PVTECH TECHTalk

WEBINAR

MODERATED BY

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

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19 AUGUST 2021

DNV

nextracker
A Flex Company

Shade Modeling for Utility-Scale PV Plants

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

Presenting:

Aron Dobos, Director of Software Product Management

Neelesh Umachandran, Performance Engineering

PVTECH TECHTalk

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.

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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.

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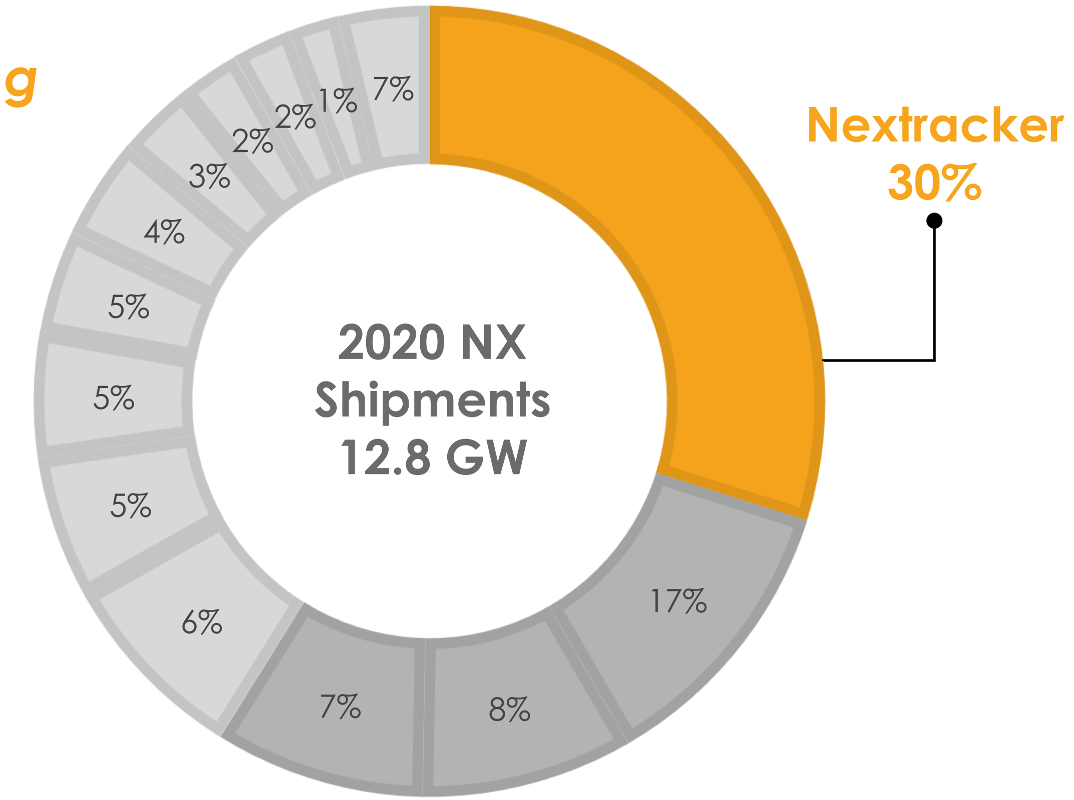


#1 market share leader six consecutive years: 2015-20

Source: IHS Markit 2021

NX Ecosystem and Evolving Industry Needs

SOLAR TRACKER PORTFOLIO

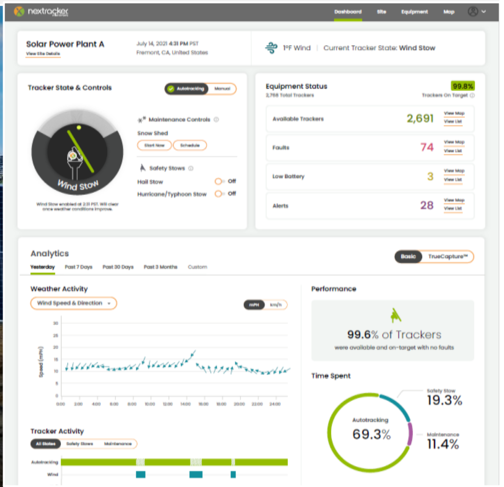

NX Horizon™ & NX Gemini™

✓ 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.

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Continued U.S. Diversification of Customer Base

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

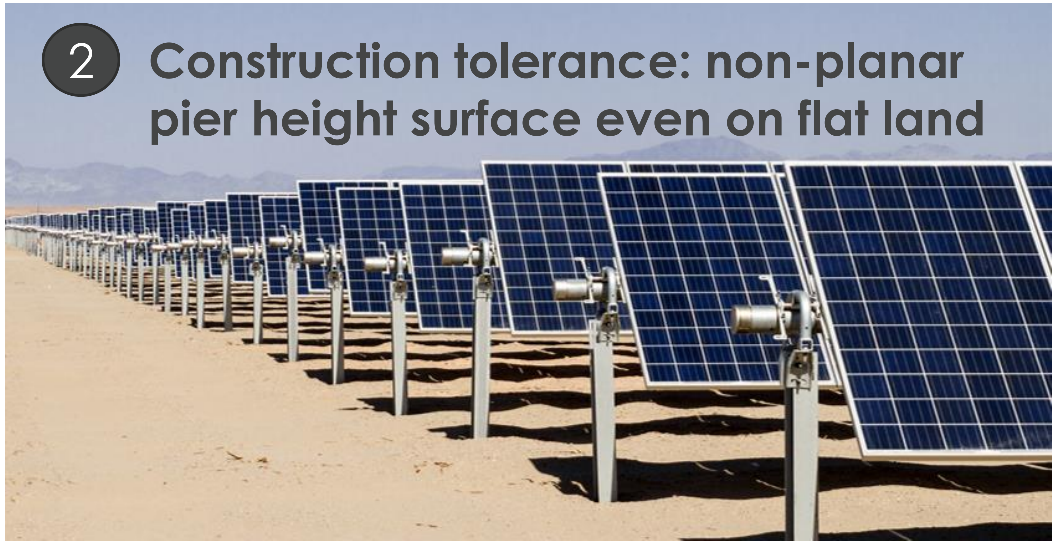
SWINERTON RENEWABLE ENERGY
AREVON
Mortenson construction
Intersect Power
BLATTNER ENERGY
174 POWER GLOBAL
DUKE ENERGY
SIGNAL ENERGY CONSTRUCTORS
Dominion Energy
EDF renewables
engie
DE Shaw & Co
NEXTera ENERGY
ROSENDIN ELECTRIC
7X.energy SOLAR EVOLVED
McCARTHY

