Research and Industry questions to be answered on PV testing

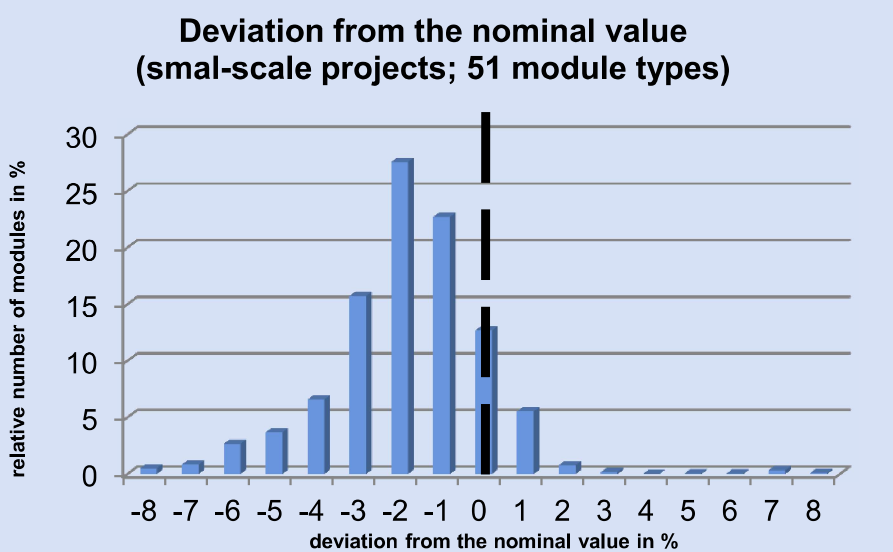
Quality, Characterization, Power Measurement, Securing Performance, Failures and Degradation Effects

TÜVRheinland®
Precisely Right.

Deviation from Rated Power

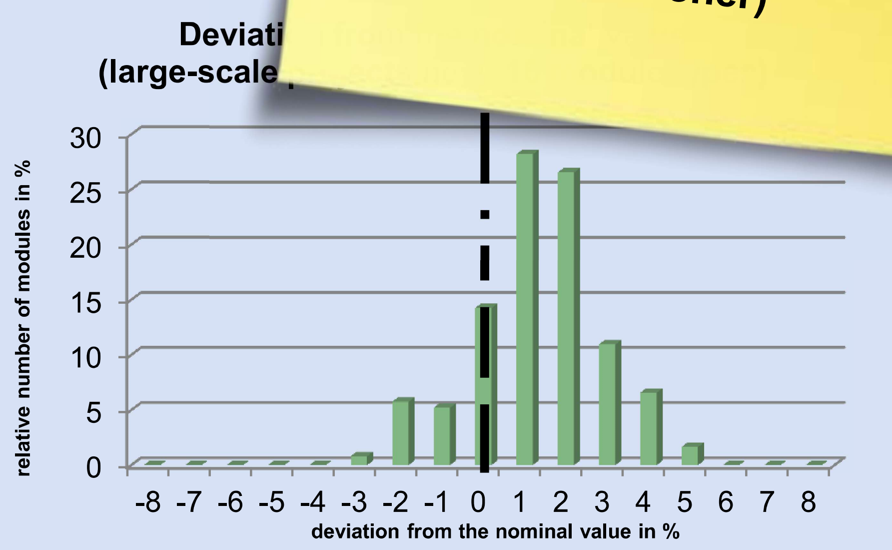
Results of performance measurements in the laboratory (2010

Following doubt about performance (modules that are new or as good as new, operation < one year)



Investors: (Court-) admissible controls necessary

Contractually prior to insta systems



Investors: Measurements secure module performance

Industry and Investor Support through CSIR:
Flash tests before and after LID and after operation
(Facilities: Outdoor exposure test stand, Flasher)

!

Critical performance evaluation (measurement) necessary

High level of measurement precision required for use in court

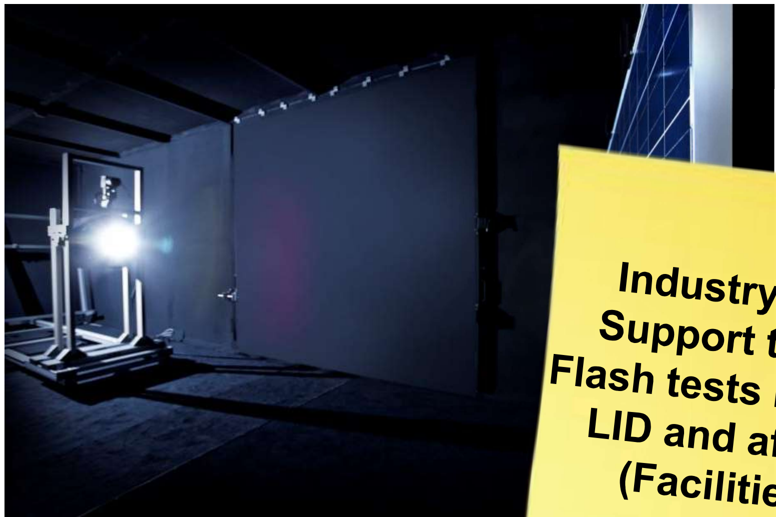
TÜVRheinland®
Precisely Right.

Power measurements (sun simulators, outdoor)

- LED based systems, Xenon based (mobile)

- Stady state sun simulator

- Systems with Xenon-flasher (laboratory, mobile)



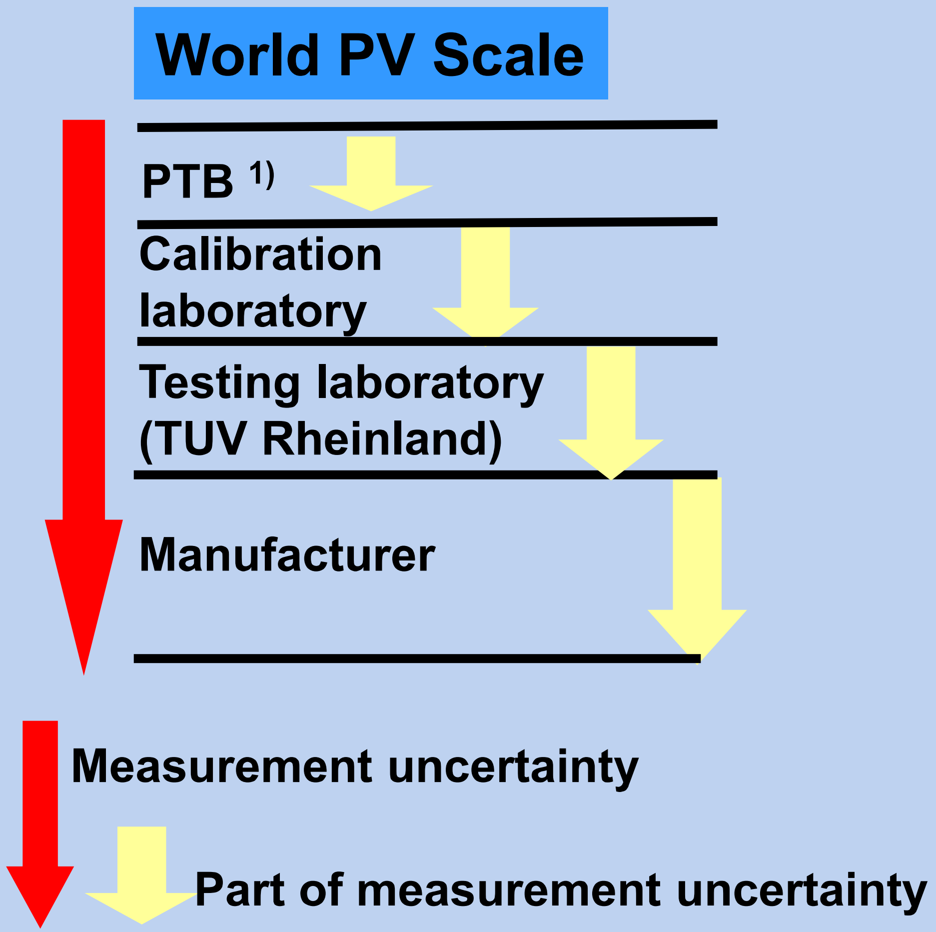
Industry and Investor Support through CSIR: Flash tests before and after LID and after operation (Facilities: Outdoor exposure test stand, Flasher)

Outdoor Measurements

- Laboratory (single module)
- Field measurements (module, strings)

TÜVRheinland®
Precisely Right.

