Understanding Outdoor-Characteristics and Bifaciality Effects of Full-Size Perovskite on Silicon Tandem Modules

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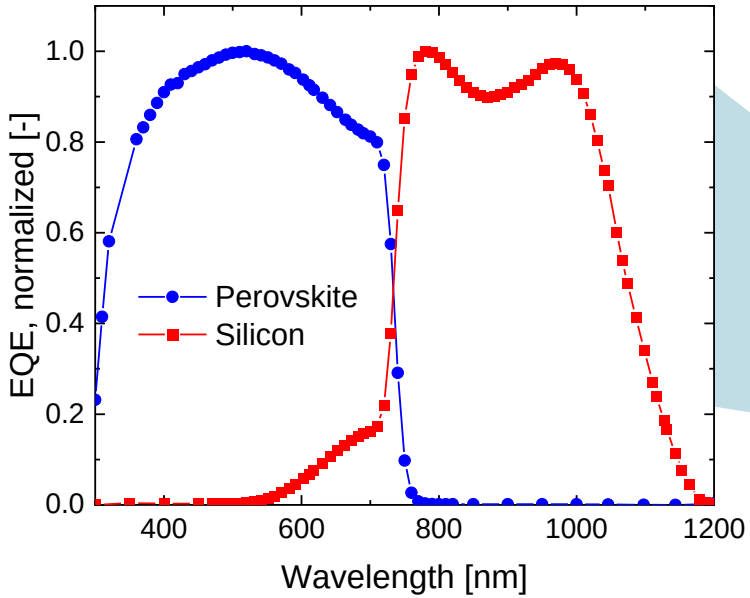
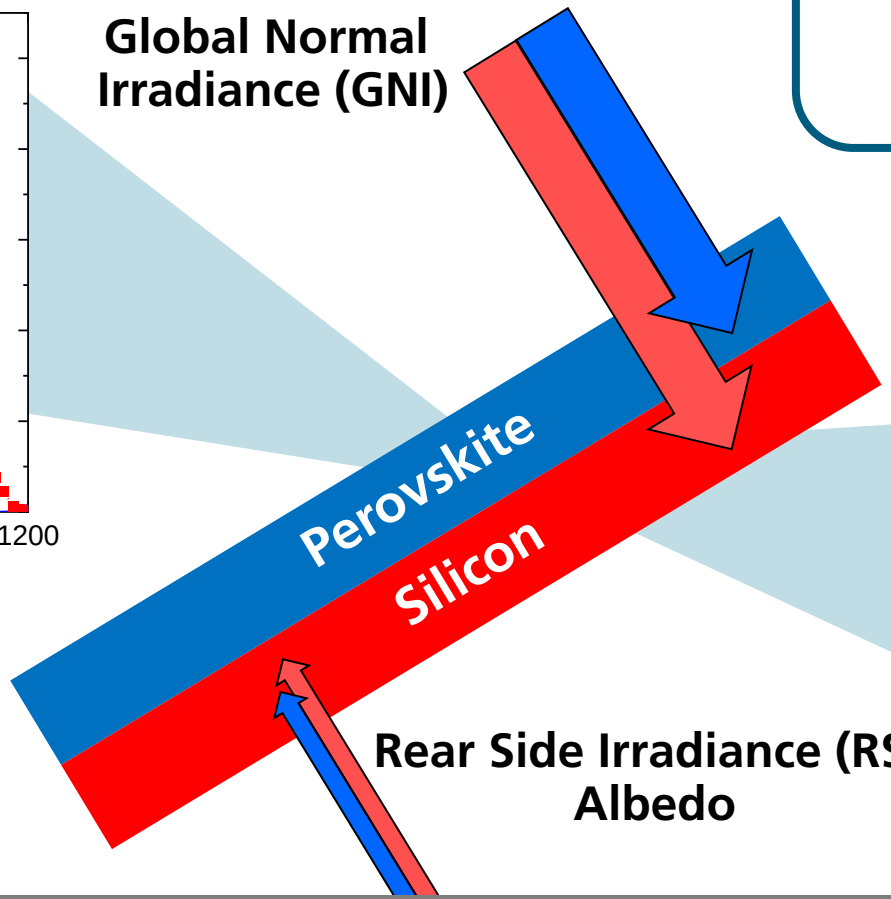
Bifacial Tandem Devices

General Concept



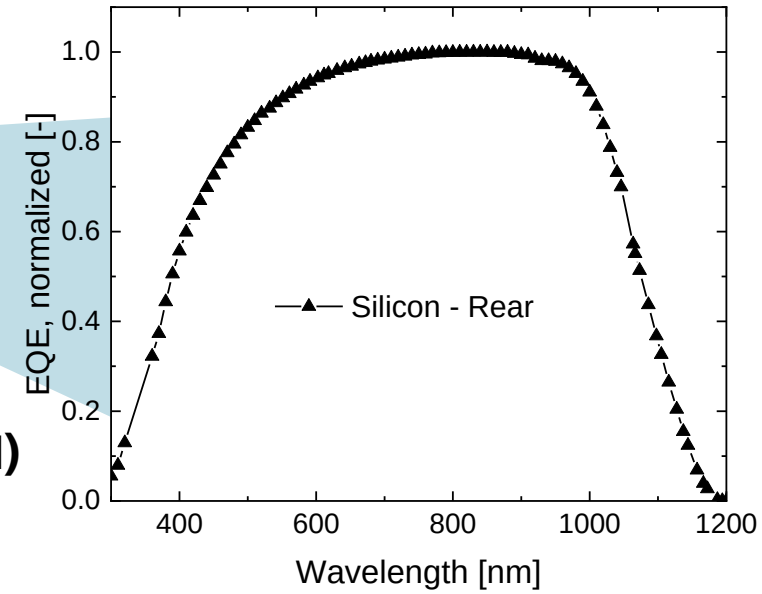
Global Normal Irradiance (GNI)



Rear Side Irradiance (RSI)
Albedo

Ground

Influence of Outdoor Effects?



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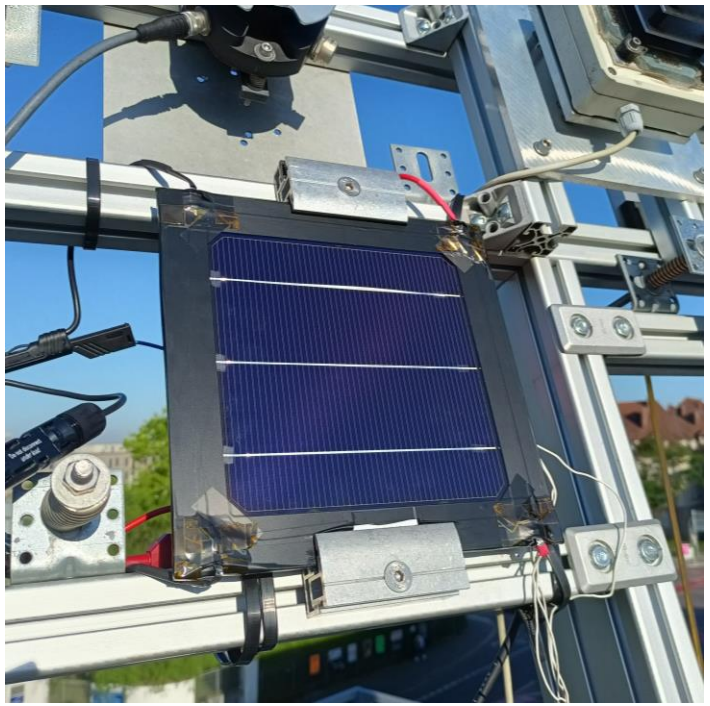
Single Cell - Bifacial Perovskite Silicon Tandem Module

Outdoor Measurement Setup

- M6 cell produced by Oxford PV laminated between two glass sheets
- Mounted on a dual axis tracker



Single Cell - Bifacial Perovskite Silicon Tandem Module

Outdoor Measurement Setup

- M6 cell produced by Oxford PV laminated between two glass sheets
- Mounted on a dual axis tracker
- Measurements carried out with open and covered rear side

Single Cell - Bifacial Perovskite Silicon Tandem Module

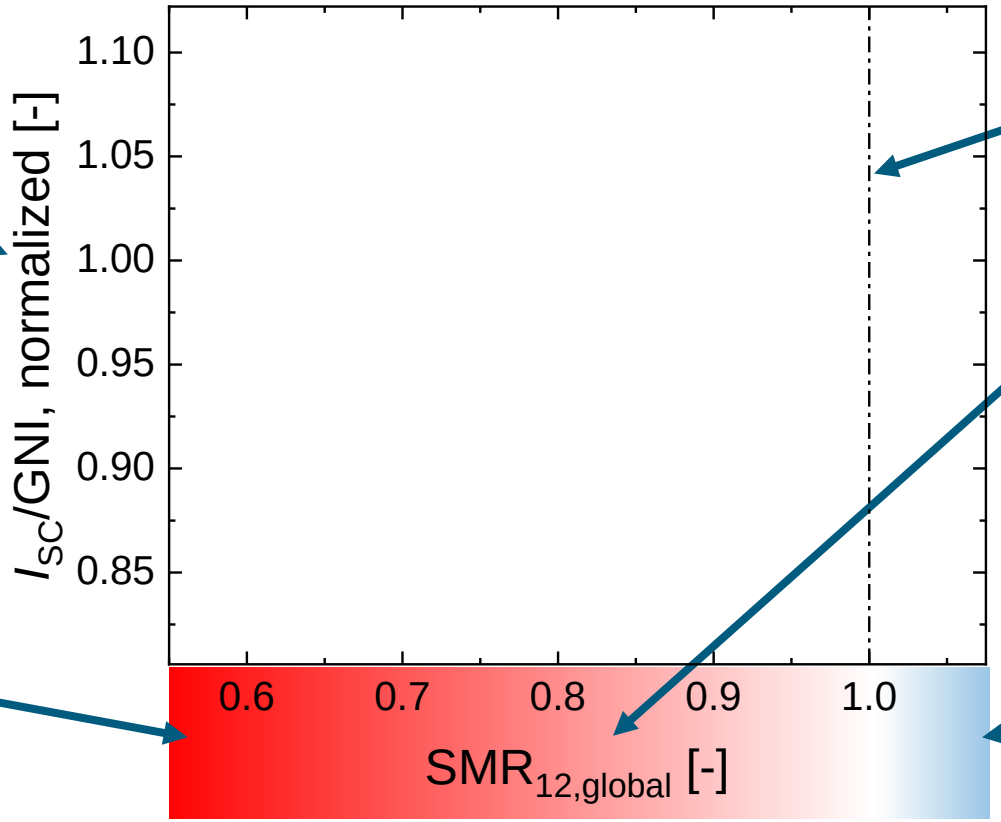
Graphical Representation of Results

$SMR_{12,global} = 1$

AM1.5g like spectral balancing

I_{SC} normalized by global normal irradiance (GNI)

