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# (Challenges of) Determining climate and PV technology specific performance loss trends

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Eurac Research



**TRUSTPV**  
SOLAR PV, PERFORMANCE & RELIABILITY

# BACKGROUND

- In TRUST-PV **Eurac + 3E** investigate performance loss in PV systems
- **PLR**: annual loss in **performance** (so, not only degradation)
- **Aim**: present a better approach than linear PLR of  $-0.5\%/yr$ 
  - Easy to implement
  - E.g. not requires many (additional) input parameters
  - To be used for long-term yield assessment
- **Aim**: investigate shape of PL trends and determine which of several PL models fit best the observed data
- **Aim**: determine, based on large monitoring dataset:
  - PLR  $\leftrightarrow$  operational climate
  - PLR  $\leftrightarrow$  PV module technology
  - PLR  $\leftrightarrow$  ....

# DATASET OVERVIEW

- In collaboration with 3E a subset of the anonymized aggregated dataset was investigated



**15 GW**

CONNECTED

**75**

COUNTRIES

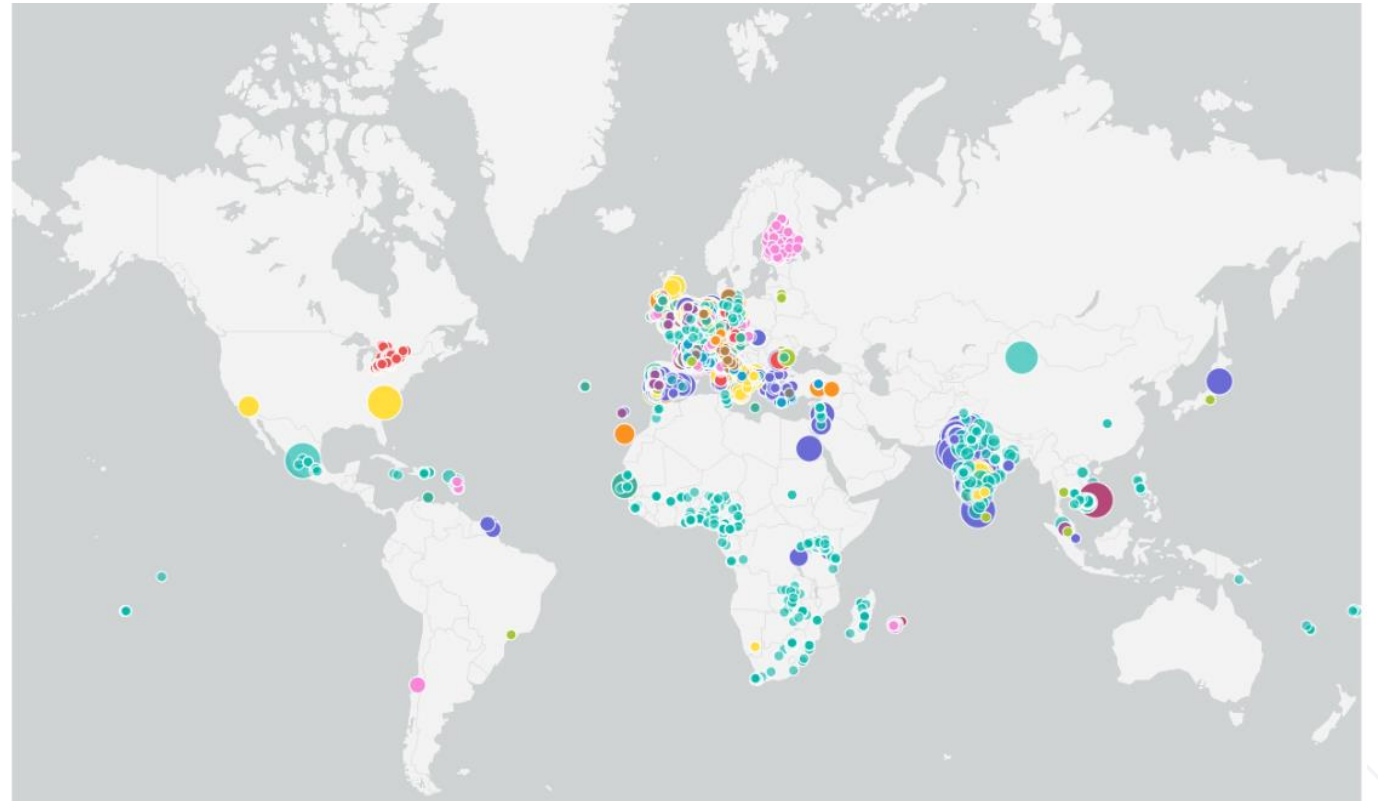
**20 million**

DEVICES

**+ 10 000**

SITES

*C&I and Utility-scale*



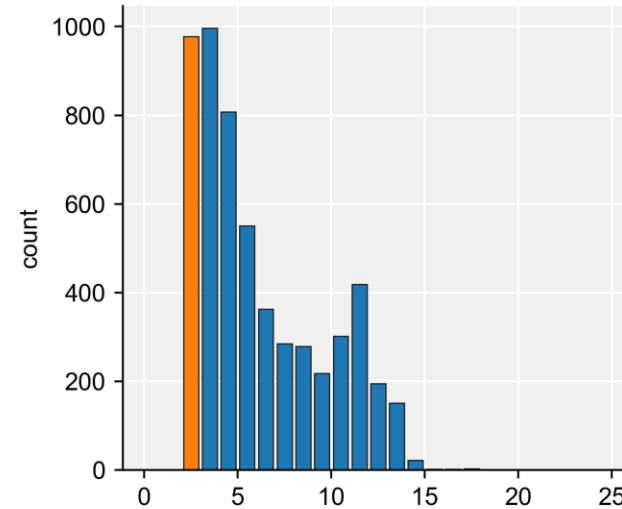
# DATASET AND FILTERING

- We use commercial PV system monitoring dataset
- ~10,000 systems, ~100,000 inverters
- Mainly in continental Europe\*
- Several filtering steps were taken
- To determine specific trends, data was combined per, e.g.
  - Climate zone (currently: KG + PV zone)
  - Module technology
  - Module manufacturer\*

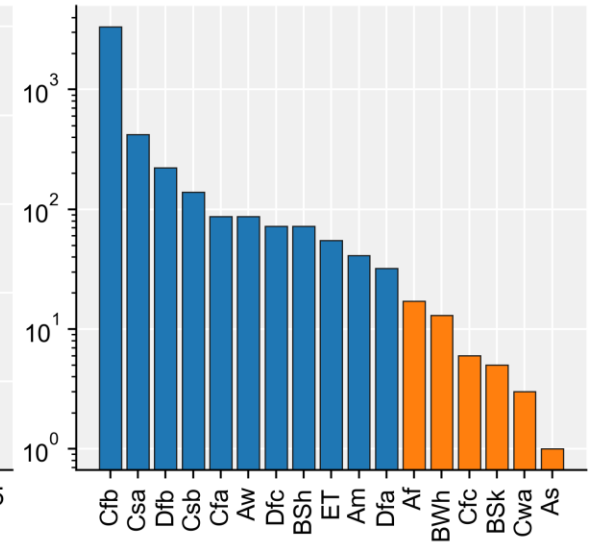
# DATASET AND FILTERING

- We use commercial PV system monitoring dataset
- ~10,000 systems, ~100,000 inverters
- System age ranges from 2->15 years
- 17 KG climate zones (11 with >30 systems)
- 14 PV climate zones (9 with > 30 systems)
- Mainly poly-Si and mono-Si

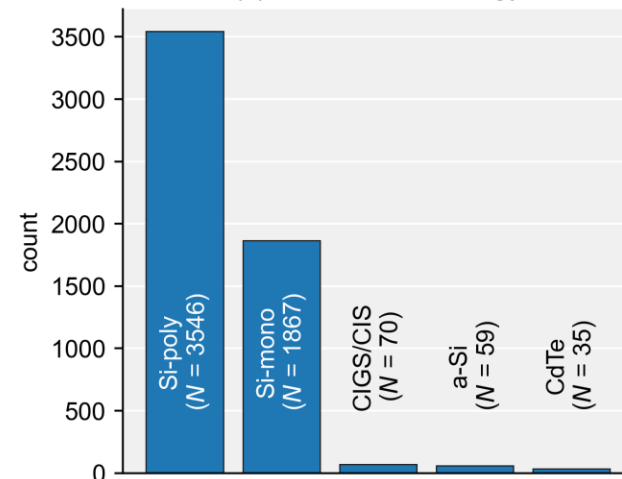
(a) system age (years)



