

WEBINAR

Shade modeling for utility-scale PV plants:
Why it matters and what you should do about it

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19 AUGUST 2021



nextracker
A Flex Company



Shade Modeling for Utility-Scale PV Plants

Why it Matters and What the PV Industry Can Do About It

Presenting:

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19 August 2021

Corporate Vision & Mission

Our Vision

Where renewable energy powers the world – delivering clean, affordable power to all.

Our Mission

To be the world's leading energy solutions company delivering the most intelligent, reliable and productive solar power for future generations.



Company Overview

#1 Global Market Share Leader in Solar Tracking

50+ GW of solar tracker systems in operation or under construction in 6 years

A Flex company

- \$25Bn annual revenue, \$14Bn balance sheet

Global presence

- 550 staff worldwide, 8 global offices

Robust product lines

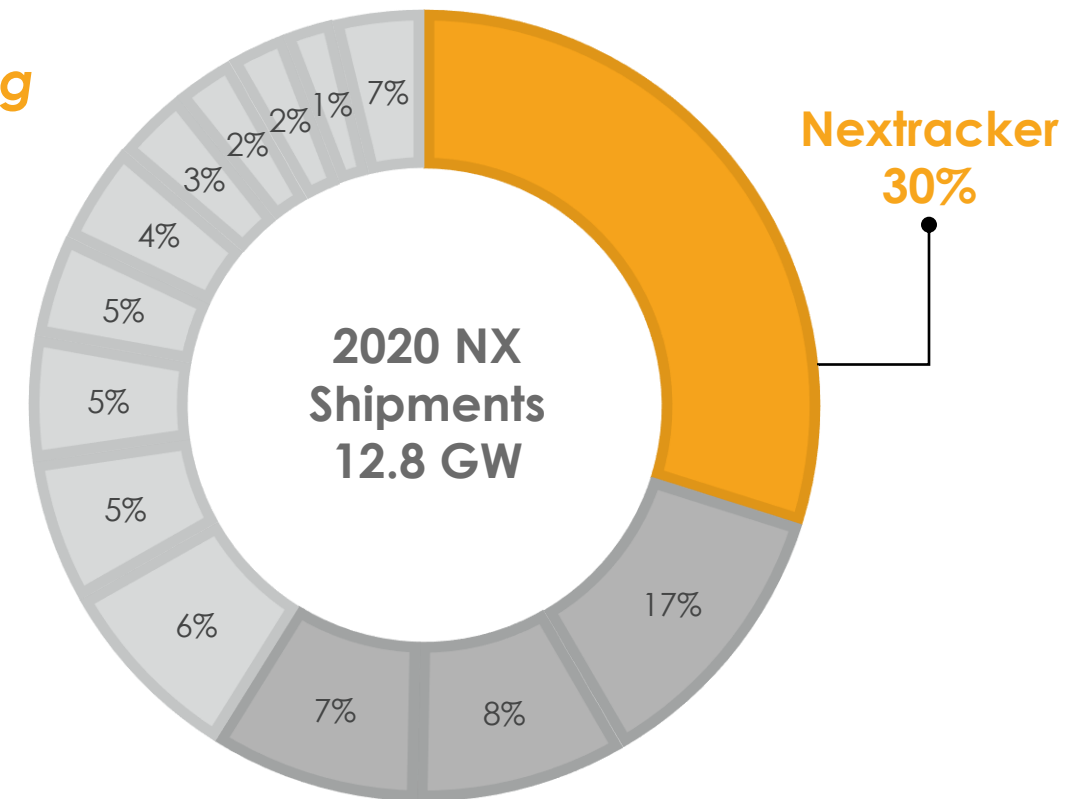
- Solar trackers, software and controls, digital O&M

Deep PV expertise and experience

- 300 years of collective PV experience on executive team

Our Vision- Renewable energy powers the world – delivering clean, affordable power to all.

Our Mission- To be the world's leading energy solutions company delivering the most intelligent, reliable and productive solar power for future generations.



#1 market share leader six consecutive years: 2015-20

Source: IHS Markit 2021

NX Ecosystem and Evolving Industry Needs

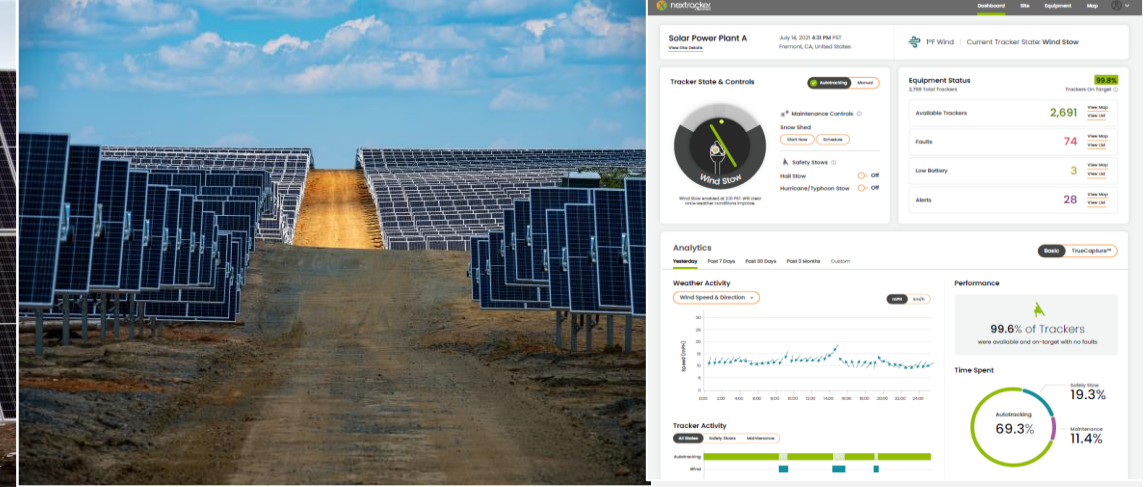
SOLAR TRACKER PORTFOLIO



NX Horizon™ & NX Gemini™

- ✓ Industry's most advanced smart solar trackers
- ✓ Optimized for the complete range of tier one modules
- ✓ Monofacial, bifacial, FSLR S6, 182- & 210-mm formats

SOFTWARE & CONTROLS



TrueCapture™ & NX Navigator™

- ✓ Smart software and control platforms
 - ✓ Improve monitoring precision
 - ✓ Increase energy yield up to 6%

NX Remote Monitoring & Management Services

Suite of advanced data and software-driven digital services that dramatically improve asset management efficiency and lower operating costs.

Continued U.S. Diversification of Customer Base

Over 300 world-class developer and EPC partners representing present and growing solar market growth



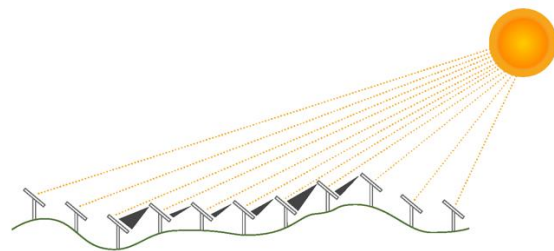


Why Shade Modeling Matters

The Industry Story on Shade Modeling

- **Do utility-scale PV plants experience shading?**
Nearly always.
- **Is this loss well quantified in current yield estimations?**
Rarely.
- **Is the shade loss significant?**
Yes, if you think several percent annual yield impact is significant.
- **Is accurate shade modeling even possible?**
With the advancement of tools available today, yes.
- **How can the industry make informed decisions on shade mitigation technologies?**
By having an accurate understanding of the shade loss and the “real” baseline.

