

DIGITAL SOLUTIONS

SolarFarmer Bifacial Modelling

PVPMC – 12

Albuquerque, NM

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15 May 2019

Outline

- Motivation
- Methods
- SolarFarmer
- Results
- Future work

Photos provided by NEXTracker

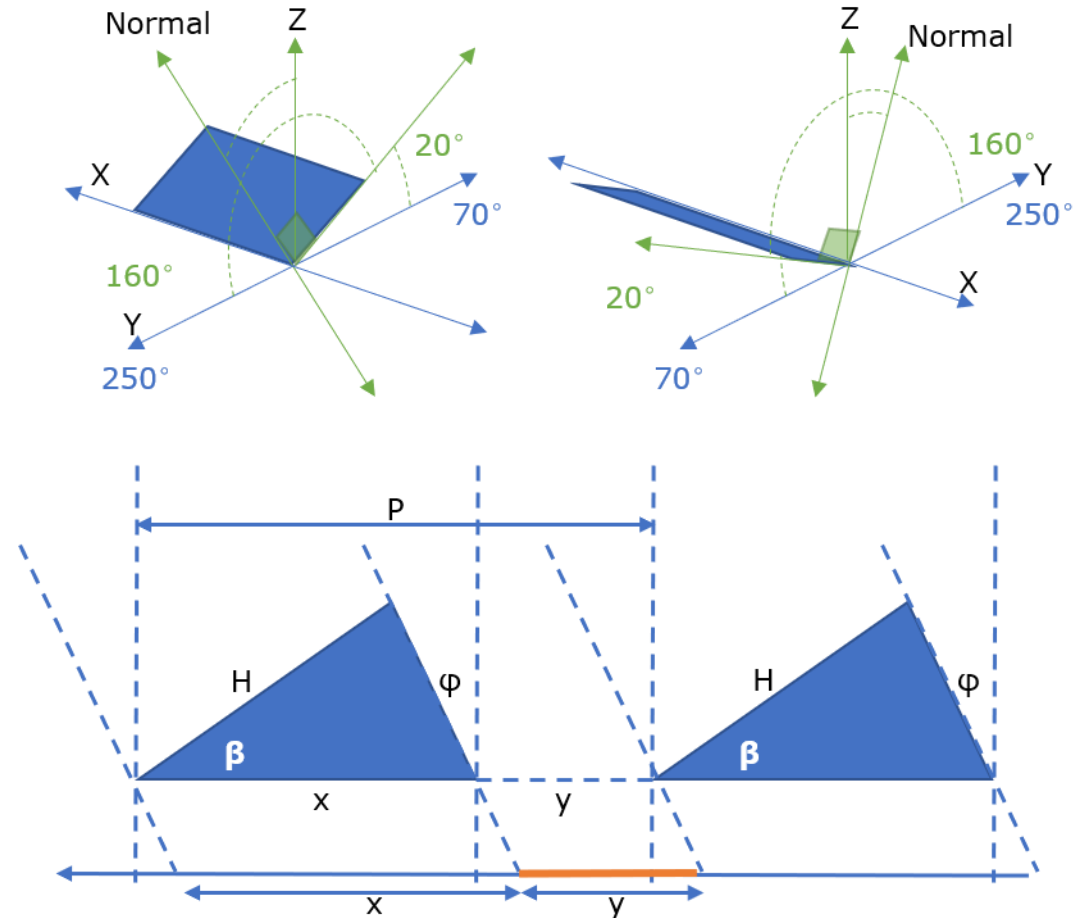


Motivation

- Rapid growth of bifacial manufacture and installations, but modelling still uncertain
 - *Bifacial modules have been around for many years and account for a tiny share of solar installations worldwide. However, the falling cost of P-type mono PERC solar cells have ignited massive interest in the use of bifacial modules, particularly in the United States. It will likely be two or three years before bifacial modules account for a significant share of demand, but tracker vendors have anticipated the shift and introduced products designed for their use*
 - “The Global PV Tracker Landscape (v2)” GTM Research / Wood-Mackenzie, 2018-07
 - *The number of manufacturers producing bifacial panels is increasing, and there is a corresponding increase in the number of installations [“Bifacial Solar Modules Inch Toward the Mainstream” GTM, 2018-08-17]. ... So far, the uptake of bifacial technology has been inhibited by the difficulty in predicting performance with a level of certainty. In 2015, bifacial modules had only a 5% market share [“Calculating the Additional energy Yield of Bifacial Solar Modules” SolarWorld, 2016-09-21].*
 - “Is Bifacial Technology About to Enter the Mainstream of Solar Power Generation?” Forbes, 2019-01-30

Methods

- Similar to existing models [Marion *et al.*, 2017]
- Treat the backside like a frontside, rotated 180° and facing the ground
- Infinite sheds approach
- Assume GHI is known (decompose if necessary) use same transposition model for both surfaces
- Reduced ground illumination from shading
- Account for obstruction of view factors from ground and sky
- Approximate total module view factor as linear average over shaded and unshaded regions
- Apply **Bifaciality** to backside and sum all components
- Apply transmission, shade, and mismatch factors

