P E A R L P V

Economic Aspects of PV system modelling

Training School: Simulation tools and models for the analysis of PV system performance, 9 July 2021

David Moser

david.moser@eurac.edu

Institute for Renewable Energy,

Eurac Research, Bolzano, Italy

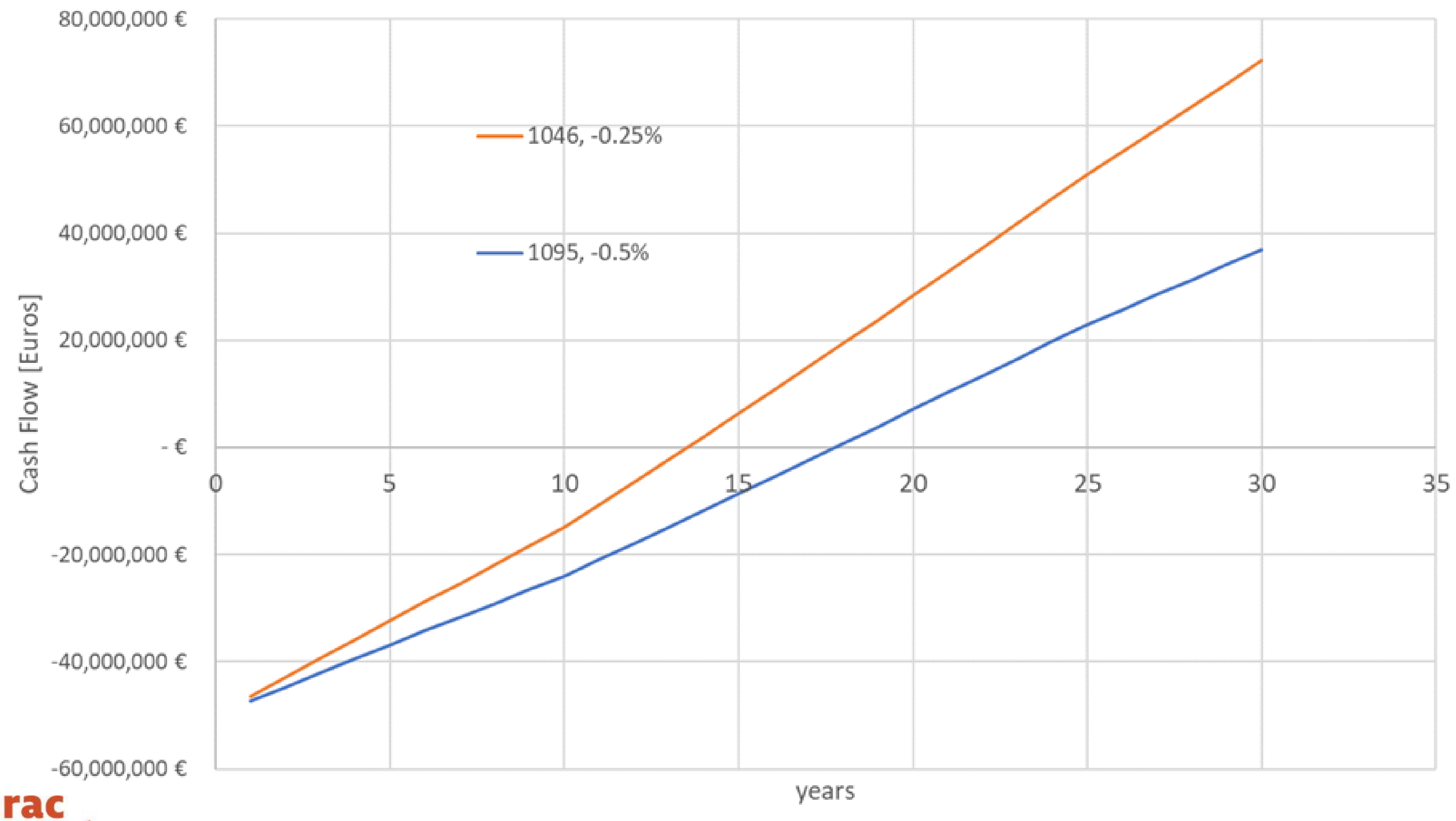
eurac research

What are we going to discuss today?

How to we calculate PV electricity generation?

The impact of poor choices in yield assessments

Can we quantify quality?

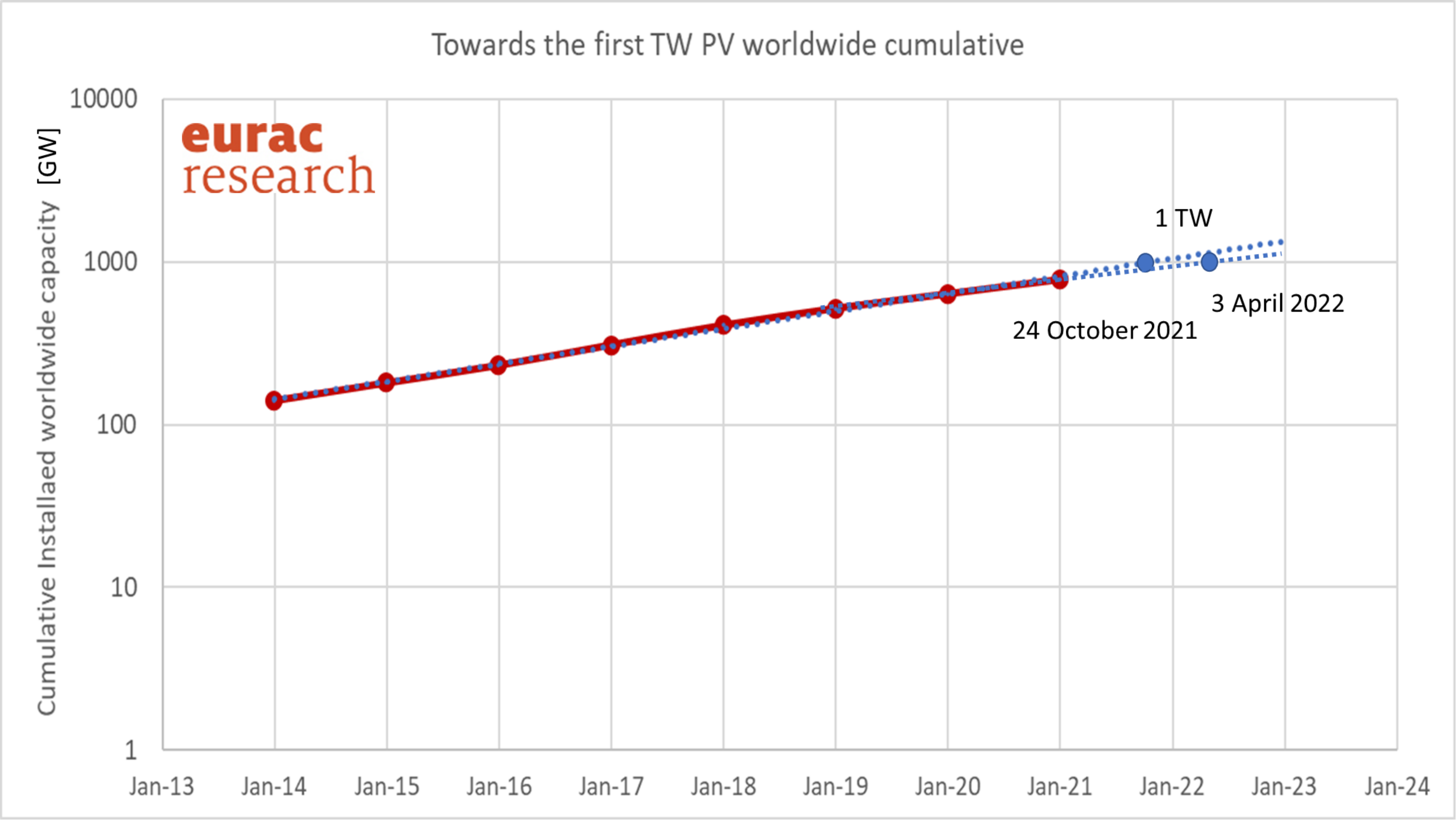


The economic impact of failures in the field

Can PV deliver for its lifetime?

Are there any best practice?

Entering the TW era (and the 1000 TWh….)



1 TW

Ensure reliable generation of PV electricity!

eurac research

Cost of PV electricity generation

What is the dominant factor in the cost of a PV system?

Should we focus on costs or efficiency?

How do I calculate it??

Is PV electricity competitive?

Cost of PV electricity generation

$$LCOE = \frac{CAPEX + \sum_{t=1}^{n}[OPEX(t)/(1+WACC_{Nom})^t]}{\sum_{t=1}^{n}[Utilisation_0 \cdot (1 - Degradation)^t / (1+WACC_{Real})^t]}$$

What are the ingredients?

t = time (in years)
n = lifetime of the system (in years)
CAPEX = total investment expenditure of the system, made at t=0 (in €/kW_p)
OPEX(t) = operation and maintenance expenditure in year t (in €/kW_p)
$WACC_{Nom}$ = nominal weighted average cost of capital (per annum)
$WACC_{Real}$ = real weighted average cost of capital (per annum)
$Utilisation_0$ = initial annual utilisation in year 0 without degradation (in kWh/kW_p)
Degradation = annual degredation of the nominal power of the system (per annum)

$WACC_{Real}$ = (1 + $WACC_{Nom}$) / (1 + Inflation) - 1

Source: PV ETIP PV costs in Europe 2014-2030

eurac research

Cost of PV electricity generation

$WACC_{Nom}$ = weighted average cost of debt and cost of equity
Example:

- cost of debt 2%
- cost of equity 12%,
- Debt to equity ratio 70:30

- WACC would be [illegible]%.

WACC rates depend on the country, market segment, investor type and risk appetite/aversion, among other things.

Cost of PV electricity generation: now-2050

OPEX
8-10 Euros/kWp/y

LID
2%

PLR
0.5%

Lifetime
25 years

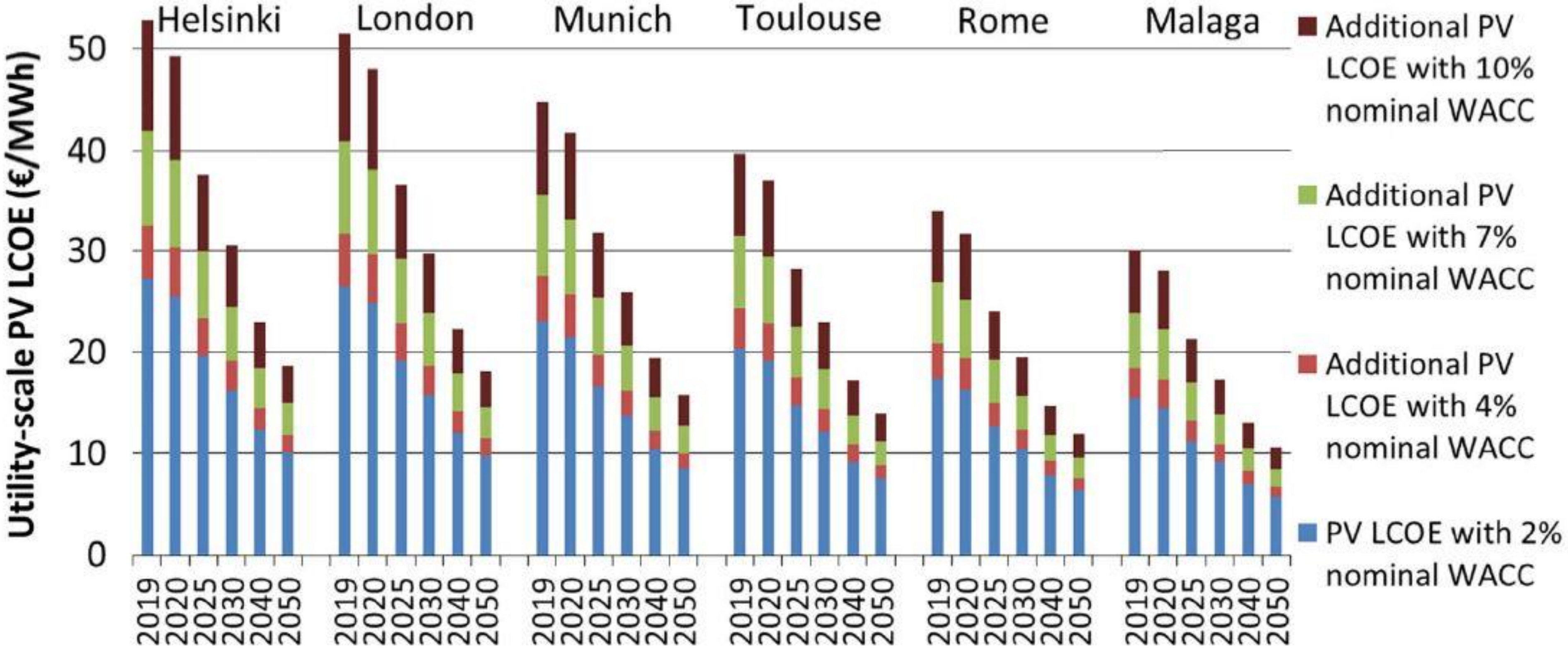


FIGURE 9 Photovoltaics (PV) levelised cost of electricity (LCOE) in six European locations for the years 2019 to 2050; in 2019 euros

Impact of weighted average cost of capital, capital expenditure, and other parameters on future utility-scale PV levelised cost of electricity, Eero Vartiainen, Gaëtan Masson, Christian Breyer, David Moser, Eduardo Román Medina, PIP 2019
https://doi.org/10.1002/pip.3189

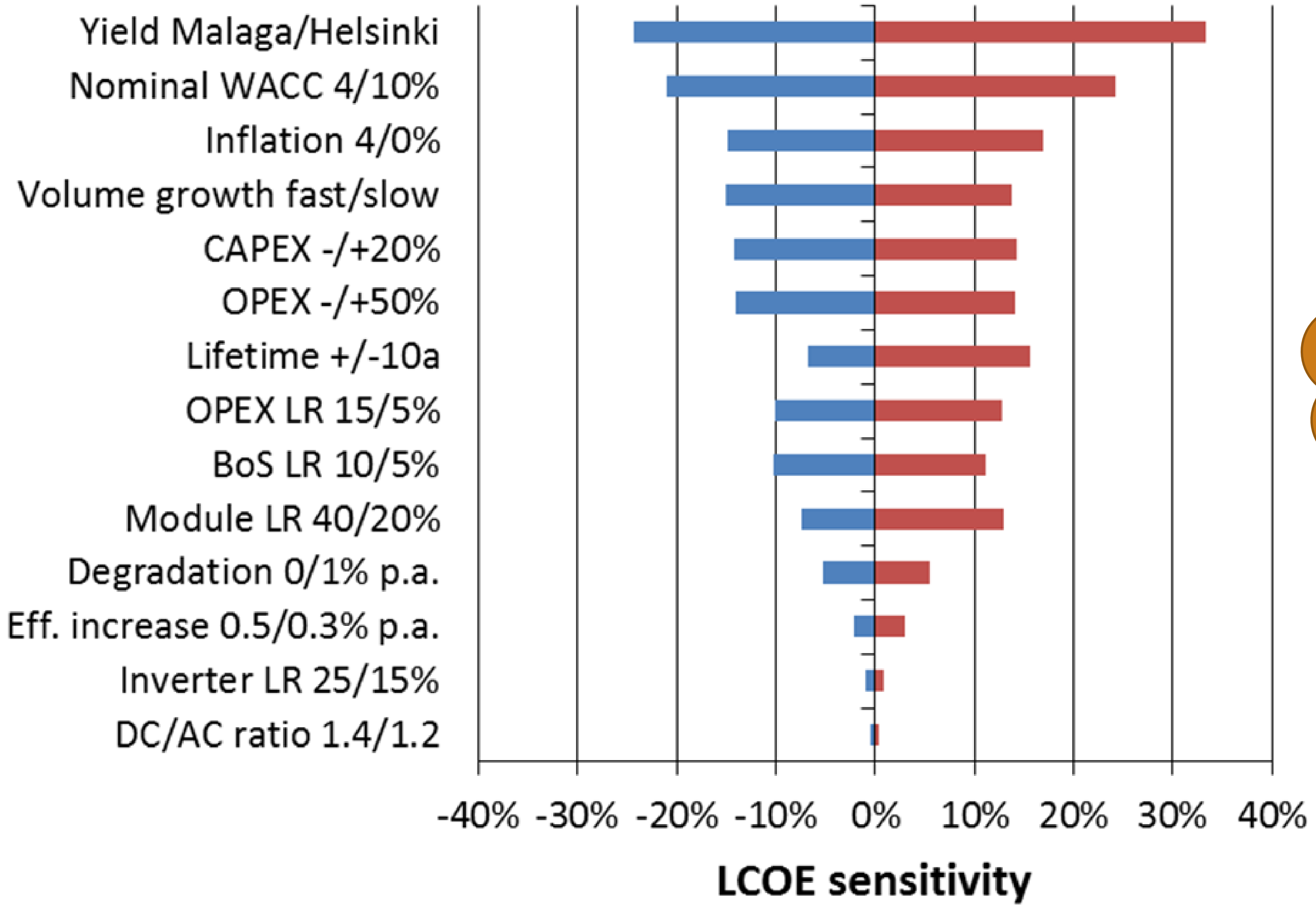
PhotoVoltaic
EUROPEAN TECHNOLOGY & INNOVATION PLATFORM

The Quest for Quality

Is quality important?

Is LCOE “killing“ some stakeholders?

Quantifying quality

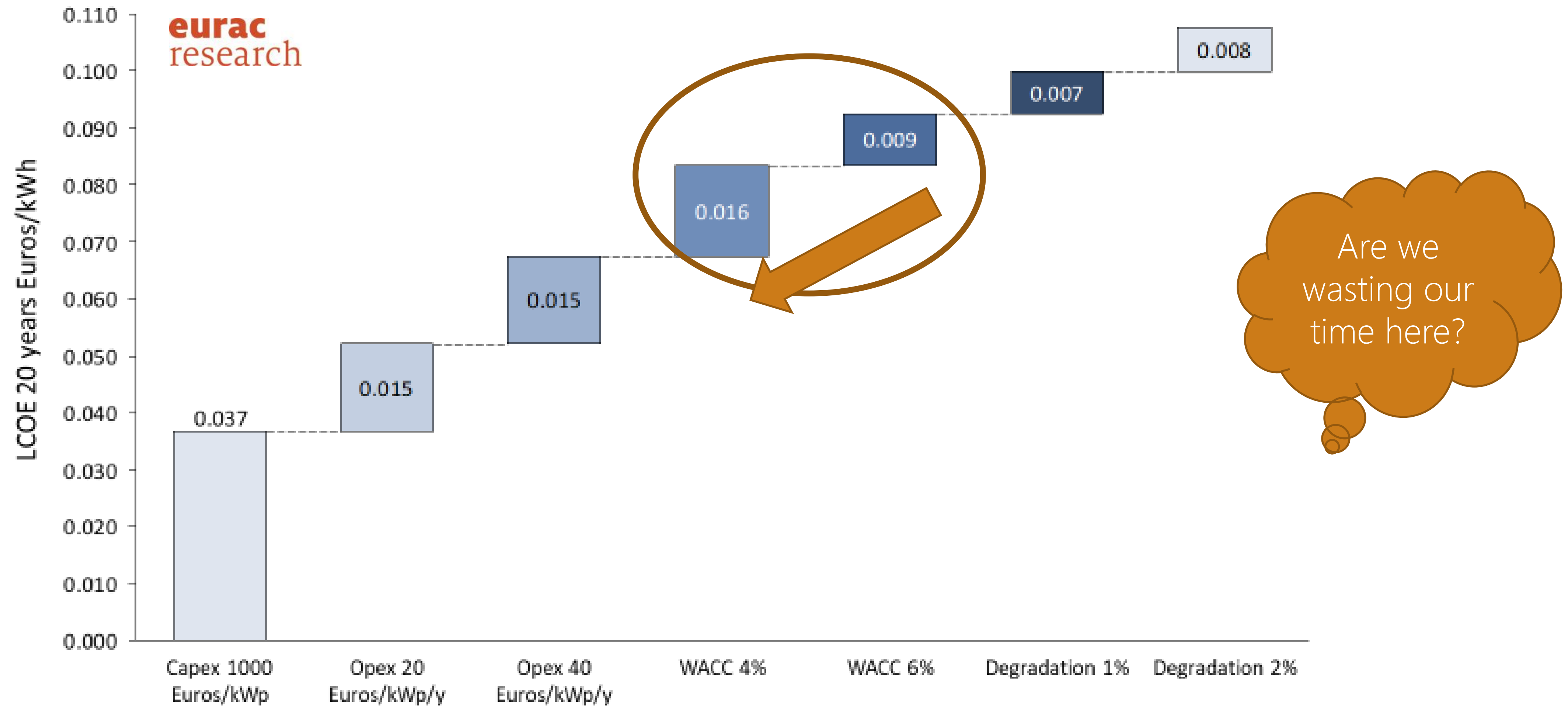


Which main parameter is derived from modelling?