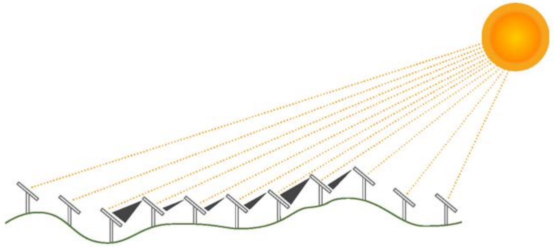
Why Shade Modeling Matters

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

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

Current State of Our Industry on Shade Modeling

Shade loss ignored or categorially derated

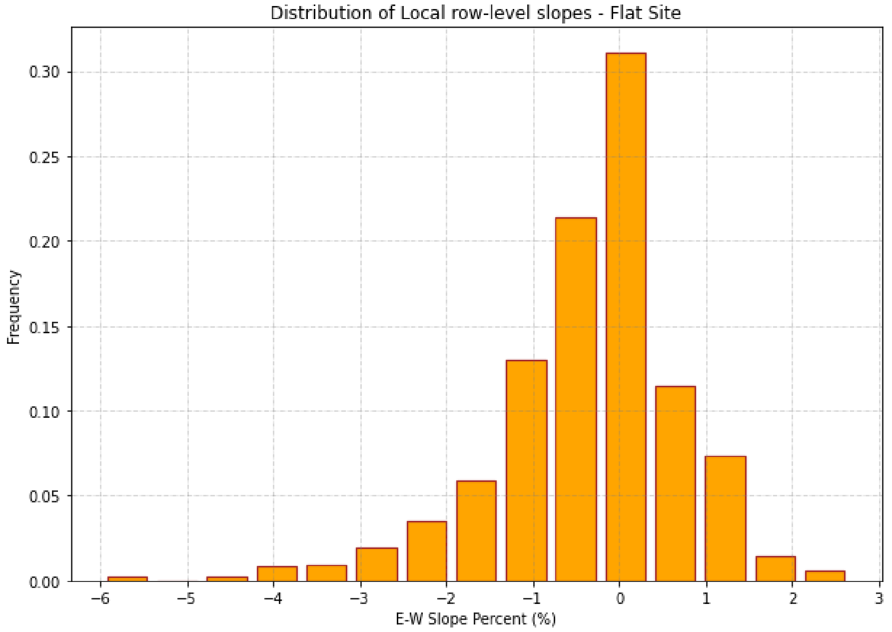
- By default, inter-row shading in utility scale systems modeling is typically ignored, or simplistically derated
- Google earth imagery and terrain data is reviewed by modelers, and standard practice has been to ignore terrain shade loss for sites with mild to moderate E-W slopes

Misguided perception of flat sites

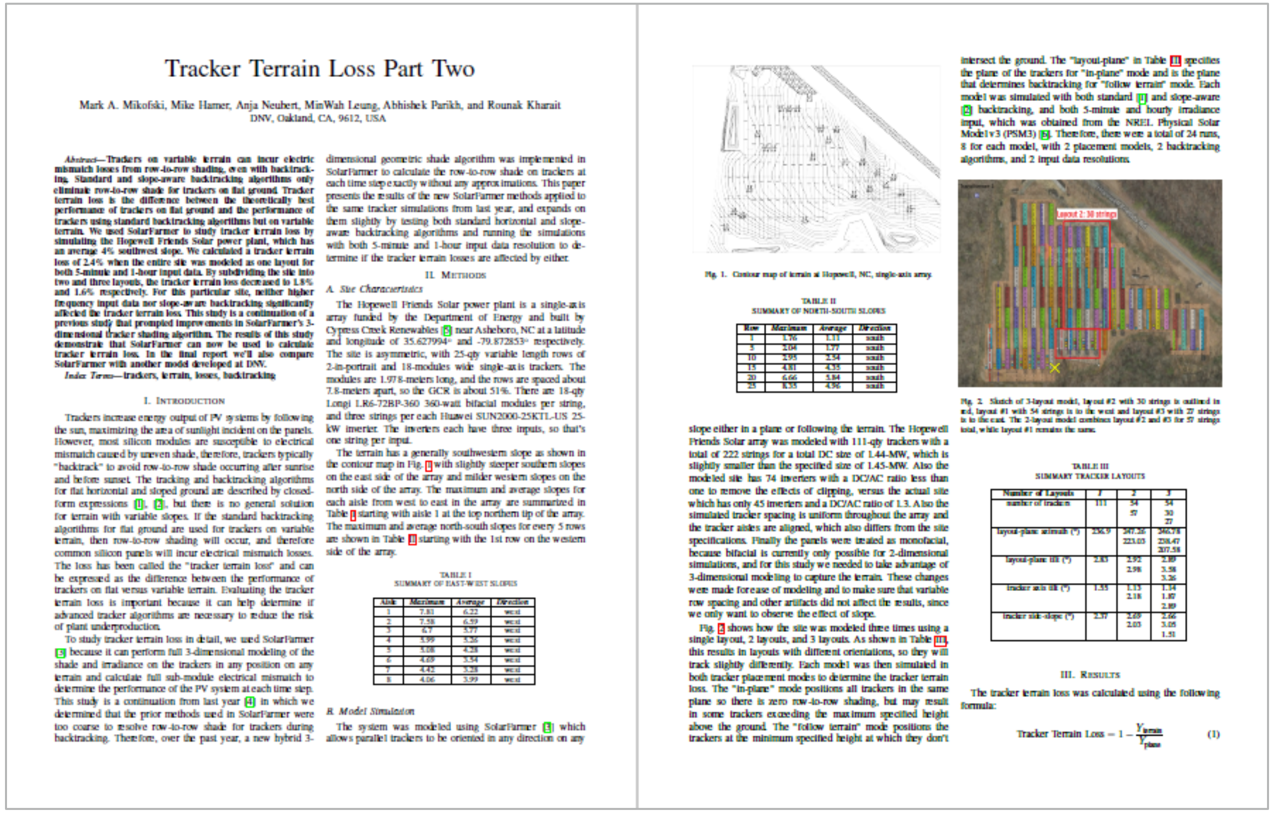
- Even a seemingly flat site may have a variety of localized slopes

