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Evaluation of the Duration of Albedo Measurement Campaigns

How Much Value Does a Short-Term Albedo Measurement Really Add?

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Abstract. Bifacial PV modules are increasingly used in commercial solar PV projects. With the use of the solar energy available at the module's rear surface, the correct estimation of the albedo during the pre-construction phase of commercial projects becomes more important. The intention of the study is to determine the impact of the duration of a short-term albedo measurement campaign to reduce the uncertainty with respect to satellite albedo, thus providing a 'beneficial campaign'. Albedo measurements from seven sites in the USA have been used to estimate the impact of 1-day and 7-day measurements (short-term measurements) on the simulated annual electrical energy production. Simulations based on monthly albedo data obtained from a recognised satellite provider have been compared with simulations where the albedo has been corrected based on short-term measurements. The study found that a 1-day campaign is often not beneficial, causing an increase in uncertainty with respect to satellite albedo. Measurement campaigns in winter do not generally reduce the error of the annual electrical energy production simulation, however, a 7-day campaign undertaken in summer appears to often reduce the uncertainty. It should be noted that the climate conditions, ground vegetation and measurement setup of the analysed seven sites in the USA may not be representative for other sites in the rest of the world.

Keywords: Bifacial, Albedo, Measurement Campaign

1. Introduction

The following different procedures are possible ways to estimate the annual irradiation available on the rear side of solar modules:

1) Long-term on-site measurement of the module's rear-side solar irradiance.
2) Long-term on-site measurement of the albedo and use of an optical model to obtain the module rear-side solar irradiance.
3) Use of long-term satellite-derived albedo together with an optical model.
4) Adaptation of long-term satellite-derived albedo with short-term on-site measurement together with an optical model.

Based on the author's experience, the latter two procedures are mostly used in commercial projects with bifacial modules. Albedo stations are often installed in Europe for bifacial sites for a short period before construction or during site commissioning. In other countries, installation of albedo stations prior to development is also becoming more commonplace.

There is various literature dealing with best practice of albedo measurements and their impact on simulated energy [1], [2], [3], where the term 'energy' refers to electrical energy if not otherwise mentioned in the following. Short-term albedo measurement campaigns often comprise only one or several days. The offset between measured and corresponding satellite-derived albedo during this period is then applied to a long-term satellite-derived albedo dataset. While Payan et al. [4] asserts that such measurements are suitable to accurately determine monthly albedo data, Lara-Fanego et al. [5] reports that short-term measurements may introduce an increased uncertainty. This paper assesses the error in the simulated annual energy yield involved with such short-term measurement campaigns. The analysis is based on publicly available long-term albedo measurement data at seven sites accessible at Surface Radiation Budget Network (SURFRAD - https://gml.noaa.gov/grad/surfrad/).

2. Approach

In this study, albedo measurements from the following seven sites in the USA accessible at SURFRAD have been used. The stations are generally considered of good quality with the ground-reflected irradiation measured at 10m height. Albedo measurements in commercial projects are instead often undertaken at 1.5m to 2m height. The measured albedo is expected to be the same at the two heights, with the 10 m measurement integrating over a larger area. The table below shows that the annual GHI is generally high for these sites, with an exceptionally high value at Desert Rock, which is comparable to central and southern Europe. Five of the sites show considerable snowfall in winter. Only Desert Rock and Goodwin Creek show snow events comparable to central Europe. The climate conditions, ground vegetation and albedo measurement at a height of 10m may mean the results of this analysis cannot be applied to all sites in Europe.

