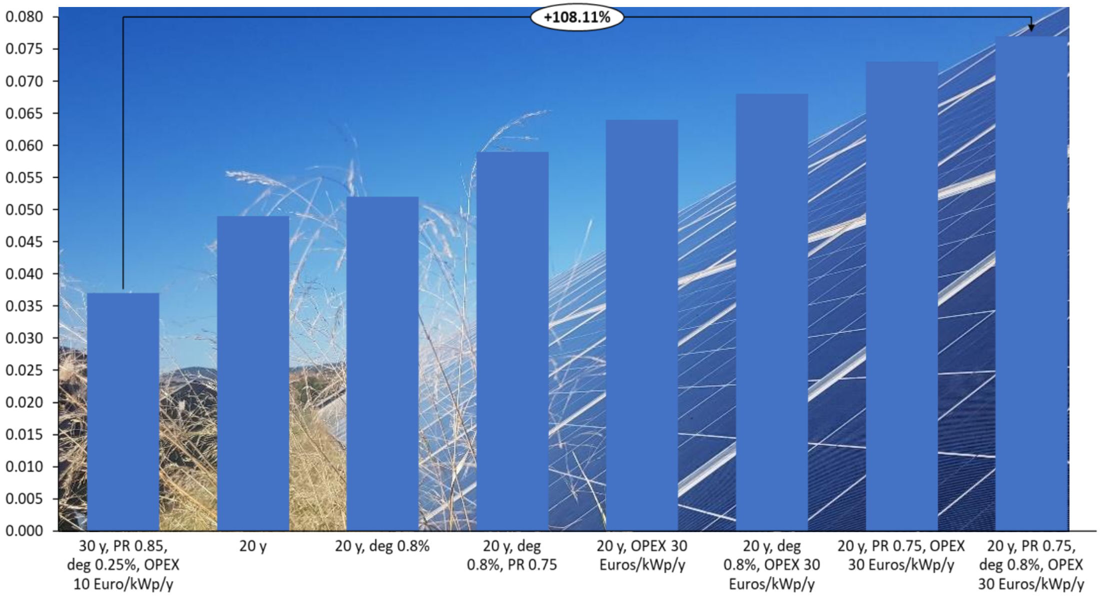
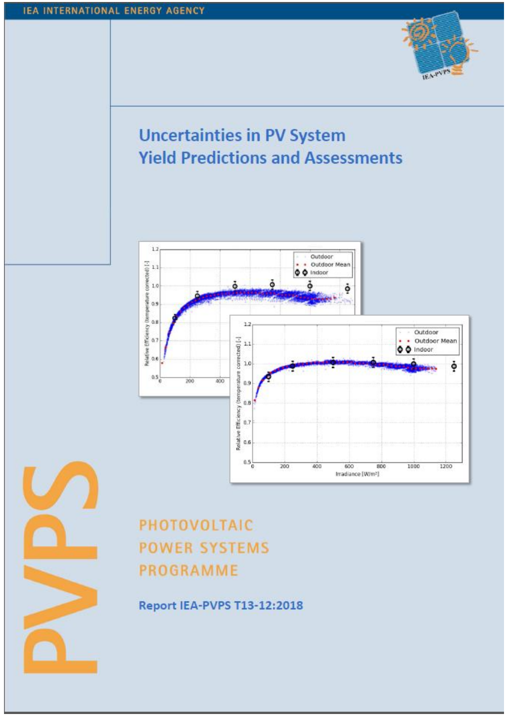


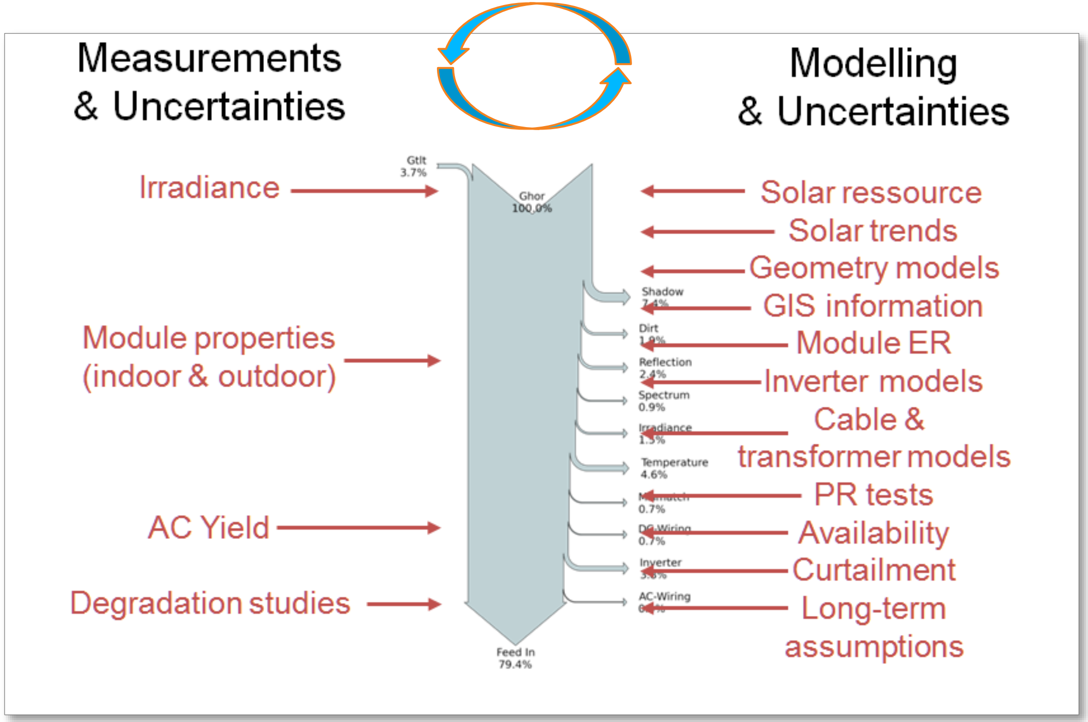
Yield Assessments and Performance Loss Rates of PV Power Systems

David Moser, Eurac Research

WCPEC, 26th September 2022

Report IEA-PVPS T13-12:2018





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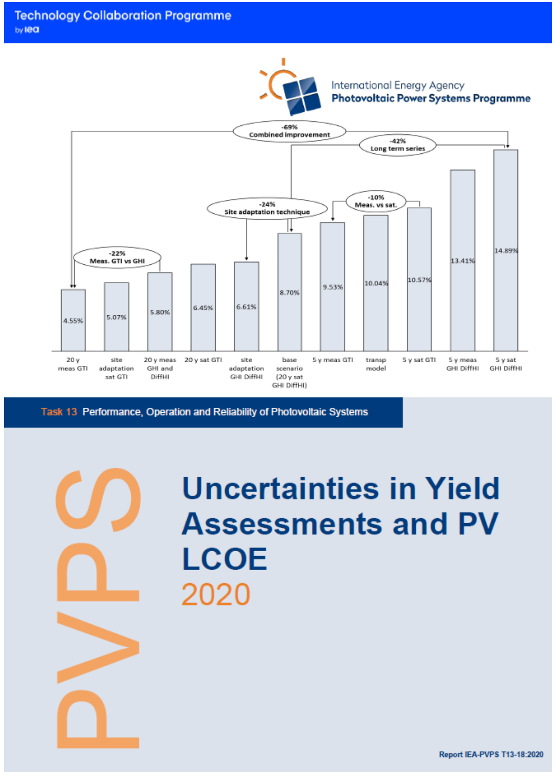
Calculation of uncertainty and framework for uncertainties in YA

Report IEA-PVPS T13-18:2020



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Benchmark and impact on LCOE and business models

