NREL

Transforming ENERGY

PV System Availability from Commercial and Utility-scale Systems

DNV Availability Webinar, Feb 1, 2024

Chris Deline with content from Dirk Jordan, Kirsten Perry, Michael Deceglie, Robert White (NREL) & Kevin Anderson (Sandia)

Mission: Reduce perceived risk by publishing detailed statistics on U.S. fleet performance

Open-source tools

Software for degradation analysis, soiling loss and Data QA

Industry partners

Aggregate sources for data sharing and tool development

Utility-scale solar

Relevant large systems and modern modules totaling **>8 GW**

Data analytics

Machine learning extraction of metadata and underperformance

Climate study

Disaggregate by climate, mounting configuration and failure mode

PV Fleet Project Overview

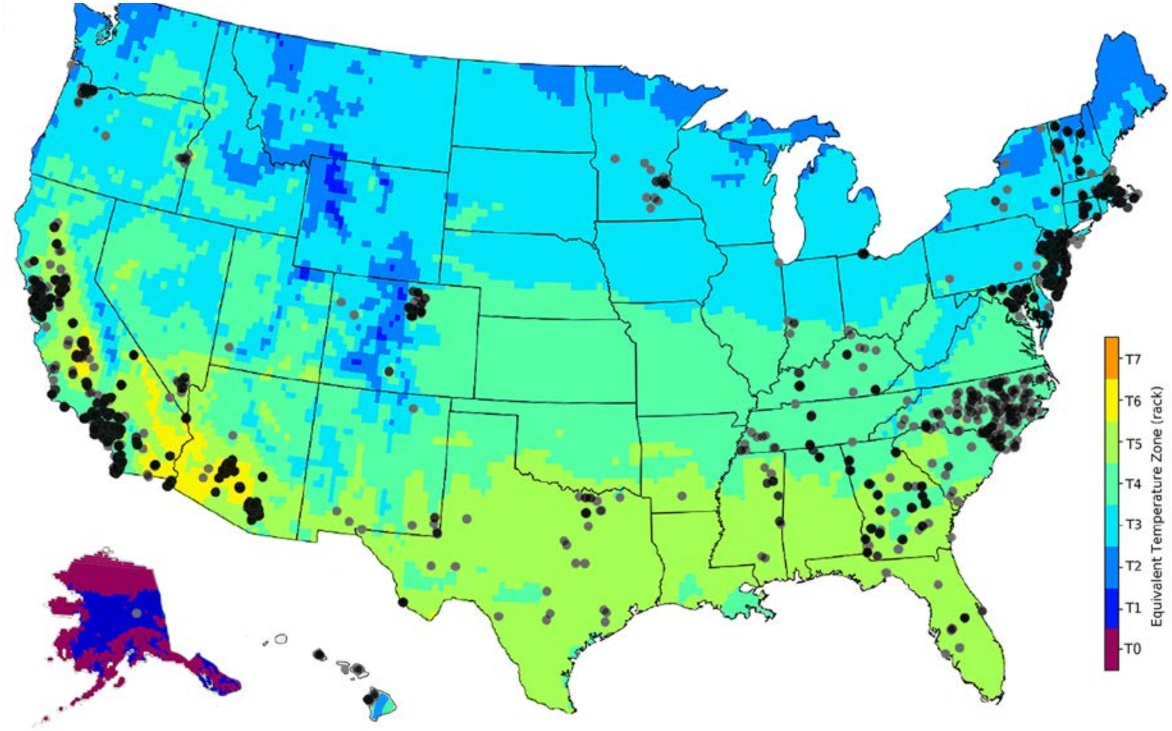
In the **PV Fleet Performance Data Initiative**, high-frequency data from commercial and utility-scale PV systems have been collected to examine performance trends at a fleet scale.

- Owners provide NDA-protected data to NREL
- Fleet-scale analysis provided in return
    - Annual degradation rate (Rd)
    - Loss factors (availability, soiling, etc)
    - Under-performing systems flagged
- Results are anonymized and aggregated for public dissemination
    - Validate pro-forma model assumptions
    - Identify performance trends by climate, technology, etc.

