

Sub task 2.3: Bifacial PV Trackers



Highlights from IEA PVPS Task 13's new report on bifacial tracking systems

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Online now!



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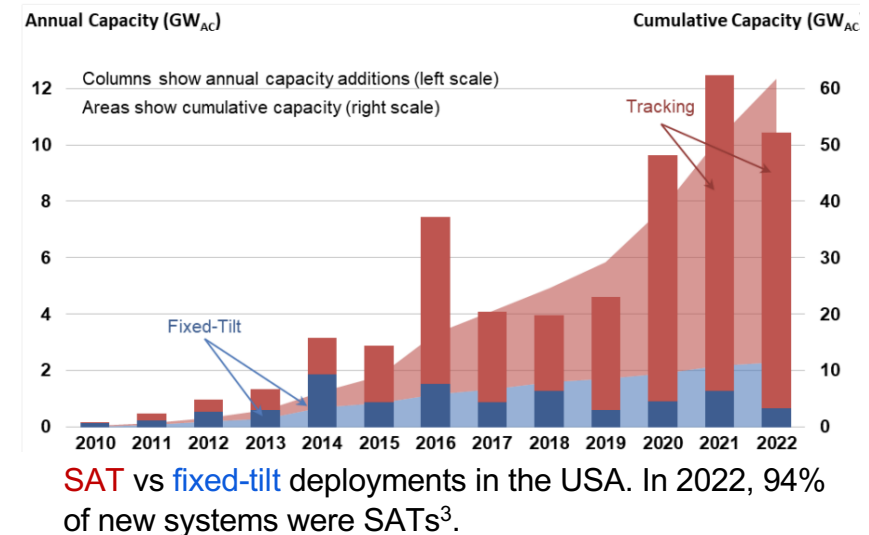


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Technology Trends



- ~95% of modules sold use bifacial cells¹.
 - 63% of all modules are 'true' bifacial
 - Price premiums for bifacial modules "do not exist anymore"
 - Bifacial gains of 5-10%
- ~60% of all PV systems installed use single-axis trackers (SATs)¹.
 - Tracking gains of 10-20%.
- Bifacial SAT configuration has lowest LCOE for ~90% of global land area².



[1] International Technology Roadmap for Photovoltaic (ITRPV), VDMA, 2024, 15th Ed.

[2] C. D. Rodríguez-Gallegos et al., Joule, 2020, doi: <https://doi.org/10.1016/j.joule.2020.05.005>.

[3] M. Bolinger et al., 2023, <https://emp.lbl.gov/publications/utility-scale-solar-2023-edition>

Best Practices for the Optimization of Bifacial PV Tracking Systems



Chapter 1: Introduction and Market Surveys (5 pgs)

- Tracker manufacturer survey
- Tracker owner/operator survey

Chapter 2: System designs for optimal value and yield (15 pgs)

- Tracker anatomy/taxonomy
- System layouts
- Extreme weather response
- Tracking algorithms and controls
- Albedo optimization
- Agrivoltaic bifacial tracking applications

Chapter 3: Performance Monitoring and Evaluations (11 pgs)

- Instrumentation best practices

Chapter 4: Performance Modeling and Yield Assessment (10 pgs)

- Modeling methods
- Blind modeling exercise

Chapter 5: Reliability Considerations (3 pgs)

- Failure modes and effects

Chapter 6: Techno-Economical Optimization (3 pgs)

- LCOE, CAPEX, OPEX, revenue, energy yield

Tracker Manufacturer Survey



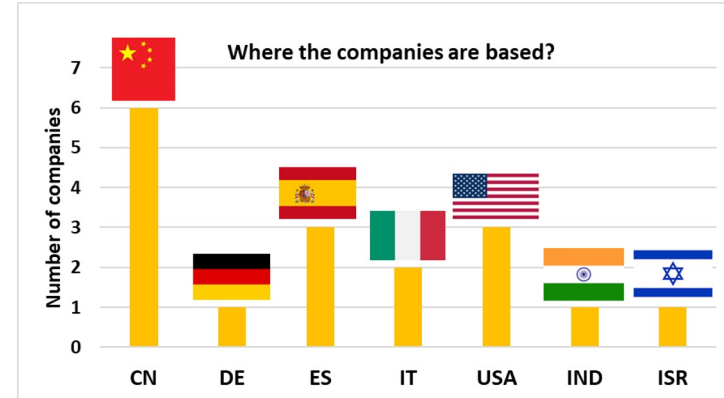
17 tracker companies participated in the survey

projects finished: **>210 GW**

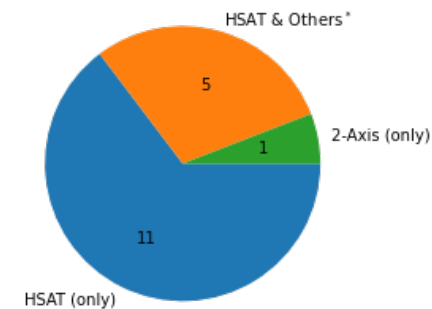
Representing **~87%** of tracker market

45 questions asked covering:

- Company overview
- Product specifications, costs, features
- Tracking algorithms
- Sustainability



TYPES OF TRACKERS OFFERED (# of companies)



* TSAT, 2-Axis, etc.