Tedious modeling methods

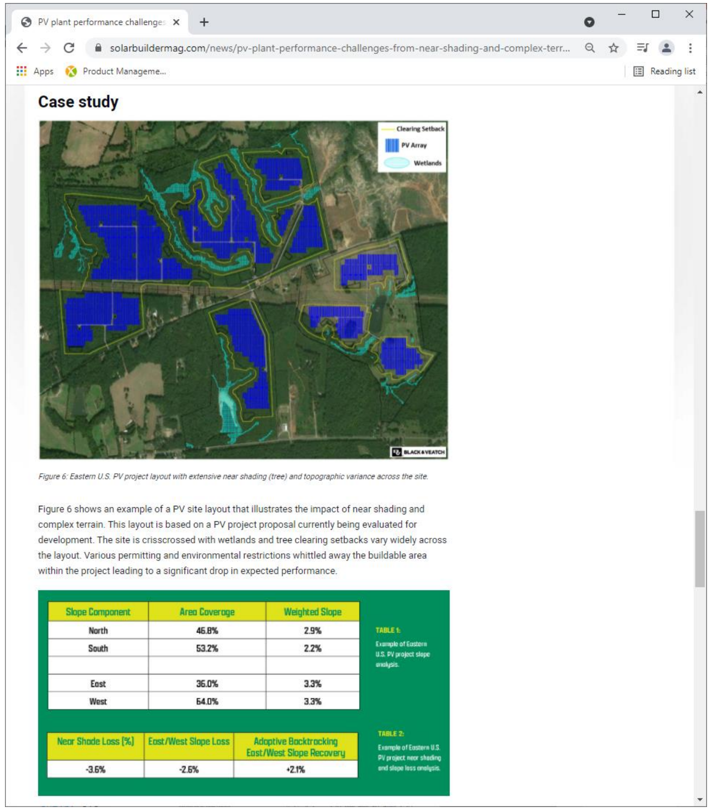
- Slope analysis and scenarios developed
- Weighted average energy loss is calculated
- Adequate tools to model terrain shade loss didn't exist until recently, and still have a long way to go



Recent IE Publications on shade modeling

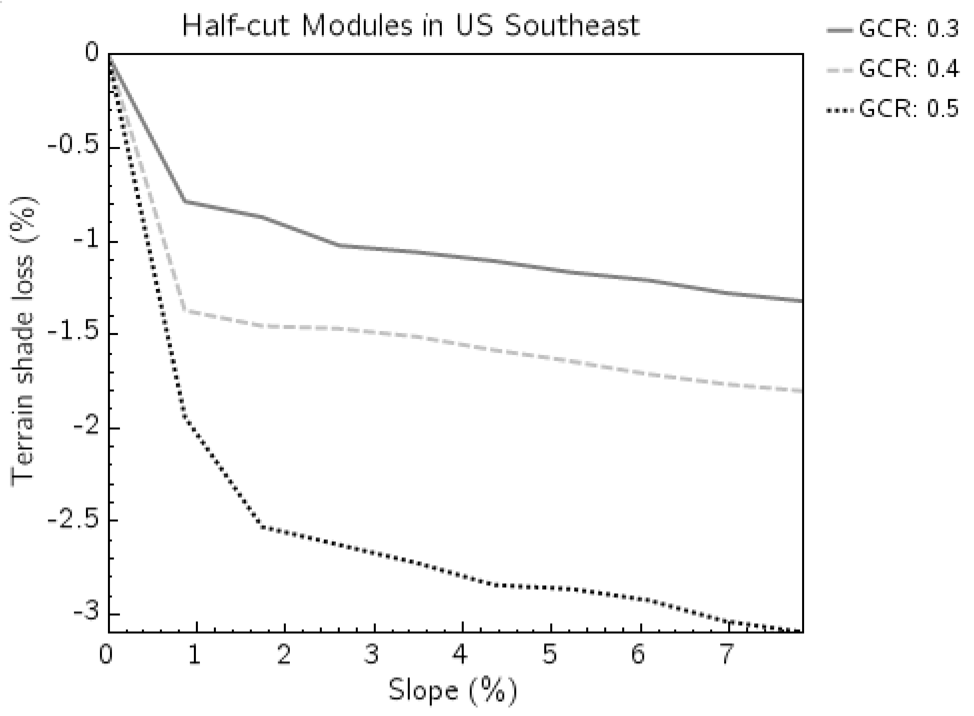


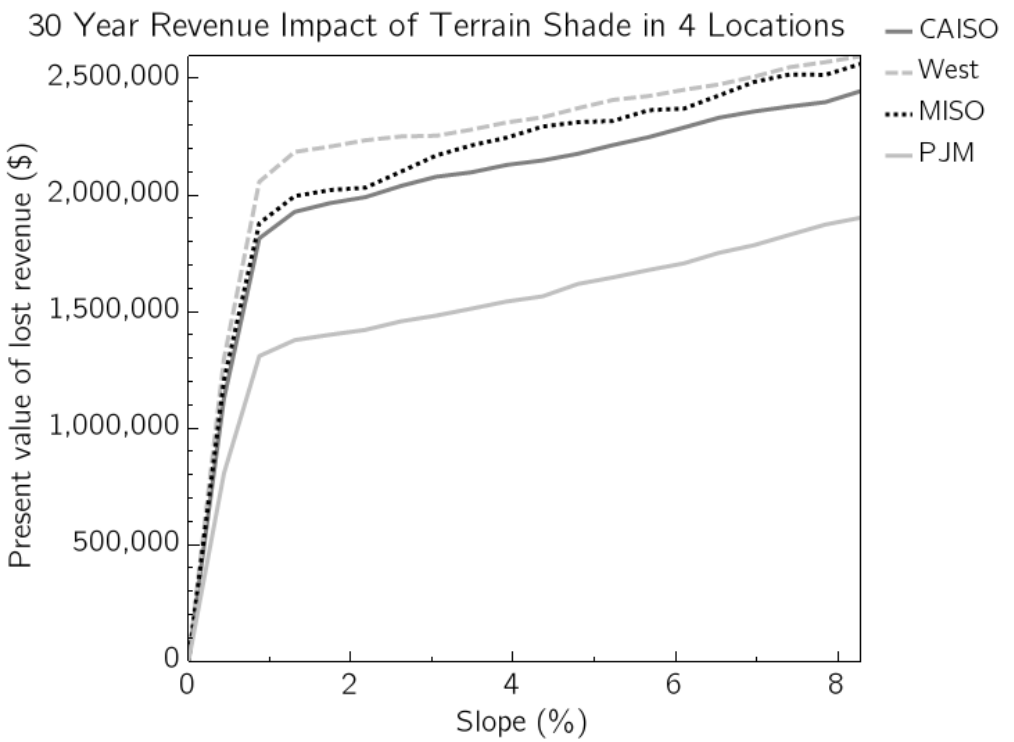
DNV PVSC Paper, June 2021:
“**Tracker Terrain Loss Part Two**”



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.

