Webinar
powered by
Jinko Solar

Casos de éxito de la tecnología bifacial

16 de Abril de 2020
10 AM – 11 AM | México, Peru
11 AM – 12 PM | Chile, Paraguay
12 PM – 1 PM | Argentina, Brasil

Emiliano Bellini
Redactor | pv magazine

Roberto Diaz
Jinko Solar

Vitor Rodrigues
TÜV Rheinland

Ricardo Garro
Jinko Solar

Measurement and validation of bifacial modules’ power output

TÜVRheinland®
Precisely Right.

Global Network for Photovoltaic Products Testing, Certification and Advisory

Number 1 in PV module and component testing worldwide.
Adviser to PV projects around the globe, representing more than 20 GW.

TÜVRheinland®
Precisely Right.

Milestones in the Global Solar Business.

More than 35 years of experience in photovoltaic.

1982 – R&D and PV product lab in Cologne

1990 – Project leader for the monitoring of the 1,000 Roof Program in Germany

1992 – Laboratory for PV module testing in Arizona (former ASU-PTL)

1996 – First type-approval certification of a crystalline PV module

1998 – Active in IEC standardization for PV products and systems

2000 – Renewable energy law implemented in Germany

New, high-tech R&D and PV product lab in Cologne

2006 – Solar operation initiated in Japan

2007 – Provide testing and certification service in Greater China

2009 – Golden Sun project initiated in China

Battery testing lab in Nuremberg

2012 – PV lab established in India

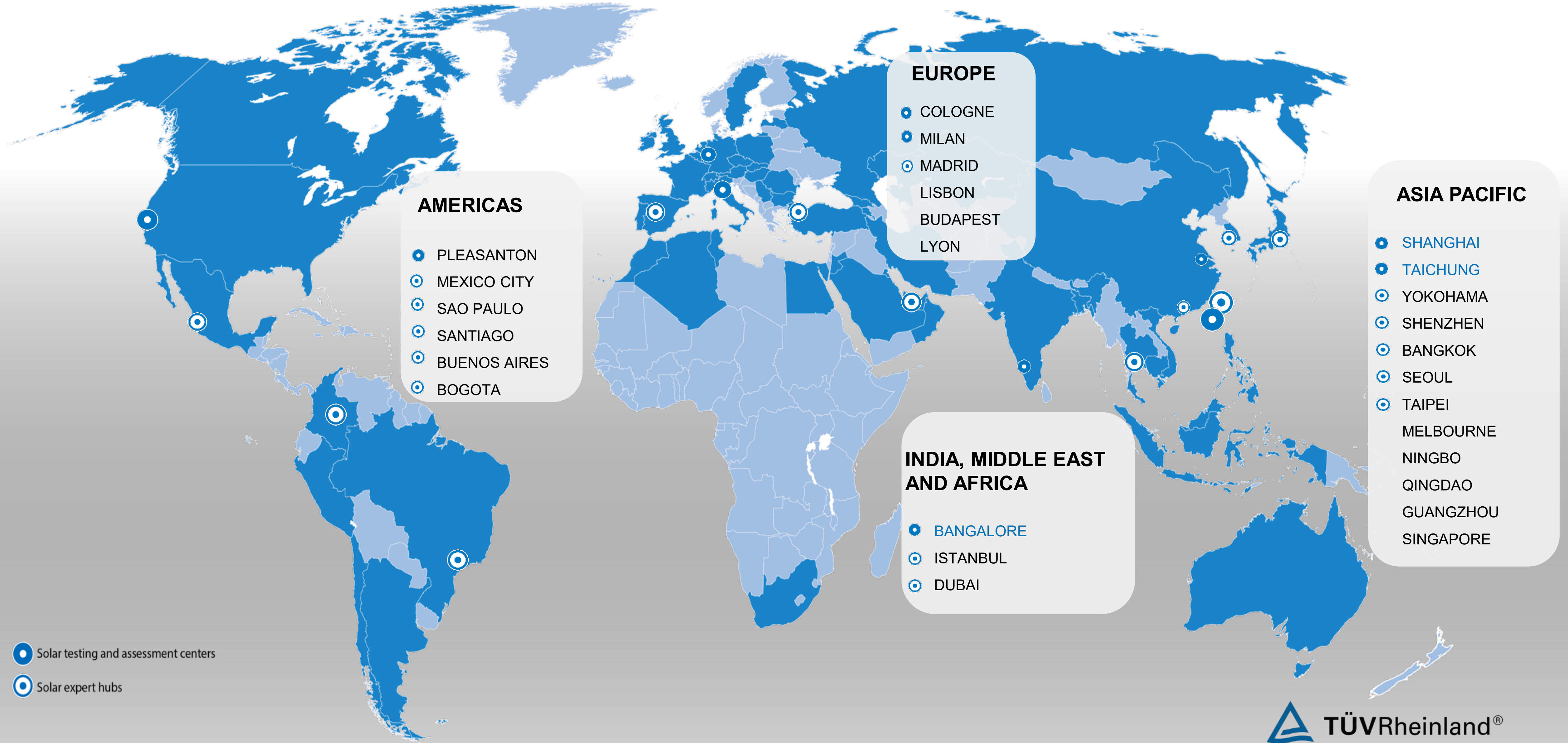
2012 – Renewable energy law implemented in Japan

2013 – OSHA accreditation according to UL1703

2014 – Solar operations start in Brazil and UAE

TÜVRheinland®
Precisely Right.

Insights: Global setup PV Power Plant Services



TÜVRheinland®
Precisely Right.

TÜV Rheinland – Solar Energy Worldwide

Quality, safety and reliability around the world

No 1 in PV module and component testing worldwide

35 Years experience in PV product testing

27 Years experience in Power plant inspections

6 PV test laboratories + several outdoor test fields

> 250 Experts

> 20 GW Inspected PV projects

PRODUCT CERTIFICATION

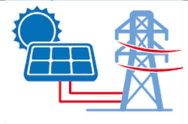
- IEC and other relevant standards
- Strongest Brand in the market
- Our main know how and our core
- International lab and certification bodies network
- Accreditations for the main standards (international, regional and local)
- Market access scheme in many countries

MARKET LEADER.
HIGH EXPERIENCE
INTERNATIONAL STANDARDIZATION COMMITTEES

TECHNICAL ADVISORY

- Feasibility Studies
- Design Reviews
- Energy Yield Predictions
- Technical Due Diligence
- Grid integration (with BS I)
- Social and Environmental Impact Assessment - SEIA (currently not in scope)
- Engineering review (basic and detail)

HIGH REVENUE
HIGH EFFORT (SENIOR EXPERTS)



PLANT FIELD SERVICES

- PV Power Plant inspecting and testing
- Construction Monitoring
- Acceptance Testing (commissioning)
- Operation Monitoring
- Performance Ratio Verification
- PV System Certification
- O&M Contractor Certification
- PV plant evaluation for secondary market

STANDARD BUSINESS
RESTRICTED MARKET
STRONG BRAND

SUPPLY CHAIN SERVICES

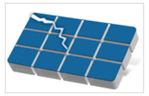
- Factory Audits
- Market Access Services for PV modules and components (testing and inspecting services)
- Factory Acceptance Test
- Site Acceptance Test
- During Production / Pre-Shipment Inspections
- Component testing
- Post-shipment inspections and testing

