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An approach to quantify benefits & risks of bifacial PV systems based on energy yield

10. September 2018, Bifacial workshop, André Richter, Meyer Burger Technology AG

The bifacial dilemma

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Higher profits, but what is the fair distribution of risks and benefits?

The main questions of investors:

Module quality ?

Module quality:
- ✓ No different materials used
- ✓ Modules get certification
- ✓ Passing same extended tests
- • Higher operating currents need investigation

Costs of modules?

Production costs of modules:
- ✓ Same materials
- ✓ Not different process (PERC bifacial)
- ✓ Less metallization (lower costs)
- • Lower flash power (only sunny side)

Guarantee of yield

Yield measurements:
- ✓ Worldwide confirmation of yield
- ✓ Little less dependent of soiling
- • Albedo constant in average
- • Simulation still developing

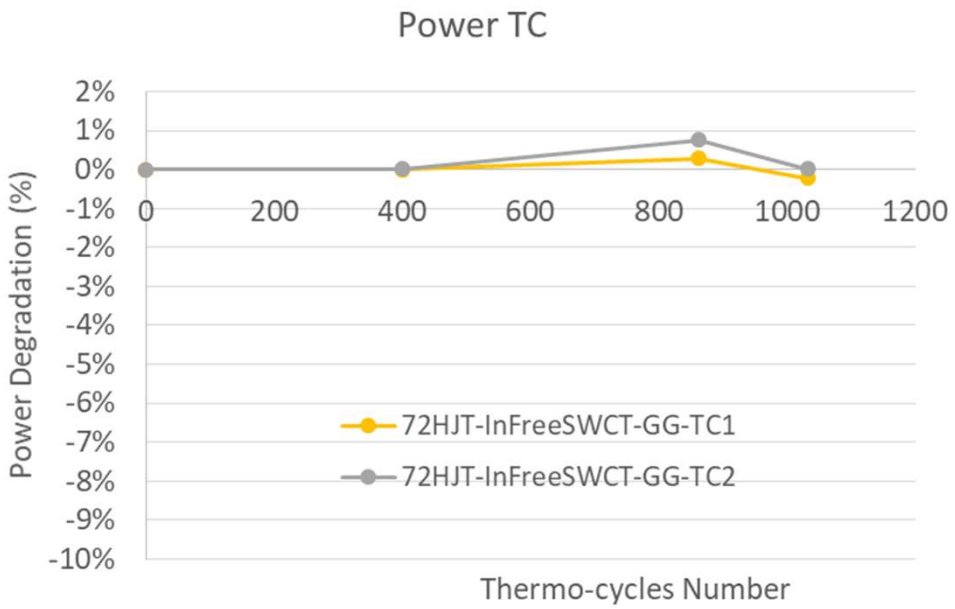
Passed certifications IEC 61215:2005 & IEC 61215:2016 here shown for HJT SWCT™

	glass/glass modules (bifacial)	glass/backsheet modules (monofacial)
SWCT for cells using high temperature pastes, e.g. Al-BSF, PERC	not yet	9x
SWCT for cells using low temperature pastes, e.g. HJT, TopCon	7x and additional 1x pending	5x and additional 4x pending

- In total 21 main BOM variants for SWCT have passed the IEC 61215:2005 or 61215:2016 certification tests and 5 main BOM variants are pending by July 2018
- Main BOM variant defined by type of cell, encapsulant, backsheet or SWCT connection
- Each main variant itself covers wide spread of power classes, amount of cells in the module, glass and wire thickness according the retesting guideline.

- Meyer Burger develops und uses SWCT since 2013 and has passed several certifications with different BOM using the Meyer Burger production process.
- Table shows high level information of successful SWCT certificates with different types of cell technologies and different module configurations.
- This table is not a complete list of the certification matrix with small variants of power, glass sizes, glass thicknesses, encapsulation types, cell types etc. nor the full set of standards tested.

Extended climate chamber testing: TC (temperature cycling)

