Impacts of Albedo Estimation Method on Energy Estimates

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Agenda

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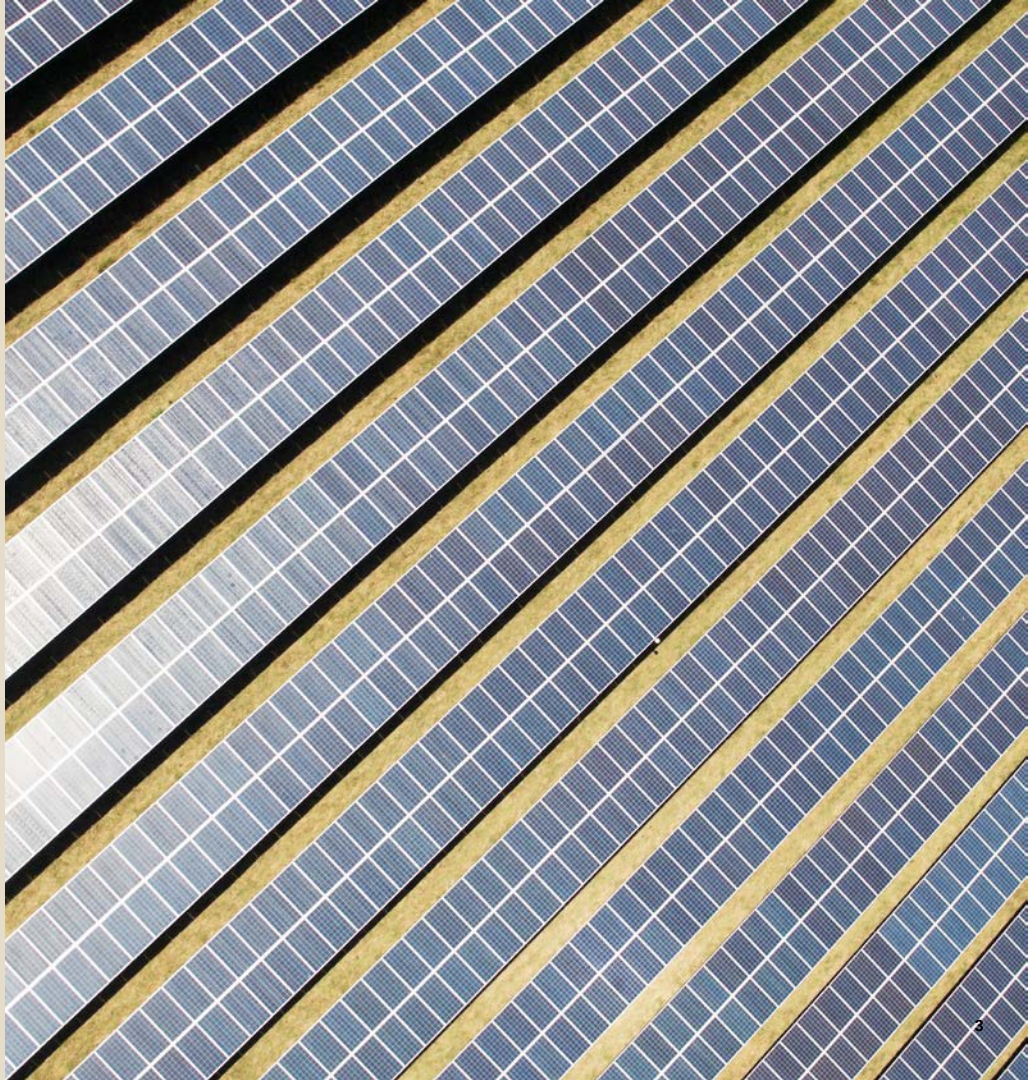
2. Albedo Measurement and Modeling
3. Sample Locations
4. Energy Modeling Assumptions
5. Results
6. Conclusions
7. Future Work