GOOD POSITION AND HIGH GROWTH RATE
LABORATORY NETWORK

CLAIM ASSESSMENT

- Analytic approach to find and verify field failures and systematic component failures
- Prognosis of failure development
- Failure risk analysis
- Provision of 3rd party data / statements in disputes
- Expert opinions
- On-site inspections
- Laboratory testing

GOOD POTENTIAL AND USP
HIGH GROWTH RATE



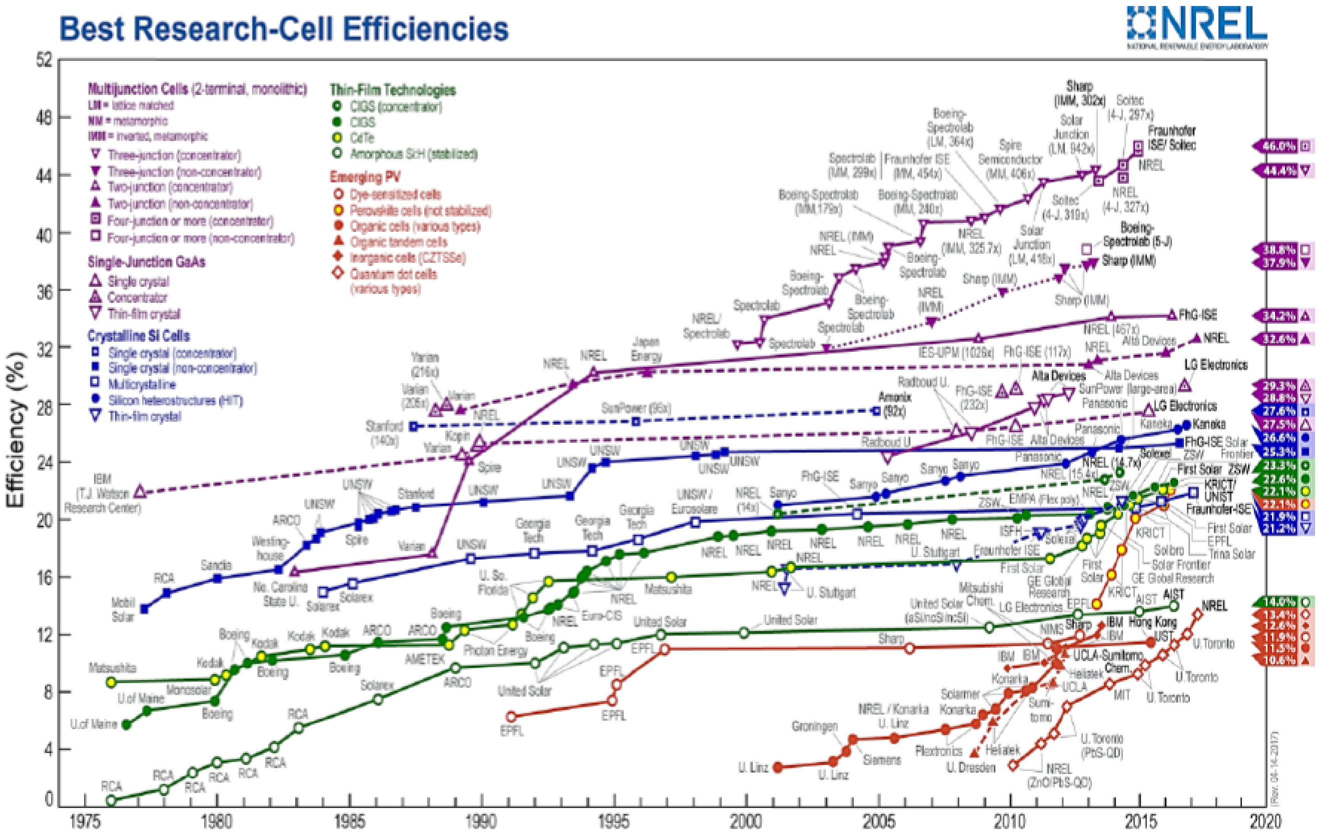
TÜVRheinland®
Precisely Right.

Bifacial State of Art

Technology state of art, reaching the efficiency pick?

Right time: Standard PV Cell Technologies & Structures are reaching their efficiency threshold

Momento ideal: Las tecnologías y estructuras fotovoltaicas **tradicionales** están llegando a su eficiencia límite



Source: http://www.nrel.gov/ncpv/
This plot is courtesy of the National Renewable Energy Laboratory, USA.

Standard PV Structure: Aluminium Back Surface Filed (BSF)

- Problem: current loses due to recombination (v < 200 cm/s)

New/first stage PV structures:

- Passivated Emitter and Rear Cell (PERC)
- Interdigitated Back Contact (IBC)
- Passivated emitter and rear, totally-diffused (PERT)
- Heterojunction

Suitable for bifacial

TÜVRheinland®
Precisely Right.

Bifacial, Market factors

- Right time for Bifacial Solar Momento oportuno para la tecnologia bifacial

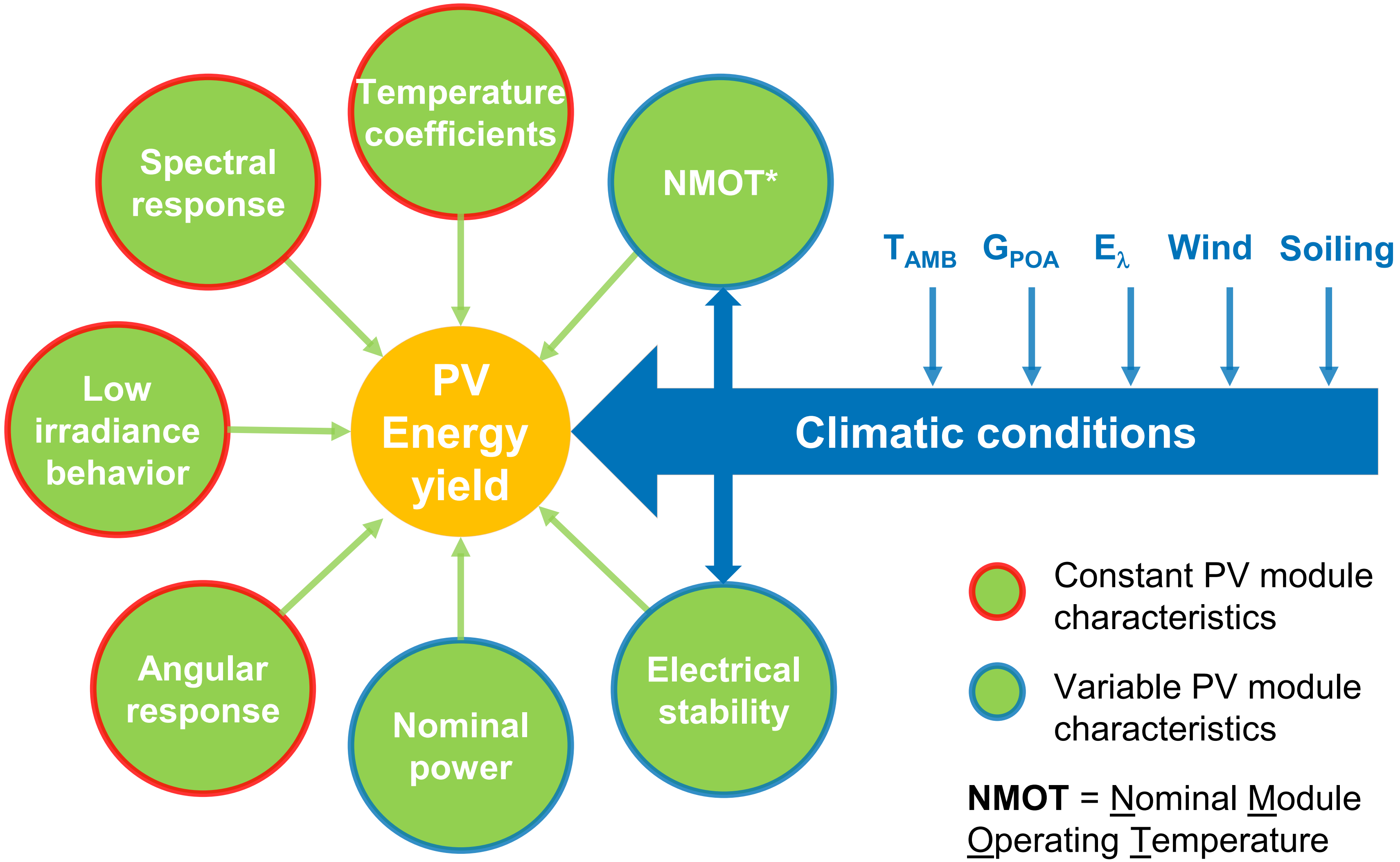
Push factors	• Higher-efficiencies pressure • Shift from alluminium-BFS to advance cell concepts
Pull factors	• Long term systems yields and power generation competition • Levelized cost of electricity (LCOE)

