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eurac research

PV Performance and Reliability

David Moser

UNSW SYDNEY – SPREE Talk 1 August 2019

Eurac Research is a private research centre founded in 1992 in Bolzano (South Tyrol).

The Institute for Renewable Energy at Eurac Research

The Institute for Renewable Energy at Eurac Research conducts **applied research** on how to **produce energy** using **advanced energy systems** based on sustainable energy sources, how to **manage** them and **reduce** their consumption.

We study and execute **products**, **technologies** and **solutions** for private businesses, utilities, public administrations, researchers and professionals working in **several sectors**.

Sustainable Heating and Cooling Systems

Photovoltaic Energy Systems

Energy efficient buildings

Energy Retrofit of Historic Buildings

Urban and Regional Energy Systems


~ 100
collaborators
~ 50 projects and
consultancies
7 labs
eurac research

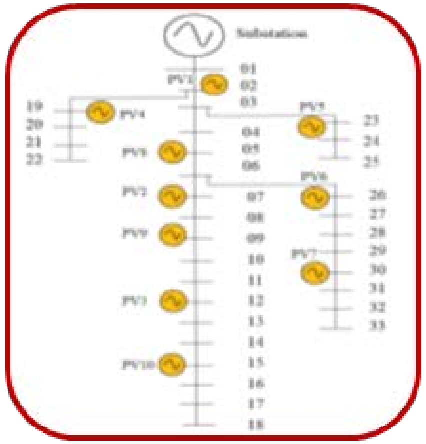
Photovoltaic Energy System group: Our topics

Quality and Sustainability of the PV sector

Performance & Reliability

PV in buildings

PV in grids



Solar Resource Assessment

Solar economics

Impact strategy

European PV Technology and Innovation Platform
Member of the steering committee

Contribution on ad-hoc groups:
BIPV
LCOE
Grid integration
Quality

EUREC
The Association of the European Renewable Energy Research Centres

Pushing renewables and energy efficiency in the EC agenda

PVPS TASK 13
PVPS TASK 15

Performance and Reliability
BIPV

PEARL PV

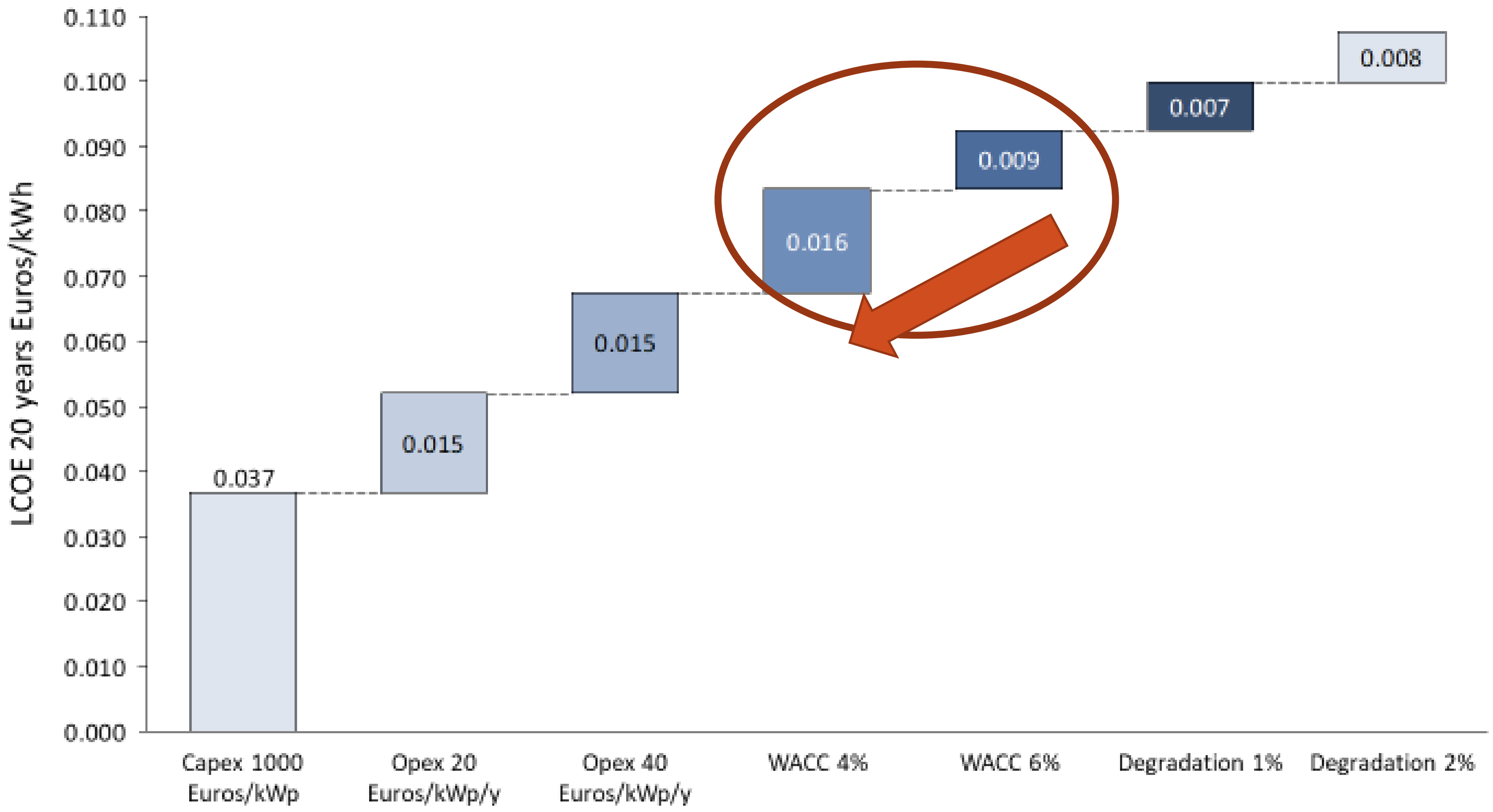
Performance and Reliability
Quality
BIPV
Grid integration

WG1 TC82

Norms and standardisation

The Quest for Quality

Does quality have a real impact on the LCOE?



ETIP PV Conference

PhotoVoltaic
EUROPEAN TECHNOLOGY & INNOVATION PLATFORM

QUALITY AND SUSTAINABILITY OF PV SYSTEMS CONFERENCE

3 May 2018 • BIP, Rue Royale 2-4, Brussels

- quality in PV has a leverage effect with the benefits that can clearly offset the added costs
- bankability is a variable concept depending on stakeholders and context while quality is an absolute value
- feedback loop from downstream to upstream is essential to define what is really needed in terms of quality checks of PV components
- large scale performance data are much needed to be able to better assess and improve the assumptions in business models

The journey: quality, performance and reliability

PhotoVoltaic European Technology & Innovation Platform

2000… 2010 2015 2017 2018 2019 2020 2022

IEA PVPS Task 2

PV performance database

IEA PVPS Task 13

PV performance database
Failure review in the field
Uncertainty framework

Solar Bankability

Technical risk framework
CPN methodology

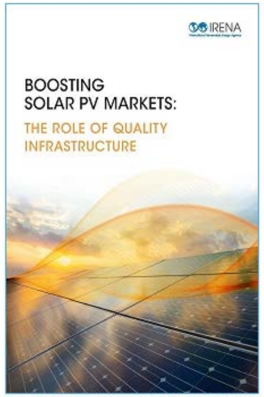
solartrain

PEARL PV

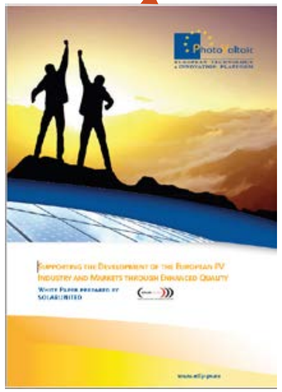
PV performance database

PV 4.0

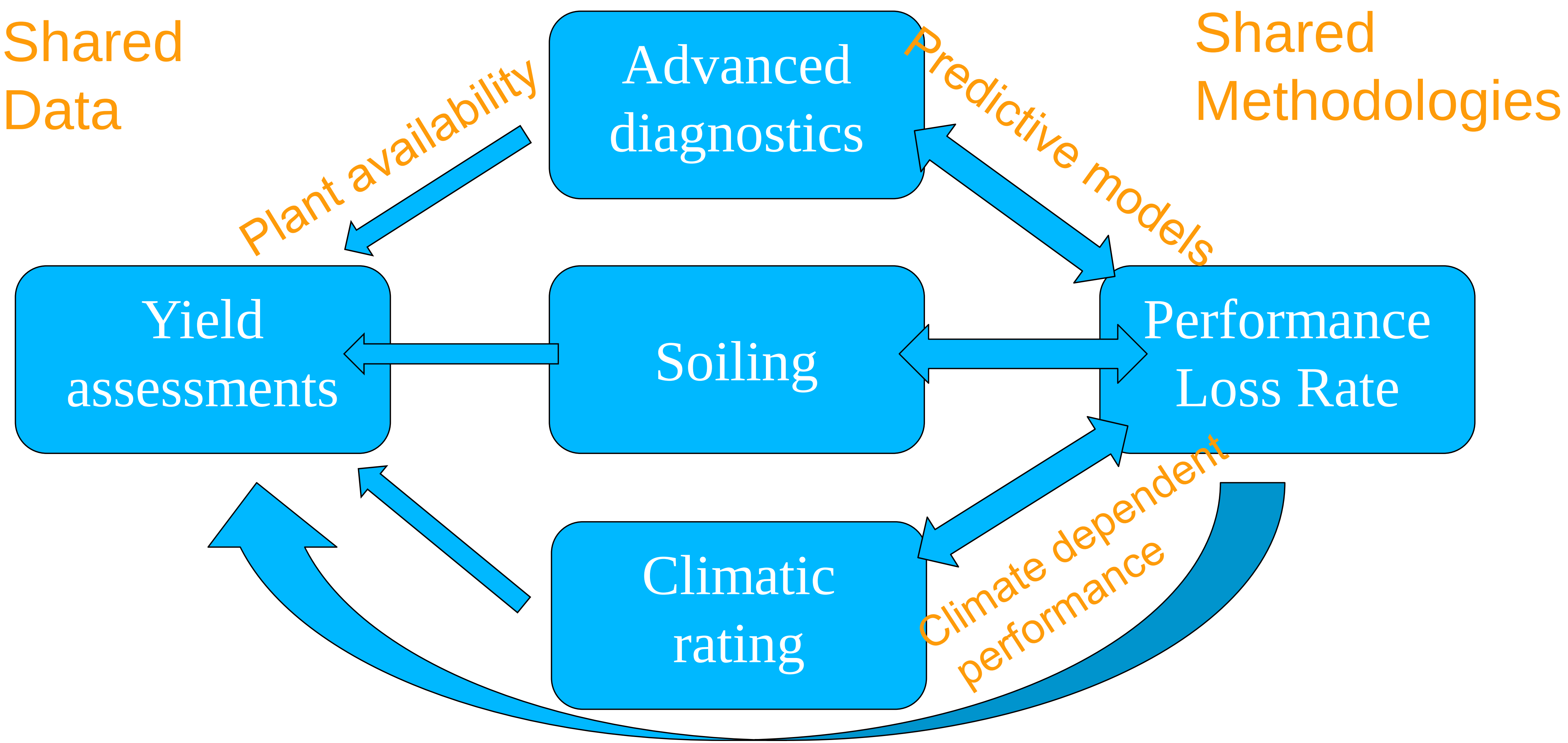
Industry4.0 + IoT platform
Big data analytics



Boosting global PV markets: The role of quality infrastructure



IEA PVPS Task 13: ST2 activities



Technical risks framework

Tracking defects in the field

International Energy Agency
Photovoltaic Power Systems Programme

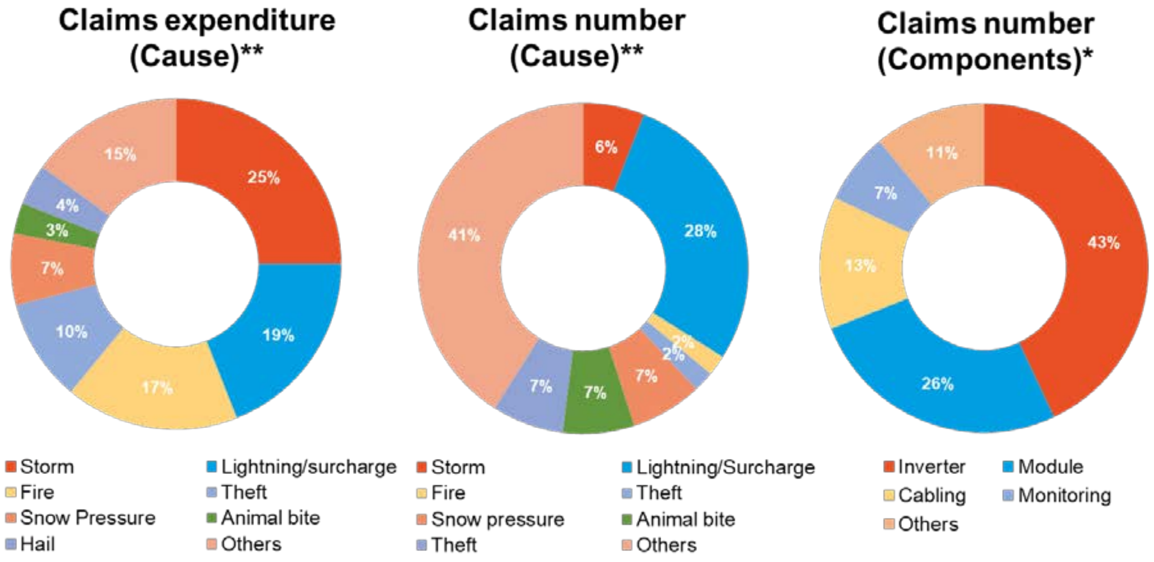
TASK13: Review of Failures of Photovoltaic Modules, M. Köntges et al

Failure description → Failure mechanisms and detection → Performance loss

Majority of returns associated with failures that can be detected visually (underestimation of other type of failures?)

Systematic use of visual inspection → Large dataset of failures

Large datasets available from
- Field inspections
- O&M ticketing system
- Insurance claims
- Third party review



* Source ACCELIOS 2012-2015
** Mannheimer 2003-13

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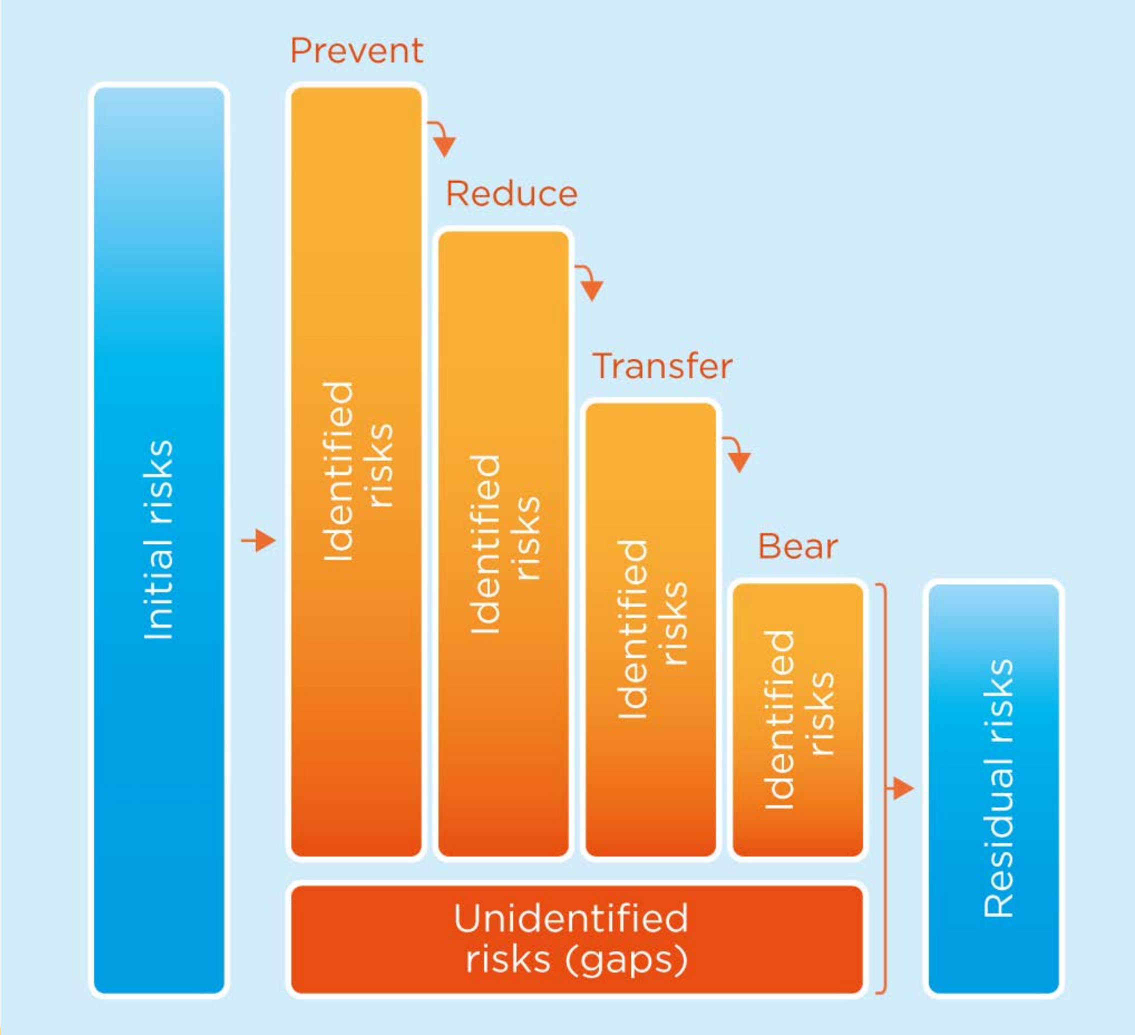
Risk assessment



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

Technical risk framework

A	Risk identification
B	Risk assessment
C	Risk management
D	Risk controlling

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Technical Risks Matrix

	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

Technical Risks Matrix

SOLAR BANKABILITY

Product Development → Assessment of PV Plants

Product testing

Modules	....	....	....	....
Inverter	....	....	....	....
Mounting stru	....	....	....	....
Connection & distribution boxes	....	....	....	....
Cabling	....	....	....	....
Potential equalization grounding, LPS	....			....
Weather station, communication, monitoring		....	....	....
Infrastructure & environmental influer	....	....	....	....
Storage system	....	....	....	....
Miscellaneous	....	....	....	....

- 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

List of failures

Uncertainty

Technical Risks Matrix

Product Development → Assessment of PV Plants

Planning

Modules	....	....	....	....	....
Inverter	....			....	....
Mounting structure				....	....
Connection & distribution boxes				....	....
Cabling	....			....	....
Potential equalization & grounding, LPS	....			....	....
Weather station, communication, monitoring	....			....	....
Infrastructure & environmental influence	....			....	....
Storage system	....			....	....
Miscellaneous	....			....	....

f failures

- 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

Uncertainty

Technical Risks Matrix

Product Development | Assessment of PV Plants

Planning

Modules	....	....	....	....	....
Inverter	....			....	....
Mounting structure				....	....
Connection & distribution boxes				....	....
Cabling	....			....	....
Potential equalization & grounding, LPS	....				....
Weather station, communication, monitoring	....			....	....
Infrastructure & environmental influence	....			....	....
Storage system	....			....	....
Miscellaneous	....			....	....

- Soiling
- Shadow diagram
- Modules mismatch
- Modules not certified
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- 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

f failures

Uncertainty

Technical Risks Matrix

Product Development → Assessment of PV Plants

Planning

Modules	....	....	....	....	....
Inverter	....			....	....
Mounting structure				....	....
Connection & distribution boxes				....	....
Cabling	....			....	....
Potential equalization & grounding, LPS	....				....
Weather station, communication, monitoring	....			....	....
Infrastructure & environmental influence	....			....	....
Storage system	....			....	....
Miscellaneous	....			....	....

f failures

- 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

Uncertainty

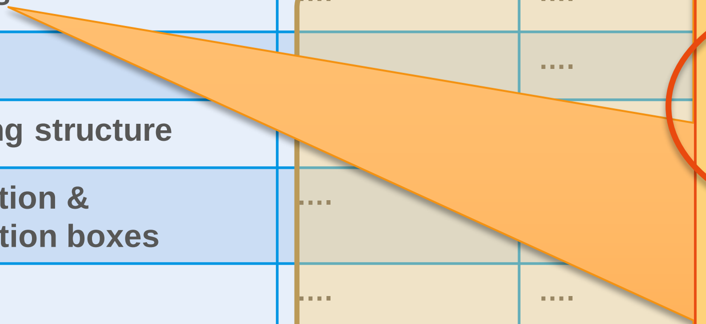
Technical Risks Matrix

Product Development → Assessment of PV Plants

Transportation / installation

Modules	....	....			....
Inverter		....			....
Mounting structure					....
Connection & distribution boxes	....				....
Cabling	....	....			....
Potential equalization & grounding, LPS	....	....			....
Weather station, communication, monitoring	....	....			....
Infrastructure & environmental influence	....	....			....
Storage system	....	....			....
Miscellaneous	....	....			....

Lis res



- **Module mishandling (glass breakage)**
- **Module mishandling (cell breakage)**
- **Module mishandling (defective backsheet)**
- **Incorrect connection of modules**
- **Bad wiring without fasteners**

Precursors

Technical Risks Matrix

Product Development → Assessment of PV Plants

O&M

Modules	....	....	....		
Inverter		....	....		
Mounting structure	....				
Connection & distribution boxes	....	....			
Cabling	....	....	....		
Potential equalization & grounding, LPS	....	....	....		
Weather station, communication, monitoring	....	....	....		
Infrastructure & environmental influence	....	....	....		
Storage system	....	....	....		
Miscellaneous	....	....	....		

List of fa

- 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

Quantifiable impact

Technical Risks Matrix

SOLAR BANKABILITY

Product Development → Assessment of PV Plants

O&M

Modules	....	....	....
Inverter		....	....
Mounting structure	....		
Connection & distribution boxes	....	....	
Cabling	....	....	....
Potential equalization & grounding, LPS	....	....	
Weather station, communication, monitoring	....	....	....
Infrastructure & environmental influence	....	....	....
Storage system	....	....	....
Miscellaneous	....	....	....

