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IMPACTS OF CLIMATE CHANGE ON SOLAR PV POWER SYSTEM: A CASE STUDY IN SUBTROPICAL ROCKHAMPTON, AUSTRALIA

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ABSTRACT

The performance of solar PV system depends on local climatic conditions. The energy conversion behaviour of PV system will change as a result of the new conditions of solar energy resources caused by climate change. This study aims to investigate the impacts of climate change on the future performance of a PV system with an existing load of 23 kWh/day and a solar array of 6 kW through predicting the future solar irradiation data and developing a simulation model of PV system. The morphing method is employed to predict the future hourly mean global solar irradiation data. Using renewable energy simulation software HOMER, the system's electricity generation and greenhouse gas emissions are analysed and compared for climatic conditions of Rockhampton, Australia, for different climate scenarios such as, current climate, 2030 Low, 2030 High, 2070 Low and 2070 High. It is found from this study that for the 2070 High scenario, the solar PV generates the most electricity, 9725 kWh/year, and has the highest renewable fraction, 57.3% compared to current climate which generates 9700 kWh/year with renewable fraction of 0.55.

INTRODUCTION

Solar PV power system is seen as an important solution for energy crisis and environmental problem. However, a long-term change of the climate has included the uncertainty in solar PV systems' response to the changing solar irradiation likewise as all the other climatic conditions.

The impacts of climate change on the solar energy resources data and PV systems' implementation have been highlighted in a number of previous studies, based on the solar irradiation data prediction [1–3]. Overall, these studies are able to confirm that under climate change the solar energy resource would be more significant, but the extent dependent on climate change would vary region to region. Few previous research projects presented quantified information on the consequence of change in electricity generation caused by potential climate change. Moreover, in spite of some studies investigated the performance of PV power generation [4–6], they used historical data not the future data considering climate change. The quantified information on the future performance of PV systems running under the future climate as yet is unclear.

This paper investigates the impacts of climate change on the performance of a PV power system running under the Australian climate. Through developing computer simulations, the extent of changed electricity generation and carbon dioxide emission mitigation imposed by external solar irradiation change is analyzed. These results provide resident occupants and energy consultants with information on what extent of energy saving and emission reduction caused by climate change. It is believed that the research results from this paper will form a basis for the formulation of government incentives policies and renewable energy subsidies regulation. For the electrical sector and industry, these results can be used as a reference to make the best solar energy strategies.

RESEARCH METHODOLOGY

This research was undertaken by using computer-based renewable energy system simulation tool, with forecast weather data as renewable energy resources data and sampling PV system model as the inputs. The data generation and PV system simulation tool is introduced. The results of an Australian PV system simulation process, regarding to all electricity generation and carbon dioxide emission reduction is discussed in the next section.

Prediction of hourly solar irradiation data

Historic solar irradiation data collection

Hourly global solar irradiation is the critical factors of solar PV energy resource, which is collected from the Bureau of Meteorology (BOM) of Australia [7]. For the Australian climatic conditions, the seven states (Queensland, Northern Territory, South Australia, Tasmania, Victoria, Western Australia and New South Wales) are listed in Table 1. The data of airport weather station of the capital cities of these seven regions are collected from BOM. The average solar data is between 3.83 (Tasmania) and 5.79 (Northern Territory) kWh/m/day. This is largely due to their different latitude. The higher latitude location has the lower solar irradiation.

Australian climate change scenarios

In 2007 the Intergovernmental Panel on Climate Change (IPCC) released their fourth assessment report about the potential impacts of climate changes on human and natural systems throughout the world including Australia [7]. The solar irradiation is predicted based on the different emissions and error scenarios until 2030 (Figure 1) or 2070 (Figure 2). As shown in Figure 1 and Figure 2, it is found that the extend of climate change of the 50th percentile is between the 10th and 90th percentile. In this paper, the 10th percentile and the 90th percentile (lowest 10% and highest 10% of the spread of model results) are used to construct the five climate scenarios.