Typical uncertainty in YA

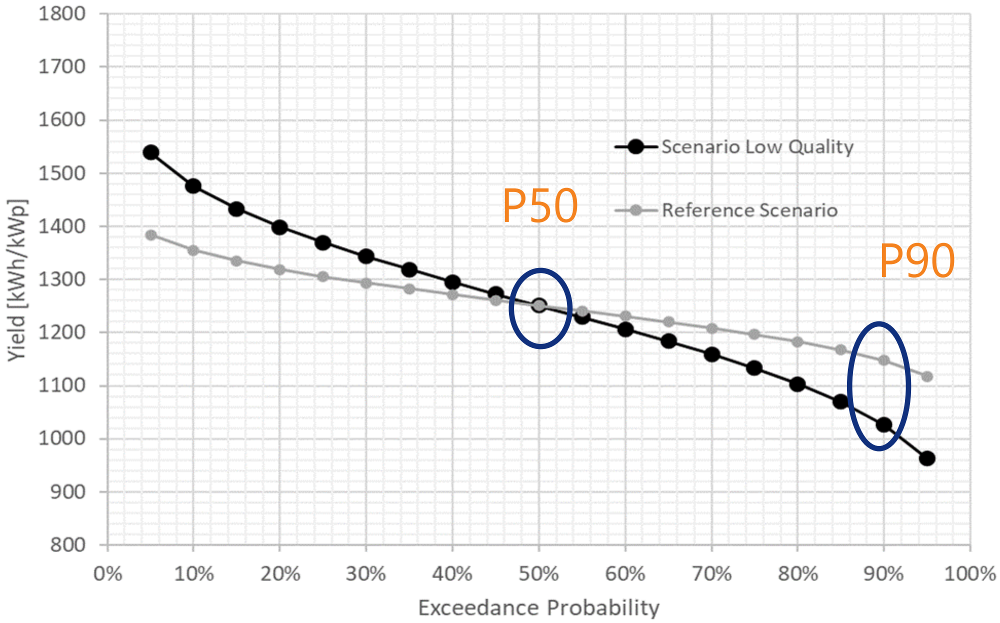
Annual values	uncertainty	value	gains/loss	PR
	%	kWh/m²	%	%
global irradiation on horizontal plane	4.0	1248		
irradiation on module plane	2.5	1448	16.0	
shading				
horizon shading	0.5	1445	-0.2	100.0
row shading	2.0	1422	-1.7	98.3
object shading	3.0	1422	0.0	98.3
soiling	0.5	1414	-0.5	97.9
deviations from STC				
reflection losses	0.5	1376	-2.7	95.2
	%	kWh/kWp	%	%
spectral losses	0.5	1363	-1.0	94.3
irradiation-dependent losses	0.8	1342	-1.5	92.9
temperature-dependent losses	1.0	1309	-2.5	90.5
mismatch losses	0.5	1298	-0.8	89.8
DC cable losses	0.5	1287	-0.8	89.1
inverter losses	1.5	1272	-1.2	88.0
inverter power limitation	0.5	1272	-0.1	88.0
additional consumption	0.5	1270	-0.1	87.9
AC cable losses low voltage	0.5	1265	-0.4	87.5
Transformer medium voltage	0.5	1253	-0.9	86.7
AC cable losses medium voltage	0.5	1252	-0.1	86.6
Transformer high voltage	0.0	1252	0.0	86.6
total	**6.5**	**1252**		**86.6**

Best practice

Typical uncertainty values (irradiance, temperature, soiling, shading, etc): ±5-10% [1]

[1] D. Moser *et al.*, “Technical Risks in PV Projects.” Solar Bankability Deliverable www.solarbankability.com

Yield and Exceedance Probability



- Utilisation rate @P90 positively affected by reduction in uncertainty
- P50 values will highly depend on the choice of the insolation database
- Wrong assumptions can lead to under/overestimation of yield by >20%

Are YA reliable?

Link with business models and LCOE calculation

Typical uncertainty values on YA (irradiance, temperature, soiling, shading, etc): ±5-10%

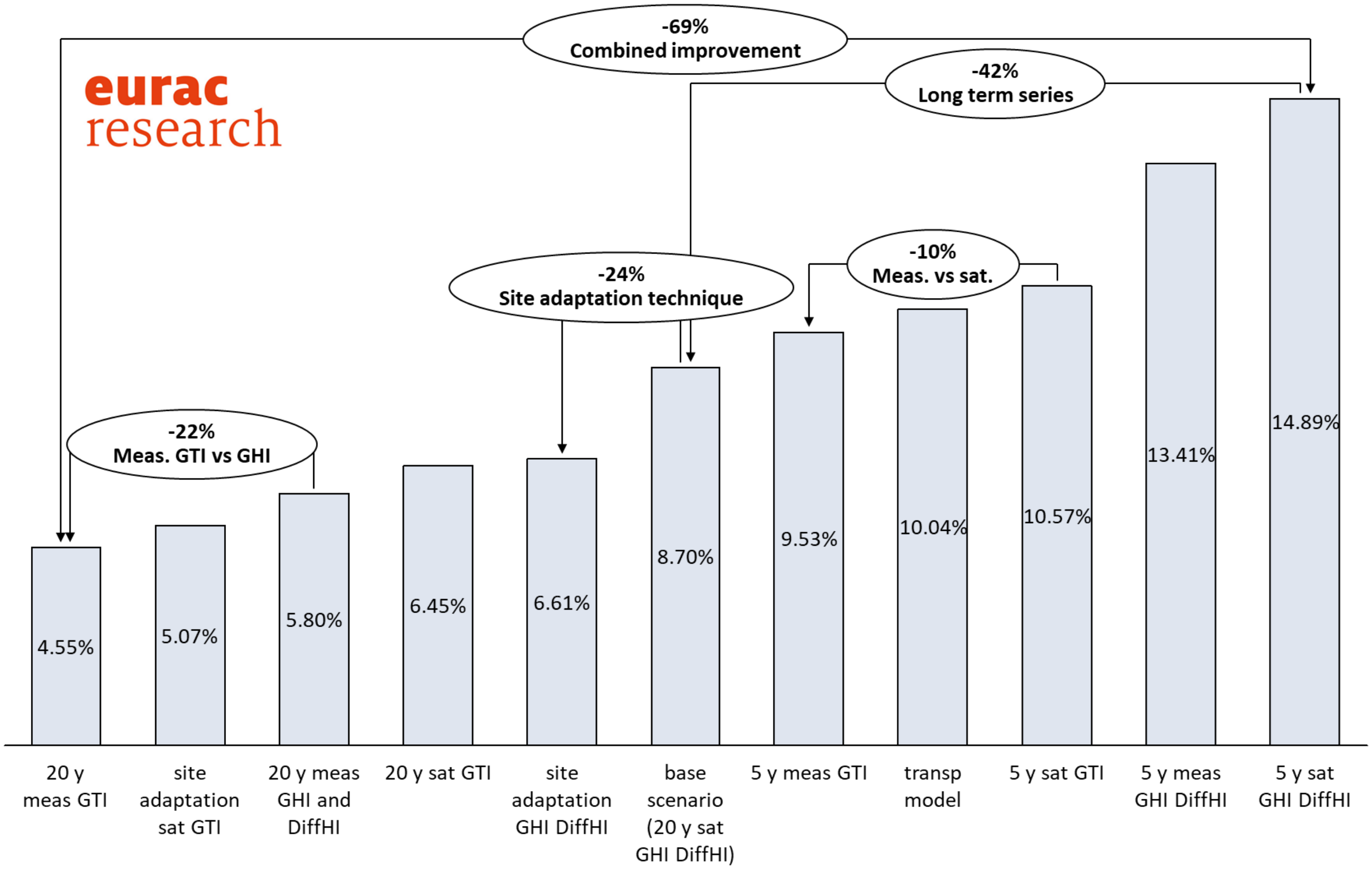
N. Reich, J. Zenke, B. Muller, K. Kiefer, and B. Farnung, “On-site performance verification to reduce yield prediction uncertainties,” in *Photovoltaic Specialist Conference (PVSC), 2015 IEEE 42nd*, 2015, pp. 1–6.

