Rear irradiance inhomogeneity of bifacial PV modules: Modeling and quantification by MoBiDiG

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2-ZHAW, Winterthur, Switzerland

6th Bifacial Workshop, Amsterdam. Sep.16h-17th, 2019

Motivations

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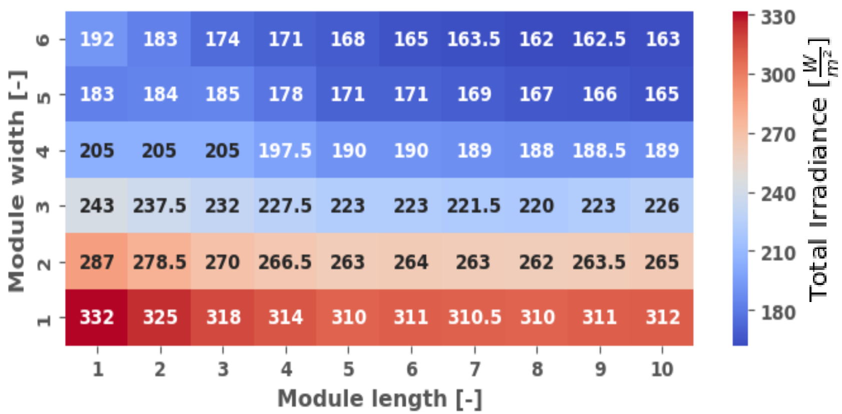
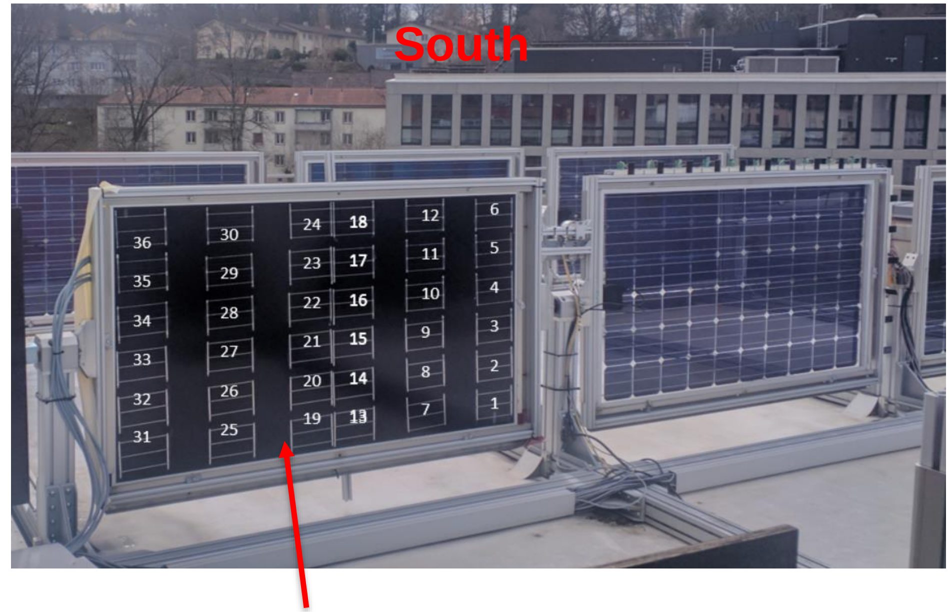


Plotting **Time:** 2019-05-01 12:01:14 **Tilt angle: 10** GHI 896 W/m2 Diffuse fraction: 12.0 % **POA: 984** W/m2. **Location : Switzerland** Rear irradiance **inhom. 34.41 %**

The rear irradiance map can be simulated by the optical models using **quasi 3D view factor** or **ray tracing**, or can be even **measured** by **a customized PV solar panels**.



The numbered solar cells are calibrated and **connected individually** to measure the rear irradiance values. The cell are looking **downwards** to measure the rear irradiance map.

Motivations

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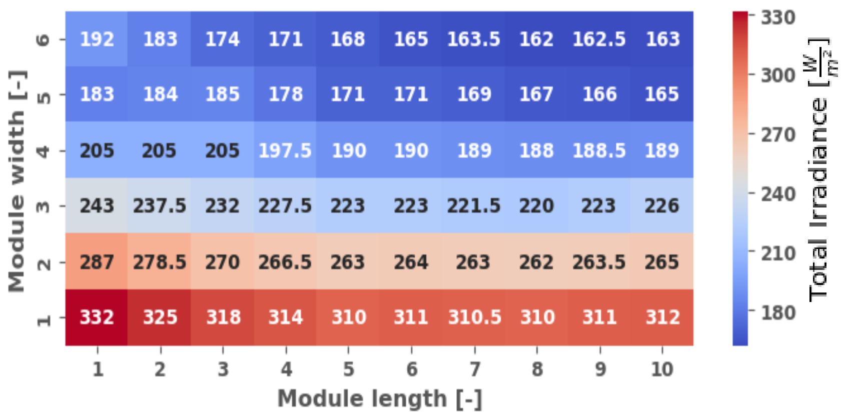

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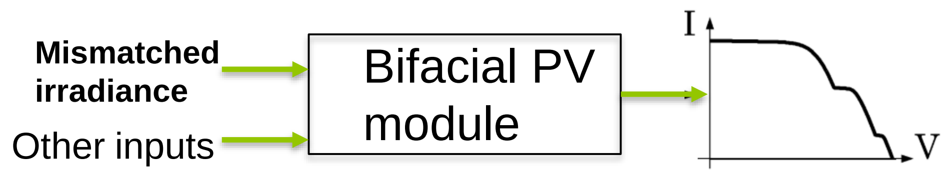
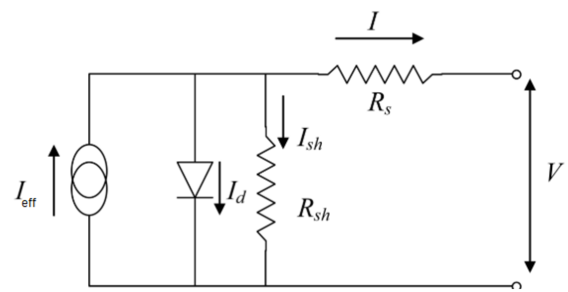
The rear irradiance map can be simulated by the optical models using **quasi 3D view factor** or **ray tracing**, or can be even **measured** by **a customized PV solar panels**.

