Peer Reviewed
2017 Solar Research Conference

ASIA-PACIFIC
SOLAR RESEARCH
CONFERENCE

Jason David

Impact of Panel Cleaning on Photovoltaic Yield in a Coastal Region – A Direct Comparison

J. David[1&2], D. Robinson[2]

[1]*Australian Power Quality and Reliability Centre, University of Wollongong, NSW, Australia*

[2]*Sustainable Buildings Research Centre, University of Wollongong, NSW, Australia*

E-mail: jasond@uow.edu.au

Abstract

The continued uptake of renewable energy and more specifically solar energy has placed an intent focus on the efficiencies of such systems. Soiling is the effect of accumulated foreign material on a photovoltaic panel and results in a reduced system yield due to partial panel shading. This effect can be mitigated simply by implementing scheduled cleaning maintenance. Based on the research however, the impact of soiling is heavily affected by the location, and thus, the conditions that the system is exposed to. Panels located in arid or desert-like conditions are susceptible to the impacts of soiling due to the increased presence of sand or dust storms and a lack of significant rain events. Whilst installations on the coast and in areas with denser vegetation are less affected by the impact that soiling is likely to have. This paper aims to determine the effect of soiling on a medium sized solar installation located on the coast of south eastern Australia. The system under review consists of six identical installations of 20 kWp each, 120 kWp total. All sections are exposed to different cleaning schedules and the generation output of each section is recorded and compared. The analysis performed results in no discernible difference in the yield of each section, suggesting that the soiling rates on this installation are minimal and have very little impact on the efficiency of each section.

1. Introduction

Solar system efficiency is of significant importance due to the continued efforts to make renewable energy a prominent electricity supplier through government support, advocacy groups and the general population. Solar energy has experienced continued growth in popularity and can expect to maintain this increase in numbers due to the ongoing support provided by government policy, businesses and people electing to install renewable energy systems.

Determining a solar system's efficiency can be complex and is dependent on a wide range of internal and external variables, including but not limited to; solar irradiation, system quality and associated losses, temperature of module, angle of panel and cleanliness of panel.

Whilst it is commonly believed that a regular cleaning regimen is advantageous for a Photovoltaic (PV) panel, it has been suggested that further studies are required to fully understand the impact that cleaning may have on a system's efficiency (Costa, Diniz et al. 2016). Other studies suggest that regular cleaning is vital to a system's performance and needs to be performed to maintain the yield capabilities of the panels (Fathi, Abderrezek et al. 2017), (Touati, Al-Hitmi et al. 2016).

This paper aims to determine the impact that a regular cleaning schedule is to have on the efficiency of six identical systems installed side by side for direct comparison. To perform this study effectively a comprehensive literature review is presented to determine projects that have previously been completed and the relevance to the area of study. A presentation of the system under analysis for this paper is outlined in Section 3. The analysis presented in Section 4 aims to ascertain the impact that the cleaning schedule had on each individual system under the climatic conditions of Wollongong NSW, Australia. A conclusion and future work suggested is given in Section 5.

2. Literature Review

Studies into the efficiency of solar systems are widely available and present a myriad of results. Holistic investigations into the impact of a range of variables on the efficiency of a solar system are presented in (Fouad, Shihata et al. 2017) and (Meral and Diner 2011). These studies mention the impact of dirt and dust deposits on a PV panel and the impact this may have on the system's generation capability. This effect is known as soiling.

2.1. Soiling

Soiling is the build-up of foreign deposits on a PV panel's surface, this can include dirt, dust, sand and any other foreign matter that partially shades the solar panel. Soiling can become a significant issue in extreme conditions, for example arid or desert-like conditions, prone to sand and dust storms. References (Touati, Al-Hitmi et al. 2016, Fathi, Abderrezek et al. 2017) present studies in these types of areas, both of which outline a significant impact experienced by the system due to soiling coverage.

Case study (Touati, Al-Hitmi et al. 2016) presents the effect that cleaning has on a system's efficiency located in Doha, capital city of Qatar. A comparison of similar days before and after cleaning displays a prominent increase in generation. The measurements presented a maximum power of $74\,W$ on the day prior to cleaning when the solar irradiance was at a level of 892 W/m^2. The panels were then cleaned and the maximum power measured on the following day increased to $112\,W$ with an exposure measured of 936 W/m^2. This result suggests an increase of 3.7 % in efficiency. This is a considerable increase when considering PV panels tend to have an energy conversion efficiency of ~10 – 30 % (Melis, Mallick et al. 2014).