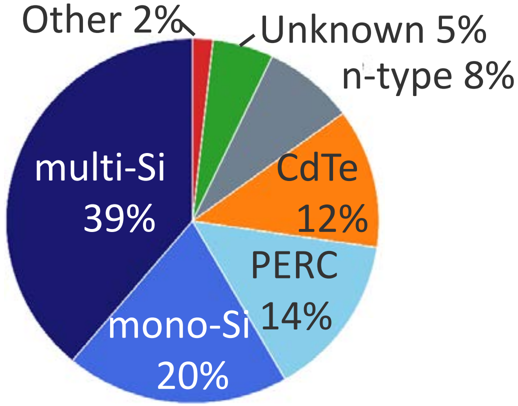
For more details or for partner opportunities, email chris.deline@nrel.gov

PV Fleet Performance Data Initiative

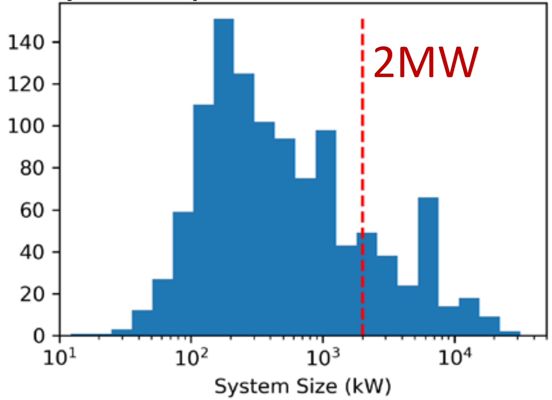
>2200 systems, > 24,000 Inverters, >8.5 GW capacity



Module technology breakdown



System power distribution



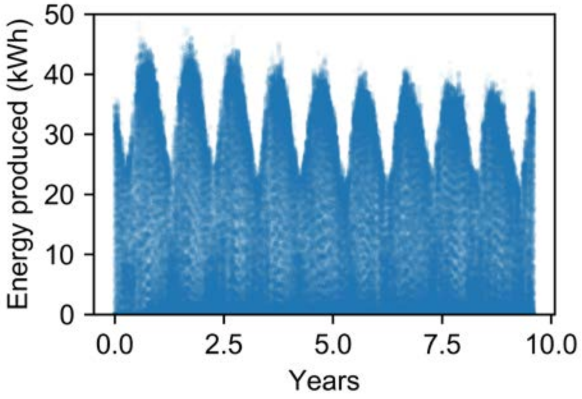
Mean system age: ~4.6 yrs

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

PV Field Performance

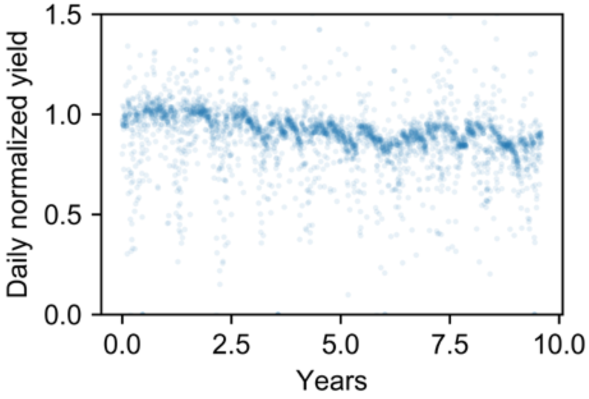
- PV power is a factor of irradiance & temperature
- Real data is messy (outages, instrumentation errors)
- Many systems -> automated analysis & data filtering