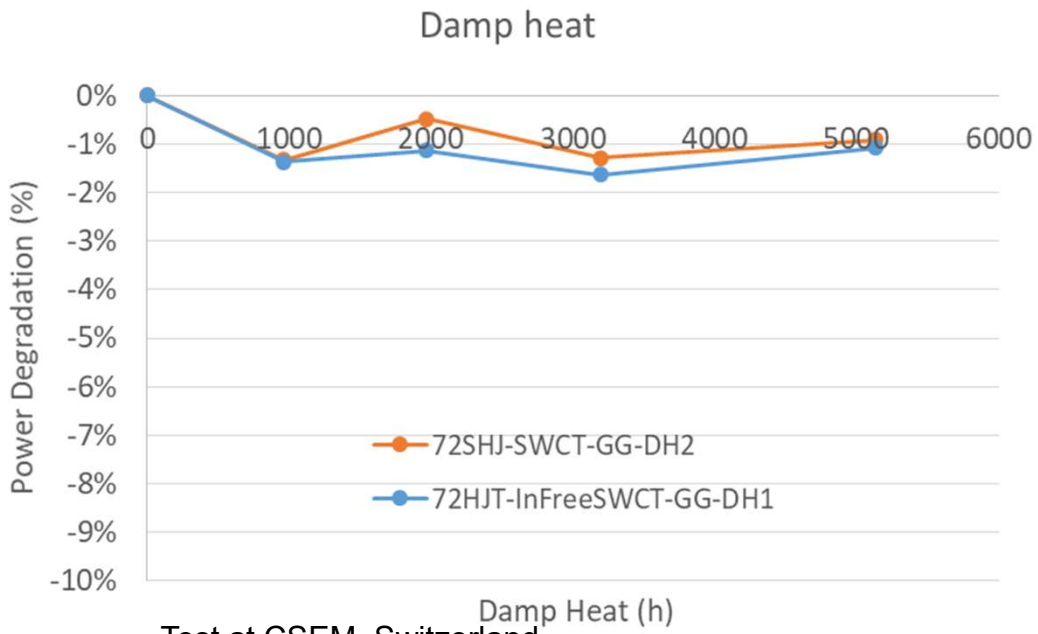


Test at CSEM, Switzerland

- TC: According IEC 61215:2016 MQT 11 temperature cycles from 40°C to 85°C, with 1.25x Impp at temperatures >25°C with less than 5% power loss are mandatory
- 5x IEC are sufficient to see most of the degradation effects
- Tests at CSEM show 5x IEC

Explanation of the MB HJT SWCT glass/glass TC performance:
SWCT™ forms an intermetallic connection but is neither soldered or bonded to the cell and mechanical stress can relax before causing damage to the cell

Extended climate chamber testing: DH (damp heat)



Test at CSEM, Switzerland

- DH: Damp heat test is performed at 85°C and 85% RH (relative humidity) according IEC61215:2016 MQT 13.
- 1,000h test duration is required in IEC, test duration up to 3x IEC to discover effects are useful.
- Tests at CSEM show 5x IEC

Explanation of the MB HJT SWCT ™glass/glass DH performance:
SWCT™ uses non-EVA based encapsulation with lower water content.
The butyl sealed glass/glass module inhibits ingress of any additional water.

Higher energy yield in different regions

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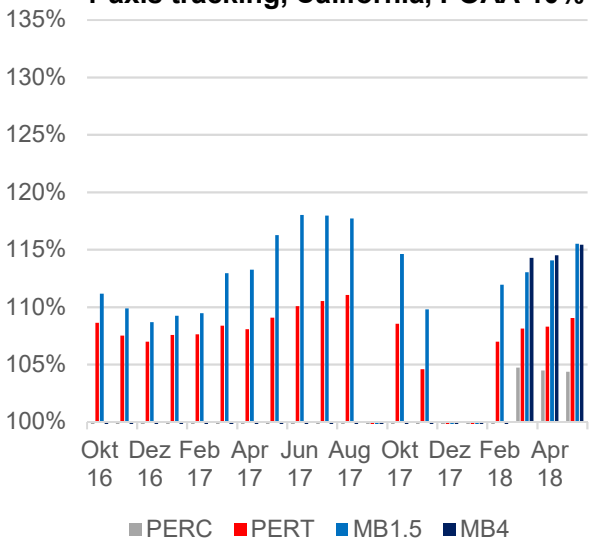
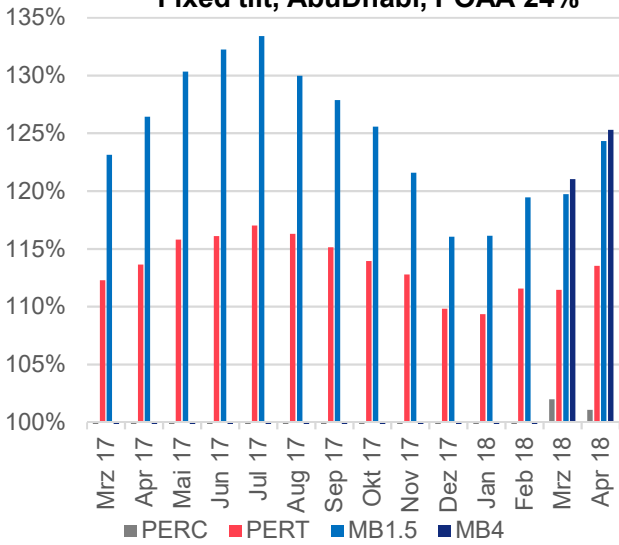
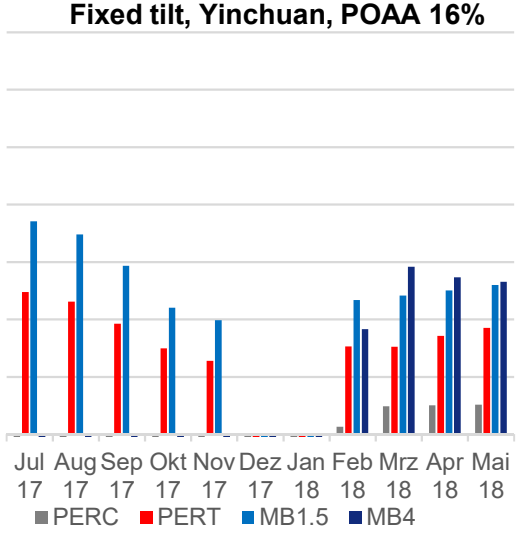
1-axis tracking, California, POAA 10%



