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Impact of Extreme Temperature on Solar Power Plant in Malaysia

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Although the subject of global warming attracts enormous attention, there is a limited number of analyses dealing with high ambient temperature impacts on energy system planning. This research aims to monitor the trend of extreme temperature and analyze its impact on solar power plants in Malaysia. Data from ClimateAP software using global climate models are used to estimate the percentage changes in annual average temperature by 2080 under high emissions scenarios in comparison to baseline data from the end of the 20th century. The heat map was used to show the projected of average temperature across Malaysia under the Radiative Concentration Pathways 8.5 scenario. Photovoltaic application is the most frequent used in solar power plant. The basic energy parameters of the solar photovoltaic module are calculated to find out the relationship between ambient temperature and power generated. It is found that the output power of the solar photovoltaic module is reduced about 0.3 to 0.5 % for every 1 °C ambient temperature increases. The temperature projection shows that all locations of solar farms showed a significant increase in temperature at above 30 °C in 2080 compared to the historical temperature. This temperature increment may risk to the solar panel degradation and reduce the efficiency of the solar module. Hence, it is important to figure out adaptation of extreme temperature for a long-term basis to maintain the efficiency of the solar module near the point of maximum power.

1. Introduction

Climate change is expected to have a significant impact globally including in Malaysia, especially by increasing the temperature year by year (Tangang et al., 2017). According to the Sixth Assessment Report by The Intergovernmental Panel on Climate Change (IPCC, 2021), the worldwide average temperature increased by 0.87 °C in the decade of 2006 to 2015 and kept rising by 0.2°C every 10 years.

Malaysia experiences hot and sunny weather throughout the year due to its location in the equatorial region. About 400 – 600 MJ/m^2 of solar irradiation produced each month with a maximum output of 6,500 MW of estimated maximum energy makes Malaysia a viable source of solar energy (Mekhilef et al., 2012). Most of the solar systems in this country apply photovoltaic technology to convert solar radiation into direct current electricity. However, in hot climate countries such as Malaysia, overheating of the surface of photovoltaic cells during operation is influenced by elevated ambient temperatures. Plus, the climate change phenomenon might worsen this situation. The degradation due to overheating of the modules might occur twice for every 10˚C increase in the surface (Kirpichnikova and Makhsumov, 2020).

Jong at al. (2019) studied the impact of climate change on Brazil's solar and wind energy resources. Their result showed that due to climate change, solar energy potential could increase slightly at solar power plant locations in the Northeast and Southeast regions in Brazil. In Malaysia, there are a few studies about the trend in extreme temperature. Yatim et al. (2019) investigates the recent extreme temperature trends across 19 stations in the Klang Valley, Malaysia, over the period 2006 to 2016. Moreover, Mohd Salleh et al. (2015) analyzed changes

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in the annual average daily temperature recorded at twenty-three meteorological stations in Malaysia. Both studies found out that warming trends in the Klang Valley and all other 23 meteorological stations especially in urban areas. To date, there is still limited number of researches about the impact of extreme temperature on the energy system. To the best of the authors' knowledge, none of the studies explicitly examined extreme temperature on the renewable energy system in Malaysia especially solar power system, although the average global temperature keeps increasing year by year and global warming has received a great attention among researchers.

This paper provides an interpretation of forecast temperature of the year 2080 for solar power plants in Malaysia. The projected of average temperature across Malaysia under the Radiative Concentration Pathways 8.5 scenario was presented using heat map from ClimateAP data. The analysis of elevated temperature on solar power generated and its efficiency was also provided. The overall objective of this study is to investigate the impact of extreme temperature on solar power plants in Malaysia. It is expected that the temperature increment may risk to the solar panel degradation and reduce the efficiency of the solar module.

2. Methods

Projection climate data relied on ClimateAP software using global climate models included in the Coupled Model Intercomparison Project Phase 5 (CMIP5) models. These models are utilized within the Sixth Assessment Report (AR6) of the Intergovernmental Panel on Climate Change (IPCC), providing estimates of future temperature. ClimateAP uses the best available interpolated climate data for the reference period 1961–1990 as baseline data. It downscales the baseline data from a moderate spatial resolution to scale-free point data through dynamic local elevation adjustments (Wang et *al*., 2017). The highest Radiative Concentration Pathways (RCP) chosen in this study is RCP 8.5, which assumes a business-as-usual scenario. The model domain extended from 95°E to 123°E and 7.5°S to 14°N, covering both Peninsular Malaysia and East Malaysia. In this research, year 2080 is chosen to indicate the latest trend of projected temperature.

