The Case for Custom TMYs: Examples Using the NSRDB

Preprint

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National Renewable Energy Laboratory

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The Case for Custom TMY's: Examples Using the NSRDB

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***Abstract* — A typical meteorological year (TMY) data set essentially represents an hourly compilation of median months constructed using multi-year datasets. Although TMY data sets are generated from irradiance data in the horizontal plane, they are used in photovoltaic (PV) modeling for systems inclined to various angles. This paper demonstrates that a POA TMY (plane of array TMY) generated by selecting median months from a multi-year POA irradiance timeseries dataset produces significantly different results than a POA TMY generated by transposing a TMY dataset constructed from horizontal data. In some months the differences can be more than 3%. These results point to the need for generating TMY's using POA irradiance timeseries representing the orientation at which PV panels will be deployed.**

I. Introduction

Typical meteorological year (TMY) datasets are constructed using multi-year hourly timeseries global horizontal Irradiance (GHI), direct normal irradiance (DNI), temperature, dew point and wind speed data [1]. TMY's were primarily developed for building simulations and the meteorological variables are weighted to represent their influence on energy use in buildings. Multi-year monthly weighted data are used to identify the most representative month. The most representative months are then concatenated to construct a single-year TMY [1]. For modeling solar generation from different technologies, various special cases of TMY can be constructed; for example, a typical GHI year (TGY) or a typical DNI year (TDY) can be constructed using only GHI or DNI respectively by weighting the other variables to 0. TMYs or TGYs are widely used in the System Advisor Model (SAM) [2], PVWatts [3], PVSyst[4] and PlantPredict[5] to simulate generation from photovoltaic (PV) plants. PV arrays are generally deployed at some plane of array (POA) angle that optimizes the energy generation from that deployment. Therefore, such energy simulations require conversion of the GHI and DNI which is traditionally available from databases such as the National Solar Radiation Database (NSRDB) [6] to the appropriate POA using transposition models [7-8]. Although TMY or TGY data sets represents median months for solar radiation in the horizontal plane, that assumption no longer hold true when they are used in a non-horizontal POA; this is mainly because of inhomogeneities in the timing of cloudy and clear periods during a day. This paper seeks to demonstrate the differences between a POA TMY constructed using a POA irradiance time-series and a POA TMY constructed by transposing a TMY dataset. Section II contains a short description of the methodology, Section III contains the results and Section IV concludes.

II. Methodology

The NSRDB provides satellite-based, half-hourly data for multiple years covering the period from 1998-2017. These data are available at a 4km by 4km resolution covering longitudes 25° W to 175° W and latitudes -20° S to 60° N. We use the Perez transposition model on long-term NSRDB time-series data for six locations to generate POA irradiance data for fixed latitude tilt and single-axis tracking (east-to-west tracking) orientations because they are widely used in PV deployments. We then use hourly data from the POA irradiance timeseries to generate a typical POA year (TPY) by setting the weight for all variables except POA to 0. For comparison, we also use the Perez transposition model to generate a POA irradiance TGY for the same pixel. For this paper we call this the typical GHI-based POA year (TGPY). The TPYs generated from fixed latitude tilt and single-axis tracking orientations are then compared to the corresponding TGPYs.

Fig. 1. Selected locations for the study (green circles). Colored polygons are climatic regions [9].

III. RESULTS

Six locations were selected that lie in regions of interest for PV development in the US and represent different latitudes and climatology (Fig. 1). Desert Rock, Nevada, represents the southwest desert region of the United States, Penn State represents the northeast United States; Fort Peck, Montana, represents the north-central region of United States and the Texas location represents the south. The two Colorado locations represent the south-west climate. For each site, the

