Investigating The Impact of Non-Traditional Foreground Surfaces for Solar PV Installations

INVESTIGATING THE IMPACT OF NON-TRADITIONAL FOREGROUND SURFACES FOR SOLAR PV INSTALLATIONS

Dr Mehreen S. Gul[1*], Yash Kotak[1] and Prof Tariq Muneer[2]

[1.]Heriot-Watt University, Edinburgh
[2.]Edinburgh Napier University, Edinburgh
* Email: m.gul@hw.ac.uk
*Telephone: +44 131 451 4082

Abstract

The current research experimentally investigates the albedo (ground reflectance) of two non-traditional foreground materials (sand and white pebbles) that can be used in solar photovoltaic (PV) applications such as solar farms and Building Integrated Photovoltaics (BIPV). The impact of varying sky conditions such as, overcast (OV), part overcast (POV) and clear (CL) sky is studied in this research. The experimental setup for this research was conducted at Heriot Watt University, U.K. using components such as pyranometers and data logger. From the analysis, it was found that both the materials had specific characteristic behaviour under varying sky conditions (based on movement of clouds). The energy generation from both the materials concluded that white pebbles have a higher energy output as compared to sand under both OV and CL sky conditions. There is a 44.60% and 14.04% difference between both material energy generation under OV and CL sky conditions.

Key Words

Photovoltaics, albedo, foreground materials, sky conditions

1. Introduction

The UK has to fill a potential electricity supply gap of up to 55% by 2025 due to the closure of coal-fired and ageing nuclear power stations. Solar energy harvesting via solar photovoltaics (PV) has a substantial role, to fill the future energy demand gap as the total national installed capacity of PV plants is approaching 10 GW (IMechE (2016)). Most of the large-scale PV installations: ground mounted and commercial buildings are based on crystalline technology which have now almost reached the efficiency apex, and thus new innovations must be made to enhance the irradiance of the modules, to increase the energy yield (Gul et al (2016)). Improved reflectance from weather-resistant surfaces that offer high albedo (ground reflectance) is one potentially strong measure to enhance the solar irradiance of PV modules, thus producing more electricity, where a higher albedo translates into greater ground reflection. According to Psiloglou et al. (1997) ground reflected component is a significant parameter and may reach up to 100 W/m^2 (Ineichen, et al., 1990). Different surfaces have different albedo values and therefore an accurate measurement of albedo is important when considering the installation of PV installations as it can severely influence the estimation of solar radiation incident on tilted surfaces (Psiloglou, et al., 1997). This paper presents an experimental investigation of two non-traditional foreground materials for PV installations where the effect of varying sky conditions (such as overcast (OV), part overcast (POV) and clear (CL) sky) are analysed to determine the change in albedo values.

Moreover, it also analyses the energy generation from both the materials under OV and CL sky conditions.

2. Background

The reflectivity of a surface is defined as the ratio of the amount of radiation reflected by the surface to the amount of radiation incident to it, and is referred to as albedo (Latin for whiteness) (Ineichen, et al., 1990, Coakley, 2003). Albedo is used in calculations for solar irradiance on a tilted surface to gage the potential performance of a PV module. Liu and Jordan (1963) were responsible for the first evaluations of ground-reflected radiation and concluded that a constant albedo of 0.2 can be applied to the global radiation incident on a horizontal plane. Ineichen et al. (1987) measured the actual ground reflected radiation and compared with the Liu and Jordan value of 0.2 for Geneva and concluded that the constant value is unsatisfactory and unrealistic. Psiloglou and Kembezidis (2009) stated that the calculated albedo coefficients vary according to the kind of surface in the vicinity of the station.

Albedo exhibits a strong seasonal dependence and it is a weather and time-dependant function Iqbal (1983). Munn & Truhlar (1963) reported albedo values for afternoon periods that were higher than the morning equivalent. Impens & Lemeur (1969) also reported a diurnal variation with marked asymmetry around noon. Bolsenga (1977) did series of measurement on ice and demonstrated the influence of solar altitude on albedo. Bray et al. (1966) showed that albedo over Quercus forest increased from 3.8% at a solar altitude from 0° to 12.3% at an altitude of 8 to 10° and then decreased to 2.4% at an altitude from 60 to 70°. The experiment conducted by Volz (1965) concluded that the effective albedo of the earth surface is increasing from 0.1 at 40° solar elevation to about 0.25 at 10° elevation.