Shade Modeling: What the Industry Should Do about It

Evolving Toolset to Model Terrain Shade Loss

- Several modeling tools/plugins in combination with **PVsyst** 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

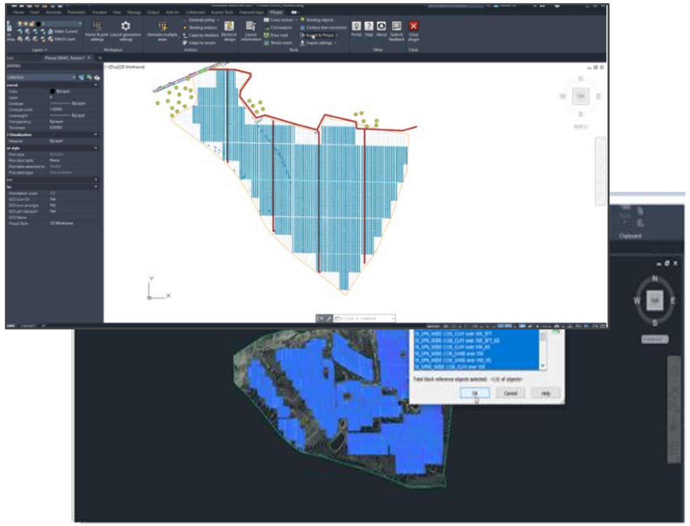
- Ex. USGS NED, SRTM, ICSM as-built site survey