Expert Team on Climate Change Detection and Indices (ETCCDI) has suggested some thresholds for the extreme temperature indices such as frost days (daily minimum temperature below 0°C), summer days (daily maximum temperature above 25°C) and tropical nights (daily minimum temperature below 20°C). However, these thresholds are not appropriate in this study as Malaysia's tropical rainforest climate is always hot and humid throughout the year, with an annual mean surface temperature ranging from 26°C to 28°C (Malaysian Meteorological Department, 2016). Hence, in this study, the threshold was adjusted above 28 °C as the threshold temperature index because it exceeds the value of the annual mean temperature. This index was derived from the daily average temperature data and only focused on annual basis.

To analyze the impact of projected temperature on solar power plant, a structural calculation scheme has been drawn up by considering the ambient temperature parameter that affect the operational parameters of the solar photovoltaic modules. Table 1 shows the technical characteristics of solar photovoltaic modules that commonly used in Malaysia. Assumptions were made during calculation such as radiation input (E) is 800 W/m^2, emission spectrum 1.5, wind speed at 1 m/s and reference of ambient temperature at 25°C.

Table 1: Technical characteristics of photovoltaic module under standard test condition

Parameters Name	Symbols	Parameter value
Peak Electrical Power	P_{max}	100 W
Voltage at max power point	V_{max}	18.78 V
Current at max point	I_{max}	5.34 A
Short circuit current	I_{sc}	5.7 A
Open circuit voltage	V_{oc}	22.64 V
Current temperature coefficient	K_i	0.04 % /°C
Voltage temperature coefficient	K_v	-0.38 % /°C
Photovoltaic module efficiency	η	17.96 %
Size	LxWxH	1470x670x35 mm
Standard test condition	STC	1,000 W/m2; AM 1.5; 25°C
No of solar cell	9x4	36

Short-circuit current (I_{shc}) for a specific incoming solar radiation area is shown in Eq(1) where I_{sc} is short circuit current under standard condition and E is solar radiation in W/m^2.

$$I_{shc} = I_{sc} \times E \tag{1}$$

Open circuit voltage (V_{opc}) as in Equation 2 below where V_{oc} represents open circuit voltage specified by the manufacturer (in Voltage), T_{amb} is recorded ambient temperature, T_{sc} is temperature solar cells and 25 is standard test temperature of the module (in ºC). The range of T_{sc} is at 33°C to 48 °C, and the worst at 58°C (Blazev, 2020).

$$V_{opc} = V_{oc} - [0.0023 \times T_{amb}(T_{sc} - 25)] \tag{2}$$

The maximum (peak) value of the output power (P_{peak}) as in Equation 3 where FF is the point of maximum power is found from the assumption that the fill factor in Equation 4 does not depend on T_{amb} and E. P_{max} is is the peak electric power according to the manufacturer (in Watt).

$$P_{peak} = I_{shc} \times V_{opc} \times FF \tag{3}$$

$$FF = P_{max}/(V_{oc} \times I_{sc}) \tag{4}$$

3. Solar in Malaysia

Photovoltaic (PV) technology is the main application used under solar energy systems in Malaysia. The type of solar system for power generation that are currently used in Malaysia is Large Scale Solar (LSS) and rooftop solar (Abdullah et *al.*, 2019). Table 2 represents the several of solar power plants in Malaysia. This table shows that most developed PV system were operated by private sectors in order to sell the generated power back to the utility supplier company, which is Tenaga National Berhad (TNB). Location of solar power plants are more scattered and built in the industrial area. The industry players were encouraged to install PV systems because of introduction of Feed-in Tariff (FiT) and Net Energy Metering (NEM) scheme by Malaysia government in 2016. LSS scheme is also another alternative made by the Energy Commision Malaysia to let the company generate their own electricity via solar PV farm with below 30 MW capacity and sell to the grid (Cheong et al., 2020). From the Table 2, most of solar power plant in Malaysia were under LSS schemes since most of them have capacity below than 30 MW. It is a win-win situation to help Malaysia achieve targeted 20 % of renewable energy generation sources from the total generation mix and at the same time it is profitable to the company. Due to the wide acceptance of solar energy, the net installed capacity of solar energy reached 1,493 MW in 2020 and is targeted to reach 18,000 MW by 2035 (International Renewable Energy Agency (IRENA), 2021).

