IEC 61853 Energy Rating of PV Modules - Measurement Methods and Lessons Learned

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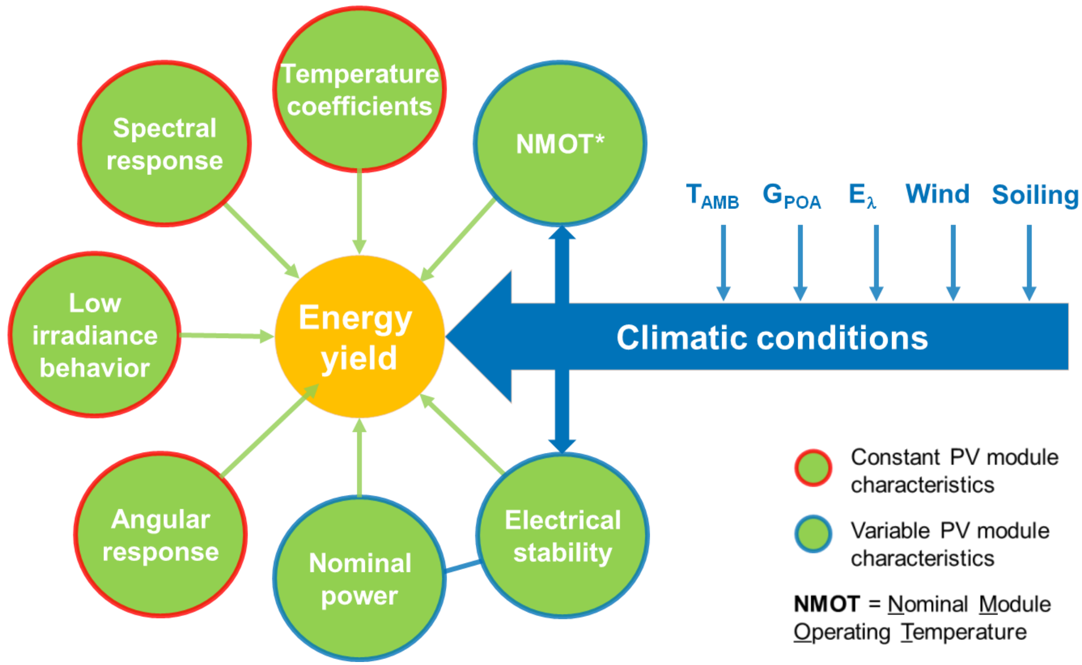
Precisely Right.

Introduction



- Assessment of the PV module energy yield performance requires knowledge of specific module parameters
- Measurement procedures are defined in IEC 61853-1 and IEC 61853-2
- TÜV Rheinland operates five energy yield test sites world-wide and has more than 10 years experience in energy rating and energy yield testing of PV modules

Output power under variable temperature and irradiation
Test equipment

- **Pulsed solar simulator:** Pasan SunSim 3b (Multiflash / Dragon-back technique, spectrally neutral attenuation masks)

  Berger Lichttechnik PSS30 (Separable test chamber for temperature conditioning of the PV module)

- **Steady state solar simulator:** Customized set-up with 12 metal halide lamps (Reduction of thermal radiation, temperature conditioning of the PV module under illumination)


Pulsed solar simulator


Steady state solar simulator

Output power under variable temperature and irradiation
PV Module I-V correction parameters (IEC 60891)

Two options to cover the range of test conditions:

a) Measurement of performance matrix in accordance with IEC 61853-1

b) I-V reference curve + Determination of I-V correction parameters in accordance with IEC 60891

$$I_2 = I_1 \cdot \left(1 + \alpha_{rel} \cdot (T_2 - T_1)\right) \cdot \frac{G_2}{G_1}$$

$$V_2 = V_1 + V_{OC1} \cdot \left(\beta_{rel} \cdot (T_2 - T_1) + a \cdot \ln\left(\frac{G_2}{G_1}\right)\right) - R'_S \cdot (I_2 - I_1) - \kappa' \cdot I_2 \cdot (T_2 - T_1)$$

IEC 60891 Procedure 2

Legend:

I_1, I_2:	Module current
V_1, V_2:	Module voltage
T_1, T_2:	Module temperature
G_1, G_2:	Irradiance
Index 1:	Measurement conditions
Index 2:	Target conditions (i.e. STC)

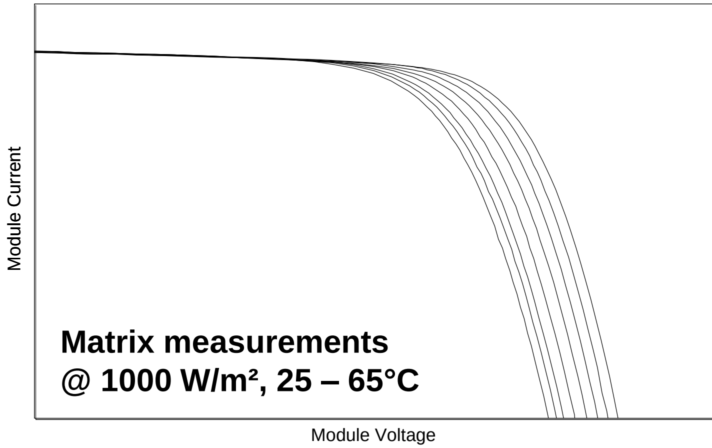
Module parameters:

α_{rel} :	Temperature coefficient I_{SC} [1/K]
β_{rel} :	Temperature coefficient V_{OC} [1/K]
R_S’:	Internal series resistance [Ω]
κ’ :	Temperature coefficient R_S [Ω/K]
a:	Irradiance correction factor of V_{OC}

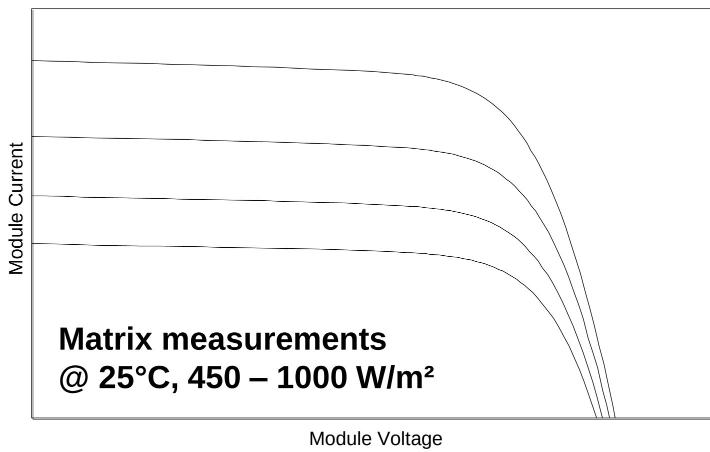
<u>Note:</u>
Temperature coefficients are typically related to STC

