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eurac research

The economic impact of failures in the field

David Moser

14 October 2019, Malta

PEARL PV

The Quest for Quality

Does quality have a real impact on the LCOE?

OPEX
8-10 Euros/kWp/y

LID
2%

PLR
0.5%

Lifetime
25 years

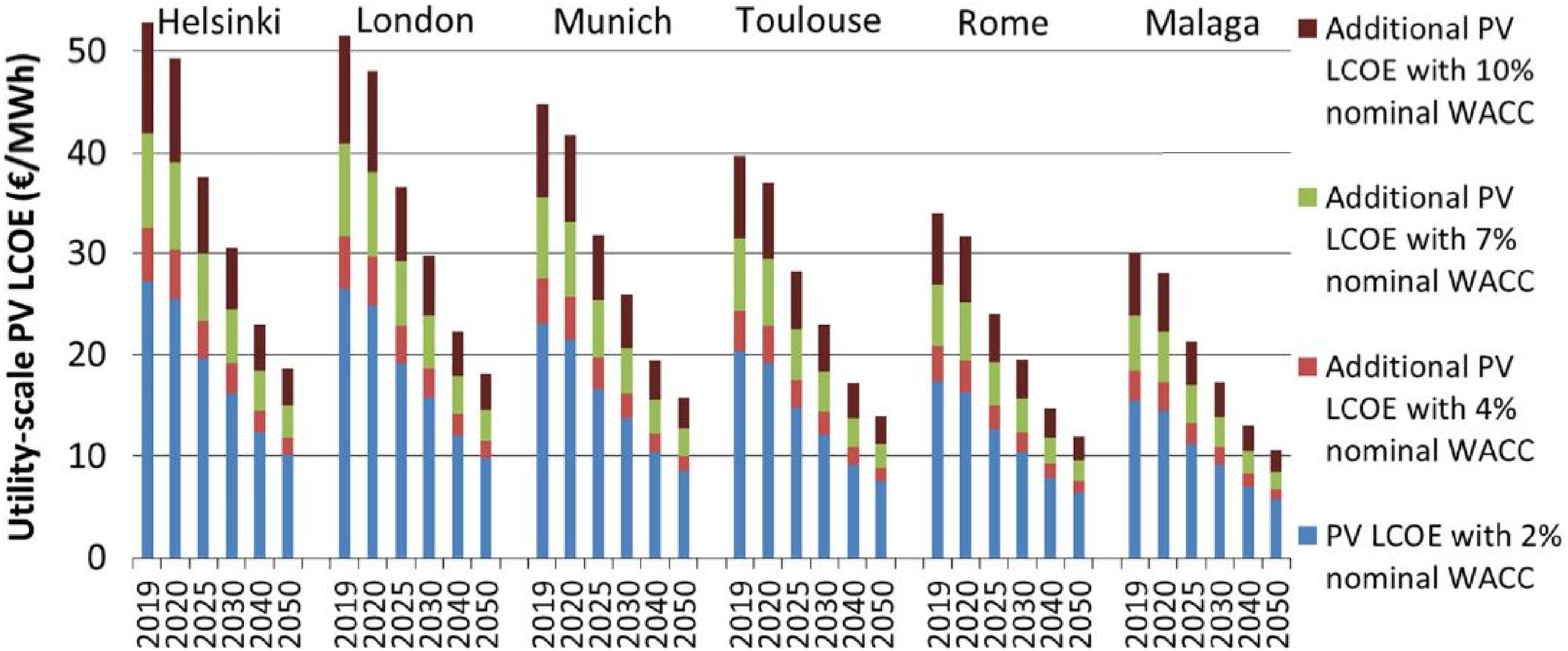
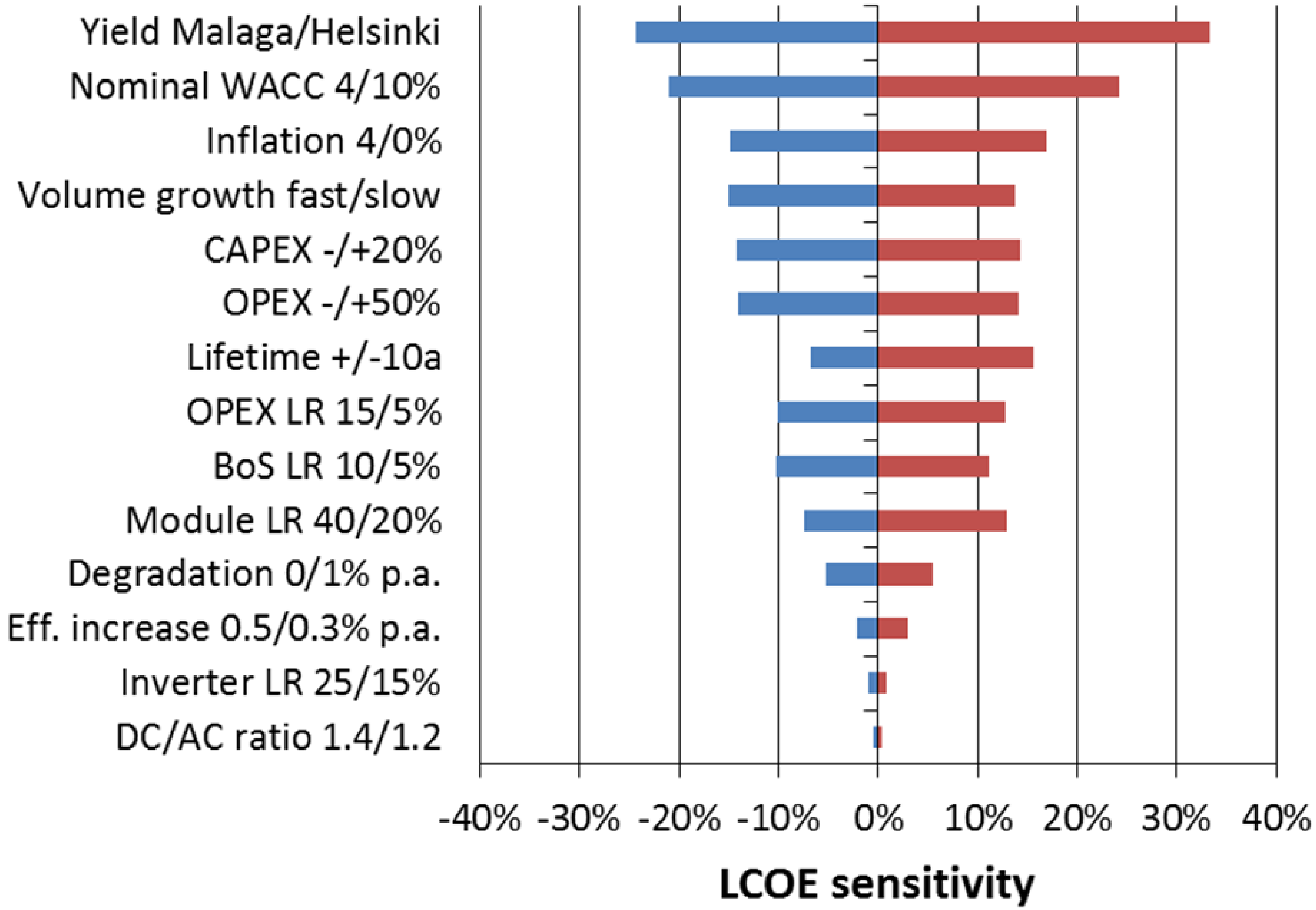


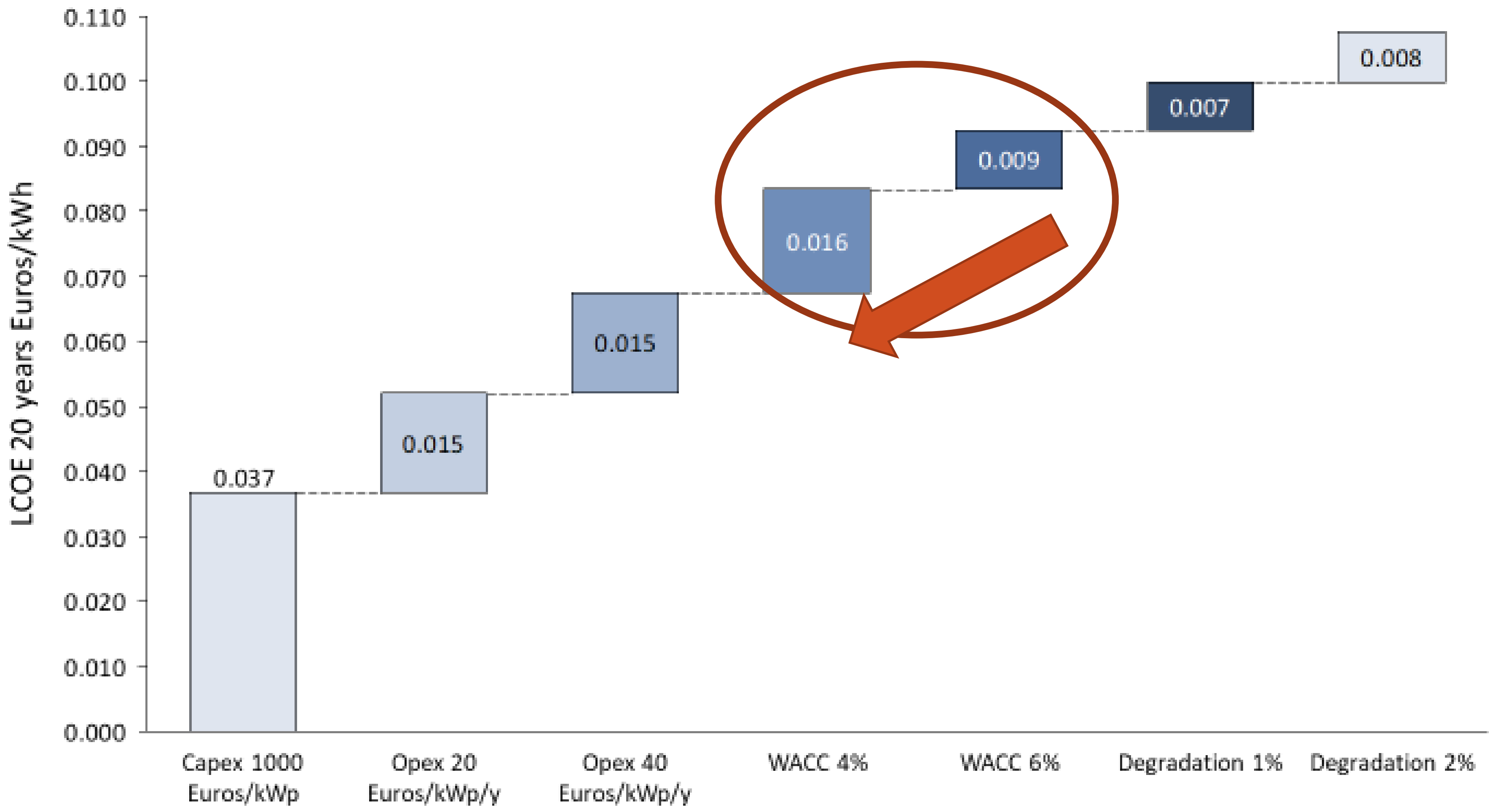
FIGURE 9 Photovoltaics (PV) levelised cost of electricity (LCOE) in six European locations for the years 2019 to 2050; in 2019 euros

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

Does quality have a real impact on the LCOE?



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

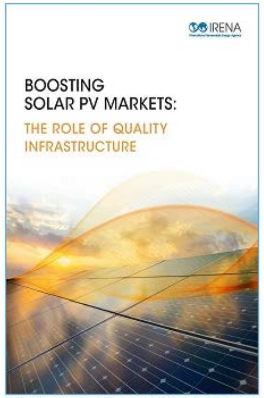
solartrain

PEARL PV

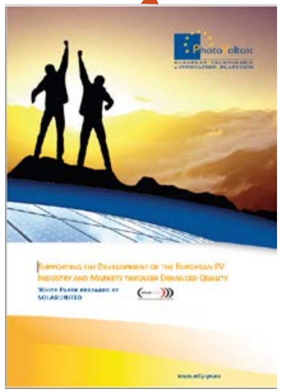
PV performance database

PV 4.0

Industry4.0 + IoT platform
Big data analytics



Boosting global PV markets: The role of quality infrastructure



Technical risks framework

Tracking defects in the field

International Energy Agency
Photovoltaic Power Systems Programme

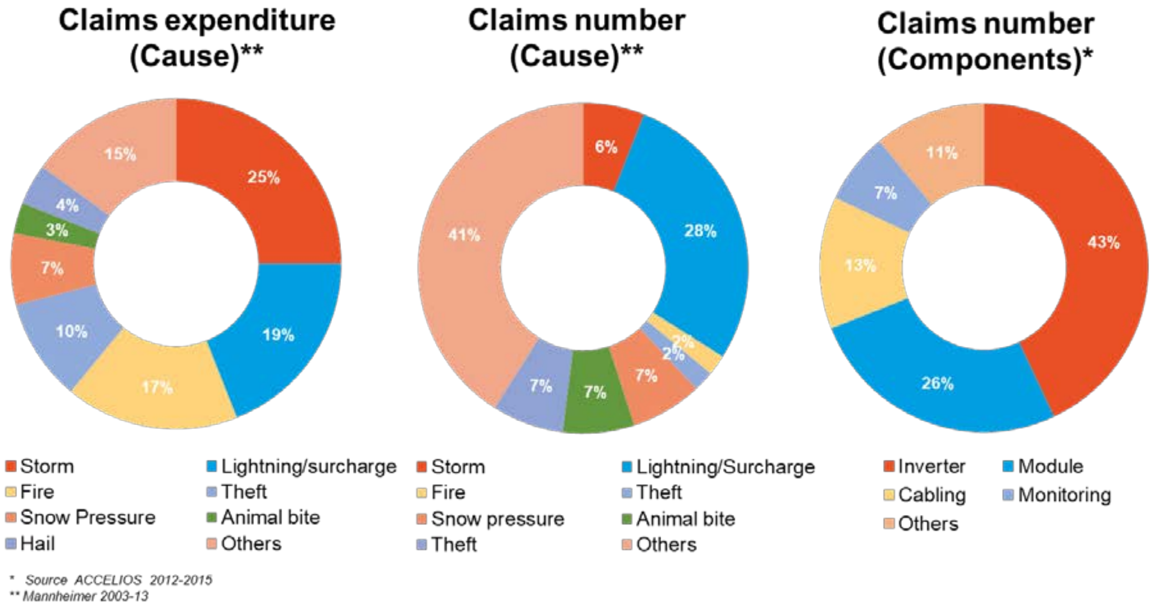
TASK13: Review of Failures of Photovoltaic Modules, M. Köntges et al

Failure description → Failure mechanisms and detection → Performance loss

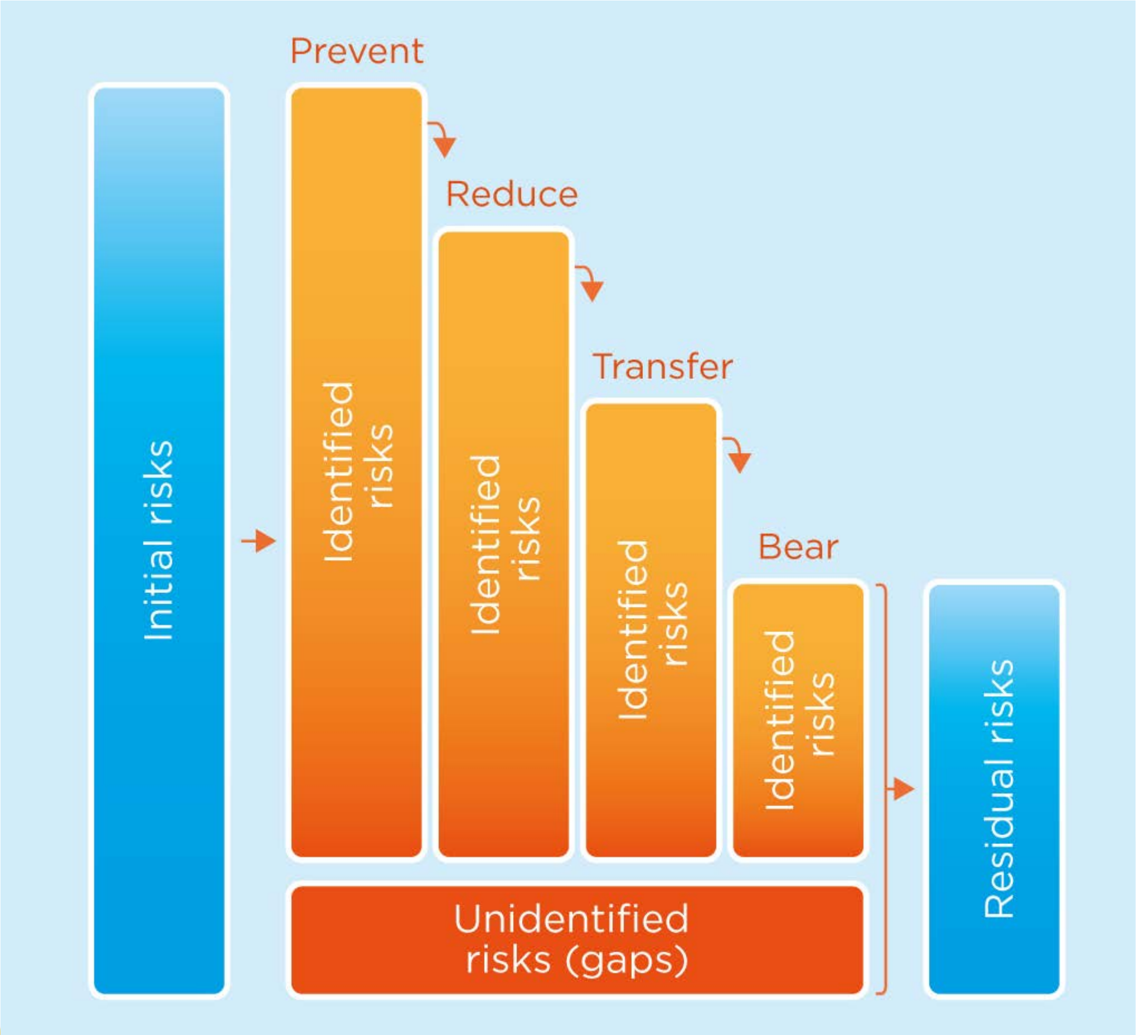
Majority of returns associated with failures that can be detected visually (underestimation of other type of failures?)

Systematic use of visual inspection → Large dataset of failures

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



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

Product Development | Assessment of PV Plants

Product testing

Modules		....	....	....	....
Inverter		....	....	....	....
Mounting str...		....	....	....	....
Connection & distribution boxes		....	....	....	....
Cabling		....	....	....	....
Potential equalization grounding, LPS		....	....	....	....
Weather station, communication, monitoring		....	....	....	....
Infrastructure & environmental influen...		....	....	....	....
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

SOLAR BANKABILITY

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
- 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

…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	....			....	....

- Soiling
- Shadow diagram
- Modules mismatch
- Modules not certified
- Flash report not available or incorrect
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- 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	....			....	....