The study in (Fathi, Abderrezek et al. 2017) describes the simulation model created using laboratory measurements of varying soiling levels based on conditions likely to be experienced in the Algerian desert. The study also considers the effect of soiling on the overall efficiency of different sized plants and with panels of different architecture. Figure 1 shows the derating experienced by a simulated 1 MW plant due to the effects of soiling. This resulted in an estimated yield loss of 180 MWh per year, also increasing the expected Return on Investment (ROI) of the system.

For systems within these arid conditions, a regular cleaning schedule is likely to be advantageous for installations, especially due to isolated significant rain events capable of naturally cleaning panels paired with high exposure to dirt, dust and sand. These conditions are likely to expose systems to a high level of soiling if regular cleaning is not performed.

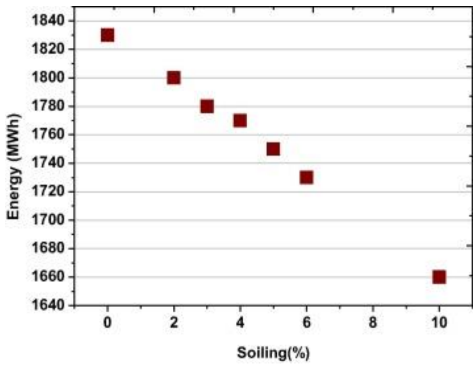

Figure 1 - Soiling vs Yield (Fathi, Abderrezek et al. 2017)

A project observed the impact of soiling in California, USA across 186 solar installations along the coast (Mejia and Kleissl 2013). This study found the impact far less severe than those performed in desert regions or areas with high exposure to sand and dust storms. The study conducted throughout 2010 resulted in an average daily calculated loss due to soiling of 0.051 %. This also factored in the impact of significant rain events to assist in determining the quantifiable effect of soiling. This result is intuitive as the location of the study performed is along the coast of a relatively temperate zone within North America.

The study presented in (Maghami, Hizam et al. 2016) states that both the soiling coverage and the material covering the panel significantly effects the impact it has on the efficiency. It outlines that six of the tested materials had a greater impact on the system's efficiency compared to others, these materials being: ash, calcium, limestone, soil, sand and silica. This result proposes that not only the level of soiling effects the panel's performance but also the type of material that is covering the panel.

A collection of many projects published related to the effects on PV panel efficiency due to soiling is presented in (Costa, Diniz et al. 2016). This shows the difference in the impact of soiling based on the area of study. Many studies have been performed in arid or desert conditions with a similar outcome, that is; the impact of soiling needs to be mitigated with repeated cleaning. The studies located in more temperate climates with lower exposure to harsh and dusty conditions show that soiling has less of an impact and can be mitigated through significant rain events or sporadic cleaning as required.

2.2. Impact and Mitigation of Soiling

Reference (Endecon Engineering 2001) uses an annual soiling reduction rate of 0.93, stating that this results in a 7 % reduction in efficiency over the course of a year. This rate of annual reduction is relative to the location of the system installation, in this case, California, North America. It should be noted that (Endecon Engineering 2001) does not offer any justification for the value, stating only that '*A typical annual dust reduction factor to use is 93% or 0.93.'*

Whilst soiling rates need to be considered on a region by region basis, deliberation on the effects that a wet/dry season must also be included. Some regions may be relatively immune to soiling effects due to regular significant weather events negating the impact that soiling has on a system. Reference (Kimber, Mitchell et al. 2006) suggests that a particular measured system noticed a significant efficiency increase after a rain event of 21 mm. However, when the analysis was widened to multiple systems exposed to varying levels of precipitation, there was no definitive amount of rainfall recorded that resulted in a confident increase in efficiency.

2.3. Summary of Literature Review

There is a wide collection of studies that have been performed attempting to determine the impact that soiling has on the performance of a PV panel, with intuitive outcomes stating that increased soiling will lead to a decrease in the PV system's efficiency. These studies cover a wide range of regions and areas around the globe and it is apparent that soiling rates are dependent on the conditions that the system is exposed to. The literature review presented in (Costa, Diniz et al. 2016) outlines the significance of the study of soiling rates in numerous regions. This is an important suggestion as a system exposed to low soiling rates is not likely to recover the expenditure required for a system clean.

