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Solar Radiation Resources Under Climate Change Scenarios - A Case Study in Kota Kinabalu, Sabah, Malaysia

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ABSTRACT Solar power is the third major renewable energy after hydropower and biopower. It constitutes an increasingly important element of the global future that is less carbon energy investment. However, the generation capacity, availability, and intermittency of this renewable energy source is strongly climate dependent. Therefore it makes this renewable energy supply system more vulnerable to climate variability and changes. When considering solar energy as a sustainable energy solution, it is important to not only quantify the present solar resource but to also anticipate how the solar resource as the indicator in electricity production potential will change under future climate change scenarios. In this study, we evaluate the climate change impact on solar photovoltaic (PV) power potential in Kota Kinabalu, a rapidly developing city in Malaysia, using the Weather Research Forecast Model (WRF) climate projections under RCP4.5 and RCP8.5 together with a PV Power Production Model (1MW). The projected median solar radiations were 193.6 Wm^{-2} and 211.9 Wm^{-2} in 2100 under RCP4.5 and RCP8.5 respectively. The changes in solar radiation were statiscally significant at 95% percentile for both climate scenarios. In comparison with the present day scenarios (181.8 Wm^{-2}), the projected future mean solar radiations were also increased to 202.8 Wm^{-2} (RCP4.5) and 210.9 Wm^{-2} (RCP8.5), an increase of about 12% and 16% respectively. Results also indicated that the calculated annual average solar radiation for Kota Kinabalu at present-day and future scenarios were 1589.7 kWh/h^2 (2014), 1773.4 kWh/h^2 (2100-RCP4.5), and 1844.2 kWh/h^2 (2100-RCP8.5), which are equivalent to 54.4 MW (2014), 60.7 MW (2100-RCP4.5), and 63.1 MW (2100-RCP8.5). Increases in energy production under future climate change scenarios show a promising trend and indicates a positive potential for solar energy to be harnessed in the Kota Kinabalu city area.

KEYWORDS: Climate change, Photovoltaic, Renewable energy, Solar radiation, WRF model

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INTRODUCTION

Malaysia has introduced a new fuel mixed strategy from Four to Five-Fuel Diversification Strategy in year 2002 (UNDP, 2007). Since then, renewable energy (RE) has been considered the 5th fuel for the new alternative source that Malaysia plans to harness a total of 985 MW in renewable energy contribution in the energy mix in year 2015 (Oh *et al.*, 2010; UNDP, 2007). At present, renewable energy provides less than 1% to the energy mix in Malaysia. By 2020, the aim is for renewable energy to comprise 11% of the overall electricity generation in the country and a long ambitious target of 50% by the year 2050 (Yee, 2011). In order to meet this goal, the Small Renewable Energy Program (SREP) was launched in May 2001, under the initiative of the Special Committee on Renewable Energy (SCORE), aimed at supporting the government's strategy in intensifying the development and utilization of RE as the fifth fuel resource in power generation. The primary focus of SREP is to facilitate the expeditious implementation of grid connected RE resource-based small power plants (Chua *et al.*, 2011; Oh *et al.*, 2010). The development pace of RE in Malaysia is rather slow and still at its nascent stage, with its current contribution at around 1% only of the total energy mix, even though the fifth fuel policy had been announced a decade ago (Mohamed *et al.*, 2006; Oh *et* *al.*, 2010; Saidur *et al.*, 2010). The RE policy has also been stipulated in the objectives of the Third Outline Perspective Plan (OPP) for 2001–2010 and the 8th Malaysia Plan (2001–2005). In the 9th Malaysia Plan (2006–2010), the emphasis on energy efficiency was intensified to address the nation's energy challenge, in line with the sustainable development agenda. Further, under the 10th Malaysia Plan, the Government wanted about 5.5% of finished electricity to come from renewable power origins by 2015. At present, the RE contributions are relatively very low and comes mainly from biomass, biogas, wind, and solar. Solar energy for example, is only contributing of about a mere 0.01% of the finished generated electricity in Peninsular Malaysia.

Solar energy is presently utilized in producing electrical current and warmth for the country (Shafiea *et al.*, 2011). The energy sector is mainly supplying solar energy to the villages, remote spans, and remote isles that are not established and not yet connected to the nationwide grid. This is mostly happening in Sabah and Sarawak where the electrification coverage rate is merely between 70 and 75% (Shafiea *et al.*, 2011). Malaysia on average collects 17MJ every single m^2 of solar radiation every day with the mean daily sunshine hours in Malaysia ranges between 4 to 8 hours each day (Energy Commission, 2008). Observation on solar radiance in Malaysia has found a drop in total solar radiation from the north to the south of Peninsular Malaysia, in which the northern states receive the highest number of solar radiation. The mean daily sunshine hours in Malaysia ranges between 4 to 8 hours each day with the highest solar radiation of 6.8 $kWh/m^{2,}$ in August and November, and the lowest at 0.61 kWh/m^2, in December (Azhari *et al.*, 2008).

In Kota Kinabalu (Sabah), it was observed that an additional displayed weakening solar radiation happened from 1990 to 1999 but later stabilized at 20 MJm^{-2}. Kota Kinabalu and a wider area of the west coast of Sabah received the highest mean daily sunshine hours in Malaysia (Mekhilef *et al*., 2012; Teong *et al.*, 2017). In terms of power supply in Sabah, it is distributed by an independent grid. The existing grid consists of the East Coast Grid and West Coast Grid (Energy Commission, 2010). Currently, Sabah is relying heavily on gas-based electricity generation. Based on the data released by the Energy Commission (2014), gas-based electricity provided 67% of the total energy, followed by marine fuel oil (MFO) and diesel at 21%, hydro at 8%, and biomass at 4%. It can be clearly seen that renewable energy resources contributed to only about 12%, which comes mainly from the combined biomass and hydro energy resources. Peak demand for electricity in Sabah between 2014 and 2020 is expected to grow at a rate of 5.13% and by the year 2020, the electricity peak demand is forecasted to be 1,331 MW (Energy Commission, 2014).