- Soiling
- Shadow diagram
- Modules mismatch
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- Flash report not available or incorrect
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- 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

Transportation / installation

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

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

Lis… res

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
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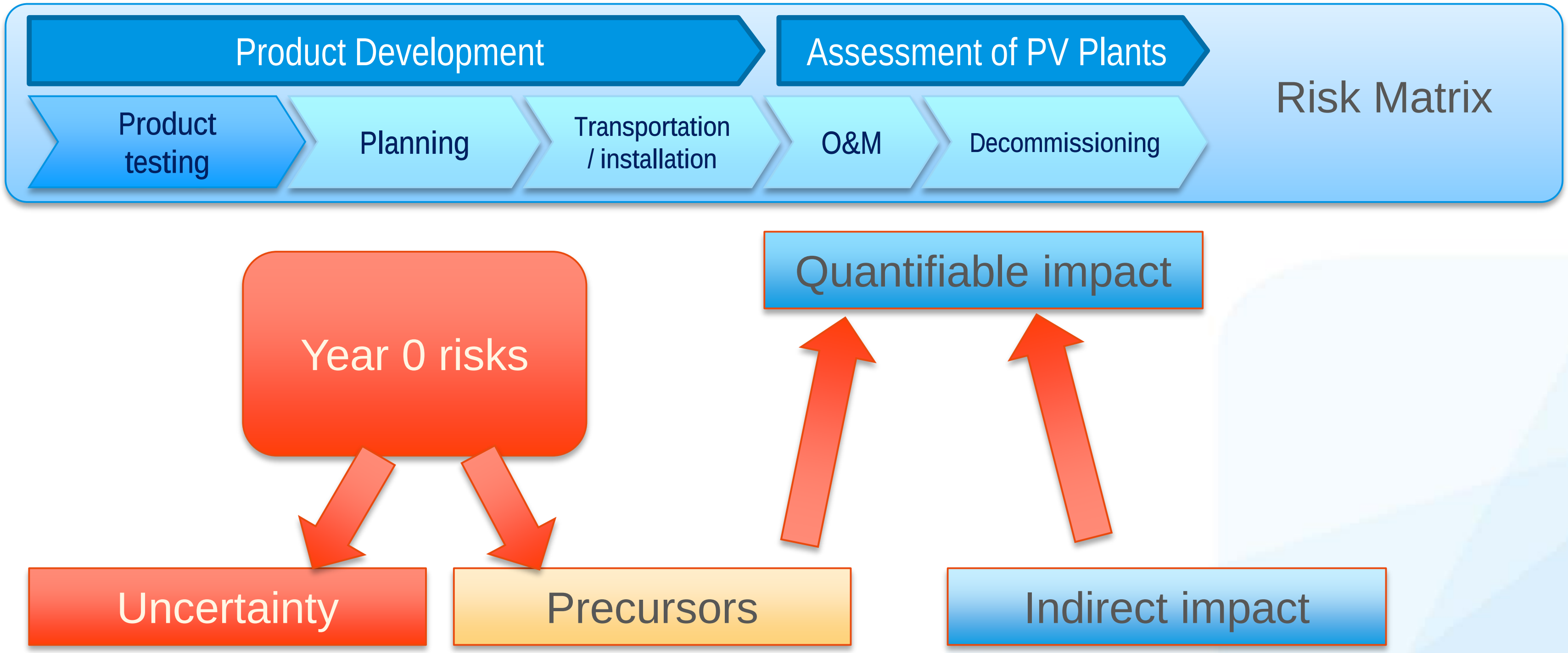
- Theft of modules
- Module degradation
- Slow reaction time for warranty claims, vague or inappropriate definition of procedure for warranty claims
- Spare modules no longer available, costly string reconfiguration

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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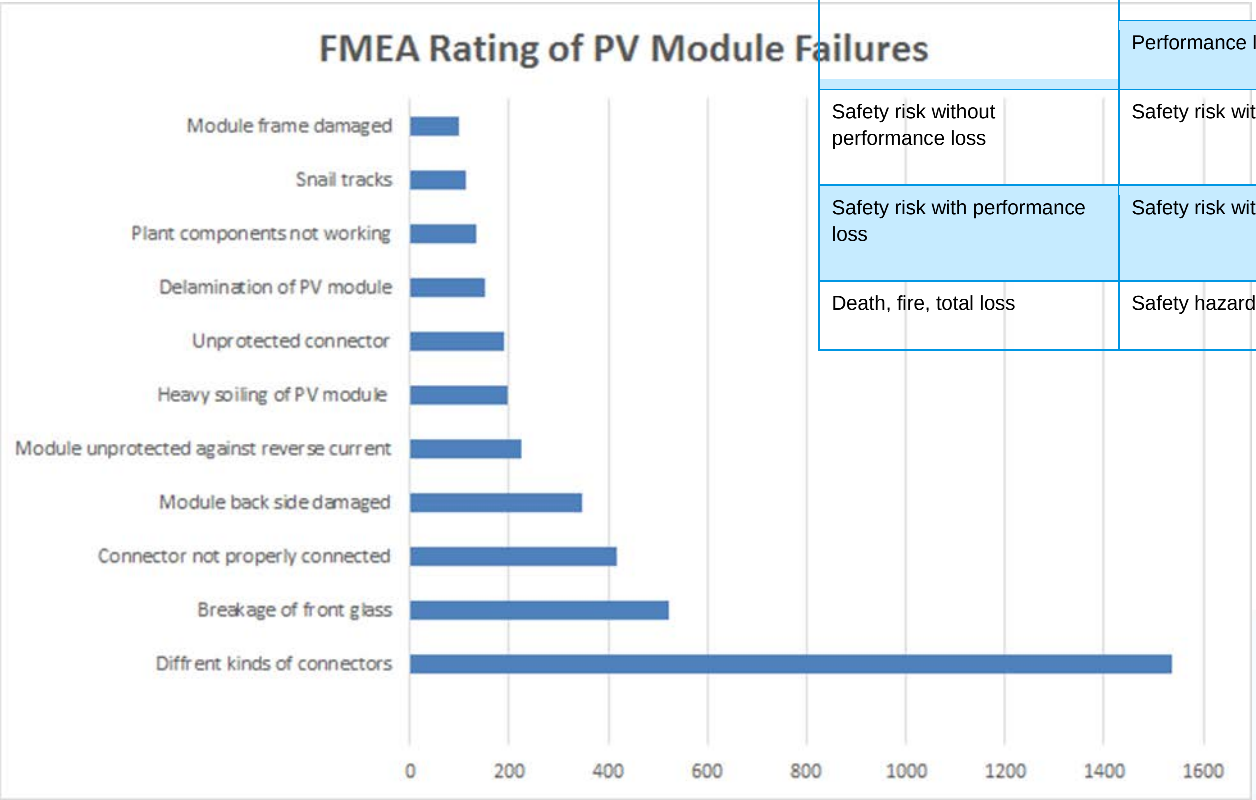
FMEA approach

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

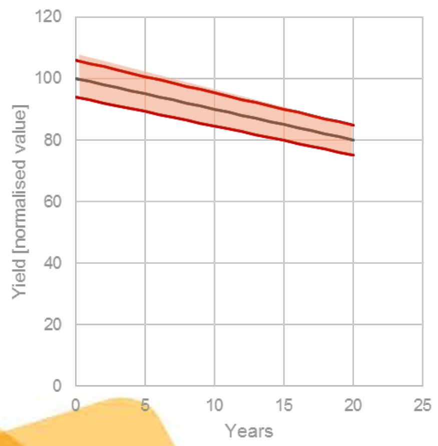
- **Risks to which we can assign an uncertainty (e.g. irradiance)**

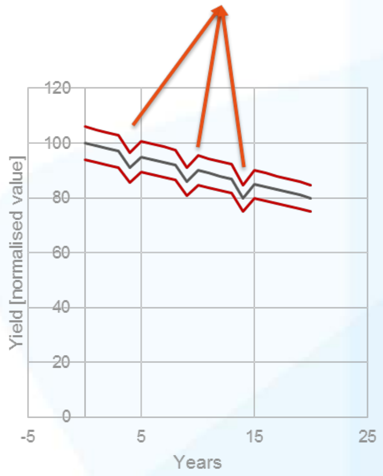
→ Impact on financial exceedance probability parameters

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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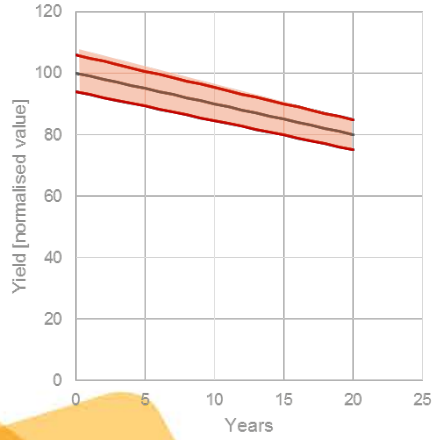
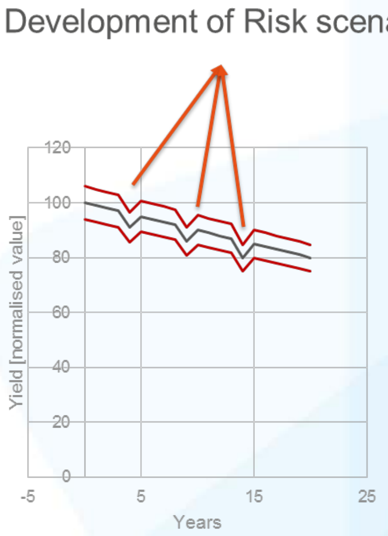
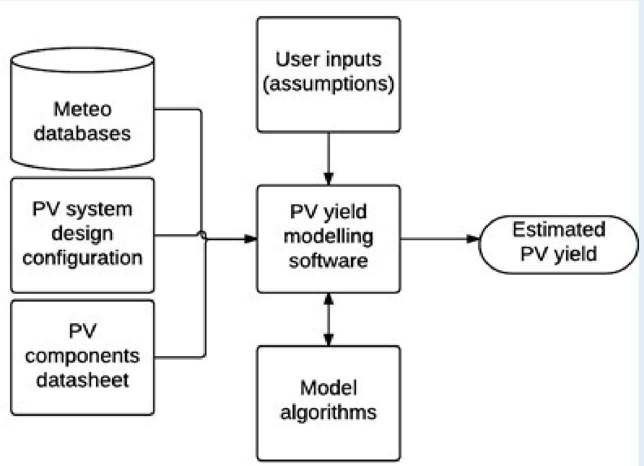
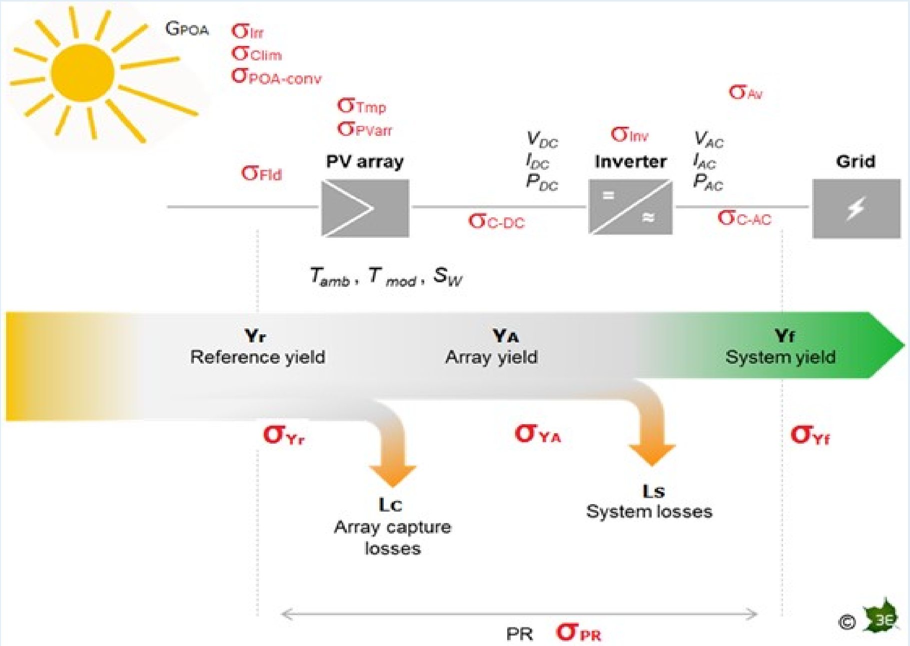
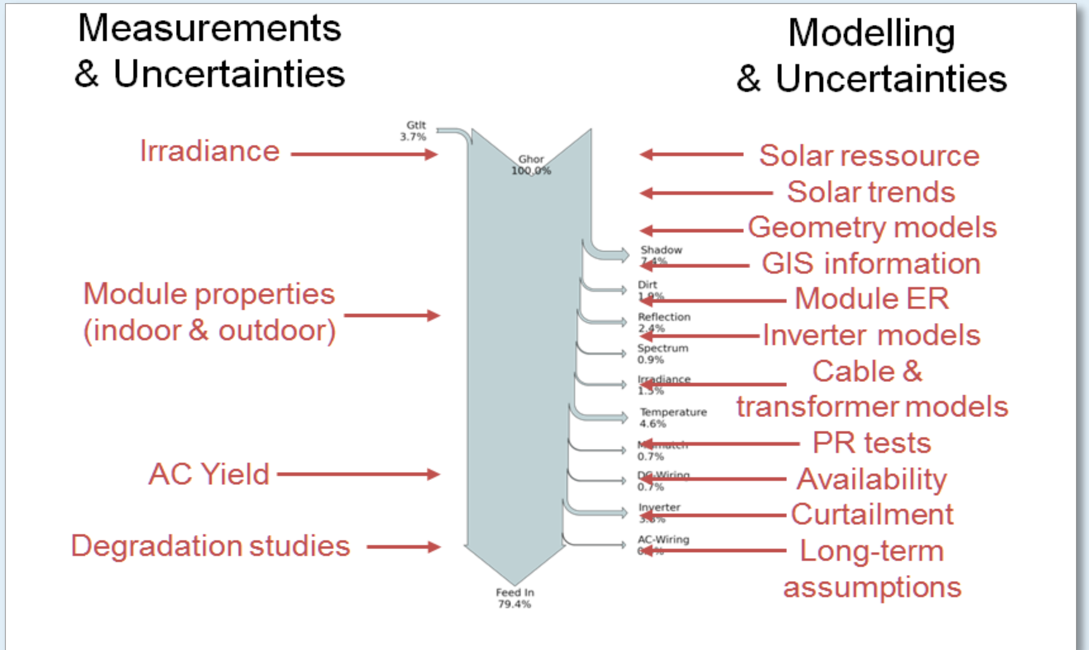




Calculation of uncertainty







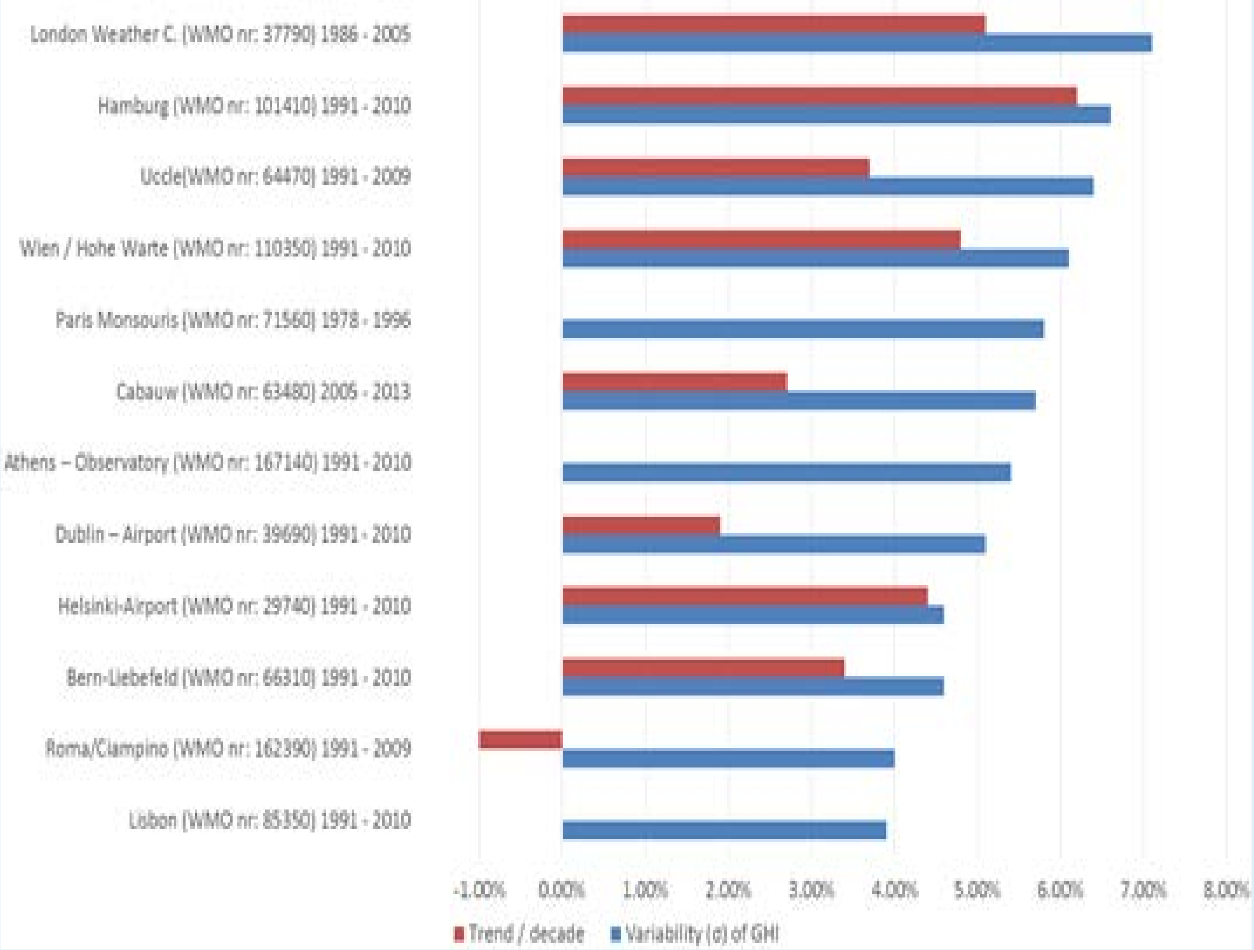
Uncertainties in PV System Yield Predictions and Assessments

