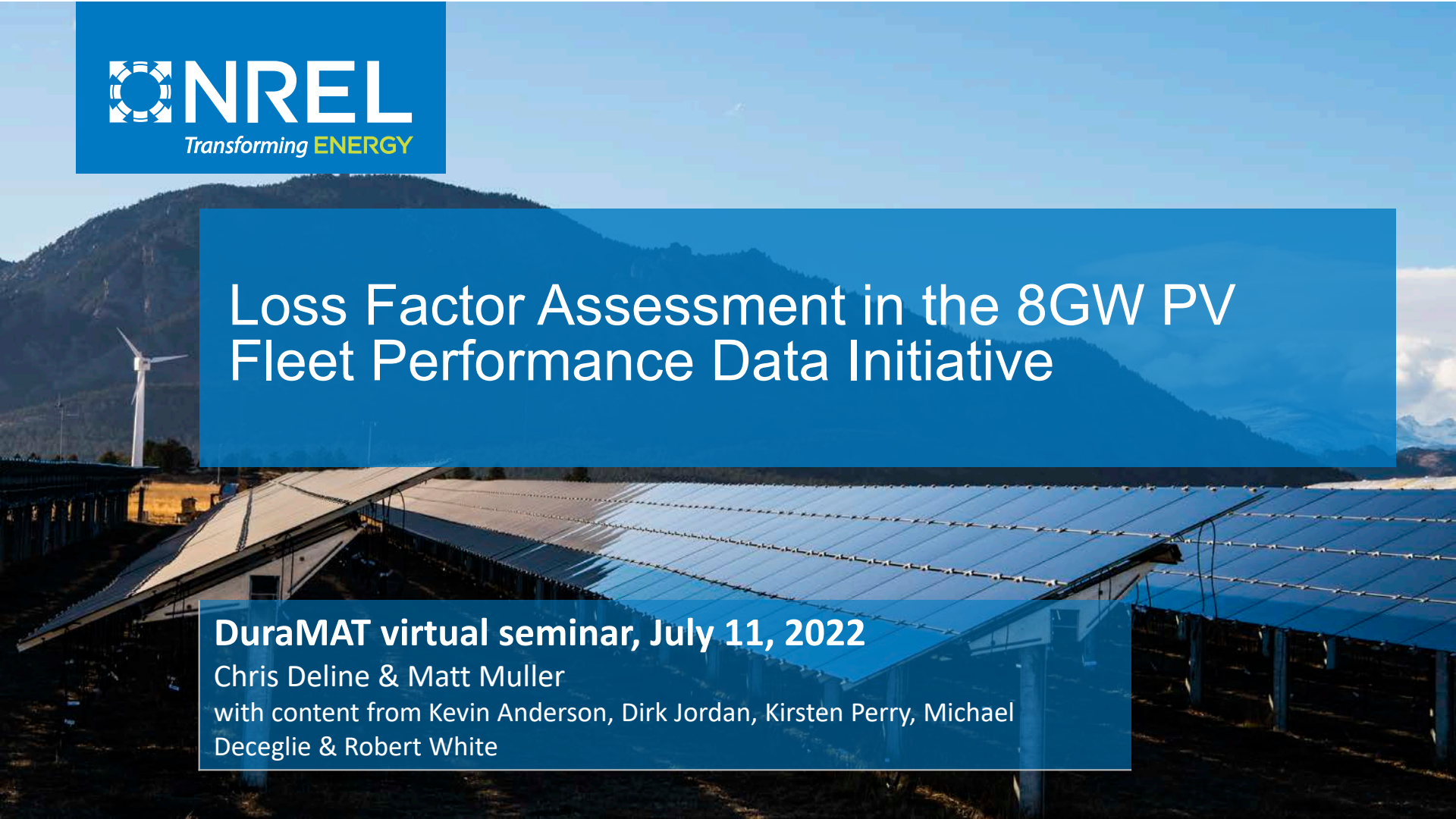


Loss Factor Assessment in the 8GW PV Fleet Performance Data Initiative

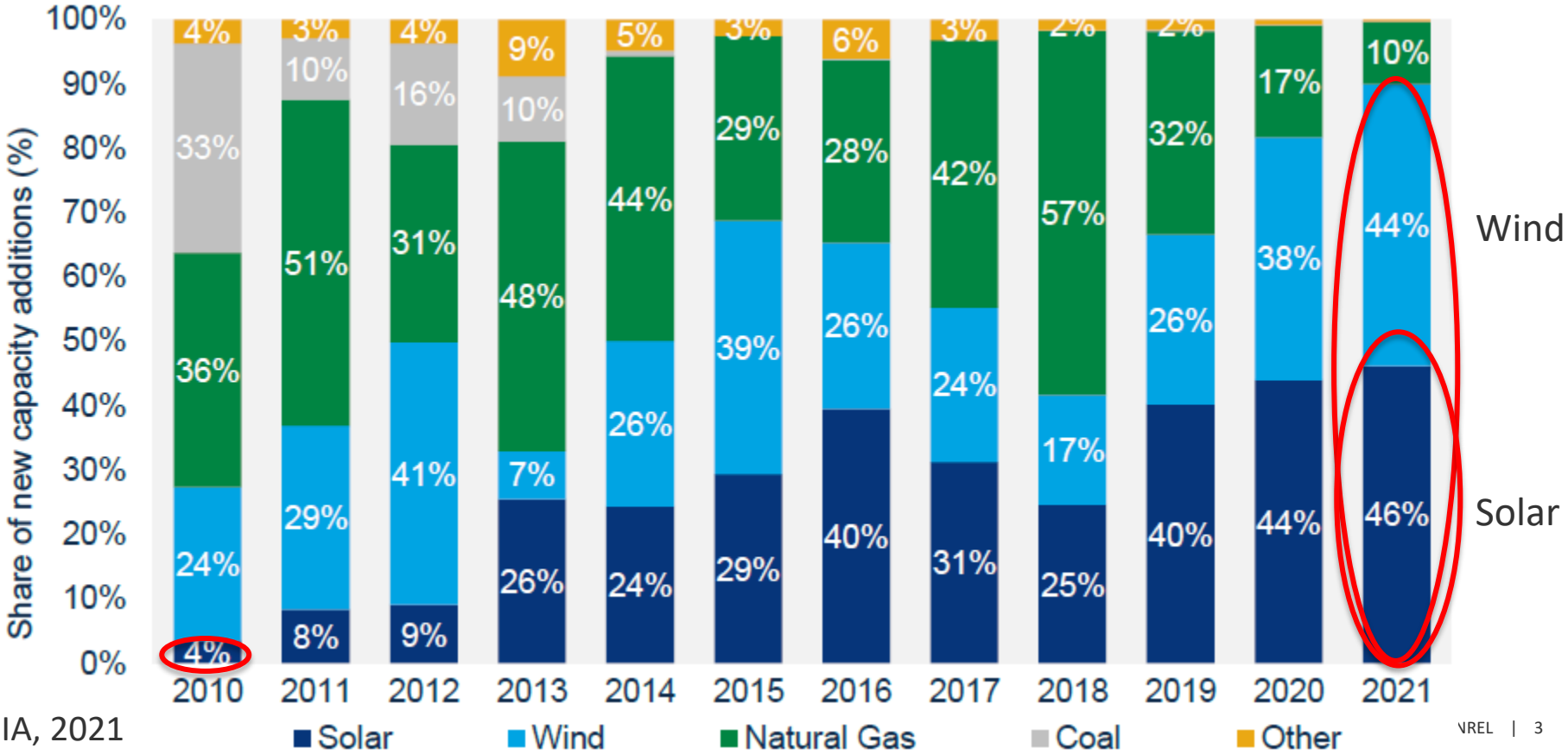
DuraMAT virtual seminar, July 11, 2022

Chris Deline & Matt Muller
with content from Kevin Anderson, Dirk Jordan, Kirsten Perry, Michael Deceglie & Robert White