Output power under variable temperature and irradiation
Determination of I-V correction parameters (IEC 60891)

Variable temperature



Variable irradiance



Module I-V correction parameters (Module type: multi c-Si)

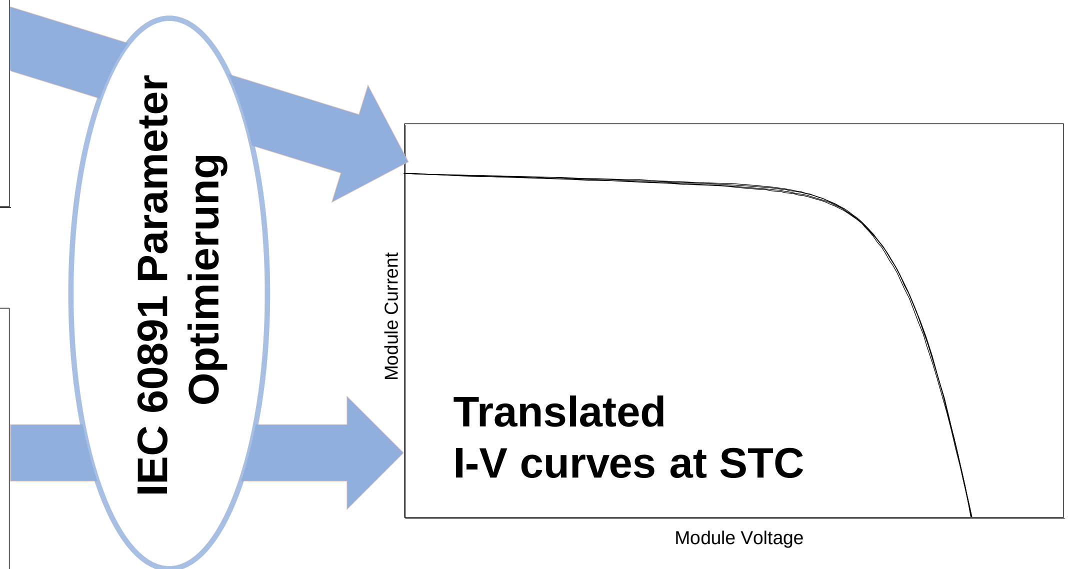
α_{REL} = -0.042% K^{-1}

β_{REL} = -0.46% K^{-1}

κ' = -0.004% K^{-1}

R_S' = 460 mOhm

a = 0.054

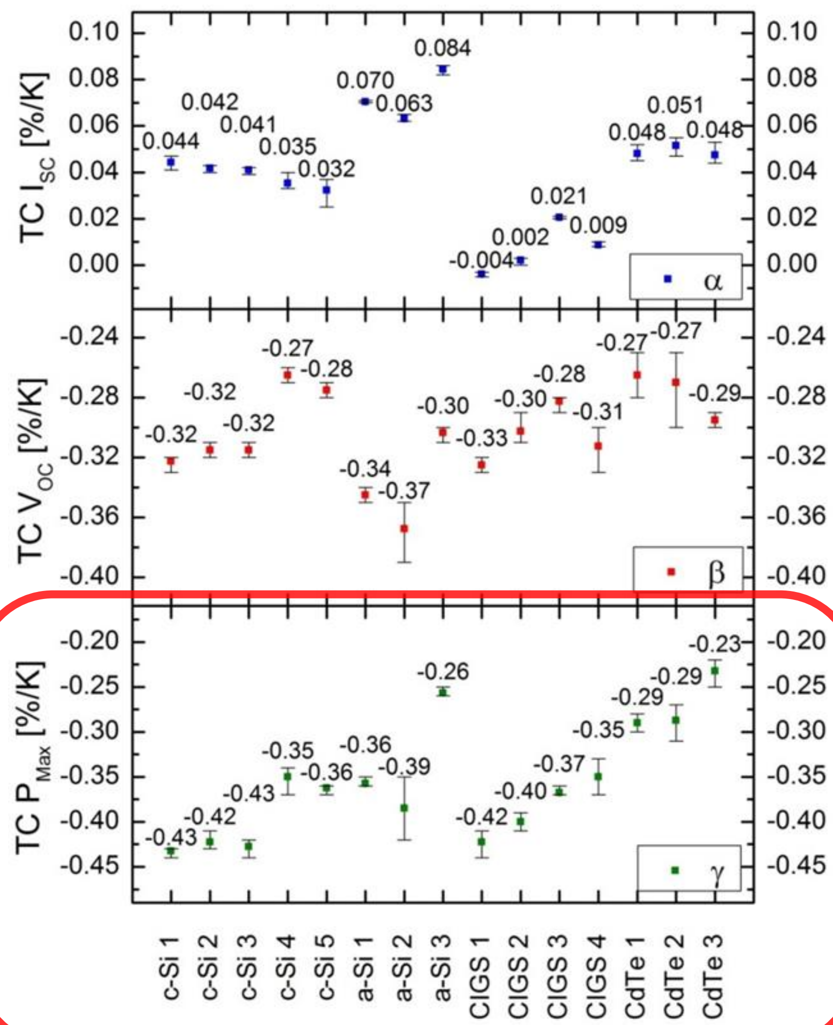


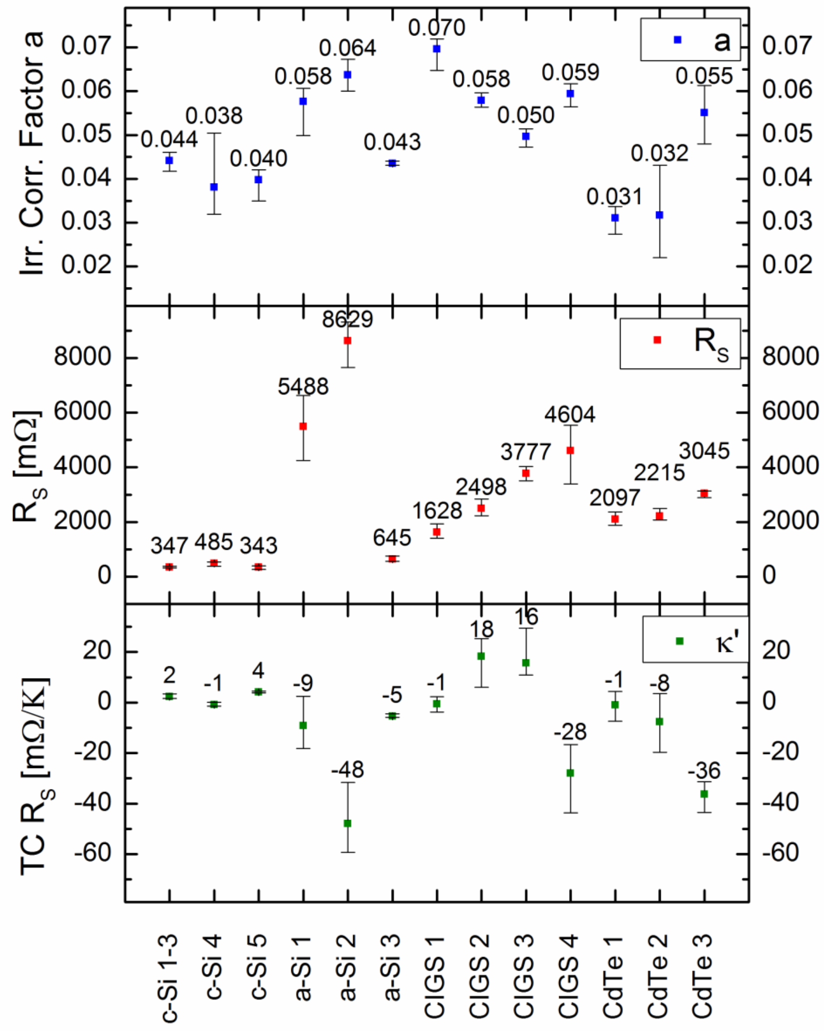
Note:
I-V correction parameters may be subject to production tolerances

Reference: M. Schweiger et al.: Fabrication Tolerance of PV-Module I-V Correction Parameters for Different PV-Module Technologies and Impact on Energy Yield Prediction EUPVSEC 2014