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

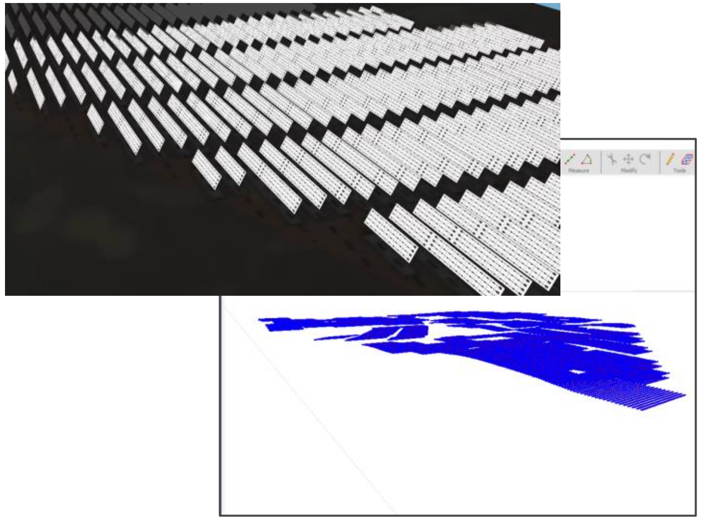
- For both trackers and fixed tilt

PV specific CAD plugins

- PVCase
- PVCAD
- Others

Bankable Modeling Tools

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



PVsyst

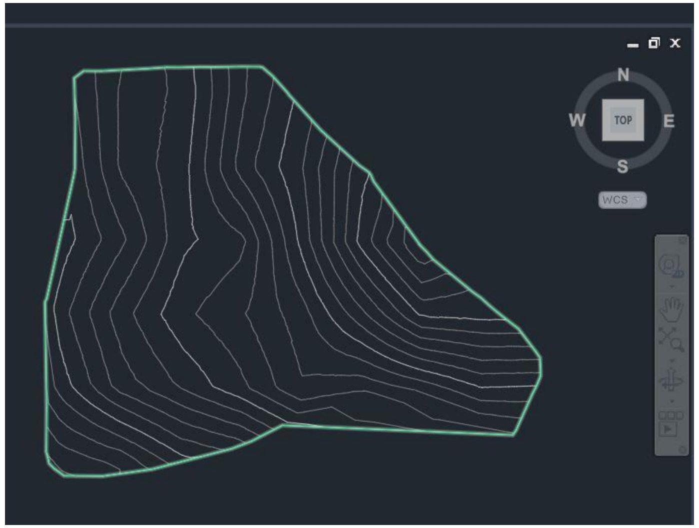
- Simple 3D shade model

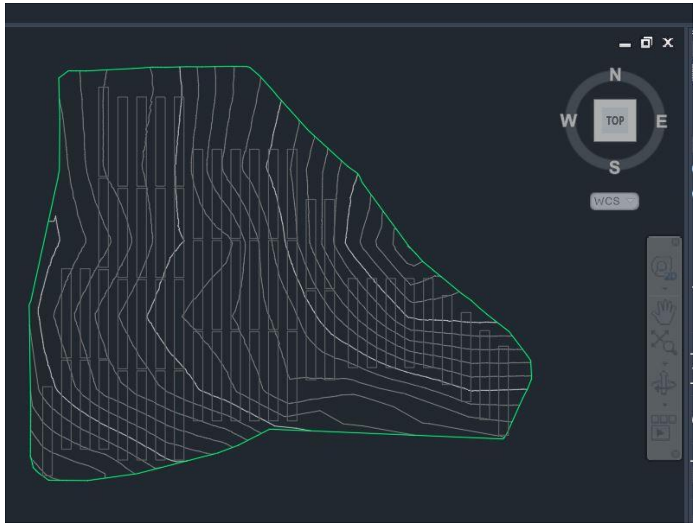
SolarFarmer

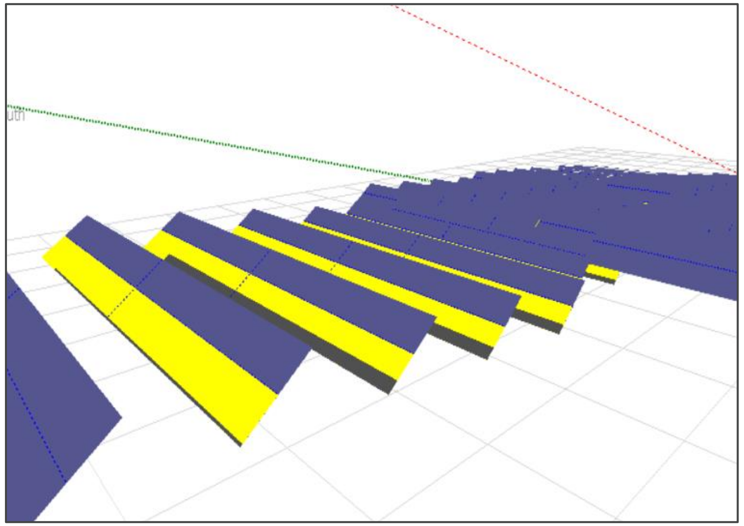
- Detailed 3D shade model

Nextracker'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

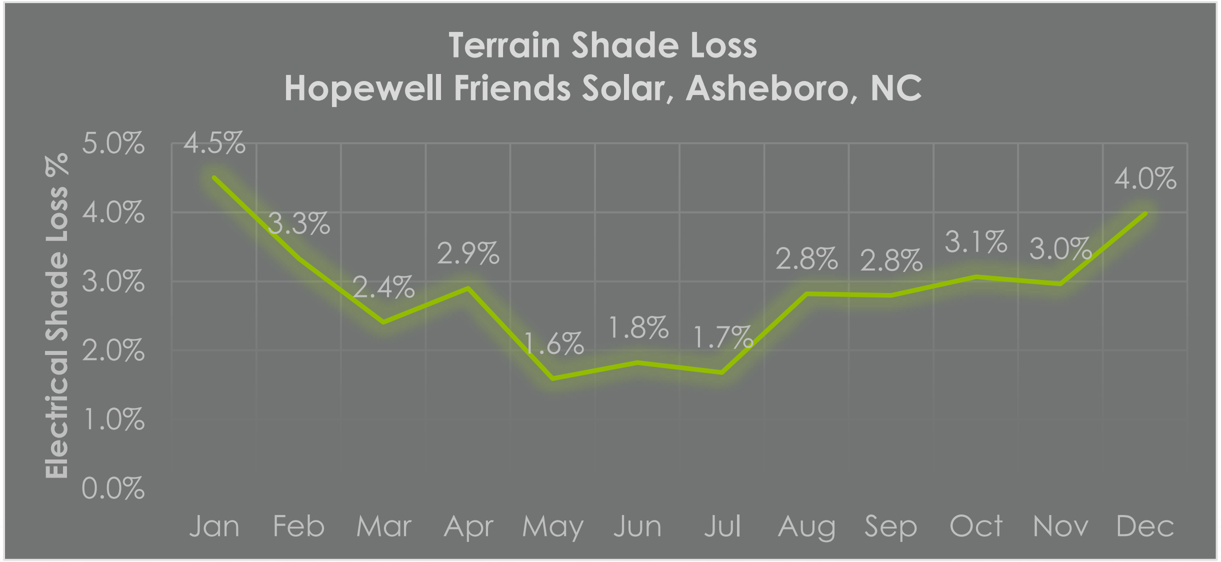
Import CAD exported DAE file PVsyst (v7) 3D shade model and a reference tracker for backtracking

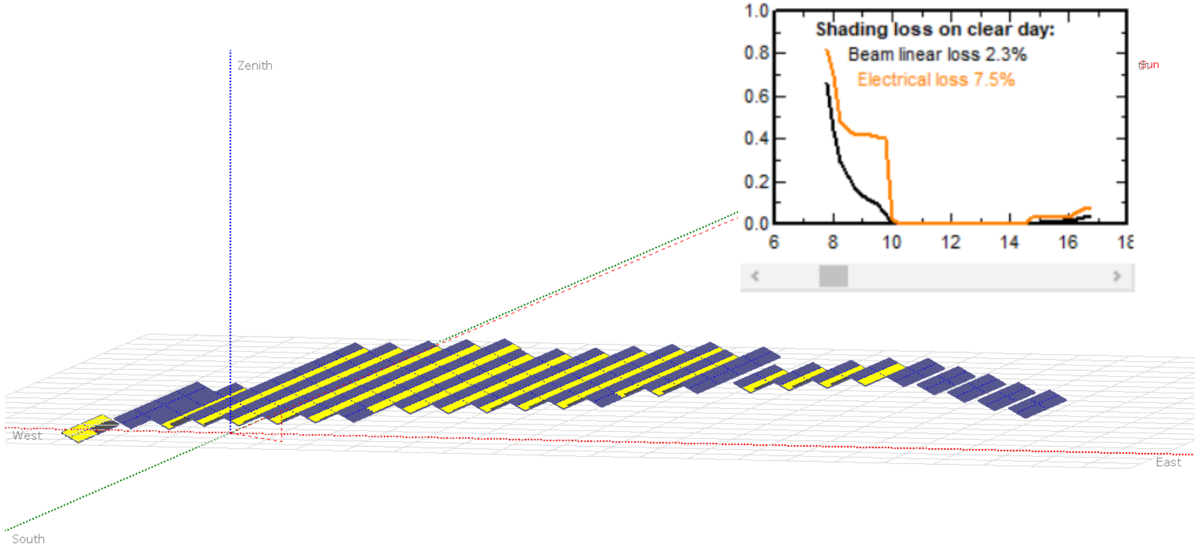
Case Study: Tracker Terrain Shade Loss Modeling