Investigation of spectral influences



Spectral Matching Ratio (SMR)

Parameter for outdoor spectral conditions

$SMR_{12,global} < 1$

Red rich spectral conditions

$SMR_{12,global} > 1$

Blue rich spectral conditions

[1] Domínguez et al.: Current-matching estimation for multijunction cells within a CPV module by means of component cells; 2012; DOI: 10.1002/pip.2227
[2] Steiner et al.: Translation of outdoor tandem PV module I–V measurements to a STC power rating; 2023; DOI: 10.1002/pip.3691
[3] Peharz et al.: Spectrometric Outdoor Characterization of CPV Modules using Isotype Monitor Cells; 2008; DOI: 10.1109/PVSC.2008.4922735

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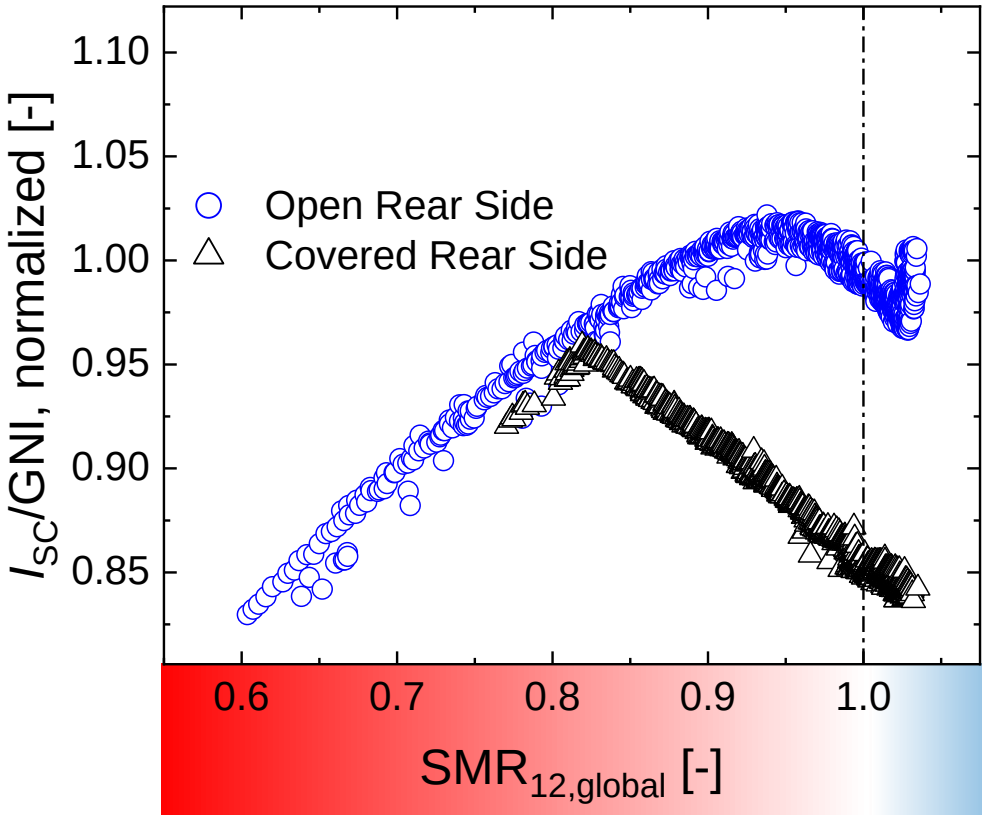
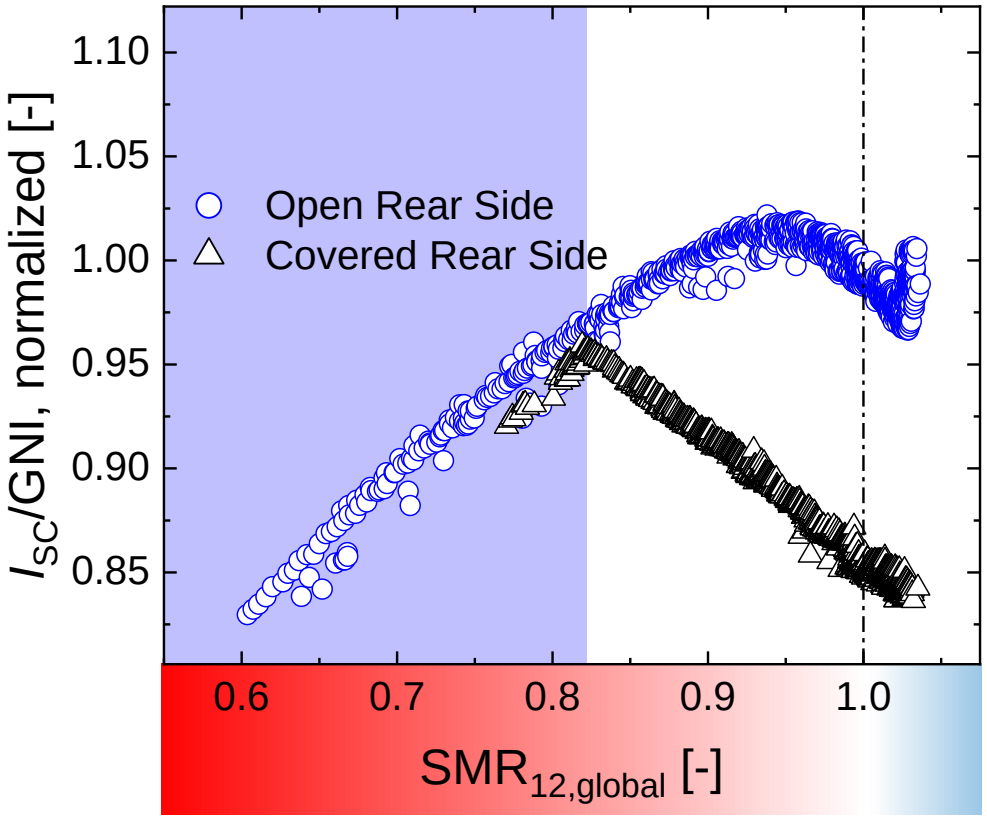
Outdoor Measurement Results



[4] Chojniak et al.: Quantifying the Rear Side Contribution in Bifacial Tandem-Photovoltaic Devices; Submitted to Energy & Environmental Science

Single Cell - Bifacial Perovskite Silicon Tandem Module

Perovskite Limiting Conditions



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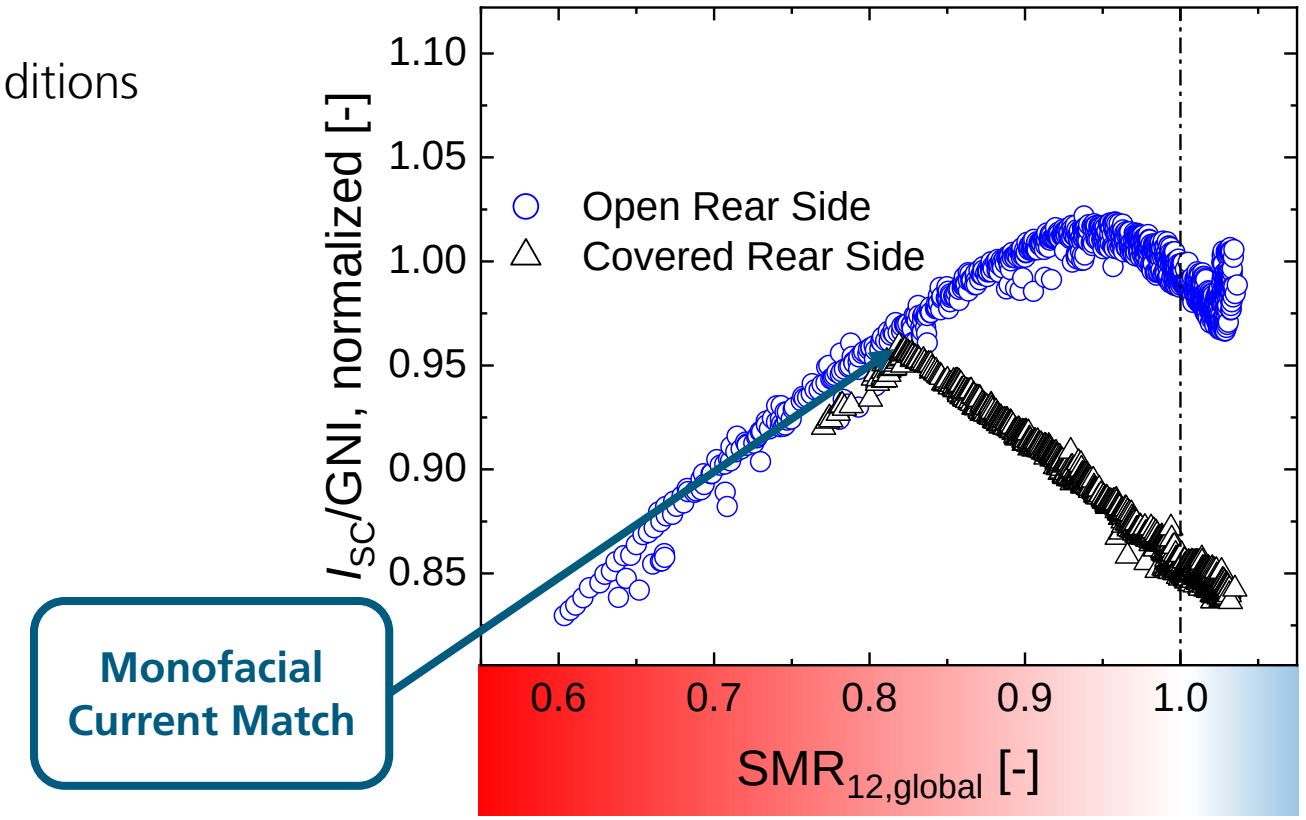
Single Cell - Bifacial Perovskite Silicon Tandem Module