M. Richter, T. Schmidt, J. Kalisch, A. Woyte, K. de Brabandere, and Lorenz, E, “Uncertainties in PV Modelling and Monitoring,” *31st European Photovoltaic Solar Energy Conference and Exhibition*, pp. 1683–1691, Nov. 2015.

D. Moser *et al.*, “Technical Risks in PV Projects.” Solar Bankability Deliverable www.solarbankability.com

D Moser, M Del Buono, U Jahn, M Herz, M Richter, K De Brabandere, Identification of technical risks in the photovoltaic value chain and quantification of the economic impact, Progress in Photovoltaics: Research and Applications 25 (7), 592-604, 2017

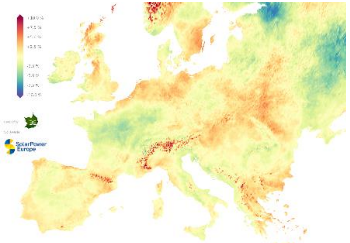
Uncertainty scenarios

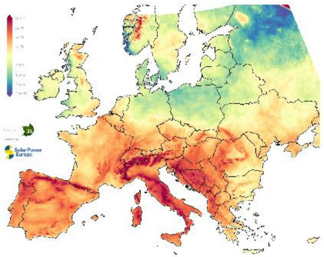


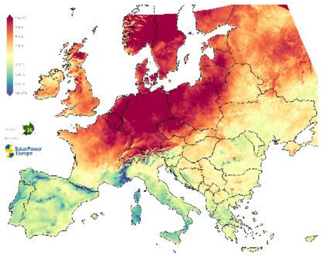
Annual insolation variability

1.1%/y 0.7%/y 0.3%/y

2016 2017 2018

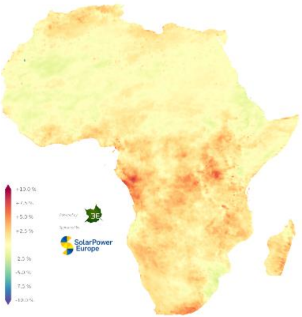


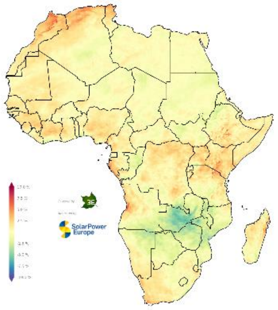


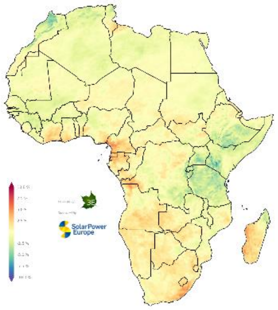


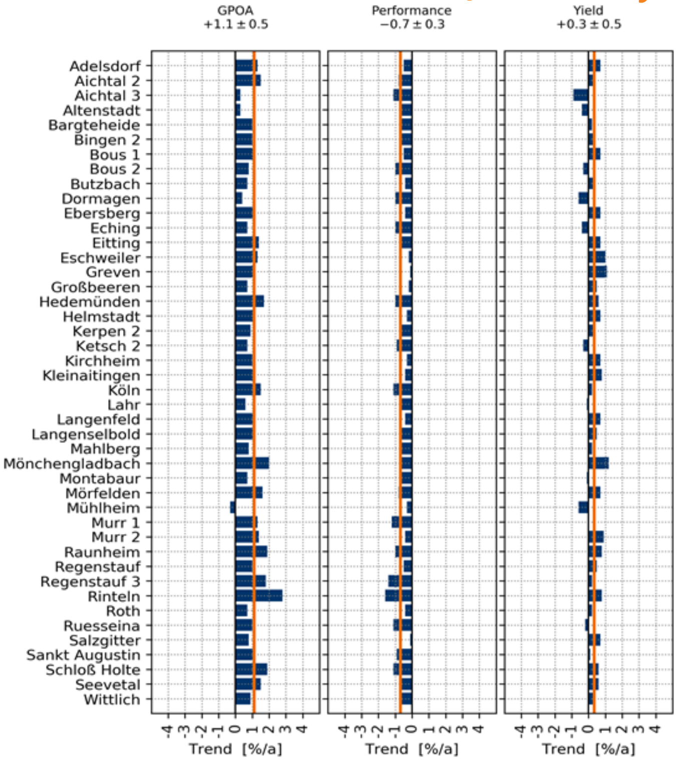
Colour code: variation compared to long term P50

2016 2017 2018









Trends for in-plane-irradiance (G_{POA} = GTI, left), Performance Loss Rate (Performance, middle) and annual energy yield (Yield, right)

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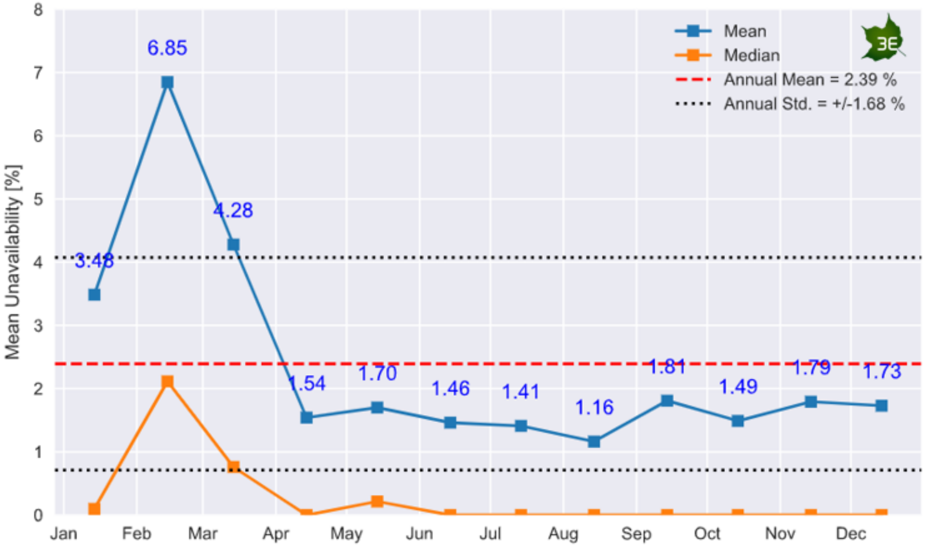
source: https://solardata.3e.eu/maps/solarindex

Unavailability



- High unavailability with harsher weather conditions (snow, winds, etc.) during the European winter.

- Unavailability has decreased over time, possibly based on improved O&M protocols

Statistical indicators of mean monthly unavailability of 533 PV plants in 2019 (majority installed in Belgium, Germany and Switzerland)

Site Selection

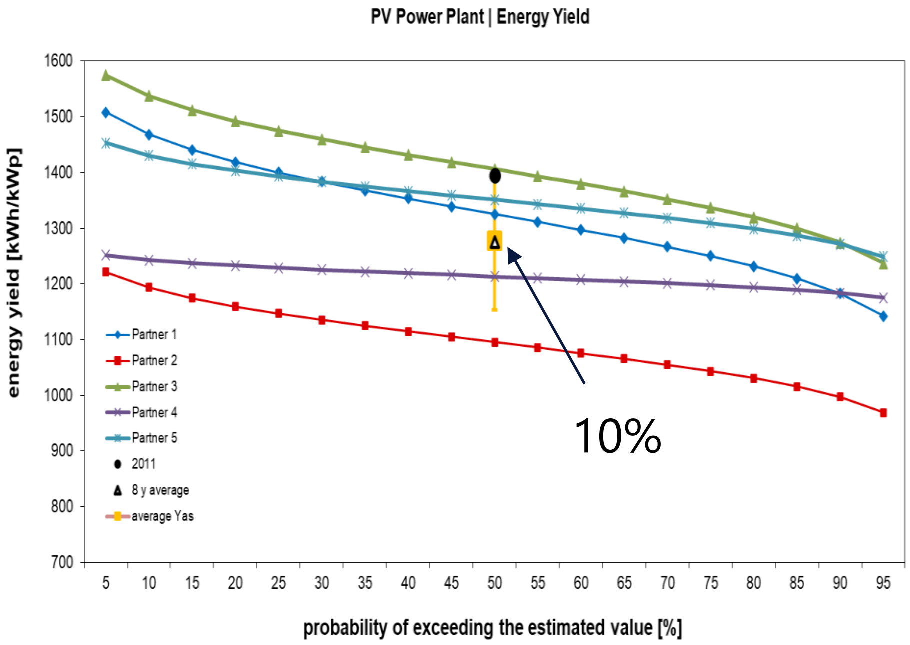
Location: Bolzano, Italy
Data available since August 2010
Technology: polycrystalline-Si

