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Prospecting solar energy in Australia: accounting for temperature losses

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Abstract

In this paper, we prospect the solar potential of 5 varieties of commercially available modules in 15 locations around Australia, accounting for regional temperature and irradiance. We employ irradiance datasets, from the Australian Solar Energy Information System (ASEIS). Through our analysis, we categorise regions around Australia, by their impact on the performance of different solar module technology. From this comparison we find coastal DNI on average is lower in the mornings owing to the high relative humidity and daily temperature variation. These irradiance conditions, slightly alter the optimum installation direction and tilt. The best performing modules are the premium back-contact c-Si modules, and the worst is the standard mc-Si module. Importantly, the impact of a module technology on yield must be determined with site-specific irradiances and ambient temperatures. We find temperature losses correlate most strongly correlated with average mean monthly temperature. An additional interesting finding is that coastal locations have lower direct normal irradiance in the morning, which infers the optimum orientation is slightly West of North.

1. Introduction

Solar panels are often marketed heavily on parameters other than their \$/kWh performance. Features often spruiked on datasheets are ascetics, warranty, low-light performance, and temperature performance. In particular low-light performance and the module temperature coefficient impact the modules performance ratio (PR) which we define as:

$$PR = \frac{P_{\mathrm{Out}}}{P_{\mathrm{STC}} \times {}^{I_{\mathrm{Real}}}/_{I_{\mathrm{STC}}}},$$

the ratio of the module output power P_{Out} to the measured standard test condition power P_{STC} adjusted for the real irradiance I_{Real}. To evaluate I_{Real} we extract the direct-normal and global-horizontal irradiance (DNI and GHI) data sets, from the Australian Solar Energy Information System (ASEIS). We do this for 15 locations around Australia, depicted in Figure 1.

This paper is set out as follows: we present our methodology for the calculation of *PR*, in particular, the temperature performance ratio PR_{temp}. In the results section, we present location dependent PR_{temp} and discuss the location specific effects. Finally, we make discuss and conclude our findings.

Figure 1: Map of locations studies for the impact of temperature on PR.

2. Methodology

The monthly hourly averaged DNI and GHI was downloaded from ASEIS online (ASEIS 2015) for the locations depicted in Figure 1. We summarise the: location, distance to the coast, a categorization of the location, the yearly integrated DNI and GHI and the DNI/GHI ratios in Table 2. We account for the module ambient temperature by using Bureau of Meteorology (BOM 2015) monthly mean min and max to give the ambient temperature T_{amb}, which we assumend varied sinusoidally with the ambient minimum and maximum temperatures aligned with the minimum and maximum GHI. We defined 5 categories of modules to model the PR_{TEMP} and summarised the pertinent performance parameters Table 2. The performance parameters are typical of the specific module varieties available from datasheets available online. The 5 module categories studied are representative of commercially available panels, include 3 c-Si and two thin-film modules.

To compute the irradiance on the module, first the incident angle of the direct radiation was determined from the relative position of the sun in the center of each recorded hourly irradiance. The direct beam on a tilted plane was then determined to calculate the direct irradiance of the solar panels; this computation considers the dot-product of the direct radiation vector with the normal vector of the module. We note the normal vector of the module results from the cross product of its tilt vector with the vector representing directional orientation. For this work, all modules were position facing North at a tilt equal to the latitude. The total irradiance was given by

$$I_{\mathrm{tot,tilt}} = I_{\mathrm{Direct,tilt}} + I_{\mathrm{Diffuse,tilt}} + I_{\mathrm{Reflected,tilt}}$$

The sum of the direct, diffuse and reflect irradiance on a tilted plane. The respective irradiances were determined using the equation

$$I_{\mathrm{tot,tilt}} = I_{\mathrm{DNI}} \times \cos(\emptyset) + I_{\mathrm{Diff}} \times {}^{(1-\cos(\beta))}/_{2} + (I_{\mathrm{GHI}}) \times R \times {}^{(1-\cos(\beta))}/_{2}$$

where I_{DNI} is the measured direct normal irradiance, $\cos(\emptyset)$ is the tilted cross product of the direct radiation vector and the module vector, I_{Diff} is the diffuse irradiance, I_{GHI} is the measured global horizontal irraciance , β is the module tilt, and R is the reflectivity surrounding the module. The reflectivity in this work is consider to be moderate 0.2. The diffuse radiation on a horizontal is determined by subtracting the DNI projected on a horizontal plane from the GHI and in

$$I_{\mathrm{Diff}} = I_{\mathrm{GHI}} - I_{\mathrm{DNI}}\cos(zen)$$

where *zen* is the Zenith angle of the direct irradiance. We calculated all required parmeters from the measured I_{DNI} and I_{GHI} and the geometric setup of the modules with respect to the sun.