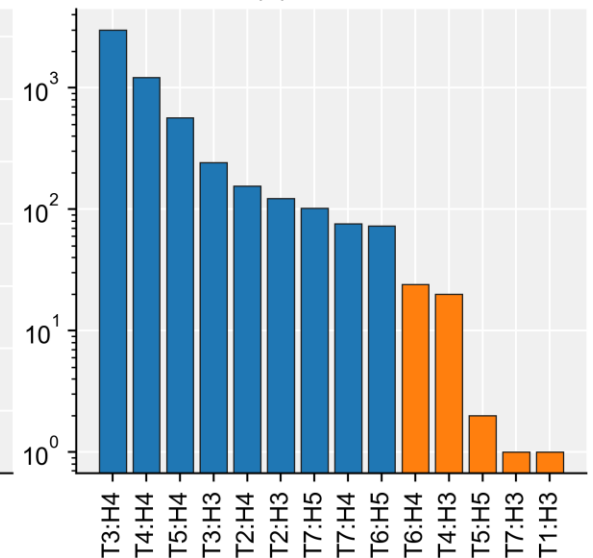
(b) KG zone



(c) module technology

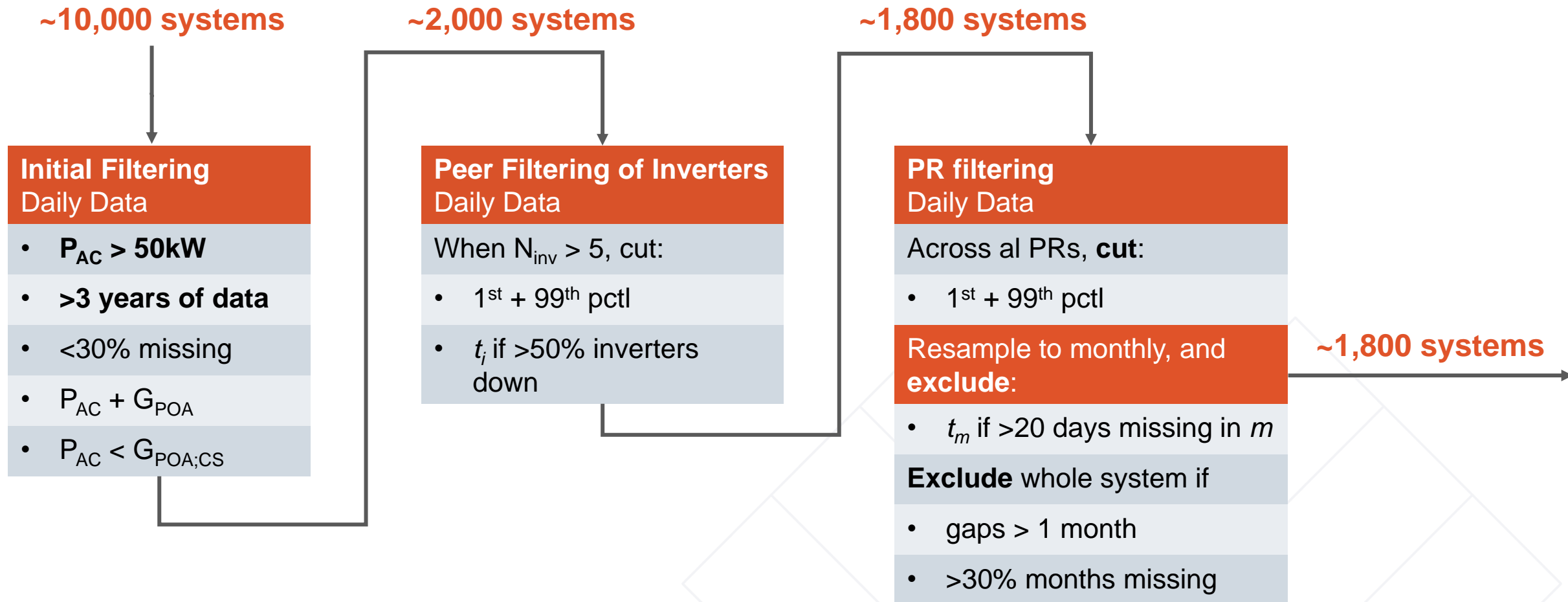


(d) PV zone





# DATASET AND FILTERING



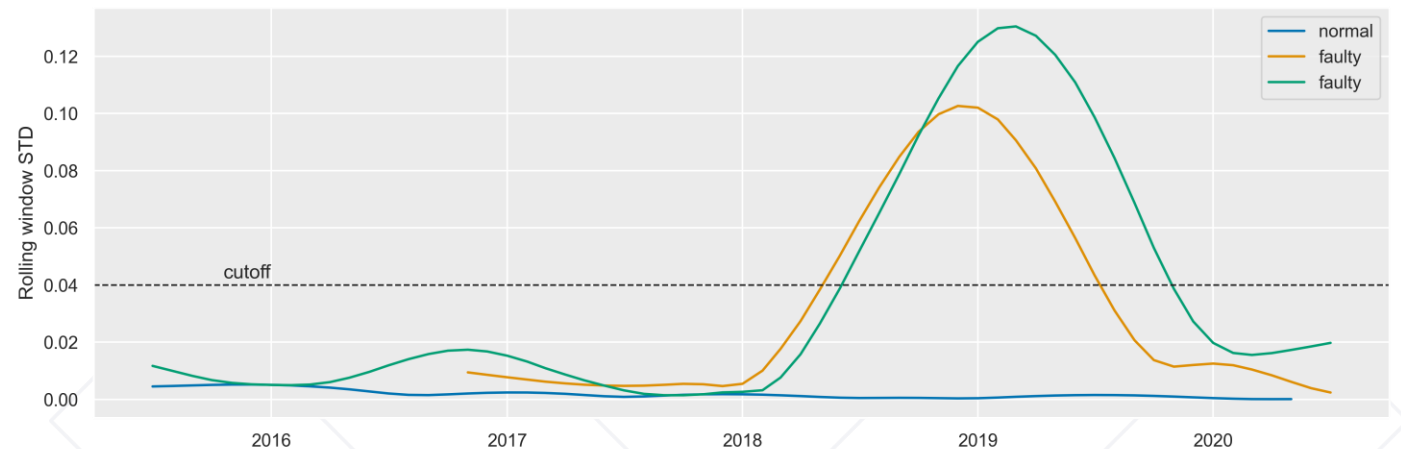
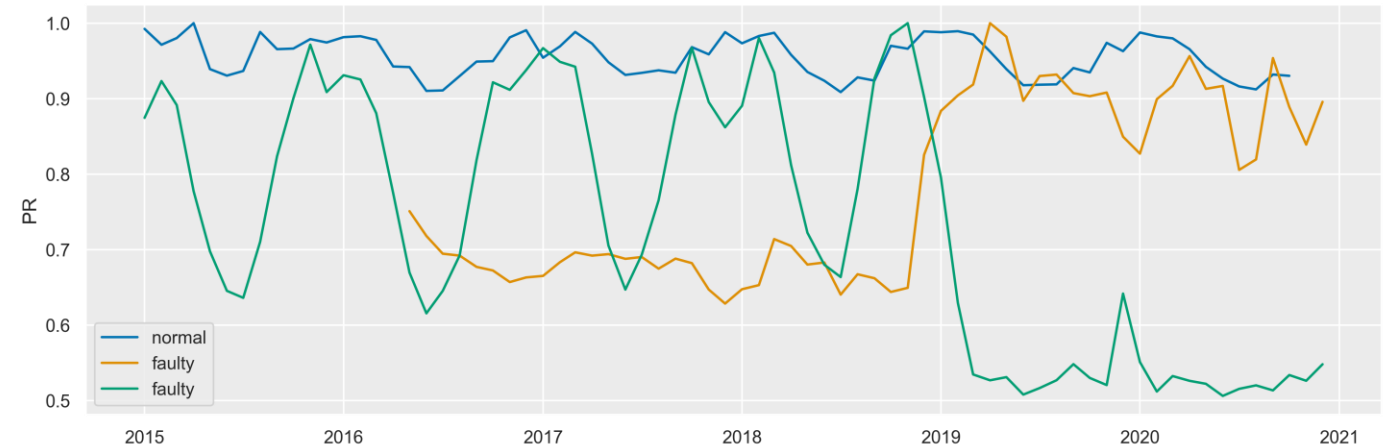
# DATASET AND FILTERING

Due to several issues, trend breaks occur

- Outages
- Changes in monitoring settings
- Issues with irradiance data or measurements

To determine trend breaks, we:

- Determine STL trends for each system
- Calculate SD of PR in rolling window
- Systems with  $SD > 0.04$  are excluded



# DATASET AND FILTERING - RESULTS

Additionally, we exclude:

- Systems with increasing performance:  $PLR > 1\%/yr$
- Systems with very high performance loss:  $PLR < -4\%/yr$

After this filtering, we have remaining:

- ~1000 systems

With at least 20 systems per group we have:

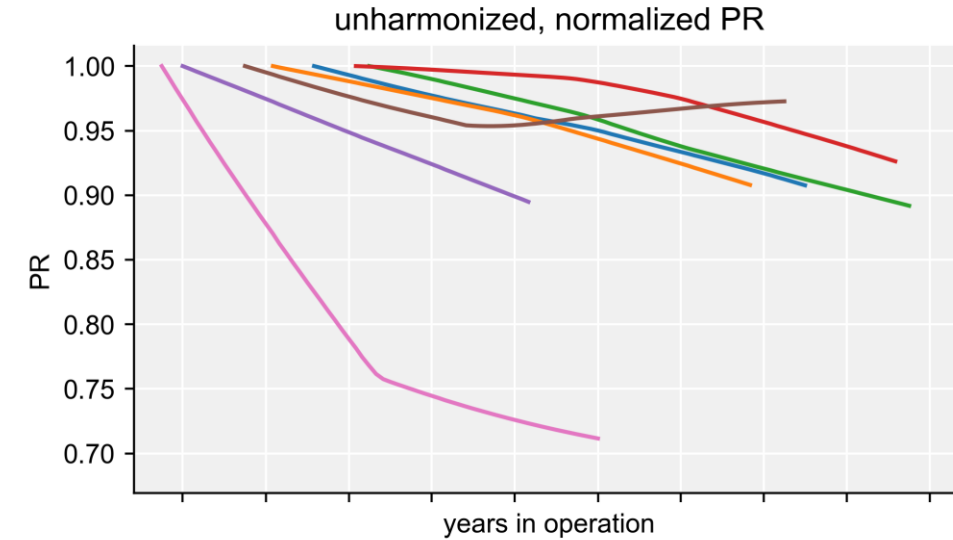
- 3 climate zones (KG climate zone / PV climate degradation zone)
- 3 PV technologies
- 4 PV module manufacturers