Location: Alice Springs, Australia
Data available since 2009
Technology: 3 crystalline technologies

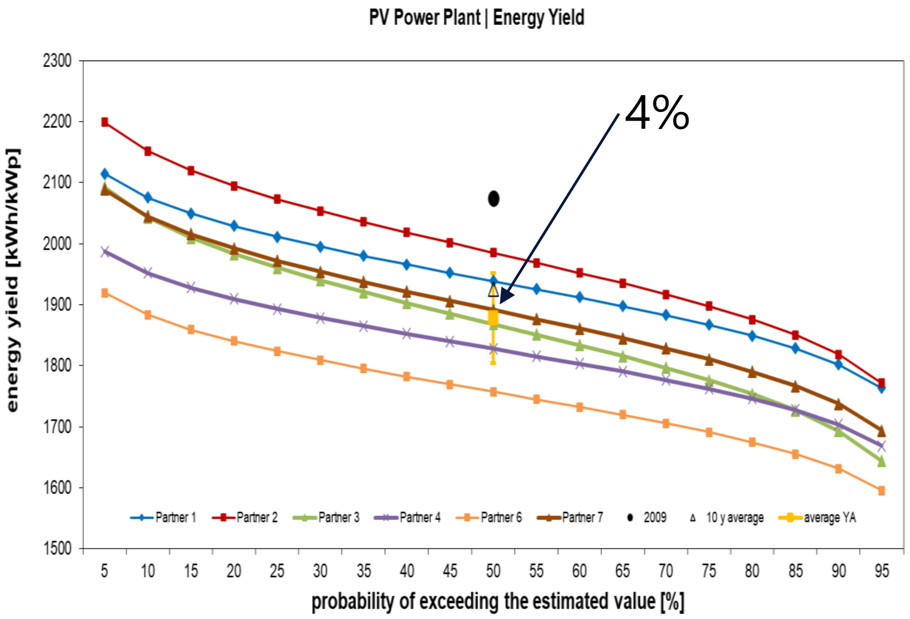
PV

Comparison of initial YAs

Bolzano



Alice Springs



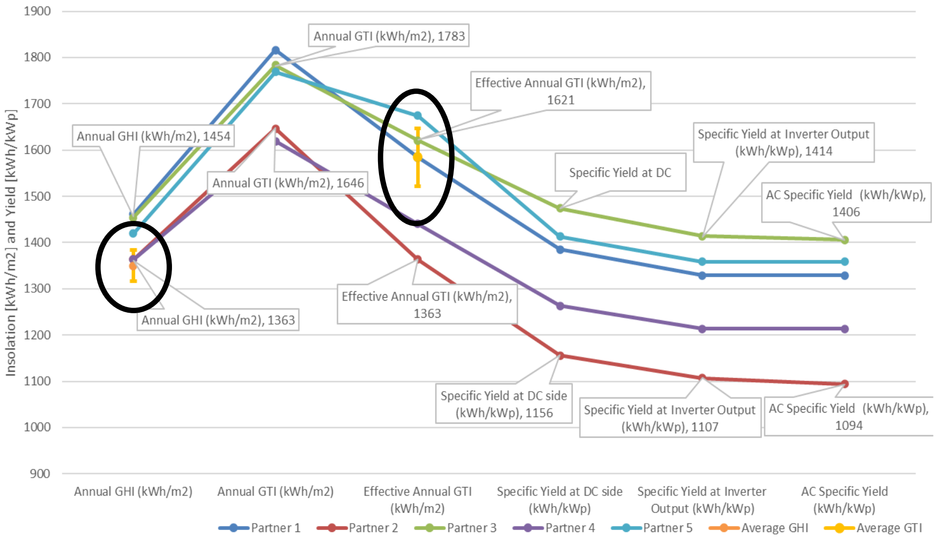
Large spread of values

Real values within the P10-P90 range only for some YAs

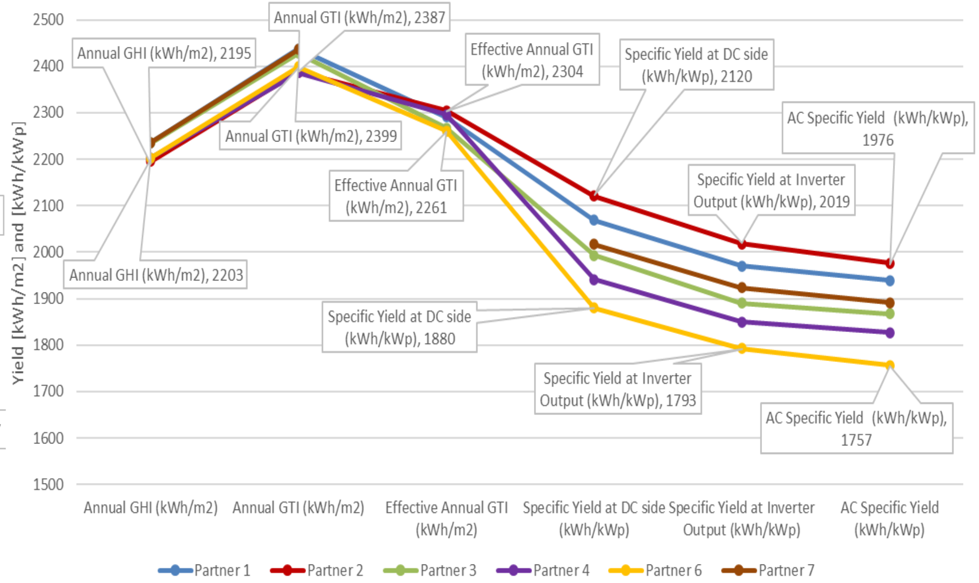
Averaging YAs might not be a good strategy!

Comparison of initial YAs

Bolzano



Alice Springs



Problems with insolation database

Far shading

Problems along the modelling steps

	TMY 2007-2016	TMY 2005	2000-2009	1994-2006	year 2011
	Partner 1	**Partner 2**	**Partner 3**	**Partner 4**	**Partner 5**
Horizon Shading Loss (%)	-9.0%	-9.7%	-5.7%	-7.7%	-5.4%

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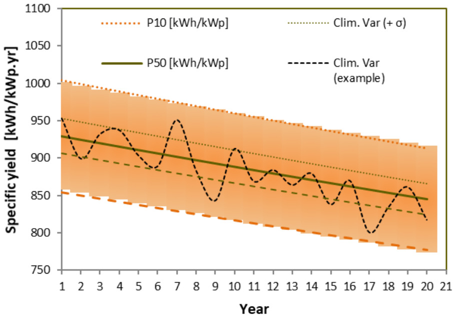
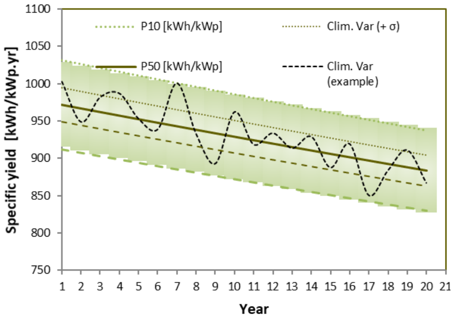
Site adaptation

