Data monitoring & analytics for better PV performance and grid integration

Training School Pearl PV

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Twente, Netherlands

Jonathan Leloux

EDUCATION

- Engineering Degree, Mining and Geology, Faculté Polytechnique de Mons, Belgium

- PhD in solar photovoltaic systems, Universidad Politécnica de Madrid – Instituto de Energía Solar (IES-UPM), Spain

WORK EXPERIENCE

- Co-Founder and Managing Director of LuciSun (2019 – Present), Belgium

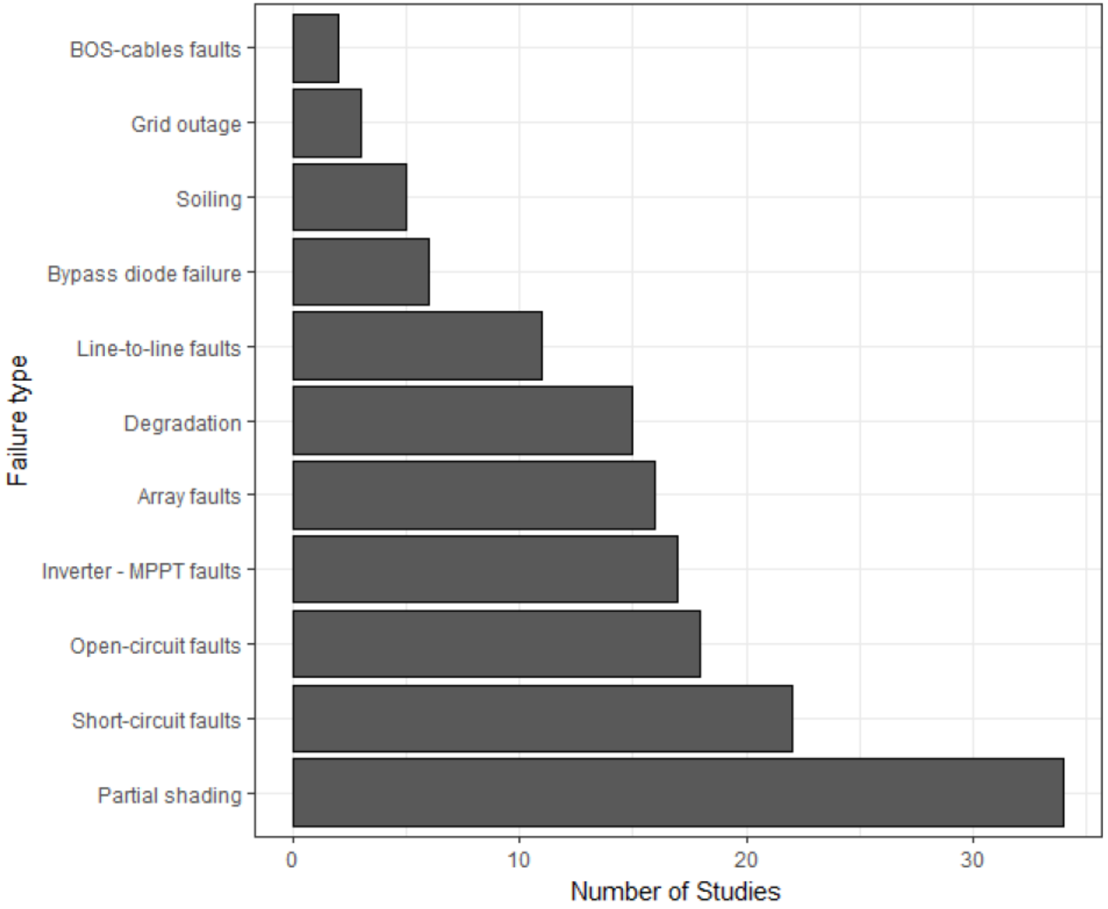
- Researcher at Universidad Politécnica de Madrid – Instituto de Energía Solar (IES-UPM) (2008 – 2019), Spain

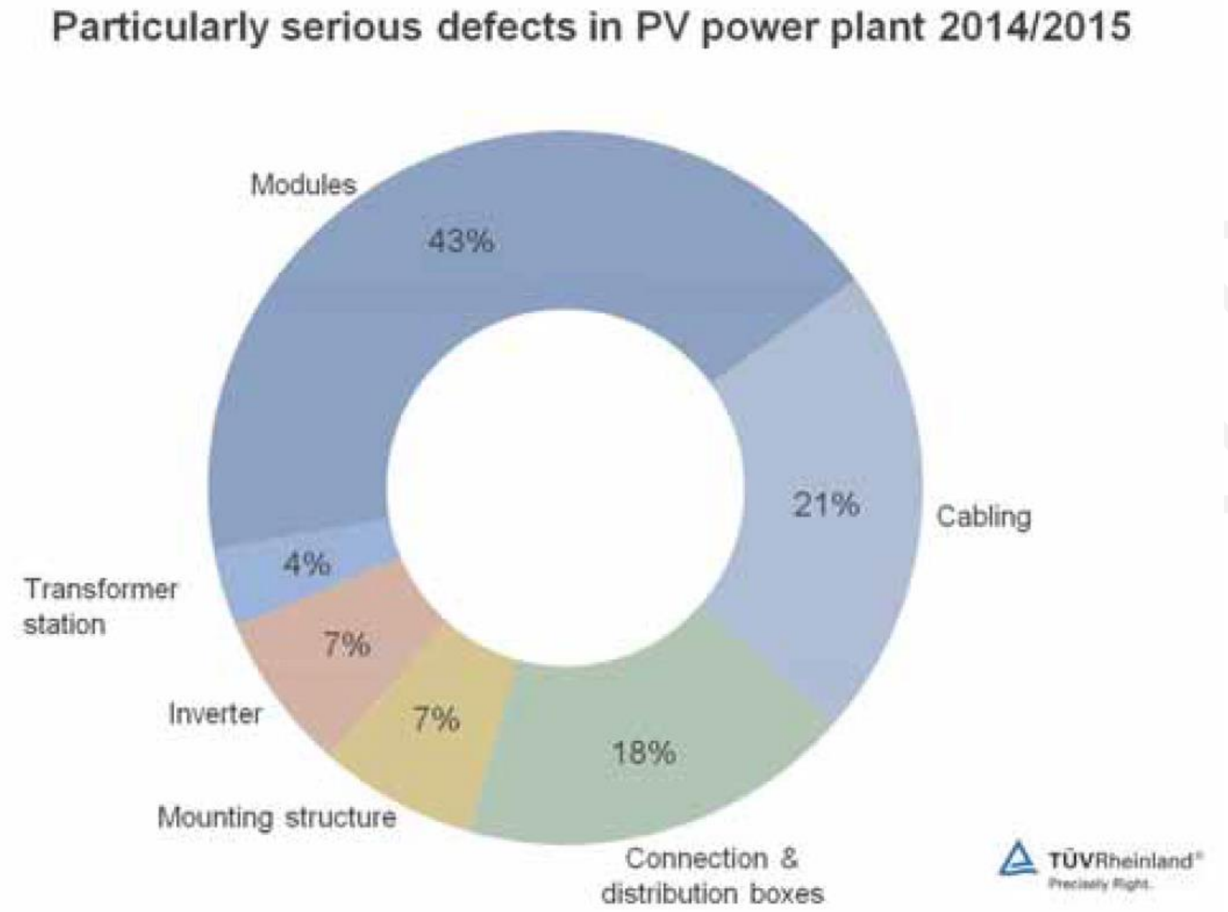
- Technology and Engineering Manager at Fotosolar – EDF Energies Nouvelles (2005 – 2008), Spain

HOBBIES

- Leader of Working Group 5 of Pearl PV: PV in grids

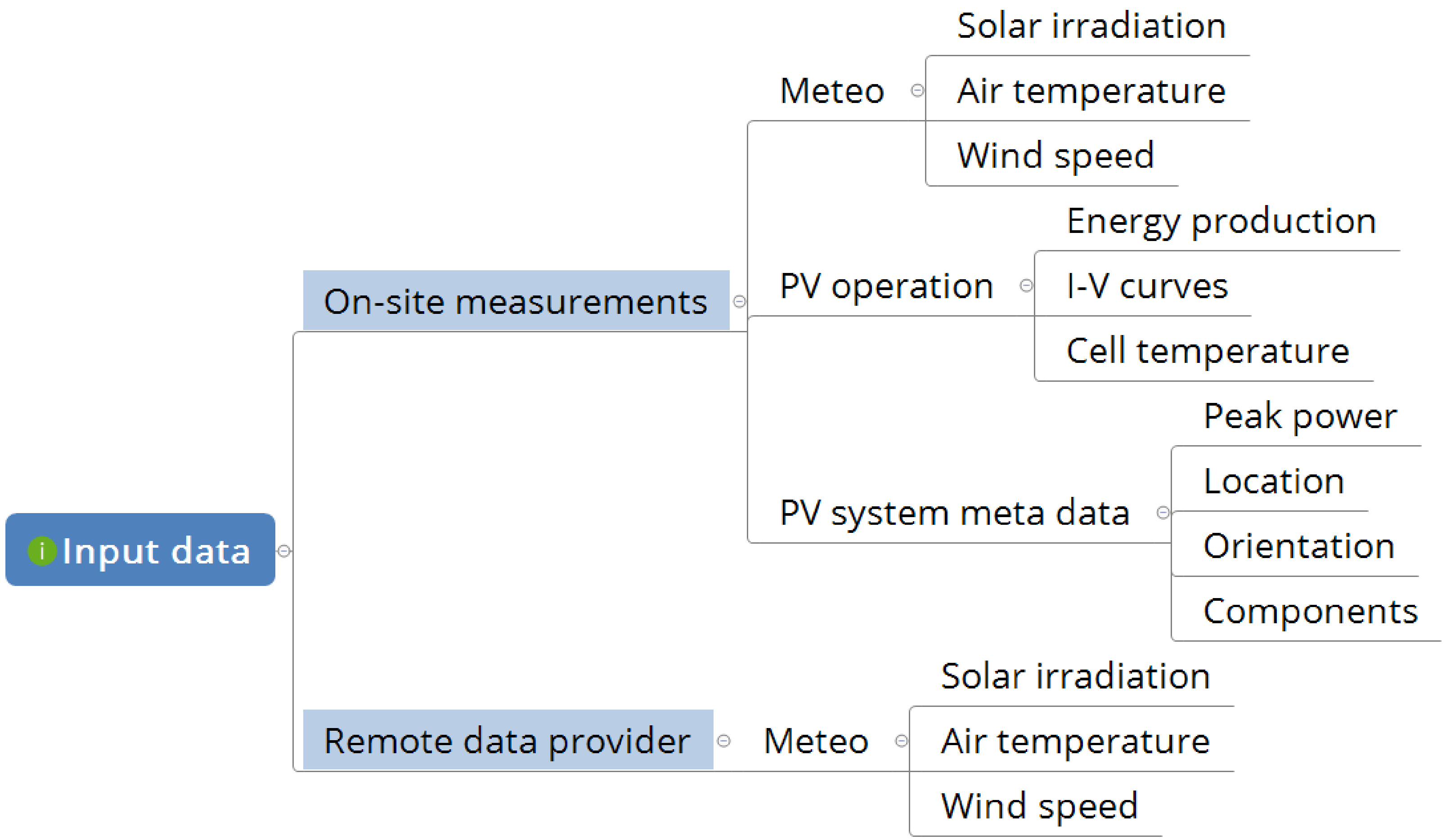
Fault detection: the good, the bad and the ugly



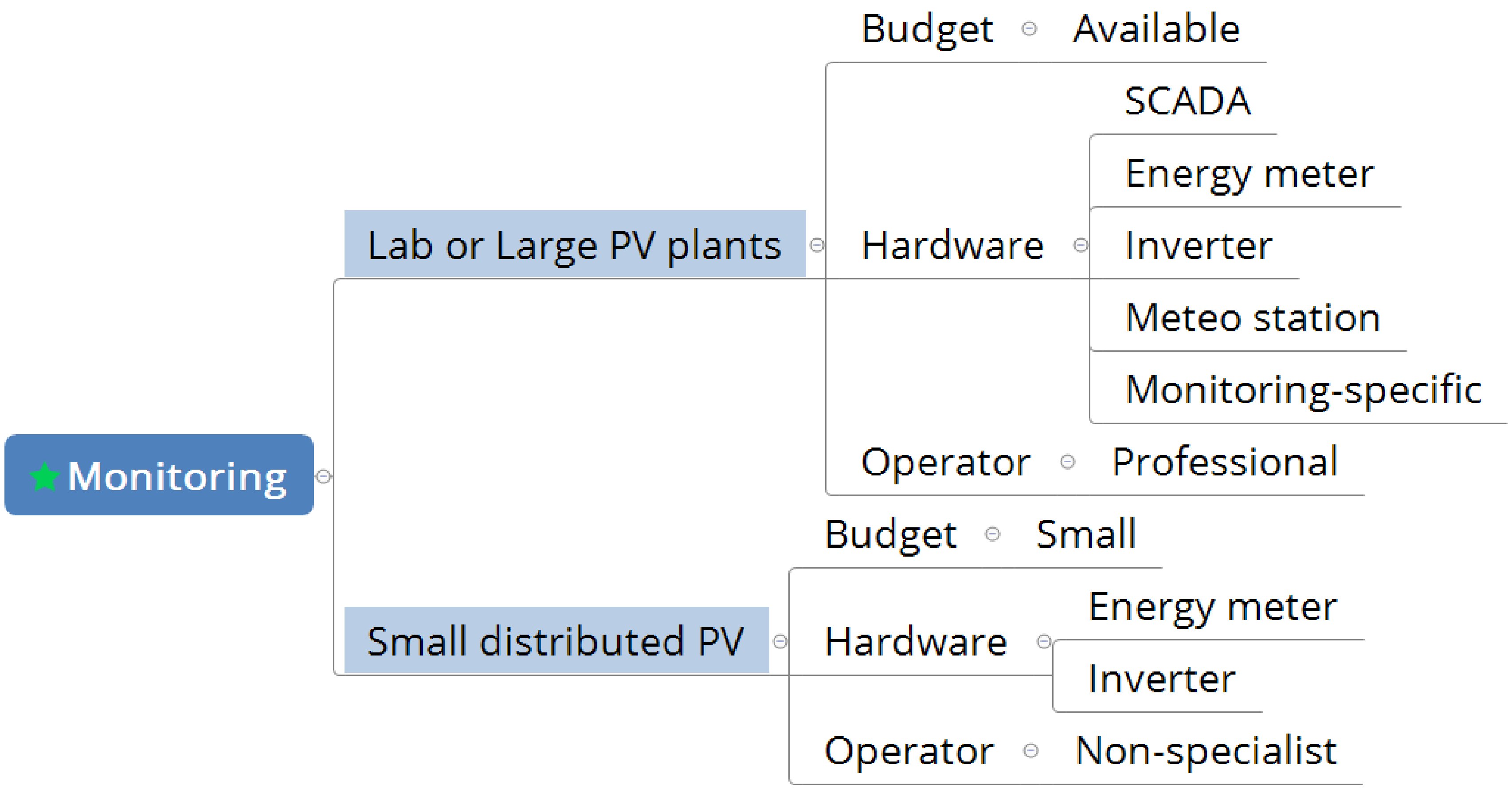


Source: Livera 2018

Every analysis must start with… some data!



Monitoring: (Lab or Large PV) ≠ (Small PV)



Large PV plants: Key field-measurements

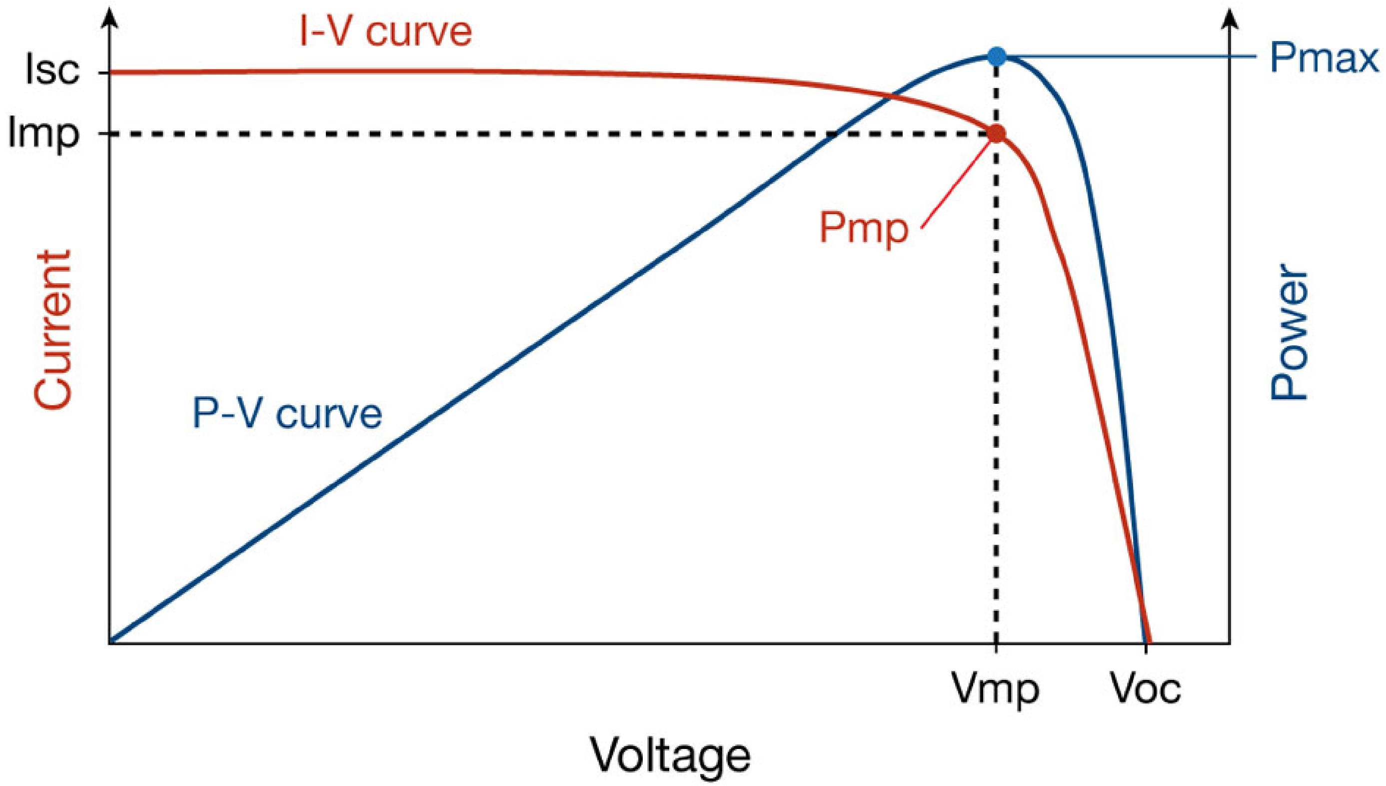
- Weather conditions
- Power (DC, AC)
- I-V curves
- Inverter yield
- Thermography / hot spots
- Electroluminescence
- Etc.

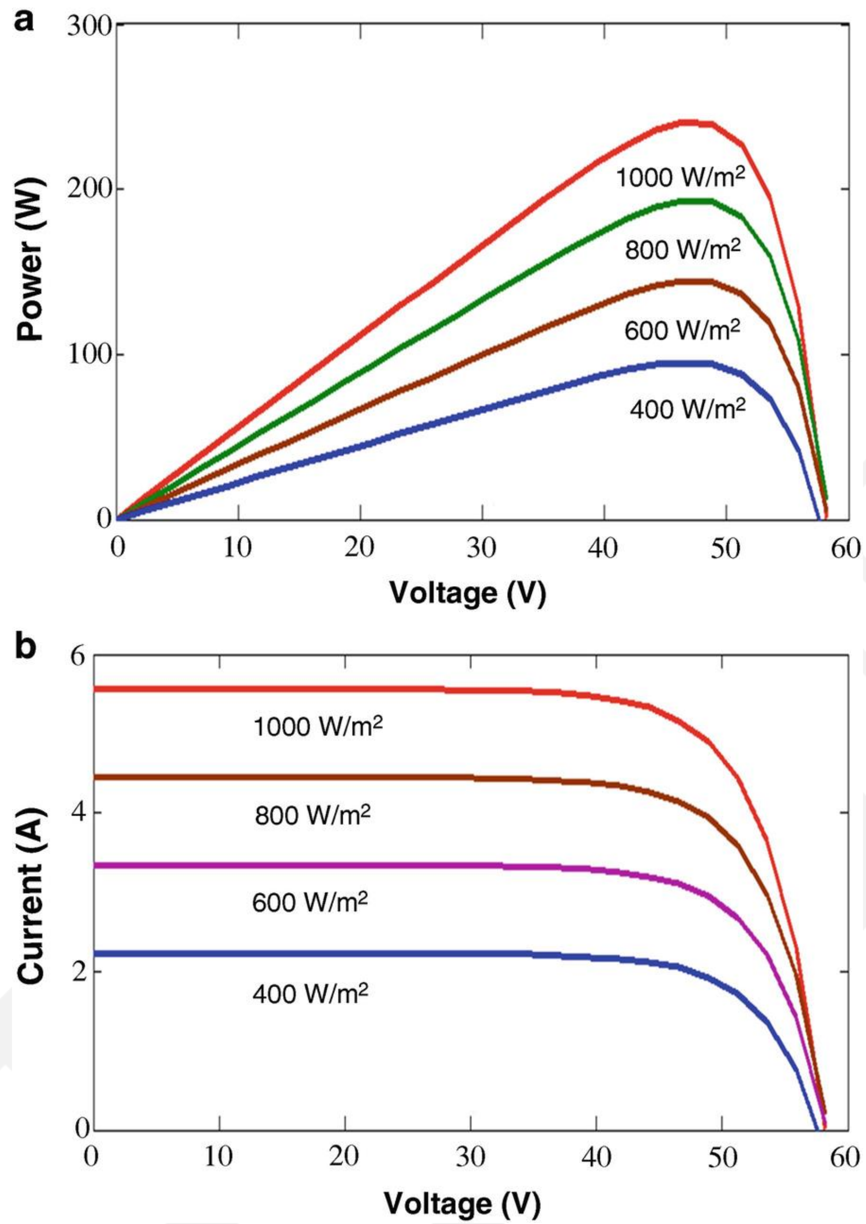
Weather conditions

- The most common
  - Solar irradiance (GHI, DNI, DIF)
  - Wind speed and direction
  - Air temperature
- Others
  - Albedo
  - Spectral irradiance
  - Air humidity
  - …

