PCCL
Polymer Competence Center Leoben

Adapting Module design and BOM for harsh climates

Understanding of material response to extreme climatic conditions

Dr. Gernot Oreski

Polymer Competence Center Leoben GmbH,
Roseggerstraße 12, 8700 Leoben
+43 664 88679331
gernot.oreski@pccl.at

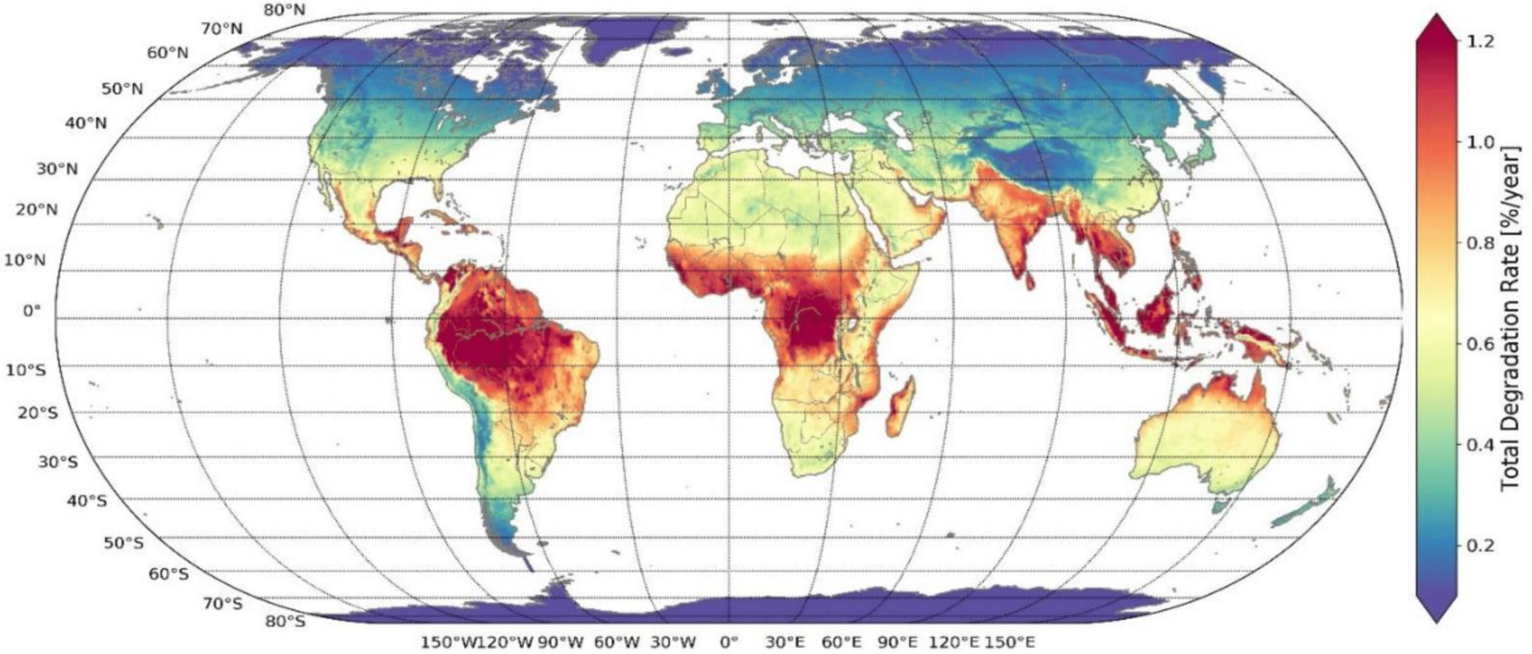
Golden (USA), October 15th 2024

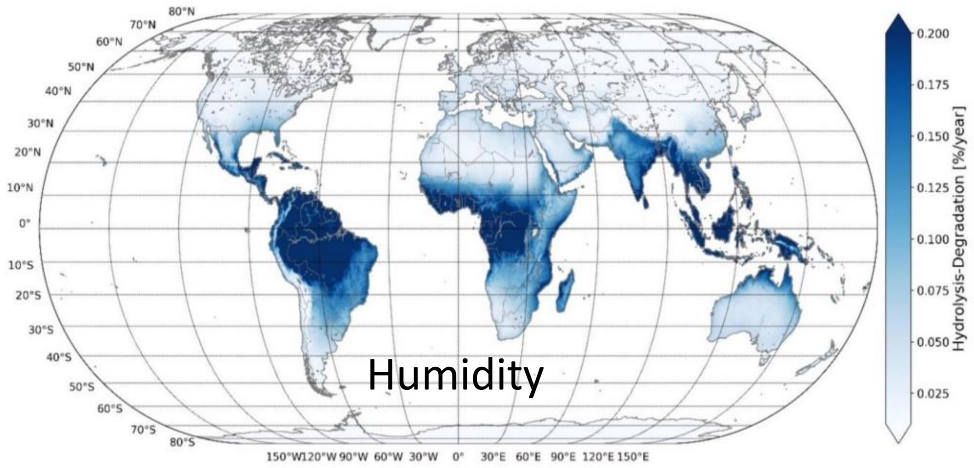
PCCL
Polymer Competence Center Leoben

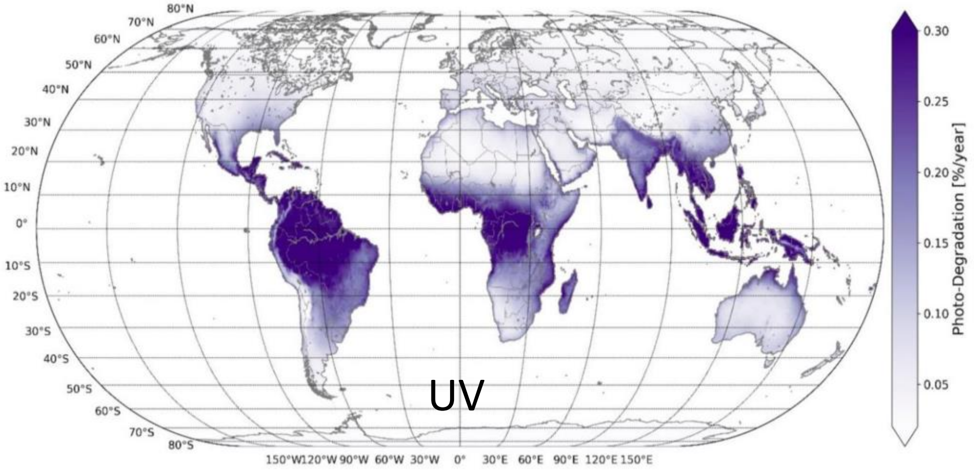
Harsh climates?