Table 1. *Site overview*

Site	Coordinates	Terrain type	Long-term satellite derived annual GHI / kWh/m^2	Long-term satellite derived albedo
Bondville - 'Bv'	40.052N, 88.373W	Native grasses	1,504	0.247
Boulder - 'Bd'	40.125N, 105.237W	Sandy with exposed rocks spare grass	1,695	0.199
Desert Rock - 'D R'	36.624N, 116.019W	Fine rock and scattered creosote bush	2,088	0.211
Fort Peck - 'F P'	48.308N, 105.102W	Native grasses	1,446	0.247
Goodwin Creek - 'G C'	34.255N, 89.873W	Pasture grass and sparse deciduous trees	1,674	0.200
Penn State - 'P S'	40.720N, 77.931W	¾ grass and ¼ crops	1,390	0.252
Sioux Falls - 'S F'	43.734N, 96.623W	Native grasses	1,479	0.238

Measurement data for horizontal GHI and ground-reflected irradiation in 1-min resolution for the full year 2020 was downloaded. The daily albedo was then calculated by dividing the sum of the daily ground-reflected irradiation by the sum of the daily GHI and applying the following criteria:

1) GHI irradiance >= 50 W/m2
2) Daily albedo < 0.5
3) Data availability > 5h/d

Considering that a PV plant starts operation at GHI values of around 50 W/m2, lower irradiance values have been excluded.

During winter months, a large scattering in the daily albedo data has been observed which is likely due to snowfall. Most of the time, however, scattering was low, and albedo values were in the range of 0.2 to 0.25. The study assumes that any albedo assessments where the soil or the modules are covered by snow do not provide representative values and that it is unlikely the measurement campaigns would be undertaken under such conditions. Therefore, days with an albedo equal or greater than 0.5 have been excluded from the analysis.

Even though data availability has generally been observed to be high, days with a data availability of less than 5 hours have been excluded. Since the albedo depends on the zenith angle, missing data (e. g., during the morning period) will cause a bias in the daily albedo.

Everoze has observed that monthly long-term albedo assessments are often corrected based on a one-day measurement. For example, if this measurement is 10% higher than the value of the corresponding month, values for all 12 months are increased by 10%. Therefore, the objective in this work was to compare the simulated annual energy of a bifacial single-axis horizontal tracking system, undertaken with a state-of-the-art simulation tool (PVsyst), for the following cases:

1) Measured albedo (six years, ‘reference albedo’).
2) Monthly albedo data obtained from a satellite provider ‘satellite albedo’).
3) Monthly albedo data corrected by 1-day measurements (‘corrected albedo’).
4) Monthly albedo data corrected by 7-day measurements (‘corrected albedo’).

Measurement periods of 1 and 7 days have been chosen for analysis as measurements are often undertaken in commercial projects during only one day. For the 7-day period, day one to seven were taken as the first period, then days two to eight as the second period, and so on for the whole year (see Figure 1 below). In this way, a January dataset allows for 25 measurement campaigns if no days were excluded. For each campaign sample period, the deviation to the monthly satellite albedo has been calculated.

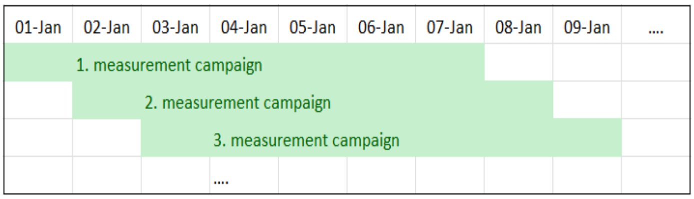

Figure 1. *7-day measurement campaigns*

3. Results and discussion

Figures 2 and 3 show the monthly distribution of albedo for Bondville and Sioux Falls. The grey lines indicate the albedo measured during the individual six years, whereas the red line represents the averaged albedo over the period, the reference albedo. The black line indicates the satellite albedo. The graph shows that the presence of snow leads to a high scattering of the albedo during winter months. For six of the seven sites, the satellite albedo was lower than the reference albedo. For Bondville, the difference between measured and satellite albedo was the most constant over the months and years (see for example the period from March to June). For Sioux Falls, the satellite albedo fitted best with the reference albedo.