Weather station at IES-UPM

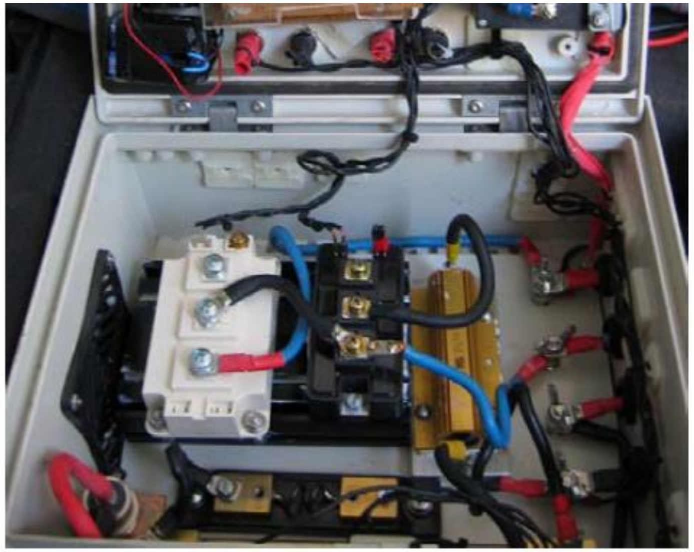
Power and I-V curves





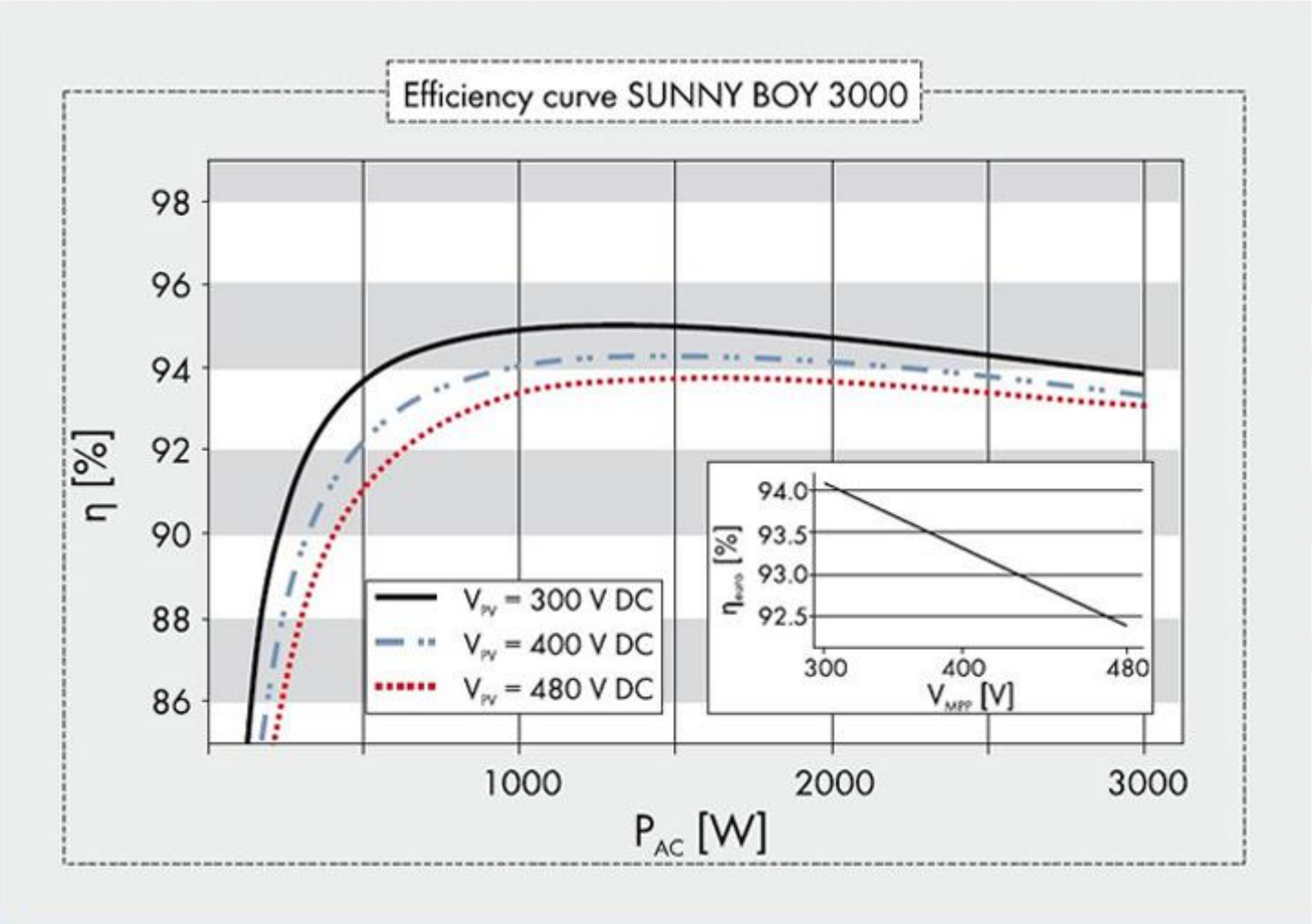
Measurement for power and I-V curve

Wattmeter for power measurements (IES-UPM)

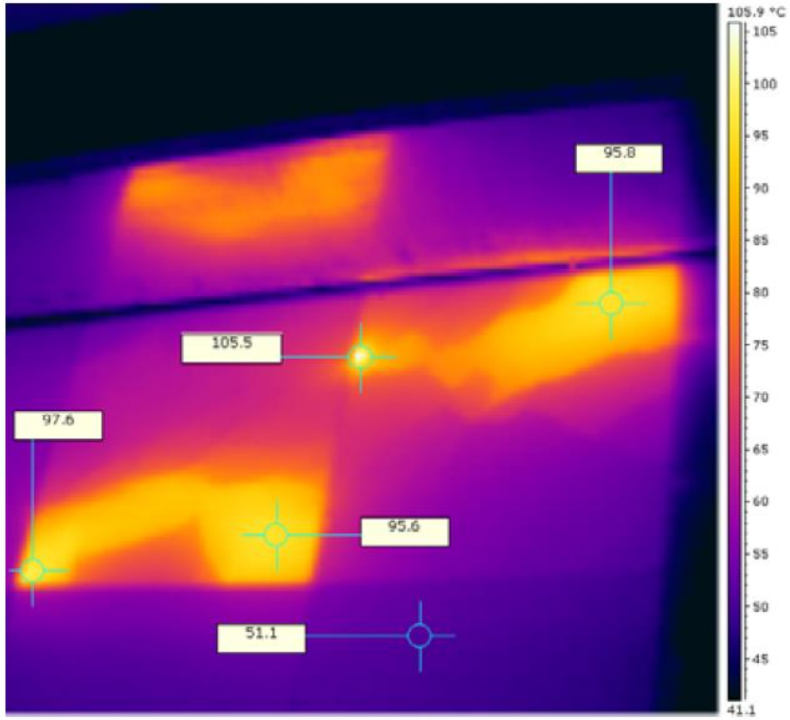


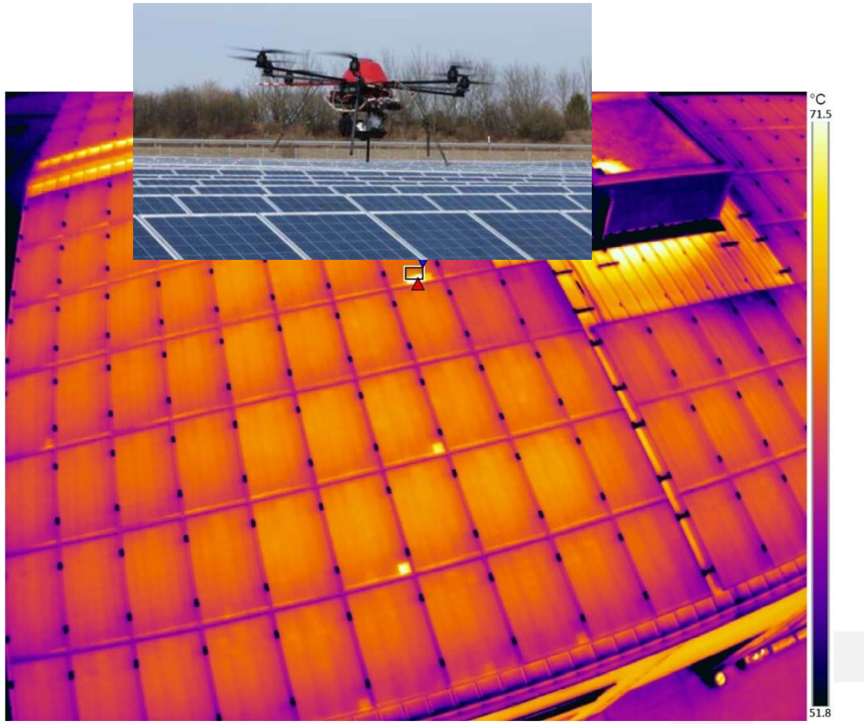
Capacitive load for I-V curves measurements (IES-UPM)

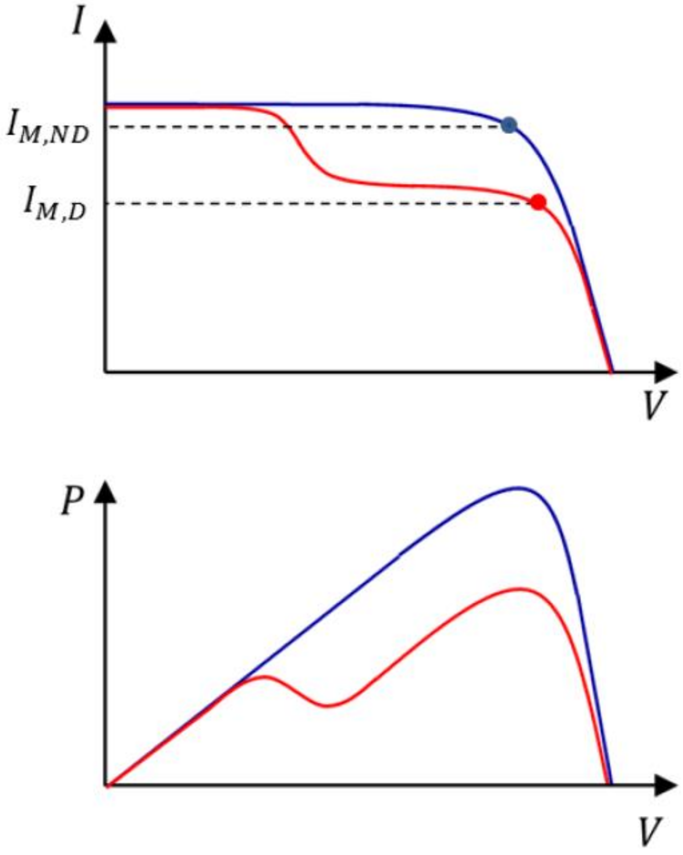
Inverter yield



Thermography / hot-spots

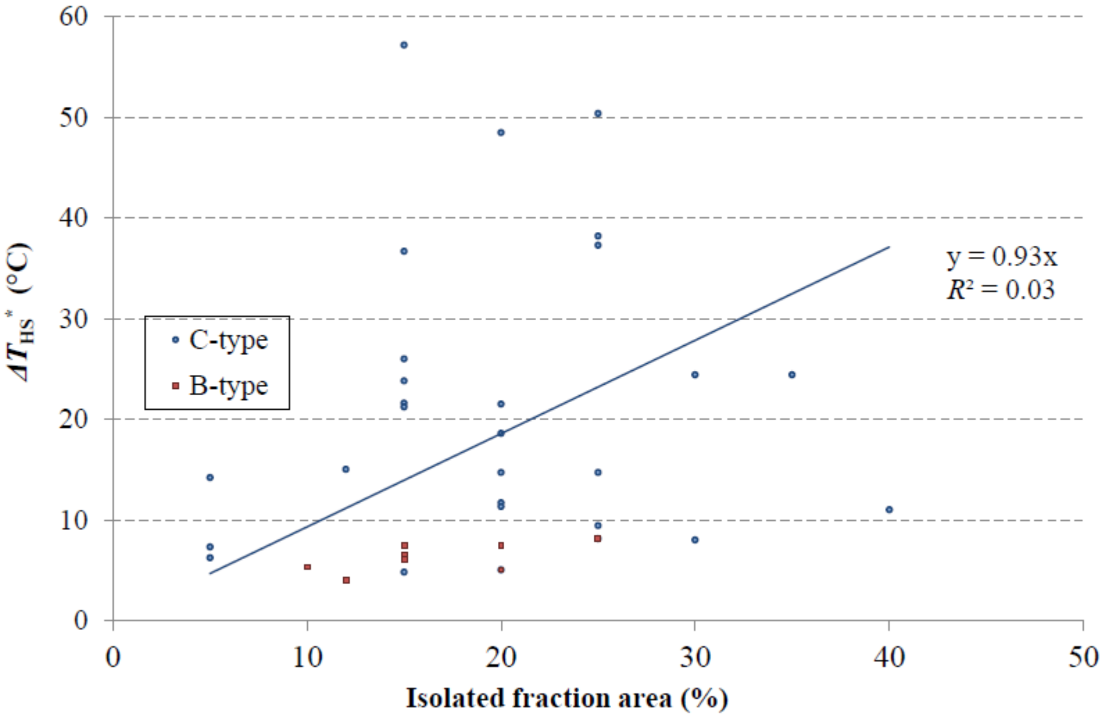




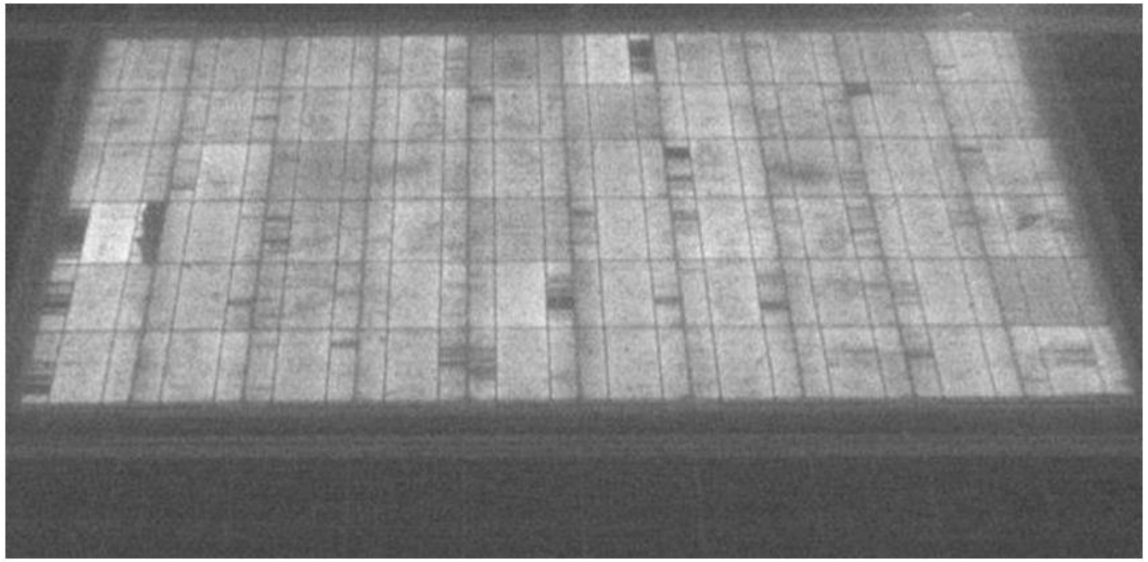


Moreton et al., 2016

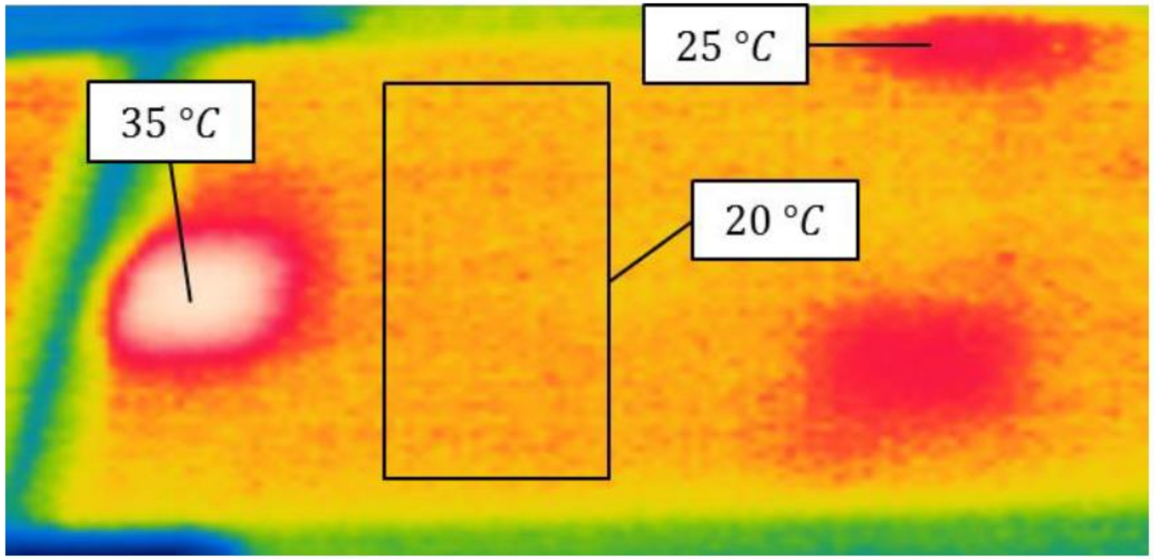
Electroluminescence



Moreton et al., 2016

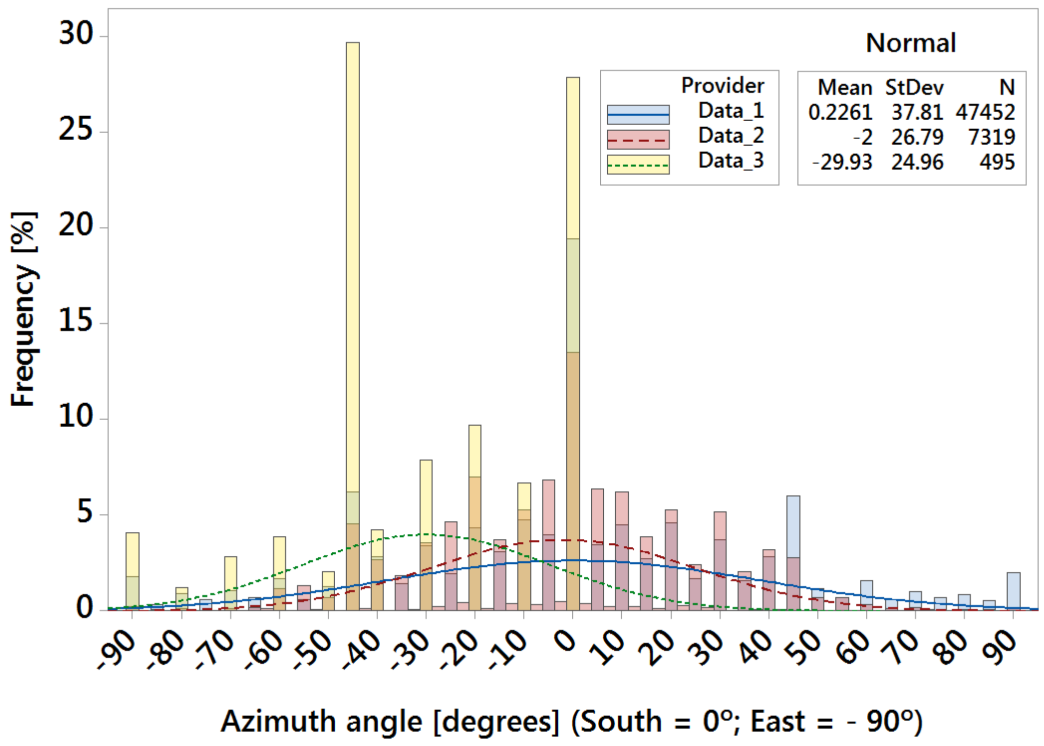


(a)

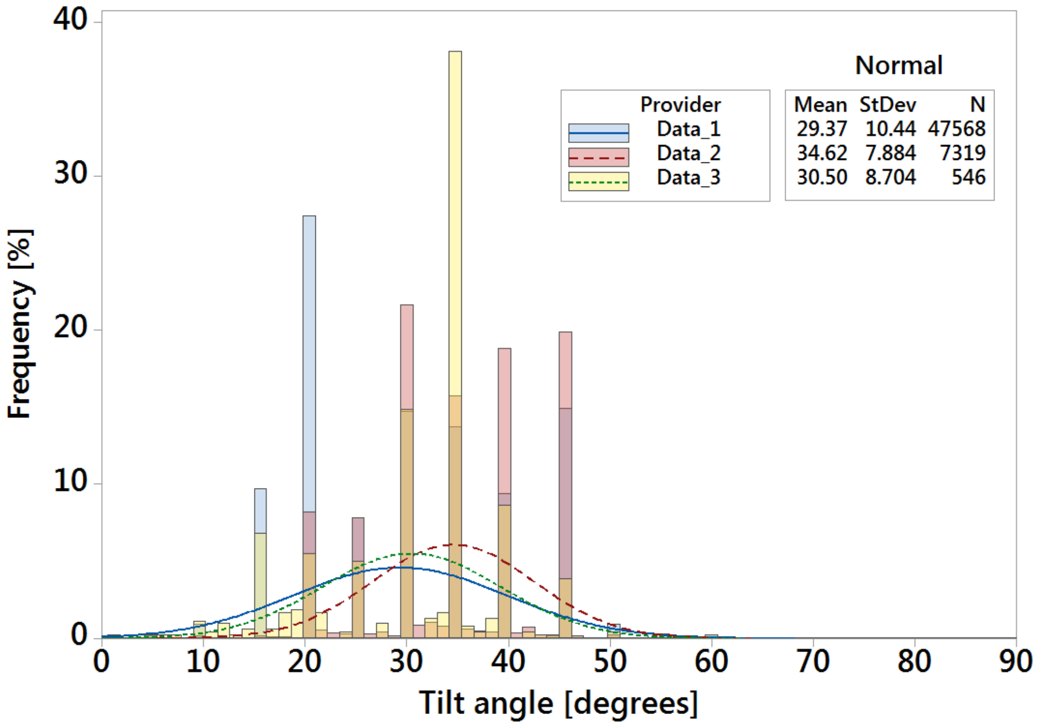


In the (raw) metadata you will not trust!