Demand for energy and corresponding services to meet the social and economic development and improve human welfare and health is critically increasing. High energy consumption is linked to more emissions of greenhouse gases that further causes global warming. Efforts to curb the climate change through the reduction of greenhouse gases but at the same time not affecting the high supply of energy is a crucial agenda. In the Fourth Assessment Report (IPCC, 2011), renewable energy options have been identified to provide wider benefits in order to provide a secure energy supply and cause relatively lower negative impacts on environmental and human health. In the recent years, renewable energy technologies have been developed and are rapidly deployed. It is projected to increase significantly under most ambitious mitigation scenarios in the coming years. When considering solar energy as a sustainable future energy option, it is therefore important to anticipate how the solar resource will change along with any climate changes in the future.

There has been some previous work done to try and gauge the effects of climate change on solar energy. Crook *et al.*, (2011) examines global changes in photovoltaic (PV) and concentrated solar power (CPS) outputs using two climate change models (HadGEM1 and HadCM3) and has found that potential solar energy power in Europe and China increased by a few percentage from 2010 to

2080. In the same period, there were a small decrease in the USA and Saudi Arabia, as well as no changes observed in Algeria and Australia. An earlier study in the USA (Pan *et al.*, 2004), based on the regional climate model, found that the seasonal-mean daily global irradiance in the US to decrease up to 20% by the end of the 2040, thus potentially contributing to the decrease in future solar power potential. In Malaysia, several modelling studies (Kong & Sentian, 2013; Kong *et al.*, 2017) has been conducted to understand the interaction between the future changes of solar radiation and cloud fraction over Malaysia region. Both models suggested that the future climate might trigger a higher level of solar radiation over most part of research domain. However, the studies did not consider the influence of future climate change towards the potential solar energy.

The objective in this study is to evaluate climate change impacts on solar photovoltaic (PV) power potential in Kota Kinabalu, a rapidly developing city in Malaysia, using the Weather Research Forecast Model (WRF) climate projections under RCP4.5 and RCP8.5 together with a PV Power Production Model (1MW). The evaluation would provide an assessment on potential exploitation of solar energy in possible future climate change scenarios.

METHODOLOGY

Study Area

The site for the case study is the Kota Kinabalu city, the capital of the State of Sabah, Malaysia (5.9804° N, 116.0735° E) (Figure 1). This area experiences a typical equatorial humid climate with high humidity, heavy rainfall usually in the afternoon, and the temperatures are uniformly high and extremely invariable throughout the year. Kota Kinabalu is also under the influence of monsoons which are the northeast monsoon (NEM) from November to March, southwest monsoon (SWM) from May to September, and inter-monsoon (April and October). Kota Kinabalu is one of the most populous city in Malaysia with a population of about 462,963 and with an area of 351 km^2.

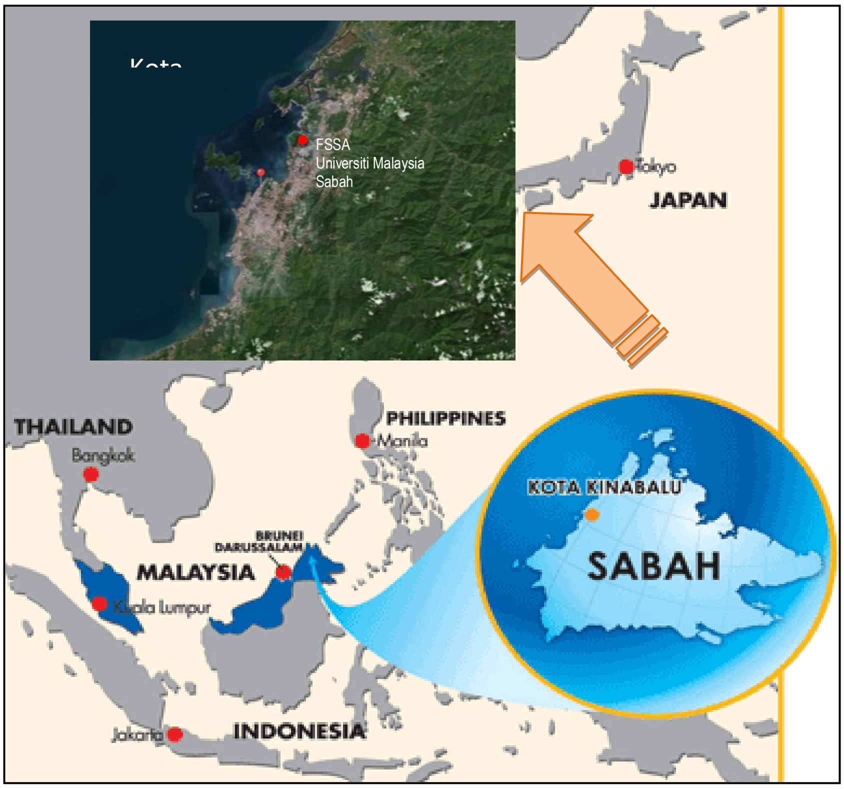


Figure 1. Location of study area, Kota Kinabalu, Sabah

Solar Radiation Measurement

A short-term solar measurement (every 10 minutes) was carried out at Universiti Malaysia Sabah, for the duration of one year (January-December 2014). The solar radiation measurement was carried out using LI-COR Pyranometer with SymphoniePLUS3 data logger to collect the solar radiation data. The average solar radiation data (hourly, daily, and monthly) was obtained and analysed. Further to that, the analysed data was used as the input to Photovoltaic (PV) System to estimate the potential energy produced from solar radiation.