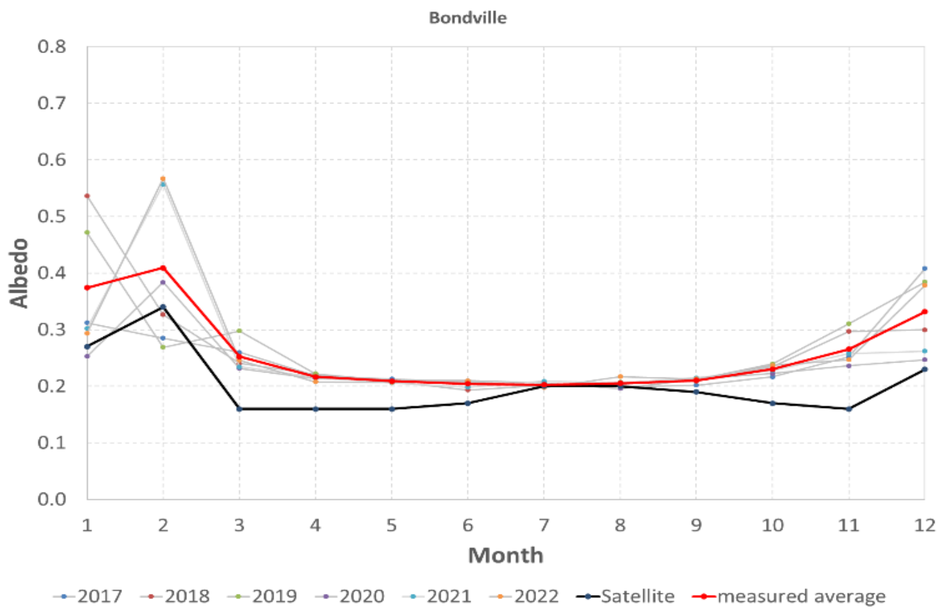

Figure 2. *Monthly albedo rates, Bondville*

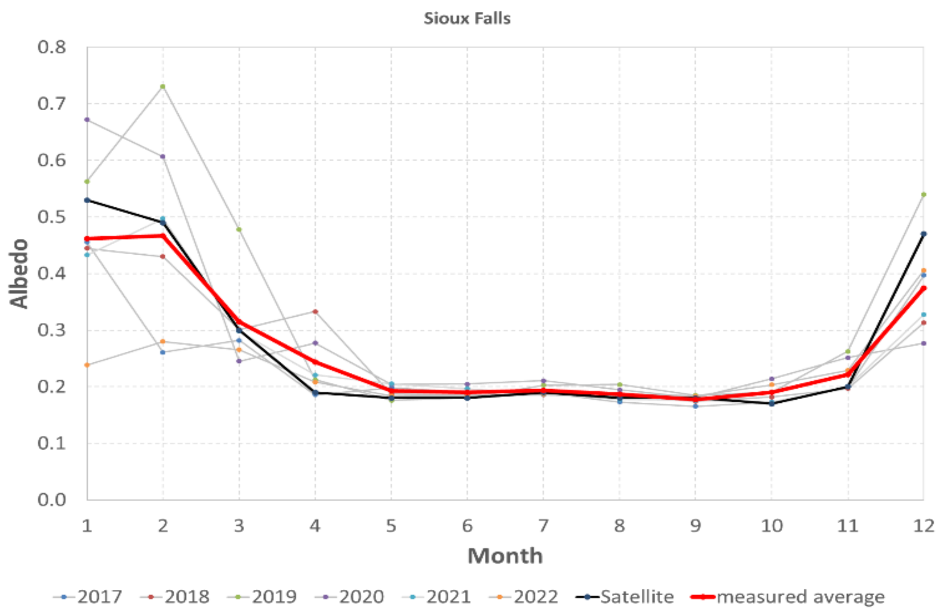

Figure 3. *Monthly albedo rates, Sioux Falls*

The satellite albedo has subsequently been corrected based on the measurement campaigns. The correction factors for Bondville for June for a 1-day measurement campaign are shown in Figure 4. A total number of 178 days from the six years were available after applying the exclusion criteria. A further two days were rejected due to a data availability of less than 5 hours. For this site, the correction factor is always > 1, indicating that the satellite albedo for June is always lower than the values obtained from the measurement campaign. Therefore, the satellite albedo is always corrected upwards. To quantify the uncertainty related to the measurement campaigns, the P10, P50 and P90 correction factors (red, blue and green points respectively) have been used to correct the satellite albedo. “P” stands for “percentile” and the value attributed to P10 is exceeded by 10% of the