# DETERMINING PLR TRENDS AND VALUES

To determine “average” PLR for groups of systems

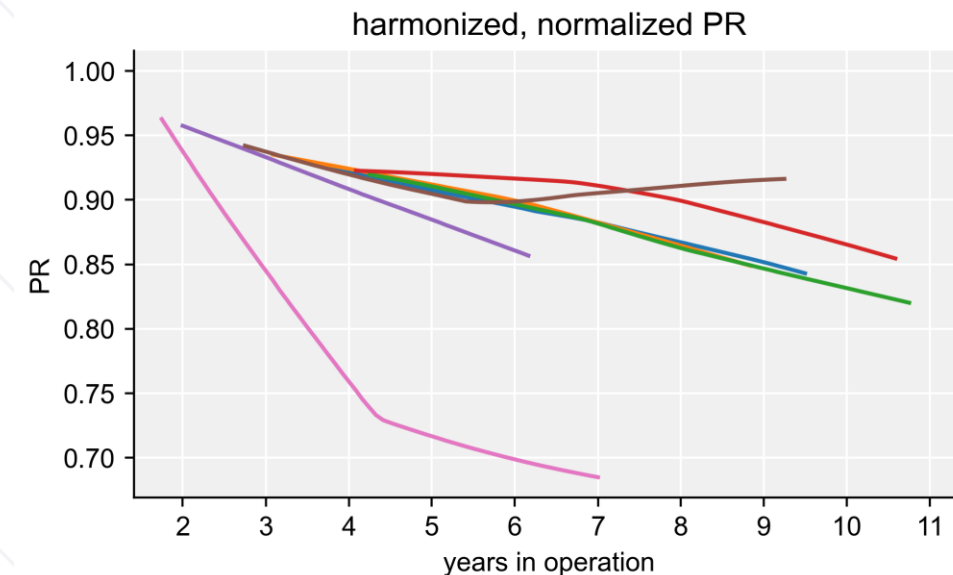
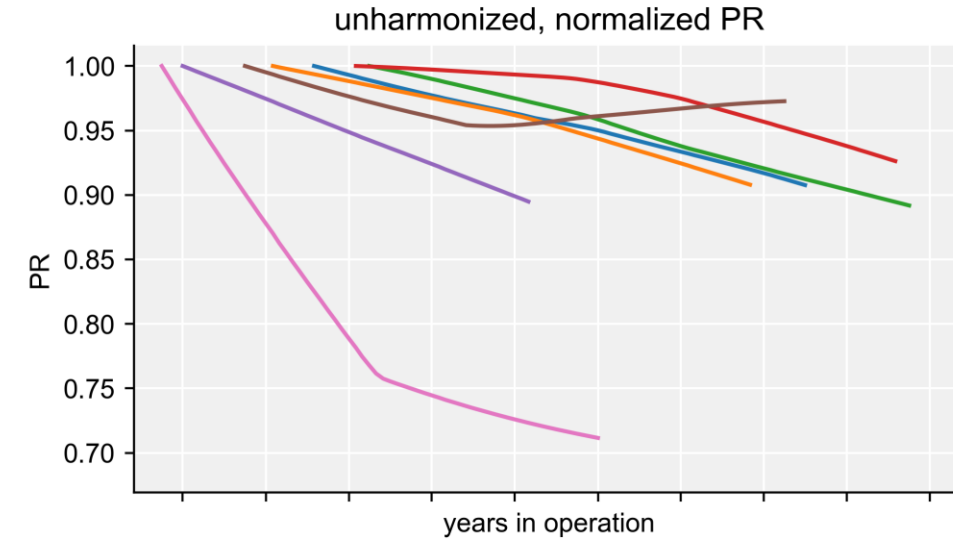
- **We align systems by operational age**



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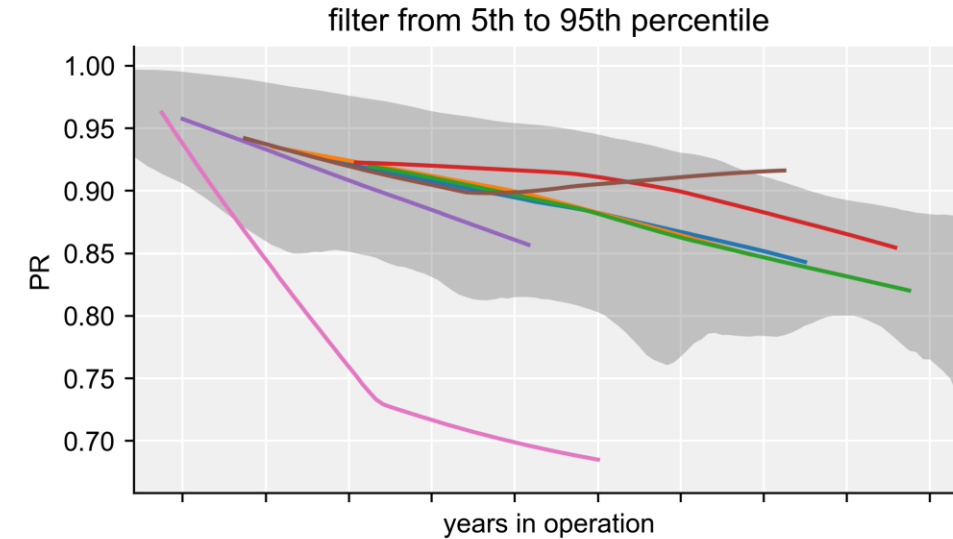
- We align the systems by operational age
- **Harmonize the PR values so initial PR aligns with the overall trend**



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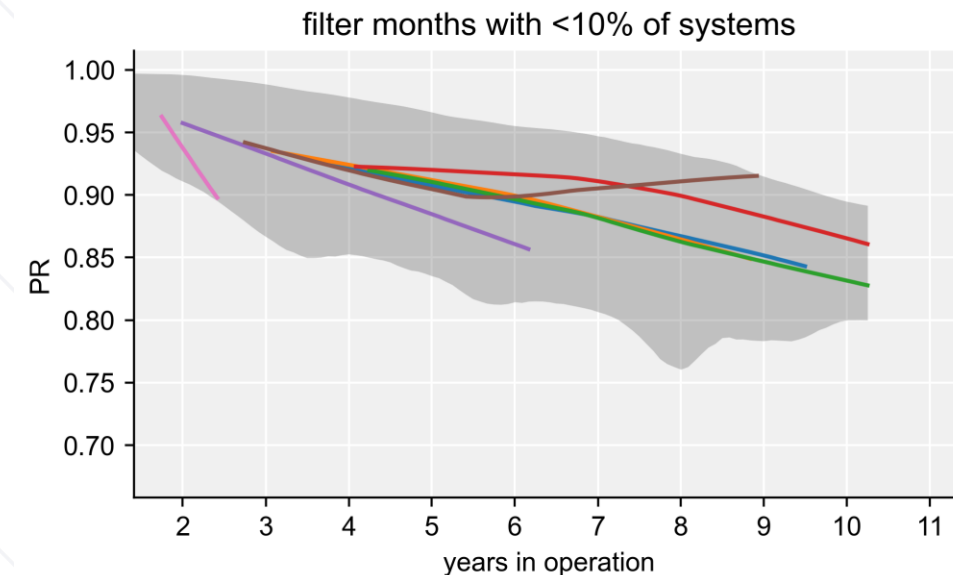
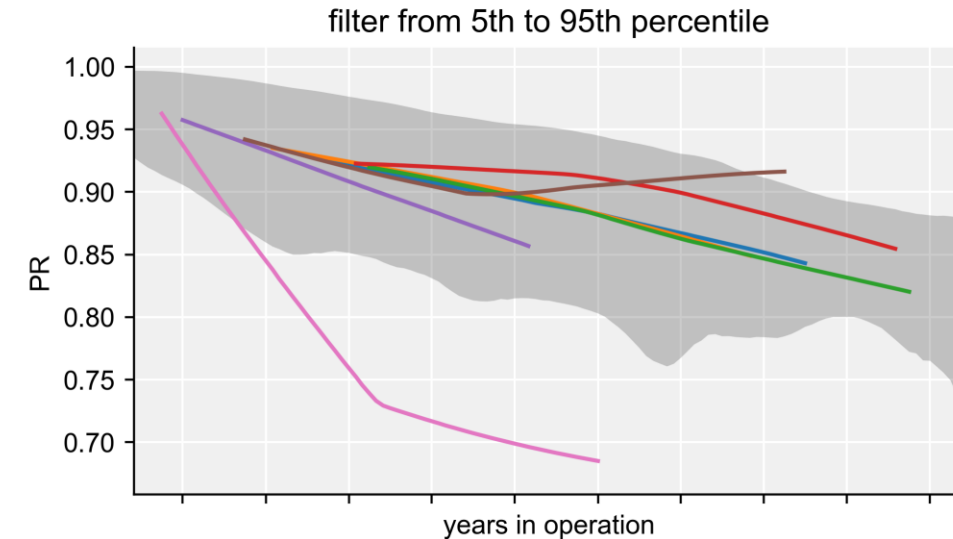
- We align the systems by operational age
- Harmonize the PR values so initial PR aligns with the overall trend
- **Include systems from 5<sup>th</sup> to 95<sup>th</sup> percentile at each timestamp (monthly data)**