Azimuth angle of PV generators as reported by data providers - Europe

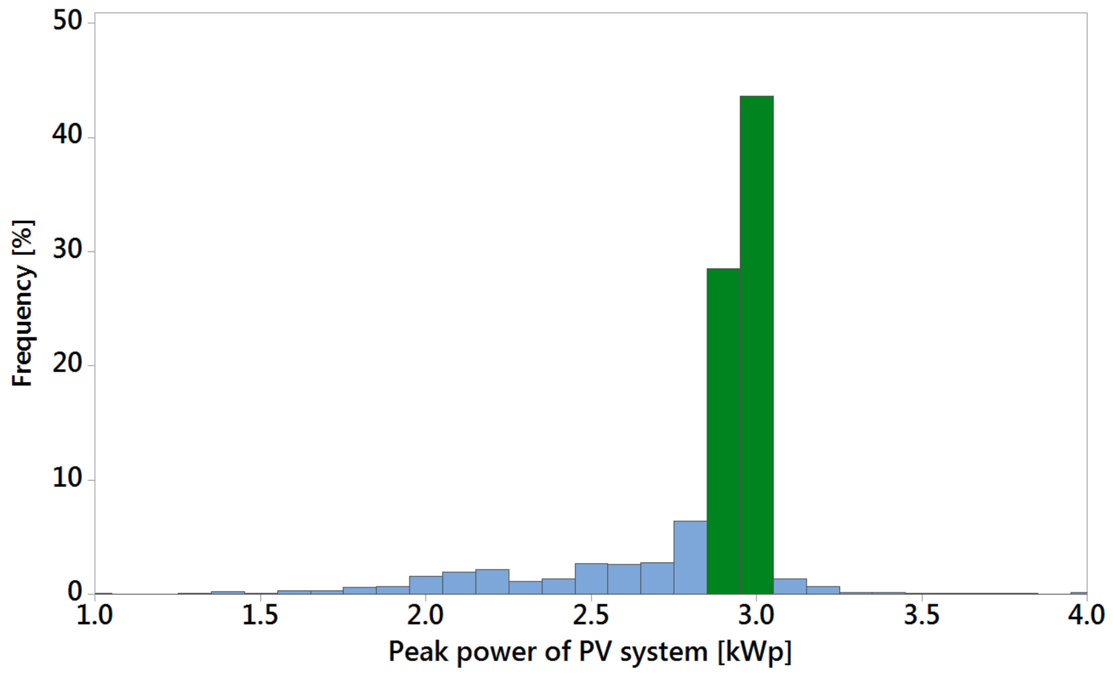


Tilt angle of PV generators as reported by data providers - Europe



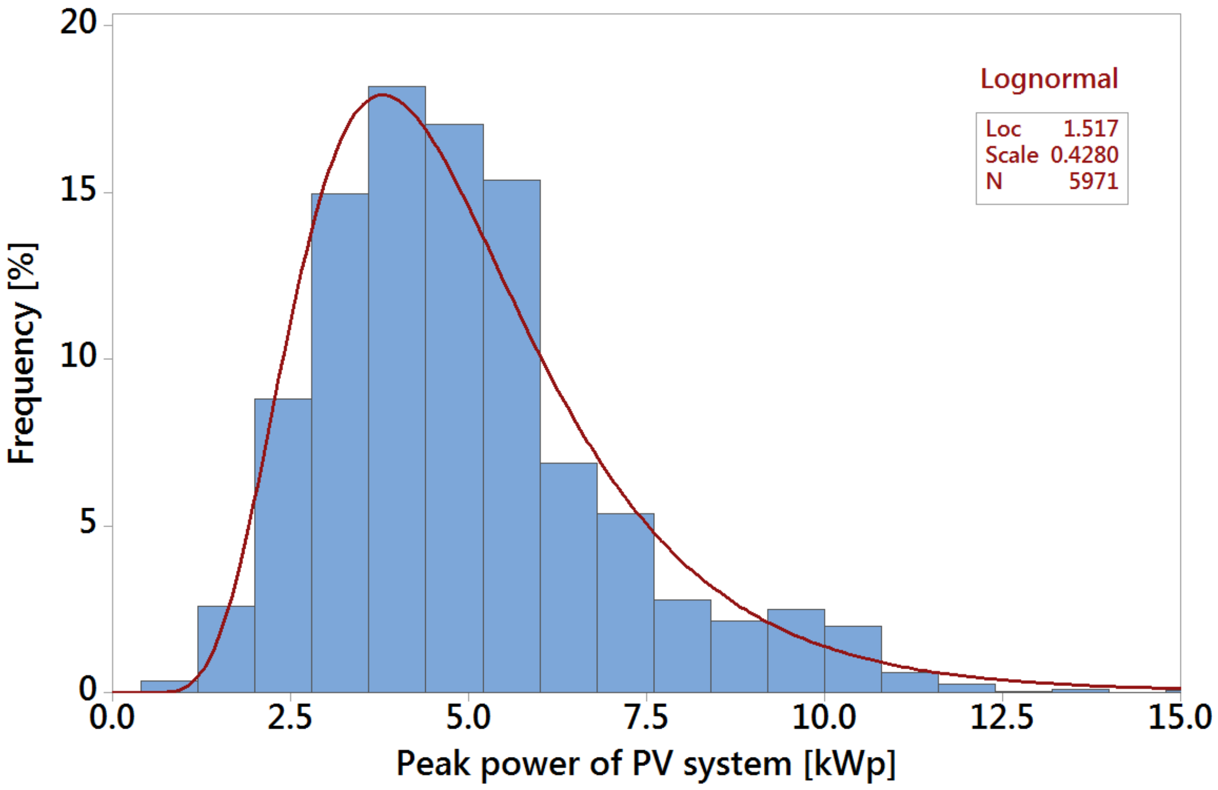
PV is still dependent on local regulation

Peak power PV systems - France



Leloux et al., 2015

Peak power PV systems - Belgium



Leloux et al., 2015

Overview of orientation losses for one country

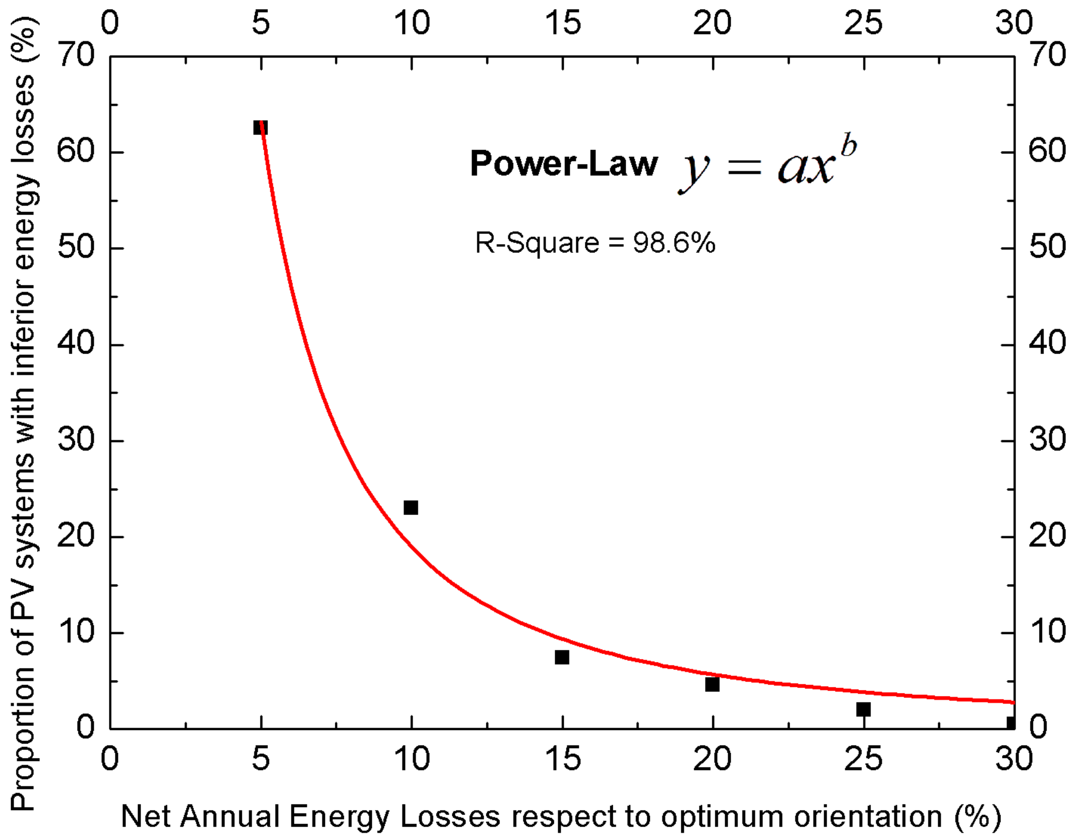
(<-- East) Deviation from South (º) (West -->)

Tilt angle (º)	-90	-80	-70	-60	-50	-40	-30	-20	-10	0	10	20	30	40	50	60	70	80	90
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
10	0	0	0	0	0.1	0.1	0	0.1	0	0.2	0	0	0	0.1	0	0	0	0	0.1
20	1	0.4	0.8	0.5	1	2	2	3	3	9	3	3	2	2	2	0.7	0.8	0.5	0.9
30	0.2	0.3	0.5	0.4	0	1	2	2	2	7	2	2	1	1	1	0.5	0.3	0.4	0.7
40	0.2	0.3	0.4	0.4	0	2	2	2	2	6	1	1	1	1	1	0.6	0.6	0.3	0.7
50	0.2	0.1	0.2	0.5	0.3	1	0.8	1	1	3	1	2	0.8	0.6	1	0.5	0.1	0.1	0.3
60	0	0	0	0	0	0	0.1	0.1	0.1	0.1	0.1	0.2	0.1	0	0	0.1	0	0	0
70	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
80	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
90	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

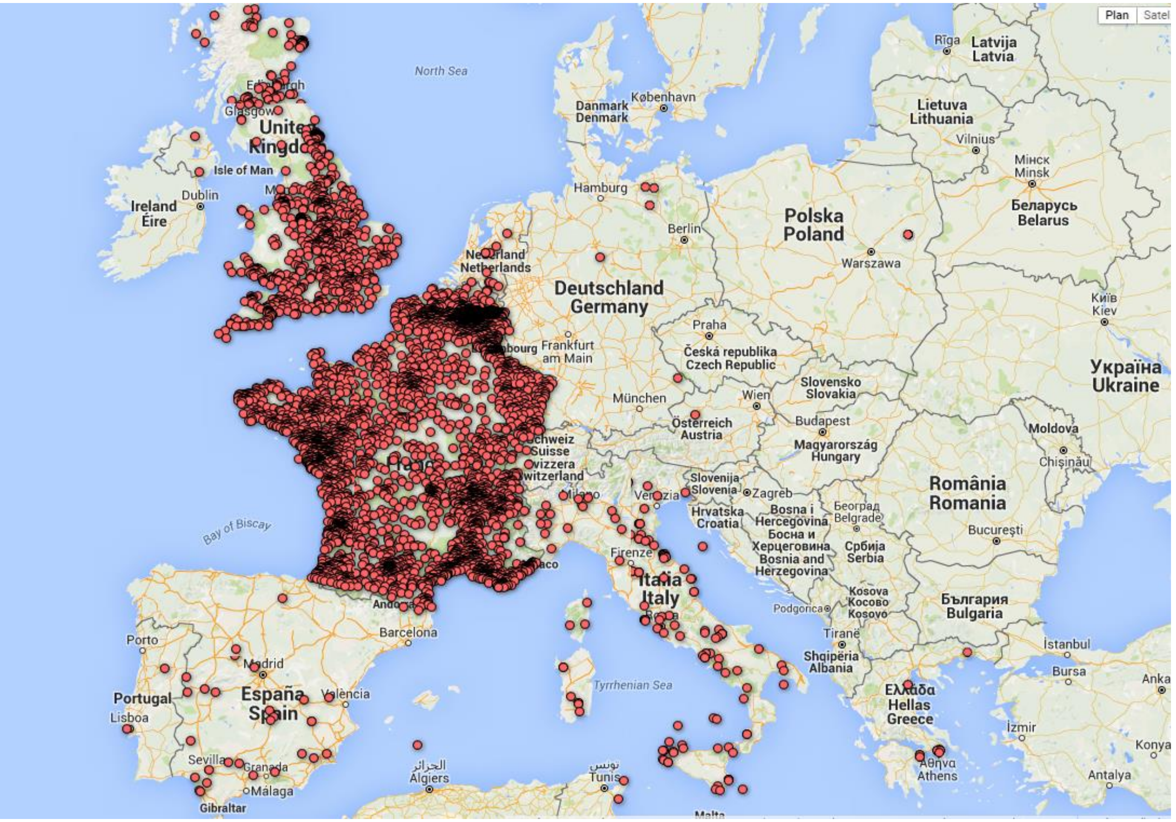
Numbers: Proportion of PV systems installed (%)

Colors: Annual energy production (E in %) relative to MAX = 100%

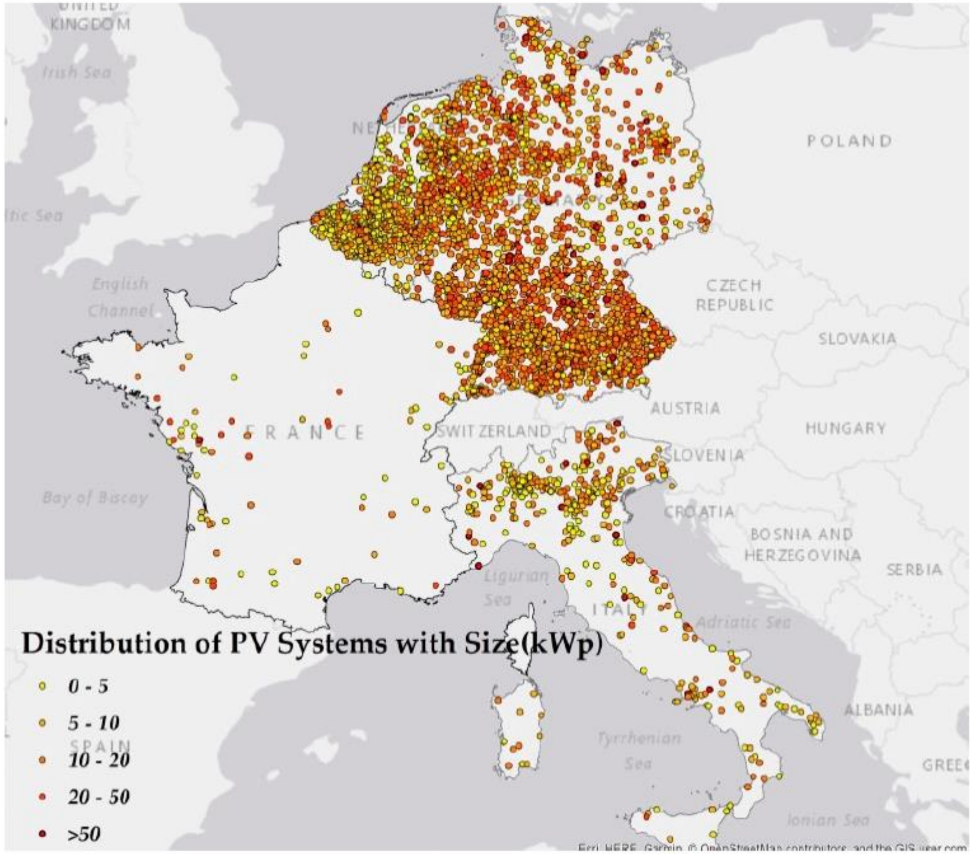
E = 100 | 100 > E ≥ 95 | 95 > E ≥ 90 | 90 > E ≥ 80 | 80 > E ≥ 60 | E < 60



Experience from PV fleet analysis on thousands of PV systems



Source: Leloux 2015



Source: Kausika 2018

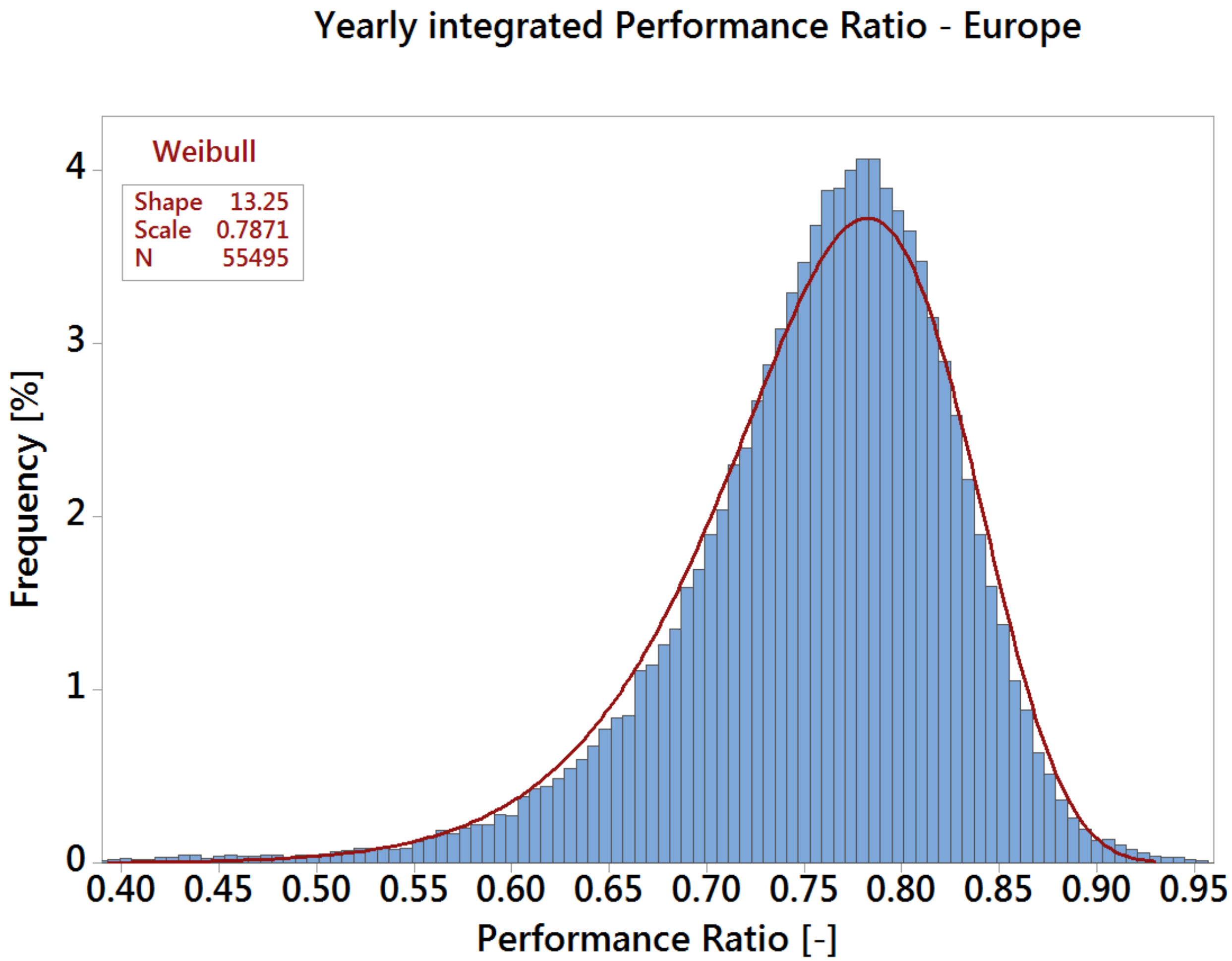
Performance Ratio (PR): most widely used PV performance indicator

$$PR = \frac{E_{produced}}{\frac{P^{STC}}{G^{STC}} \int G dt}$$

- The PV system is compared with a PV system under Standard Test Conditions (STC)
- Allows comparisons with other works
- Influenced by other parameters than quality (Tº, radiation, spectrum,…)