Root-cause of Shade Loss in Utility-scale Systems



All result in row-to-row shading and power loss

$$\text{Terrain shade loss} = 1 - \frac{Y_{\text{terrain}}}{Y_{\text{flat}}}$$



Current State of Our Industry on Shade Modeling

Shade loss ignored or categorially derated

- By default, inter-row shading in utility scale systems modeling is typically ignored, or simplistically derated
- Google earth imagery and terrain data is reviewed by modelers, and standard practice has been to ignore terrain shade loss for sites with mild to moderate E-W slopes

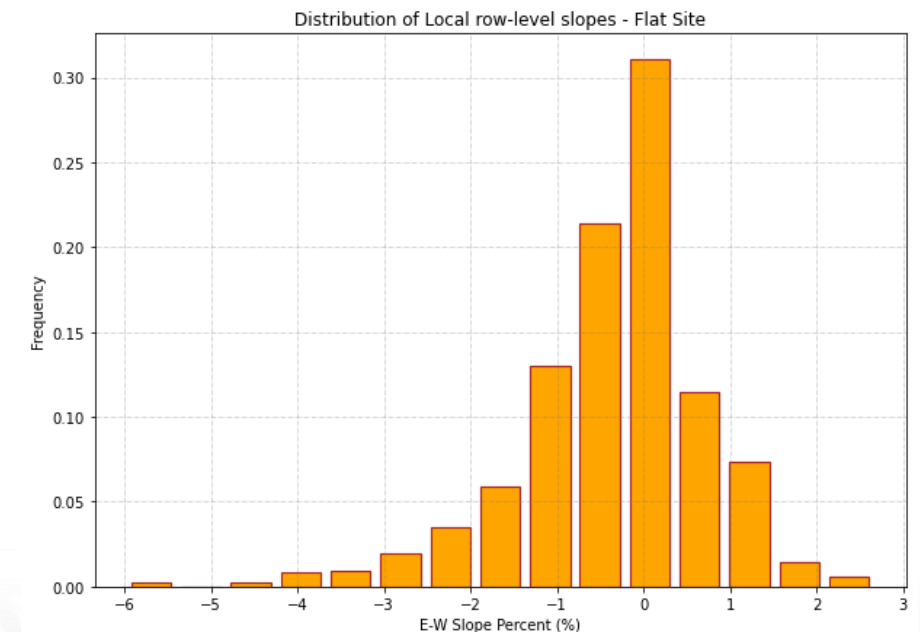


Misguided perception of flat sites

- Even a seemingly flat site may have a variety of localized slopes

Tedious modeling methods

- Slope analysis and scenarios developed
- Weighted average energy loss is calculated
- Adequate tools to model terrain shade loss didn't exist until recently, and still have a long way to go



Recent IE Publications on shade modeling

Tracker Terrain Loss Part Two

Mark A. Mikofski, Mike Hamer, Anja Neubert, MinWah Leung, Abhishek Parikh, and Rounak Kharati
DNV, Oakland, CA, 94612, USA

Abstract—Trackers on variable terrain can incur electric mismatch losses from row-to-row shading, even with backtracking. Standard and slope-aware backtracking algorithms only eliminate row-to-row shade for trackers on flat ground. Tracker terrain loss is the difference between the theoretically best performance of trackers on flat ground and the performance of trackers using standard backtracking algorithms but on variable terrain. We used Solarfarms to study tracker terrain loss by simulating the Hopewell Friends Solar power plant, which has an average 4% southwest slope. We calculated a tracker terrain loss of 2.4% when the entire site was modeled as one layout for both 5-minute and 1-hour input data. By subdividing the site into two and three layouts, the tracker terrain loss decreased to 1.8% and 1.6%, respectively. For this particular site, neither higher frequency input data nor slope-aware backtracking significantly affected the tracker terrain loss. This study is a continuation of a previous study that prompted improvements in Solarfarms' 3-dimensional tracker shading algorithm. The results of this study demonstrate that Solarfarms can now be used to calculate tracker terrain loss. In the final report we'll also compare Solarfarms with another model developed at DNV.

Index Terms—trackers, terrain, losses, backtracking

I. INTRODUCTION

Trackers increase energy output of PV systems by following the sun, maximizing the area of sunlight incident on the panels. However, most silicon modules are susceptible to electrical mismatch caused by uneven shade; therefore, trackers typically "backtrack" to avoid row-to-row shade occurring after sunrise and before sunset. The tracking and backtracking algorithms for flat horizontal and sloped ground are described by closed-form expressions [1], [2], but there is no general solution for terrain with variable slopes. If the standard backtracking algorithms for flat ground are used for trackers on variable terrain, then row-to-row shading will occur, and therefore common silicon panels will incur electrical mismatch losses. The loss has been called the "tracker terrain loss" and can be expressed as the difference between the performance of trackers on flat versus variable terrain. Evaluating the tracker terrain loss is important because it can help determine if advanced tracker algorithms are necessary to reduce the risk of plant underproduction.

To study tracker terrain loss in detail, we used Solarfarms [3] because it can perform full 3-dimensional modeling of the shade and irradiance on the trackers in any position on any terrain and calculate full sub-module electrical mismatch to determine the performance of the PV system at each time step. This study is a continuation from last year [4] in which we determined that the prior methods used in Solarfarms were too coarse to resolve row-to-row shade for trackers during backtracking. Therefore, over the past year, a new hybrid 3-

dimensional geometric shade algorithm was implemented in Solarfarms to calculate the row-to-row shade on trackers at each time step exactly without any approximations. This paper presents the results of the new Solarfarms methods applied to the same tracker simulations from last year, and expands on them slightly by testing both standard horizontal and slope-aware backtracking algorithms and running the simulations with both 5-minute and 1-hour input data resolution to determine if the tracker terrain losses are affected by either.

II. METHODS

A. Site Characteristics

The Hopewell Friends Solar power plant is a single-axis array funded by the Department of Energy and built by Cypress Creek Renewables [5] near Asheville, NC at a latitude and longitude of 35.627994° and -79.872833° respectively. The site is asymmetric, with 25-qty variable length rows of 2-in-portrait and 18-modules wide single-axis trackers. The modules are 1.978-meters long, and the rows are spaced about 7.8-meters apart, so the GCR is about 51%. There are 18-qty Longi LRS-72BP-360 360-watt bifacial modules per string, and three strings per each Huawei SUN2000-25KTL-US 25-kW inverter. The inverters each have three inputs, so that's one string per input.

The terrain has a generally southwestern slope as shown in the contour map in Fig. 1 with slightly steeper southern slopes on the east side of the array and milder western slopes on the north side of the array. The maximum and average slopes for each side from west to east in the array are summarized in Table I starting with aisle 1 at the top northern tip of the array. The maximum and average north-south slopes for every 5 rows is shown in Table II starting with the 1st row on the western side of the array.