- Teething problems Problemas iniciales

Standarization	• Measurement procedures for bifacial PV modules will be addressed in a new standard
Power and Energy Rating	• Production line aspects-front&rear measurements not practical • IEC 61853 should be extended for bifacial applications • STC needed? Albedo

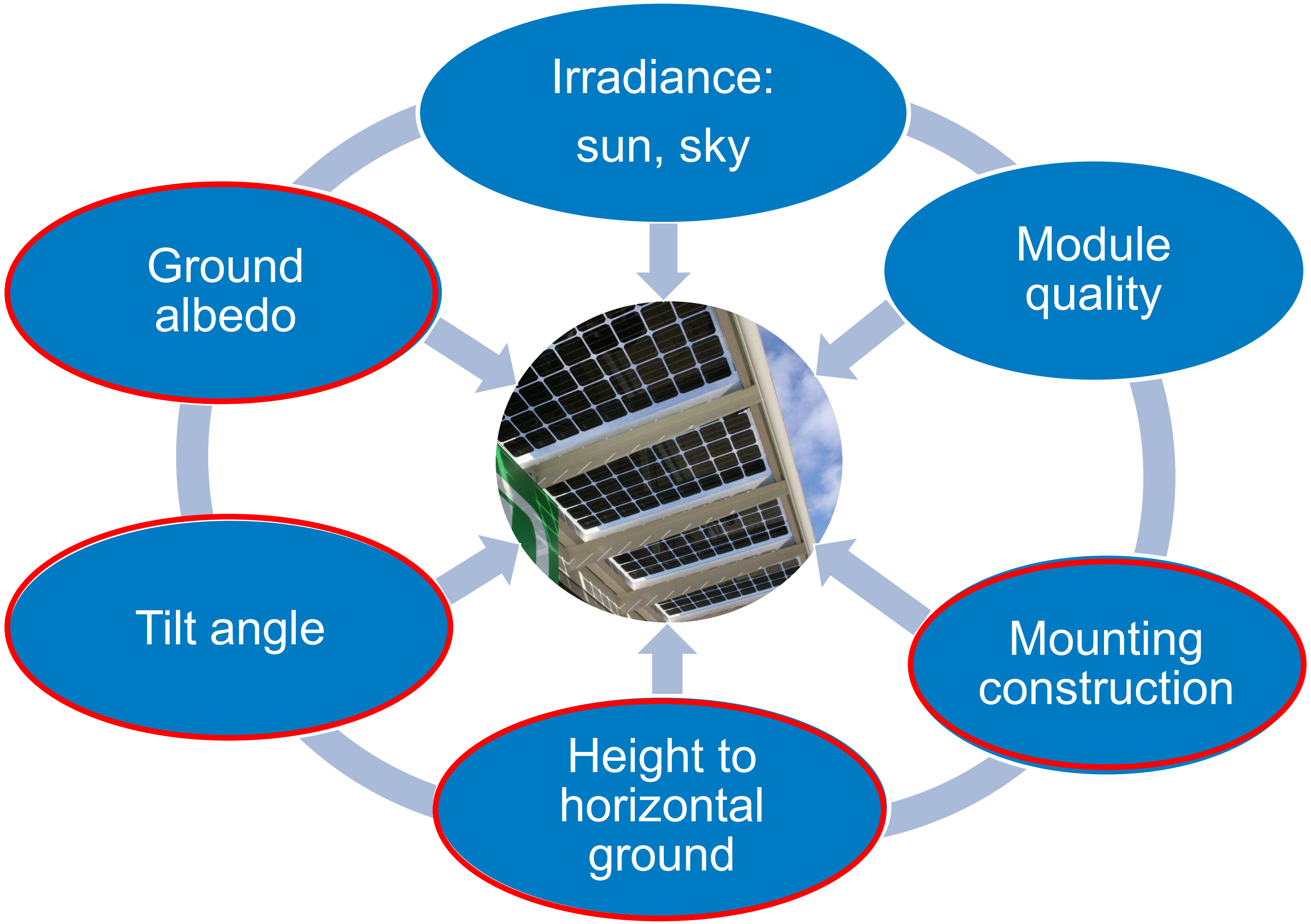
Key factors affecting performance and energy yield of bifacial PV modules