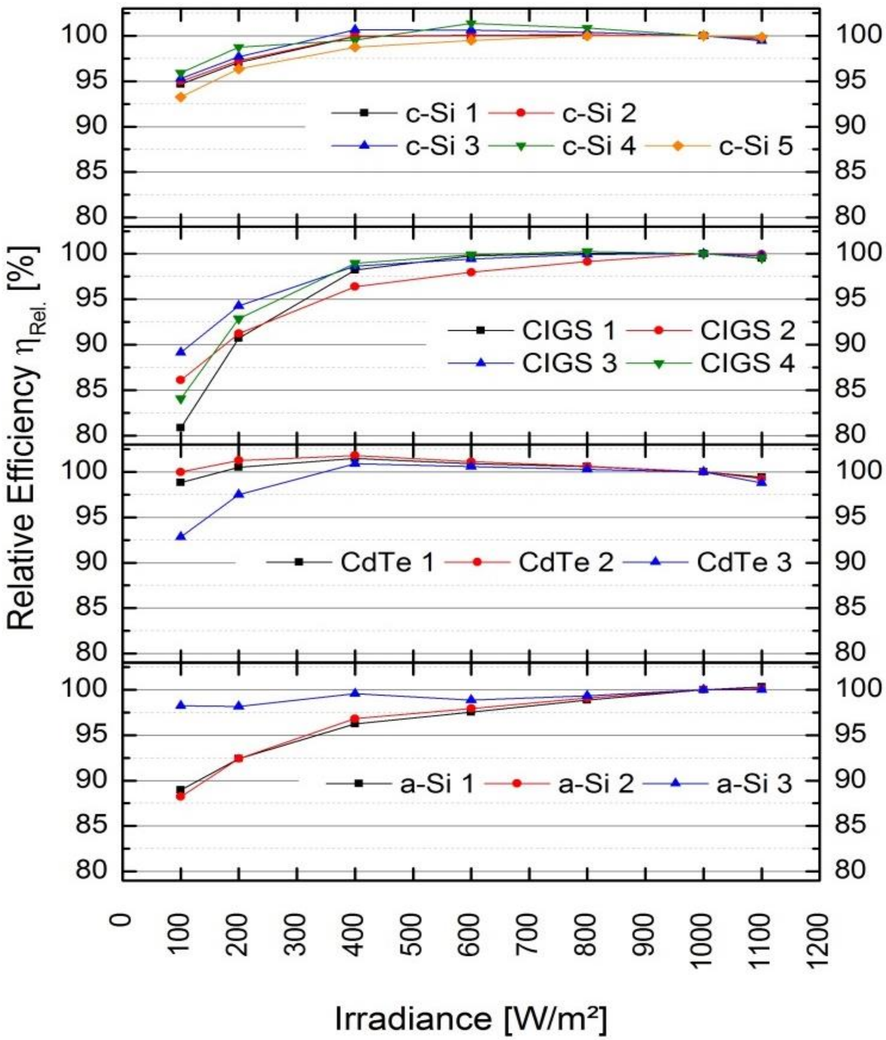
Output power under variable temperature and irradiation

Spread of I-V correction parameters





Output power under variable temperature and irradiation
Low irradiance behavior of different PV modules



Drop of module efficiency in the low irradiance range <200 W/m²

- c-Si PV technologies: -2% to -4%
- CIGS thin-film: -5% to -10%
- CdTe thin-film: 0% to -3%
- a-Si thin-film: -2% to -8%

No generalization possible! **!**

PV module performance under variable irradiation is important for locations with high low irradiance contribution to annual insolated solar radiation (i.e. Cologne: 19%) or non optimal mounting conditions