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*	



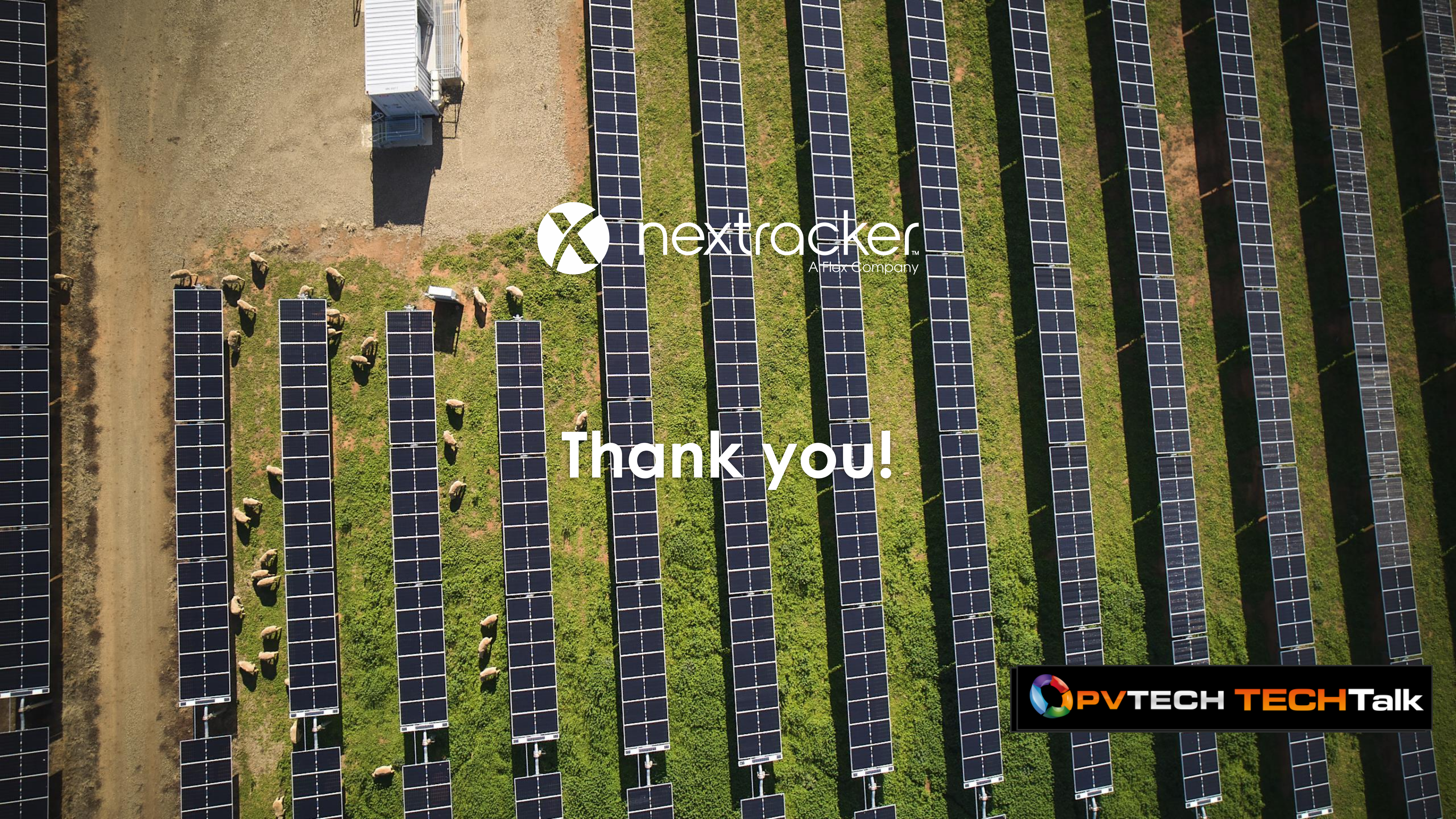


Trackers on terrain - Shaded sub-strings appear as yellow areas

[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.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WHEN TRUST MATTERS

Tracker terrain modelling

MinWah Leung

Senior Engineer, Solar Technology

19 August 2021

Broad and deep expertise in solar projects

FEASIBILITY	ENGINEERING & DEVELOPMENT	CONSTRUCTION & COMMISSIONING	OPERATION

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

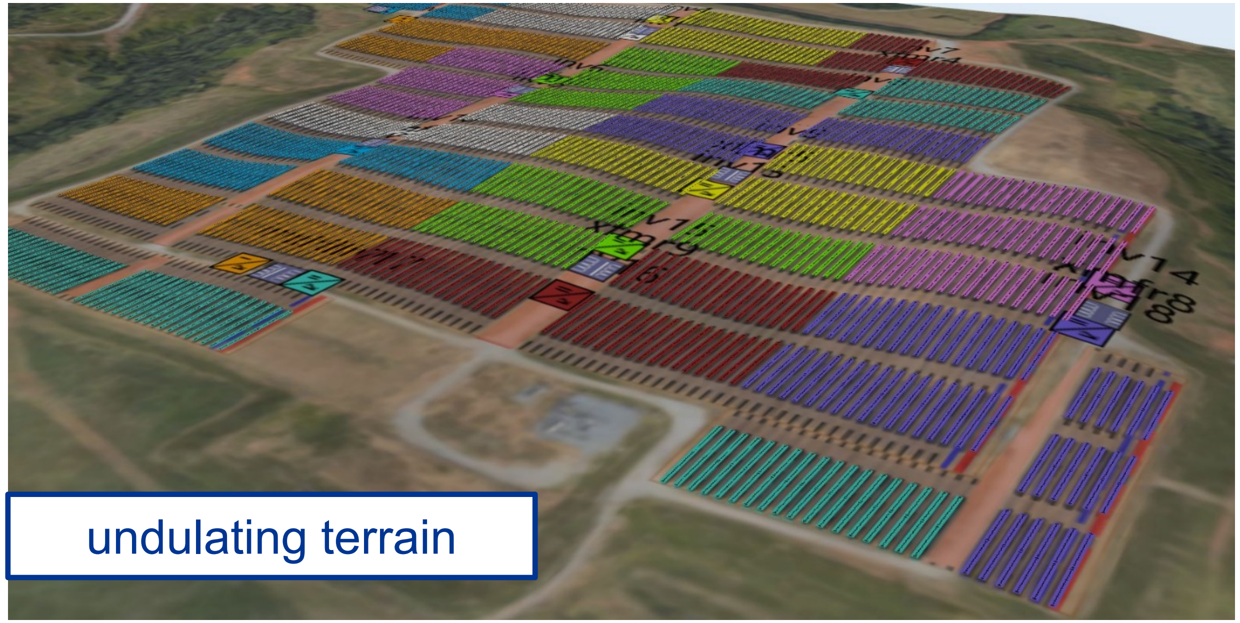
CONSTRUCTION & COMMISSIONING

- 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

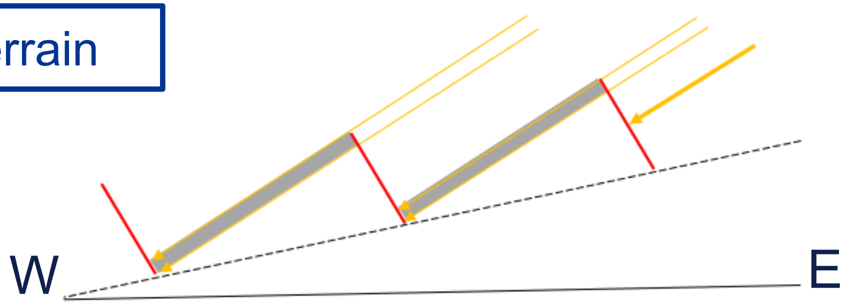
- Performance validation
- Resource and energy forecasting
- Existing asset consulting, inspections and decommissioning
- Refinancing and mergers and acquisitions advisory services
- Forensic investigations
- Monitoring, control and asset management
- Project certification