Raw energy time series



0. Data quality check
1. Normalize to model
2. Filter
3. Aggregate

Daily normalized energy yield

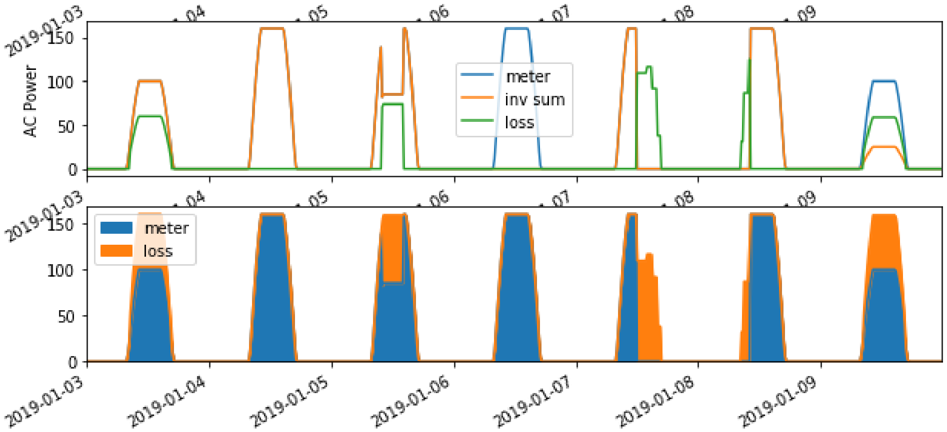


github.com/pvlib/pvanalytics

www.nrel.gov/pv/rdtools.html

Inverter availability analysis in RdTools

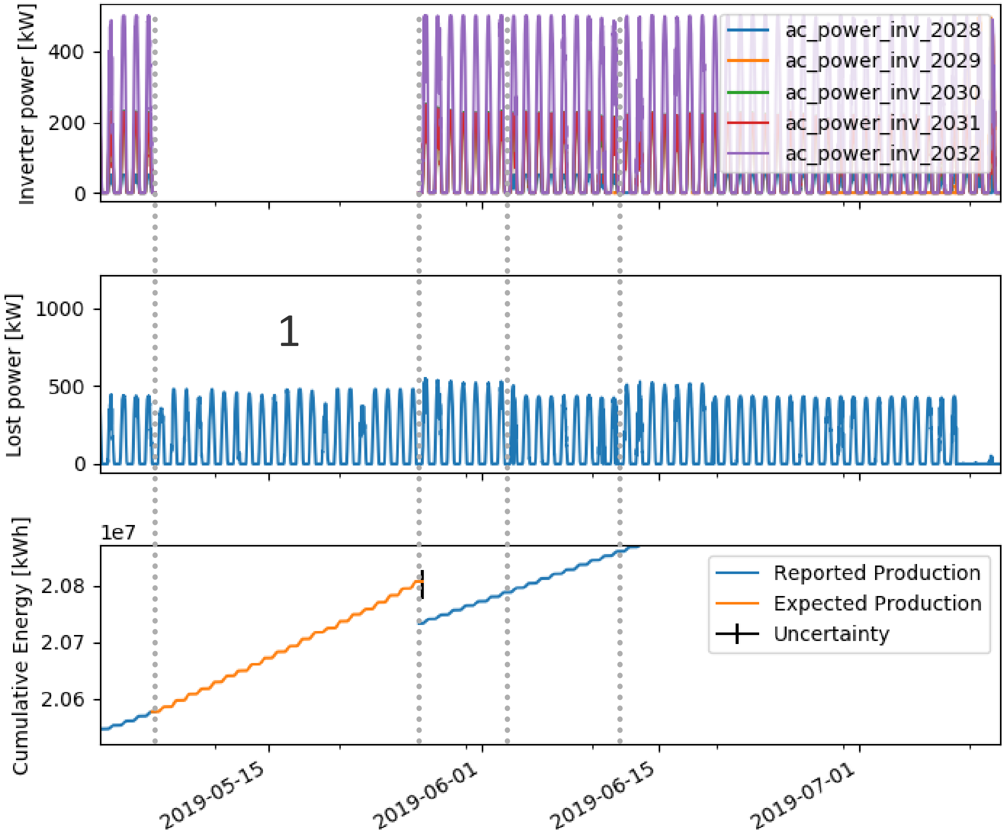
- Availability analysis conducted using RdTools.availability
- Goal: Autonomous quantification of lost energy from inverter downtime
- Compare inverters vs nearest neighbors and identify times of zero production at the subsystem-level
- Availability calculated as an energy-weighted (not time-weighted) value and rolled up monthly per system



- K. Anderson, R Blumenthal “Overcoming Communications Outages in Inverter Downtime Analysis”, 47th IEEE PVSC, 2020
- nrel.gov/pv/rdtools.html