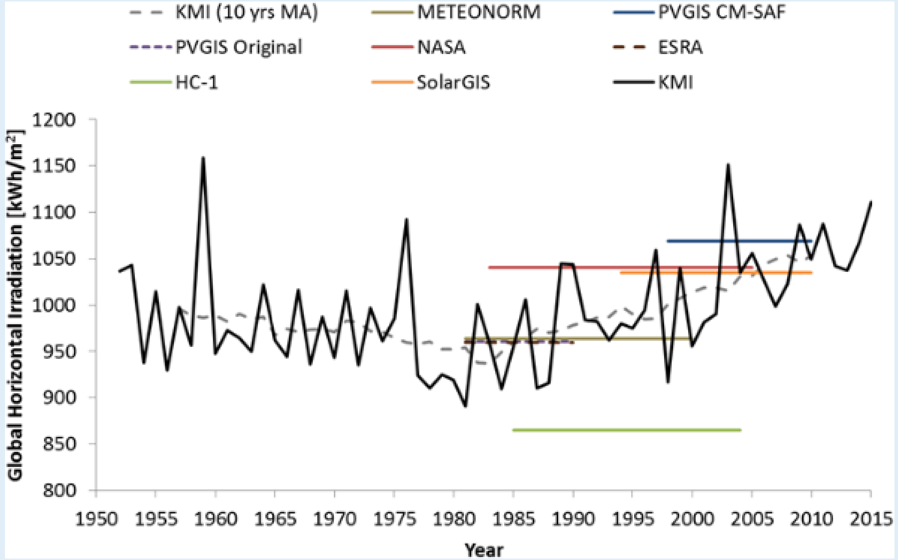
Christian Reise, Alexandra Schmid, Björn Müller, Daniela Dirnberger, Nils Reich, Giorgio Belluardo, David Moser, Philip Ingenhoven, Mauricio Richter, Joshua S. Stein, Clifford W. Hansen, Anton Driesse, Lyndon Frearson, Bert Herteleer

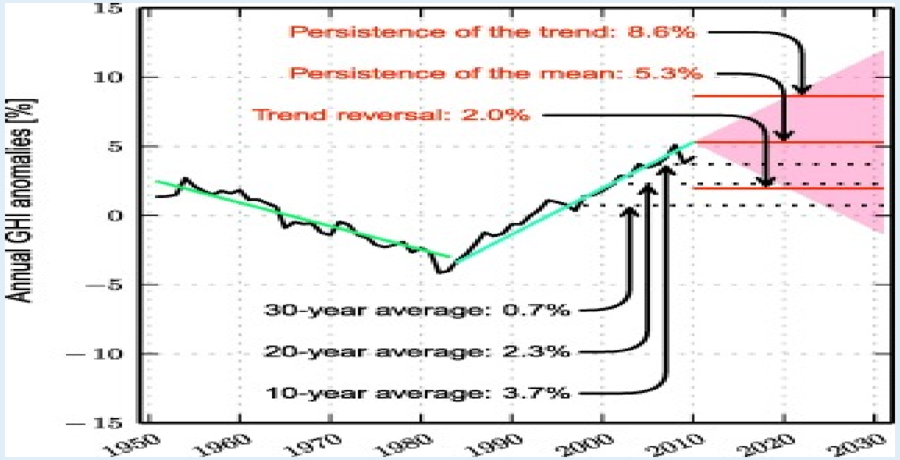
IEA PVPS Task 13, Subtasks 2.3 & 3.1 Report IEA-PVPS T13-12:2018 April 2018

PVPS

Irradiance measurements and solar resource assessment: irradiance variability and trends





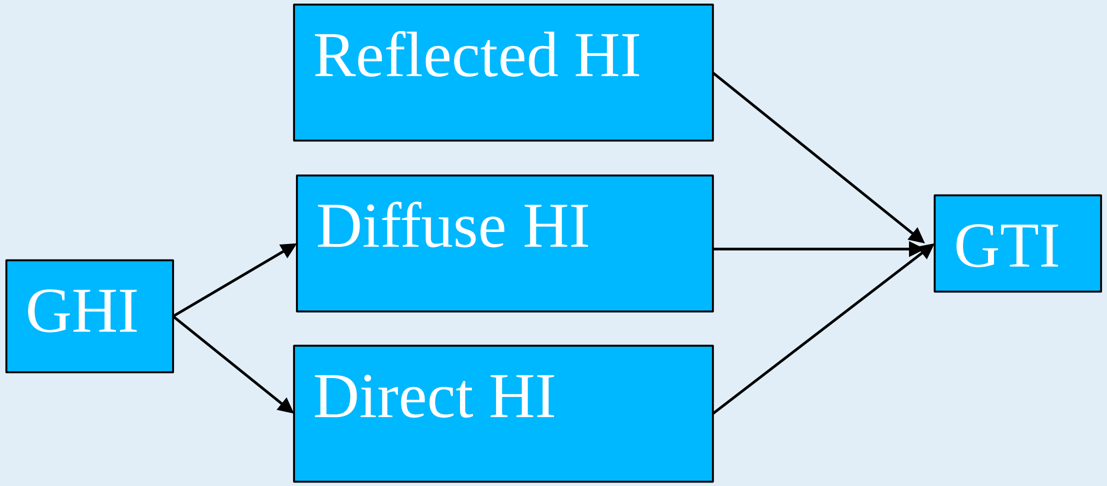


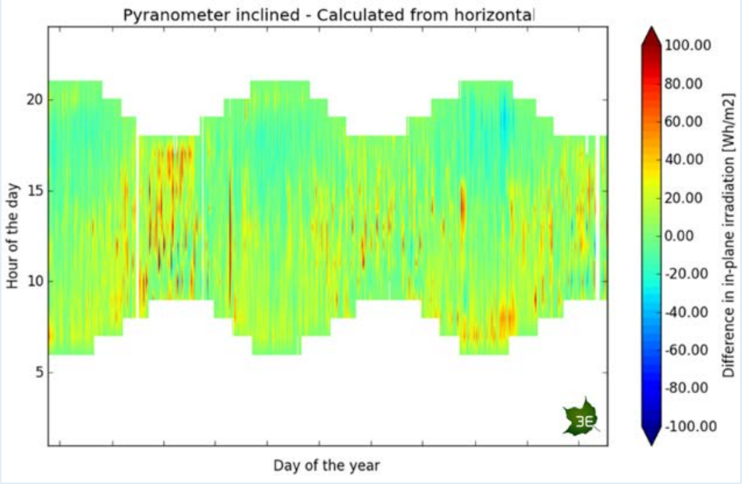
D. Moser *et al.*, "Technical Risks in PV Projects." Solar Bankability Deliverable www.solarbankability.com

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%

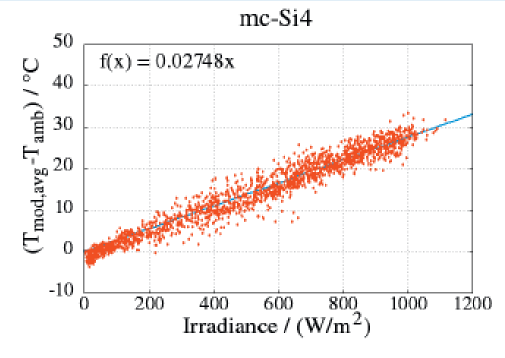


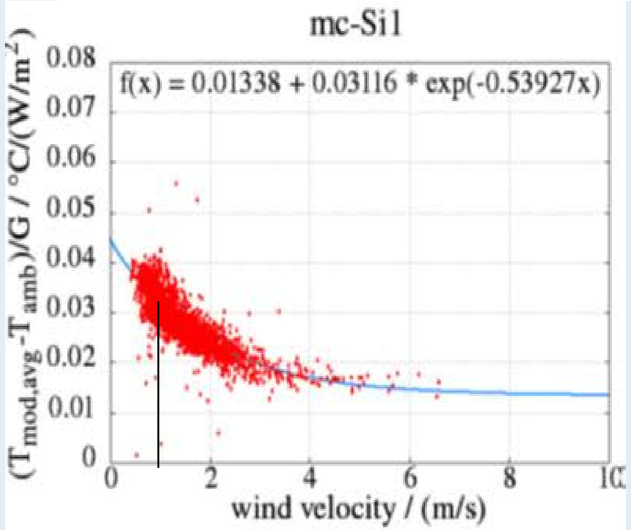


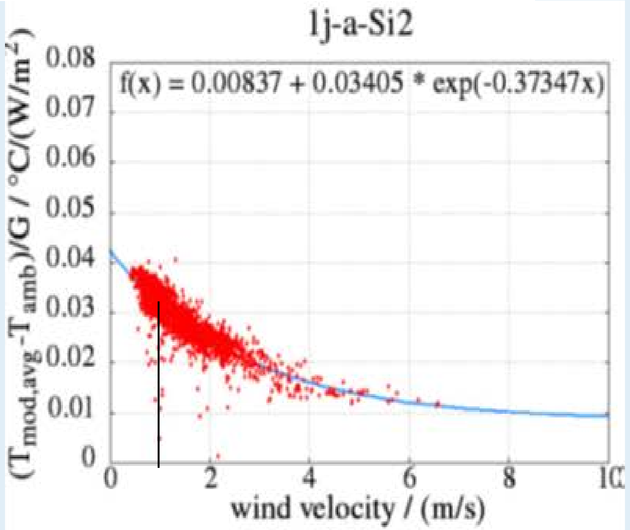
Credits: 3e

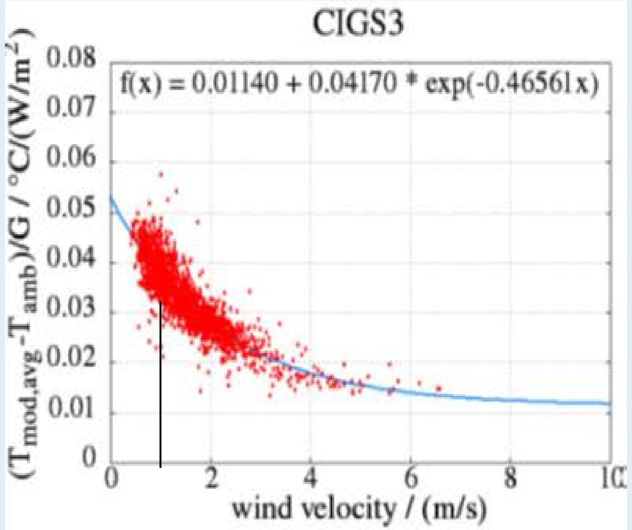
Temperature: environmental conditions and module temperature calculation

nr.	name	technology	Stratigraphy	Frame	$k_{Tmod,c}$ (K m²/W)	$RMSE_{k\_T\ mod,c}$
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 ($G\text{-}G_{bs}$)	NF	0.035	2.4
6	1j-a-Si2	a-Si	glass-tedlar (G-T)	WF	0.031	1.7



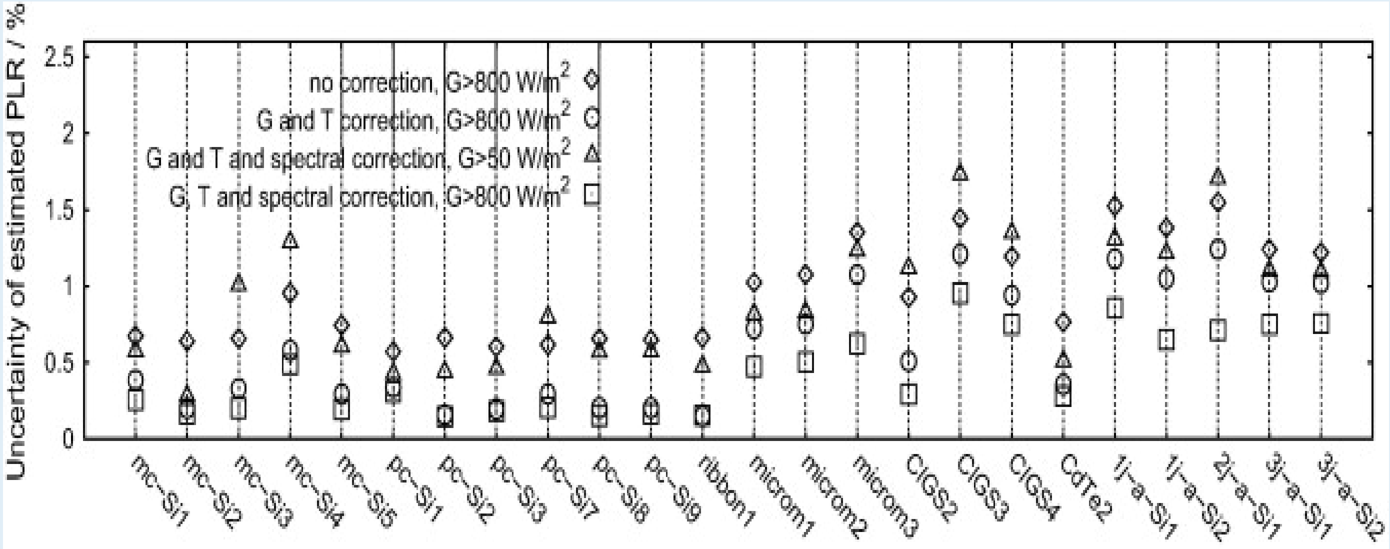


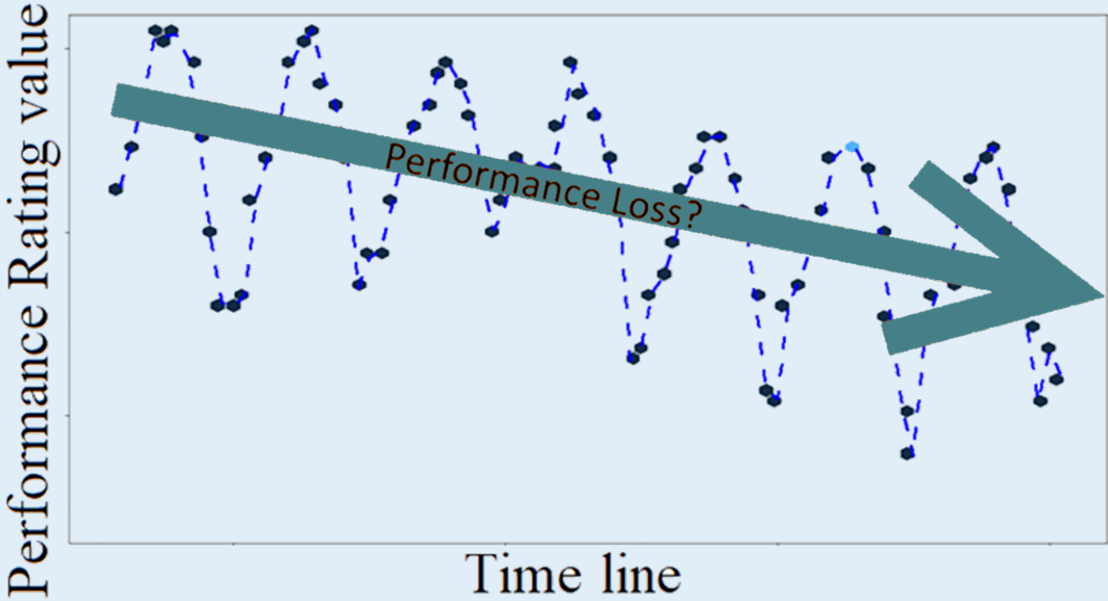




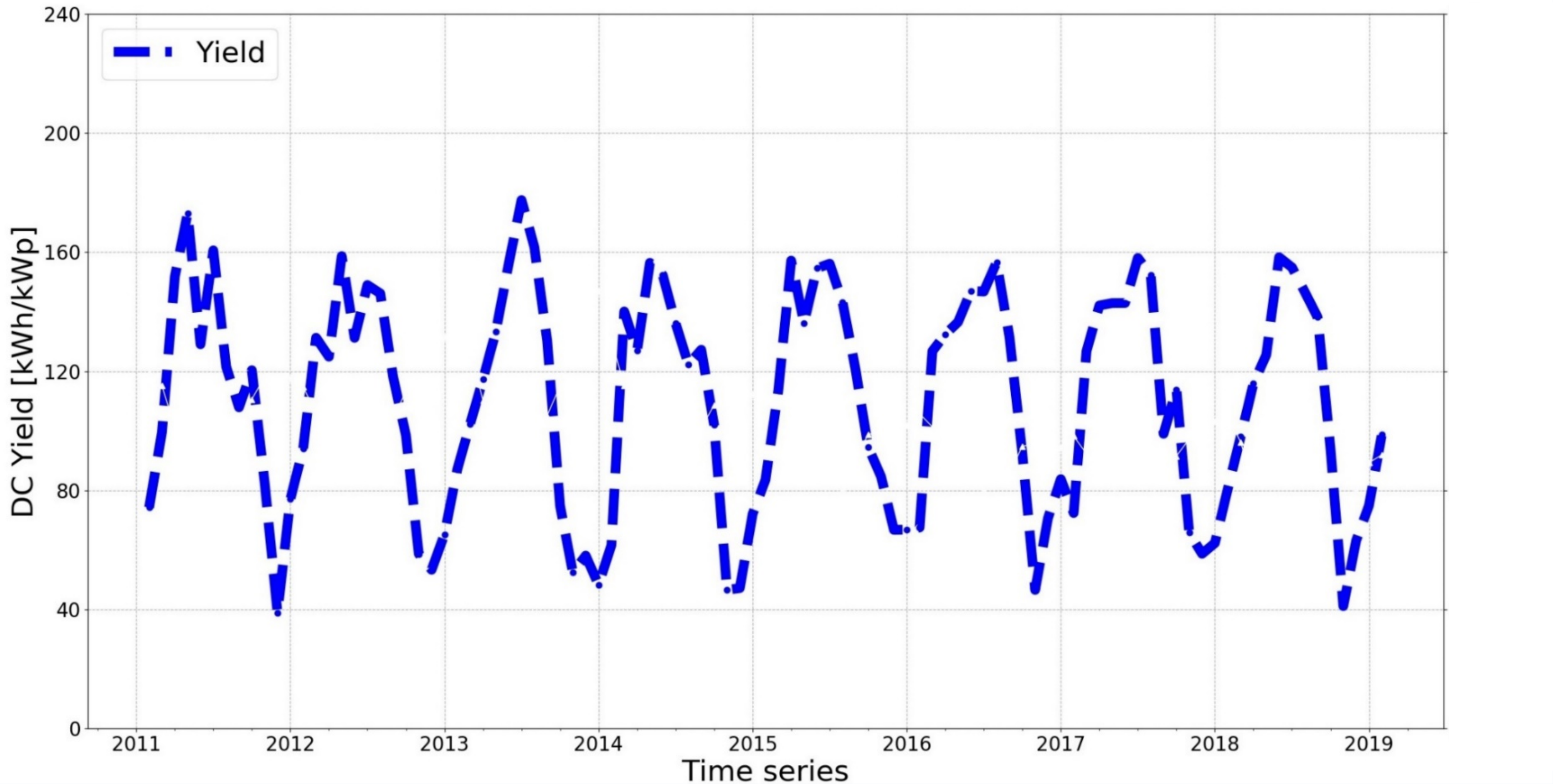
Maturi L., BiPV System Performance and Efficiency Drops: Overview on PV Module Temperature Conditions of Different Module Types, Energy Procedia 48 2014 1311-1319