Agenda

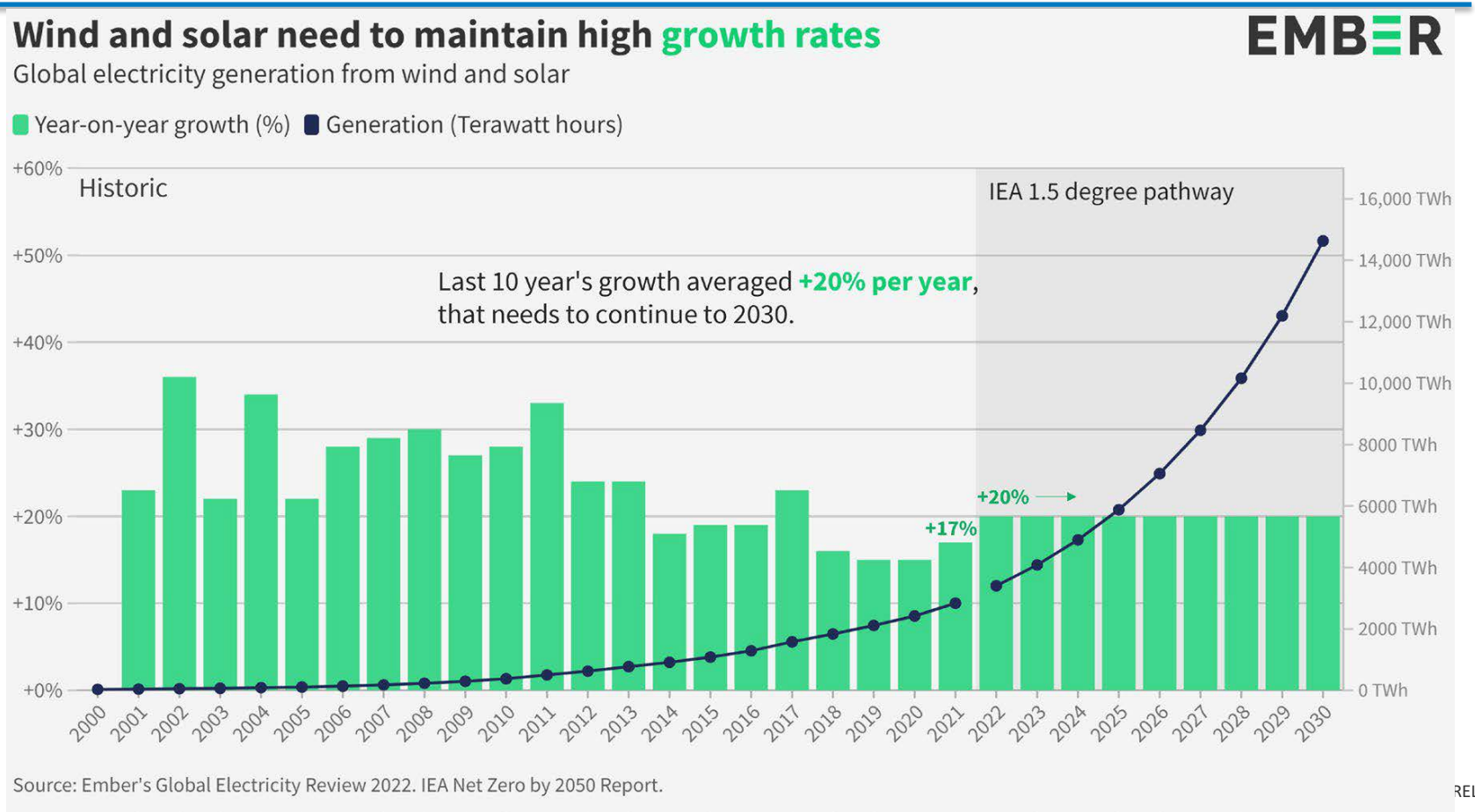
1. **Photovoltaics (PV) current and future deployment**
2. The PV Fleet Performance Data Initiative
3. Fleet degradation trends
4. High-efficiency module performance
5. Other system loss factors
6. Conclusions