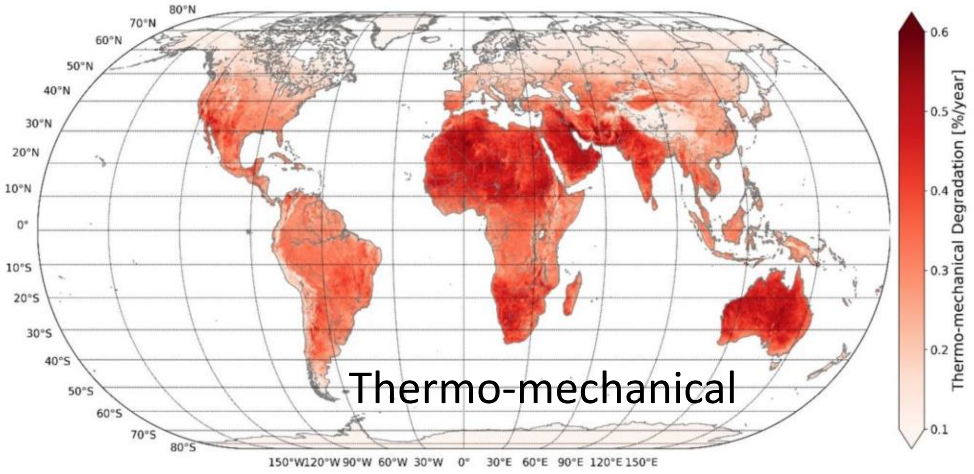
Introduction

Harsh climates?







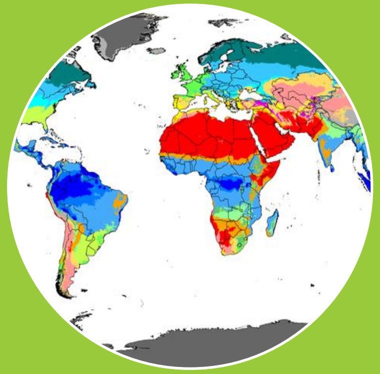


Ascencio-Vásquez, J.; Kaaya, I.; Brecl, K.; Weiss, K.-A.; Topič, M. Global Climate Data Processing and Mapping of Degradation Mechanisms and Degradation Rates of PV Modules. *Energies* **2019**, *12*, 4749. https://doi.org/10.3390/en12244749

Introduction - Motivation

PCCL
Polymer Competence Center Leoben

What do we need to know in order to adapt PV module design for harsh climatic conditions?