Uncorrected satellite-based irradiation		After site adaption application
		
GTI unc. (σ_{irr})	±5.0%	±3.0%
Clim. Variability (σ_{clim})	±2.5%	±2.5%
PV modelling unc. (σ_{mod})	±2.0%	±2.0%
Total uncertainty (σ_{total})	±6.3%	±4.8%
GTI P50:	1100 kWh/m^2	1150 kWh/m^2
Specific yield–yr1 (P50):	930 kWh/kWp	972 kWh/kWp
Specific yield–yr1 (P90):	855 kWh/kWp	913 kWh/kWp
P90/P50 (lifetime yield):	7.4%	5.2%

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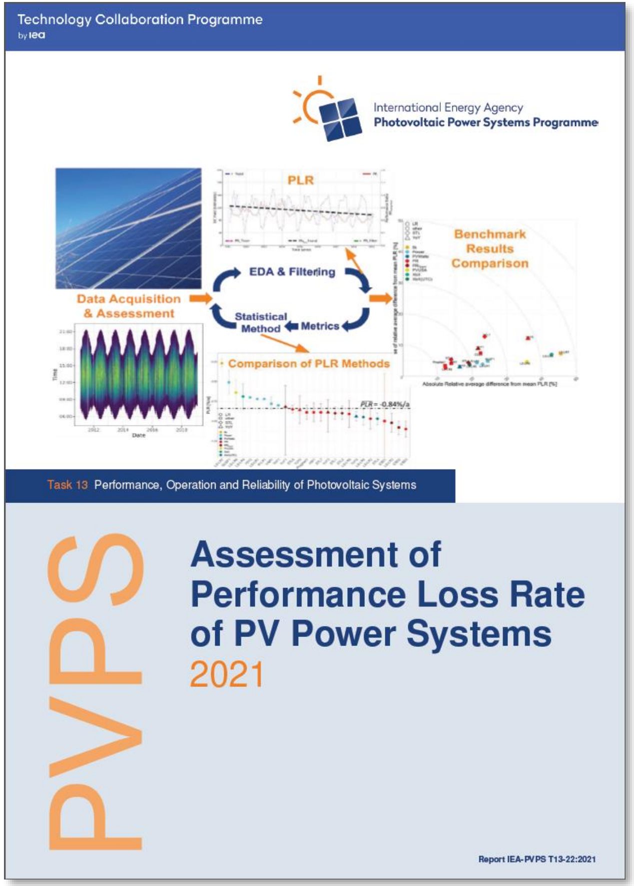
Report IEA-PVPS T13-22:2021



- Definition performance loss rates
- Critical review of existing calculation methodologies
- Best practice guidelines
- Development of data quality grading scheme

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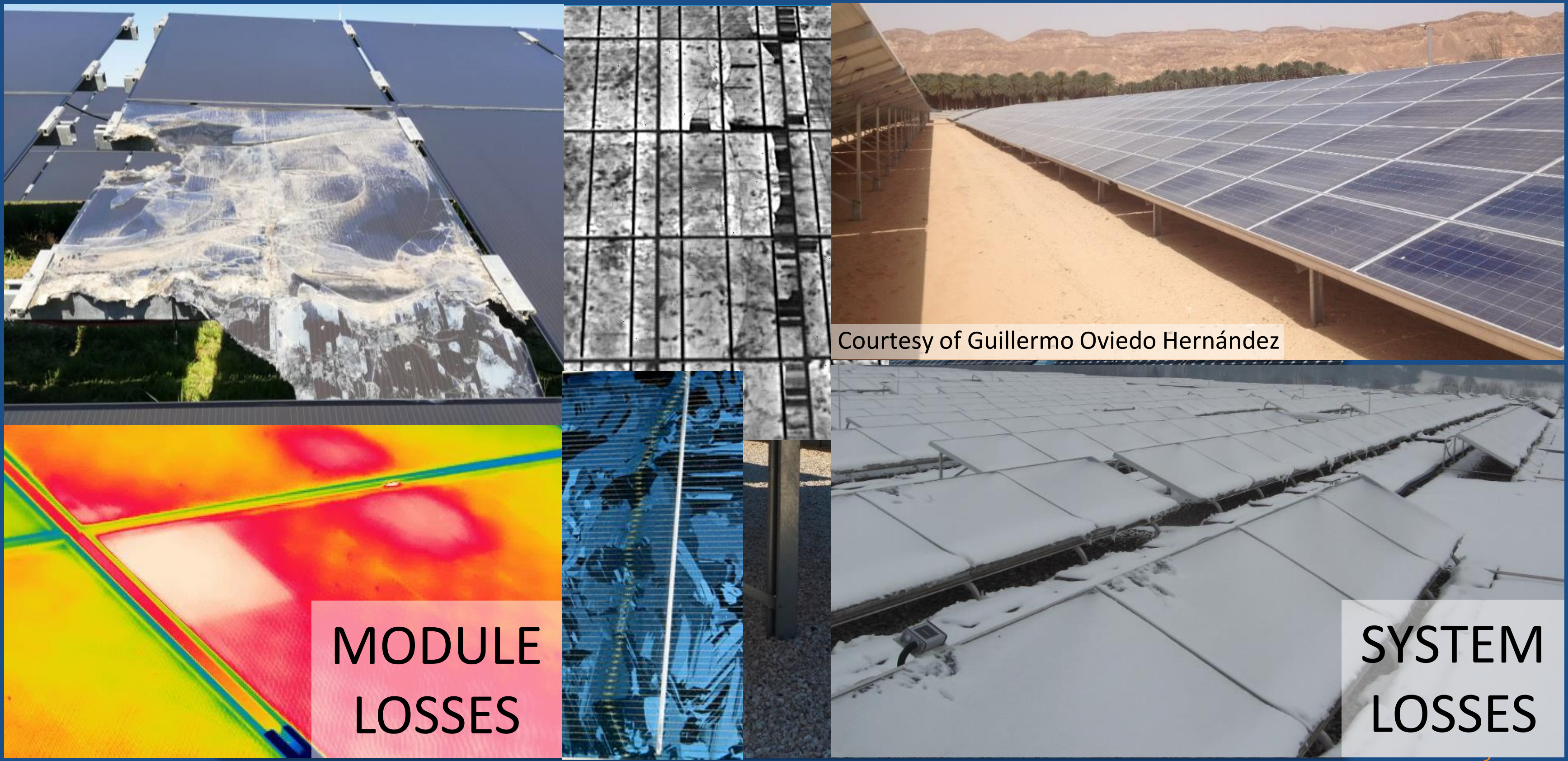
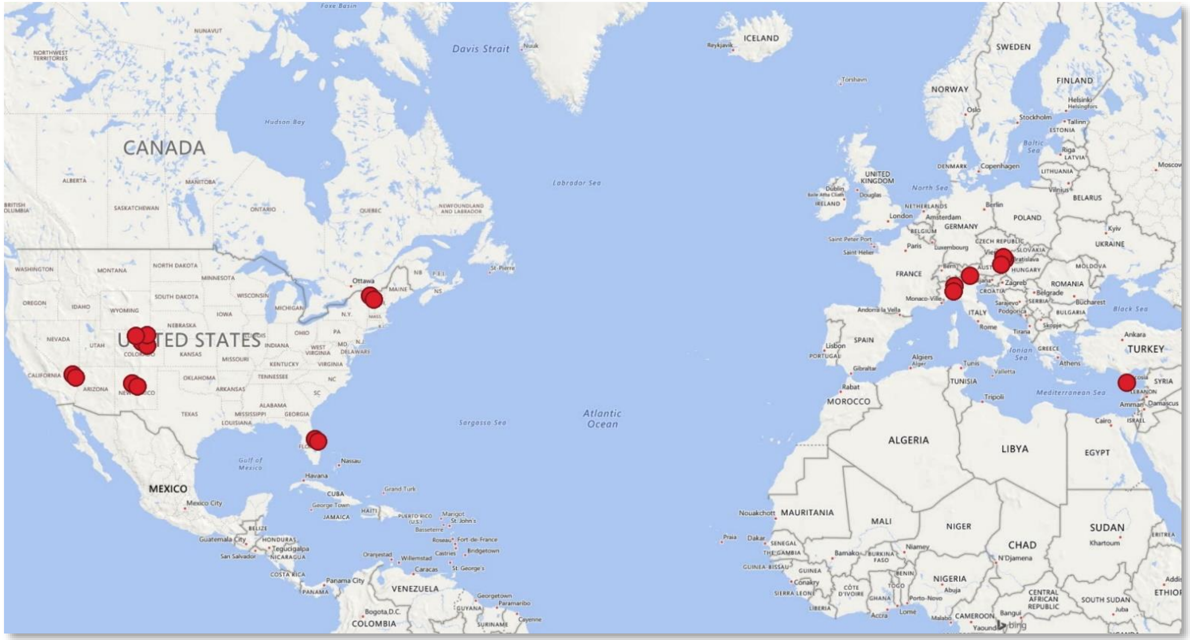
Motivation