Energy yield of mono-facial PV modules



NMOT = Nominal Module Operating Temperature

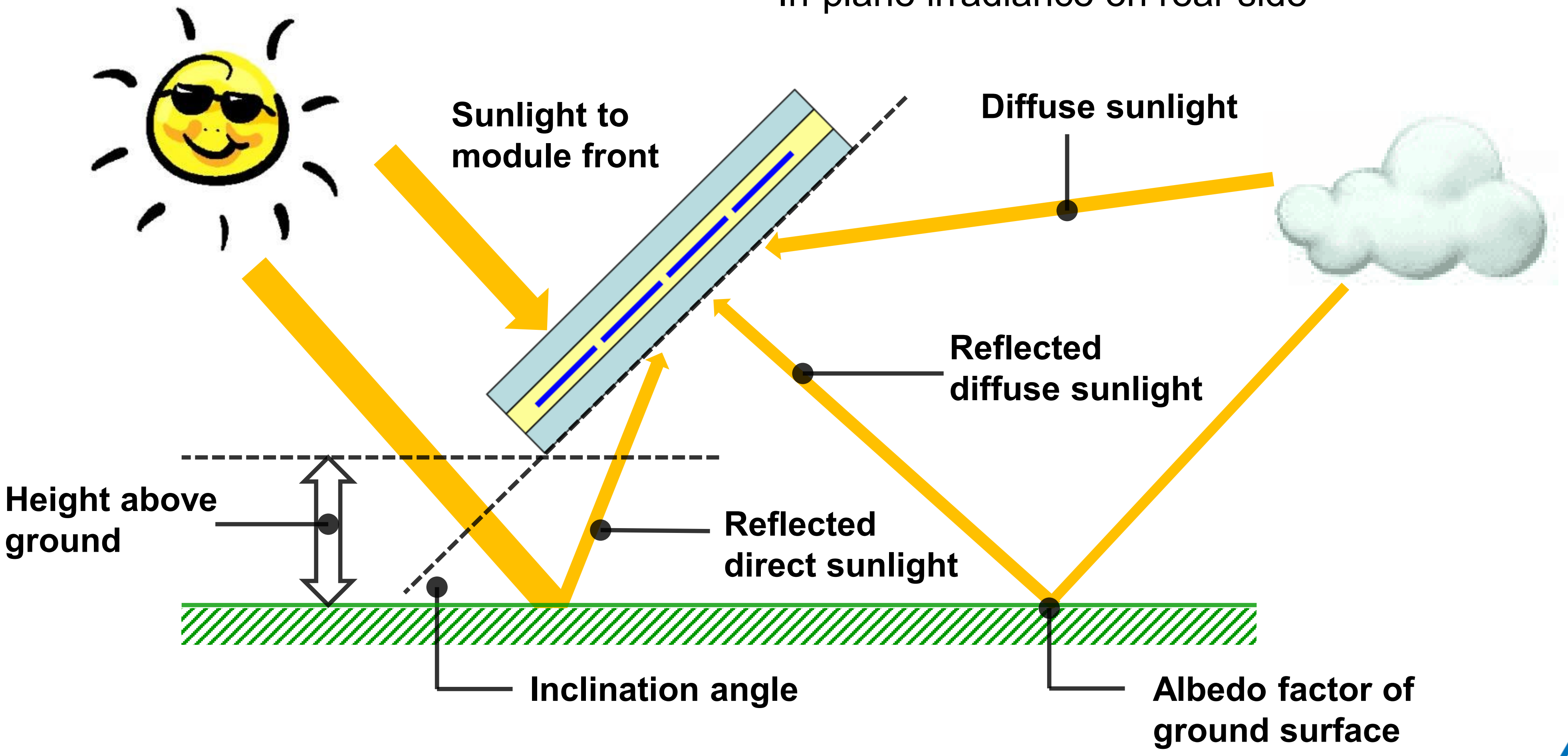
Key factors affecting performance and energy yield of bifacial PV modules



Energy yield of bi-facial PV modules – Location and Installation

Factors influencing the bifacial gain:

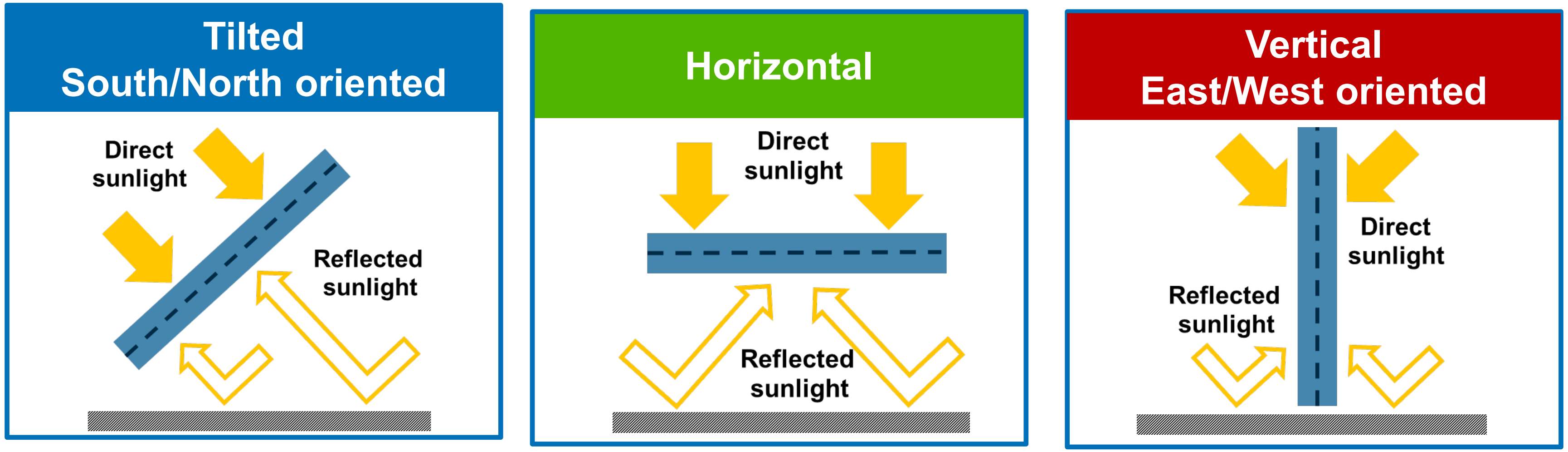
- Electrical performance of rear side
- Bifaciality factor φ_{Pmax}
- In-plane irradiance on rear side

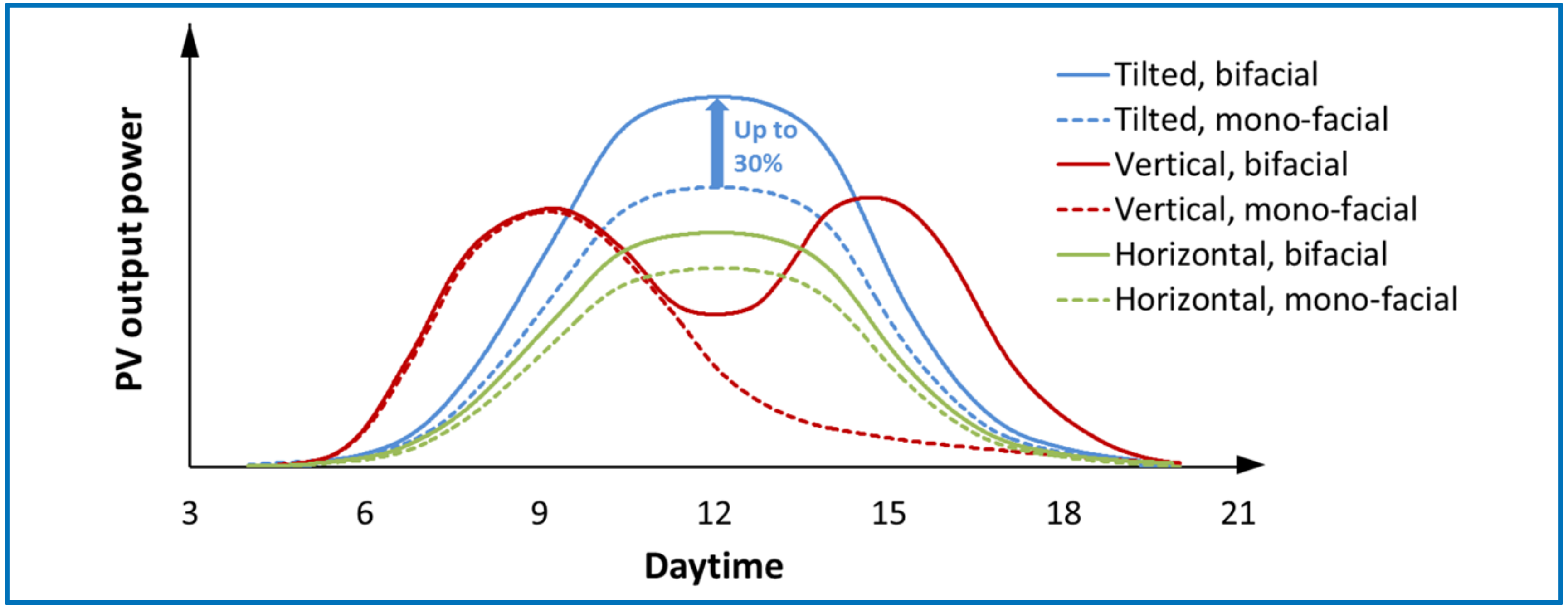


Location & Installation:

- Ground albedo
- Height above ground
- Rear shading

Energy yield of bi-facial PV modules –Tilt Angle





- Depending on ground albedo, irradiance and installation conditions up to 30% bifacial energy yield gains for fixed inclination angle.
- Solar tracking of PV array can result in up to 50% bifacial energy yield gain.

