A Modeling Framework for Technology-specific Shading Impacts on Annual Energy Yield

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Introduction

This study introduces an annual energy modeling framework and methodology to study the performance of PV arrays under shading and mismatch conditions. Many shade studies (either modeling or in the field) focus on specific shade scenarios, but usually stop short of incorporating data on the occurrence of different shade cases to properly generalize the results. The goal of this study is to use observed shade scenarios in different market segments to estimate realistic distributions of annual energy impact for various module technologies and designs. This poster presents preliminary results from the first phase of work covering residential systems.

Analysis Setup

Table 1: Module technologies and system configurations used in this study. Each module/system is modeled in both AC & DC configurations.

Module Types	Module Description	Number of modules	System Tilt (deg)	System Azimuth (deg)	System Orientation	Location (TMY)
IBC	IBC 66 cell, Series	6	15	90	Portrait	Fort Myers, FL
Conventional Series 3-diode	72 G1 cells, Series, 3 diodes, Mono PERC	10	20	180	Landscape	Newark, NJ
HJT	Half-Cut M12 cells, Series, 4 diodes, HJT	16	30	270		Sacramento, CA
Shingled	Shingled PERC, 5 parallel substrings, 3 diodes					Phoenix, AZ
Half-cut	Half-Cut M6 cells, 2 parallel substrings, 3 diodes, Mono PERC	Total number of configurations simulated = 24				
Total = 10 (5 x AC & DC)						

Table 2: Shade scenarios considered, and the modeling method used.

Shade Type	Modeling Method
Chimney	Simplified Ray Tracing
Vent Pipe	Simplified Ray Tracing
Pole	Simplified Ray Tracing
Tree	Simplified Ray Tracing
Wall	Simplified Ray Tracing
Wire	Simplified Ray Tracing
Leaves & Bird Droppings	Static
Bottom Edge Soiling	Static

Acknowledgments

The authors would like to thank Chris Deline from NREL for sharing previous shade survey data[2].

Methodology: Shade Scenario Distributions

A close object shade survey of 112 Residential Systems was performed using Google Earth & Street View. The shade object positions were clustered, and the percentage of irradiance loss was estimated using Ray Tracing for multiple system configurations. Distributions for sun position-independent scenarios like bottom edge soiling were generated using static models. Realistic shade distributions were obtained by combining the estimated distributions with previous surveys, notably an NREL survey of 66 residential systems[2].

Figure 1: Individual and clustered shade object positions around a normalized system (Top), and the respective annual irradiance loss distributions (Bottom).