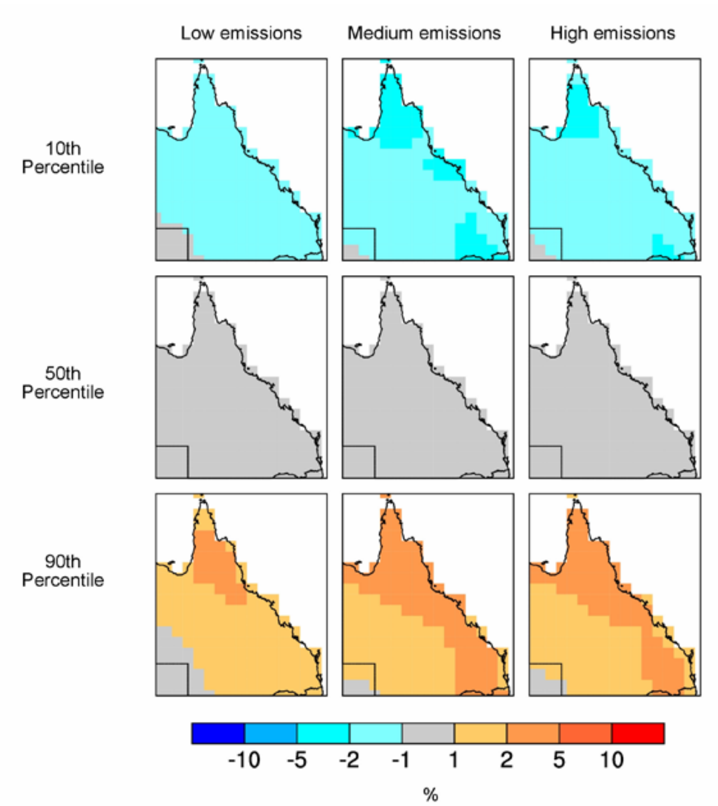

Figure 1 Solar irradiation prediction of Queensland for 2030

In this study, five different weather data files are generated to represent the five weather scenarios [8]:

- Scenario 1: Present climate - actual observed hourly weather data selected as the test reference year for a specific study site
- Scenario 2: Future climate - year of 2030, low case, 10% percentile
- Scenario 3: Future climate - year of 2030, high case, 90% percentile
- Scenario 4: Future climate - year of 2070, low case, 10% percentile
- Scenario 5: Future climate - year of 2070, high case, 90% percentile