Background and Motivation

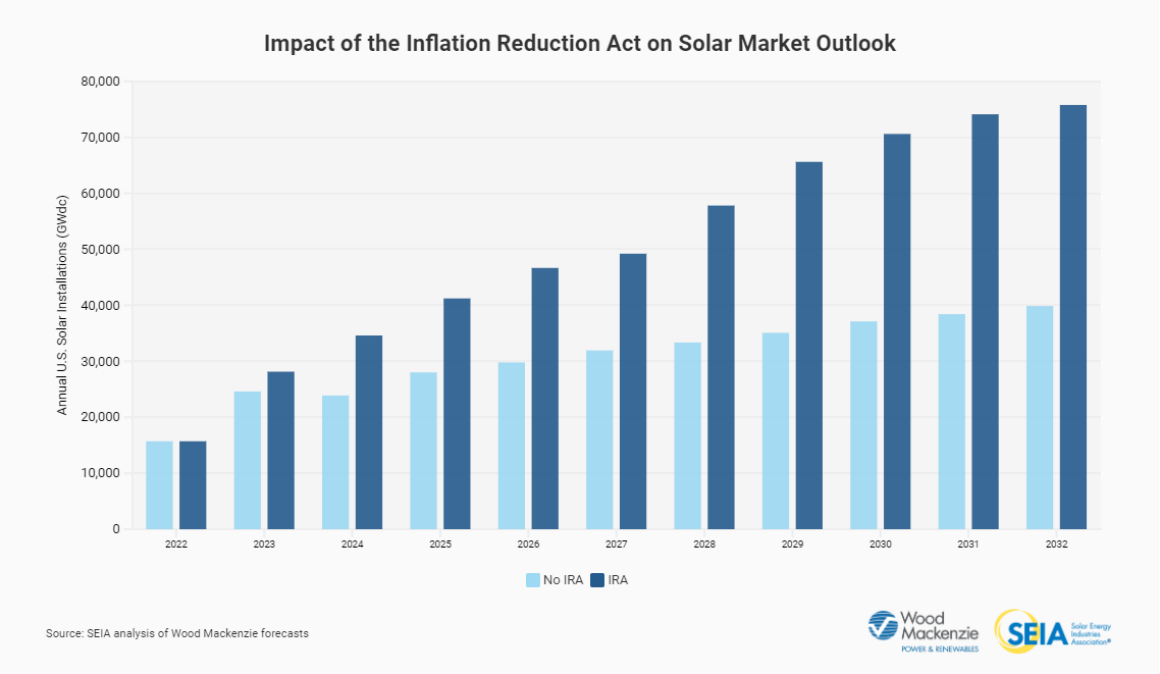


Albedo

- Albedo is the ratio of reflected solar irradiance over global irradiance and depends heavily on the reflectivity of the surface material
- Typical ranges are 0.15-0.20 for darker soil, 0.20-0.30 for very light soil, 0.20-0.25 for vegetation, and up to ~0.75-0.85 for fresh snow
- Albedo can have a significant effect on bifacial energy; $Albedo_{inc}$ is the incident irradiation on the back of the panel, ρ is the ground surface albedo under the panel, and θ is the angle of the panel

$$Albedo_{inc}\left[\frac{W}{m^2}\right] = \rho \cdot GHI \cdot \frac{1-\cos(\theta)}{2}$$

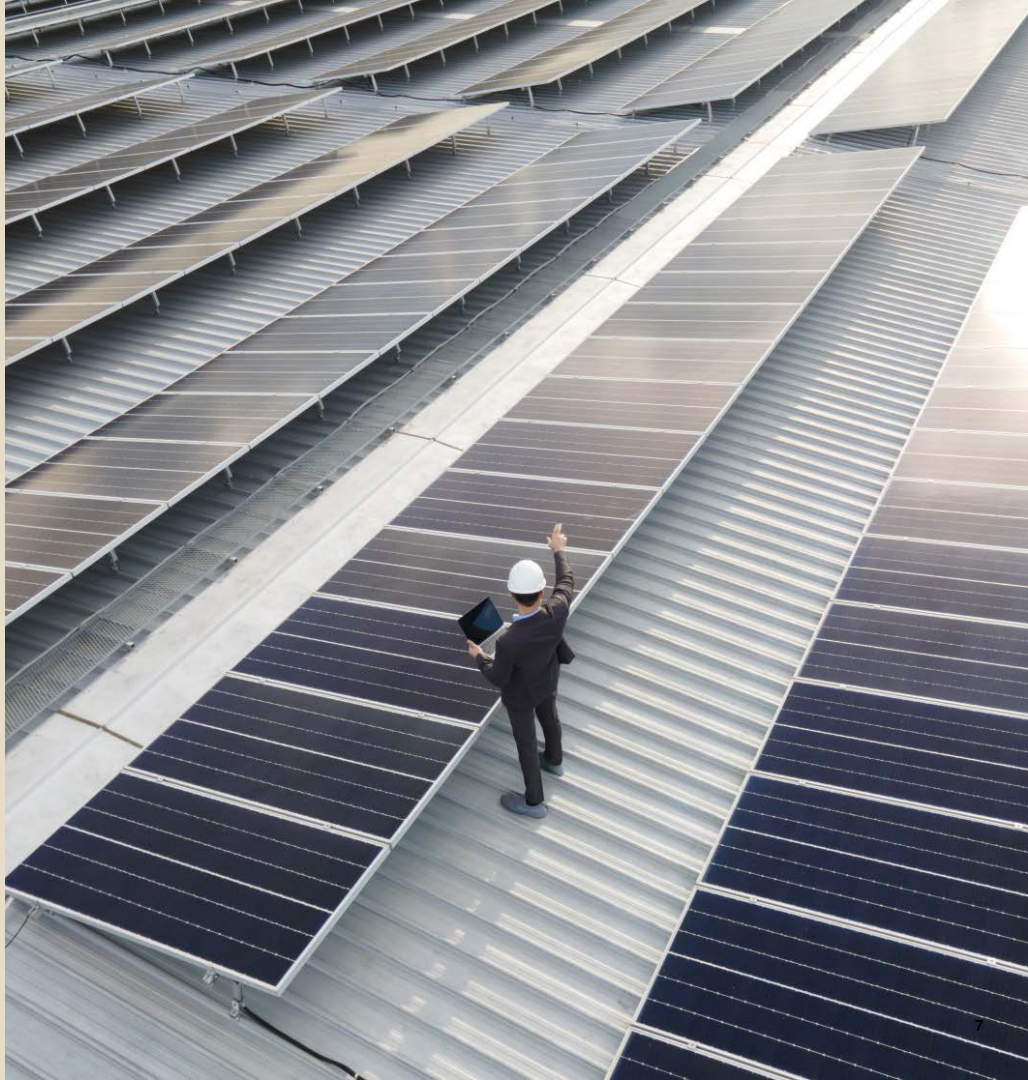
Inflation Reduction Act (2022) Impacts on Solar Installations



Motivation

- How much difference do different sources of annualized albedo produce?
- Given different albedo estimates, how much does a generic bifacial project vary in energy?
- Is there a relationship between differences in albedo and the resulting difference in energy?
- Do on-site measurements capture typical long-term albedo conditions?