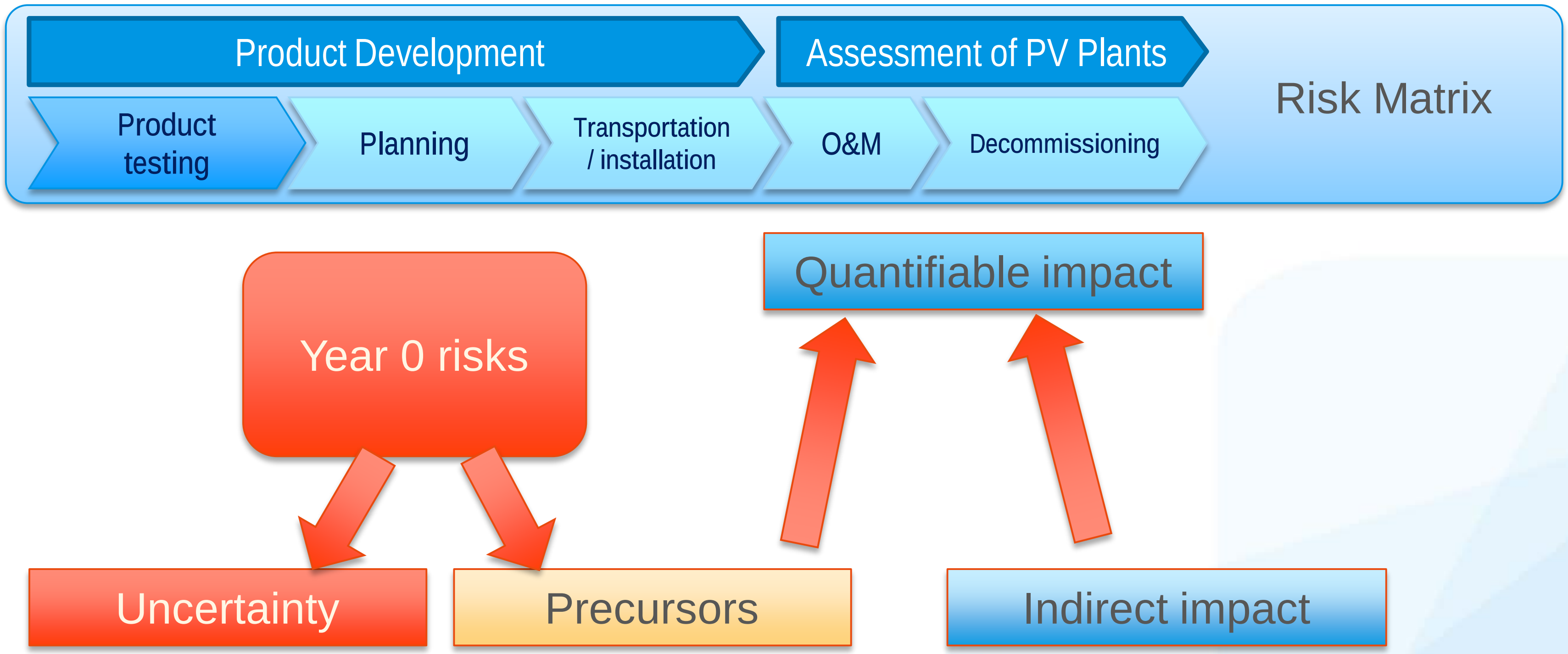
List of fa

- 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

Indirect impact

Classification of technical risks

- Category of risk
- Common nomenclature
- Standardised quantification



Impact
- on uncertainty (exceedance Probability)
- on CAPEX
- on CPN (O&M)

Technical risk framework

A	Risk identification
B	Risk assessment
C	Risk management
D	Risk controlling

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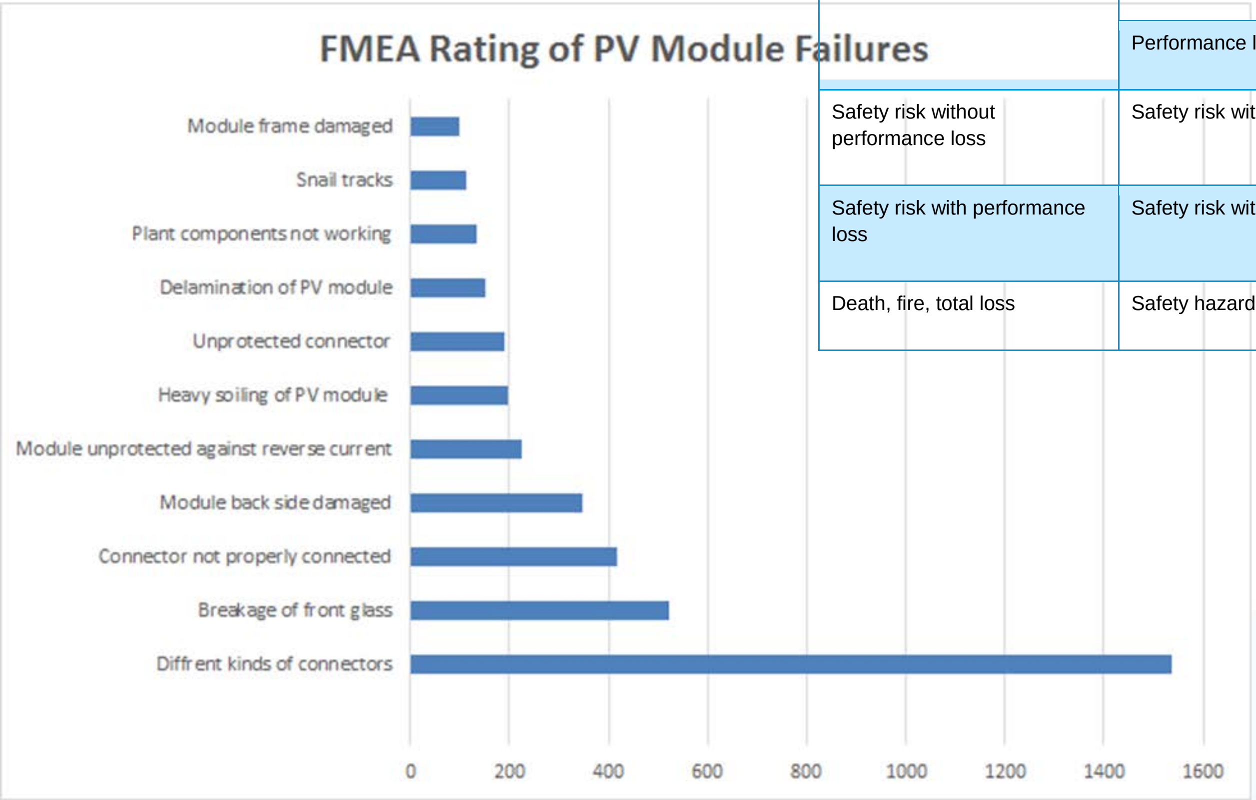
FMEA approach

RPN = S x O x D

Severity	Criteria	Ranking
None	No effect, Performance loss < 0.5%	1
Low	Performance loss < 1 %	2
	Performance loss < 3 %	3
Moderate	Performance loss < 5 %	4
	Performance loss < 10 %	5
High	Performance loss < 25 %	6
	Performance loss > 25%	7
Safety risk without performance loss	Safety risk without performance loss	8
Safety risk with performance loss	Safety risk with performance loss	9
Death, fire, total loss	Safety hazard	10



In Solar Bankability we have created a cost based FMEA methodology

Quantification of the economic impact of technical risks

Planning

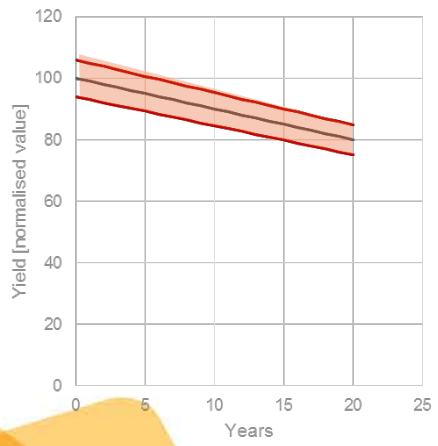
- **Risks to which we can assign an uncertainty (e.g. irradiance)**

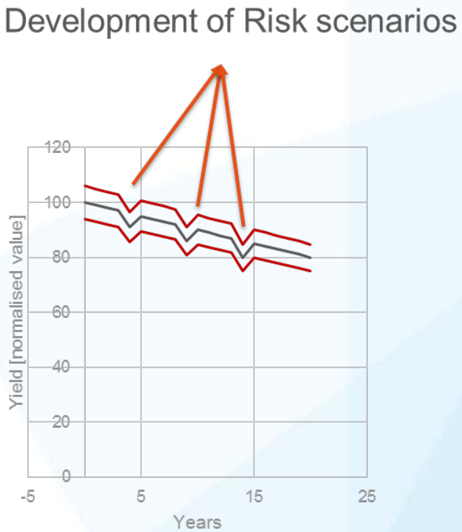
→ Impact on financial exceedance probability parameters

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





Quantification of the economic impact of technical risks

Planning

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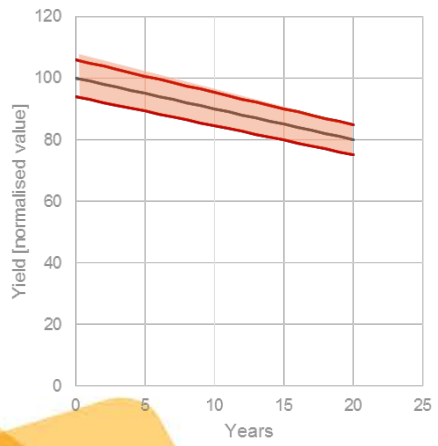
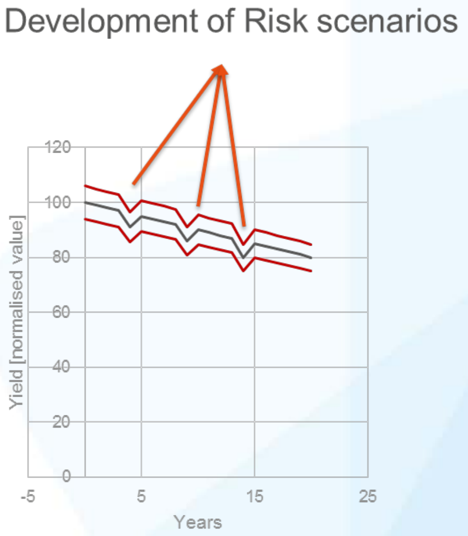
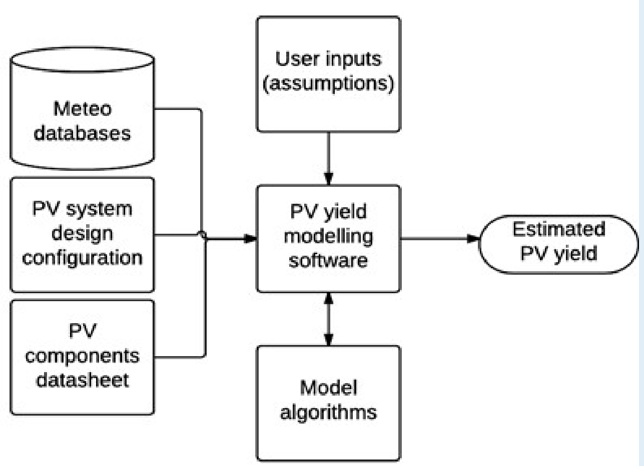
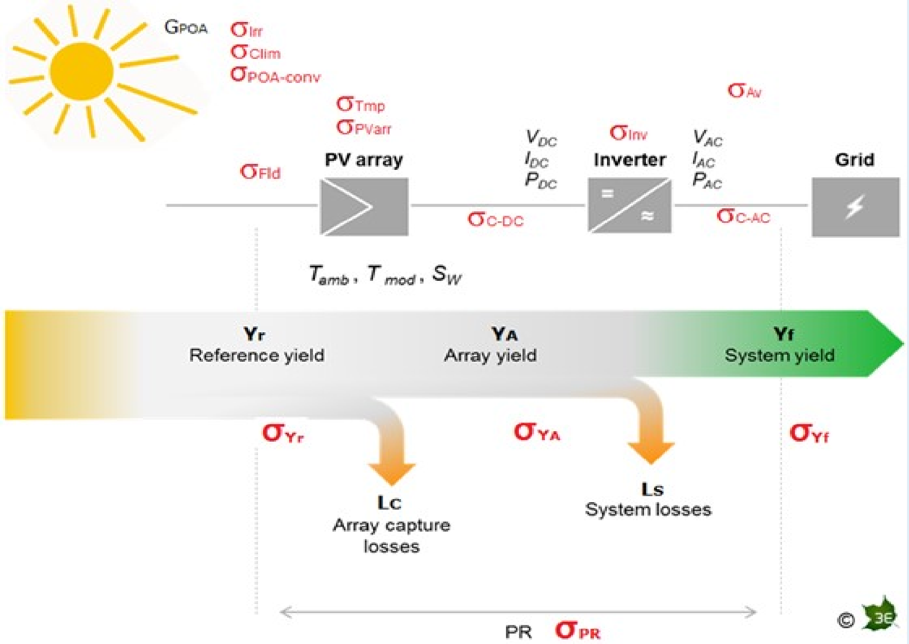
  → Impact on financial exceedance probability parameters

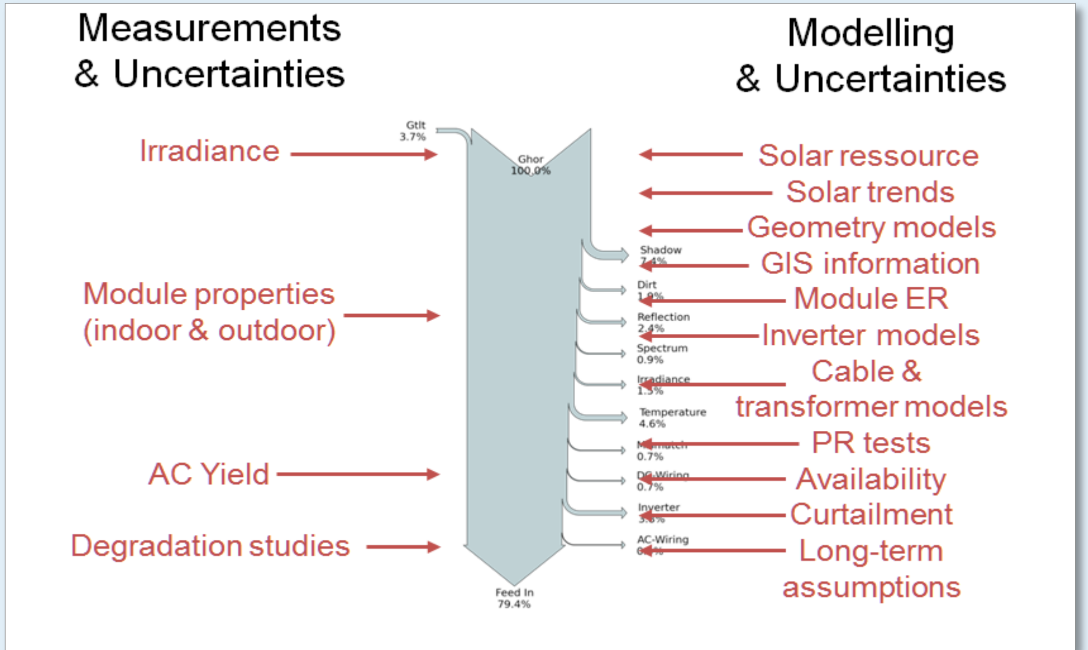




Calculation of uncertainty







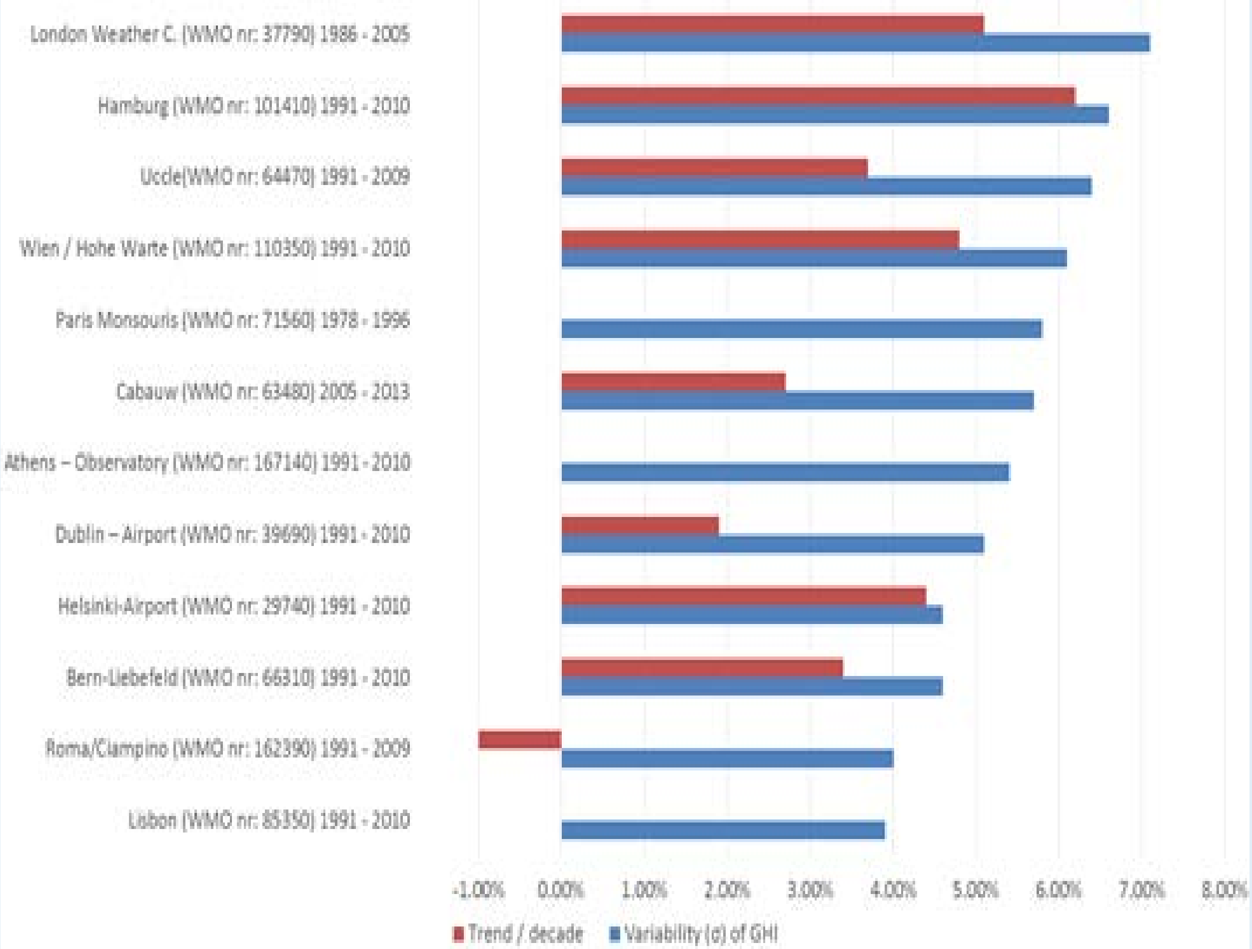
Uncertainties in PV System Yield Predictions and Assessments

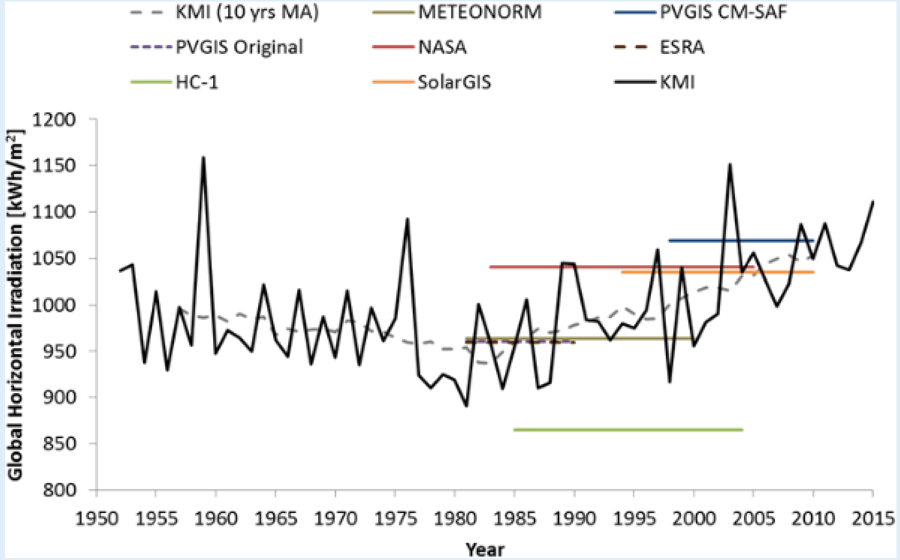
Christian Reise, Alexandra Schmid, Björn Müller, Daniela Dirnberger, Nils Reich, Giorgio Belluardo, David Moser, Philip Ingenhoven, Mauricio Richter, Joshua S. Stein, Clifford W. Hansen, Anton Driesse, Lyndon Frearson, Bert Herteleer

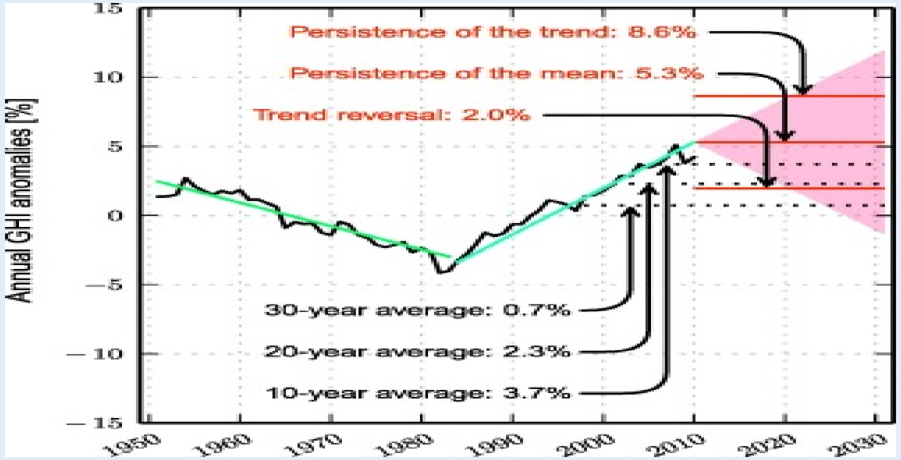
IEA PVPS Task 13, Subtasks 2.3 & 3.1 Report IEA-PVPS T13-12:2018 April 2018

eurac research

Irradiance measurements and solar resource assessment: irradiance variability and trends







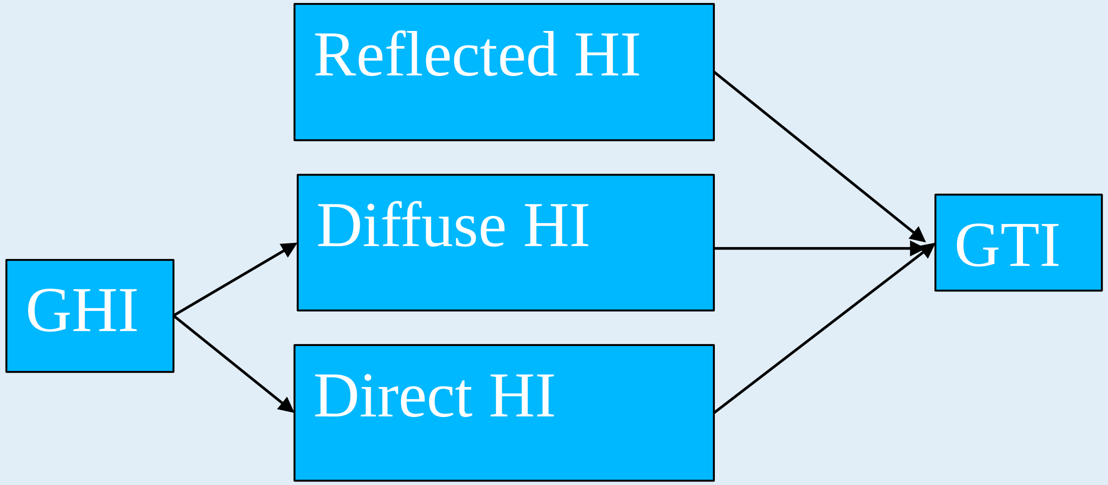
D. Moser *et al.*, "Technical Risks in PV Projects." Solar Bankability Deliverable www.solarbankability.com