Uneven terrain



undulating terrain

mono-slope terrain



IE perspective

industry trend towards more hilly terrain

Energy impact - slopes

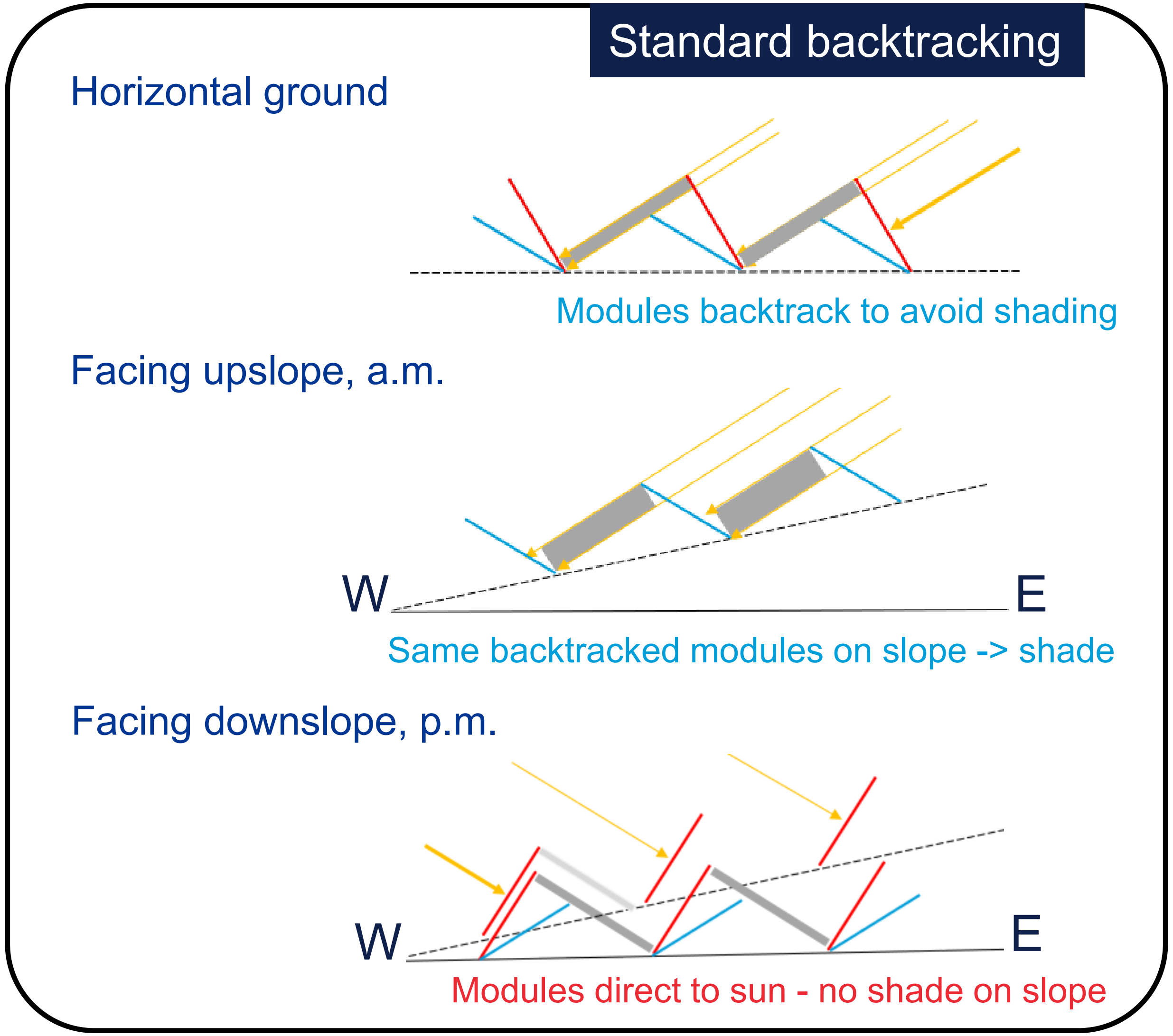
North-South: energy boost when tracker axis tilted towards equator

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:

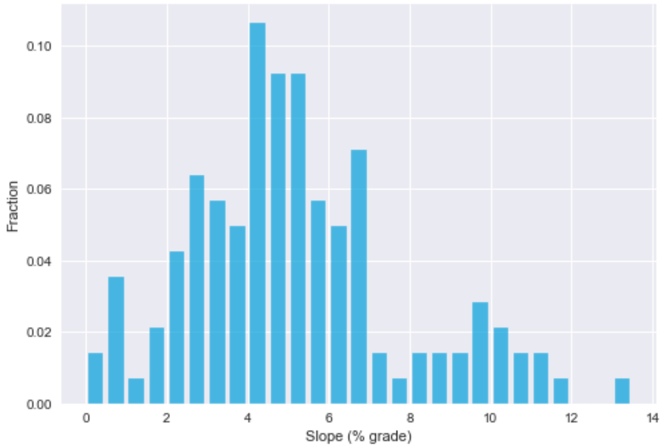
Diffuse Fraction, Ground Cover Ratio, & E-W slope

Site terrain data analysis

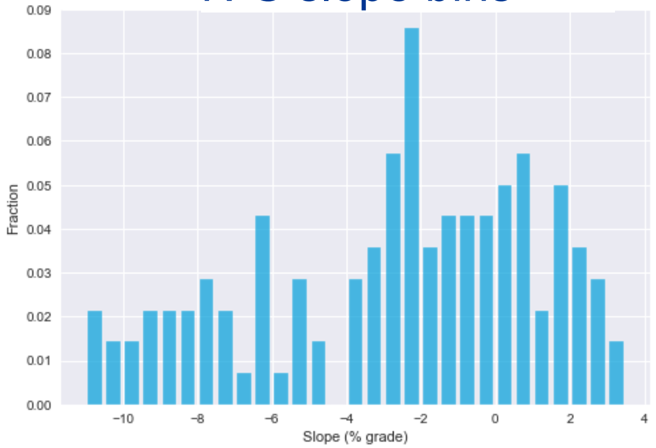
- Evaluate terrain (or pile heights) into slope bins
- E-W impact: apply shade loss equations for each bin
- N-S impact: apply directly in Pvsyst