observations meanwhile the value attributed to P90 is exceeded by 90% of the observations. Therefore, to determine the P50 corrected albedo of this site, each of the twelve monthly values of the satellite albedo have been multiplied with 1.21. In this way, three corrected albedo datasets have been obtained for the annual energy simulation, only based on the measurements undertaken in June.

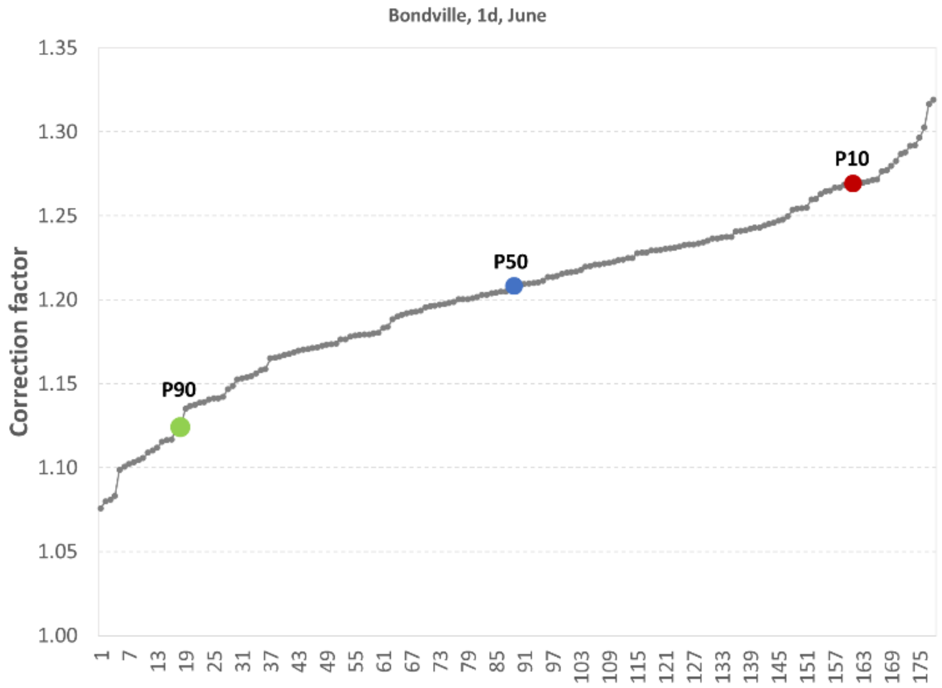

Figure 4. *Correction factor in June for a 1-day campaign in Bondville*

The following energy simulations have been undertaken for a bifacial horizontal single-axis tracking system. From these, it has been observed that a relative 10% change in the albedo assessment leads to a 0.2% change in the annual energy assessment. The annual energies corresponding to use of the reference albedo, satellite albedo and corrected albedo are called reference energy, satellite energy and corrected energy, respectively, as seen in the following figures. The reference energy has been on average 0.4% higher than the satellite energy.