How this will affect **the power output** and **the IV curve** of the bifacial module **?**



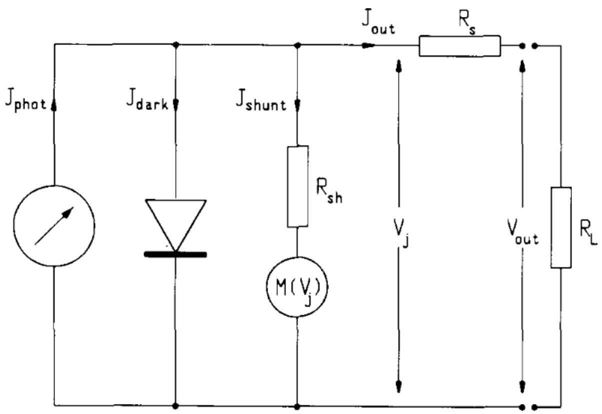


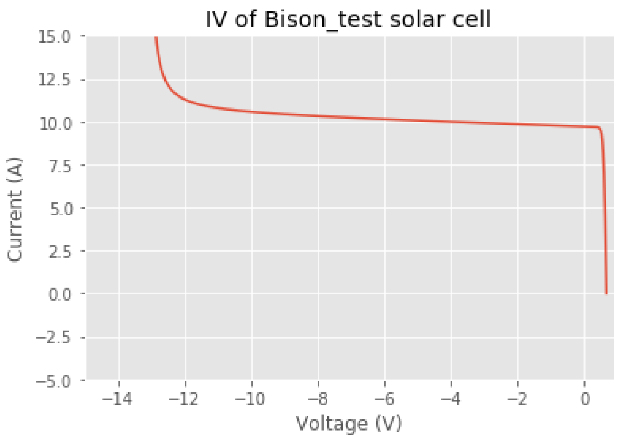
$$E_{eff} = E_{front} + {}^*\beta \times E_{rear}$$

When using the **IV data of the PV module** (.Pan file) which value of E_{rear} we should use: $E_{rear\ (minimum)}$ or the $E_{rear\ (mean)}$ **?**

*β: bifaciality factor

3 Simulation Procedures





$$E_{eff} = E_{front} + {}^*\beta \times E_{rear}$$

a) IV data of the bifacial PV module **+** the **mean of E_{rear}**

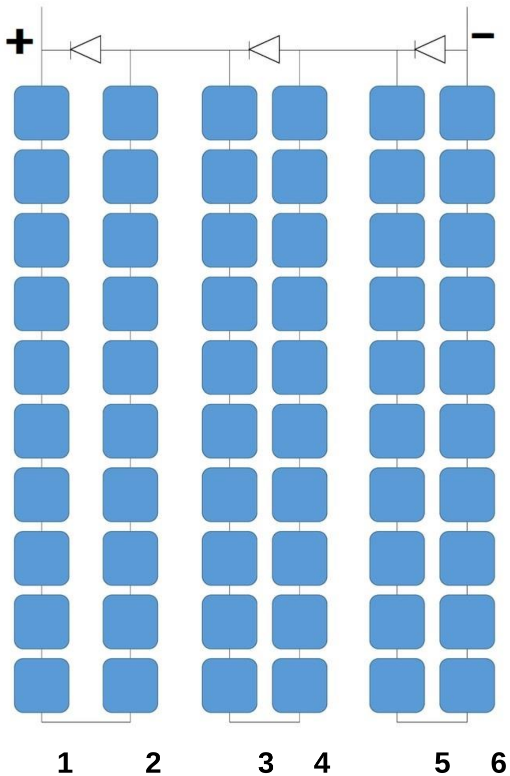
b) IV data of the bifacial PV module **+** the **minimum of E_{rear}**

c) IV data of the solar cell **+ the exact irradiance value** of each solar cell within the bifacial PV module

→ For each solar cell we solve the IV curve for a given timestamp using the Bishop model.

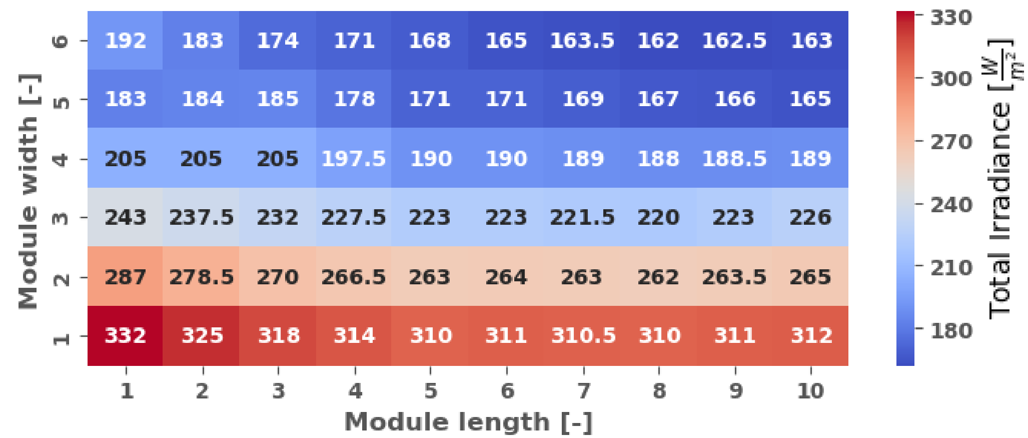
Bishop, J. W. "Computer simulation of the effects of electrical mismatches in photovoltaic cell interconnection circuits." *Solar cells* 25.1 (1988): 73-89.