Photovoltaic System (PVS) Modelling

The solar radiation dataset obtained from the measurement was used as the input to PVS Model (Photovoltaic Software, 2015; Markos & Sentian, 2016) to estimate current potential of solar photovoltaic energy in Kota Kinabalu, which is based on the following equation:

$$E = A * r * H * PR$$

where;

E	Energy output (kWh)
A	Total solar panel area (m^2)
r	Solar panel yield (%)
H	Annual average irradiation on tilted panels (shadings not included)(kWh/m^2)
PR	Performance ratio, coefficient for losses (default value =0.75)

Statistical analysis of the PVS model in estimating the potential electricity energy output were also described in previous studies (see Borhanazad *et al.*, 2013; Lim *et al.*,2008; Park *et al.*, 2006). Similarly in this study, it was assumed that the solar panel used in the system model was one solar panel with an area of $1.6m^2$ and electric power of 250 Watt Peak (Wp). The yield of the solar panel (r) is the ratio of electrical power (in kWp) and the area of one solar panel. The total power of the PVS was calculated by multiplying the electrical power of one solar panel to the total number of solar panels used. H value was obtained based on the annual average of solar irradiation that was measured in Kota Kinabalu. Meanwhile, PR coefficient was 0.75, which was depending on a number of losses factors (losses due to inverter, temperature, DC & AC cables, shading, weak irradiation, dust or pollution, etc). In estimating the present-day energy output in Kota Kinabalu using the PVS model, solar radiations data from the measurement in Kota Kinabalu in 2014 was used.

Climate Change Modelling

In investigating the potential impact of climate change on future solar radiation energy output based on PVS model, future projections of solar radiation were obtained from the climate model WRF (Weather Forecast Model) under RCP4.5 and RCP8.5 climate scenarios. The times-sliced for the future solar radiation projection under both climate scenarios was 2070-2100. The projected potential solar energy in Kota Kinabalu using PVS Model was estimated based on the projected solar radiation obtained from the climate model. The Weather Research Forecast Model (WRF Model) employs the physical parameterization as shown in Table 1.

The performance of the model was evaluated by comparing the model output with ERA40-reanalysis data. These can be carried out by using statistical analysis formulae namely, Fractional Bias (FB), Normalised Mean Square Error (NMSE) and Factor of Two (Fa2):

$$\text{Fractional Bias (FB)} = 2\times\left(\sum_1^N (\text{Sim - Obs}) / \sum_1^N (\text{Sim + Obs})\right)$$

$$\text{Normalised Mean Square Error (NMSE)} = \frac{\sum_{i=1}^{n}(O_i - P_i)^2}{\sum_{i=1}^{n}(O_i P_i)}$$

$$\text{Factor of Two (Fa2)} = \text{Fraction of data which } 0.5 \leq \overline{P}/\overline{O} \leq +2.0$$

Table 1. Physical Parameterization of WRF modelling system

Parameterization	Option
Cumulus	Kain-Fritsch scheme (Kain, 2014)
Planetary Boundary Layer (PBL)	Yonsei University (YSU) scheme (Hong & Han, 1996)
Long Wave Physics Radiation	Rapid Radiation Transfer Model (RRTM) (Hong & Han, 1996)
Microphysics	WRF single-momentum 6-class scheme (WSM6) (Hong *et al.*, 2004)
Short Wave Physics Radiation	Dudhia short-wave radiation scheme (Dudhia, 1989)
Layers of soil (four layers) and canopy layer (one layer)	Noah Land Surface Model (LSM) (Chen & Dudhia, 2001)

RESULTS AND DISCUSSION

Solar Radiation and Energy Potential

Based on the short-term solar measurement, the hourly, daily, and monthly averages of solar radiation received in Kota Kinabalu city in 2014 were analysed. The hourly average of solar radiation for all of the twelve months showed the same pattern, with the highest received solar radiation observed in the mid-afternoon around 12pm. Moreover, the solar radiation was zero between 6pm and 6am at the next day, which is the during the night period. The highest hourly peak reading was observed in the months of March and April indicating a sunnier day and less precipitation during this period. On the other side, the lowest hourly peak reading was recorded in the month of December, since this month was the rainy season in Sabah (Figure 2). Temporally, solar radiation was comparatively higher in February to April, with the highest peak value of 224.25 W/m^2 in April (Figure 3(a)). The lowest solar radiation was observed in the month of January with the value of 151.77 W/m^2. Annually, the average solar radiation in Kota Kinabalu was 182 W/m^2. The results also show that the daily and monthly solar radiation variabilities were influenced by the Southeast Asian circulation monsoons, which are dominated by northeast monsoon (December to February) and southwest monsoon (June to August) (Figure 4) During the observation period, relatively, solar radiation was higher during the intermediate monsoons with highest value recorded around March to May (207.34 W/m^2). The local weather such as the total precipitation has influenced the amount of solar radiation received. In 2014, Kota Kinabalu received less precipitation in February to April, which corresponds to high solar radiation (Figure 3(b)).

Based on Photovoltaic System (PVS) Model, the energy potentials from the solar irradiance received in Kota Kinabalu city were calculated. Based on the annual average solar radiation received in Kota Kinabalu, the calculated potential energy received was 1,590 kWh/m^2 or roughly 4.4 kWh/m^2 on daily average. Practically, this high amount of solar radiation is obviously giving solar energy a huge potential to be harnessed to produce electricity, but technically it would still depend on the system's performances and the environmental conditions.