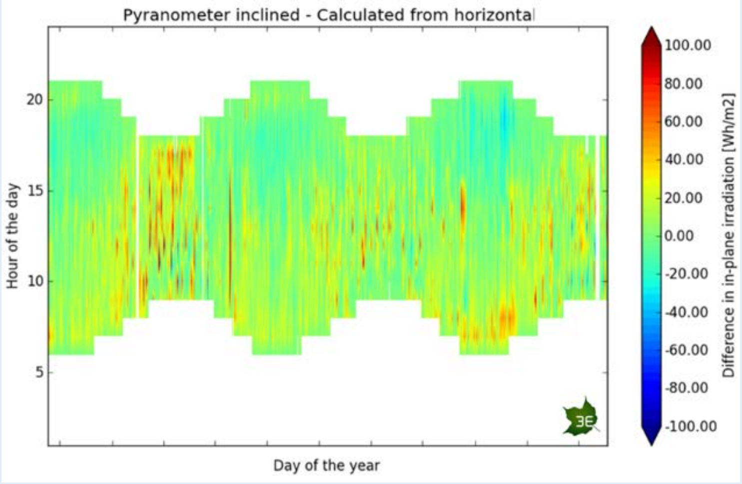
IEA PVPS Task 13, Subtasks 2.3 & 3.1 Report IEA-PVPS T13-12:2018 April 2018

PVPS

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%



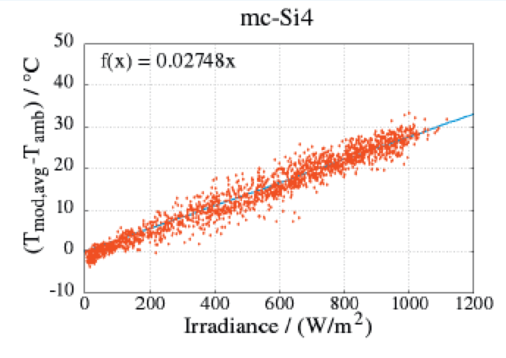


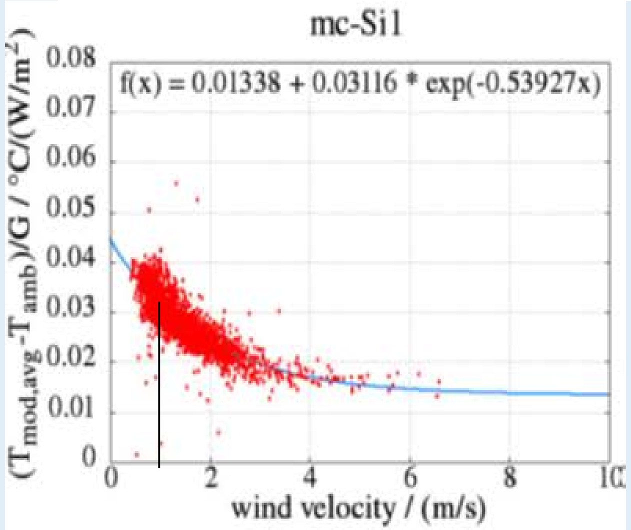
Credits: 3e

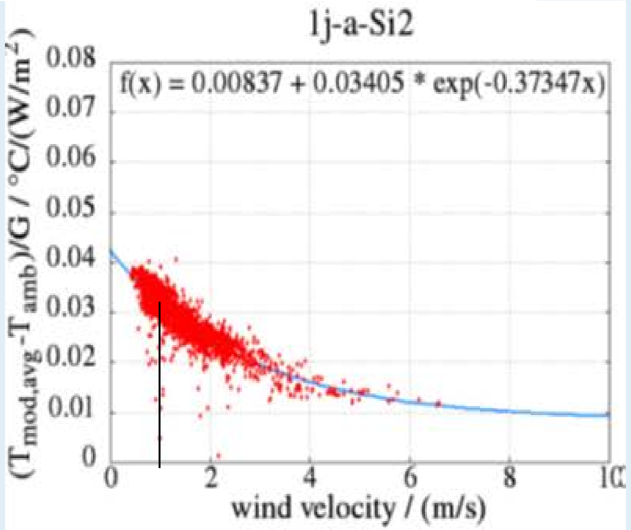
PVPS

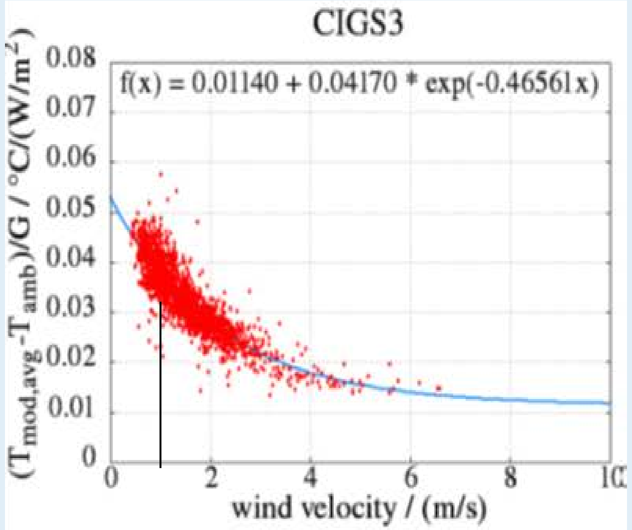
Temperature: environmental conditions and module temperature calculation

nr.	name	technology	Stratigraphy	Frame	$k_{Tmod,c}$ (K m²/W)	$RMSE_{k\_T\ mod,c}$
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



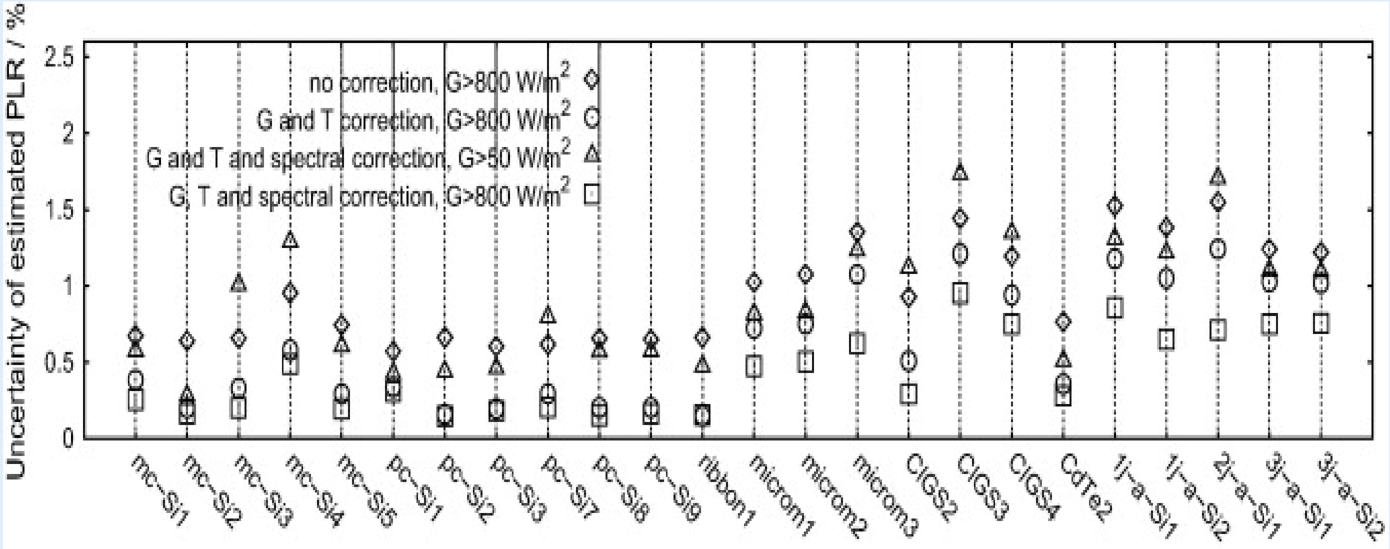


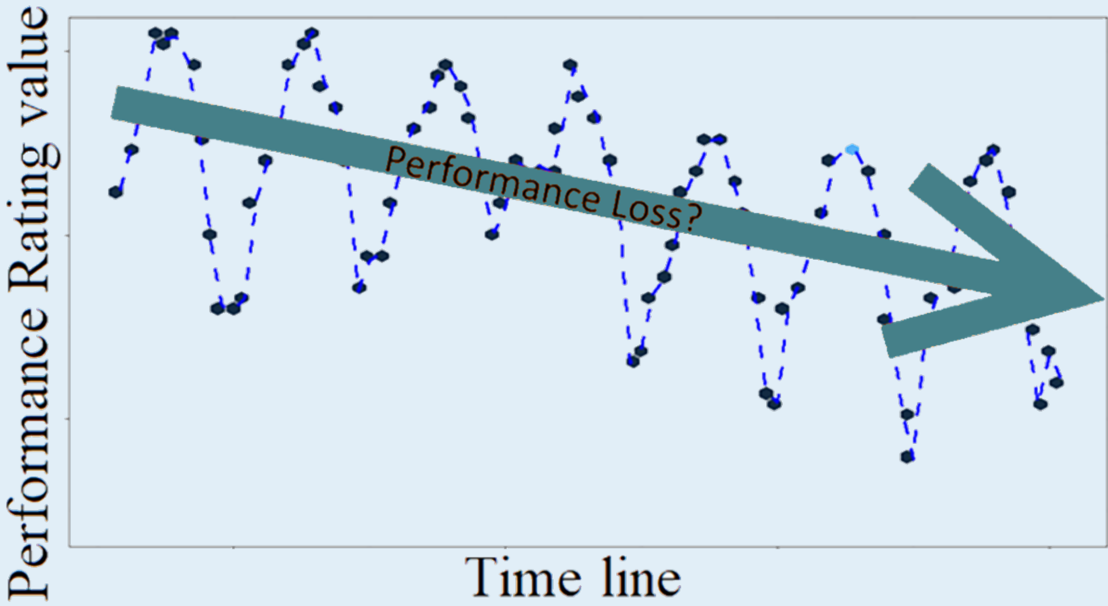




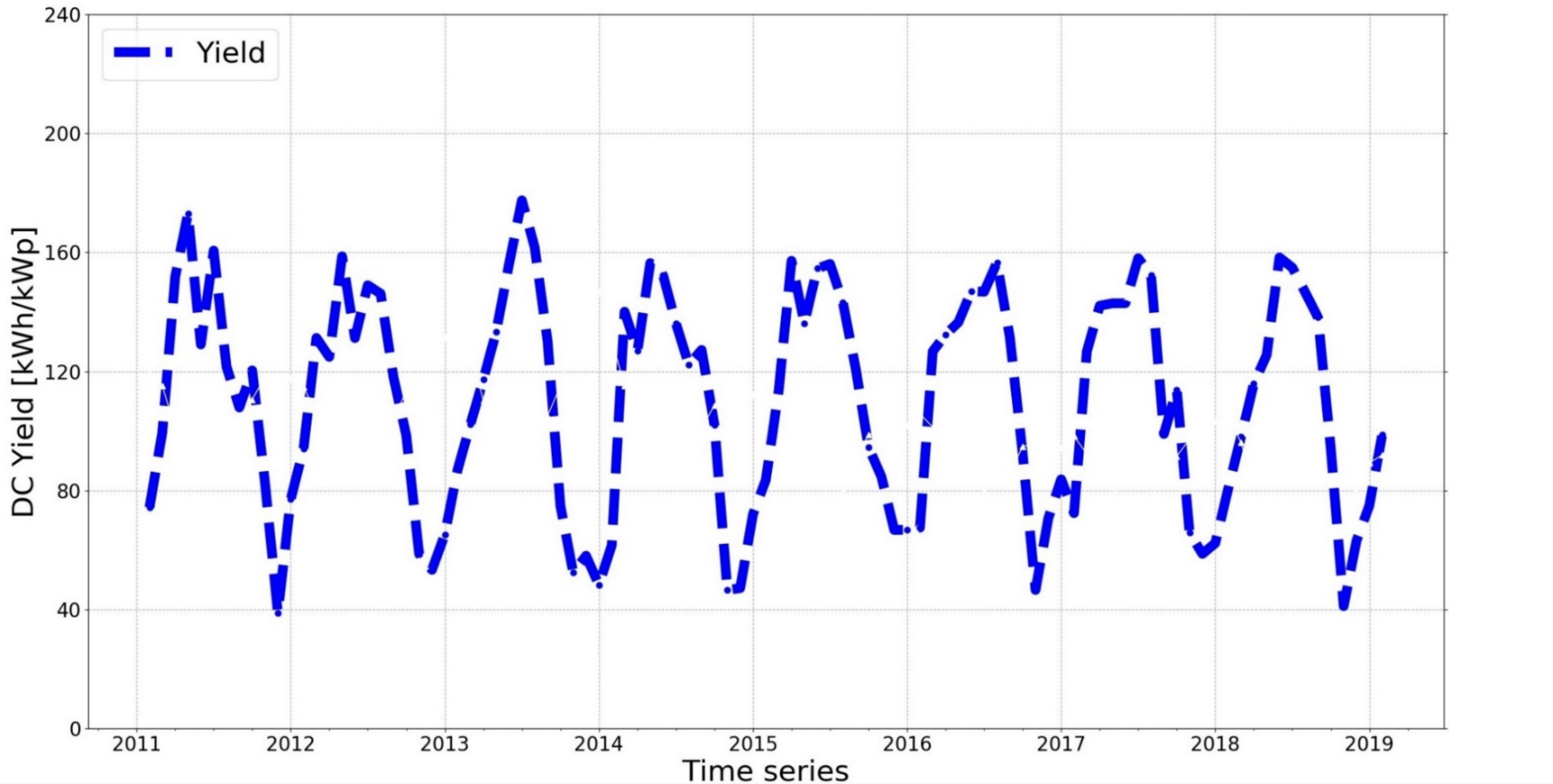
Maturi L., BiPV System Performance and Efficiency Drops: Overview on PV Module Temperature Conditions of Different Module Types, Energy Procedia 48 2014 1311-1319