# DETERMINING PLR TRENDS AND VALUES

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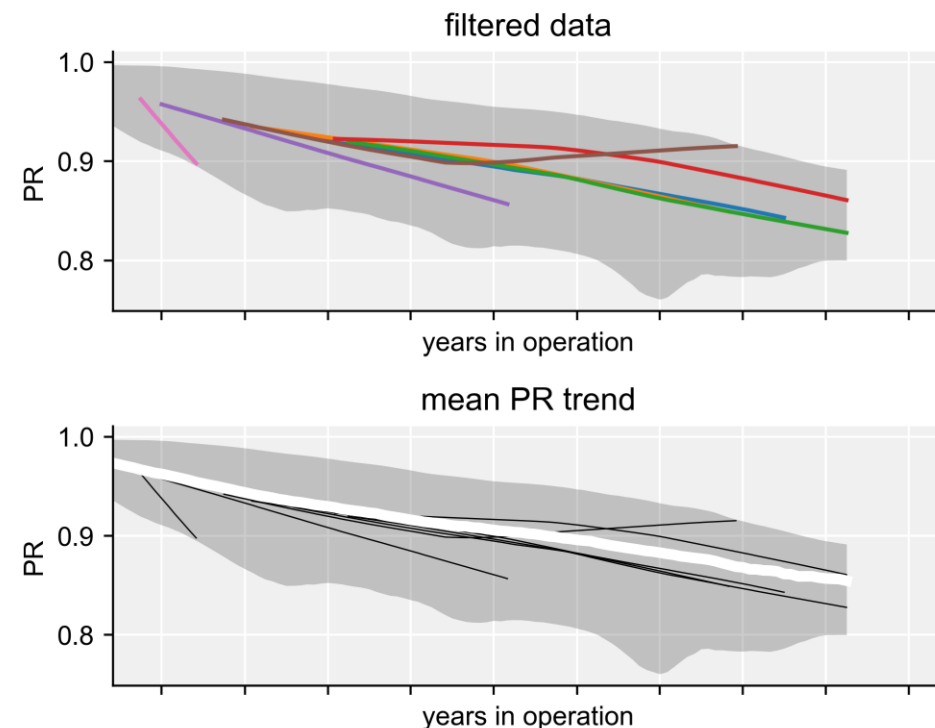
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- Include systems from 5<sup>th</sup> to 95<sup>th</sup> percentile at each timestamp (monthly data)
- **Exclude months with <10% of systems**



# DETERMINING PLR TRENDS AND VALUES

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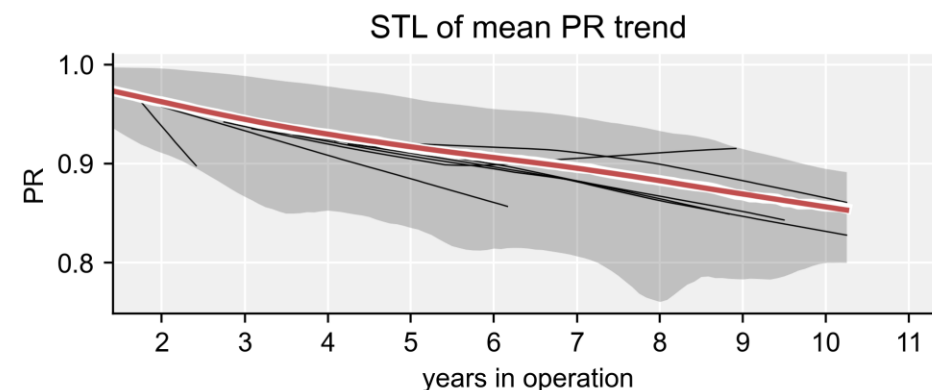
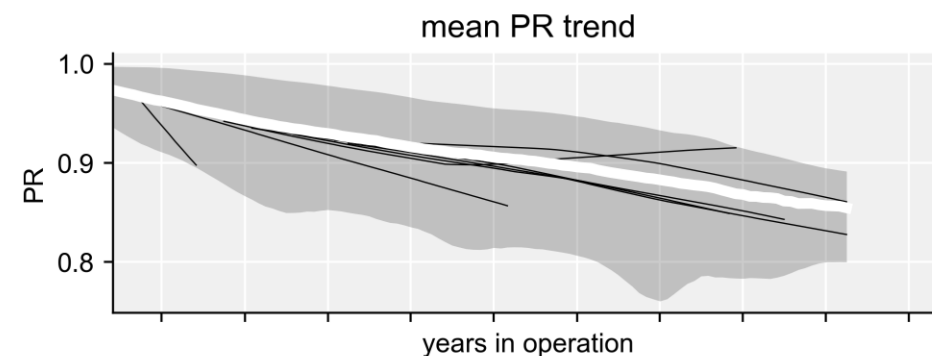
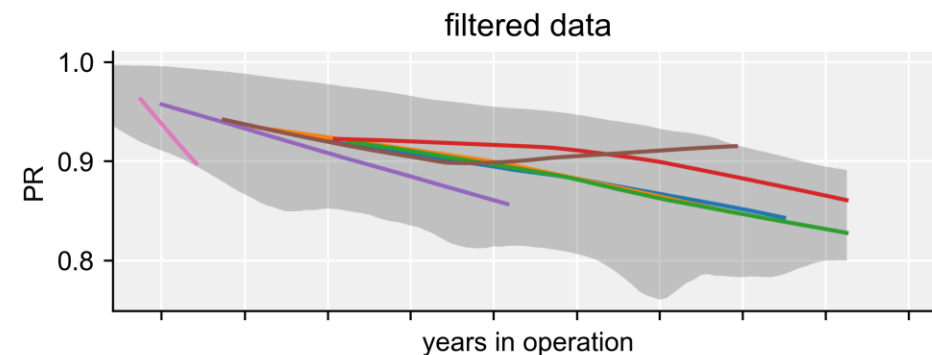
- We align the systems by operational age
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- Include systems from 5<sup>th</sup> to 95<sup>th</sup> percentile at each timestamp (monthly data)
- Exclude months with <10% of systems
- **Calculate mean trend of remaining systems**



# DETERMINING PLR TRENDS AND VALUES

To determine “average” PLR for groups of systems

- We align the systems by operational age
- Harmonize the PR values so initial PR aligns with the overall trend
- Include systems from 5<sup>th</sup> to 95<sup>th</sup> percentile at each timestamp (monthly data)
- Exclude months with <10% of systems
- Calculate mean trend of remaining systems
- **To avoid remaining seasonality we take STL trend of mean PR**
- **Overall PLR value calculated by LR of trend**





# TWO CLIMATE ZONES COMPARED

## Köppen-Geiger (KG)

- Well known climate classification
- Not tuned to PV
- Three-letter system
- Tropical (A), Arid (B) Temperate (C), Continental (D), Polar (E)
- E.g. **Cfa** and **Cfb**:
  - C = mild temperate
  - f = fully humid (no dry season)
  - a = hot summer / b = warm summer

## PV climate degradation zones (PVCZ)

- Tuned specifically to PV degradation stressors
- Takes into account temperature (cycling) + humidity
- **TX:HY** system
- T value from 1-10, H from 1-5
- E.g.
  - T4: module temp. 24-29°C
  - H4: specific humidity 5.9-10.5 g/kg
- [doi.org/10.1109/PVSC40753.2019.8980831](https://doi.org/10.1109/PVSC40753.2019.8980831)