Albedo Measurement and Modeling



Satellite Modeled Albedo

- Services offering solar resource modeling from satellite sources have begun to offer albedo estimates as well in the last few years
- Each provider uses custom algorithms for albedo modeling, often involving imagery resolutions of 1-4km, and historical and modeled snow fall timeseries data
- Satellite modeling can offer long-term solar resource (20+ years) at hourly or finer temporal resolutions; however, albedo statistics are generally reported as monthly (typical/average year or specific years)
- This study tests PVsyst albedo default of 0.20, 3 monthly average albedo sources (A, B, C) and a monthly average of all three models
- Additionally, IAV statistics are generated from 2 timeseries based albedo datasets (Models 1 and 2)

Solar Meteorological Stations (SMS)

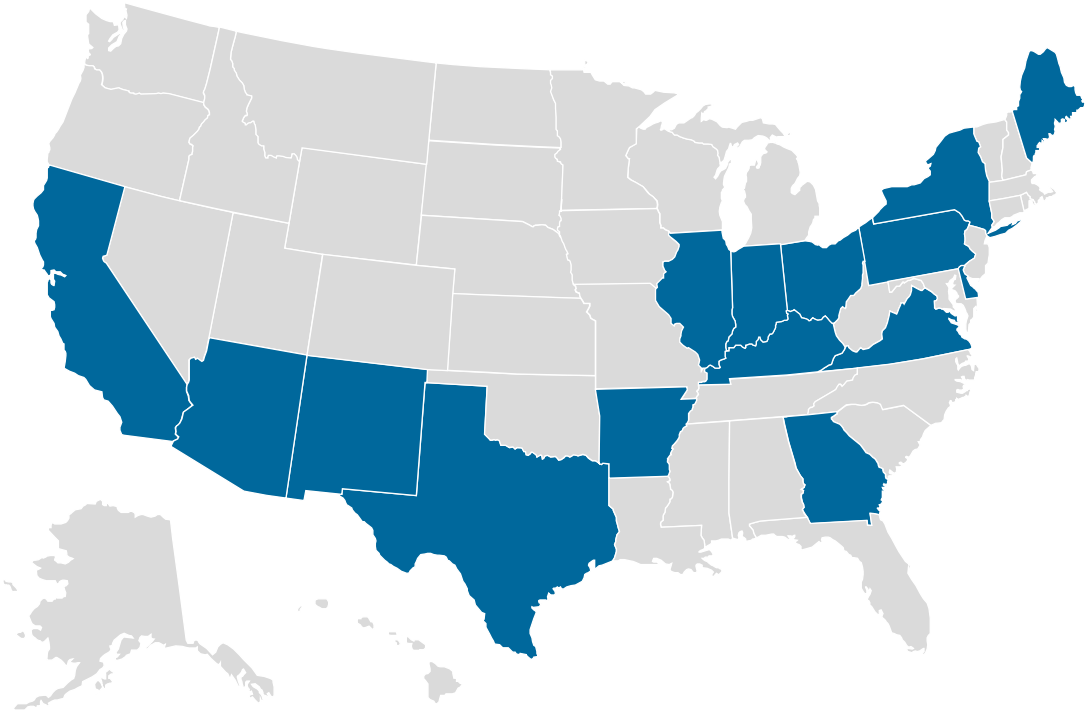
- SMS are used to obtain point location solar resource, often at a future development site
- Stations are often deployed for 1-2 years (See our MCP poster for deployment length uncertainty impact on long term GHI estimates!)
- Solar resource often uses a combination of long-term satellite modeling and on-site measurements to derive a long-term adjusted solar resource values using a Measure-Correlate-Predict (MCP) approach
- Stations often include several pyranometers, including a downward-facing pyranometer to calculate albedo

Sample Locations

UL Solutions Field Services

- UL's albedo calculation is derived from high-frequency pyranometer data
- Having collected albedometer data at over 150 locations, UL has a strong understanding of irradiance and albedo distribution across the United States
- From this data, it is possible to understand regional differences in albedo
- Extensive manual validation and QAQC practices remove systematic biases and erroneous values due to dew, frost, unlevelness, soiling and other issues

Locations of 34 Sample Sites with On-Site Albedo



Energy Modeling Assumptions

PVsyst Setup

General

- Single inverter block simulations in PVsyst
- Generic PAN and OND from PVsyst library
- 440W Mono-PERC panel with 80% bifaciality
- Fresnel Anti-reflective coating
- 1.6m height above ground
- Unlimited trackers for bifacial and shading simulations