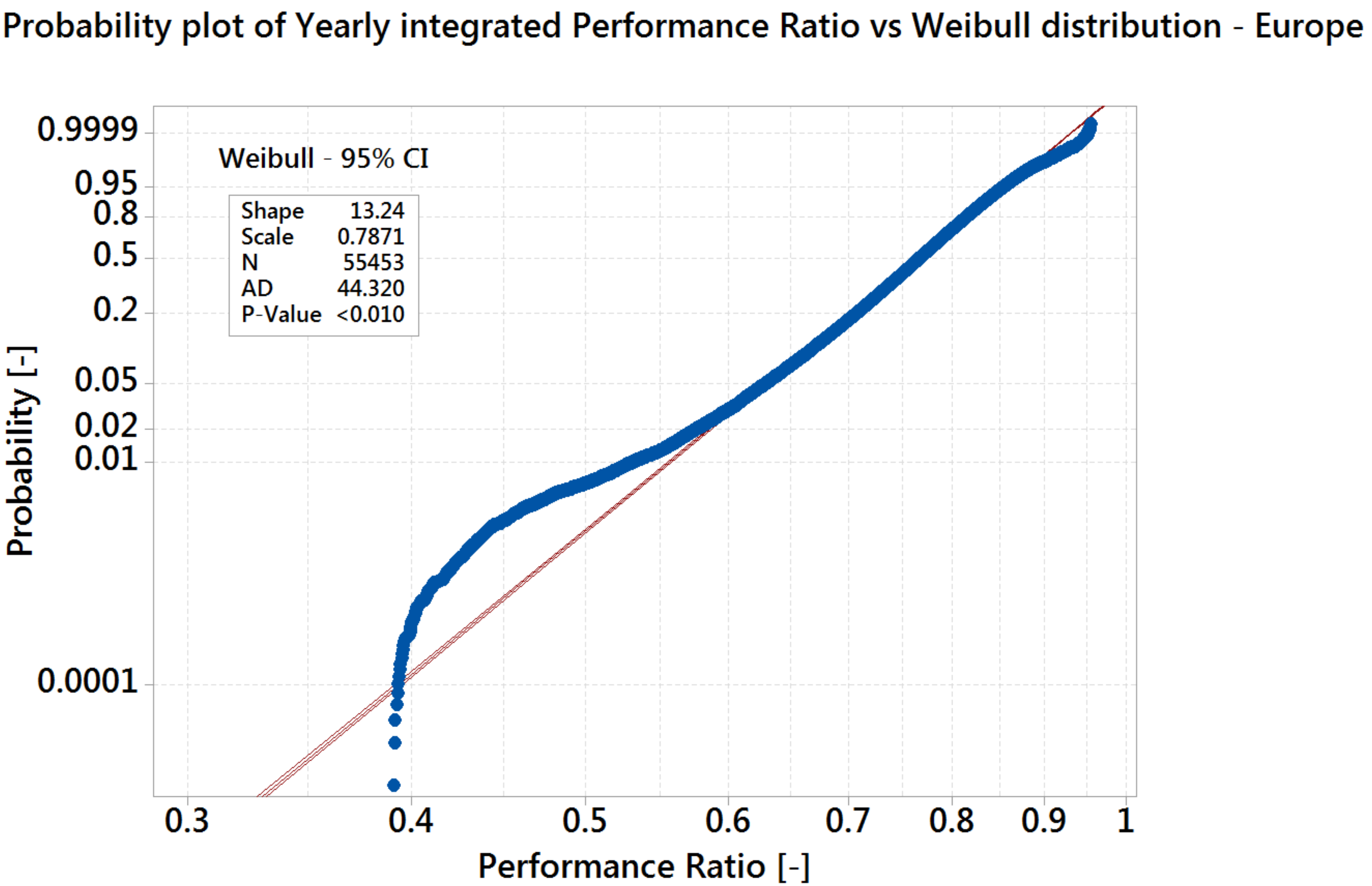
Leloux et al., 2015

Performance Ratio in Europe: 60%-90%

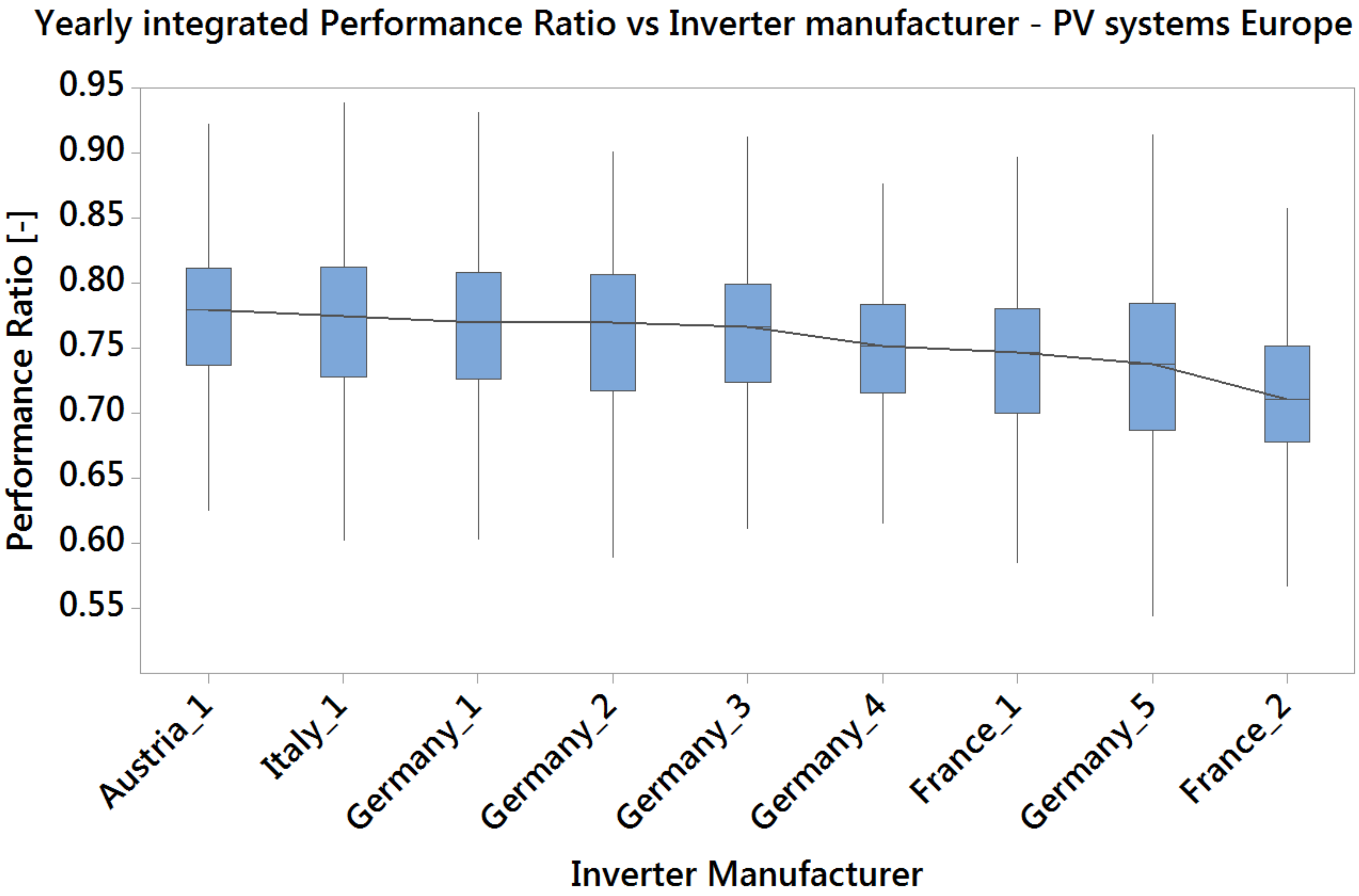


Leloux et al., 2015

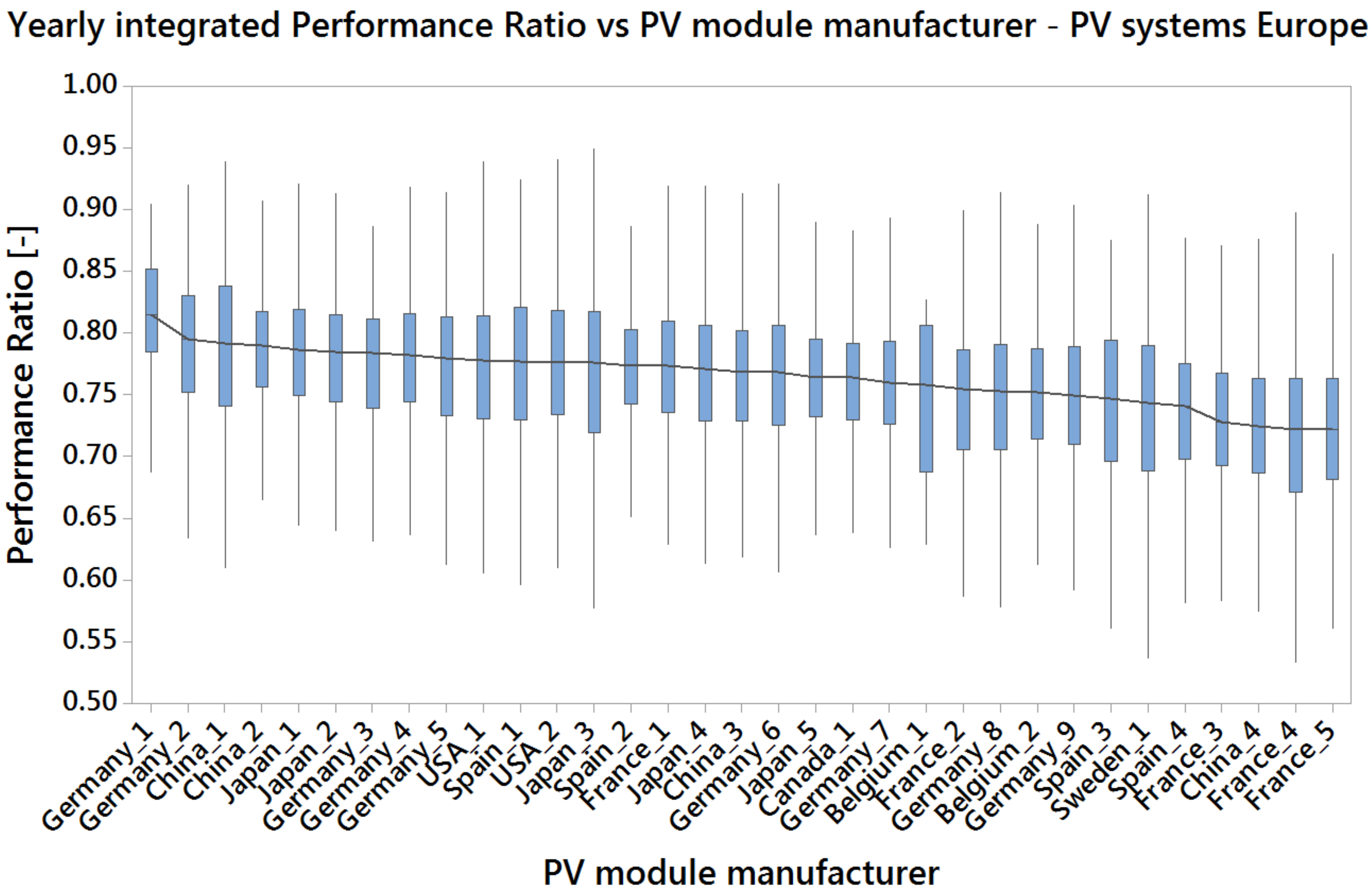
Probability plot and Weibull distribution for 0.6 < PR < 0.9



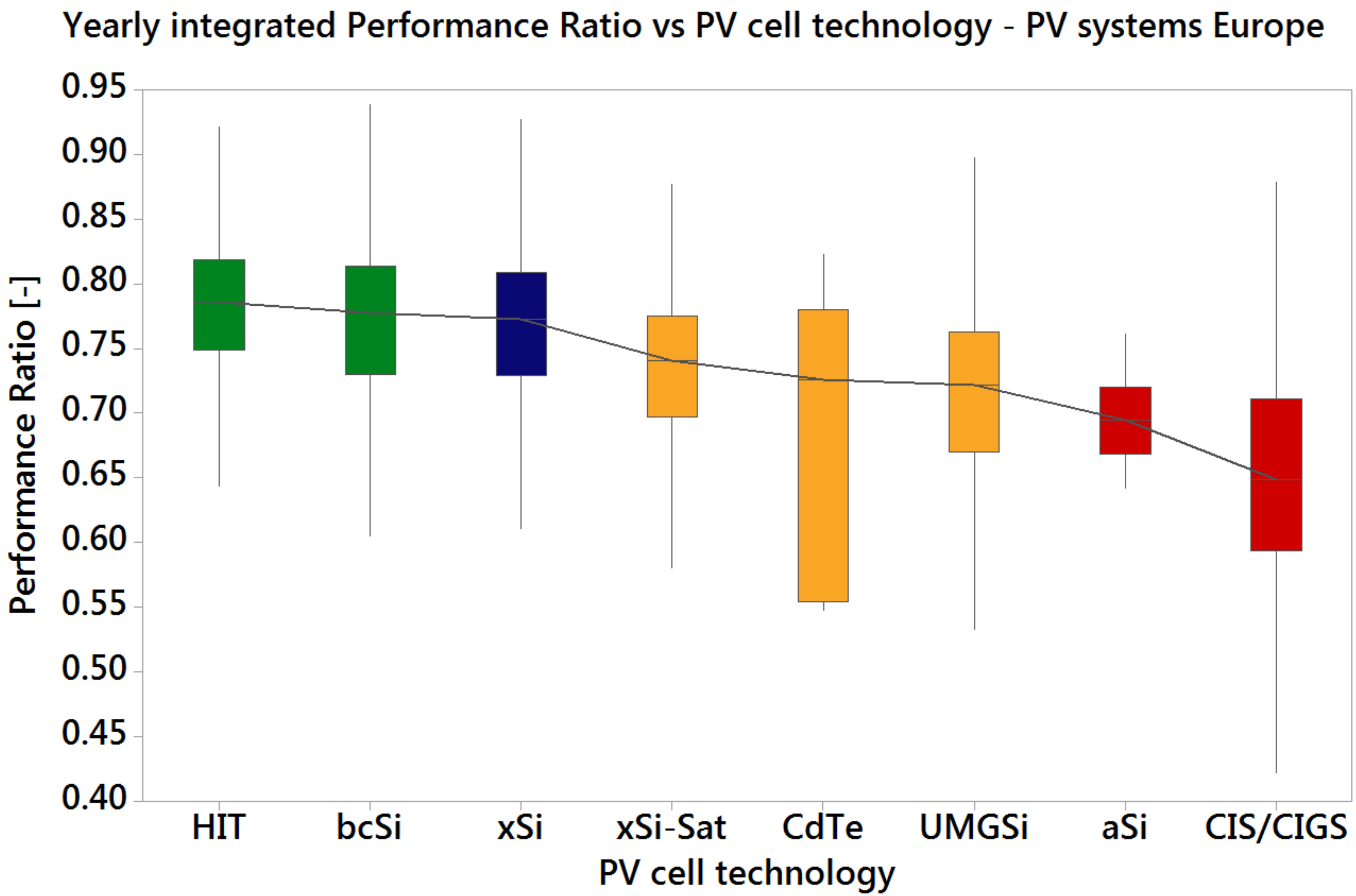
Difference in PR between inverters: 1-5 %



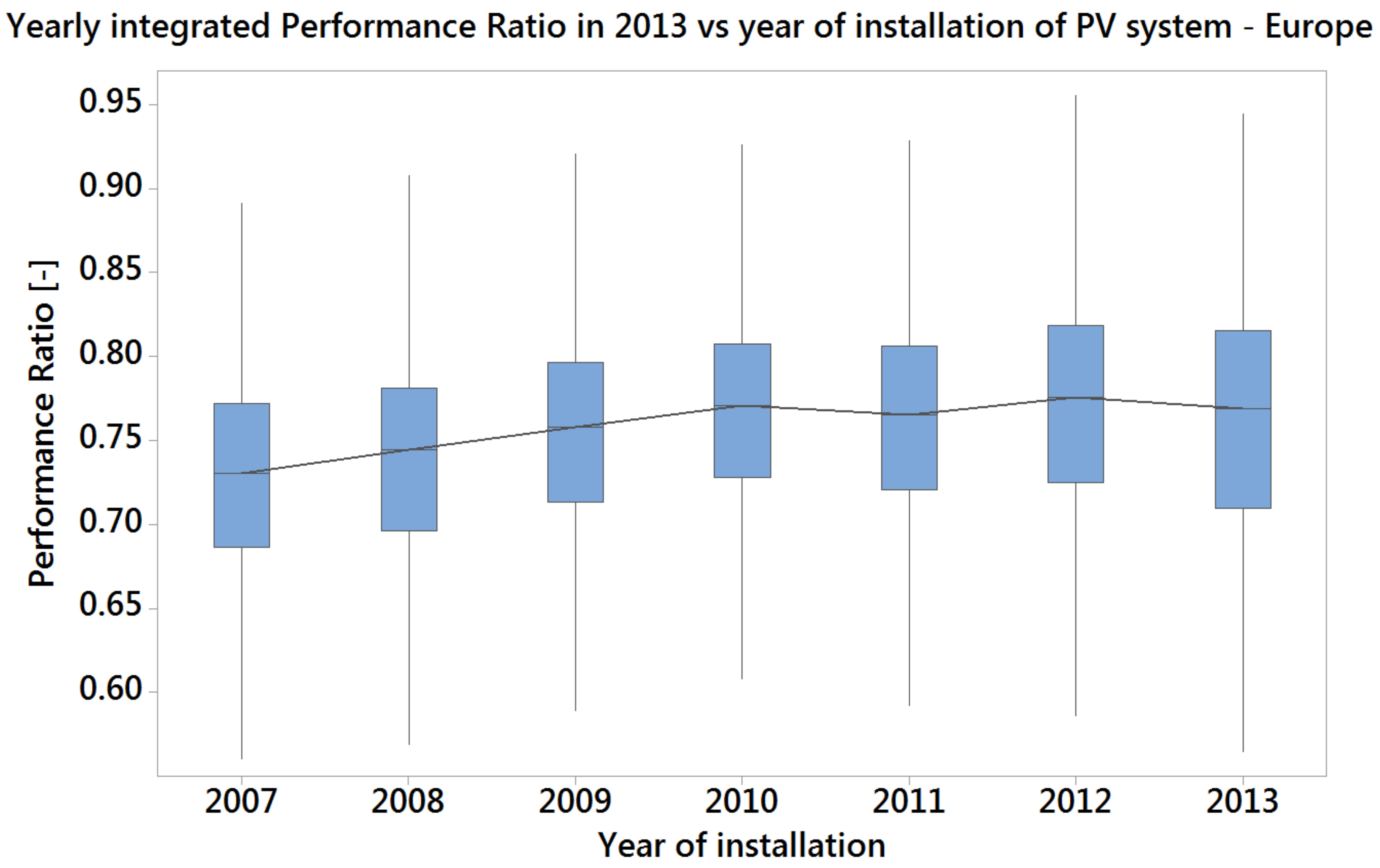
Difference in PR between modules (no thin-film): 1-6%



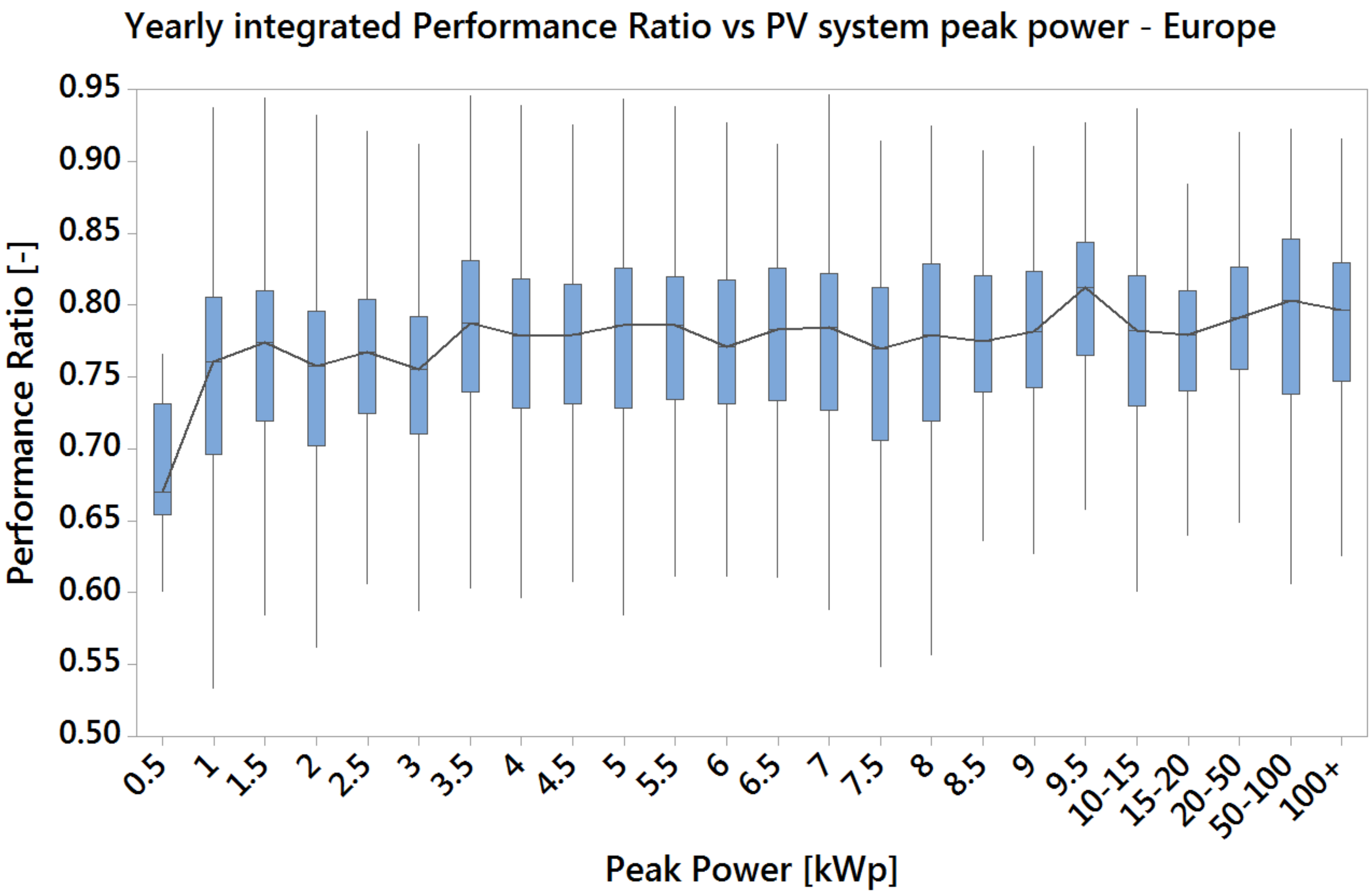
PV modules technology greatly affects performance



PV system performance has improved over time



The small PV systems have a lower PR

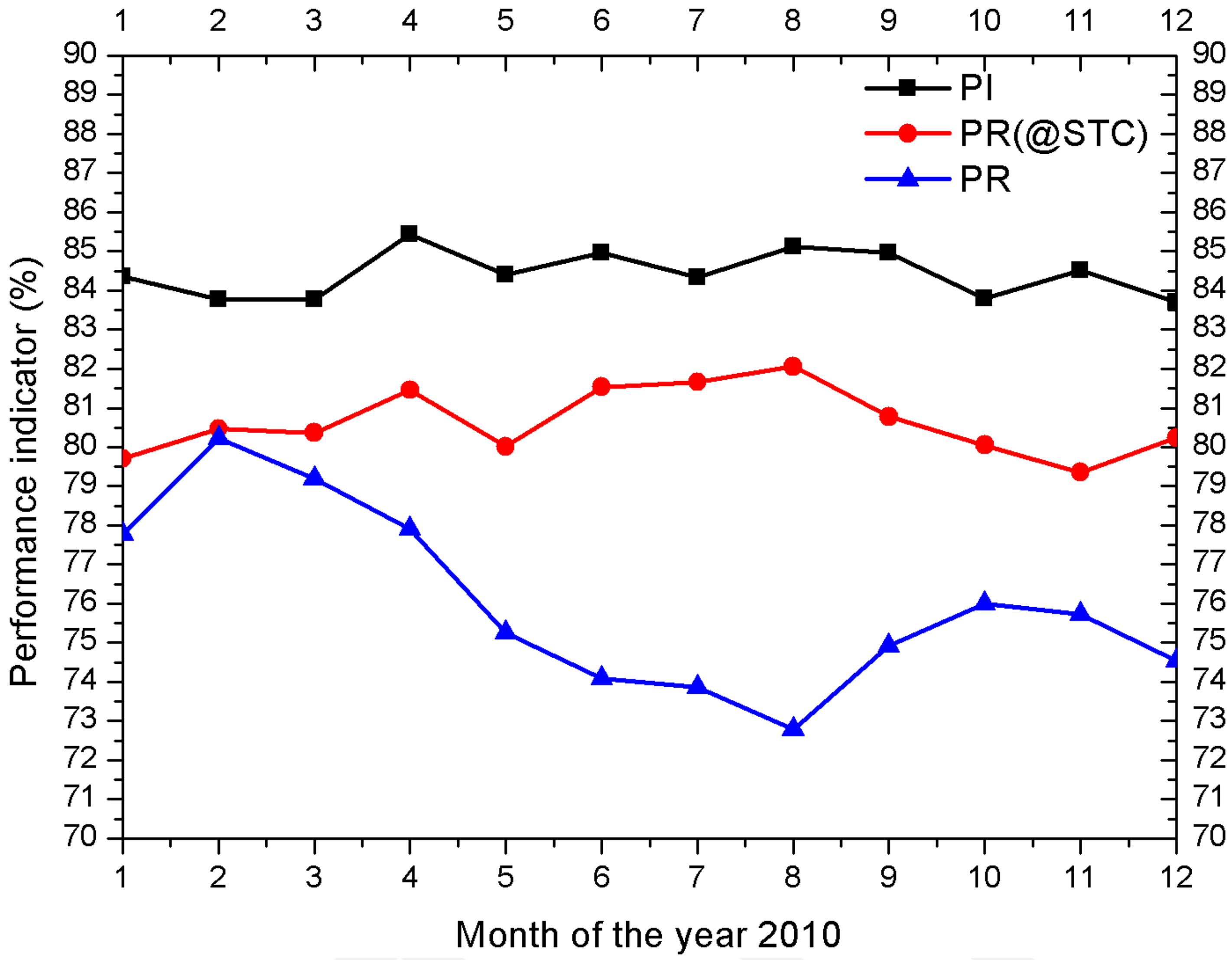


Performance Index (PI): an alternative to Performance Ratio (PR)

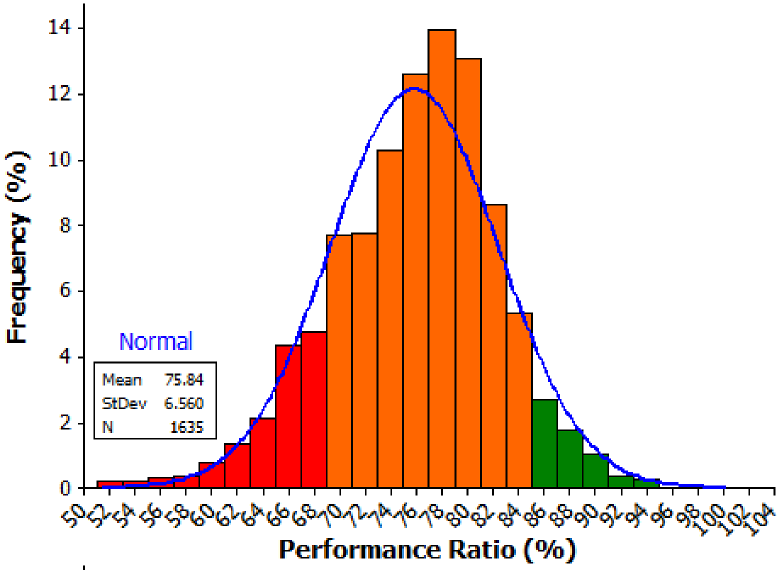
$$PI = \frac{E_{produced}}{\frac{P^{STC}}{G^{STC}} \int G(1-\Delta P_{STC})(1-\Delta P_{DC/AC})dt}$$