Monofacial Current Match

- Monofacial Current Match
  - Current match based on frontside conditions



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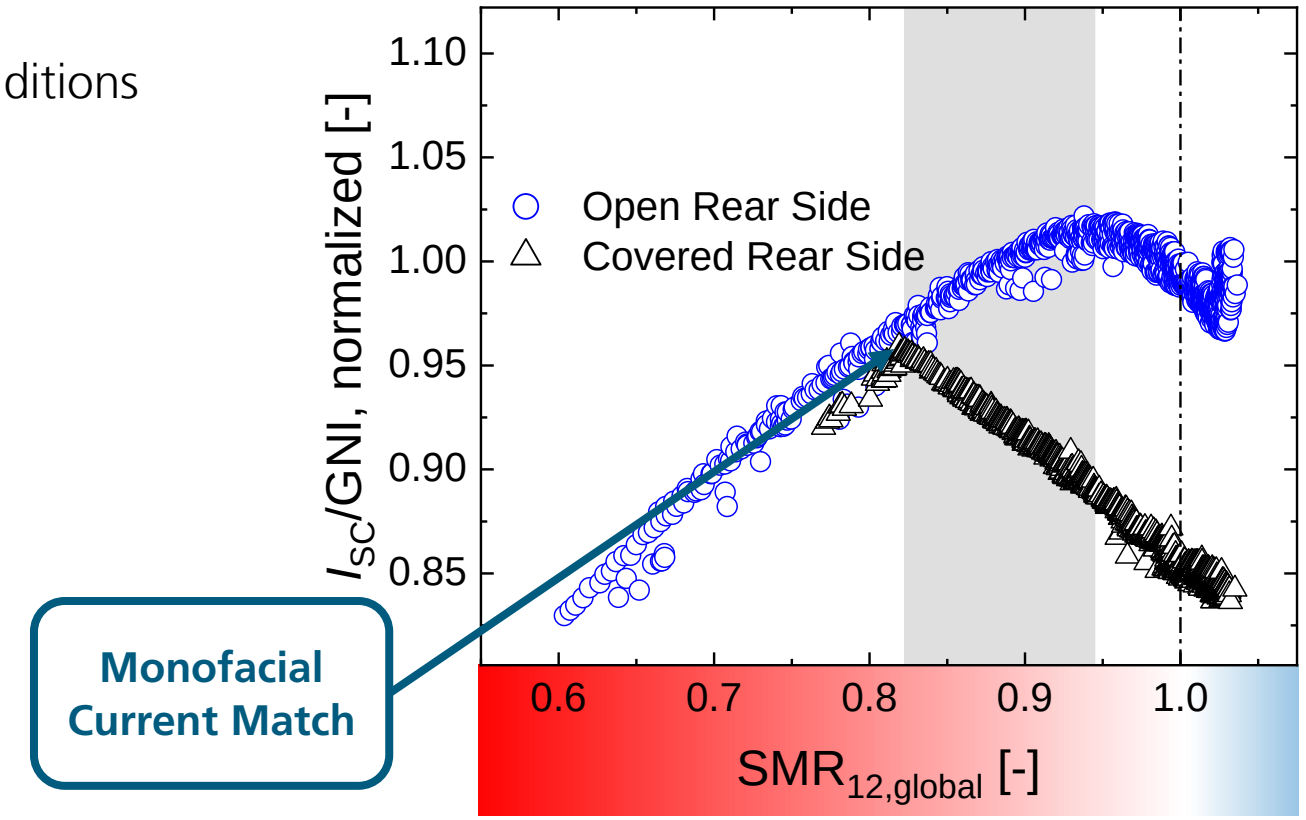
Usable Rear Side Irradiance

- Monofacial Current Match
  - Current match based on frontside conditions



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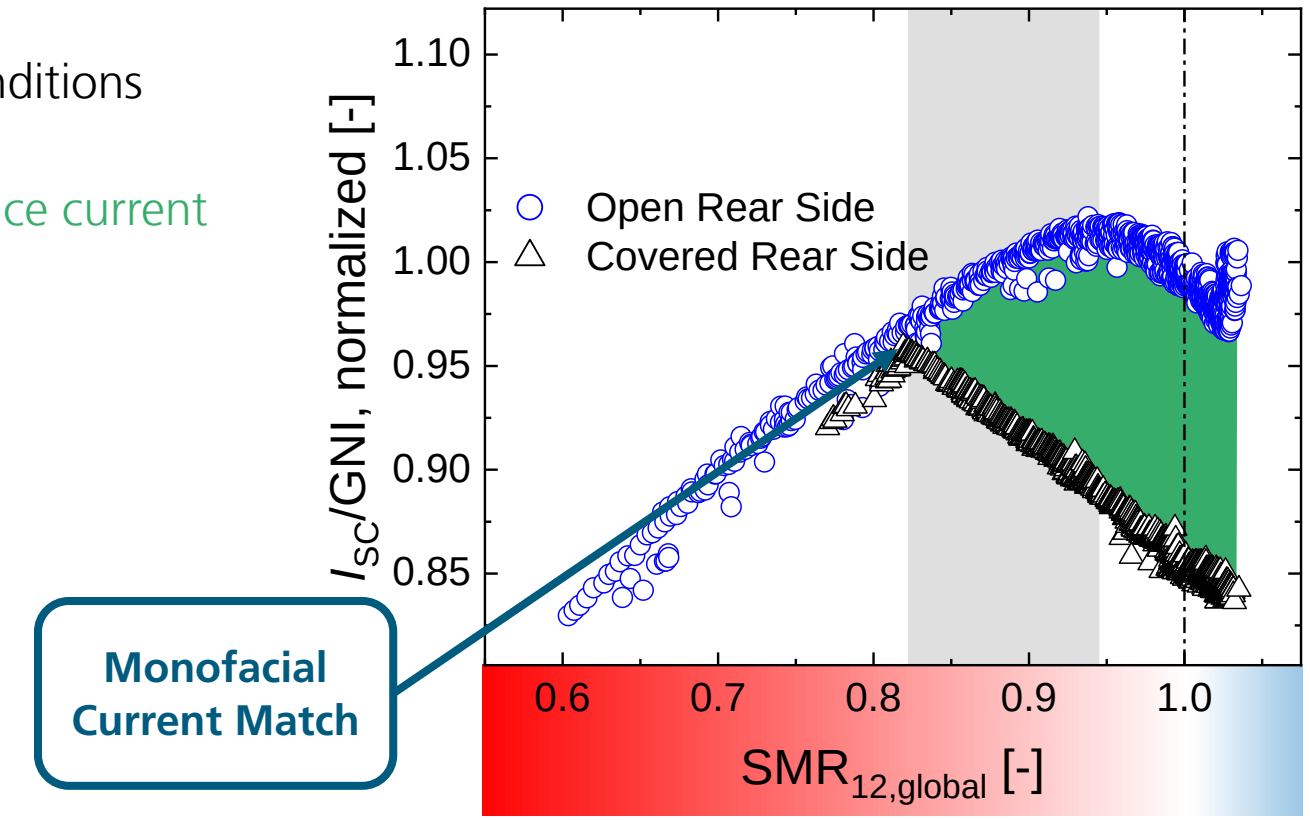
Single Cell - Bifacial Perovskite Silicon Tandem Module

Usable Rear Side Irradiance

- Monofacial Current Match
  - Current match based on frontside conditions
- Rear side irradiance contributing to device current



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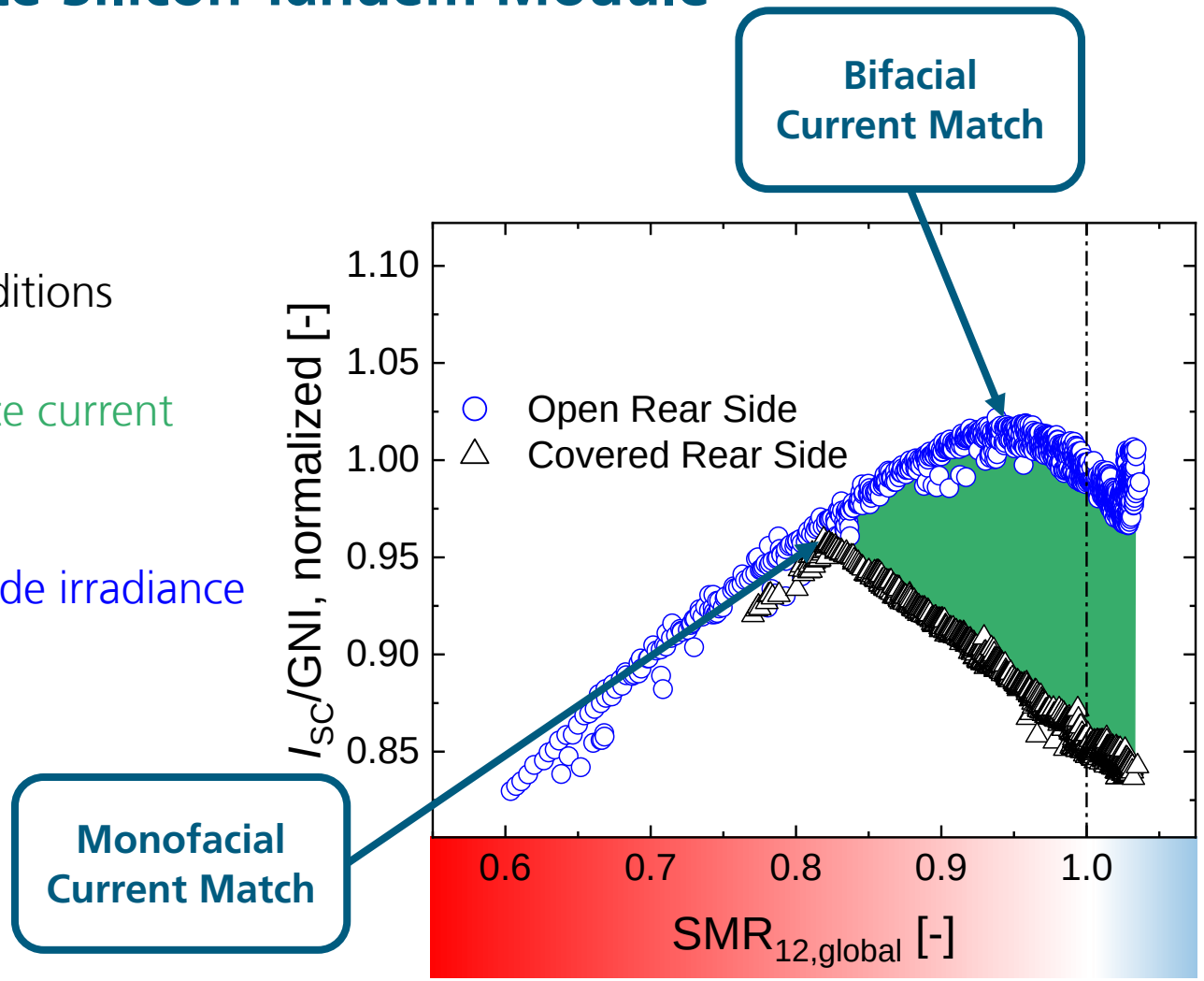
Single Cell - Bifacial Perovskite Silicon Tandem Module