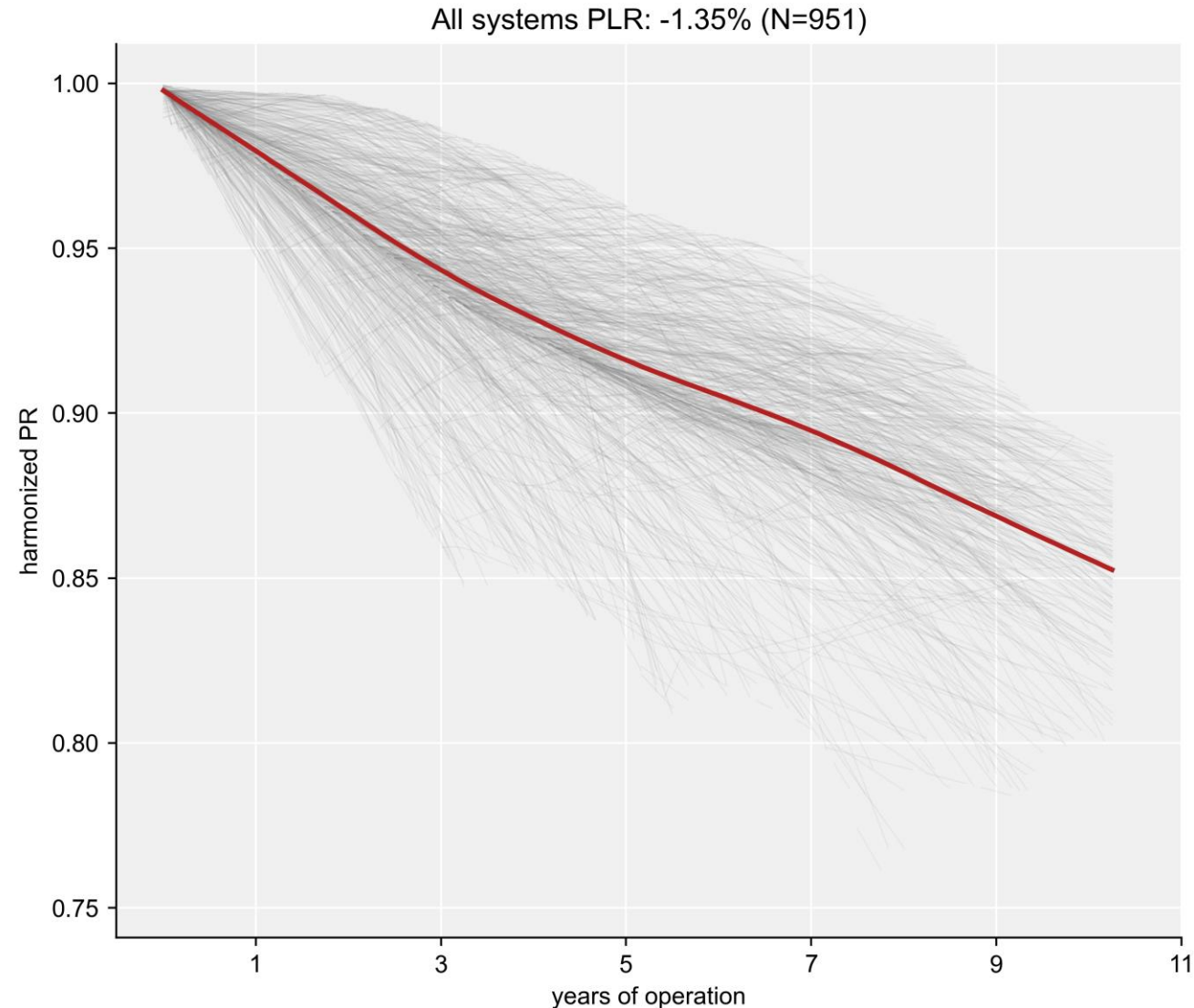
# RESULTS



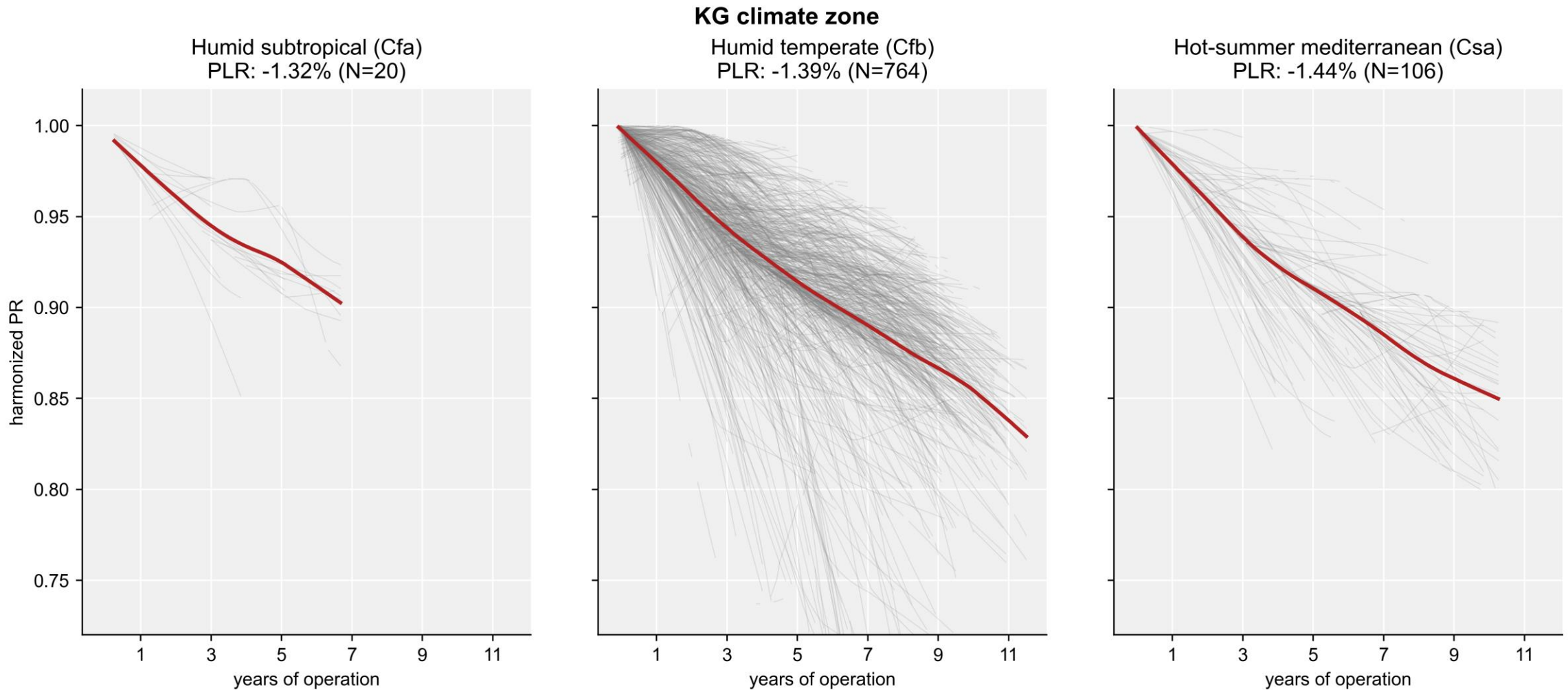
# RESULTS - OVERALL

Across all remaining systems:

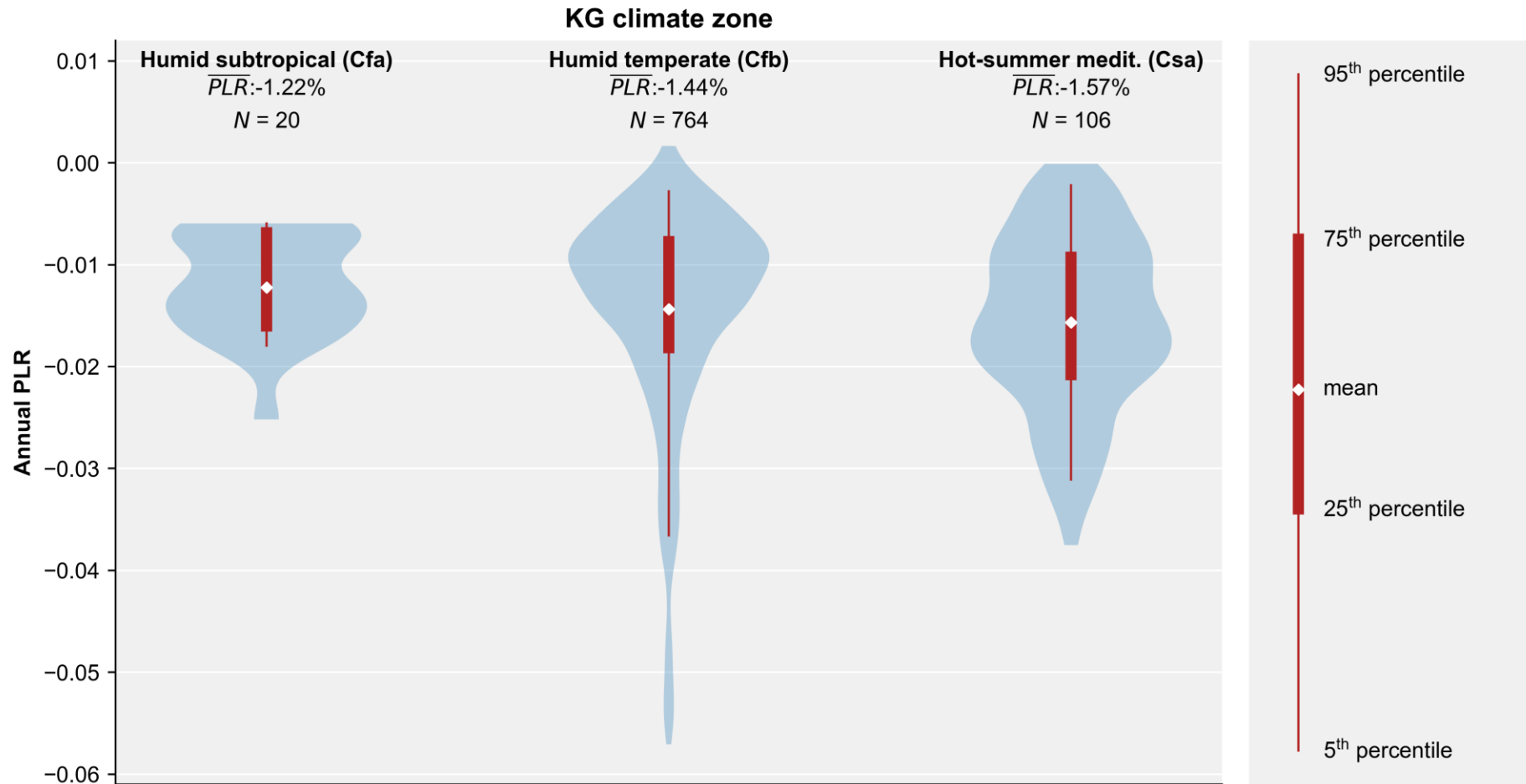
- Overall average PLR trend roughly linear ( $R^2 = 0.994$ )
- Slightly faster initial performance loss
- PLR of this trend is **-1.35%/yr**
- Average PLR is **-1.69%/yr**