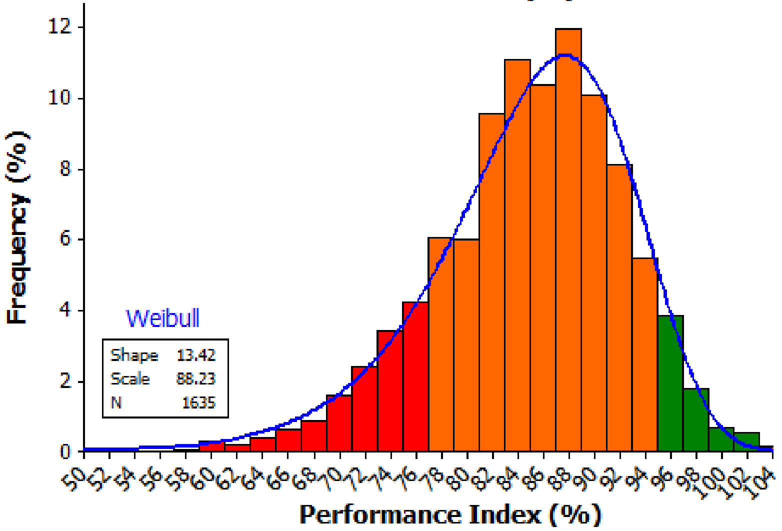
- Comparison with a PV system of high quality chosen as reference
- Reference PV system = highest quality, no shadings, operating under the same conditions than the real system
- Only represents the intrinsic quality of the PV systems
- Allows for comparisons in different conditions, at different places, and for different technologies

Stability of PI vs PR: example for a PV installation in France



Distribution of PR and PI for PV systems (France + Belgium)

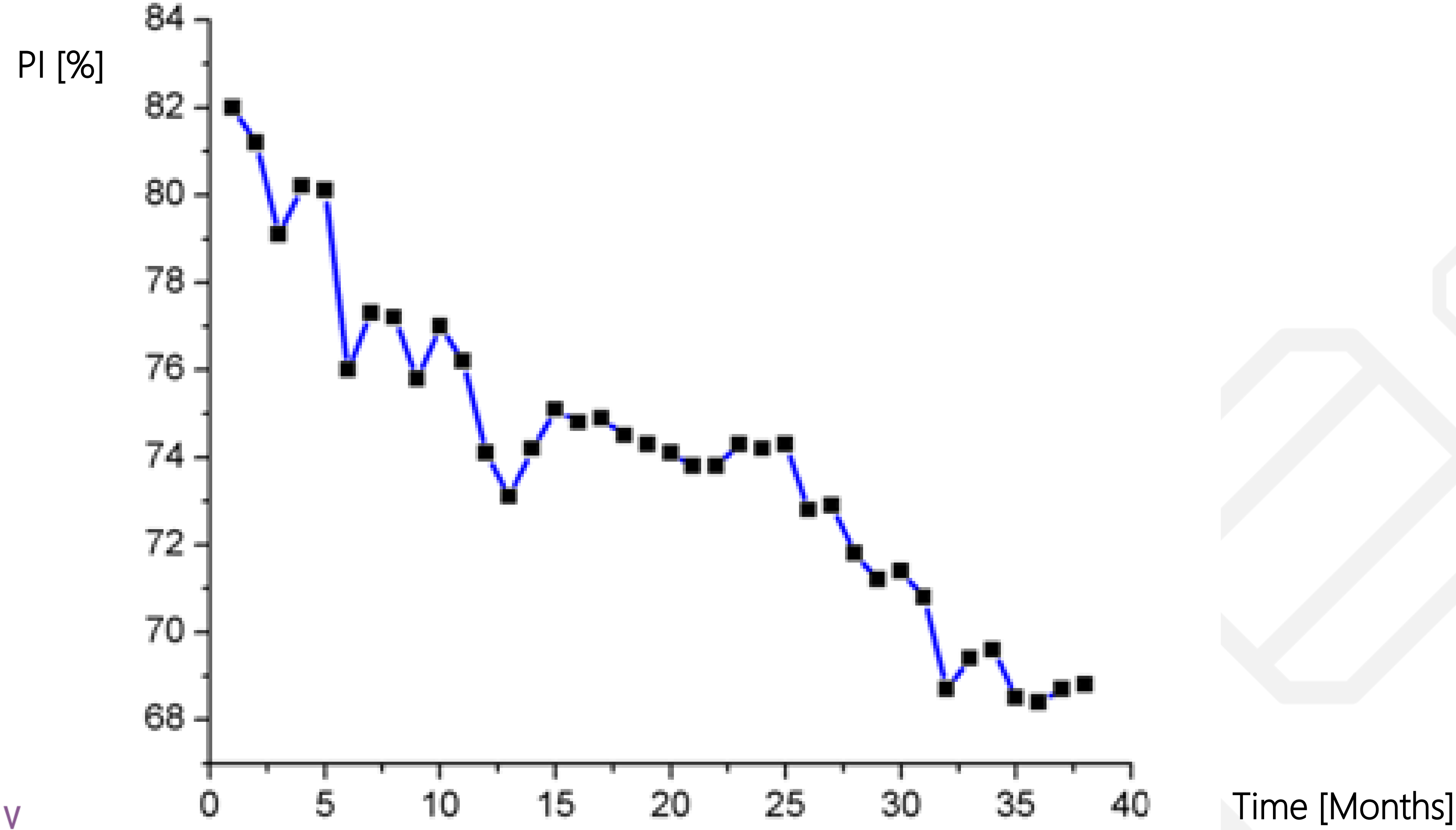




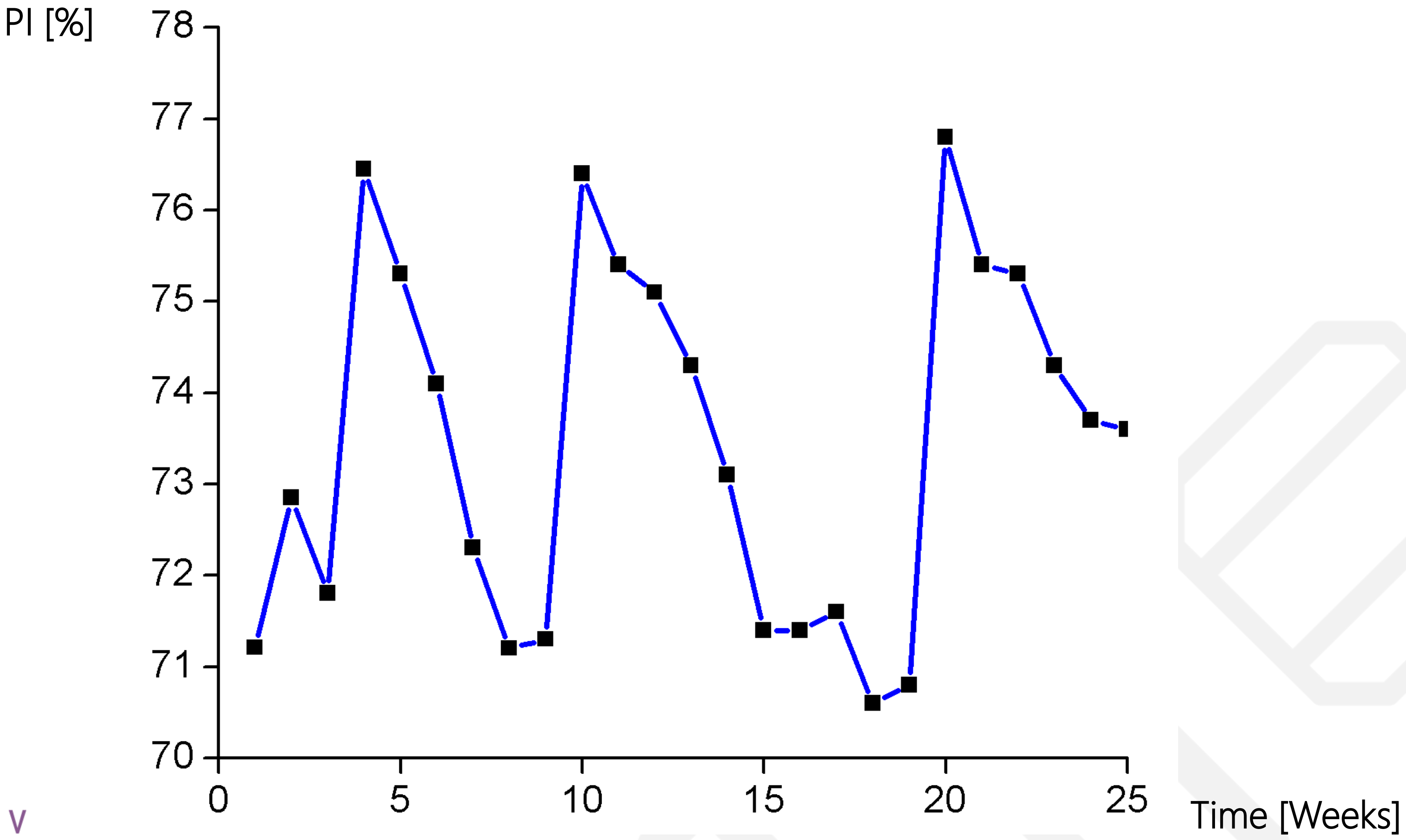
Performance Ratio (PR)
- Mean value: 76% Fr; 78% Be - Normal distribution