For modelling the commercial module performance, we used the parameters in Table 1. In this instance, we only considered the effect of temperature loss where we determine the module temperature T_{mod} from the equation

$$T_{\mathrm{mod}} = (T_{\mathrm{NOCT}} - 20) \times I_{\mathrm{G,tilt}} \times \frac{\left(1 - P_{\mathrm{max}}\left(1 + {}^{\gamma}/_{100}\,(T_{\mathrm{mod}} - 25)\right)\right)}{0.8} + T_{\mathrm{amb}}.$$

where T_{NOCT} is the datasheet listed nominal operating cell temperature (NOCT), $I_{\mathrm{tot,tilt}}$ is the global tilted irradiance, computed as outlined above, in kW/m^2, T_{amb} is the ambient temperature, P_{mpp} is the module power output per unit area and γ is the power loss coefficient form STC. We note T_{mod} is solved iteratively as it is an implicit equation. The relative temperature power loss is then determined hour by hour, considering the relative power loss coefficient. The impact of the temperature losses is integrated over a year to give the temperature performance ratio PR_{TEMP}.

Table 1: Modules where the temperature PR was compared across Australia.

Manufacturer/Source	Type	P_{max} (W)	P_{max}/m² (W/m²)	T_{NOCT} (°C)	γ (P_{max}%/°C)
A	CdTe	90	125	45.0	-0.25
B	c-Si (premium)	345	212	41.5	-0.30
C	mc-Si (standard)	260	159	45.0	-0.40
D	CIGS	150	138	46.5	-0.31
E	Heterojunction	240	190	44.0	-0.29

Table 2: Summary of the locations and yearly integrated DNI and GHI energy in terms of kWh/m²

City	Long.	Lat.	Distance to coast		I_DNI	I_GHI	DNI/GHI
Canberra	149	-35.3	112	inland	2005	1768	1.13
Sydney	151	-33.9	6.5	Coastal	1822	1701	1.07
Melbourne	145	-37.8	5.2	Coastal	1615	1572	1.03
Adelaide	139	-34.8	4.8	Coastal	2019	1804	1.12
Perth	116	-31.9	9.6	Coastal	2231	1965	1.14
Broome	122	-17.8	3.8	Coastal	2386	2223	1.07
Darwin	131	-12.4	1.5	Coastal	1979	2105	0.94
Mount Isa	139	-20.5	344	inland	2490	2214	1.12
Alice Springs	134	-23.5	925	inland	2574	2196	1.17
Cairns	146	-16.9	0.6	Coastal	1821	1999	0.91
Brisbane	153	-27.1	15.8	inland	2012	1912	1.05
Moree	150	-29.3	331	inland	2287	1979	1.16
Broken Hill	141	-31.8	549	inland	2467	2015	1.22
WA	114	-22.8	623	inland	2590	2254	1.15
Hobart	147	-42.4	0.8	Coastal	1596	1496	1.07

3. Results

Prior to evaluating module performance ratio we investigate the solar resource at 3 key location, Canberra, Alice Springs and Brisbane plotted in Figure 2 respectively. We see that the DNI is typically higher in the afternoon compare to the morning for all three locations, but this effect is the strongest for Brisbane. We note this changes the optimum orientation, for Brisbane it is 13° West of North. Improving the orientation would yield and additional 0.5% available energy.