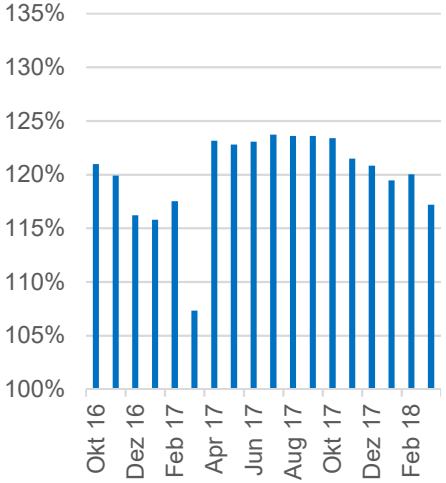
Fixed tilt, AbuDhabi, POAA 24%



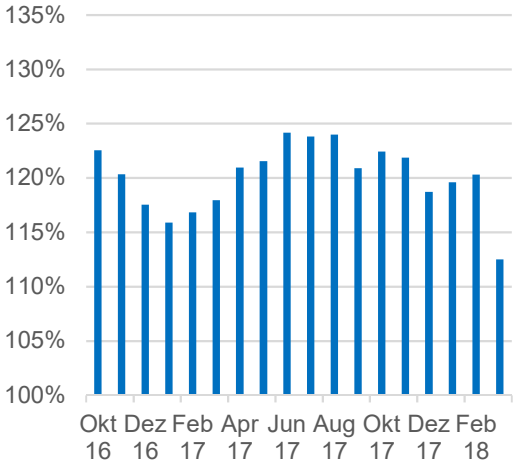
Fixed tilt, Yinchuan, POAA 16%



Fixed tilt, Arizona, POAA 10%



2-axis tracking, Arizona, POAA 10%



- Bifacial HJT SWCT modules have a monthly average of **around 10-25% more energy yield**
- Bifacial HJT SWCT modules have **highest yield of all tested technologies** (PERT, PERC, Al-BSF)
- Bifacial **yield is increasing with increasing diffuse light**
- HJT SWCT **yield is increasing with higher temperatures**
- HJT SWCT generation 4 **increases energy yield**
- **All figures referenced to kWh/kWp and to monofacial Al-BSF technology**

Yield overview

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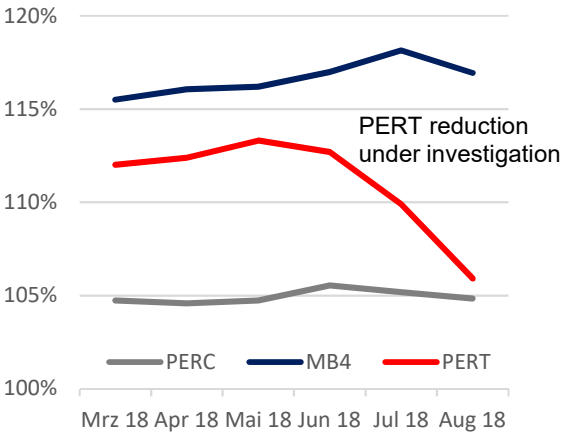
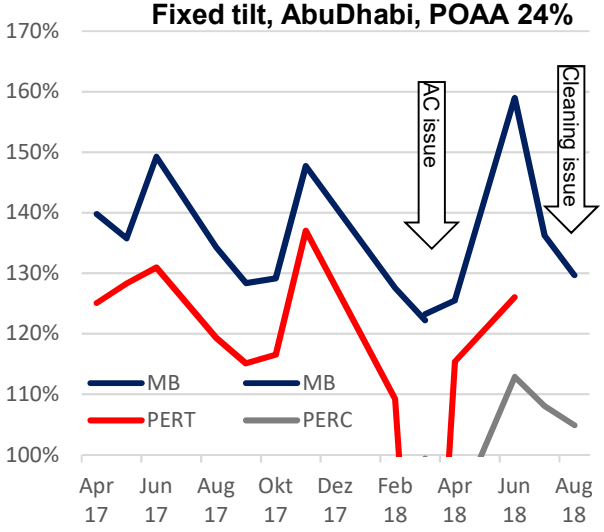
1-axis tracking, California, POAA 10%



Fixed tilt, AbuDhabi, POAA 24%



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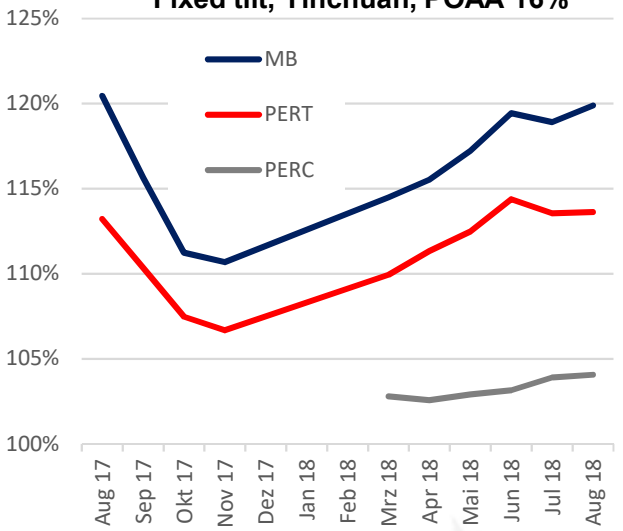