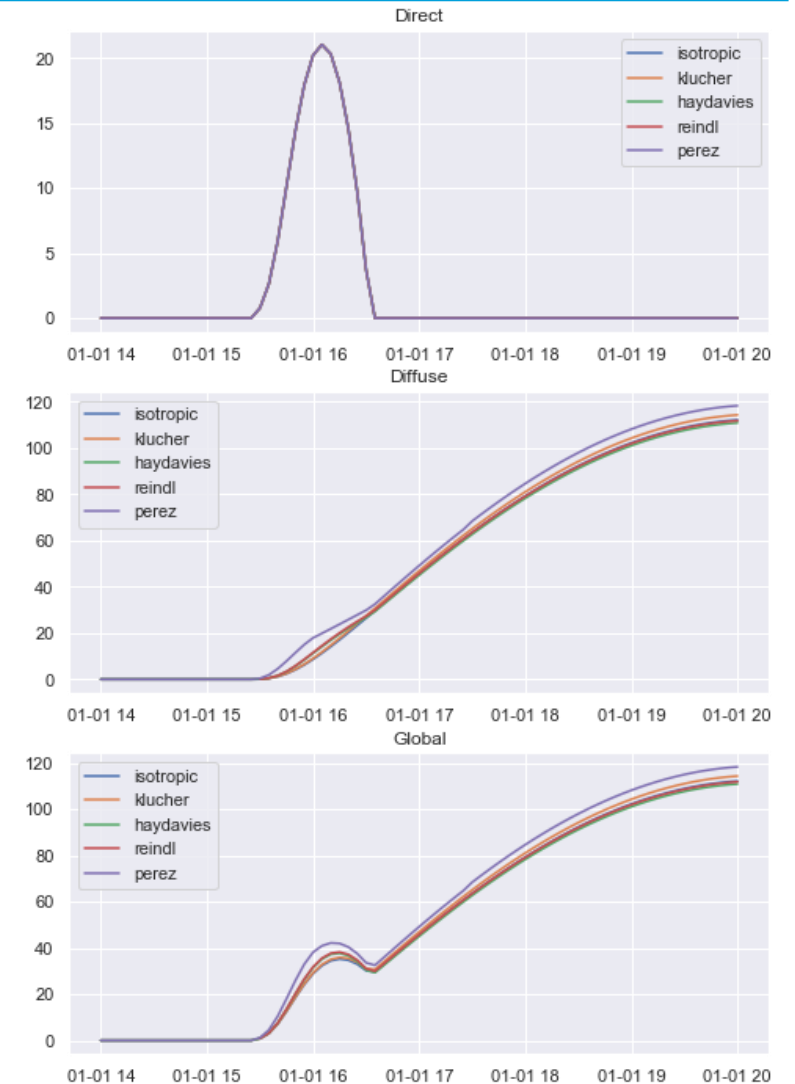
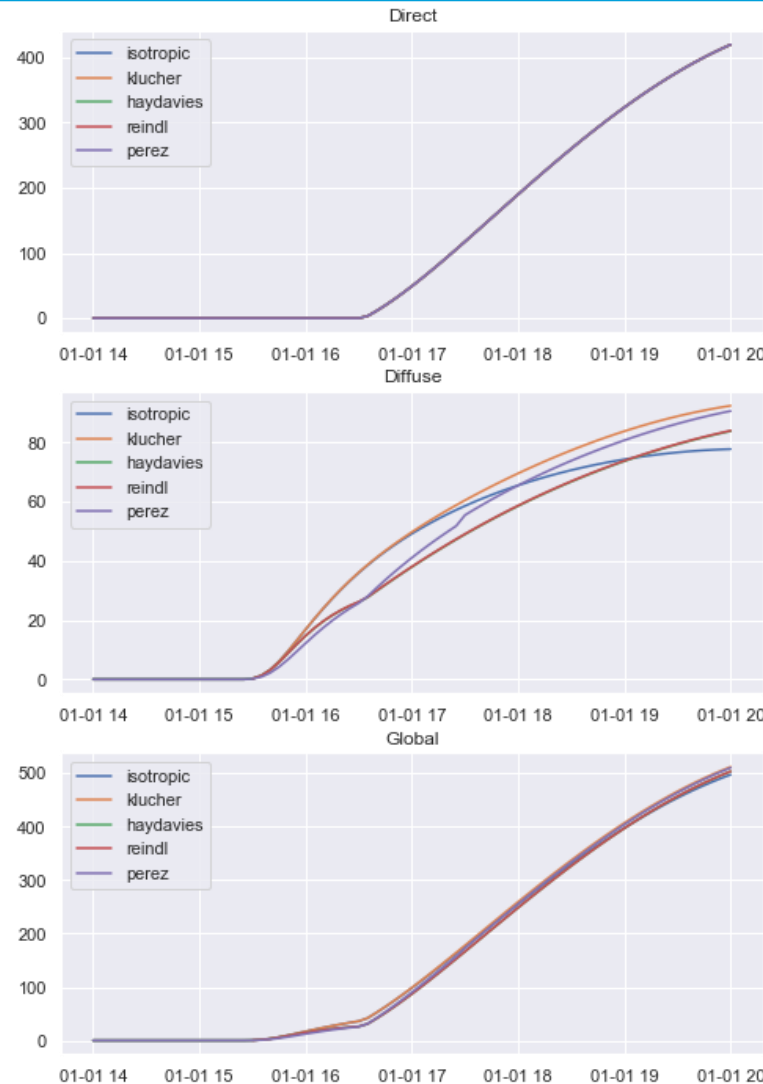