Performance Loss Rate

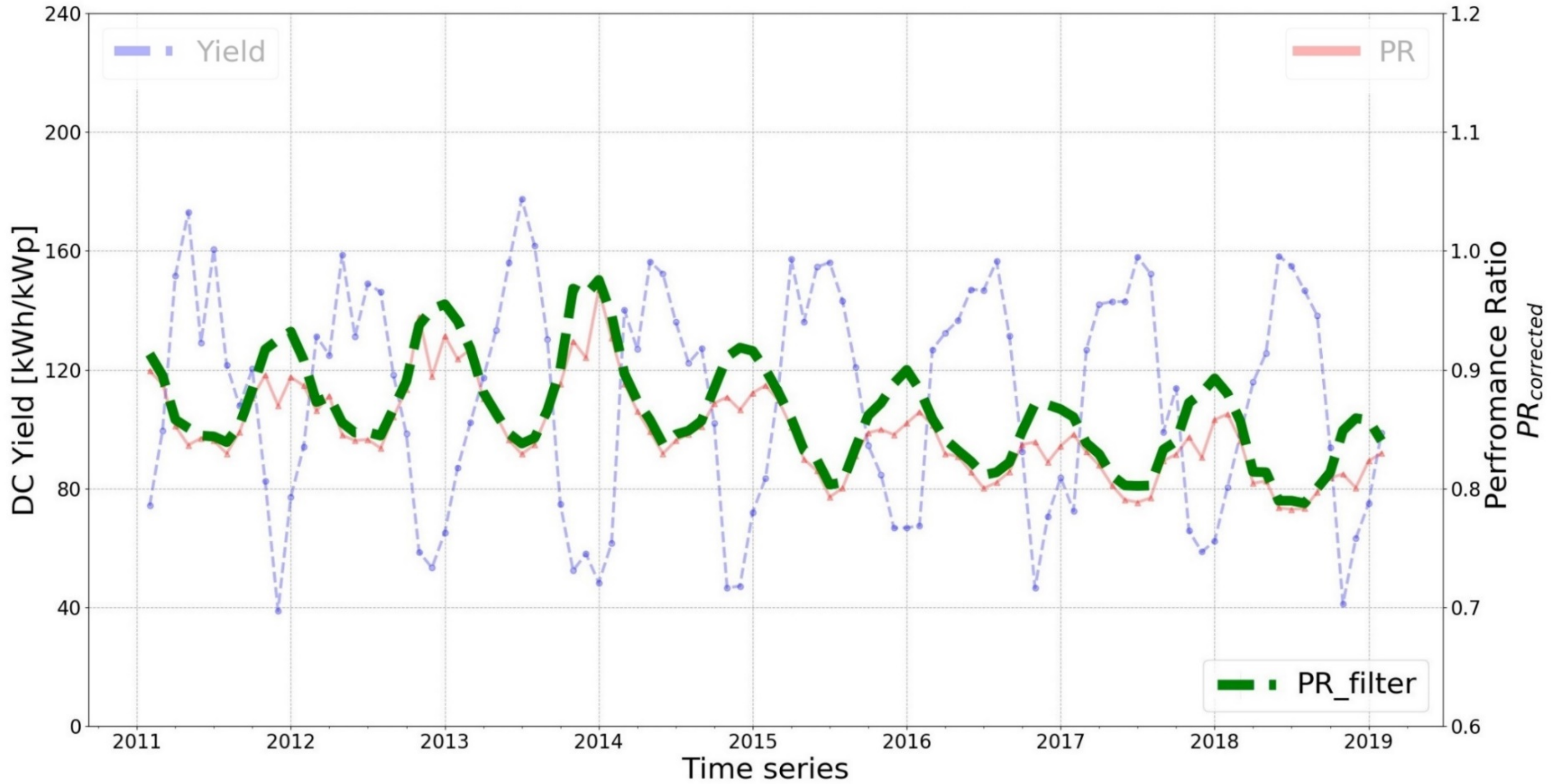




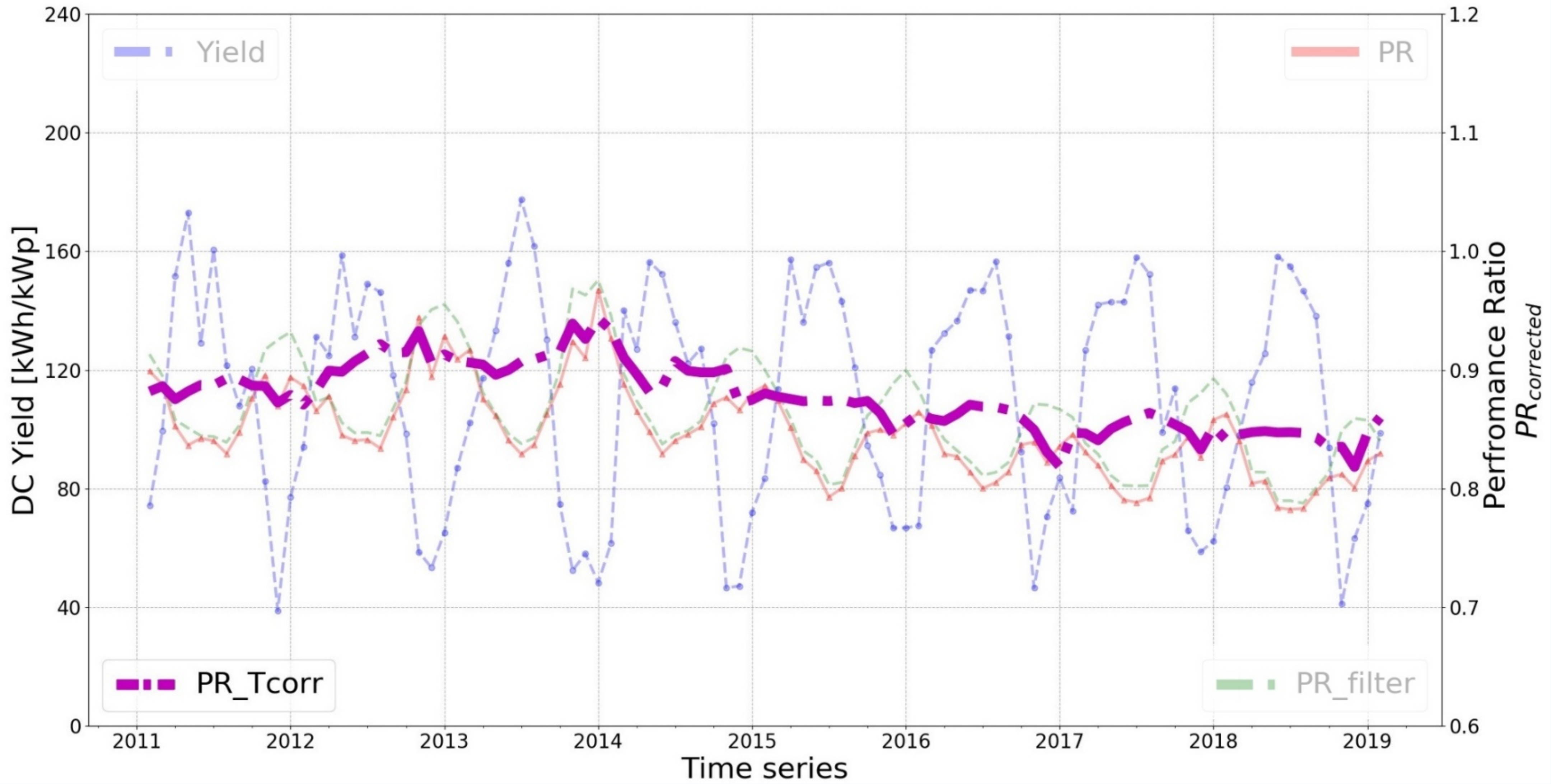
State of the art



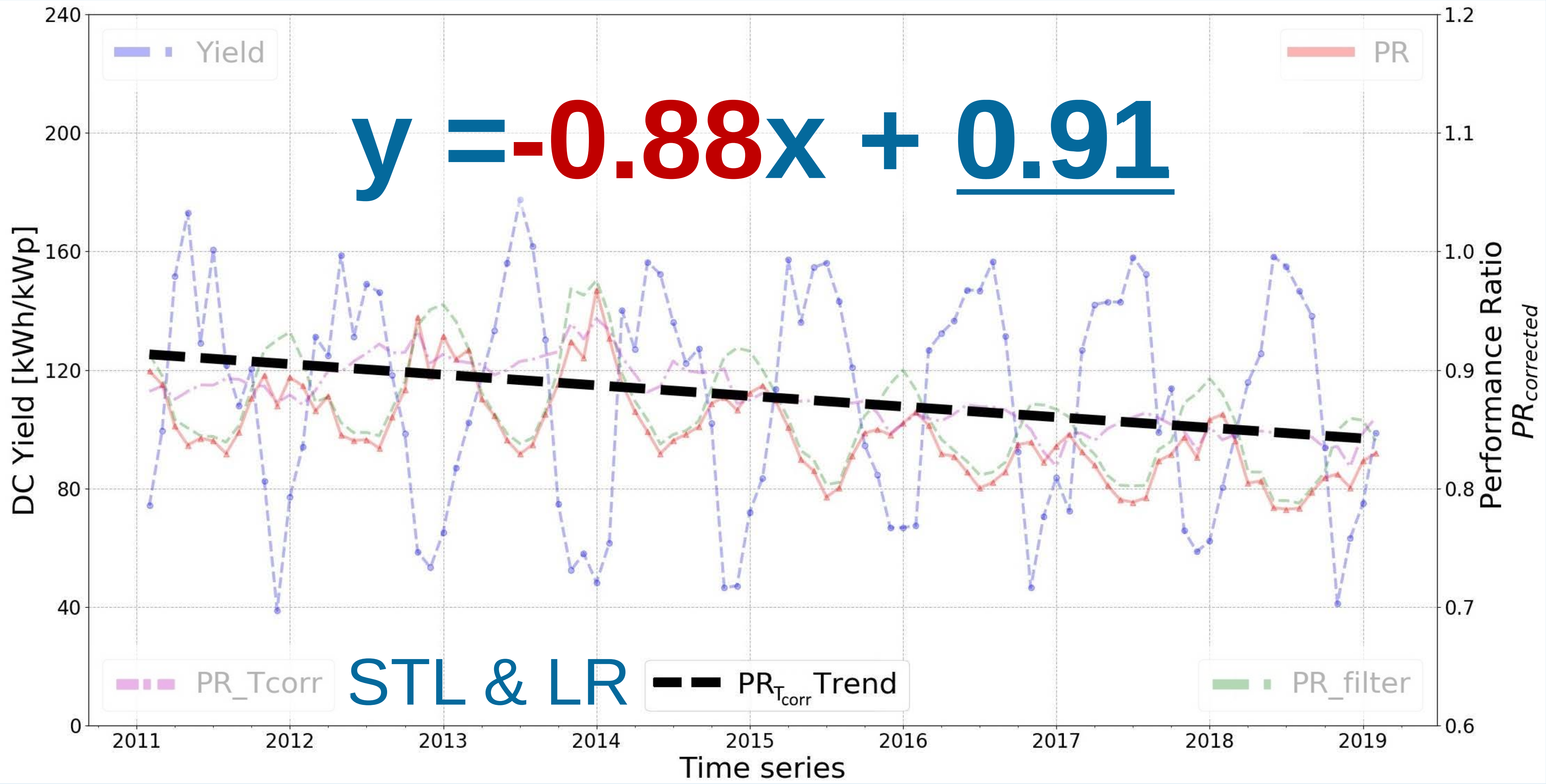
State of the art



State of the art



State of the art



Work in progress

Factors affecting the overall PLR

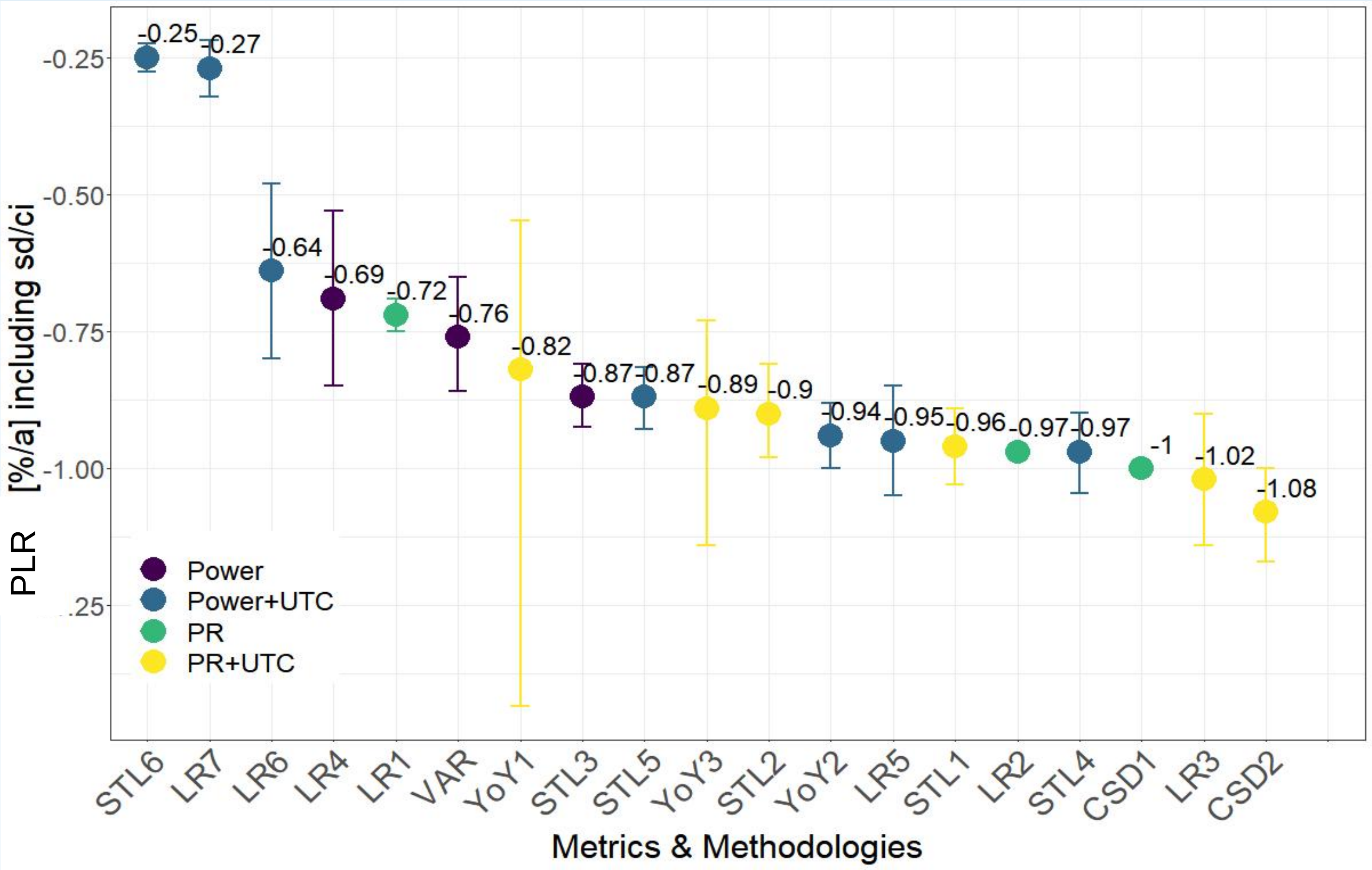
- Data quality
- Filtering
- Metrics
- Methodologies

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



PVPS

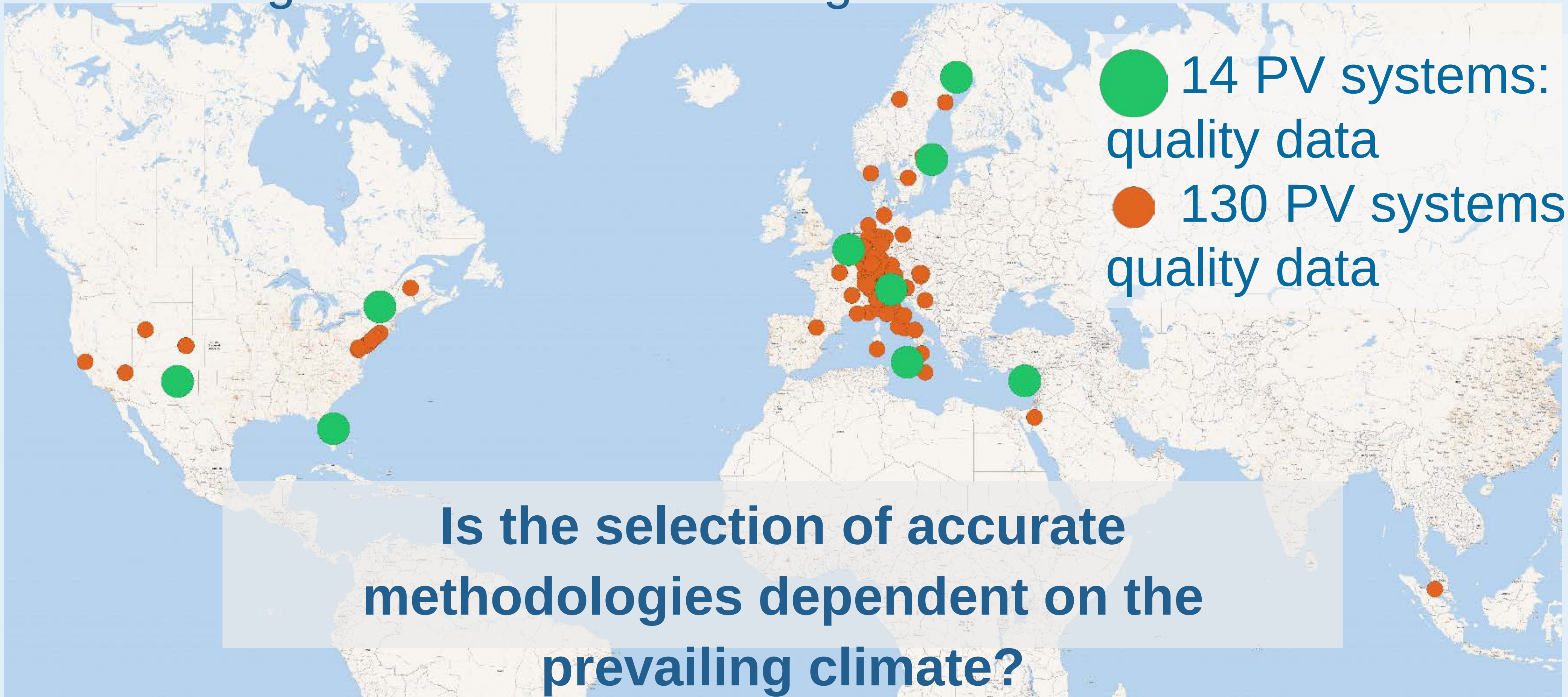
Work in progress

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)

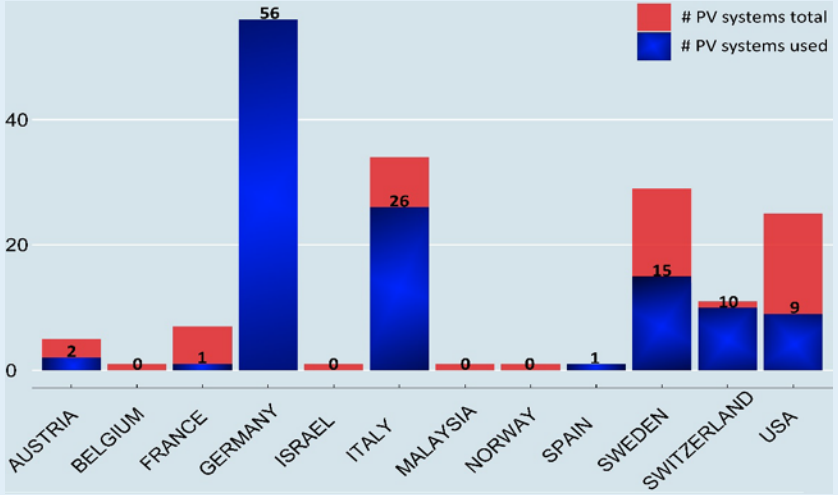
Benchmark will be extended to several PV plants to understand shortcomings of certain methodologies