Inverter availability analysis – comms outage

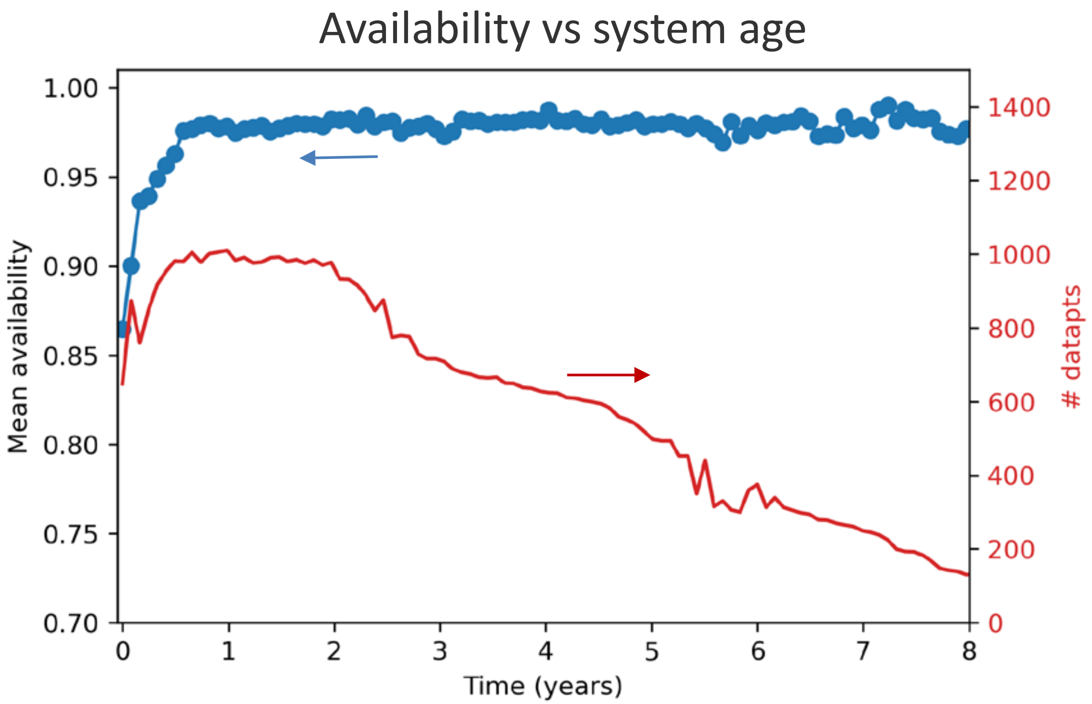
- Algorithm must be robust to communication outages/missing data to not bias lost energy estimates.
- Communication outage (period 1): compare cumulative meter energy with expected.
- A difference in actual vs expected energy during this period can be attributed to availability loss



K. Anderson, R Blumenthal "Overcoming Communications Outages in Inverter Downtime Analysis", 47th IEEE PVSC, 2020

Inverter Availability over System Lifespan

- Availability assessed for 1128 high-quality systems, grouped by time since t0
- Steady-state reached after first year, 97.9% avg availability
- Start-up phase in first 6 months shows lower availability (80%-90%)

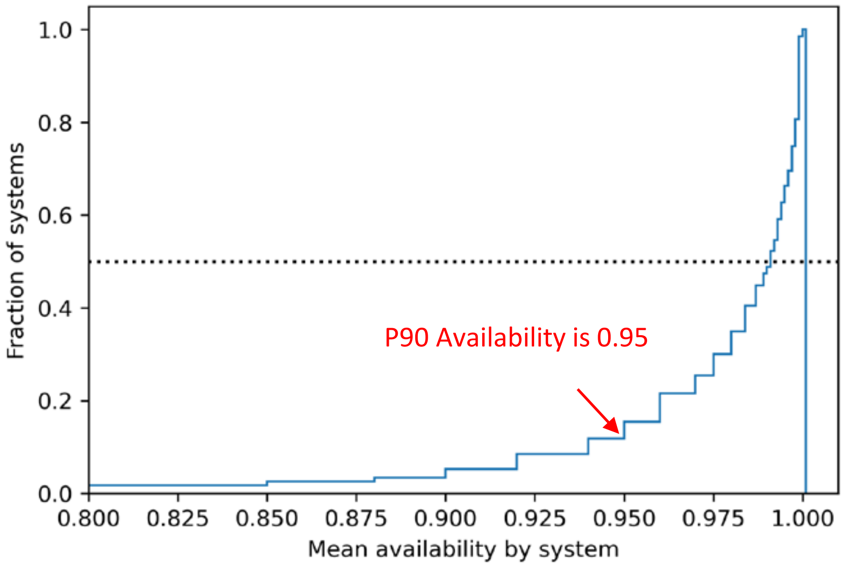


C. Deline et al. unpublished

System-level availability

- Grouping by system, we find the 97.9% overall avg is impacted by a **long tail of low availability systems**.
- Median P50 and P90 values can be calculated from the CDF of mean system availability.
- P90 system availability: **0.95**