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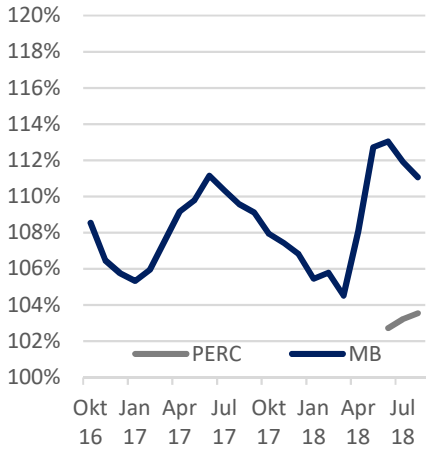
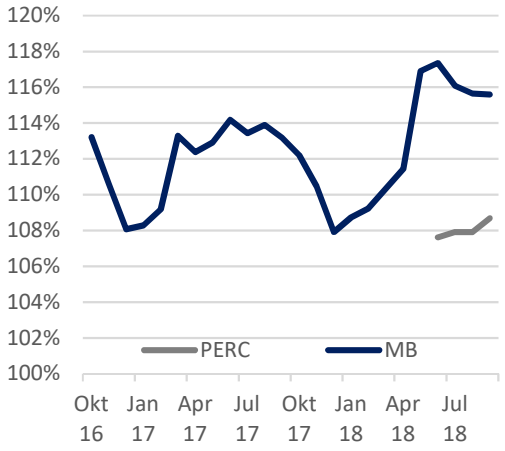


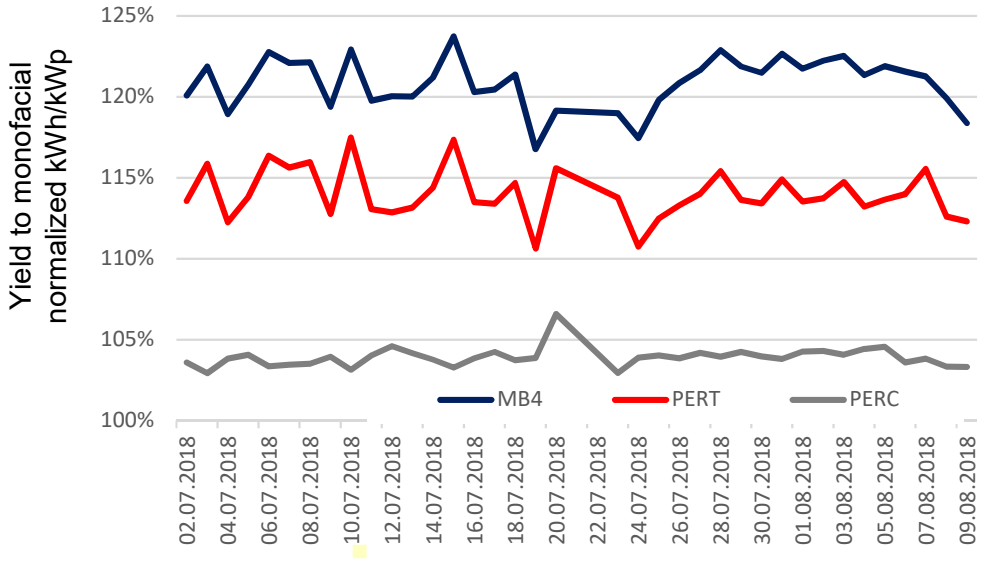
2-axis tracking, Arizona, POAA 10%



- MB bifacial HJT SWCT modules have **around 10 to 25% more energy yield** in yearly average
- MB bifacial HJT SWCT have **highest yield of all tested technologies** (PERT, PERC, Al-BSF)
- Bifacial **yield is increasing with increasing diffuse light**
- HJT SWCT **yield is increasing with higher temperatures**
- MB HJT SWCT generation 4 has **increased energy yield**
- **All figures are referenced to kWh/kWp and to monofacial Al-BSF technology**

China: Yinchuan

Yinchuan: normalized monthly yields to monofacial
Summer 2018



Summary for summer 2018:

- hot and and very hot temperatures
- New types of modules since Feb 2018

- Monofacial PERC av. 4% over monofacial
- Bifacial PERT av. 14% over monofacial
- Bifacial MB av. 22% over monofacial
- Very high single day gains

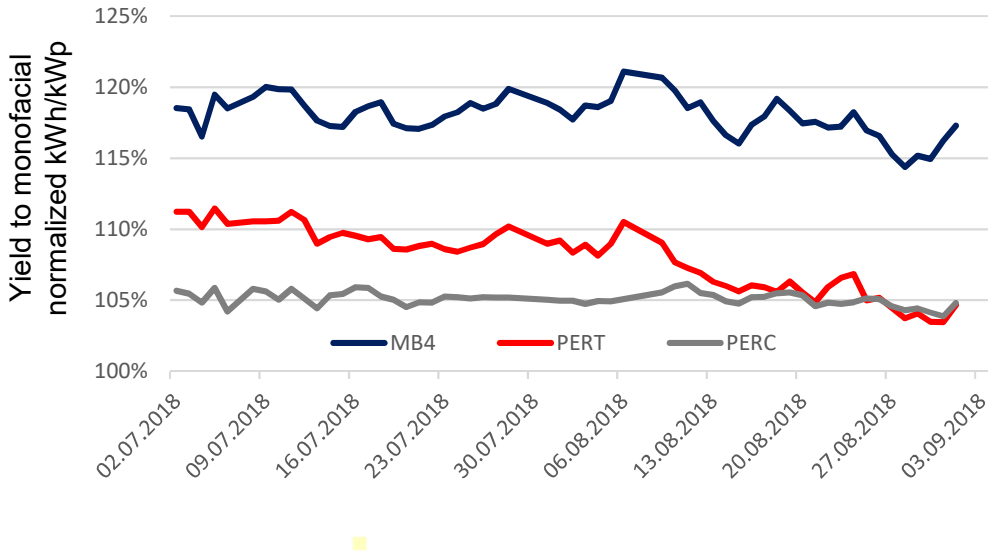
- Yinchuan: fixed tilt
- PERC and MB4 since 02/2018