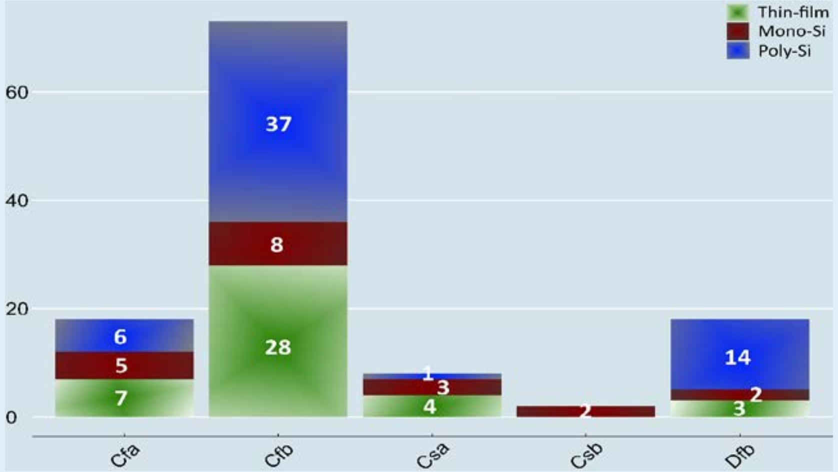


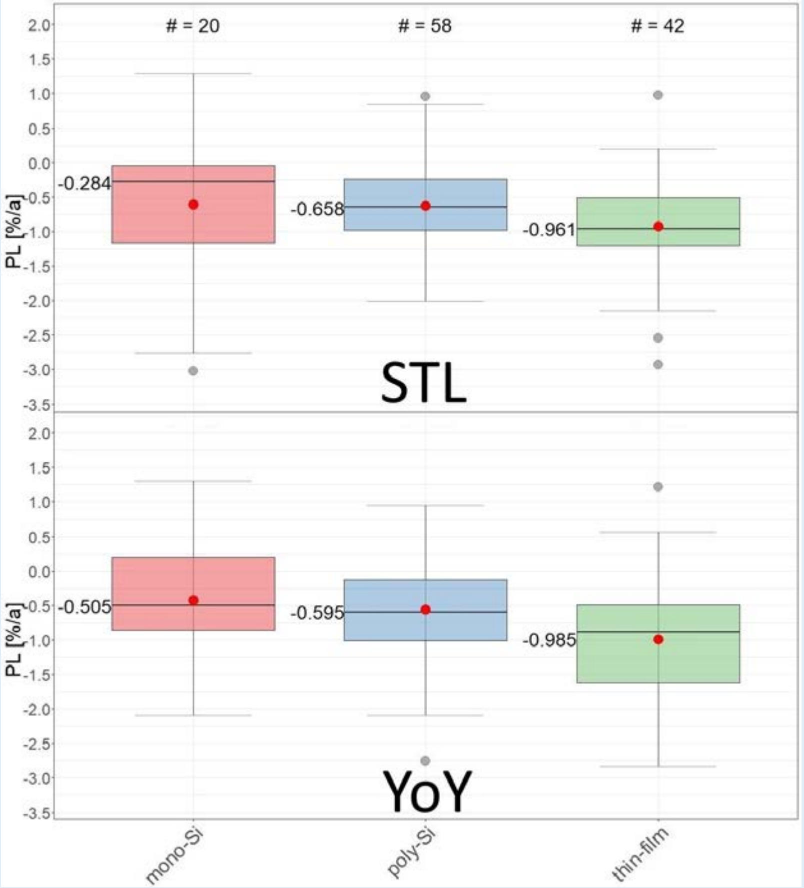
● 14 PV systems: high quality data

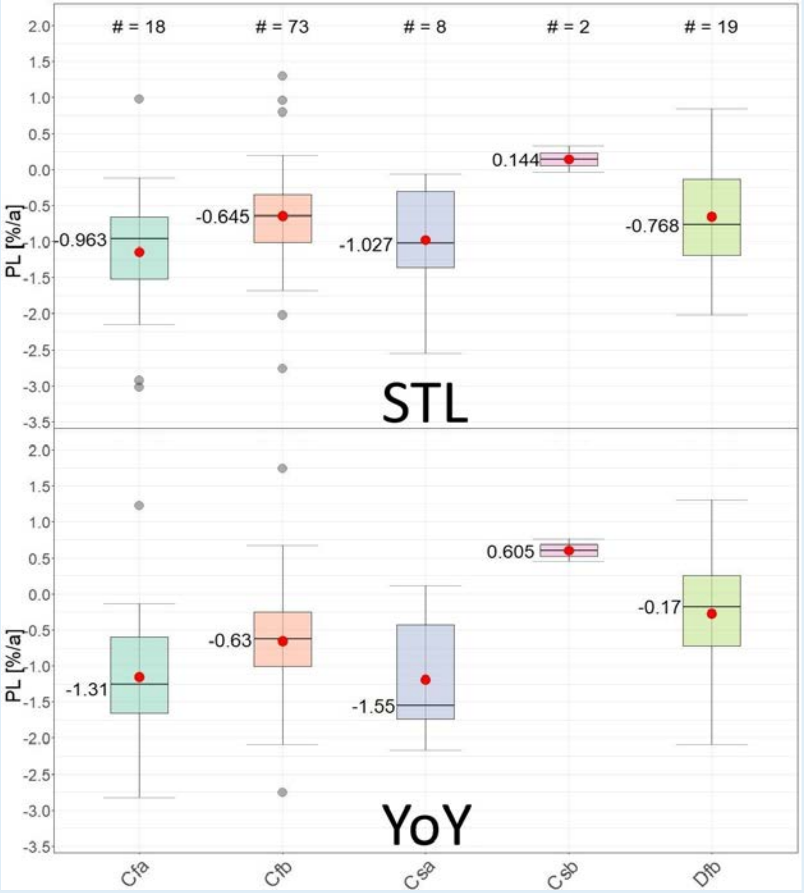
● 130 PV systems: low quality data

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





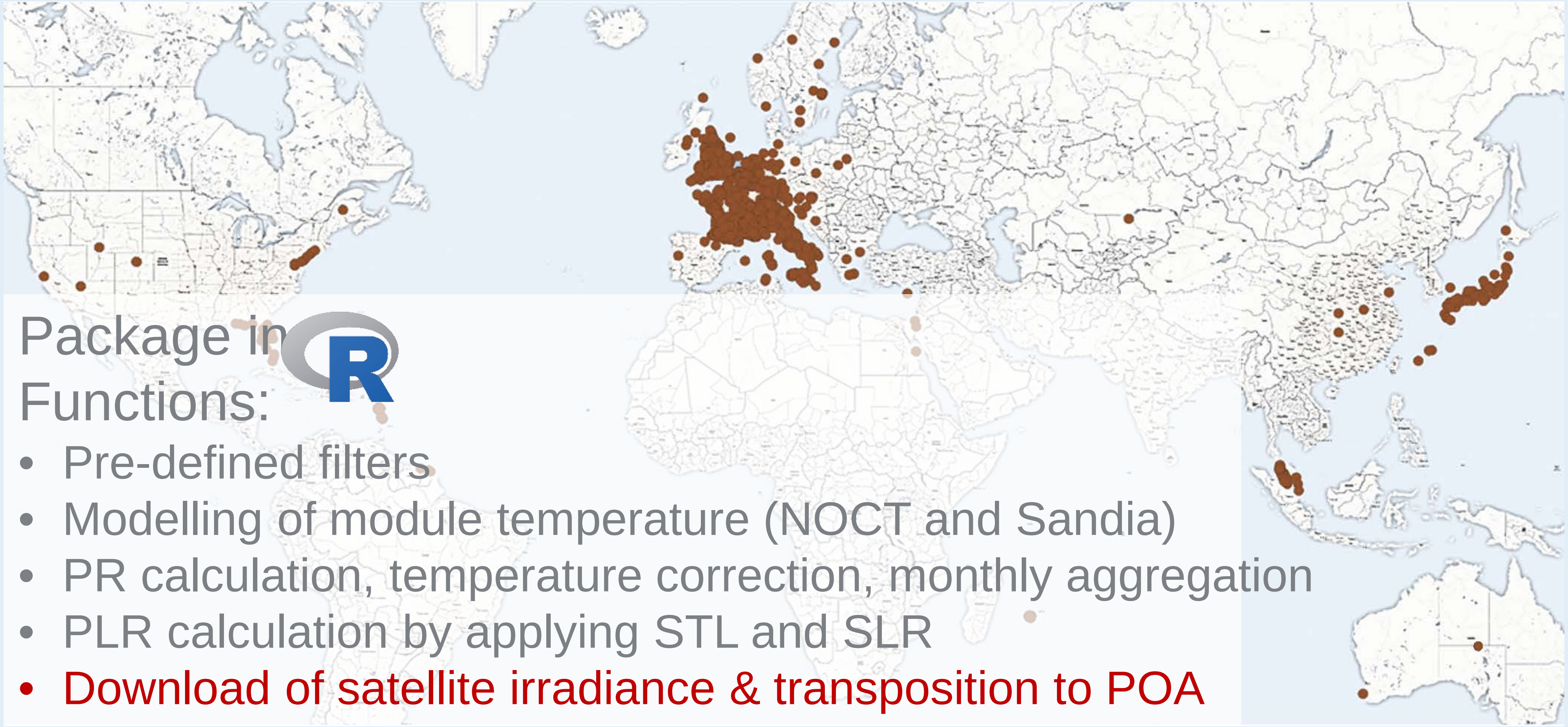




PVPS

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

PEARL PV + PVPS TASK 13



Package in R

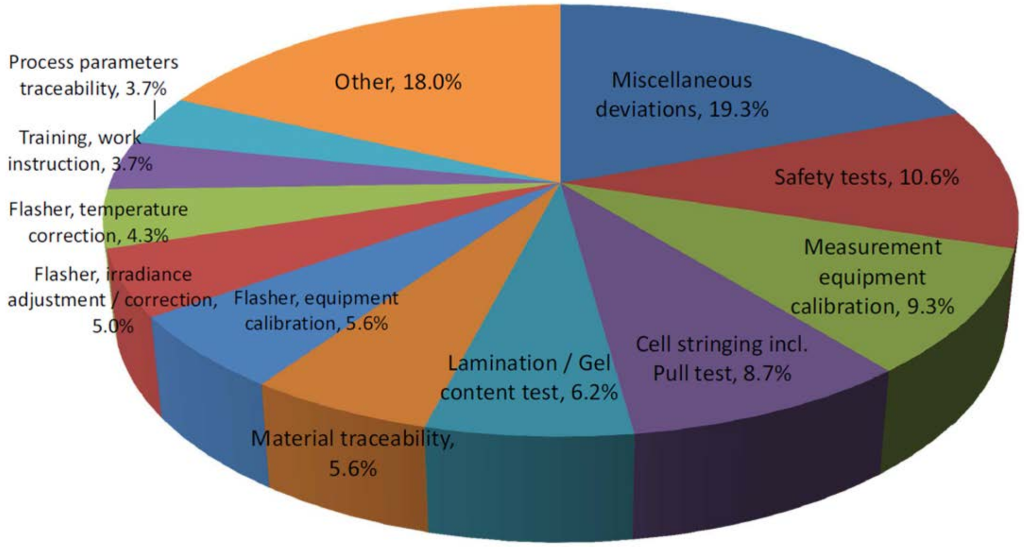
Functions:

- 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

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

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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%

PVPS

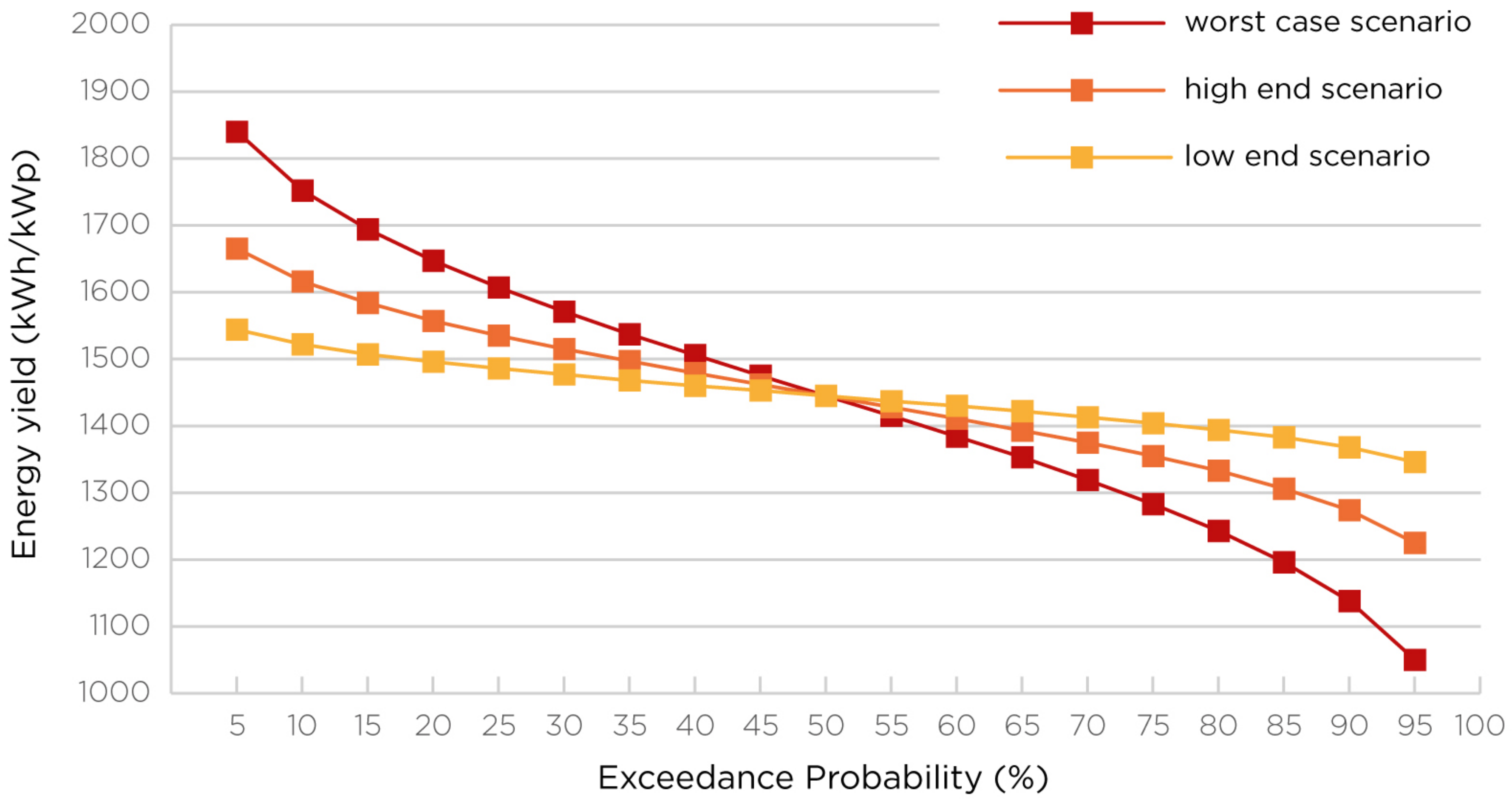
[1] D. Moser *et al.*, “Technical Risks in PV Projects.” Solar Bankability Deliverable www.solarbankability.com

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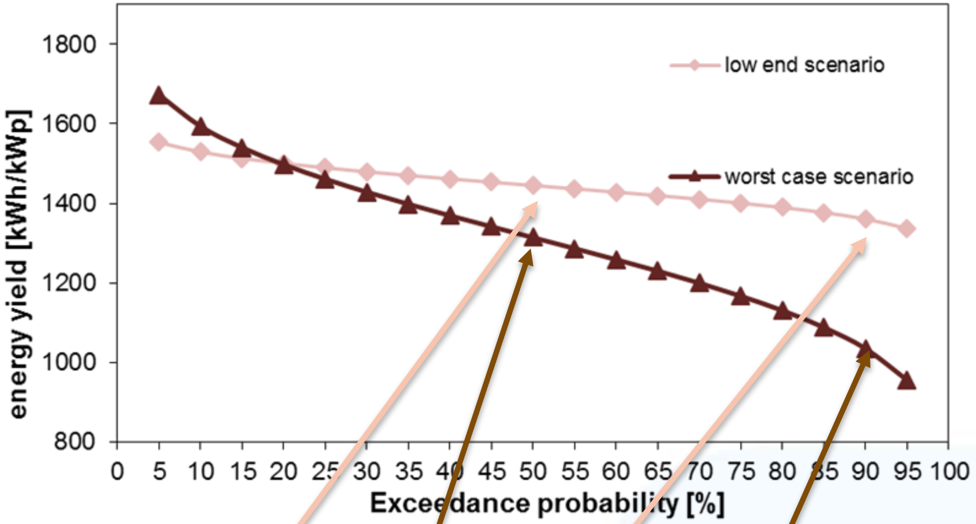
Objectives:
- More precise estimation of uncertainty in yield estimation
- Reduction of uncertainty