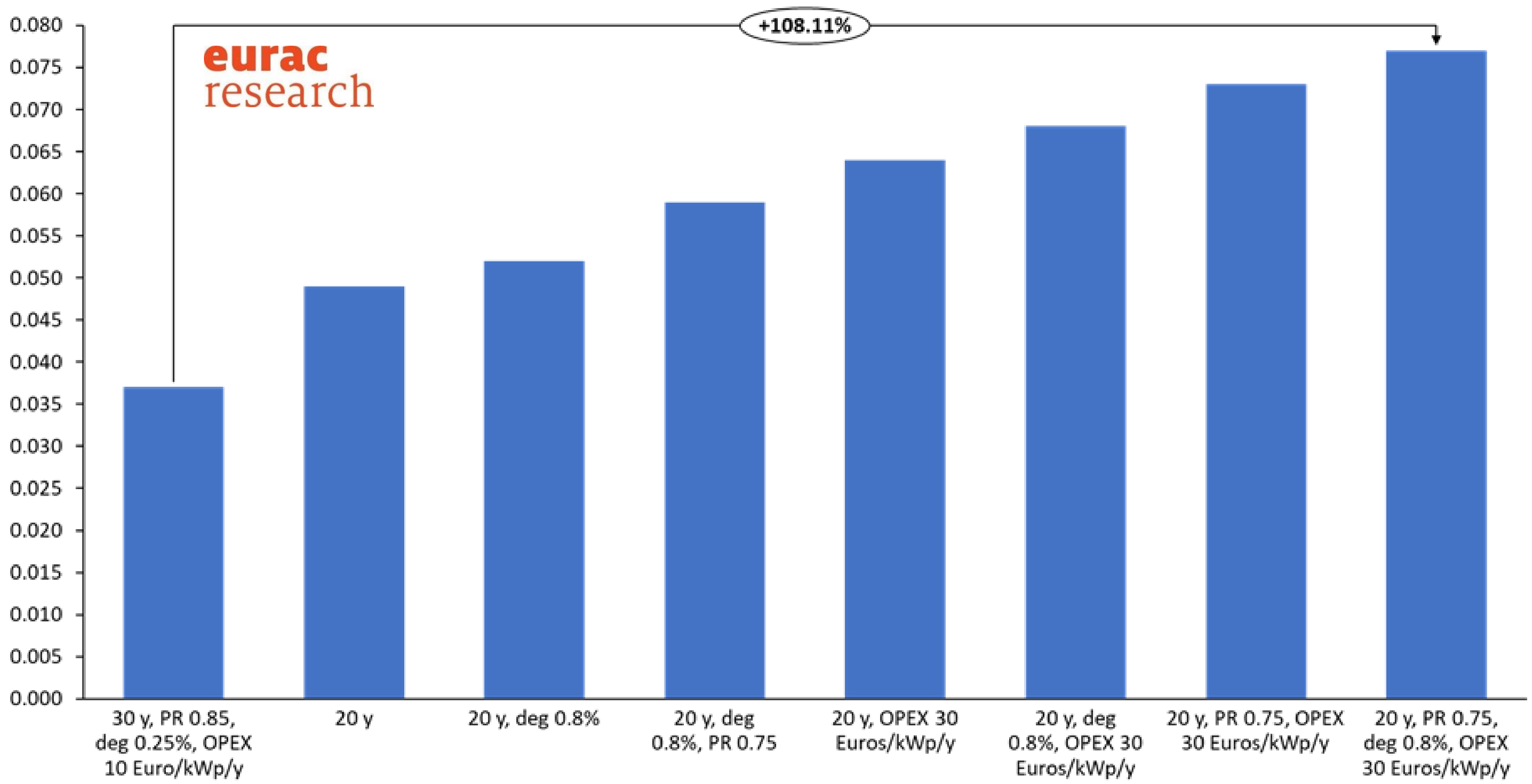
Which parameters are related to reliability?

PhotoVoltaic
EUROPEAN TECHNOLOGY & INNOVATION PLATFORM

Quantifying quality: derisking



Quantifying quality



Reliability related parameters

Risk ownership

Dealing with quality is complex

Transfer of information / breaking SILOS

Transfer of technical risks

	Engineering Procurement Contruction	Operations	Decommissioning
	Year 0	Year 1-N	Year > N
EPC/ Installer	Service warranty (material & workmanship)		
O&M		Service warranty (material & workmanship)	
Component manufacturer	Product warranty (material & workmanship)	Performance guarantee	Product return and disposal guarantee
Insurance	General liability insurance Construction risk insurance	General liability insurance Property damage insurance Business interruption insurance Performance guarantee insurance	
Investor (Owner/Operator)	Residual risks	Residual risks	Residual risks
Bank	Creditor default risk (Pre-financing)	Creditor default risk (Financing)	

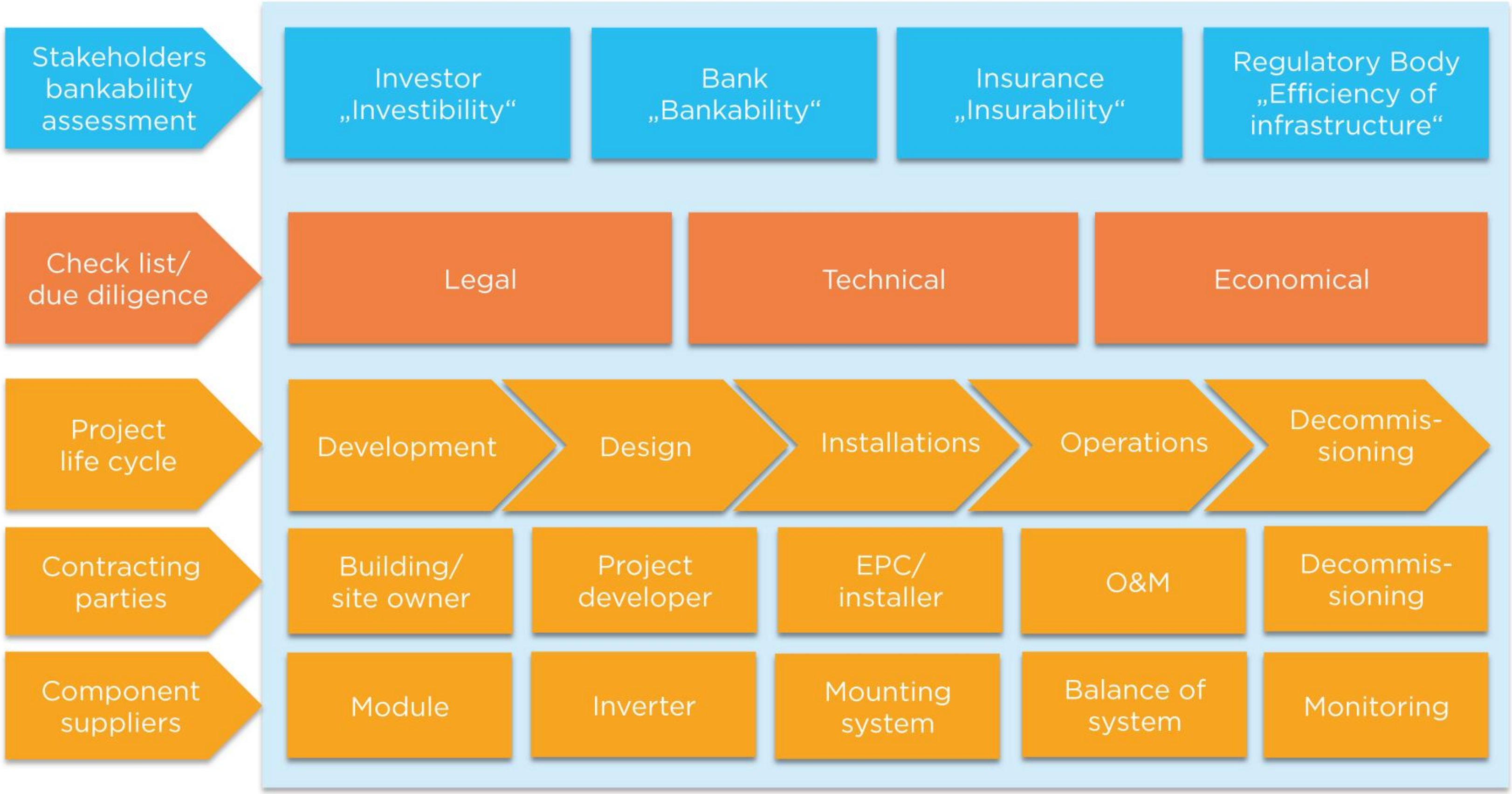
Stakeholders' needs

Transfer of technical risks

EPC/ Installer	short defect warranty periods, minimum of additional guarantees and warranties, high sale price with low OPEX (short time horizon)
O&M	manage all the conflicting requirements for a long period of time. The best condition for O&M operators is in fact in the presence of long defect warranty period and low sale price to allow for higher OPEX.
Component manufacturer	?
Insurance	limit their liability to failures PV plants, which meet technical market standards and are maintained on a regular basis
Investor (Owner/Operator)	long defect warranty periods, performance guarantees, reasonable low CAPEX and OPEX, high long-term plant performance and lifetime (ideally above the initial prediction).
Bank	projects with a 10-15 year financing period and PV plant performance which can also be slightly below prediction.

Bankability in PV projects

www.solarbankability.org



Solar bankability is an active quality management process, where all stakeholders in the approval process of a PV project attempt to identify potential legal, technical and economical risks throughout the entire project life cycle. These risks need to be quantitatively and qualitatively assessed, managed and controlled. Despite a wide overlap in this quality management process, the focus and the assessment criteria will vary whether the stakeholder represents an investor, a bank, an insurance or a regulatory body.

Great definition!!

And in practice?

Technical risks framework and economic impact of failures in design and operation

Can I quantify quality?

Can I track failure in the field?

Can I quantify the design flaws?

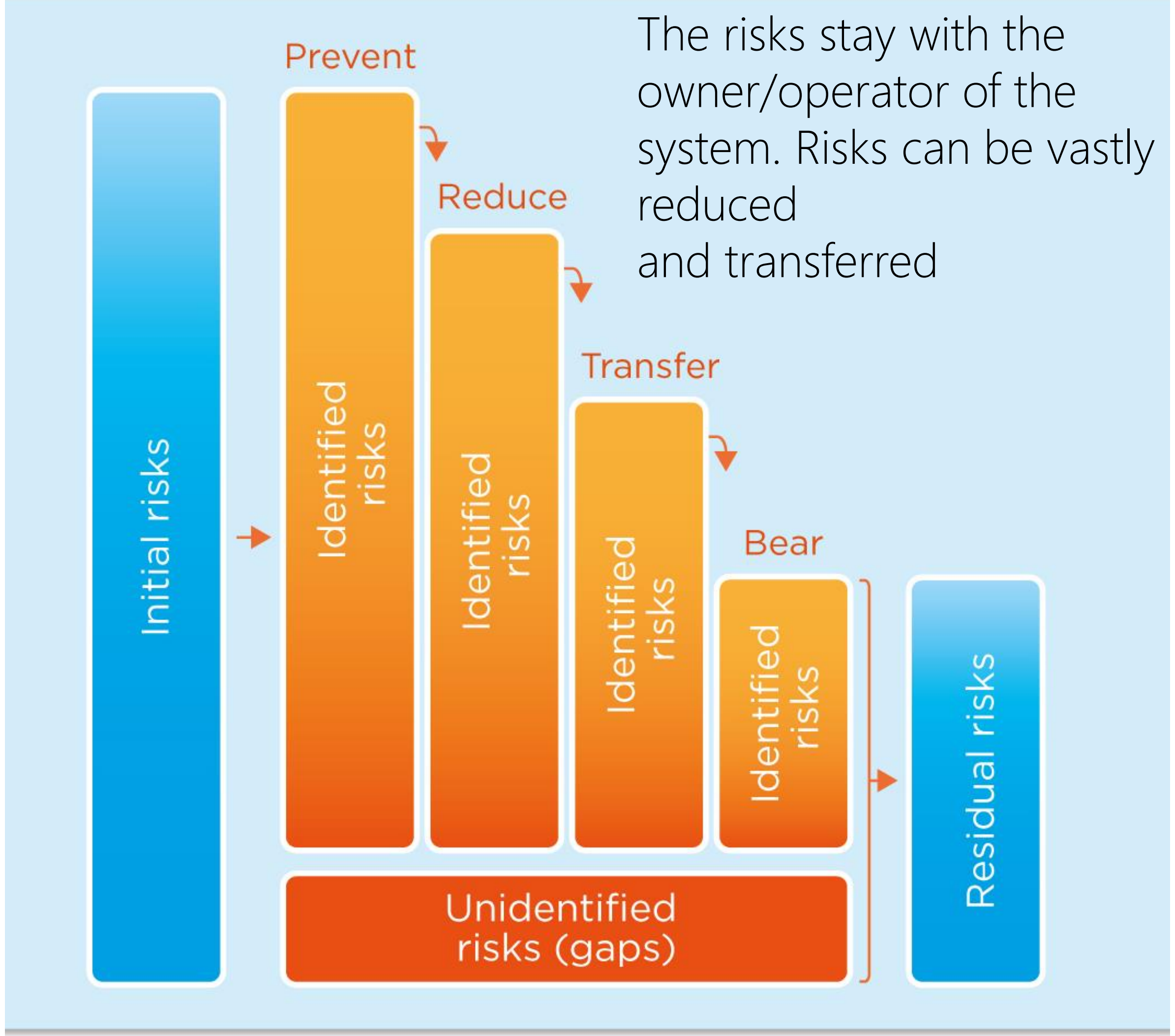
Data availability

Large datasets are available:
- Procurement / Testing
- Monitoring
- Field inspection
- Ticketing O&M
- Insurance claims
- Third party inspections

HOWEVER

These datasets are rarely:
- Organised
- Interoperable and digitalised
- Rely on interlinked digital platforms

Bankability must be data-driven



The risks stay with the owner/operator of the system. Risks can be vastly reduced and transferred

D. Moser et al, Identification of technical risks in the photovoltaic value chain and quantification of the economic impact, Progress in Photovoltaics, 7, 2017

Risk matrix: taxonomy

The importance of using common dictionaries

Product Development			Assessment of PV Plants	
Product testing	Planning	Transportation / installation	O&M	Decommissioning
Modules ….	….	….	….	….
• Insulation test • Incorrect cell soldering • Undersized bypass diode • Junction box adhesion • Delamination at the edges • Arcing spots on the module • Visually detectable hot spots • Incorrect power rating (flash test issue) • Uncertified components or production line	• Soiling • Shadow diagram • Modules mismatch • Modules not certified • Flash report not available or incorrect • Special climatic conditions not considered (salt corrosion, ammonia, ...) • Incorrect assumptions of module degradation, light induced degradation unclear • Module quality unclear (lamination, soldering) • Simulation parameters (low irradiance, temperature….) unclear, missing PAN files	• Module mishandling (glass breakage) • Module mishandling (cell breakage) • Module mishandling (defective backsheet) • Incorrect connection of modules • Bad wiring without fasteners	• Hotspot • Delamination • Glass breakage • Soiling • Shading • Snail tracks • Cell cracks • PID • Failure bypass diode and junction box • Corrosion in the junction box • Theft of modules • Module degradation • Slow reaction time for warranty claims, vague or inappropriate definition of procedure for warranty claims • Spare modules no longer available, costly string reconfiguration	• Undefined product recycling procedure

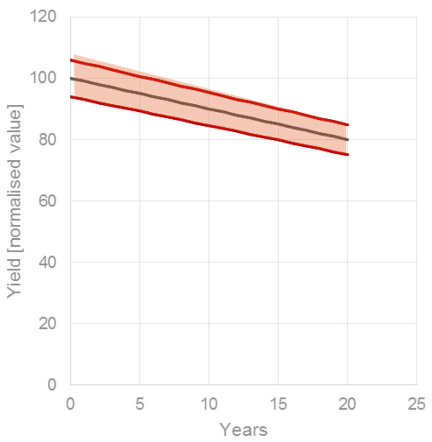
Quantification of technical risks

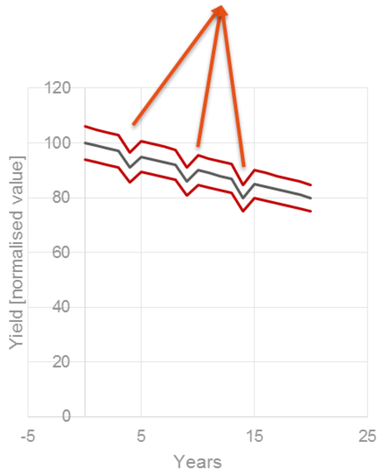
Planning

- **Risks to which we can assign an uncertainty (e.g. irradiance)**
→ Impact on financial exceedance probability parameters

O&M

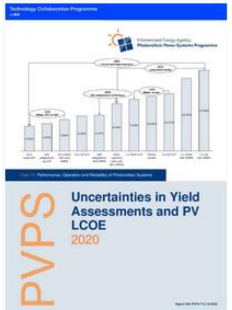
- Risks to which we can assign a Cost Priority Number CPN (e.g. module and inverter failure) given in Euros/kWp/year
→ Impact on cash flow





eurac research

Typical uncertainties in YA



Uncertainties in Yield Assessments and PV LCOE https://iea-pvps.org/key-topics/uncertainties-yield-assessments/

	Uncertainty	Range
Solar resource	Climate variability Irradiation quantification Conversion to POA	±4% - ±7% ±2% - ±5% ±2% - ±5%
PV modeling	Temperature model PV array model PV inverter model	1°C - 2°C ±1% - ±3% ±0.2% - ±0.5%
Other	Soiling Mismatch Degradation Cabling Availability…	±5% - ±6%
Overall uncertainty on estimated yield		±5% - ±10%

annual values

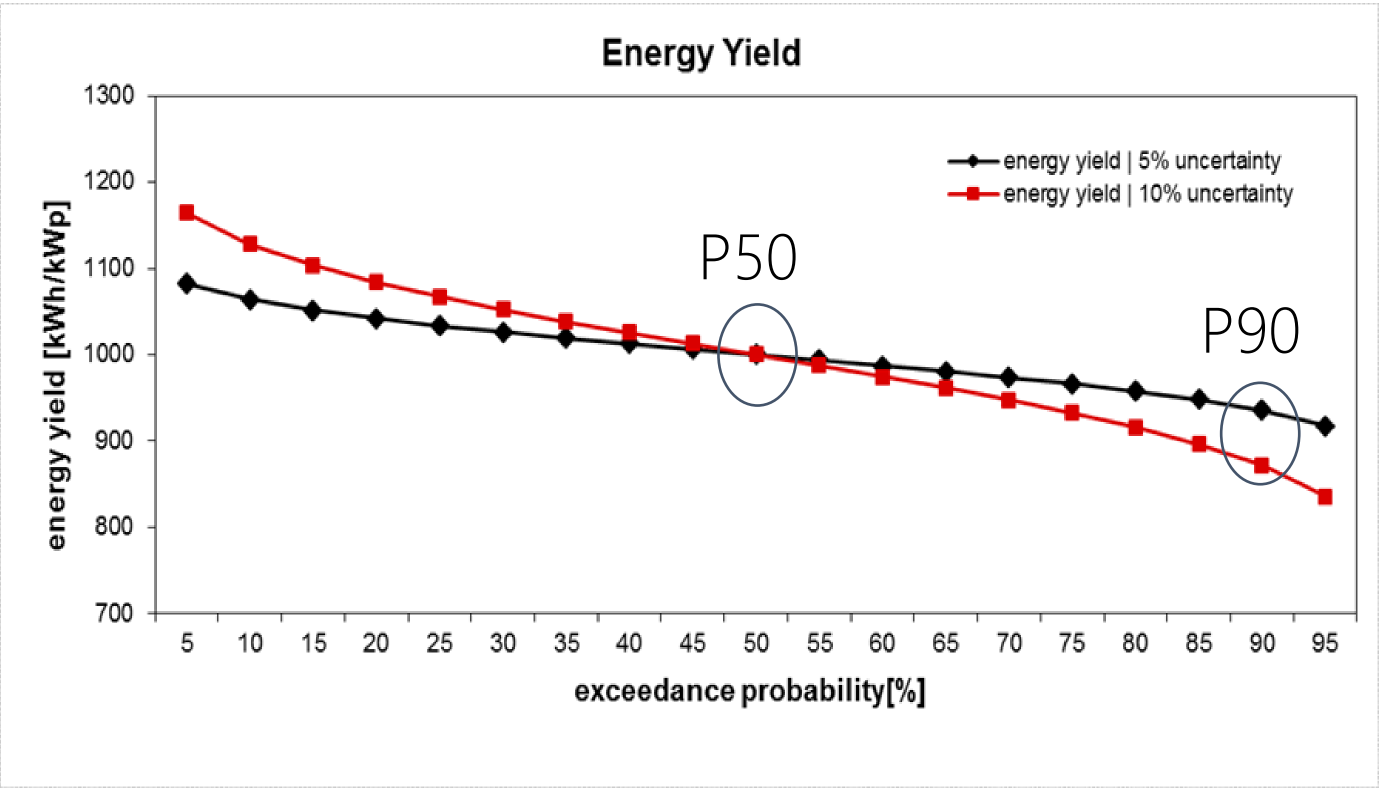
Fraunhofer ISE	uncer-tainty	value	gains/ losses	PR
	%	kWh/m²	%	%
global irradiation on horizontal plane	5.0	1454		
irradiation on module plane	2.5	1783	22.6	
shading				
horizon shading	0.5	1681	-5.7	100.0
row shading	2.0	1664	-1.0	99.0
object shading	3.0	1664	0.0	99.0
soiling	2.0	1655	-0.5	98.5
deviations from STC				
reflection losses	0.5	1621	-2.1	96.4
	%	kWh/kWp	%	%
spectral losses	0.5	1605	-1.0	95.5
irradiation-dependent losses	0.6	1586	-1.2	94.3
temperature-dependent losses	1.0	1500	-5.4	89.2
mismatch losses	0.5	1488	-0.8	88.5
DC cable losses	0.5	1474	-0.9	87.7
inverter losses	1.5	1414	-4.1	84.1
inverter power limitation	0.5	1414	0.0	84.1
additional consumption	0.0	1414	0.0	84.1
AC cable losses low voltage	0.5	1406	-0.6	83.6
total	**7.3**	**1406**		**83.6**

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.