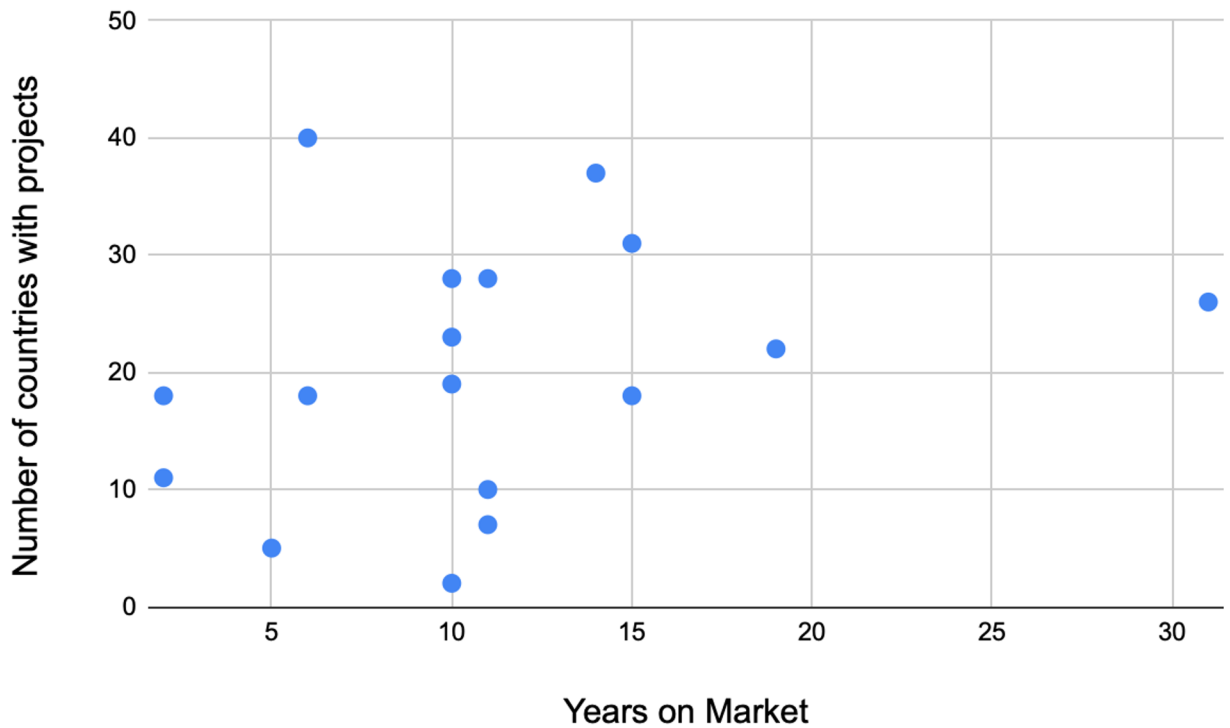


See also: Stein et al., EU PVSEC 2023, <https://doi.org/10.2172/2335912>

Tracker Companies are International



- 70% of companies have been in business for at least 10 years.
- ~50% of companies sell trackers in more than 20 countries.
- >80% of companies sell in more than 10 countries.



Tracker owner/operator survey (field experience)

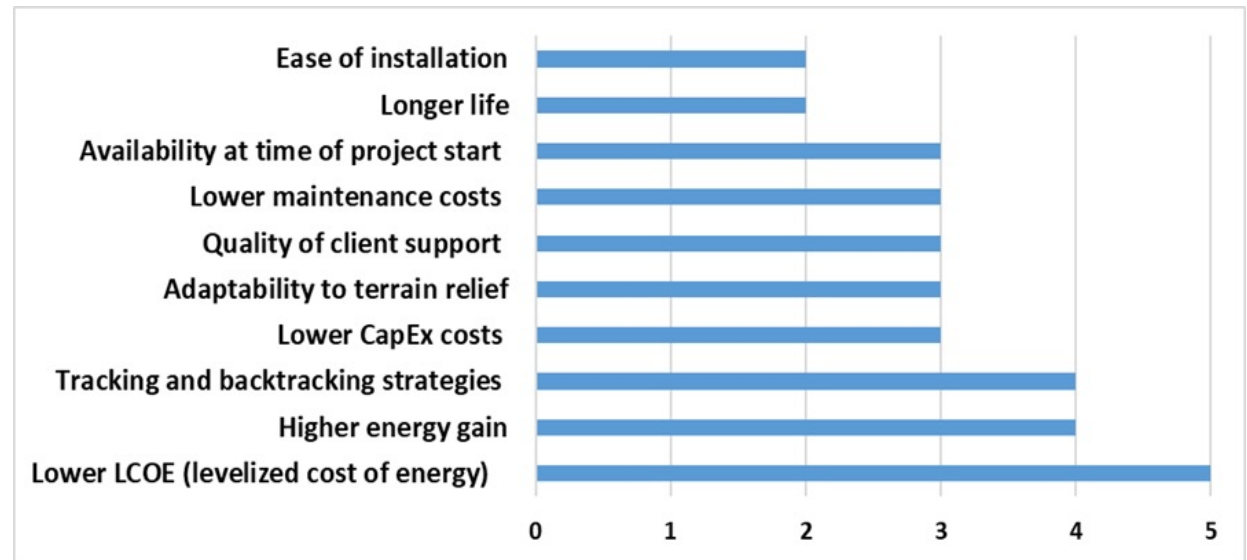


- Represents a major contribution to tracker reliability literature
- **15** participants involved with **13.2 GW** of tracker projects
 - Min=20 MW; Max=3GW
- Oldest working systems between **12-18 years**
- Average of **82%** of the systems use **bifacial** PV
- **20+ questions** regarding design choices and field experience with trackers

Top reasons for trackers



- Responses to each question given on 1-5 scale
- **Lower LCOE** is the most common reason for tracker adoption.
- **1-in-portrait** (1P) module distribution is preferred.