Transposition

- Here's an example of the module from the last slide facing 250° and tilted 20° , so it's backside is facing 70° and tilted at 160°
- Transposing the components onto the backside demonstrates
 - back sees the sun rise at 7:25
 - then beam moves to the front side by 8:35
 - but DHI is over-estimated b/c panel assumed transparent
- So we have to account for ground shading to fix this →

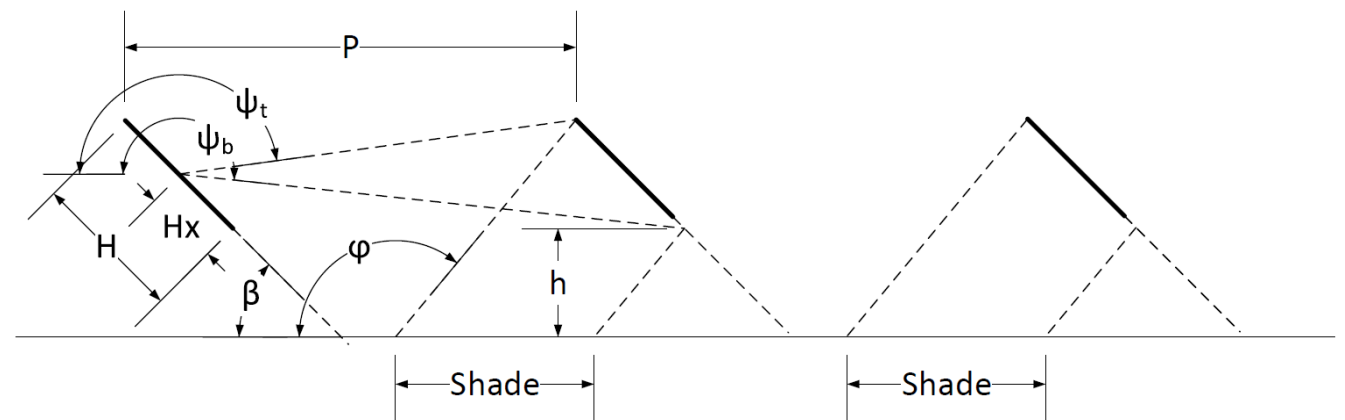
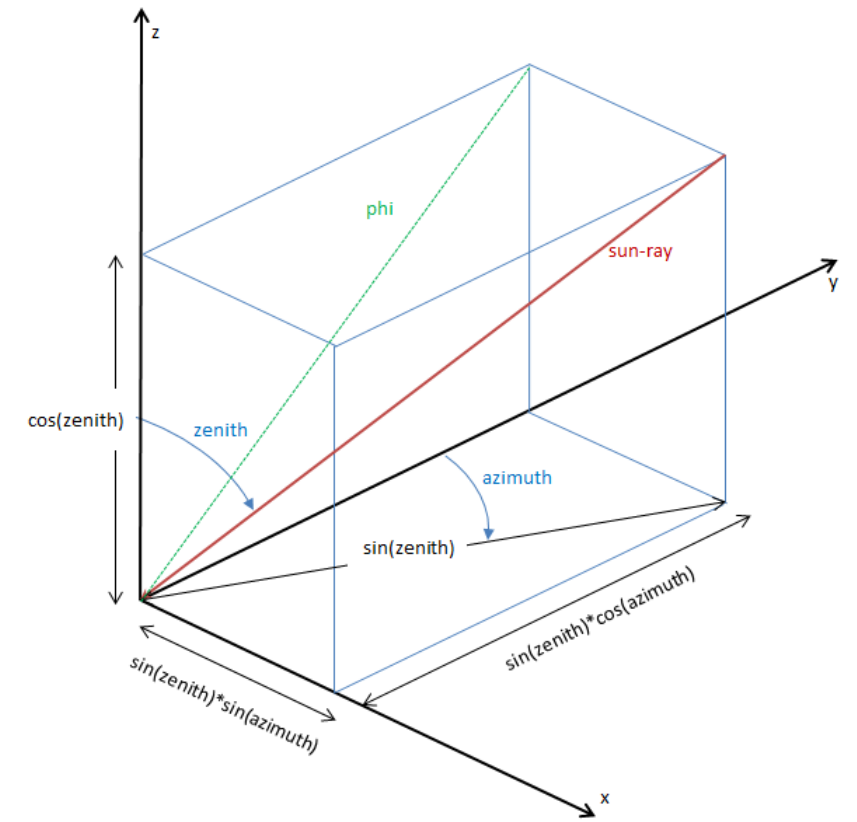
Front Side