TÜVRheinland®
Precisely Right.

Energy yield of bi-facial PV modules

Ground albedo

Impact of ground reflectance

Surface	Albedo	Expected yield gain
Water	5-8%	4-6%
Bare soil	10-20%	6-8%
Green grassland, gravel	15-25%	7-9%
Concrete ground / white gravel	25-35%	8-10%
Dry / dune sand	35-45%	10-15%
Reflective roof coatings	80-90%	23-25%
Fresh snow	80-95%	25-30%

Height above ground

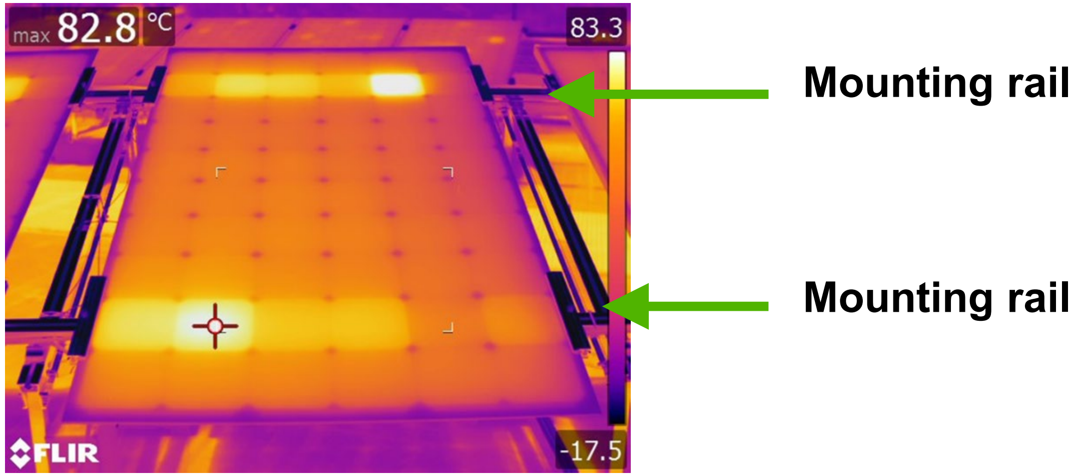
Impact of ground clearance

A larger distance from the ground increases the bifacial gain. For ground clearance larger than 2m the rear side will be homogeneously illuminated and bifacial gain saturates.

Rear shading

Impact of rear shading from mounting structure

Rear shading can eliminate bifacial gain and cause cell heating.



R&D results on real-world measurements and validation with simulations

TÜVRheinland®
Precisely Right.

TÜV Rheinland test sites for PV module energy yield measurement

Cologne, Germany


Tempe, Arizona, USA


Thuwal, Saudi-Arabia


Chennai, India

Location	Köppen-Geiger climatic classification	Tilt angle	Yearly sum of in-plane solar radiation	Fraction of low irradiance (GPOA < 200 W/m²)	Average ambient temperature (GPOA> 15 W/m²)	Annual precipitation	Average relative humidity
Cologne (Germany)	Cfb (temperate)	35° (Gravel)	1257 kWh/m²	19 %	13,0 °C	774 mm	74.3%
Tempe (Arizona, USA)	Bwh (desert)	33.5° (Gravel)	2396 kWh/m²	5 %	25,6 °C	219 mm	33.4%
Chennai (India)	Aw (sub-tropical)	15° (Concrete)	2102 kWh/m²	9 %	30,5 °C	1197 mm	74.7%
Thuwal (Saudi-Arabia)	Bwh (desert)	25° (Gravel)	2329 kWh/m²	4 %	30,2 °C	70 mm	66.8%

Source: TÜV Rheinland, 3 years data monitoring

Comparative energy yield assessment of mono-facial and bifacial PV modules

Mounting rack with mono-facial PV modules

Mounting rack with mono-facial, **bifacial (Height above ground = 1.5 m)**, and thin-film PV modules

Data recording period: from JUL 2017

Irradiance measurement: In-plane front and rear, Global and diffuse horizontal, direct normal

Module temperature: Pt100 surface temperature probes (PV module center and edge)

PV module output power: Individual MPP tracking with electronic loads

Data recording interval: 30 seconds, time-synchronous

Comparative energy yield assessment of mono-facial and bifacial PV modules

1. Initial laboratory measurements

- STC: class A+A+A+ pulsed solar simulator, one-side illumination method
- Temperature coefficients, TCs
- Spectral Response, SR
- Angular Response, IAM
- Low Irradiance, Lirr

2. One-year outdoor exposure (test site Cologne)

- MPP tracking (30 sec)
- I-V curve adquisition (10 min)
- Module temperature (10 min)
- Spectrometer (300-1600nm)
- Meteorological data: Irradiance, ambient temperature, wind speed and humidity(30 sec)

3. EY Analysis & final laboratory measurements

- Module performance ratio, MPR
- Specific energy yield, EY_{spec}
- Operational efficiencies, $\eta_{operational}$
- Electrical performance stability at STC
- Linear performance loss analysis (LPLA)