CDF of mean system availability

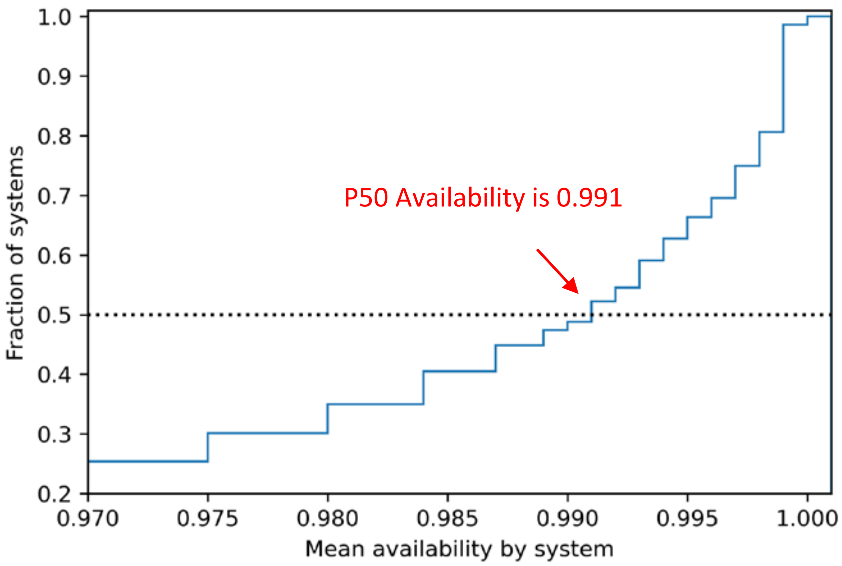


C. Deline et al. unpublished

System-level availability

- Grouping by system, we find the 97.9% overall avg is impacted by a **long tail of low availability systems**.
- Median P50 and P90 values can be calculated from the CDF of mean system availability.
- P50 system availability: **0.991**

CDF of mean system availability (zoomed)

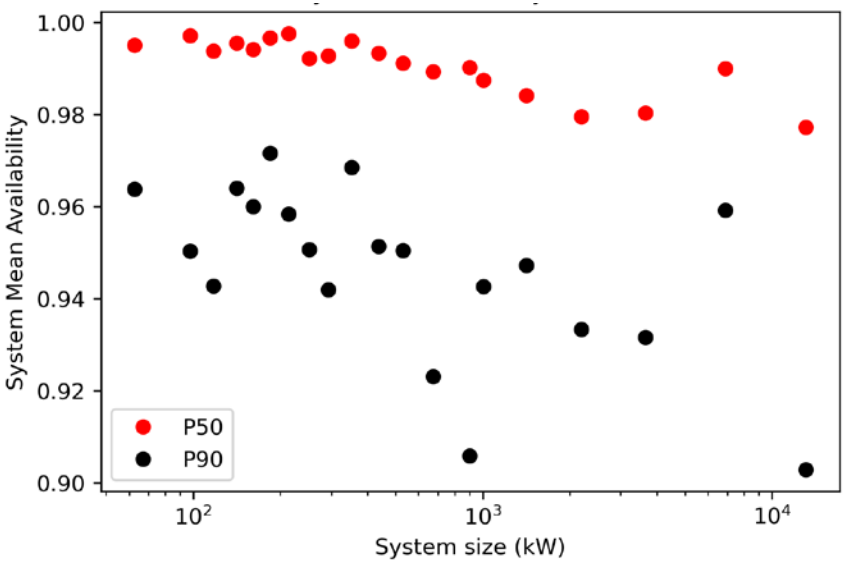


C. Deline et al. unpublished

System-level availability vs system size

- At both the P50 and P90 level, system availability appears to have a negative trend vs system size.
- P50 for systems <1 MW is 0.994. For larger systems 1MW – 30MW, median system availability is 0.984