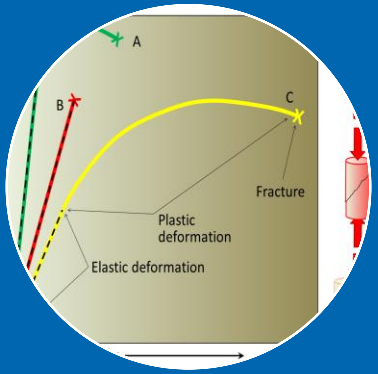


Climate

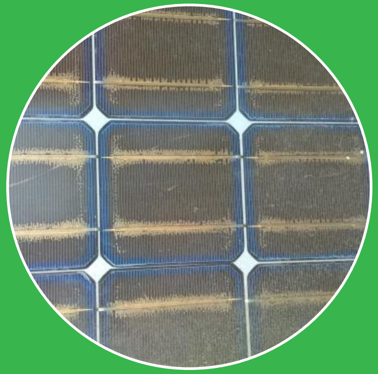
N Engl J Med 2012; 366:e25
DOI: 10.1056/NEJMicm1104059

Microclimate

Stressors



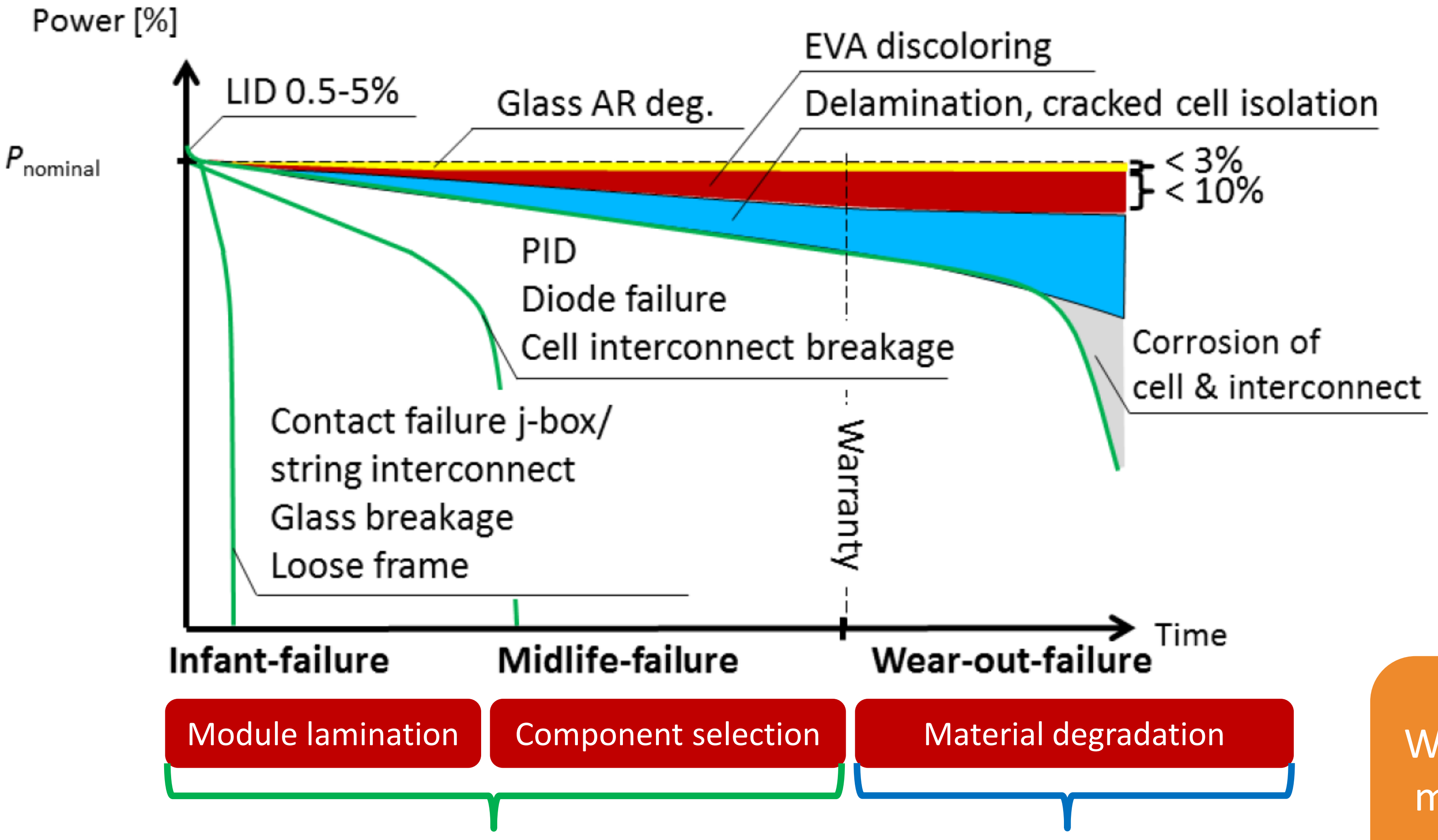
Material response



Failure modes

Failure scenarios of c-Si PV modules

PCCL Polymer Competence Center Leoben



***Mostly avoidable:** Extensive R&D, quality and reliability testing needed*

***Delayable** to some extent with proper stabilization*

International Energy Agency
Photovoltaic Power Systems Programme

Task 13 Performance, Operation and Reliability of Photovoltaic Systems

- Köntges et al. (2014) IEA-PVPS Task 13 Report on "Review of Failures of Photovoltaic Modules"
- Update to be published end of 2024