- **All figures are referenced to kWh/kWp and to monofacial Al-BSF technology**

Albedo_POA (POAA): average albedo measured in tilt of module with silicon sensors.

USA: California

California: normalized monthly yields to monofacial
Summer2018



Summary summer 2018:

- Moderate hot and cold climate
- Relative low albedo

- Monofacial PERC 5% over monofacial
- Bifacial PERT av. 8% over monofacial
- Bifacial MB av. 18% over monofacial

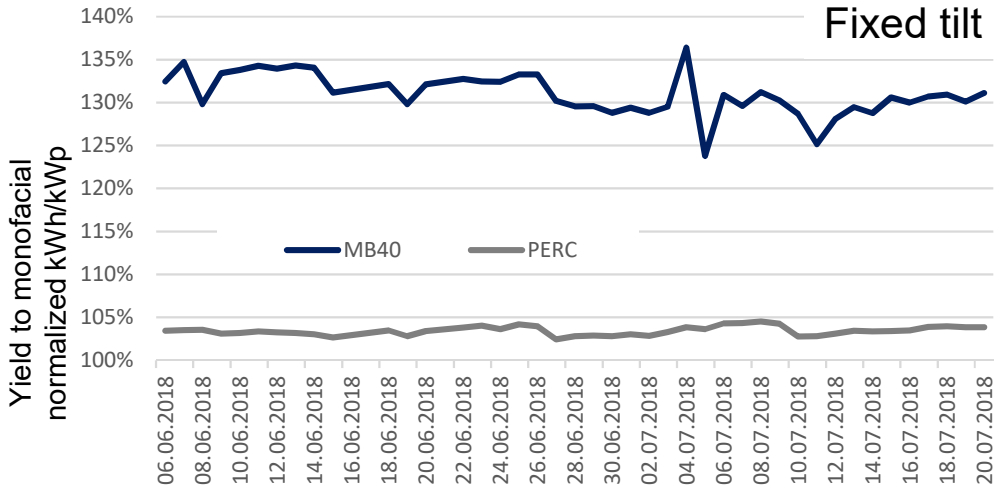
- 1-axis tracking system
- PERC and MB4 since 02/2018
- Power drop after 08/06 of PERT under investigation

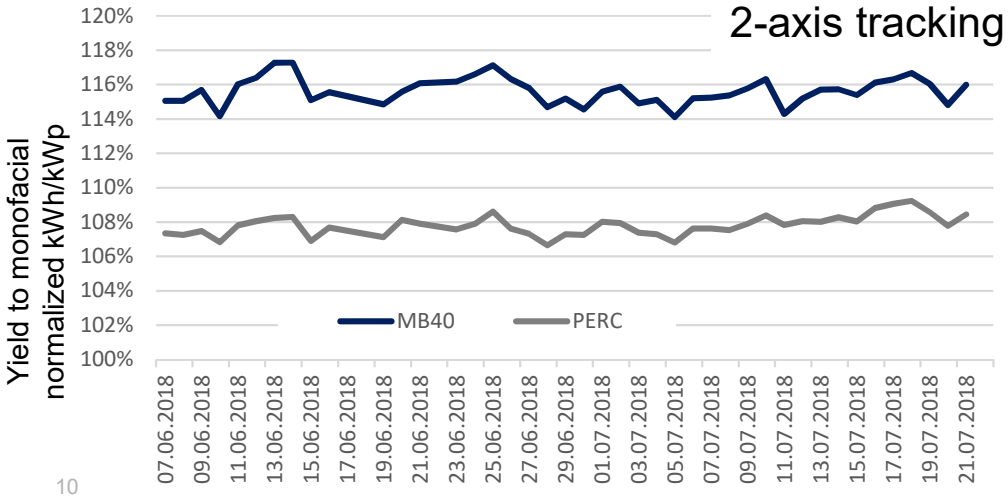
- **All figures are referenced to kWh/kWp and to monofacial Al-BSF technology**

Albedo_POA (POAA): average albedo measured in tilt of module with silicon sensors.