Measurement Uncertainty and Traceability of Power Measurements



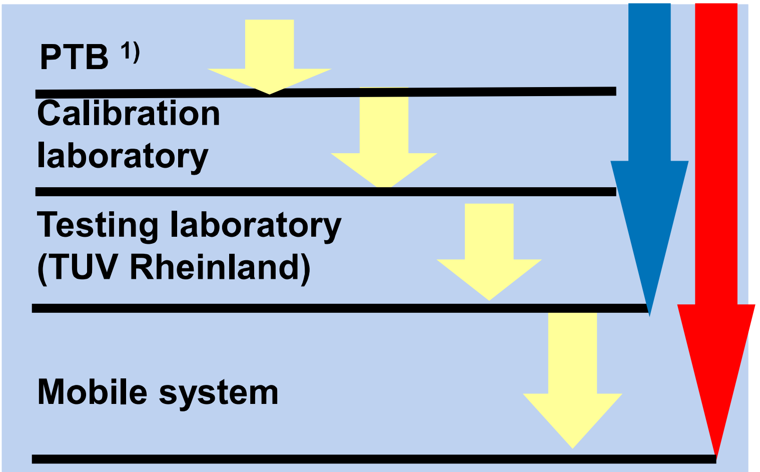
	Measurement Uncertainty
Primary calibration of a reference cell (WPVS)	± 0.5%
Secondary calibration of a reference cell	± 1.0 - 2.0%
Calibration of a reference module	± 1.8 - 2.5%
Usage of reference modules for flasher adjustment in production	(3.0 - 5.0%)

1) "The Physikalisch-Technische Bundesanstalt (PTB) is the national metrology institute of Germany"

TÜVRheinland® Precisely Right.

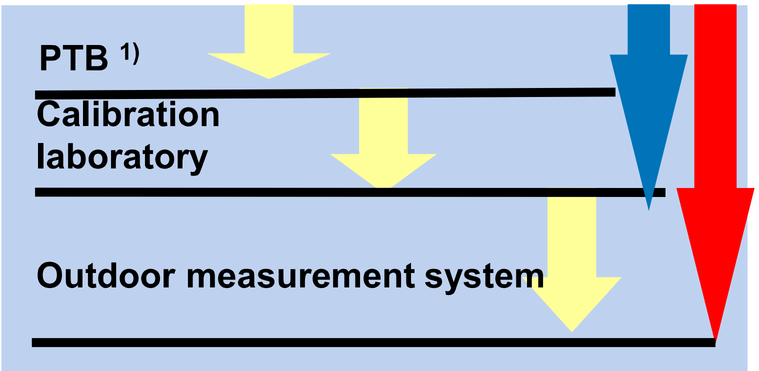
Measurement Uncertainty and Traceability of Power Measurements

- LED based systems, Xenon based (mobile)



	Estimated Measurement Uncertainty
Calibration of a reference module	± 1.8 - 2.5%
Usage of reference modules for flasher adjustment in mobile systems	(4.0 - 5.0%)

- Outdoor field measurements

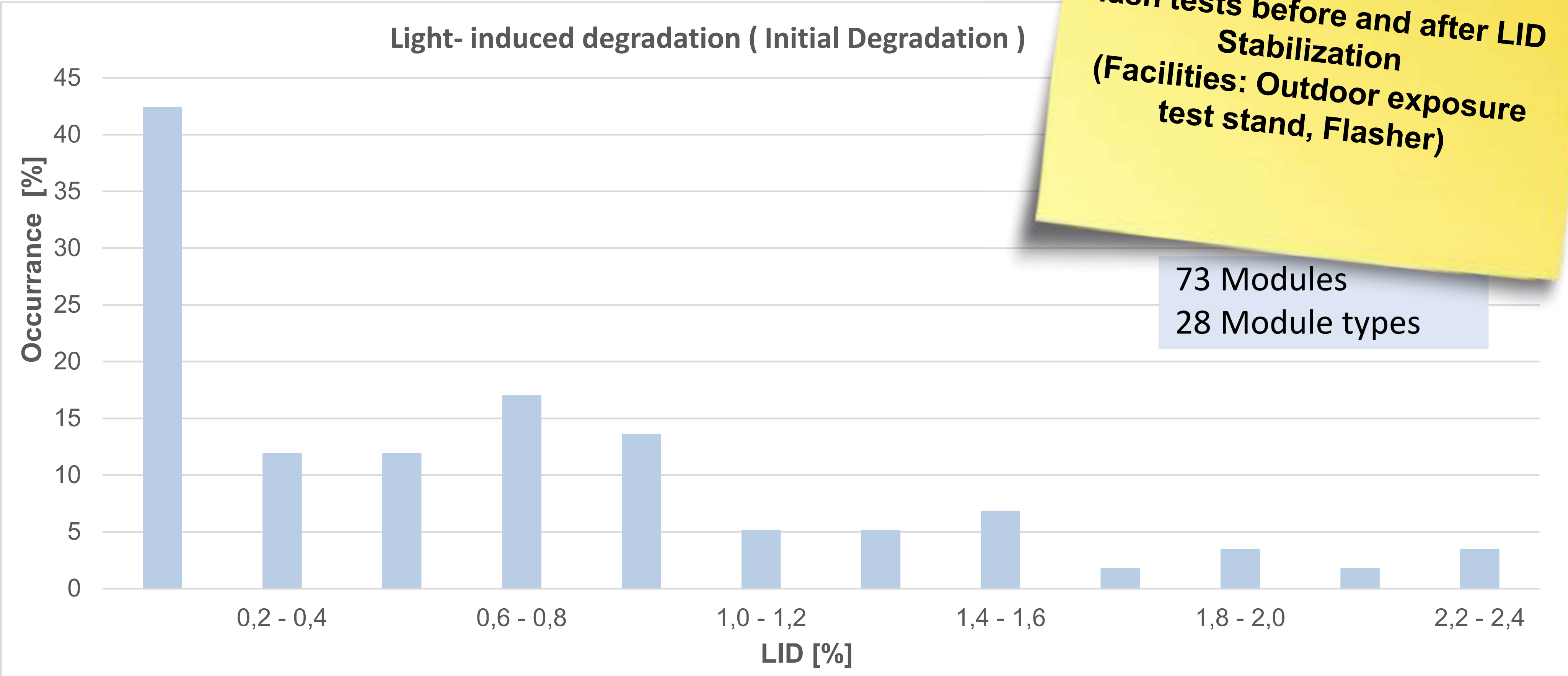


	Estimated Measurement Uncertainty
Sekundary calibration of a reference cell	± 2,0 – 3.0%
Usage of reference cell (often low uncertainity) for outdoor measurements	(6.0 - 7.0%)

TÜVRheinland®
Precisely Right.

Light-induced (initial) Degradation

Industry and Investor Support by CSIR:
Flash tests before and after LID Stabilization
(Facilities: Outdoor exposure test stand, Flasher)



! Through 'light induced degradation' (LID) initial power changes by a few percent in the course of hours.