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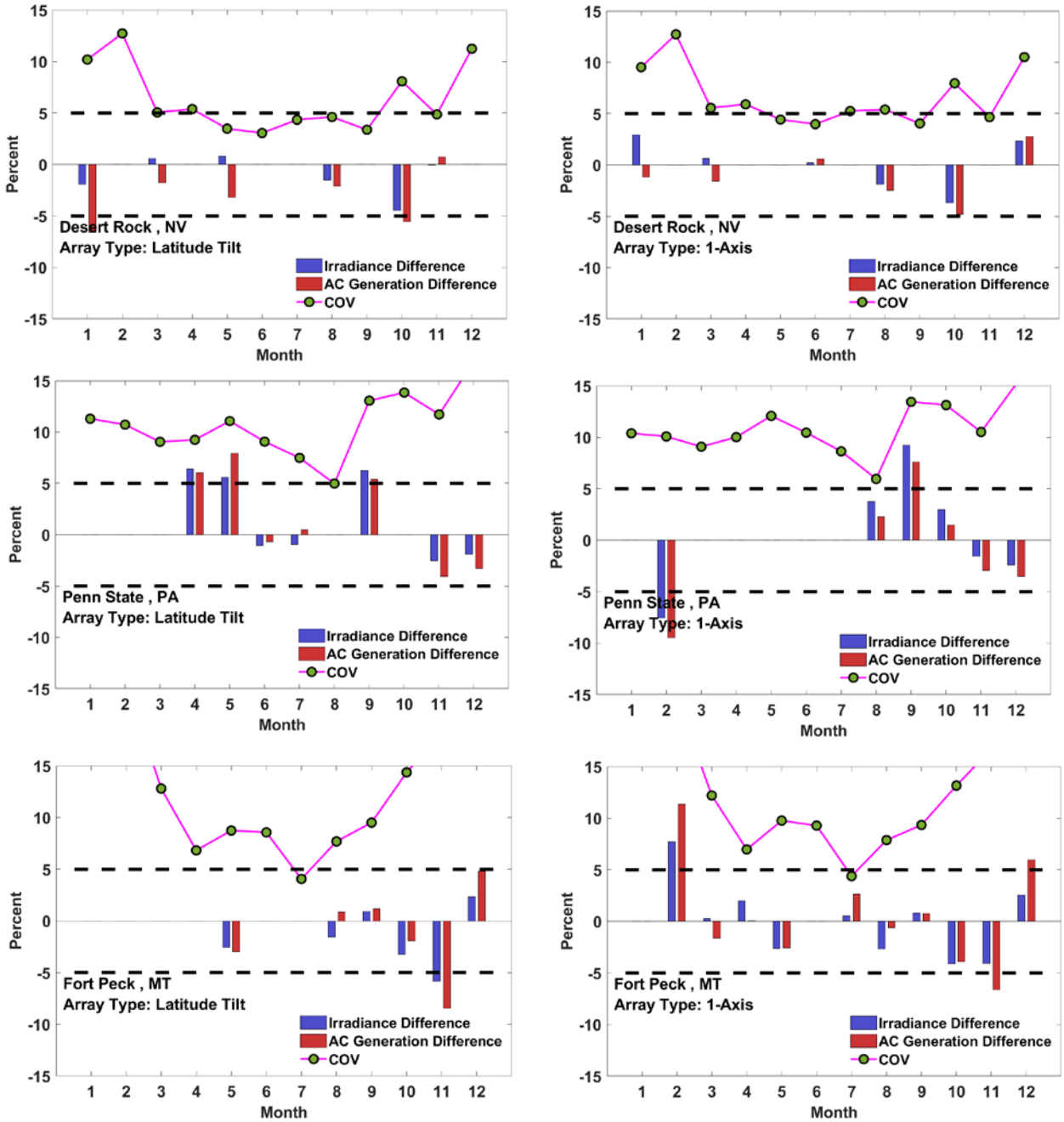
TPY was calculated for two orientations: fixed latitude tilt and single-axis (1-axis east-west) tracking. The TMY for each site was likewise transposed to fixed latitude tilt and single-axis tracking orientations to create the TGPY.