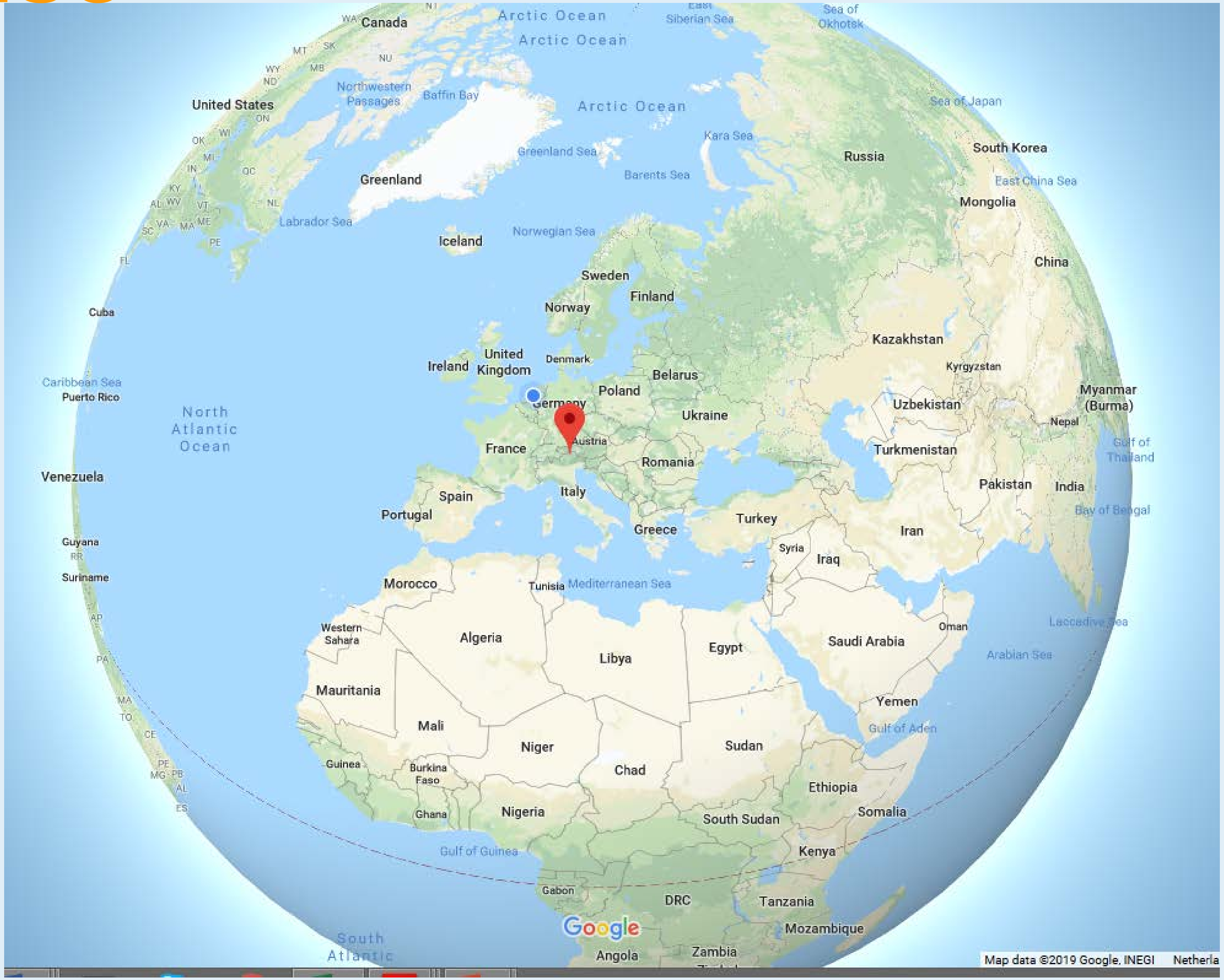


	σ (k=1)	P50 (kWh/kWp)	P90 (kWh/kWp)	P90/P50 (P50 reference case)
Ref. case (sum of squares)	**8.7%**	**1445**	**1283**	**89%**
Low end scenario	4.6%	1445	1365	94%
High end scenario	9.3%	1445	1273	88%
Worst case scenario	16.6%	1445	1138	79%
Worst case scenario (different mean value)	16.6%	1314	1034	72%

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

Task 13 YA exercise

Fraunhofer ISE
TÜVRheinland
eurac research
Ekistica
imec
M.G.LIGHTNING



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

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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)

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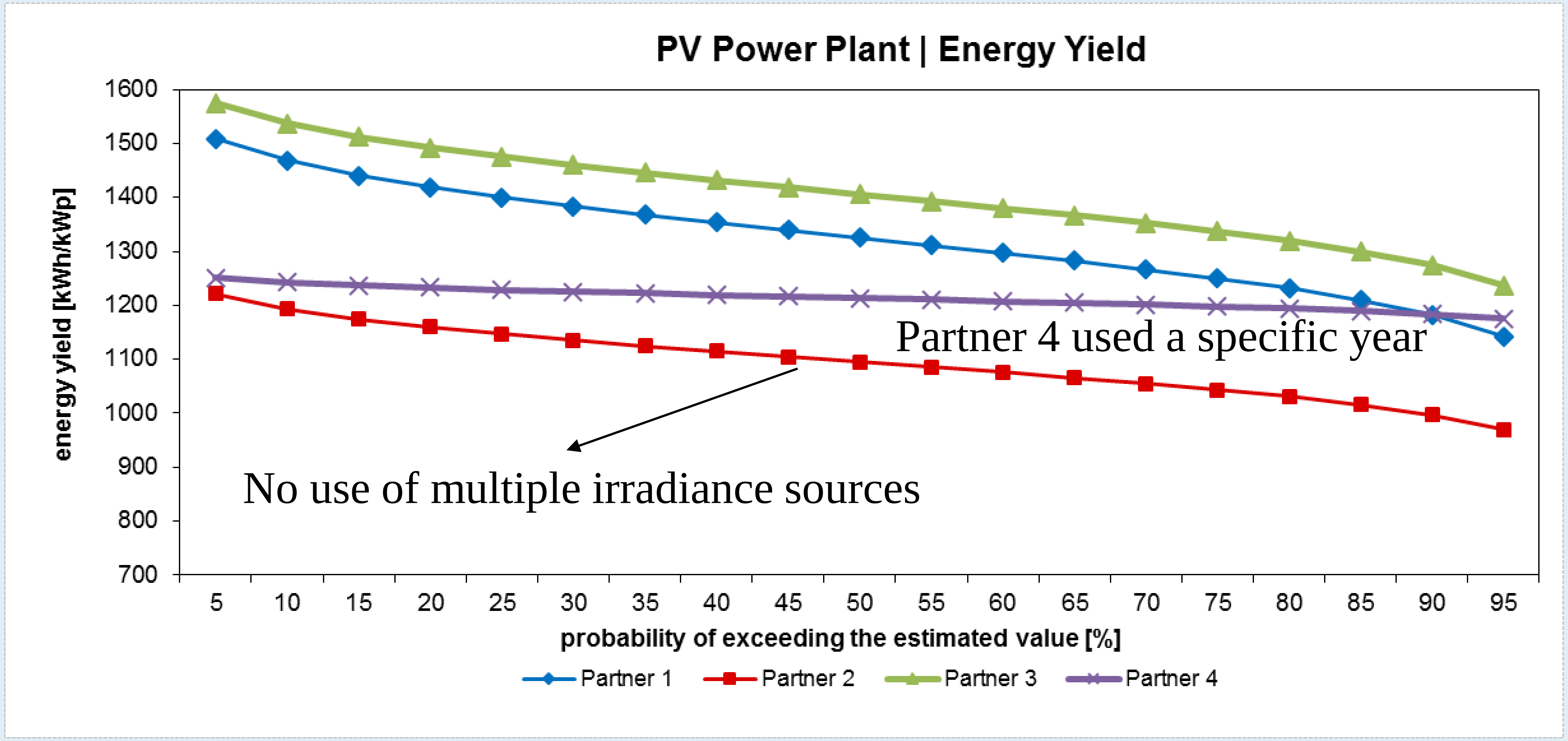
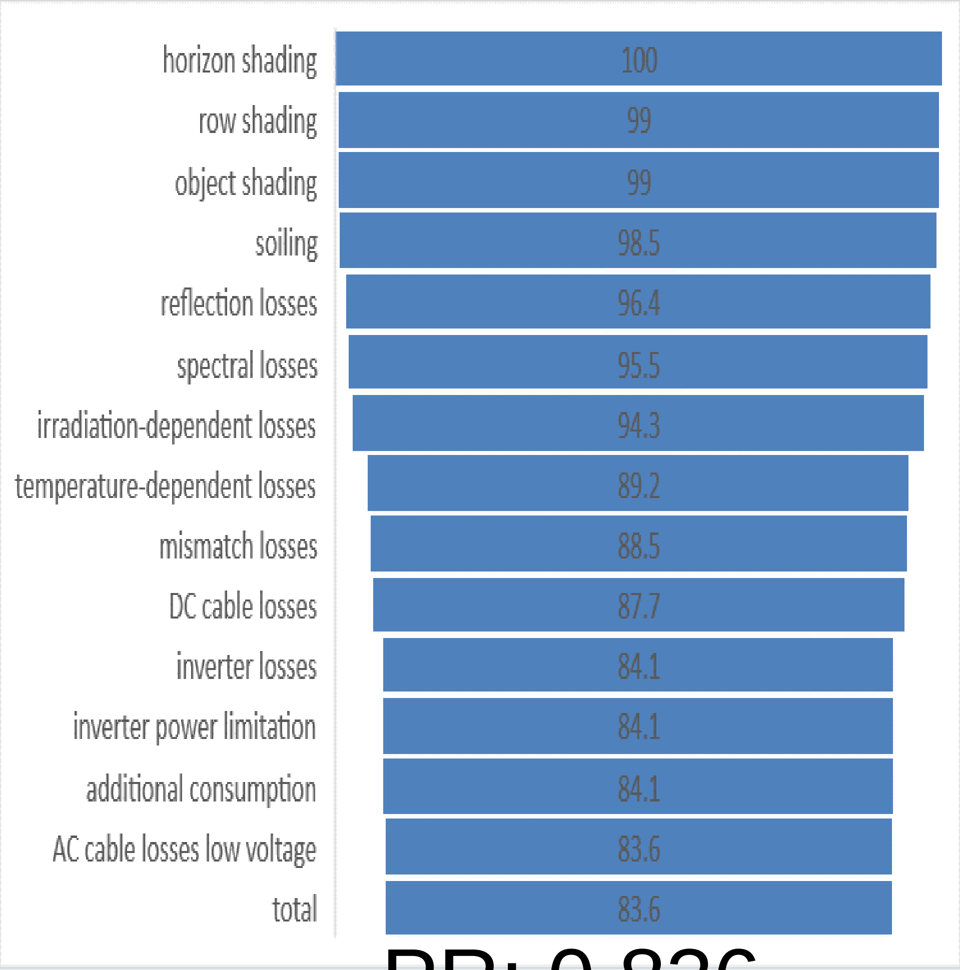
Initial Yield Assessment