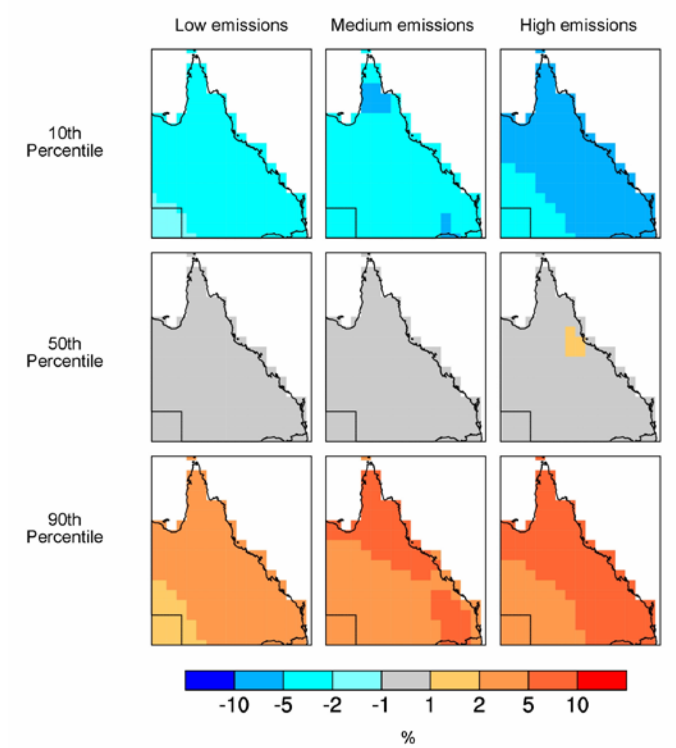

Figure 2 Solar irradiation prediction of Queensland for 2070

Based on the five climate scenarios predicted by the government research agency Australian Commonwealth Scientific and Industrial Research Organization (CSIRO), the solar data is generated by the morphing method to predict the future hourly global solar irradiation for the Rockhampton city.

The morphing method

The morphing method was developed by Belcher et al. in 2005 [9]. The method was used to produce design weather data for building thermal system and other energy systems simulations that accounts for future changes to climate.

In the morphing method, the baseline climate is defined as the present day weather sequence averaged over a number of years. The appropriate scaling factor can be obtained from the absolute change and the monthly mean value from the observed baseline climate [9].

$$\alpha gsr_m = 1 + \left(\Delta DSWF_m / < gsr_0 >_m \right) \qquad (1)$$

Where $DSWF_m$ is the total downward surface short-wave flux, W/m^2; gsr_0 means the global solar radiation of the current climate conditions, W/m^2; and, αgsr_m mean the global solar radiation scaling factor. This scaling factor is then applied to the m-th month in the time series using Equation 2.

Table 1 The information of weather stations

States or Territories	Weather Station	Coordinator	Global Solar Irradiation (kWh/m/day)	Evaluation (m)
Queensland	Brisbane International Airport	27.4° S, 153.1° E	4.99	10
Northern Territory	Dawin Airport	23.8° S, 133.9° E	5.79	30
South Australia	Adelaide International Airport	35.0° S, 138.5° E	4.95	8
Tasmania	Hobart Airport	42.8° S, 147.5° E	3.83	27
Victoria	Melbourne International Airport	37.7° S, 144.9° E	4.22	119
Western Australia	Perth International Airport	31.9° S, 116.0° E	5.22	20
New South Wales	Sydney International Airport	33.9° S, 151.2° E	4.55	5

$$gsr = \alpha\, gsr_m \times gsr_0 \qquad (2)$$

Where *gsr* is the generated global solar radiation of the future weather condition.

The correct absolute increase in monthly means for the transformed time series is obtained. According to this method there is increased solar irradiance on sunny days, but the number of sunny days is unchanged [9].

System simulation

The sample PV system, as shown in Figure 3, has a DC (Direct Current) PV array as the energy generator. The system also has DC battery as electricity storage system, as well as inverter converting electricity between DC and AC (Alternating Current), because the grid and load is AC and different from PV current type.

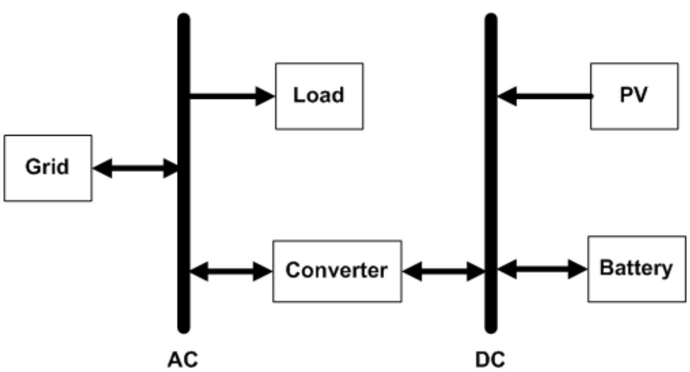

Figure 3 PV system configuration

PV modelling

PV array converts solar energy into DC electricity energy in direct proportion to the global solar irradiation incident upon it. The power output of the PV array is calculated by Equation 3 [10] which is a relation of PV de-rating factor.

$$P_{PV} = f_{PV} Y_{PV} \frac{I_T}{I_S} \qquad (3)$$

Where, f_{PV} is the PV de-rating factor; Y_{PV} the rated capacity of the PV array, in kW; I_T the global solar irradiation (beam plus diffuse) incident on the surface of the PV array, in kW/m^2; and I_S the standard amount of irradiation used to rate the capacity of the PV array which is 1 kW/m^2.