TABLE I
SUMMARY OF EAST-WEST SLOPES

Aisle	Maximum	Average	Direction
1	7.1%	6.22%	west
2	7.1%	6.89%	west
3	7.1%	6.97%	west
4	7.9%	7.55%	west
5	7.0%	4.3%	west
6	4.0%	5.54%	west
7	6.4%	3.4%	west
8	4.0%	3.9%	west

B. Model Simulation

The system was modeled using Solarfarms [3] which allows parallel trackers to be oriented in any direction on any



Fig. 1. Contour map of terrain at Hopewell, NC, single-axis array

TABLE II
SUMMARY OF NORTH-SOUTH SLOPES

Row	Maximum	Average	Direction
1	1.7%	1.1%	south
2	2.0%	1.7%	south
3	2.0%	1.5%	south
4	4.3%	4.3%	south
5	4.0%	3.6%	south
6	4.3%	2.9%	south

slope either in a plane or following the terrain. The Hopewell Friends Solar array was modeled with 111-qty trackers with a total of 222 strings for a total DC size of 1.44-MW, which is slightly smaller than the specified size of 1.45-MW. Also the modeled site has 74 inverters with a DC/AC ratio less than one to remove the effects of clipping, versus the actual site which has only 45 inverters and a DC/AC ratio of 1.3. Also the simulated tracker spacing is uniform throughout the array and the tracker aisles are aligned, which also differs from the site specifications. Finally the panels were treated as monofacial, because bifacial is currently only possible for 2-dimensional simulations, and for this study we needed to take advantage of 3-dimensional modeling to capture the terrain. These changes were made for ease of modeling and to make sure that variable row spacing and other artifacts did not affect the results, since we only want to observe the effect of slope.

Fig. 2 shows how the site was modeled three times using a single layout, 2 layouts, and 3 layouts. As shown in Table III, this results in layouts with different orientations, so they will track slightly differently. Each model was then simulated in both tracker placement modes to determine the tracker terrain loss. The "in-plane" mode positions all trackers in the same plane so there is zero row-to-row shading, but may result in some trackers exceeding the maximum specified height above the ground. The "follow terrain" mode positions the trackers at the minimum specified height at which they don't

intersect the ground. The "layout-plane" in Table III specifies the plane of the trackers for "in-plane" mode and is the plane that determines backtracking for "follow terrain" mode. Each model was simulated with both standard [1] and slope-aware [2] backtracking, and both 5-minute and hourly irradiance input, which was obtained from the NREL Physical Solar Model v3 (PSM3) [6]. Therefore, there were a total of 24 runs, 8 for each model, with 2 placement models, 2 backtracking algorithms, and 2 input data resolutions.



Fig. 2. Sketch of 3-layout model, layout #2 with 30 strings in outlined in red, layout #1 with 54 strings in to the west and layout #3 with 27 strings in to the east. The 2-layout model contains layout #1 and #3 for 27 strings total, while layout #1 remains the same.

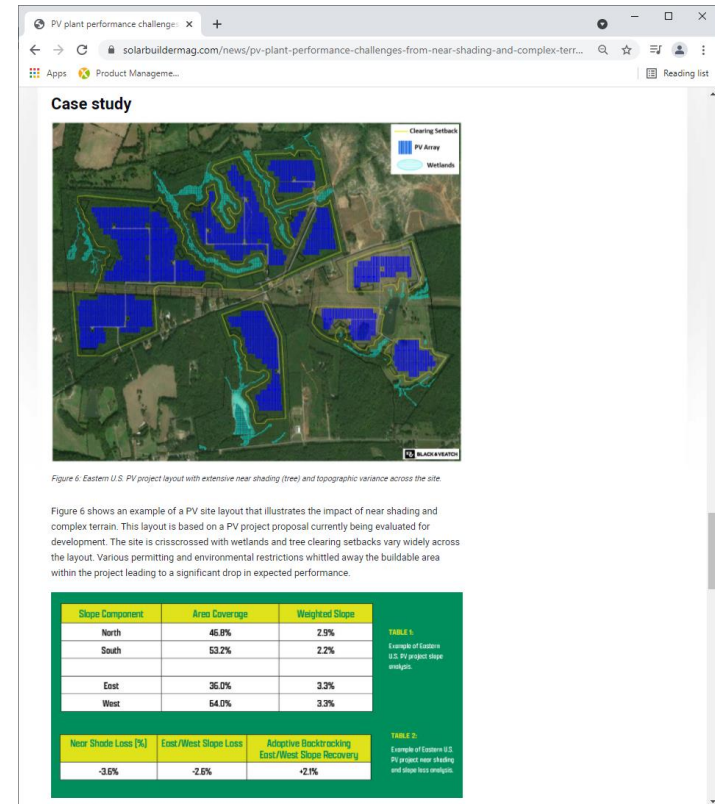
TABLE III
SUMMARY TRACKER LAYOUTS

Number of Layouts	1	2	3
Number of trackers	111	54	57
Layout plane azimuth (°)	256.9	247.26	262.18
	223.03	226.47	207.58
Layout plane tilt (°)	3.83	1.92	2.89
	1.98	1.36	2.58
Tracker tilt tilt (°)	1.85	1.13	1.14
	1.18	1.18	1.87
Tracker tilt slope (°)	2.37	2.09	2.06
	2.03	1.95	1.85

III. RESULTS

The tracker terrain loss was calculated using the following formula:

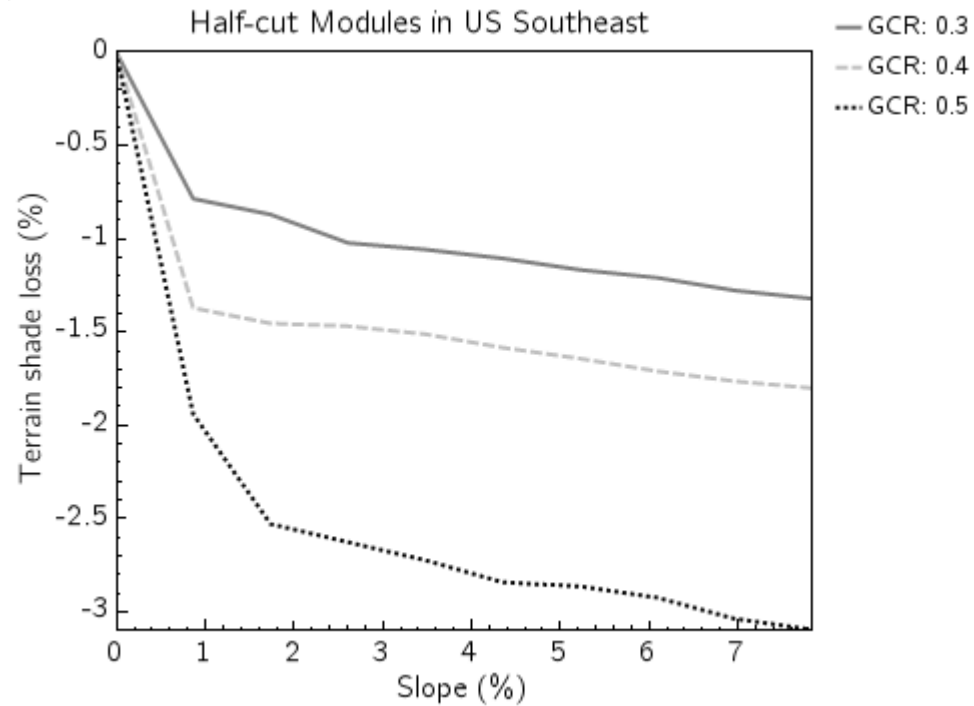
$$\text{Tracker Terrain Loss} = 1 - \frac{Y_{\text{terrain}}}{Y_{\text{plane}}} \quad (1)$$



DNV PVSC Paper, June 2021:
"Tracker Terrain Loss Part Two"