Example: simulation for one timestamp



Method C takes into account the bypass diodes effect

The rear irradiance map used for the simulation



Module width \ Module length	1	2	3	4	5	6	7	8	9	10
6	192	183	174	171	168	165	163.5	162	162.5	163
5	183	184	185	178	171	171	169	167	166	165
4	205	205	205	197.5	190	190	189	188	188.5	189
3	243	237.5	232	227.5	223	223	221.5	220	223	226
2	287	278.5	270	266.5	263	264	263	262	263.5	265
1	332	325	318	314	310	311	310.5	310	311	312

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E_{front} : 984 W/m2 cte.

a) $E_{eff} = E_{front} + {}^*\beta \times$ **min**(E_{rear}) + Module IV

b) $E_{eff} = E_{front} + {}^*\beta \times$ **mean**(E_{rear}) + Module IV

c) $E_{eff} = E_{front} + {}^*\beta \times E_{rear}$ for **each Cell** + Cell IV

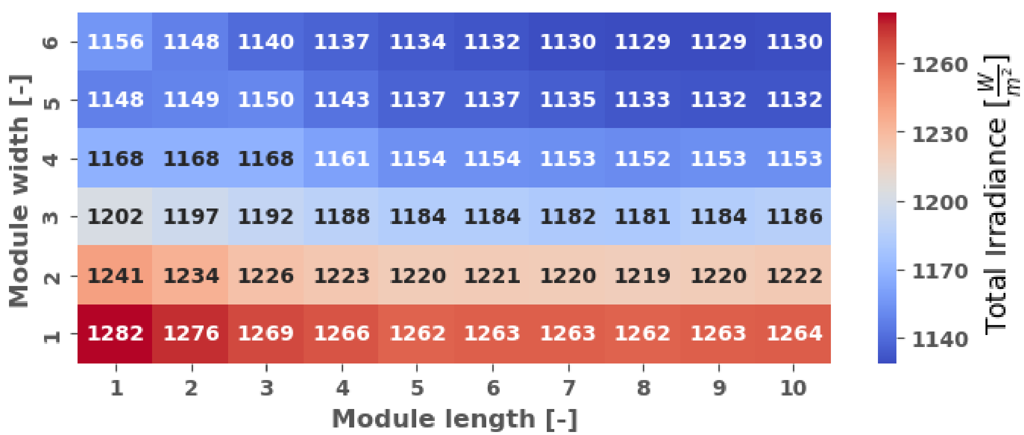
Example: simulation for one timestamp

E_{front} : 984 W/m2 cte.

a) $E_{eff} = E_{front} + {}^*\beta \times$ **min**(E_{rear}) ➔ **1146 W/m2**
b) $E_{eff} = E_{front} + {}^*\beta \times$ **mean**(E_{rear}) ➔ **1209 W/m2**

c) $E_{eff} = E_{front} + {}^*\beta \times E_{rear}$ for **each Cell** + Cell IV

The **effective** irradiance map used for the simulation



Plotting **Time:** 2019-05-01 12:01:14 **Tilt angle: 10** GHI 896 W/m2 Diffuse fraction: 12.0 % **POA: 984** W/m2. Rear irradiance **inhom. 34.41 %**

Results: Minimum or Mean ?

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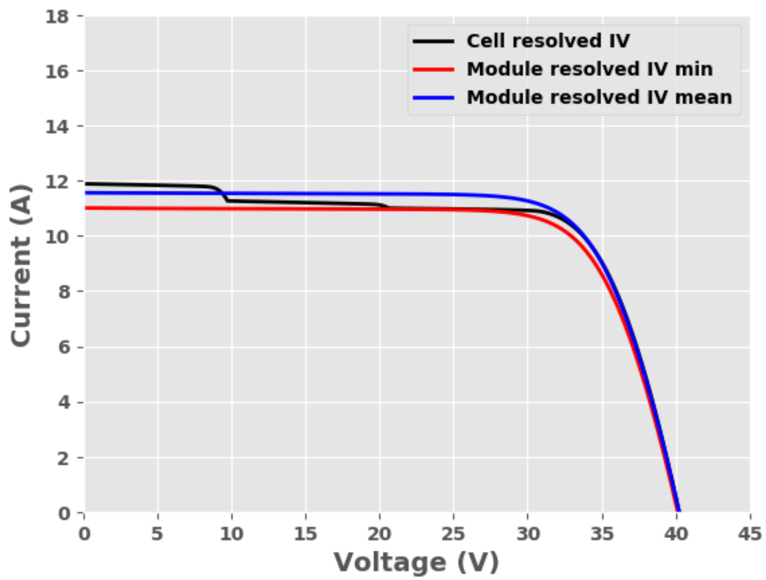