# RESULTS – KG ZONES



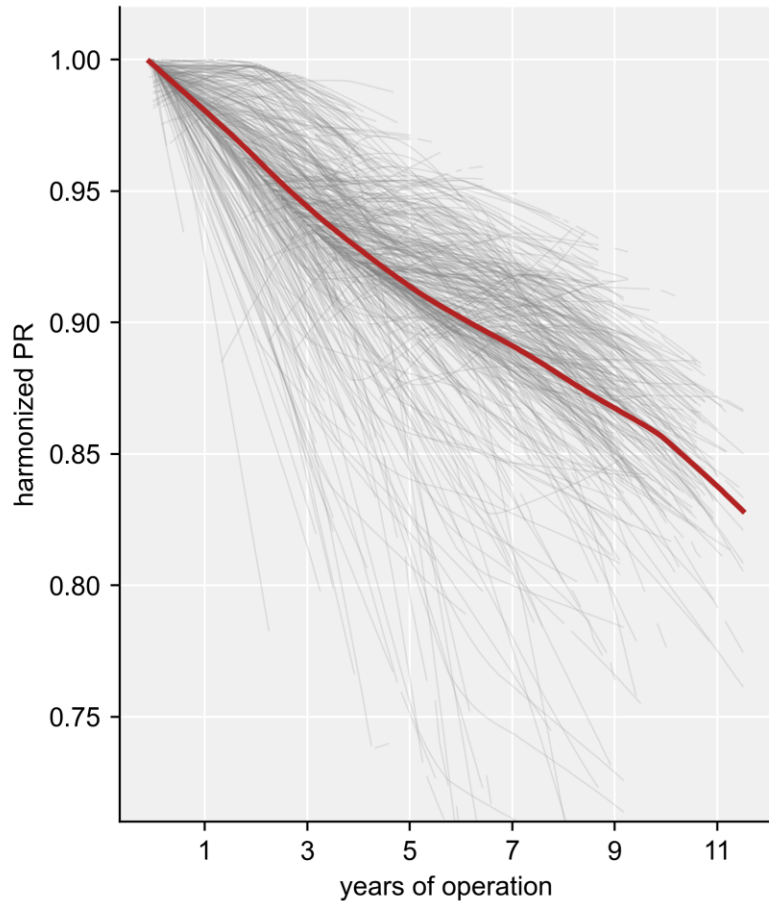
# RESULTS – KG ZONES



# RESULTS – PV DEGRADATION CLIMATE ZONES

## PV climate zone

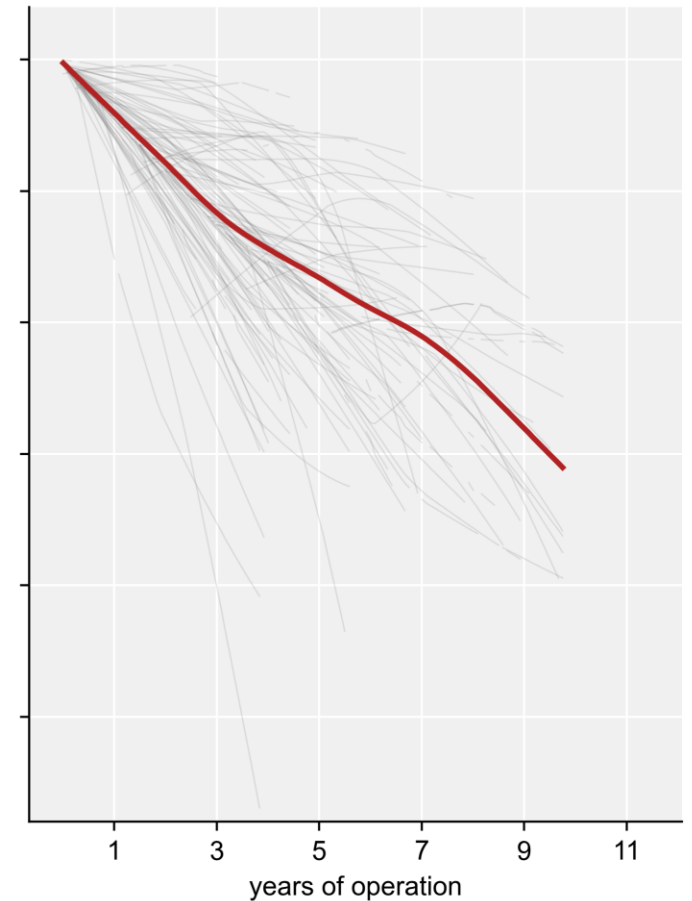
T3:H4 - PLR: -1.39% (N=545)



T4:H4 - PLR: -1.41% (N=203)

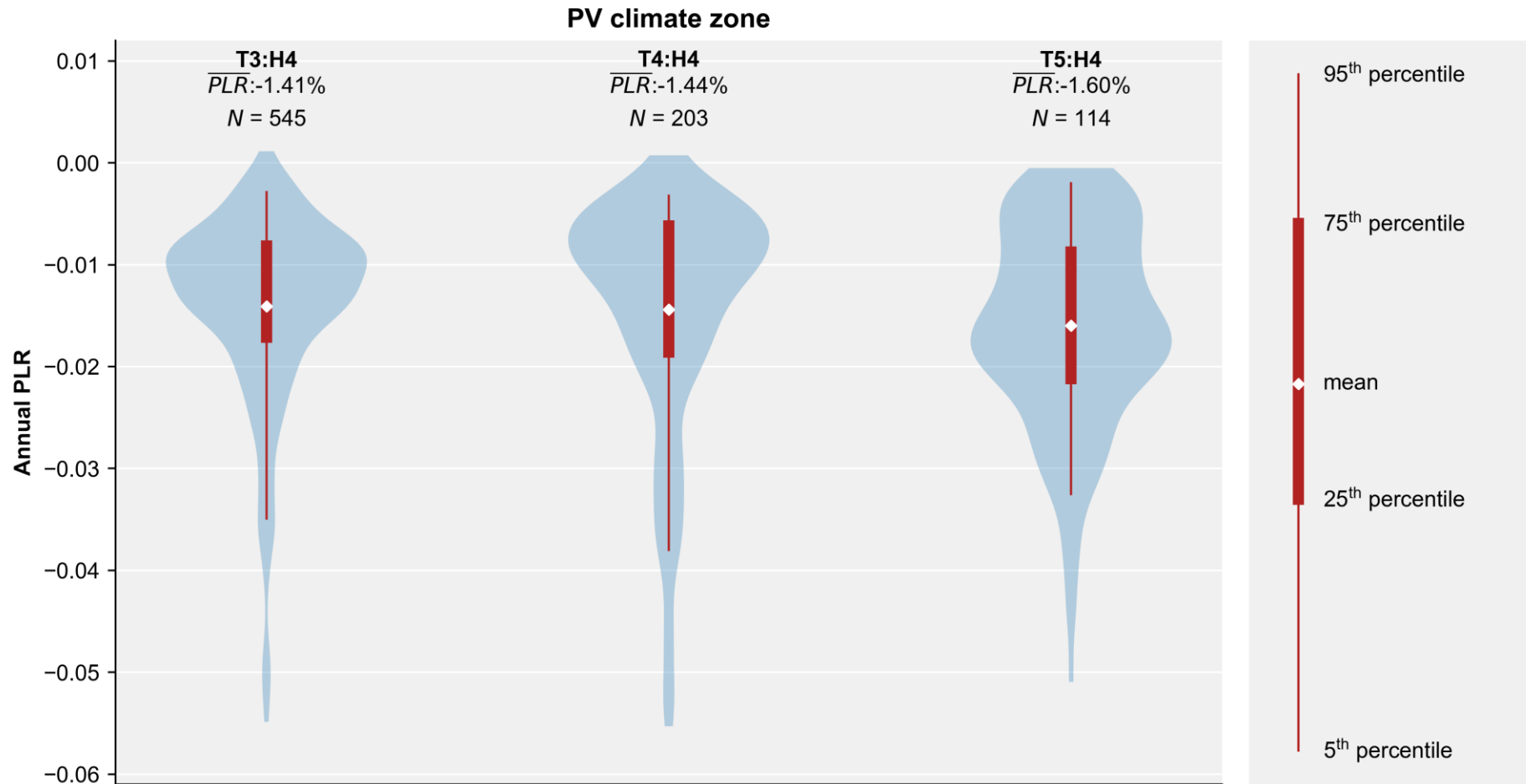


T5:H4 - PLR: -1.44% (N=114)