Site-Specific

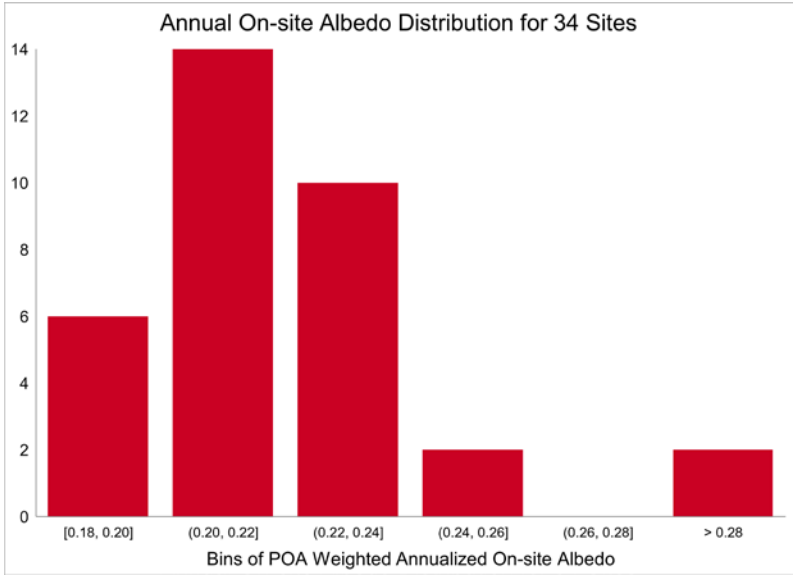
- Site (.SIT) and Meteo (.MET) files
  - Meteo from solar resource MCP analysis where available
- Soiling losses from dust and snow
  - Bifacial benefit from snow reflection and penalty from backside soiling included

Modeling Assumptions

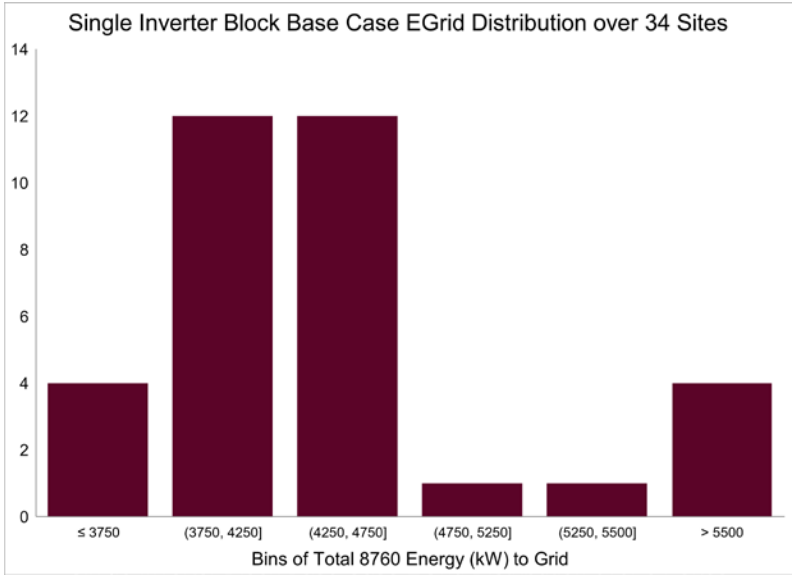
- Project-level albedo specification remains default; no albedo benefit to front-side for these simulations
- Losses from complex terrain and specific tracker shading not included
- Horizon profile excluded from PVsyst as horizon impacts are accounted for from on-site solar resource data MCP analysis
- Standard assumptions for electrical and transformer losses
- No post-processing losses applied, such as POI clipping, wind stow, sub-hourly clipping, and availability
- Energy evaluated on a First-Year basis; no material degradation