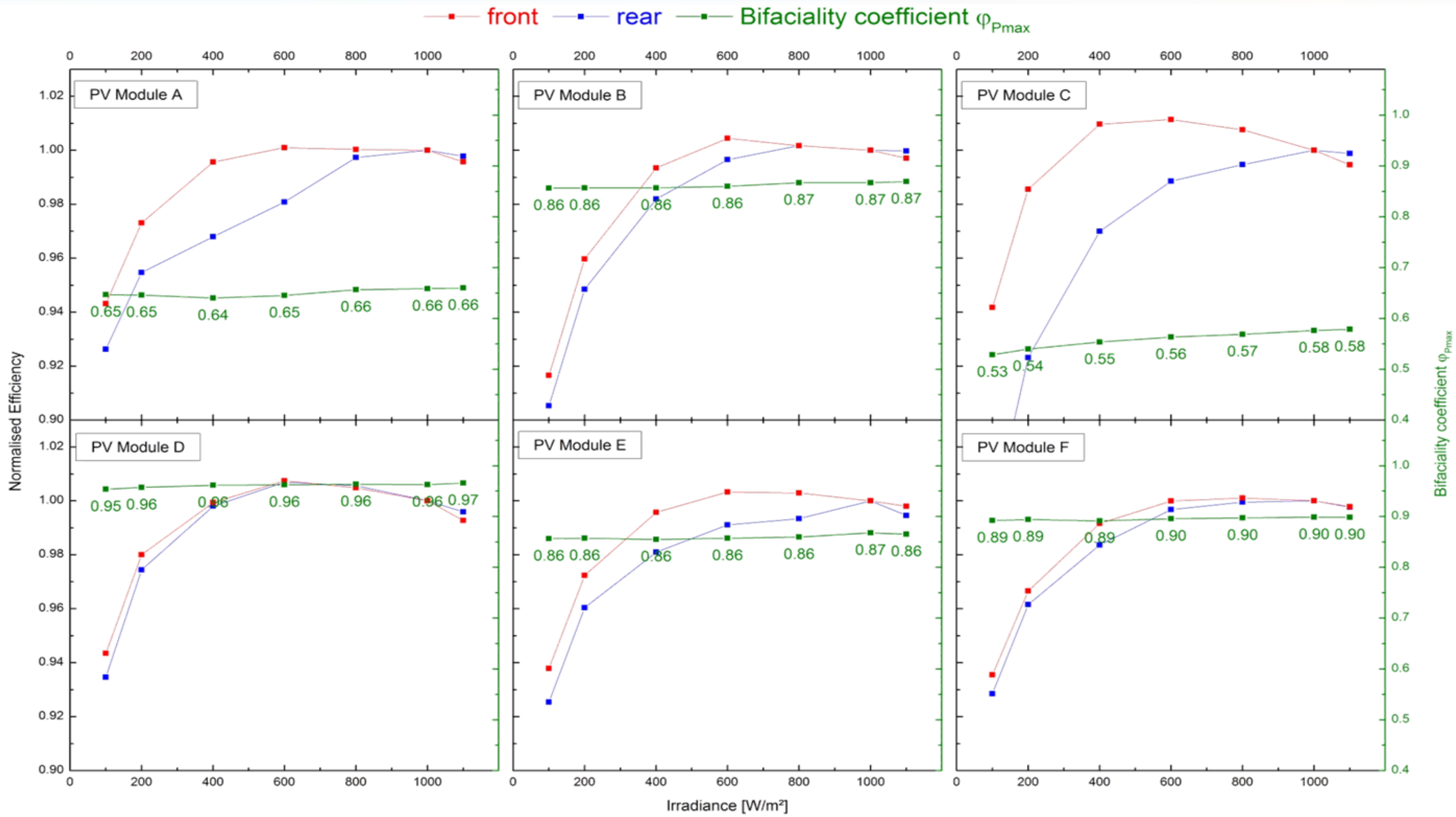
References:

M. Schweiger et al.: Understanding the energy yield of photovoltaic modules in different climates by linear performance loss analysis of the module performance ratio, IET Renewable Power Generation, ISSN 1752-1416, 2017

M. Schweiger et al.: Performance Stability of Photovoltaic Modules in Different Climates, Paper submitted to Progress in PV

Output power under variable temperature and irradiation

Low irradiance behavior of bifacial PV modules



- Low sensitivity of bifaciality coefficient φ_{Pmax} on irradiance level

$$\varphi_{PMAX}(G) = \left. \frac{Pmax_r}{Pmax_f} \right|_G$$

- Shading of module rear side by label, J-boxes or cables negatively impact φ_{Pmax}

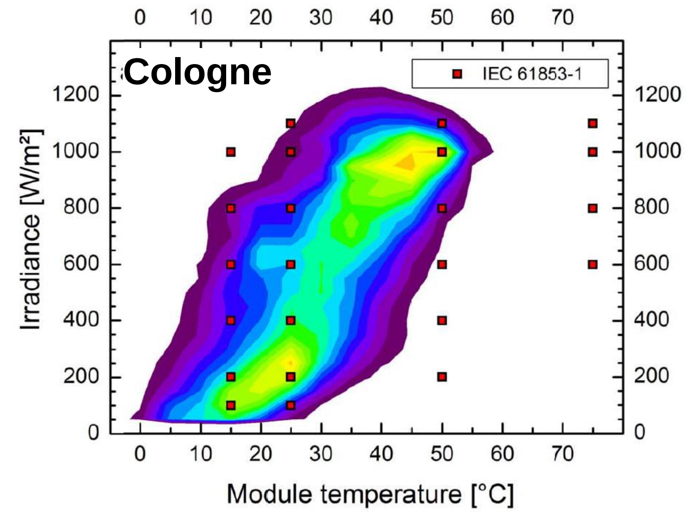
Output power under variable temperature and irradiation
Improvement of IEC 61853-1

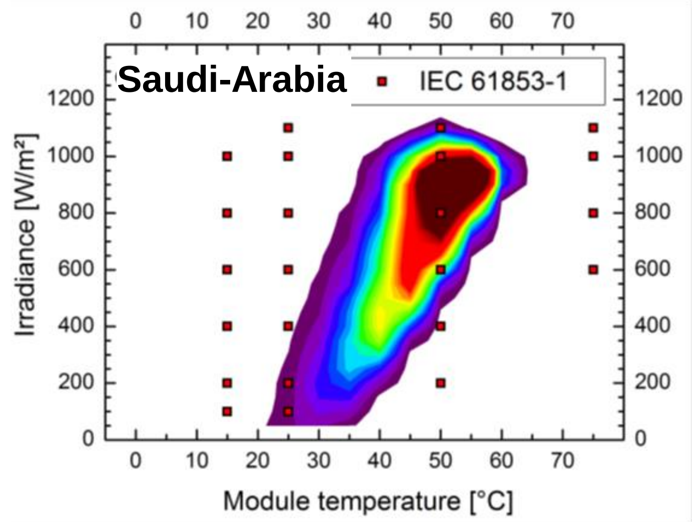
IRRADIANCE	Spectrum	Module Temperature			
$W \cdot m^{-2}$		15°C	25°C	50°C	75°C
1100	AM1.5	NA	●	●	●
1000	AM1.5	●	● STC	●	●
800	AM1.5	●	●	●	●
600	AM1.5	●	●	●	●
400	AM1.5	●	●	●	NA
200	AM1.5	●	●	●	NA
100	AM1.5	●	●	NA	NA