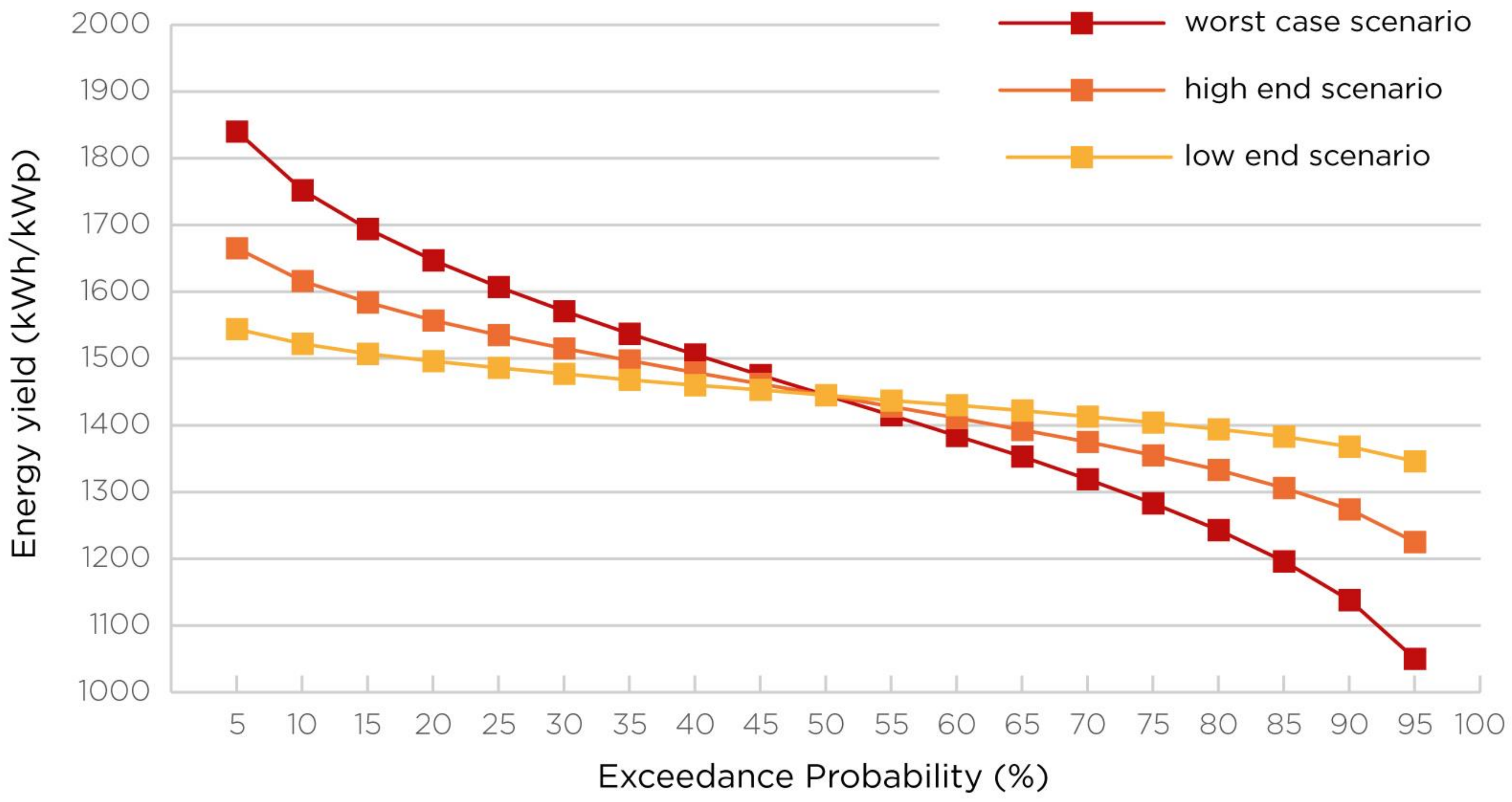
D. Moser *et al.*, "Technical Risks in PV Projects." Solar Bankability Deliverable www.solarbankability.com

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

Planning

- **Risks to which we can assign an uncertainty (e.g. irradiance)**

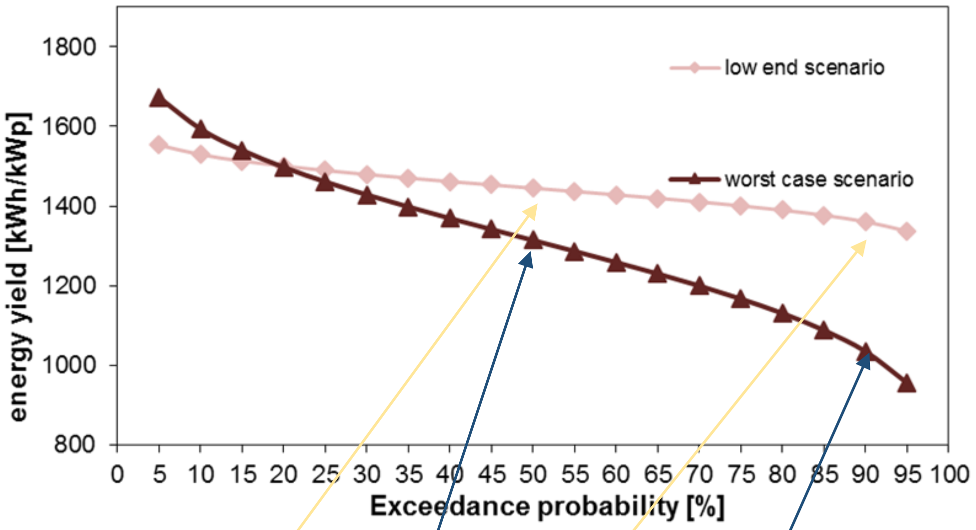
→ Impact on financial exceedance probability parameters



Planning

- **Risks to which we can assign an uncertainty (e.g. irradiance)**
→ Impact on financial exceedance probability parameters

Objectives:
- More precise estimation of uncertainty in yield estimation
- Reduction of uncertainty



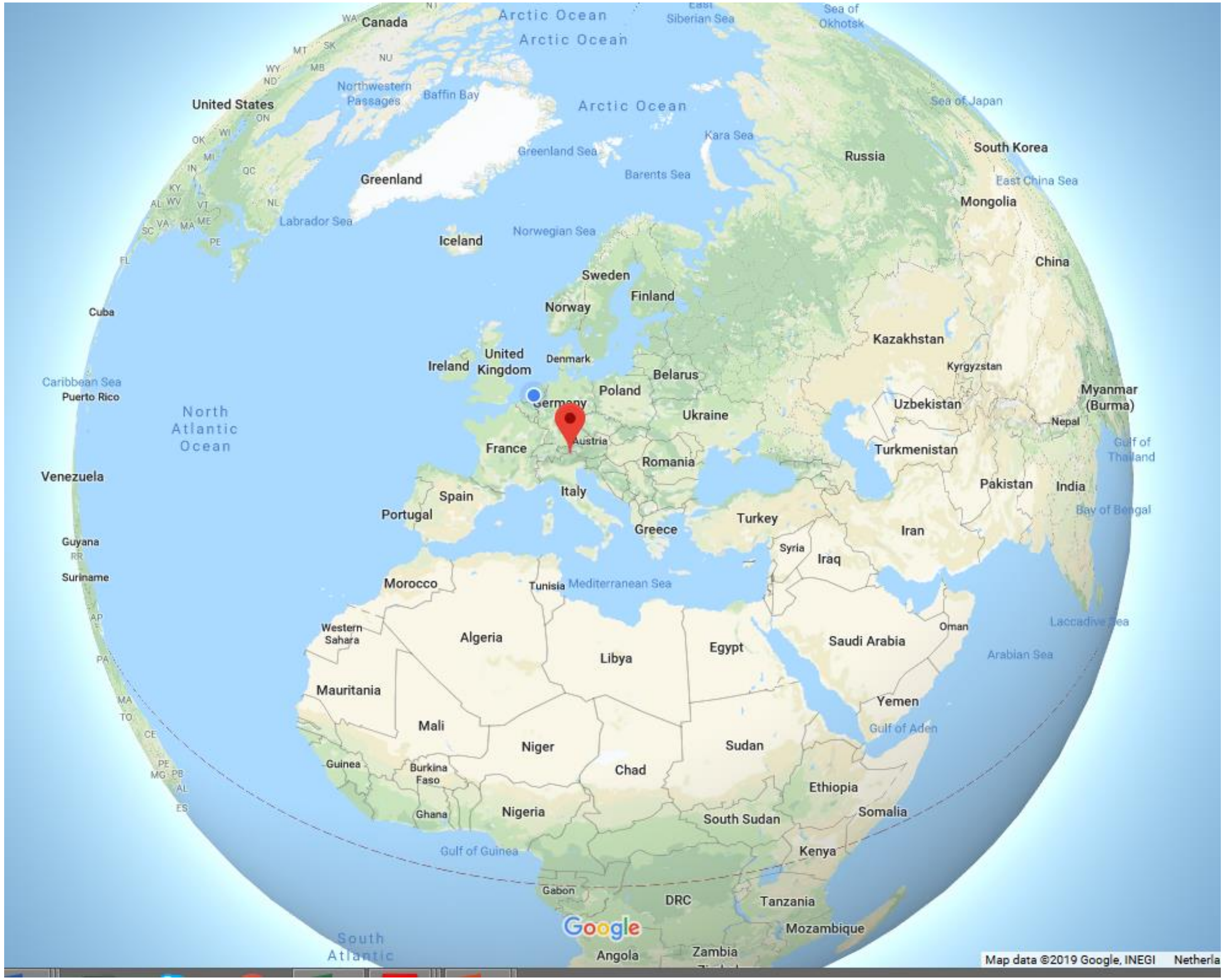
	σ (k=1)	P50 (kWh/kWp)	P90 (kWh/kWp)	P90/P50 (P50 reference case)
Ref. case (sum of squares)	**8.7%**	**1445**	**1283**	**89%**
Low end scenario	4.6%	1445	1365	94%
High end scenario	9.3%	1445	1273	88%
Worst case scenario	16.6%	1445	1138	79%
Worst case scenario (different mean value)	16.6%	1314	1034	72%

22% difference in terms of yield used in the business model

eurac research

Site selection

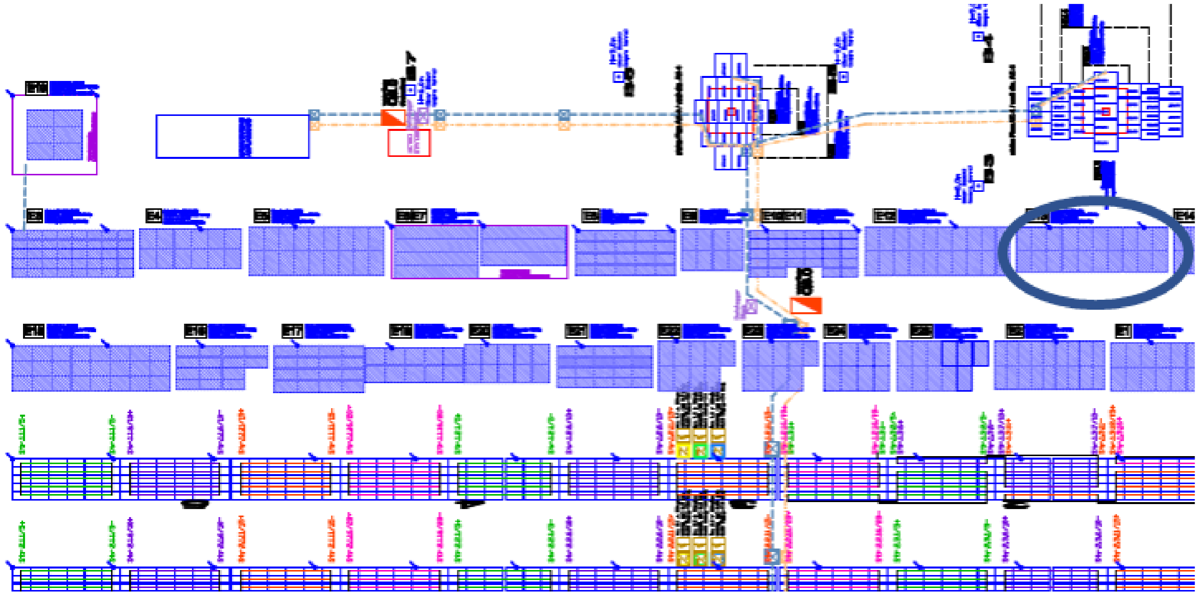
Location: Bolzano, Italy
Data available since August 2010
Technology: polycrystalline-Si



Site selection

Parameter	Assumption
Location	Given Latitude/Longitude, tilt angle and azimuth
Irradiance and transposition	Each independent YA used their favourite database
Temperature	Each independent YA used their favourite database
Technology and mismatch	PV module technology given (module datasheet). Mismatch and power tolerance, each YA applied their own consideration
Inverter	Given (datasheet)
Shading	Bolzano: Given shading diagram
Soiling	Each independent YA applied their own considerations
Wind speed	Each independent YA used their favourite database
Long term insolation effects	Each independent YA used their own considerations
Degradation	Each independent YA applied their own considerations
Snow loss / snow fall	Each independent YA applied their own considerations
Availability	Each independent YA applied their own considerations
Uncertainties	**Please provide uncertainties for each parameter (when possible) and for the yield (mandatory).**

Location: Bolzano, Italy
Data available since August 2010
Technology: 4.2 kWp mc-Si
Shading diagram provided
Data used also for benchmarking activity of PLR



Site selection

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

eurac research

Site selection

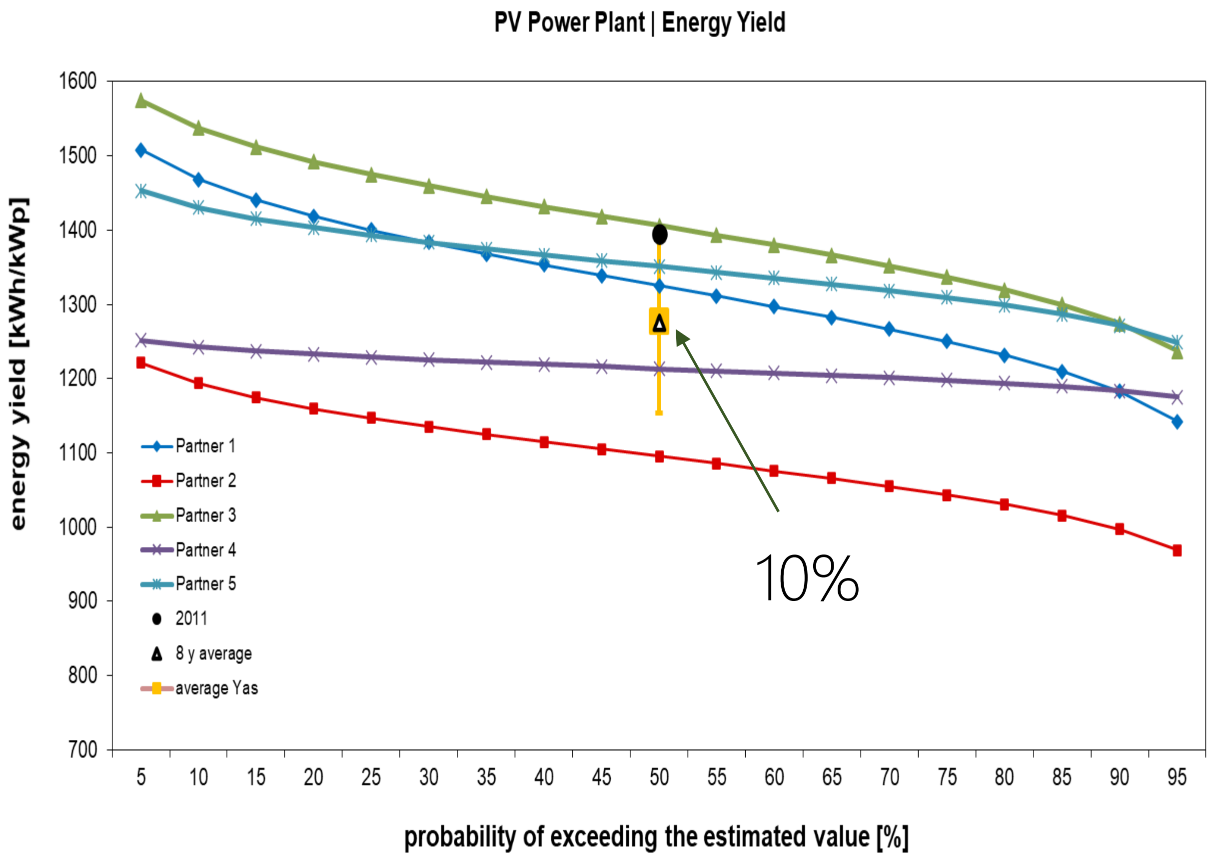
Parameter	Assumption
Location	Given Latitude/Longitude, tilt angle and azimuth
Irradiance and transposition	Each independent YA used their favourite database
Temperature	Each independent YA used their favourite database
Technology and mismatch	PV module technology given (module datasheet). Mismatch and power tolerance, each YA applied their own consideration. Flash list with measure power was provided
Inverter	Given (datasheet)
Shading	Photos provided of near objects
Soiling	Each independent YA applied their own considerations
Wind speed	Each independent YA used their favourite database
Long term insolation effects	Each independent YA used their own considerations
Degradation	Each independent YA applied their own considerations
Snow loss / snow fall	Each independent YA applied their own considerations
Availability	Each independent YA applied their own considerations
Uncertainties	**Please provide uncertainties for each parameter (when possible) and for the yield (mandatory).**

Location: Alice Springs, Australia
Data available since 2009
Technology: 3 crystalline technologies
Photos provided for near shading

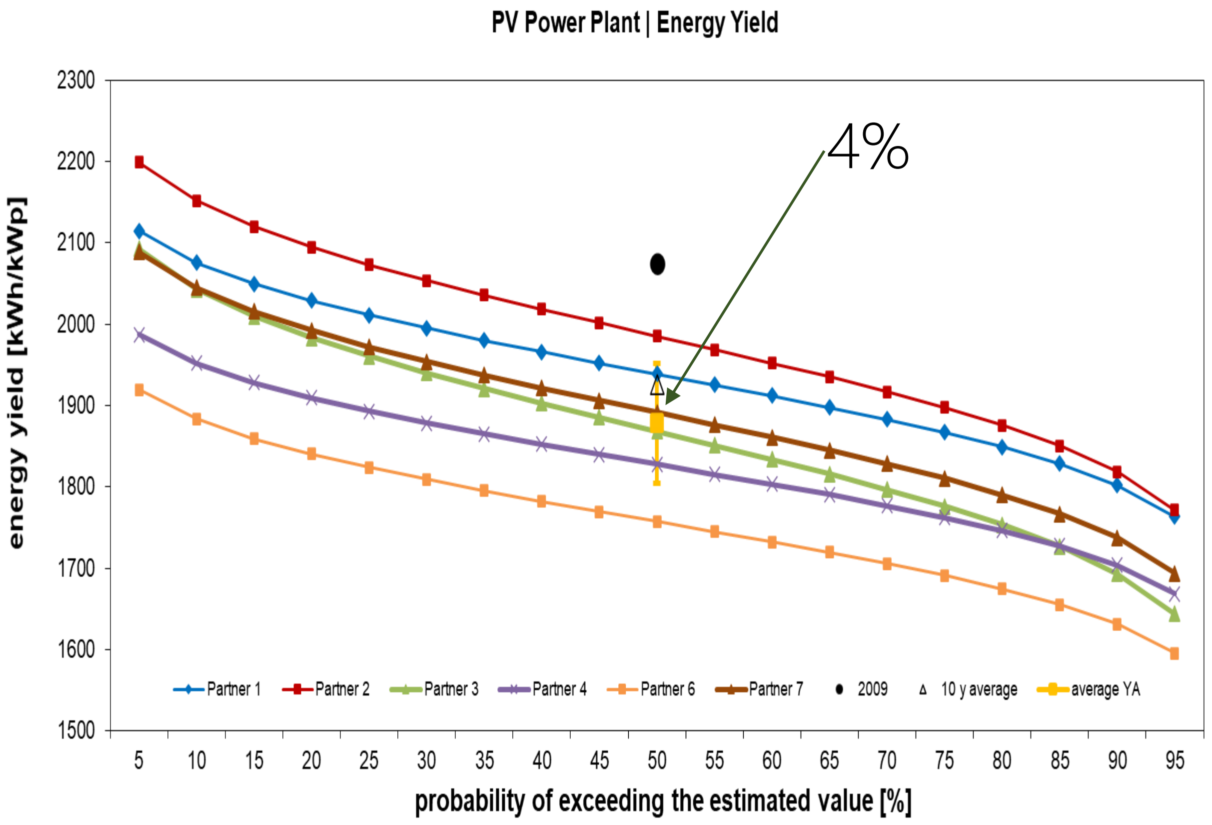
5.805 kWp array at DKASC, Alice Springs, Australia
5.25 kWp array at DKASC, Alice Springs, Australia
5.4 kWp array at DKASC, Alice Springs, Australia

Comparison of initial YAs

Bolzano



Alice Springs



Large spread of values

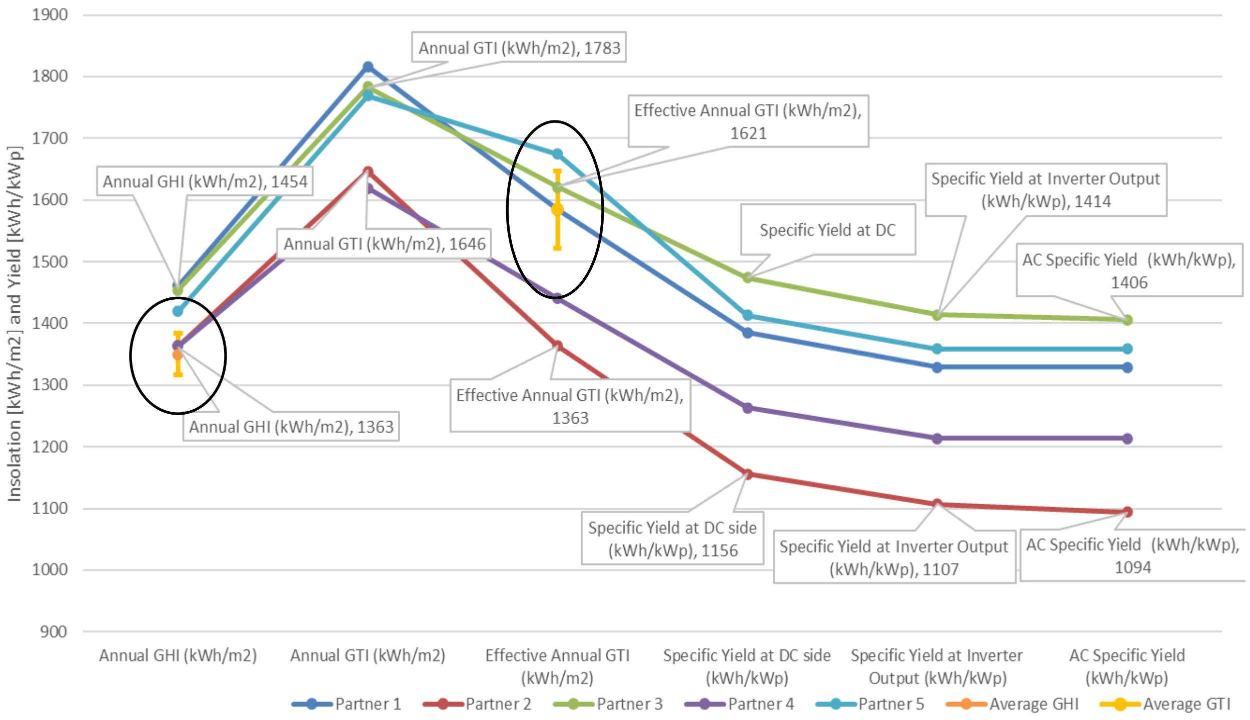
Real values within the P10-P90 range only for some Yas

Averaging YAs might not be a good strategy!