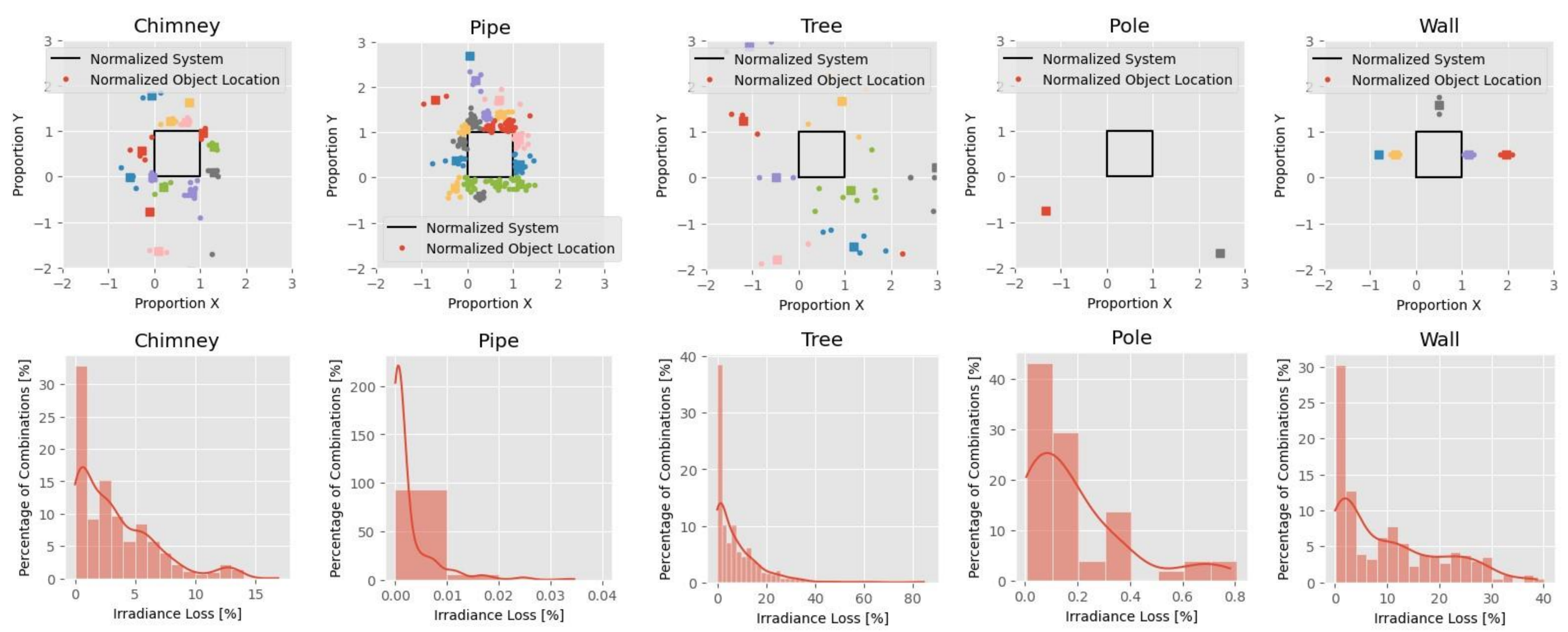
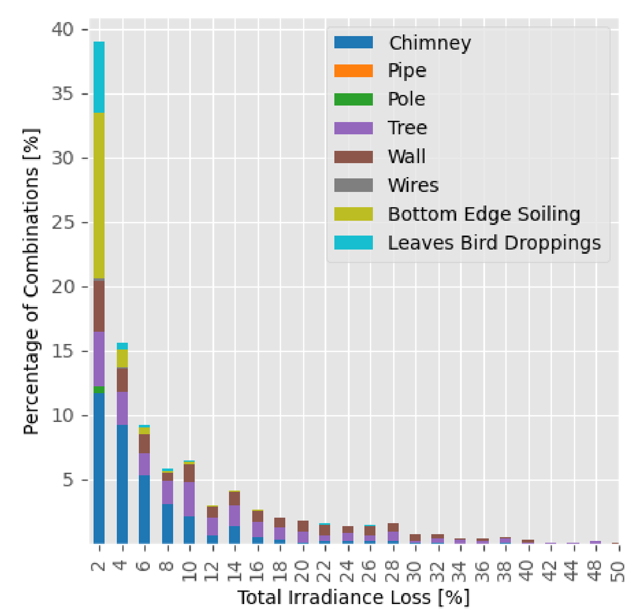


Figure 2: Shade object irradiance loss distributions.



Methodology: Modeling Framework

The modeling framework includes geometric models of the PV array and the shade scenario. An electrical model (PVMismatch[4]) is used to calculate the instantaneous maximum power output of the PV system. The framework is built to provide useful predictions of annual energy impact across PV market segments.

Figure 3: Architecture of Annual Energy modeling framework proposed in this study.