Back Side



Ground Illumination

- Fraction of the ground that is visible from the sky
 - $F_{gnd,sky} = 1 - \min(1, GCR * \text{abs}(\cos \beta_{front} + \sin \beta_{front} \tan \varphi_{front}))$
 - $GCR = H / P =$ ground coverage ratio
 - $\beta =$ tilt of front side
 - $\tan \varphi = \frac{\cos(\text{solar azimuth} - \text{system azimuth}) \sin(\text{solar zenith})}{\cos(\text{solar zenith})} =$ sun ray projection on y-z plane, vertical perpendicular to panels
- Combine with albedo, DHI in shade, and GHI elsewhere
- $E_{gnd,alb} = GHI * \text{albedo} * (F_{gnd,sky}(1 - df) + df)$
 - $df = DHI / GHI =$ diffuse fraction
- Now just need to apply view factors, but $F_{pv \rightarrow gnd} = \frac{1 - \cos \beta}{2}$ and $F_{pv \rightarrow sky} = \frac{1 + \cos \beta}{2}$ don't account for the adjacent rows and we need to know where shade line is on panel



View Factors and Shade Line

- Shade line from bottom of module at x

$$- F_x = 1 - \frac{1}{GCR(\cos \beta + \sin \beta \tan \varphi)}$$

$$- F_x = x / H = \text{fraction of module shaded}$$

- Angle ψ from shade line to sky (ψ_t)/ground (ψ_b)

$$- \tan \psi_t = \frac{GCR(1-F_x) \sin \beta}{1-GCR(1-F_x) \cos \beta} \text{ an}$$

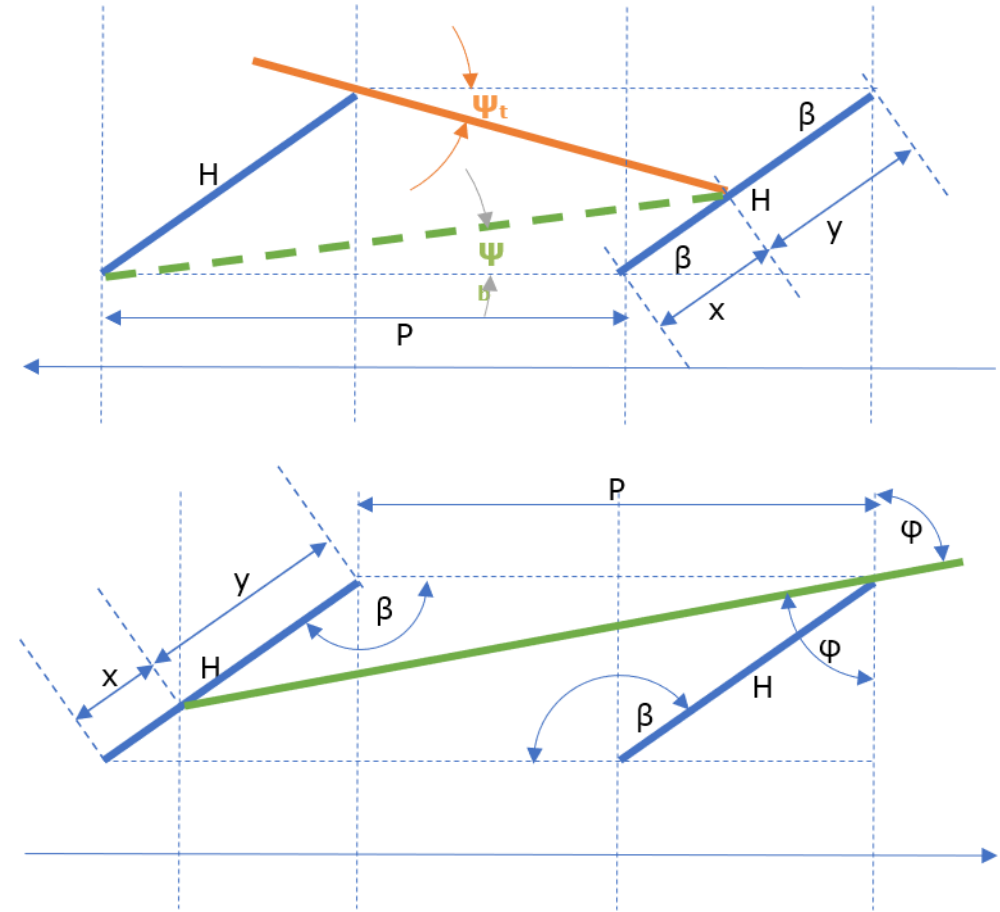
$$- \tan \psi_b = \frac{F_x GCR \sin \beta}{1+F_x GCR \cos \beta}$$

- Sky/Ground blocked by next row, view from β to ψ

$$- F_{nextrow,top \rightarrow pv} = \frac{1 + \cos(\psi_t + \beta)}{2}$$

$$- F_{nextrow,bottom \rightarrow pv} = \frac{1 - \cos(\beta - \psi_b)}{2}$$

- Now split panel into shaded and unshaded regions



Approximate POA

- View factors look linear
- Ignore mismatch, IAM
- Approximate average over unshaded and shade parts

- $POA_{sky} =$

$$GHI(F_x F_{nextrow,top \rightarrow pv,shade} + (1 - F_x) F_{nextrow,top \rightarrow pv,NOshade})$$