Bifacial Current Match

- Monofacial Current Match
  - Current match based on frontside conditions
- Rear side irradiance contributing to device current
- Bifacial Current Match
  - Strongly dependent on available rear side irradiance



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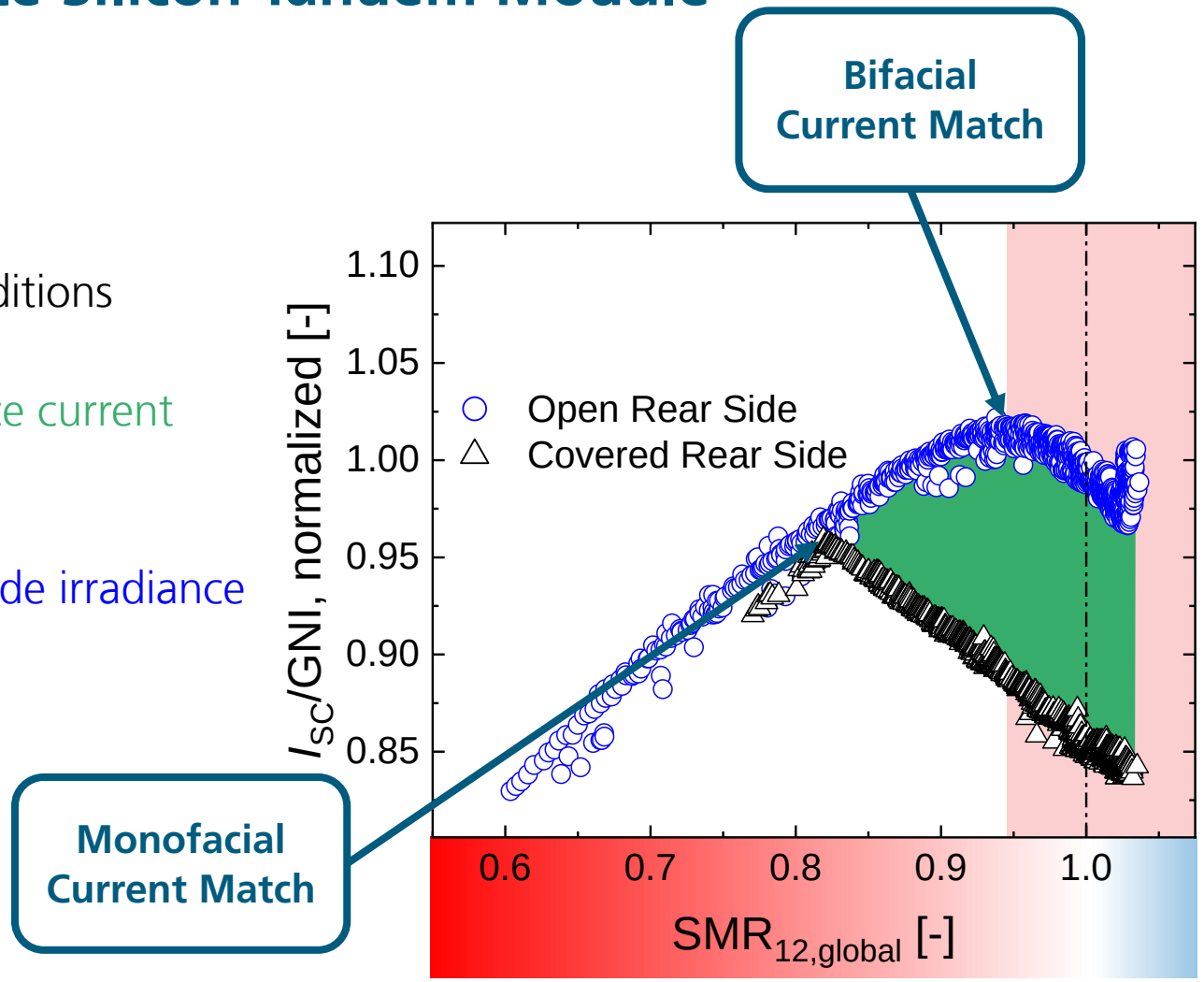
Single Cell - Bifacial Perovskite Silicon Tandem Module

Silicon Limiting Conditions

- Monofacial Current Match
  - Current match based on frontside conditions
- Rear side irradiance contributing to device current
- Bifacial Current Match
  - Strongly dependent on available rear side irradiance



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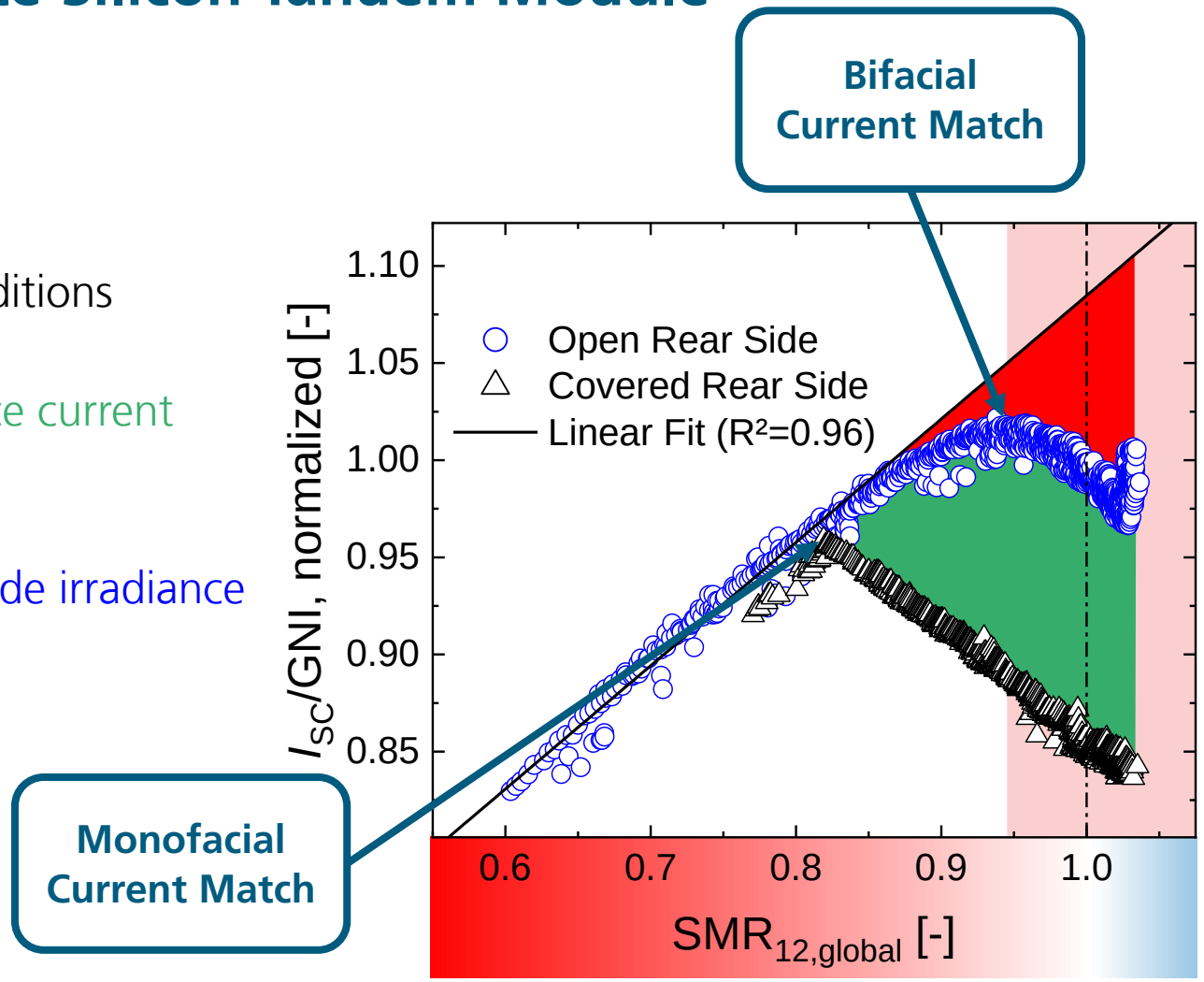
Single Cell - Bifacial Perovskite Silicon Tandem Module

Silicon Limiting Conditions

- Monofacial Current Match
  - Current match based on frontside conditions
- Rear side irradiance contributing to device current
- Bifacial Current Match
  - Strongly dependent on available rear side irradiance
- Rear side irradiance that could contribute to device current



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Full-Size - Bifacial Perovskite Silicon Tandem Module