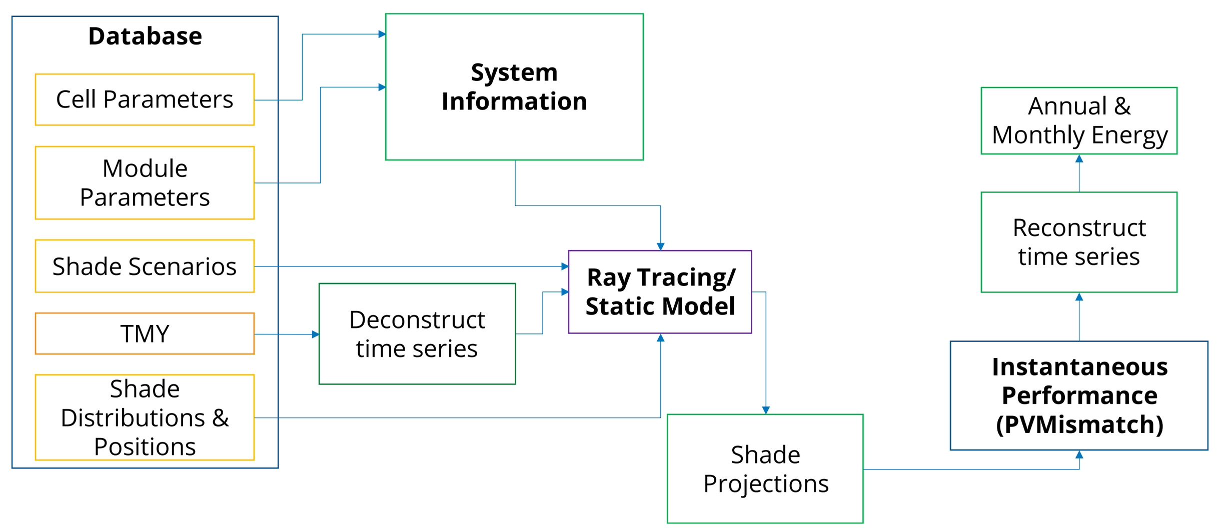
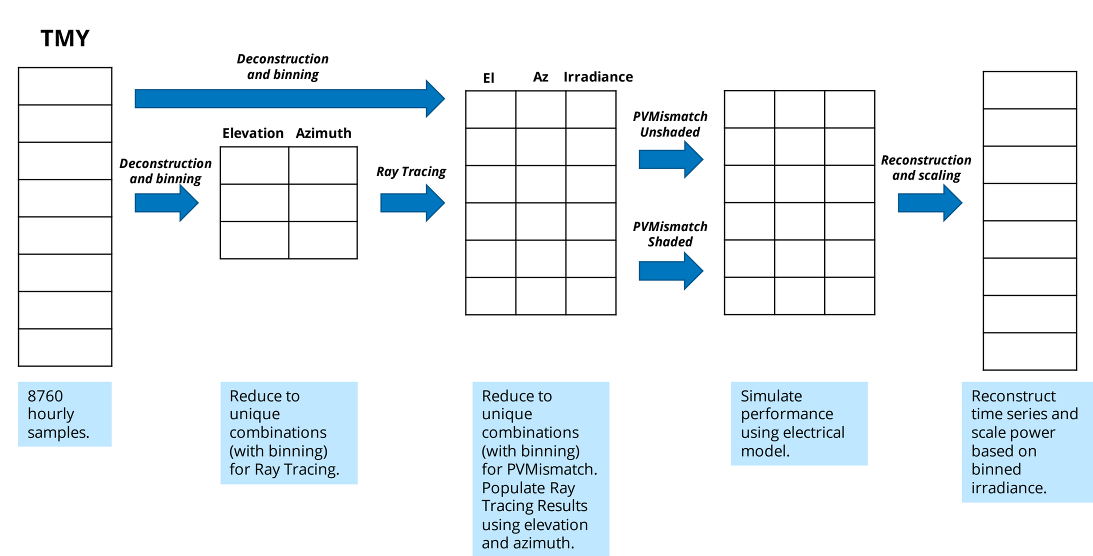


Figure 4: Flow chart describing the process used to reduce the computational complexity of the simulation.