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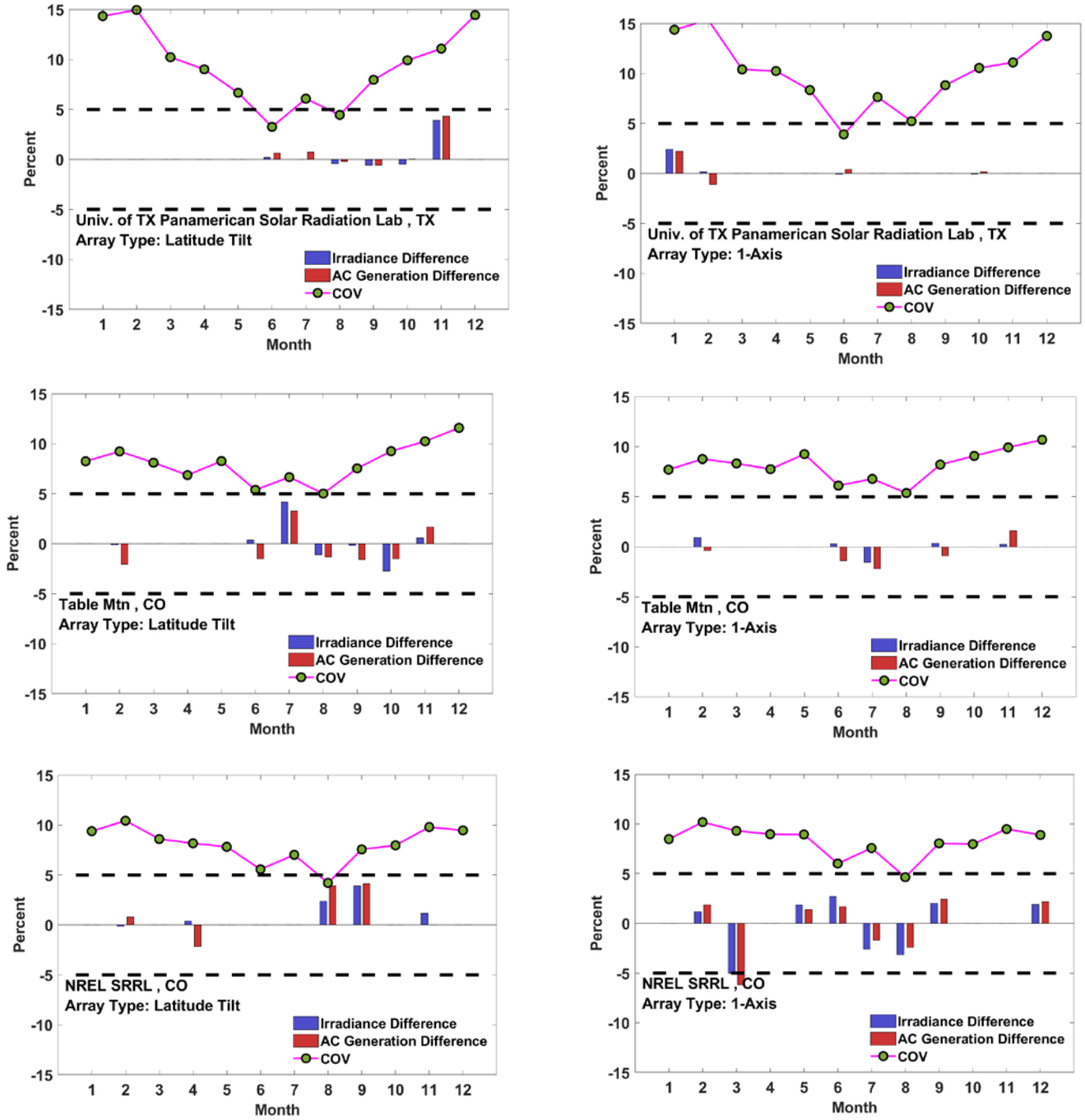

Fig. 2. Comparison of TPY to TGPY for six locations and two possible orientations on a monthly basis. The percentage differences are shown.

For each the TPY and the TGPY, the irradiance is averaged on a monthly basis. A percent difference of the TPY compared to the TGPY for each month is calculated at each location using (TPY – TGPY) / TGPY x 100. These monthly percent differences between the TPY and TGPY are shown in Fig. 2 for each site and orientation.

It is clearly observed that the differences between the TPY and TGPY vary widely in different months. Because the Perez algorithm was used on a serially complete month to create both the TPY and the TGPY, any month where the difference is zero means that the same month from the long-term dataset was selected for both the TPY and the TGPY. However, non-zero differences between the TPY and TGPY signify that the two methodologies actually selected *different* months as "most

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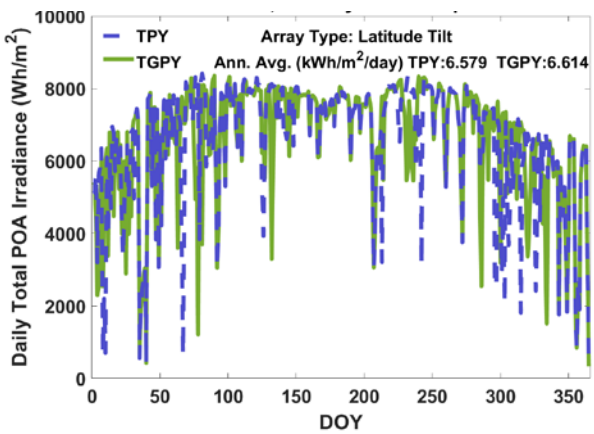
representative" from the long-term dataset. This has enormous implications for annual energy predictions of PV systems that rely on a typical year. Out of all 12 scenarios, different months were chosen for no less than 4 months in the year, with the maximum case showing different months chosen for 10 months out of the year. On average, 6 months were different between the TPY and TGPY for each site. Where different months were selected, the differences in average monthly irradiance range from -8% to +9%. For the fixed tilt systems, the monthly irradiance differences are up to_6%, and for the single-axis tracking systems, the monthly irradiance differences are up to 9%.