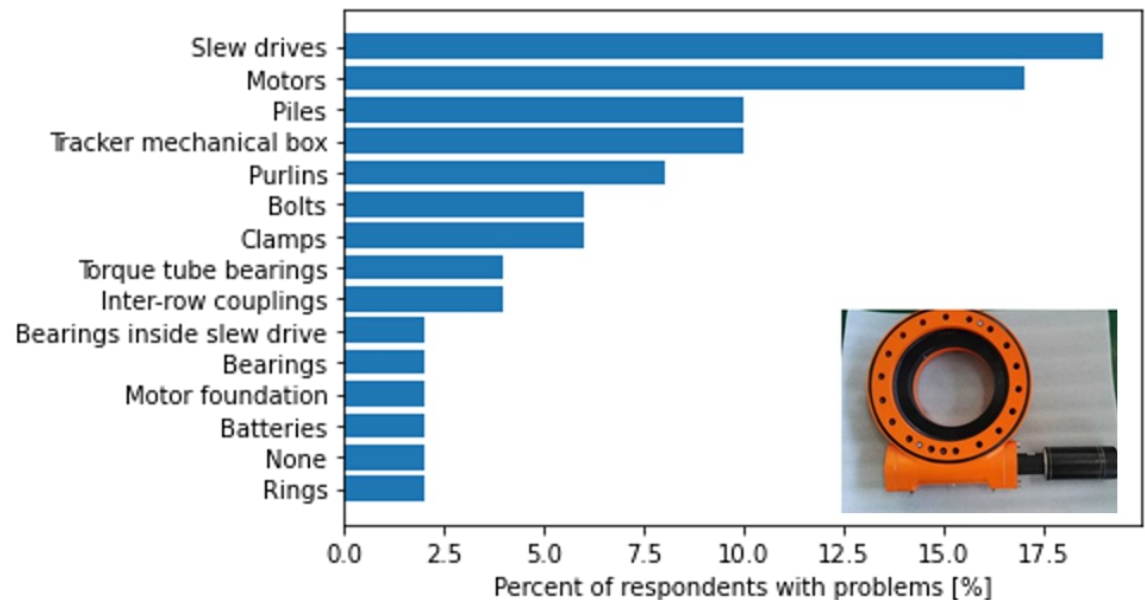


Average ranking of all responses rounded to the nearest integer

Tracker owner/operator survey



- Most common mechanical failures are related to **slew drives and motors**
 - Tracker motors are often made from 60+ individual parts¹.
- 26% of respondents reported tracker **misalignment issues**
- 65% reported some form of damage from extreme weather events.
 - Tracker response not triggered
 - Incorrect wind stow parameters
 - Event exceeded manufacturer's specifications
 - Difficult to isolate blame to a single component

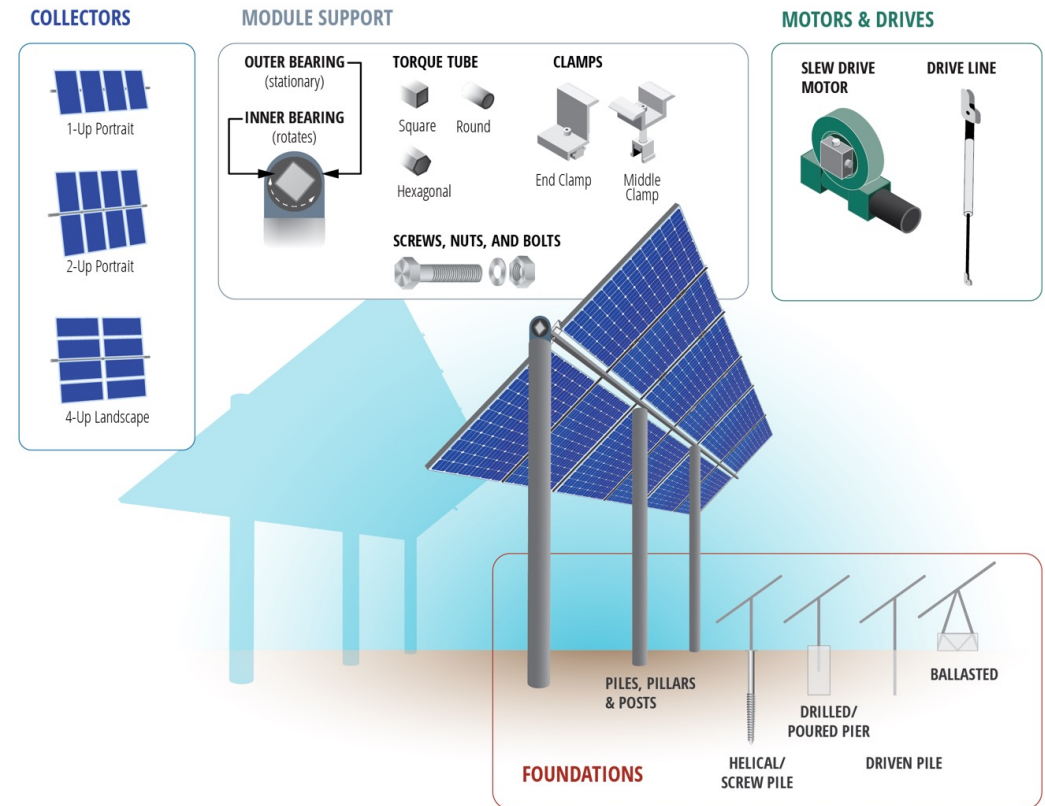


[1] Althaus and Hudson, "Racking and trackers: quality issues in the factory and design considerations for utility-scale solar installations", PV Magazine, June 2024