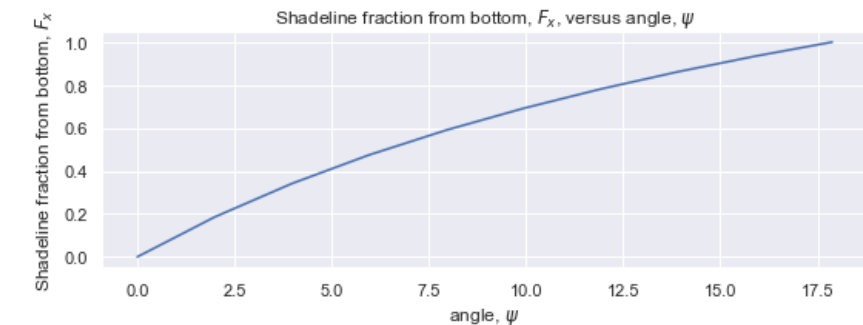
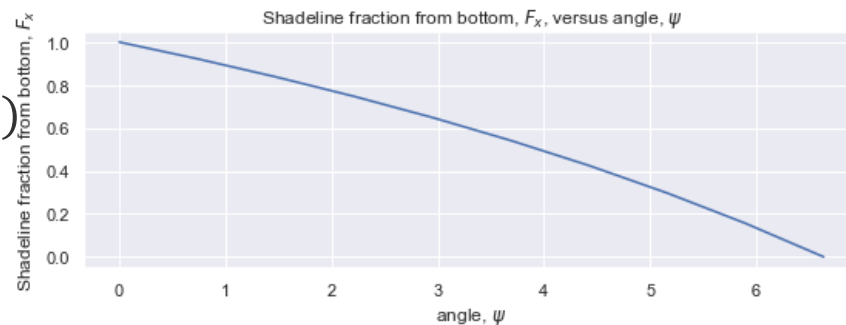
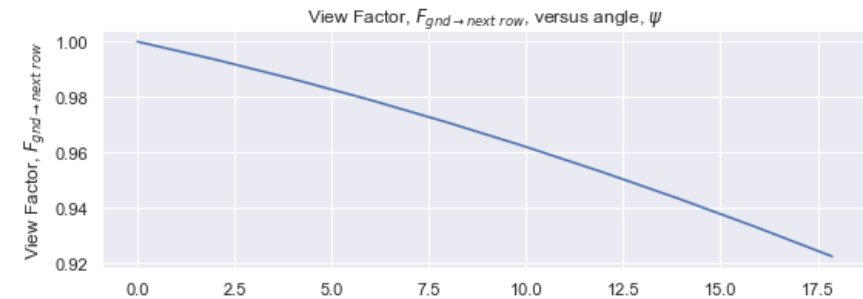
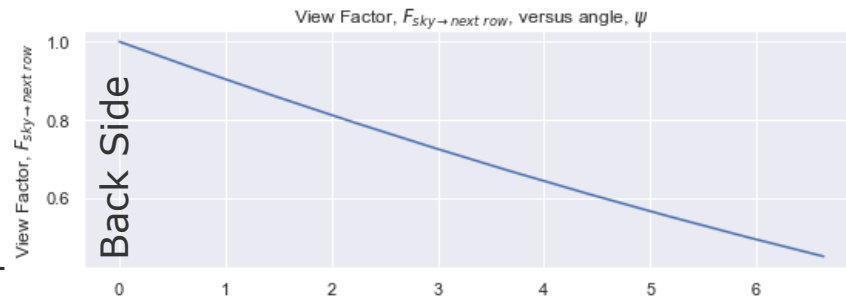
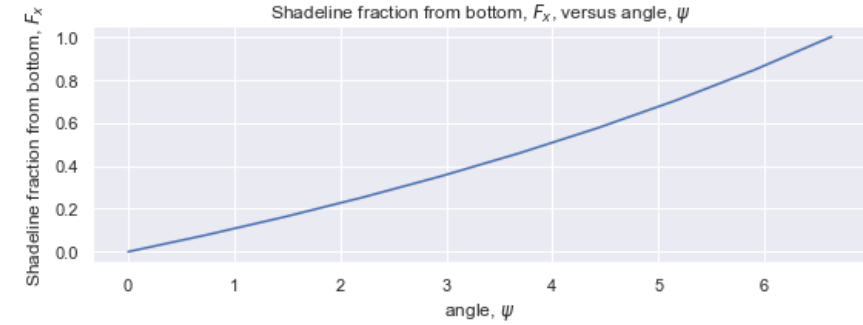
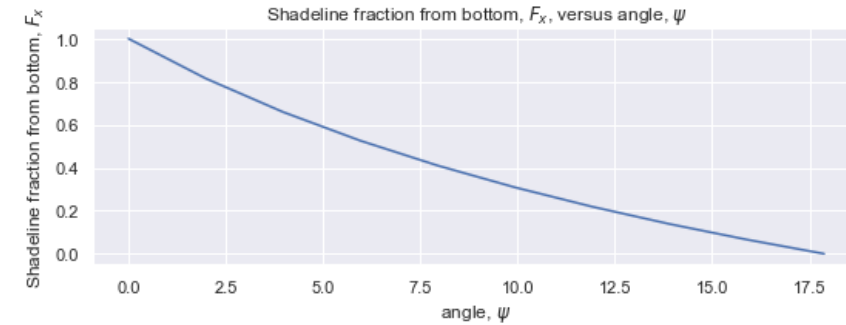
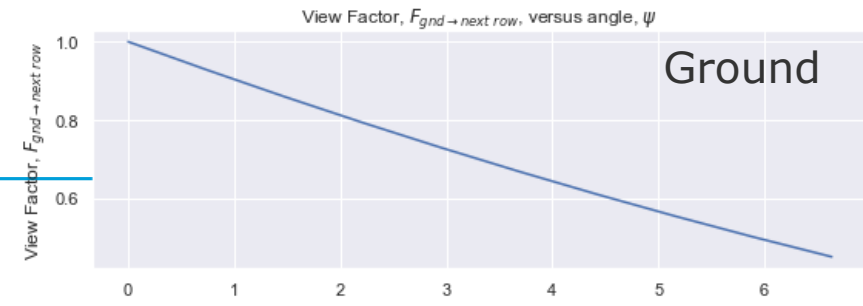
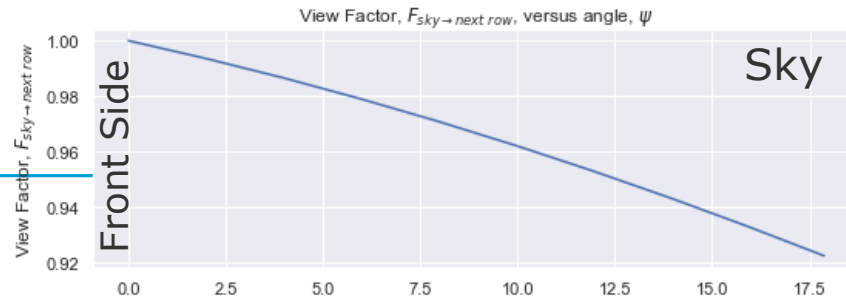
- $POA_{ground} =$