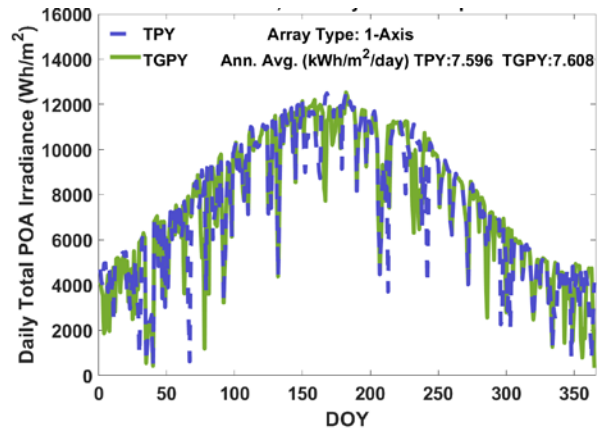
For locations where the clouds are not very variable, such as Desert Rock with very few clouds and Texas with consistent cloudiness, the differences between the TPY and TGPY are small for most of the year. However, locations that experience much more variable cloudiness, such as Penn State and Fort Peck, there are significant differences between the TPY and TGPY for most of the year for both fixed latitude-tilt and single-axis tracking orientations.

Furthermore, a monthly coefficient of variation (COV) was calculated as a percentage using a ratio of the standard deviation to the mean of each month. This measures the dispersion of values in a data series around the mean. From Fig. 2, shows increased variability in some months in relation to the mean which demonstrates a limitation of the TPY or TPGY for those months to represent the long-term variations. Desert Rock and the two Colorado locations demonstrate less COV% for most months compared to the other locations. These is because these locations have few variable-sky conditions for which the TPY and TGPY represent the long-term variations adequately.

To further demonstrate the differences between the TPY and the TGPY at a more granular time scale, Fig. 3 demonstrates the differences in the daily sum of irradiance between the TPY and the TGPY for the Nevada (mostly clear site) and Texas locations.

The study also analyzed the effect of these monthly irradiance differences on energy yield predictions using PVWatts [10]. The DC-to-AC ratio was assumed to be 1 for both array types in order to reduce clipping effects. The energy effects of the differences between the TPY and the TGPY were a similar magnitude to the irradiance differences, with the difference in average energy between the two ranging from -9% to 11% where different months were selected. The energy effects are not exactly the same as the irradiance effects because the calculations to go from irradiance to power are (1) not completely linear— specifically in the inverter model at low light levels— and (2) do not rely on irradiance alone, but also temperature. If a selected month had higher irradiance but also higher temperatures than another month, the gain in energy would not be as large of a percentage as if the system generation depended on irradiance alone. Conversely, if a month were selected with higher irradiance and lower temperatures, then the gain in energy generation could be greater than just the irradiance gain.





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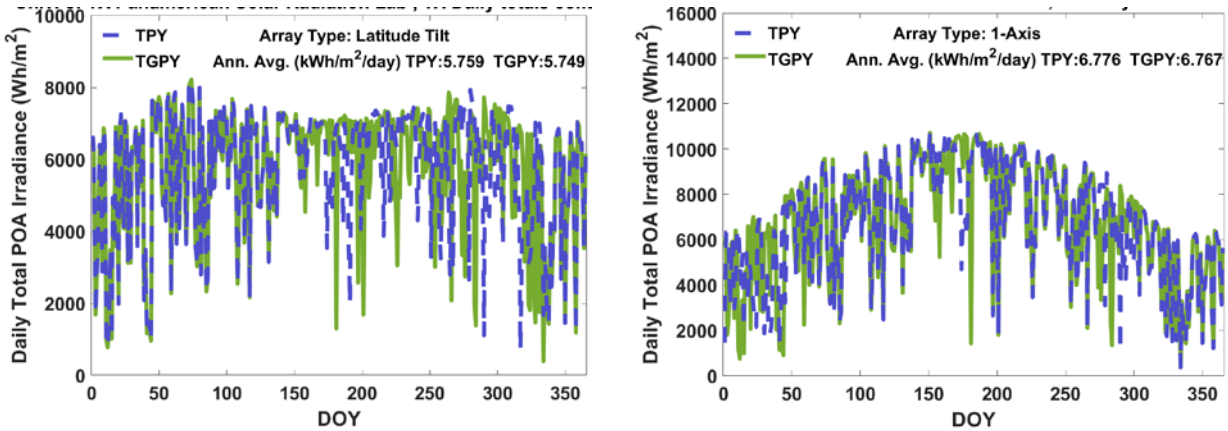

Fig. 3. Daily total irradiance for Desert Rock (top) and UTPA, Texas (bottom).