RE dominates new US power generation assets

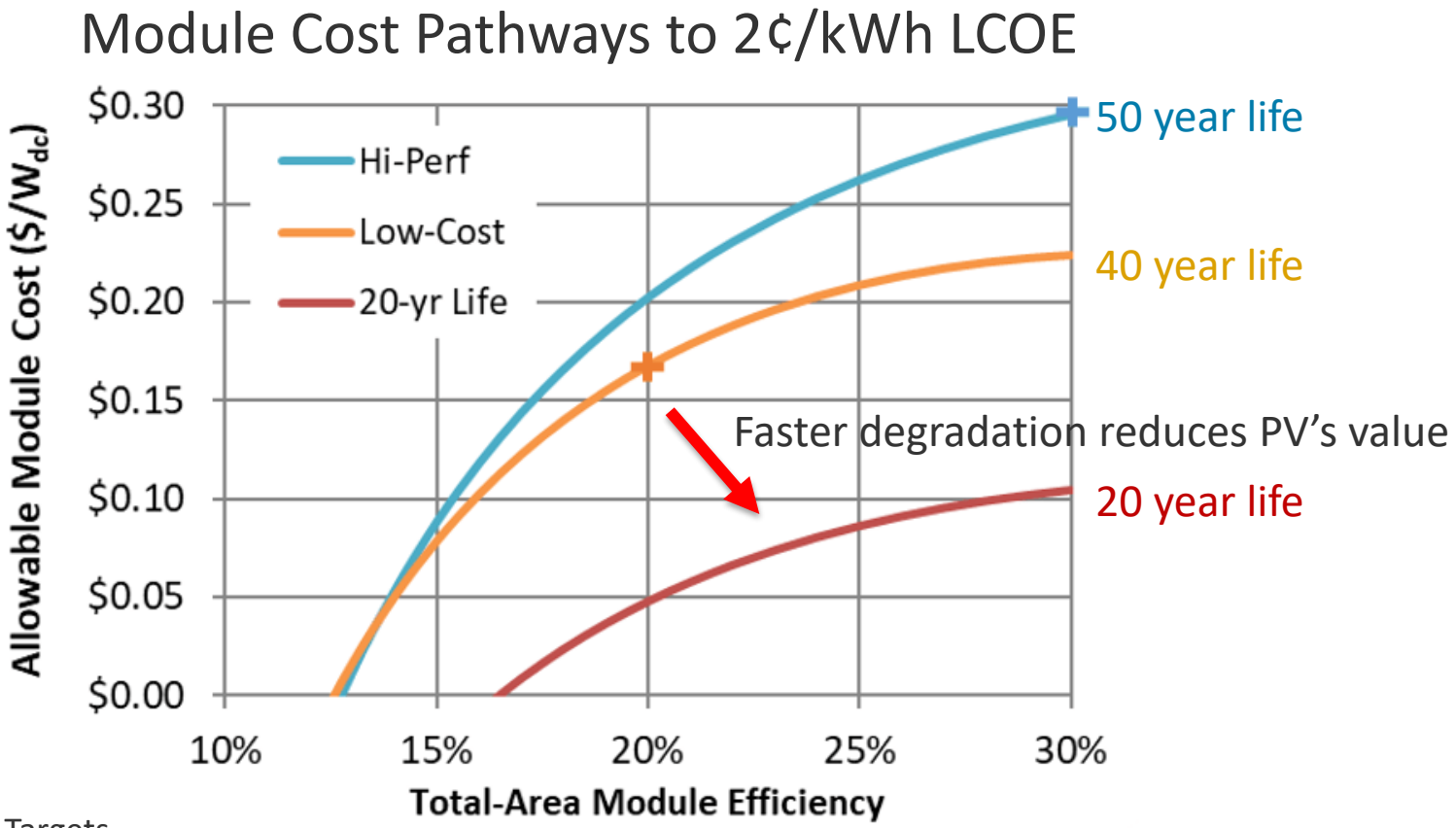


SEIA, 2021

1.5° C climate target requires steady deployment



Accelerated degradation will erode project value



DOE 2030 Solar Cost Targets

Agenda

1. Photovoltaics (PV) current and future deployment
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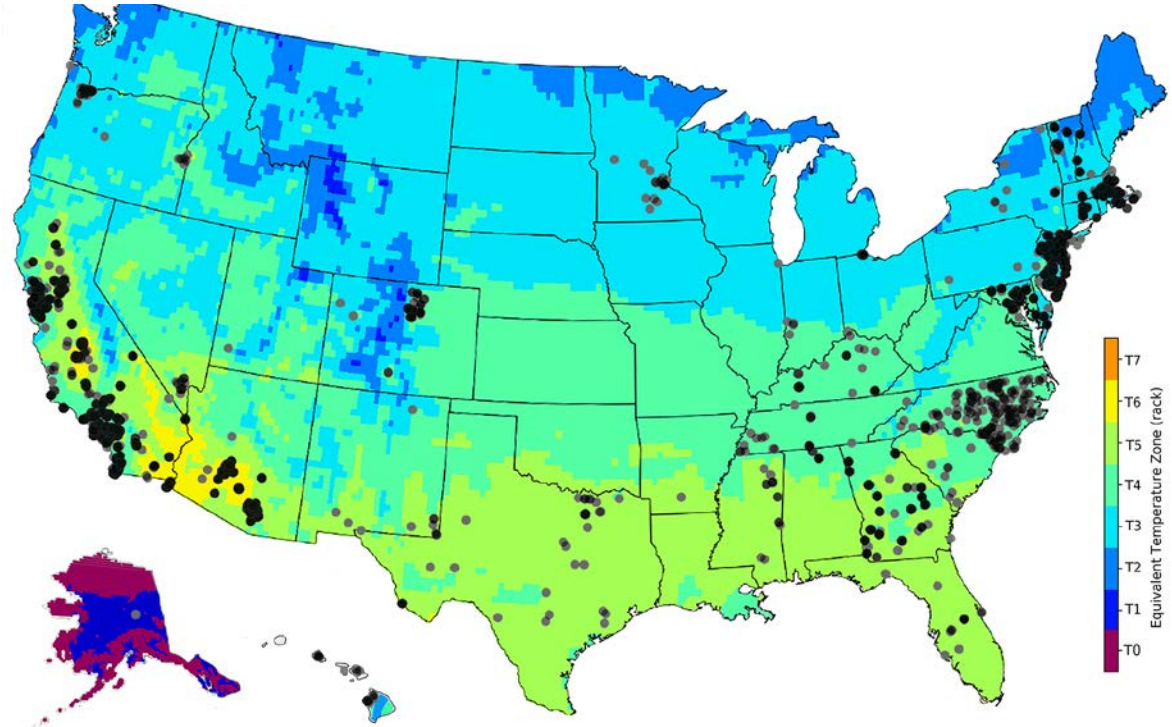
PV Fleet Project Overview

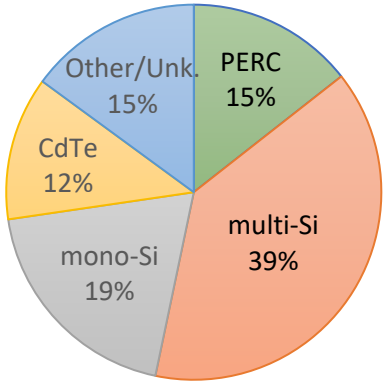
In the **PV Fleet Performance Data Initiative**, high-frequency data from commercial and utility-scale PV systems have been collected to examine performance trends at a fleet scale. To date, data from more than ~~7.2~~ 8.1 gigawatt (GW) capacity, ~~1700~~ 2200 sites and ~~19,000~~ 23,000 inverters—approximately equivalent to 6-7 % of the entire US PV market— have been collected.

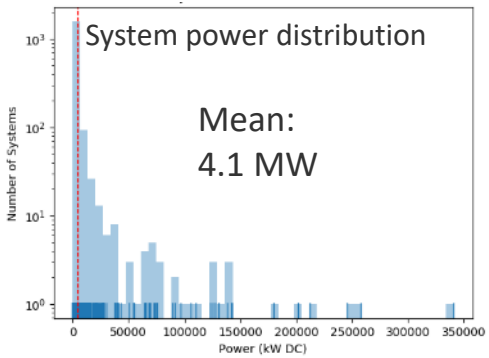
PV Fleet Initiative

>2200 systems, > 23,000 Inverters, >8.1 GW capacity



Module technology breakdown



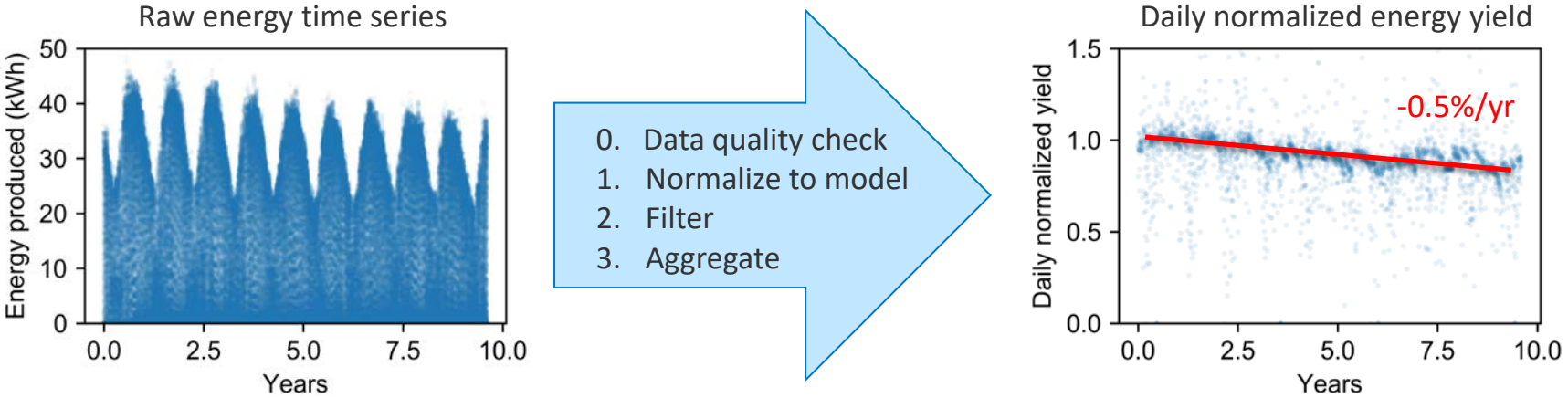


Mean system age: ~4.6 yrs

Deline et al., PVSC 2021
Temperature zones: Karin 2019

PV Field Performance

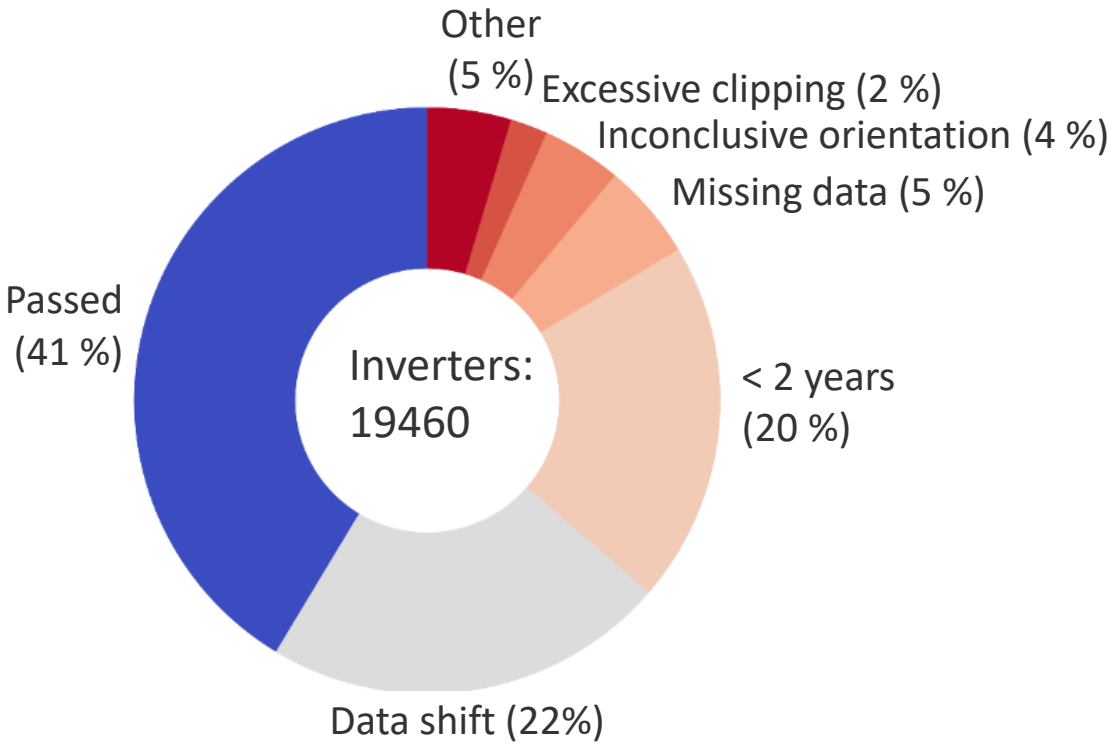
- PV power is a factor of irradiance & temperature
- Real data is messy (outages, instrumentation errors)
- Many systems -> automated analysis & data filtering