Courtesy of Guillermo Oviedo Hernández
MODULE LOSSES
SYSTEM LOSSES

Methodology comparison



Data analysis / quality

Data cleaning / filtering

Performance metric selection

Timeseries features correction

PLR results

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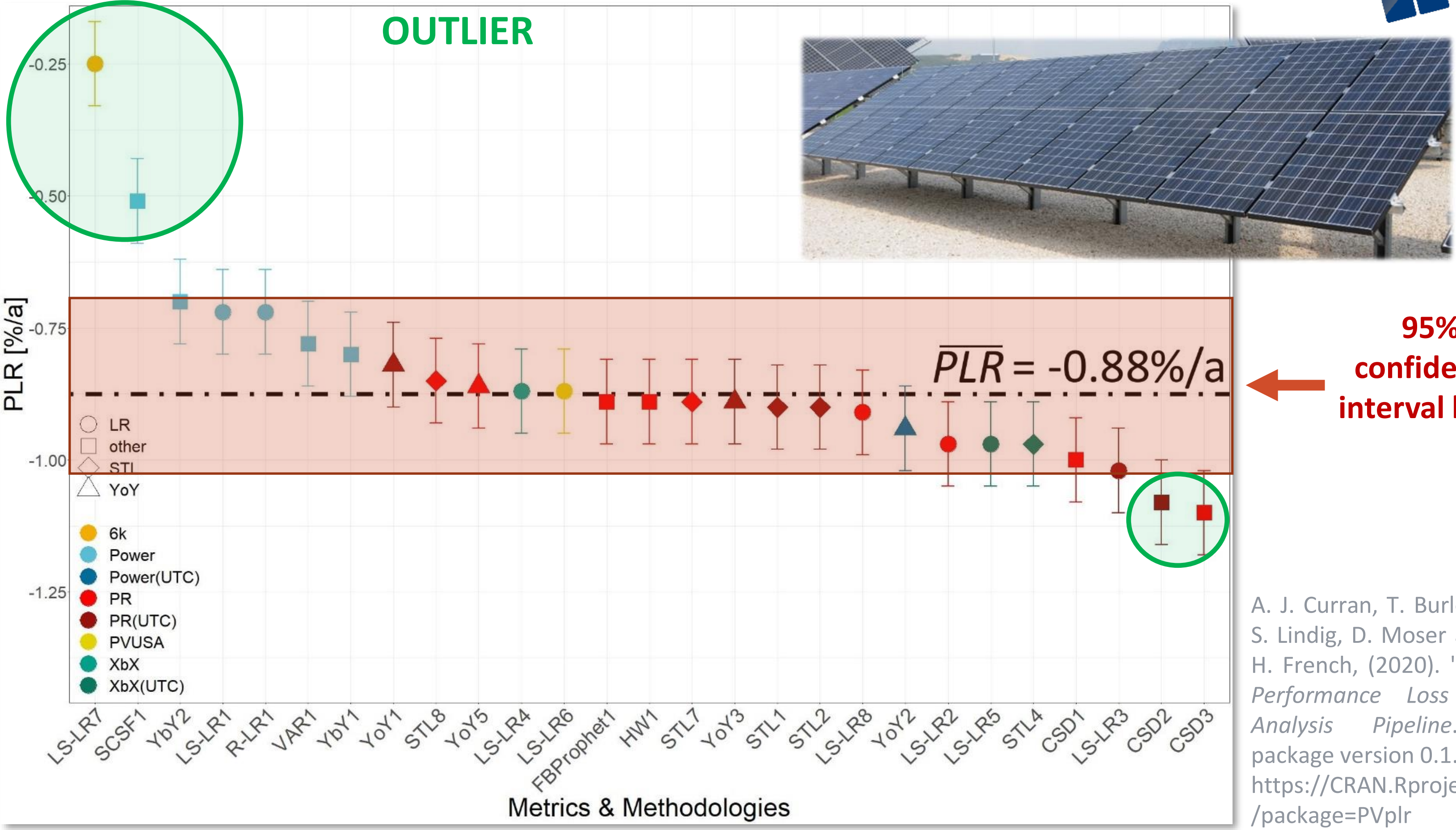
S. Lindig, A. Curran, K. Rath, et al., "*IEA PVPS Task 13-ST2.5: PLR Determination Benchmark Study,*" Case Western Reserve University, 30-Aug-2020 [Online]. Available: https://osf.io/vtr2s/.

Methodology comparison



95% confidence interval band

A. J. Curran, T. Burleyson, S. Lindig, D. Moser and R. H. French, (2020). "*PVplr: Performance Loss Rate Analysis Pipeline.*" R package version 0.1.0. https://CRAN.Rproject.org/package=PVplr