Test program:

3 Test samples
x 23 Test conditions
x 3 I-V measurements
207 I-V measurements

- Number of test conditions shall be reduced:
  - Temperature coefficients at 200 /1000 W/m²
  - Variable irradiation at 25°C
- Other data points can be extrapolated (IEC 60891)





Spectral response
Spectral response measurement (IEC 60904-8)

Test equipment:

High resolution monochromator, Model: Bunkoh-Keiki CEP-M77

Features:

- Non-destructive measurement of full-size PV module
- Measurement procedures for crystalline silicon and thin-film PV modules
- White and color bias light: Single junction and multi junction measurements
- Measurement of SR non-uniformity in the active module area

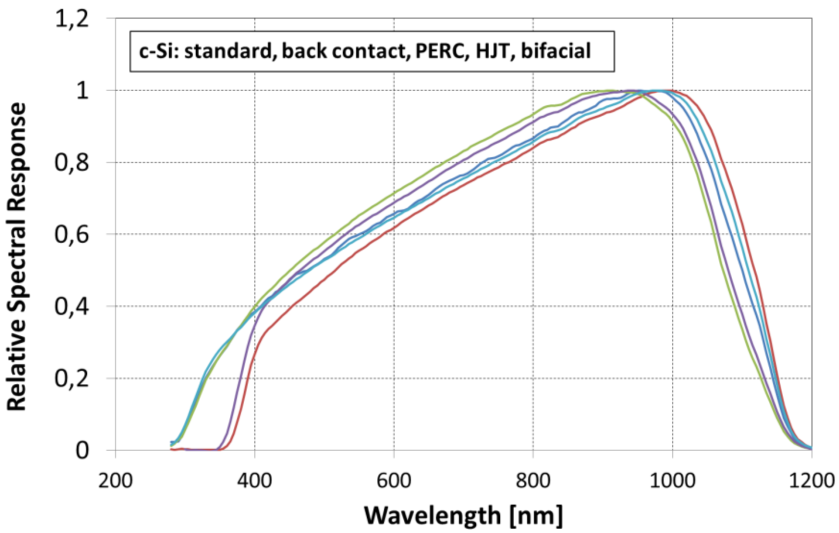
Technical data:	
Monochromatic light:	50 mm x 50 mm
Wavelength range:	300 – 1700 nm
Wavelength interval:	1, 5, 10, 50 nm
Max. module dimension:	200 cm

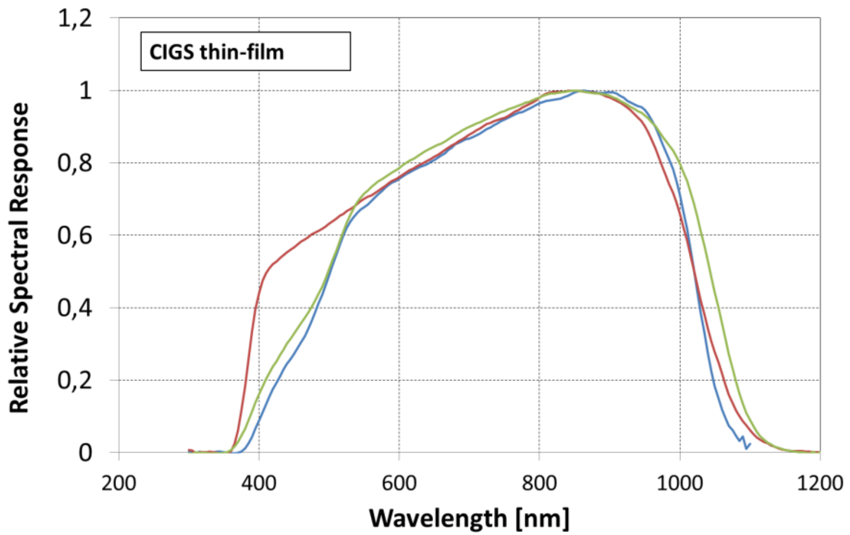
References:

Y. Hishikawa et al.: Spectral response measurements of PV modules and multi-junction devices, 22nd EU PVSEC, 2007

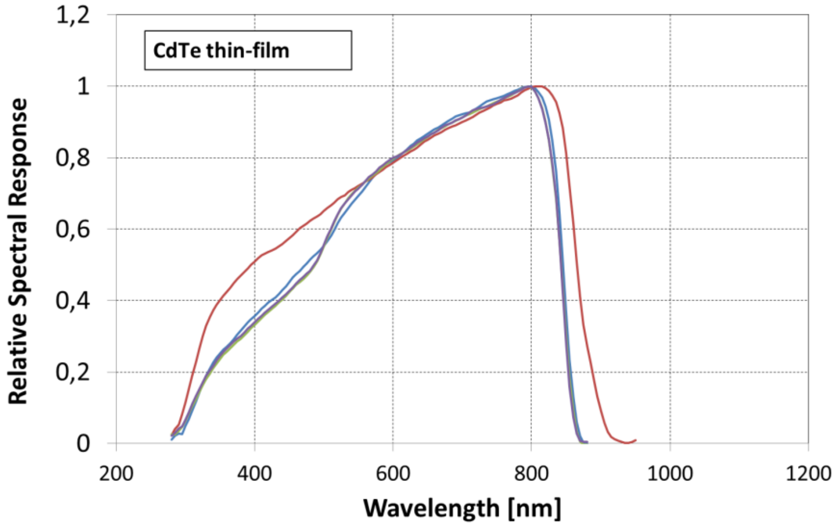
Y. Tsuno et al.: A method for spectral response measurements of various PV modules, 23rd EU PVSEC, 2008