TÜVRheinland®
Precisely Right.

Verification of Power Output and Stability is Important for the Return on Investment

Industry and Investor Support by CSIR:
Flash tests before and after LID Stabilizsation
(Facilities: Outdoor exposure test stand, Flasher)

New series of standards

IEC 61215-1: Power output verification: P_{max}(Lab) ≥ P_{max}(Nameplate)

(considering measuring uncertainties, production tolerances and LID effects)

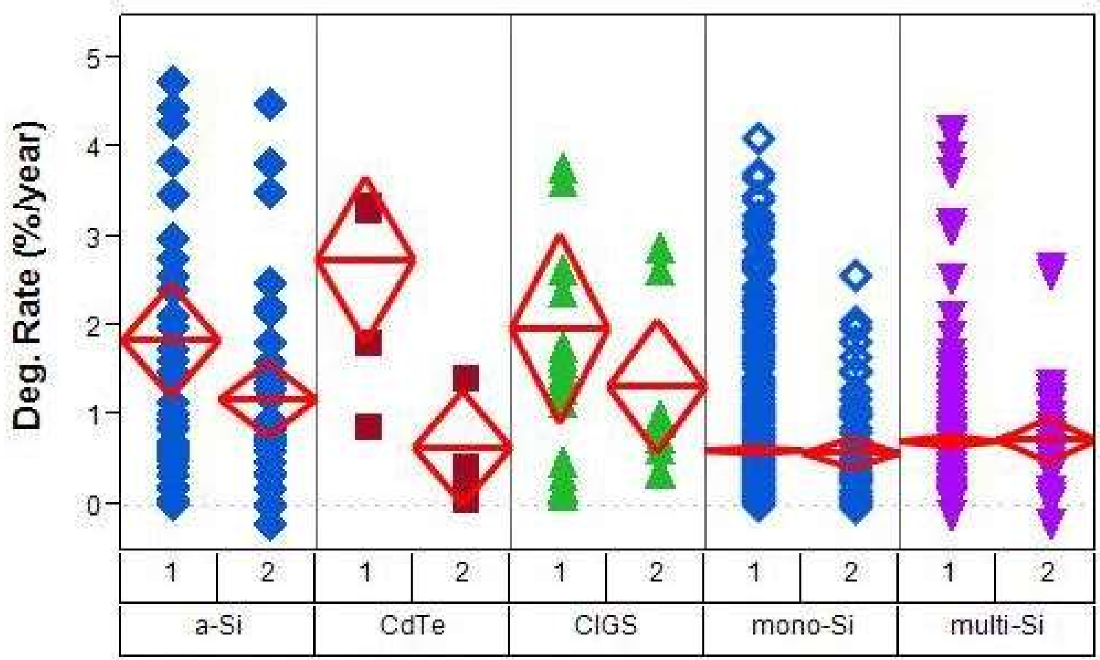
IEC 61215-2: Criterion definition for stabilization (3 measurements):

$$(P_{\max} - P_{\min}) / P_{average} < x$$

Standard	Scope	Irradiation dose Initial stabilization	Irradiation dose final stabilization	Stabilization criterion x
IEC 61215-1-1	c-Si	2 x 5kWh/m²	not required	1%
IEC 61215-1-2	CdTe	2 x 20kWh/m²	2 x 20kWh/m²	2%
IEC 61215-1-3	a-Si	2 x 43kWh/m²	2 x 43kWh/m²	2%
IEC 61215-1-4	CIGS	2 x 20kWh/m²	2 x 10kWh/m²	2%

Degradation, Service Lifetime of PV Modules

Industry and Investor Support by CSIR:
Evaluation of degradation
(Facilities: Outdoor exposure test stand, Flasher)



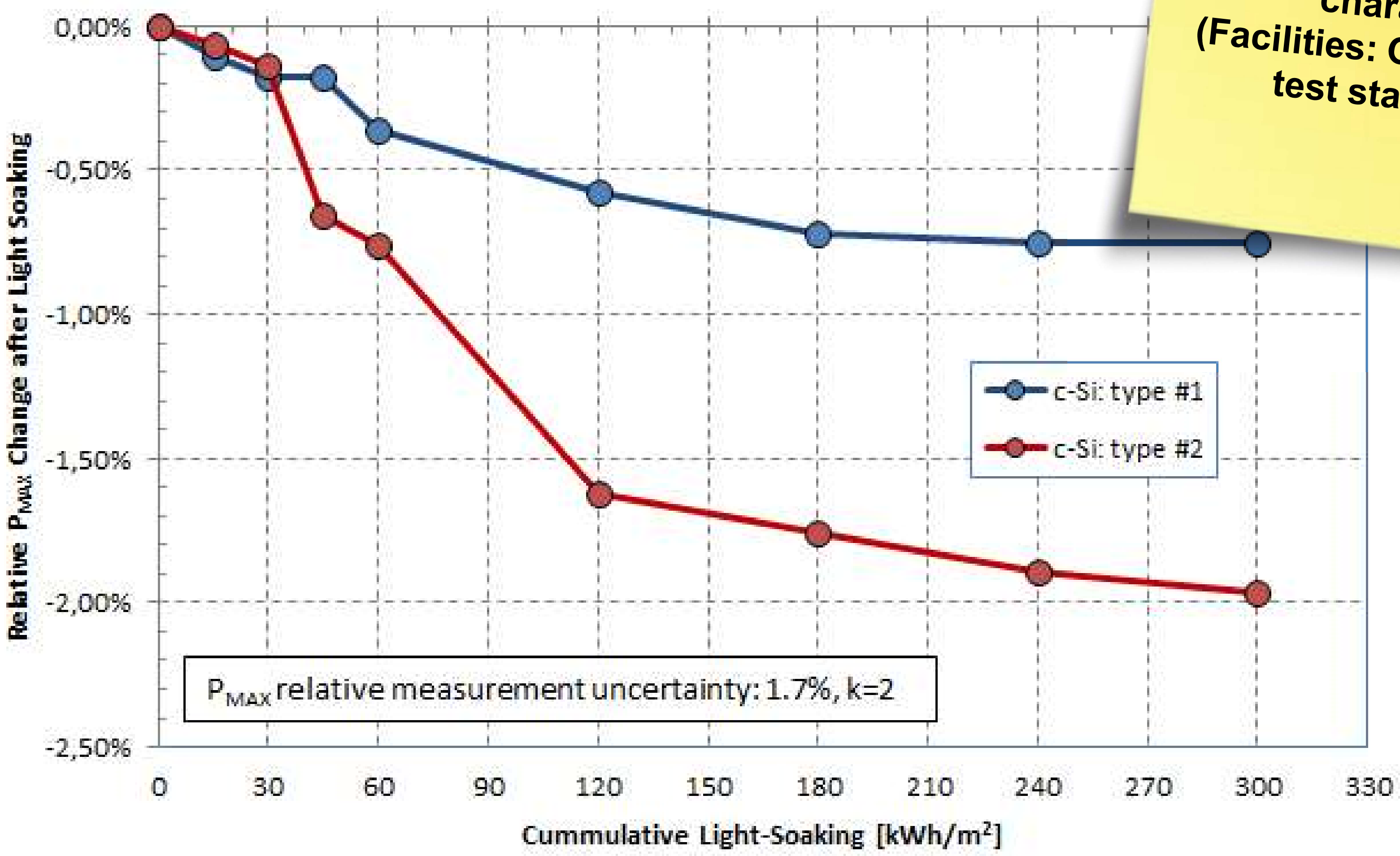
Published degradation rates for different module technologies. 1 exposed before 2000, 2 exposed after 2000

TÜV Rheinland estimation shows that crystalline modules of high quality will exhibit annual degradation rates of < 0.3%.