Performance Index (PI) - Mean value: 85% (Fr & Be)
- Weibull distribution

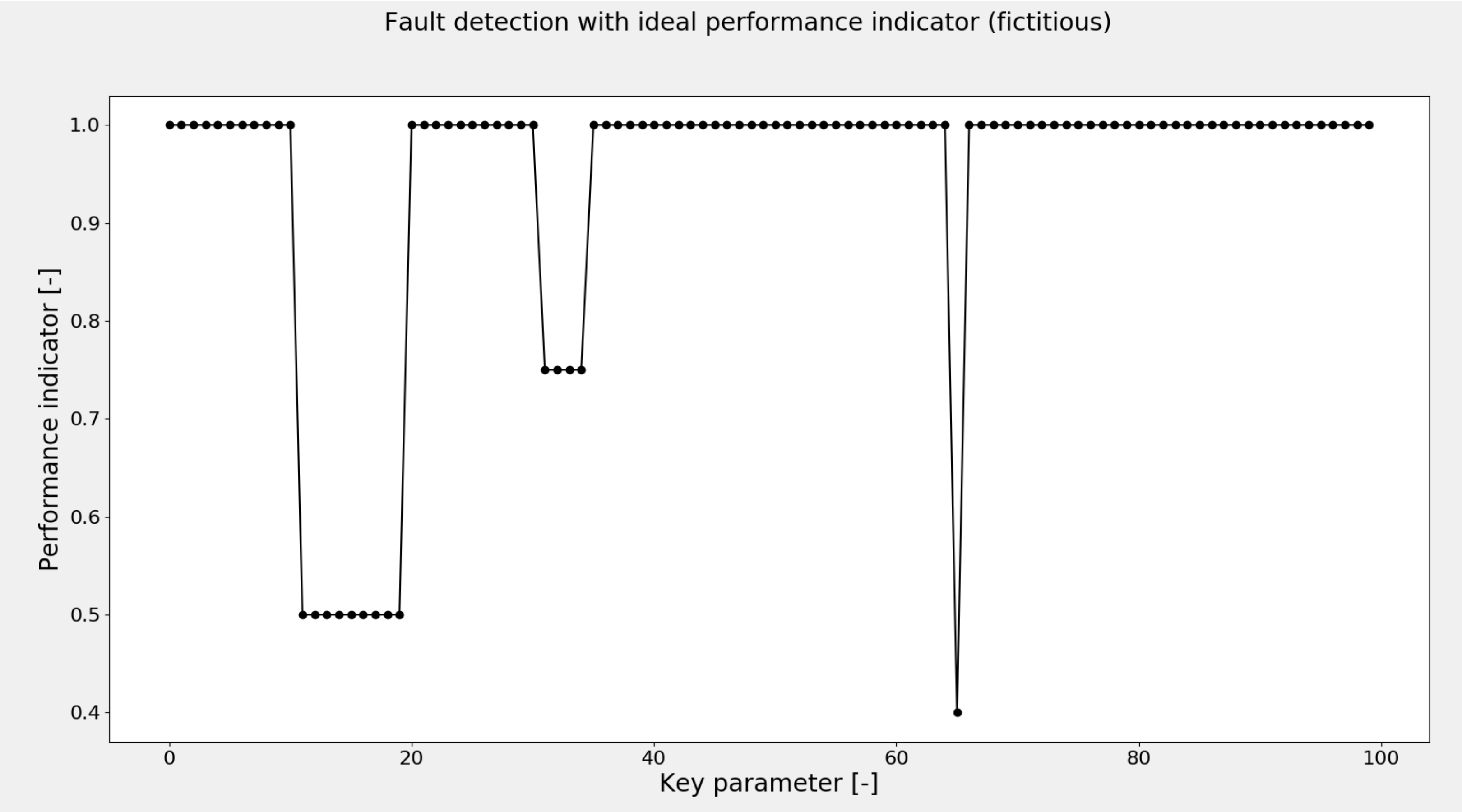
Excessive degradation on PV system



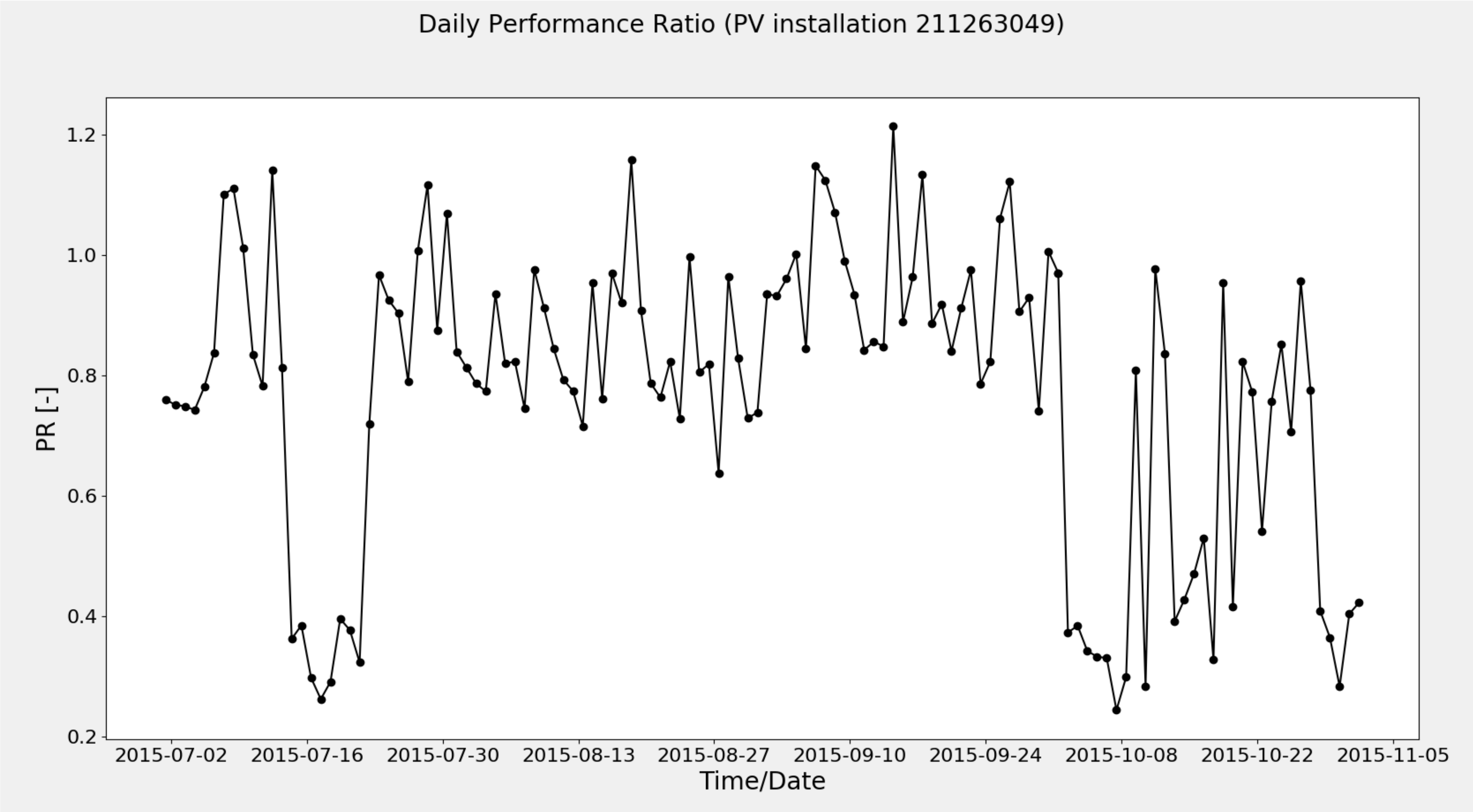
Soiling/cleaning patterns



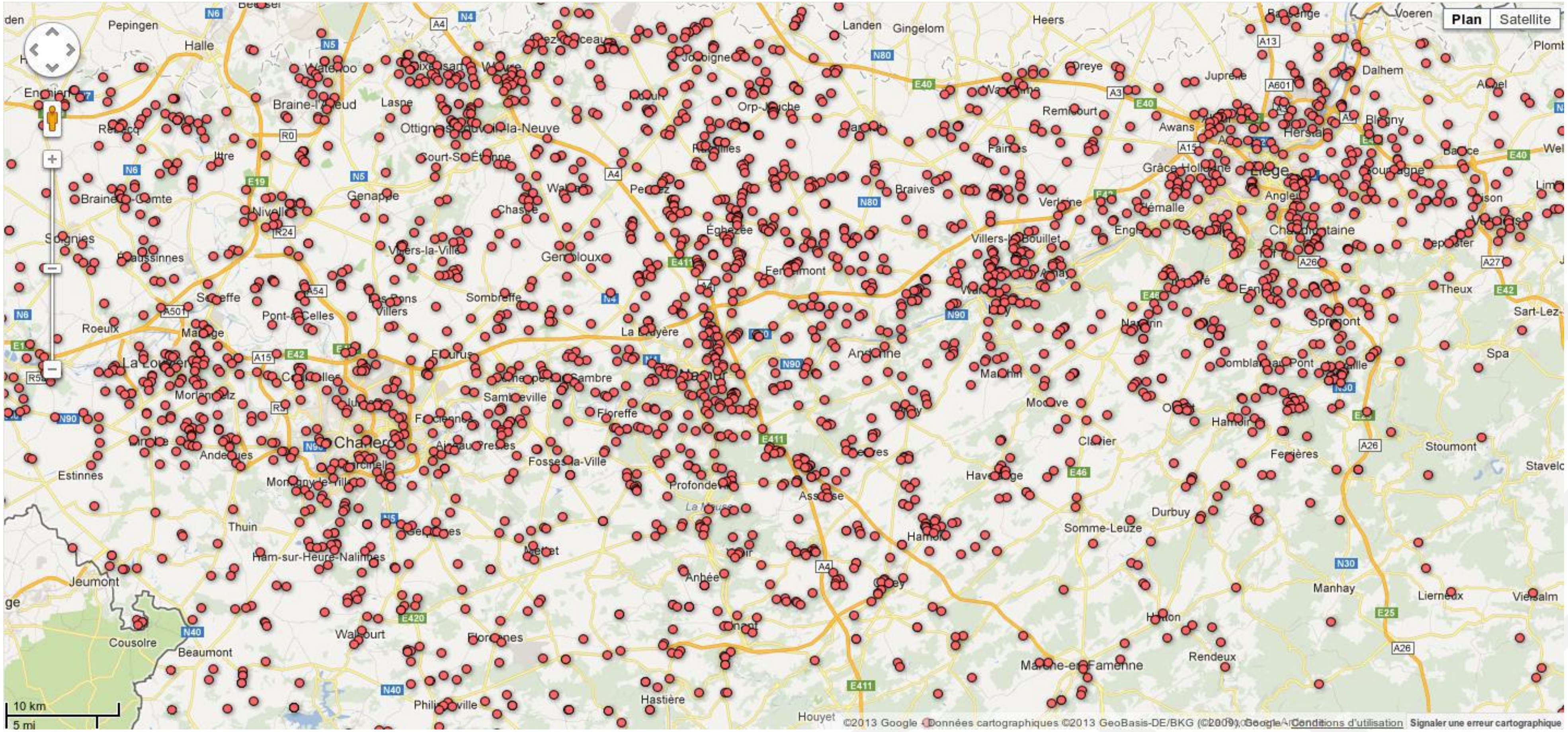
Fault detection in a “perfect” world



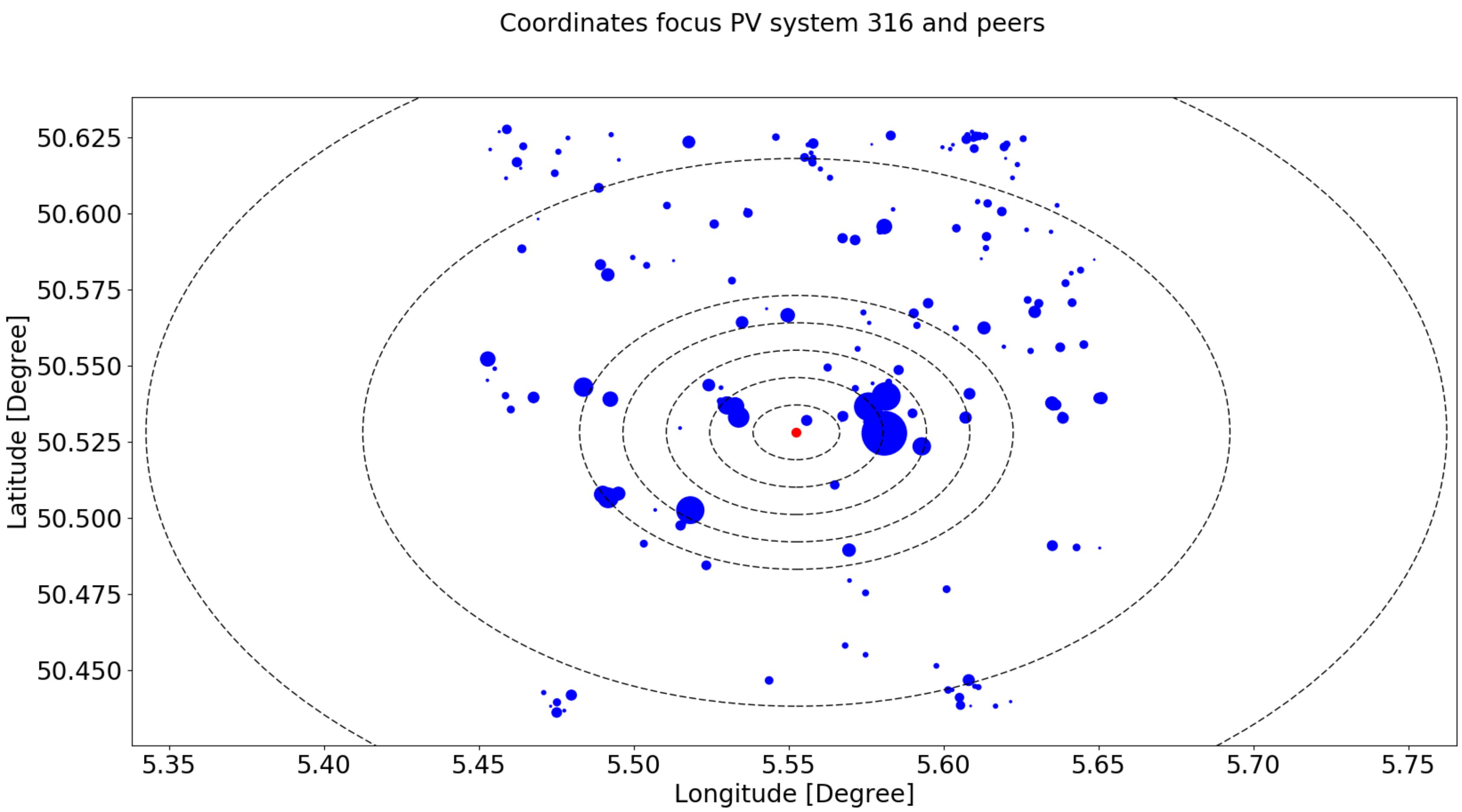
Faut detection: not so simple with PR



Belgium: a wonderful play-field for PV fleets

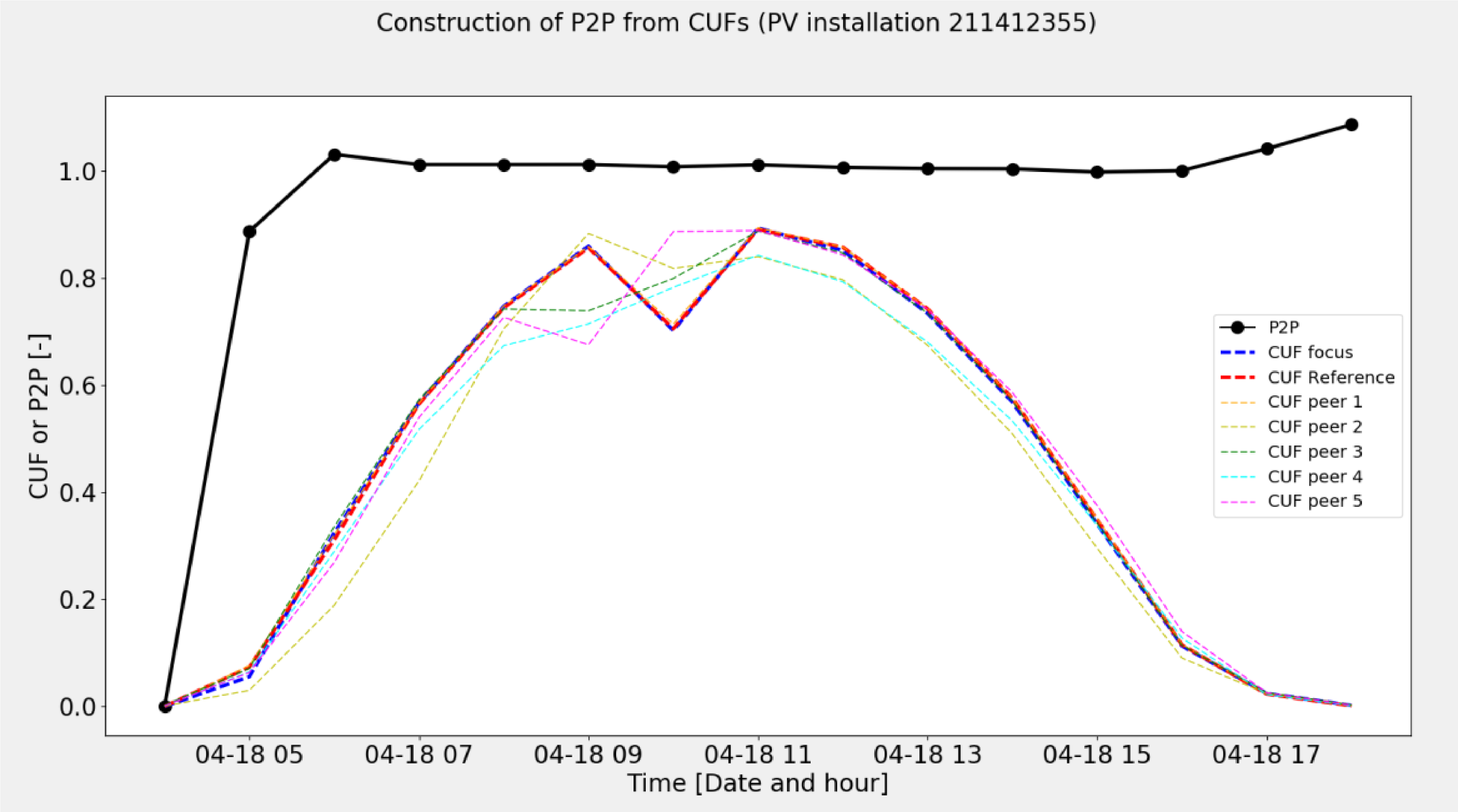


Looking for the best peers in neighborhood



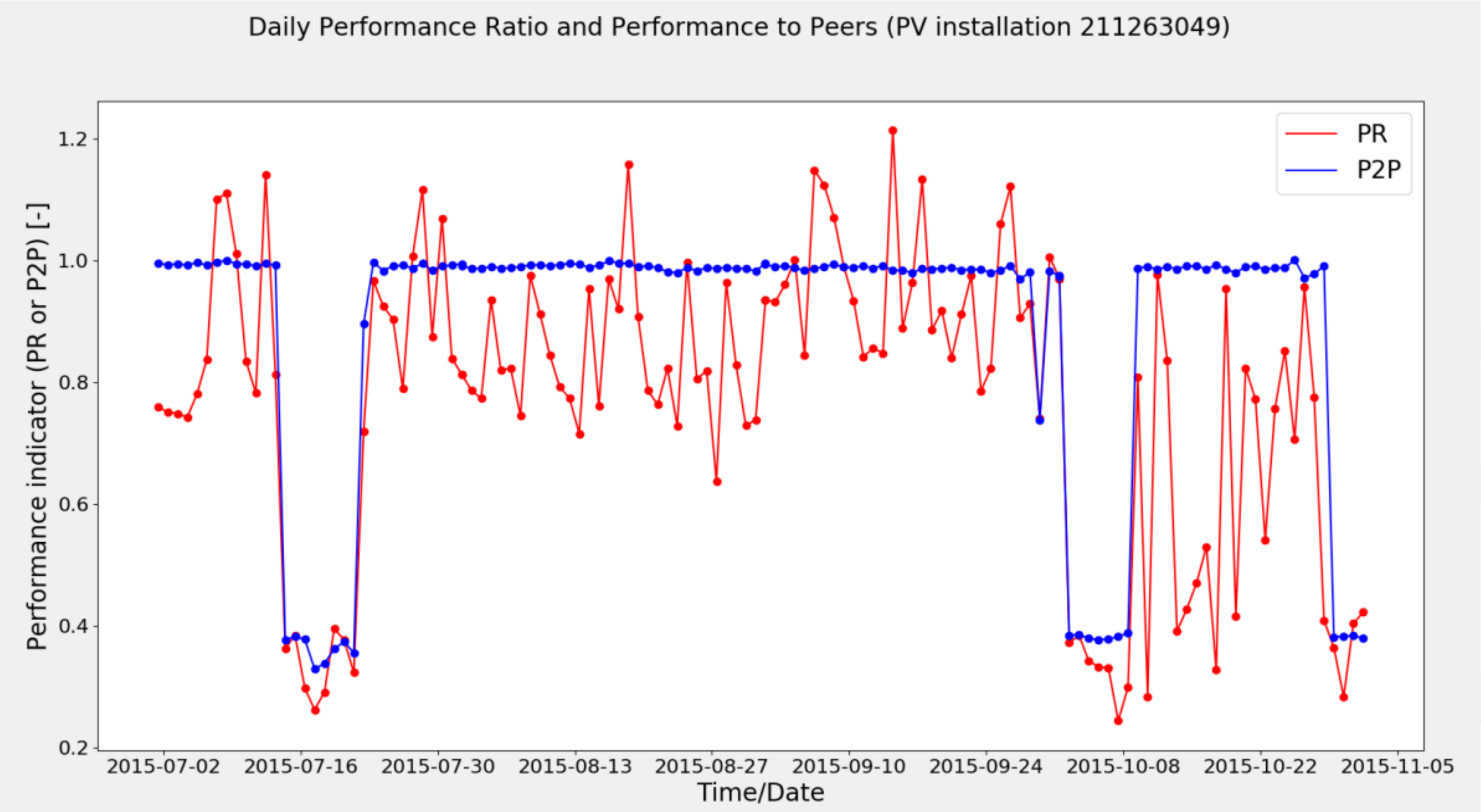
Use of correlations between energy outputs of neighboring PV installations to deduce goodness of peers

Constructing Performance to Peers (P2P)

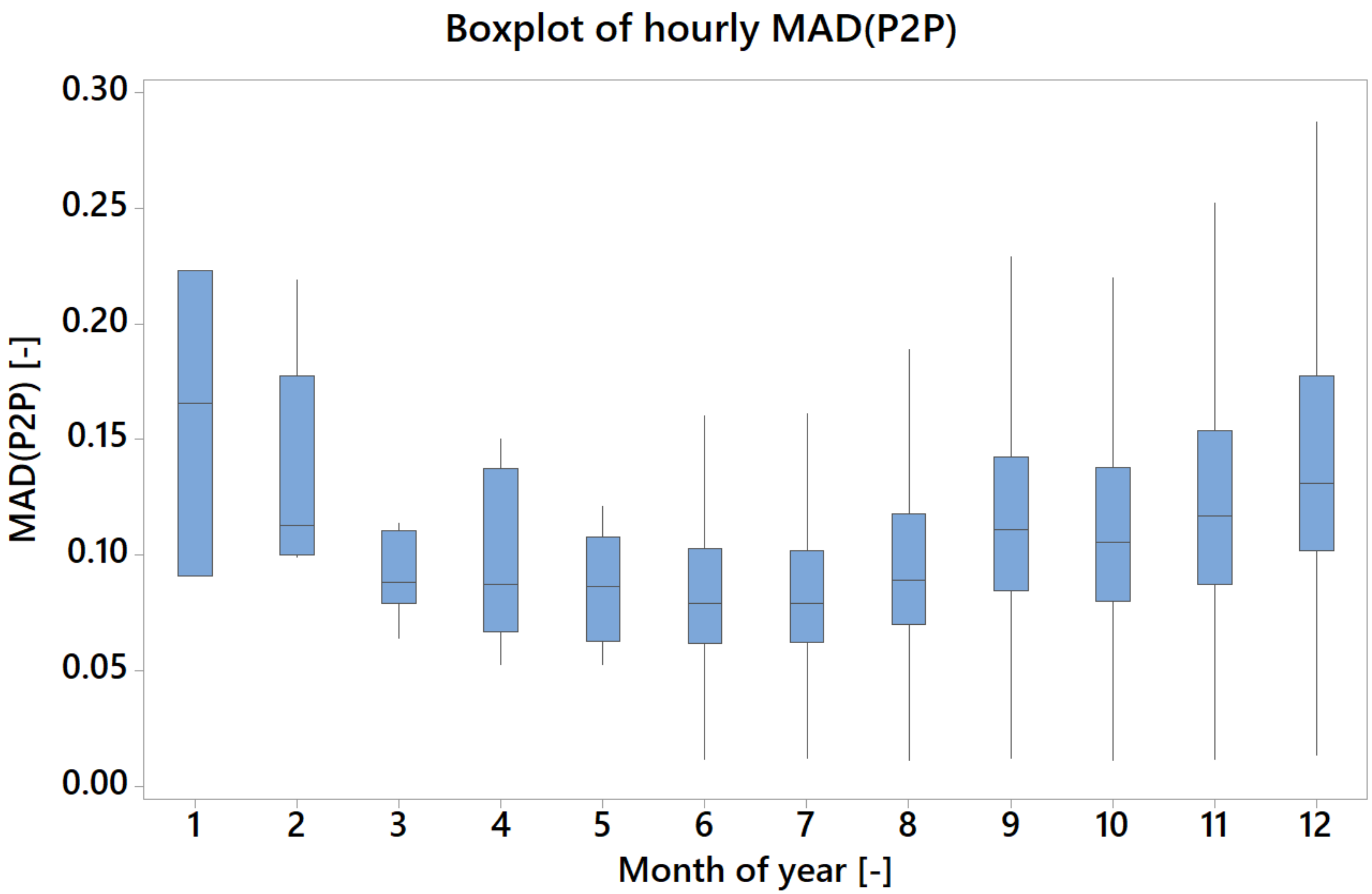


P A R L P V

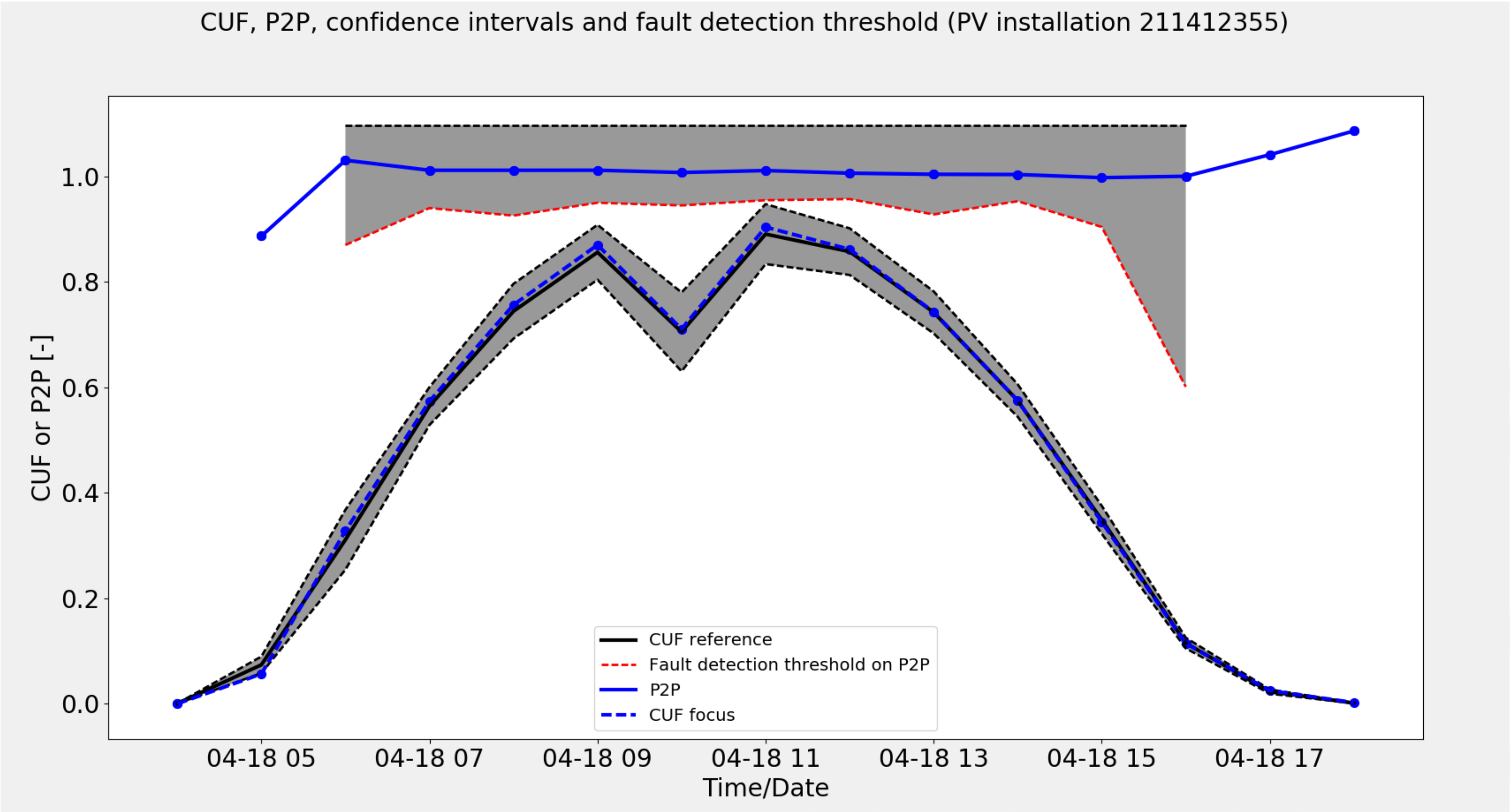
P2P vs PR: more stable better signal/noise



Stability of P2P vs season of year



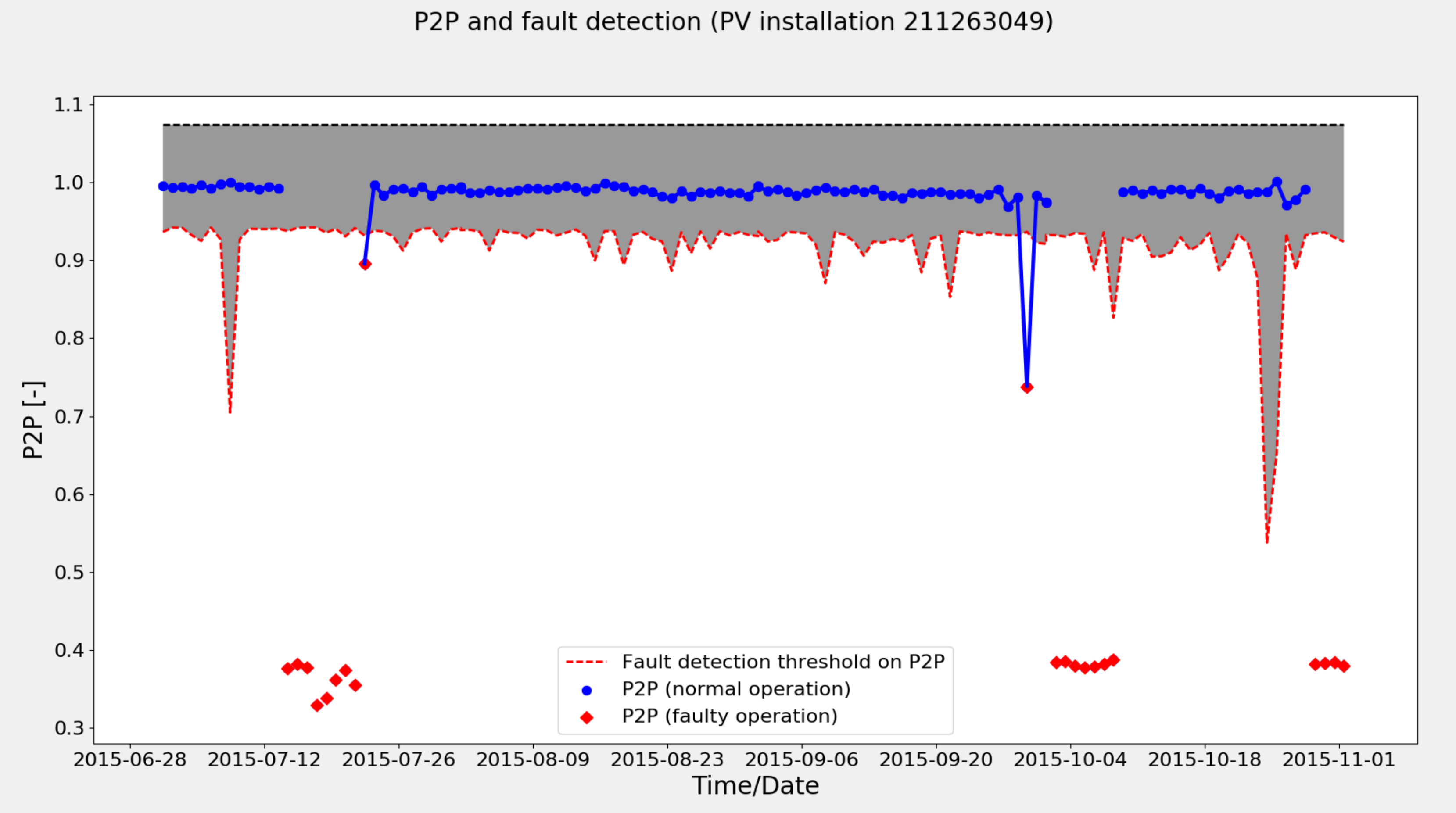
Fault detection with P2P: dynamical thresholds



Dynamic Confidence Intervals as a function of instantaneous uncertainty around P2P