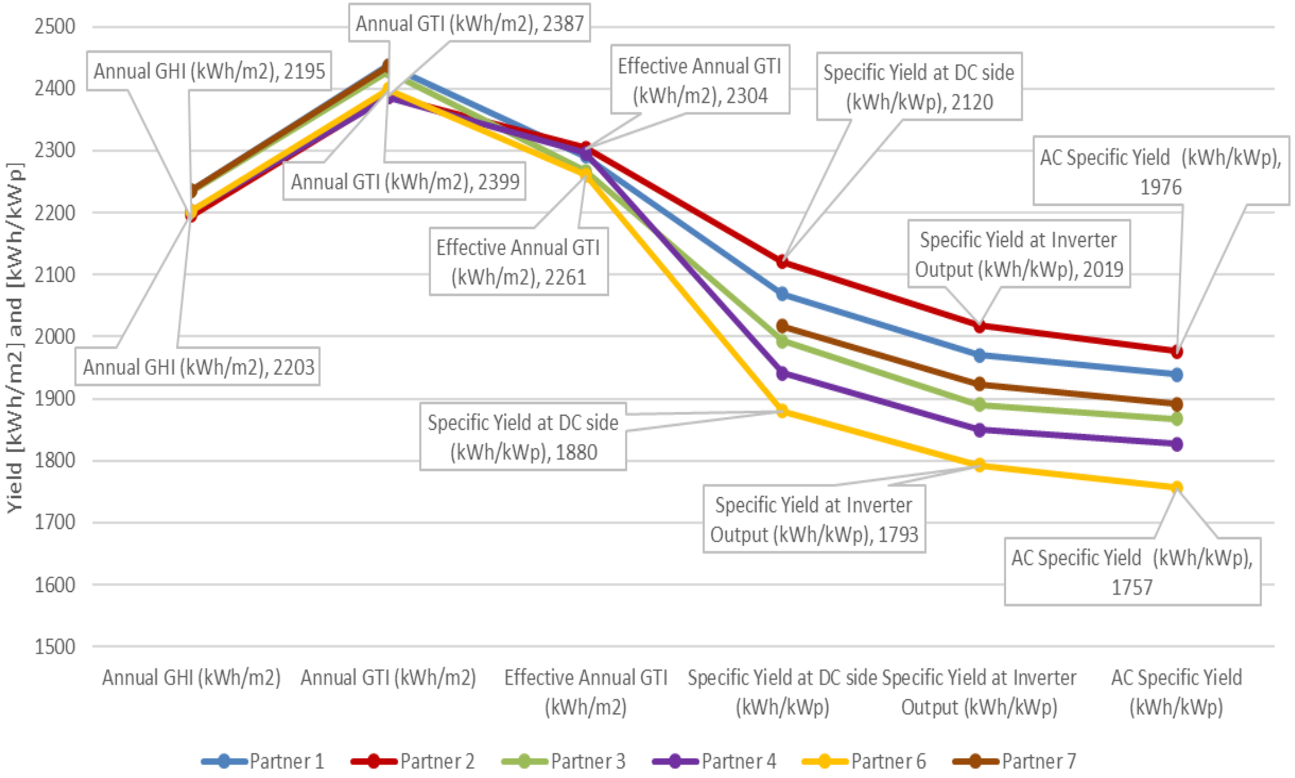
eurac research

Comparison of initial YAs

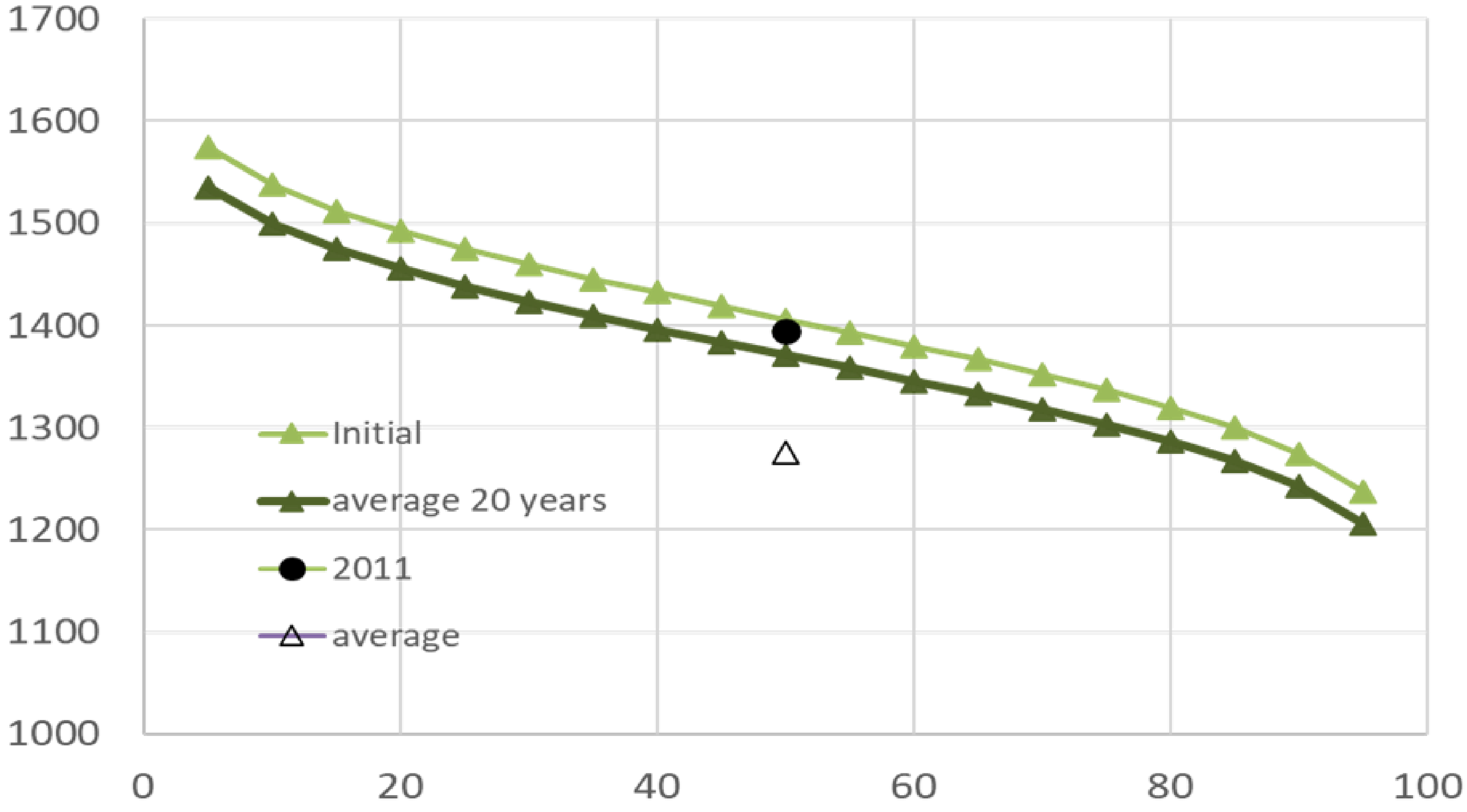
Bolzano



Alice Springs



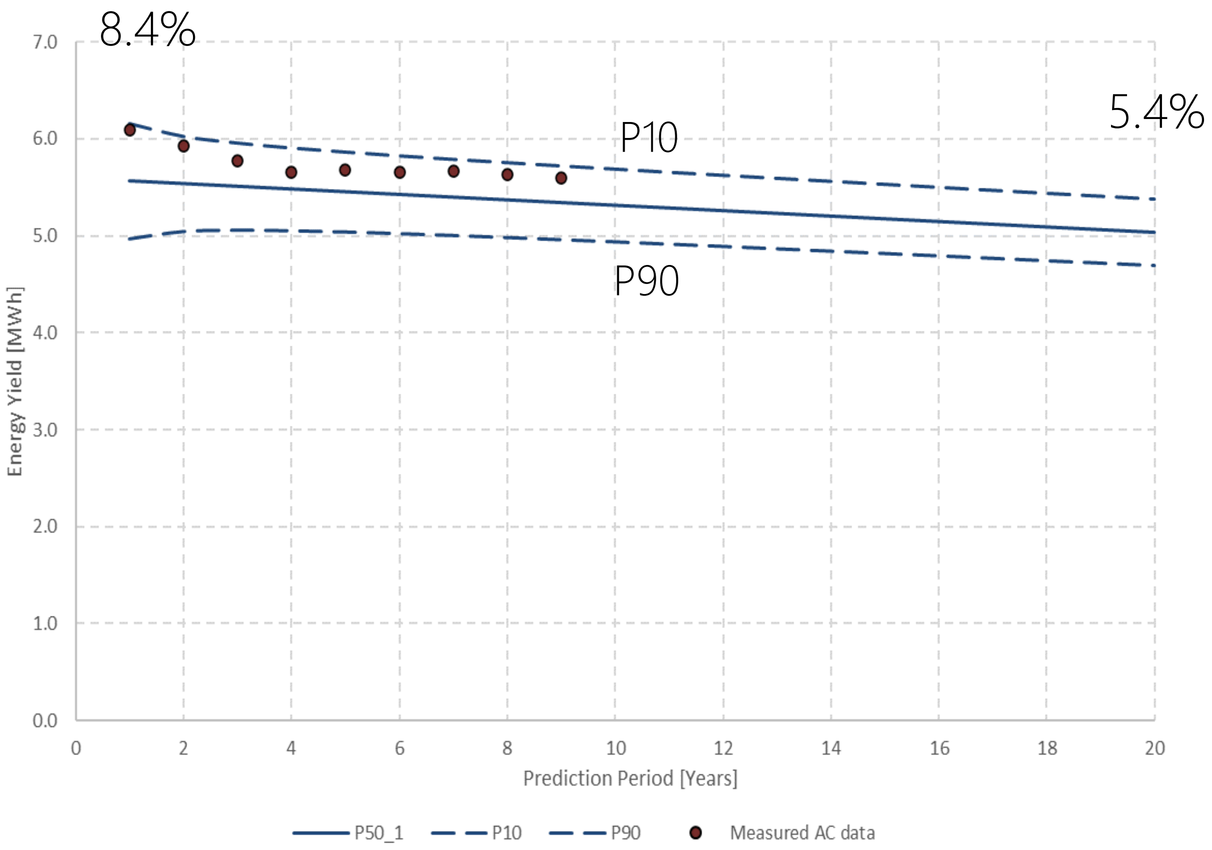
Initial YA and average yield



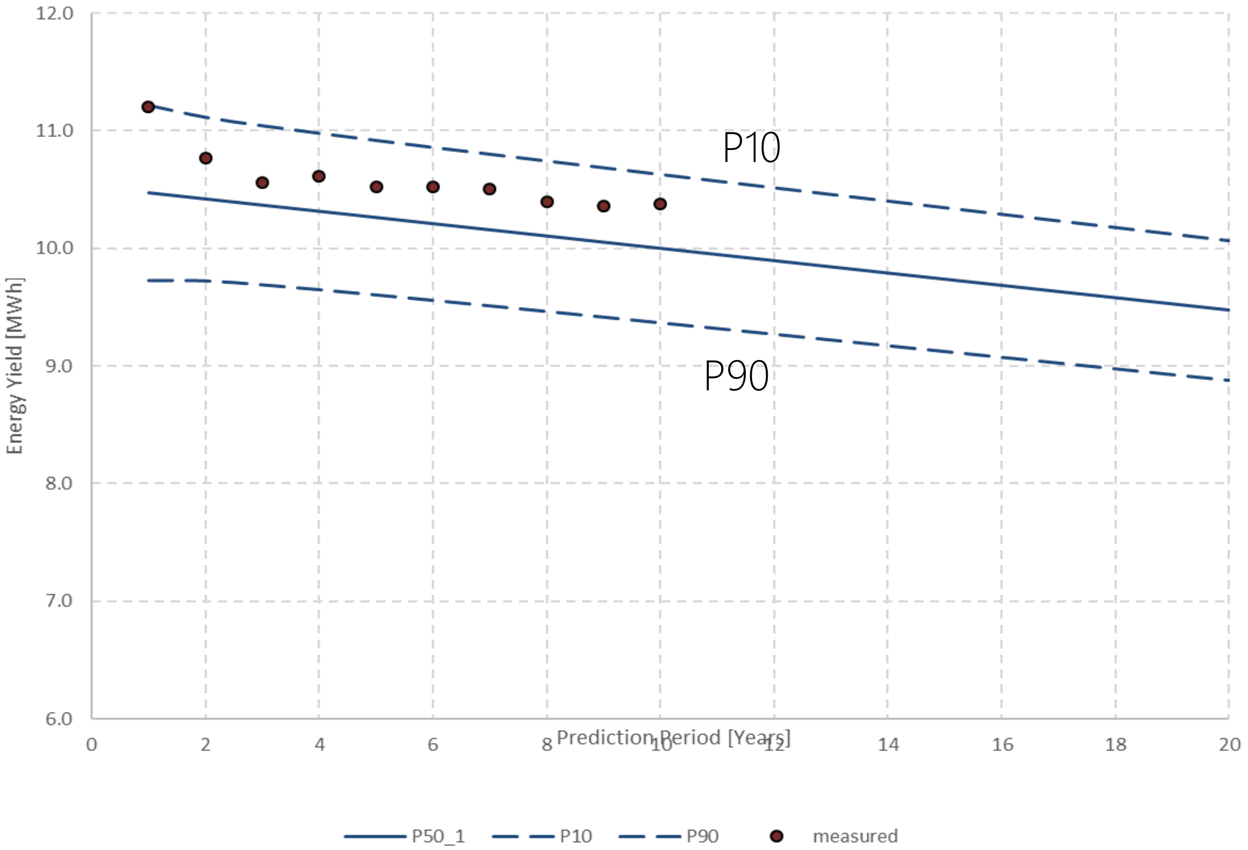
The use of PV module degradation (-0.25%/y) instead of typical Performance Loss Rates (PLR) can underestimate the losses over time (PLR = -0.84%/y)

Comparison of LTYPs

Bolzano

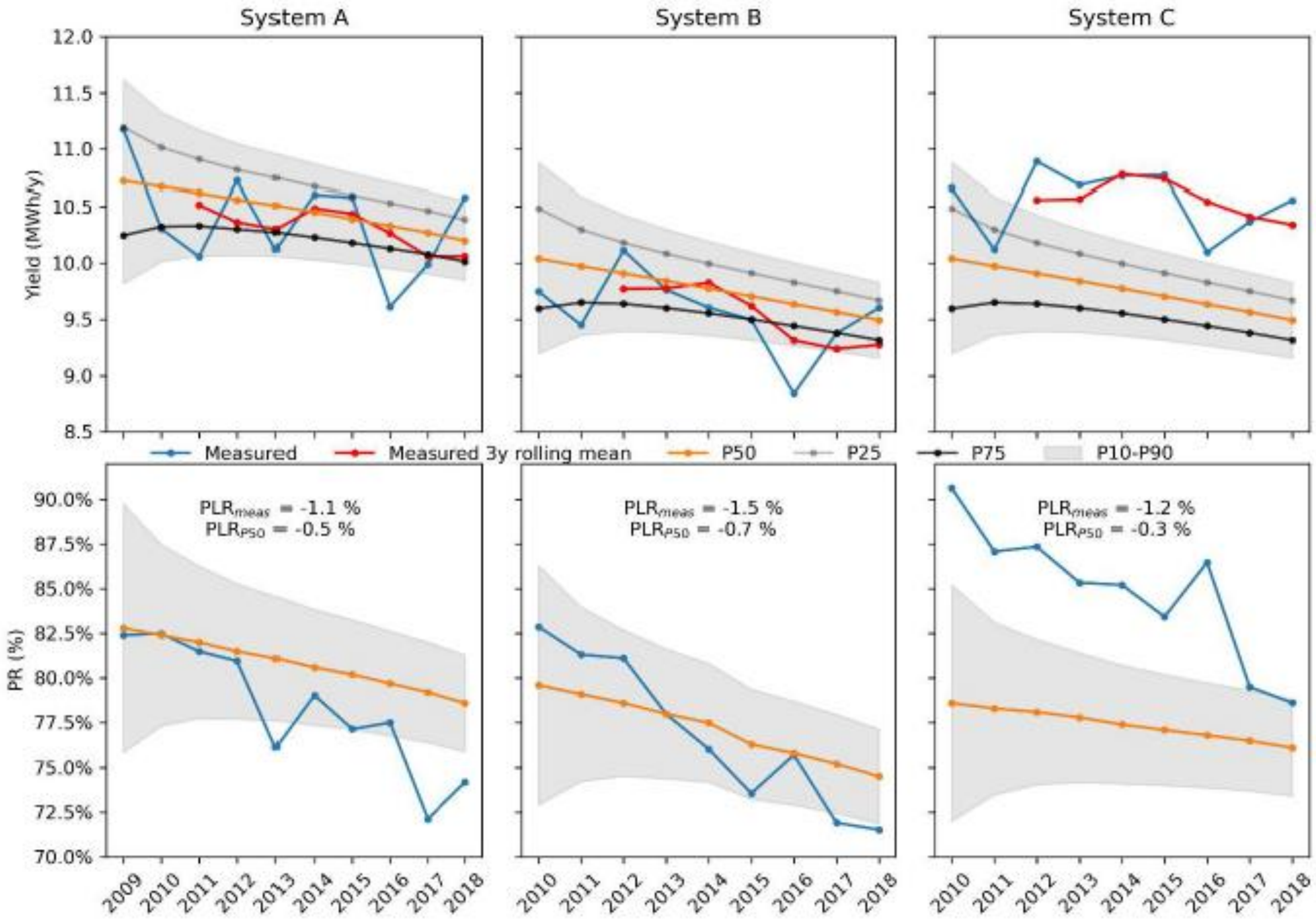


Alice Springs



Measured values are averaged (rolling average) over the previous years

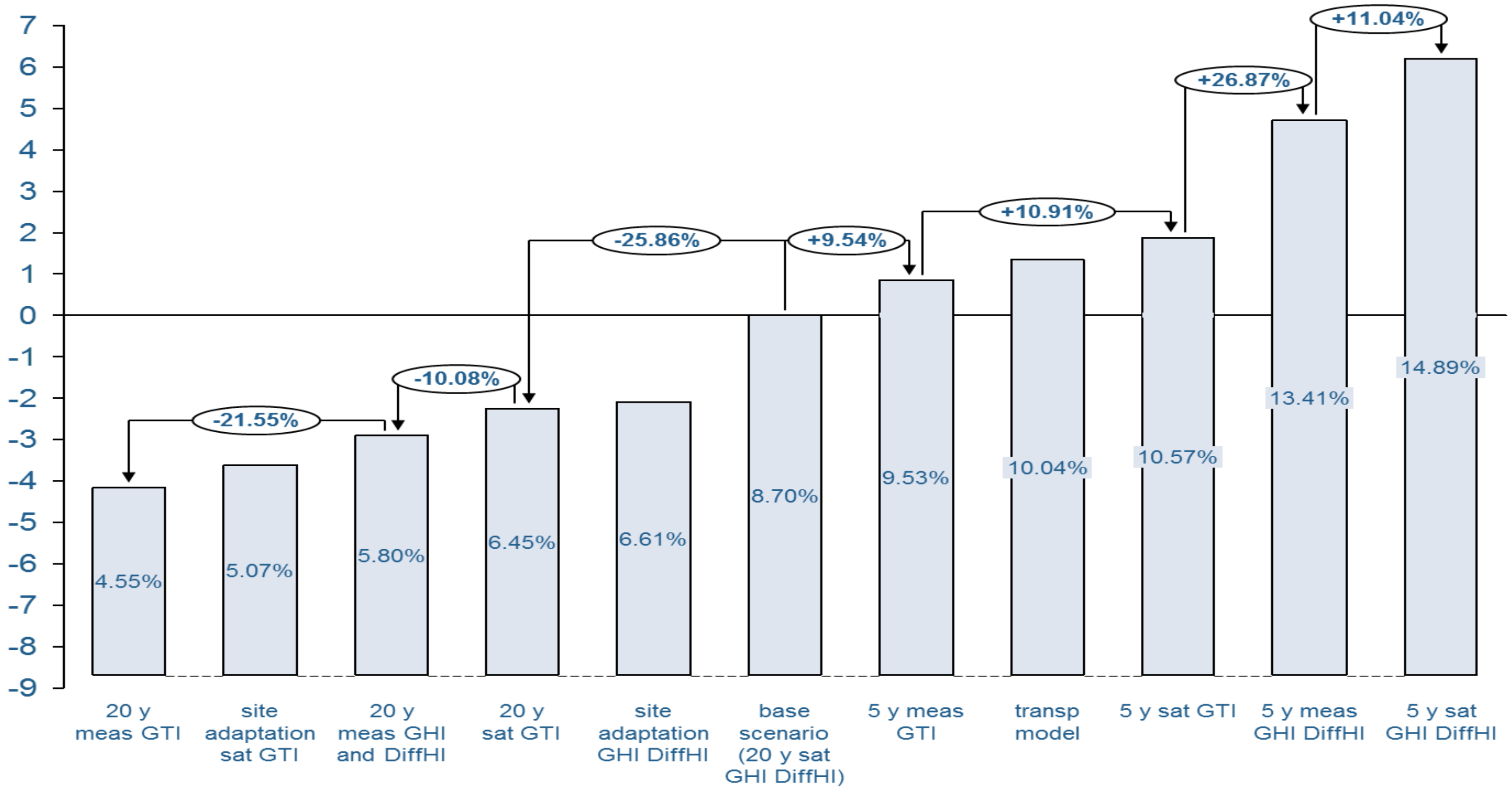
Comparison of LTYPs



It appears that the **annual performance loss rate** in Arid desert hot (BWh Köppen-Geiger climate zone) is **much higher than expected**, with all three systems discussed seeing a PLR of -1.1 %/year or worse, instead of the (historical) industry-standard assumption of -0.5 %/year.

The significant over-performance by System C compared to predicted values suggests that **thermal losses were over-estimated** (for example by using not validated temperature coefficients and/or Nominal Module Operating Temperature, NMOT), and likely also suggests better light capture by these modules.