USA: Arizona

Arizona: normalized monthly yields to monofacial
Summer 2018





Summary:

- Hot and dry climate
- Two different mounting systems

Fixed tilt (benchmark to fixed monofacial):
- Very high constant gain for MB bifacial
- yield of PERC expected with 5% over reference

2-axis tracking (benchmark to 2-axis monofacial):
- Bifacial MB av. 15% over monofacial 2-axis
- PERC av. 9% over monofacial 2-axis

- monofacial 2-axis to fixed av. +14% yield
- Bifacial help to improve tracking yield

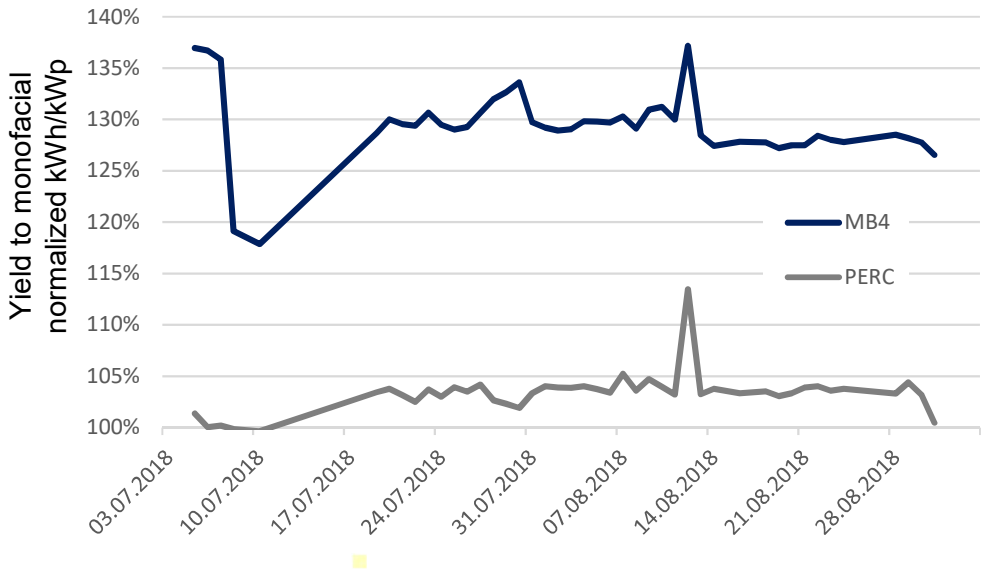
Yield of bifacial technology depends on overall conditions: temperature and diffuse/direct light

New modules PERC and MB4 since 06/2018

POA_Albeo (POAA) 10%

UAE: AbuDhabi

Abu Dhabi: normalized monthly yields to monofacial
Summer 2018



Summary for summer 2018:

- Very hot climate

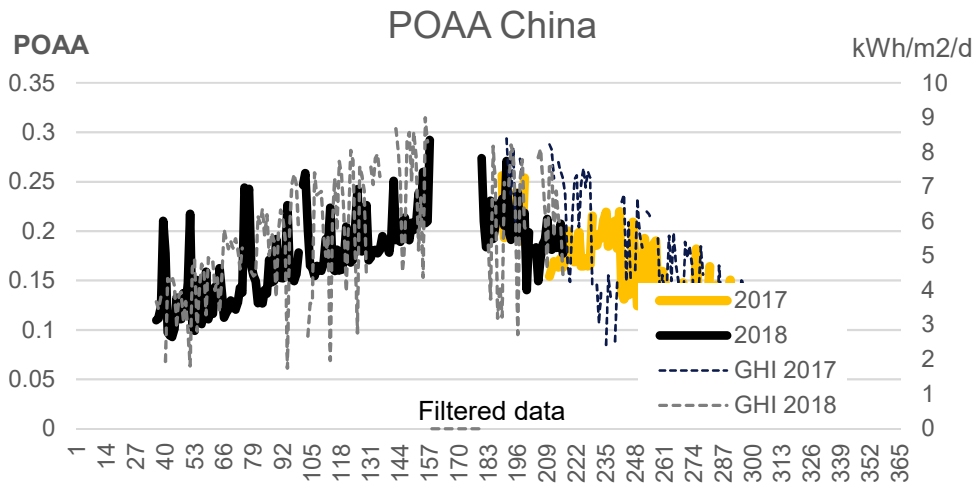
- Bifacial PERT av. like monofacial
- Bifacial MB av. 25% over monofacial

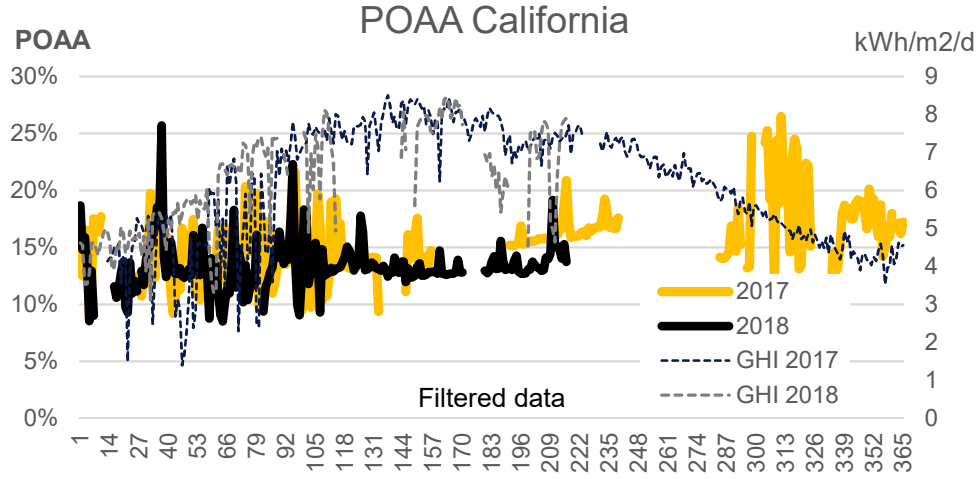
- Abu Dhabi: fixed tilt
- Issues with cleaning in hot summer 2018
- New types of modules since 02/2018

- **All figures are referenced to kWh/kWp and to monofacial Al-BSF technology**

Albedo_POA (POAA): average albedo measured in tilt of module with silicon sensors.