[1] Photovoltaic Degradation Rates — An Analytical Review Dirk C. Jordan et al., Journal Article NREL/JA-5200-51664 (2012)

TÜVRheinland® Precisely Right.

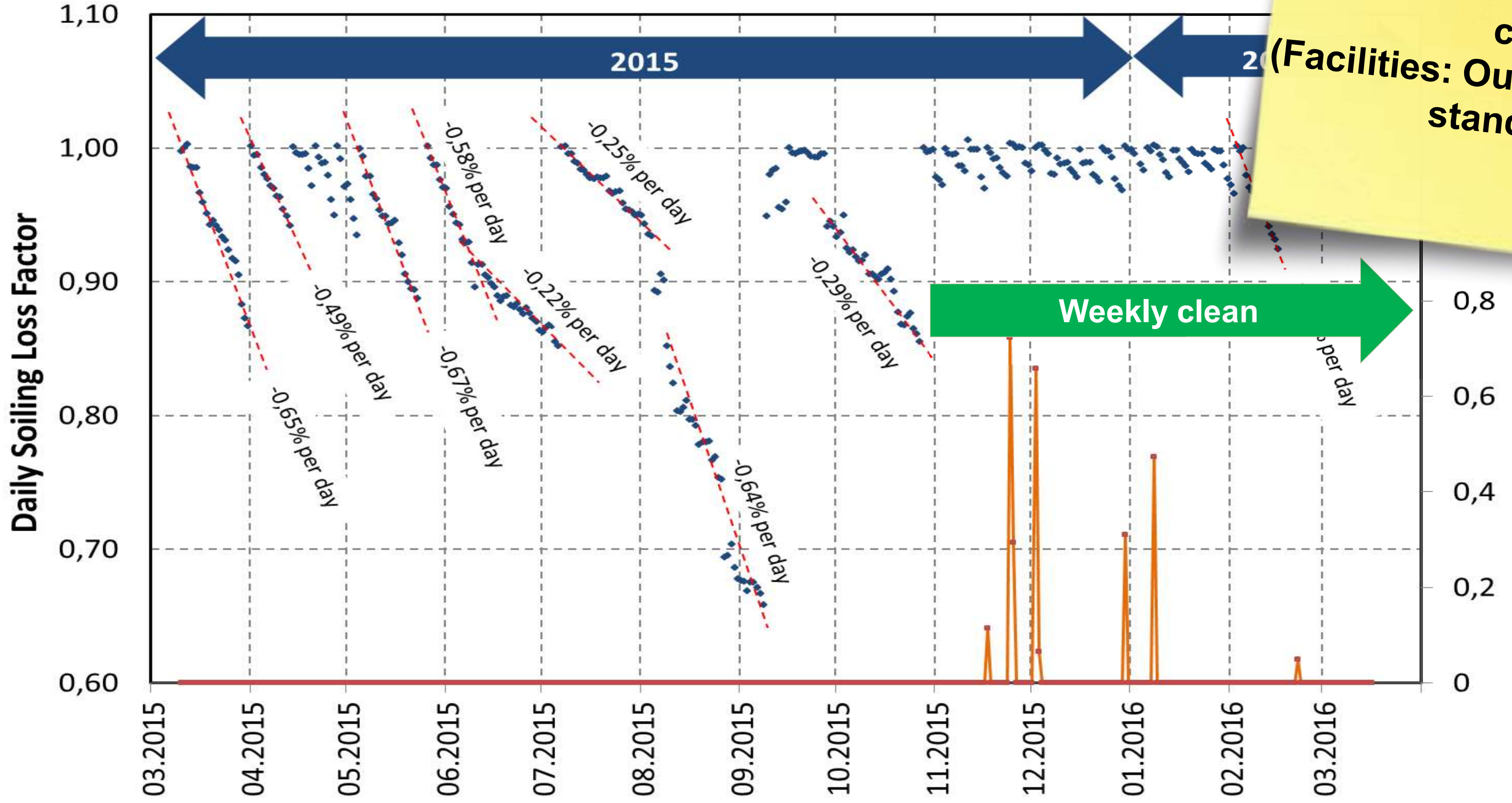
Accurate Power Output at STC after Stabilization



Industry and Investor Support by CSIR:
Evaluation of stabilization characteristics
(Facilities: Outdoor exposure test stand, Flasher)

TÜVRheinland® Precisely Right.

Soiling
Example Arizona



Industry and Investor Support through CSIR:
Flash tests before and after cleaning
(Facilities: Outdoor exposure test stand, Flasher)

Annual soiling loss
2014: -3.6 %
2015: -1.2 %
Average daily SLF
- 0.22 % to - 0.67 %

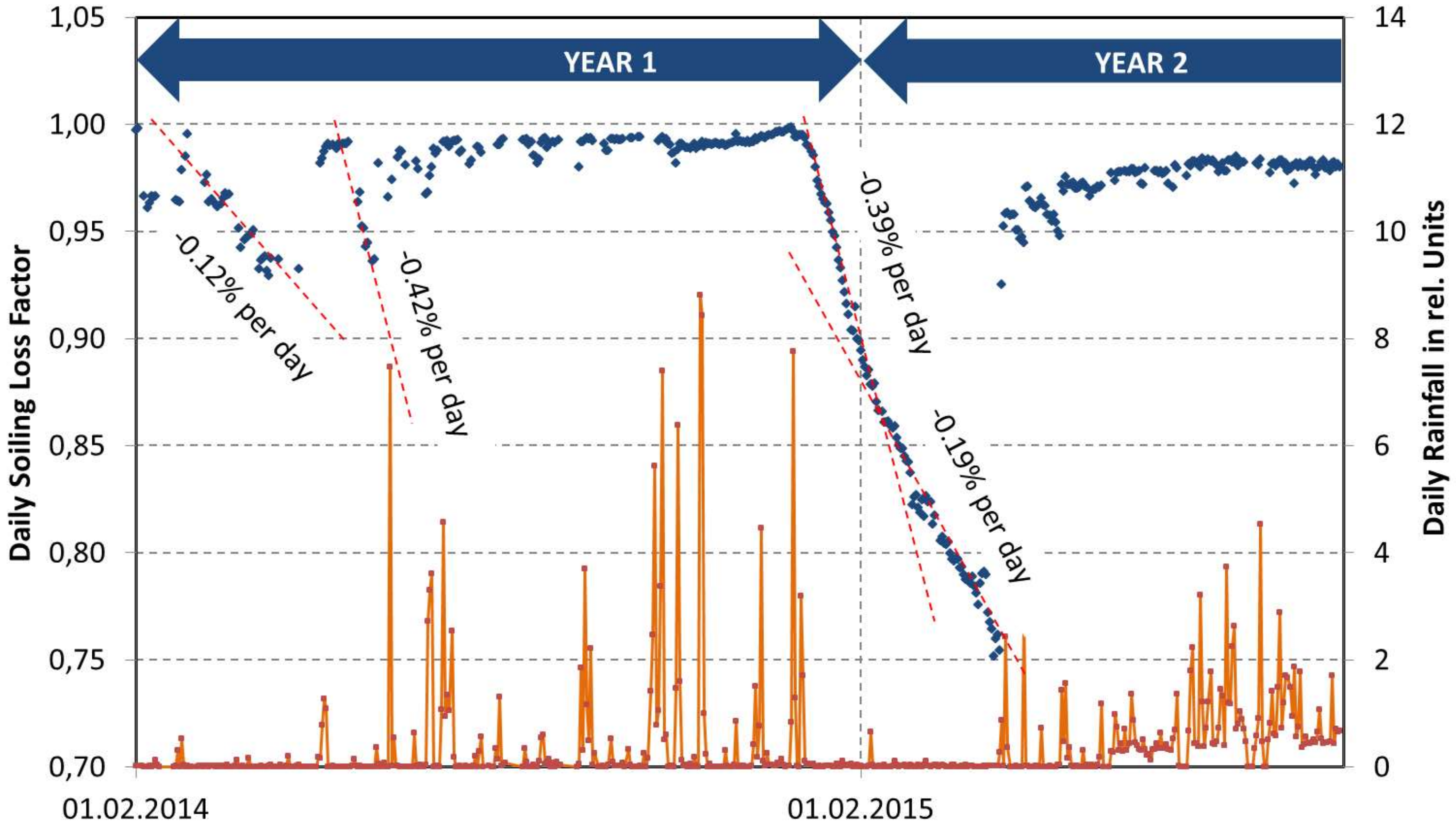
!