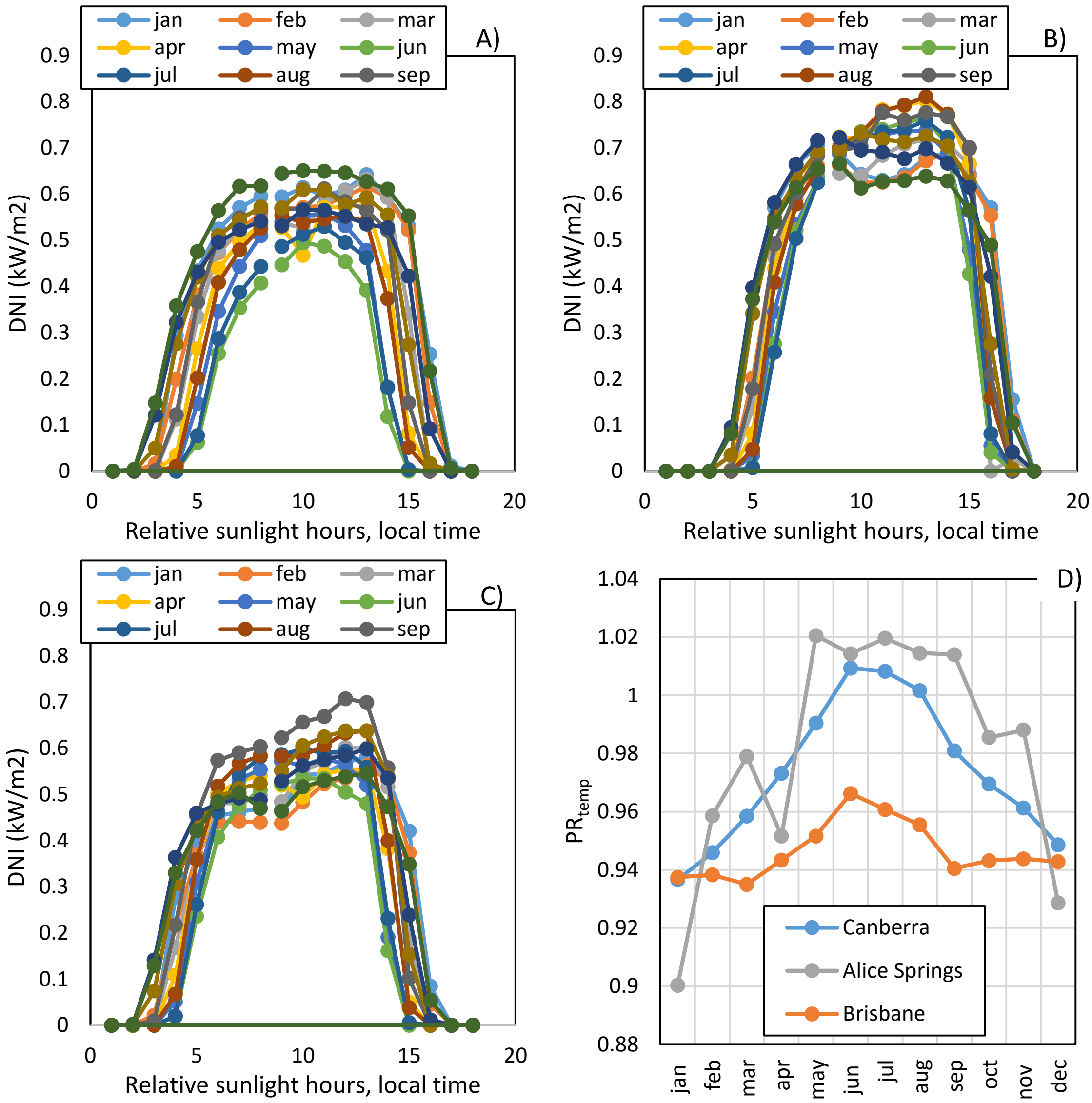

Figure 2: ASEIS measured monthly, hourly average hourly DNI, for Canberra A), Alice Springs B) and Brisbane C). Monthly modelled PR_{Temp} for the mc-Si modules D).