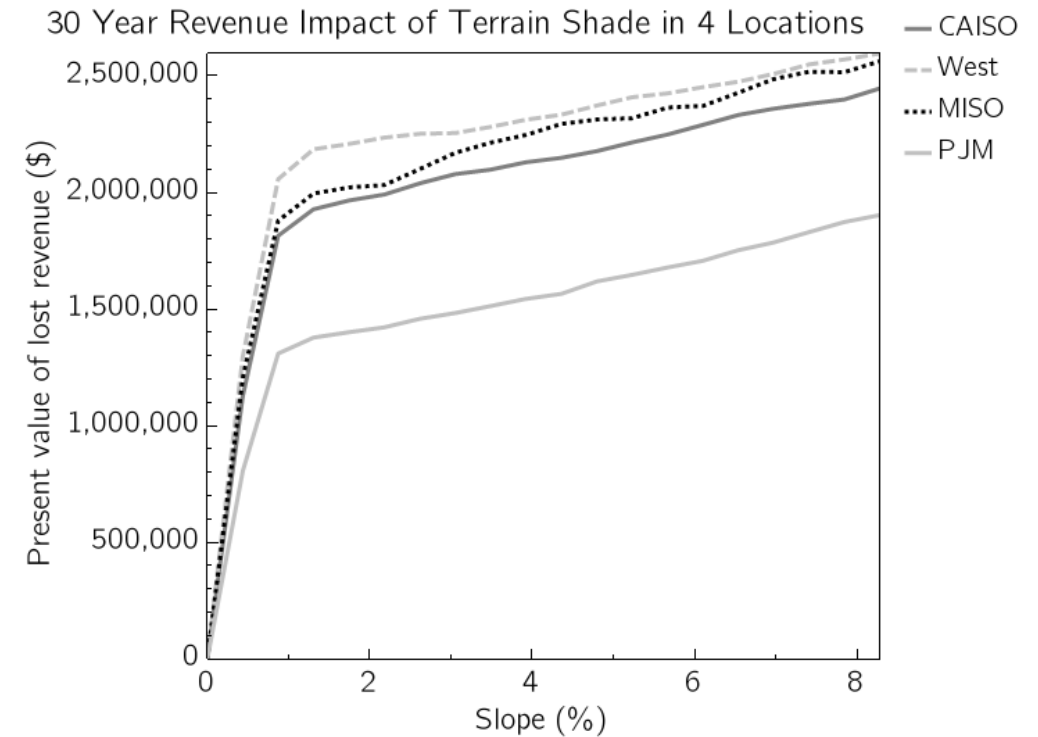
Black & Veatch Solar Builder Magazine
Online Article, May 2021
"PV plant performance challenges from
near shading and complex terrain"

How Big of a Problem is this Really?



Even for “shade tolerant” half-cut modules, in a location with high diffuse content:

- 3 % grade can result in **annual losses between 1%-2.5%** depending on GCR using standard backtracking, relative to flat terrain.



Shade loss can lead to potentially **\$Millions lost revenue.**

- Present value of terrain shade loss over 30 years discounted at 5 %, for a 100 MW plant in various locations using typical year weather data, standard backtracking, and regional PPA rates, relative to flat terrain.

Why Shade Modeling is the Low Hanging Fruit

- ❖ It helps explain at least part of the industry storyline of “underperforming solar assets”
- ❖ We now have tools to take a more systematic and disciplined approach
- ❖ Even simplistic single plane east-west ground slope modeling is better than nothing
- ❖ Once terrain shade loss is appropriately quantified, the industry can make informed investment decisions on yield boosting technologies like TrueCapture™

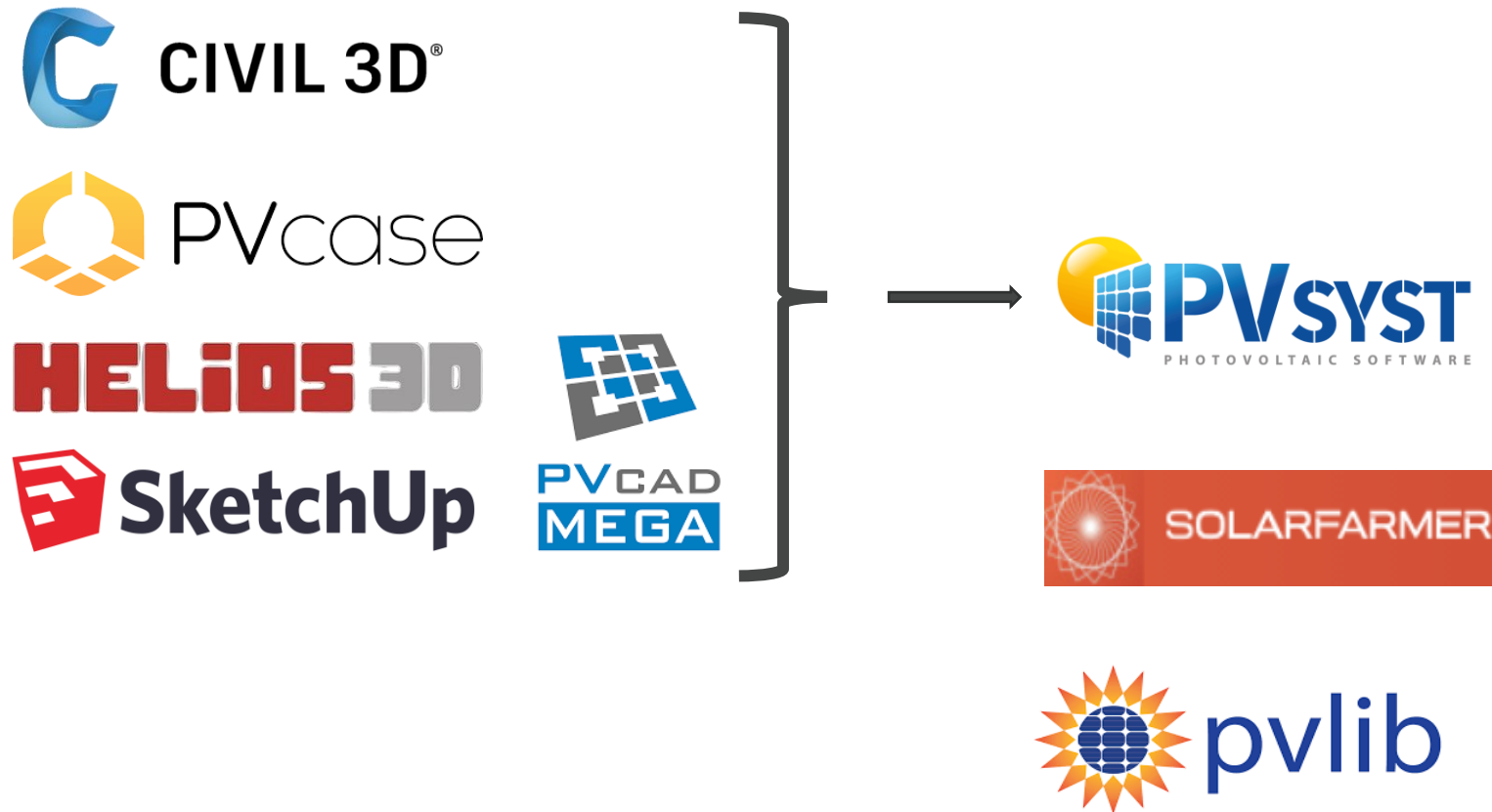
Standard backtracking on flat ground is no longer “reality” in the utility-scale solar industry.



An aerial photograph of a vast solar farm. The image shows numerous long, parallel rows of solar panels stretching across a flat, open landscape. The panels are tilted at an angle, and their shadows are cast onto the ground, creating a rhythmic pattern of light and dark. The sky is clear and blue, and the horizon is visible in the distance. The text "Shade Modeling: What the Industry Should Do about It" is overlaid on the left side of the image, with a yellow rectangular graphic element to its left.