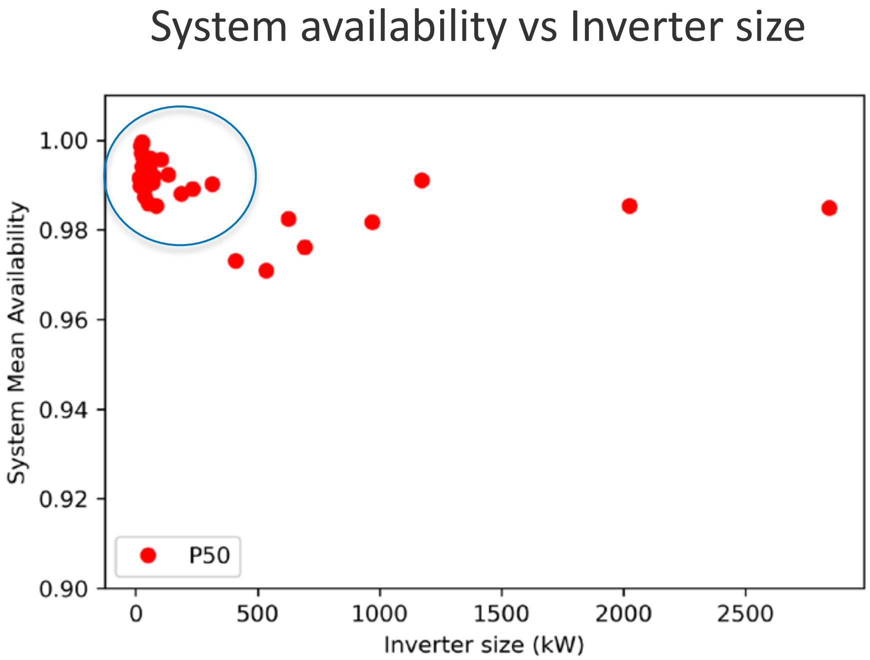
System availability vs System size



C. Deline et al. unpublished

System-level availability vs Inverter size

- Some of the availability trend may be due to inverter size: smaller inverters < 300kW tend to have better availability.
- This is the old string inverter vs central inverter debate!

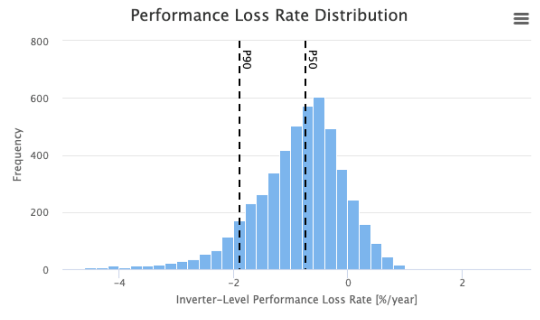


C. Deline et al. unpublished

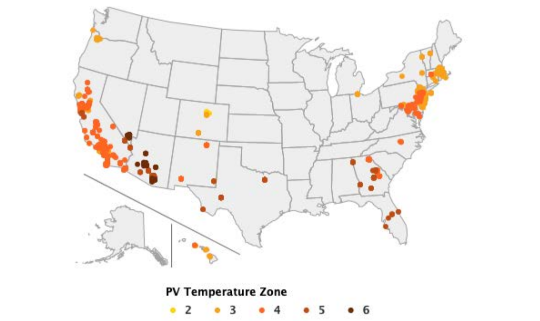
Conclusion

- PV Fleet Performance Data Initiative covers 6%-7% of US solar capacity (8.5 GW)
- System P50 availability is 0.991 following a ~6 month startup period
- Preliminary indication is that smaller systems may have better availability, possibly due to string vs central inverter equipment benefits.
- Reports, visualizations, raw data at nrel.gov/pv/fleet-performance-data-initiative.html

Interactive Fleet visualizations



The current aggregated inverter-level PLR distribution. Median PLR for the fleet is −0.75 %/year based on 4915 inverters passing automated data quality checks.



US PV Temperature Zone for each system, based on Karin et al. 2019 and pvcz 0.2.4.

Thank you

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NREL/PR-5K00-88590

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Thank You to DOE and our PV Fleet Partners!