	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

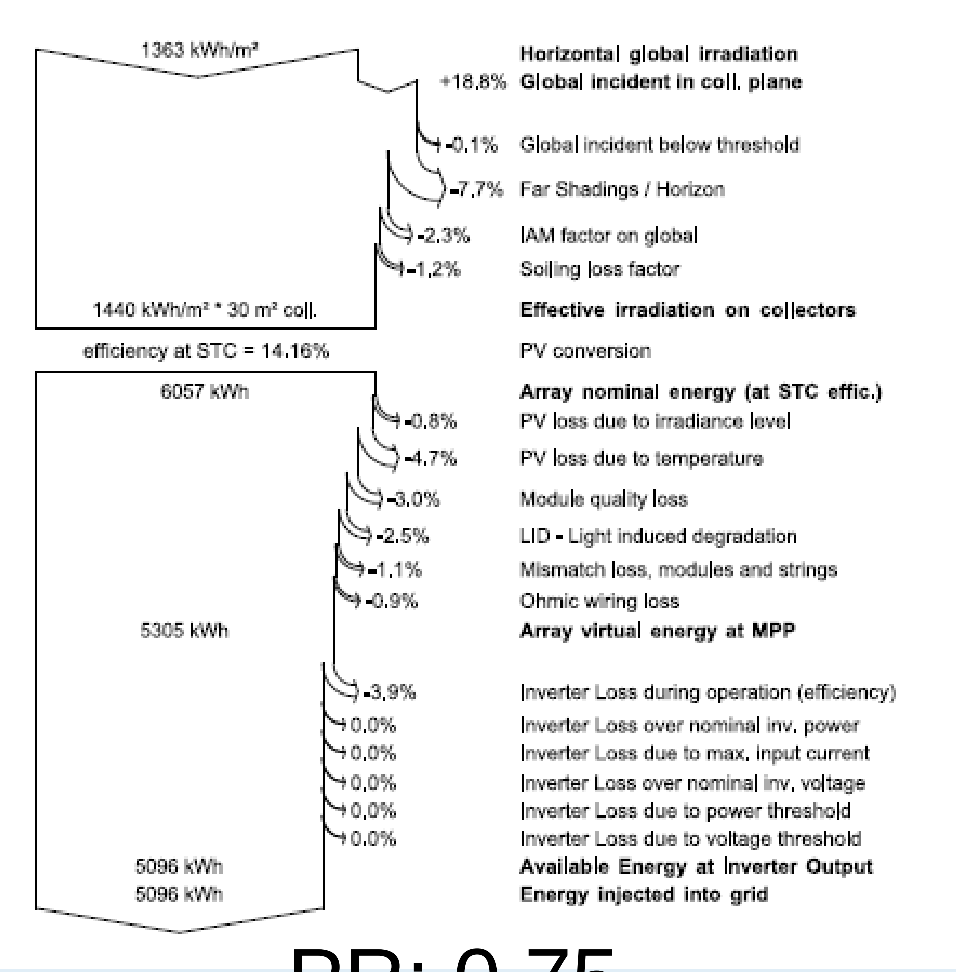
Derating factors

Partner 3



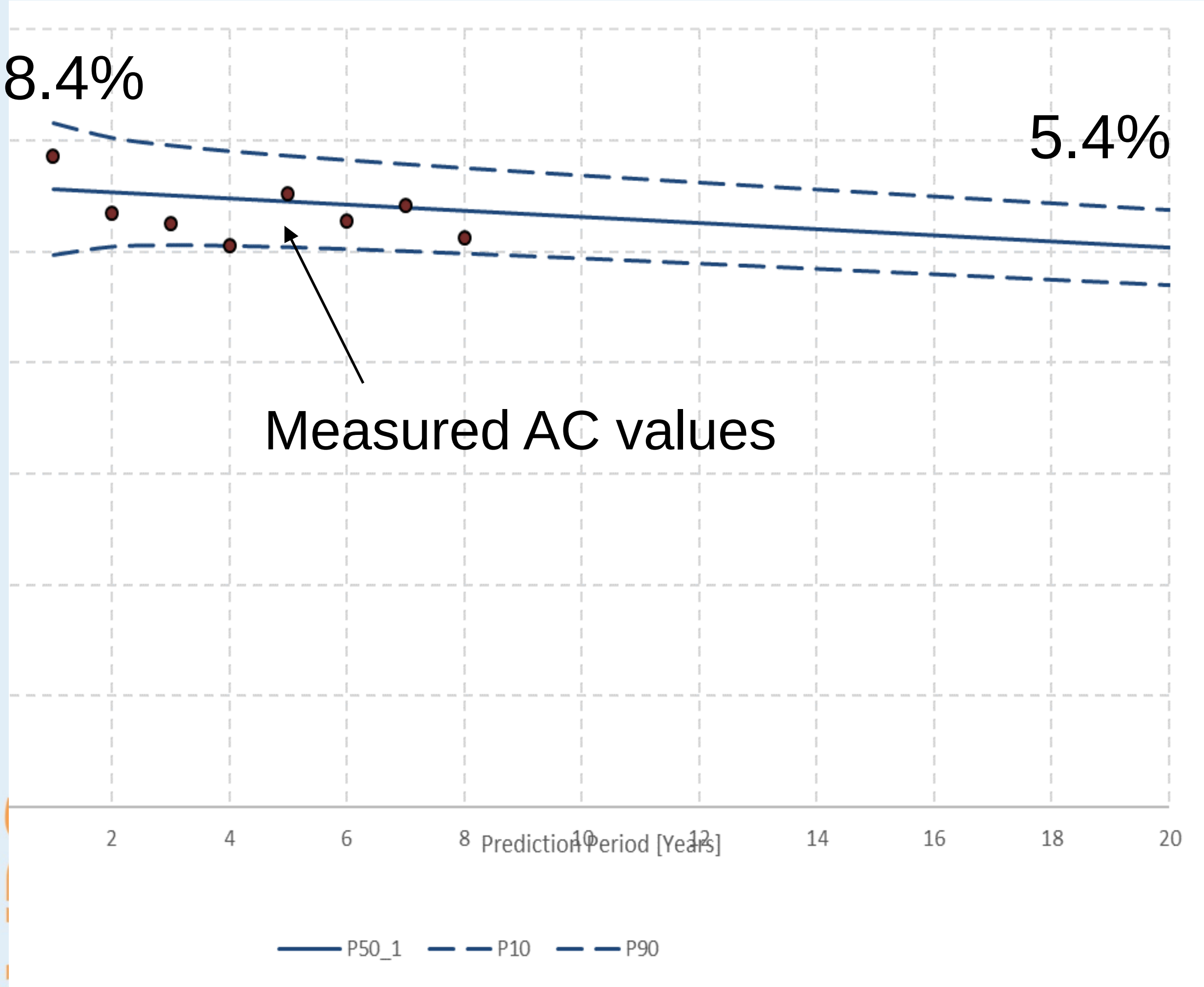
PR: 0.836

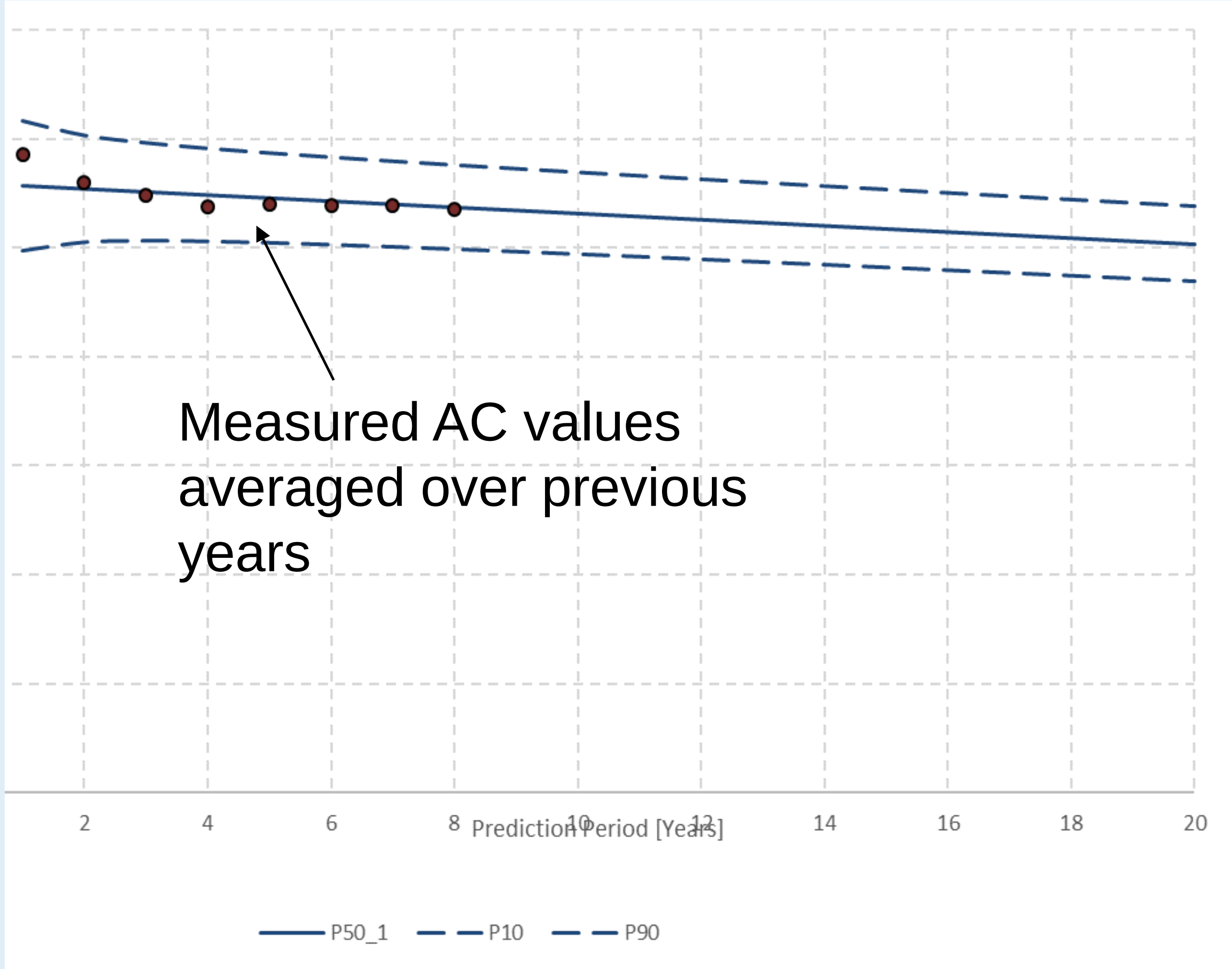
Partner 4



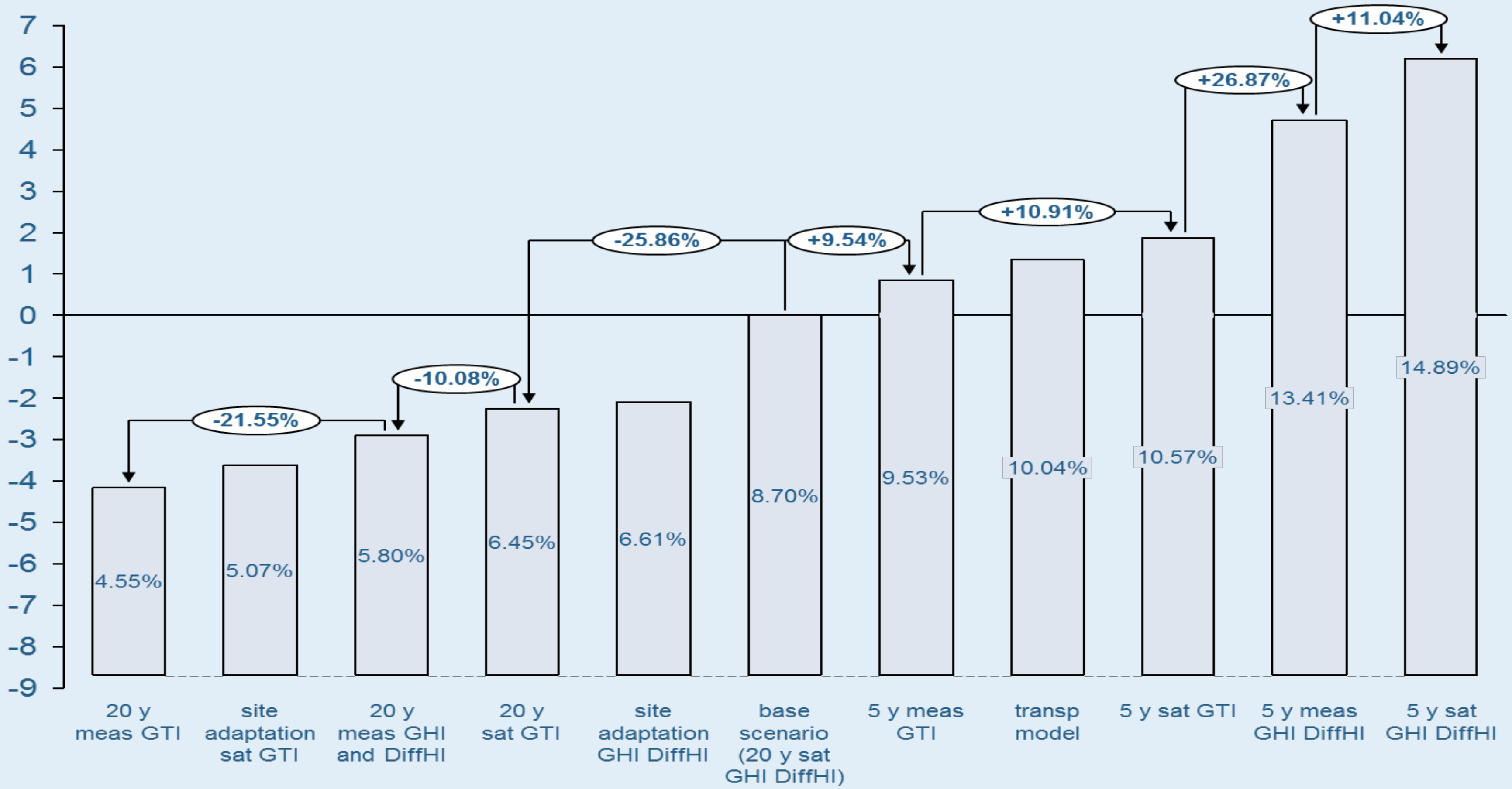
PR: 0.75

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

Uncertainty scenarios



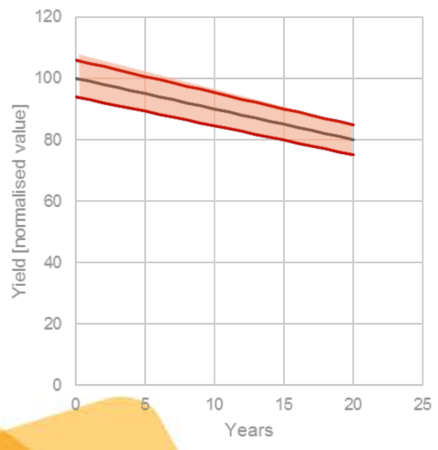
Based on the findings of the benchmarking exercise we will show how uncertainty plays a role for various parameters

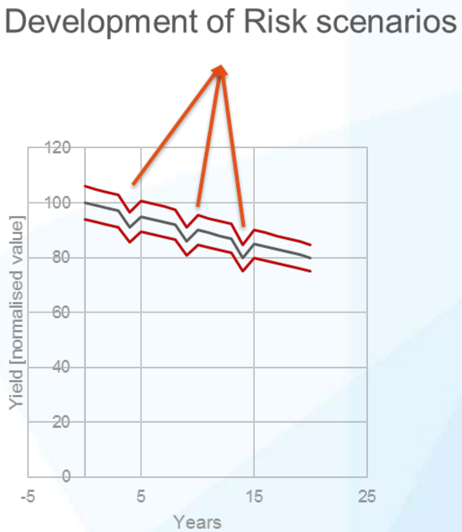
Quantification of the economic impact of technical risks

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

+

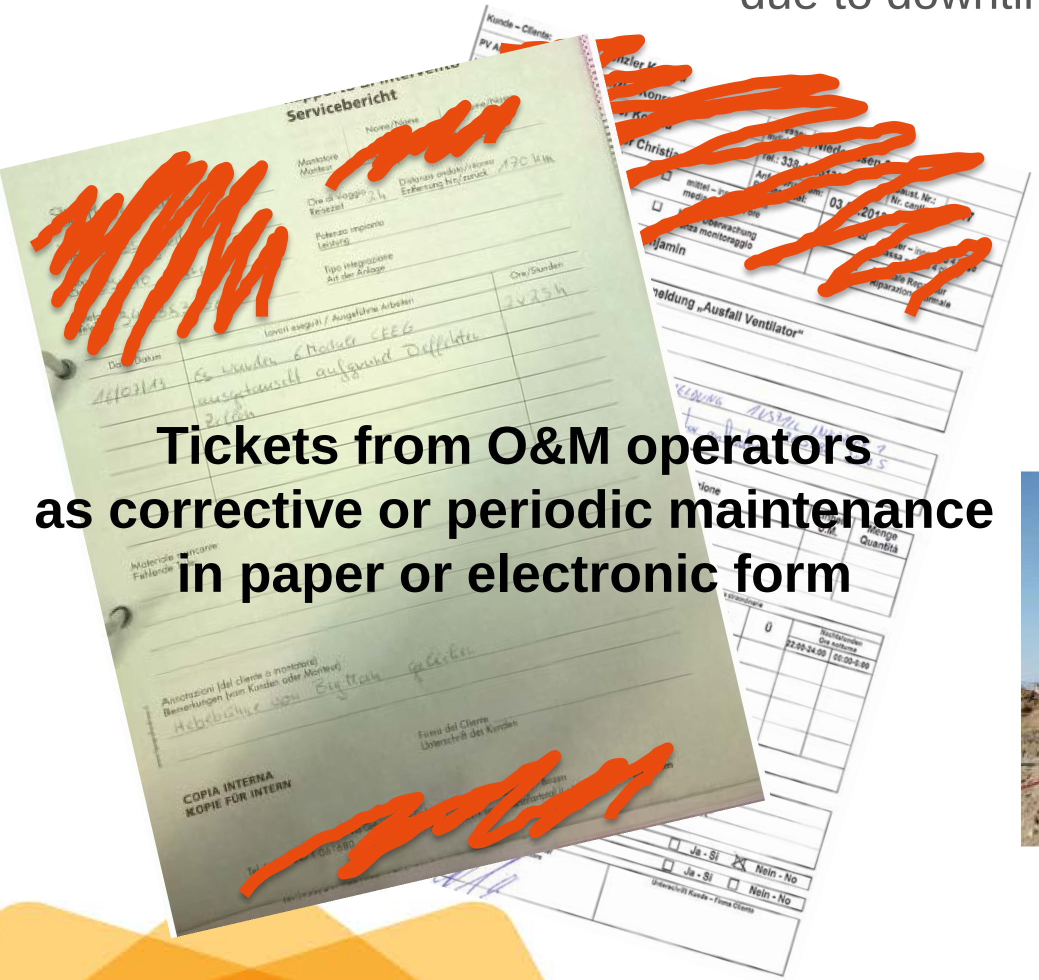
b) Economic impact due to repair/substitution costs (Euros)
- Cost of detection (field inspection, indoor measurements, etc)
- Cost of transportation of component
- Cost of labour (linked to downtime)
- Cost of repair/substitution

→ Increase in maintenance costs
Reduction of reserves

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

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%

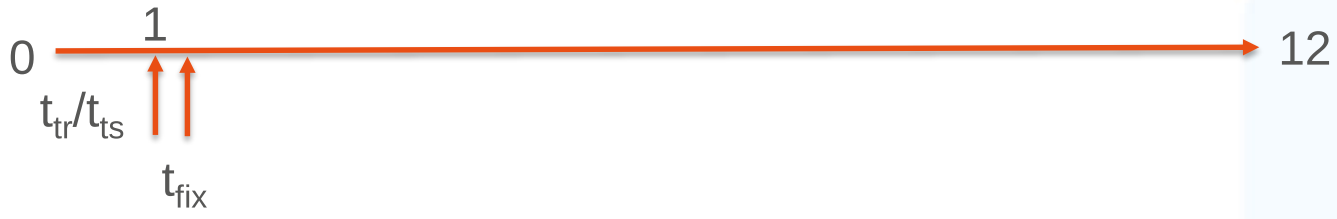
Definition of scenarios

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

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

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

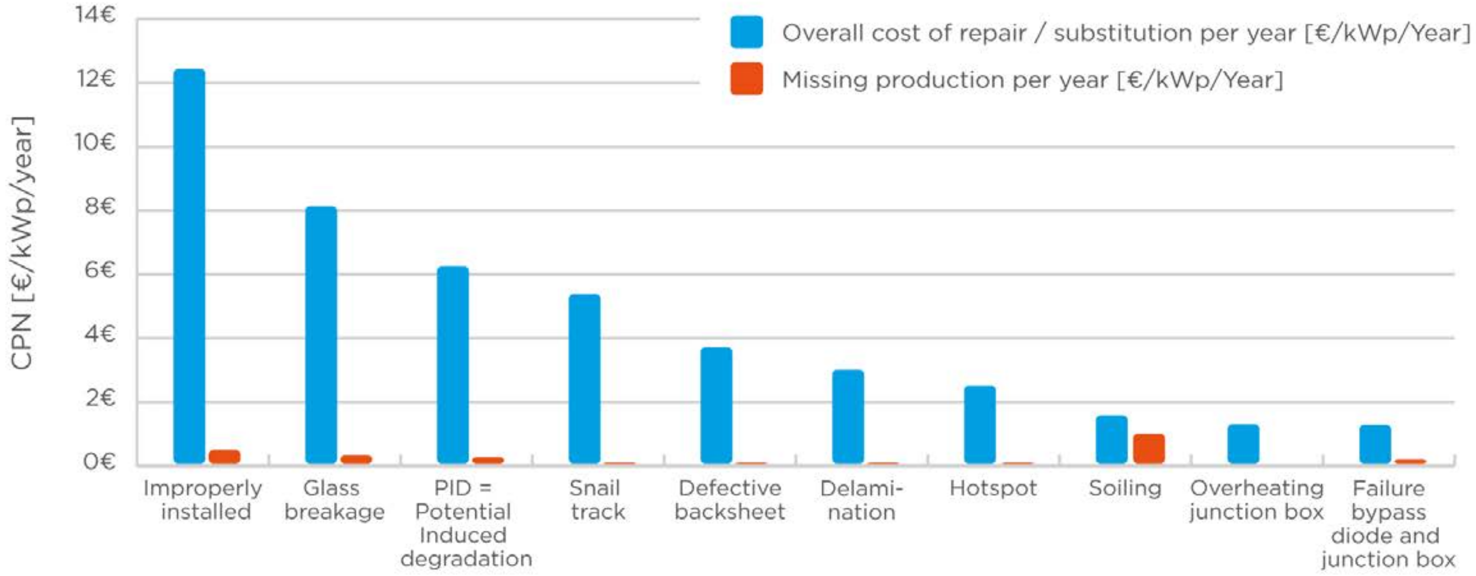
Failure is detected. 1 Month of lead time to repair/substitution



- 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

CPN Results - Components and Market Segments

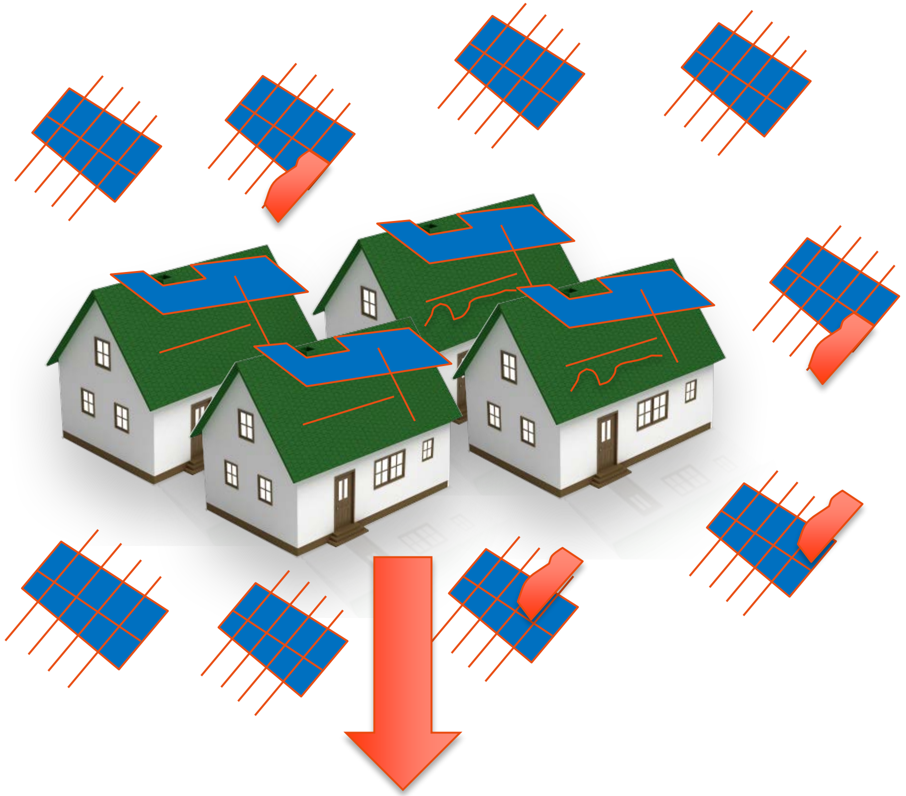
- PV modules - Utility scale



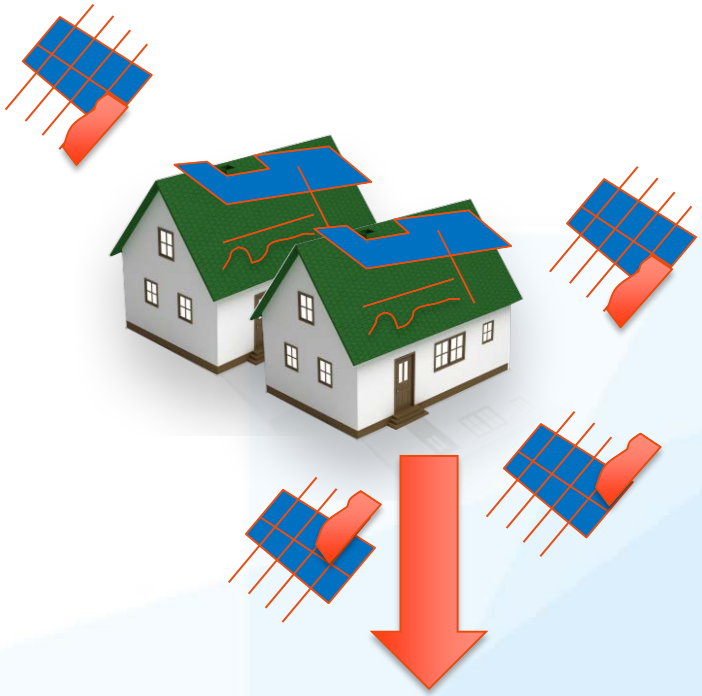
- Highest risk consists of a group of installation failures (mishandling, connection failures, missing fixation, etc.)
- Variety of failures detected by different techniques (VI, IR, EL, IV-Curves)