The impact of the albedo on the energy simulation is presented for Bondville in Figure 5 for 1-day and Figure 6 for 7-day measurement campaigns. The x-axis represents the months and the y-axis the error with respect to the reference energy. The satellite energy is 0.6% below the reference energy for this site, as indicated by black horizontal line. The red, blue and green lines represent the error of the corrected energies P10, P50 and P90, respectively. When the corrected energy is within the ±0.6% window, as indicated by the straight and dashed lines, the correction improved the results with respect to the satellite albedo, indicating a beneficial measurement. One can see this improvement for measurements campaigns undertaken from April to June at this site, while all measurement campaigns undertaken in February would lead to a worse result. Increasing the measurement period to 7 days brings the three lines closer together as the impact of individual outlier days is reduced. If the P10, P50 and P90 lines are within the two horizontal lines, we consider this a beneficial campaign, meaning that the likelihood of an increased error due to the campaign is theoretically less than 20%, but often much lower as seen for measurements from April to June at this site. For Bondville, 7-day campaigns in April to June and August to October are beneficial. In May, a 7-day campaign reduces the 0.6% error of the satellite albedo with an 80% likelihood to less than 0.15%. It should be noted that, in July and August, the campaigns barely reduce the error for this site. As can be seen from Figure 2, the satellite albedo for Bondville for the months of June and August is already close to the reference albedo, so the campaigns tend to increase the uncertainty. On the other hand, from April to June, the satellite albedo is considerably below the reference albedo and even a 1-day measurement reduces the error.