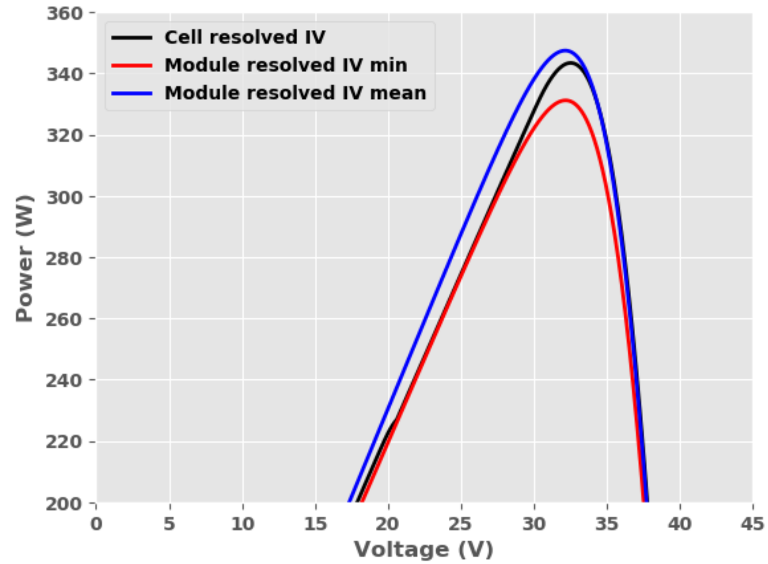

Method	Cell resolved IV+ Exact irradiance value	PV module IV +Mean	PV module IV+ Minimum
I_{SC} (A)	11.9	11.6	11.0
	Relative difference to Cell resolved IV	-2.5%	-7.4%

Method	cell_by_cell	Mean	Minimum
I_{MPP} (A)	10.6	10.8	10.3
	Relative difference to Cell resolved IV	1.9%	-2.8%

Method	cell_by_cell	Mean	Minimum
P_{MPP} (W)	343.4	347.4	331.2
	Relative difference to Cell resolved IV	1.2%	-3.6%

Neither mean nor minimum approach **gives the same results as cell by cell** approach. However, using **the mean** irradiance way gives **closer results to the cell by cell** approach than the Minimum irradiance.

Field data of **rear** irradiance inhomogeneity values

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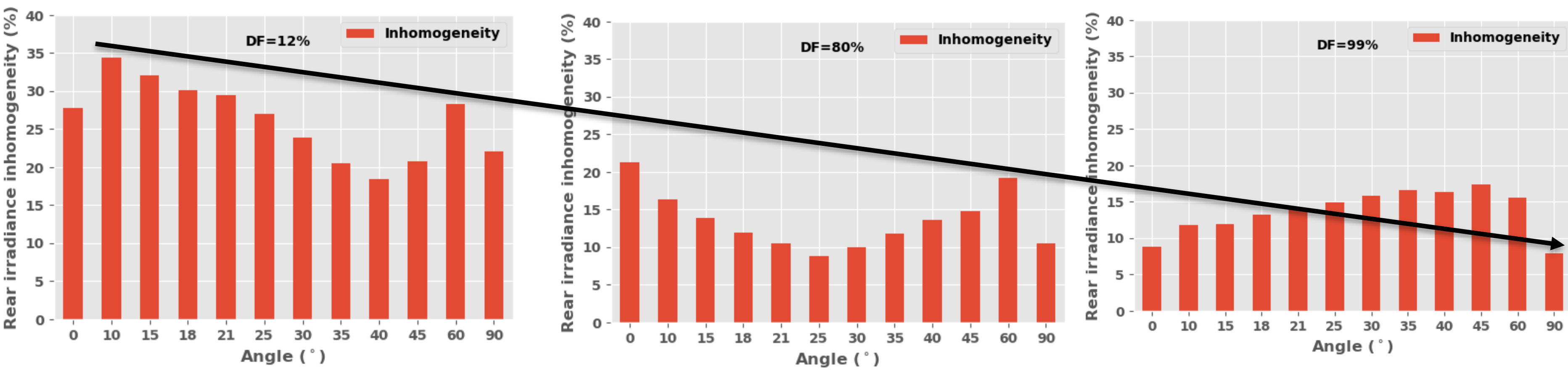

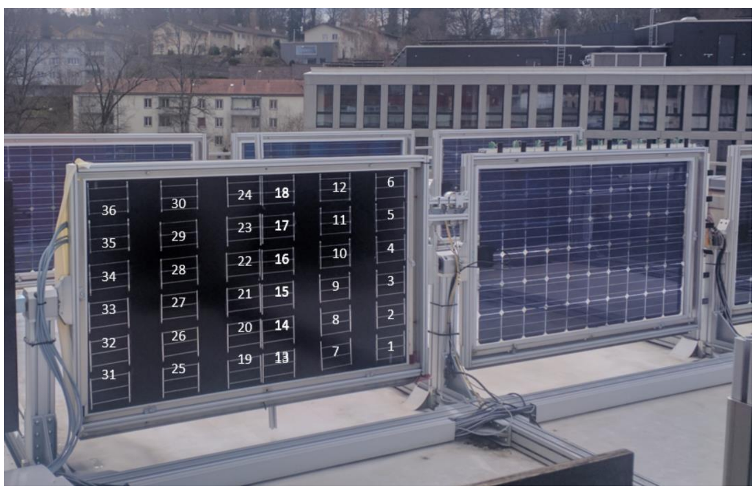

Biforot setup has rear irradiance measurement included

- The rear irradiance inhomogeneity **decreases with increasing diffuse fraction.** i.e in cloudy days the inhomogeneity is lower than sunny days.
- The rear irradiance **inhomogeneity is tilt angle dependent.**
- The measured rear irradiance inh. is in a **range of 7% to 35%.**