github.com/pvlib/pvanalytics

www.nrel.gov/pv/rdtools.html

Breakdown of quality issues – PV Fleet



Jordan et al., Progress in PV, 2022

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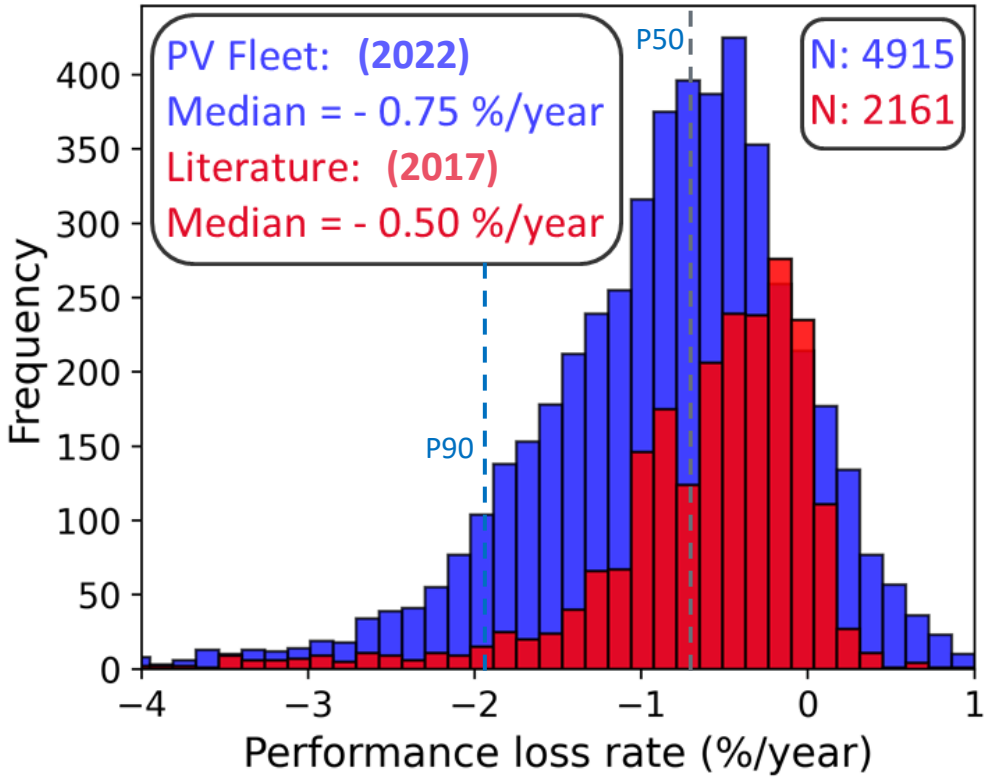
Degradation Rate Distribution 2017 - 2022



Each inverter in the fleet gets one 'vote'

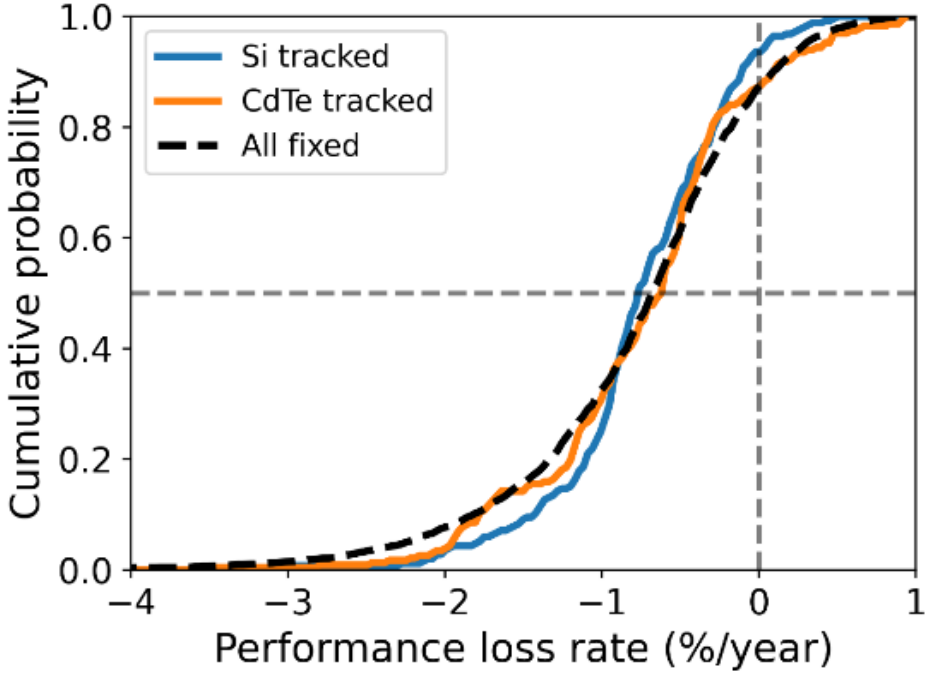
Median system degradation: -0.75 %/year.

This is slightly higher than historical (module-based) values

2022 PV Fleet: Systems
2017 Literature: Mostly modules

Jordan et al., Progress in PV, 2017, 2022

Performance Loss Rate: Si vs Thin-Film



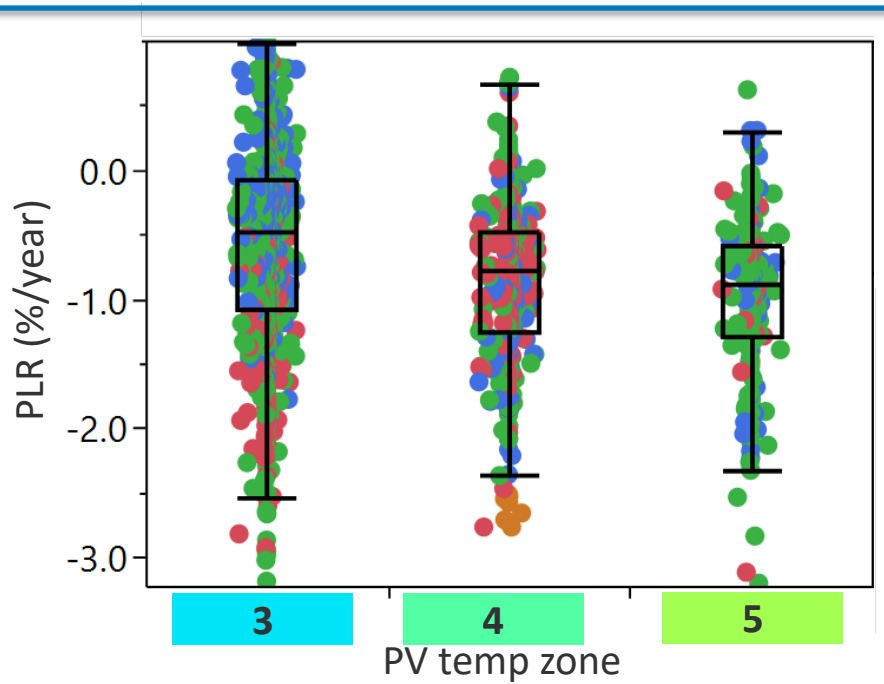
Mounting	Median (%/year)	Mean (%/year)	Inverters	Sites	Capacity (MW)
Fixed	-0.68	-0.79	3873	538	966
Tracked Si	-0.76	-0.76	252	37	124
Tracked CdTe	-0.61	-0.72	235	6	381