Spectral response
Spread of SR curves for different PV technologies

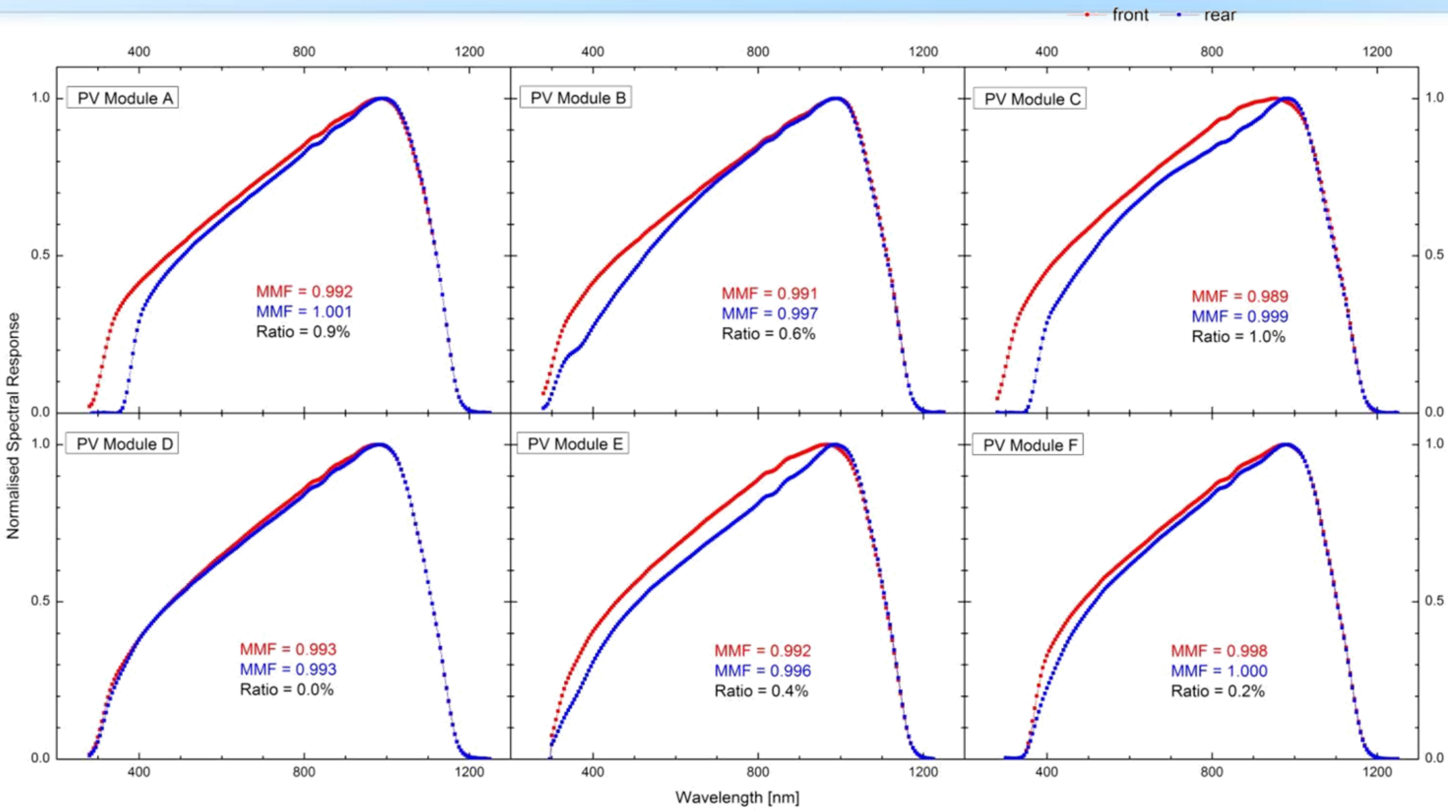




- Spread of SR curves is observed for all PV technologies
- Future advances in cell technology will increase the spread



Spectral response
Spread of SR curves for bifacial PV technologies

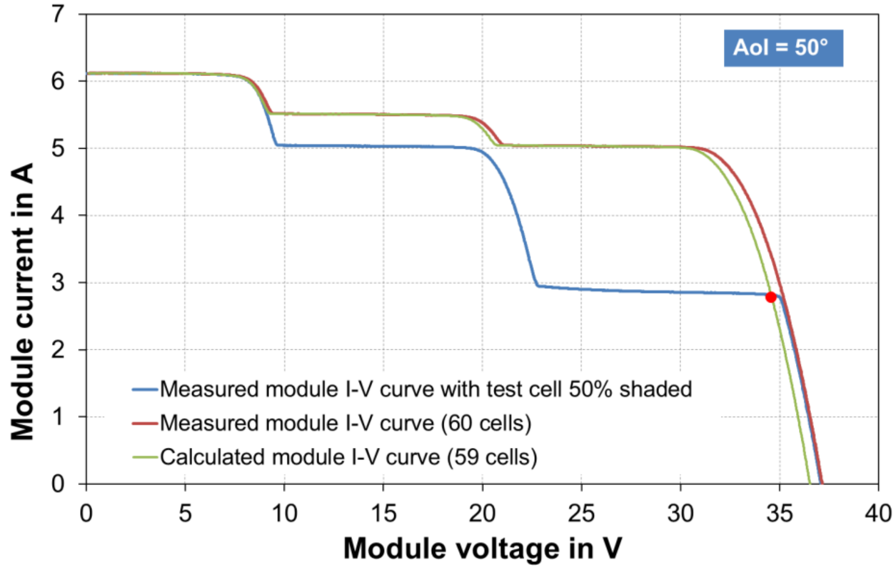


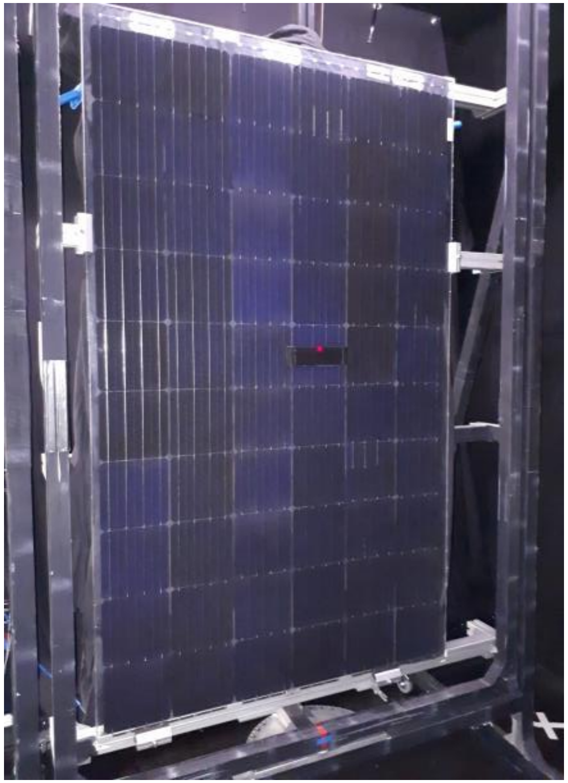
- Spectral response of front and rear side is often different
- Leading to a combined spectral mismatch factor weighted with irradiance contribution