Local conditions need to be taken into account for O&M contract.
Cleaning measures increase O&M cost significantly.

TÜVRheinland®
Precisely Right.

Soiling

Field Study – Chennai, India; inclination angle = 15°



Average daily SLF decrease in dry periods:
-0.12 % to -0.39 %

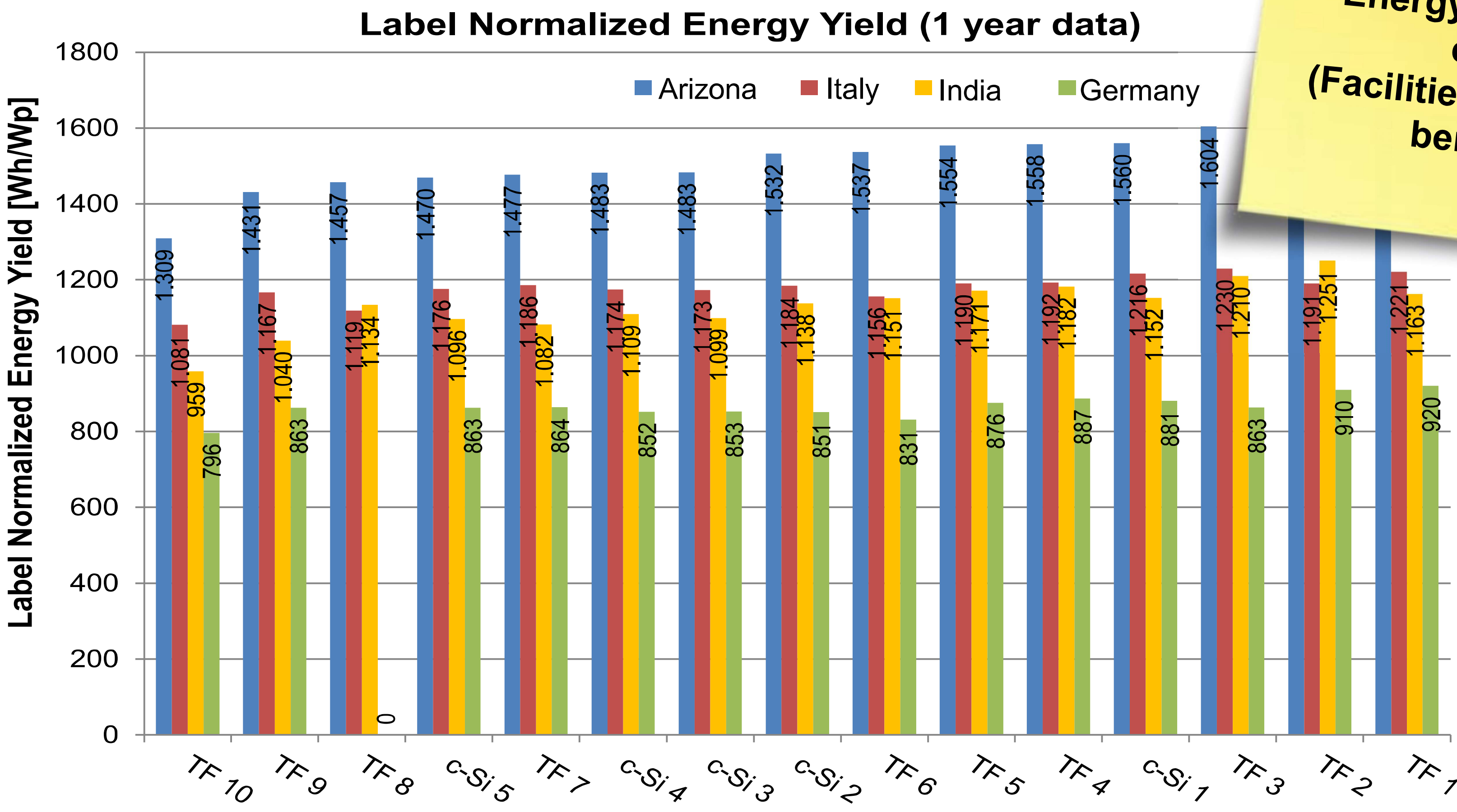
Annual soiling loss (year 1):
-2.2 % total loss

- 3-months dry season ⇨ 25 % soiling loss observed
- Recovery in rainy season: SLF >99 % in first year, SLF >98 % in second year
- Significant differences in soiling patterns for 1st and 2nd year

TÜVRheinland®
Precisely Right.

Choice of Technology

Global Energy Yield Benchmark



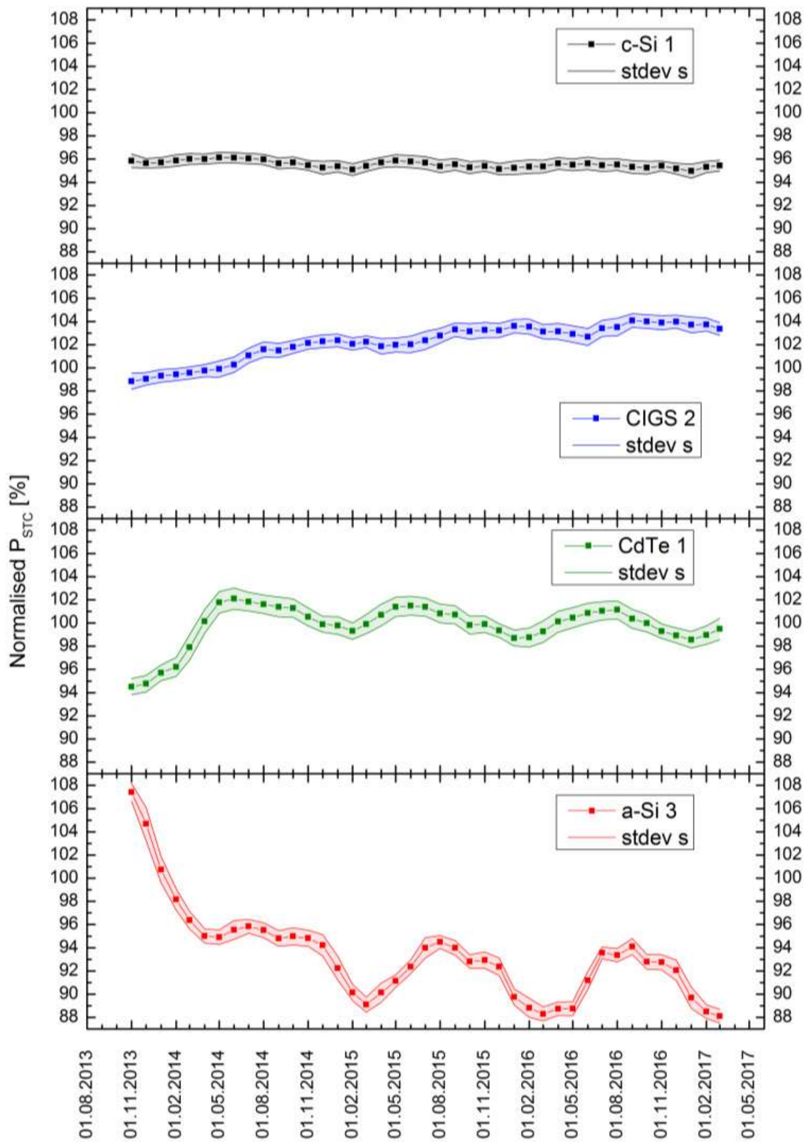
Industry and Investor Support by CSIR:
Energy Yield Testing and comparison
(Facilities: Energy yield test bench, Flasher)

	Variation between technologies
Italy	**12 %**
Germany	**14 %**
India	**23 %**
Arizona	**21 %**
Saudi Arabia	Not available yet

! Choice of technology and optimised product is crucial for high energy yield and return of investment.