2.4. Case Study

This paper aims to determine the effect that soiling is likely to have on a system in Wollongong NSW, Australia. Wollongong is a coastal Australian town with an average rainfall of 94 mm/month and an average maximum temperature of 21.3 °C (Bureau of Meteorology 2017).

3. System and Measurement Setup

3.1. System

The system under review is installed at the Sustainable Buildings Research Centre (SBRC) on the Innovation Campus - University of Wollongong NSW, Australia. This is a 120 kWp system split into six identical 20 kWp sub-systems, each with their own designated cleaning schedules (Figure 2).

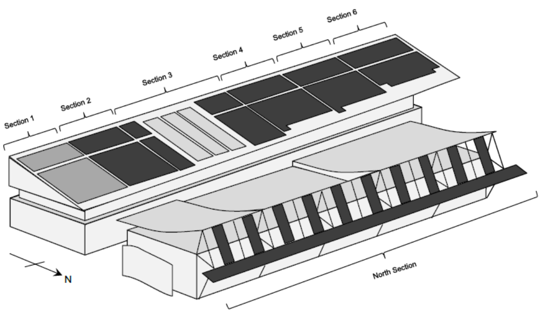

Figure 2 - SBRC Solar Installation

The details of all solar sections are presented in Table 1 and Table 2 displays the cleaning schedule each section has been exposed to.

Table 1 – Section Parameters

Solar Panels	REC260PE
STC Rating (W)	260
Peak Efficiency (%)	15.76
Modules per Section	78
Inverter	Power-One PVI-Trio 20k

Table 2 - Cleaning schedule for all sections

Section	Cleaning Frequency (months)
1	Not Cleaned
2	6
3	4
4	3
5	2
6	1

As can be seen in Table 2, Section 1 was not cleaned throughout the study whilst Section 6 was exposed to the most regular cleaning schedule being cleaned every month. Each section is fundamentally identical as presented in Table 1, whilst a split in Section 3 may be noticed (Figure 2) it contains the exact same elements as the other five sections. All sections are connected to separate, identical inverters, all located on the same distribution board within close proximity of each other. This would lend to the argument that any significant difference in yield could be attributed to the variation in cleaning frequency.

3.2. Measurement

The power yield of each section was measured throughout the experiment. Due to the likeness of each section, it is fair to suggest that any considerable difference in yield is likely to be due to the frequency of cleaning. The measurement period for this project ranged from July 2016 through to June 2017.

A SolarLog was connected to all 6 inverters. The SolarLog is a device designed to retrieve specific information from an inverter or collection of inverters and post the information to a dedicated monitoring website. A Hioki PW3198 PQ meter was also used for the duration of the experiment in an attempt to confirm the measurements of both devices via comparison. The meter was connected to the inverters of Section 1 and Section 6. Figure 3 is a scatter plot comparison of the two devices. This confirms the metering equipment used performed adequately and analysis performed on either data set would be an indicative result for the system.

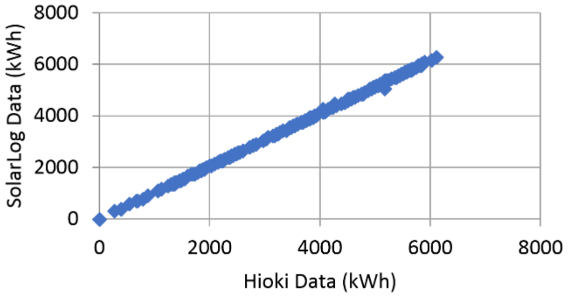

Figure 3 - Power Monitoring Comparison

As per (Kimber, Mitchell et al. 2006) rain events can have significant impact on the effect of soiling on PV panel efficiency. Serious rain events were therefore considered and defined to be

>10 mm. This value was chosen based on data presented in (Kimber, Mitchell et al. 2006) regarding the minimum rainfall required to adequately clean PV panels, along with average rainfall data for the region. The daily rainfall data was obtained from (Bureau of Meteorology 2017) and used to determine if it had any noticeable impact on each section's efficiency.

4. Results and Analysis

For the initial analysis, the measured data of sections 1 and 6 only were considered. As can be seen in Table 2 these two sections are exposed to the two most varied scenarios, never cleaned and most regularly cleaned. It could be intuitively suggested then, that if any discernible difference is to be noticed due to the effect of soiling, the most noticeable would be between Sections 1 and 6.