Quantifying the mismatch loss in power due to rear irradiance inhomogeneity

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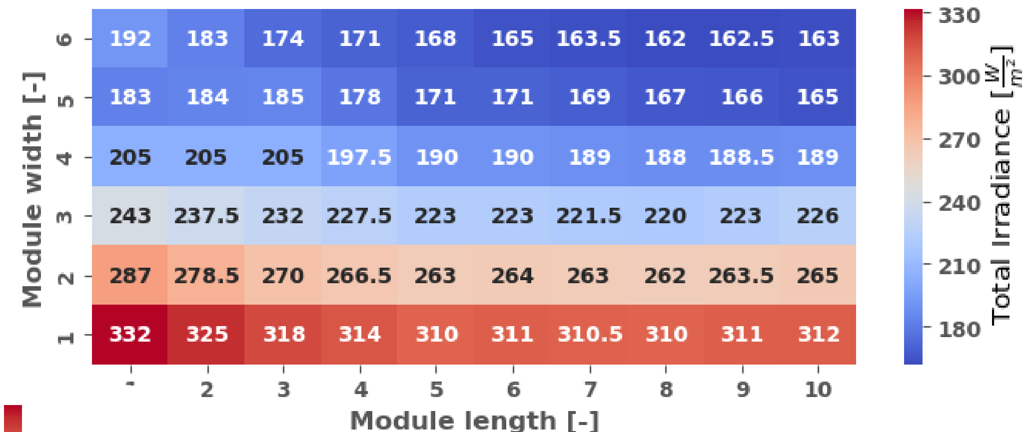
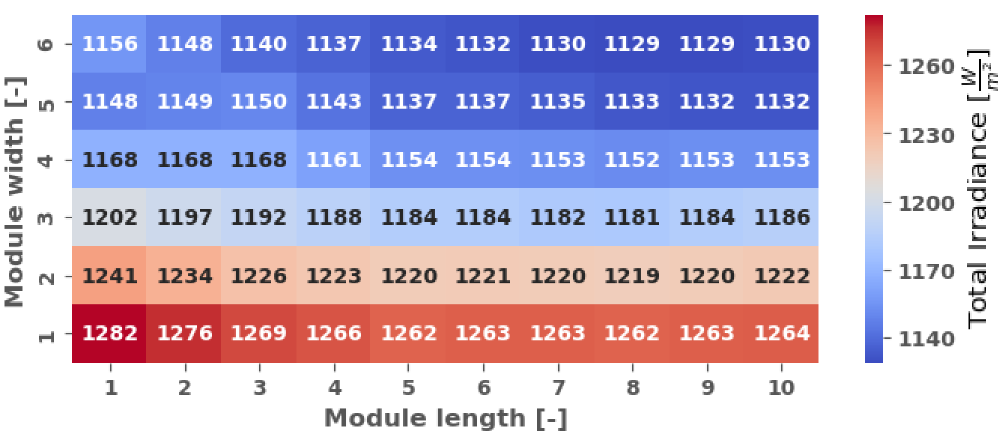
What does matter more, the **rear irradiance inhomogeneity** or **overall inhomogeneity?**

Plotting Time: 2019-05-01 12:01:14 Tilt angle: 10 GHI 896 W/m2 Diffuse fraction: 12.0 % POA: 984 W/m2.

Rear irradiance inhomogeneity 34.4 %



$$E_{eff} = E_{front} + {}^{*}\beta \times E_{rear}$$



Overall inhomogeneity 6.3 %

Overall inhomogeneity matters more because the power output of the bifacial PV **module depends on E_{front}** also **not only E_{rear}.**

A significant drop in **inhomogeneity** when taking into account **the front side contribution.**

*β: bifaciality factor =0.9

Quantifying the mismatch loss in power due to rear irradiance inhomogeneity

- A dataset (several days with different diffuse irradiance fractions) of measured GHI and DHI values has been used in order to generate simulated values of **overall irradiance inhomogeneity**

- Thereby, **3 scenarios** with **3 different albedos** have been simulated by MoBiDiG VF. A part from the albedo, all other input values (**installation configuration** and GHI/DHI dataset) **have been the same** for all 3 scenarios.

- The simulated values of the overall irradiance inhomogeneity have been used to calculate the mismatch loss in power according to the following definition:

Mismatch loss (%) =

$$\frac{\text{Power output of Bifacial PV modules} - \sum Power\ output\ of\ bifacial\ solar\ cells\ individually}{\sum Power\ output\ of\ bifacial\ solar\ cells\ individually}$$

- The results (showing the absolute values of the mismatch loss) are shown in the following slide