Base Cases - 34 Sites

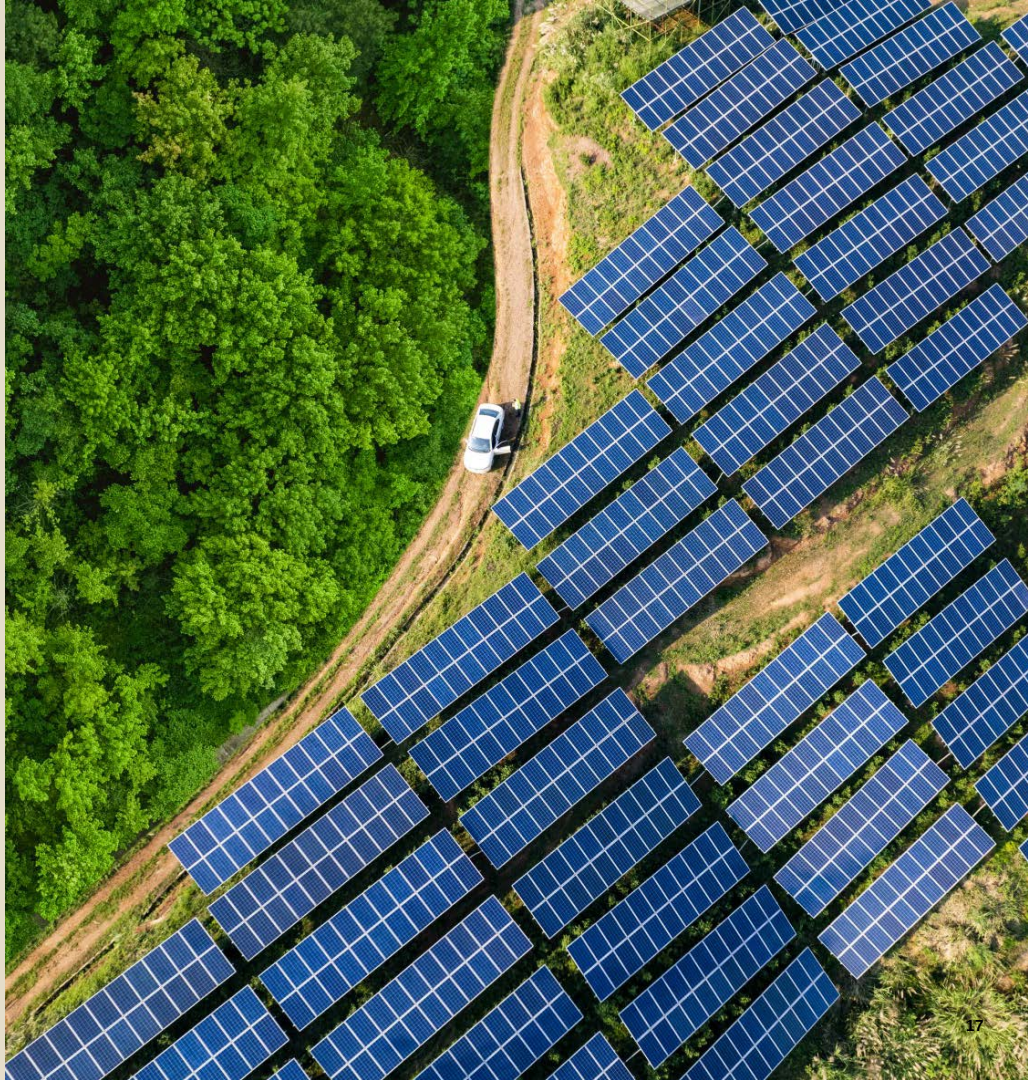
Albedo



Energy

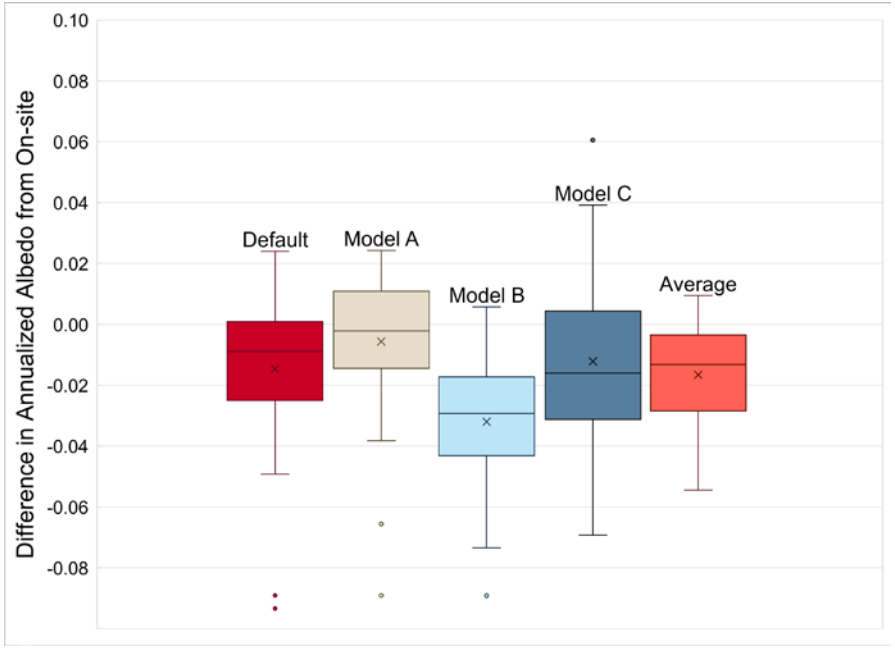


Results

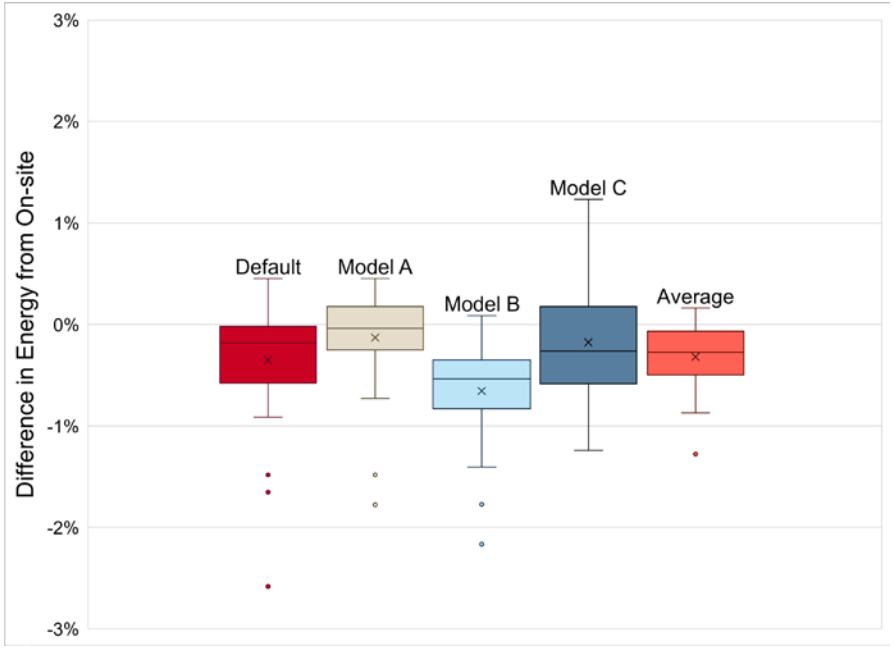


Differences from On-Site Scenario for 34 Sites

Albedo



Energy



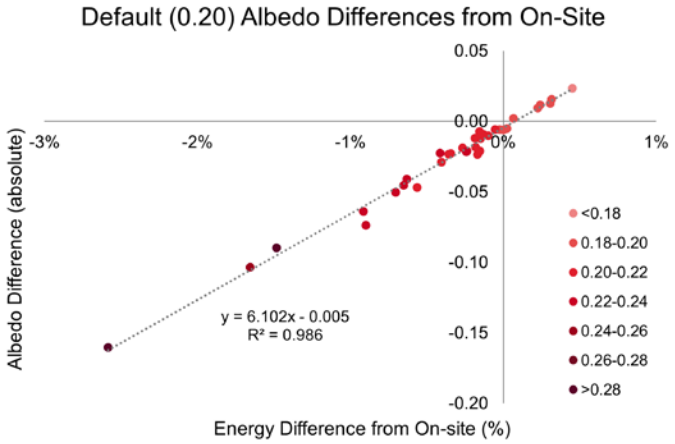
Differences from On-Site Scenario for 34 Sites (Tabular)

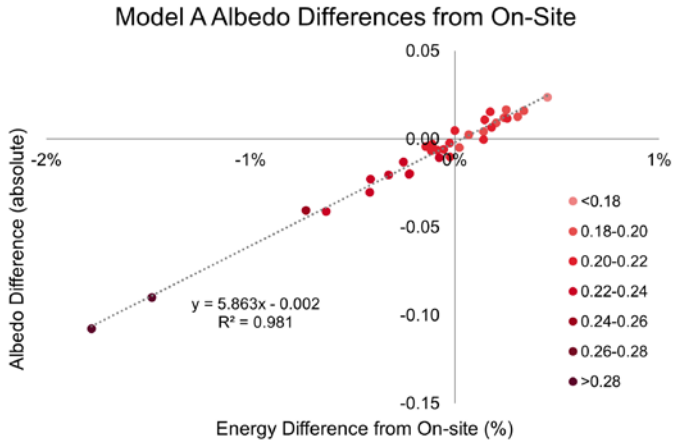
Albedo

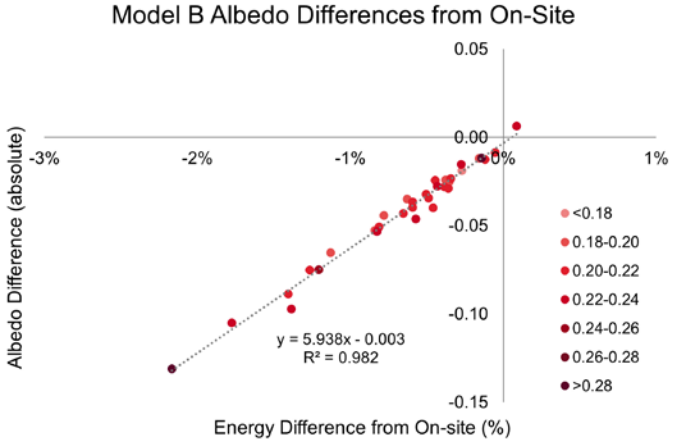