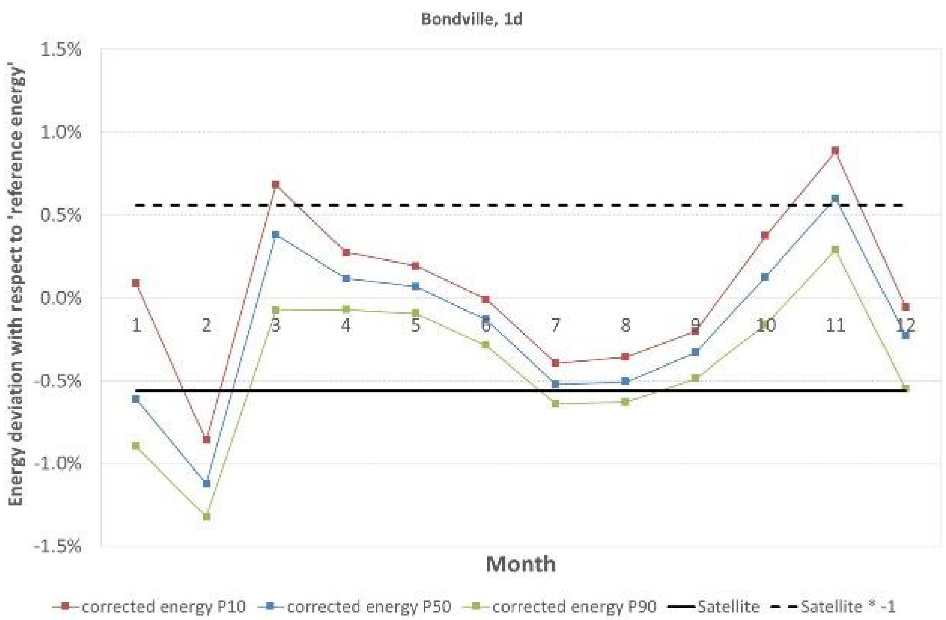

Figure 5. *Error with respect to reference energy, Bondville 1-day*

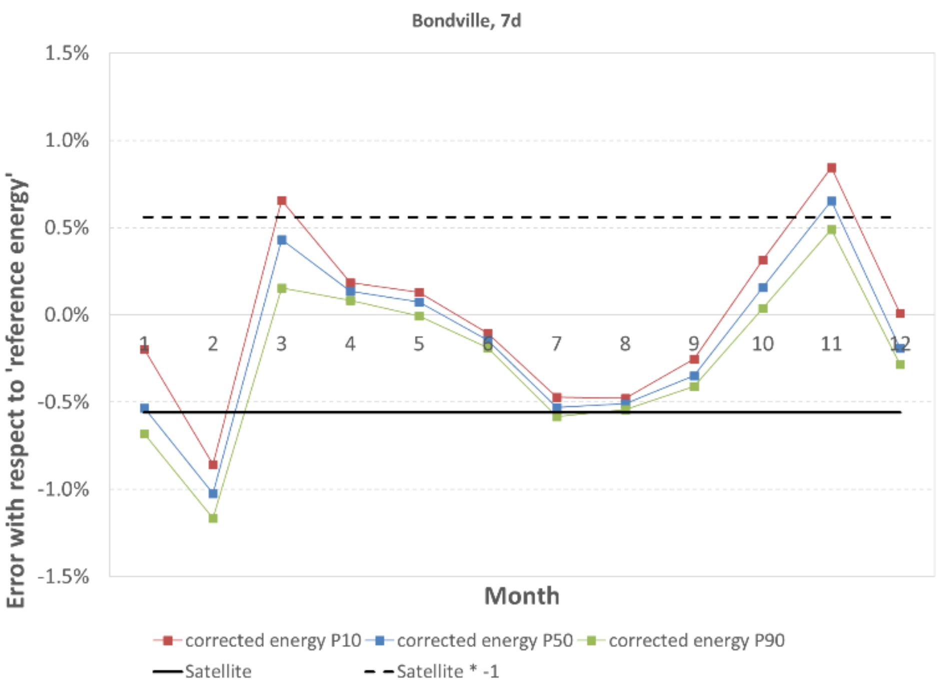

Figure 6. *Error with respect to reference energy, Bondville 7-day*

Whether a campaign is beneficial or not is presented in Figure 7 for a 1-day and Figure 8 for 7-day campaign for all 7 sites. The color code is as follows:

	beneficial campaign, low snow month
	no beneficial campaign, low snow month
	befeficial campaign, high snow month
	no beneficial campaign, high snow month

For Sioux Falls, a short-term campaign was found not to be beneficial for either a 1- or 7-day period. The reason is that the satellite energy was already so close to the reference energy that any correction caused an increased error. In general, campaigns undertaken in winter are not beneficial. A 1-day campaign undertaken in summer appears to be beneficial for some of the sites, but there is still a considerable risk that it is not beneficial. If the campaign is extended to 7 days, it is often beneficial.