Idso et al. (1975) and Idso & Reginato (1974) described the diurnal variation of the albedo of a field of Avondale loam soil and noted three categories of characteristic daily albedo variations. He also showed the correlation between albedo and solar altitude and plotted the graphs of both wet and dry soils. Similarly, Matthias et al. (1998) also presented tables of albedo values from two soil types with diverse combinations of wet/dry conditions and roughness, measured at six solar angles (ranging from 20^{o} to 70^{o}C) as occurred in generally cloudless days between April and August in 1995 and 1996 at the University of Arizona Campus Agricultural Center in Tucson. The resulted values for dry soil conditions were higher than for wet soil conditions, at any solar elevation angle.

The measurement and detailed analysis of albedo of a foreground material is therefore prerequisite to determine the incident ground reflected irradiance on a PV module and the impact it has on the output (energy yield) of the module. This will help to decide the most suitable foreground material for the installation of PV plants.

3. Research Methodology

The components that are installed in the experimental setup are one PV module, one rheostat with two extra resistors, three pyranometers, three thermocouples and one data logger. Figure. 1 is a picture of the installed setup at Heriot Watt University. However, for current research, pyranometers (P1, P2 and P3), one thermocouple and only the data logger were used, marked in the yellow box, blue and red circles in figure 1. P1 and P2 pyranometers were used to measure Global and ground-reflected radiation, while P3 was used to record total incident slope radiation. Thermocouple (Tm) was used to measure module temperature and data logger to record readings.

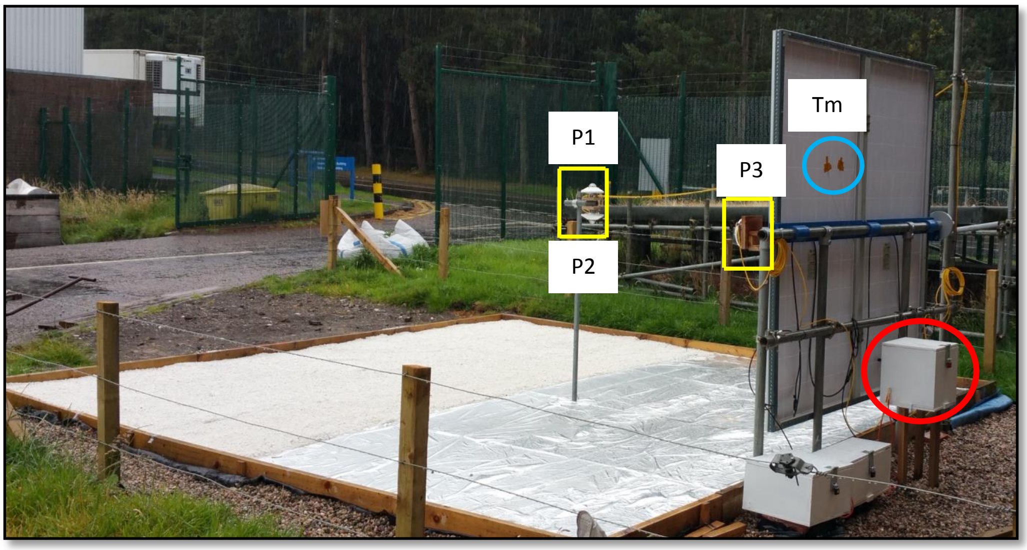

Figure 1: Experimental setup at Heriot Watt University

For the purpose of analysis, the data logger was set to record data every ten seconds (from 5:00 am to 10:00 pm) from all pyranometers. The recorder timings were set on the basis of sunshine hours i.e. daylight, in Edinburgh. By considering the number of materials, it was decided that each material should be tested for two weeks (14 days). Hence, the data logger was set to automatic mode, in which it started at 5:00 am, recorded data every ten seconds and finally stopped at 10:00 pm. This automatic recording was kept continuous for two weeks for each material, unless it was necessary to stop for any unforeseen circumstances. In such cases the material was kept for more than two weeks, so that at least 14 days of data was collected for each material. Lastly, the data was downloaded to a memory card (fitted into the data logger) and then downloaded to computer for analysis and the data logger reset for another material.