TABLE I
ANNUAL INSOLATION AVERAGES OF THE SCENARIOS

Location	Short Name	Latitude	Longitude	Annual Average (kWh/m2/day)			
				TGPY		TPY	
				Latitude tilt	1-axis	Latitude tilt	1-axis
Desert Rock, Nevada	DRA	36.62	-116.02	6.614	7.608	6.579	7.596
Penn State, PA	PSU	40.72	-77.93	4.513	5.010	4.568	5.055
Fort Peck, MT	FPK	48.31	-105.10	4.688	5.074	4.648	5.057
University of Texas Pan-American, TX	UTPA	26.49	-98.17	5.749	6.767	5.759	6.767
Table Mountain Boulder, CO	TBL	40.13	-105.24	5.379	5.841	5.383	5.838
NREL SRRL, CO	SRRL	39.74	-105.18	5.497	6.006	5.534	5.992

Table 1 shows the differences in annual values when the TPY and TGPY are compared for the six locations and for the two different orientations. For both the fixed latitude tilt and single-axis systems some of the monthly errors are cancelled out, thereby showing better agreement on an annual basis. However, as PV penetration increases, a larger number of systems are compensated at time-varying rates, making intra-year effects increasingly important.

IV. CONCLUSIONS

This study demonstrated the difference in the estimation of solar irradiance in the POA when a POA-based timeseries is used to compute a TMY (represented by TPY) compared to a TGY being directly transposed (represented by TGPY). Monthly differences in average irradiance can range up to -8% to +9%. in some cases because the two methodologies select different months from the historical timeseries as being most representative, which implies significant errors in potential energy yield prediction at a site. The Penn State and Fort Peck sites clearly demonstrate large differences in monthly irradiance and energy yield prediction if the TGPY is used instead of the TPY. Currently the TGPY is widely used by the industry to estimate annual production, but this study showed that this will lead to significant errors. Although this study is preliminary, it indicates that there might be a need to build "custom" TMYs for each individual case to account for the impact of orientation.

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REFERENCES

[1] S. Wilcox and B.Marion, "Users Manual for TMY3 Data Sets," *NREL Technical Report*, NREL/TP-581-43156, https://www.nrel.gov/docs/fy08osti/43156.pdf , 2008.

[2] Blair, N.; Dobos, A.; Freeman, J.; Neises, T.; Wagner, M.; Ferguson, T.; Gilman, P.; Janzou, S., "System Advisor Model, SAM 2014.1.14: General Description," *NREL Technical Report,* NREL/TP-6A20-61019, http://www.nrel.gov/docs/fy14osti/61019.pdf.https://sam.nrel.gov/content/downloads, 2014.

[3] Dobos, A. P., "PVWatts Version 5 Manual," NREL Technical Report, NREL/TP-6A20-62641, DOI: 10.2172/1158421 https://www.nrel.gov/docs/fy14osti/62641.pdf, 2014.

[4] PVSyst. https://www.pvsyst.com/

[5] PlantPredict. https://plantpredict.com/

[6] M. Sengupta, Y. Xie, A. Lopez, A. Habte, G. Maclaurin, and J. Shelby, "The National Solar Radiation Data Base (NSRDB)," *Renew. Sustain. Energy Rev.,* vol. 89, pp. 51-60, 2018.

[7] R. Perez, P. Ineichen, R. Seals, and J. Michalsky,"Modeling daylight availability and irradiance components from direct and global irradiance," Sol. Energy, vol. 44, pp. 271-289, 1990.

[8] J. Hay and J. Davies, "Calculations of the solar radiation incident on an inclined surface," in Proc. of First Canadian Solar Radiation Data Workshop, 59. Ministry of Supply and Services, Canada.

[9] Habte, A., Sengupta, M., Lopez, A., 2017. Evaluation of the National Solar Radiation Database (NSRDB): 1998–2015. Technical Report NREL/TP-5D00-67722. National Renewable Energy Laboratory. https://www.nrel.gov/docs/fy17osti/67722.pdf.

[10] National Renewable Energy Laboratory, System Advisor Model, http://www.nrel.gov/analysis/sam

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