Quantifying the mismatch loss and its correlation to irradiance inhomogeneity

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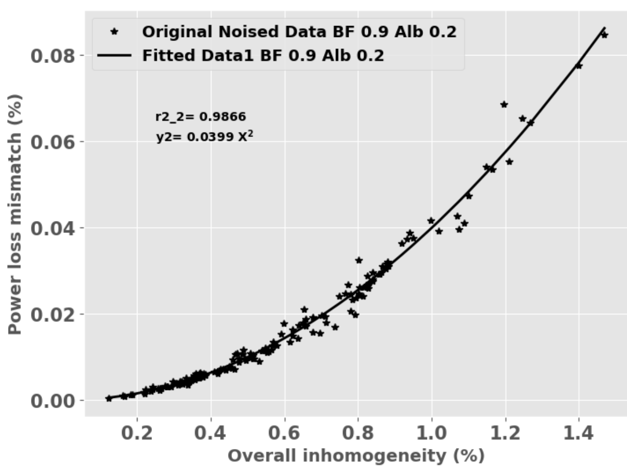
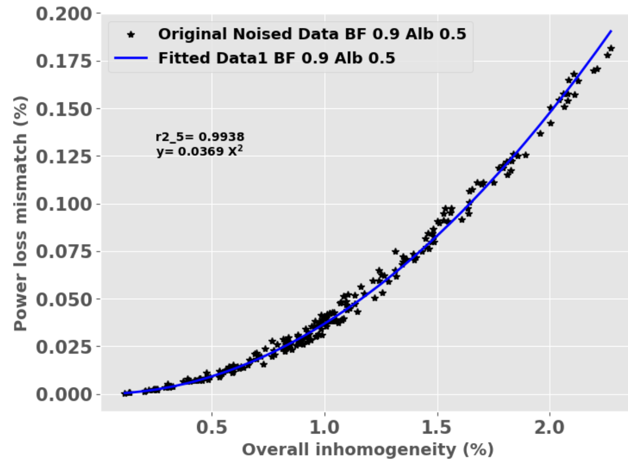
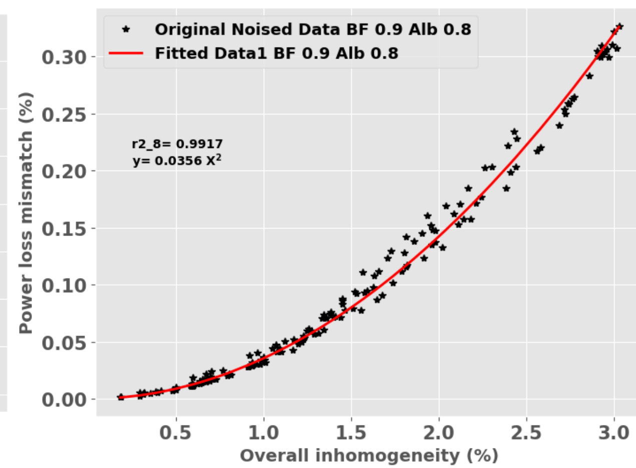
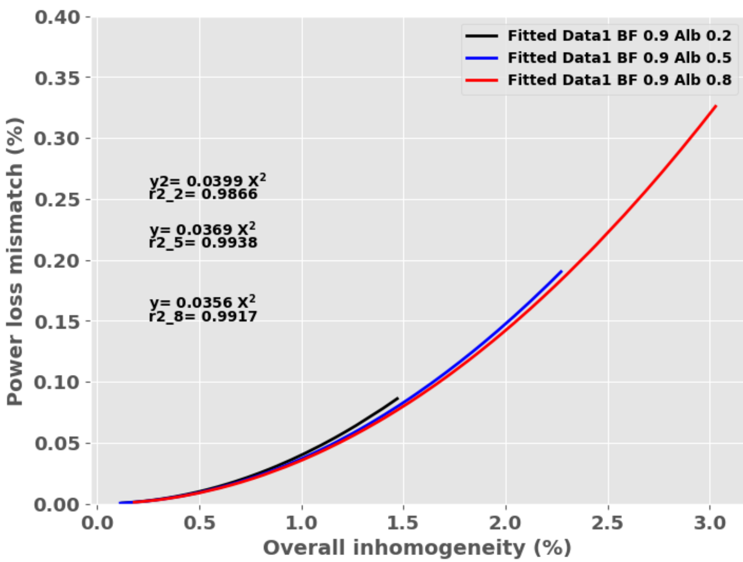






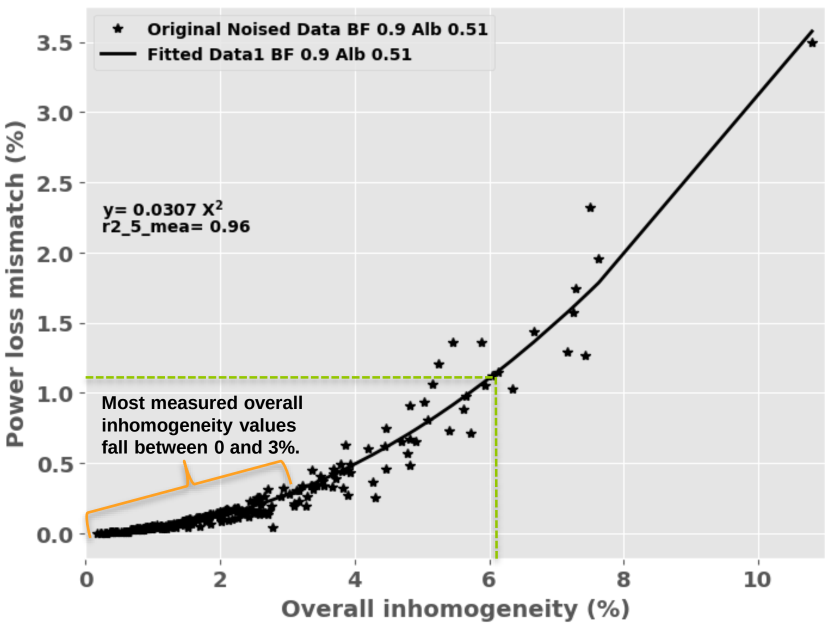


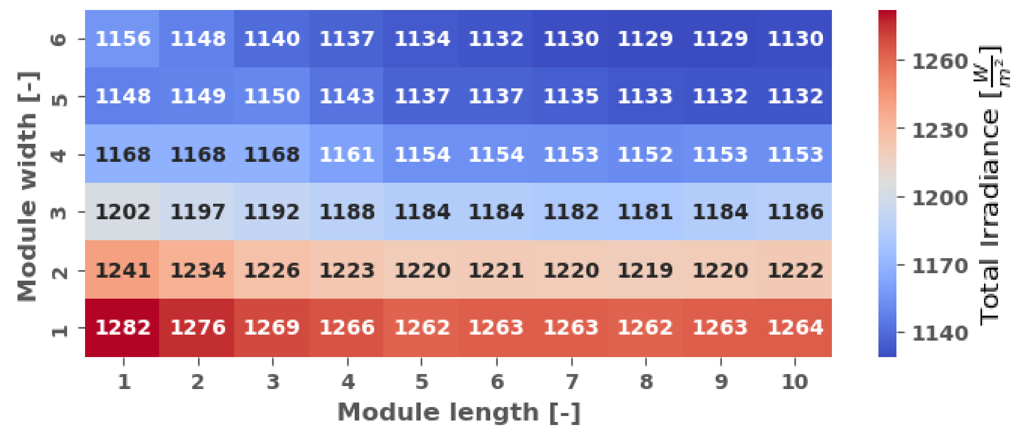
Notes :These values have been found for several days at different diffuse fraction values.