	Default (0.20)	Model A	Model B	Model C	Average
mean	-0.01	-0.01	-0.03	-0.01	-0.03
max	0.02	0.02	0.01	0.06	0.02
min	-0.09	-0.09	-0.09	-0.07	-0.09
std	0.03	0.02	0.02	0.03	0.02

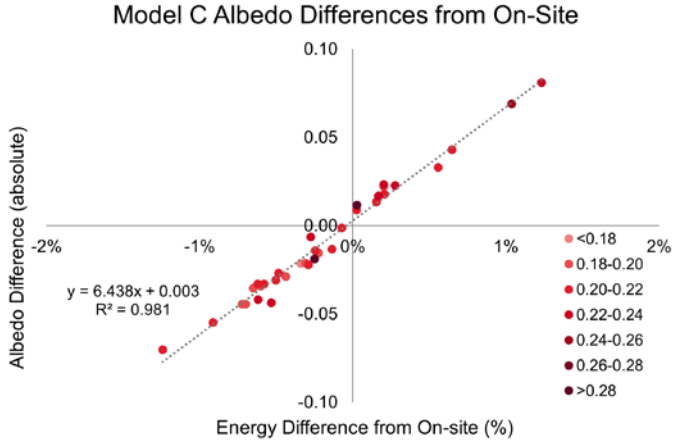
Energy

	Default (0.20)	Model A	Model B	Model C	Average
mean	-0.4%	-0.1%	-0.7%	-0.2%	-0.3%
max	0.5%	0.5%	0.1%	1.2%	0.2%
min	-2.6%	-1.8%	-2.2%	-1.2%	-1.3%
std	0.6%	0.5%	0.5%	0.5%	0.3%