NREL NATIONAL RENEWABLE ENERGY LABORATORY

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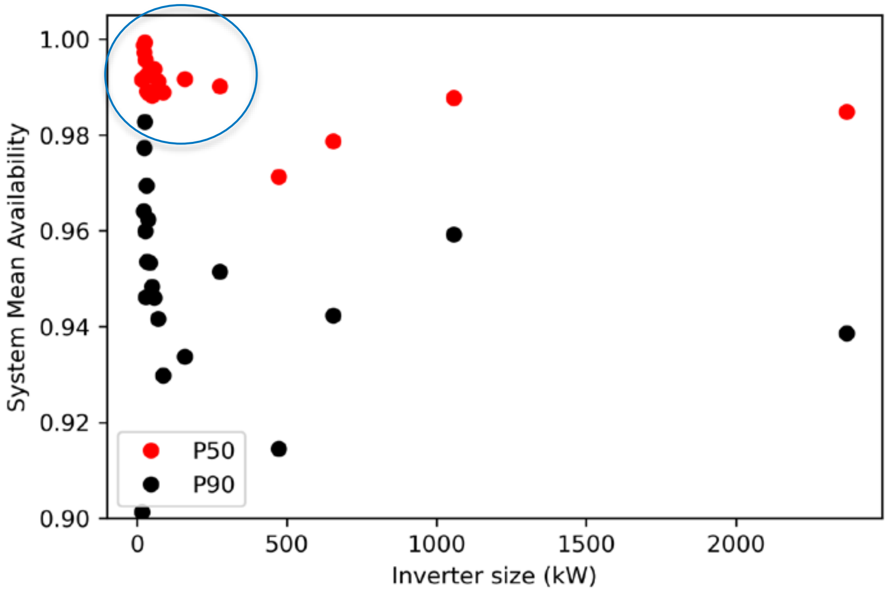
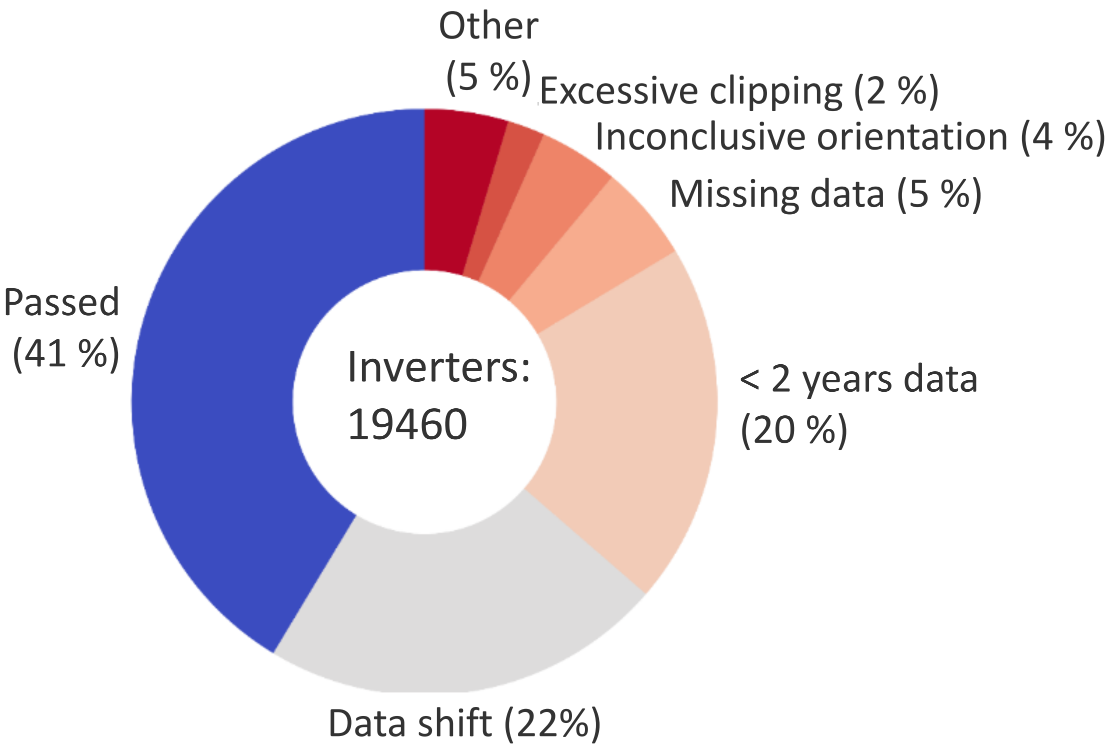
System availability vs Inverter size