No significant difference between c-Si & CdTe

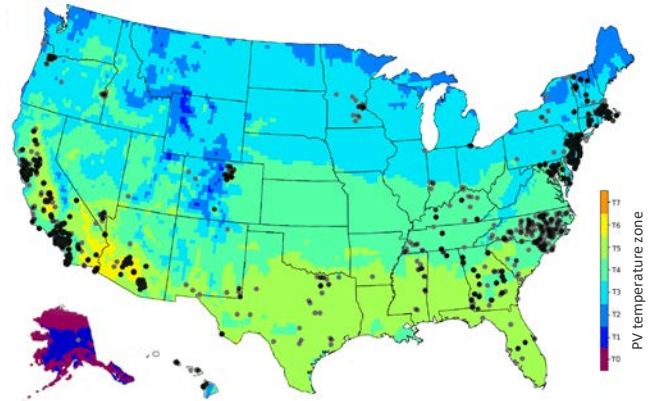
.. or fixed vs tracked

Jordan et al., Progress in PV 2022

Performance Loss Rate: Climate Dependence



Hotter climate = faster performance loss



Temperature zone	Median (%/year)	Mean (%/year)	Inverters	Sites
3	-0.48	-0.63	904	44
4	-0.78	-0.91	407	43
5	-0.88	-1.14	217	25

Jordan et al., Progress in PV 2022
Temperature zones: Karin 2019

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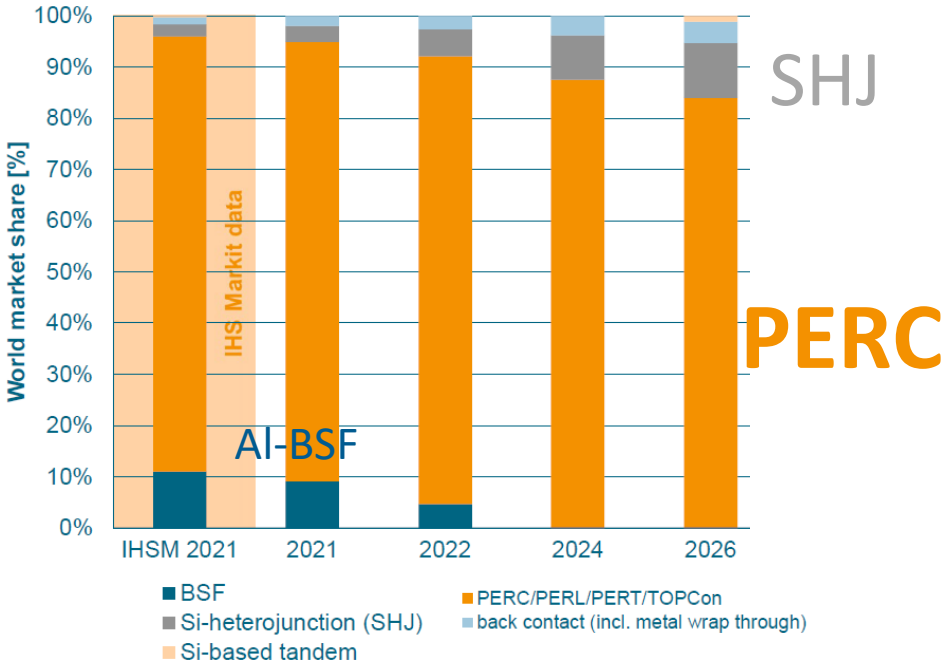
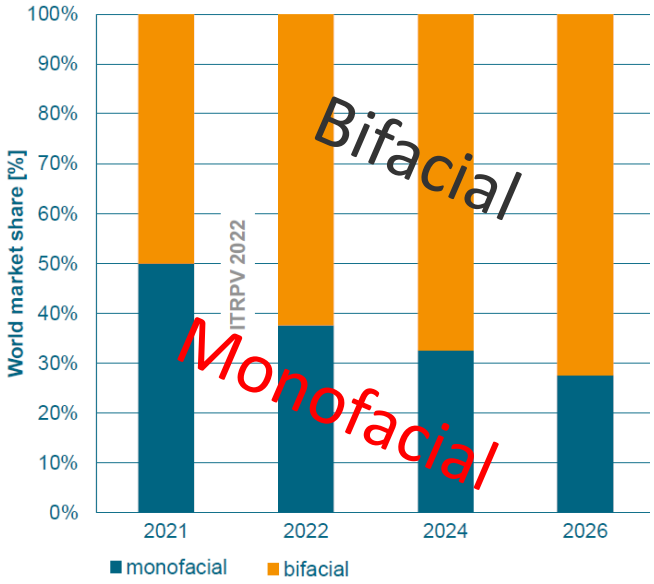
Module evolution with time

Different cell technology



Bifacial cell in world market



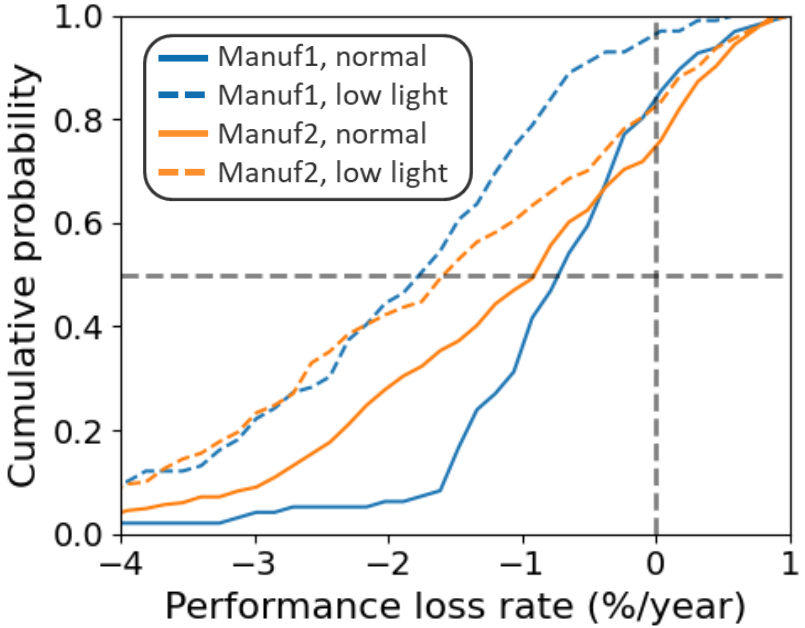
PERC and Bifacial now have substantially increased market share

ITRPV, March 2022

PERC performance at low-light

Same:

- ✓ Modules
- ✓ Climate (LA area)
- ✓ Mounting (carport)
- ✓ 3 year field exposure

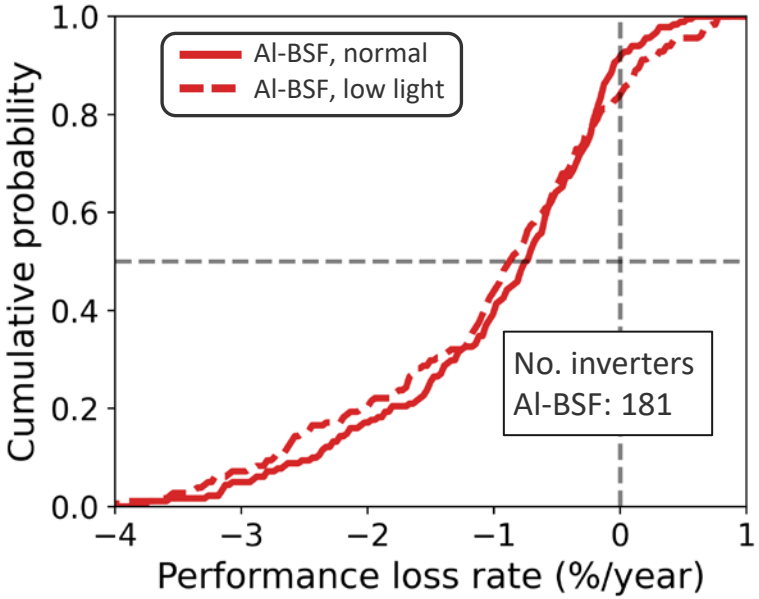


Manuf.	Upper Irrad. limit (W/m^2)	Median (%/yr)	Data pts.
1	1200	-0.69	99
1	600	-1.79	99
2	1200	-0.91	268
2	600	-1.60	268