Renewable fraction

In such an energy system, the renewable fraction specifies the contribution from different renewable sources. PV energy fraction f_{PV} is given by Equation 4:

$$f_{PV} = \frac{E_{PV}}{E_{ann,tot}} \qquad (4)$$

Where $E_{ann;tot}$ is the amount of annual energy consumption, in kWh and it is calculated by Equation 5.

$$E_{ann,tot} = E_{PV} + + E_{Grid} \qquad (5)$$

Where E_{Grid} is the electricity purchased from the grid, in kWh.

Emissions

In Australia, grid electricity is mainly generated from coal, petrol and nature gas. As a result, the grid produces high emission. The carbon dioxide emission is calculated by Equation 6.

$$Em = Q_{Grid} F_{EM} \qquad (6)$$

Where *Em* is the emissions, kg/year. E_{Grid} is the electricity purchased from the grid, kg. F_{EM} is the GHG emissions (g CO_2-equivalent per kg) [11].

All the calculations of those parameters and equations are carried out by HOMER software [10].

A CASE STUDY OF ROCKHAMPTON

The research location of this study Rockhampton is a major regional centre of Central Queensland. The historical solar irradiation data and climate change scenarios are collected aiming to the Rockhampton city. The station details are:

- Weather station name: Rockhampton Aero;
- Coordinator: (-23.3753, 150.4775);
- Height of the weather station: 10m;
- WMO (World Meteorological Organization) Index Number: 94374;
- Historical data Period: 1/Jan/2008 - 31/Dec/2008;
- Daily solar irradiation and the fitted cosine function:
- $S_T = 1.564cos(\frac{2\pi D}{365} + 0.3674) + 5.6837$ as shown in Figure 4, where S_T is the irradiation in kW/m^2 and D is time in day;

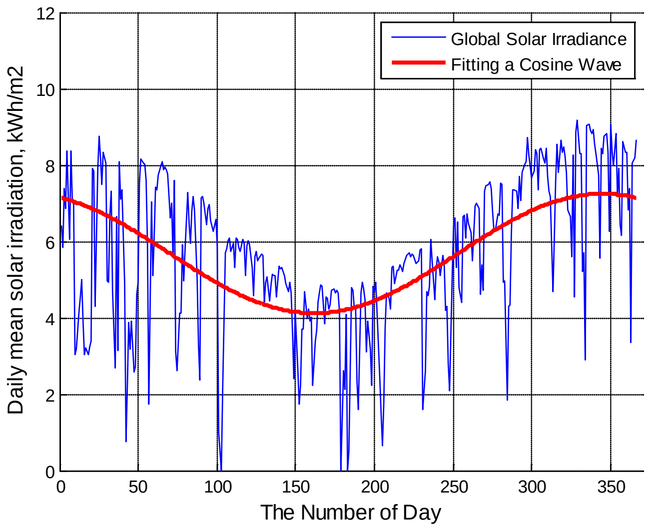

Figure 4 The daily mean global solar irradiation of Rockhampton, Australia

System description

The sample system in Rockhampton is simulated by HOMER software. As the details shown in Table 2, the PV array size is 6 kW, and the type is thin films PV generating DC power. Two S4KS25P batteries, produced by Rolls/Surrete company [12], are chosen as a storage component. Six inverters are added as the CD/AC converter.

The grid which has 924 g/kWh CO_2 emission is also connected in the model. When the PV power generation is more than the electricity consumption, the PV electricity is sold to the grid. When the PV power generation is less than the electricity consumption, users purchase electricity from the grid.