4.1. Direct Comparison

Figure 4 displays the strong correlation that exists between Sections 1 and 6 of the SBRC PV solar installation. Regardless of the extensive cleaning schedule that Section 1 is exposed to, Section 6 generates a very comparative yield. This comparison was performed for all sections against Section 1 which resulted in similar correlation in all cases.

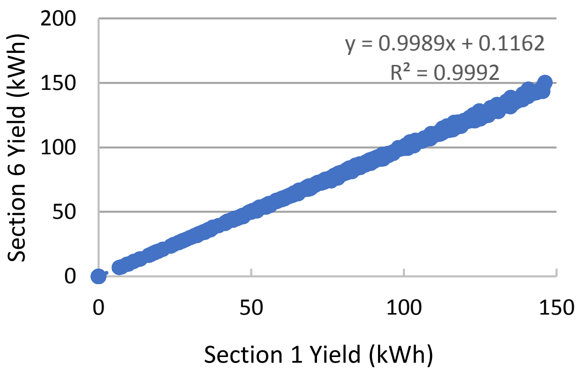

Figure 4 - Comparison of Section 1 and Section 6 Yield

Fitting a trendline to the scatter data in Figure 4 resulted in a straight line with equation (1), suggesting that the two systems studied are very similar and the effect of soiling had very little impact on the yield of either system.

$$y = 0.9989x + 0.1162\ kWh \tag{1}$$

Equation (1) fitted to the data in Figure 4 returns a R^2 value of 0.99. This states that (1) results in very little variance when compared to the actual measured values.

4.2. *Daily Yield Comparison*

A more explicit graph is presented in Figure 5. This is the daily yield for a select portion of the project, (September 25, 2016 to January 25, 2017) for both Section 1, presented in blue, and section 6 presented in orange.

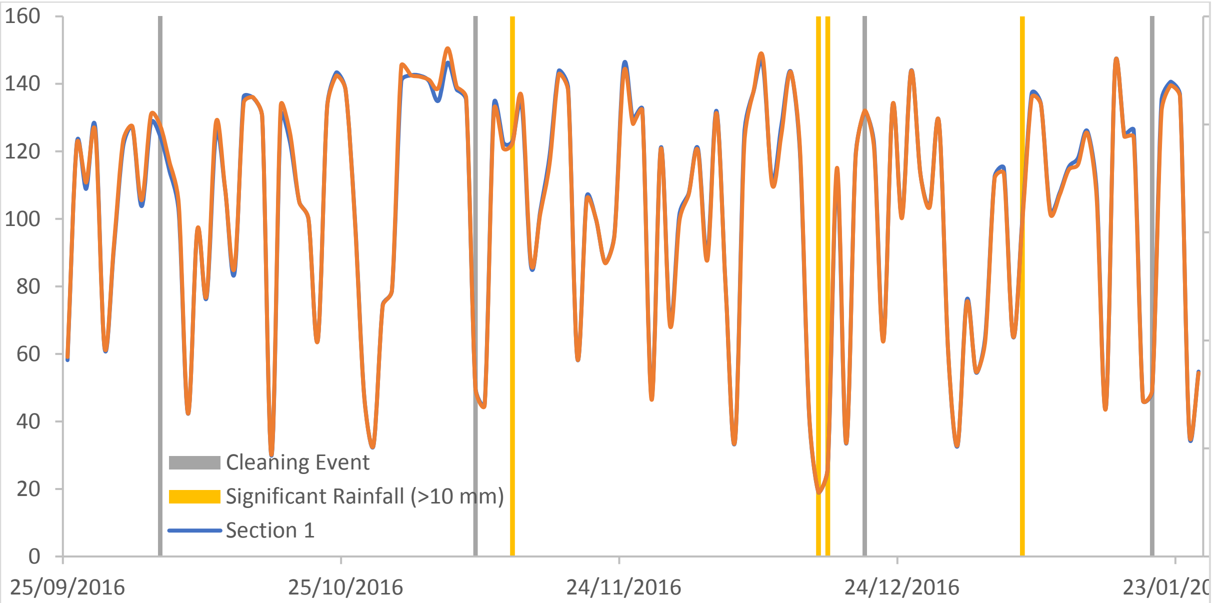

Figure 5 - Daily Yield Comparison with cleaning events

Cleaning events, displayed as grey vertical markers, and significant rain events presented as yellow vertical markers have also been graphed. Any day that recorded more 10 mm of rain was considered to be a significant rain event. The date range chosen is indicative of the entire data set which is too large to be presented in the allotted space. Figure 5 shows again the strong correlation that exists between the two systems.