Average albedo of sites is stable





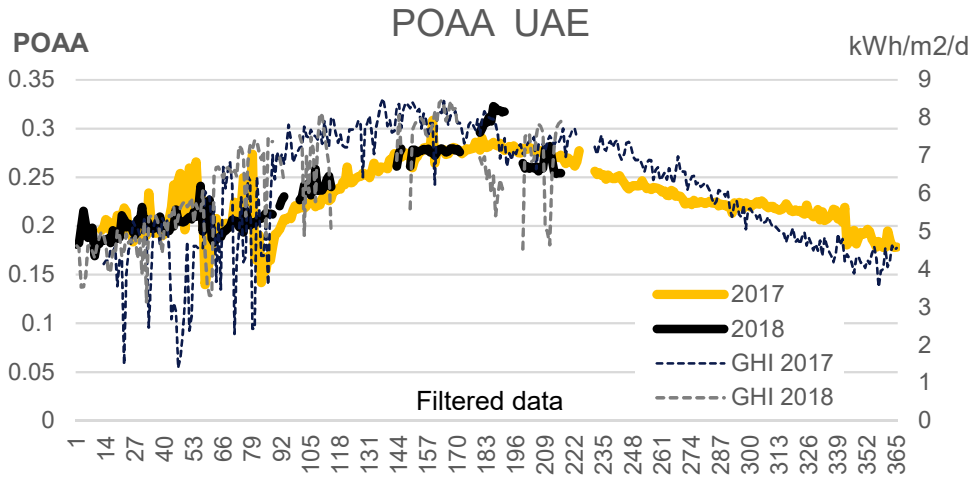
China:

- Variation of POAA proportional to GHI
- UAE: No vegetation, only seasonal variation
- Variation ±5%

California:

- POAA have same seasonal variation
- More tolerance due to vegetation
- Variation ±7%

Average albedo of sites is stable



UAE:

- Variation of POAA proportional to GHI
- UAE: No vegetation, only seasonal variation
- Variation is ±5%

- Sunny side simulation is accepted today
- Rear side is strongly related to
  - 1) direct albedo reflection
  - 2) indirect light
- Variation of albedo will add some tolerance to system, but only in a small fraction
  - 3) Tolerance of POAA around ±5% to ±7% w/o seasonal variation