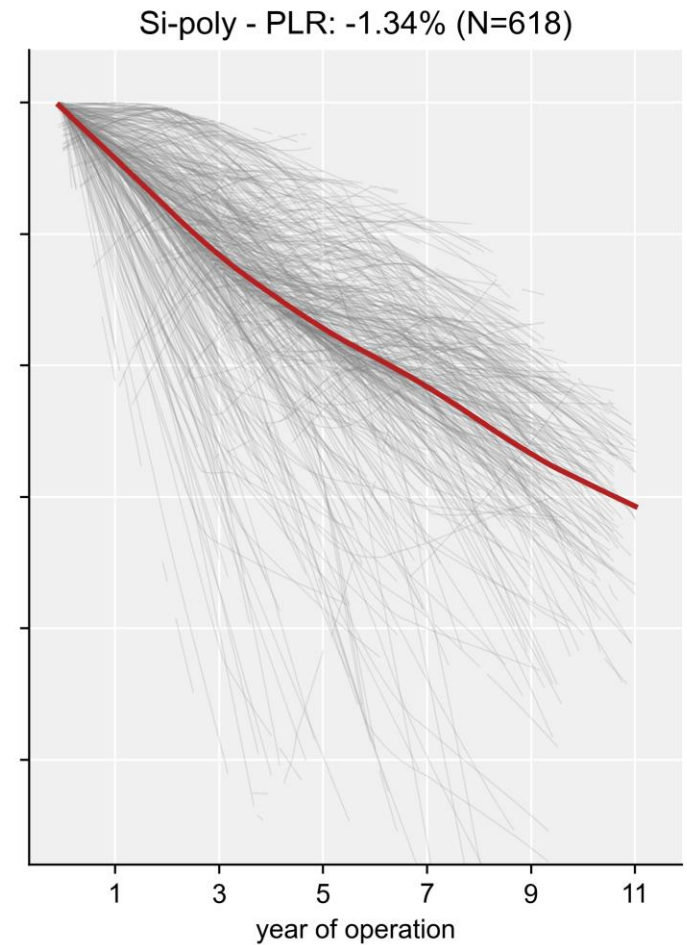
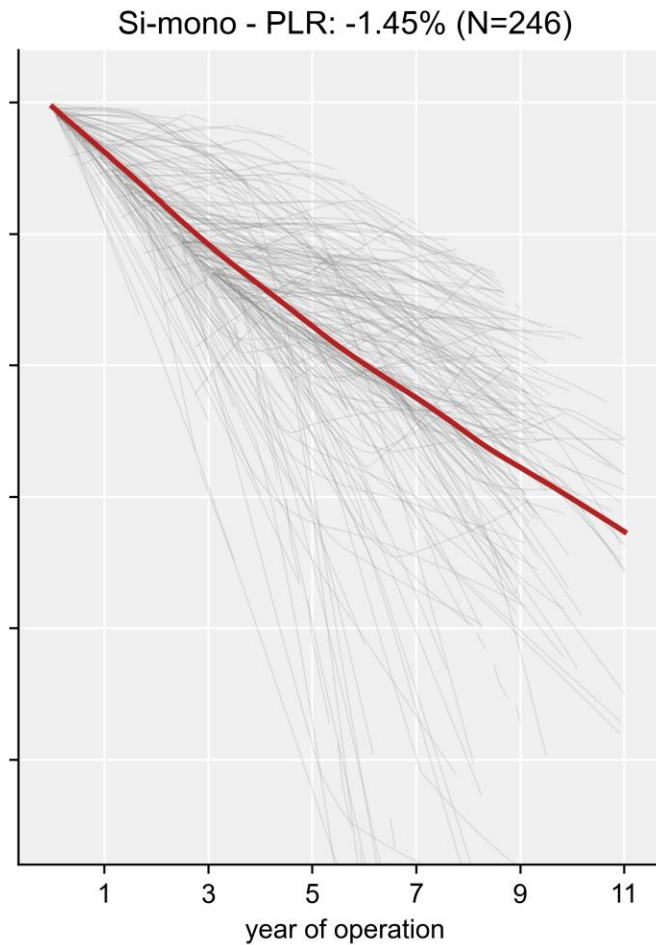
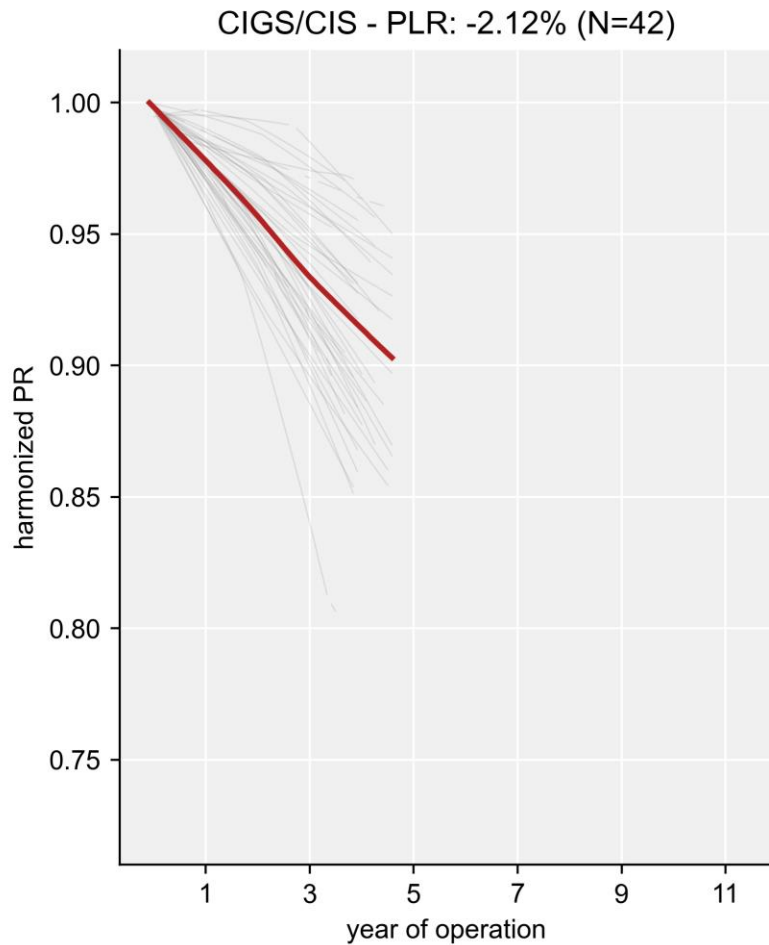