Performance Loss Rate

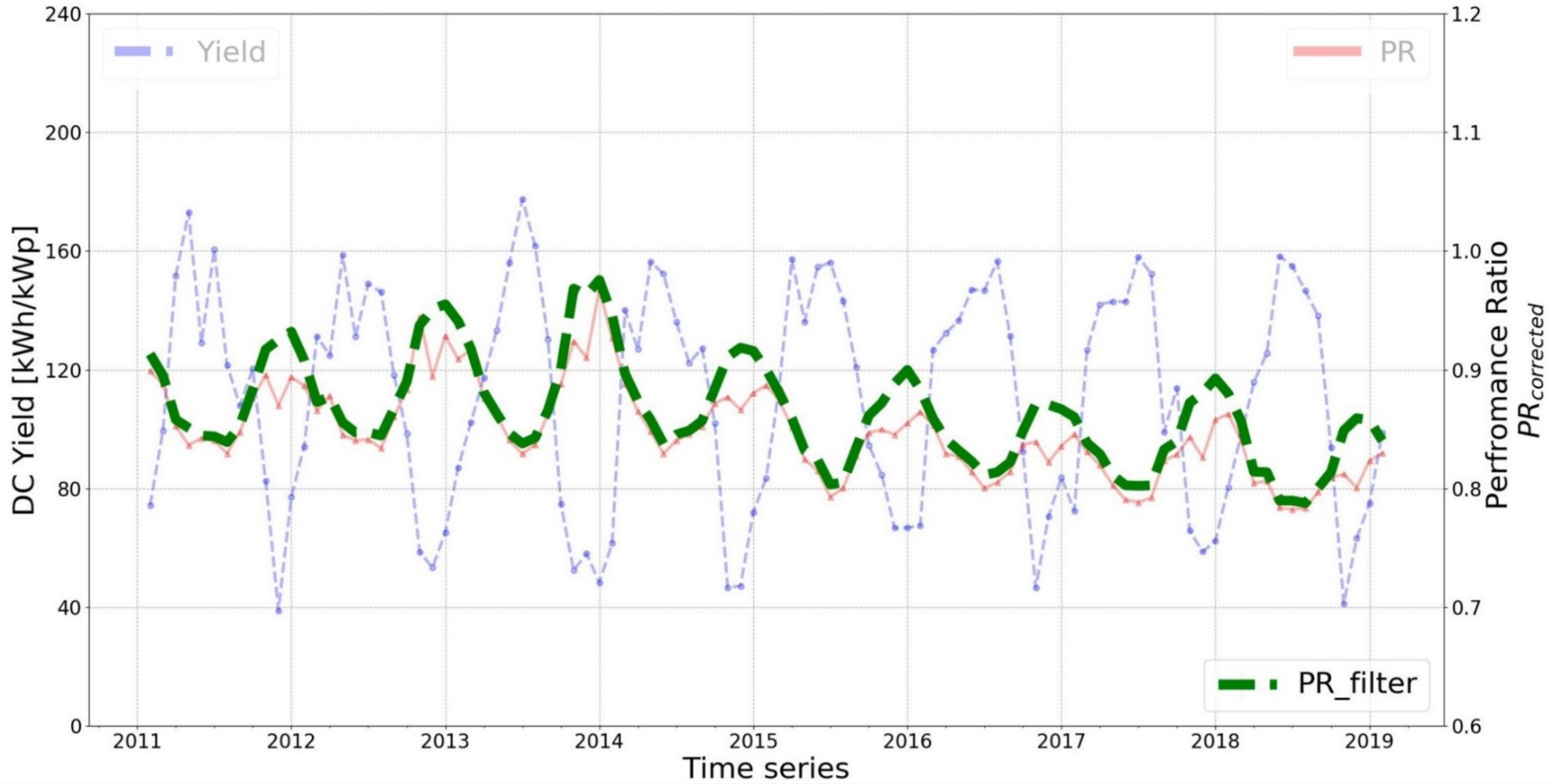




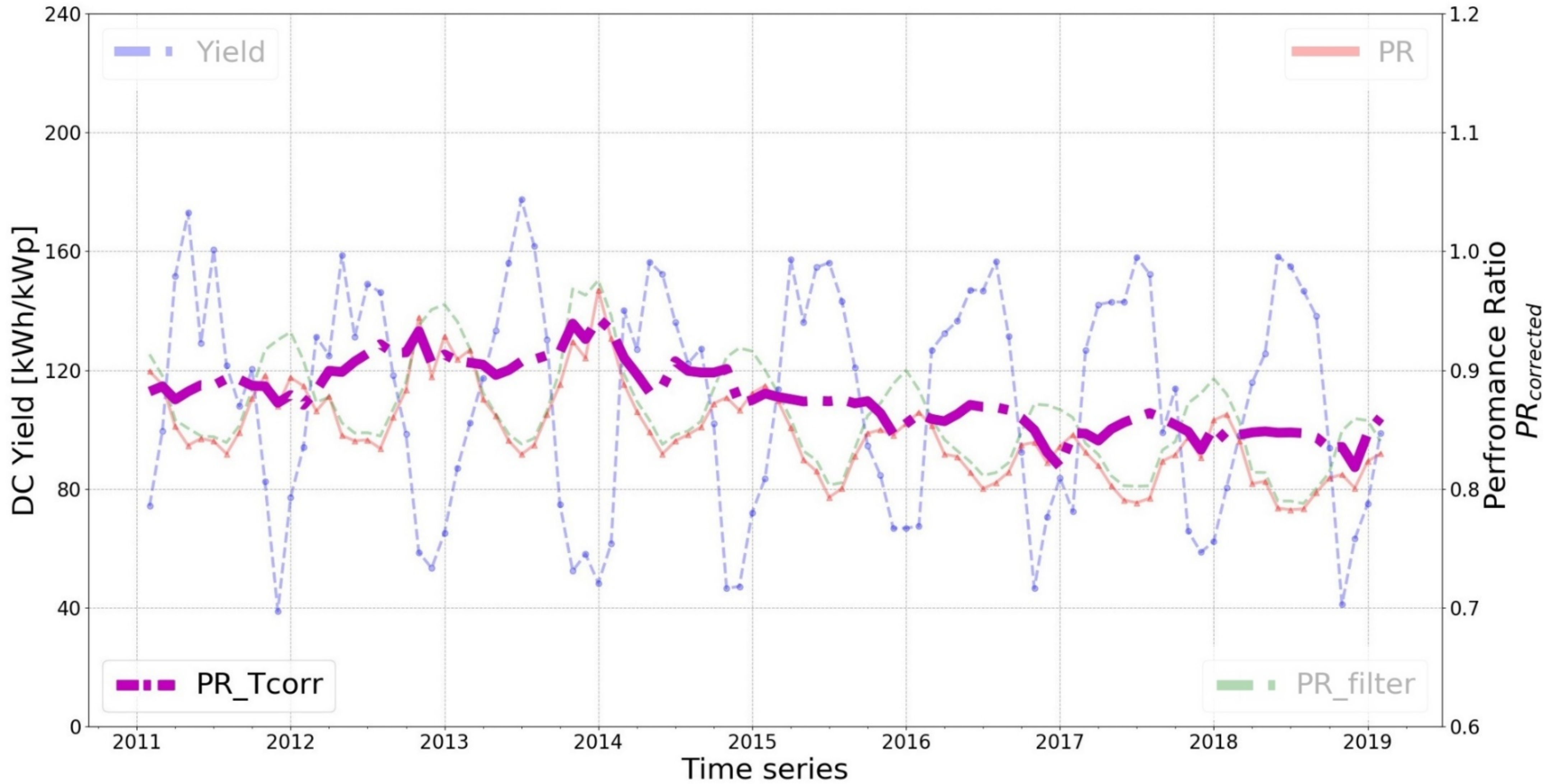
State of the art



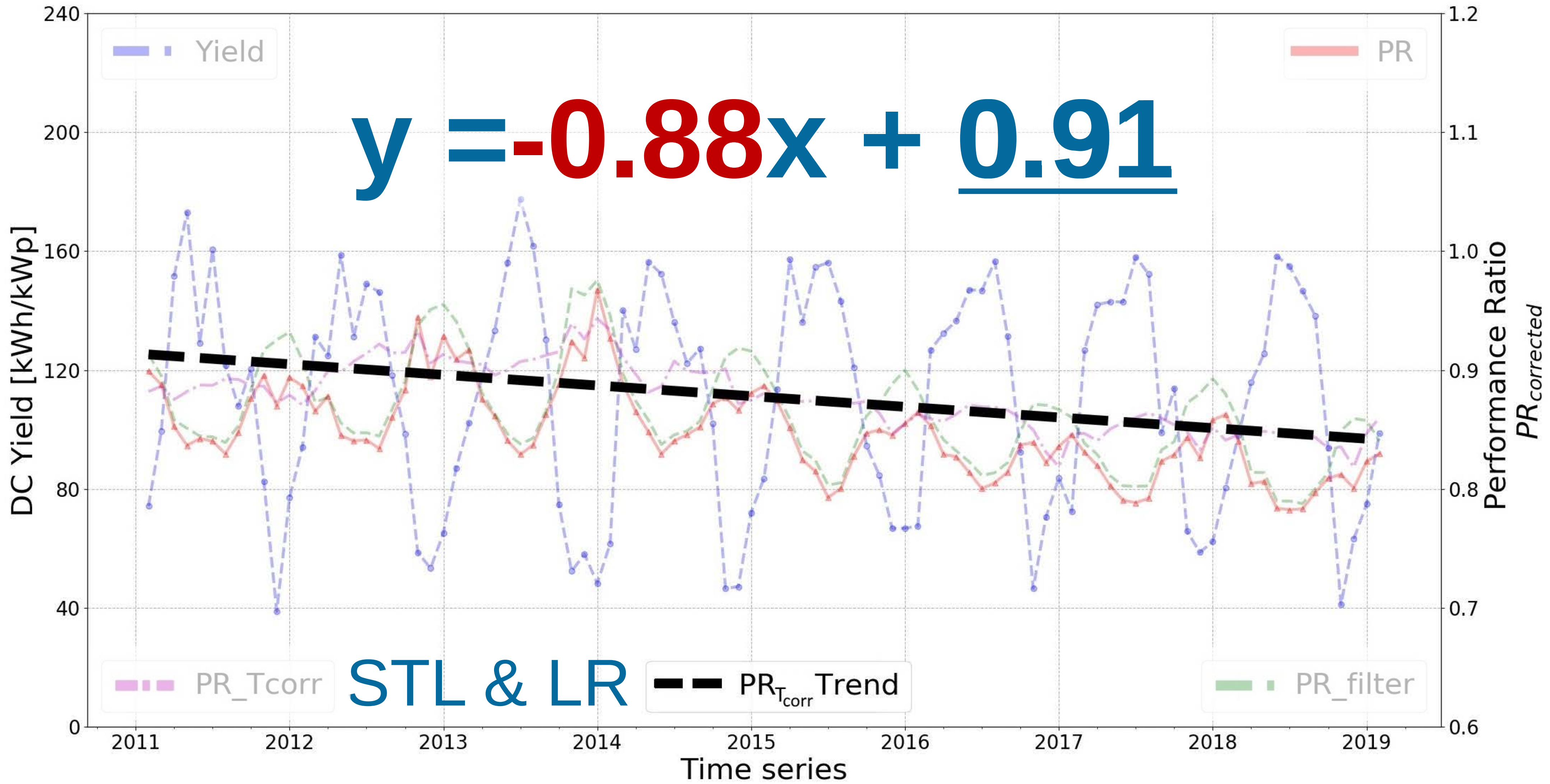
State of the art



State of the art



State of the art



Work in progress

Factors affecting the overall PLR

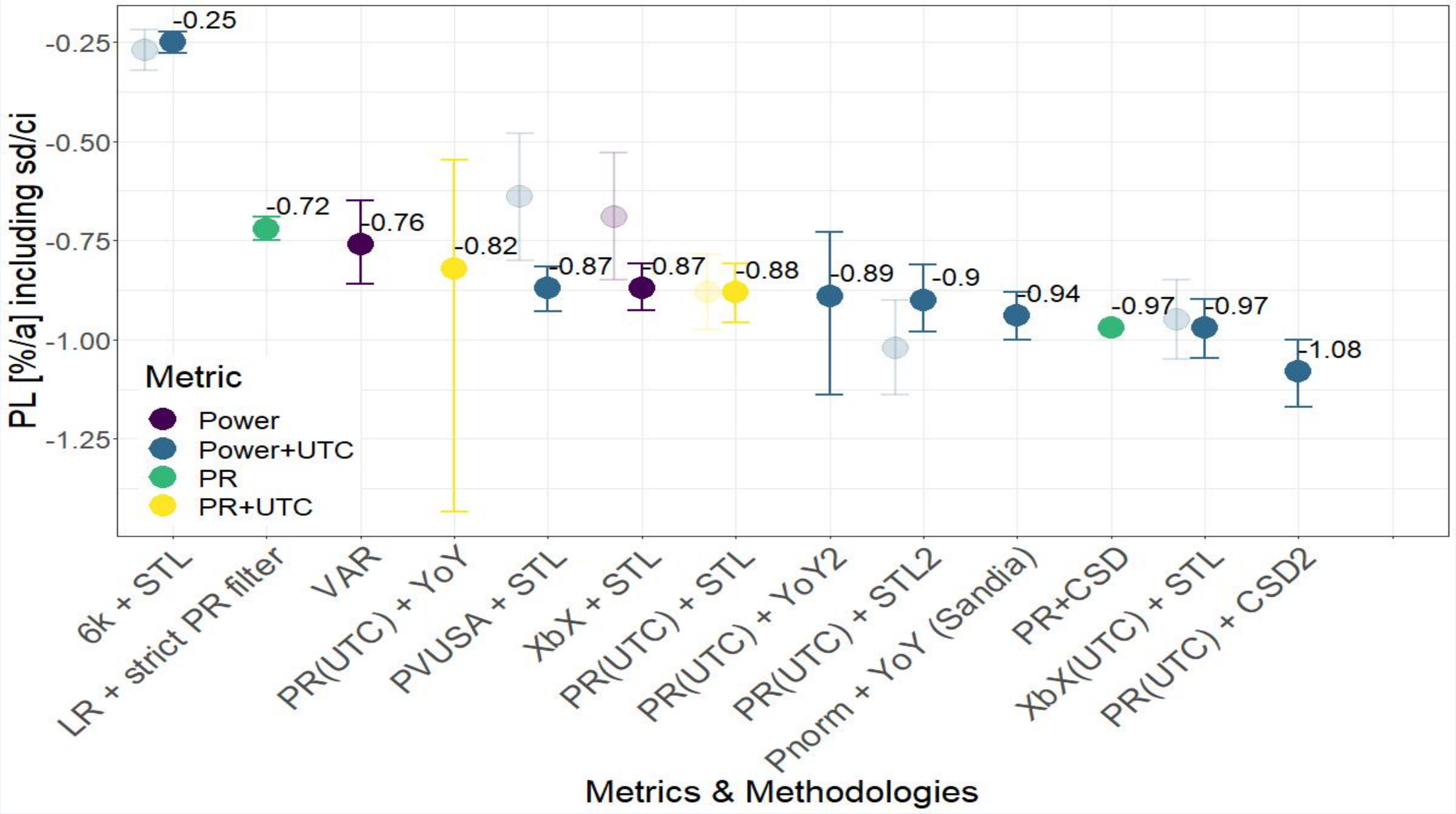
- Data quality
- Filtering
- Metrics
- Methodologies

3 approaches to assess PLR results

- Shared algorithms/filtering used on shared data
- Confidential algorithms/filtering used on shared data
- Shared algorithms/filtering used on confidential data

Work in progress

First step is to benchmark different existing methodologies to see initial differences in the final results



Work in progress

Benchmark will be extended to several PV plants to understand shortcomings of certain methodologies

“Low” quality data

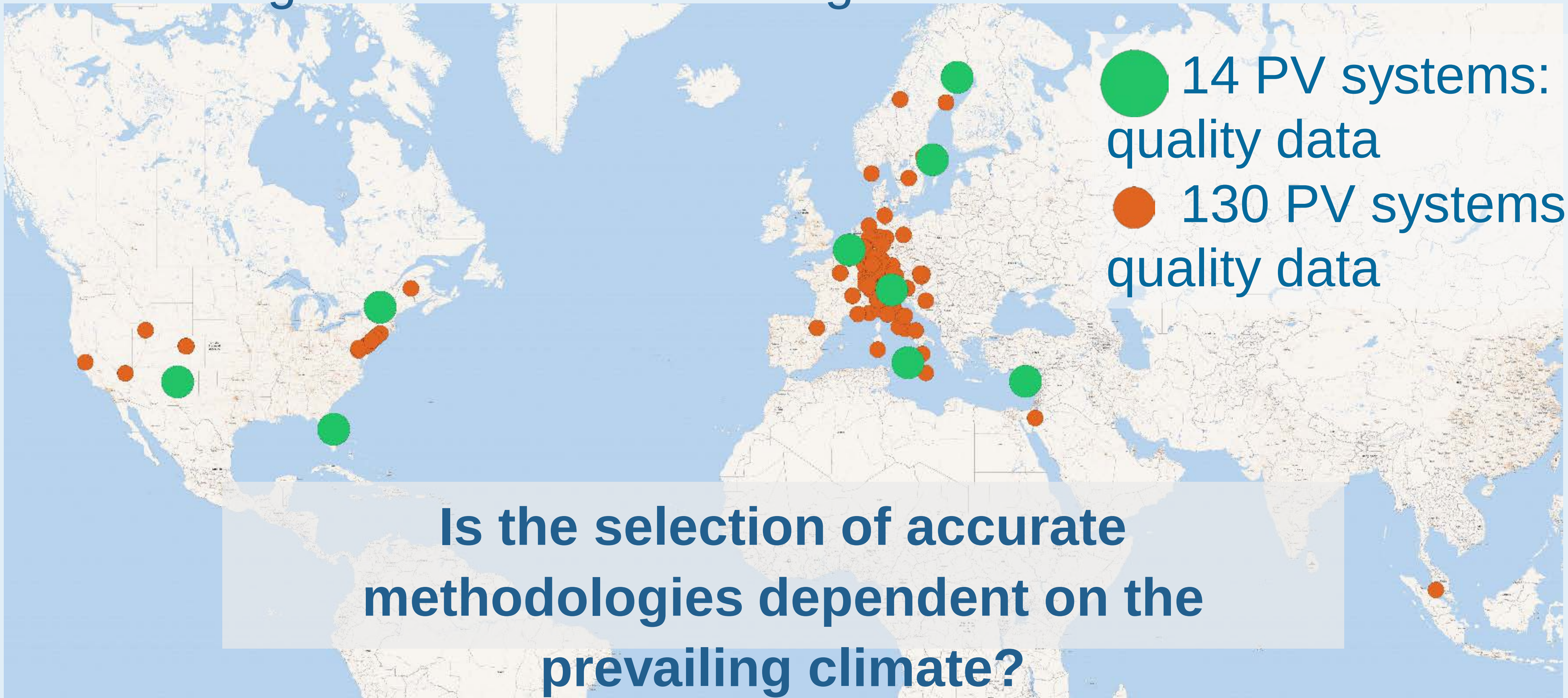
- pre-processed
- given PR/Power/Energy production
- Low resolution
- used only to compare PLR methods

“High” quality data

- Unfiltered PV system time series of high resolution
- can be used to compare performance models
- and filtering criteria

Work in progress (Task 13)

Benchmark will be extended to several PV plants to understand shortcomings of certain methodologies

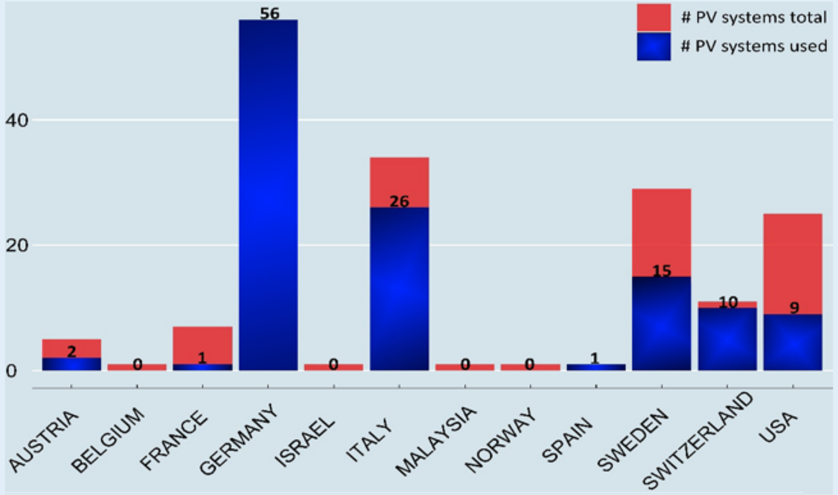


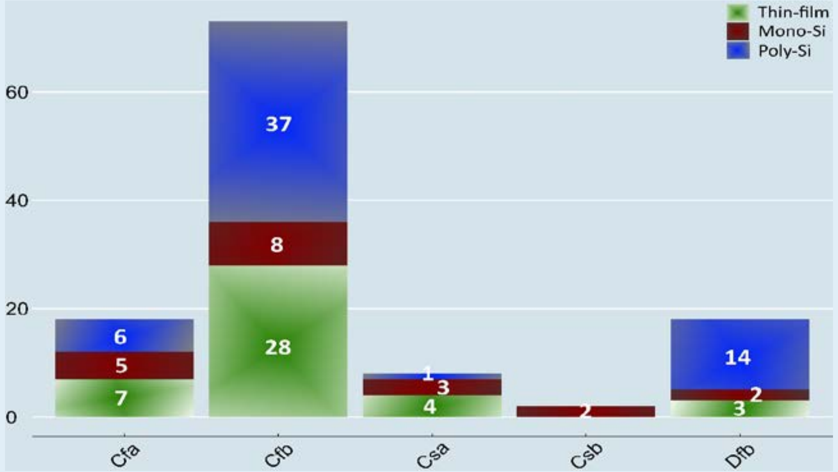
14 PV systems: high quality data

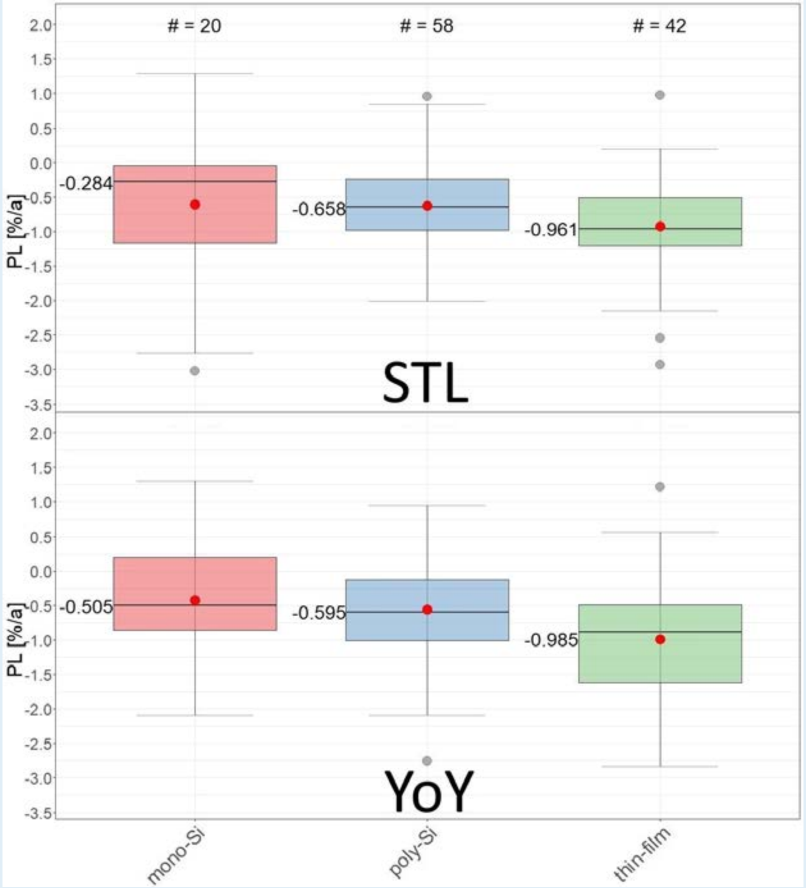
130 PV systems: low quality data

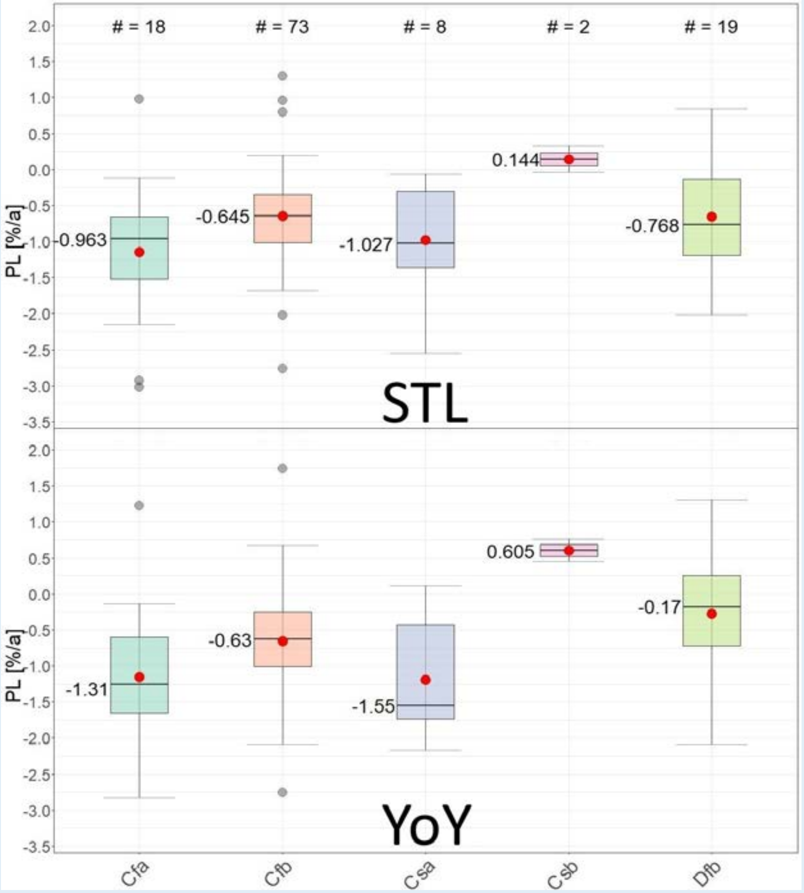
Is the selection of accurate methodologies dependent on the prevailing climate?