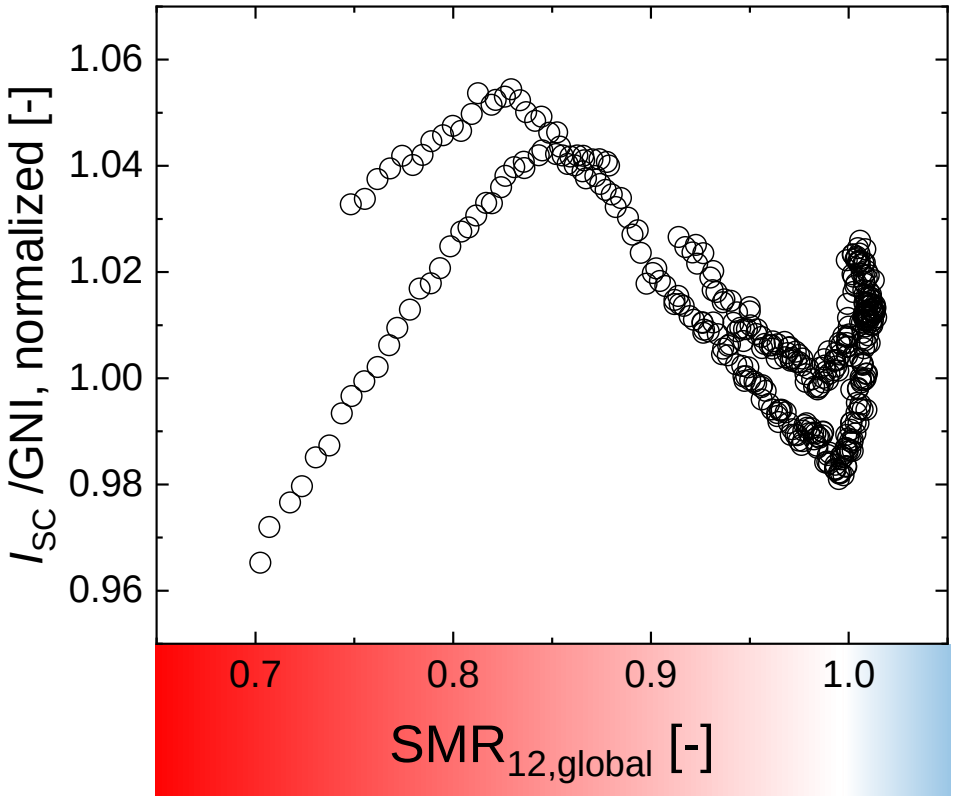
Outdoor Measurement Setup

- Module built of 60 M4 cells from Oxford PV
  - Total area: 1.91 m²
- Mounted on a dual axis tracker
- Measurements carried out with an open rear side

[5] Chojniak et al.: Outdoor measurements of a full-size bifacial Pero/Si tandem module under different spectral conditions; 2023; DOI: 10.1002/pip.3753

Full-Size - Bifacial Perovskite Silicon Tandem Module

Understanding Outdoor Measurement Results



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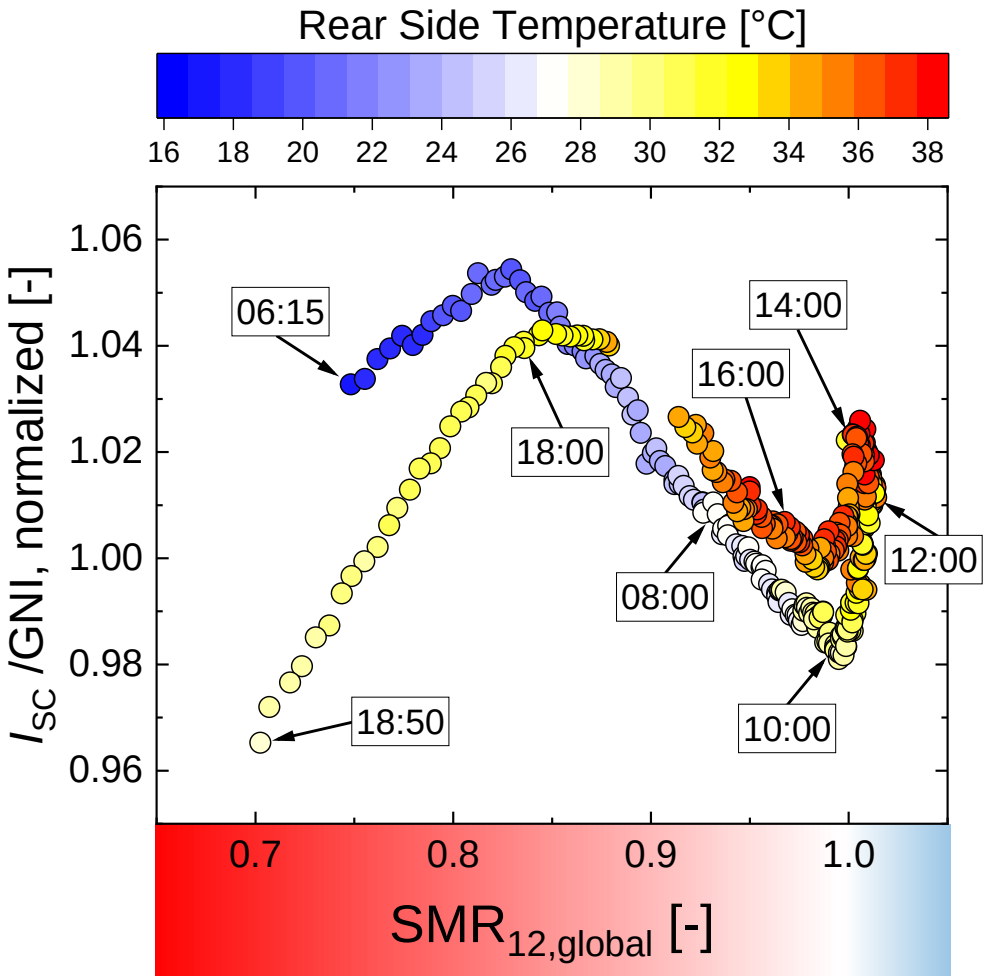

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Full-Size - Bifacial Perovskite Silicon Tandem Module

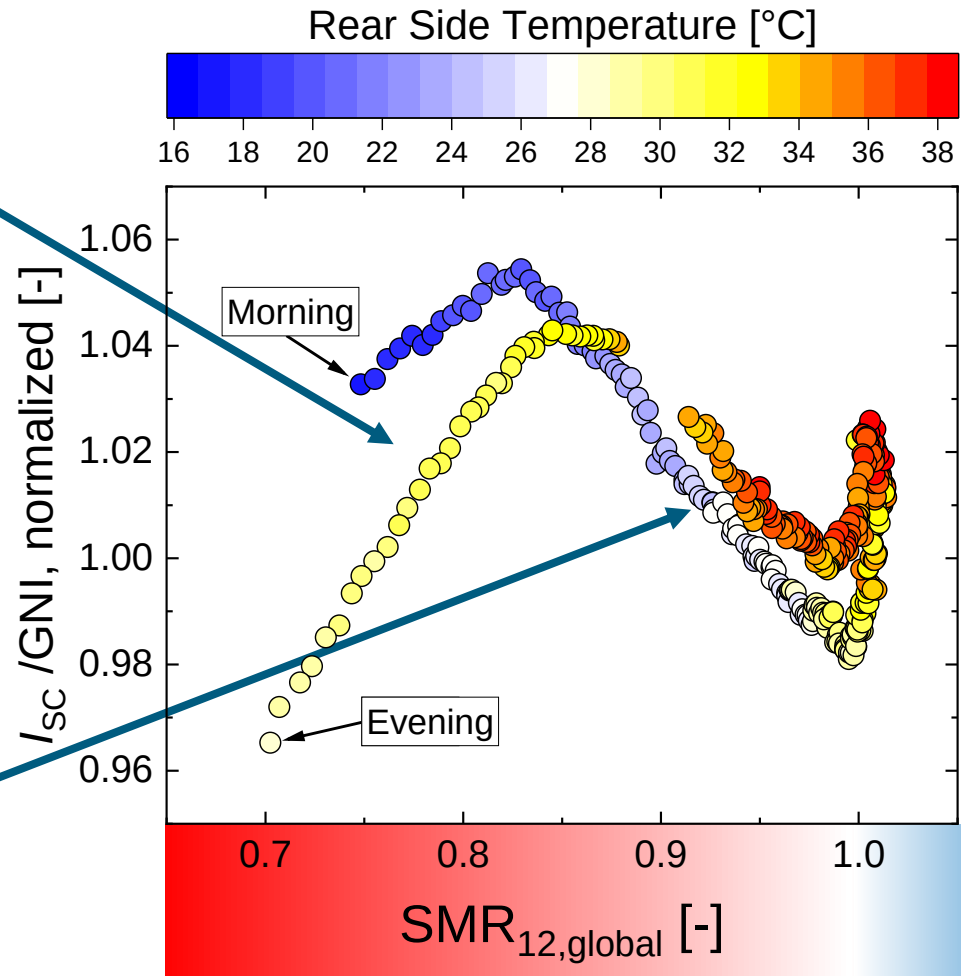
Understanding Outdoor Measurement Results

Perovskite limiting conditions

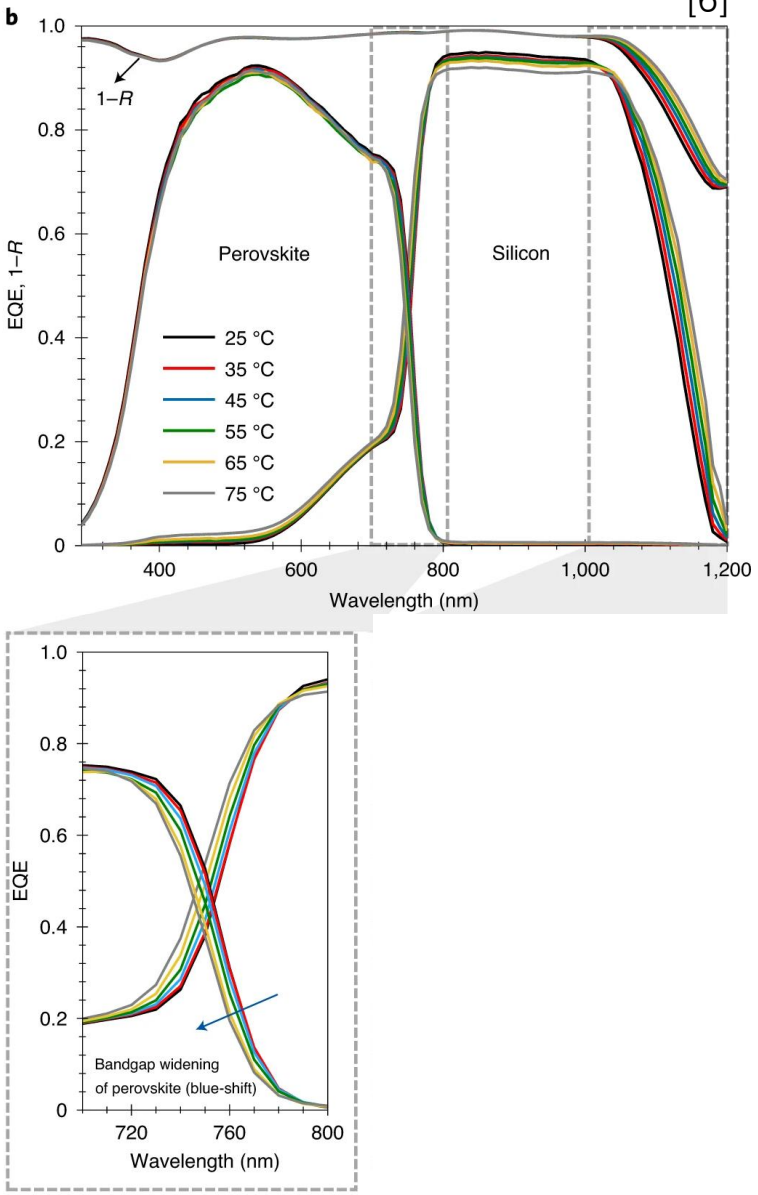
Negative I_{SC} temperature coefficient [6]