Reference:
M. Schweiger et al.: Electrical Performance of Bifacial PV Modules: Comparative Measurements of Market-Ready Products, 27th EUPVSEC, Amsterdam, 2017

Angular response
Non-destructive angular response measurement

- AR measurement requires rotation of PV module in the test area of a solar simulator
  - High non-uniformity of irradiance in the rotational volume
  - Angular measurement of c-Si modules must be performed on cell basis
- Non-destructive test method required for double glass modules: Isc of test cell is concluded from PV module I-V curve under partially shading



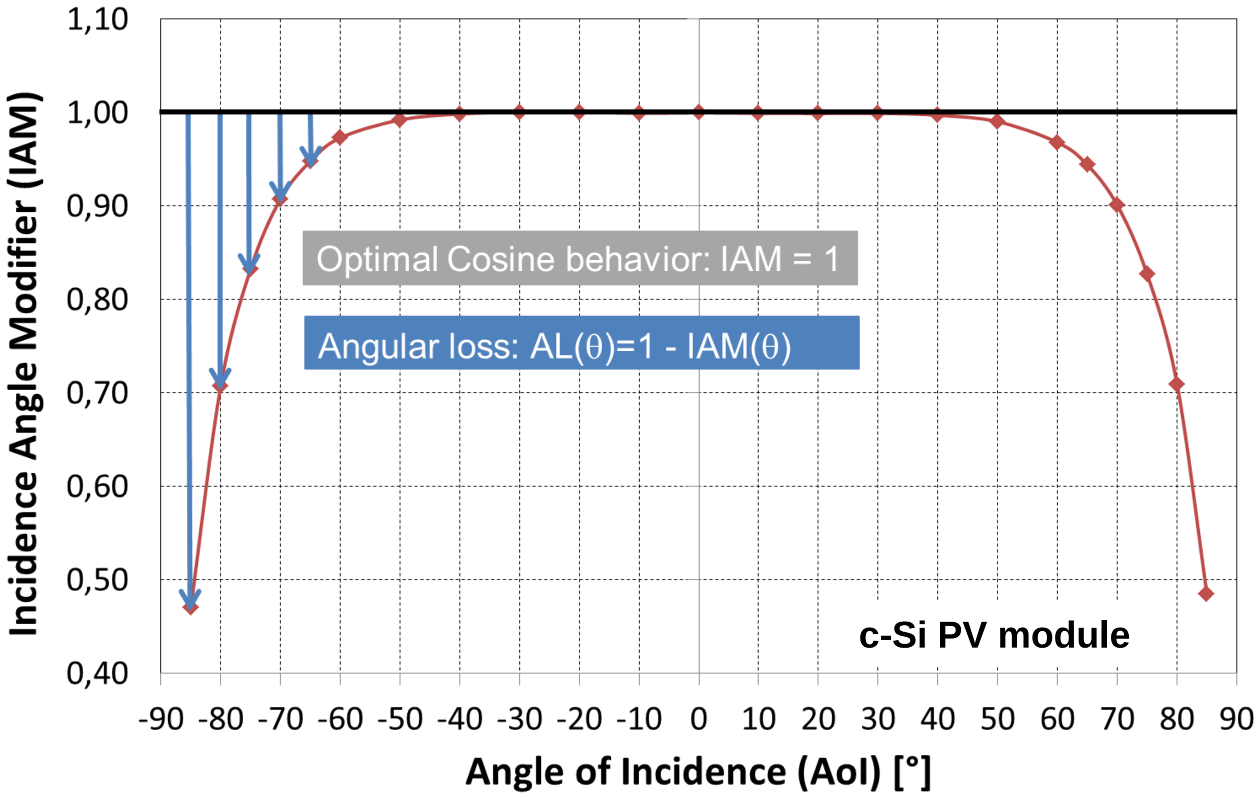


Reference:
W. Herrmann et al.: Solar simulator measurement procedures for determination of the angular characteristic of PV modules, 29th EUPVSEC, Amsterdam, 2014

Angular response
Non-destructive angular response measurement

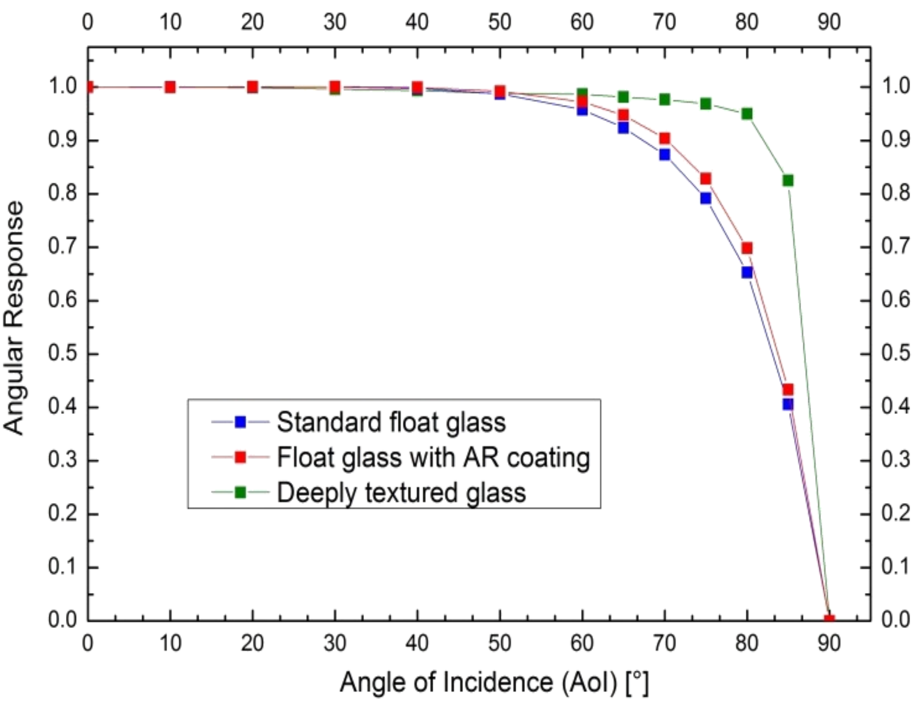
Angular response (AR) curve /Incident angle modifier (IAM)