Data prediction results

The hourly global solar irradiation data is obtained by Equation 4 and 5. Five solar resources data files with 8760 hourly data for each are generated for the five climate scenarios. As shown in Figure 5, the daily mean global solar irradiation for different scenarios have the same profile but the values vary from scenario to scenario. The scenario 5 (2070 High) has the highest solar irradiation more than 700 W/m^2 at 14:00, and the scenario 4 (2070 Low) has the least solar irradiation around 650 W/m^2 at the same time. As seen from the five curves, the morphing ratio is dependent on the percentiles and emission amount of the scenarios as introduced above.

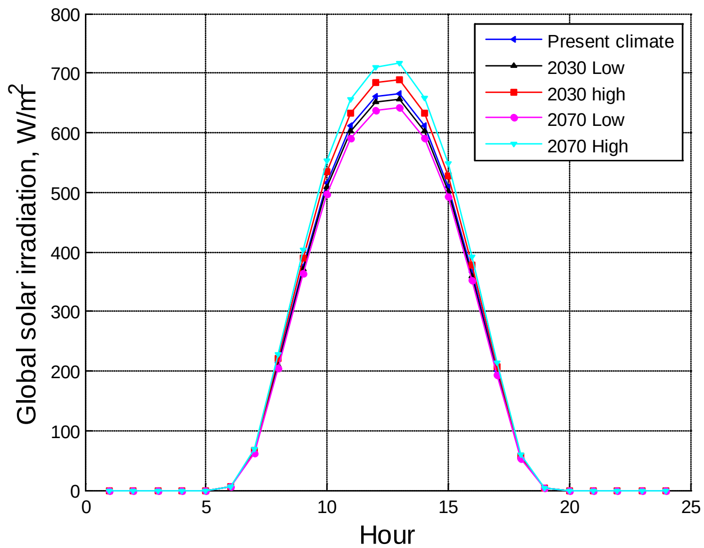

Figure 5 The daily mean global solar irradiation of Rockhampton, Australia

System simulation results

The system simulation results are shown in Table 3. The system running under the present climate generates electricity 9000 kWh/year and its renewable fraction is 55% and annual CO_2 emission is 1461 kg. The most PV power generation is seen from the 2070 High scenario which is 9725 kWh/year. This scenario has the least CO_2 emission 931 kg/year and the highest renewable fraction 57.3%. Following that, the 2030 High scenario has the second most PV power generation of 9344 kWh/year and second highest renewable fraction of 56.1%. The PV power generation of the scenarios of 2030 Low and 2070 High which are respectively 8837 kWh/year and 8654 kWh/year, are less than the present climate scenario. Their renewable fraction (respectively 54.4% and 53.8%) are also lower than others, and their annual CO_2 emissions (respectively 1585 and 1727 kg/year) are more than in other scenarios.

Figure 6 takes the January 1 as an example to compare the PV power generation, grid purchases and AC primary load for the present climate scenario, and Figure 7 is for the 2070 High scenario. The diagram demonstrates that the PV power generation is more than the AC primary load between 9:00 and 16:00 of one day. The peaks of both AC primary load and PV power generation occur during this period. This shows that there are three peaks of purchasing electricity from the grid: 4:00 to 7:00, 9:00 to 10:00 and 16:00 to 23:00. Another reason for these purchasing peaks is the solar irradiation changes during one day. It is easy to see that the daily PV power generation of present climate scenario is just a little less than the 2070 High scenario. The profiles of PV power generation, AC primary load (strictly equal) and gird purchases of these five scenarios are quite similar.