Tracker anatomy and design features



- Independent vs multi-row control may depend on site terrain
- Foundation options for various geotechnical and load requirements
- Control algorithms abound:
 - Backtracking, slope-aware, diffuse light, half-cell, wind stow, snow, rain, agriPV, extreme weather
- Companies report using more steel since advent of large-format modules ~2022

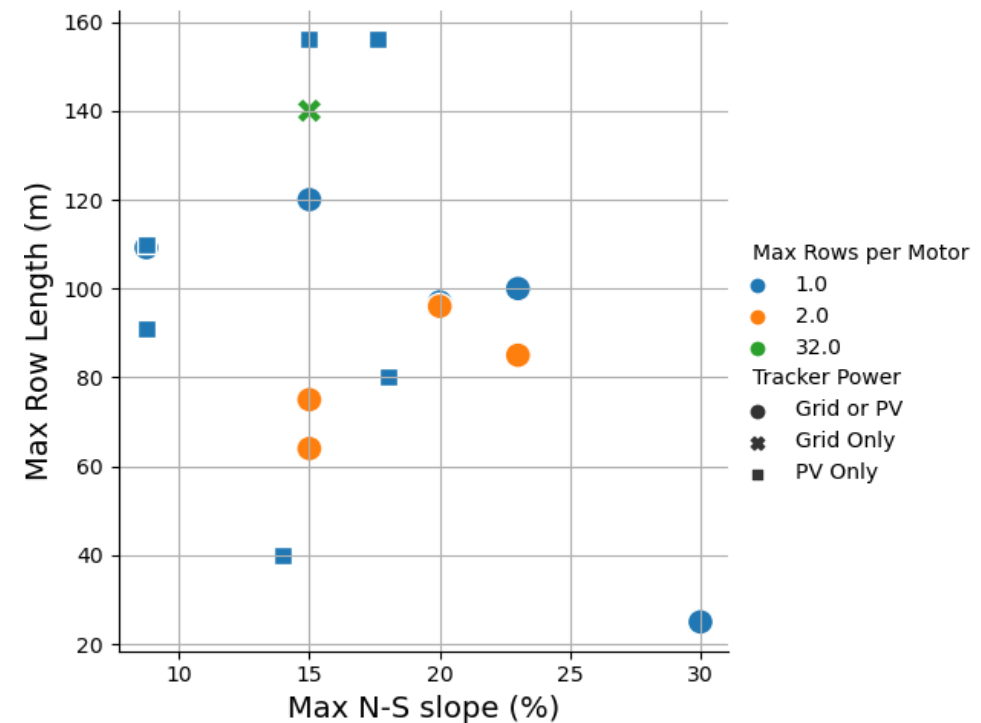


Single-axis tracker anatomy with common components and features

Tracker features cont.



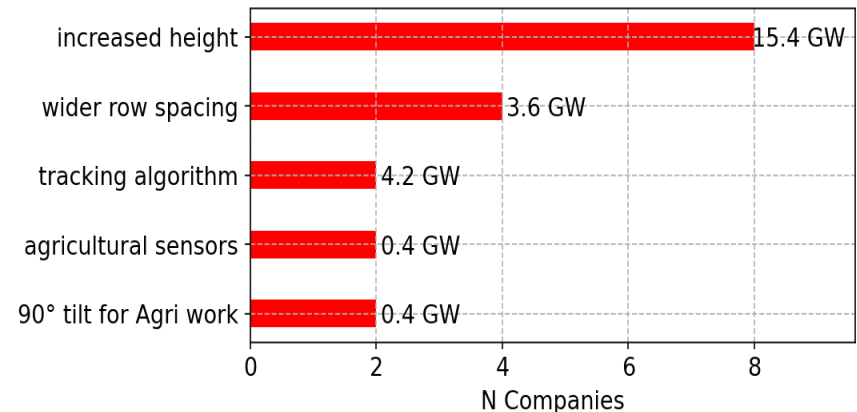
- Most companies report 15% max N-S grade
 - E-W grade typically can be much steeper.
- Max N-S slope tends to increase with smaller tracker lengths.
- All companies offer a PV powered option
 - 'PV' = Sub-string or a dedicated PV panel
 - Grid power option tends to be recommended for Northern latitudes.
- Most companies use $\pm 55^\circ$ or $\pm 60^\circ$ max angles
 - 2 have 90° max (for agriPV harvest)



Trackers are common in agrivoltaic systems



- 11 of 17 companies interviewed sell trackers for agrivoltaic projects:
 - Representing *total* tracker sales 20GW/yr
 - Large commercial interest
- Movement offers versatility: eg anti-tracking algorithms that move PV array 'off-sun' when light is most needed by plants
- Trackers provide more homogenous ground irradiance than fixed tilt systems
- Note: IEA PVPS 13 subtask 2.2 is preparing a detailed report on agrivoltaics



Summary of the most common modifications reported by 11 tracker companies who indicated that they design trackers specifically for agrivoltaic projects.