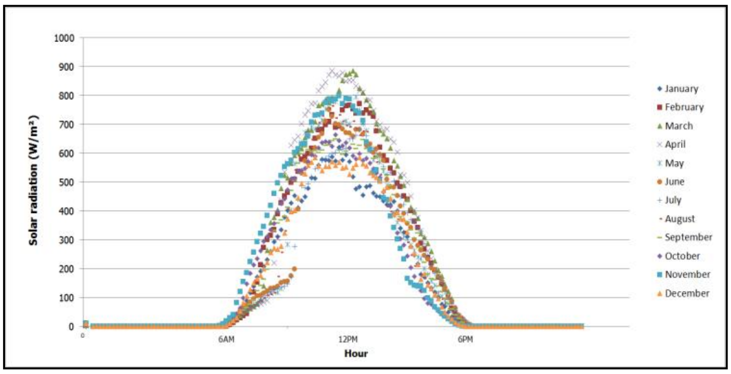
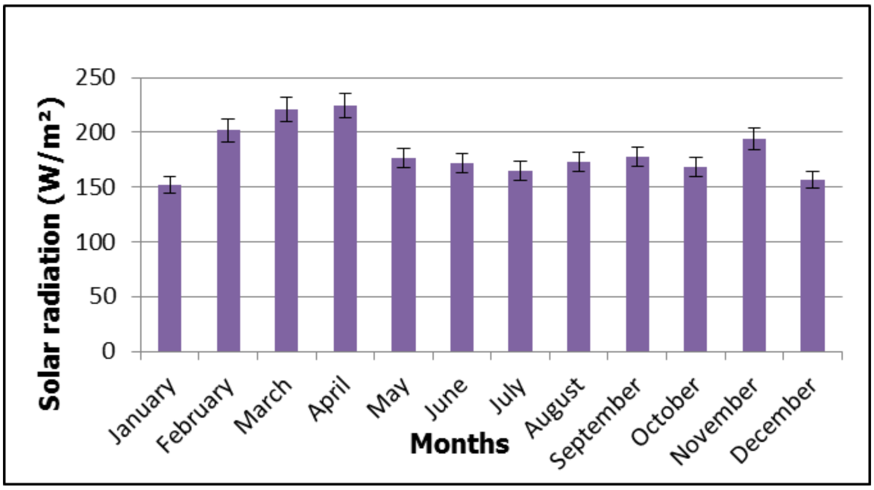


Figure 2: Kota Kinabalu: Hourly average of solar radiation for a year in 2014

(a)



(b)

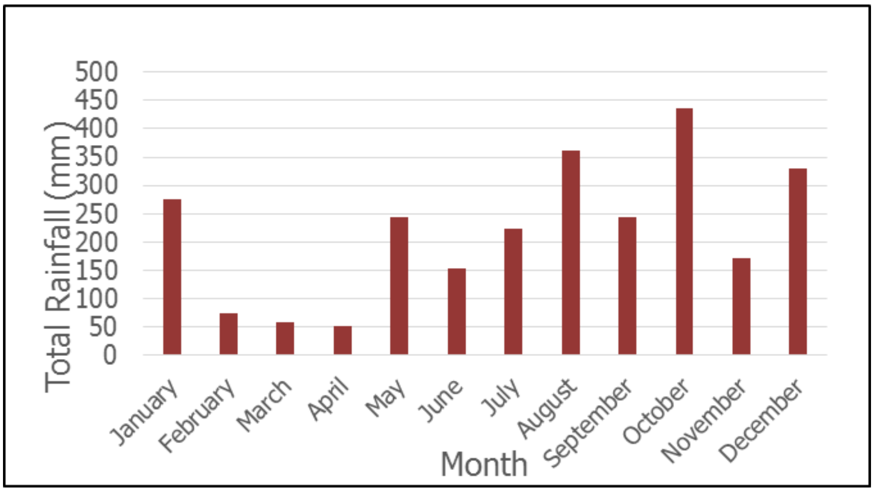


Figure 3. Kota Kinabalu: Monthly variation of (a) average solar radiation and (b) total rainfall in 2014. *(Source: MMD, Malaysia, 2016)*

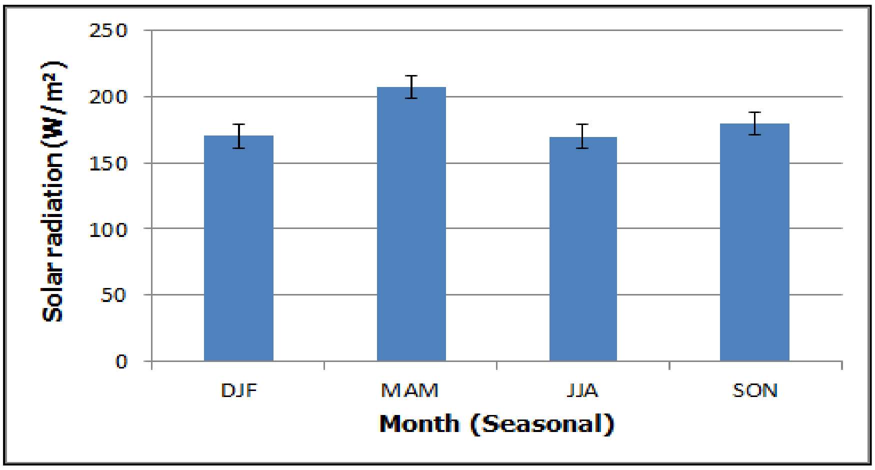


Figure 4: Kota Kinabalu: Seasonal average solar radiation in 2014

(Note: DJF-December, January, February; MAM-March, Apriol May; JJA-June, July, August; SON-September, October, November)

Table 2 shows the estimated solar energy produced by using the PVS model which was calculated based on one solar panel (with a capacity of about 0.25 kWp). Based on the annual average solar radiation of 1,590 kWh/m^2, 0.25 kWp capacity of PVS would produce about 29,794 kWh/m^2 of electricity in a year, which is equivalent to 0.014 MW. To build a PV system with 1 MW capacity, it would need about 4,000 solar panels. Considering one solar panel has a surface area of 1.6 m^2, then 4,000 solar panels would cover a total area of 6,400 m^2 just for the PVS installation. Kota Kinabalu is a city with an area of about 351 km^2 and 1 MW capacity of PVS installation would take only about 0.002% from the total area of the city and potentially would produce about 55 MW of electricity annually. Considering the power demand in the State of Sabah by 2020 is 1,331 MW (Energy Commission, 2014), 1 MW capacity of PVS can contribute to around 4% to the state electricity demand. An increase of 25 MW capacities of PVS (which requires about 100,000 solar panels) was estimated to generate 1,361 MW of electricity and only occupy about 0.05% of the city area.