Uncertainty scenarios

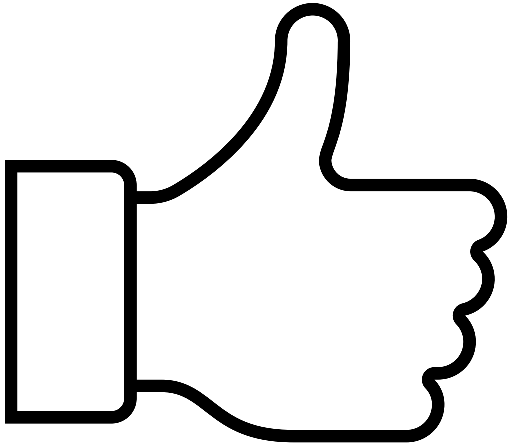


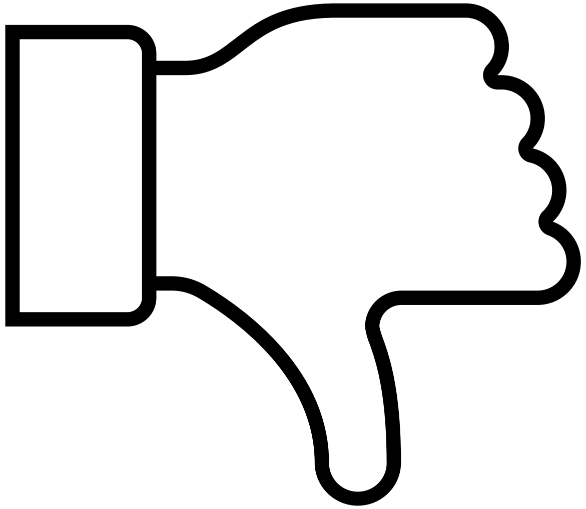
Based on the findings of the benchmarking exercise we have shown how uncertainty plays a role for various parameters

Uncertainties in Yield Assessments and PV LCOE

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
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

Do we still have some time left?





Economic impact on business model and LCOE

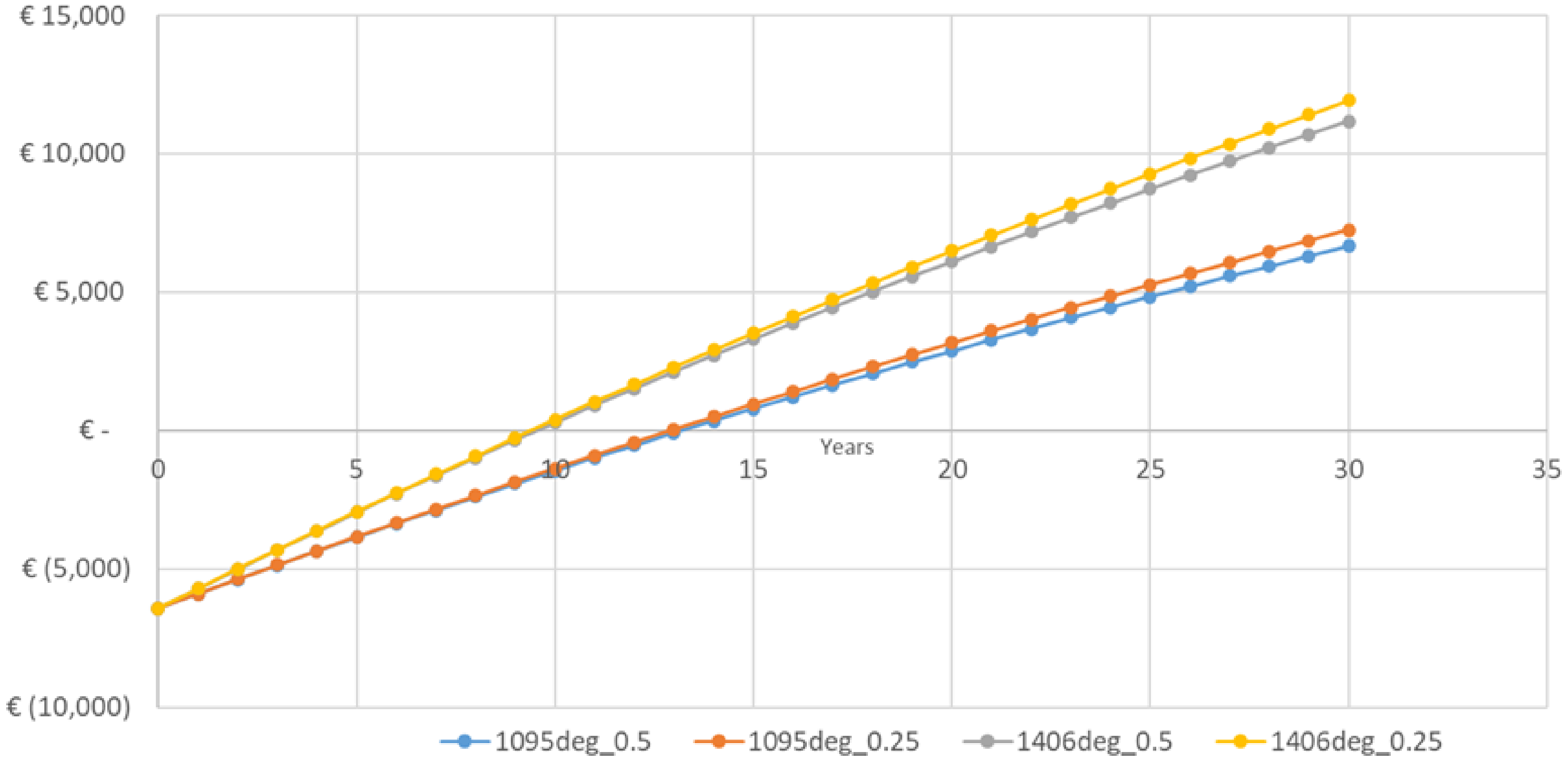
How can I valorise my PV electricity?

How does quality impact a business model?

Economic impact on business model and LCOE

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



€/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

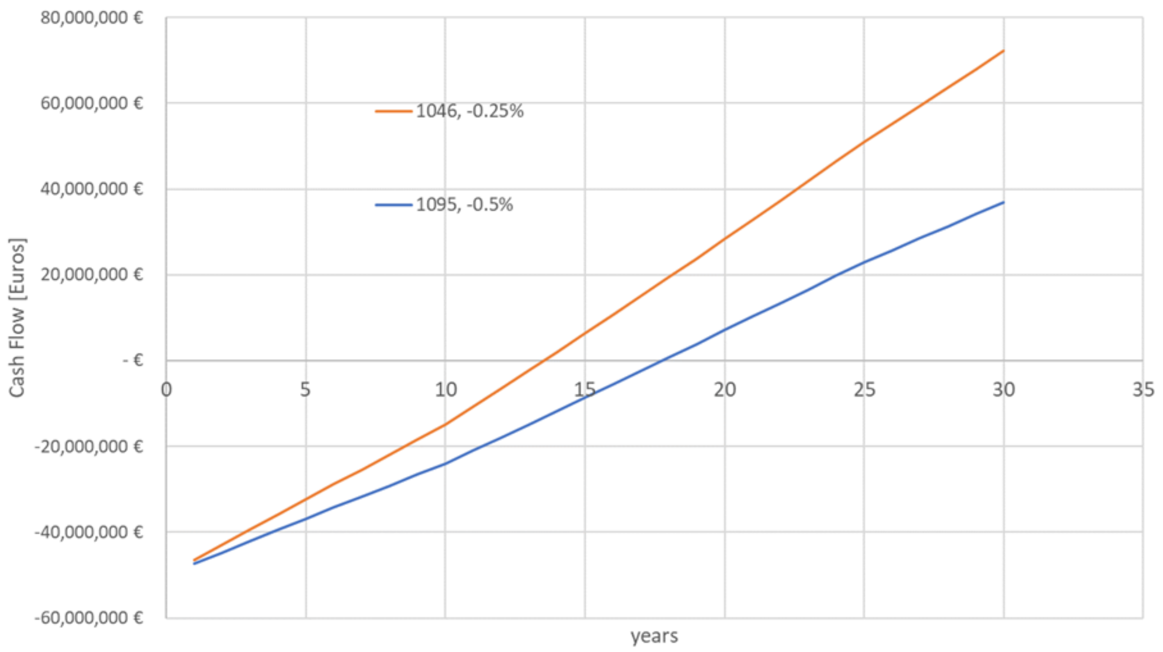
Economic impact on business model and LCOE

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

Earnings		1095 / -0.5%	1406 / -0.25%	
Free cashflow (EBIDTA) IRR by CAPEX	[%]	4.7%	7.9%	IRR from free cashflow (EBIDTA) based on CapEx (not project cost)
Unleveraged IRR after tax and depreciation by CAPEX	[%]	3.9%	6.6%	IRR from free cashflow - unleveraged case
LCOE in total	[EUR/ MWh]	36.9	27.9	Levelised Cost of Electricity

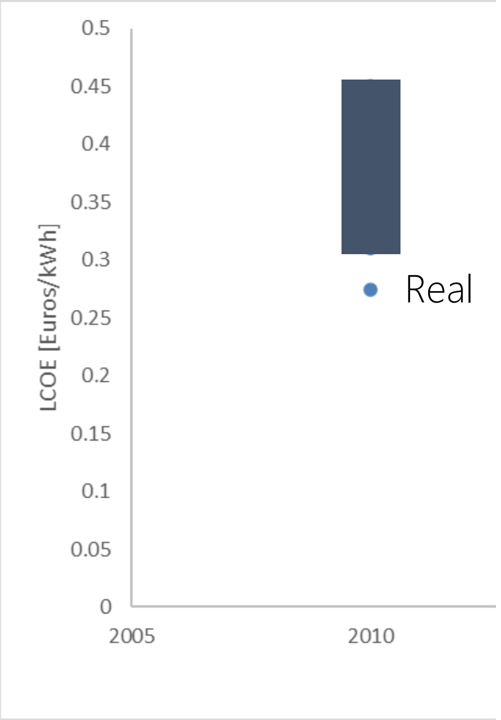


Economic impact on business model and LCOE

Calculation assumptions				
CAPEX	4500	4500		Euros/kWp
OPEX	1% CAPEX = 45	Real data, 27 2020 onward		Euros/kWp/y
Nominal WACC	7.4%	7.4%		
Real WACC	5.1%	5.1%		
Inflation	2.3%	2.3%		
Lifetime	20	20-25		
Yield	From YA	Measured data		kWh/kWp
Degradation/PLR	From YA	Calculated from measured data, -0.84		%

	PR	P50 Yield [kWh/kWp]	P90 Yield [kWh/kWp]	Degradation/ PLR
Partner 1	80.4%	1329	1183	0.5%
Partner 2	73.6%	1094	997	0.5%
Partner 3	83.6%	1406	1274	0.25%
Partner 4	81.2%	1213	1184	
Partner 5	81.1%	1445	1270	0.5%

	$LCOE_{50}$ €/kWh 2010	$LCOE_{90}$ €/kWh 2010
Partner 1	0.338	0.379
Partner 2	0.410	0.450
Partner 3	0.314	0.346
Partner 5	0.310	0.353

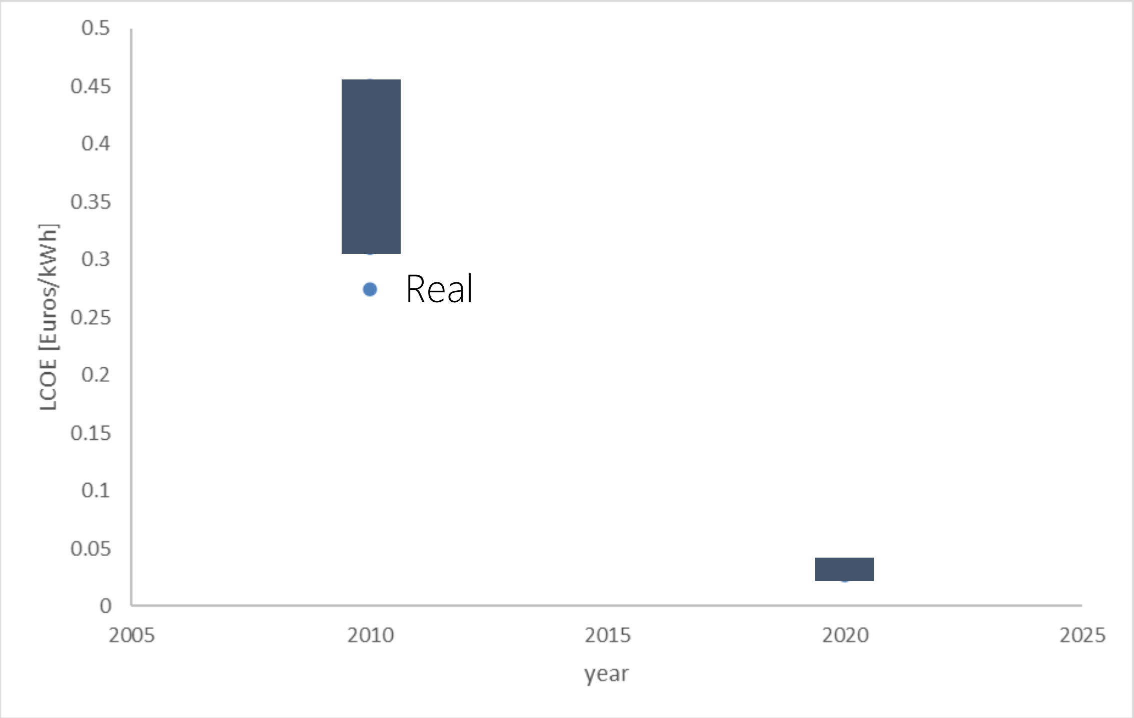


Economic impact on business model and LCOE

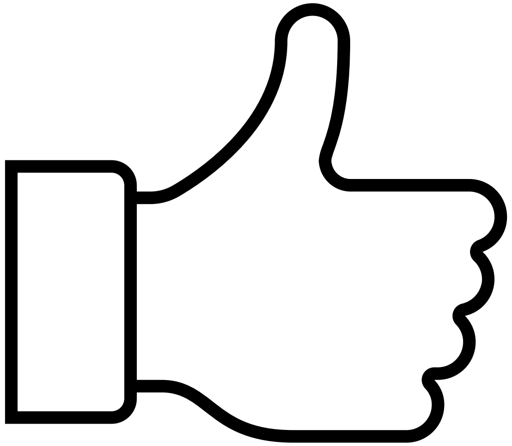
Calculation assumptions				
CAPEX	4500	4500	430	Euros/kWp
OPEX	1% CAPEX = 45	Real data, 27 2020 onward	8.5	Euros/kWp/y
Nominal WACC	7.4%	7.4%	7.4%	
Real WACC	5.1%	5.1%	5.1%	
Inflation	2.3%	2.3%	2.3%	
Lifetime	20	20-25	25	
Yield	From YA	Measured data	From YA	kWh/kWp
Degradation/PLR	From YA	Calculated from measured data, -0.84	From YA	%

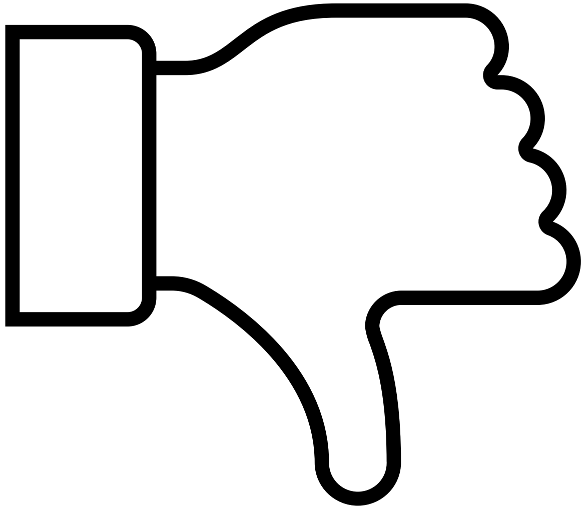
	PR	P50 Yield [kWh/kWp]	P90 Yield [kWh/kWp]	Degradation/ PLR
Partner 1	80.4%	1329	1183	0.5%
Partner 2	73.6%	1094	997	0.5%
Partner 3	83.6%	1406	1274	0.25%
Partner 4	81.2%	1213	1184	
Partner 5	81.1%	1445	1270	0.5%

Scenario	LCOE €/kWh
Modelled LCOE 2010	0.310-0.450
Real LCOE 2010	0.274
Modelled LCOE 2020 residential	0.068-0.099
Modelled LCOE 2020 utility scale	0.027-0.039



Do we still have some time left?



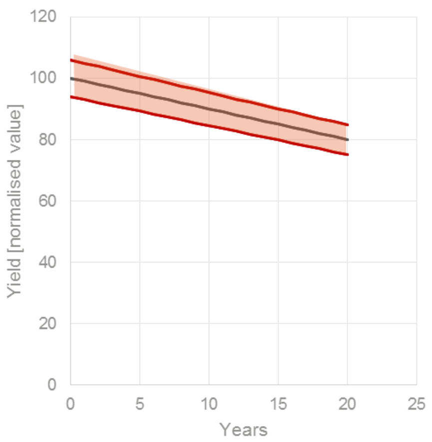


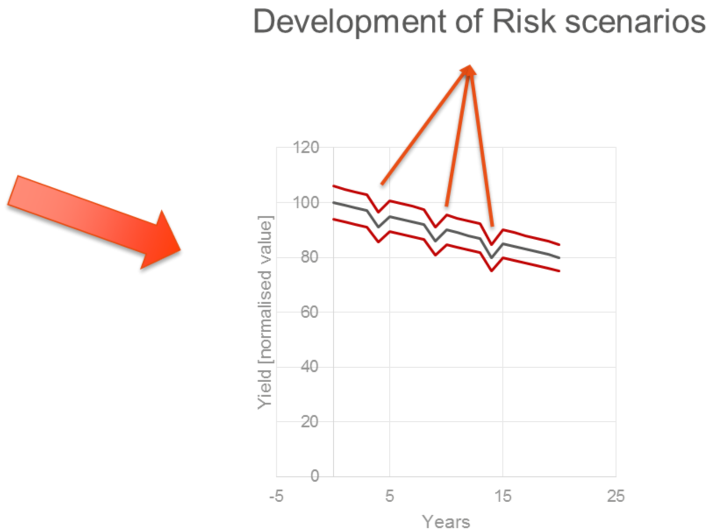
Quantification of the economic impact of technical risks

O&M

- Risks to which we can assign a Cost Priority Number CPN (e.g. module and inverter failure) given in Euros/kWp/year

→ Impact on cash flow





eurac research

Economic impact of failures

New metrics

Cost-based Failure Modes and Effects Analysis (FMEA) for PV

CPN: metric that allows for
- Comparison between asset within the same PV plant portfolio (AM, O&M)
- Evaluate best strategies in EPC, O&M
- Act as a link between the various phases of the value chain

a) Economic impact due to downtime and/or power loss (kWh to Euros)
- Failures might cause downtime or % in power loss
- Time is from failure to repair/substitution and should include: time to detection, response time, repair/substitution time
- Failures at component level might affect other components (e.g. module failure might bring down the whole string)

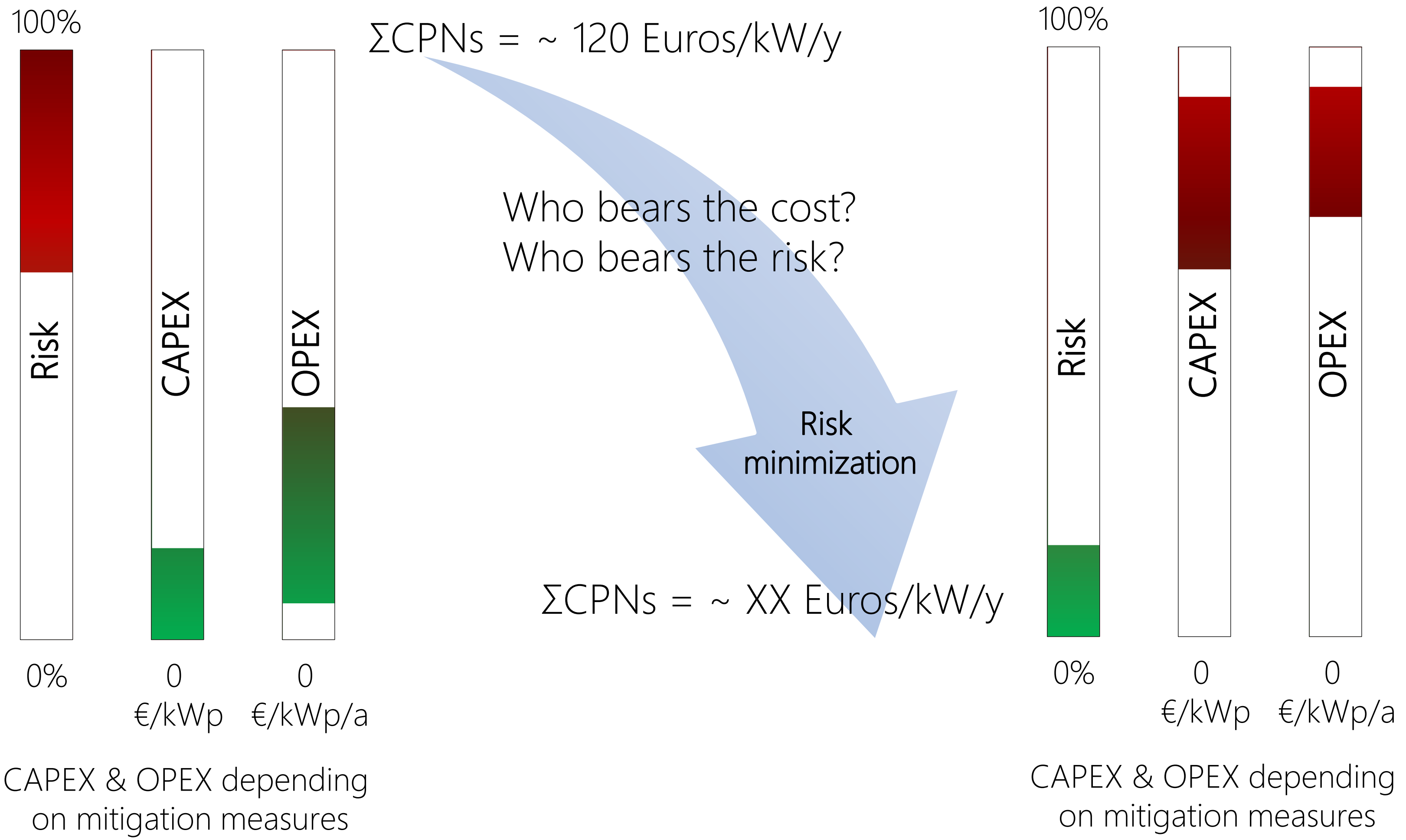
Income / savings reduction

+

b) Economic impact due to repair/substitution costs (Euros)
- Cost of detection (field inspection, indoor measurements, etc)
- Cost of transportation of component
- Cost of labour (linked to downtime)
- Cost of repair/substitution