Pyranometers (P1 and P2) data were used to calculate the albedo of each foreground material using the formula (equation 1) as follows:

$$\text{Albedo } (\rho) = \frac{\text{Reflected radiation (P2)}}{\text{Global radiation (P1)}} \quad (1)$$

Readings from P3 and Tm were used for the evaluation of energy generation by a PV module. The formula (equation 2) was used to calculate the energy generation from a PV module.

$$E_{actual} = P_m \times S \times [1 - \lambda (T_m - 25)] \quad (2)$$

where,

E_{actual}	=	Actual energy output
Pm	=	Maximum power rating of the module
S	=	Slope irradiance (P3)
Tm	=	Module Temperature
λ	=	Maximum temperature coefficient of a PV module

Microsoft Excel VBA codes were developed to generate a quality dataset from raw data obtained from the data logger, to compute albedo as a function of solar altitude and sky conditions and to estimate the energy generation of a PV module.

4. Results and Discussion

Based on the above research methodology, the albedo value of sand and white pebbles was recorded for two weeks each as shown in figure 2. This figure demonstrates the ten seconds' albedo values of both the materials, obtained using Microsoft VBA code which was developed to generate a quality dataset. It can be easily seen from the figure that for all data points (throughout the day) the albedo value of white pebbled is higher than the sand. Please note that this figure does not take into account any factors that can impact the albedo value (such as cloud cover) of a foreground material.

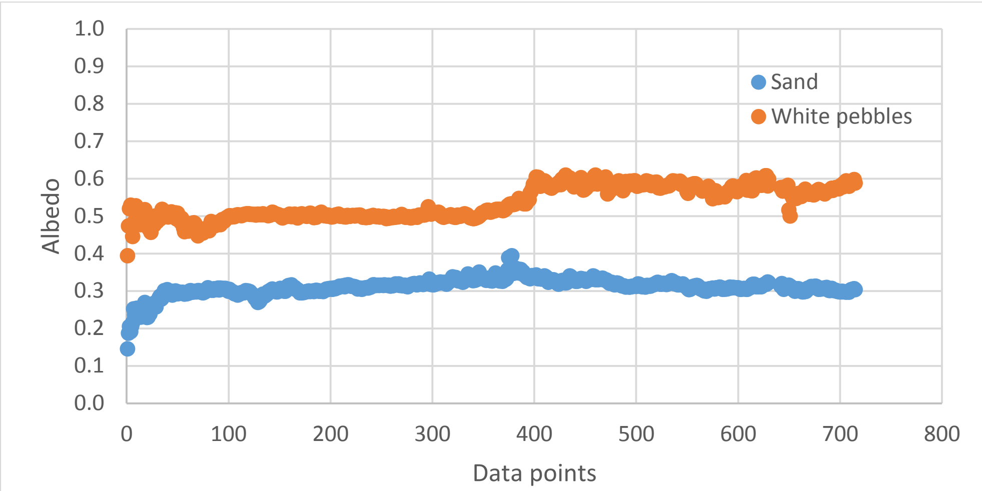

Figure 2: Albedo value from filtered raw data (per ten seconds) for sand and white pebbles

Further, an in-depth analysis was conducted on both the materials in terms of the impact of cloud cover (sky condition). Figures 3 and 4 show the average albedo value of sand and white pebbles against solar altitude under OV, POV and CL sky conditions. It can be noticed from both the figures (for both materials) that, as the cloud cover decreases, the albedo value increases. However, for sand (figure 3) at some solar altitudes, this trend was not noticed. For example, at 35° of solar altitude, the albedo value under the POV condition was higher than the CL as well as OV. The reason for this is due to the rapid movement of clouds within a short duration of time i.e. during specific solar altitude degrees. Overall, it can be said that the albedo value of sand and white pebbles under varying sky condition ranges from 0.3 to 0.4 and 0.5 to 0.6 respectively.