$$E_{gnd,alb}(F_x F_{nextrow,bot \rightarrow pv,shade} + (1 - F_x) F_{nextrow,bot \rightarrow pv,NOshade})$$

- $POA_{beam} = (1 - F_x) DNI \cos(AOI)$

- $POA_{dif} = POA_{sky} + POA_{ground}$

- $POA = POA_{beam} + POA_{dif}$



Bifaciality, Other Effects, and Total POA

- **Bifaciality, B** , is efficiency of back side relative to front

$$- B = \frac{P_{mpp,STC,back}}{P_{mpp,STC,front}} = \frac{\eta_{STC,back}}{\eta_{STC,front}}$$

- Combine both sides with **Bifaciality**

$$- E_{front} + E_{back}B(1 + K_{shade})(1 + K_{transmit})$$

- Other effects:

- K_{shade} reduces backside irradiance from support structures shade
- $K_{transmit}$ accounts for reduced concentration from clear backsheet and slightly increased ground illumination from gaps between cells and modules

Photo provided by NEXTracker



SolarFarmer

- Set Bifaciality in PV Module component definition
- Mismatch due to non-uniform backside irradiance
- Set shade, transmission, and mismatch factors for each layout region
- Only available for simple model
- Disable bifacial model for yield calc

Bifacial	
Is the module bifacial?	<input checked="" type="checkbox"/>
Bifaciality factor (%)	80

Shading Settings

Near shading radius (m)