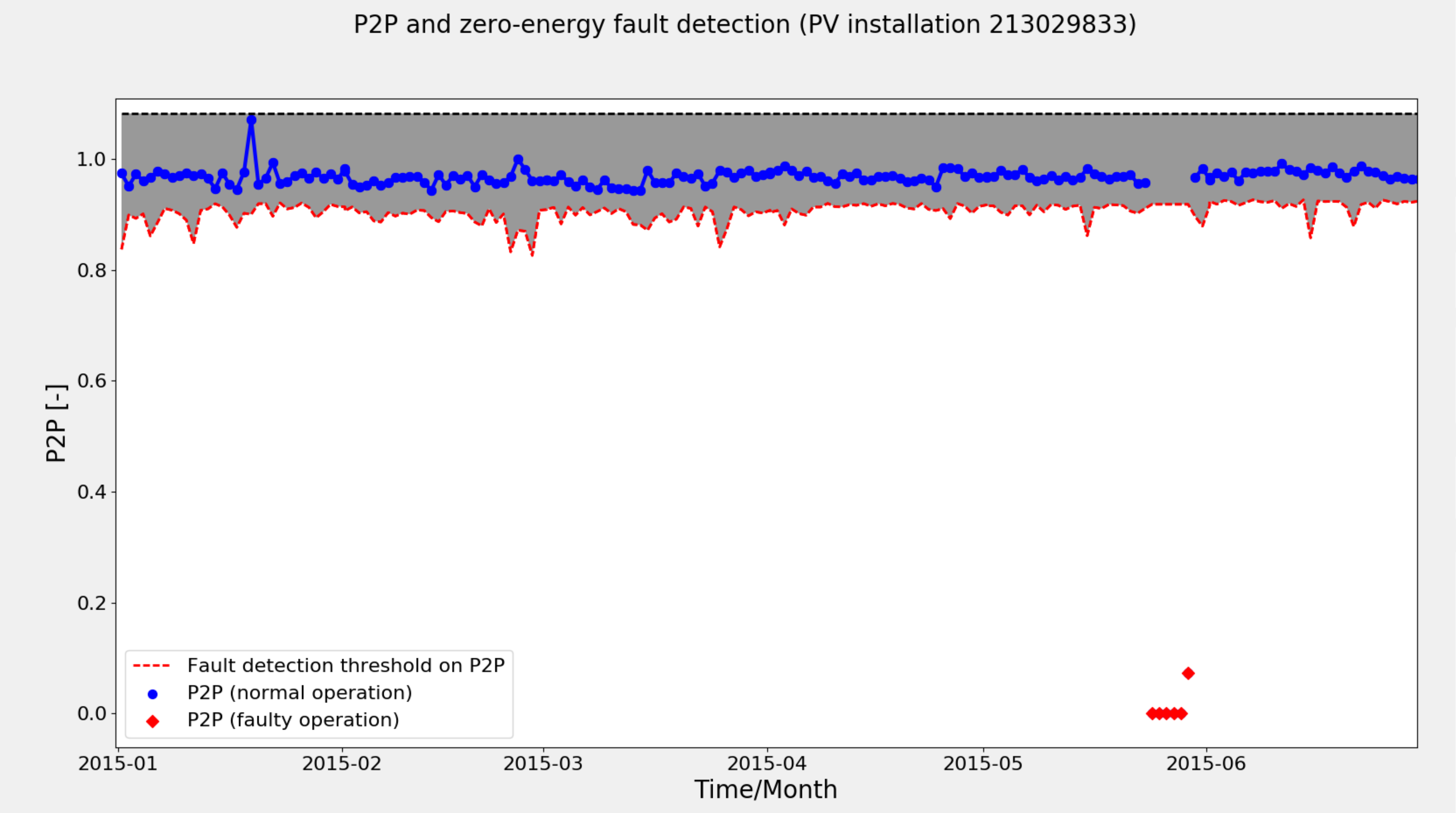
PARL PV

Fault detection with P2P and quantification of energy losses

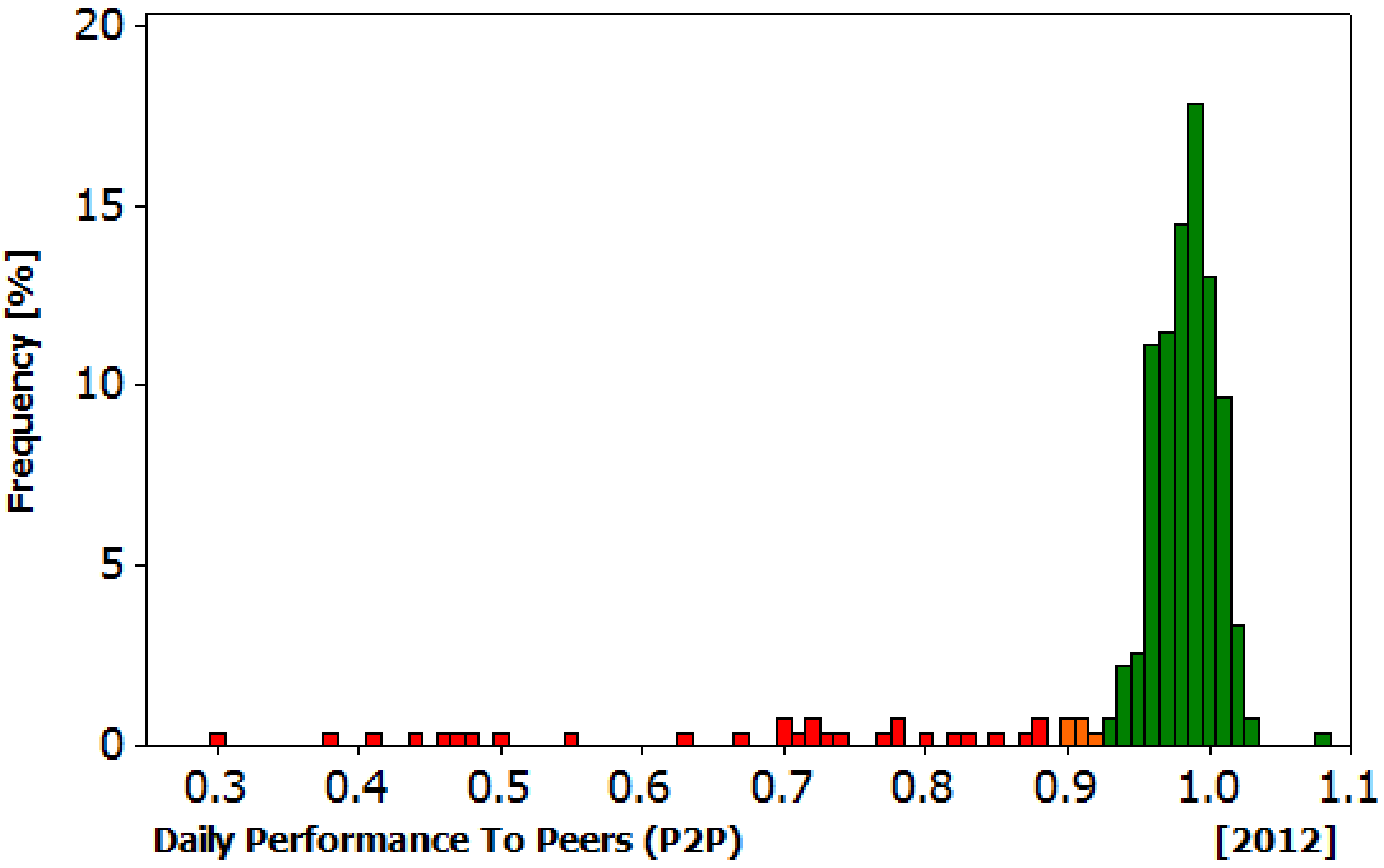


$$\Delta E_{fault} = \frac{\mu_{1/2}(P2P) - P2P_{fault}}{\mu_{1/2}(P2P)}$$

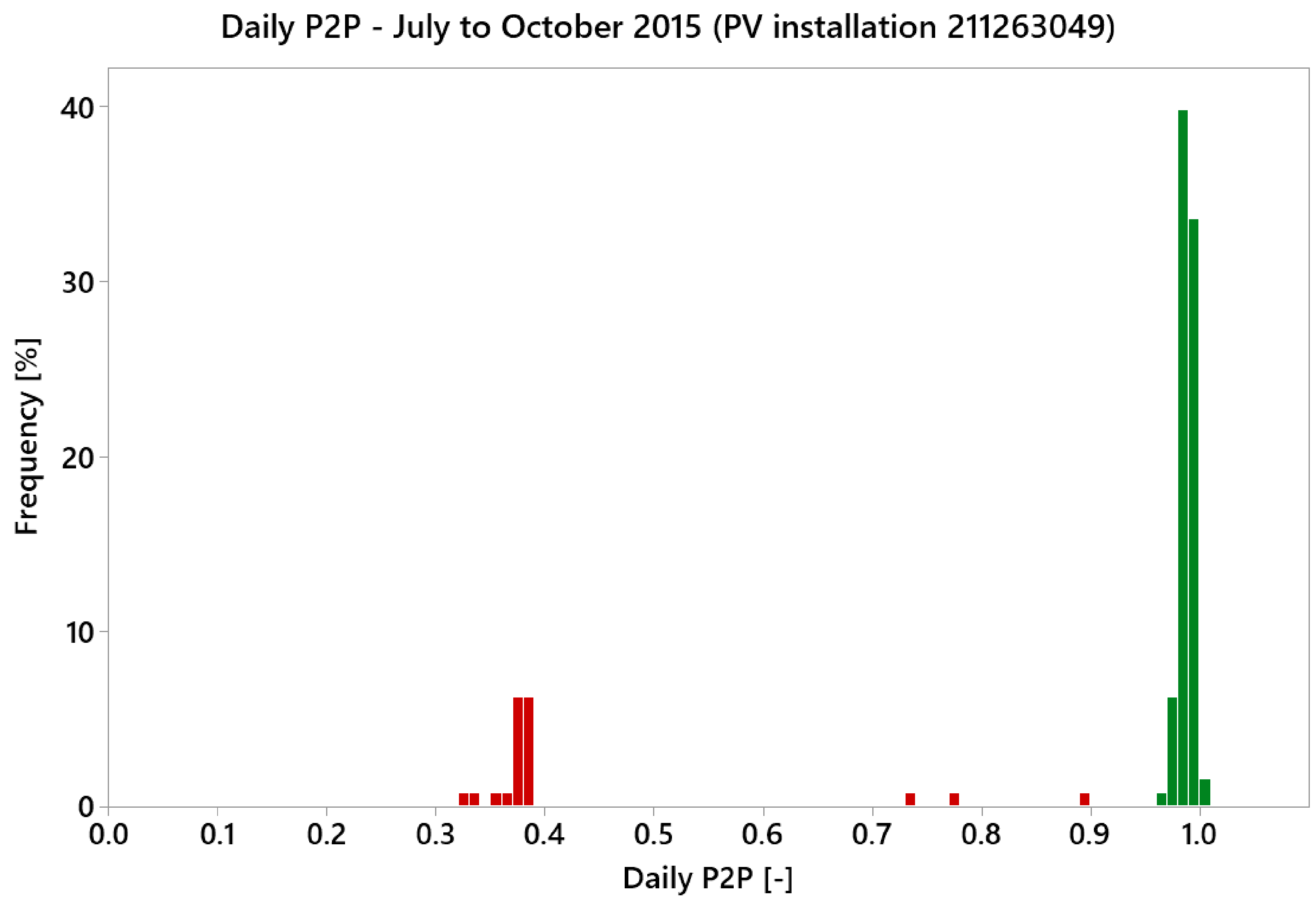
Diagnosis of zero-energy faults



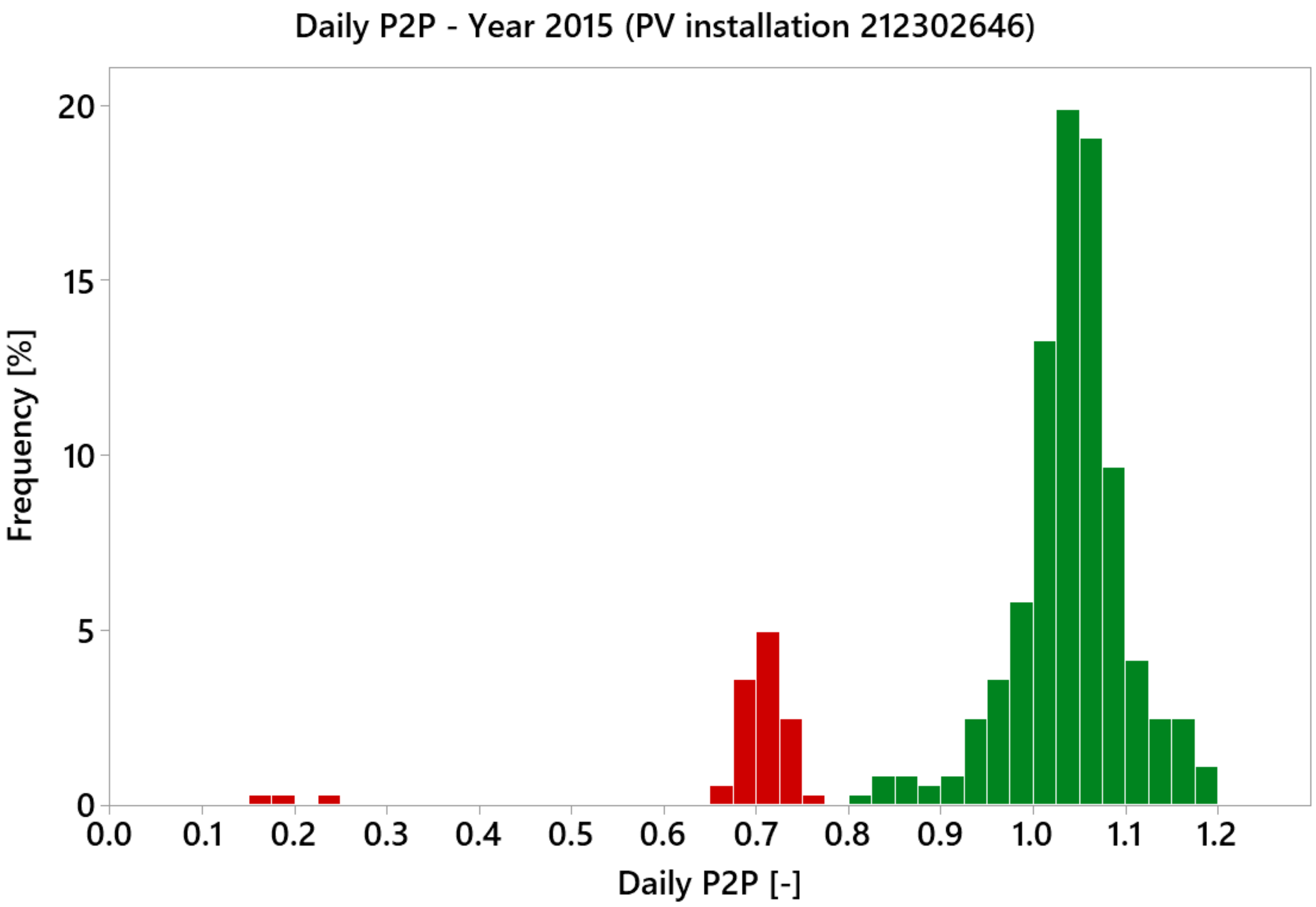
Fault detection from P2P: clustering approach



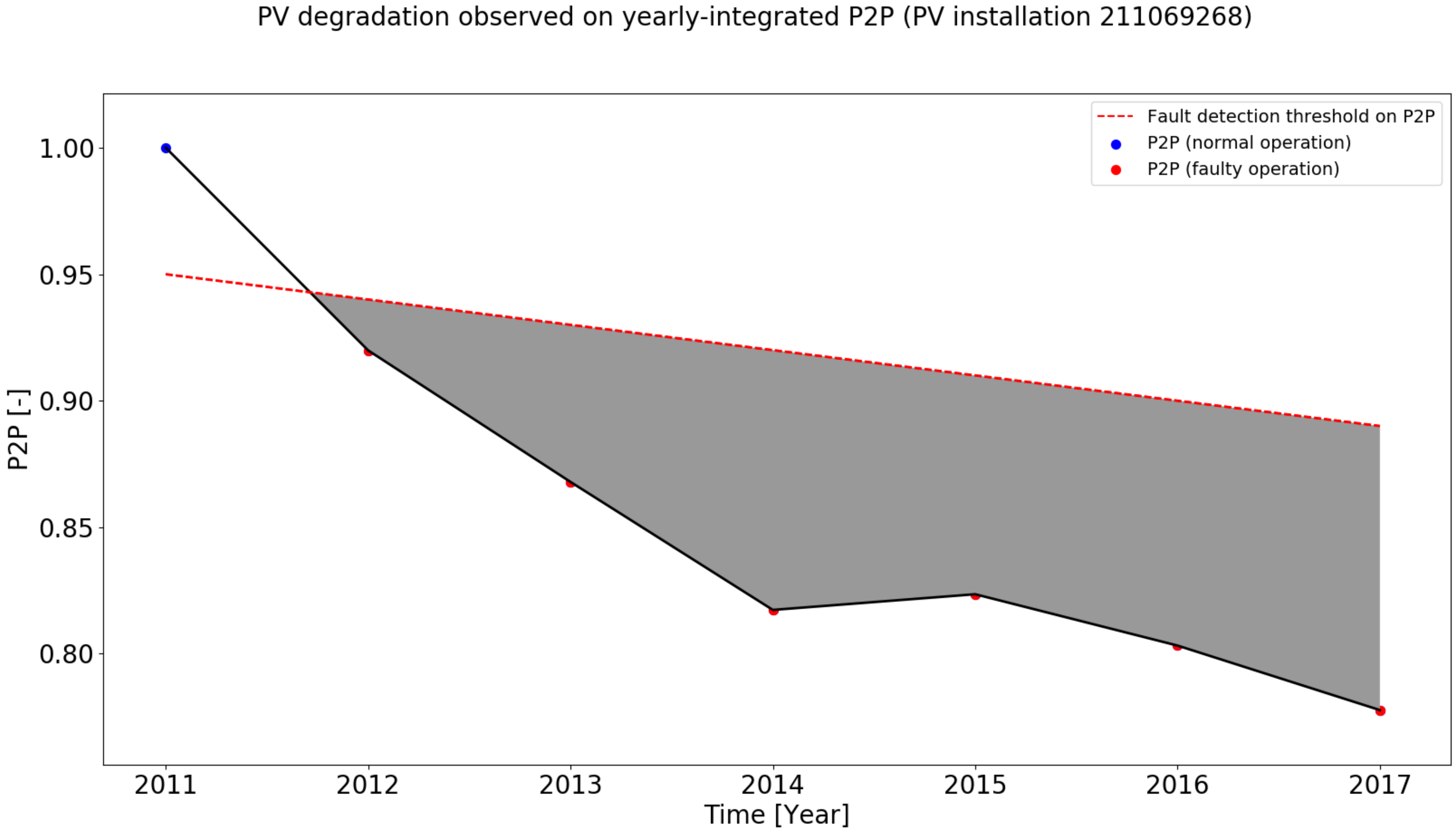
Diagnosis of inverter fault with KR-clustering approach



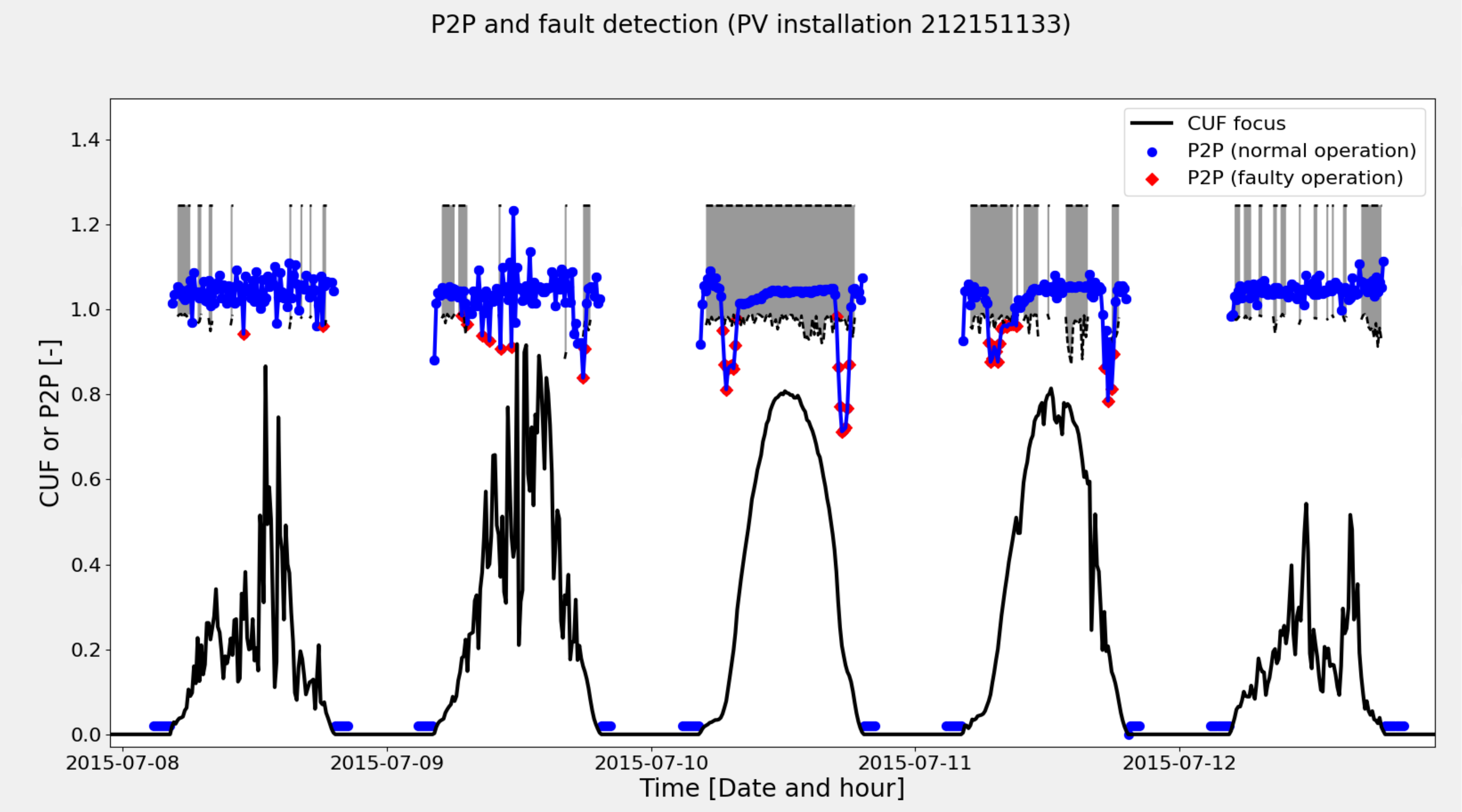
Diagnosis of by-pass diode fault with KR-clustering approach



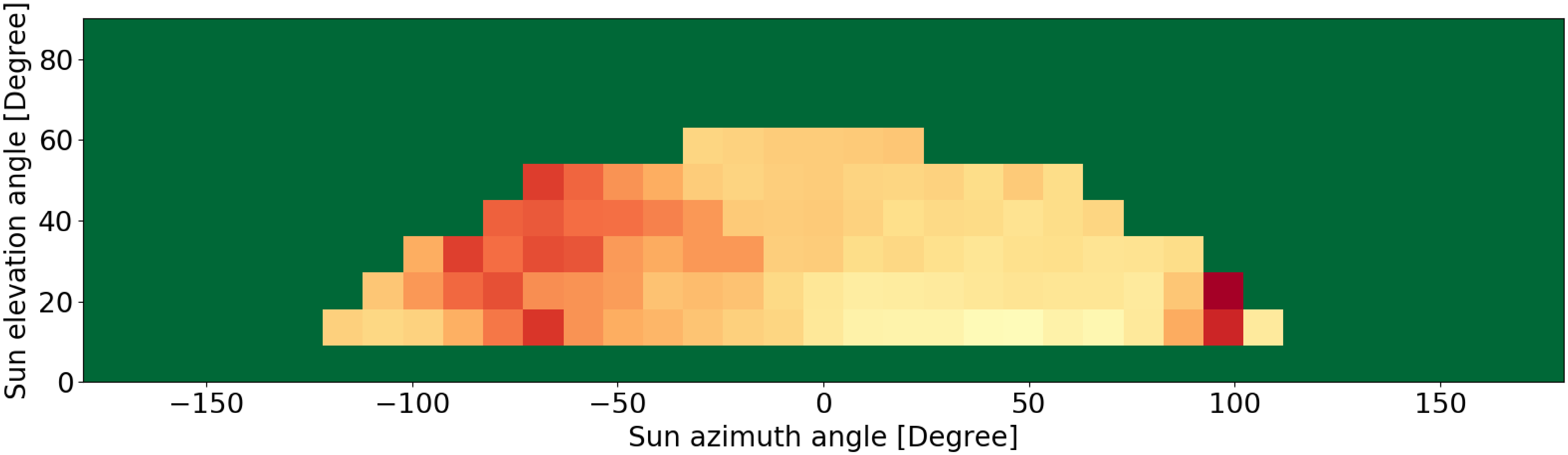
Fault diagnosis of PV module degradation on annual P2P trends