Table 2. Output of PV System model

Size of PV System	Num. of Solar Panel	Output (MW)
0.25 kW	1	0.014
1 MW	4000	54.45
25 MW	100,000	1,361

Climate Model Evaluation and Climate Change Impacts on Solar Radiation

The climate model results over Borneo domain were evaluated against ERA40-Reanalysis datasets. Table 3 presents the statistical analysis of the modelled solar radiation and ERA40-Reanalysis data. Results showed that the seasonal mean differences of solar radiation between modelled and ERA40 were small (between 1.13 and 5.55 Wm^{-2}). In terms of fractional bias (FB), the modelled results were under-predicted by 0.014 during the winter monsoon (December, January, and February) and 0.012 during the summer monsoon (June, July, and August). In addition, NMSEs were very small at 0.005 during the winter monsoon (DJF) and 0.002 during the summer monsoon (JJA). The climate model performed well in simulating solar radiation as its Fa2 values were close or equal to 1 for the whole seasons. Differences in solar radiations were found significant at 95% confidence level over east coast of Sabah and most parts of the seas during DJF and most parts of Sabah during JJA.

Table 3. Climate model evaluation by comparing the modelled data with ERA40

Variable		Modelled Baseline (2014)		ERA40 (2014)		Fractional Bias (FB)	Normalised Mean Square Error (NMSE)	Factor of Two (Fa2)
		Mean	sd	Mean	sd			
Solar Radiation (Wm^{-2})	DJF	222.86	19.15	219.70	21.99	-0.014	0.005	1.01
	MAM	246.32	10.71	245.19	11.55	-0.005	0.002	1.00
	JJA	235.31	7.81	232.56	9.78	-0.012	0.002	1.01
	SON	232.20	13.08	226.65	15.95	-0.024	0.003	1.02

The seasonal average projected solar radiations in Kota Kinabalu, Sabah, for 30 years period (2071-2100) under RCP4.5 and RCP8.5 climate scenarios are shown in Figure 6 and Figure 7. Generally, the amount of solar radiation over the region under RCP4.5 and RCP8.5 scenarios were increased for the whole seasons. Similar trends were also observed over Malaysian and Southeast Asia regions in the previous studies under the same climate scenarios (Sentian and Kong, 2013; Kong and Sentian; 2013; Sentian *et al*., 2010). The increment in solar radiation has also been observed to be related to the increase in surface temperature. The increased solar radiation increases the presence of heat over the Earth's surface which makes the surface temperature increased. In addition, this changes were also related to less precipitation over the region. Less total precipitation means clearer days which allows more amount of solar radiation from the sun to reach the Earth's surface (Klemen, 2006).

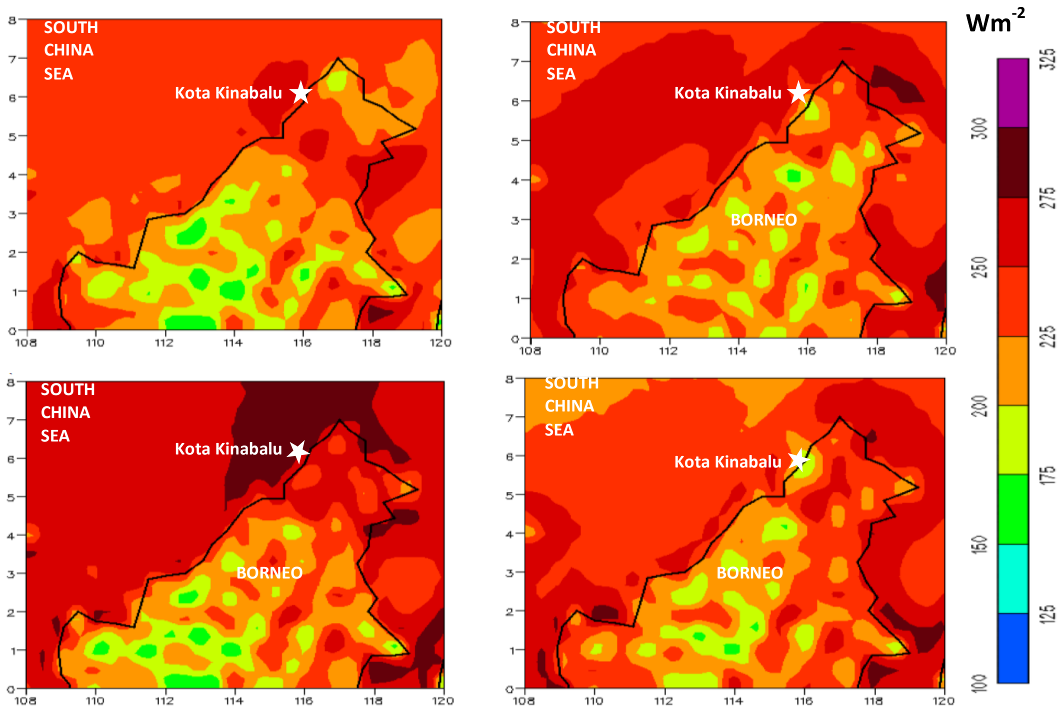


Figure 6. RCP4.5 (2071-2100): Seasonal mean variables of solar radiation during DJF (December, January, February), MAM (March, April, May), JJA (June, July, August) and SON (September, October, November)