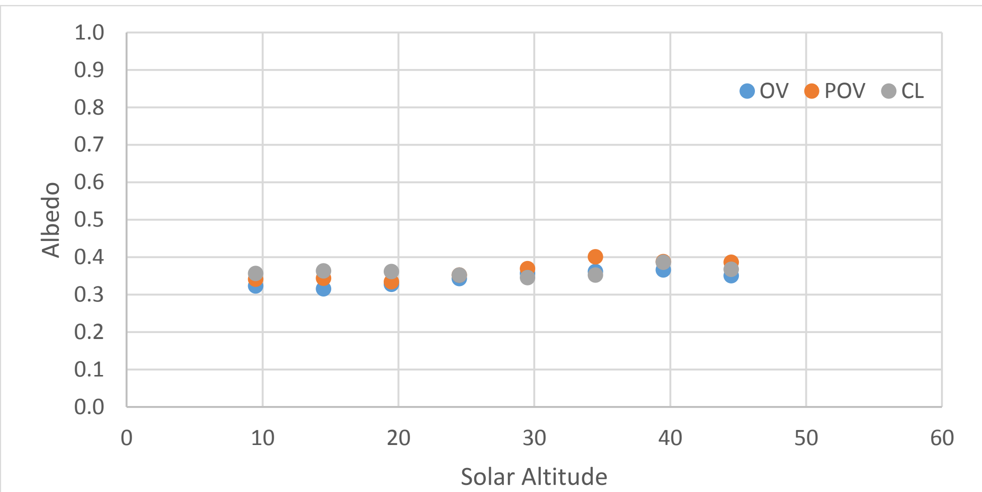

Figure 3: Sand albedo under varying sky conditions

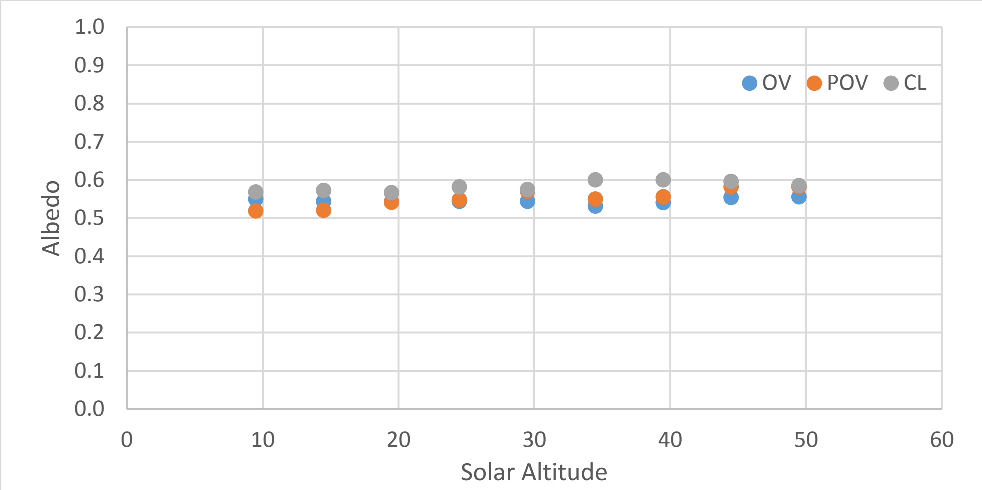

Figure 4: White pebbles albedo under varying sky condition

In addition to sky condition, energy generation analysis was also conducted on both the materials for two weeks. Based on the readings obtained, it was found that there was 8% energy difference between both the materials. However, during this period of two weeks, it was noticed that there were a few days with a higher proportion of OV and CL sky conditions. Therefore, from the total experimented days, a suitable day with OV and CL sky conditions was selected for each material. Table 1 shows the daily total energy generation and the percentage difference between both the materials under OV and CL sky conditions. There was negligible difference noted between energy generation under OV and POV sky condition days. Therefore, the POV condition is not included in table 1. From the table, under OV sky condition the percentage difference between both materials is 46.46%, while under CL sky condition it is 14.04% i.e. difference is less than in OV sky condition. The reason for a higher percentage difference under OV sky condition is due to a high proportion of diffuse irradiation in the total global irradiation falling on the pyranometer throughout the day. In addition, for white pebbles, comparing CL with OV sky condition, the difference between energy generation is less because white pebbles reflect diffusively and has no major significance on CL sky condition since it has a greater beam irradiation component.

Table 1: Energy generation analysis of Sand and White pebbles

Sky Conditions	**Materials**	**Energy Generation, kWh/m^2**	**% difference in energy generation between both materials**
OV	Sand	3.61	46.46
	White Pebbles	5.22	
CL	Sand	4.17	14.04
	White Pebbles	4.80	

5. Conclusion

From the above analysis of the two non-traditional solar PV foreground materials (sand and white pebbles), it can be concluded that both the materials have different characteristic behaviour under varying sky conditions (OV, POV and CL sky conditions). It was found that white pebbles have higher albedo value (in a range of 0.5 to 0.6), as compared to sand (from 0.3 and 0.4). Therefore, this resulted in a higher energy generation from white pebbles (5.22 kWh/m^2) as compared to sand (3.61 kWh/m^2) under OV sky condition. However, under CL sky condition there was a 14.04% difference noted i.e. this is less than CL sky condition, as both the materials reflect total incident radiation diffusively. From the overall analysis, it can be concluded that the energy generation under CL sky condition is relatively higher than OV sky condition.

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