CPN results - Comparison studies

- Affected components vs total components: CPN ratio



Failures calculated over the whole database

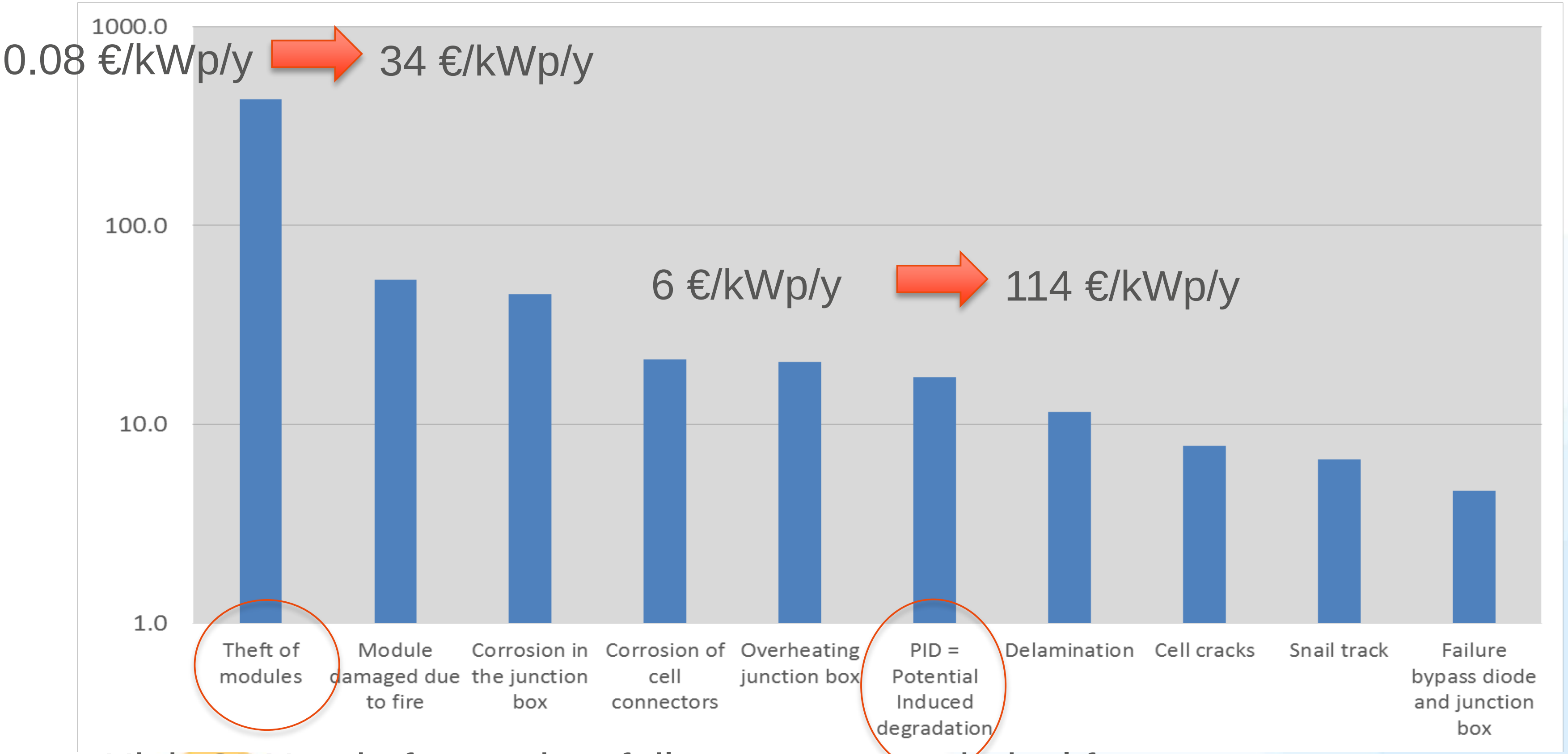


Failures calculated over the affected plants

O&M

CPN results - Comparison studies

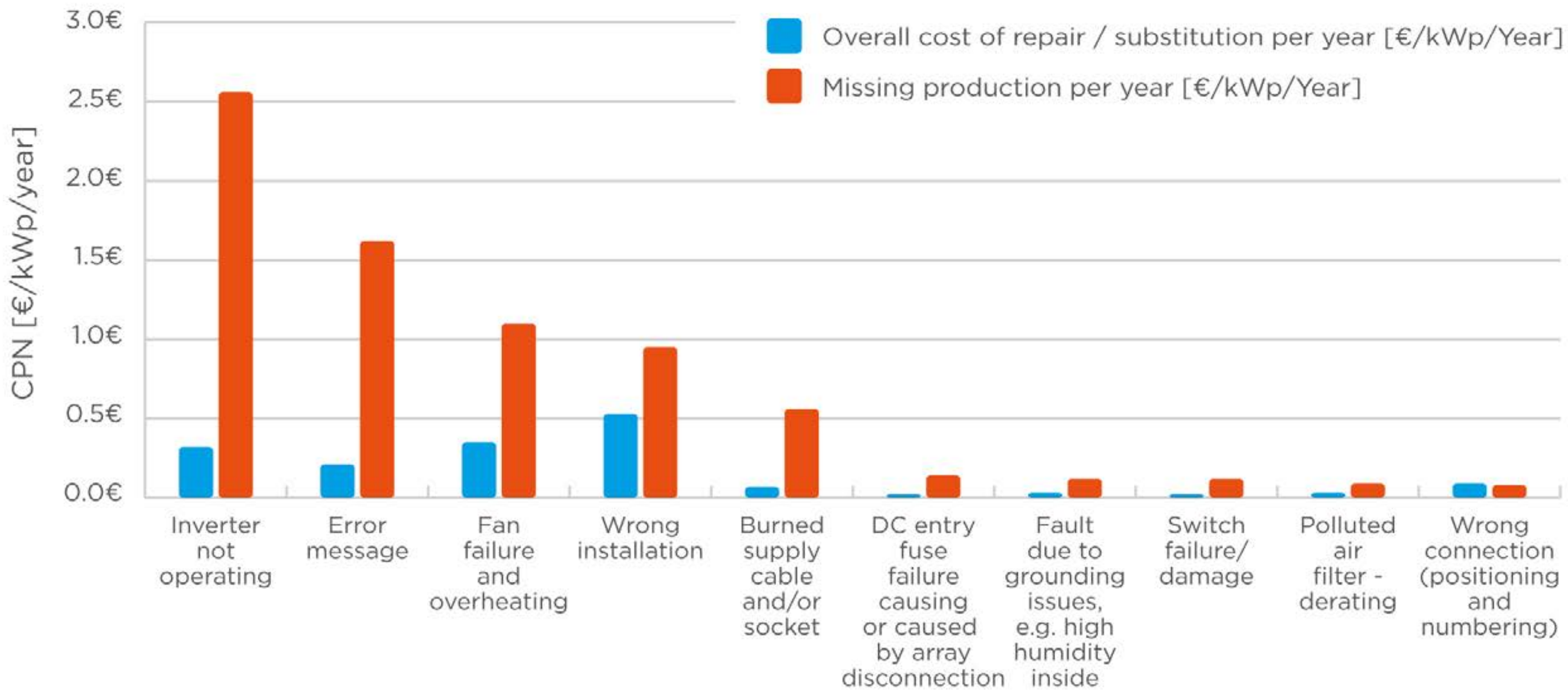
- Some failures do not occur very often and are not equally spread over the portfolio but when they do, the economic impact is very high



- High CPN ratio for product failures or non technical factors

CPN Results - Components and Market Segments

- Inverters



Technical risk framework

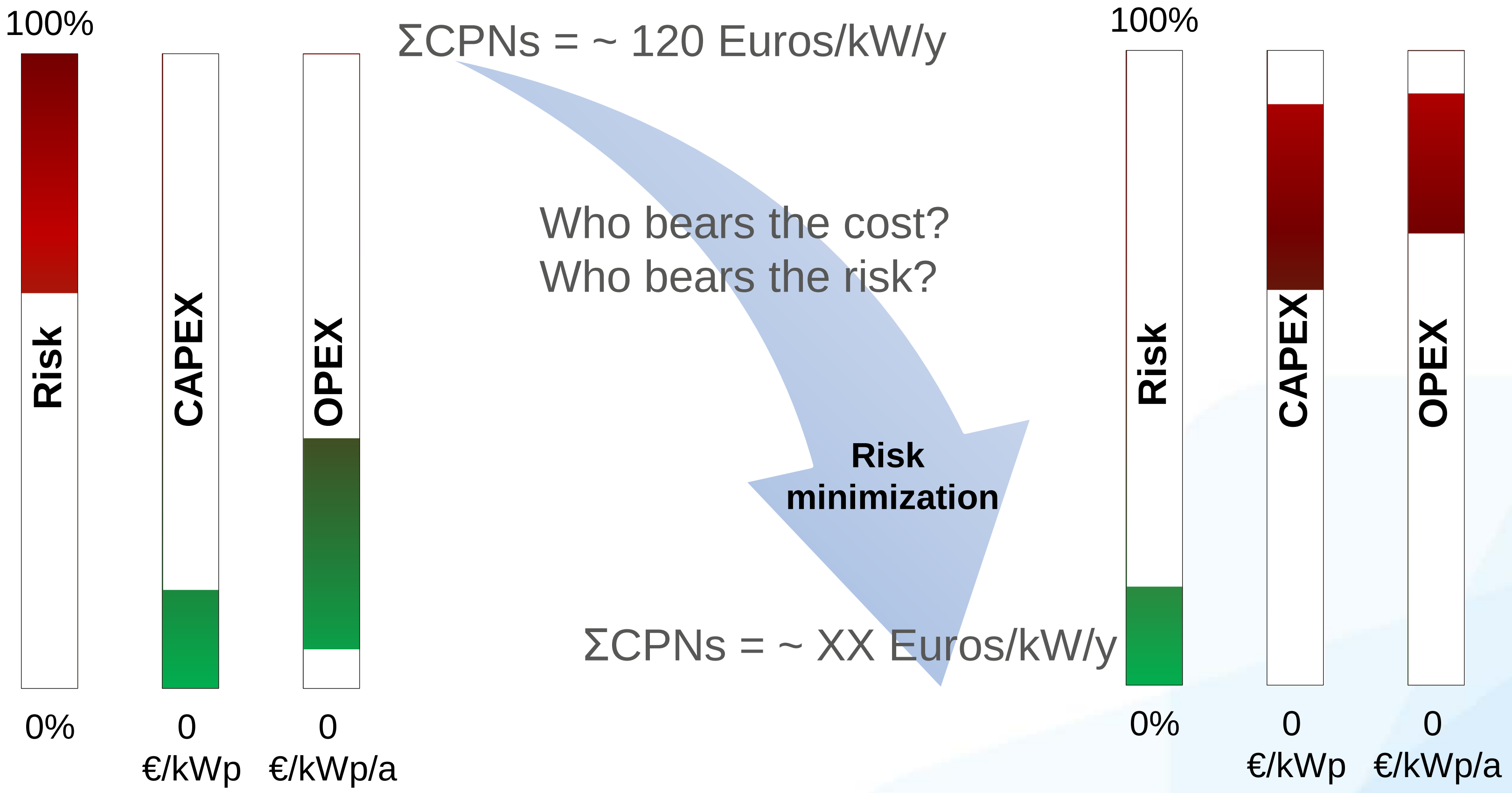
A	Risk identification
B	Risk assessment
C	Risk management
D	Risk controlling

Risk Mitigation

Risk Transfer

www.solarbankability.eu

Risk mitigation



CAPEX & OPEX depending on mitigation measures

CAPEX & OPEX depending on mitigation measures

Mitigation Measure Approach

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

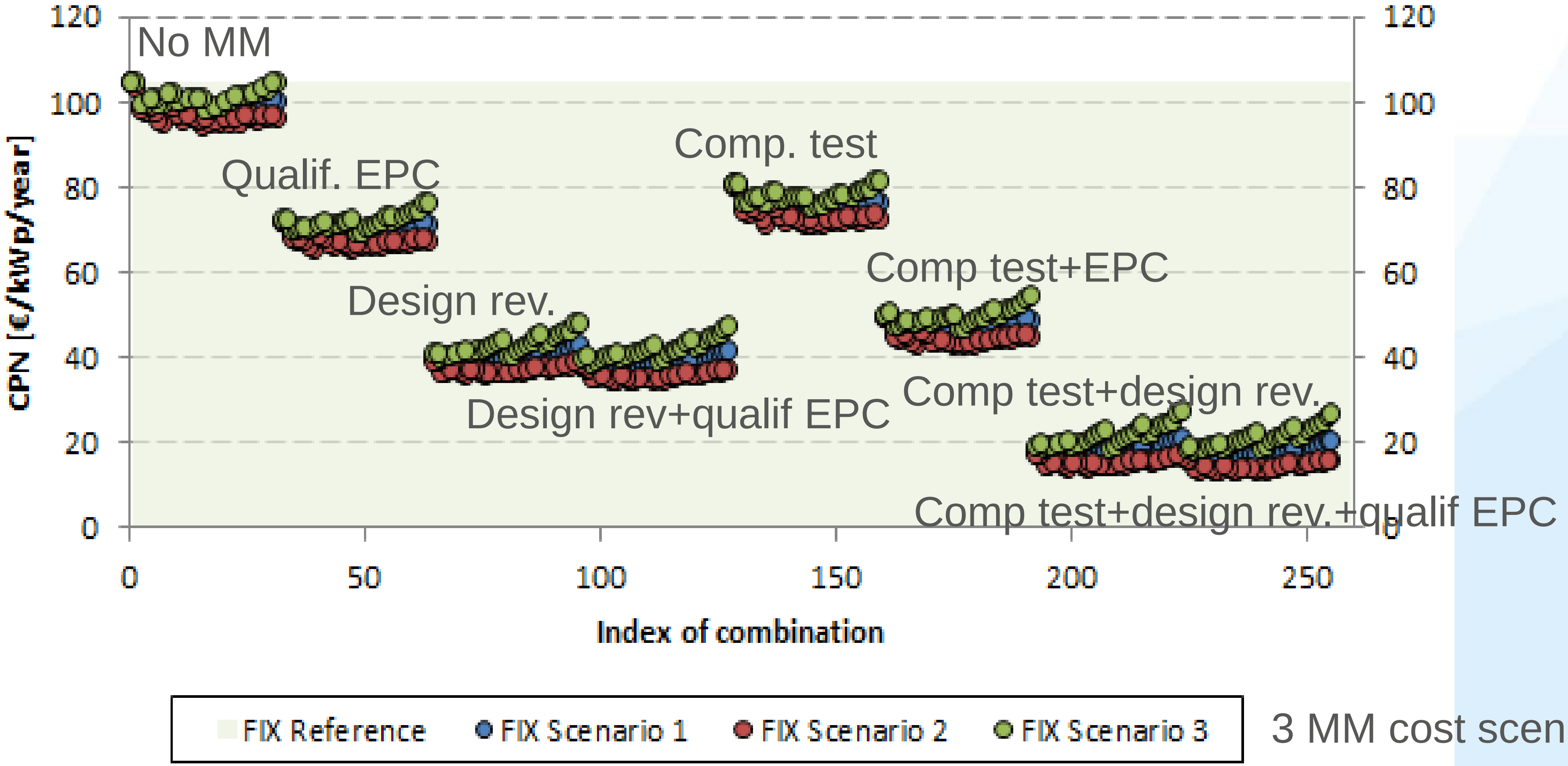
- **Preventive measures**
- **Corrective measures**

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

Improved CPN methodology for the needs of O&M operators

When a failure occurs, e.g. performance deviation beyond allowed threshold or inverter error code generated. **An alarm is triggered**

failure time

Acknowledgement of the fault by the O&M Contractor. **A maintenance ticket is opened**

acknowledgement time

The technician arrives on-site with all the tools and spare parts needed to fix the problem

intervention time

Problem fixed and acknowledged by the O&M Contractor. **The maintenance ticket is closed**

resolution time

Detection time

Time that it takes to detect the occurrence of a problem

Response time

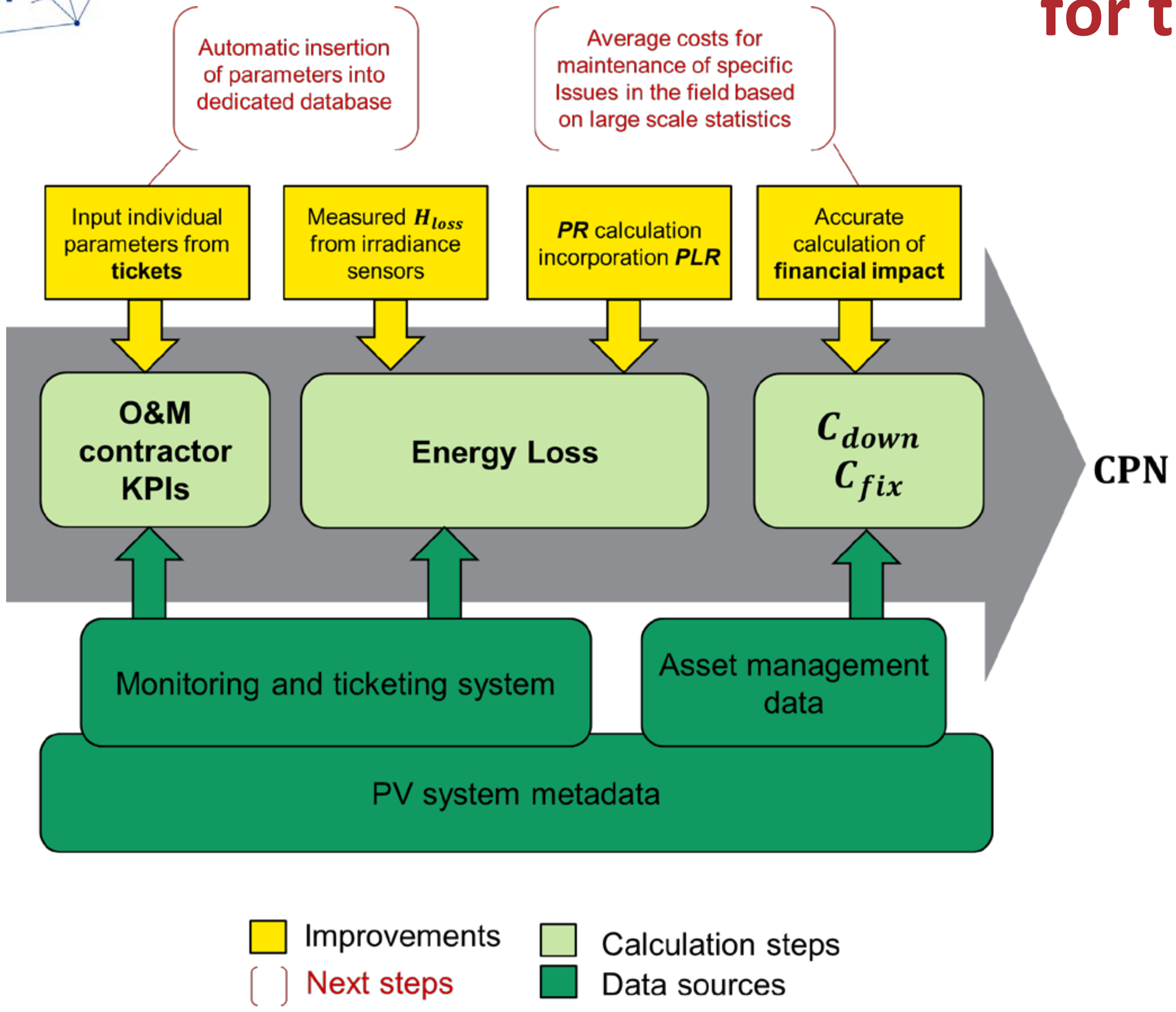
Time that it takes to organise the repair or substitution

Repair time

Time that it takes the technician to fix the problem

OPTIMIZATION OF THE COST PRIORITY NUMBER (CPN) METHODOLOGY TO THE NEEDS OF A LARGE O&M OPERATOR, G. Oviedo Hernandez et al, EUPVSEC 2019, Marseille 5CV.4.19

Improved CPN methodology for the needs of O&M operators



Development of an automated and therefore time-efficient solution for extracting key parameters from maintenance tickets to gain statistical insights from a large number of PV plants.

Development of a software tool for field technicians that would allow the precise and error-free recording of standardised parameters for the calculation of the O&M contractors KPIs necessary for an efficient implementation of the methodology

The O&M field practices must definitely move away from a manual input of tickets in text format and adopt a more standardised approach when human intervention is limited

Take home messages

- Link high quality to low risk in PV project financing
- Risk categorisation
- Common nomenclature
- Standardised quantification
- Availability of large datasets is key (field inspections, monitored data, O&M tickets, etc)
- Dataset interoperability through digitalisation
- Improved Yield Assessment (reduction of uncertainty)

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

Thank you!

david.moser@eurac.edu

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