Silicon limiting conditions

Positive I_{SC} temperature coefficient



[6]



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[6] Aydin et al.: Interplay between temperature and bandgap energies on the outdoor performance of perovskite/silicon tandem solar cells; 2020; DOI: 10.1038/s41560-020-00687-4

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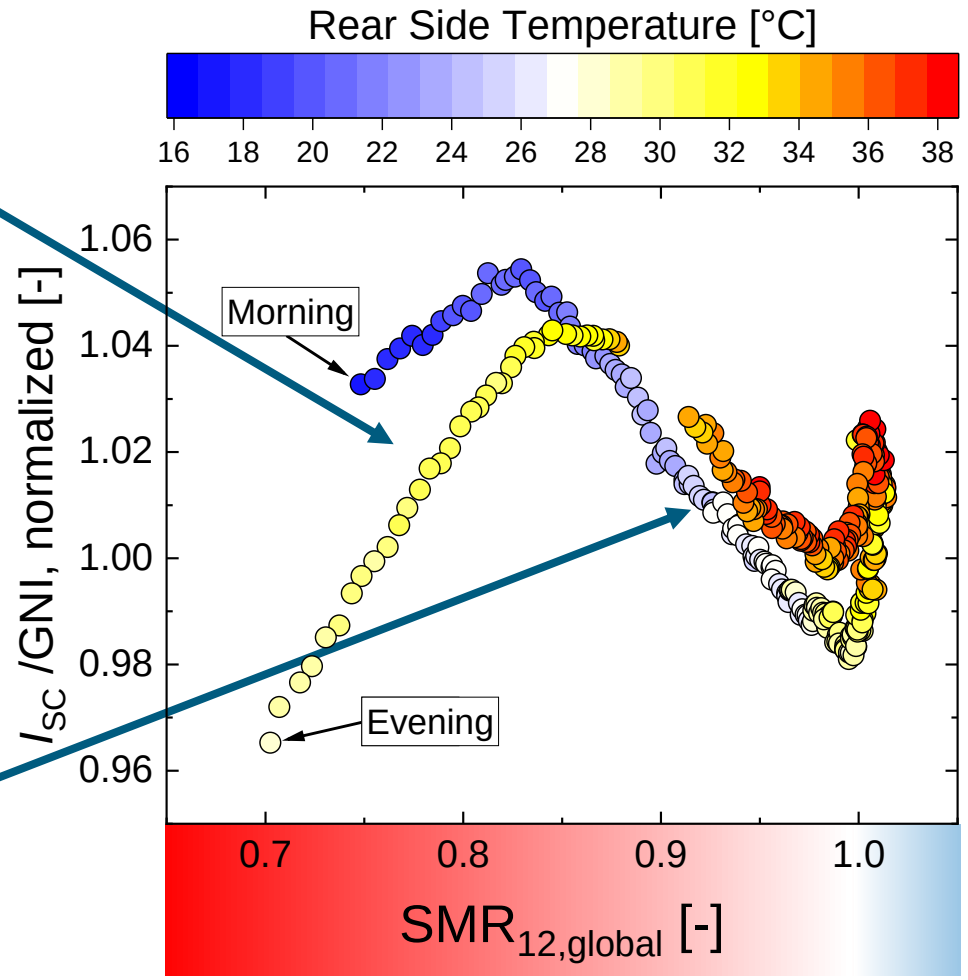

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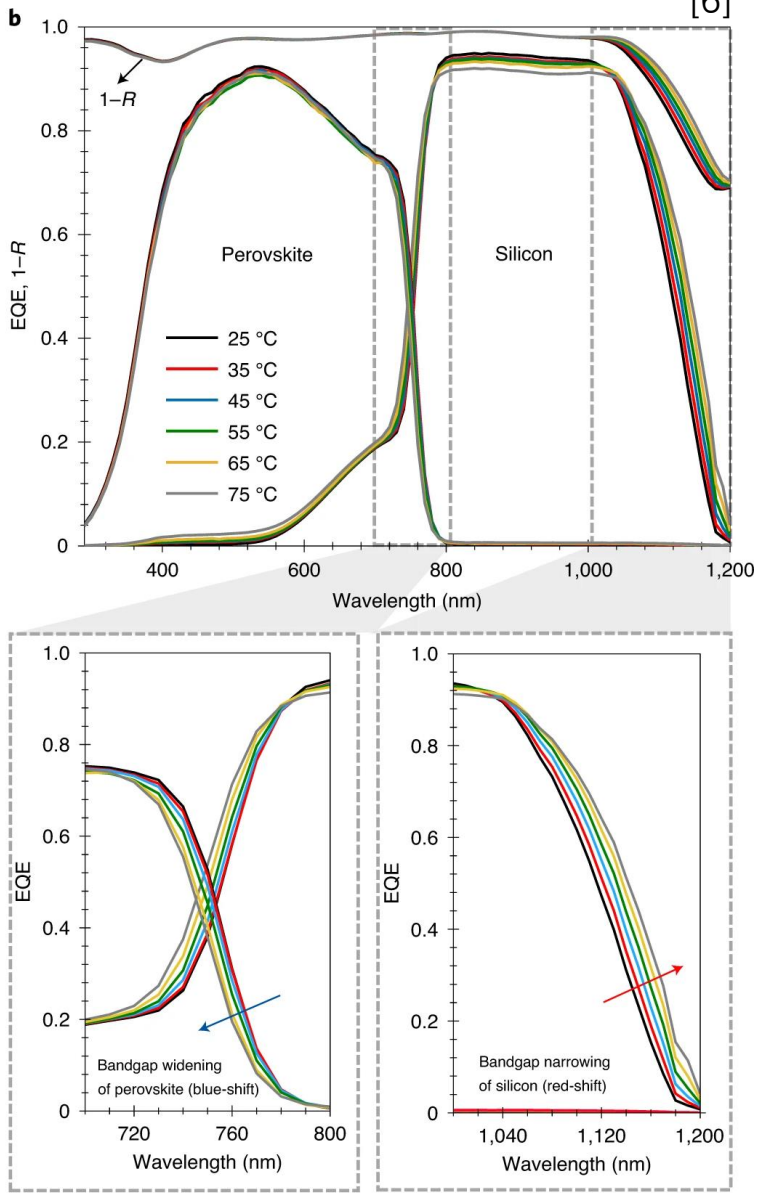

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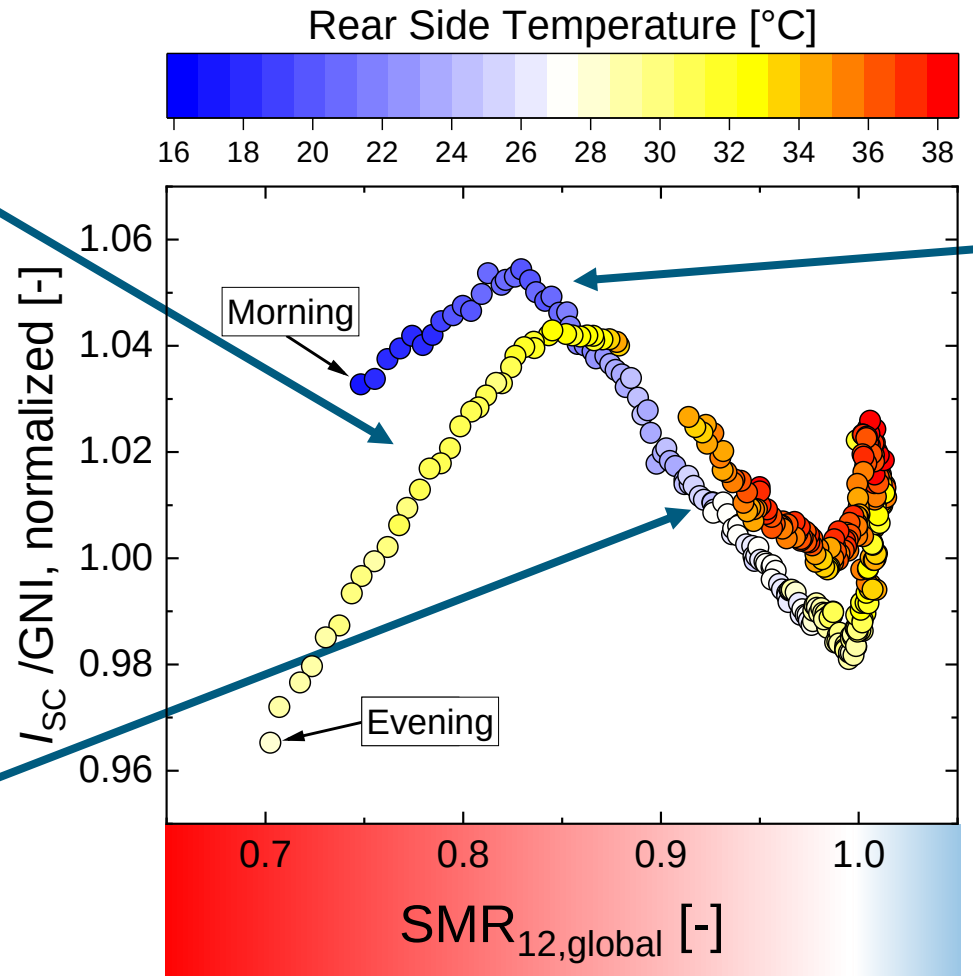