O&M cost increase
Reserves decrease

Risk mitigation



Mitigation Measure Approach

- List of 8 defined MMs, their mitigation factors and affected parameters

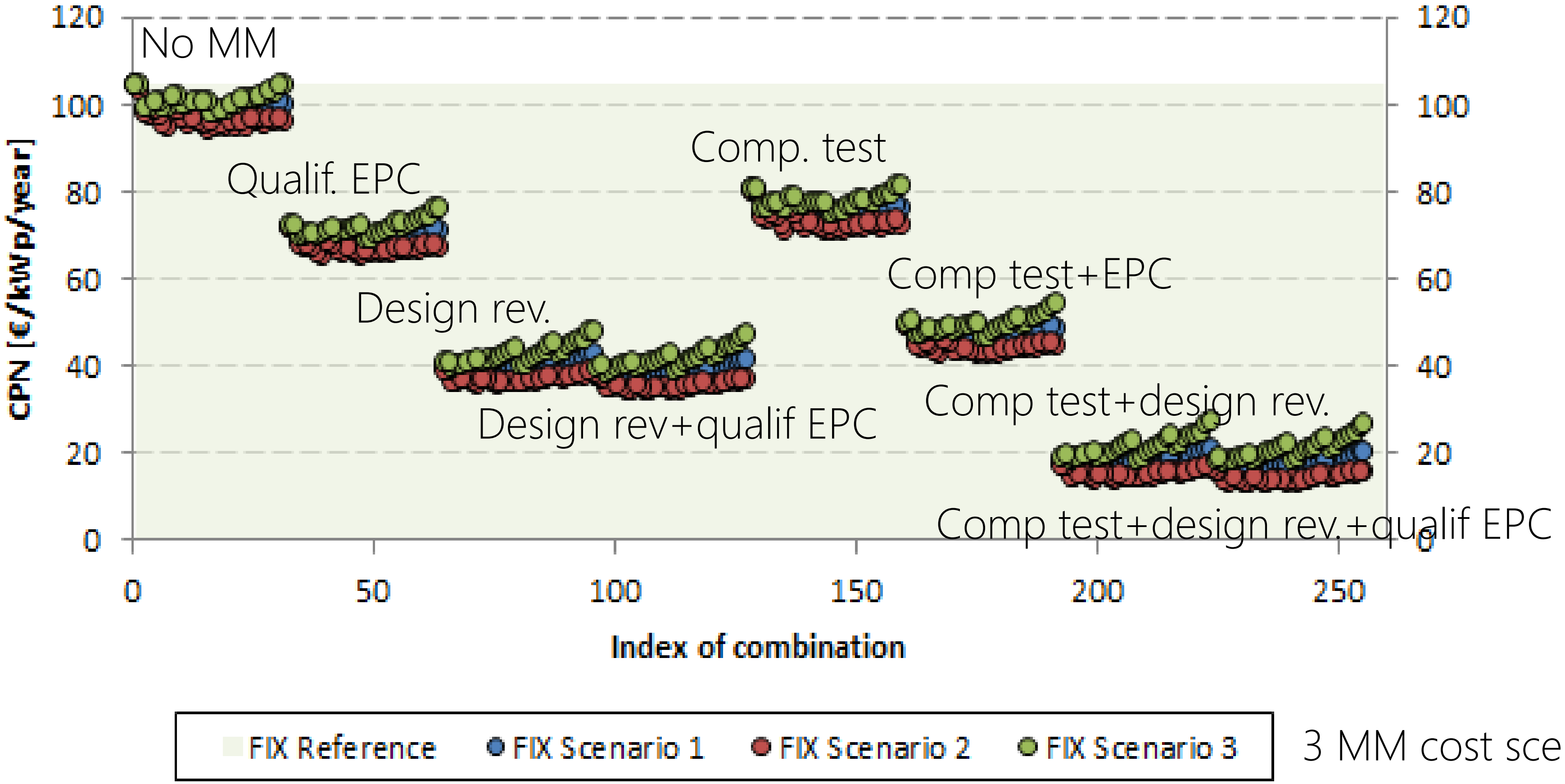
- Preventive measures
- Corrective measures

Mitigation Measure	Affected Parameter
Component testing – PV modules	number of failures
Design review + construction monitoring	number of failures
Qualification of EPC	number of failures
Advanced monitoring system	time to detection
Basic monitoring system	time to detection
Advanced inspection	time to detection
Visual inspection	time to detection
Spare part management	time to repair/substitution

Impact of Applied Mitigation Measures

- New CPN results of mitigation measure combinations for different cost scenarios compared to CPN without mitigation measures

Preventive measures have higher impact



3 MM cost scenarios

Risk Scenario

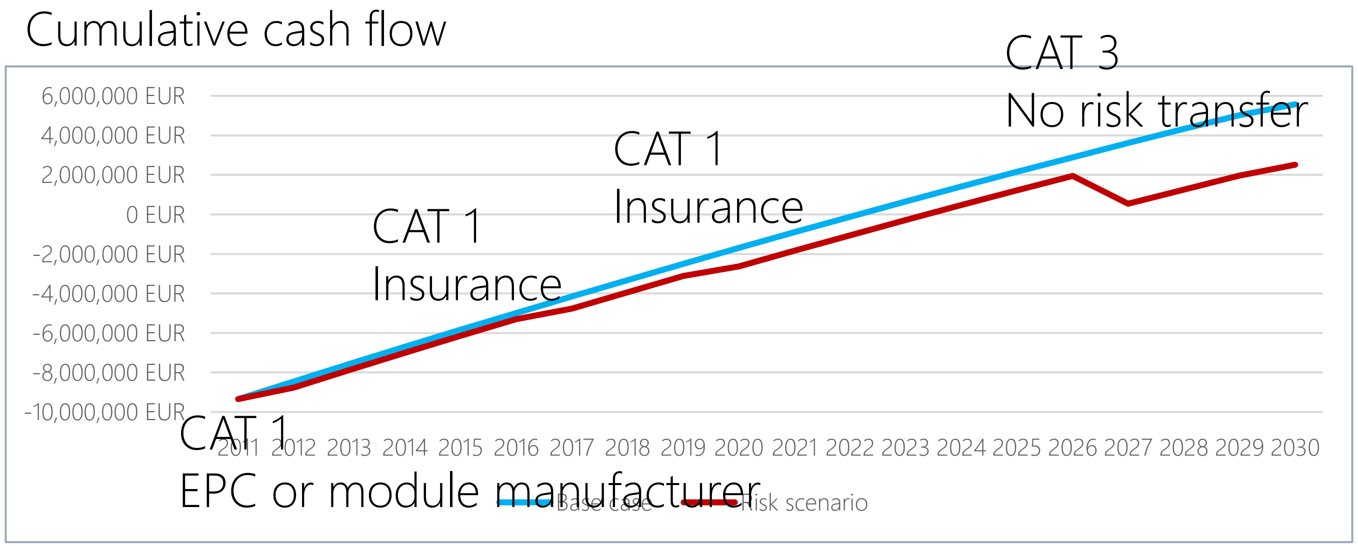
Risk scenario - businss model 3

Risk	Risk number	Risk name	Start Date	Case	Phase
Risk 1	3020	Hotspot of modules	01.01.2012	Best	Infant
Risk 2[2)]	3101	Flooding of inverter	01.08.2017	Worst	Mid-life
Risk 3[1)]	3051	Lightning strike of inverter	01.06.2020	Worst	Mid-life
Risk 4	3011	Failure of bypass diode and juction box	01.10.2026	Worst	Wear-out

Comments

1) External cause independent from project phase

2) Business model specific risk, i.e. due to system design/technology, geographic/climatic conditions



eurac research

Take home messages

- Availability of large datasets is key (field inspections, monitored data, O&M tickets, etc)
- Improved Yield Assessment (reduction of uncertainty)
- Economic impact of failures in the field can be modelled and calculated
- **Yield modelling will also have an impact on LCC / LCA analysis!**

LCOE: the best friend and enemy of the PV sector

Try always to quantify quality!

Literature on quality

O&M Best Practice Guidelines Version 4.0

At the O&M and Asset Management 2019 conference in London, SolarPower Europe launched Version 4.0 of the O&M Best Practice Guidelines. This new version builds

05/12/2019

Asset Management Best Practice Guidelines Version 2.0

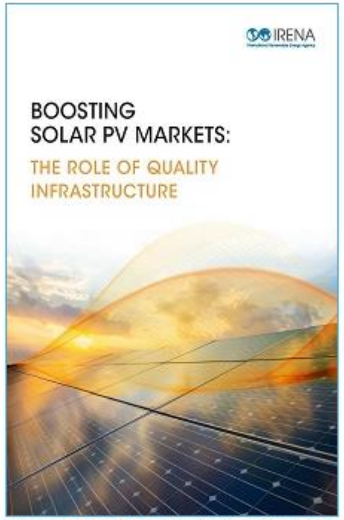
SolarPower Europe has launched Version 2.0 of the Asset Management Best Practice Guidelines. Building on a successful Version 1.0 published in December 2019, this update

23/11/2020

Engineering, Procurement & Construction Best Practice Guidelines Version 1.0

SolarPower Europe has launched the Engineering, Procurement and Construction (EPC) Best Practice Guidelines. Following a year of intensive work, we are very proud to present

24/11/2020

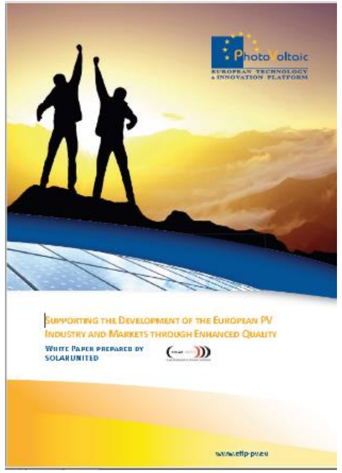


Boosting global PV markets: The role of quality infrastructure

SolarPower Europe

PhotoVoltaic European Technology & Innovation Platform

International Energy Agency Photovoltaic Power Systems Programme



IRENA International Renewable Energy Agency

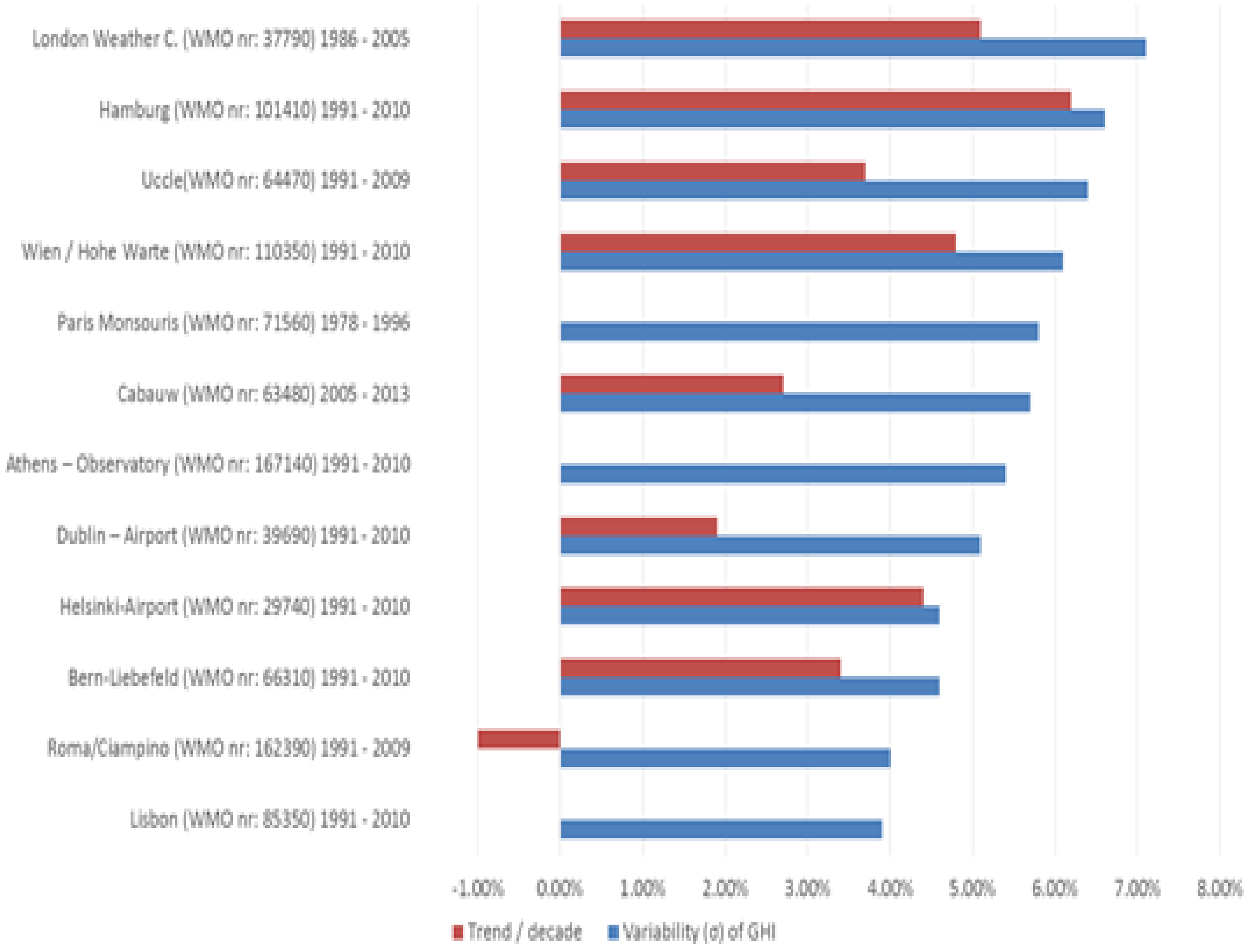
SOLARUNITED

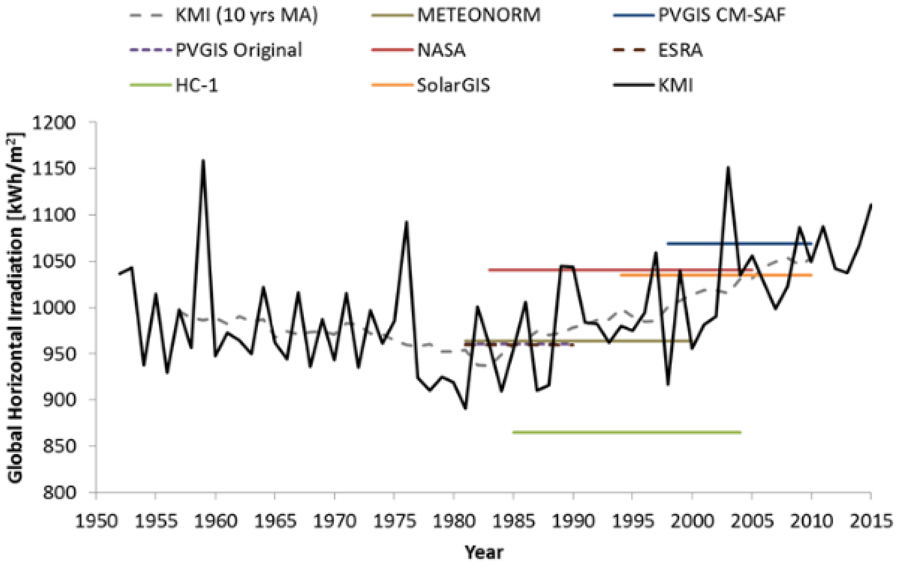
PVQAT International PV Quality Assurance Task Force

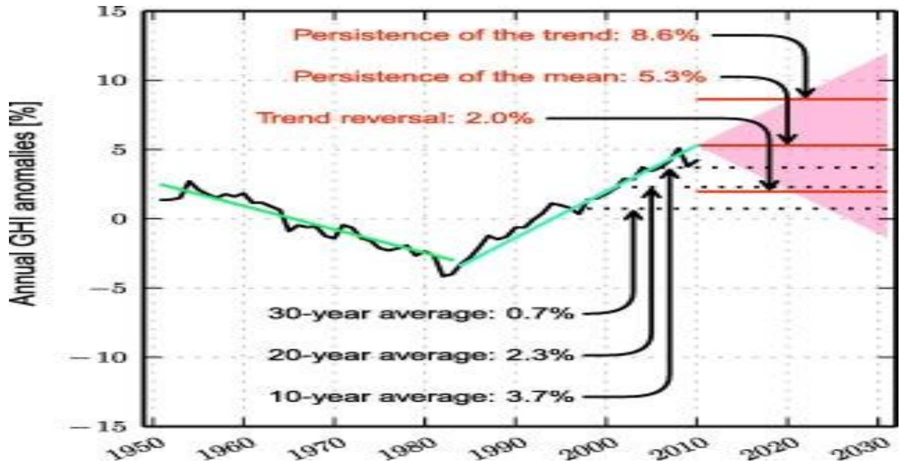
Thank you for your attention

www.eurac.edu/
David.moser@eurac.edu

Irradiance measurements and solar resource assessment: irradiance variability and trends





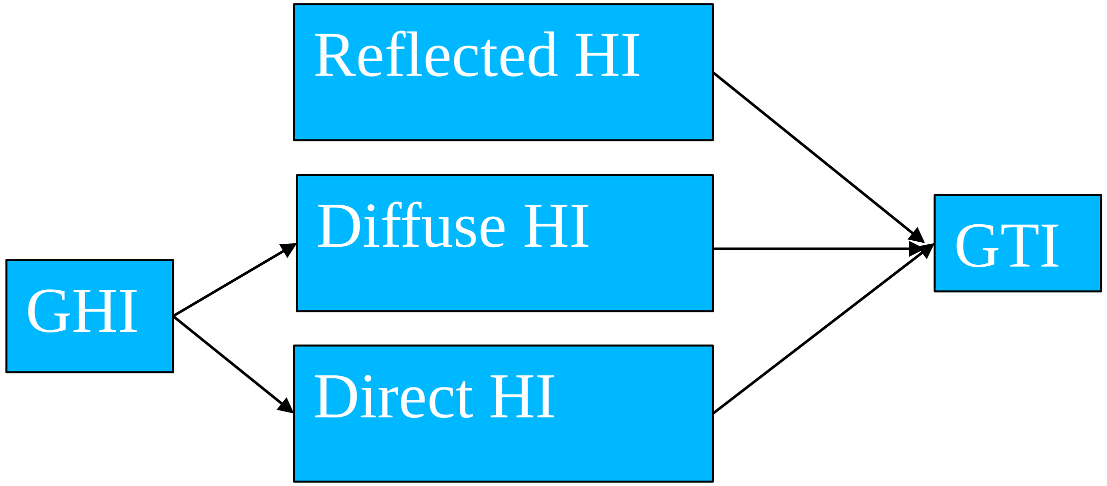


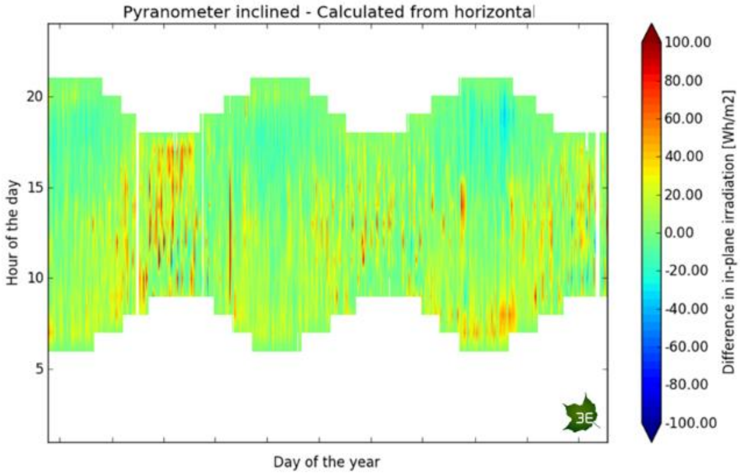
D. Moser *et al.*, "Technical Risks in PV Projects." Solar Bankability Deliverable www.solarbankability.com

IEA PVPS Task 13, Subtasks 2.3 & 3.1 Report IEA-PVPS T13-12:2018 April 2018

Irradiance measurements and solar resource assessment: G_POA, decomposition and transposition models

		Hay	Isotropic	Muneer	Perez
nrmse	Erbs	28.8%	28.8%	28.9%	18.7%
	Ruiz_G0	5.1%	5.8%	5.3%	6.3%
	Ruiz_G2	5.4%	5.4%	5.6%	6.4%
	Skartveit	4.8%	6.6%	4.8%	5.2%
nmbe	Erbs	-14.7%	-14.8%	-14.7%	-9.7%
	Ruiz_G0	1.1%	-1.3%	1.5%	2.7%
	Ruiz_G2	1.3%	-1.0%	1.7%	2.8%
	Skartveit	0.0%	-2.5%	0.4%	1.4%
nmae	Erbs	17.3%	17.3%	17.3%	11.3%
	Ruiz_G0	3.4%	3.8%	3.5%	4.3%
	Ruiz_G2	3.5%	3.6%	3.6%	4.3%
	Skartveit	3.0%	4.2%	3.1%	3.5%