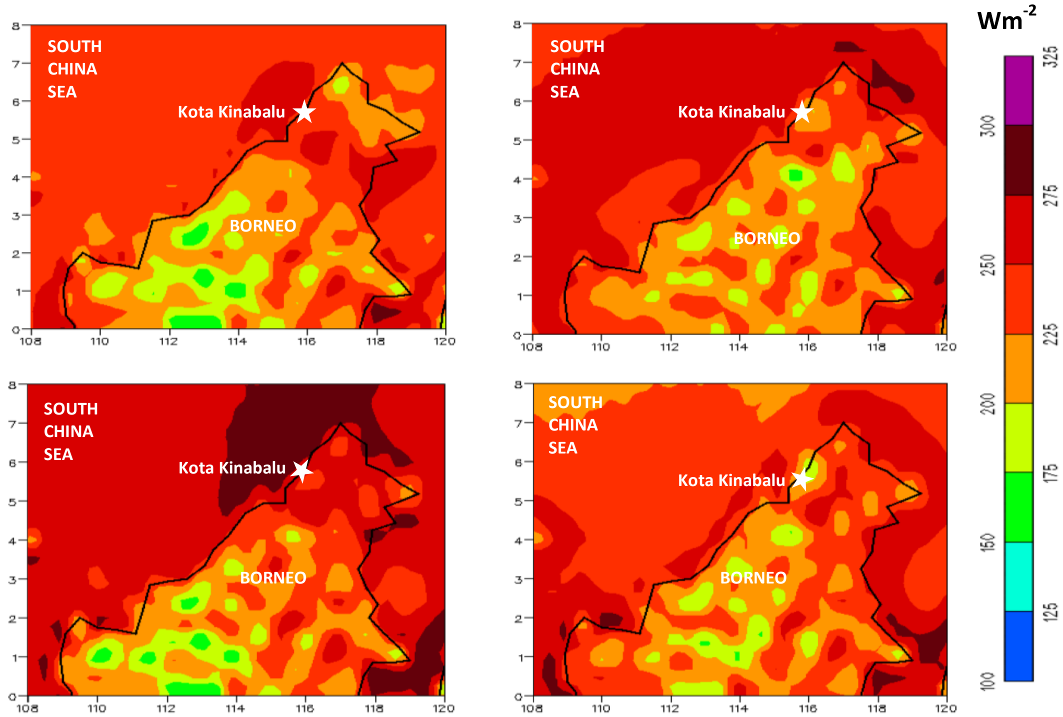


Figure 7. RCP8.5 (2071-2100): Seasonal mean variables of solar radiation during DJF (December, January, February), MAM (March, April, May), JJA (June, July, August) and SON (September, October, November)

Baseline scenario (2014) was the monthly average data collected using pyranometer in 2014. The comparative trends between the baseline and the future (2070-2100) solar radiations both under RCP4.5 and RCP8.5 in Kota Kinabalu are shown in Figure 8. The monthly patterns for the baseline and future climate scenarios were showing similar patterns. In both climate scenarios, the first quarter of the year have shown the solar radiation increased and then started to decrease from April to October before it increases again towards the year end. Relatively, RCP8.5 scenario was projecting a higher solar radiation than RCP4.5 scenarios. This can be due to the higher emission of greenhouse gases (GHG) embedded within the RCP8.5 scenario as compared to RCP4.5 scenario, where more GHG causing more radiative forcing trapping inside the atmosphere (IPCC, 2013). The incident could also have related to the future projection of surface temperature as shown by Kong *et al.* (2015). The model suggested a more warming under RCP8.5 scenario than RCP4.5 scenario over Malaysia region, where high surface temperature could linked with high exposure of solar radiation. The highest projections of solar radiation were in March with values of 295.42 a Wm^{-2} (RCP8.5) and 294.65 Wm^{-2} (RCP4.5) respectively. The lowest projections were in October with values of 142.65 Wm^{-2} (RCP8.5) and 132.95 Wm^{-2} (RCP4.5). The most significant solar radiation changes under both climate scenarios were observed in January to March with ranges from 74.16 to 88.50 Wm^{-2} (RCP8.5) and 73.40 to 86.66 Wm^{-2} (RCP4.5) respectively. This can be due to the less rainfall in this specific months as shown in Figure 3(b). Less rainfall showed a clearer sky, and more solar radiation from the sun can reach the earth surface (Kong and Sentian, 2015).

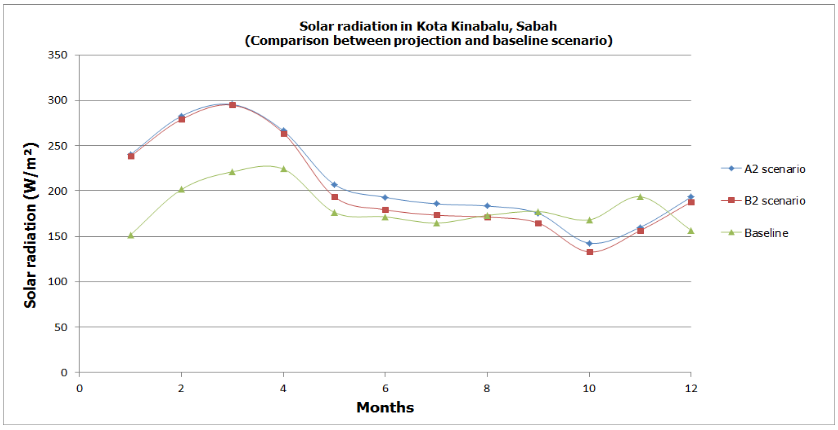


Figure 8. Monthly solar radiation under Baseline (2014) and future climate scenarios (2070-2100) under RCP4.5 and RCP8.5 in Kota Kinabalu

Future Solar Radiations and Energy Potential

The impact of climate change on solar energy was investigated using the same PVS model. Based on 1 MW capacity PVS model, under baseline scenario with annual average solar radiation of 1589.67 kWh/m^2 was projected to produce 54.41 MW of electricity. Based on projected future solar radiations under RCP4.5 and RCP8.5 scenarios of 1773.40 kWh/m^2 1844.21 kWh/m^2; both scenarios were estimated to produce around 63.16 MW and 60.73 MW of electricity respectively with 1 MW capacity PV system. The impact of climate change showed that the performance of 1 MW of capacity of the PVS model exhibits a positive linear dependence on the projected climate change resulting in 11% and 16% increase in energy output for both RCP8.5 and RCP4.5 scenarios as shown in Table 4.