Close inspection of Figure 5 confirms there is very little difference in the daily yield values for both sections, reinforcing the outcome seen in Figure 4 and subsequent analysis. The cleaning events of Section 6 are shown to have no discernible difference in yield before or after the event. Significant rainfall events are also marked on the figure with very little impact noticed in daily yield for both sections.

4.3. *Numerical Comparison*

The differences in daily yield seven days prior and after cleaning events was performed to determine if there was perhaps a small but consistent difference in the yield of the two sections. An average difference in yield over a number of days, n is given by (2):

$$\Delta_{6,1} = \frac{\sum(Daily\ Yield_6 - Daily\ Yield_1)}{n} \quad (2)$$

Any increase in efficiency for the cleaned section would result in $\Delta_{6,1\ After}$ being larger than $\Delta_{6,1\ Prior}$. To determine this over the course of the project, Equation (3) was calculated and the results are presented in Table 3.

$$\Delta\eta = \Delta_{6,1\ After} - \Delta_{6,1\ Prior} \quad (3)$$

Table 3 - Comparison of Average Yield Before and After Clean

Date of Clean	$\Delta\eta$ (kWh)	Rainfall Since Last Clean (mm)	Days with rainfall >10 mm
29/07/16	-1.04	NA	NA
01/09/16	-0.605	112	4
05/10/16	0.536	47.4	2
08/11/16	-1.706	6.6	0
20/12/16	-0.989	73.8	3
20/01/17	-0.147	29.8	1
20/02/17	0.246	85.4	3
March*	NA	422.6**	13
April*	NA	498.2**	5
31/05/17	-0.577	529**	1
26/06/17	0.310	75.2	2

***Cleaning during March and April were missed due to scheduling issues and inclement weather**
****As cleaning did not occur in these months this is a cumulative total, sum taken at end of month**

Inspection of Table 3 suggests that there is no evidence that the cleaning events performed increased the efficiency of Section 1. Majority of the calculations performed resulted in section 6 being less efficient directly after the cleaning event. Whilst this result appears to be counter intuitive, the differences are relatively small and can be attributed to imperfections within the physical system hardware, measurement errors and the inherent variability of solar generation. To determine an average instantaneous variance (4) could be used:

$$\Delta P = \frac{\Delta\eta\,(kWh)}{24\ hrs}\ W \tag{4}$$

Applying (4) to the largest value found in Table 3, during July, results in an average difference in instantaneous power of 43.3 W, <1 % of the rated peak output of a single section. Based on this small variance, a discernible difference cannot be confidently suggested.

5. Conclusion and Future Work

The results of the measurements taken and presented in Section 4 suggest a simple result. In the region of Wollongong, or more specifically, the SBRC, regularly scheduled cleaning has minimal effect on the efficiency of the system. With the only variable between all systems being the frequency of cleaning, one can confidently suggest that soiling rates within the area are too low and overshadowed by significant rain events to justify the use of a cleaning regimen to increase efficiency.

Cost considerations must be taken into account when determining the need for panel cleaning to take place. For a system clean to be financially viable a considerable increase of efficiency and thus, power generated, must be resultant in order to recoup the money spent on the cleaning.

In the case presented within this paper the cost is not redeemed throughout the entirety of the project.

5.1. Future Work

5.1.1. Identification of Soiling Rates

The results and analysis presented in this paper may be significant, but only for a specific region of the world. To better understand the effect of soiling rates in all regions, similar studies must be continued and reported. This is important information as the outcomes may affect a system owner's decision to undergo expensive system maintenance. Severe soiling also needs to be identified as systems located in highly affected areas benefit greatly from regular panel maintenance, as presented in Section 2.

5.1.2. Measurement of Soiling Rates

A live measurement of soiling may not be feasible in all regions however those that are exposed to high soiling rates could benefit greatly from a live measurement.