Figure 3 plots PR_{TEMP} for the locations studied in this work. We rank in terms from lowest to highest yearly irradiance. The dependence of PR_{TEMP} on module type is clear, the best performing module is the IBC premium (B) owing to the high efficiency, low NOCT and reasonable temperature coefficient. The performance of the CdTe (A) and c-Si heterojunction (E) modules are similar and rank equal second. Although the CdTe module has the lowest temperature coefficient, its comparatively low efficiency and moderate NOCT limit its temperature performance. The CIGS (D) module is forth, and the standard c-Si (C) module is fifth. The difference between the standard c-Si (C) and the high performing modules is significant ranging from 1.1% to 3.3%

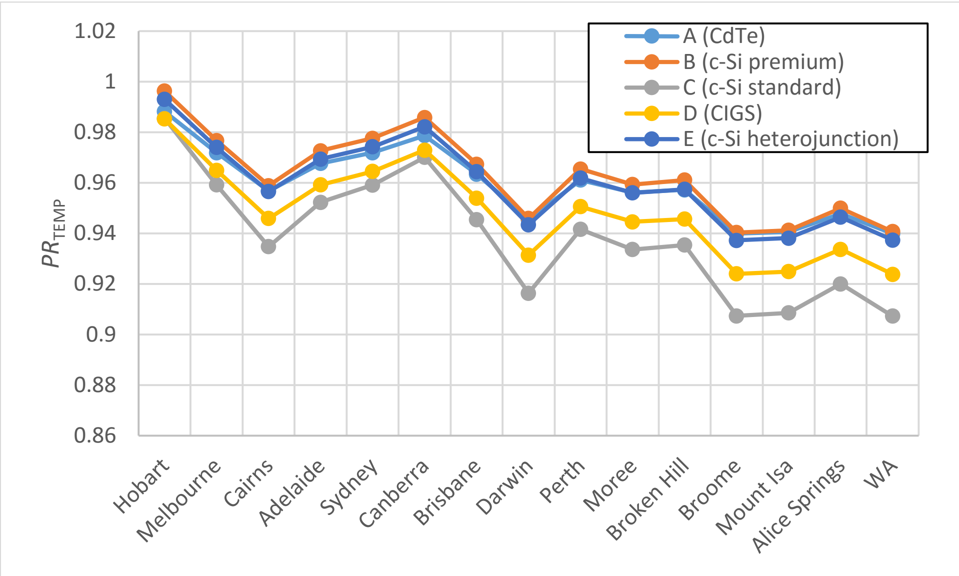

Figure 3: PR_{TEMP} plotted for the locations listed in Table 2 and depicted in Figure 1. The PR_{TEMP} is plotted for each module variety listed in Table 1.

To further investigate the root drivers of temperature loss, the PR_{TEMP} is plotted as a function of average monthly mean maximum temperature in Figure 4. A strong correlation is observed. Of the obvious independent parameters available such as annual yearly irradiance, longitude, latitude, we found the PR_{TEMP} is most strongly correlated with the average mean monthly max temperature. This effect was universal for all module types.

Also, we plot the location specific annual energy generation accounting for temperature losses on the left vertical axis, versus location with the location specific annual energy irradiance on the right axis. Again ranked from lowest to highest annual irradiance. Although the irradiance and the energy yield are similar in magnitude, they have different units. The annual energy yield is in terms of MWh/kWp. It is normalised to the kW_p rating of the installed system, therefore normalising for module efficiency. The annual irradiance is in MWh/kW_p. From this analysis, we see the normalised energy generation ranges from 1.13 to 1.77 MWh/kW_p. We note there is a reasonable correlation with reducing PR_{TEMP} and total insolation, as the average mean monthly max temperature are also correlated.

