): 529-543.

[31] Khatib T., Mohamed A., Mahmoud M., and Sopian K., 2015. Optimization of the tilt angle of solar panels for Malaysia. *Energy Sources Part a-Recovery Utilization and Environmental Effects* 37(6): 606-613.

[32] Saadatian O., Sopian K., Elhab B., Ruslan M., and Asim N., 2013. Optimal solar panels' tilt angles and orientations in Kuala Lumpur, Malaysia. *Advances in Environment, Biotechnology and Biomedicine*: 978-971.

[33] UNDP. 2016. United Nations Development Program Global Environment Facility. *Malaysia: Building integrated photovoltaic (BIPV) technology application project.* Retrieved February 23, 2017 from the World Wide Web: http://www.undp.org/content/dam/malaysia/docs/EnE/EnEProDocs/Building%20Integrated%20Photovoltaic%20Technology%20Application%20Prodoc.pdf

[34] Haris A., 2006. Grid-connected and building integrated photovoltaic: application status and prospect for Malaysia. *Master Builders Journal* 3: 91-95.

[35] Seng L.Y., Lalchand G., and Lin G.M.S., 2008. Economical, environmental and technical analysis of building integrated photovoltaic systems in Malaysia. *Energy Policy* 36(6): 2130-2142.

[36] Khaenson W., Maneewan S., and Punlek C., 2017. environmental impact analysis of solar power generation process using multicrystalline and amorphous silicon solar cells in Thailand. *International Energy Journal* 17(3): 113-124.

[37] Rao S., Bayudi R., Inangda S., and Haw L., 2003. Building integrated photovoltaics under the Malaysia climate. *Seminar Penyelidikan Jangka Pendek* pp. 1-5.

[38] Ghazali A.M. and A.M.A. Rahman. 2012. The performance of three different solar panels for solar electricity applying solar tracking device under the Malaysian climate condition. *Energy and Environment Research* 2(1): 235.

[39] Energy Commission. 2016. *Energy Commission Malaysia*. Retrieved December 12, 2016 from the World Wide Web: www.st.gov.my

[40] IEA-PVPS, 2015. National Survey Report of PV Power Applications in Malaysia 2014. *International Energy Agency - Photovoltaic Power System Programme (IEA-PVPS).* Retrieved February 15, 2017 from the World Wide Web: http://www.iea-pvps.org/index.php?id=93&eID=dam_frontend_push&docID=3353

[41] IEA-PVPS, 2016. National Survey Report of PV Power Applications in Malaysia 2015. *International Energy Agency - Photovoltaic Power System Programme (IEA-PVPS).* Retrieved February 15, 2017 from the World Wide Web: http://www.iea-pvps.org/index.php?id=93&eID=dam_frontend_push&docID=3353

[42] Jordan D.C. and S.R. Kurtz. 2013. Photovoltaic degradation rates-an analytical review. *Progress in Photovoltaics* 21(1): 12-29.

[43] Dong S.X., Davies S.J., Ashton P.S., Bunyavejchewin S., Supardi M.N., Kassim A.R., Tan S., and Moorcroft P.R. 2012. Variability in solar radiation and temperature explains observed patterns and trends in tree growth rates across four tropical forests. *Proceedings of the Royal Society of London B: Biological Sciences* 279: 3923-3931.

[44] Andrew. 2017. *Capacity factors at Danish offshore wind farms*. Retrieved July 07, 2017 from the World Wide Web: http://energynumbers.info/capacity-factors-at-danish-offshore-wind-farms

[45] IEA, 2015. *Southeast Asia Energy Outlook.* International Energy Agency (IEA), France.

[46] IEA, 2010. National Renewable Energy Policy and Action Plan. *The Ministry of Energy, Green Technology and Water.* Retrieved March 16, 2017 from the World Wide Web: https://www.iea.org/media/pams/malaysia/PAMS_Malaysia_NationalRenewableEnergyPolicyandActionPlan.pdf.