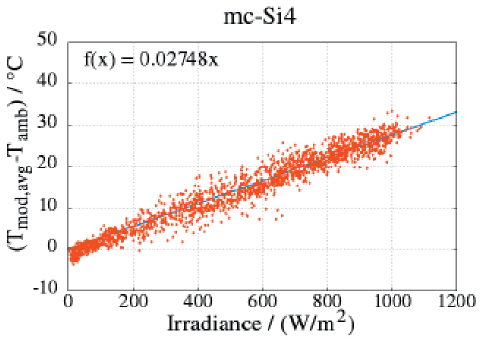


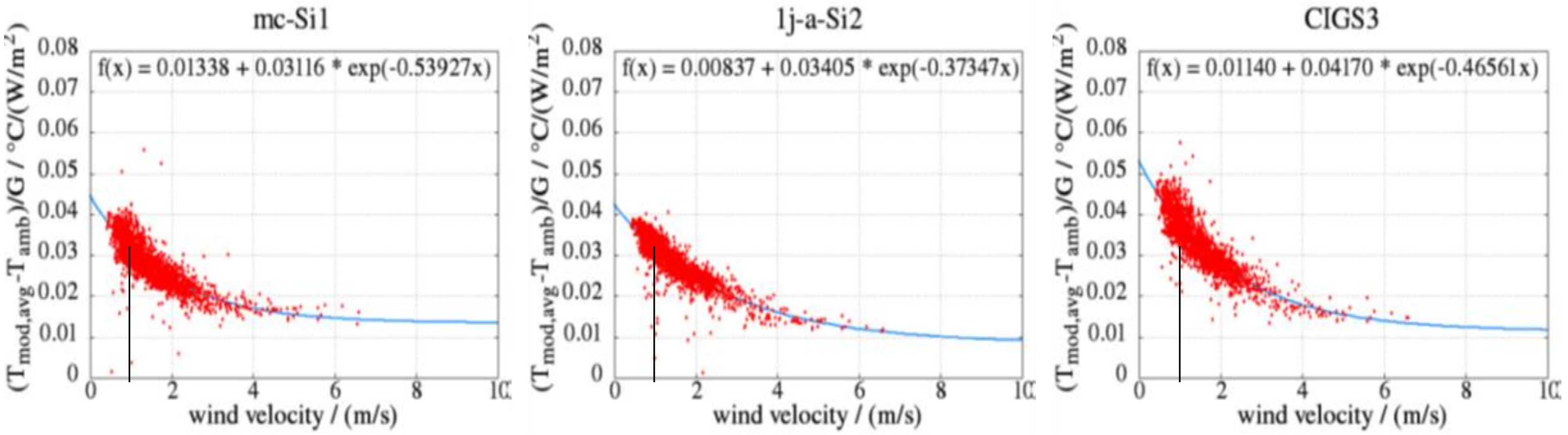


Credits: 3e

Temperature: environmental conditions and module temperature calculation

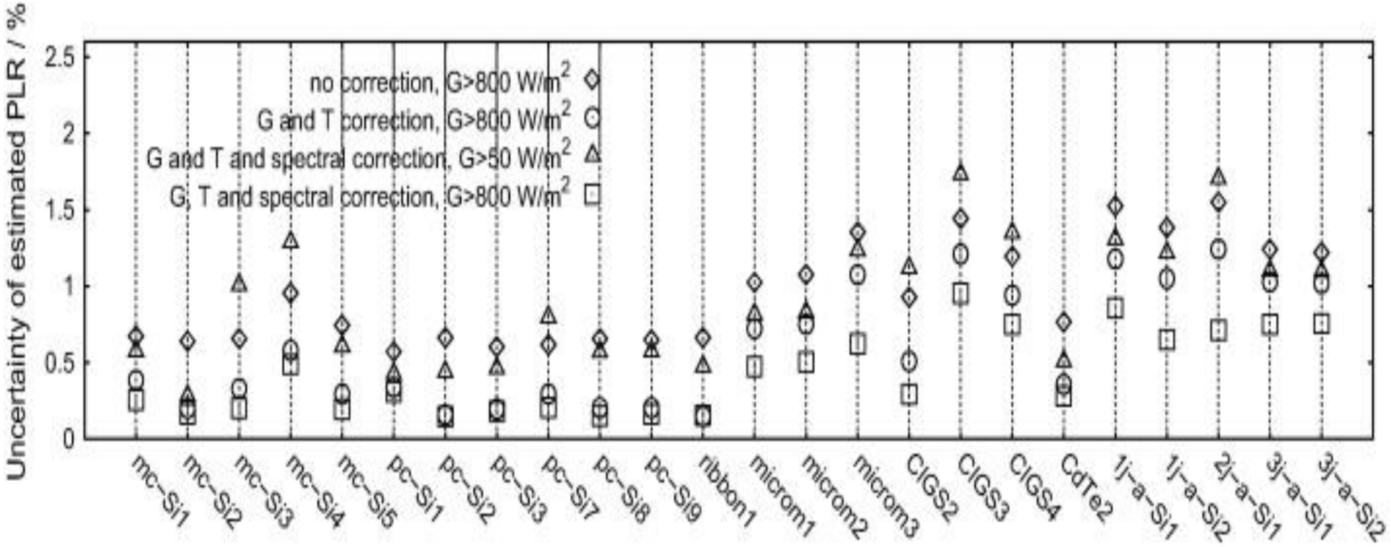
nr.	name	technology	Stratigraphy	Frame	$k_{Tmod,c}$ (K m²/W)	RMSE$_{k_Tmod,c}$
1	CIGS3	CIGS	glass-glass (G-G)	WF	0.037	2.3
2	mc-Si4	m-Si-back contact	glass-tedlar (G-T)	WF	0.029	2.0
3	mc-Si3	m-Si	glass-tedlar (G-T)	WF	0.032	2.2
4	mc-Si1	m-Si	glass-glass (G-G)	NF	0.033	2.0
5	mc-Si2	m-Si	glass-glass-black sheet (G-G$_{bs}$)	NF	0.035	2.4
6	1j-a-Si2	a-Si	glass-tedlar (G-T)	WF	0.031	1.7

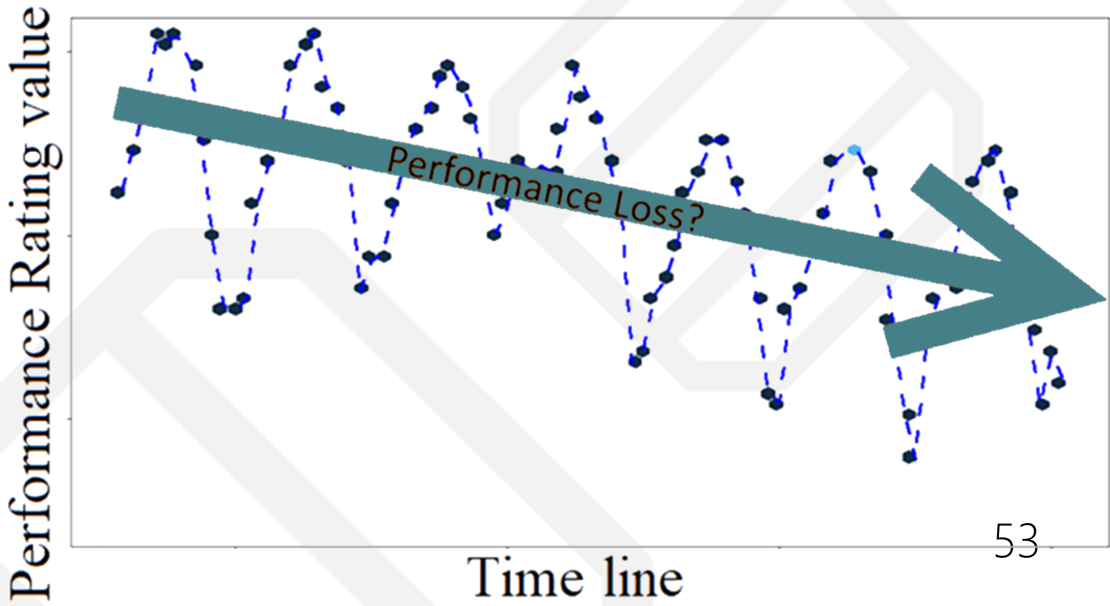




Maturi L., BiPV System Performance and Efficiency Drops: Overview on PV Module Temperature Conditions of Different Module Types, Energy Procedia 48 2014 1311-1319

Performance Loss Rate

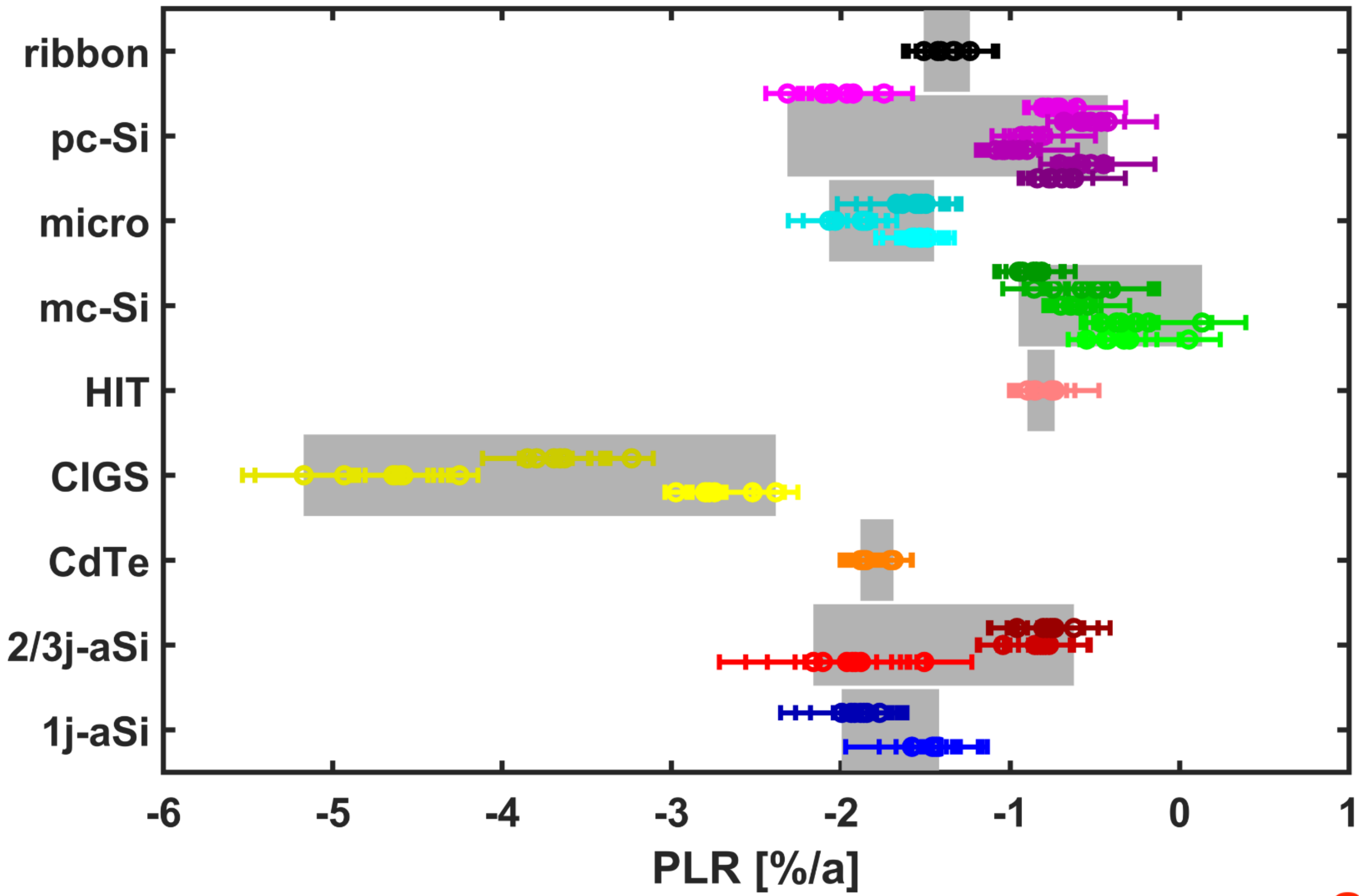




PEARL PV

The cost of PV electricity: system lifetime

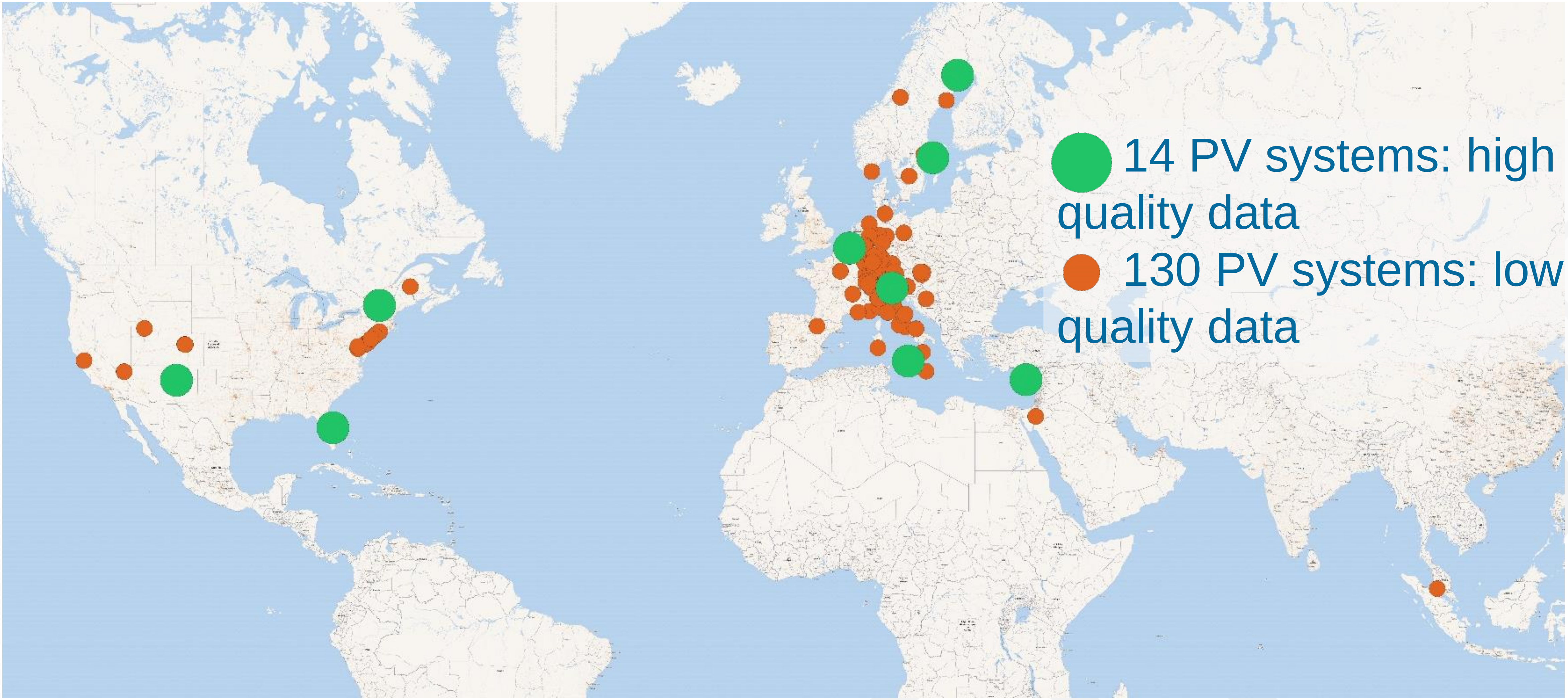
Data from ABD plant



Source: EURAC

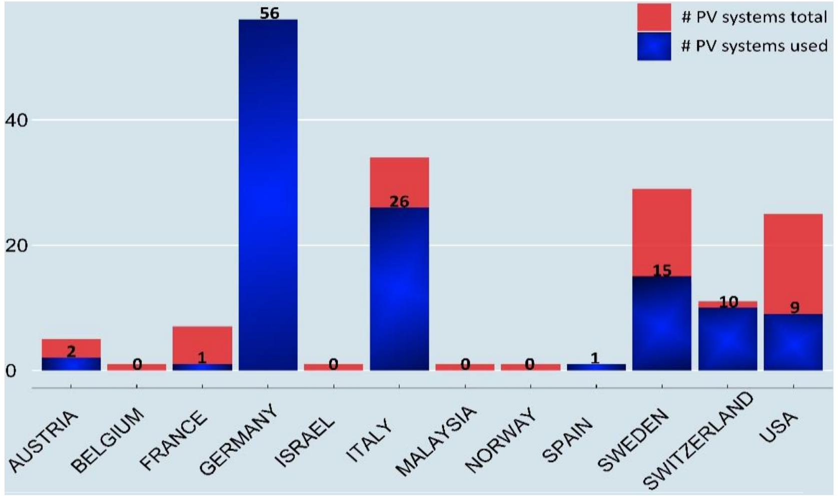
eurac research

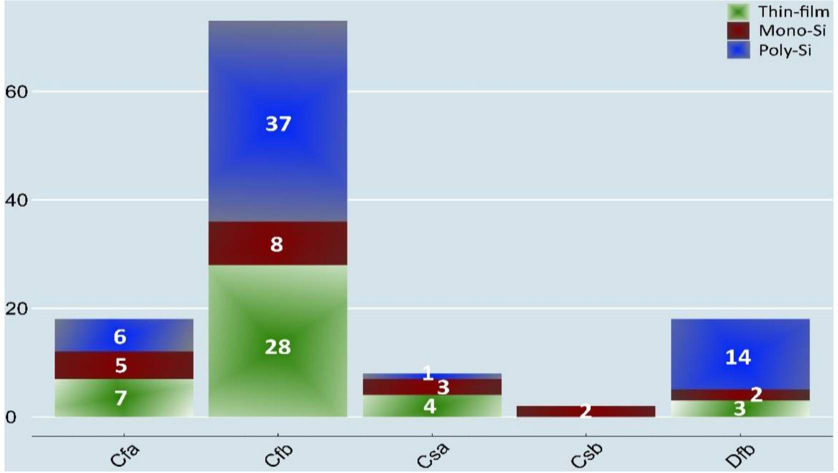
Benchmarking in IEA-PVPS Task 13



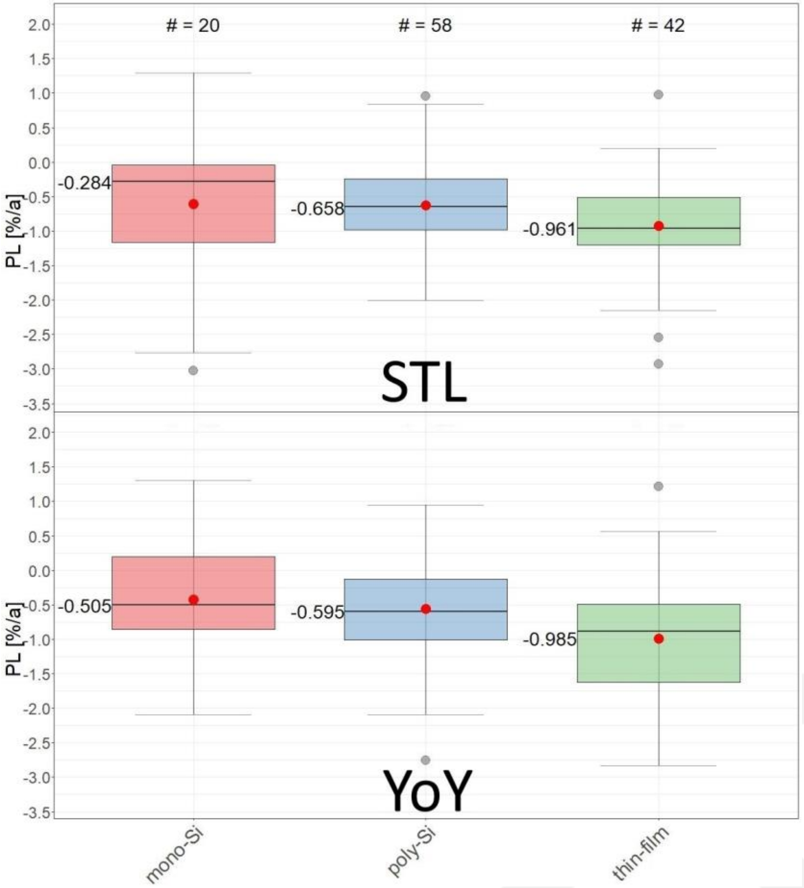
Benchmarking in IEA-PVPS Task 13

Performance Loss Rate

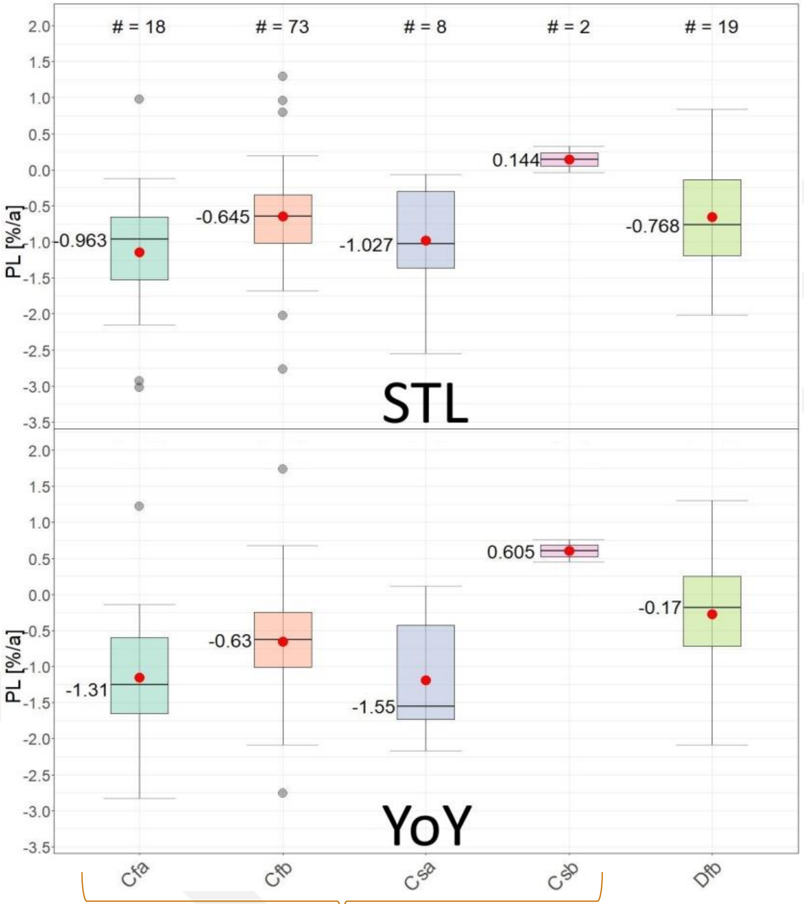




Technology



Climate



Temperate
Continental

P A R L P V

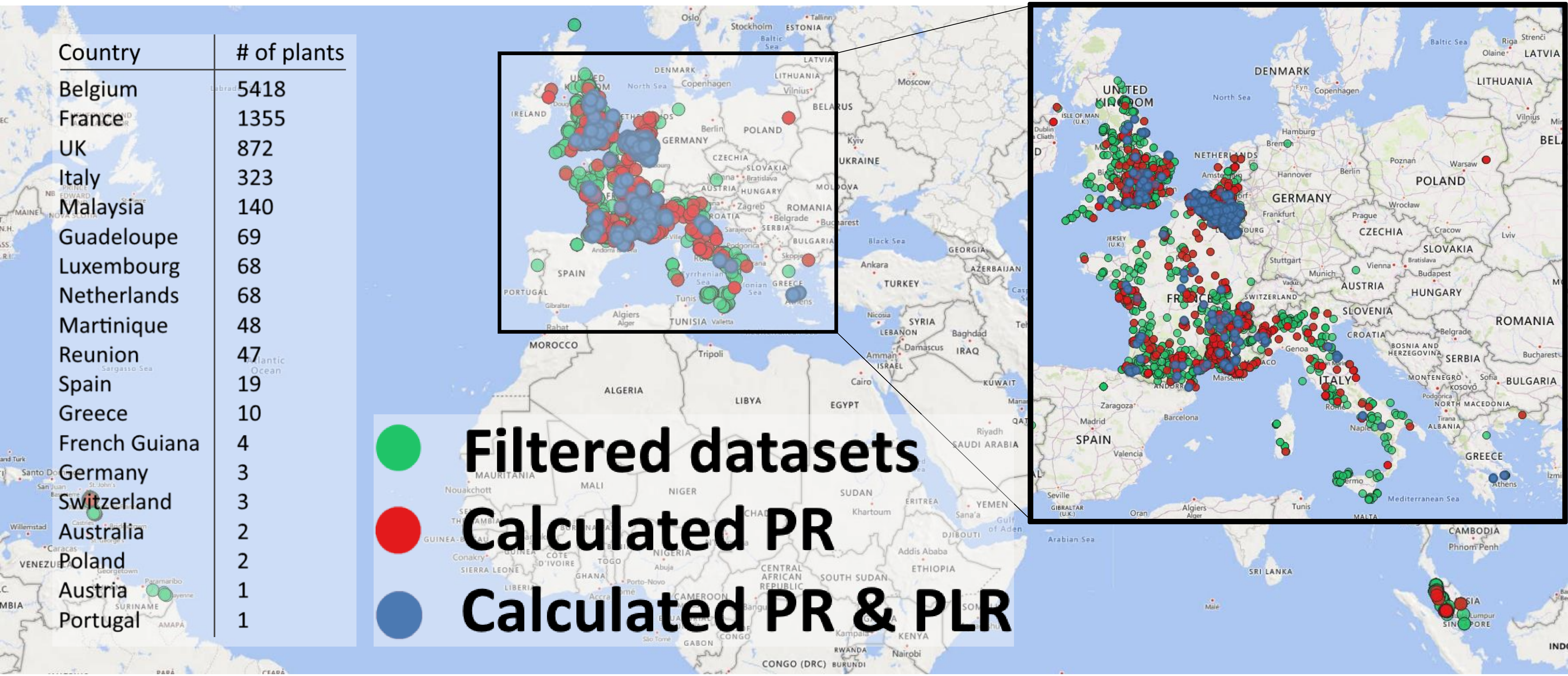
Performance Loss Rates of PV systems of Task 13 database, Sascha Lindig, David Moser, Alan Curran and Roger French, IEEE PVSC Chicago 2019