eurac research





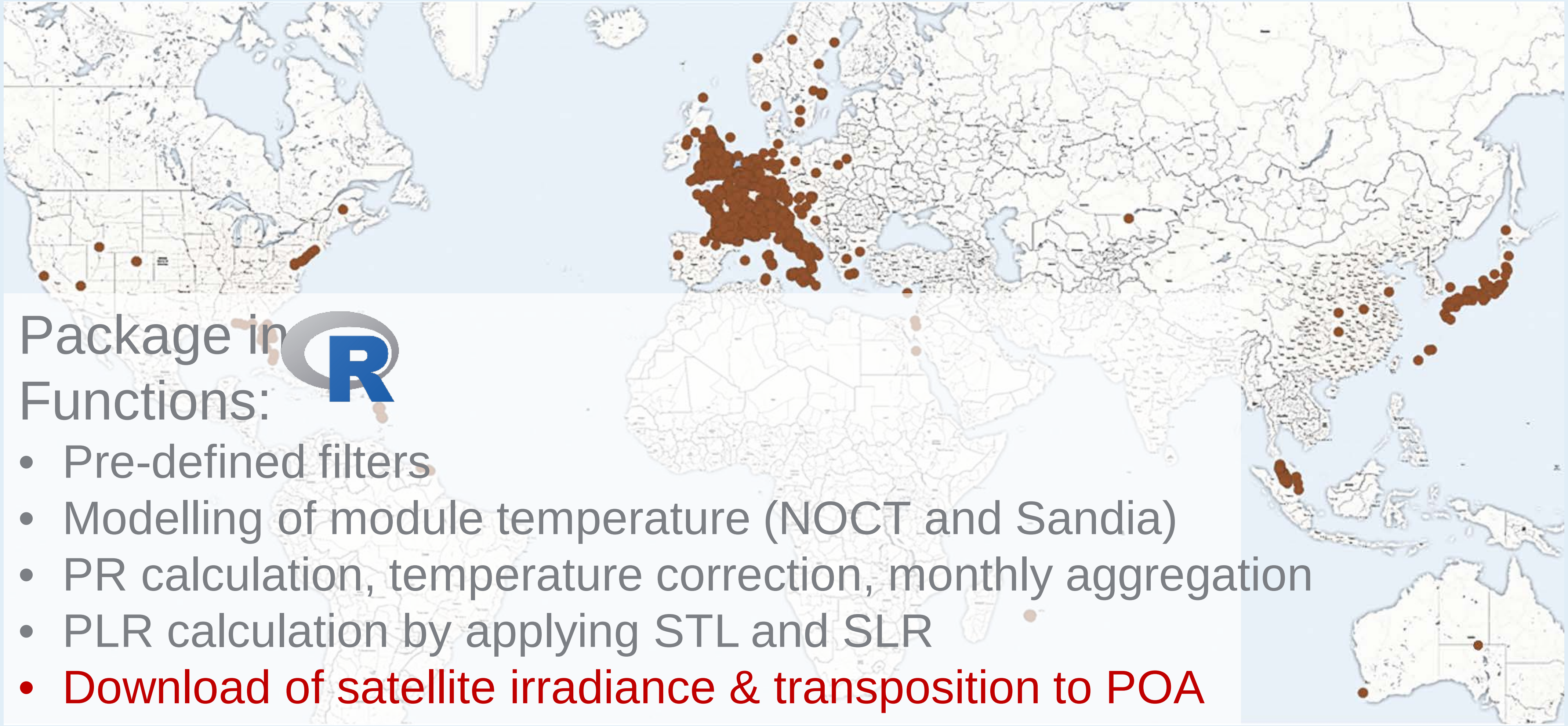




PVPS

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

P A R L P V + PVPS TASK 13

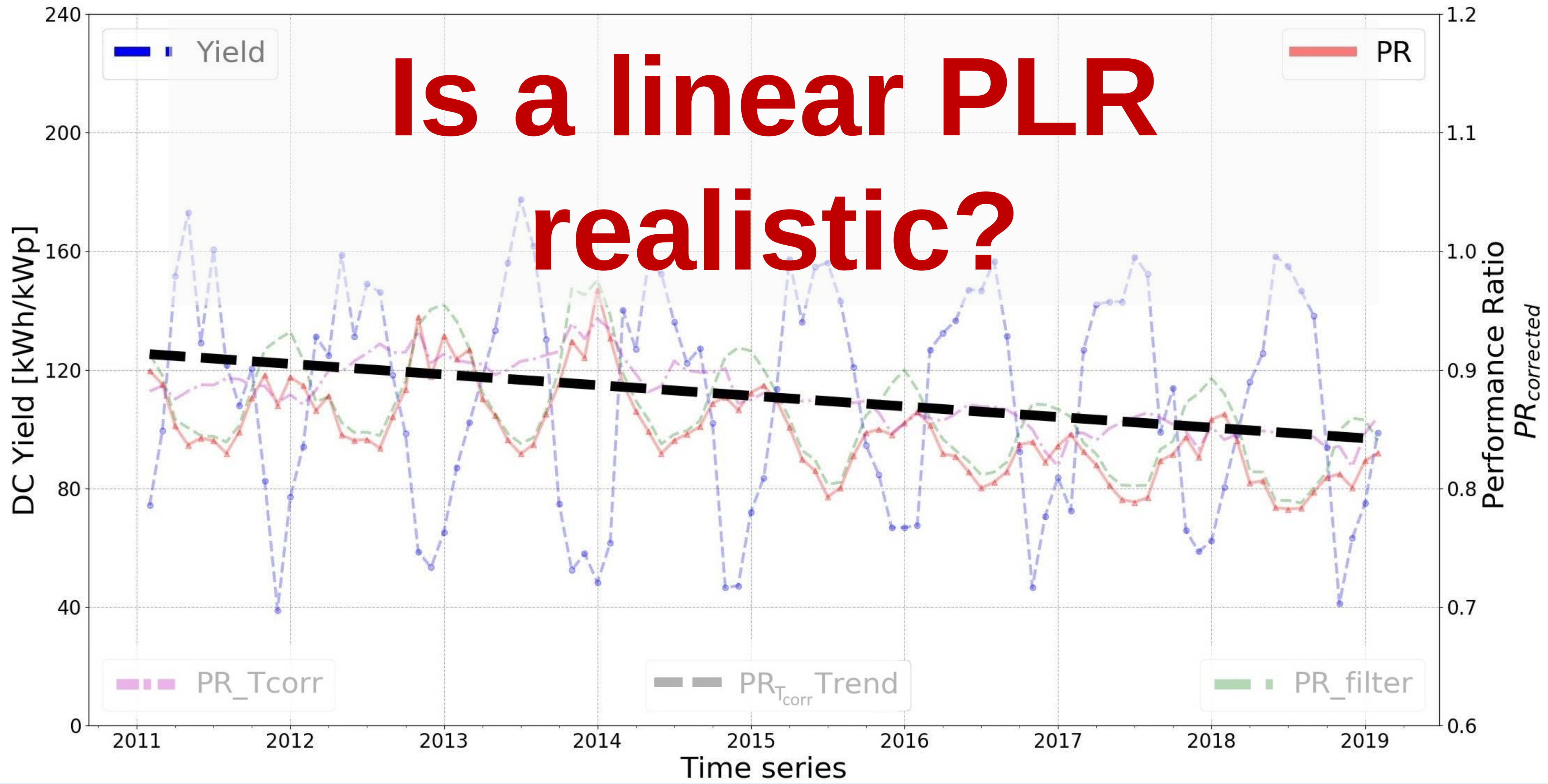


Package in R

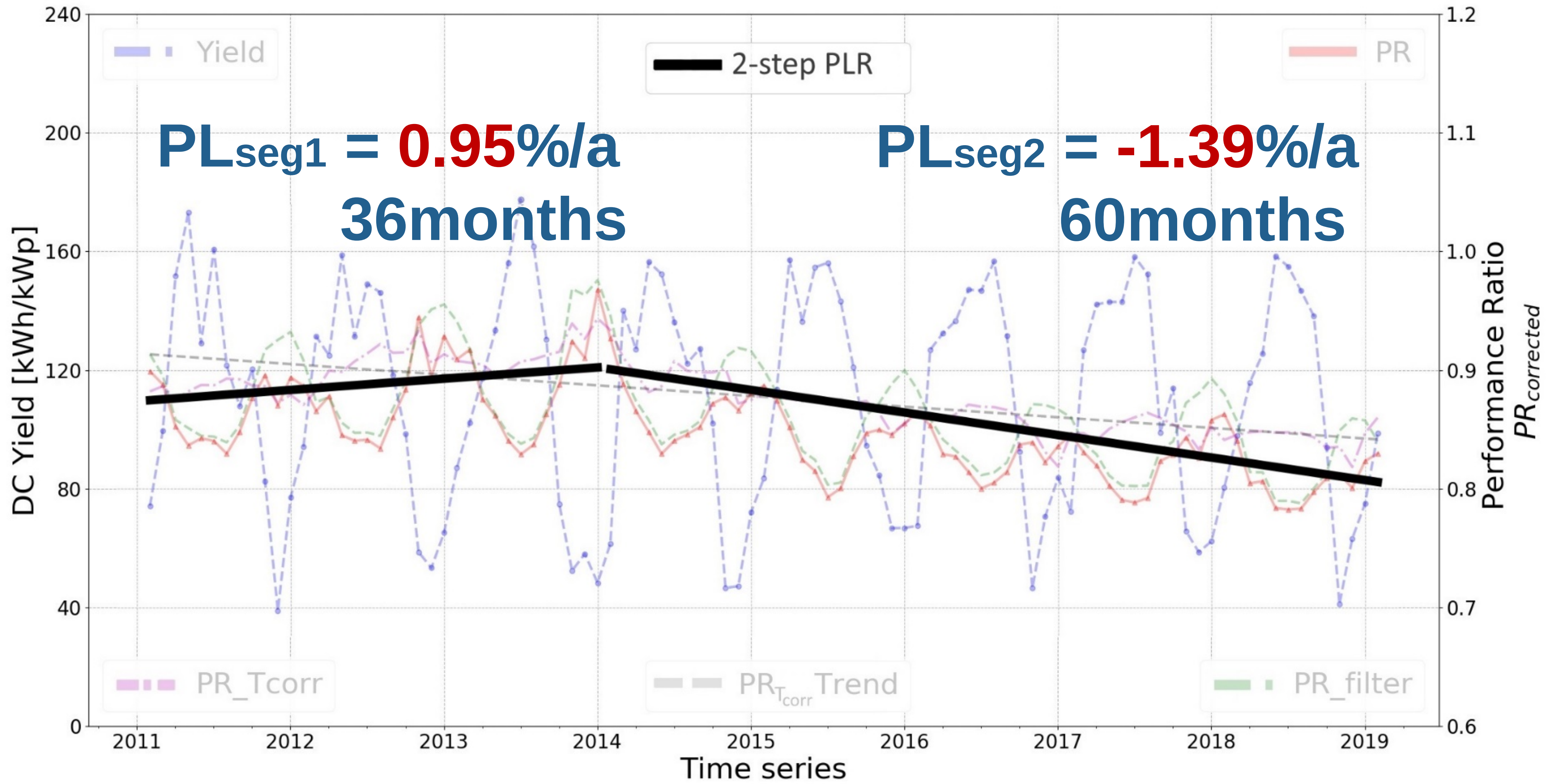
Functions:

- Pre-defined filters
- Modelling of module temperature (NOCT and Sandia)
- PR calculation, temperature correction, monthly aggregation
- PLR calculation by applying STL and SLR
- Download of satellite irradiance & transposition to POA

Work in progress



Work in progress

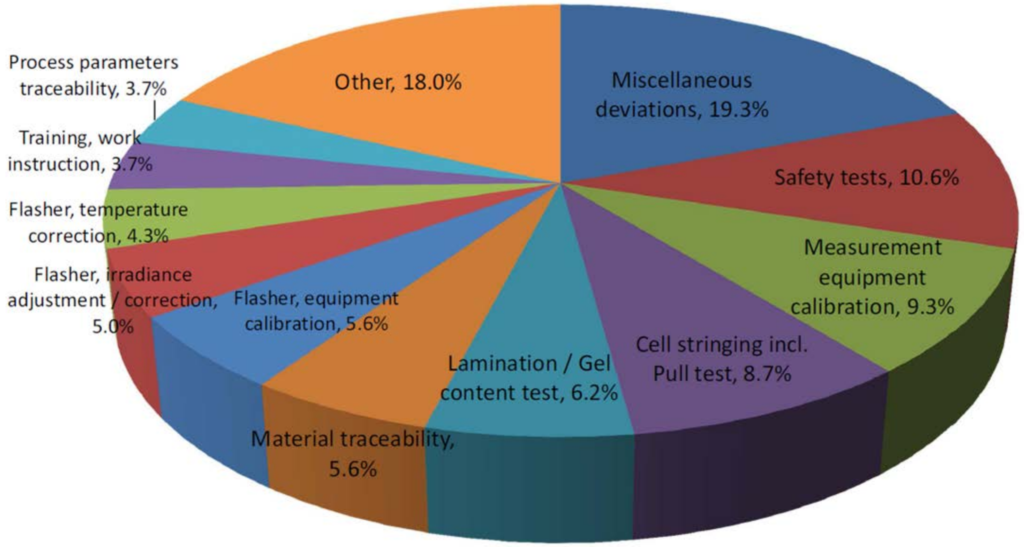


PVPS

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.

Typical uncertainty range in LTYA

	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%

Effect	Overall uncertainty range (1 STD)
Insolation variability POA transposition model	± 4-7% (see 5.1.1 in [1]) ± 2-5% (see 5.1.1 in [1])
Temperature coefficients and temperature effects	± 0.02%/ºC (5% relative error for crystalline silicon based modules) (lab measurements)
Temperature deviation due to environmental conditions	1-2 ºC (± 0.5-1%) (see 5.1.3 in [1]) Up to ±2% if environmental conditions are not included
PV array and inverter model	±0.2% to ±0.5% (see 5.1.3 in [1]) for the inverter model ±1% to ±3% for the PV array model
Degradation	± 0.25-2% (see 5.1.2 in [1], [2])
Shading	Site dependent
Soiling	± 2% (see 5.1.3 in [1]) (Also site dependent)
Spectral Mismatch (modelled)	± 0.01% - 9% (depending on PV technologies, [3]) ± 1% to ±1.5% for c-Si
Nominal power	±1-2%
Overall uncertainty	± 5-10%

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

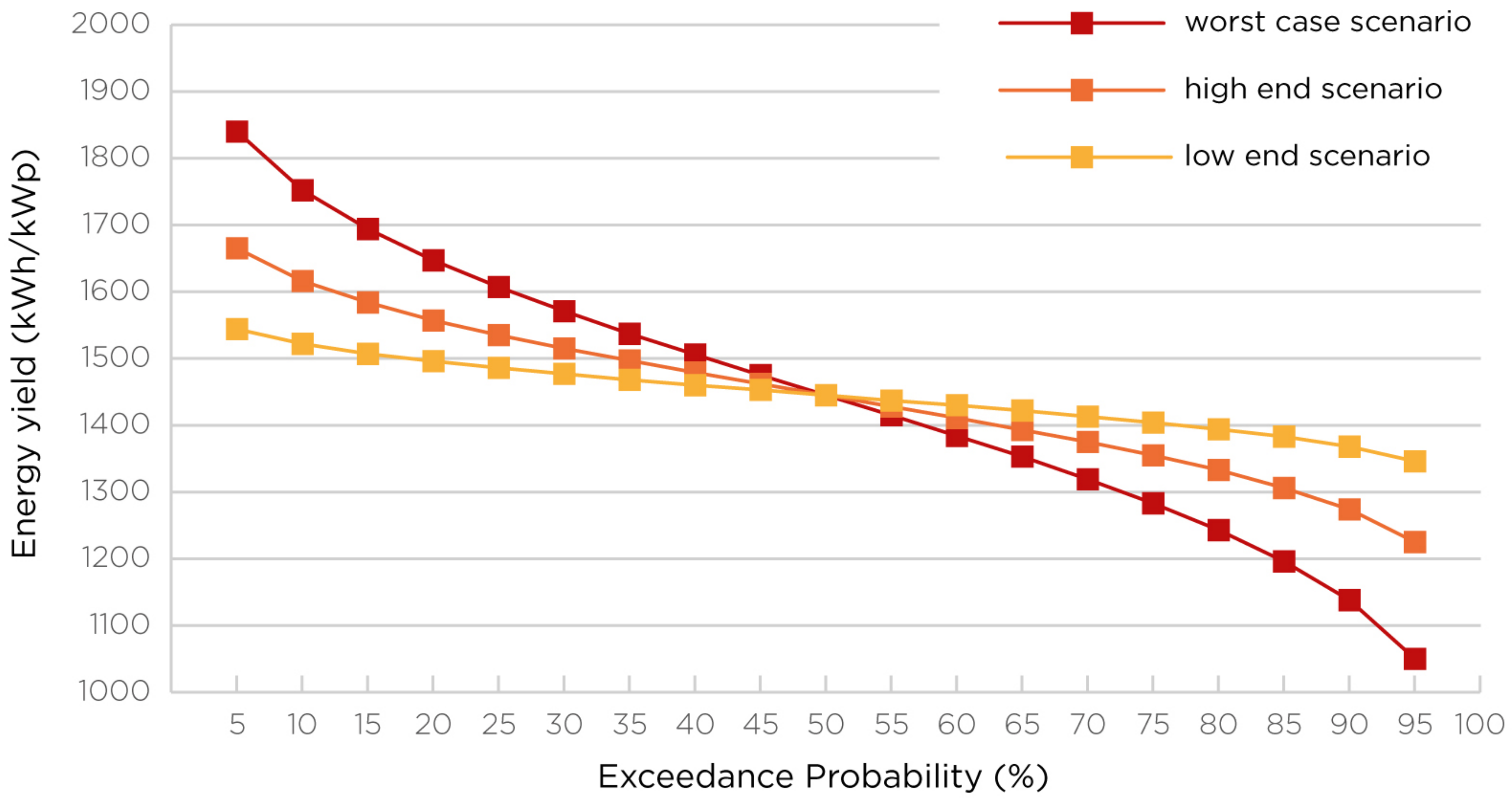
[1] D. Moser *et al.*, "Technical Risks in PV Projects." Solar Bankability Deliverable www.solarbankability.com

[2] G. Belluardo, P. Ingenhoven, W. Sparber, J. Wagner, P. Weihs, and D. Moser, "Novel method for the improvement in the evaluation of outdoor performance loss rate in different PV technologies and comparison with two other methods," *Solar Energy*, vol. 117, pp. 139–152, Jul. 2015.

[3] G. Belluardo, G. Barchi, D. Baumgartner, M. Rennhofer, P. Weihs, and D. Moser, "Uncertainty analysis of a radiative transfer model using Monte Carlo method within 280–2500 nm region," *Solar Energy*, vol. 132, pp. 558–569, Jul. 2016

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

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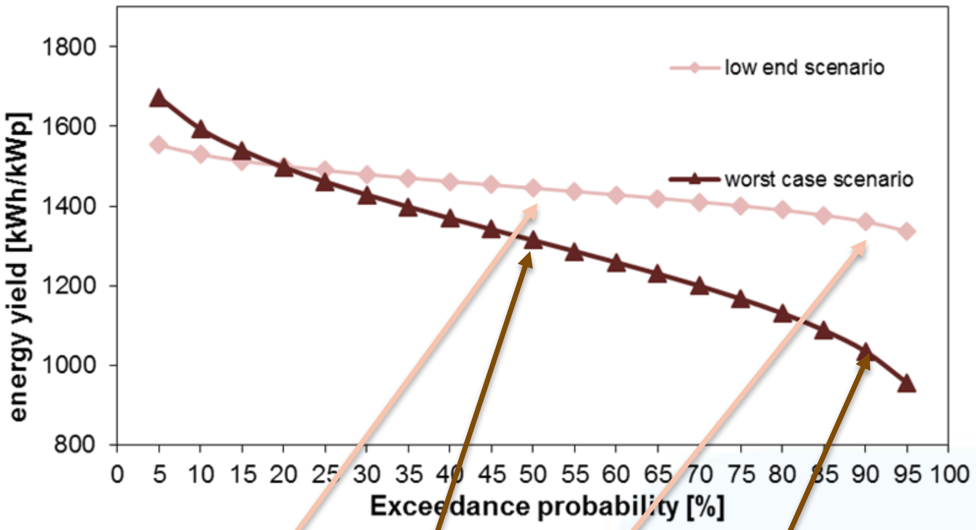
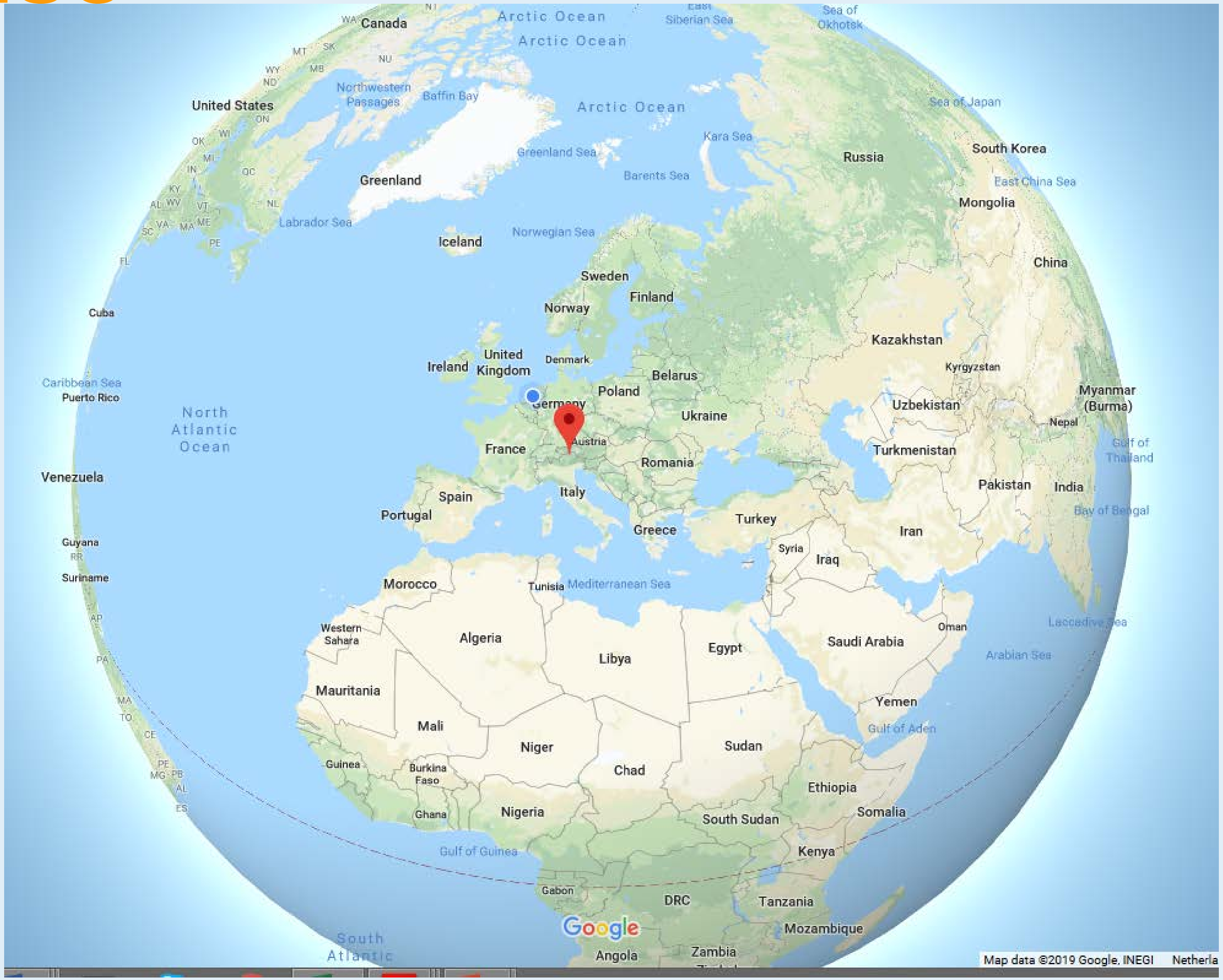
Objectives:
- More precise estimation of uncertainty in yield estimation
- Reduction of uncertainty



	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

Task 13 YA exercise



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

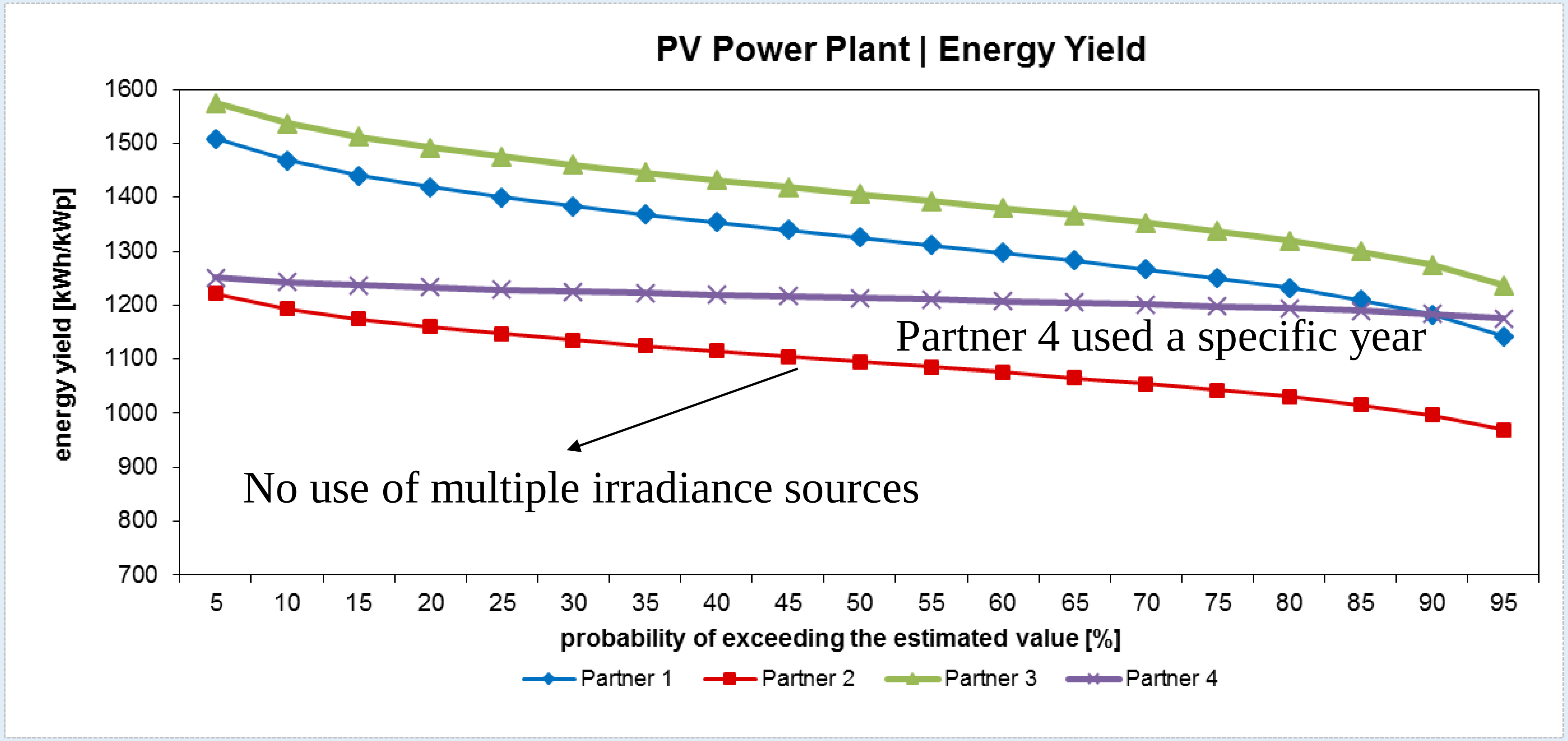
Real Yield Assessments (anonymized) provided by T13 partners will be analysed and benchmarked.
Uncertainty scenarios will be created to show impact on P90/P50

PVPS

Yield assessment on selected sites

Parameter	Assumption
Location	Given Latitude/Longitude, tilt angle and azimuth
Irradiance and transposition	Each independent YA will use their favourite database
Temperature	Each independent YA will use their favourite database
Technology and mismatch	Technology Given, each YA will apply their own considerations
Inverter	Given
Shading	Given shading diagram
Soiling	Each independent YA will apply their own considerations
Wind speed	Each independent YA will use their favourite database
Long term insolation effects	Each independent YA will apply their own considerations
Degradation	Each independent YA will apply their own considerations
Snow loss / snow fall	Each independent YA will apply their own considerations
Availability	Each independent YA will apply their own considerations
Uncertainties	Please provide uncertainties for each parameter (when possible) and for the yield (compulsory). Also please provide the type of assumed distribution for each parameter (when available) and for the Yield (compulsory)