# RESULTS – PV DEGRADATION CLIMATE ZONES

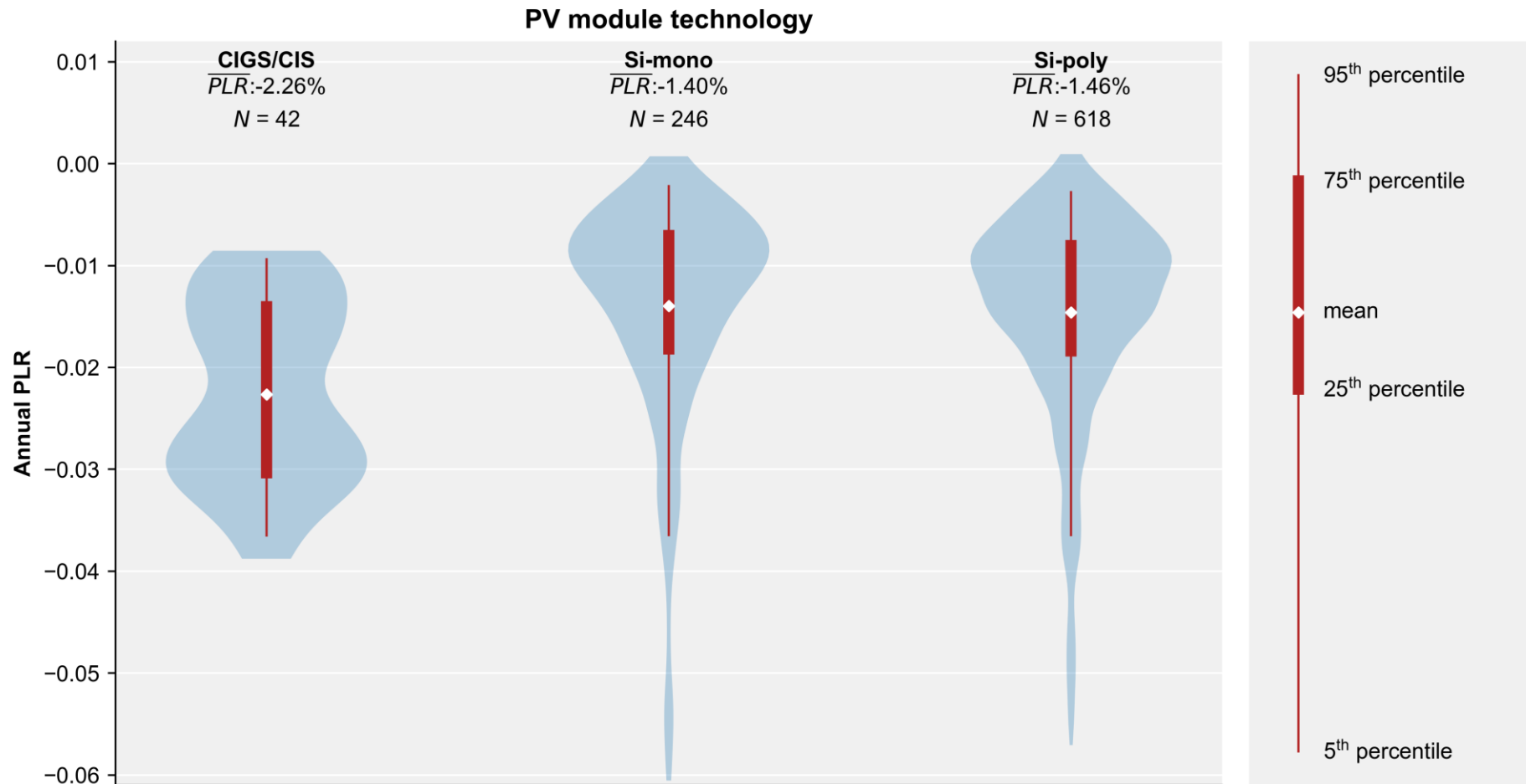


# RESULTS – PV MODULE TECHNOLOGY

## PV module technology

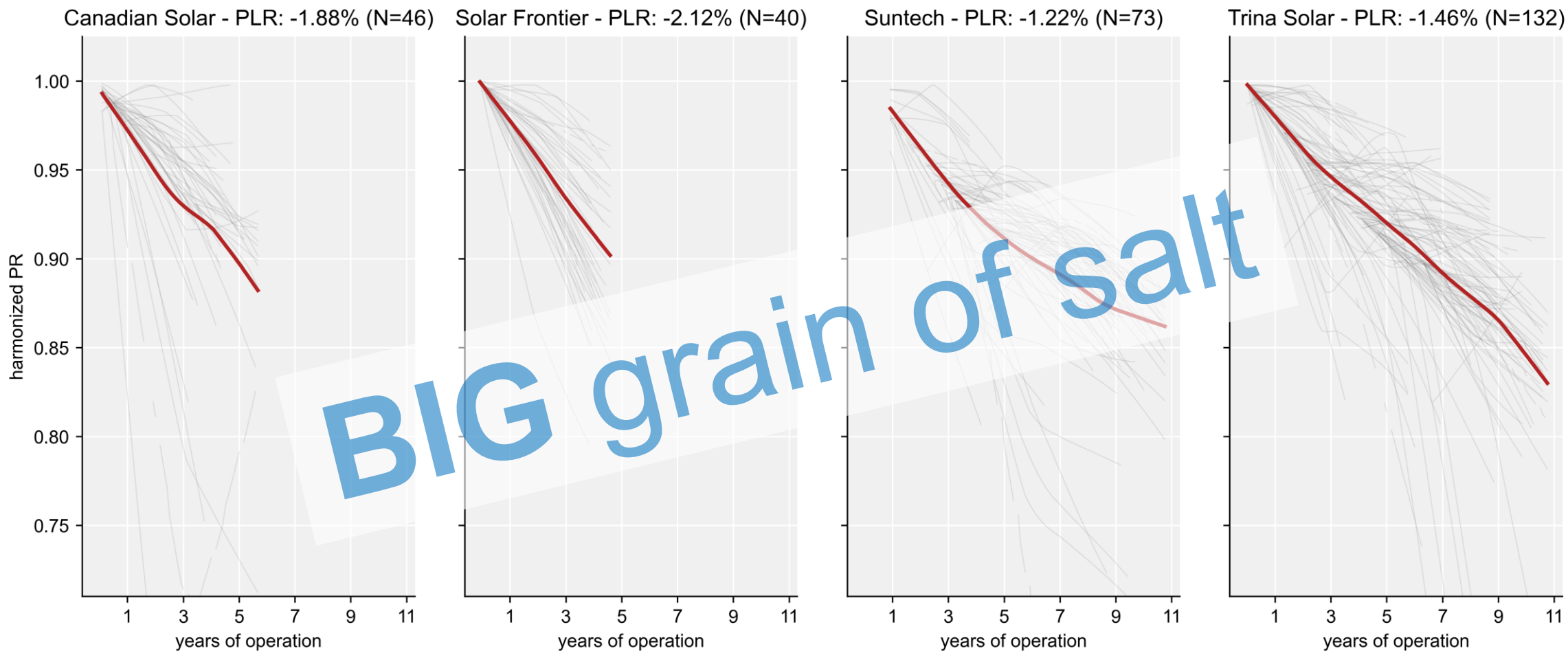


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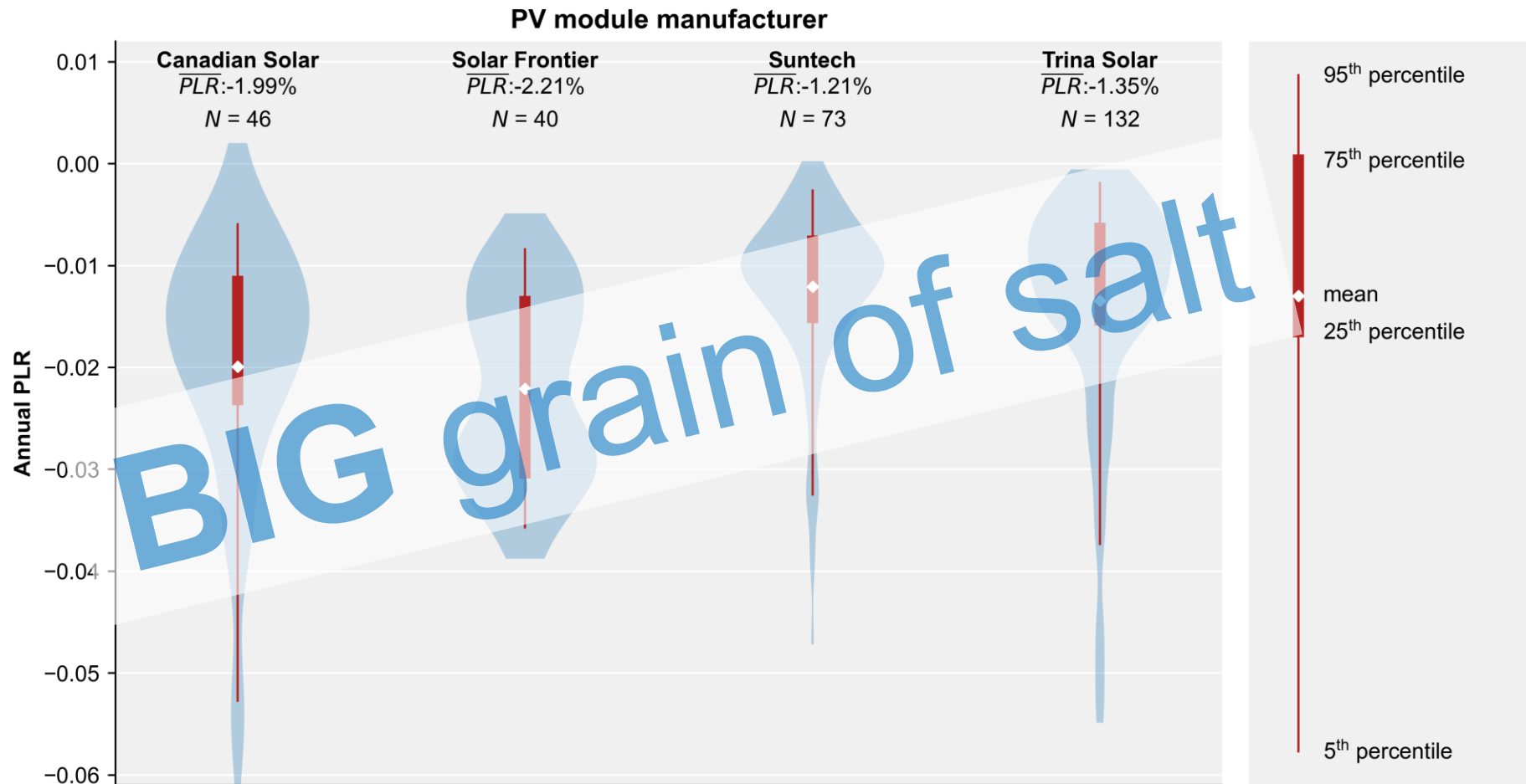


# RESULTS – PV MODULE MANUFACTURER

## PV module manufacturer

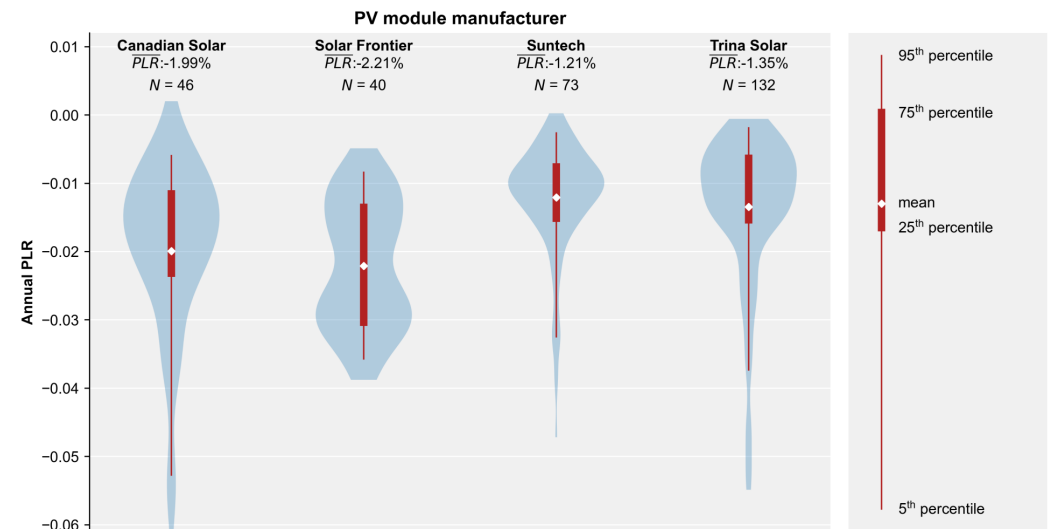
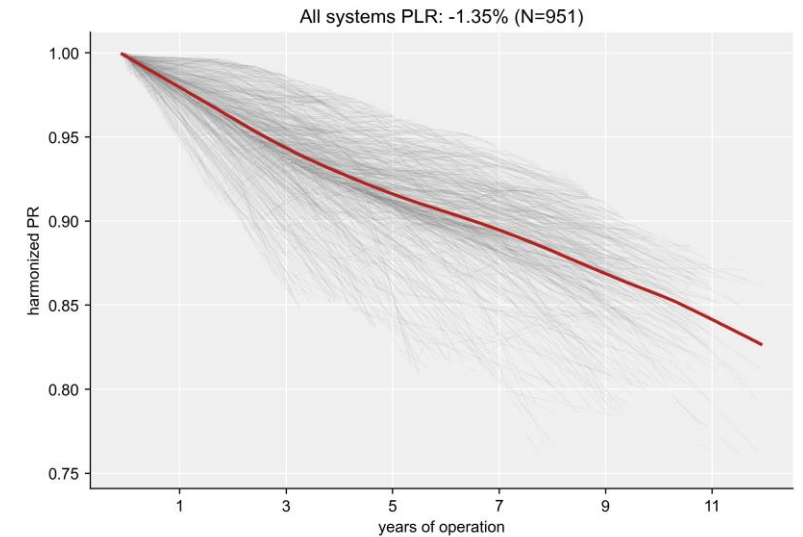


# RESULTS – PV MODULE MANUFACTURERS



# DISCUSSION

- Dataset heavily skewed to Cfb KG
- No sufficient data on non-Si technologies
- PLR's for manufacturers to be taken with a **BIG** grain of salt!!
  - Did not check/correct for anything: (climate, age, installation, etc.)



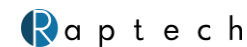


# NEXT STEPS

- Investigate optimal data filtering approach
- Compare different methods for PLR determination
- Analyse different other climate classification schemes
  - KG-PV
  - IEC 61853 climate specific energy rating (6 climates)
- Analyse different PL models
  - Multi-step PLR
  - Non-linear models
- See if we can separate BSF, PERC, SHJ, etc.
- Redo analysis with updated data
- Go to Lisbon EUPVSEC and present

# THANK YOU!

## PROJECT PARTNERS



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