Table 2 The system components sizes description

Components	Size options	Interpretation
PV (kW)	6	Thin films PV; DC power generation
Battery (count)	2	S45S25P
Converter (count)	6	DC/AC converter
Gird electricity	-	CO_2 emission factor 924 g/kWh

Table 3 Simulation results for all the climate scenarios

Scenarios	PV generation (kWh/year)	Electricity consumed from the grid (kWh/year)	Electricity sale to the grid (kWh/year)	Renewable fraction (%)	CO_2 emissions (kg/year)
Present climate	9000	7360	5779	55.0%	1461
2030 Low	8837	7393	5678	54.4%	1585
2030 High	9344	7299	5994	56.1%	1206
2070 Low	8654	7427	5558	53.8%	1727
2070 High	9725	7241	4980	57.3%	931

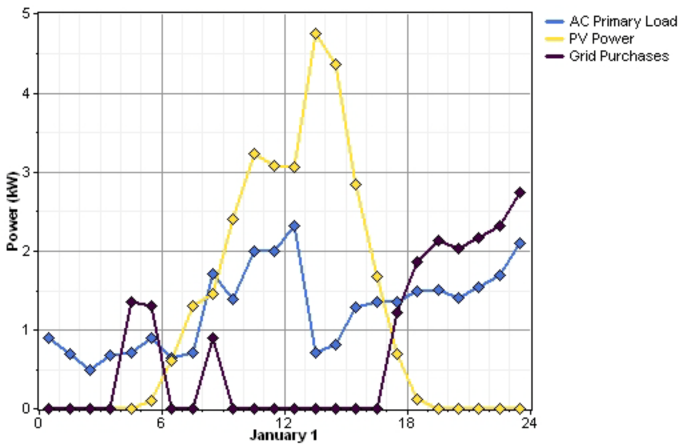

Figure 6 System daily performances, present climate

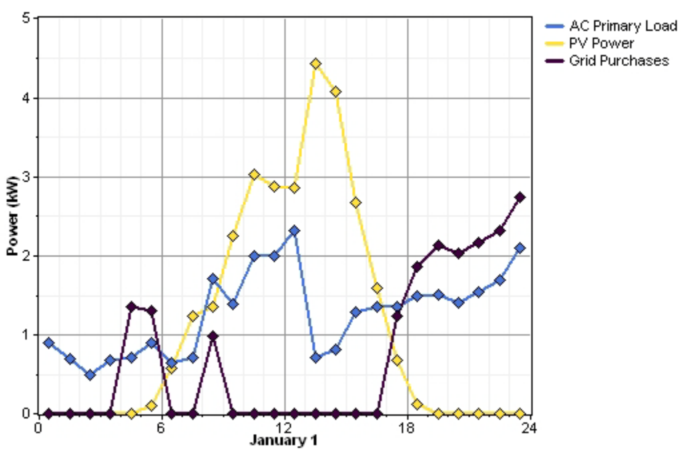

Figure 7 System daily performances, 2070 High

CONCLUSION

Through investigating the historical solar resource data and Australian climate change scenarios, the future solar data is predicted for solar PV system simulation. The morphing method is used to generate the hourly global solar irradiation data for Rockhampton, Queensland, Australia. A PV system with a load of 23 kWh/day and 6 kW of solar array is simulated by HOMER software. The electricity generation and CO_2 emission reduction are compared between different climate scenarios (present climate, 2030 Low, 2030 High, 2070 Low and 2070 High).

It is found that for the 2070 High scenario, the solar PV generates the most electricity (9725 kWh/year) and has the highest renewable fraction (57.3%). This performance is better than the PV system running under the present climatic conditions. The least PV power generation and the lowest renewable fraction is seen from the 2070 Low scenario, respectively 8654 kWh/year and 54.4%. Taking the date of January 1 as an example, the PV power generation occurs between 9:00 to 16:00, and this leads to three peaks of grid purchases between the periods of 4:00 - 7:00, 9:00 - 10:00 and 16:00 - 23:00. It is also found that the PV power generation curves and grid purchases peaks have the same profiles for different scenarios, but the values vary from climate scenario to other one.

REFERENCES