This could include a secondary irradiance meter that is placed under a small sheet of transparent glass with similar characteristics as the solar panel. If the secondary irradiance meter is reading a significantly lower value than the primary, this could be a sign of excessive soiling and thus the system is due for cleaning.

5.1.3. Autonomous Systems

Perhaps of more importance is to further the abilities of monitoring systems to extend to soiling detection and overall performance degradation. PV system autonomy is of increasing interest as large scale plants become more prevalent. Whilst it is common for systems to have a wide range of data able to be monitored by the end user and even automated alerts to installers as faults occur, long term automated analysis would benefit every system by determining the system's instantaneous efficiency compared to the expected efficiency. Ongoing analysis of this type would provide valuable information regarding system performance due to hardware, installation location, solar exposure, weather events, cleaning and scheduled maintenance for example. This information could be used to provide manufacturers, installers and customers with information that could greatly assist decisions regarding installations and required maintenance.

To effectively implement this type of autonomy a pairing of hardware and software would be able to supply monitoring information and then perform ongoing analysis. Based on this analysis, a notification event may trigger to notify the customer that panel cleaning is required or a physical inspection of the panel to determine the reason behind lower than expected efficiency should be performed.

5.2. Conclusion

Soiling has been identified to have an impact on the efficiency of PV installations. The effect can be mitigated with panel cleaning however the cost of cleaning needs to be recovered by the regained panel efficiency. This paper shows that the system under review installed on the SBRC in Wollongong NSW, Australia, does not significantly benefit from a regular cleaning regimen. This was found by a direct comparison of measured yield values collected over 12 months. It is likely that the conditions the system was exposed to, frequent rain events for example, naturally limited the effect that soiling is to have on PV efficiency.

Whilst the result is relevant for one particular installation, the soiling rates experienced by systems in different regions are likely to have a more severe effect. It is suggested that soiling rate studies performed across many regions would benefit the knowledge base and inform the industry and customers.

Furthermore, advancement in PV installation autonomy is suggested to assist in maintaining solar installations and automatically determining when a panel clean would be beneficial.

References

Bureau of Meteorology. (2017, July 13, 2017). "Climatic Statistics for Australian Locations." Retrieved July 18, 2017, from http://www.bom.gov.au/climate/averages/tables/cw_068228.shtml.

Costa, S. C. S., A. S. A. C. Diniz and L. L. Kazmerski (2016). "Dust and soiling issues and impacts relating to solar energy systems: Literature review update for 2012–2015." Renewable and Sustainable Energy Reviews **63**: 33-61.

Endecon Engineering (2001). A GuideTo Photovoltaic (PV) System Design and Installation.

Fathi, M., M. Abderrezek and P. Grana (2017). "Technical and economic assessment of cleaning protocol for photovoltaic power plants: Case of Algerian Sahara sites." Solar Energy **147**: 358-367.

Fouad, M. M., L. A. Shihata and E. I. Morgan (2017). "An integrated review of factors influencing the performance of photovoltaic panels." Renewable and Sustainable Energy Reviews **80**: 1499-1511.

Kimber, A., L. Mitchell, S. Nogradi and H. Wenger (2006). The Effect of Soiling on Large Grid-Connected Photovoltaic Systems in California and the Southwest Region of the United States. 2006 IEEE 4th World Conference on Photovoltaic Energy Conference.

Maghami, M. R., H. Hizam, C. Gomes, M. A. Radzi, M. I. Rezadad and S. Hajighorbani (2016). "Power loss due to soiling on solar panel: A review." Renewable and Sustainable Energy Reviews **59**: 1307-1316.

Mejia, F. A. and J. Kleissl (2013). "Soiling losses for solar photovoltaic systems in California." Solar Energy **95**: 357-363.

Melis, W. J. C., S. K. Mallick and P. Relf (2014). Increasing solar panel efficiency in a sustainable manner. 2014 IEEE International Energy Conference (ENERGYCON).

Meral, M. E. and F. Diner (2011). "A review of the factors affecting operation and efficiency of photovoltaic based electricity generation systems." Renewable and Sustainable Energy Reviews **15**(5): 2176-2184.

Touati, F., M. A. Al-Hitmi, N. A. Chowdhury, J. A. Hamad and A. J. R. San Pedro Gonzales (2016). "Investigation of solar PV performance under Doha weather using a customized measurement and monitoring system." Renewable Energy **89**: 564-577.