Opposing I_{SC} temperature coefficients

Position of bifacial current match changes

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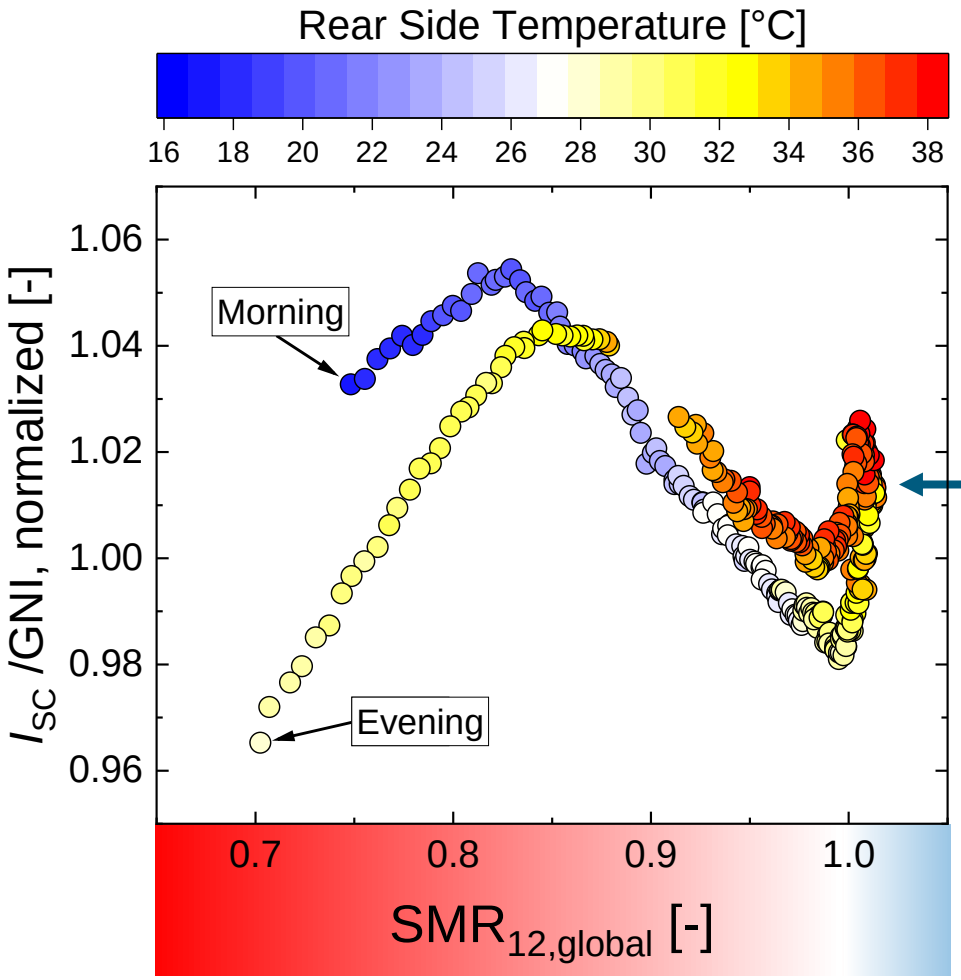

Silicon limiting conditions

Increasing RSI and temperature

Relatively constant frontside conditions

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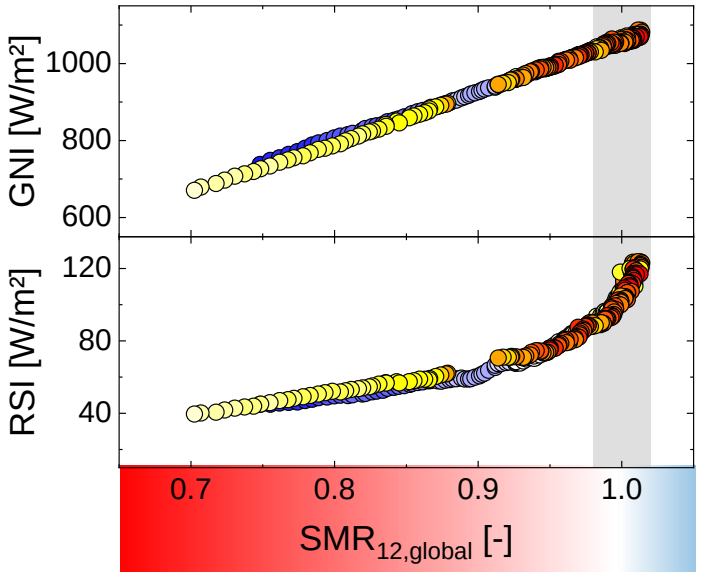

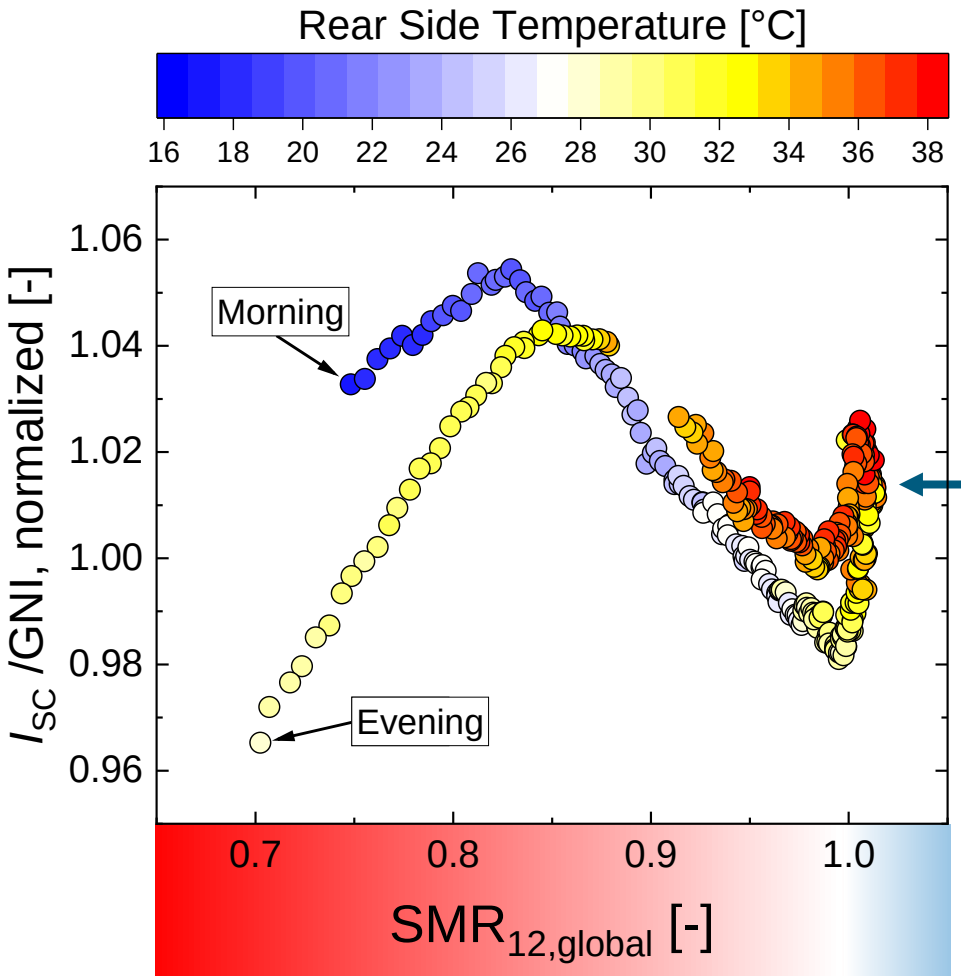

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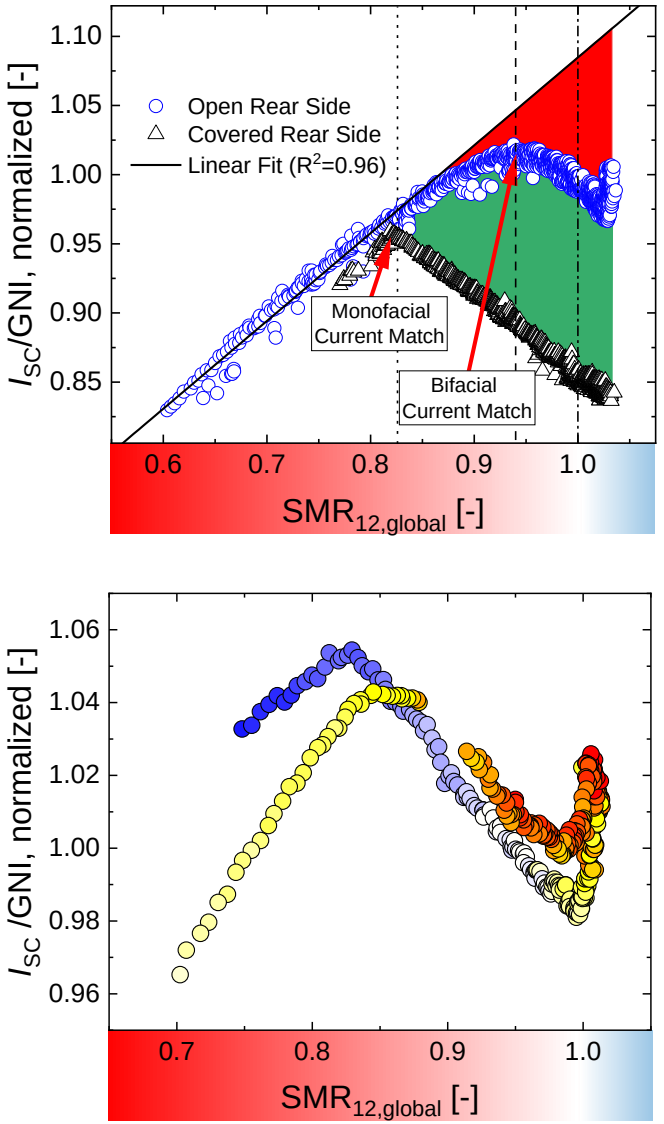
Conclusion