Table 2: Solar power plant in Malaysia (Abdul Rahman et al., 2020)

Plant	Location	Owner/ operator	Capacity (MWE)
Kuala Perlis Solar Power Plant	Kuala Perlis, Perlis	Cypark Resources Berhad	6.0
Rimba Terjun Solar Power Plant	Rimba Terjun, Pontian, Johor	Cypark Resources Berhad	2.0
Kuala Sawah Solar Power Plant	Rantau, Negeri Sembilan	Cypark Resources Berhad	5.3
Pajam Solar Power Plant	Pajam, Negeri Sembilan	Cypark Resources Berhad	6.0
Bukit Palong Solar Power Plant	Bukit Palong, Negeri Sembilan	Cypark Resources Berhad	3.0
ZEC Solar Farm	Kota Tinggi, Johor	Malakoff	29.0
Gebeng Solar Power Plant	Gebeng, Pahang	Petronas	10.0
Gemas Solar Power Plant	Gemas, Negeri Sembilan	Amcorp Power	10.0
SunEdison Long Term Parking Solar Power Station	Rooftop KLIA, Sepang	SunEdison	4.0
KLIA Solar Power Plant	KLIA2, Sepang, Selangor	SunEdison	10.0
KMB Power Plant	Alor Gajah, Melaka	Kumpulan Melaka Berhad	5.0
LSS Gambang-UITM Solar Power Plant	Gambang, Perak	UITM Energy & Facility Sdn Bhd (UESB)	61.0
Jasin Quantum Solar PV Park	Jasin, Melaka	ItraMAS Corporation Sdn Bhd; Scatec	65.0
Merchang Quantum Solar PV Park	Merchang, Terengganu	ItraMAS Corporation Sdn Bhd; Scatec	66.0
Gurun Quantum Solar PV Park	Gurun, Kedah	ItraMAS Corporation Sdn Bhd; Scatec	65.0
Bidor Solar Power Plant	Bidor, Perak	Gading Kencana Sdn Bhd	30.0
Ayer Keroh Power Plant	Ayer Keroh, Melaka	Gading Kencana Sdn Bhd	8.0
TNB Sepang Solar Power Plant	Sepang, Selangor	Tenaga Nasional Berhad	50.0
TTL Energy Solar Power Plant	Papar, Sabah	TTL Energy Sdn Bhd	1.0
Kudat Solar Power Plant	Kudat, Sabah	Tadau Energy Sdn Bhd	2.0
LSS Tadau Solar Power Plant	Kudat, Sabah	Tadau Energy Sdn Bhd	48.0

Despite being blessed with high average solar radiation; solar energy only has small uptake in the overall energy mix in Malaysia. Another identified reason for this to happened is because of the solar electricity tariff rate and the uneconomical photovoltaic cells (Mekhilef et al., 2012). Due to its intermittent availability, it is hard to make PV system as a baseload supply because the system needs a bigger storage system to do so and the storage system is expensive as well (Abdul Rahman et al., 2020). These challenges prompted more comprehensive research in this area to close the gap and boost solar energy to its full potential.

4. Impact of extreme temperature on solar power plant

Photovoltaic cells can directly convert up to 20 % of solar radiation into electricity through the photovoltaic effect. Surrounding temperature brings significant impact on energy production of solar photovoltaic and its efficiency. As ambient temperature increases, photovoltaic efficiency decreases because of weaker panel cooling. An extreme heat poses more threat to the functioning of a solar panel than extreme cold.
Figure 1 illustrates the heat map of average maximum temperature of Malaysia in 2080. The heat map was obtained based on the average temperature of all the districts in each state. Average annual temperature in Malaysia is between 25 °C to 28 °C (Tang, 2019). Based on projected calculation from ClimateAP software, the average temperature measured in Malaysia has increased by approximately about 5 to 7 °C by year 2080 under the RCP8.5 high emission scenario. Referring to the map in Figure 1, Sabah, Sarawak and Kelantan have lower projected temperature compared to other states in Malaysia. Perlis and Kedah recorded as the highest maximum temperature in 2080 which are 35.07 °C and 34.62 °C.
Normally, a solar cell can get as hot as 65 °C, causing the panel to become less efficient and therefore producing less power. For instance, if a panel with a temperature coefficient of -0.5%/°C was to reach an extreme heat of 65 °C, it would reduce output by as much as 32.5 % (-0.5% x 65). Findings on the impact of ambient temperature on solar photovoltaic systems by Pasicko et *al*. (2012) found that approximately 0.5 % power capacity was reduced for every 1 °C increase in air temperature.
Figure 2 illustrates the impact of ambient temperature on power characteristic of solar photovoltaic. It is clearly seen that increase of ambient temperature negatively affects the output power of the solar module. The operation of solar modules at elevated temperatures leads to their accelerated degradation and negatively affects its energy characteristics. The decrease in open circuit voltage when the surface of the solar module is overheated leads to a decrease in the output power of the solar module to 50 % or more. From Figure 2, power output reduced about 5 % when the ambient temperature roses at 35 °C compared to 25 °C.