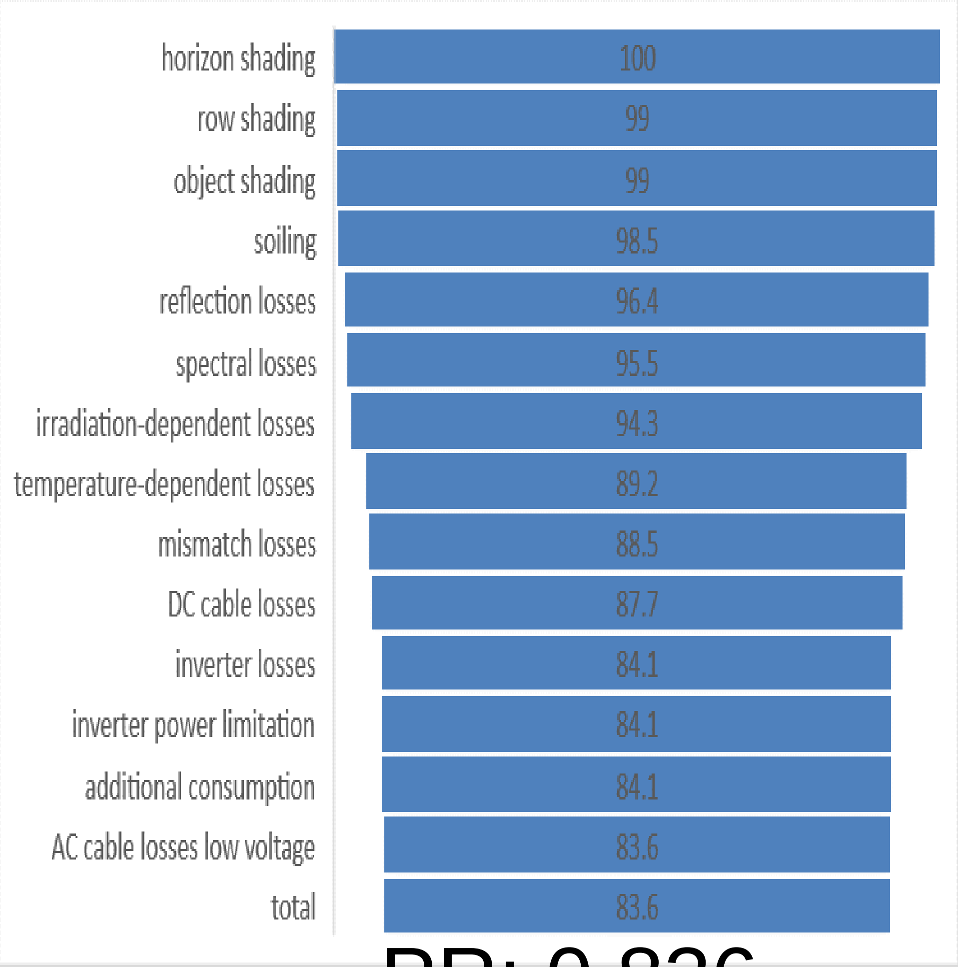
Initial Yield Assessment



	P50 [kWh/kWp]	σ (k=2)	σ (k=2)	P90 [kWh/kWp]	P90/P50 ratio
Partner 1	1325	8.40%	111	1183	0.89
Partner 2	1095	7.00%	77	997	0.91
Partner 3	1406	7.30%	103	1274	0.91
Partner 4	1213	1.90%	23	1184	0.98

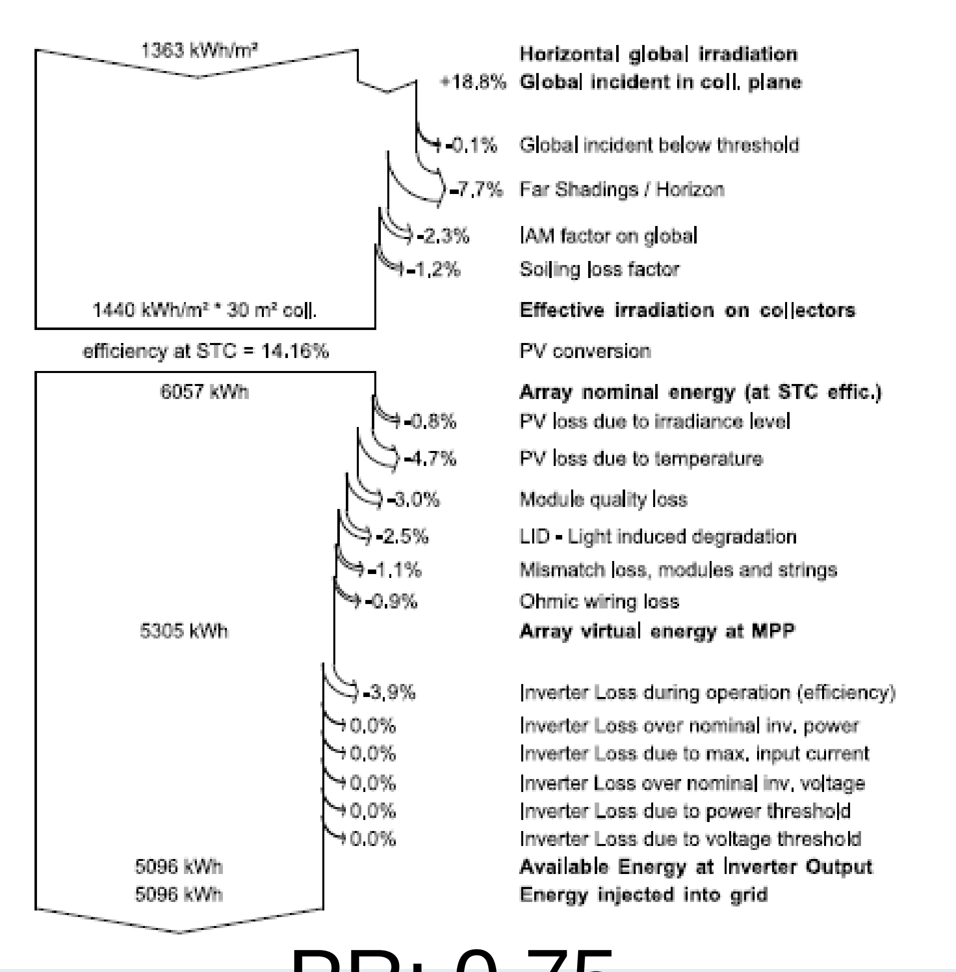
Derating factors

Partner 3



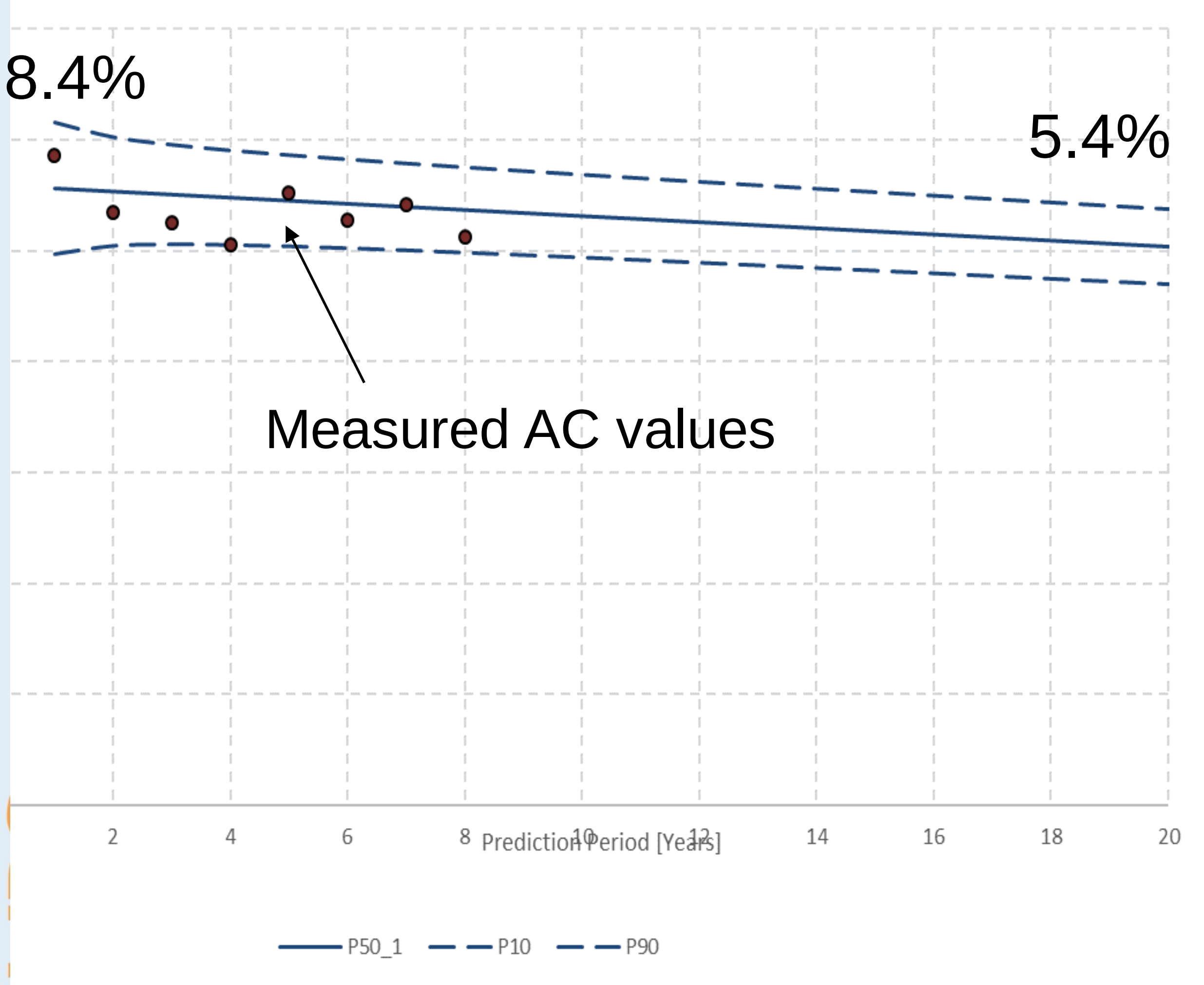
PR: 0.836

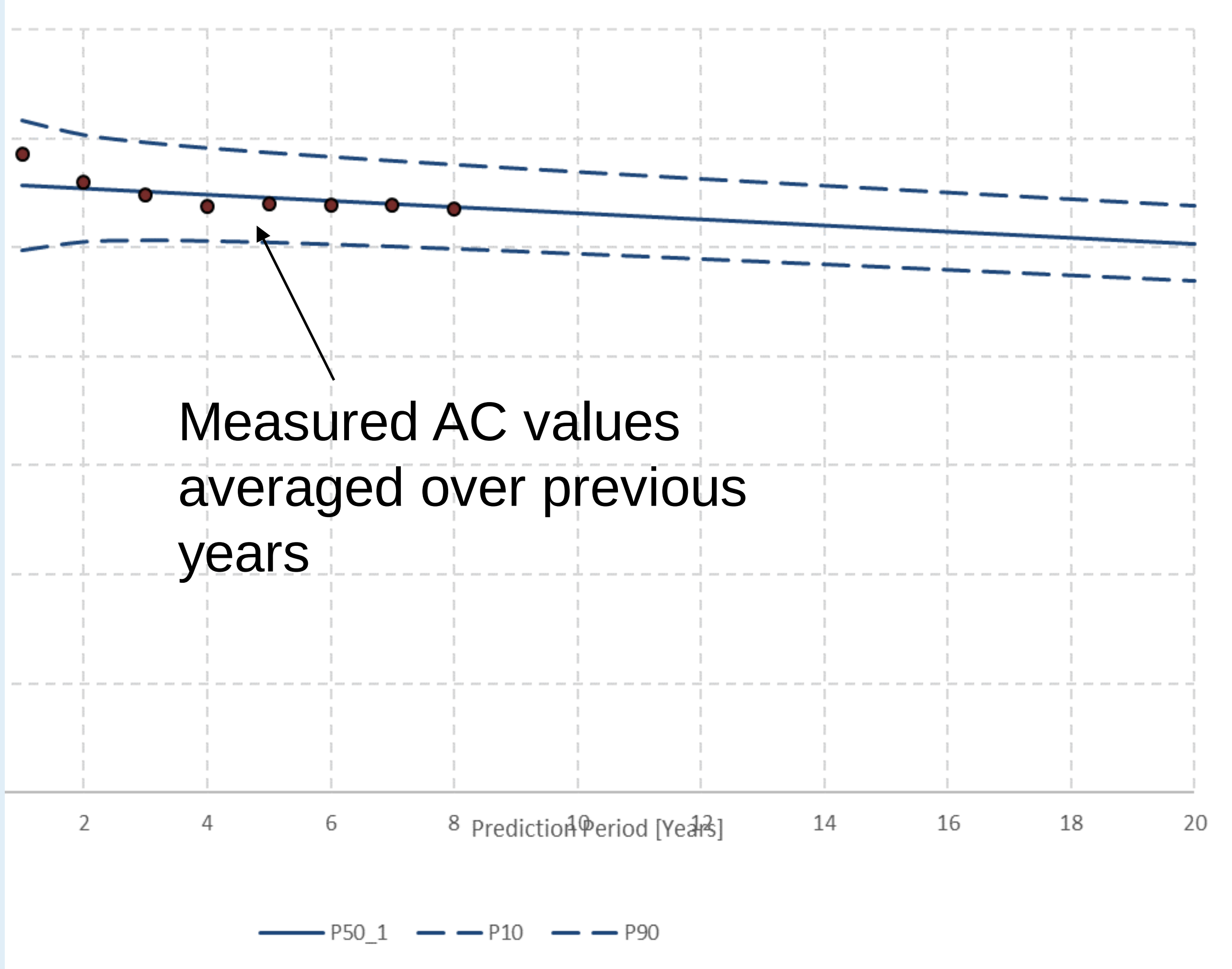
Partner 4



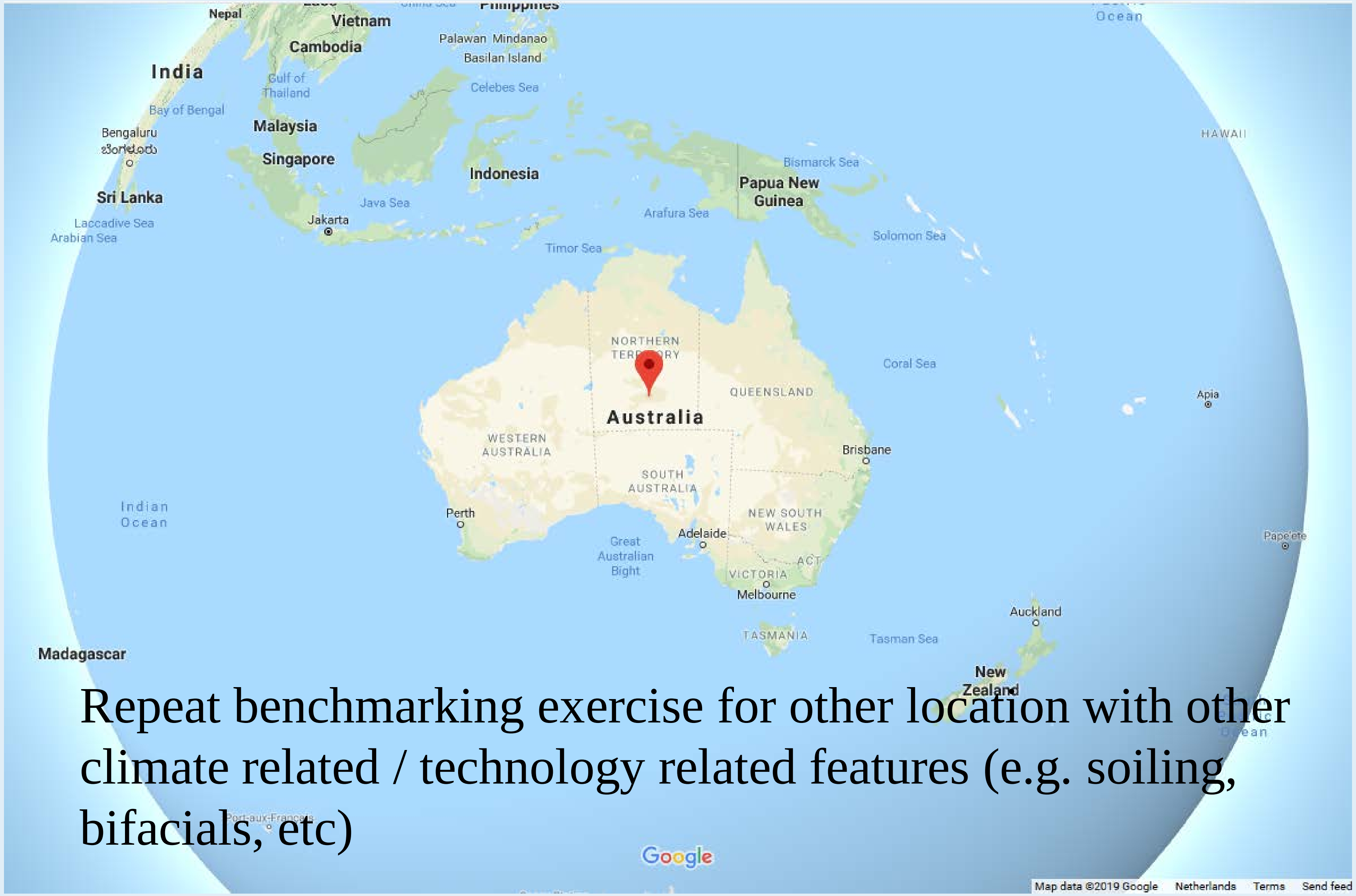
PR: 0.75

LTYA / LTYP


8.4%
5.4%
Measured AC values
2
4
6
8
Prediction Period [Years]
10
12
14
16
18
20
P50_1
P10
P90

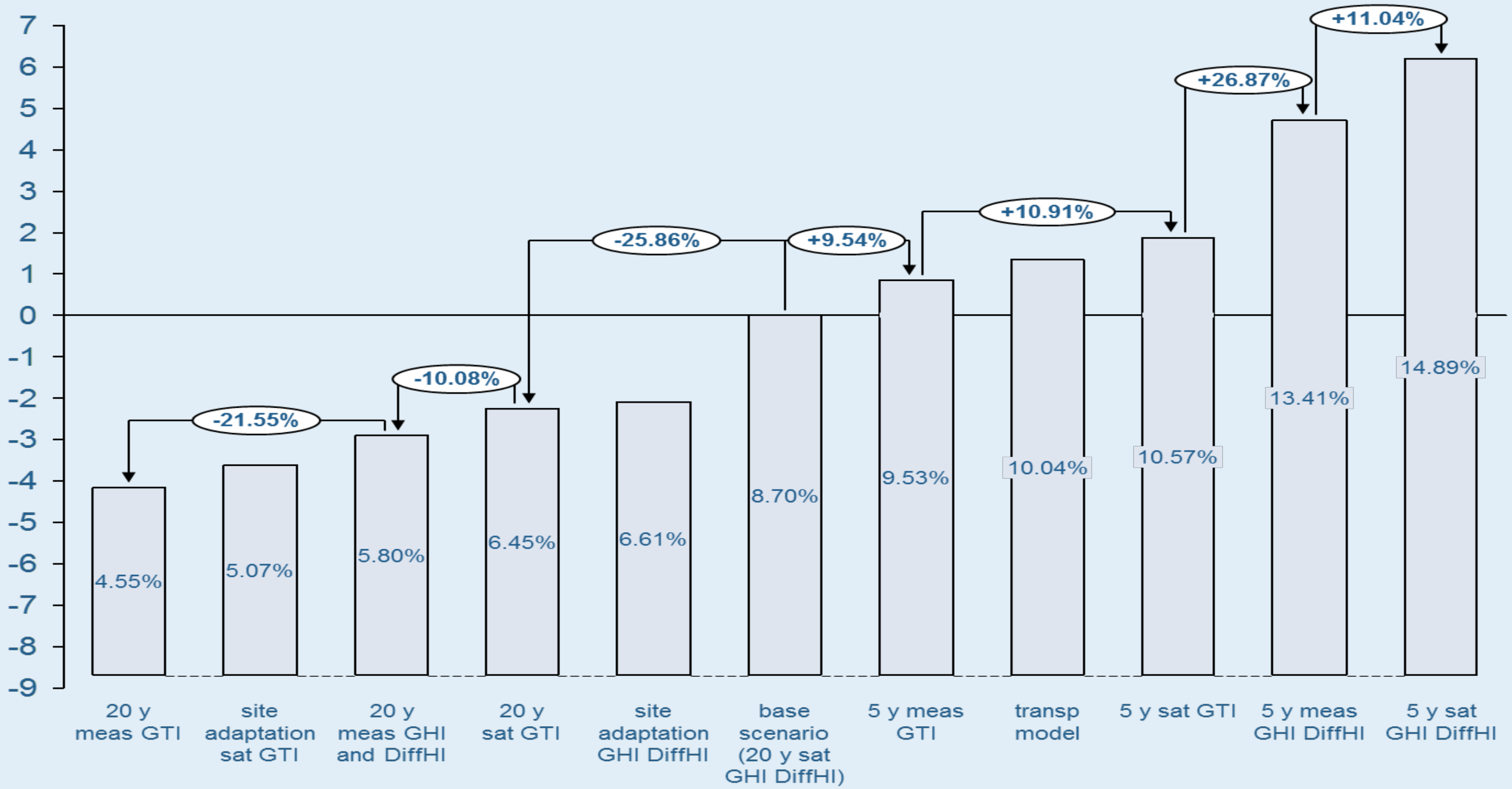

Measured AC values averaged over previous years
2
4
6
8
Prediction Period [Years]
10
12
14
16
18
20
P50_1
P10
P90

Benchmarking exercise



Repeat benchmarking exercise for other location with other climate related / technology related features (e.g. soiling, bifacials, etc)

Uncertainty scenarios



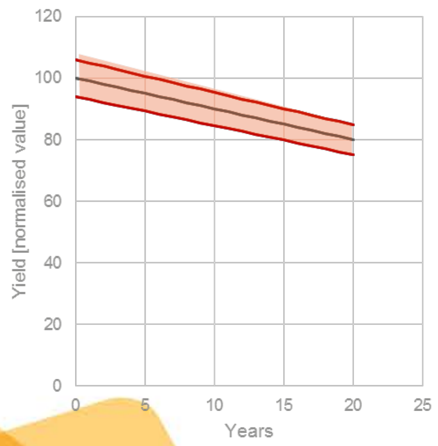
Based on the findings of the benchmarking exercise we will show how uncertainty plays a role for various parameters

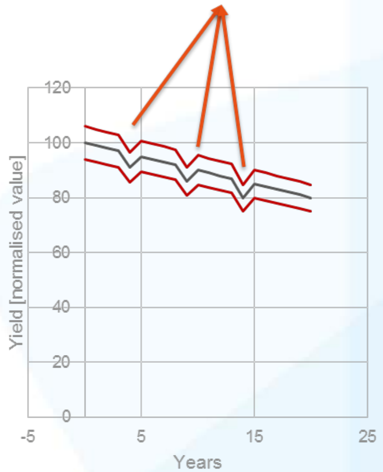
Quantification of the economic impact of technical risks

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





Procedure for the calculation of a Cost Priority Number (CPN)

Creating a cost-based Failure Modes and Effects Analysis (FMEA) for PV

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 reduction
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