Instrumentation best practices for bifacial SATs

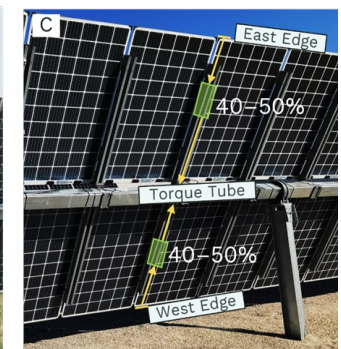
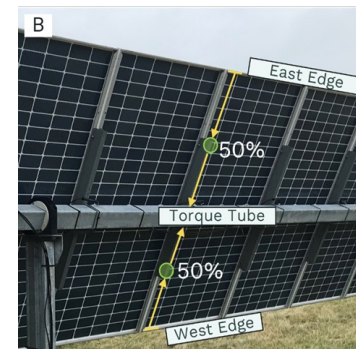
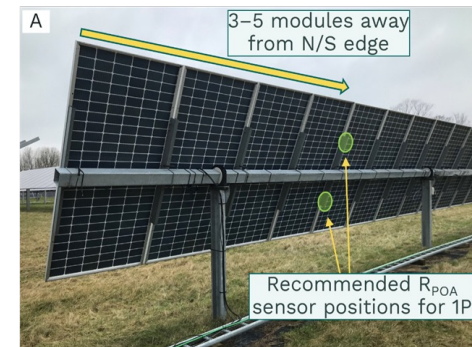


Sensor considerations provided for:

- Front POA, rear POA, T_{MOD} , albedo

Rear POA Irradiance recommendations:

- Mount at least two sensors on the back of the tracker
- Mounted halfway (50%) between an east/west edge and the center of the torque tube
 - 2P can be placed slightly wider (40-50%)
 - 5 modules away from the north or south edge to avoid brightening effects
- Fix sensors to the transverse beams (purlins) or between modules to avoid shade



A) Recommended sensor positions to avoid edge brightening, B) for 1P, C) for 2P systems

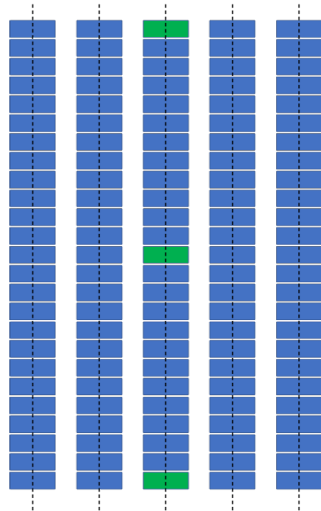


Blind modeling exercise of bifacial tracker systems

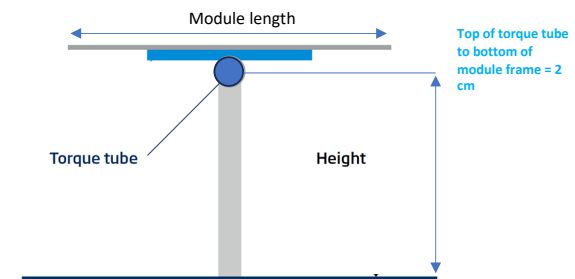


Scenarios are hypothetical and cover variations in:

- GCR
- Albedo
- Hub height
- Configuration
- Ground slope



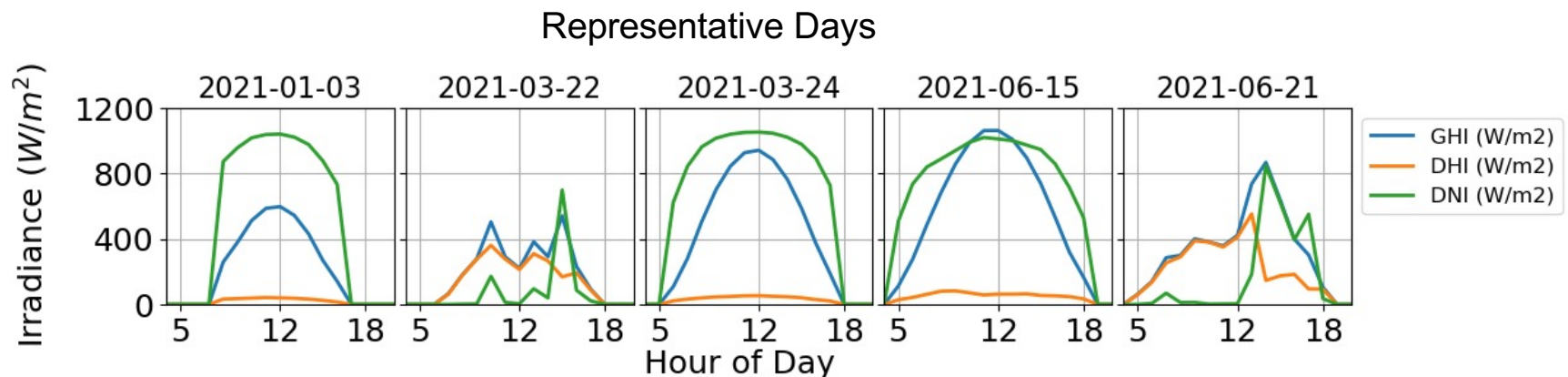
Scenario number	Scenario name	GCR*	Albedo	Hub Height	Configuration	Ground surface
1	Ref-A	0.4	0.2	1.5 m	1-Up portrait	Horizontal
2	A1	0.25	0.2	1.5 m	1-Up portrait	Horizontal
3	A2	0.4	0.5	1.5 m	1-Up portrait	Horizontal
4	A3	0.4	0.2	3.5 m	1-Up portrait	Horizontal
5	A4	0.4	0.2	1.5 m	1-Up portrait	10% grade down to the East
6	A5	0.4	0.2	1.5 m	1-Up portrait	10% grade down to the SW
7	Ref-B	0.4	0.2	3.5 m	2-Up portrait	Horizontal



Blind modeling exercise of bifacial tracker systems



- Nine participants
- **Irradiance models:** perez transposition, bifacial_radiance, pvlib-python infinite sheds, pvlib-python PVfactors, internal model.
- **Module/cell temperature models:** Sandia Array Performance Model (SAPM), PVsyst, pvlib-python pvsyst_cell, internal model.
- **PV power models:** CEC, Heydenreich, 2-diode model from PVMismatch, SolarFarmer, PVsyst, BIGEYE