PERC performance loss appears to be faster for low-light conditions
SHJ (not shown) shows performance loss similar to this too

Jordan et al., Progress in PV 2022

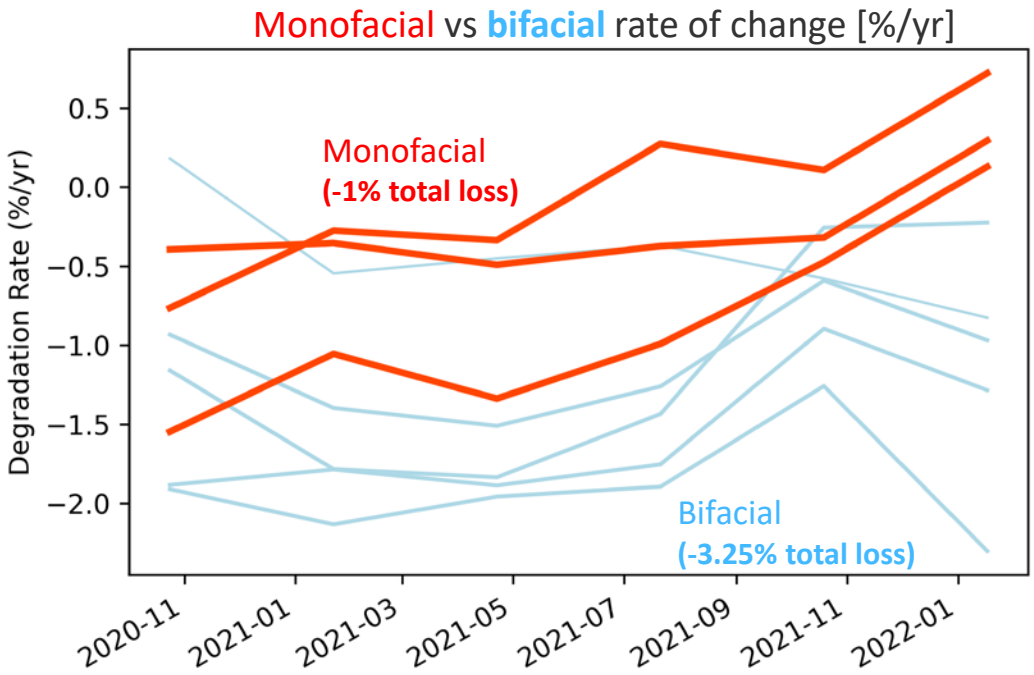
Al-BSF performance at low-light



Al-BSF does not show accelerated low-light degradation

Jordan et al., Progress in PV 2022

Bifacial systems can show faster **initial** loss



- 75kW test site at NREL
- 8 rows of comparisons
- PERC & SHJ

On average, bifacial (GG) modules degraded 2% more than monofacial (GB) counterparts (so far)

RdTools

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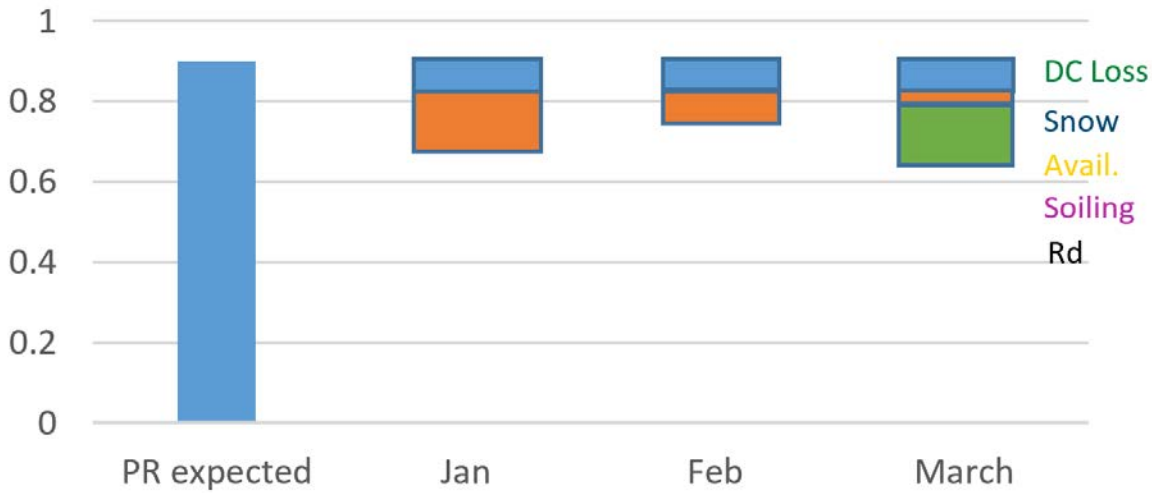
Performance index analysis

Measured vs expected monthly roll-up with loss factors identified



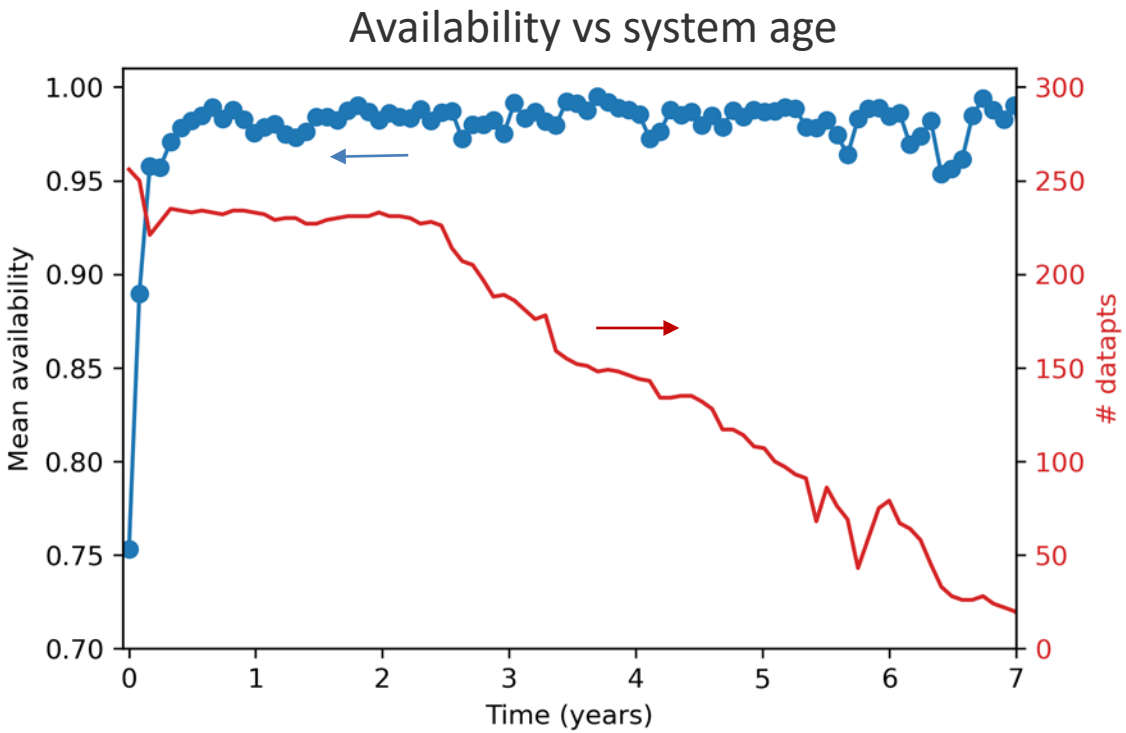
$$\text{Performance Index} = \frac{\text{Actual Production}}{\text{Expected Production}}$$