Shade Modeling: What the Industry Should Do about It

Evolving Toolset to Model Terrain Shade Loss



- Several modeling tools/plugins in combination with **PVsynt** can be used to model trackers on a terrain to estimate inter-row shade loss
- **DNV's SolarFarmer** employs 3D shade modeling to estimate terrain caused shade loss at sub-module level
- **PVLib** (open-source) has capability to model trackers with backtracking on a uniform E-W slope scenarios

Developing Standards and Best Practices

Topographic Source

Is the topographic source from a credible source?



National survey data

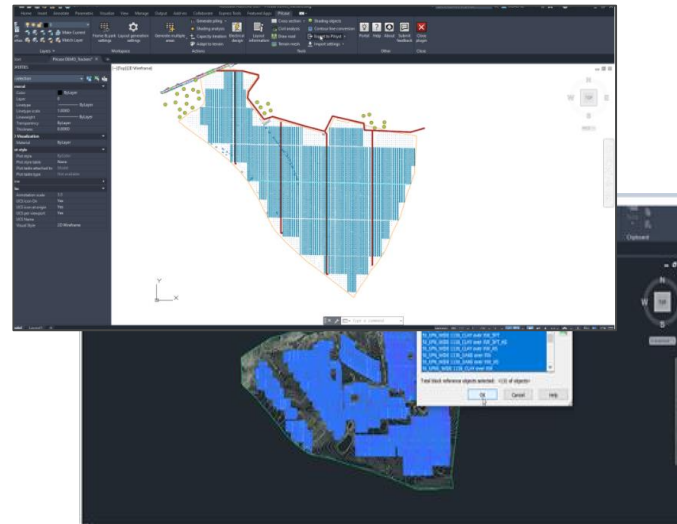
- Ex. USGS NED, SRTM, ICSM as-built site survey

Aerial topographic site survey data

- As-built

Standardized Tools

Are you using standardized tools to create site layouts with topography?



CAD based tools in civil 3D

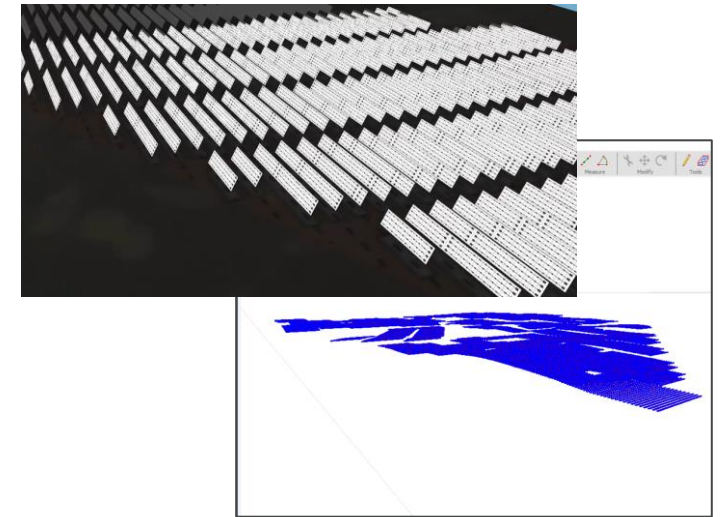
- For both trackers and fixed tilt

PV specific CAD plugins

- PVCASE
- PVCAD
- Others

Bankable Modeling Tools

Are you using available shade loss models in bankable PV modeling tools?



PVsyst

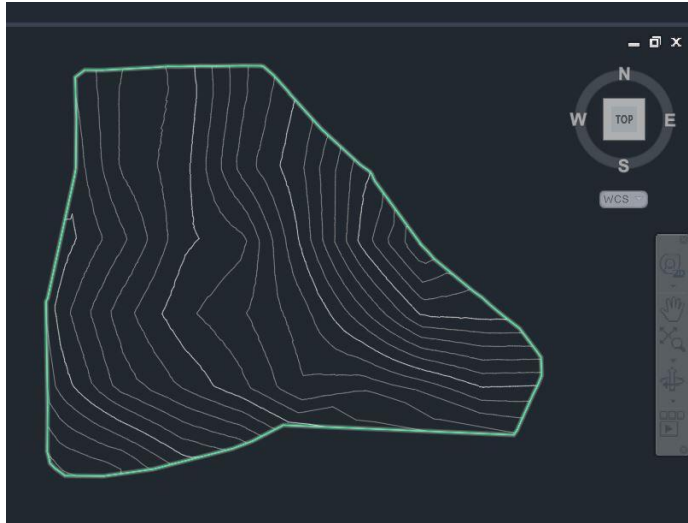
- Simple 3D shade model

SolarFarmer

- Detailed 3D shade model

Nexttracker's Recommended Process

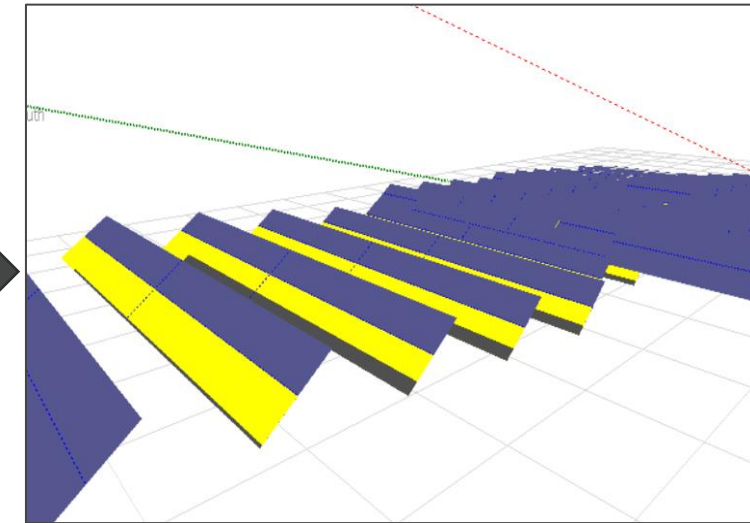
Shade modeling using AutoCAD and PVSyst combined



Translate topographic data into contour maps



Overlay project layouts with contour maps using civil 3D and convert all arrays into 3D Faces



Import CAD exported DAE file PVSyst (v7) 3D shade model and a reference tracker for backtracking