P E A R L P V

https://www.pearlpv-cost.eu/

Benchmarking in PEARL-PV

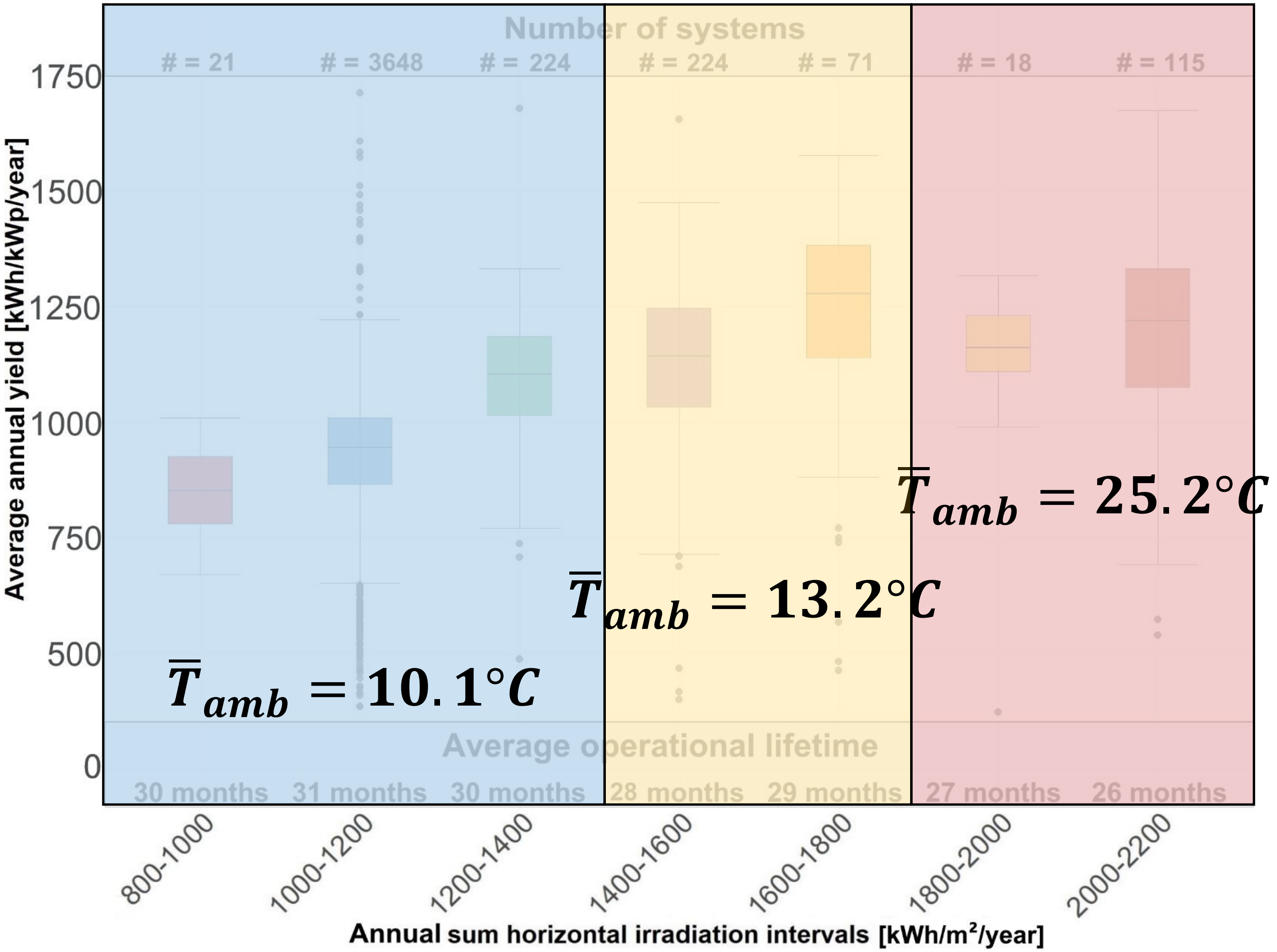
Country	# of plants
Belgium	5418
France	1355
UK	872
Italy	323
Malaysia	140
Guadeloupe	69
Luxembourg	68
Netherlands	68
Martinique	48
Reunion	47
Spain	19
Greece	10
French Guiana	4
Germany	3
Switzerland	3
Australia	2
Poland	2
Austria	1
Portugal	1



- Filtered datasets (green)
- Calculated PR (red)
- Calculated PR & PLR (blue)

Performance analysis and degradation of a large fleet of PV systems, S. Lindig et al, IEEE Journal of Photovoltaics, accepted, 2021

Energy Yield

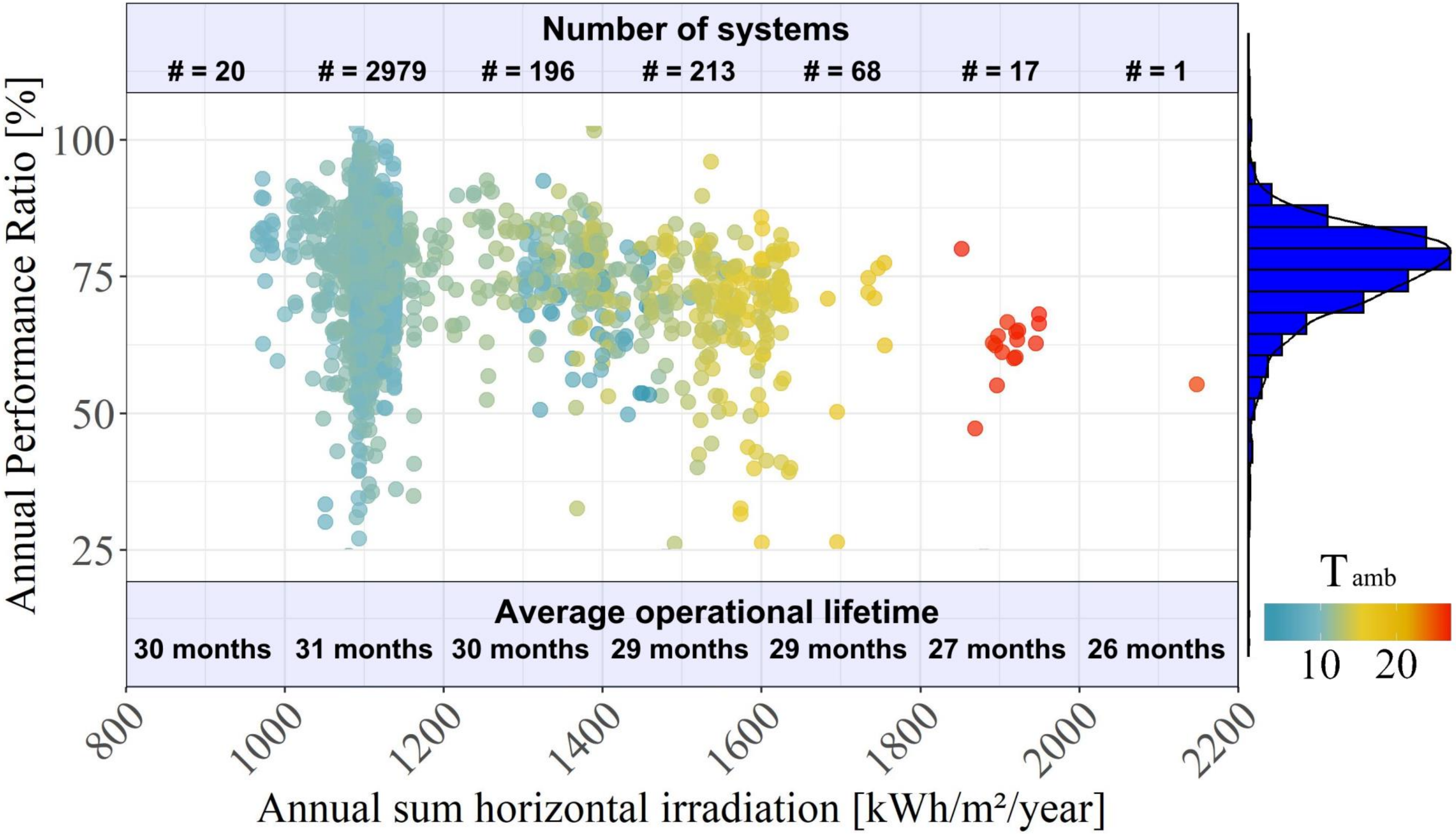


$\overline{yield} = 954.9 \frac{kWh}{kWp}$ per year

$\widetilde{yield} = 961.5 \frac{kWh}{kWp}$ per year

Performance analysis and degradation of a large fleet of PV systems, S. Lindig et al, IEEE Journal of Photovoltaics, accepted, 2021

Performance Ratio



$\overline{PR} = 76.7\%$

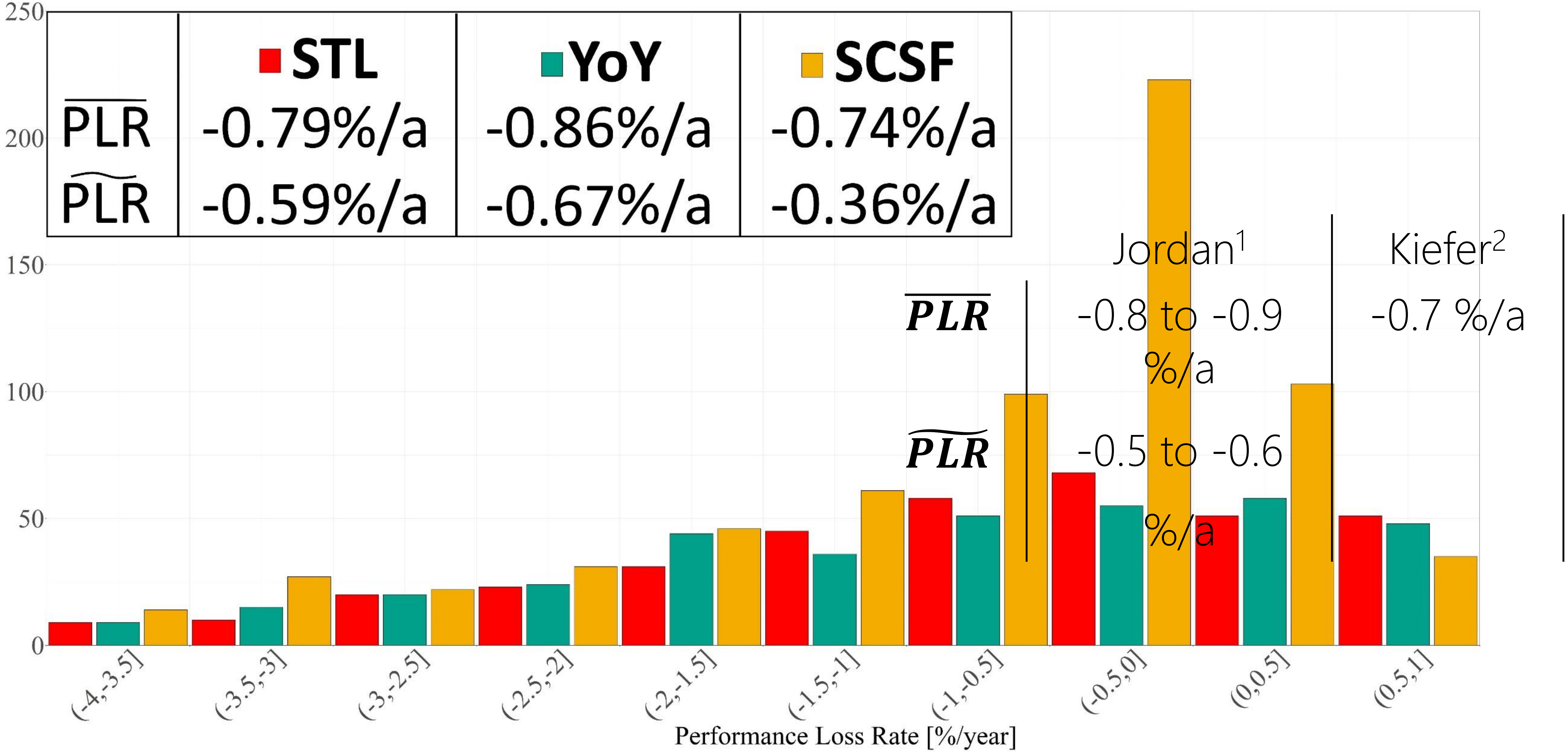
$\widetilde{PR} = 78.4\%$

Performance analysis and degradation of a large fleet of PV systems, S. Lindig et al, IEEE Journal of Photovoltaics, accepted, 2021

Performance Loss Rates

	STL	YoY	SCSF
$\overline{PLR}$	-0.79%/a	-0.86%/a	-0.74%/a
$\widetilde{PLR}$	-0.59%/a	-0.67%/a	-0.36%/a

	Jordan[1]	Kiefer[2]
$\overline{PLR}$	-0.8 to -0.9 %/a	-0.7 %/a
$\widetilde{PLR}$	-0.5 to -0.6 %/a	



[1] D. C. Jordan, et al, "Compendium of photovoltaic degradation rates," *Progress in Photovoltaics Research and Application*, vol. 24, no. 7, pp. 978-980, 2016.
[2] K. Kiefer, et al, "Degradation in PV Power Plants: Theory and Practice," in *36th EU PVSEC, Marseille*, 2019.

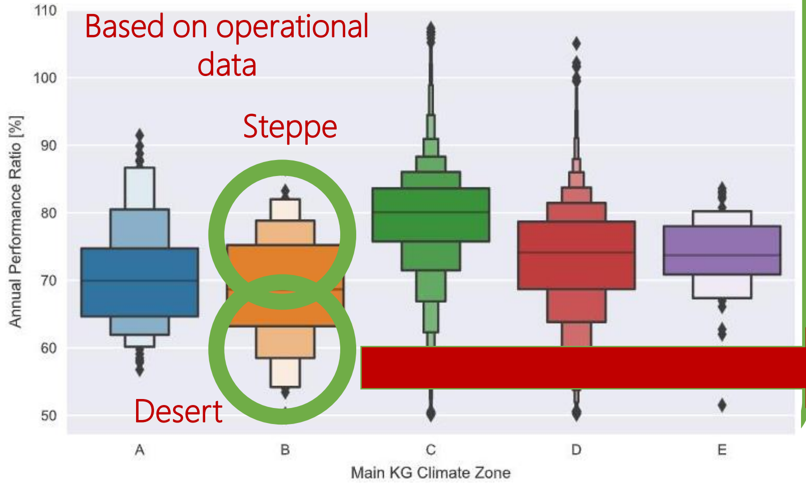
PV Component-Benchmarking

TRUSTPV
SOLAR PV, PERFORMANCE & RELIABILITY

Big data techniques applied on one of the largest PV portfolio (+16GW) including metadata, operational data and ticketing data to evaluate the performance and reliability of PV components

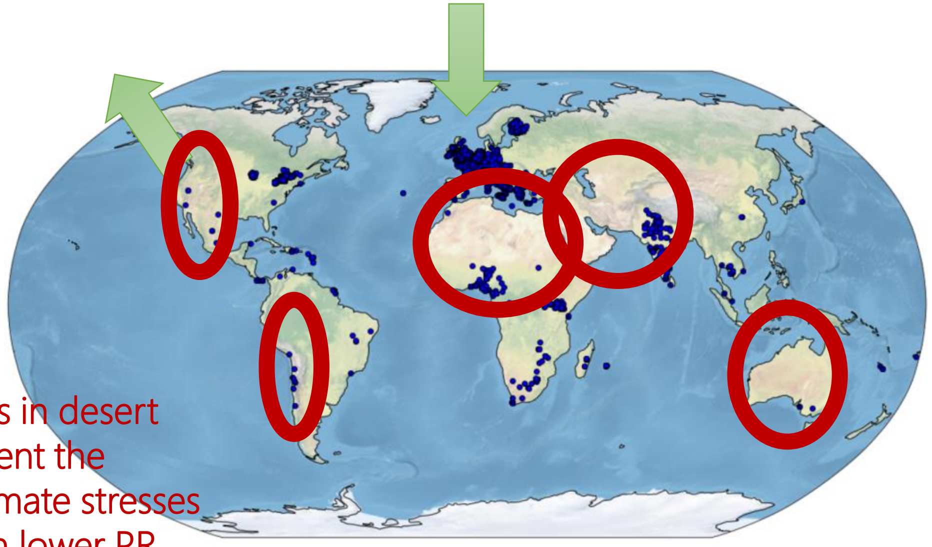
- Identify main performance and degradation losses factors
- Modelling Climate Stressors and Reliability Indicators (time-to-fail, lifetime,…)
- Improve manufacturing processes, system designs, and O&M activities
- Establish the needs of new labels

KG Climate Zone
- A (Tropical)
- B (Arid)
- C (Temperate)
- D (Continental)
- E (Polar)



Extending the datasets to Desert Climates would enable…

Until now, data mainly on Temperate Climates

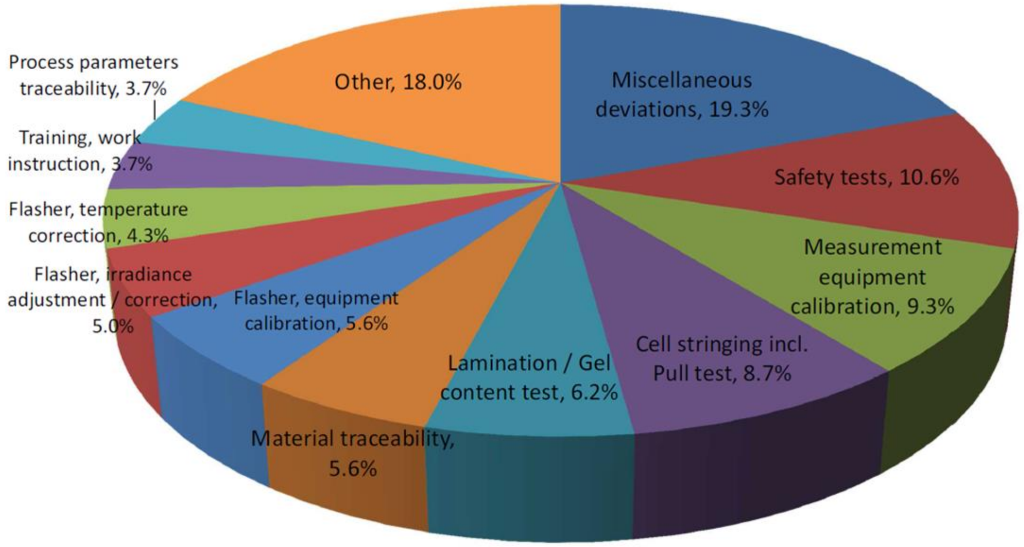


PV systems in desert areas present the highest climate stresses reflected in lower PR (and higher PLRs)

Quantification of the economic impact of technical risks

Shading problems due to nearby object / bad planning

Quantification of the economic impact of technical risks



161 deviations in 73 factory inspections carried out in around 2 years were identified, resulting in an average of 2.2 deviations per inspection

Many deviations are related to determination of Pn. Overestimation of output power is a problem

TÜVRheinland®
Precisely Right.