References

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[3] C. Chaudhari, T. Lance, G. M. Kimball and B. Bourne, "PVOPEL: A Scalable Opto-Electrical Performance Model of PV systems using Ray Tracing and PVMismatch," 2019 IEEE 46th Photovoltaic Specialists Conference (PVSC), Chicago, IL, USA, 2019, pp. 1232-1236, doi: 10.1109/PVSC40753.2019.8981230.
[4] B. Meyers and M. Mikofski, "Accurate Modeling of Partially Shaded PV Arrays," 2017 IEEE 44th Photovoltaic Specialist Conference (PVSC), Washington, DC, USA, 2017, pp. 3354-3359, doi: 10.1109/PVSC.2017.8521559.

Validation

1. Validation of Instantaneous Performance Framework & PVMismatch with measured data

Two versions of IBC modules (with different forward and reverse IV characteristics) were tested. The shade scenarios tested include Short & Long edge shading, and Vent Pipe shading. The modeled energy losses include uncertainty due to test assembly tolerances. The measured and modeled energy losses are similar.

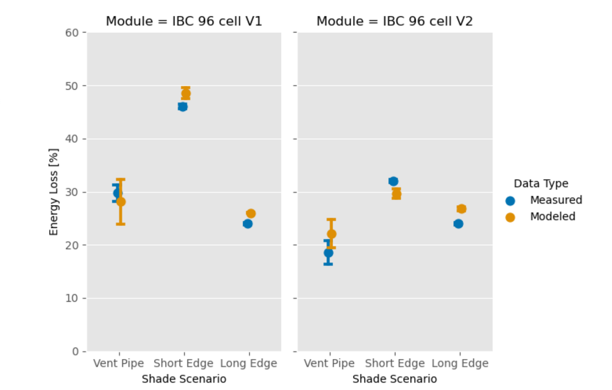


Figure 5: Comparison of the energy loss from the instantaneous framework model with field data.

Figure 5: Pictures showing the shading test setup at the Maxeon test facility in Davis, CA.

2. Validation of Annual Energy modeling framework utilizing the Instantaneous Performance Framework

A string of 10 modules in landscape orientation was modeled. Both DC & AC versions were simulated in both modeling frameworks. The results were found to be nearly identical for both models.

Table 4: Comparison of the energy losses from the instantaneous and annual energy models.

Module Technology	Shading Type	Instantaneous Energy Modeled Loss [%]	Annual Energy Modeled Loss [%]
IBC 66 cell V1 DC	Chimney	10.4	10.4
IBC 66 cell V1 AC	Chimney	6.8	6.8-6.9

Preliminary Results

Figure 6: Annual Energy loss results for variably shaded systems for AC/DC variants of all module technologies.