Table 4. Photovoltaic System (PVS) Model (Capacity = 1MW)

	Climate Scenarios		
	Baseline (2014)	Future Projection (2071-2100) RCP4.5	RCP8.5
Annual average solar radiation (W/m^2)	181.8	210.9	202.8
Annual average solar radiation (kWh/m^2)	1589.67	1844.21	1773.40
PV System Model output (MW)	54.41	63.12	60.70
Climate change impact (Increment of energy produced) MW	-	8.71	6.29
Percentage of increment (%)	-	16%	11%

In terms of solar energy output, future climate change has shown promising and positive impact in Kota Kinabalu, Sabah. Given the fact that less greenhouse gas emissions come from solar power, increasing its usage is an essential strategy in efforts to fight climate change at an individual and national level. Solar panel installations can reduce the electric-power carbon footprint at a scale and pace that is not only consistent with, but vastly accelerates with larger size of installations. By installing clean energy systems, it can contribute to progress in a number of environmental and social categories, such as combatting climate change, creating a safe workplace, and improving energy access for off-grid communities.

Feasibility scale solar power plants are just part of the solution to reducing the air pollution that is causing global warming. Distributed generation solar energy will play an important task in deploying more clean energy. Not only can home and business owners generate their own electricity with photovoltaic panels, it can reduce the amount of fossil fuels consumed to heat water and to cool their buildings with solar thermal technology. It's all part of the diverse energy portfolio that is needed. Solar energy is indeed a cleaner and safer option than the status quo. With enough knowledge and research, the solar energy industry is ready to power Kota Kinabalu, Sabah.

CONCLUSION

In Kota Kinabalu, the highest solar radiation received by hour was during March when it reached its peak time in the afternoon with 886.46 Wm^{-2}. The highest daily average solar radiation received was during the end of February with 284.38 Wm^{-2} whereas the lowest was recorded during early December with only 23.02 Wm^{-2}. Among the highest monthly average solar radiation received was in April with 224.25 Wm^{-2}. Seasonally, the highest average solar radiation received was during the inter-monsoon (March-April-May) with 207.34 Wm^{-2}. Meanwhile, the annual average solar radiation received in Kota Kinabalu was 182 Wm^{-2}.

Based on PVS model, Kota Kinabalu area was estimated to produce around 29,794 kWh/m^2 of electricity with an annual average of 182 Wm^{-2} solar radiation. This is equivalent to 0.014 MW of electricity produced by using one solar panel with characteristics (area = 1.6 m^2 and electrical power = 250 Wp). To build a 1 MW capacity of PVS, this model would need a total of 4,000 solar panels and requires an area the size of 6,400 m^2. Considering the size of Kota Kinabalu that is about 351 km^2, producing 1 MW capacity of PVS would take only about 0.0018% of the city area. The PVS model showed that with 1 MW capacity size of PVS, it would produce electricity equivalent to 55 MW in a year. Based on the power demand by 2020 that is 1,331 MW, 1 MW capacity of PVS could contribute to around 4% to the overall electricity for Sabah.

Under climate change scenarios, future solar radiation under RCP4.5 and RCP8.5 scenarios in Kota Kinabalu were projected to increase by 21.01 W/m^2 and 29.11 Wm^{-2} respectively. The impact of climate change showed that the performance of 1 MW capacity of PVS exhibited a positive linear dependence on the projected climate change, which resulted in an increase of 11% and 16% respectively in energy output under RCP4.5 and RCP8.5 scenarios. This is a positive indicator for the viability of solar technology, particularly for Kota Kinabalu where the demand for sustainable power in the future is highly sought. Currently, there is no large utility-scale solar PV plant or solar energy in the state. To explore the solar energy potential, the awareness and economics of this renewable source of energy need to be explored. While the solar energy potential has not been examined in great detail, it is evident that climate change would result in higher potential for energy generated from solar resource in Kota Kinabalu, Sabah.

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REFERENCES

[1] Azhari, A. W., Sopian, K., Zaharim, A. & Ghoul, M. A. 2008. A New Approach For Predicting Solar Radiation In Tropical Environment Using Satellite Images – Case Study Of Malaysia. *WSEAS Transactions on Environment and Development*, **4**, 373-378.

[2] Borhanazad, H., Mekhilef, S., Saidur, R. & Boroumandjazi, G. 2013. Potential application of renewable energy for rural electrification in Malaysia. *Renewable Energy*, **59**, 210-219.

[3] Chen, F. & Dudhia, J. 2001. Coupling an advances land surface-hydrology model with the Penn State-NCAR MM5 modeling system. Part I: Model implementation and sensitivity. *Monthly Weather Review*, **129**, 569-585.

[4] Chua, S. C., Oh, T. H. & Goh, W. W. (2011). Feed-in tariff outlook in Malaysia. *Renewable and Sustainable Energy Reviews*, **15**, 705-712.

[5] Crook, J. A., Jones, L. A., Forster, P. M. & Crook, R. 2011. Climate change impacts on future photovoltaic and concentrated solar power energy output. *Energy and Environmental Science*, 4, 3101–3109.

[6] Dudhia, J. (1989). Numerical study of convection observed during the winter monsoon experiment using a mesoscale two-dimensional model. *Journal of the Atmospheric Science*, **46**, 3077–3107.

[7] Energy Commission. (2010). *Interim Report on the Performance of the Electricity Supply in Malaysia for the First Half Year of 2010*. Energy Commission.

[8] Energy Commission. (2014). *Sabah Electricity Supply Industry Outlook*. Energy Commission.

[9] Hong, S. Y. & Han, H. L. 1996. Nonlocal boundary layer vertical diffusion in a medium-range forecast model. *Monthly Weather Review*, **124**, 2322–2339.

[10] Hong, S. Y., Dudhia, J. & Chen, S. H. (2004). A revised approach to ice microphysical processes for the bulk parameterization of clouds and precipitation. *Monthly Weather Review*, **132**, 103–120.