Case Study: Tracker Terrain Shade Loss Modeling

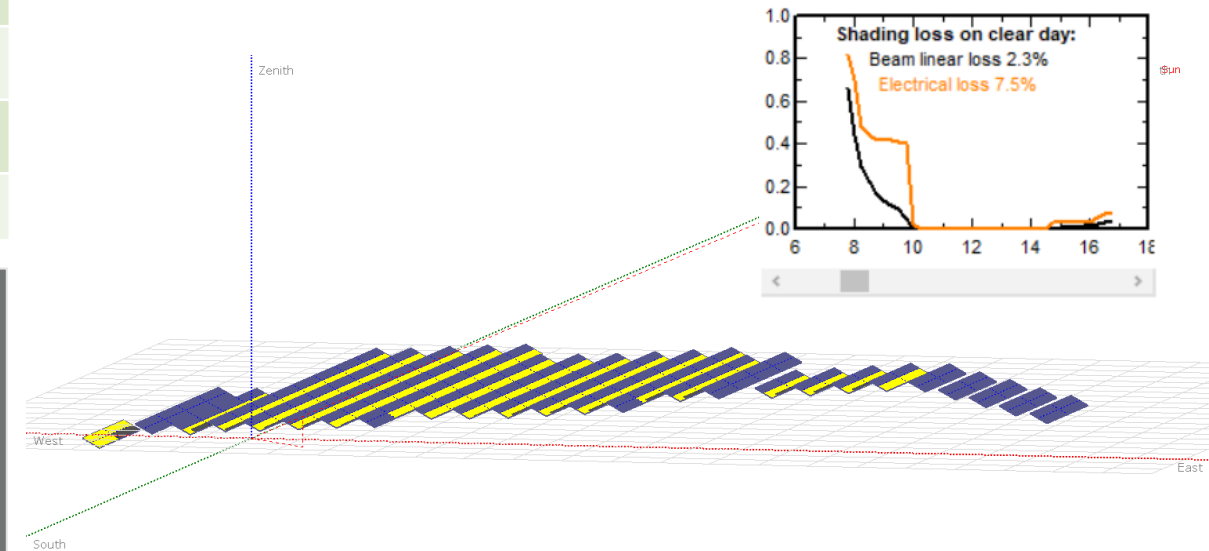
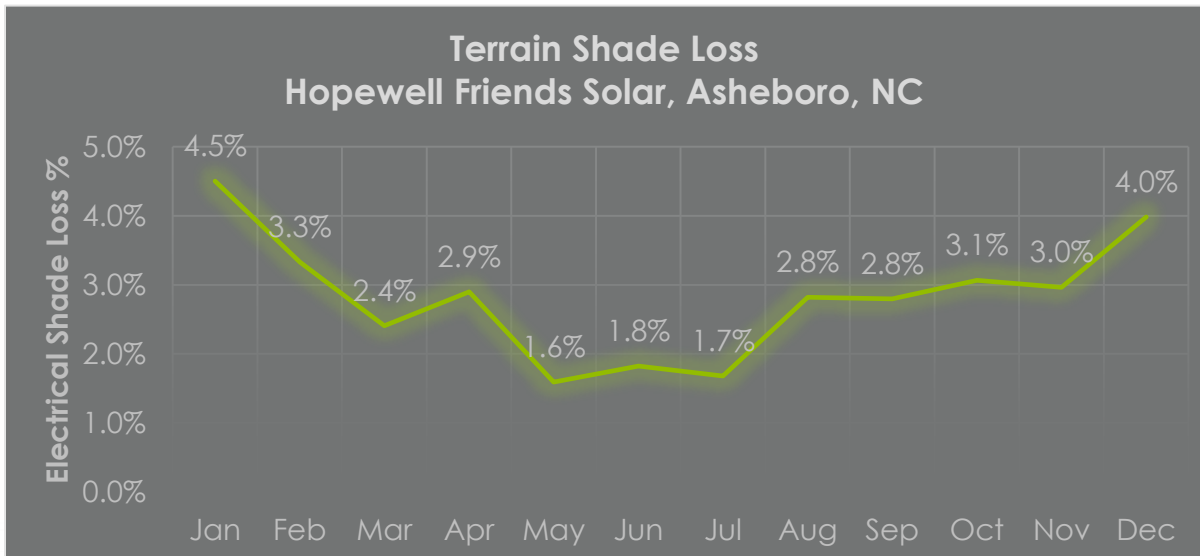
Asheboro, NC – 1.44 MW

Module Type	Longi LR6-72BP-360 Bifacial (2 in Portrait)
Average E-W slope	4.3%
Average N-S slope	2.8° S (68%); 1.2° N (36%)
GCR	51%
Diffuse Fraction	39%
Tracking Algorithm	Standard Back-tracking
Weather Source	NSRDB PSM v3 (hourly)



Case Study: Tracker Terrain Shade Loss Modeling (cont.)

Shade Loss Model	Annual Terrain Shade Loss %
PVsyst*	-2.9%
DNV SolarFarmer ^[1]	-2.3%
DNV Simple Terrain Model ^[1]	-2.1%
* Includes N-S Slope contribution	



Trackers on terrain - Shaded sub-strings appear as yellow areas

[1] Mikofski, M.; Hamer, M.; Neubert, A.; Leung, M.; Parikh, A.; Kharait, R.; Tracker Terrain Loss Part Two. IEEE Photovoltaic Specialists Conference, June 2021.

Summary

- Terrain caused shade loss is not a trivial problem anymore, that can be ignored during pre-construction system design and performance modeling
- Terrain shade loss can be incurred on sites with traditional backtracking strategies. Custom backtracking algorithms are available to mitigate these shade losses
- Designers can use wide range of tools to include site topography within traditional design practices using CAD
- PVsyst can now support file formats exported from CAD based tools to model performance impact of terrain for single-axis tracker systems
- Standardized terrain shade modeling process should be developed to create accurate & bankable production expectations.



Thank you!



Tracker terrain modelling

MinWah Leung

Senior Engineer, Solar Technology

19 August 2021

Broad and deep expertise in solar projects



| FEASIBILITY

- › Feasibility studies
- › Utility grid integration
- › Environmental permitting
- › Component technology reviews
- › Component qualification testing
- › Type and component certification of PV inverters

| ENGINEERING & DEVELOPMENT

- › Due diligence / Independent engineering
- › Owner's engineering
- › Energy assessment
- › Pre-construction engineering
- › Interconnection support
- › Project certification

| CONSTRUCTION & COMMISSIONING

- › Due diligence/ Independent engineering
- › Owner's engineering
- › Construction oversight
- › System testing and inspection
- › Project certification and grid code compliance
- › Declaration of conformity
- › Project certification

| OPERATION

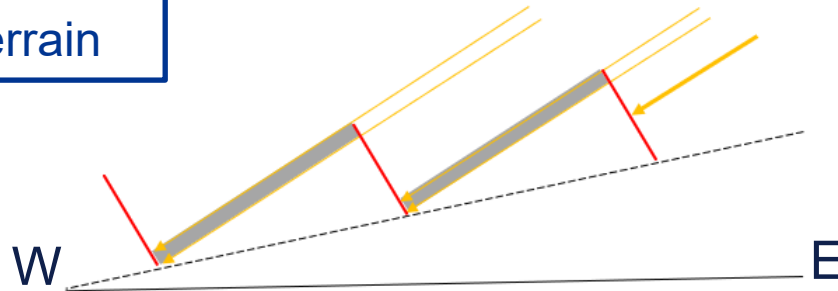
- › Performance validation
- › Resource and energy forecasting
- › Existing asset consulting, inspections and decommissioning
- › Refinancing and mergers and acquisitions advisory services
- › Forensic investigations
- › Monitoring, control and asset management
- › Project certification