TÜVRheinland® Precisely Right.

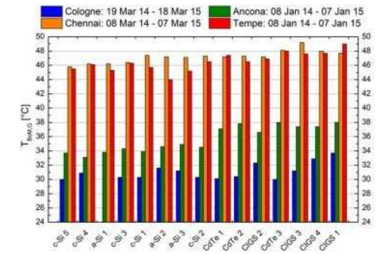
Long time behavior of different Technologies, Metastabilities

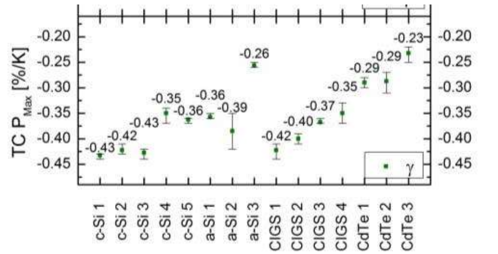


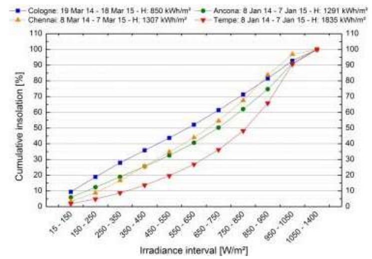
Industry and Investor Support by CSIR:
Energy Yield Testing and comparison
(Facilities: Energy yield test bench, Flasher)

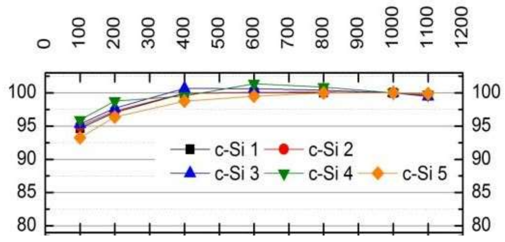
TÜVRheinland® Precisely Right.

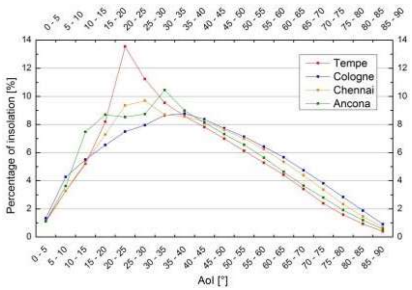
Calculate and Compare the Energy Yield Performance of PV Modules

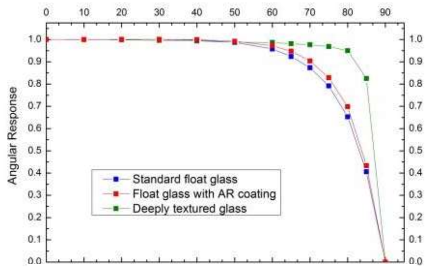


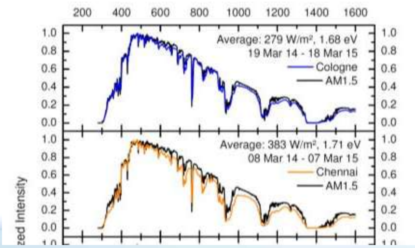


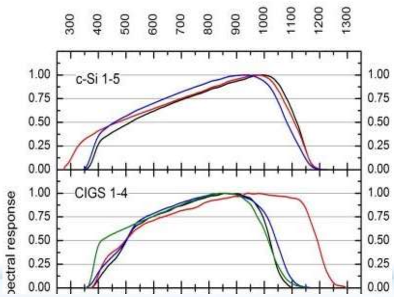












$MPR_{Estimated}$ =

$\Delta MPR_{Temperature}$

+

$\Delta MPR_{LowIrra}$

+

$\Delta MPR_{AngularEffects}$

+

$\Delta MPR_{SpectralEffects}$

$(+ \Delta MPR_{Soiling})$

Industry and Investor Support by CSIR: Energy Yield Testing and comparison (Facilities: Energy yield test bench, Flasher)

TÜVRheinland®
Precisely Right.

Testing of small grid connected PV-System under local conditions

Test of grid connected systems
- Direct connected
- With battery

- Long time behavior
- Efficiency depend on irradiation and status of battery
- Utilization factor

**Industry and Investor Support by CSIR:
System tests of grid connected systems with and without batteries (Facilities: System test bench with and without battery)**

TÜVRheinland®
Precisely Right.

Research and Industry questions to be answered on PV testing

Outlock: Different Climates, Soiling, Sand

TÜVRheinland®
Precisely Right.

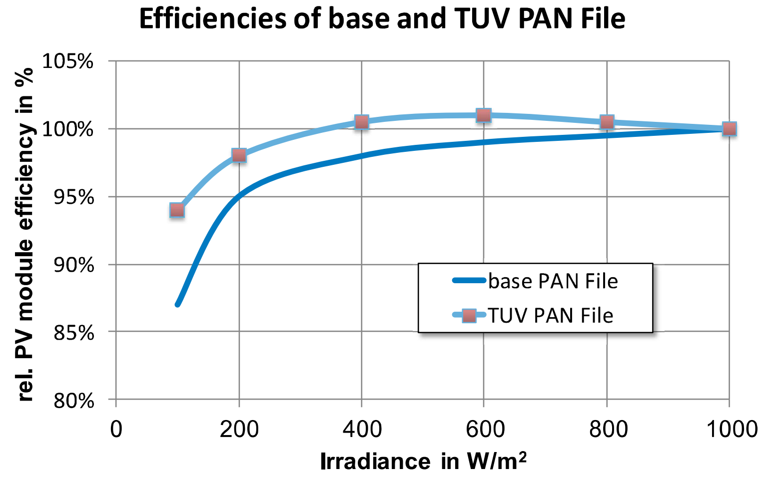
Energy Yield Prediction based on Precise Data

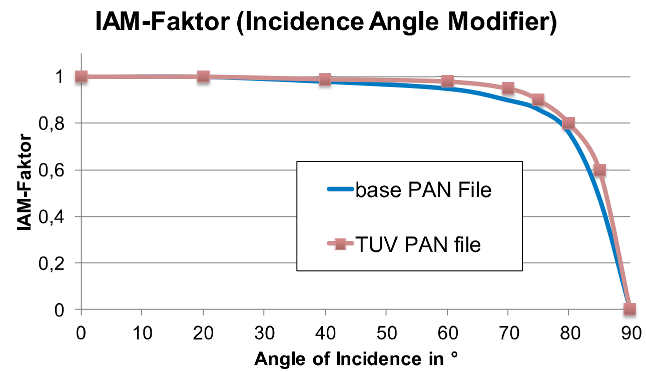
IEC 61853-1 → IEC 61853-2 → TUV PAN File

Irradi-ance	Module temperature			
W m-2	15 °C	25 °C	50 °C	75 °C
1100	NA	▪	▪	▪
1000	▪	▪	▪	▪
800	▪	▪	▪	▪
600	▪	▪	▪	▪
400	▪	▪	▪	NA
200	▪	▪	NA	NA
100	▪	▪	NA	NA

▪ measuring points

Incidence angle	IAM
°	0-1
0	▪
±10	▪
±20	▪
±30	▪
±40	▪
±50	▪
±60	▪
±65	▪
±70	▪
±75	▪
±80	▪
±85	▪





! The complete set of measurements leads to more precise energy yield prediction and reduction of risk of over- or underestimation of revenues by several percent.