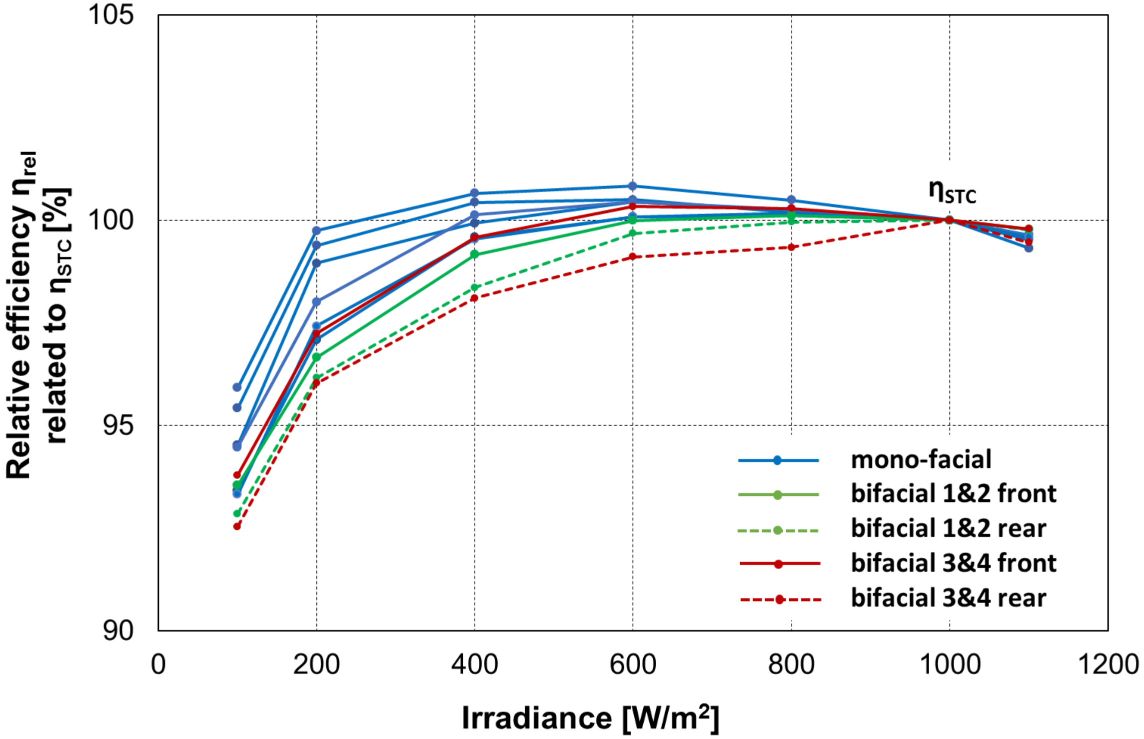
4. Simulation comparison

- Collected climate data, installation layout and laboratory measurements as input parameters
- Irradiance comparison
- MPR, EY results comparison

TÜVRheinland®
Precisely Right.

Comparative energy yield assessment of mono-facial and bifacial PV modules

Test samples – Efficiency loss due to low irradiance & Pmax temperature coefficients



PV Module Type	Bifaciality Factor φPmax	Pmax Temperature Coefficient		Efficiency Loss @ 200 W/m²	
				Front	Rear
mofi 2		-0,00405	1/K	-2,9%	
mofi 3&4		-0,00389	1/K	-1,0%	
mofi 5&6		-0,00403	1/K	-0,6%	
mofi 7&8		-0,00417	1/K	-0,3%	
mofi 9&10		-0,00396	1/K	-2,0%	
mofi 11&12		-0,00424	1/K	-2,6%	
bifi 1&2	0,884	-0,0042	1/K	-3,4%	-3,8%
bifi 3&4	0,875	-0,0041	1/K	-2,8%	-4,0%

n-type PERT

- Electrical performance bifacial module types is slightly worse compared to mono-facial modules types.
- Rear performance of bifacial PV modules is worse compared to front side.

TÜVRheinland®
Precisely Right.

Comparative energy yield assessment of mono-facial and bifacial PV modules

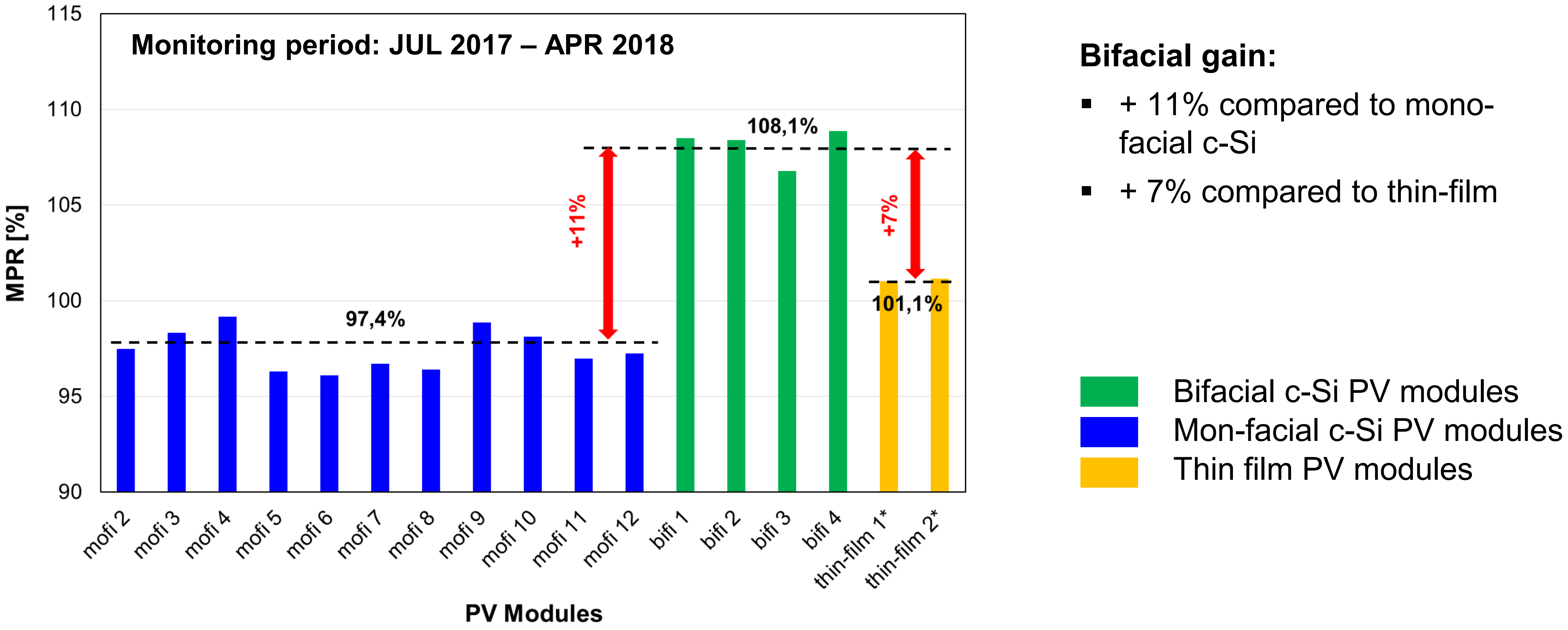
Energy yield performance of PV modules is commonly expressed by the **Module Performance Ratio (MPR)**:

$$MPR = \frac{Measured\ energy\ yield\ (E)/Reference\ power\ \ (P_{stc})}{Measured\ solar\ radiation\ (H)/Reference\ irradiance\ \ (G_{stc} = 1000\,\frac{W}{m^2})}$$

- **MPR** is a normalized parameter, which is independent of received irradiance. It allows to compare PV modules with different output power, which are measured at different sites, with different orientations or in different periods.

TÜVRheinland®
Precisely Right.