Uneven terrain



undulating terrain

mono-slope terrain



IE perspective

industry trend towards more hilly terrain

Energy impact - slopes

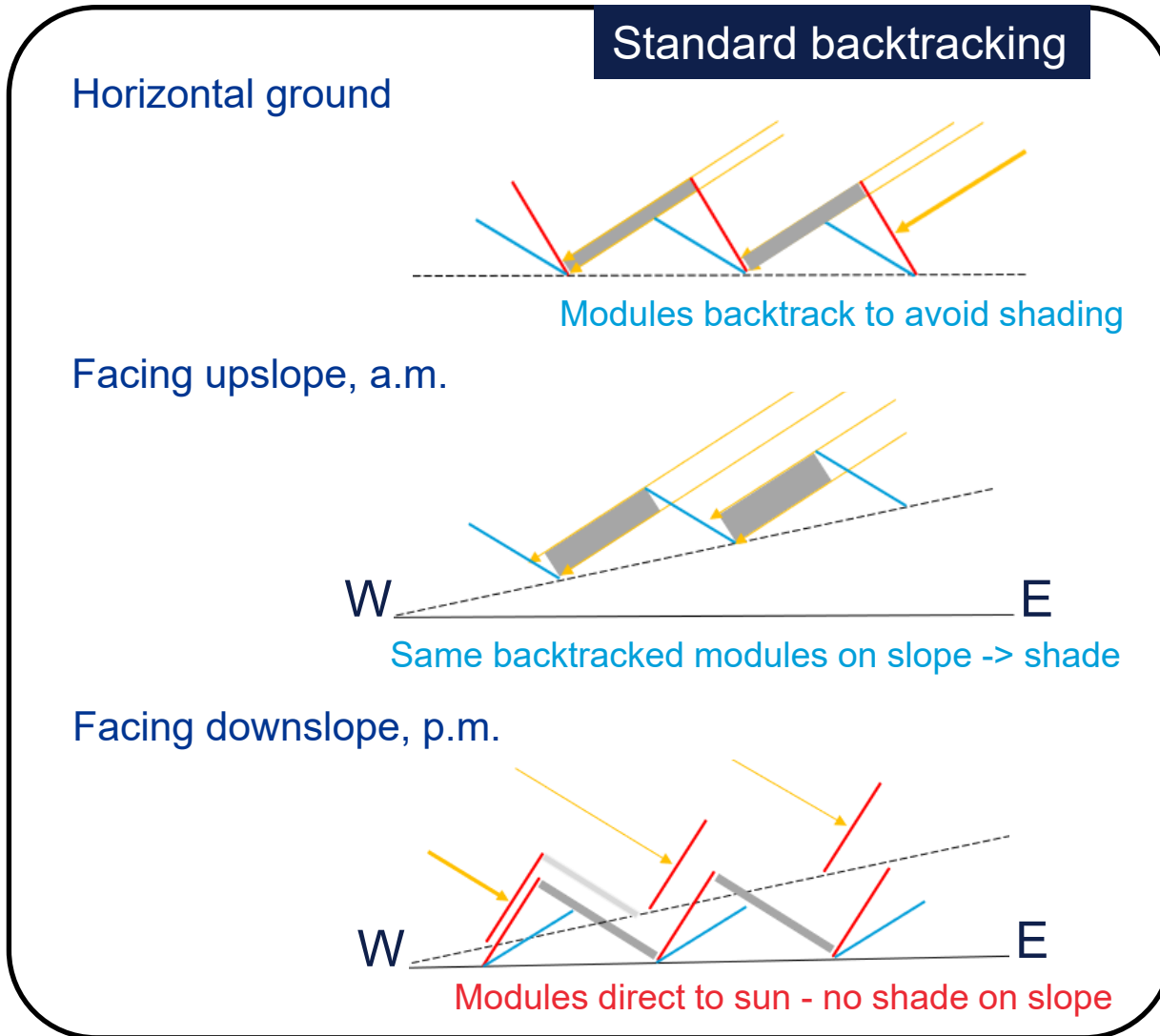
North-South: energy boost when tracker axis tilted towards equator

East-West: row-to-row shade loss (dominant energy loss factor)

DNV models

- Shade loss correlation
- SolarFarmer

What is tracker terrain loss?



$$\text{Tracker Terrain Loss} = 1 - \frac{Y_{\text{terrain}}}{Y_{\text{horizontal}}}$$

Standard backtracking prevents row shading only for trackers on horizontal ground

Array needs to go to flatter angle to avoid row shading

Array backtracks to flatter angle prematurely

DNV terrain loss model

Shade loss correlation

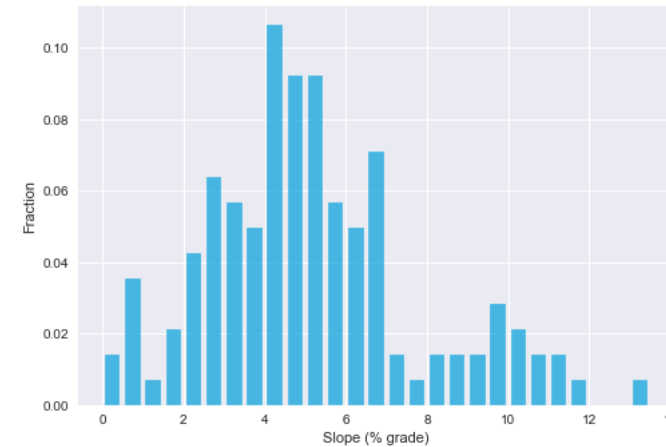
- DNV developed correlation equations from 240 Pvsyst simulations
- Calculate shade loss using only 3 factors from project site:
Diffuse Fraction, Ground Cover Ratio, & E-W slope

Site terrain data analysis

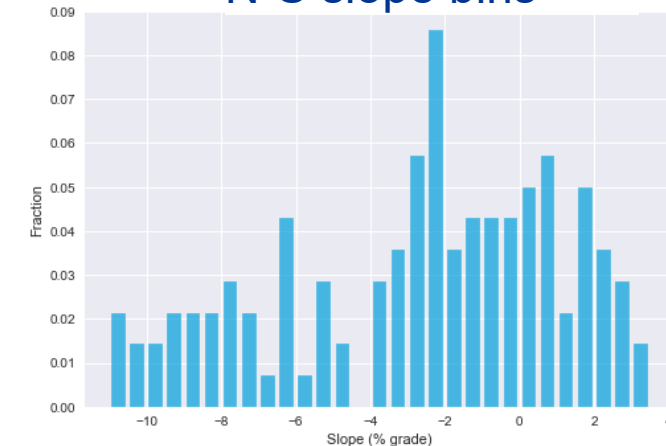
- Evaluate terrain (or pile heights) into slope bins
- E-W impact: apply shade loss equations for each bin
- N-S impact: apply directly in Pvsyst