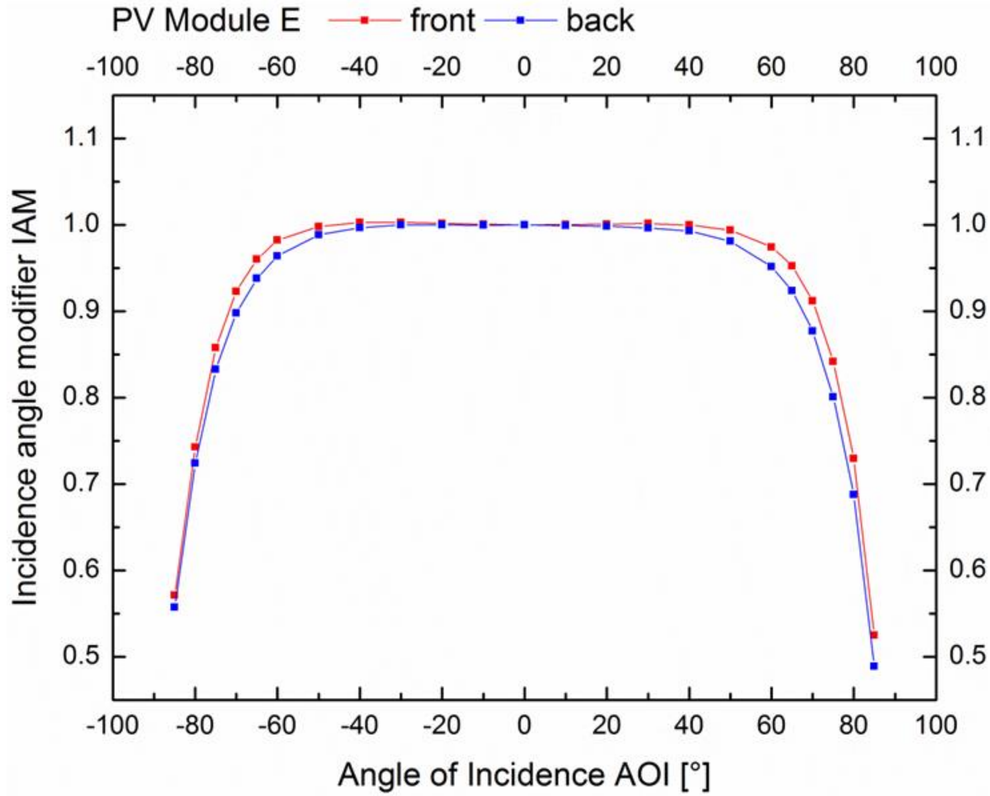
$$IAM(\theta) = \frac{Isc(\theta)/Isc(0°)}{\cos(\theta)}$$



Angular response
Non-destructive angular response measurement

- AR response depends on type of glass, materials and AR coatings
- Transmittance gain at 0° is already considered in absolute value
- **Bifacial:** Higher angular losses for rear side observed





Nominal module operating temperature NMOT
IEC 61853-2 procedure

Modelling of module operating temperature:

$$T_{mod} = T_{amb} + \frac{G_{corr,AOI}}{u_0 + u_1 v}$$

u_0 ⇔ Impact of solar irradiance
u_1 ⇔ Impact of wind speed (WS)

Note:
Coefficients are dependent on installation conditions and test location

Data filtering ⇨ No valid data set for Cologne since March 2016! !

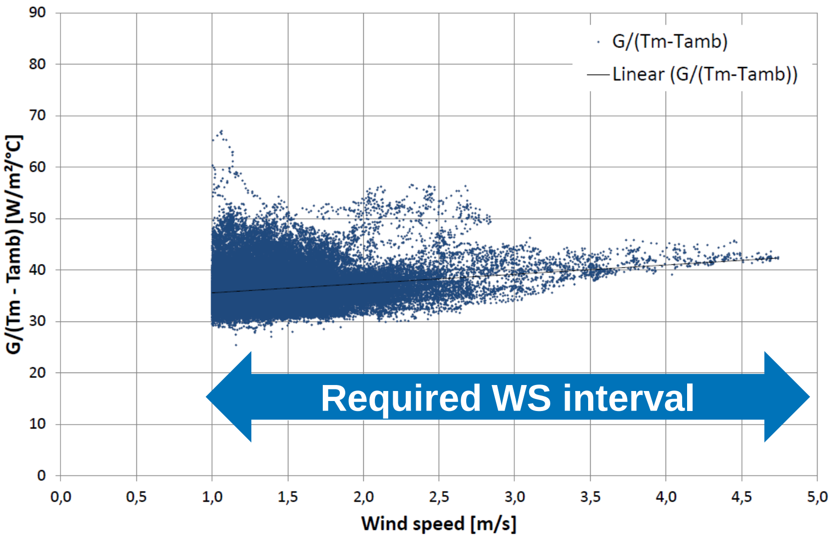
Problems:

- Required wind speed interval of 4 m/s is too large for urban test locations

  ⇨ Reduce minimum WS interval to 3 m/s

- Data filtering still results in large scattering of accepted data points

  ⇨ Wind direction should be considered



Conclusions

- Within all PV technologies (thin-film and c-Si) significant scattering of energy yield performance was observed
- Individual performance characterization of a module type is required
- Data sheet information of PV modules does not cover the needs for energy rating
- Test requirements of IEC 61853-1 and IEC 61853-2 can be optimized to perform measurements with reasonable constrains of costs and time
- IEC 60891 shall be applied to reduce test work in the laboratory
- Emerging technologies (as bifacial) must be considered appropriately in the energy rating standard and also in stabilization procedures

Thank you for your attention!

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Back-up slides
IEC 61853-2, NMOT test procedure

Test conditions:

- Data from minimum 10 sunny days
- Four hours time window before and after solar noon

Data acquisition:

- Measurement parameters: Module temperature (4 locations), ambient temperature, solar irradiance, wind speed (WS)
- Data sampling rate: <1 sec
- Data recording interval: 5 sec
- Calculate: Average module temperature
- Calculate: 5 min running average of wind speed

Data filtering:

- Reject data with solar irradiance <400 W/m²
- Reject data with irradiance fluctuation >10%
- Reject data with wind gusts and low wind speed
- Reject data with 5 min running WS average <1 m/s or >8 m/s
- Reject days with <10 data points

Test requirement:

- Data points shall span wind speed interval of minimum 4 m/s