- A very good **quadratic relationship** between **power loss mismatch** and **inhomogeneity** was found**.**
- **Higher albedo values** leads to **higher mismatch loss in power.**
- This correlation is useful for the approximation of power loss mismatch(%).

Quantifying the mismatch loss in power due to rear irradiance inhomogeneity

Evaluation of measured values of overall inhomogeneity





$$E_{eff} = E_{front} + {}^{*}\beta \times E_{rear}$$

Overall inhomogeneity 6.3 %

- **Most measured** overall **inhomogeneity** values are in a range of 0 to 3% which has been also found by the simulation.
- A **quadratic trend** between power loss and overall inhomogeneity is found too
- **6.3% overall inhomogeneity** correspond to **a mismatch loss of 1.2%** per bifacial PV module.

*β: bifaciality factor =0.9

Summary and takeaways

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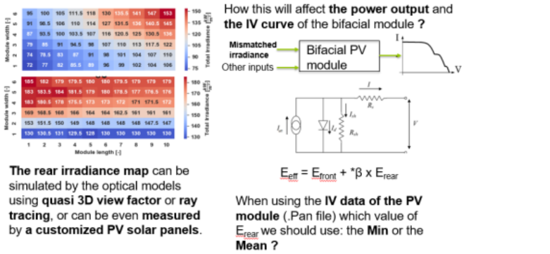
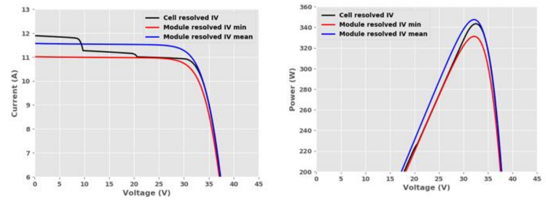
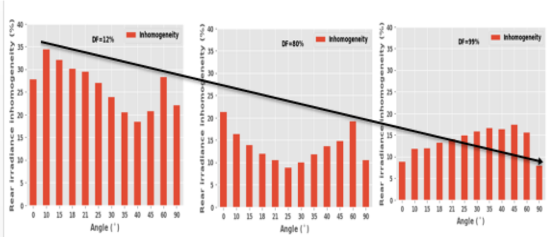
- A comparison between **PV module solved IV curve** to PV **cell solved IV** curve have shown that taking the **mean value of the rear irradiance** map matrix leads to **similar results** as cell solved IV.



- The field **measured data** confirm that the **% of rear irradiance inhomogeneity** depends on the **condition of the day** (sunny or cloudy) and installation configuration. Values of **7% to 35%** have been **measured.**



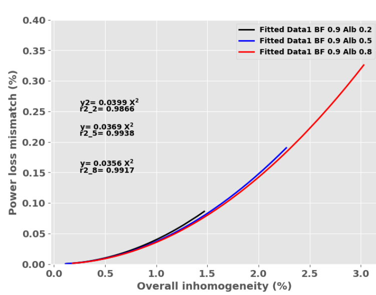
- When it comes to **power mismatch loss** in bifacial PV modules, **overall inhomogeneity** matters more than **the inhomogeneity of rear irradiance.**



- A very high **quadratic relationship** between **power loss mismatch** and **inhomogeneity** was found**.**

- **Higher albedo values** leads to **higher mismatch loss in power.**

- The **most likely power loss mismatch** due to rear irradiance inhomogeneity **does not exceed 0.5%.**



Thank You For Your Attention !

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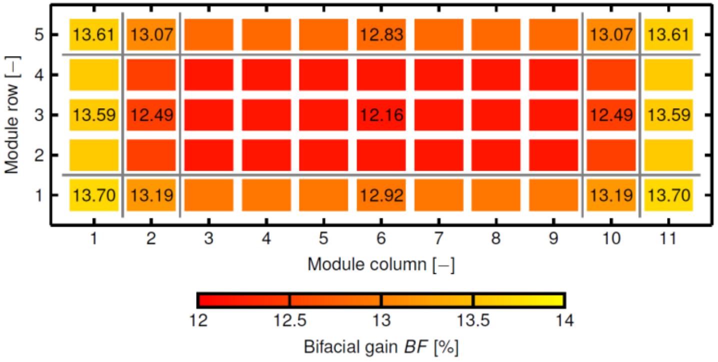
MoBiDiG Services

Using MoBiDiG, ISC Konstanz is offering the following services to all interested parties (EPC, project developers, investors, …):

- **Energy yield assessments and detailed studies** for specific bifacial PV projects (fixed tilt as well as horizontal single axis tracking).

- Development of the **optimum system configuration** (height, tilt, GCR, module technology …) for a given system location



The development of a cloud computing based version of MoBiDiG, allowing the energy yield prediction for base scenarios, is currently under development and is expected to be available to the public in Q1/2020.

Thank You For Your Attention !