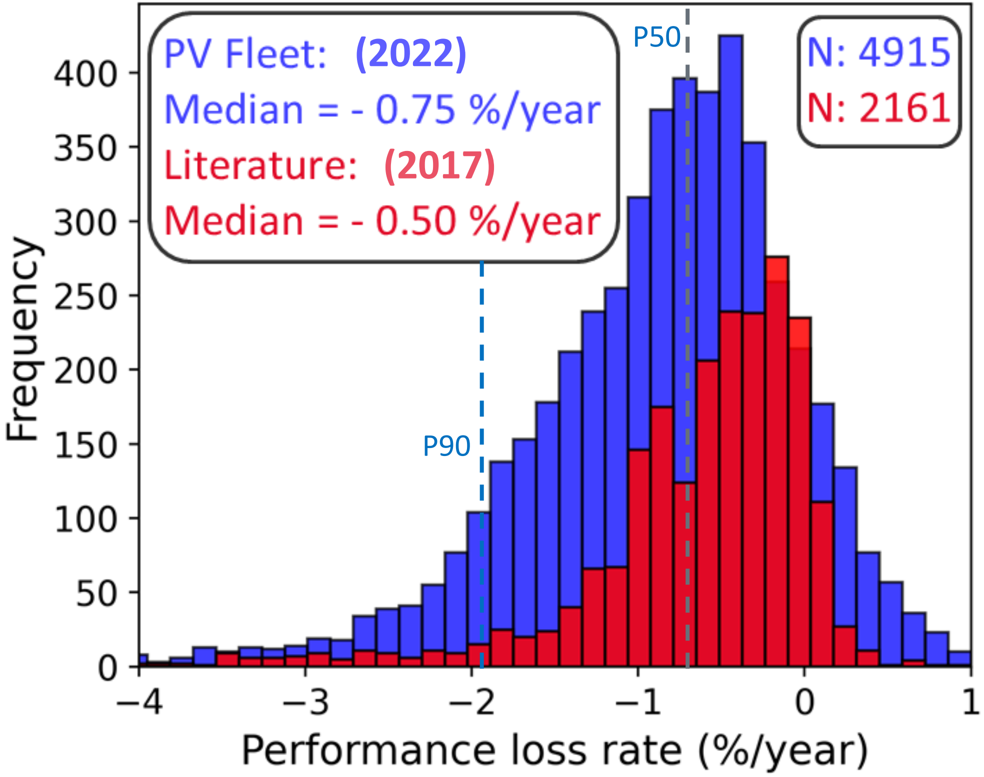
C. Deline et al. unpublished

Breakdown of quality issues – PV Fleet



Jordan et al., Progress in PV, 2022

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 index analysis

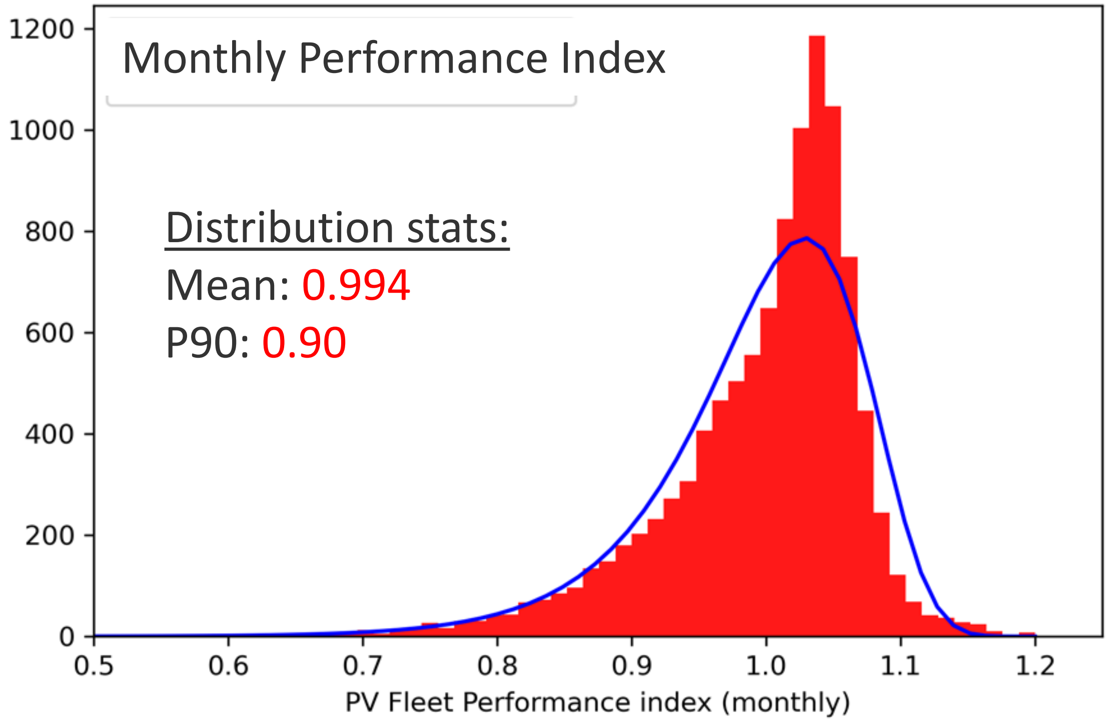
Measured vs expected monthly roll-up with loss factors identified

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

Expected Production estimated with PVWatts model and NSRDB weather

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

Monthly Performance Index distribution



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

Quantitative Findings – pro forma loss factors

Energy Loss Term	PVWatts Default	PV Fleet Loss
Soiling	2%	2%
Shading	3%	
Snow	0%	0% - 10%
Mismatch	2%	
Wiring	2%	
Connections	0.5%	
LID	1.5%	0%
Nameplate	1%	
Age	0%	0.7%/yr
Availability	3%	1%
Total	**14.1%**	**11.8% + 0.7%/yr**

* In high-soiling areas

* Climate dependent

* Excluding initial startup