Modeling Exercise: Results Summary

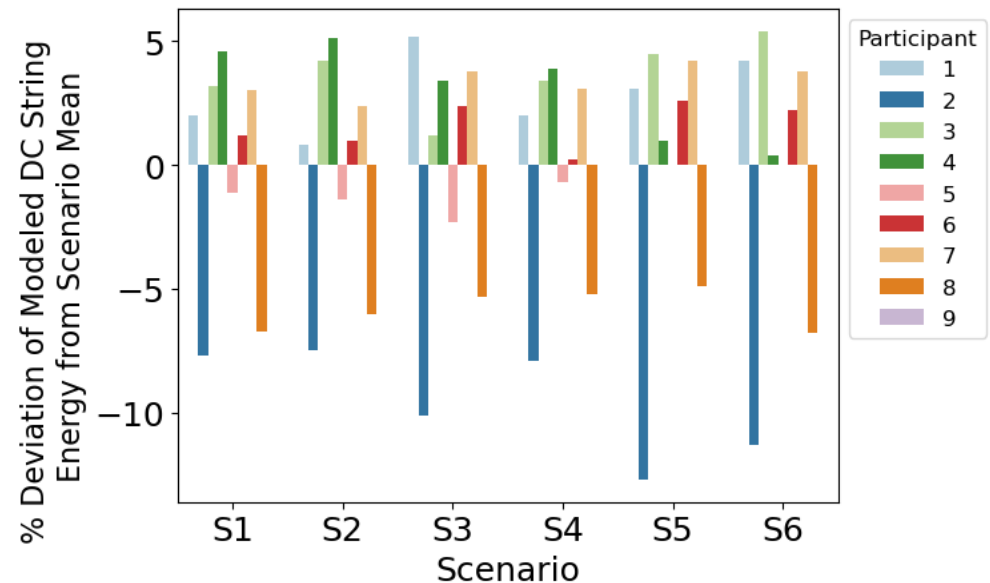


Simulated string power differed between participants by +5% to -10% from the mean of all participants.

- Accuracy unknown (no ground truth)

Notable differences found in all values reported:

- Front side POA irradiance
 - Despite being a standard modeled parameter
- Rear POA irradiance
 - In all days/scenarios (deltas of 50-100 W/m²)
- Module temperature
 - Mostly during sunny days ($\pm 10^{\circ}\text{C}$!)
- Tracker inclination
 - Mostly during backtracking and sloped scenarios
- See report for more details



Conclusions



- **Bifacial PV on single-axis trackers** are the dominant system type being installed today and will continue to grow.
- IEA PVPS Task 13's new report provides: extensive industry surveys, a blind modeling study, and **best practices** for optimizing the performance of such systems.
- The report addresses critical areas for designing high quality tracking systems (e.g., algorithms, acceptance tests, monitoring, albedo enhancement, performance modeling, and dual land use).
- Important challenges have been identified regarding divided modeling practices as well as some reliability issues.

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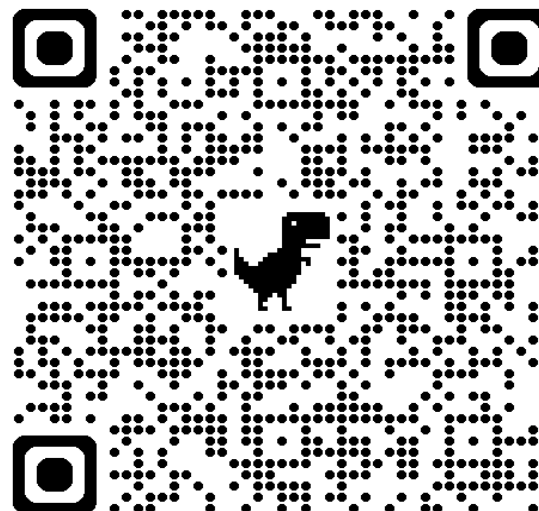


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Thank you

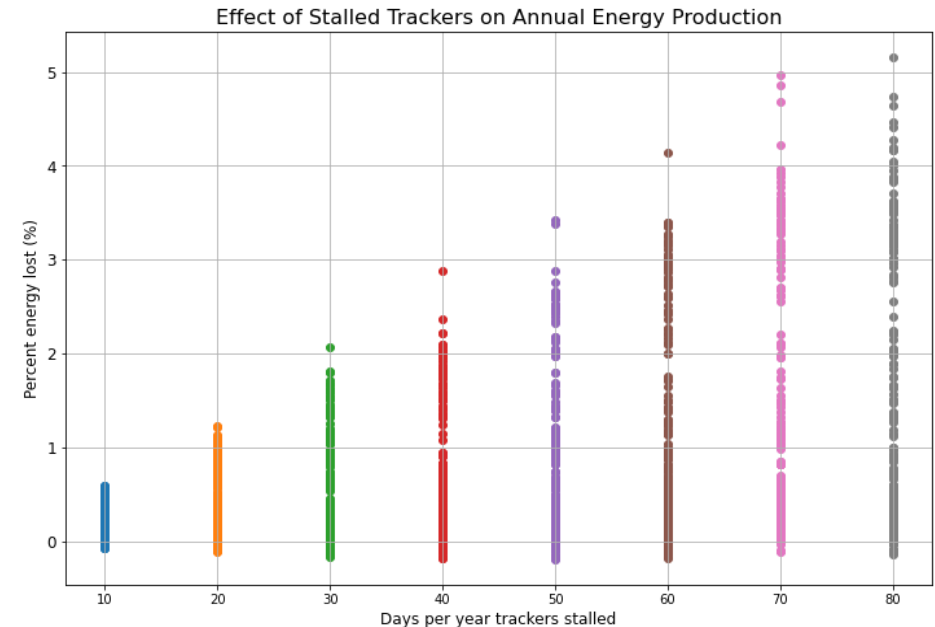
Appendix Slides



Tracker failure modes and effects



- Tracker failures result in the tracker getting stuck or moving to the wrong position.
- Such failures rarely cause the PV array to become disconnected.
- Energy losses tend to increase with the duration of failure
 - so does the range of losses, depending on when the failure occurs.