Comparative energy yield assessment of mono-facial and bifacial PV modules

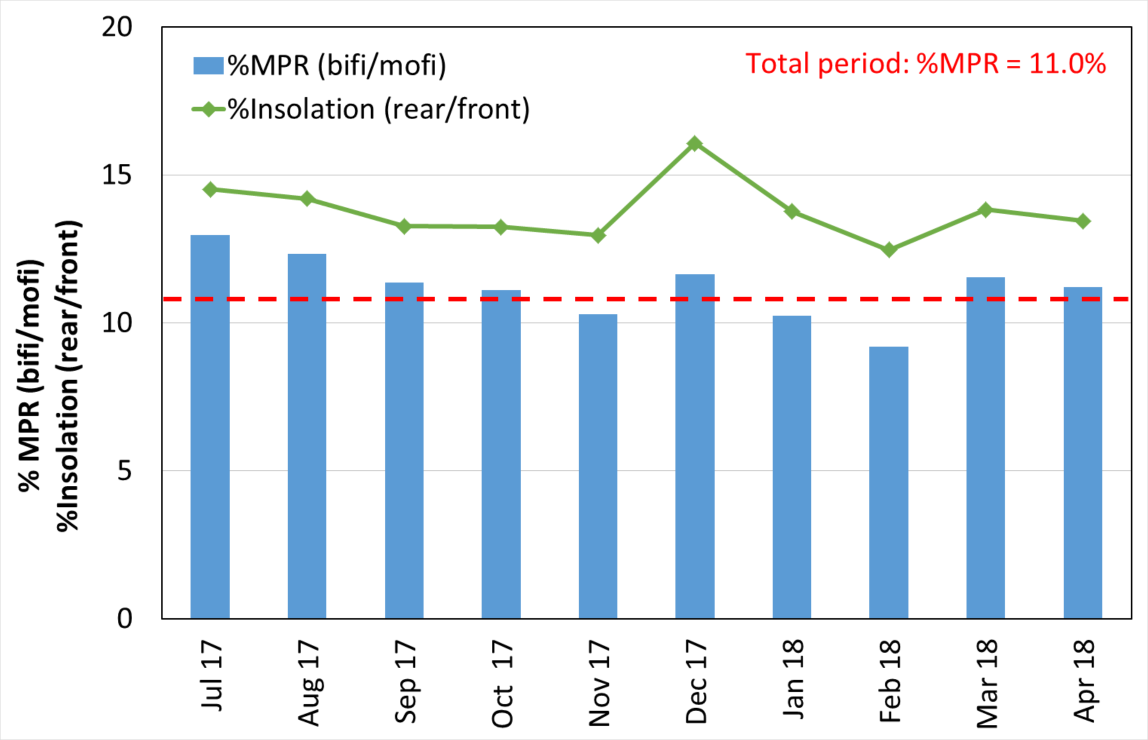


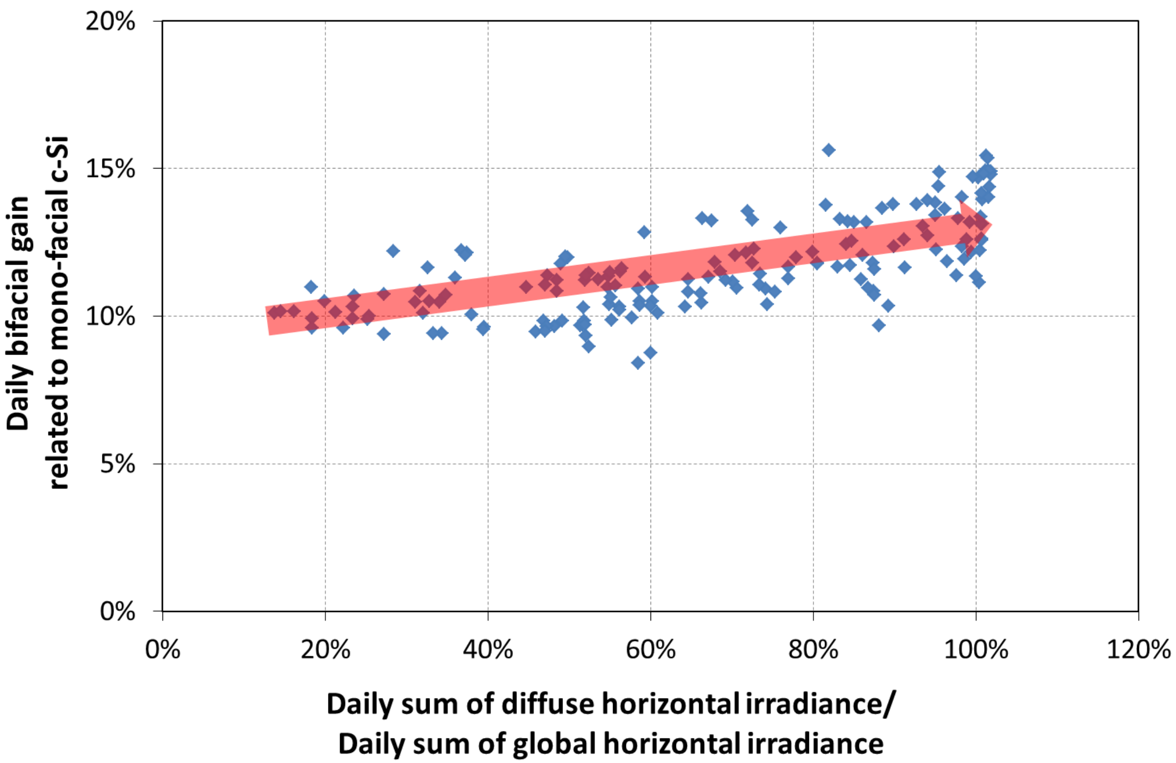
Bifacial gain:

- + 11% compared to mono-facial c-Si
- + 7% compared to thin-film

TÜVRheinland®
Precisely Right.

Comparative energy yield assessment of mono-facial and bifacial PV modules





- Bifacial gain (blue bars) is well correlated with fraction of rear side irradiance (green line)
- The difference is mainly determined by the bifaciality factor φ_{Pmax}
- Bifacial gain increases with fraction of diffuse solar irradiance

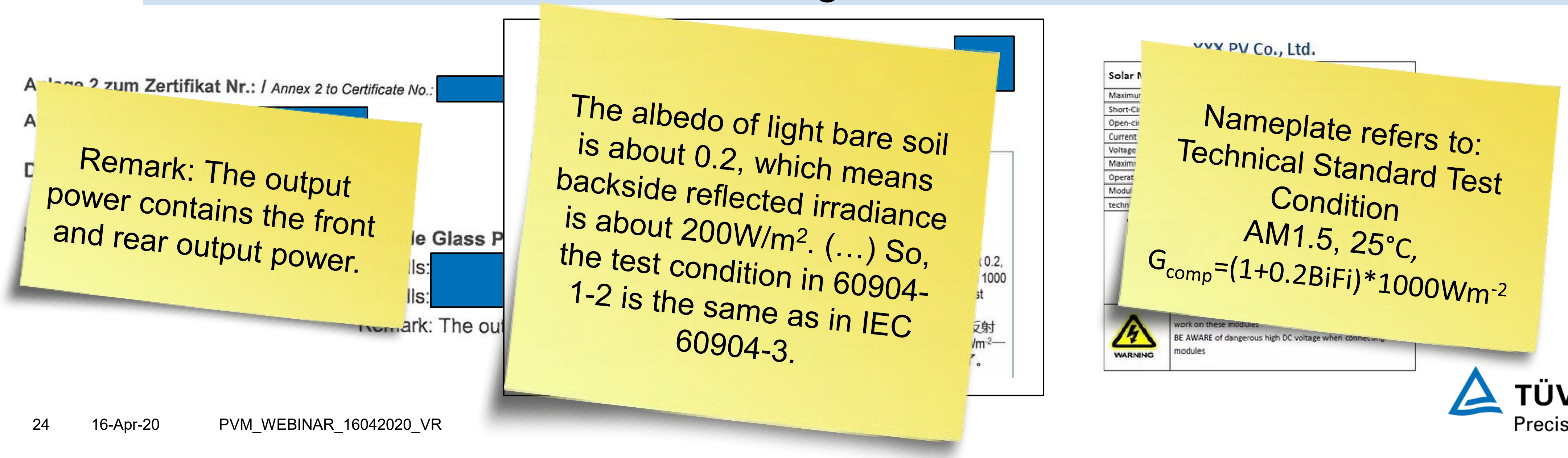
TÜVRheinland®
Precisely Right.