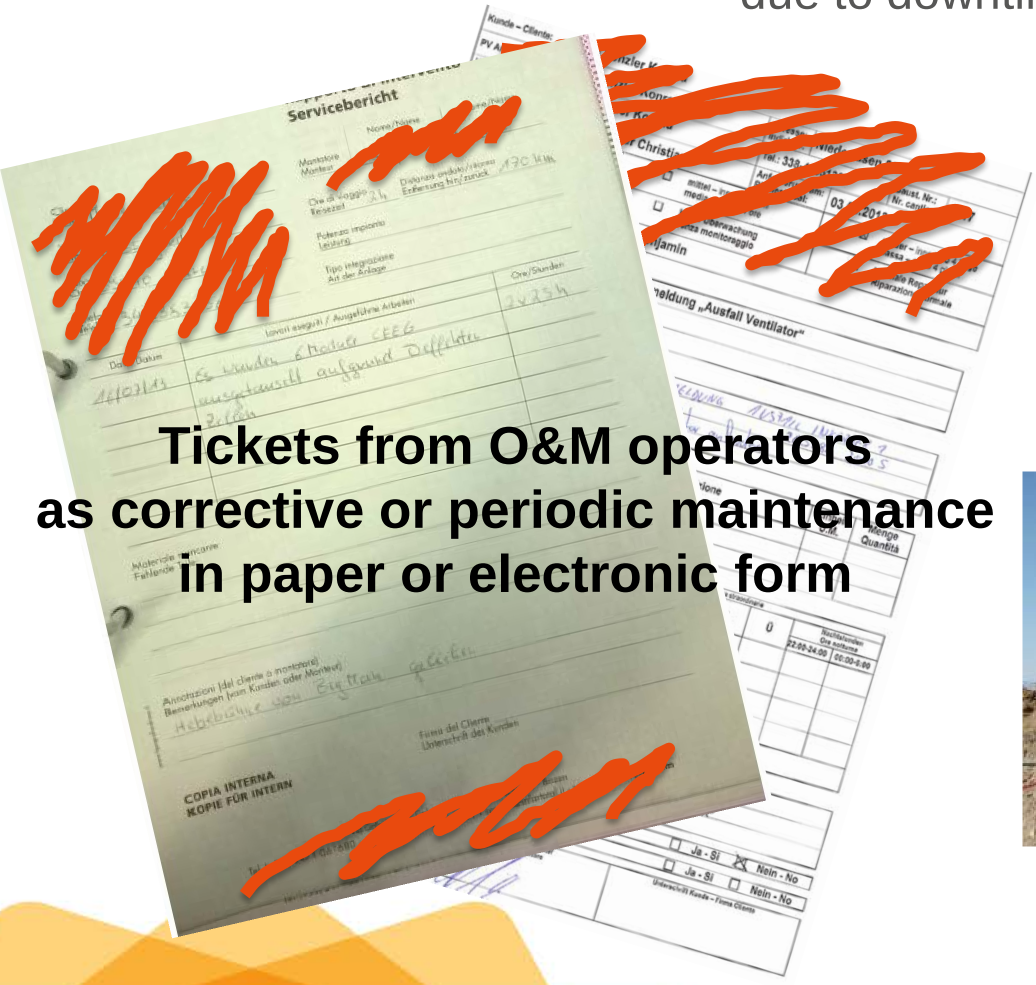
→ Increase in maintenance costs
Reduction of reserves

O&M

Technical Risks collection

$CPN = C_{down} + C_{fix}$

CPN is given in Euros/kWp/year
It gives an indication of the economic impact of a failure due to downtime and investment cost



Tickets from O&M operators as corrective or periodic maintenance in paper or electronic form

Visual and detailed inspection

Technical Risks collection

$CPN = C_{down} + C_{fix}$

CPN is given in Euros/kW/year
It gives an indication of the economic impact of a failure due to downtime and investment cost

	Total number of plants	Total Power [kWp]	Average number of years
TOTAL	772	441676	2.7
Components	**No. tickets**	**No. Cases**	**No. Components**
Modules	473	678801	2058721
Inverters	476	2548	11967
Mounting structures	420	15809	43057
Connection & Distribution boxes	221	12343	20372
Cabling	614	367724	238546
Transformer station & MV/HV	53	220	558
Total	2257	1077445	2373222

- Tickets from O&M operators from preventive and corrective maintenance
- Visual and detailed PV plant inspections

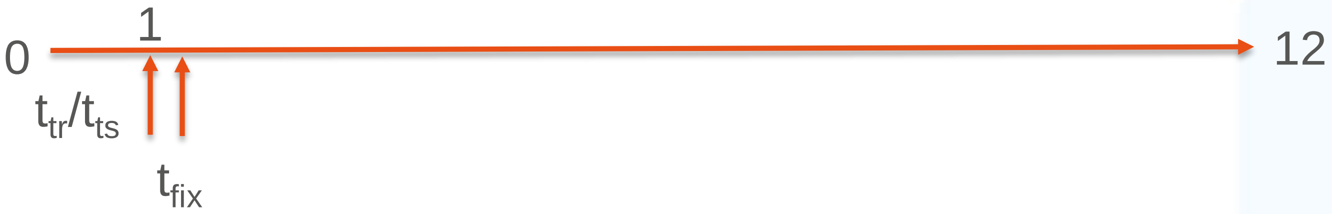
Definition of scenarios

- **Never detected (CPN_{ndet})**

Failure is undetected. **Losses due to downtime** over a time t_{td}

- **Failure fix ($CPN_{failfix}$)**

Failure is detected. 1 Month of lead time to repair/substitution



- Failures are equally distributed over time
- No increase in Performance Losses over time
- Yield is considered as an average at national level (not site specific)
- The real scenario would be a combination of the two

Technical Risks collection: some statistics

	no. cases	no. components	Years	Share of failures	Share of failures/ year
Modules	678,640	2,058,721	2.68	33%	12%
Inverters	2,474	11,967	2.68	21%	8%

Module	Failure share
Soiling	23.4%
Shading	16.8%
EVA discoloration	11.6%
Glass breakage	6.5%
PID	5.0%

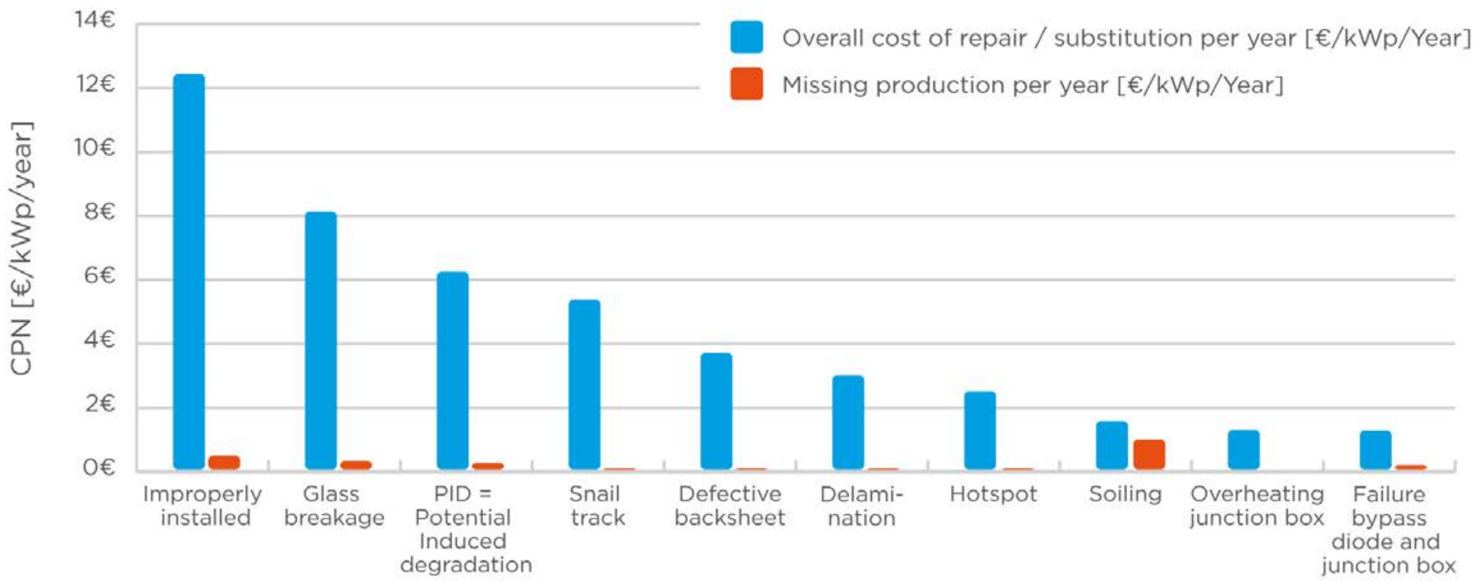
Inverter	Failure share
Fan failure and overheating	21.8%
Fault due to grounding issues	4.9%
Inverter firmware issue	3.8%
Burned supply cable and/or socket	2.2%
Polluted air filter	3.3%
Inverter pollution	1.5%

O_{CPN} from the cost-based FMEA (power loss)

occurrence	portfolio	affected
modules	1.010%	14.958%
inverters	2.687%	22.046%
Mounting structure	0.206%	10.820%
Connection & Distribution boxes	0.145%	15.175%
Cabling	2.765%	6.855%
Transformer station & MV/HV	0.452%	0.393%

CPN Results - Components and Market Segments

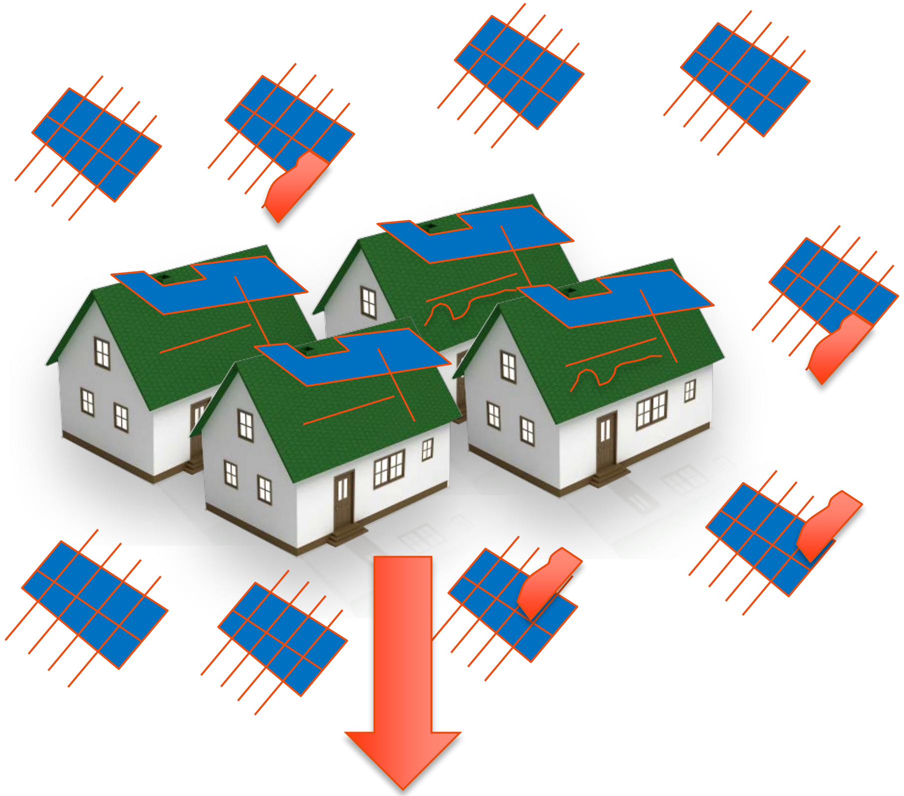
- PV modules - Utility scale



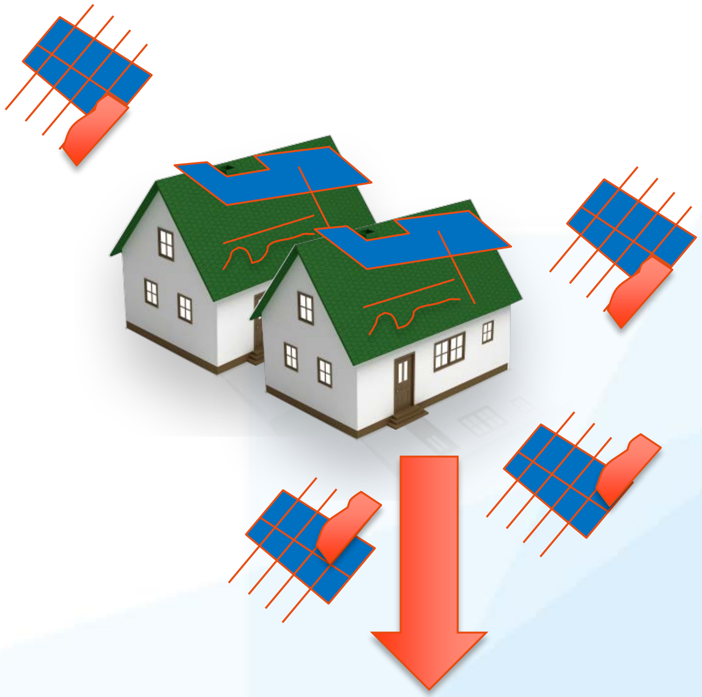
- Highest risk consists of a group of installation failures (mishandling, connection failures, missing fixation, etc.)
- Variety of failures detected by different techniques (VI, IR, EL, IV-Curves)

CPN results - Comparison studies

- Affected components vs total components: CPN ratio



Failures calculated over the whole database

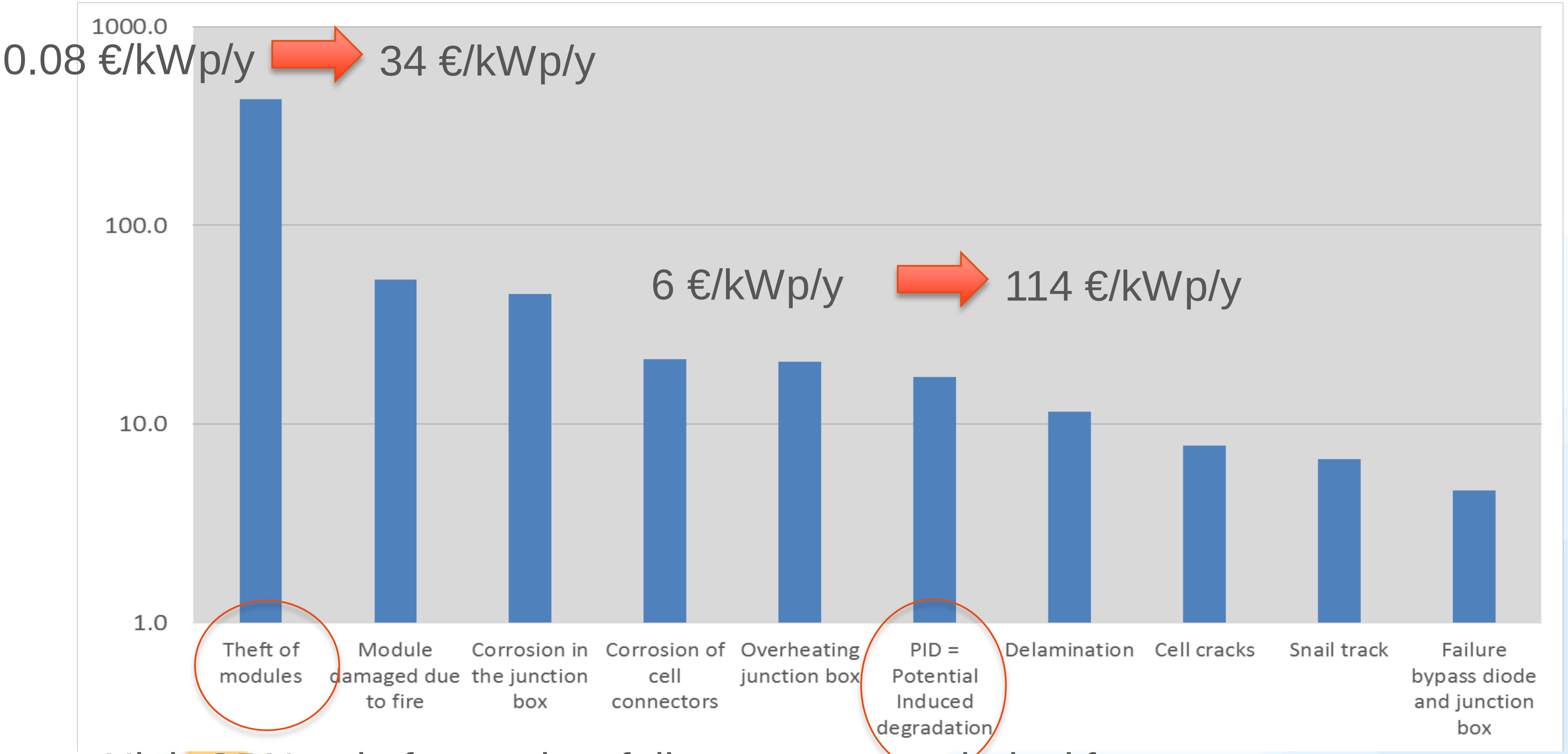


Failures calculated over the affected plants

O&M

CPN results - Comparison studies

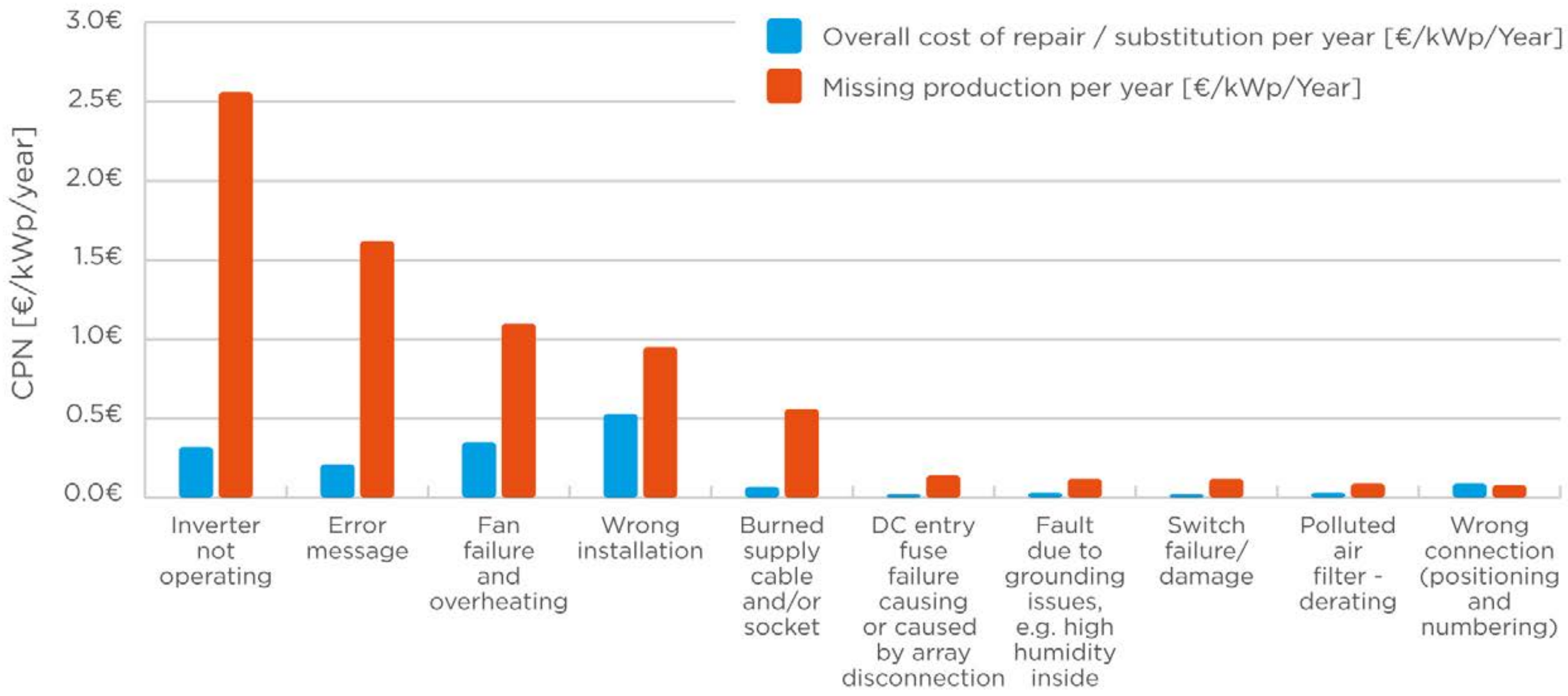
- Some failures do not occur very often and are not equally spread over the portfolio but when they do, the economic impact is very high



- High CPN ratio for product failures or non technical factors

CPN Results - Components and Market Segments

- Inverters



Technical risk framework

A	Risk identification
B	Risk assessment
C	Risk management
D	Risk controlling

Risk management:
- Risk Mitigation
- Risk Transfer

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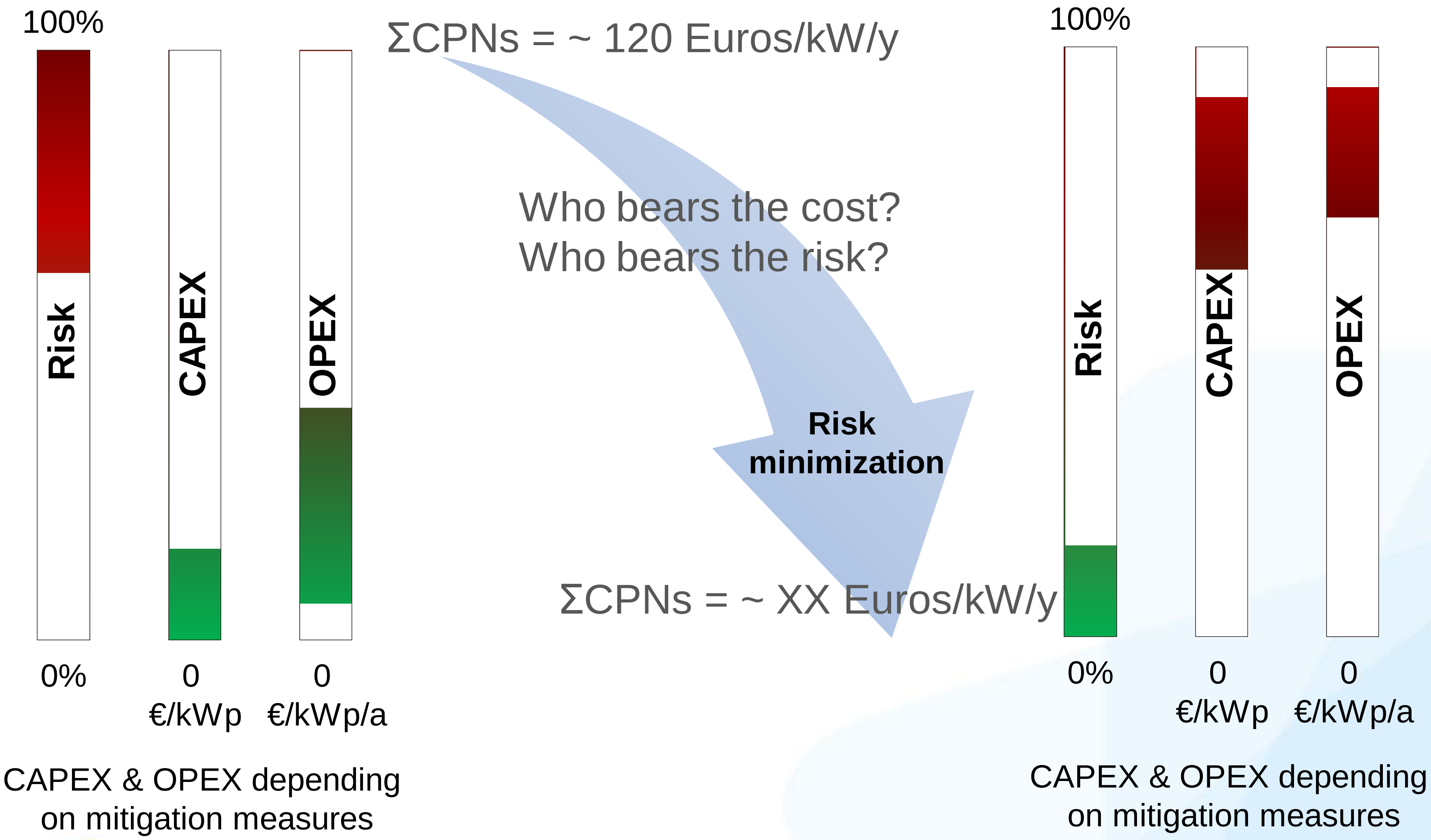
Risk mitigation