Key Messages

- "**Useable**" rear side irradiance is strongly dependent on front side conditions



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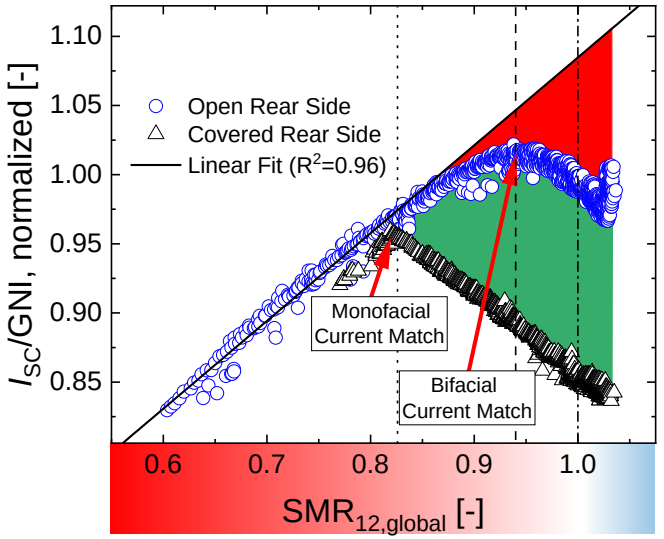
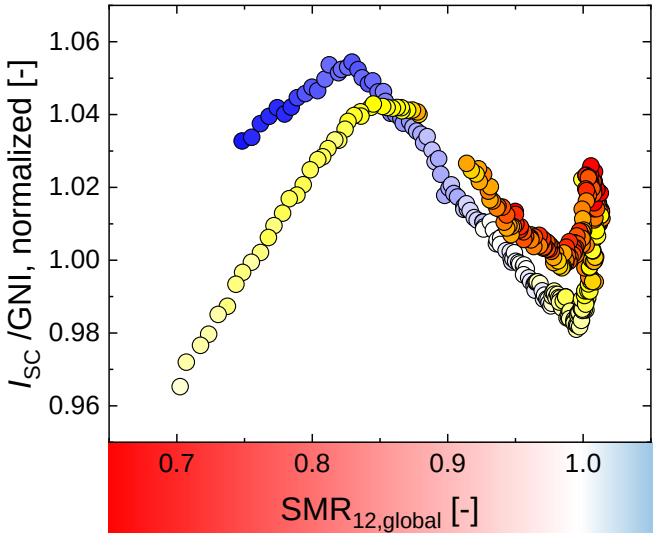
Conclusion

Key Messages

- "**Useable**" rear side irradiance is strongly dependent on front side conditions
- The position of the bifacial current match is determined by the available rear side irradiance





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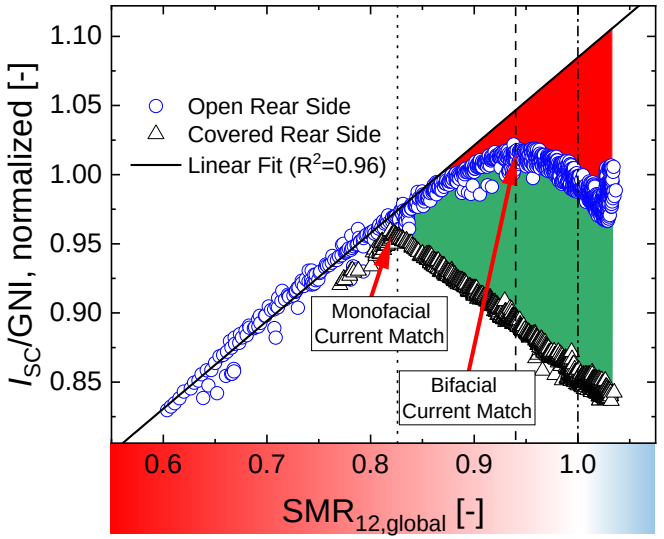
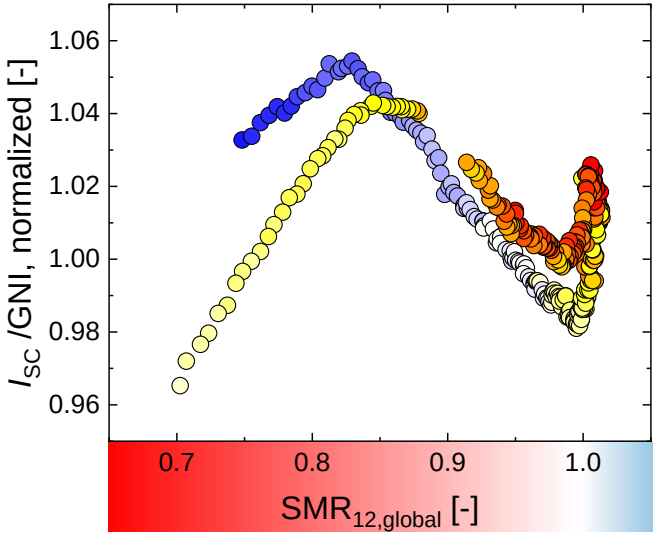
Conclusion

Key Messages

- "**Useable**" rear side irradiance is strongly dependent on front side conditions
- The position of the bifacial current match is determined by the available rear side irradiance
- Ideal performance → Carefully evaluating outdoor conditions and understanding the sub-cells' interplay mainly driven by:
  - Frontside spectral conditions
  - Rear side irradiance intensity
  - Device Temperature





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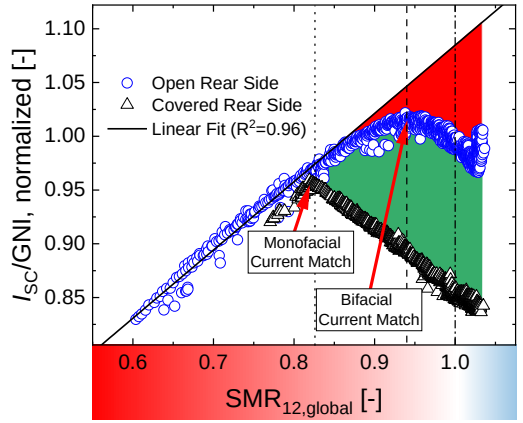

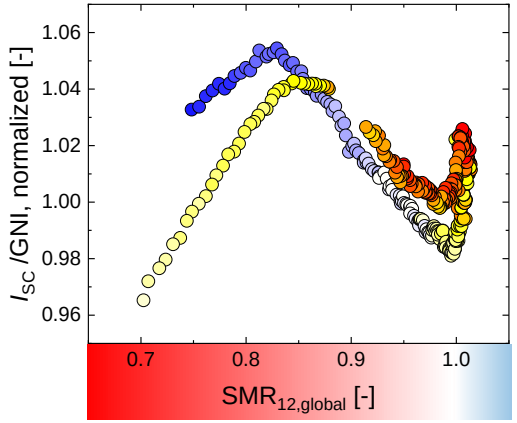

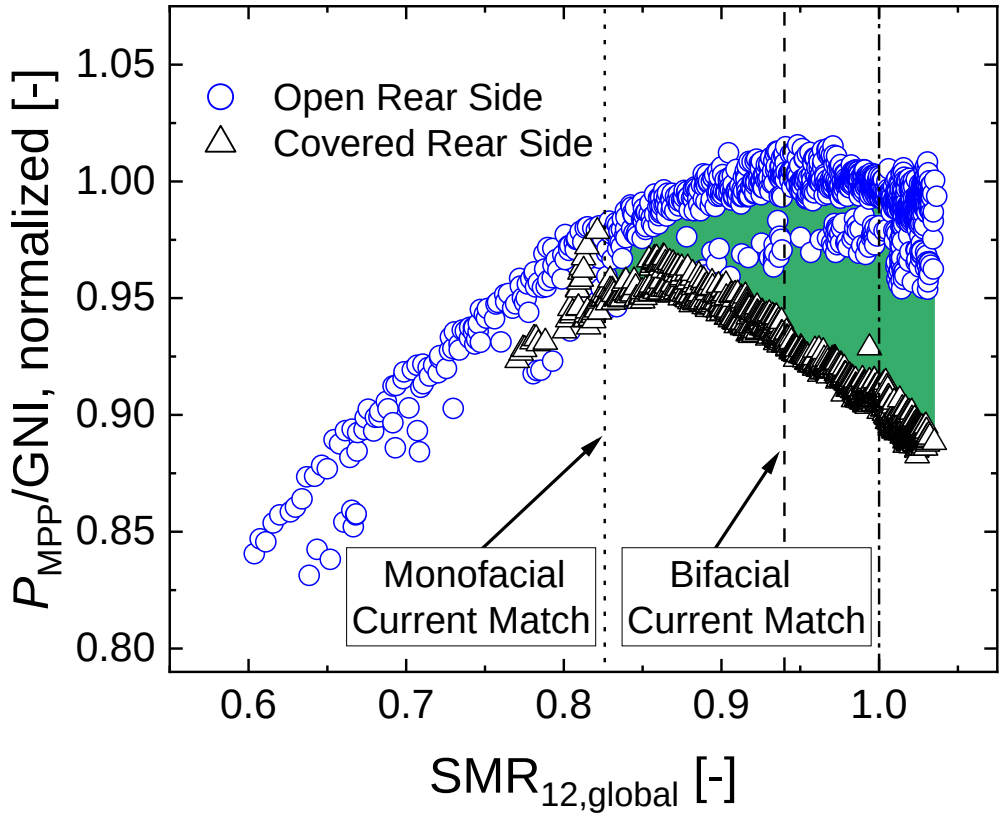

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Acknowledgements

- **Thank you for your attention**
- **Thanks to all co-workers and colleagues**
- **Thanks to Oxford PV for providing measurement objects**
- **Thanks for funding**
  - German Federal Ministry for Economic Affairs and Climate Action, project **KATANA** (contract number 03EE1087A)

Bundesministerium für Wirtschaft und Klimaschutz

OXFORD PV™
The Perovskite Company

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