Expected Production estimated with PVWatts model and NSRDB weather

C. Deline et al., NREL/TP-5K00-78720, December 2020

Inverter Availability over System Lifespan

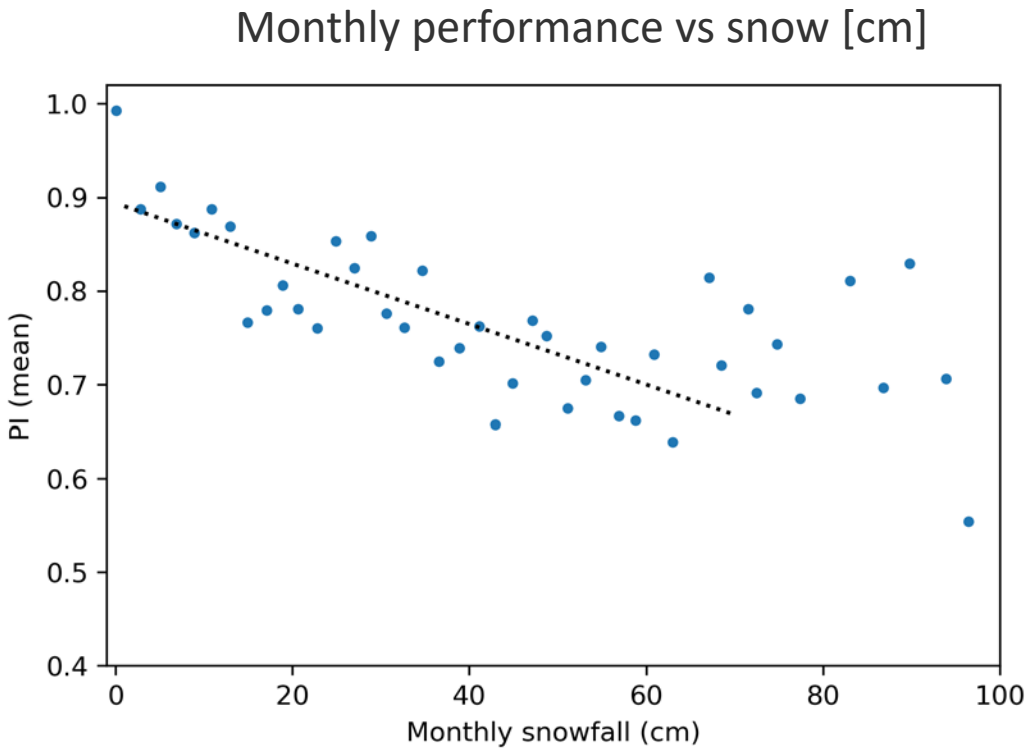
- Monthly PI data assessed for 250 high-quality systems
- Steady-state reached after first year, 97.7% avg availability
- Start-up phase in first 6 months shows lower availability (80%-90%)



C. Deline, K. Anderson et al., PV Fleet Performance Data Initiative: Performance Index–Based Analysis, NREL/TP-5K00-78720, 2020

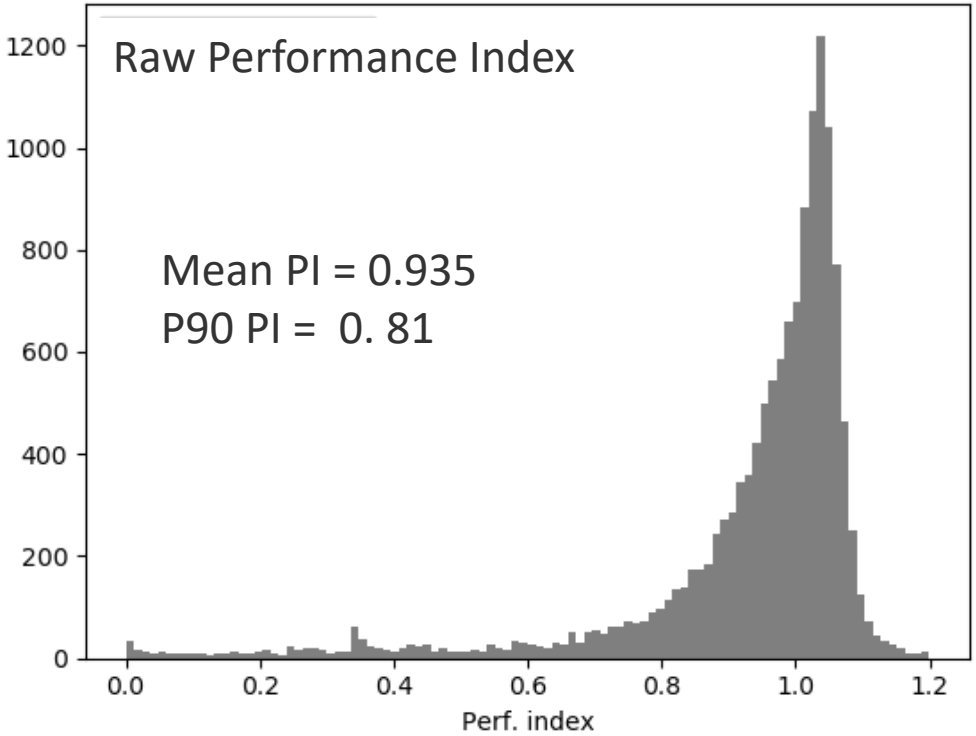
Snow losses in winter months

- Winter underperformance is 5%-10% on average
- Comparing monthly PI data vs snowfall [cm] shows negative trend
- Averaging all points within 2cm bin tidies things up
- 10%-30% loss depending on monthly snowfall
- Your results may vary



C. Deline, K. Anderson et al., PV Fleet Performance Data Initiative: Performance Index–Based Analysis, NREL/TP-5K00-78720, 2020

Monthly Performance Index distribution



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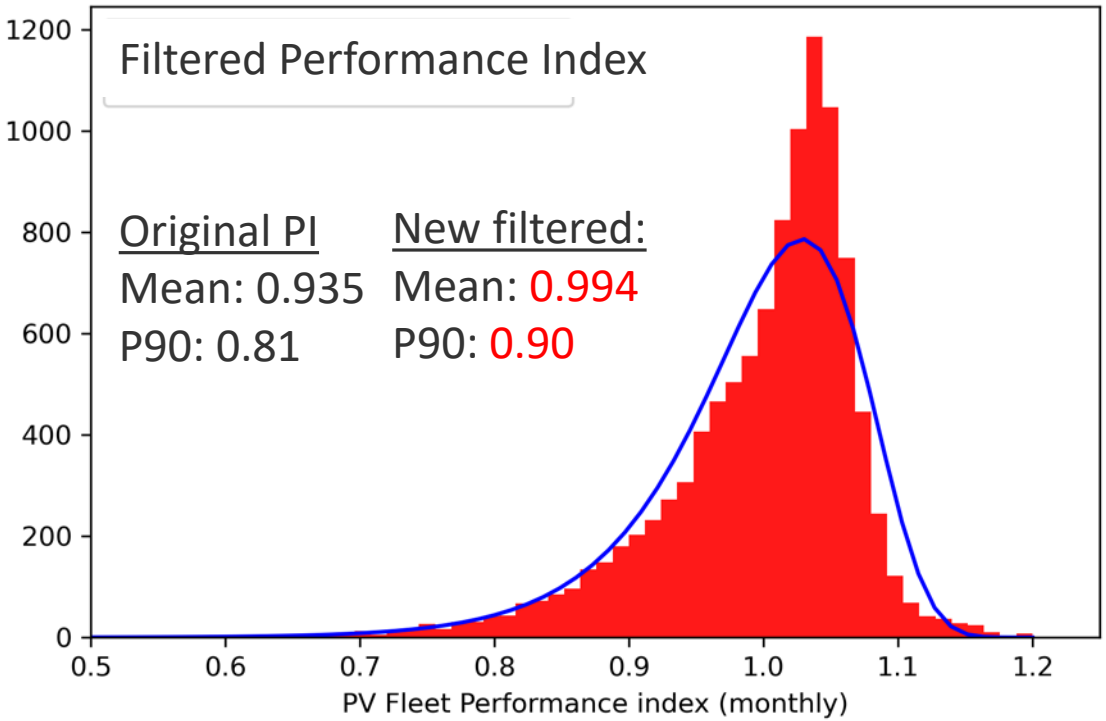
C. Deline, K. Anderson et al., PV Fleet Performance Data Initiative: Performance Index–Based Analysis, NREL/TP-5K00-78720, 2020