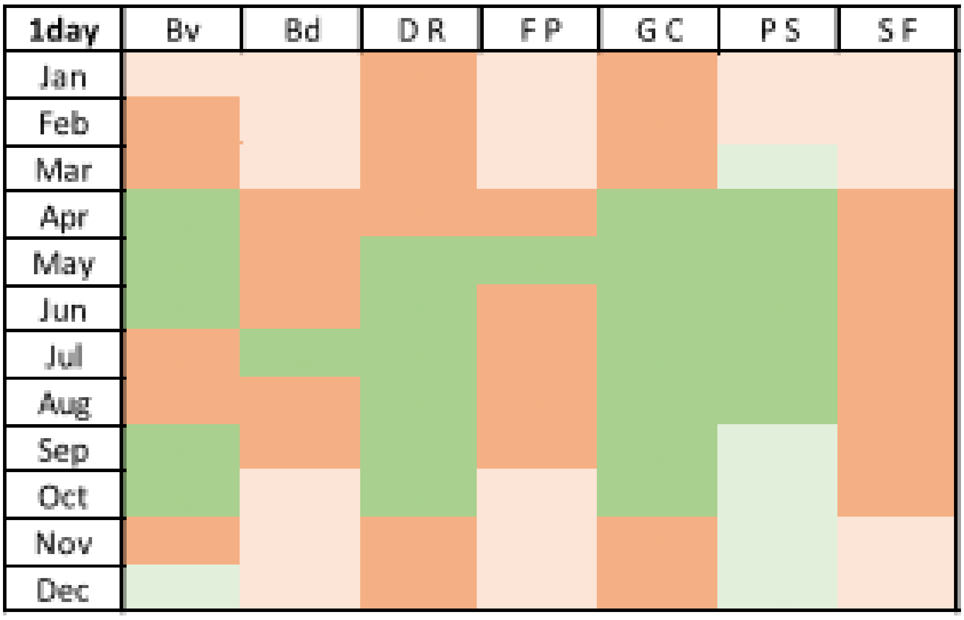

Figure 7. *Benefit of measurement campaigns, Bondville 1-day*

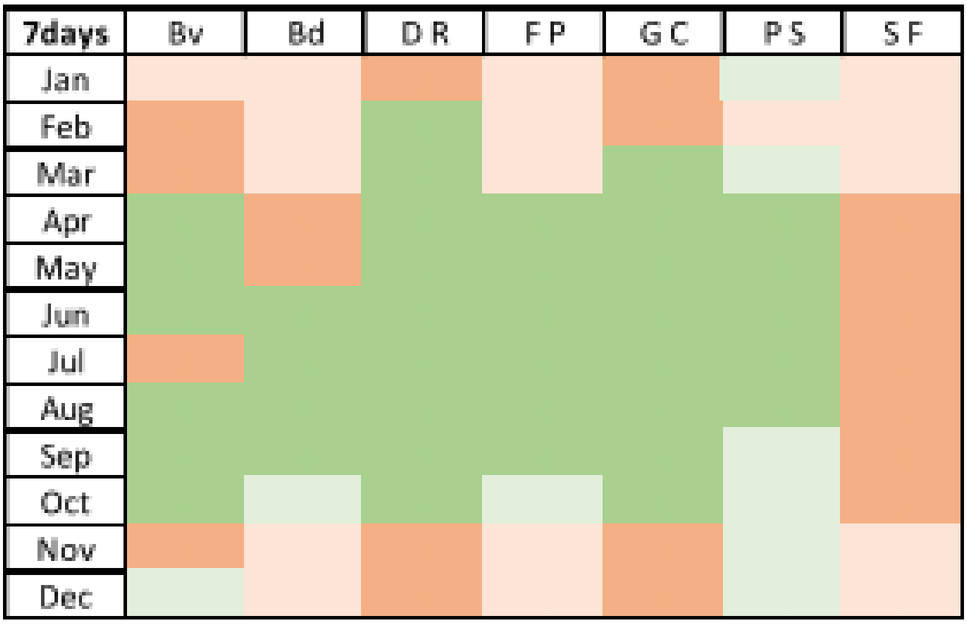

Figure 8. *Benefit of measurement campaigns, Bondville 7-day*

4. Conclusion

Based on the measured albedo values from seven sites in the USA accessible at SURFRAD, the impact of correcting pure satellite albedo data with results from a 1-day and 7-day measurement campaign has been investigated. It has been found that:

- Measurement campaigns in winter are generally not beneficial for more accurate energy yield predictions.
- A 1-day campaign is often not beneficial, causing an increase in uncertainty with respect to satellite albedo.

- A 7-day campaign undertaken in summer is often beneficial.

Everoze, therefore, recommends avoiding 1-day measurements. It should be noted that the climate conditions, ground vegetation, and measurement setup of the SURFRAD sites located in the USA may not be representative for other sites in the rest of the world. Everoze recommends careful adherence to best practice when undertaking albedo measurement campaigns.

Data availability statement

The data supporting the results of our article can be accessed via ftp://aftp.cmdl.noaa.gov/data/radiation/surfrad/.

Author contributions

Stefan Mau: writing – original draft, supervision

Adam Sharpe: validation

Christian Gertig: validation

Christophe Campistron: writing – review and editing

Julia Garcia: visualization

Nicolas Chouleur: project administration

Competing interests

The authors declare that they have no competing interests

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