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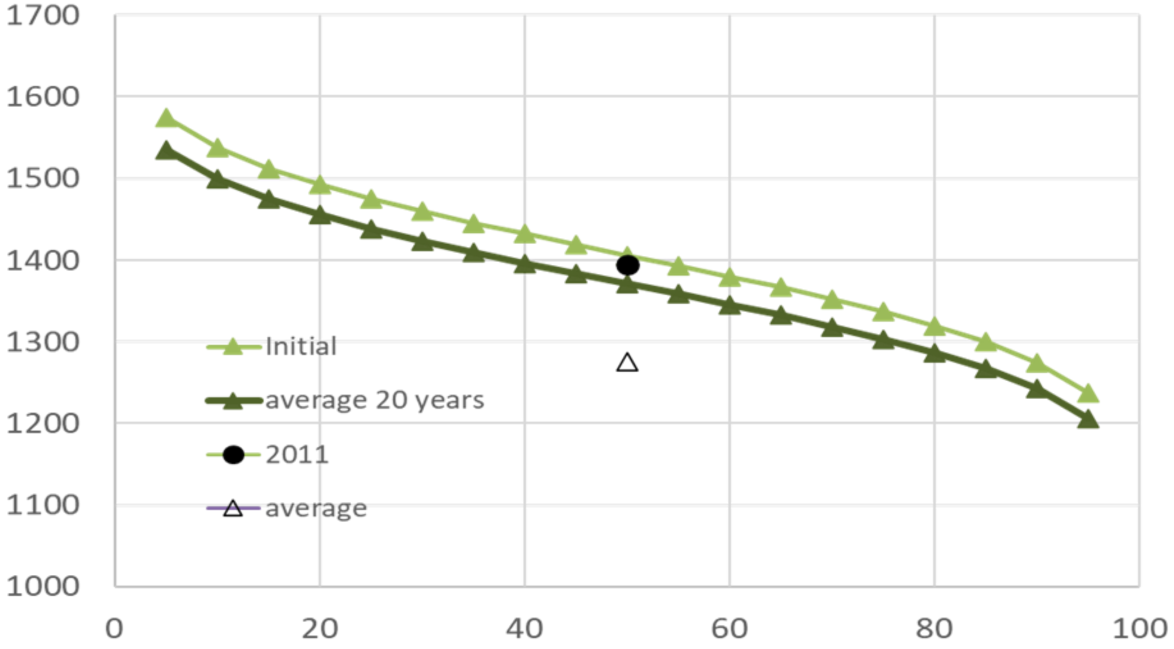
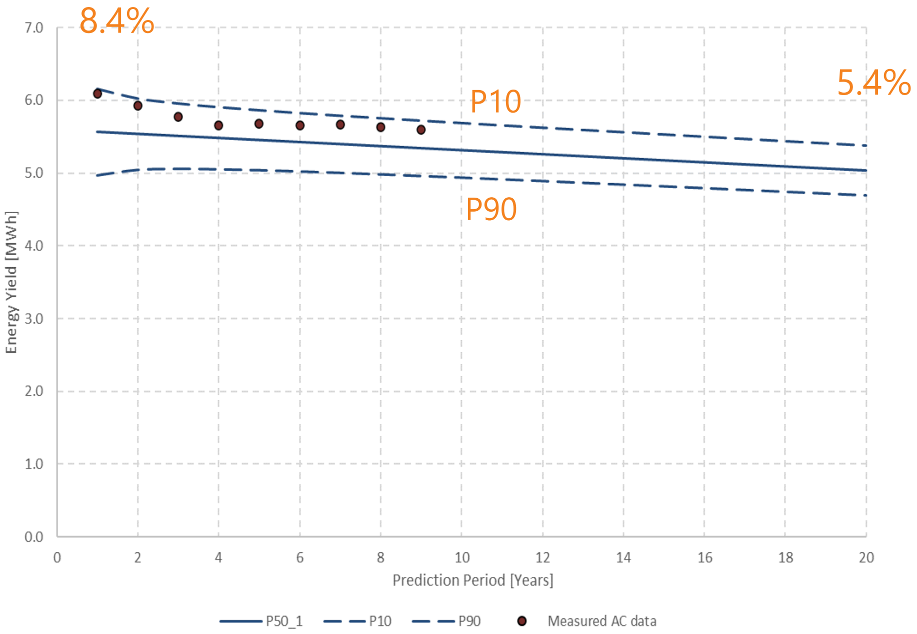
Initial YA and average yield



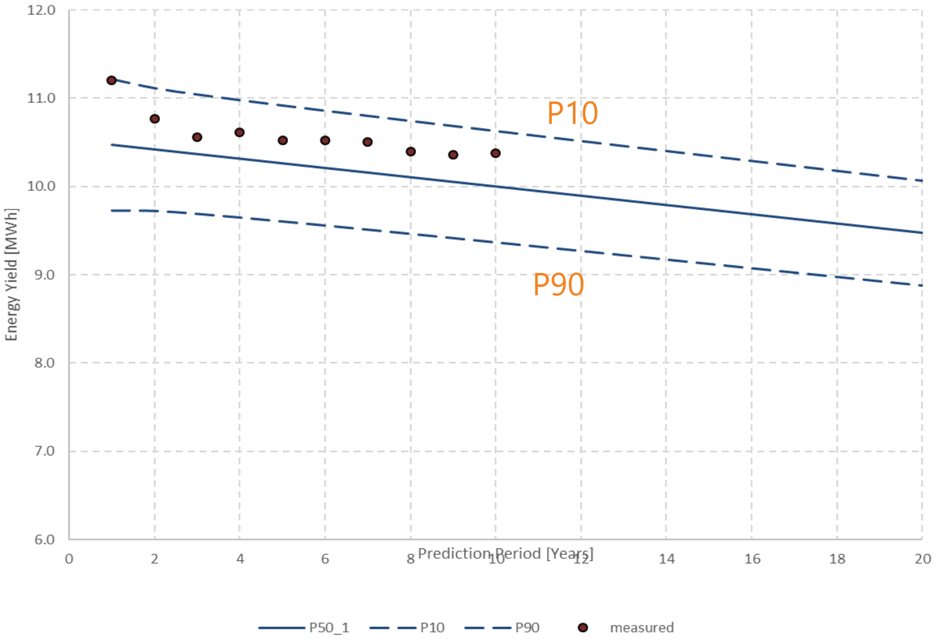
The use of PV module degradation (-0.25%/y) instead of typical Performance Loss Rates (PLR) can underestimate the losses over time (PLR = -0.88%/y)

Comparison of LTYPs

Bolzano



Alice Springs



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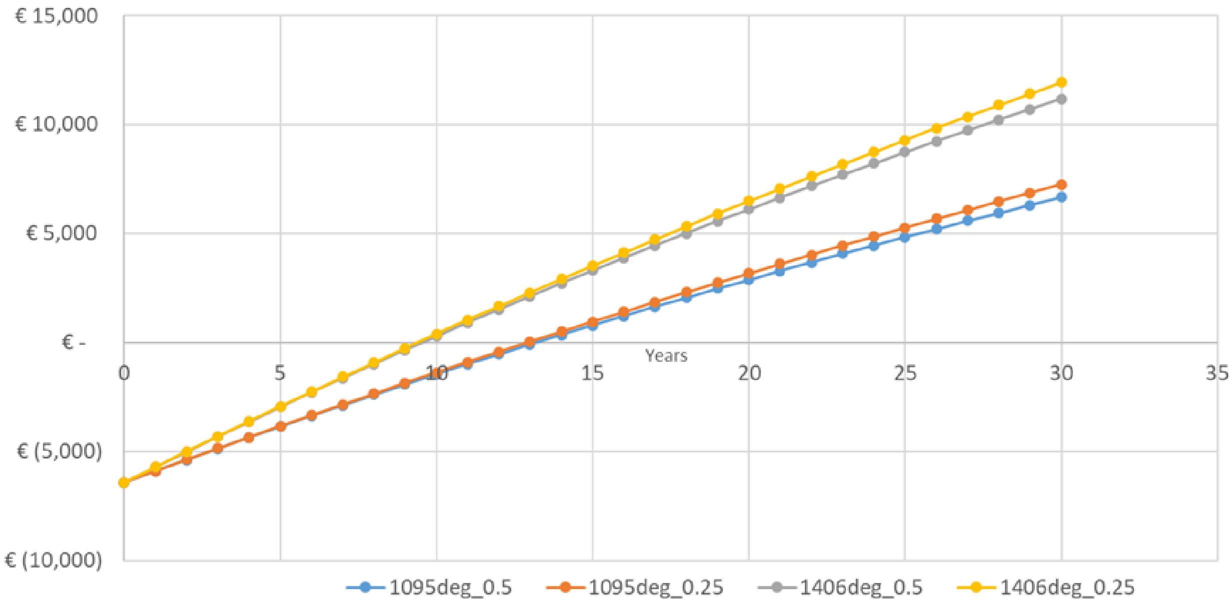
Measured values are averaged (rolling average)

Economic impact on business model and LCOE

NET BILLING

Scenario 1) P50 = 1095 kWh/m^2, 1a) PLR = 0.25 %/y, 1b) PLR = 0.5 %/y

Scenario 2) P50 = 1406 kWh/m^2, 2a) PLR = 0.25 %/y, 2b) PLR = 0.5 %/y



€/kWh	Scenario 1a	Scenario 1b	Scenario 2a	Scenario 2b
LCOE 20 years	0.102	0.099	0.079	0.077
LCOE 30 years	0.080	0.078	0.063	0.060