Mitigation Measure Approach

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

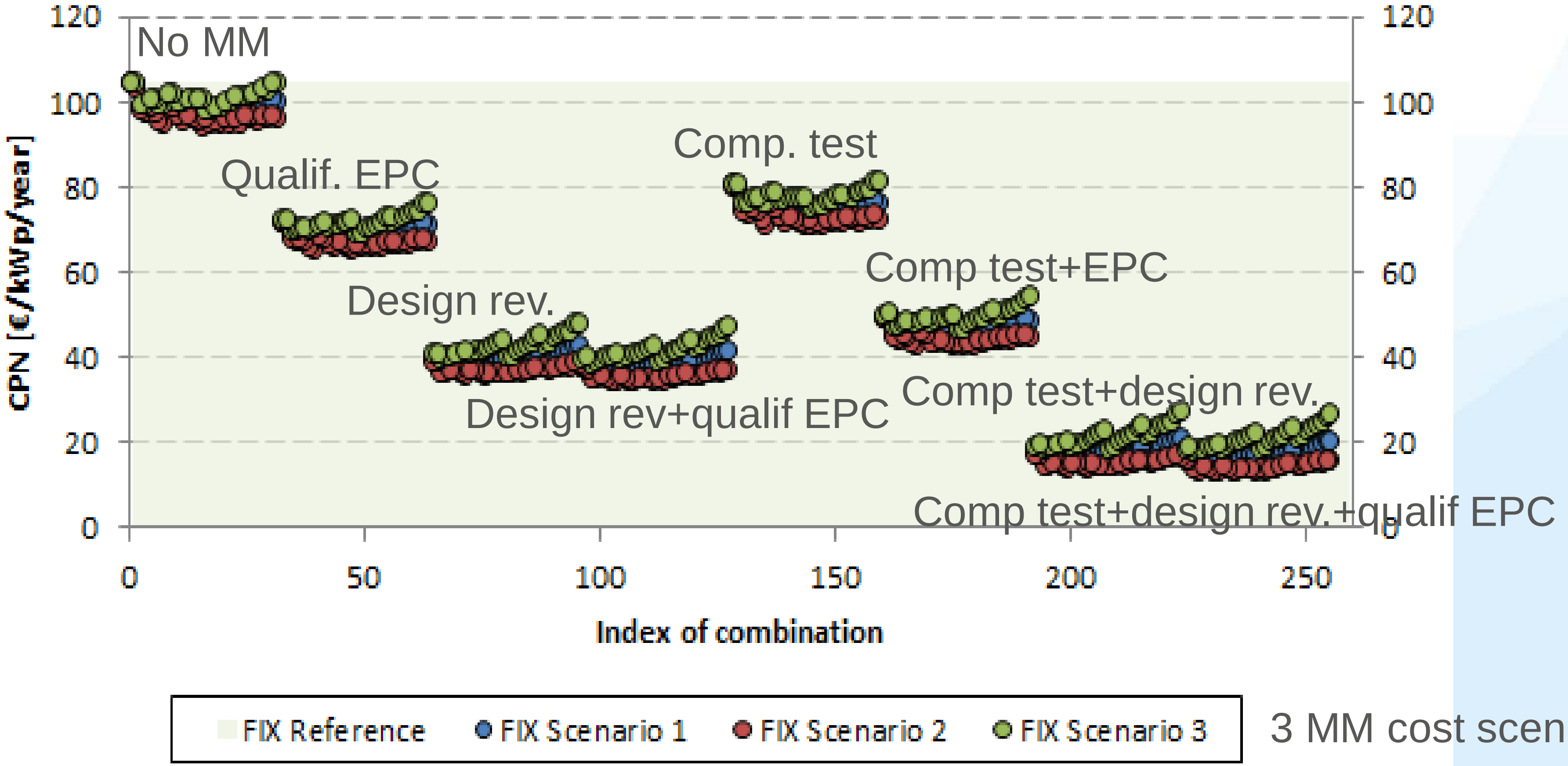
- **Preventive measures**
- **Corrective measures**

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

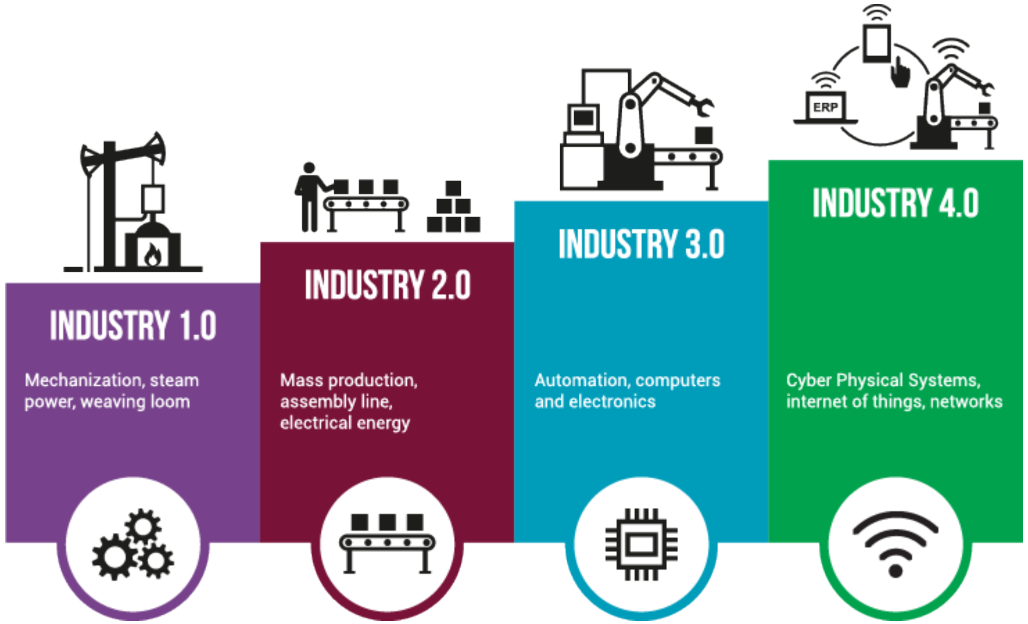
Preventive measures have higher impact



3 MM cost scenarios

From theory to practice

PV4.0: Use of Industry 4.0 and IoT logics in the PV sector



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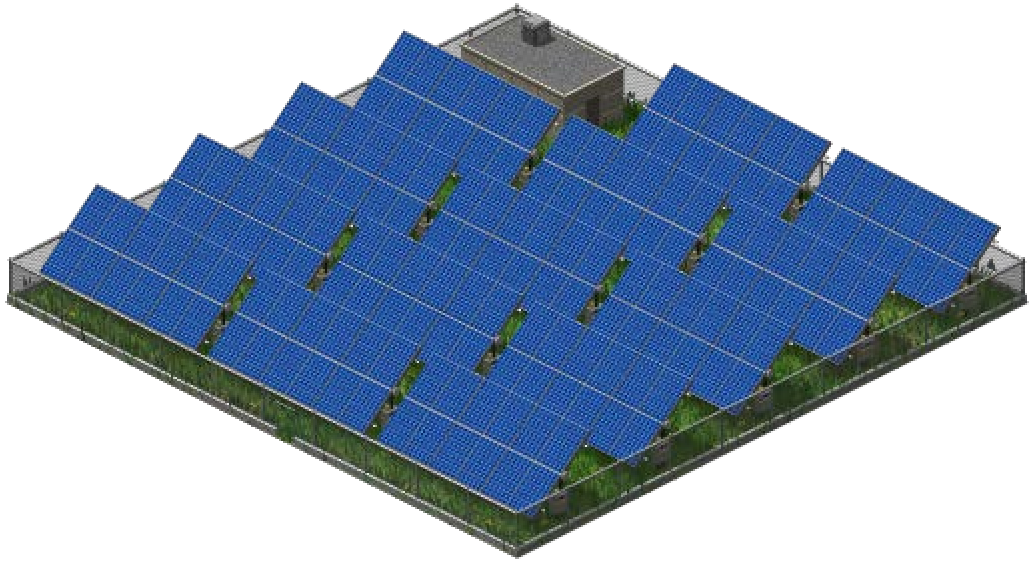

PV4.0

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EUROPEAN UNION
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eurac research
saidea informatica

Different market segments

- Medium/Large PV systems: facilitate due diligence and hand-over in the secondary market / create a benchmark to compare PV plants
- Small PV systems: log every maintenance intervention to keep track of the health status of the plants and to facilitate O&M


The overall objective of the project is to develop a concept for the effective management of the activities of various stakeholders (asset managers, O&M companies, etc) inspired by Industry 4.0 and so to optimise the decision process minimising time and operational costs.
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eurac research
saidea

Before

.time to detection: no monitoring system or warning thresholds too broad or inaccurate (up to months to detect deviations)

.time to response: time required to organise repair or substitution. Time to understand the appropriate action.

.time to repair: assessment of situation only once on site

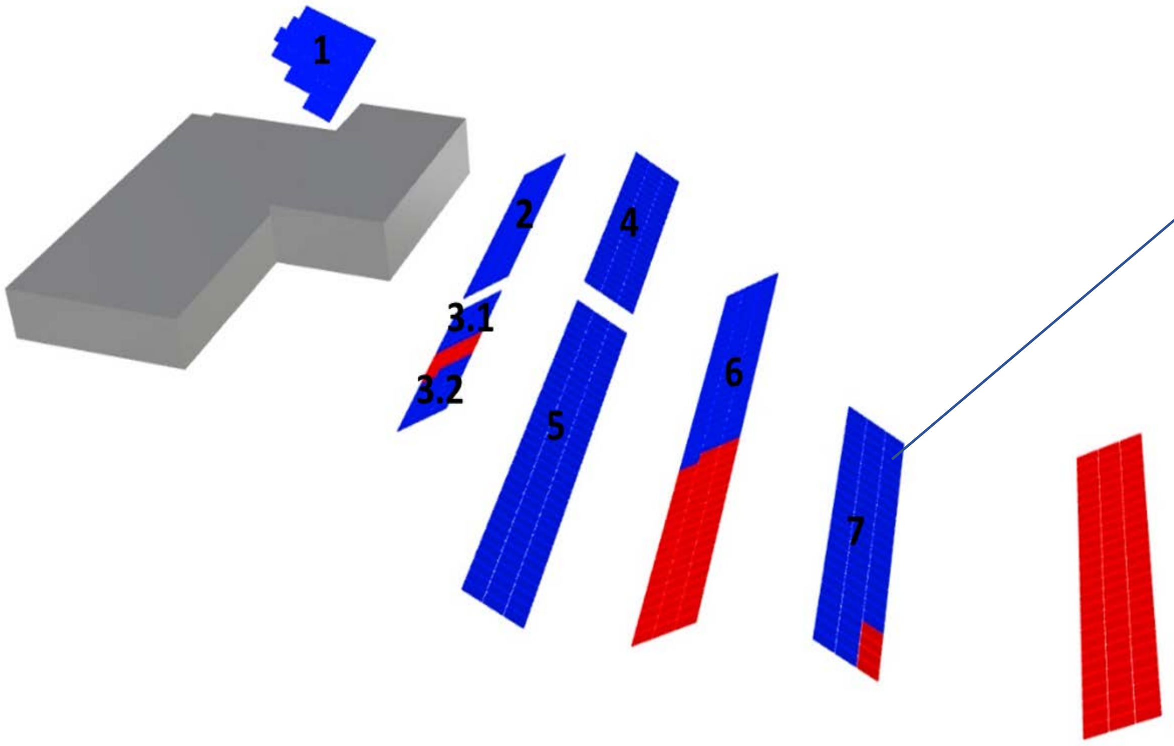
After (PV4.0ed)

.time to detection: use of advance diagnostics and predictive monitoring / big data analytics

.time to response: use of self-learning Decision Support System (DSS) to suggest actions based on techno-economic analysis

.time to repair: use of DSS to optimise spare parts management

Develop a BIM inspired system to have a 3D visualisation of PV plants



01/06/2018 Module cleaned
01/08/2018 Glass breakage identified
15/08/2018 Module substituted (spare part)

Component log

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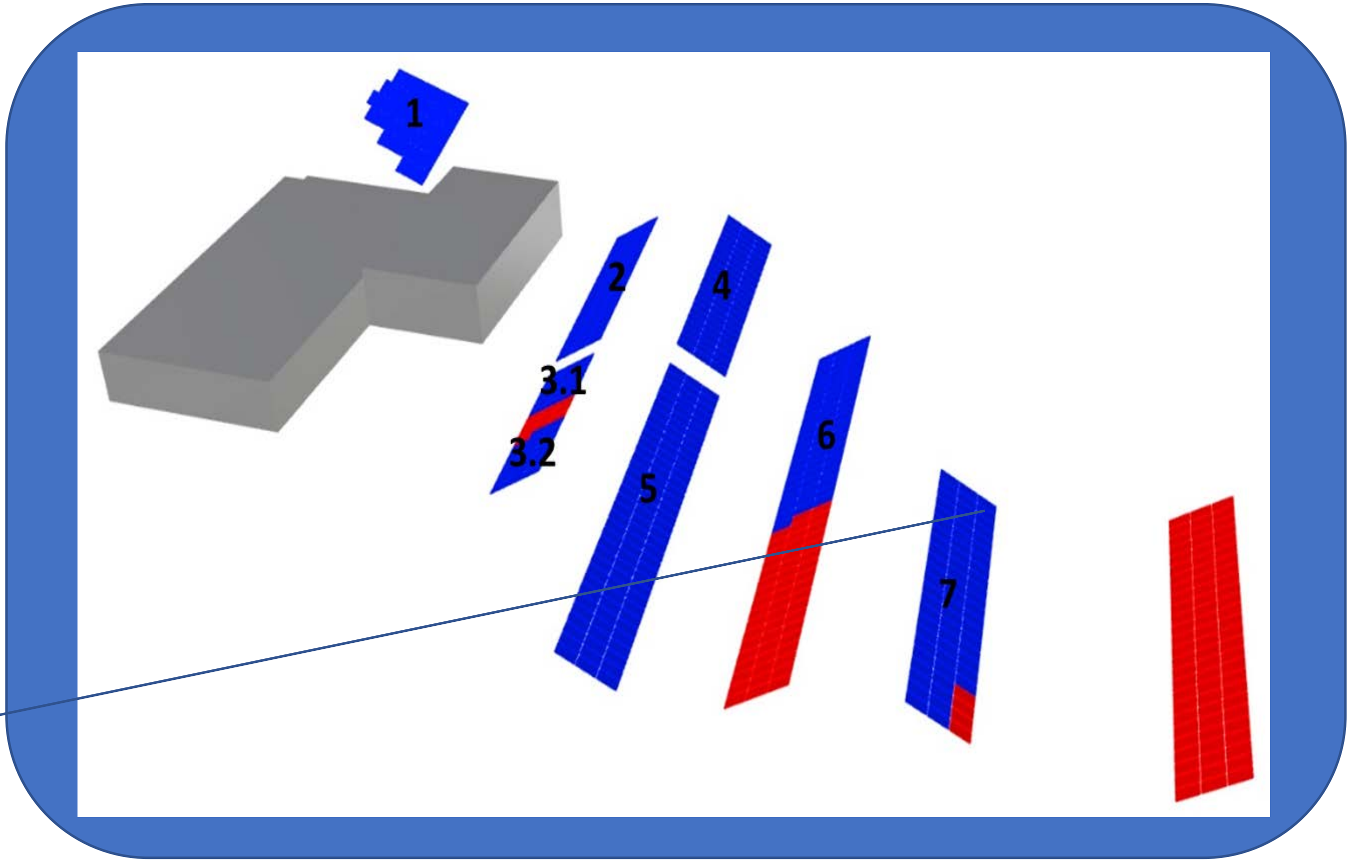
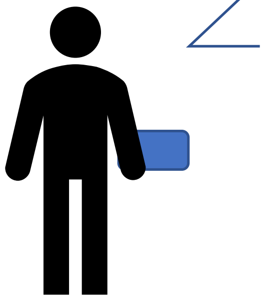
Develop the PV4.0 hardware

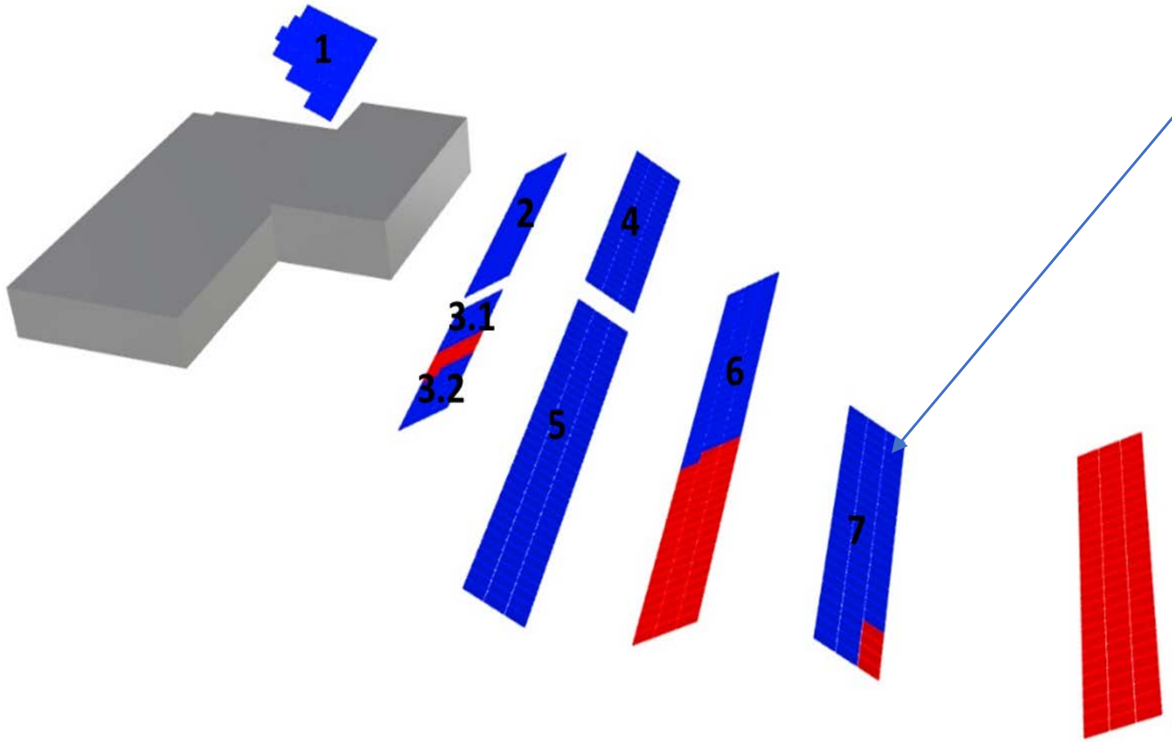
Use of cloud based systems
Use of wireless sensor networks





Select diagnostic tool: thermal image
Select failure: hotspot

Develop models, algorithms and big-data back end for PV4.0



20/08/2018 Warning, deviation detected component module XY

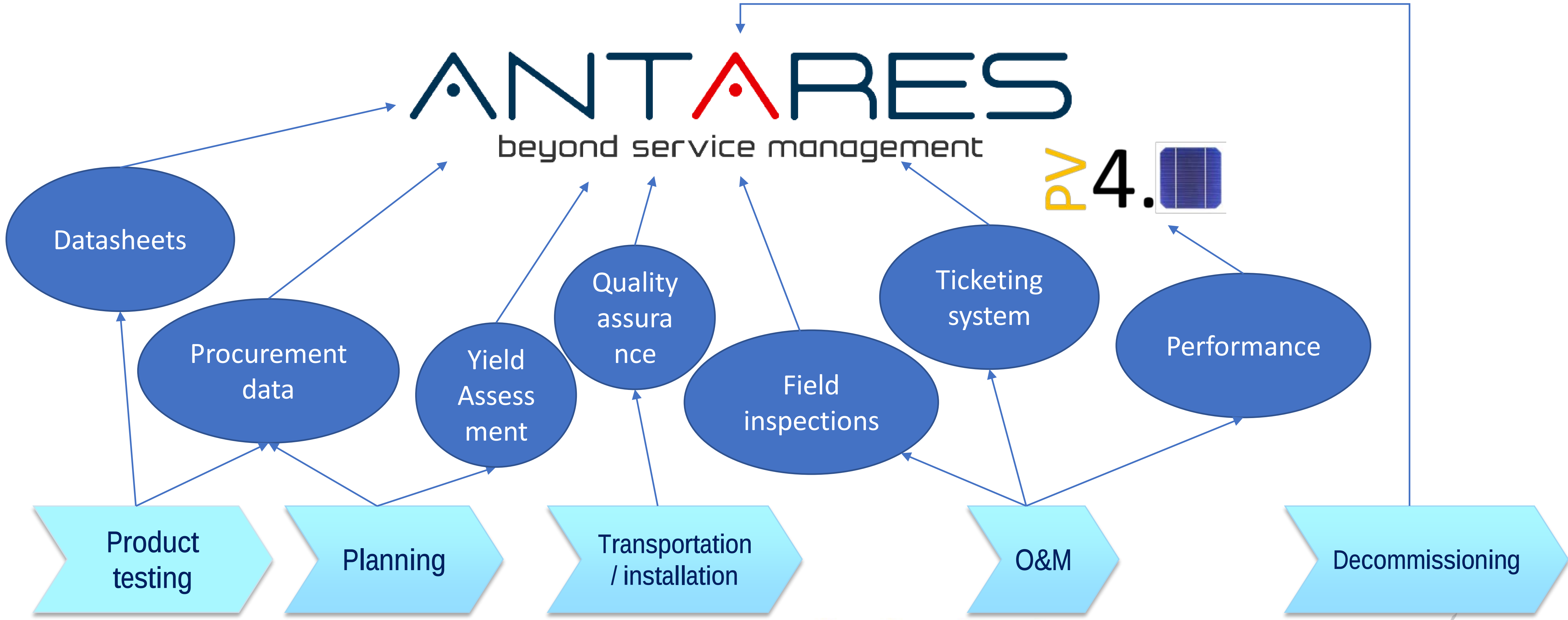
Warnings

CPN calculation
O&M strategy optimiser

20/08/2018 Sent operator

Actions

Develop the PV4.0 software



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Thank you!

“We ensure quality and sustainability in a PV driven energy transition”

david.moser@eurac.edu

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