The shading points setup

The diffuse shading scheme

Disable Models

Disable diffuse transposition model

Disable IAM model

Disable near shading model

Disable cell temperature model

Disable spectral model

Disable bifacial model

Run the Energy Calculation

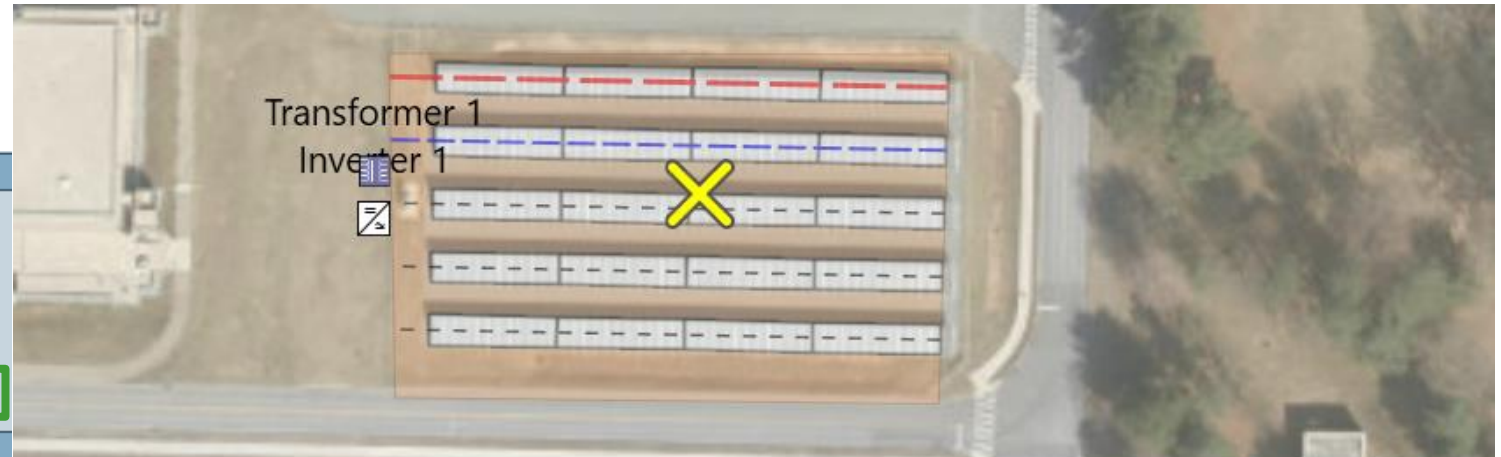
⚠ 2 Warnings i Performance Statistics

Use the simple model calculation

Use the full model calculation

▶ Run calculation scenario

Write out testing validation files



Layout Regions							Inverters	Transformers	
Name	Azimuth (deg)	Tilt (deg)	Uc (W/m ² K)	Uv (W/m ² sK)	Rack System	Shade factor (%)	Transmission factor (%)	Mismatch factor (%)	Auto fill
Layout Region 1	181.1	20	29	0	four front southern shells	-2	0	-10	<input type="checkbox"/>

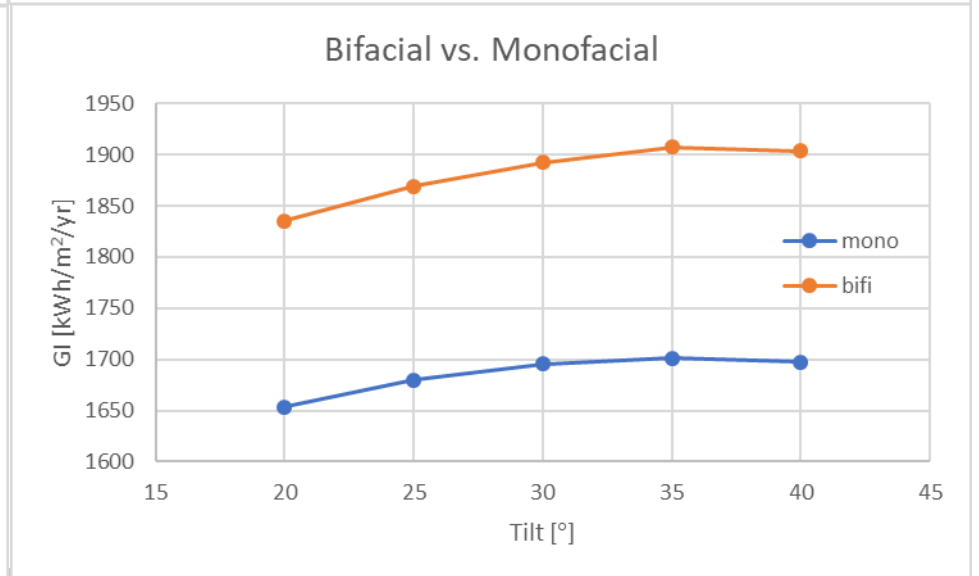
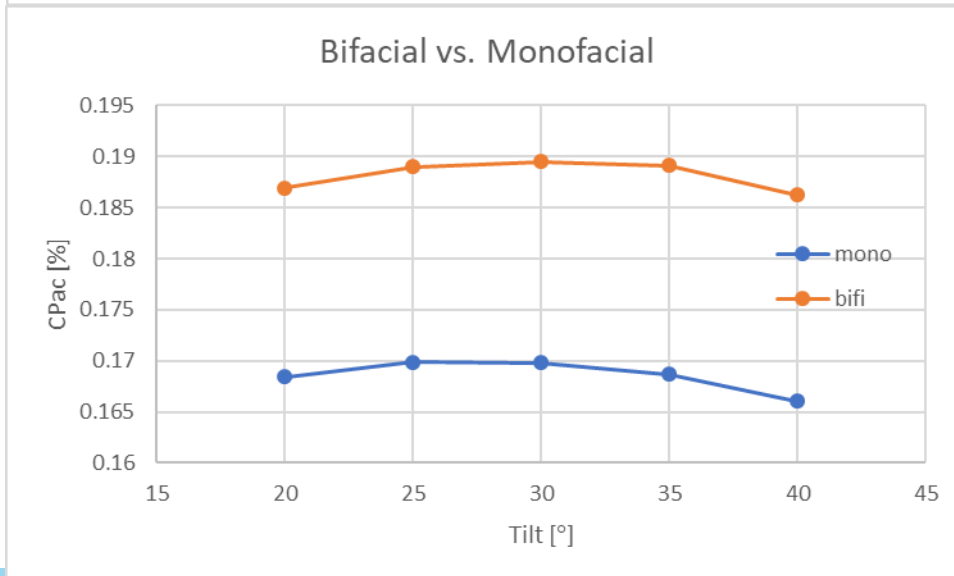
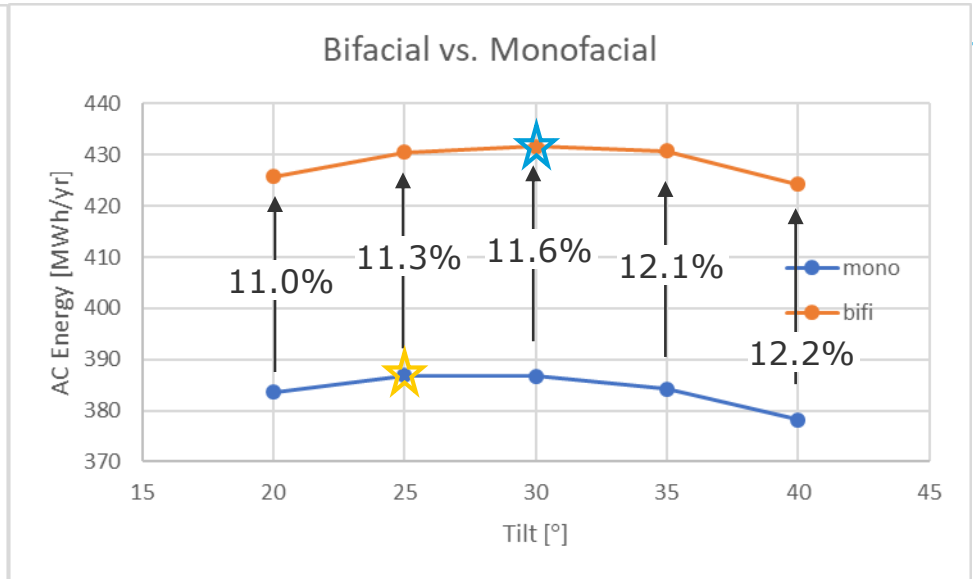
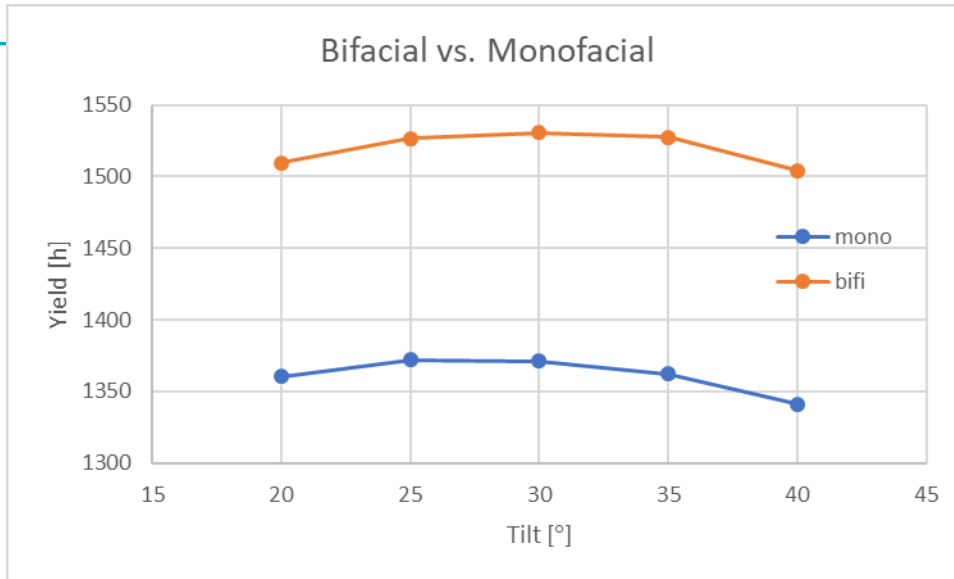
Results: NIST with AFB, B = 80%, shade = -2%, no mismatch or transmission