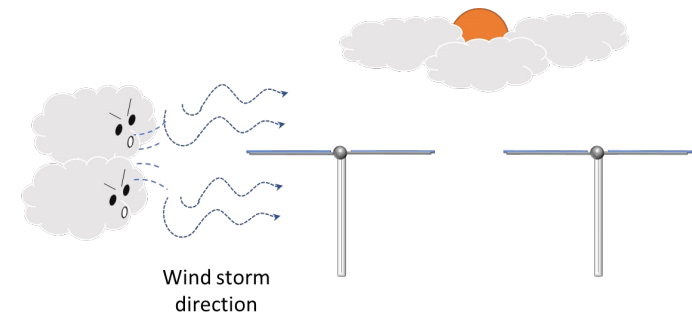
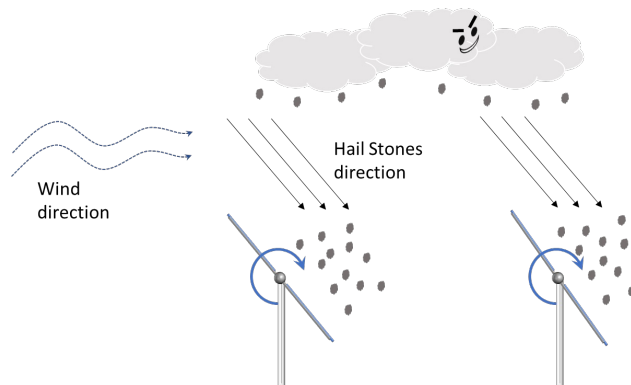
Percent of annual energy lost due to tracker stalls of different durations **simulated in Albuquerque, NM U.S.** Each point represents one of 200 randomly selected times when the stall initiated at each increment of duration.

Tracker Survey User Perspective



Weather Resilience Responses

	Hail	Flood	Snow	Wind
Yes	30%	45%	70%	100%
How	weather forecast	on site sensor	on site sensor	on site sensor
What	rotates to maximum tilt wind stow strategy dominates	Moves to flat stow position	Moves to full tilt position	Moves to flat stow position



Tracker Survey User Perspective



Tracker Reliability Responses

PV Plant Environment

Animal-related problems

8%

Corrosion

15%

Row-to-row shading despite backtracking

21%

Ground subsidence after construction

15%

Misalignment

26%

Flooding and erosion

13%

Sand dune formation

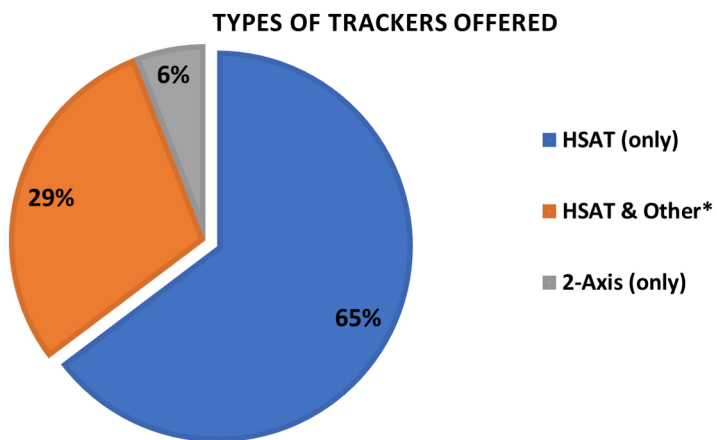
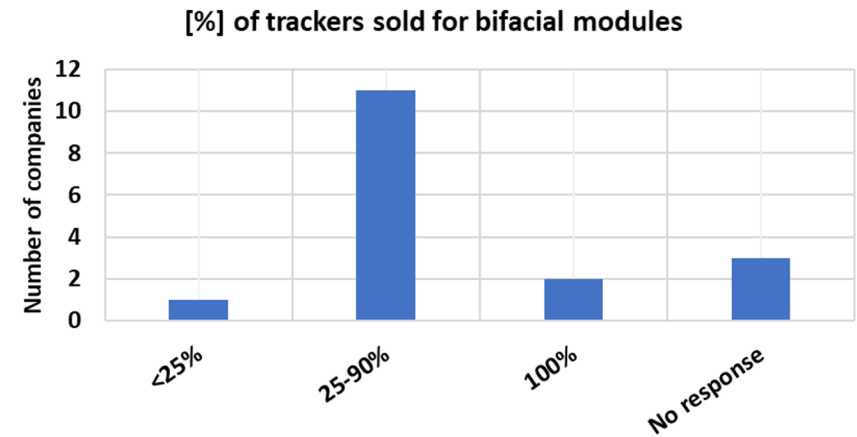
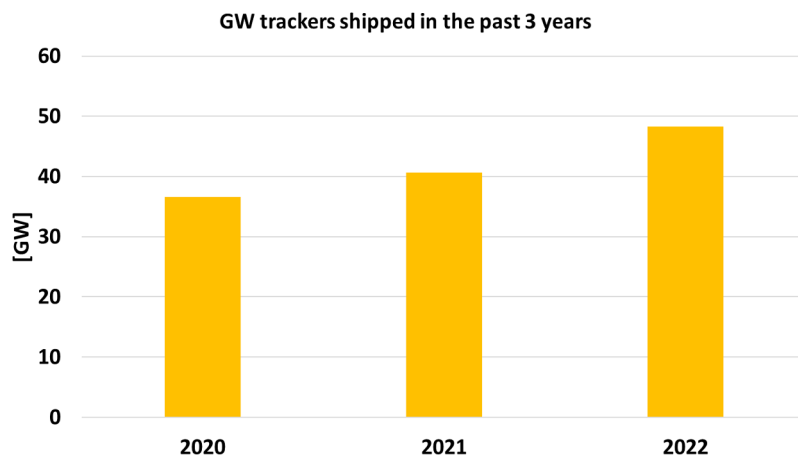
3%