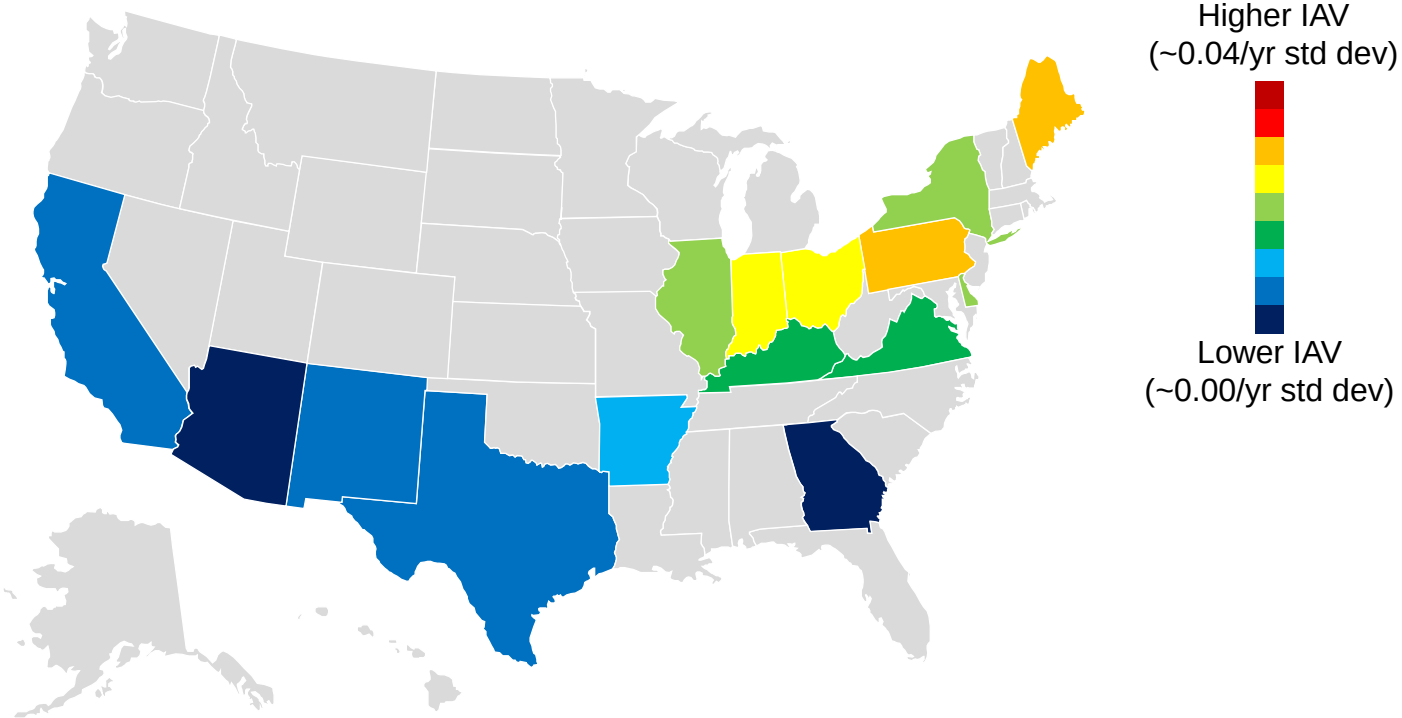

Default (0.20) Albedo Differences from On-Site
Albedo Difference (absolute)
Energy Difference from On-site (%)
y = 6.102x - 0.005
R² = 0.986
<0.18
0.18-0.20
0.20-0.22
0.22-0.24
0.24-0.26
0.26-0.28
>0.28


Model A Albedo Differences from On-Site
Albedo Difference (absolute)
Energy Difference from On-site (%)
y = 5.863x - 0.002
R² = 0.981
<0.18
0.18-0.20
0.20-0.22
0.22-0.24
0.24-0.26
0.26-0.28
>0.28