Figure 1: Heat map projected maximum temperature of Malaysia in 2080

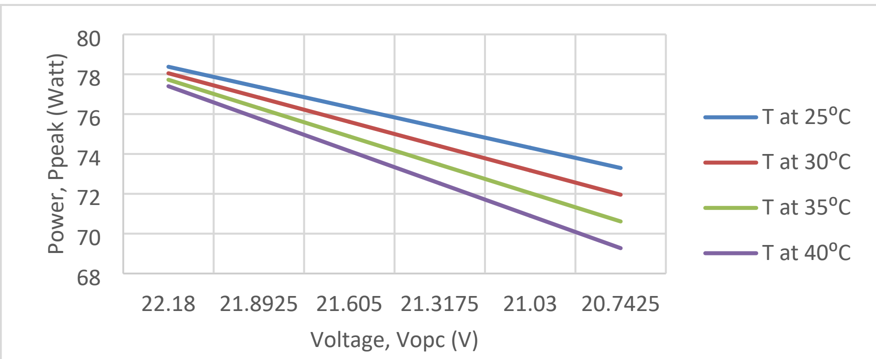

Figure 2: Impact of ambient temperature on power characteristic of solar photovoltaic

By considering the list of solar power plant locations shown in Table 2, the changes in annual temperature projected for 2080 compared to the baseline period of 1981 - 2010 can be observed in Table 3. From Table 3, all location of solar farms showed a significant increase in temperature. The average temperature of all solar power plants in Malaysia were projected to be above 30 °C in 2080 with the highest is forecasted in Kuala Perlis. Meanwhile, solar power plants in Sabah were projected below 31 °C. Based on the record in WorldData website, Sabah is one of the coldest regions in Malaysia with an average daily maximum temperature of only 32 °C (WorldData.Info, 2022).

Table 3: Changes in average temperature at various solar PV plants.

Plant	Historical temperature 1981 - 2010 (°C)	Projected temperature 2080 (°C)	Percentage Changes
Kuala Perlis Solar Power Plant	28.7	34.3	19.51
Rimba Terjun Solar Power Plant	28.1	31.4	11.74
Kuala Sawah Solar Power Plant	27	31.7	17.41
Pajam Solar Power Plant	27	31.8	17.78
Bukit Palong Solar Power Plant	27.7	32.4	16.97
ZEC Solar Farm	27.7	31.2	12.64
Gebeng Solar Power Plant	27	32.1	18.89
Gemas Solar Power Plant	27.8	32.4	16.55
SunEdison Long Term Parking Solar Power Station	28.3	33.2	17.31
KLIA Solar Power Plant	28.3	33.2	17.31
KMB Power Plant	28	32.5	16.07
LSS Gambang-UITM Solar Power Plant	26.5	32.7	23.40
Jasin Quantum Solar PV Park	28.2	32.6	15.60
Merchang Quantum Solar PV Park	26.8	31.6	17.91
Gurun Quantum Solar PV Park	28.3	33.3	17.67
Bidor Solar Power Plant	27.2	32.3	18.75
Ayer Keroh Power Plant	28.1	33.5	19.22
TNB Sepang Solar Power Plant	27.9	32.6	16.85
TTL Energy Solar Power Plant	25.8	30.6	18.60
Kudat Solar Power Plant	26.9	30.4	13.01
LSS Tadau Solar Power Plant	27	30.4	13.70

5. Adaptation of extreme temperature on solar power plants

Based on previous section, high ambient temperature could reduce power generated and efficiency of solar panel. It is essential to find out the suitable adaptation of extreme temperature in order to maintain the efficiency of the solar module near the point of maximum power. Firstly, it is necessary to provide thermal protection of the surface from the influence of high temperatures, which will affect the energy parameters of the module during operation. Next, it is suggested to install passive cooling or natural air flows on the panels to improve efficiency. Finally, the energy provider may choose location with lower probability of high temperature in future such as Sabah or East Coast Malaysia.

6. Conclusions

This study investigates the impact of extreme temperature on solar power plants in Malaysia. Projection climate data relied on ClimateAP software using global climate models to find out the percent increase of temperature in 2080 compared to the base line 1980 - 2010. It is found that all location of solar farms showed a significant increase in temperature with average 14 % projected. The impact of ambient temperature on power characteristic of solar photovoltaic was also studied. The operation of solar modules at elevated temperatures leads to their accelerated degradation and negatively affects its energy characteristics. Other than that, the temperature coefficient of power, the material of solar panels and the type of installation also influence the degree of degradation of the photovoltaic module. The installation of thermal protection on solar panel surfaces or natural air flows on the panels may improve the efficiency of solar panels.

The changes in extreme temperature have significant impacts to the living conditions and sustainability of economic development including energy systems. However, it is very challenging and difficult to estimate the probability of the occurrence, severity, duration, when and where the event will take place. It is crucial to keep monitor and predict the temperature variability as accurate as possible. For long-term projection, the use of a climate model ensemble mean can reduce the uncertainty due to differences between climate models. For future planning, further study on the level of risk of extreme temperature on solar power plants and design reviews need to be developed in order to investigate whether the existing solar power plants are still relevant in coming decades.

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