Current method used in DNV's independent energy assessments

E-W slope bins



N-S slope bins

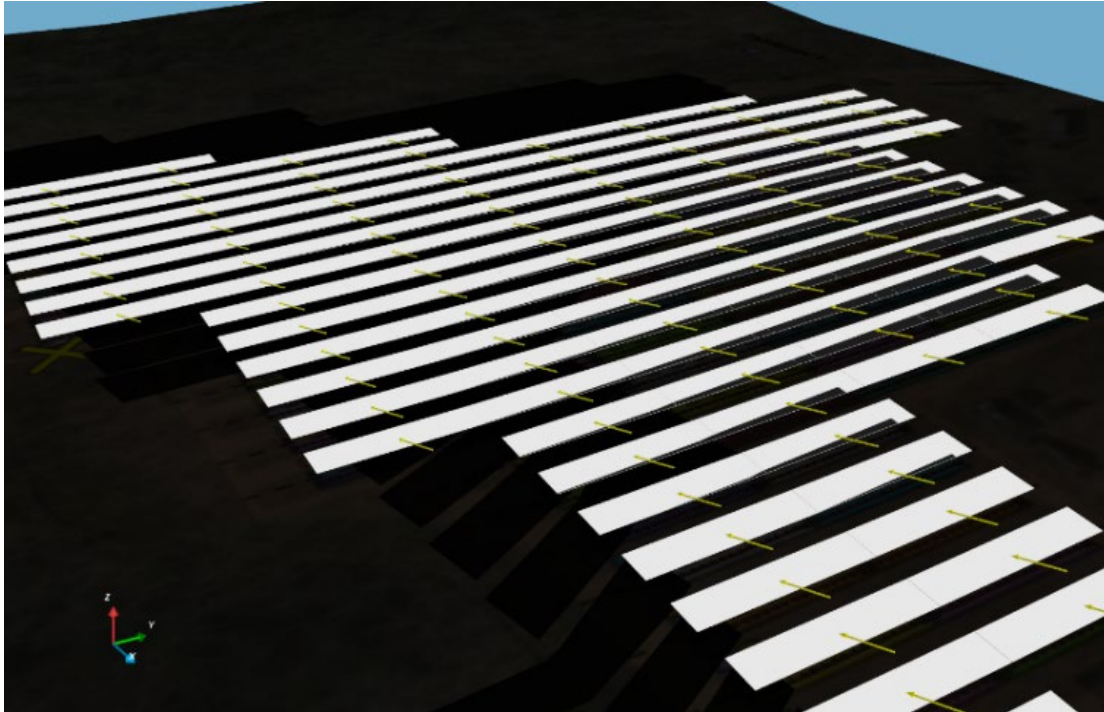


DNV shade loss correlation model

40% GCR	Shading Loss*		
E-W slope %	Diffuse Fraction		
	0.3	0.4	0.5
2	4 %	3 %	3 %
5	7 %	5 %	5 %
10	8.5 %	7 %	6 %
15	10 %	8 %	7 %
20	12 %	10 %	8 %
25	14 %	11 %	9.5 %

*not recovery gains – losses may or may not be completely recoverable through custom algorithms

SolarFarmer model



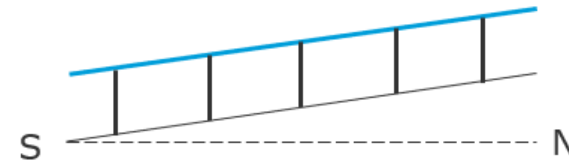
SolarFarmer: DNV's energy modelling software

- Detailed 3D terrain modeling
- Performs custom backtracking algorithms
 - Adjust GCR inputs
 - Slope-aware backtracking (NREL)
 - Input custom angles for each tracker row
- Can adjust tracker placement on terrain

SolarFarmer tracker placement

in-plane

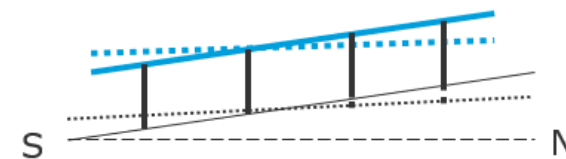
Tracker axes form a plane



Can have N-S tracker axis tilt as well as E-W slope

follows terrain

Tracker axes are not co-planar



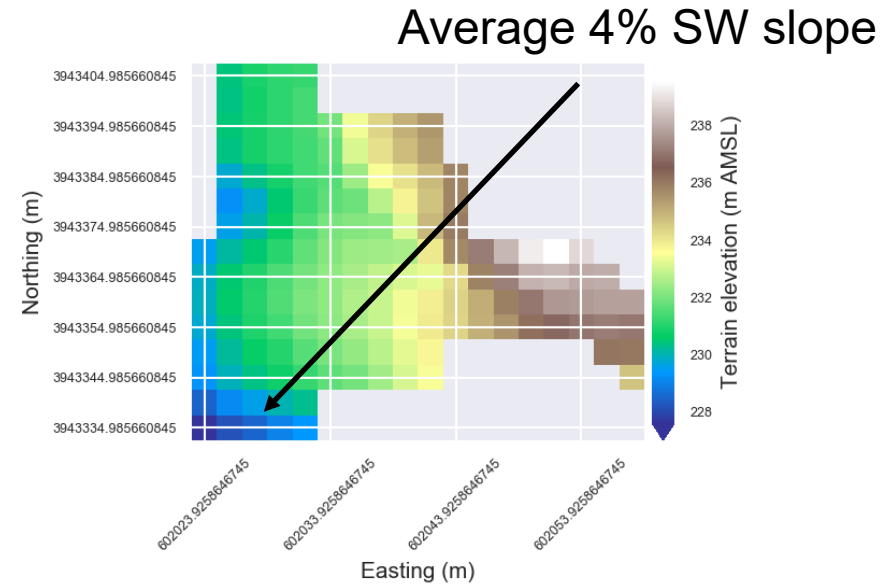
Offset tracker axes create non-uniform triangular shadows

Project simulation

<i>Location</i>	Asheboro, North Carolina
<i>Diffuse fraction</i>	0.39
<i>Ground cover ratio</i>	0.51

	Standard backtrack
SolarFarmer	- 2.3%
DNV terrain model (Net impact)	- 2.1%
E-W slope impact	- 3.2%
N-S slope impact	+1.1%

- DNV terrain loss model results similar to SolarFarmer
- SolarFarmer: detailed analysis, more setup options, longer computation time
- DNV terrain loss model: shorter computation time



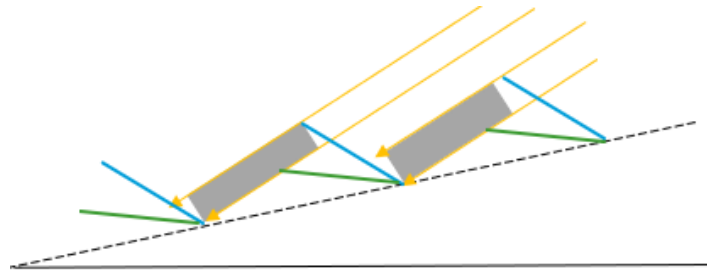
Shade loss mitigation



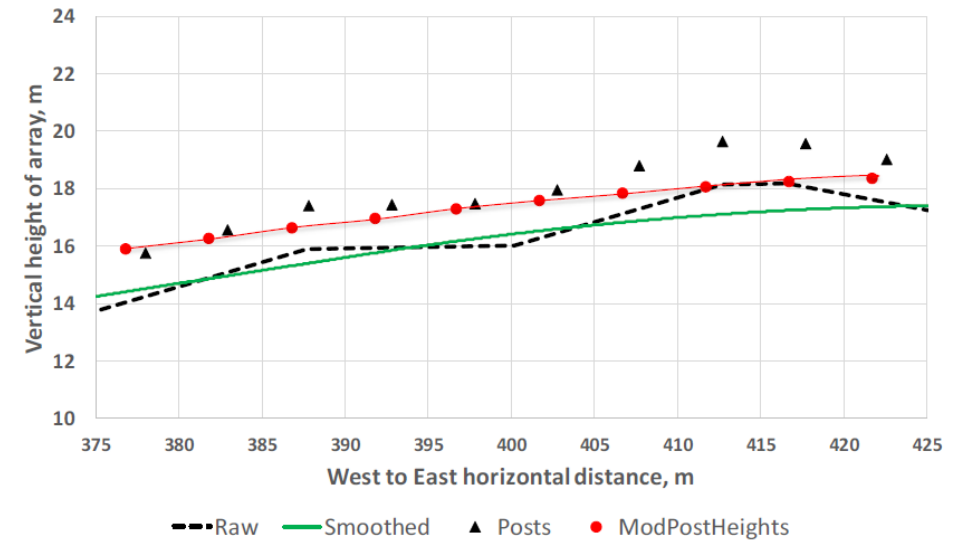
Shade-tolerant modules
(e.g. half-cut)

10

Custom backtracking software



Spot grading
Pile height adjustments



Conclusions

- Slopes and varying terrain becoming more common in solar projects
- Modeling hilly terrain increasingly important
- DNV considers terrain modeling as standard best practice
- DNV has incorporated terrain modeling into independent energy assessments



Thank you!

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