[11] IPCC (Intergovernmental Panel on Climate Change) (2011). IPCC Special Report on Renewable Energy Sources and Climate Change Mitigation [Edenhofer, O., Pichs-Madruga, R., Sokona, Y., Seyboth, K., Matschoss, P., Kadner, S., Zwickel, T., Eickemeier, P., Hansen, G., Schlömer, S. and Stechow, C.V. (eds)]. *Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.*

[12] IPCC (Intergovernmental Panel on Climate Change). (2013). Climate Change The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change (T.F. Stocker, D. Qin, G.-K. Plattner, M.Tignor, S.K. Allen, J. Boschufng, A. Nauels, Y. Xia, V. Bex, and P.M Midgley, eds). Cambridge University Press.

[13] Kain, J. S. (2004). The Kain-Fritsch convective parameterization: an update. *Journal of Applied Meteorology and Climatology*, **43**, 170–181.

[14] Klemen, B. (2006). *Climate Change Scenarios for Macedonia*. Report from University of Nova Gorcia, Centre For Atmospheric Research. Slovenia.

[15] Kong, S. S. K. & Sentian, J. (2013). Climate change simulations in terms of solar radiation and cloud fraction based on PRECIS over Malaysia region. *Borneo Science*, **33**, 40-55.

[16] Kong, S. S. K., Sentian, J. & Bidin, K. (2015). Projection of Future Surface Temperature and Precipitation over Malaysia Region under the RCP4.5 and RCP 8.5 Scenarios. *Australian Journal of Basic and Applied Sciences*, **9**(32), 338-345.

[17] Kong, S. S. K. & Sentian, J. (2015). Present-day and future climate on seasonal surface temperature and precipitation over Malaysia using PRECIS regional model. *International Journal of Engineering Technology Science and Research*, **2**(6), 25–44.

[18] Kong, S. S. K., Sentian, J. & Bidin, K. (2017). Future Simulation of Solar Radiation and Cloud Fraction over the Malaysia region under RCP4.5 and RCP8.5 Scenarios. *Journal of Engineering and Applied Sciences*, **12**(12), 3042-3050

[19] Lim, Y. S., Lalchand, G. & Gladys, M. S. L. (2008). Economical, environmental and technical analysis of building integrated photovoltaic systems in Malaysia. *Energy Policy*, **36**, 2130–2142.

[20] Markos, M. F. & Sentian, J. (2016). Potential of Solar Energy in Kota Kinabalu, Sabah: An Estimate Using a Photovoltaic System Model. *Journal of Physics: Conference Series.* **710**, 012032.

[21] 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**, 389-396.

[22] MMD (Malaysian Meteorological Department). (2016). General Climate of Malaysia-Seasonal Rainfall Variation in Sabah and Sarawak. Retrieved on November 26th, 2016 from http://www.met.gov.my/en/web/metmalaysia/climate/generalinformation/malaysia?p_p_id=56_INSTANCE_zMn7KdXJhAGe&p_p_lifecycle=0&p_p_state=normal&p_p_mode=view&p_p_col_id=column 1&p_p_col_pos=1&p_p_col_count=2&_56_INSTANCE_zMn7KdXJhAGe_page=2

[23] Mohamed, A. R. & Lee, K. T. (2006). Energy for sustainable development in Malaysia: Energy policy and alternative energy. *Energy Policy*, **34**, 2388–2397.

[24] Oh, T. H., Pang, S. Y. & Chua, S. C. (2010). Energy policy and alternative energy in Malaysia: Issues and challenges for sustainable growth. *Renewable and Sustainable Energy Reviews*, **14**, 1241–1252.

[25] Pan, Z., Segal, M., Arritt, R. W. & Takle, E. S. (2004). On the potential change in solar radiation over the US due to increases of atmospheric greenhouse gases. *Renewable Energy*, **29**, 1923-1928.

[26] Park, J. H., Ahn, J. Y., Cho, B. H. & Yu, G. J. (2006). Dual-module based maximum power point tracking control of photovoltaic systems. *IEEE Transactions on Industrial Electronics*, **53,** 1036-1047.

[27] Photovoltaic-software. (2015). *How to calculate the annual solar energy output of a photovoltaic system*. Retrieved on September, 2015 from http://photovoltaic-software.com/PV-solar-energy calculation.php

[28] Saidur, R., Islam, M. R., Rahim, N. A. & Solangi, K. H. (2010). A review on global wind energy policy. *Renewable Sustainable Energy Review,* **14**, 1744-1762.

[29] Sentian, J. & Kong, S. S. K. 2013. High Resolution Climate Change Projection Under SRES A2 Scenario during Summer and Winter Monsoons over Southeast Asia using PRECIS Regional Climate Modeling System. *The SIJ Transactions on Computer Science Engineering & its Applications (CSEA)*, **1**(4), 163-173.

[30] Sentian, J., Mackenzie, R. A. & Hewitt, C. N. (2011). The Regional Biogenic Emissions Response to Climate Change's and Ambient CO_2 in Southeast Asia. *The International Journal of Climate Change: Impacts and Response*, **2**(3), 125–142.

[31] Shafiea, S., Mahliaa, T., Masjuki, H. & Andriyana, A. (2011). Current energy usage and sustainable energy in Malaysia: A review. *Renewable and Sustainable Energy Reviews*, **15**, 4370–4377.

[32] Teong, K. V., Sukarno, K., Chang, J. H. W., Chee, F. P., Ho, C. M. & Dayou, J. (2017). The Monsoon Effect on Rainfall and Solar Radiation in Kota Kinabalu. *Transactions on Science and Technology*, **4**(4), 460 - 465.

[33] UNDP (United Nations Development Programme). (2007). *Energy sector embracing climate change by Pusat Tenaga Malaysia.* In: National conference on climate change preparedness towards policy changes. Retrieved on May, 2011 from http://www.undp.org.my/uploads/a Energy sector PTM.pdf

[34] Yee, L. H. (2011). Renewable energy needs a push. *THE STAR*, 26 March 2011.