Approach to quantify bifacial gains by comparing to reference PV system

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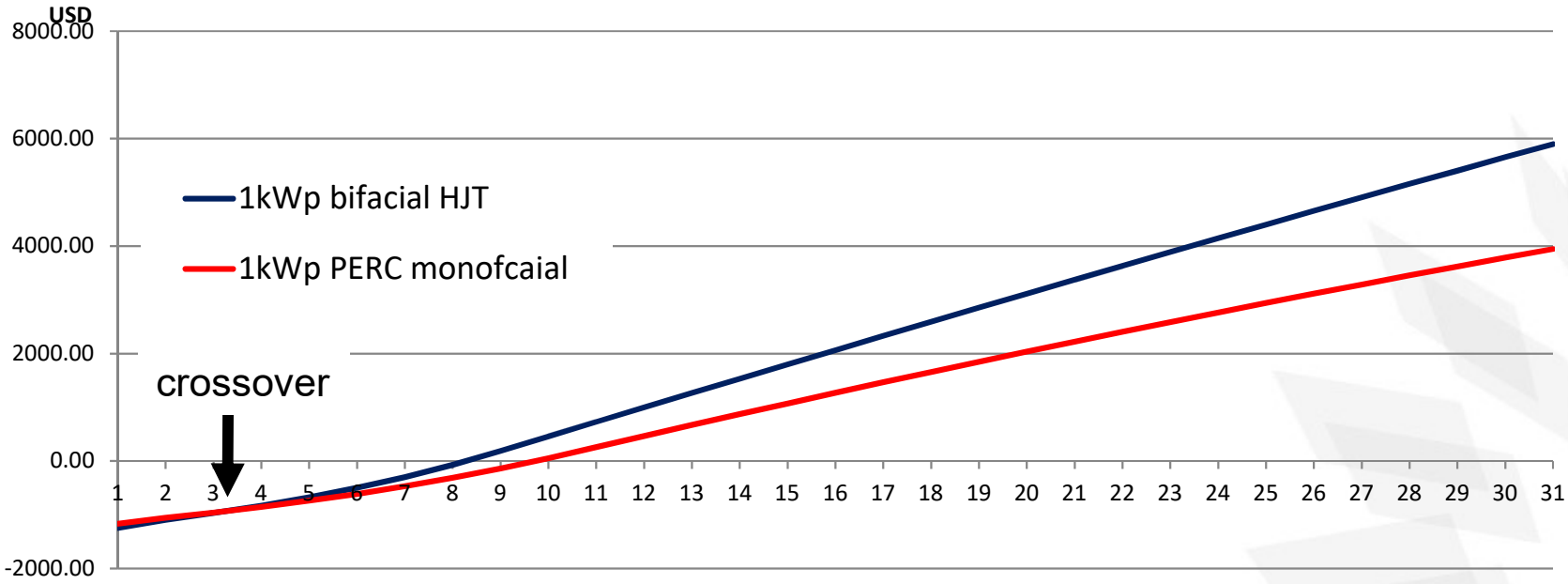
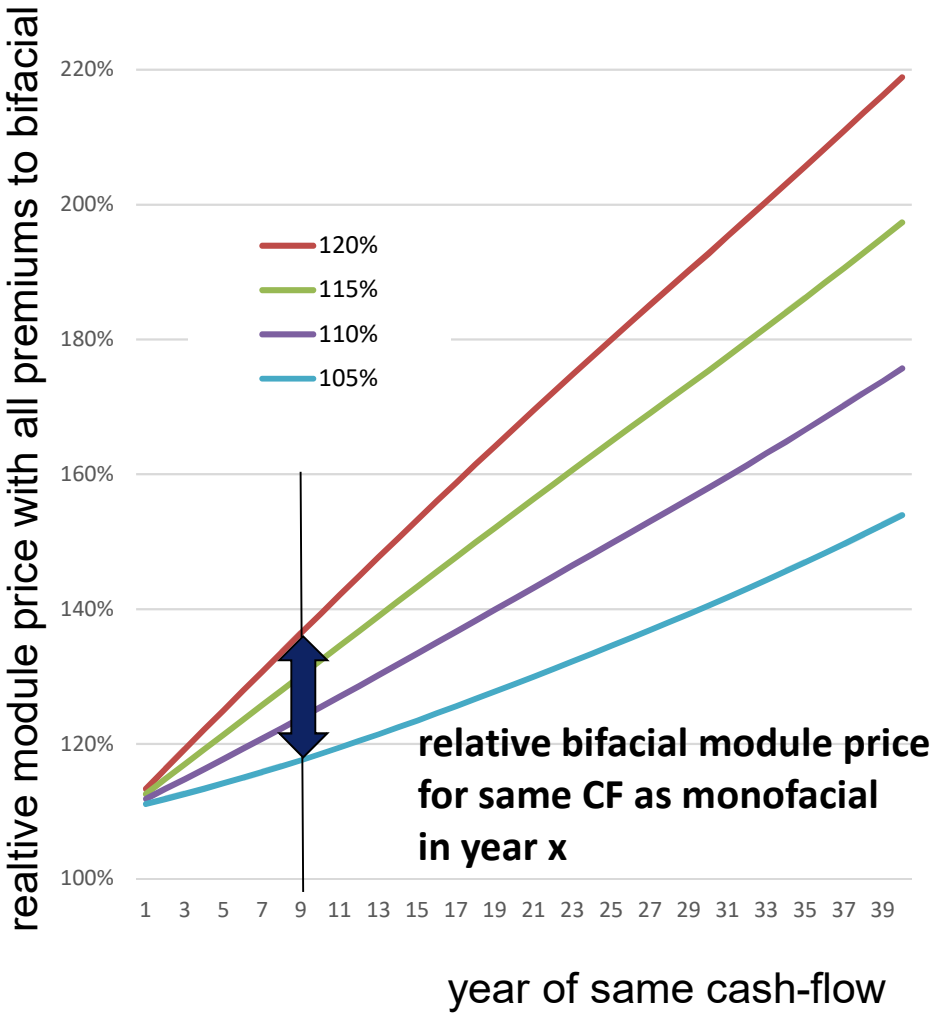
- The simulations and energy ratings of the “standard” PV systems are accepted
- Measurements show clear superior energy yield of bifacial modules
- Cumulative cash-flow (CCF)
- Later investigated discounted cash-flow (DCF)



transfer energy yield in financial value assumption of risk mitigation



- Monofacial module good known in real life and simulations
- Relative bifacial to monofacial yield good known in measurements, but specific to site
- Relative calculations

assumptions		
power sales	**USD/MWh**	***30***
monofacial power generation	kWh/kWp/a	1725
monofacial module price	USD/Wp	0.32
monofacial 60c module power	Wp	310
monofacial system (module+B	**USD/Wp**	**0.78**
monofacial total system costs	**USD/Wp**	**0.88**
monofacial O&M costs	USD/kWp/a	6.00
debt		***80%***
interest rate		***2%***

Summary

- Bifacial PV systems have higher energy yield compared to monofacial, but there is a hight difference in different technologies.
- Quantification is possible, if compared to well known systems
- Bifacial PV systems consist of the same materials and components, but care should be taken for higher currents (may create risk of hot-spots) and module power to string power (might be mitigated by module inverter).
- Bifacial PV modules pass the same tests and accelerated tests, there should be no additional quality issue.
- Bifacial systems have higher economic value (more specific energy generation) which can mitigate the perceived risks.

What is the best and fair distribution of profits and risks?

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Thank you.