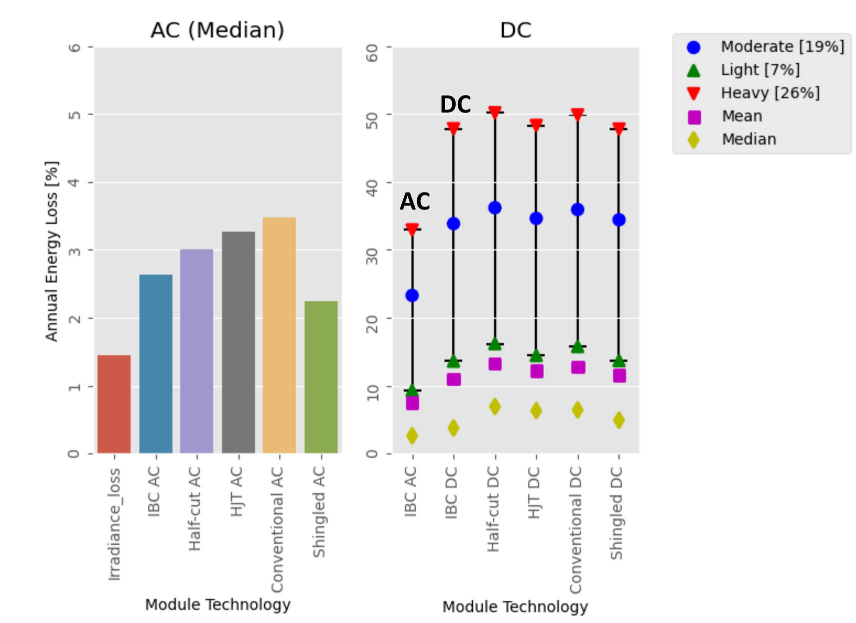


Figure 7: Annual Energy loss versus Reverse Breakdown Voltage for a 108 M10 Half-cut cell AC & DC module.

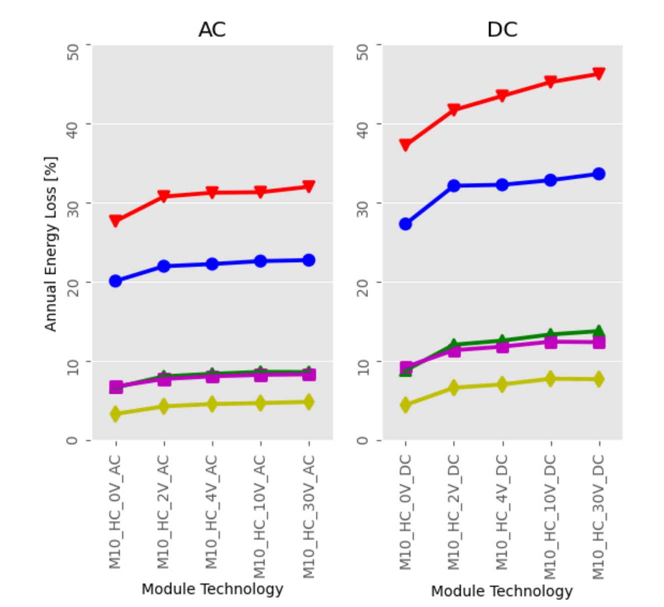
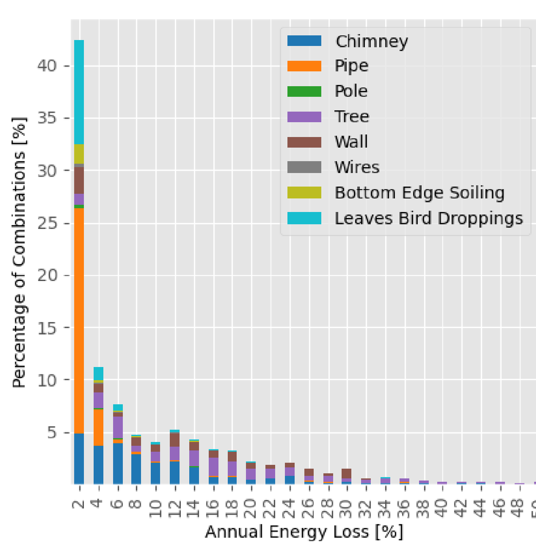


Figure 8: Sample Annual Energy loss distributions for the IBC AC module.



Selected preliminary results are shown. The light, moderate, and heavy shading levels are obtained from the NREL study[2]. For the AC variants, IBC and shingled modules show 1-1.5% higher annual energy yield at the median shading level. For the DC variants, IBC, shingled, and HJT modules show 1-3% higher annual energy yield depending on the shading level. AC (microinverters) provides the largest benefit vs. DC systems. We also explore the benefit of low cell reverse breakdown voltage (RBV). Note that these results only consider shading losses, not other yield factors.

Ongoing Work

- Validation of the Ray Tracing modeling framework component.
- Expand the framework for commercial rooftop and utility power plant market segments.
- Additional modeling studies on cell and module design parameters such as Reverse Breakdown Voltage, wafer size, bypass diodes configuration, etc.