TÜVRheinland® Precisely Right.

Type Testing and is Limitations

From IEC 61215 / 61646 / 61730:

“…design qualification and type approval of terrestrial photovoltaic modules suitable for long-term operation in general open air climates, as defined in IEC 60721-2-1….”

Arid area stresses:

- Higher daily and annual irradiance
- Increased UV
- Higher temperatures
- Sandstorms
- Dust
- more operational hours per day

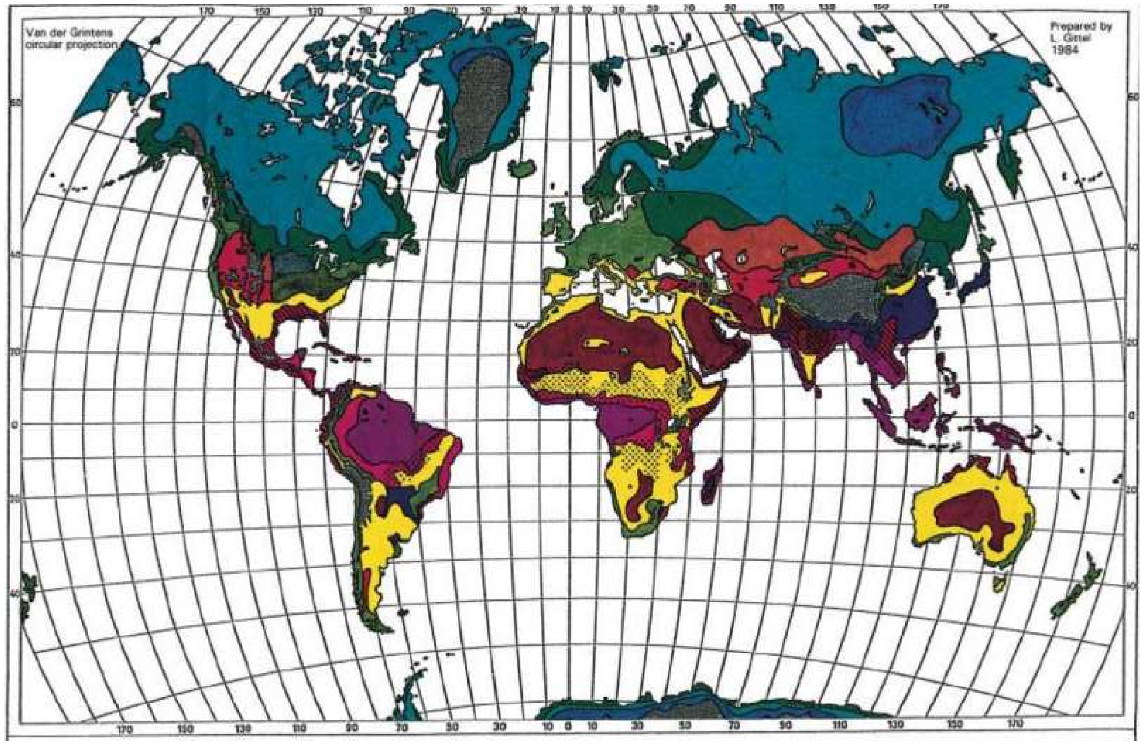


Figure A1 from IEC 60721-1

TÜVRheinland® Precisely Right.

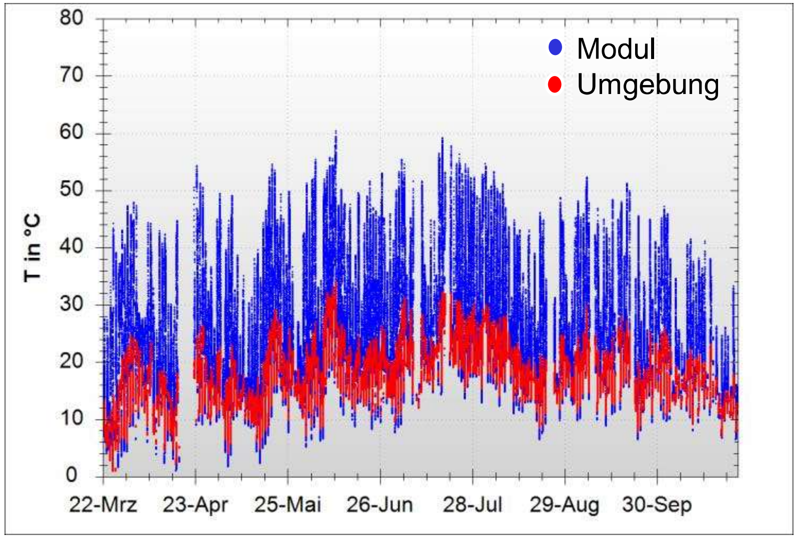
Type Testing and is Limitations

Standard insufficiencies:

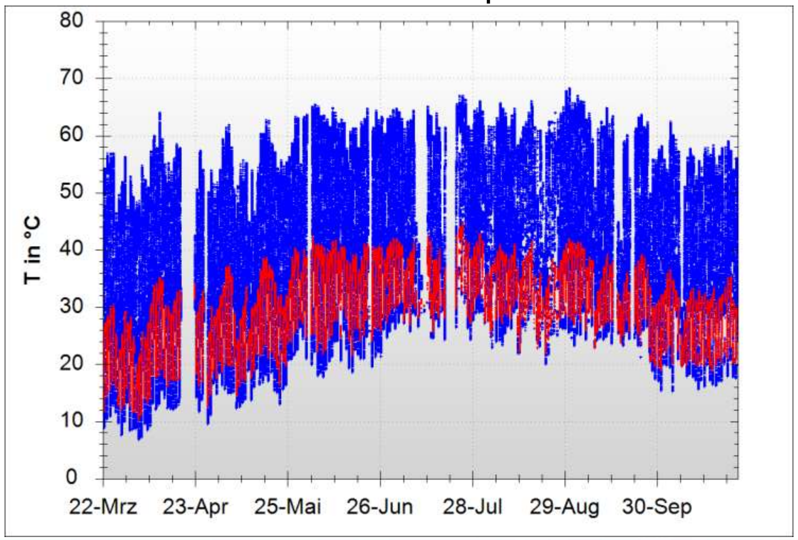
- Characterization with focus on different climate (IEC 61853 energy matrix)
- Unrealistic Nominal Operating Cell Temperature (NOCT) at 800 W/m² / 20° C
- Temperature range of tests -45° C to +85°
- Module temperature for stress test 75° C
- Max irradiance for tests 1000 W/m²
- Insufficient UV test
- No sand abrasion test
- Max. temp. determination parameters

	normalized temperatures [°C]			
	backsheet	junction box	terminal	diode
1000 W/m²/ 40 °C	79,3	72,1	70,2	79,6
1100 W/m²/ 50 °C	102,6	86,6	82,2	92,9