Electrical

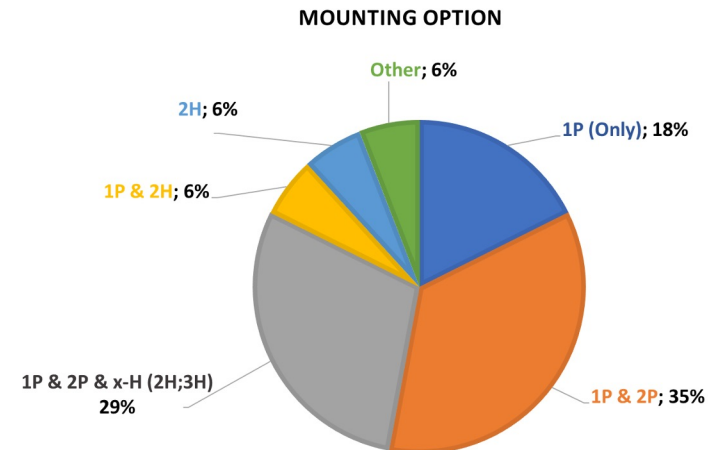
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**Fewer Electrical Faults, More Communication Errors Reported !
Battery-Powered Trackers Perform Poorly in Northern Winter Climates**

Companies Overview



(*) : (TSAT, 2-Axis, F-PV, R-PV)



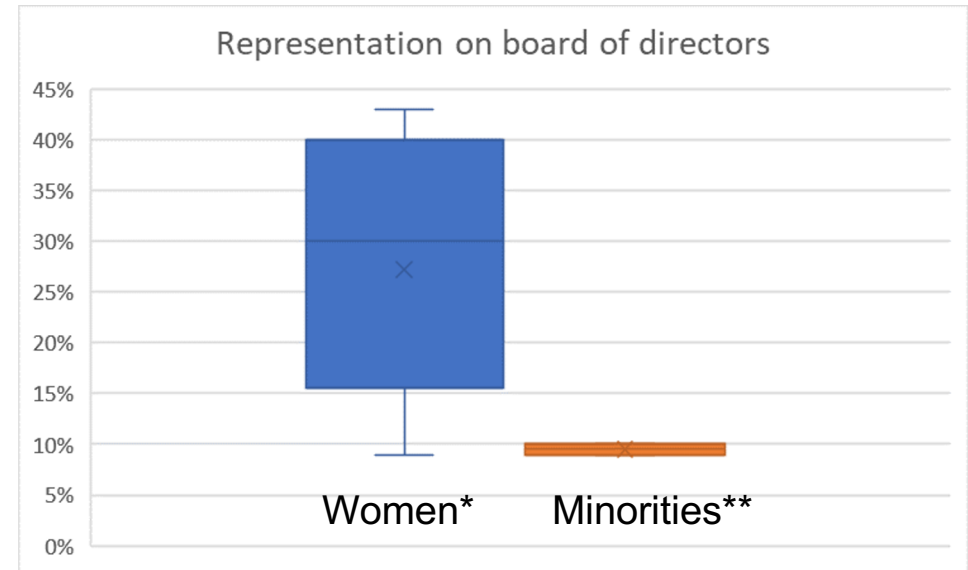
ESG and diversity

Environmental, Social, Governance



- ESG is being requested by clients
- Nearly all companies have ESG strategies and a few have comprehensive reports.
- Strategies include:
 - ❑ Increasing efficiency of electric motors
 - ❑ Carbon footprint certificates
 - ❑ Reducing materials usage (e.g., concrete, steel)
 - ❑ Eliminating child labor via supply chain requirements
 - ❑ Promotion of local manufacturing.
 - ❑ Partnering with local universities for workforce development.

PVPS



*based on 50% of the surveyed companies

**only two self-declared values

Market trends and drivers



- **Reported Cost Range** of 0.06 – 0.14 \$/W for 1-axis, and 0.2 – 0.4 \$/W for 2-axis trackers.
 - Wind speed risk, cost of concrete, design factors affect cost (2P is more expensive)
 - In general, SAT systems increase yields by ~20% over fixed-tilt systems (location and site-specific)
- **Supply chain issues** and market prices are important (i.e. cement and steel).
- Some companies use **local providers** of these two materials to offset cost and carbon emissions.
- Developers value **reliable delivery schedule** and **availability of equipment** and are willing to pay more.
- Companies are focusing on certain market sectors (e.g., dual-uses for AgriPV, deployment on non-agricultural or usable land, highly sloped terrains). **Divergent perspectives on land-use and value.**
- Companies cite many certifications and wind tunnel tests.
 - UL 2703 "Mounting Systems, Mounting Devices, Clamping/Retention Devices, and Ground Lugs for Use with Flat-Plate Photovoltaic Modules and Panels",
 - UL 3703 "Solar Trackers",
 - IEC 62817 "Photovoltaic Systems - Design Qualification Of Solar Trackers",
 - ISO 9001, ISO 45001, ISO 14001