Current method used in DNV's independent energy assessments

E-W slope bins



N-S slope bins

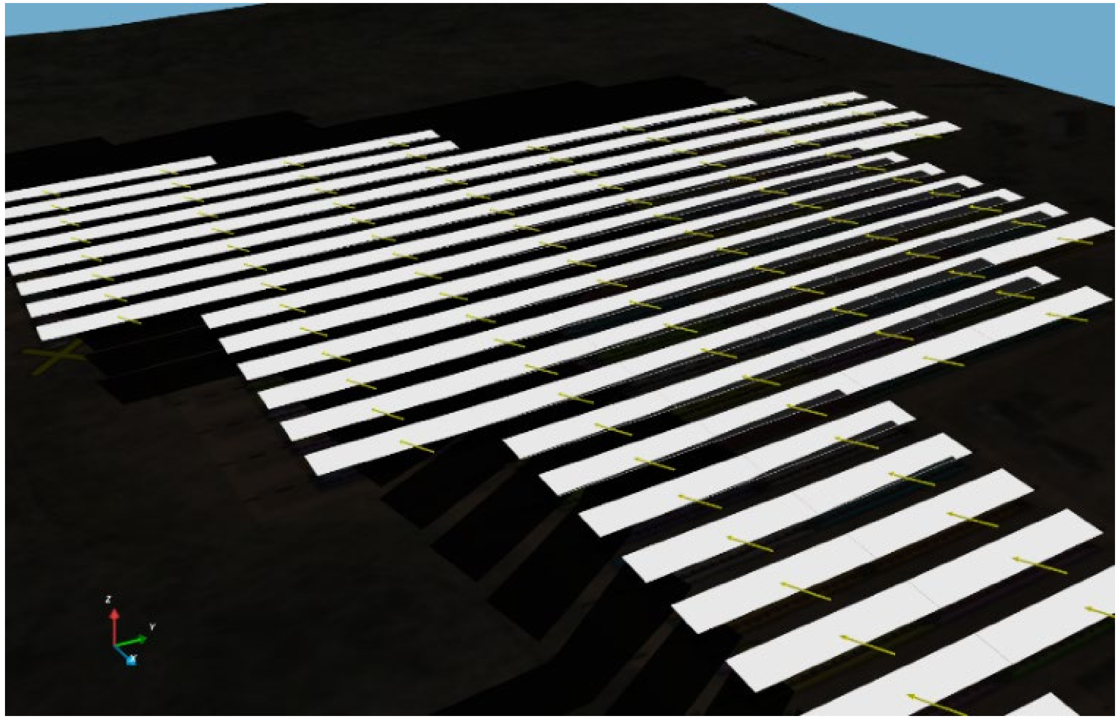


DNV shade loss correlation model

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



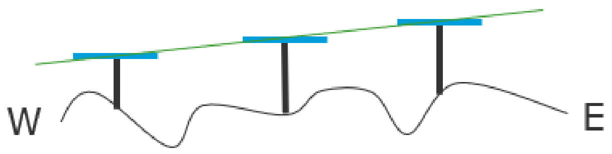
SolarFarmer: DNV's energy modelling software

- 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

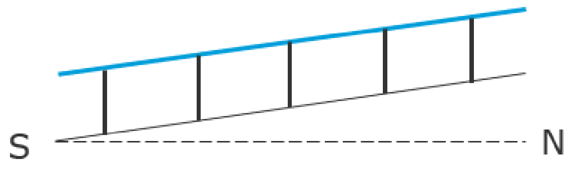
SolarFarmer tracker placement

in-plane

Tracker axes form a plane



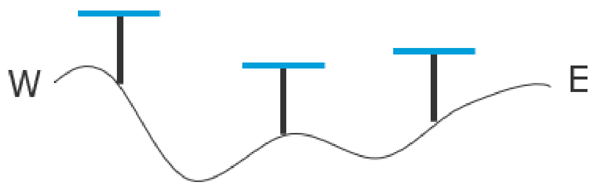
Pile height may vary above install tolerance



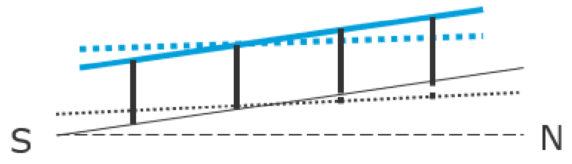
Can have N-S tracker axis tilt as well as E-W slope

follows terrain

Tracker axes are not co-planar



Pile height remains same from ground



Offset tracker axes create non-uniform triangular shadows

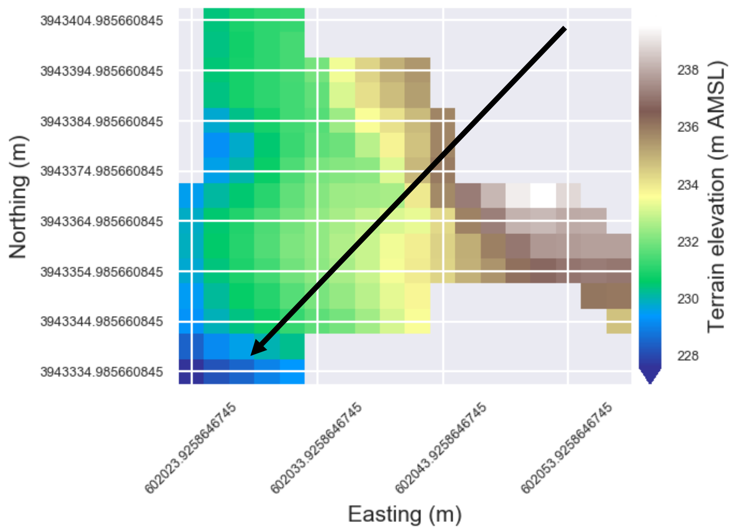
Project simulation

Location	Asheboro, North Carolina
Diffuse fraction	0.39
Ground cover ratio	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

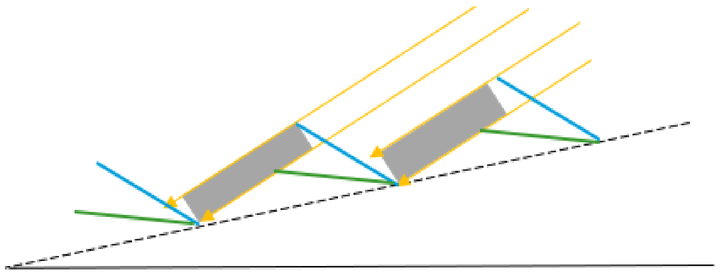
Average 4% SW slope



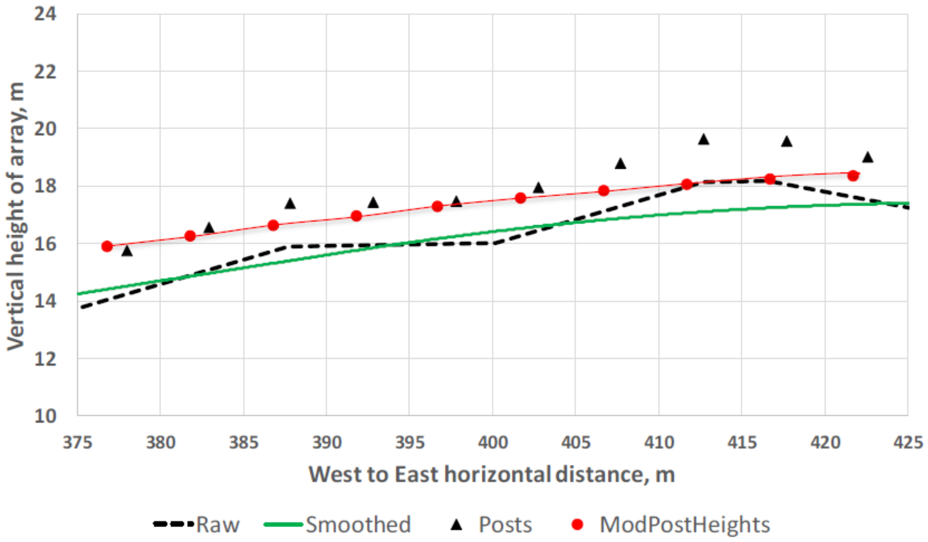
Shade loss mitigation

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

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

DNV

Thank you!

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