Module and environmental temperatures: Köln

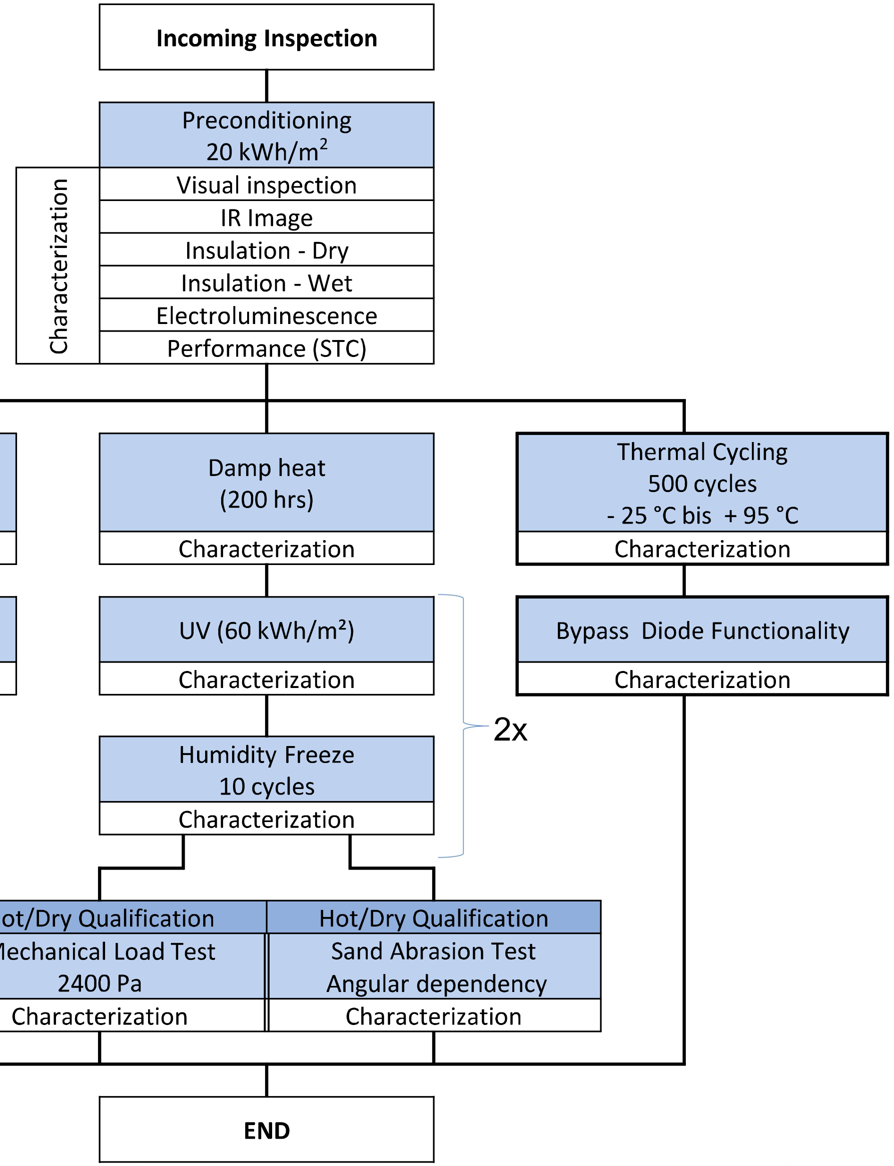


Module and environmental temperatures: Arizona



TÜVRheinland®
Precisely Right.

Type Testing and is Limitations
Possible Test Scenario with Adapted Test Parameters

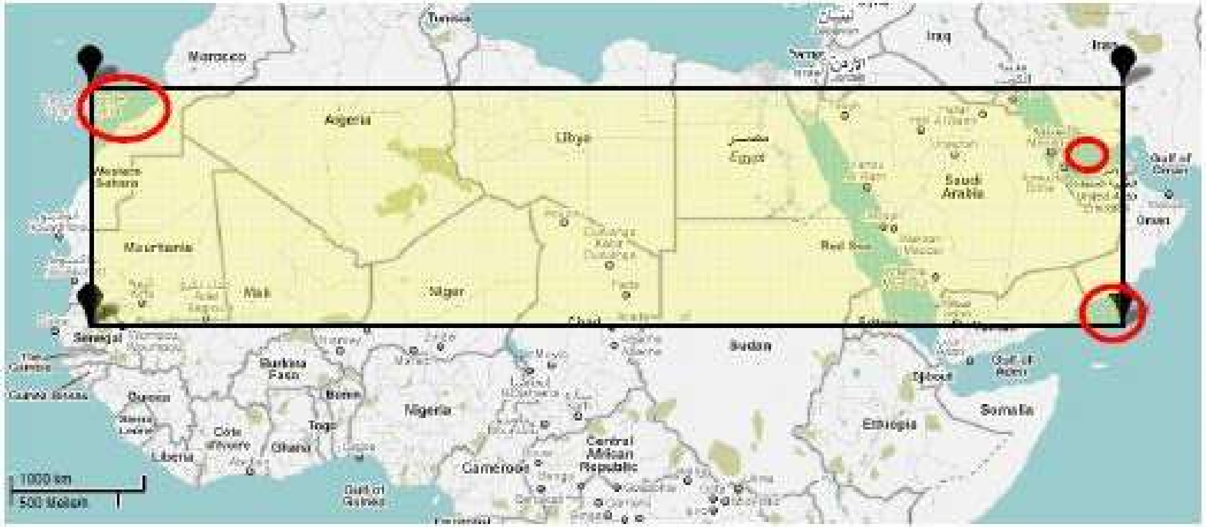


TÜVRheinland®
Precisely Right.

Sand and Dust

Sand Abrasion – Test Methods

Adaptation to specific region



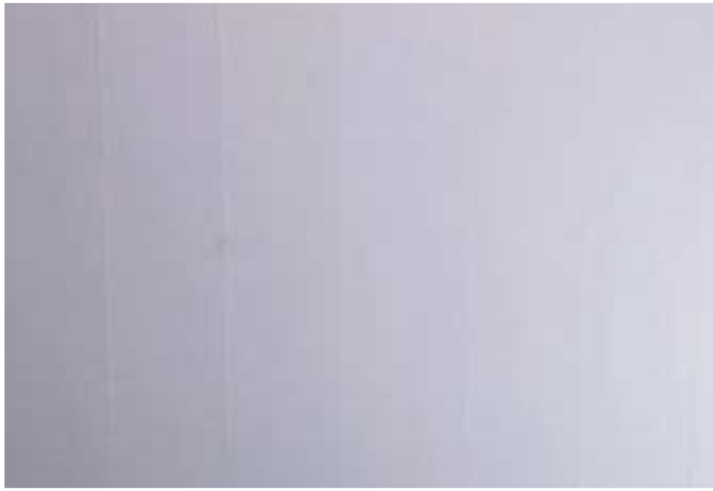
- Available standards:
  - MIL 810G – Method 510.5
  - DEF - STD 00-35
  - IEC 60068-2-68
  - AECTP 300 – Method 313
- Different regions were examined and with compared with standard parameters
- Parameters differ from region to region
- The military standard MIL 810G covers most of the conditions quite well
- Until now field experience from long-term exposure in desert regions is limited
- Benchmark tests are useful and available for modules and components

TÜVRheinland®
Precisely Right.

Sand and Dust
Sand Abrasion - Experiments

Surface structure of backsheet

- Photos of backsheet in sand blasted areas show surface changes compared to unconditioned areas.
- Effects are visible after 90 minutes
- Until now no final assessment of effects
- Microscopic imaging and cross sectional analysis will bring further information (ongoing work)
- Further modules are currently under test



Summary

- Hot and extreme climate zones impose special requirements to PV system components

- Sand is only one of many stress factors
  - Impact on transmission of glass
  - Impact on backsheet

- Until now there is no adapted standard available
  - A proposal by TÜV Rheinland is available
  - A standard is needed to allow adapted product development

- Cleaning and maintenance cost are often underestimated

Thank you for you attention!

Image:www.spineuniverse.com

TÜVRheinland® Precisely Right.