- NIST with AFB, B = 80%, shade = -2%, no mismatch or transmission, GHI = 1456.2 [kWh/m²]

Tilt[°]	Yield [h]	POI [MWh]	CP _{ac} [%]	DC [kWh]	AC [kWh]	BG [%]/PR[%]	GI [kWh/m ²]
20	1510	425.7	18.7	440336.9	425674.4	11.0	1835.2
20	1360	383.6	16.8	395833.8	383581.8	82.3	1653.7
25	1527	430.5	18.9	446024.3	430467	11.3	1868.9
25	1372	386.9	17.0	399365	386921.6	81.7	1679.6
30	1530	431.6	18.9	448001.9	431650	11.6	1892.3
30	1371	386.7	17.0	399234	386714.7	80.9	1695.4
35	1527	430.7	18.9	447429.7	430669.1	12.1	1907.3
35	1362	384.2	16.9	396670.8	384167.4	80.1	1701.4
40	1504	424.2	18.6	443528.3	424192.5	12.2	1903.7
40	1341	378.2	16.6	390864.5	378240.2	79.0	1697.3

Results

- Bifacial gain 10%
- Increases with tilt
- Bifacial AC peaks around 30° but monofacial peaks at closer to 25°
- Doesn't change performance ratio
- Does effect AC capacity factor
- Optimal layouts may differ between bifacial and monofacial systems



Future Work

- There are bugs ☹️ hopefully we'll fix these by now 😊
- Need to implement mismatch better (currently not implemented ☹️ not even the "factor")
- Account for irradiance gradient on backside
- add loss tree effects ☹️
- Implement with trackers
 - need simple shade with trackers first
- On sloped system plane
- Account for edge effects (not-infinite)
- Any arbitrary distance and height between rows
- Account for height above ground better (currently not considered ☹️ and tends to overestimate)
- Bifacial in full hemicube model
- Submit to pvlib python see: <https://github.com/pvlib/pvlib-python/pull/717>

Thank You

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