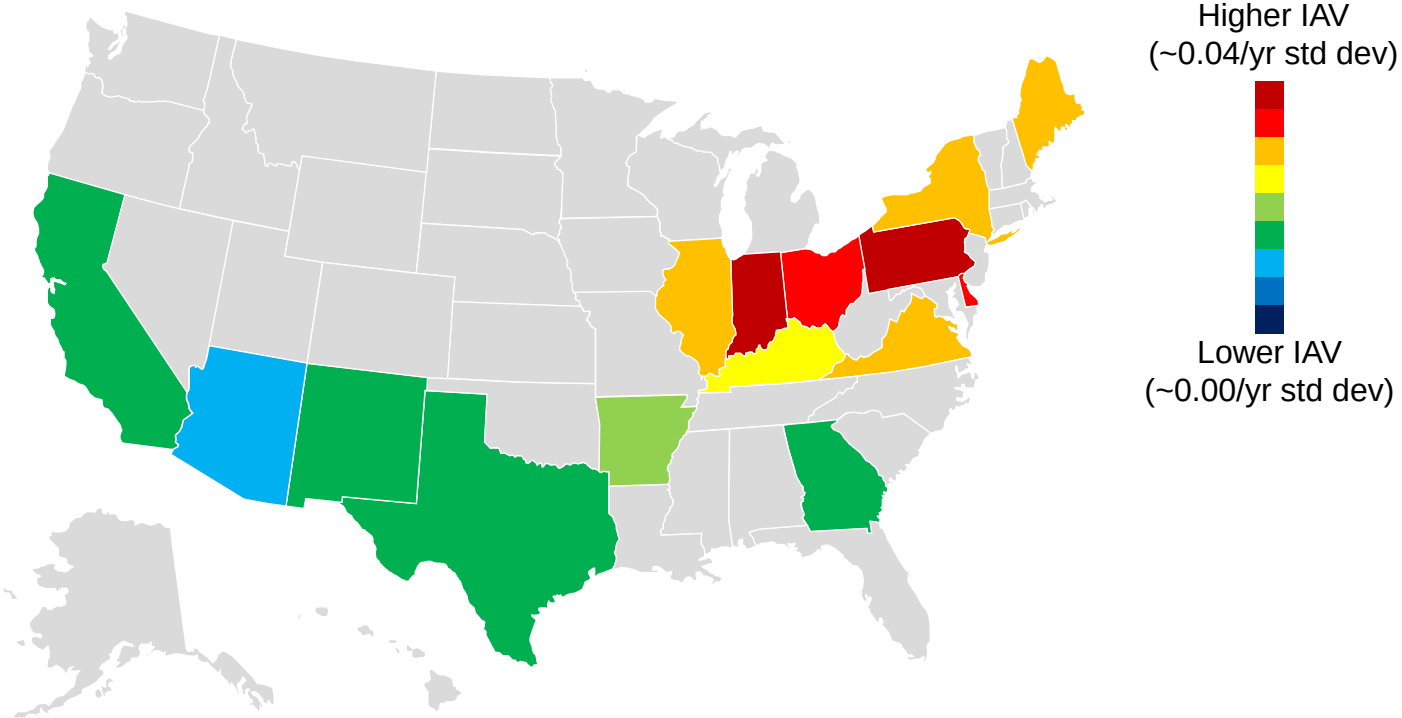

Model B Albedo Differences from On-Site
Albedo Difference (absolute)
Energy Difference from On-site (%)
y = 5.938x - 0.003
R² = 0.982
<0.18
0.18-0.20
0.20-0.22
0.22-0.24
0.24-0.26
0.26-0.28
>0.28


Model C Albedo Differences from On-Site
Albedo Difference (absolute)
Energy Difference from On-site (%)
y = 6.438x + 0.003
R² = 0.981
<0.18
0.18-0.20
0.20-0.22
0.22-0.24
0.24-0.26
0.26-0.28
>0.28

Model 1 Albedo IAV by State (1-8 sites per state)



Model 2 Albedo IAV by State (1-8 sites per state)



IAV over Two Years of On-Site Data

- 5 sample sites were selected with two years of albedo data
- Note that these data are a small sample of both sites and years of operation and serve to demonstrate potential areas of risk regionally regarding on-site albedo
- Sites in the low IAV regions identified in the two long-term albedo estimates also show low IAV over this two-year period, whereas sites in regions identified as greater IAV potential also show similar results
- Maximum monthly differences reported here are primarily winter and demonstrate the variability of snowfall dates

Site	1 (CA)	2 (PA)	3 (PA)	4 (TX)	5 (OH)
Year 1	0.23	0.29	0.28	0.19	0.25
Year 2	0.22	0.24	0.22	0.18	0.24
Avg	0.22	0.26	0.25	0.19	0.24
±	0.00	0.02	0.02	0.01	0.01
Max Monthly	0.02	0.13	0.13	0.07	0.13

Conclusions

Conclusions

- Annual albedo estimates differ from on-site measurements on average by -0.017 ±0.023 across three models, but only translates to a -0.3% ±0.5% Energy difference
- Averaging these three models monthly before analysis maintains the same average difference, but further reduces standard deviation to ±0.015 albedo and ±0.3% Energy
- Regressions of albedo difference to energy impact suggest a 1/6 factor for this experiment, i.e., 0.06 annual albedo difference = 1% Energy difference
- On-site albedo measurement of only 1 year does not inherently capture inter-annual variability, which 2 models predict 0.00-0.04 albedo standard year-to-year differences; 2 years of albedo data at highly varied sites in snow regions may provide additional coverage
- In these high IAV environments on-site albedo measured at max or min could result in ~1% energy difference from a typical albedo year

Motivation Revisited

- How much difference do different sources of annualized albedo produce? 0.017 ±0.023
- Given different albedo estimates, how much does a generic bifacial project vary in energy? -0.3% ±0.5
- Is there a relationship between differences in albedo and the resulting difference in energy? Potentially, 1/6 for this system
- Do on-site measurements capture typical long-term albedo conditions? Depends on the IAV of the region and length of on-site measurement campaign

Future Work

Future Work

Albedo MCP

- Measure-Correlate-Predict analyses have produced strong solar resource long-term results
- High quality modeled albedo datasets may be used in conjunction with on-site measurements to produce statistical regressions on a monthly basis to capture the effects of IAV and measurement time periods
- Best applied to regions with high IAV but verifying the low effects to low IAV regions may also provide a benefit

Sub-Monthly Modeling

- On-site albedo measurements can provide finer temporal resolution than monthly
- Modeling daily or even hourly may produce different results than this study
- Likely would need pvlib to customize this albedo application
- Unlikely to affect current energy modeling practices but understanding the effects can help better categorize the effects

Thank you

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