Monthly Performance Index distribution



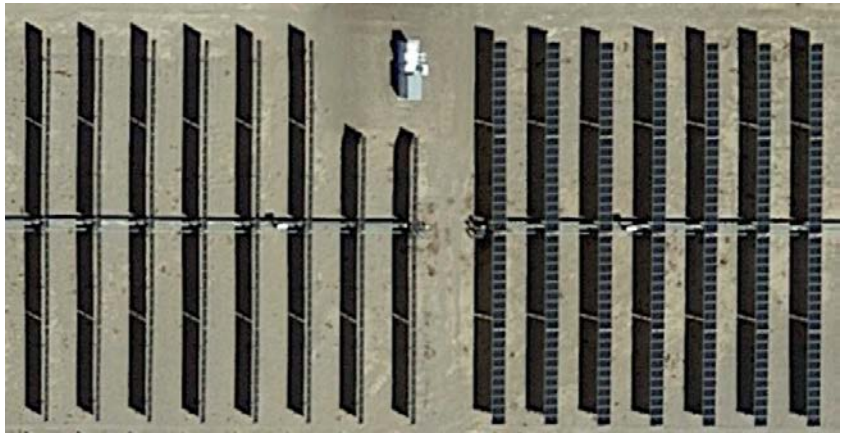
- Adjusted for availability
- Removed 6-month startup and snow months
- Best fit extreme-value distribution shows good agreement:

$$P(x) = \frac{1}{\beta}\exp\left[\frac{x-\mu}{\beta} - \exp\left(\frac{x-\mu}{\beta}\right)\right]$$

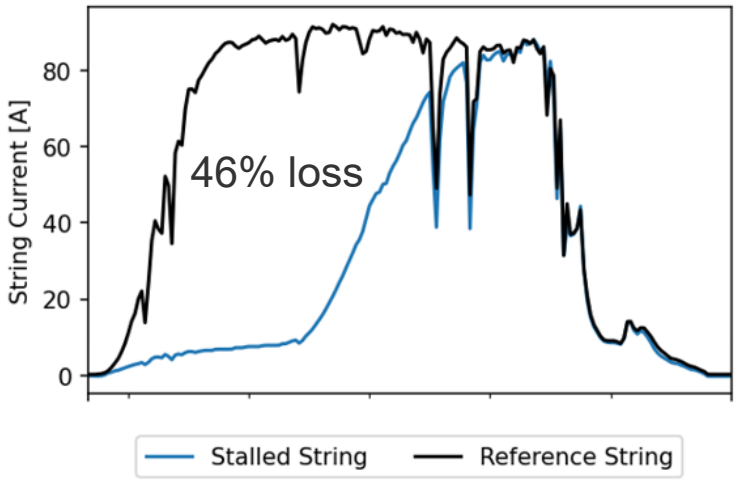
C. Deline, K. Anderson et al., PV Fleet Performance Data Initiative: Performance Index–Based Analysis, NREL/TP-5K00-78720, 2020

Future evaluation: Tracker stall detection

Tracker outage -> lost production



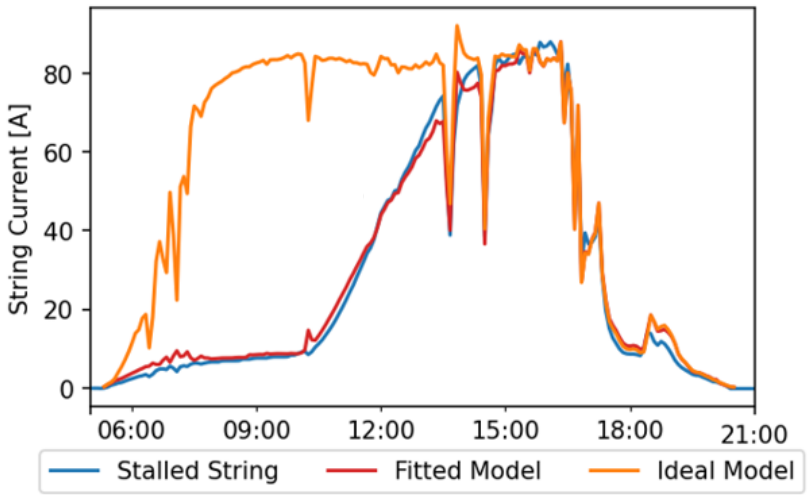
Timeseries Power

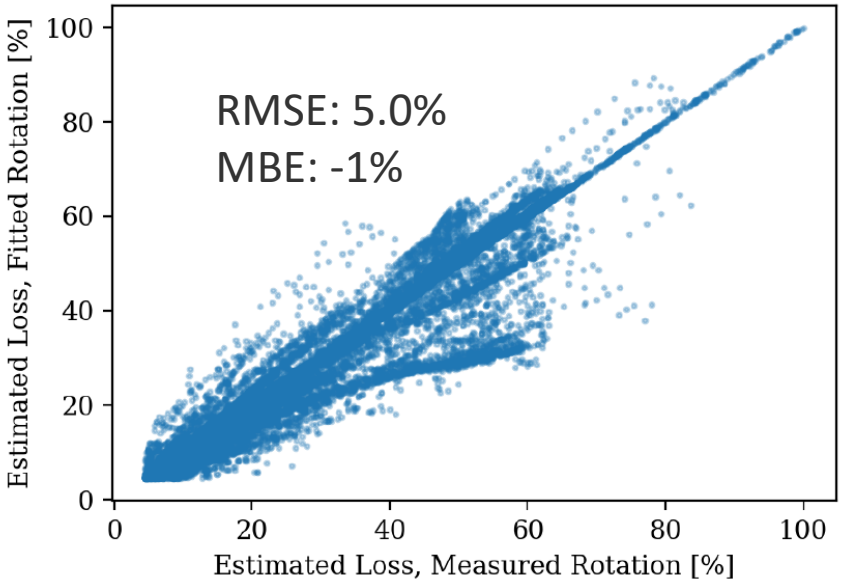


- Timeseries power is an alternative to measured rotation angle (often not available in industry datasets) or onsite inspection

K. Anderson et al., A method for estimating time series PV production loss from solar tracking failures, JPV 2022

Tracker stall model validation





- Identify best fit stall angle → estimate loss
- Validate vs loss modeled using known stall angle

K. Anderson et al., A method for estimating time series PV production loss from solar tracking failures, JPV 2022

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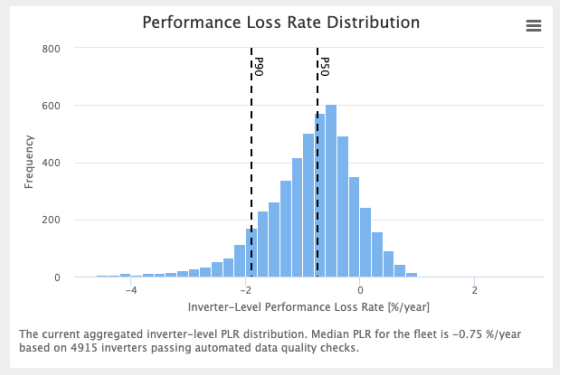
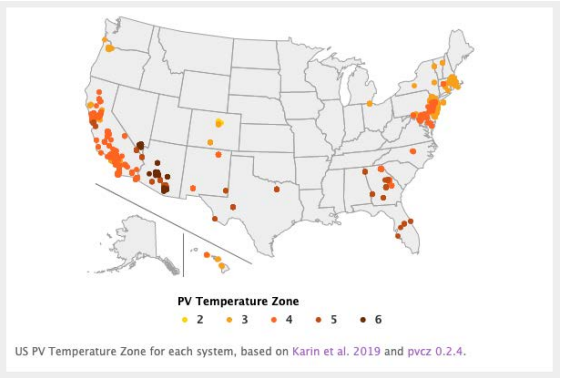
Conclusion – Chris' half

- PV Fleet Performance Data Initiative covers 6%-7% of US solar capacity (7.2 GW)
- Median system performance loss rate of –0.75%/yr, has a slight temperature dependence
- Overall performance of systems is within 10% of expected for 90% of systems. Mean value = 0.994
- Reports, visualizations, raw data at nrel.gov/pv/fleet-performance-data-initiative.html

Interactive Fleet visualizations





Thank you

www.nrel.gov

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NREL/PR-5K00-83487

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Thank You to DOE and our PV Fleet Partners!