Overview of different power measurement approaches, standards, and R&D results

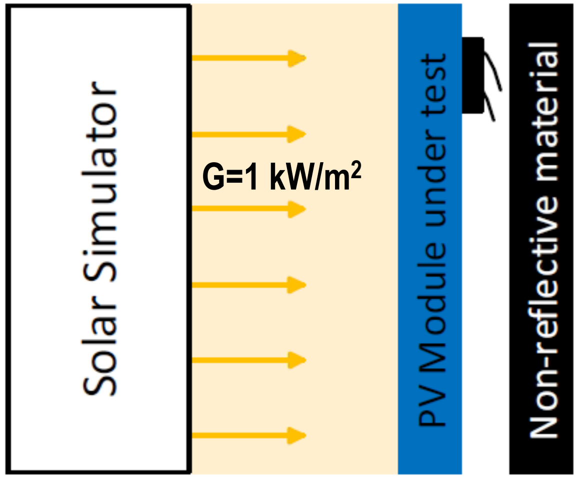
TÜVRheinland®
Precisely Right.

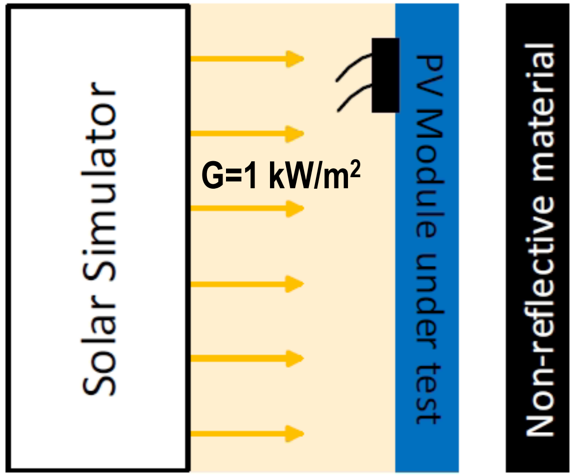
Motivation and Background for Measurement Standards

- Sales price of PV modules is based on STC measurements
- Bifacial modules have higher performance (PR>100%) than monofacial, due to the contribution of rear face irradiance
- PV-modules with unclear rating conditions were seen in the market



Bifacial Standard Test Condition (BSTC)

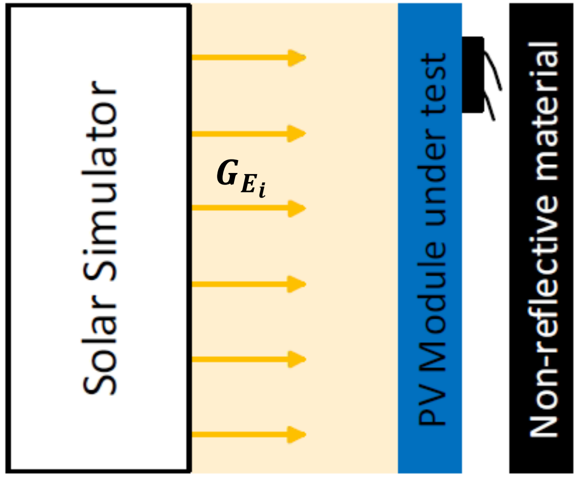




$$\varphi_{Isc} = \frac{Isc_r}{Isc_f}$$

$$\varphi_{Voc} = \frac{Voc_r}{Voc_f}$$

$$\varphi_{Pmax} = \frac{Pmax_r}{Pmax_f}$$



G_{E_i} = 1000 W/m² + $\varphi * G_{R_i}$

$\boldsymbol{\varphi}$= Min ($\boldsymbol{\varphi Isc}$, $\boldsymbol{\varphi Pmax}$)

IEC 60904-1-2 CD	G_{R_1} = 100 W/m²	G_{R_2} = 200 W/m²	G_{R_3} = xxx W/m²
2PfG 2645/11.17	G_{R_1} = 100 W/m²	G_{R_2} = 200 W/m²	G_{R_3} = **135 W/m²**

Bifacial Standard Test Condition (BSTC) : [1]

- Front irradiance: 1000 W/m²
- Rear irradiance: 135 W/m²
- Equivalent irradiance: 1000 + φ·135 W/m²
- Module temperature: 25° C
- Spectral irradiance: AM1.5G

[1] 2PfG 2645/11.17: Measurement of *I-V* characteristics of bifacial photovoltaic devices and label requirements

TÜVRheinland®
Precisely Right.

Example of nameplate design for bifacial PV modules

Electrical Data		
	STC	BSTC
Nominal Power	300 W (±3%, k=2)	330 W (± 3.5%, k=2)
Open-Circuit Voltage (Voc)	38.5 V (± 1%, k=2)	39 V (± 1.2%, k=2)
Short-Circuit Current (Isc)	9.4 A (± 2.8%, k=2)	10.2 A (± 3%, k=2)
Bifaciality (φ)	0.7 (± 0.05, k=2)	
Maximum System Voltage	1000 V IEC	
Maximum OC Protection Rating	20 A	
Power Temp Coef. (Pmpp)	-0.4% / K (±0.05%, k=2)	
Voltage Temp Coef. (Voc)	-0.31% / K (±0.02%, k=2)	
Current Temp Coef. (Isc)	0.05% / K (±0.01%, k=2)	
STC: AM1.5G; Temp. = 25°C; Irradiance = 1000 W/m^2 BSTC: AM1.5G; Temp. = 25°C; Irradiance = 1000+ φ·135 W/m^2		

Bifacial Standard Test Condition (BSTC) and 2PfG 2645/11.17

Bifacial Standard Test Condition (BSTC) :
defined in the same environment as defined in IEC 60904-3 with 1m ground clearance of bifacial PV modules

- Front irradiance : 1000 W/m^2
- **Rear irradiance : 135 W/m^2**
- **Equivalent irradiance: 1000 + $\varphi \cdot 135$ W/m^2**
- Module temperature : 25 ^oC
- Angle of Incidence : 0 ^{o}
- Spectral irradiance : AM1.5G

2PfG 2645/11.17

Measurement of current-voltage characteristics of bifacial photovoltaic (PV) devices

Customer Value:

- Supplementary Rating (BSTC)
- Additional Labelling Information
- Verification of Labelling System

Conclusion und Outlook

- BiFi module performance ratio (MPR) up to 11% compared to c-Si and 6,5% compared to thin film
- Sky clearness index and air mass are driving factors behind specific yield gains
- Loss analysis revealed that losses are comparable between mofi and bifi
- The use of extensive laboratory measurements and high accurate climate datasets led to a reduction of the EY model uncertainty to ±1%.
- Electrical stabilization effects to be further analyzed to enhance the precision of computer simulation tolls and reduce investment risks
- Further investigation for similar bifacial PV technologies at additional sites with different climatic and albedo conditions
- Bifaciality coefficient: easy indicator, simple design modifications can affect rear performance, low dependency on irradiance
- Expected high penetration on the PV modules pipeline (Americas and other) in the next years
- LCOE as a pull factor
- Need of standardization and more investigation on new BOM`s (DG Vs GBS)

Thank you for your attention !

Vitor Rodrigues
Regional Field Manager Solar SAM
Local Field Manager Solar Spain
TÜV Rheinland

Vitor.rodrigues@es.tuv.com
www.tuv.com

TÜVRheinland®
Precisely Right.