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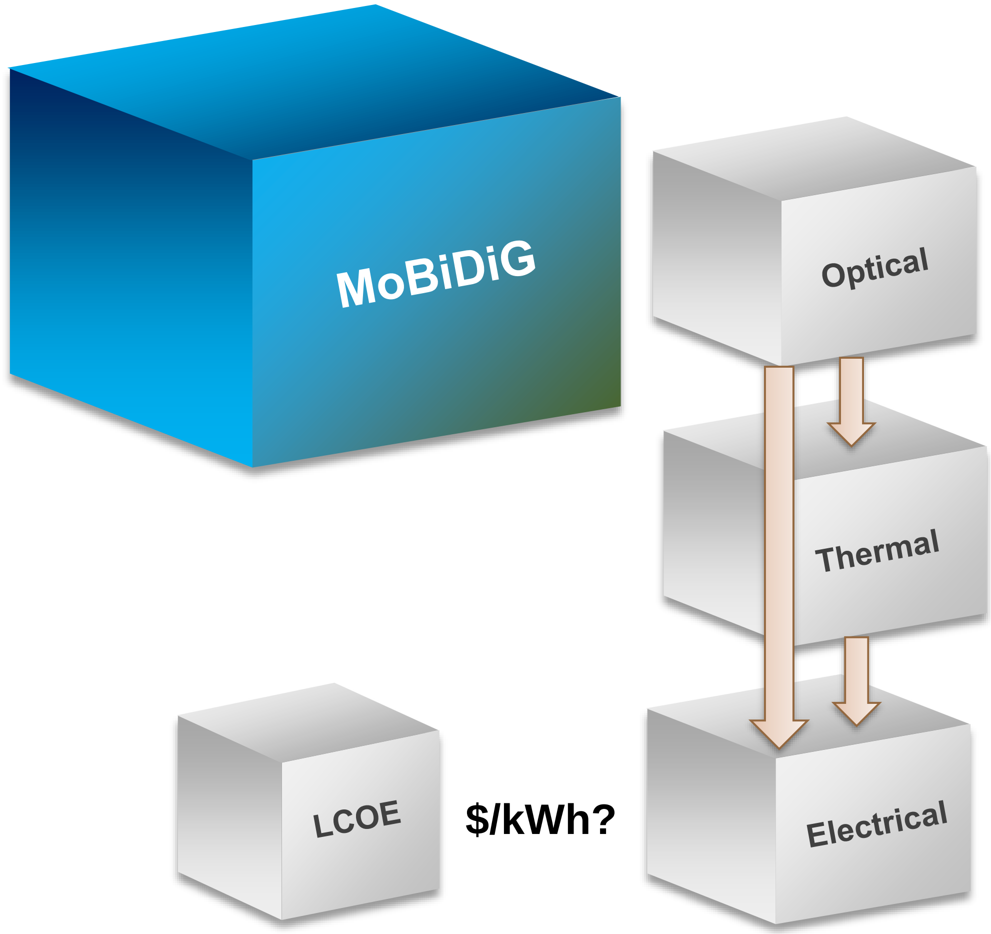
This work has been funded by the EC (HORIZON 2020) and by the German BMWi (FKZ 0324088A) within the Solar-era.net project “Bifalo”

Federal Ministry for Economic Affairs and Energy

European Commission

SOLAR-era.net

Backup slides
Overview of MoBiDiG models



How much solar energy is available for PV energy conversion?

Front

Rear

Prediction of the module temperature?

What is the power output of a PV module?

Impp

Umpp

Backup slides
The Rear Side Optical Model

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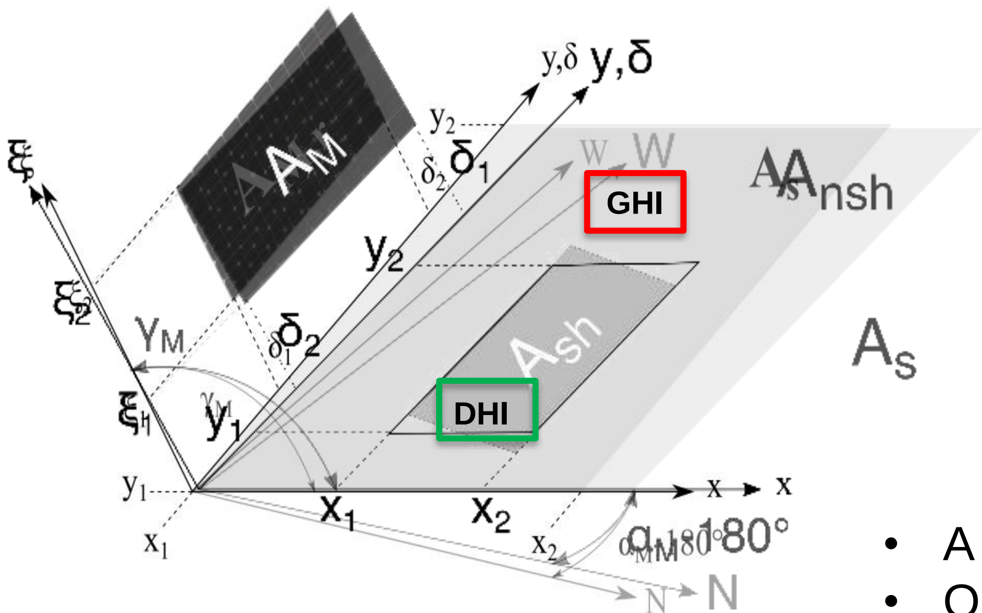

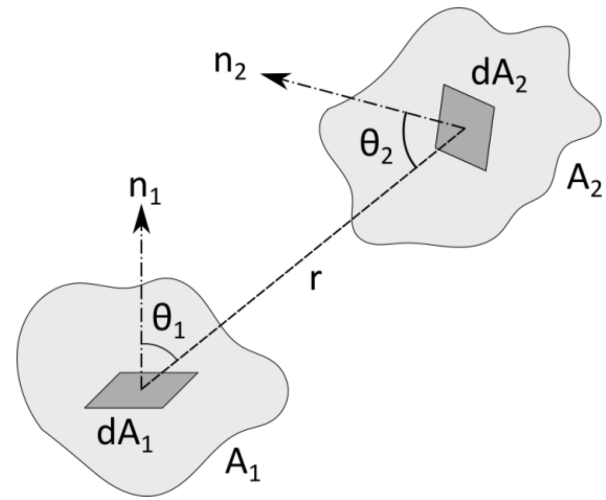

- A Geometrical parameter
- Quantifies the amount of irradiation leaving A1 and reaching A2.
- Dimensionless factor.

$$I_{refl,r} = \alpha \, GHI \, F_{A_{nsh} \rightarrow A_M} + \alpha \, DHI \, F_{A_{sh} \rightarrow A_M}$$

Backup slides

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Overall inhomogeneity