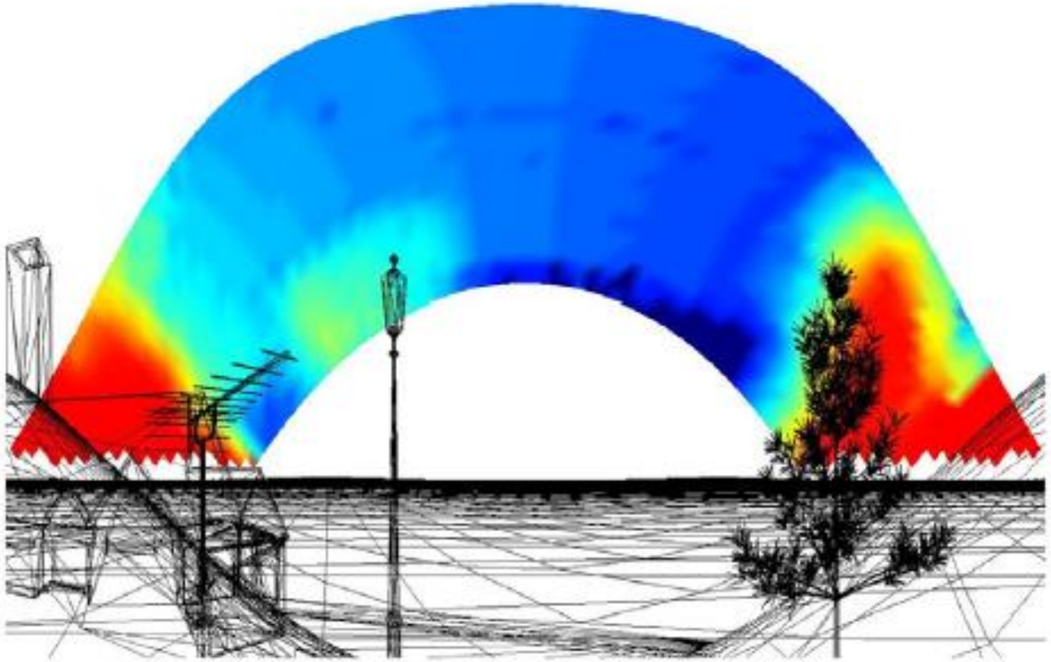
Fault detection with P2P on 10-min data



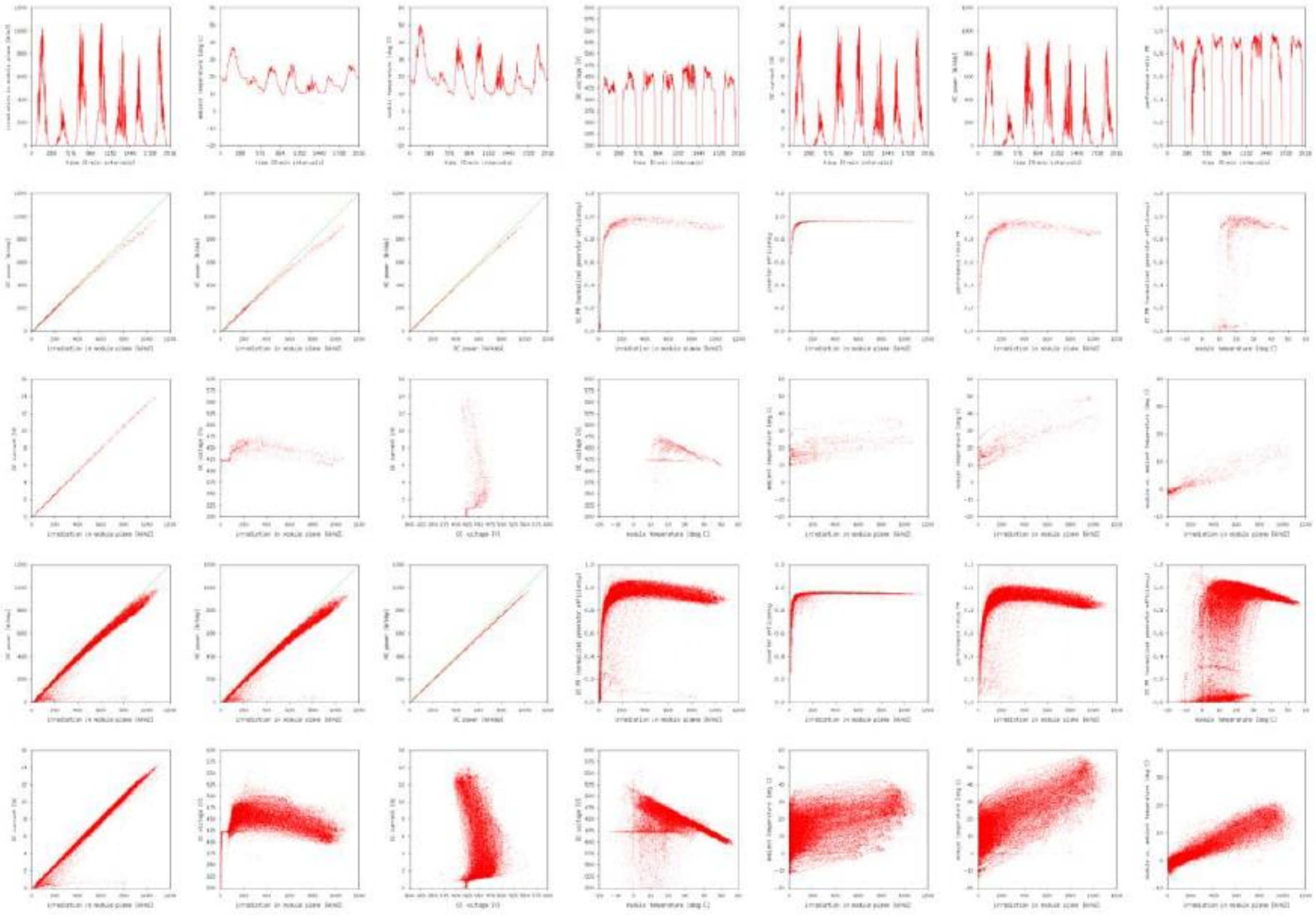
Shading diagnosis from P2P vs sun position



Shading detection from performance vs sun position



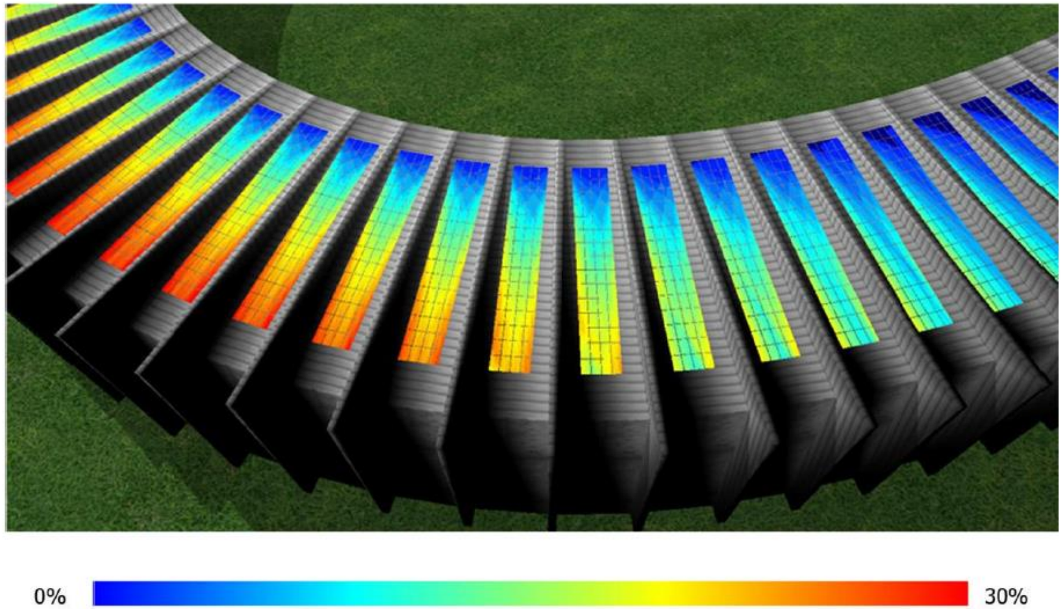
The stamp collection approach



Woyte et al., 2014

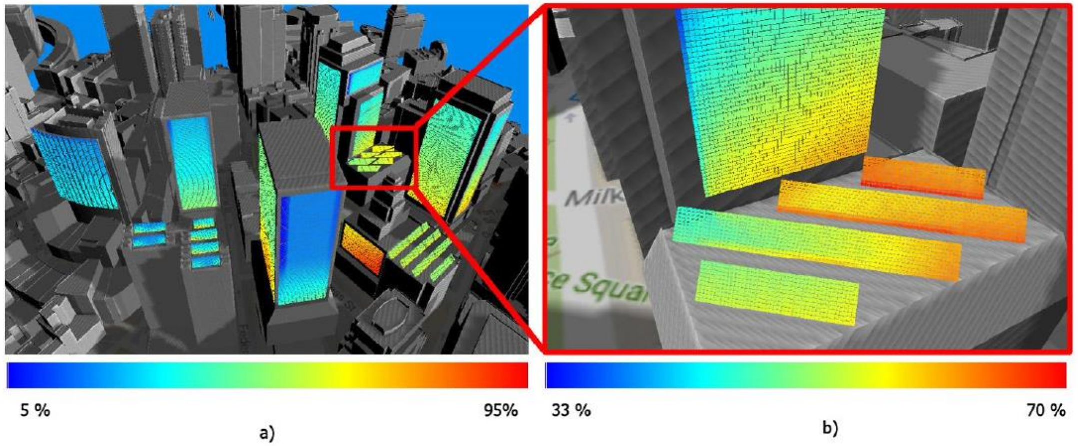
Future needs for analyses: BIPV

BIPV Copenhagen



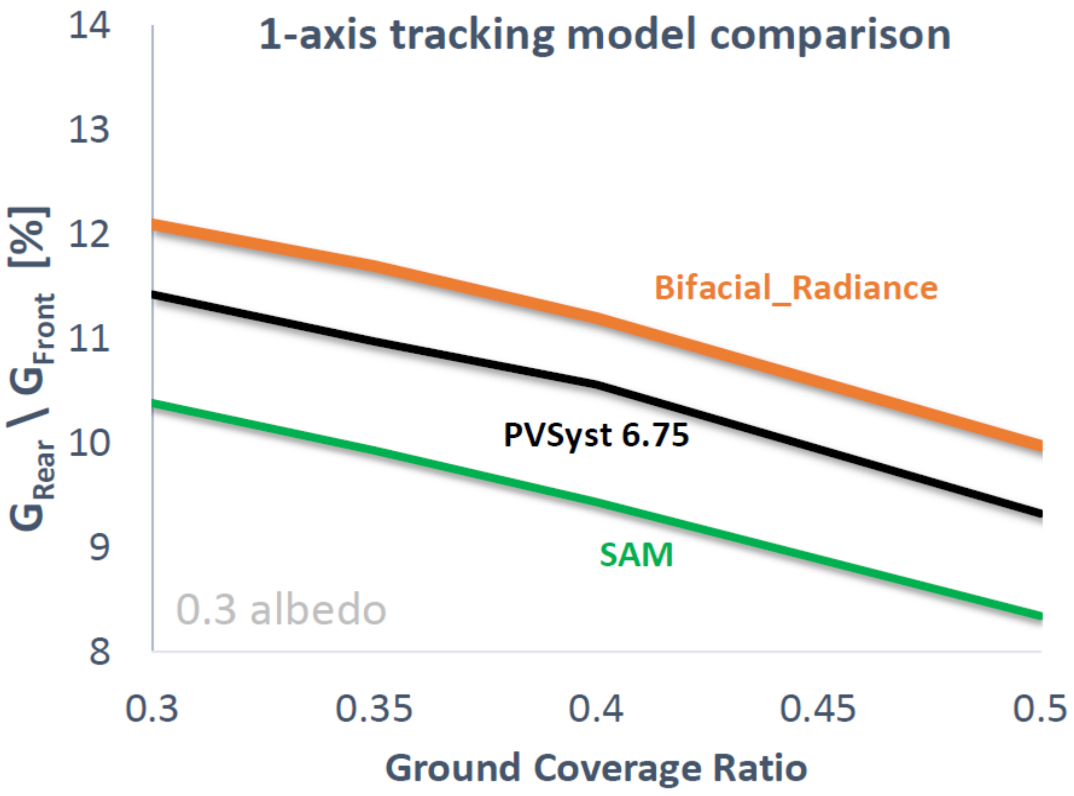
Mineirao Stadium, Brasil
(Robledo et al., 2019)

Boston Solar (Robledo et al., 2019)

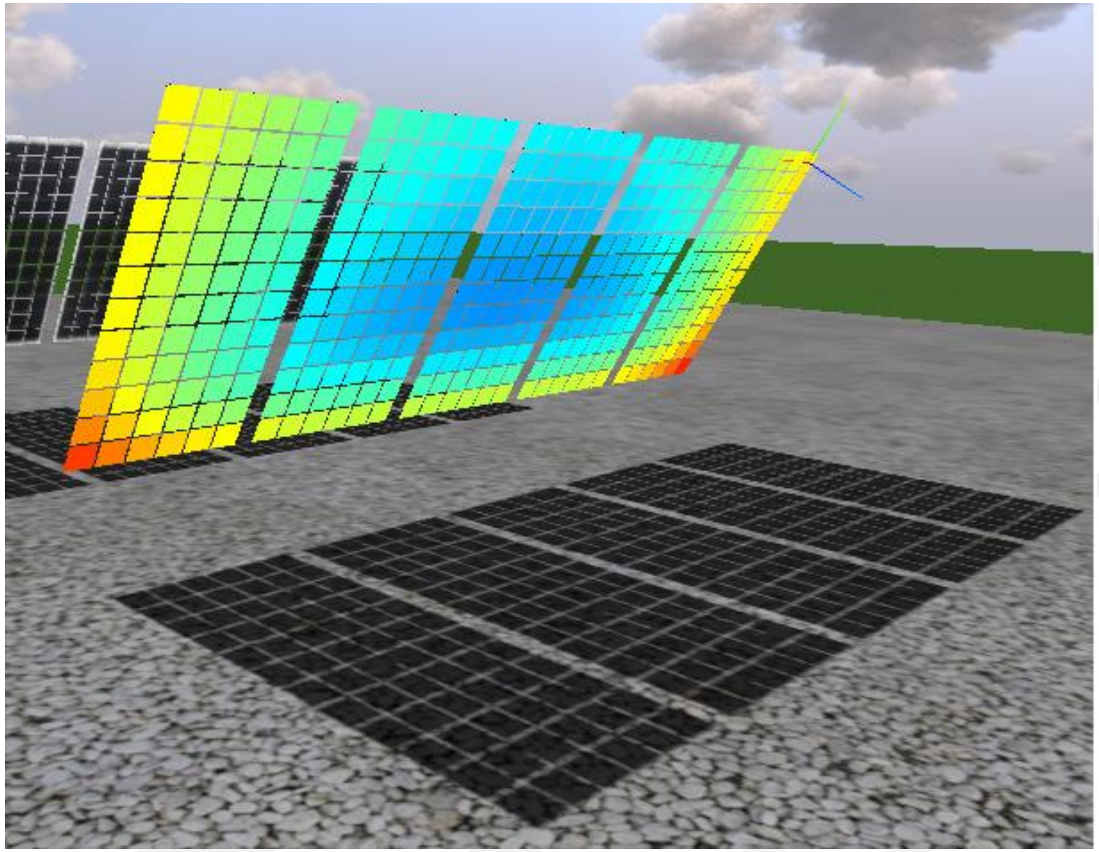


P EARL PV

Future needs for analyses: Bifacial PV



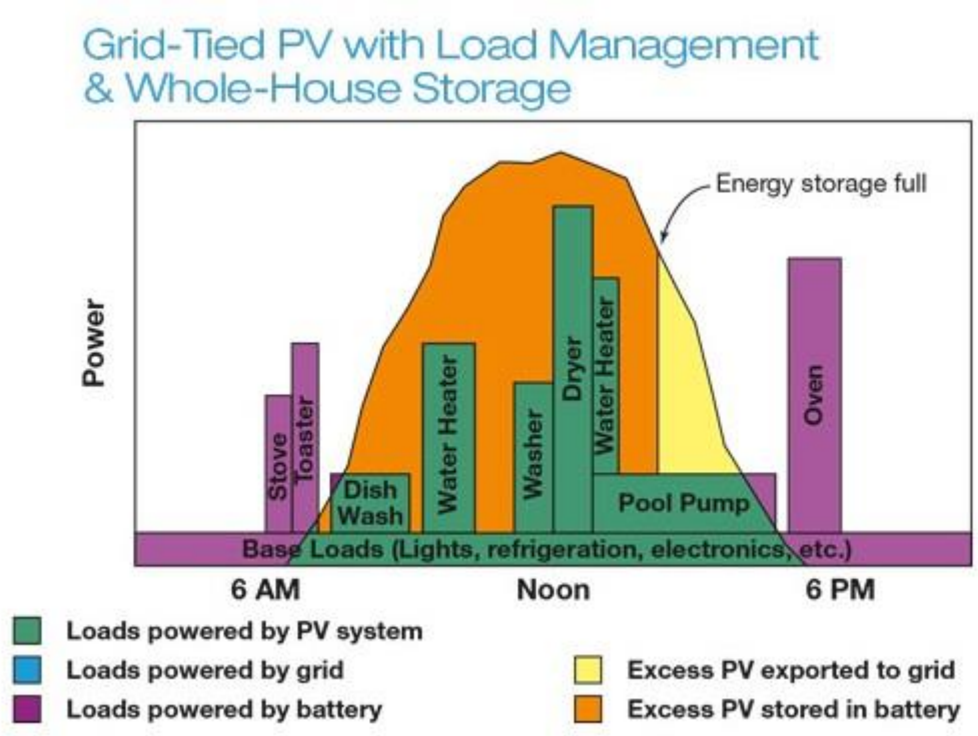
Ayala Pelaez et al., 2019



Lusim simulation toolbox (LuciSun)

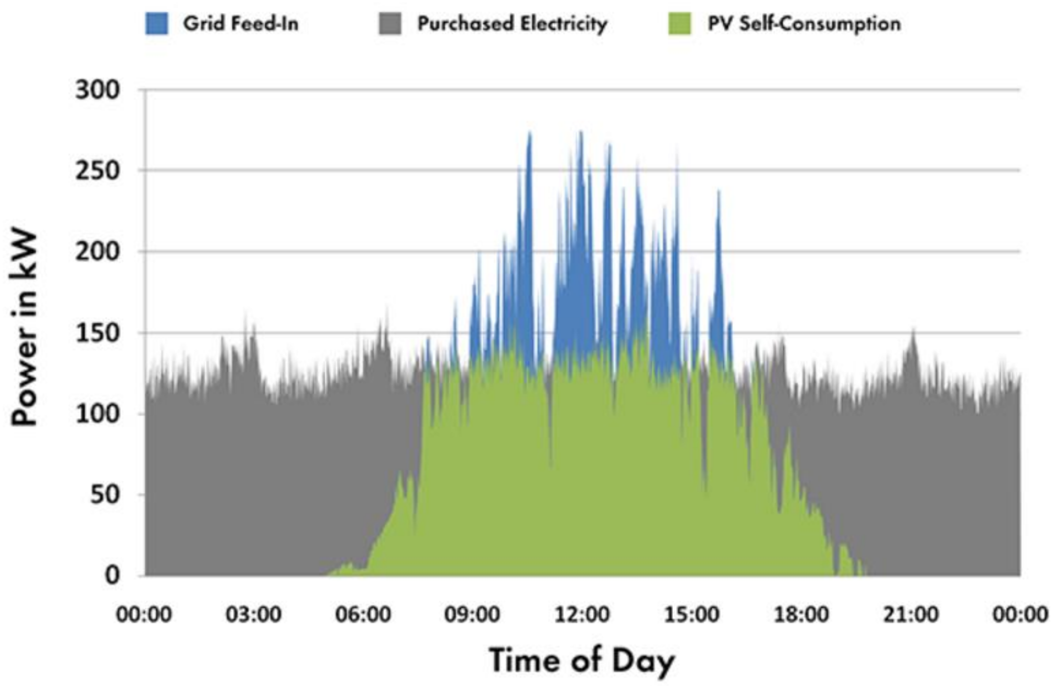
Future needs for analyses: Self-consumption

In a "perfect" world: load management at will



Source: Home Power Magazine 2018

In practice: need for forecasting



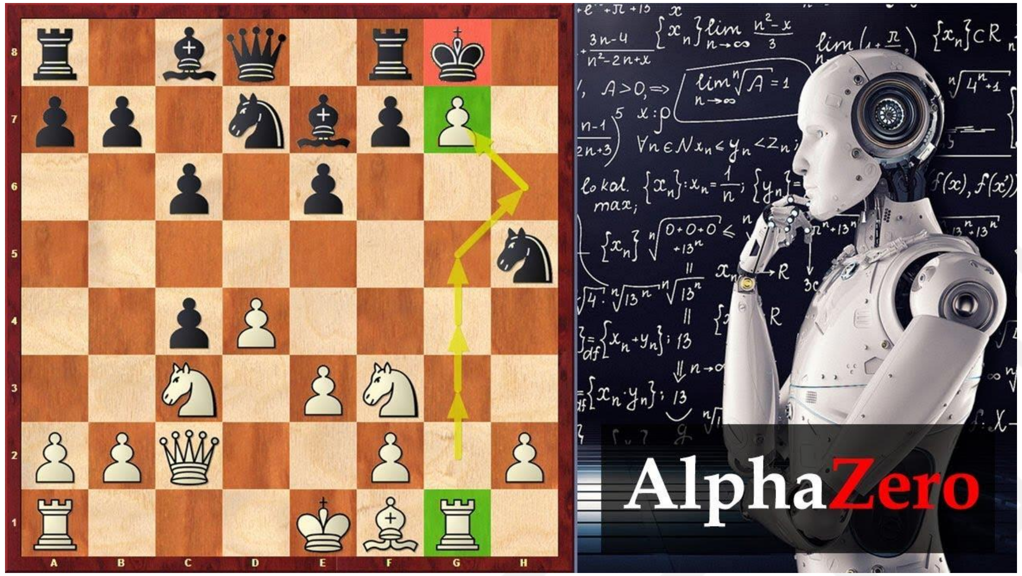
Source: SMA 2018

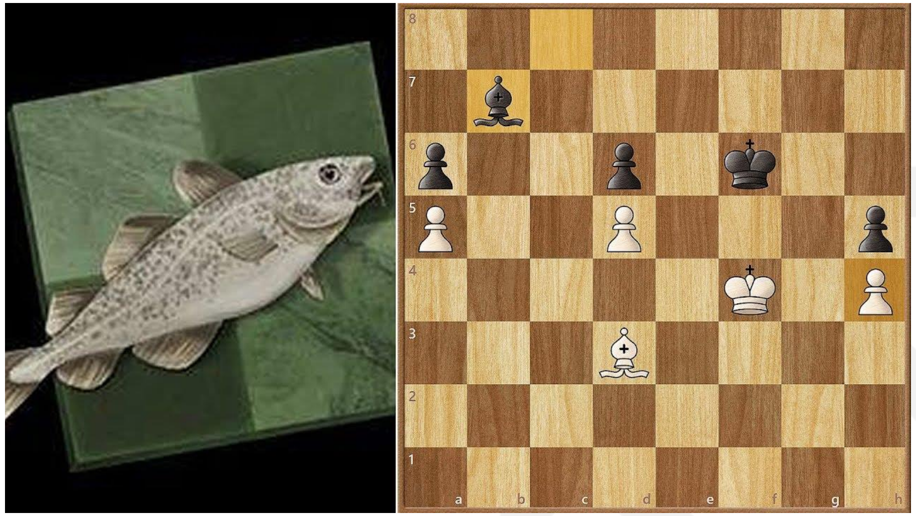
Data analysis methods: a wide/wild topic

Methods

- Performance Ratio
- Energy yield simulation
- I-V curves modeling
- Power losses
- Scatter plots, stamp collections
- Benchmark, inter-system comparisons
- Data mining
- ANN, Fuzzy logic, Neuro-Fuzzy
- Machine learning, AI

Evolution of PV fault detection: chess analogy





Thank you for your attention!