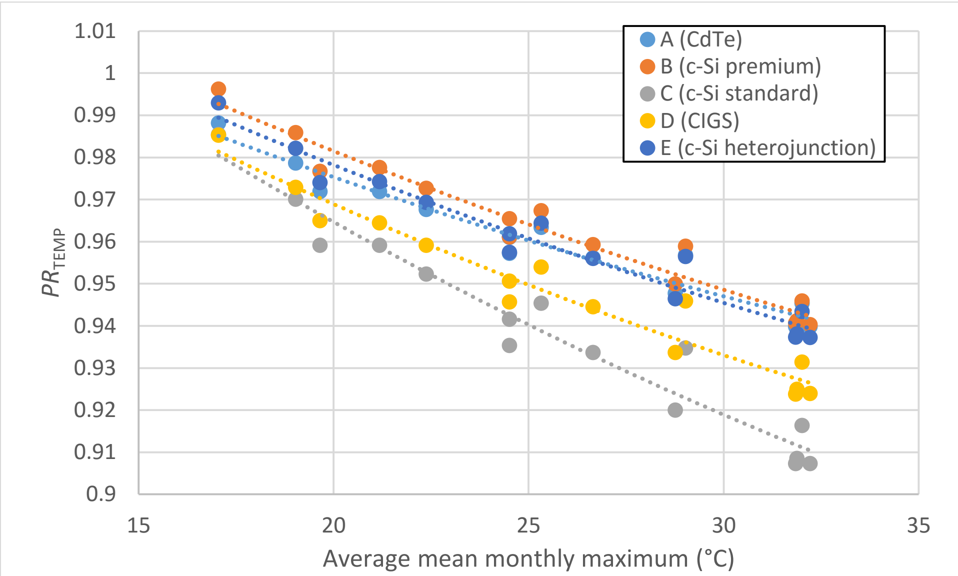

Figure 4: *PR*TEMP plotted as function of the average mean monthly temperature. The *PR*TEMP is plotted for each module variety listed in Table 1.

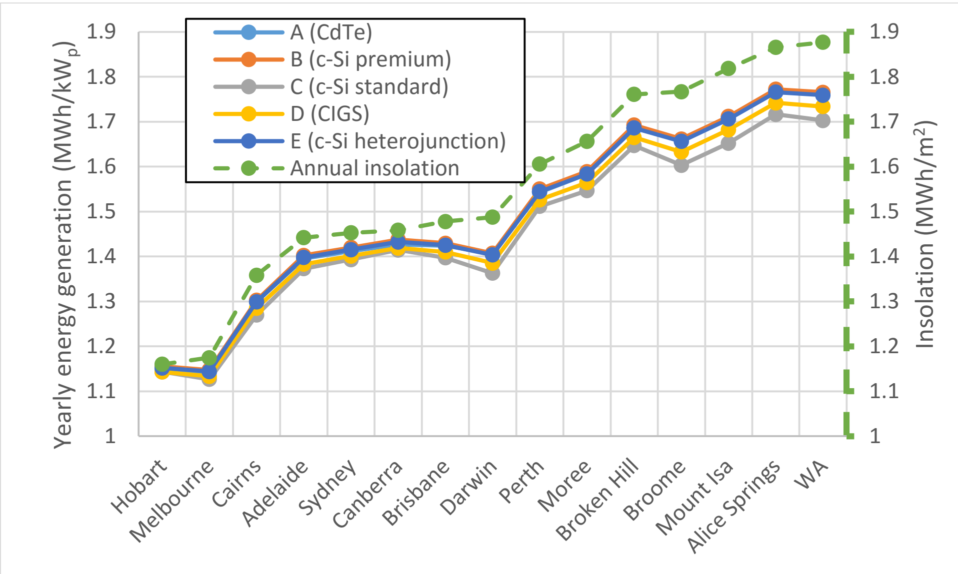

Figure 5: Total annual energy yield for different module types and annual insolation plotted against location.

4. Discussion and Conclusions

We have used freely available online resources to evaluate the temperature losses for 5 different module varieties at 15 different locations around Australia. While the PR_{TENP} of the different module technology ranged between 0.907 and 0.996, the maximum variation due to module type was 3.3%. The temperature losses are more strongly correlated with the location than the module variety.

By far the worst performing module variety were the standard c-Si technology. This low performance owes to the high temperature coefficient and NOCT, and moderate efficiency. Through the PV-Mate project, we will see to develop modules with lower NOCT and hence better temperature performance in Australia.

In addition to the impact of module type on PR_{TEMP} we have noticed that the insolation in many of the cities studied is skewed. That is there is significantly more direct irradiance in the afternoon compared with the morning. The higher morning insolation infers that a module orientation of North is not optimum, and that module should be orientated slightly to the west. This effect was fairly strong for all coastal cities; it is likely related to evaporation and precipitation moisture in the mornings which is burnt off throughout the day. The climate date indicates that the insolation is strong and more direct in the afternoons. The effect is not overly large at best it could be used to enhance yield by 0.5%. However when choosing between a Northeast and Northwest orientation, the effect is significant, in Brisbane they yield from a Northwest orientation is 5.5% higher than a Northeast orientation.

References

ASEIS (2015). "http://www.ga.gov.au/solarmapping/?".

BOM (2015). "http://www.bom.gov.au/jsp/ncc/cdio/weatherData/av?p_nccObsCode=36&p_display_type=dataFile&p_stn_num=066196."