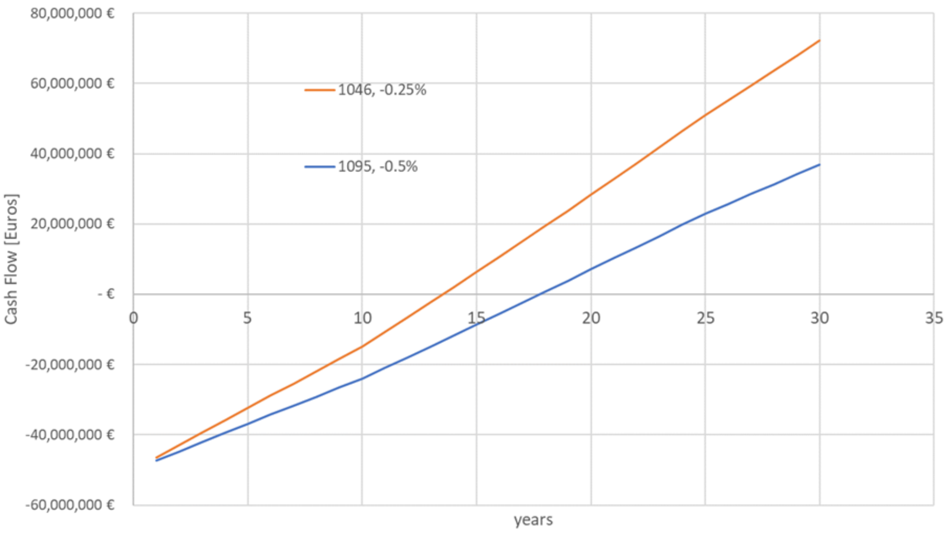
Economic impact on business model and LCOE

PPA

Scenario 1) P50 = 1095 kWh/m², 1a) PLR = 0.25 %/y, 1b) PLR = 0.5 %/y

Scenario 2) P50 = 1406 kWh/m², 2a) PLR = 0.25 %/y, 2b) PLR = 0.5 %/y

		1095 / -0.5%	1406 / -0.25%
Free cashflow (EBIDTA) IRR by CAPEX	[%]	4.7%	7.9%
Unleveraged IRR after tax and depreciation by CAPEX	[%]	3.9%	6.6%
LCOE in total	[EUR/MWh]	36.9	27.9



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BEST PRACTICE AND GUIDELINES

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Possible issue:	Best practice
Estimation of correct site insolation	Check various sources of satellite data Ask satellite data provider for validated data with ground measurements Apply site adaptation
Long-term trend	Check the trend over different time-periods (.e.g 2011-2020, 2001-2010)
Transposition of GHI to GTI	Check in the literature which is the best combination of decomposition and transposition models for the specific climate Check for consistency in the % contribution by using various irradiance sources
Parameterization of components (PV Modules, Inverters)	Check reliability of provided files, ask manufacturer for qualified data (e.g. independent PAN Files)
Shading	In case of far shading check the sensitivity of the yield on different hourly profiles
Soiling	In case of measurements, evaluate non-uniformity over the selected site
Temperature effects	Check various sources of satellite data Ask satellite data provider for validated data with ground measurements
Performance Loss Rates	Make sure that one includes not only module degradation and that also unavailability and reversible failures are considered
Calculation of uncertainty	Use semi-empirical calculation methods if long-term data is available and distribution deviates from normal (gaussian)
O&M costs in business models	Based the assumptions on real cost data and not on a % of CAPEX

Uncertainties in Yield Assessments and PV LCOE

- We moved forward from the uncertainty framework to real implementations of it and the impact that uncertainties can have on lifetime yield predictions, on the LCOE and on the cash flow.
- The most important parameter influencing the energy yield assessment is the site-specific irradiation.
- YA is not only about the software used, it is mainly about the user (personal experience, assumptions).
- Seven highly skilled specialists did not arrive at the same result in the two benchmarking exercises
- From an industry perspective, it would be beneficial if more “live” post-mortem analyses (i.e. comparison of the LTYP and measured data, every 5 years of system life) would be made and published.

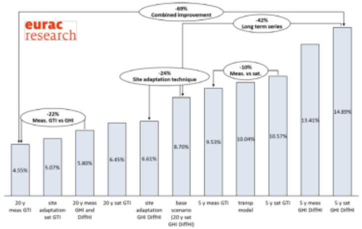


Figure 16: Reduction of uncertainty

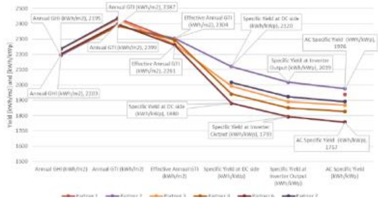


Figure 22: YA comparison

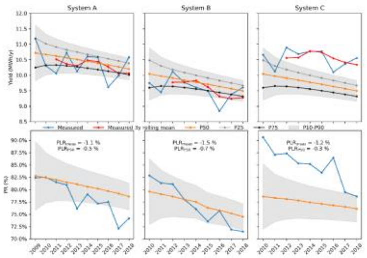
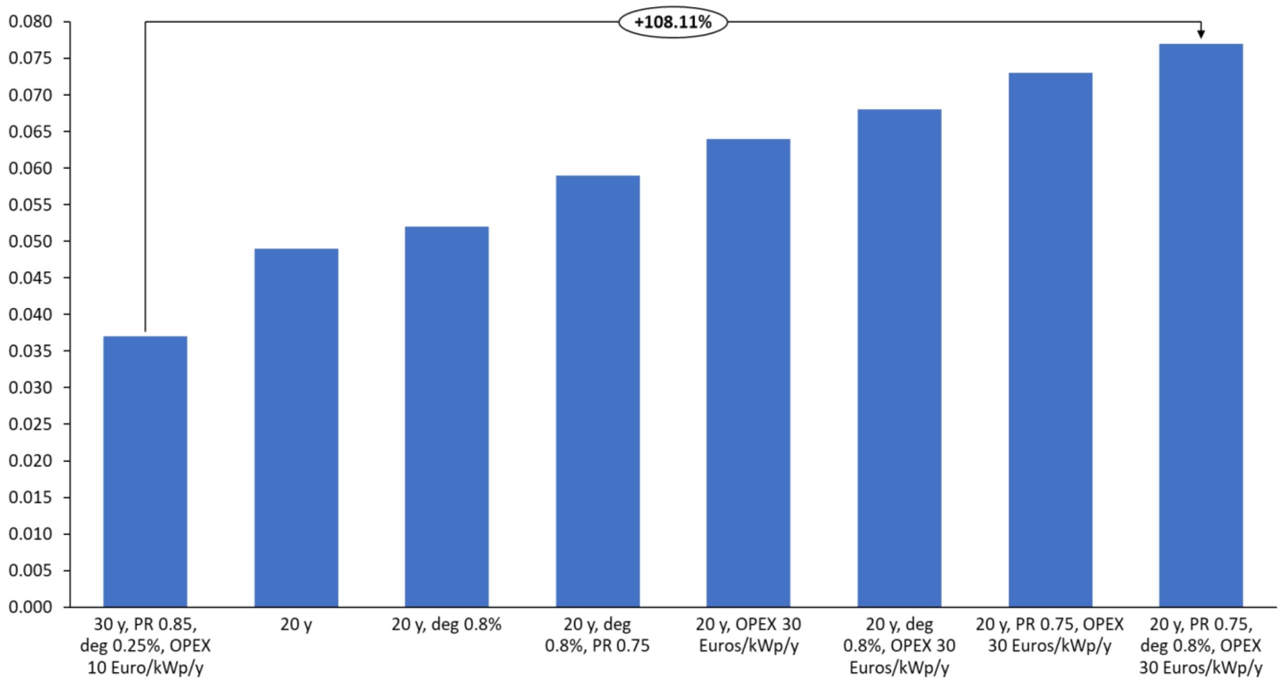


Figure 26: Post-mortem analysis

Next phase: Impact of decisions



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Thank you for your attention

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