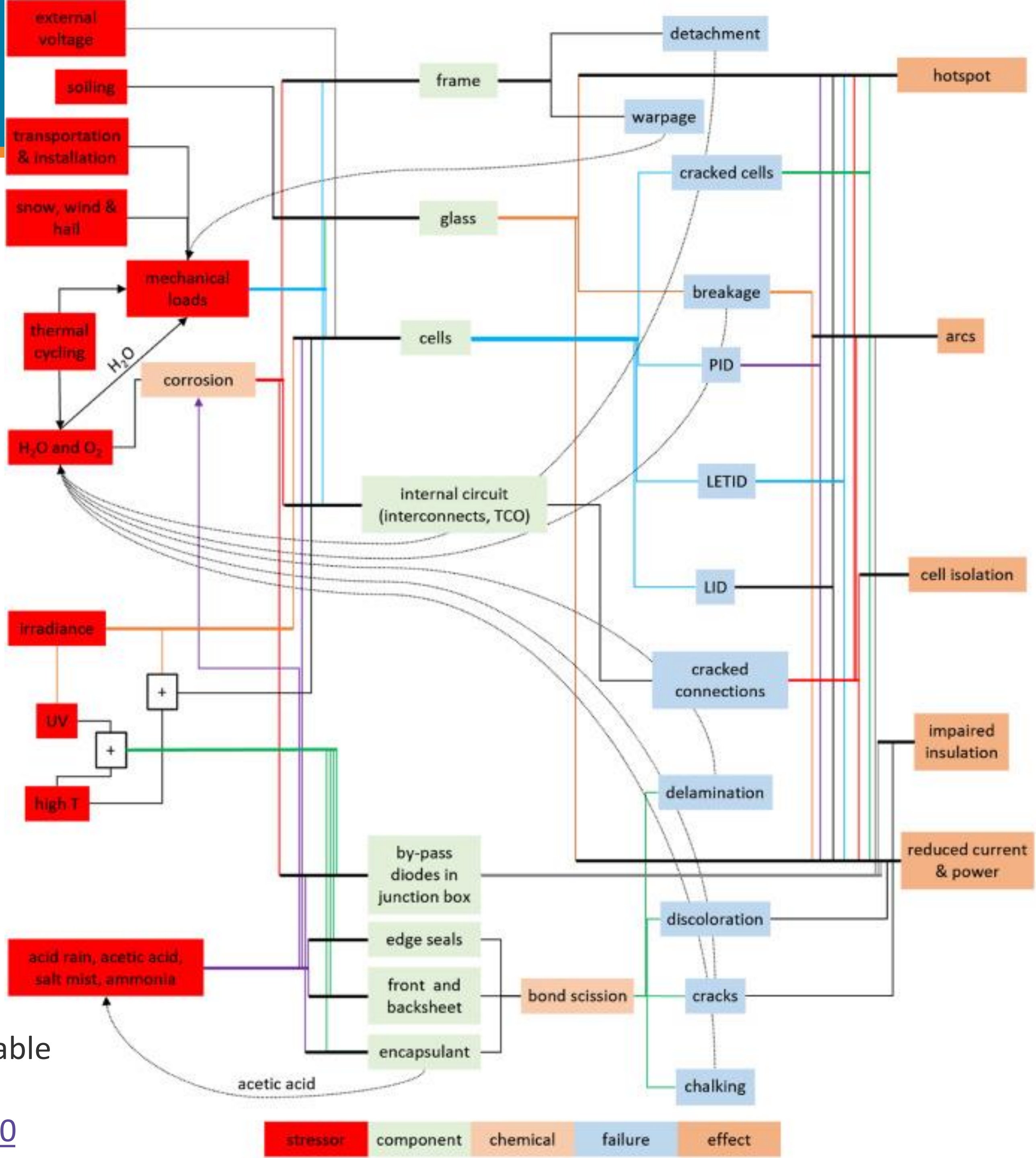
Wear out failure and midlife failure modes are strongly dependent on micro-climatic conditions

Importance of bill of materials

Flow diagram representing the relationships between stressor, component, failure and effect

Change of one component/material may affect the noted relationships

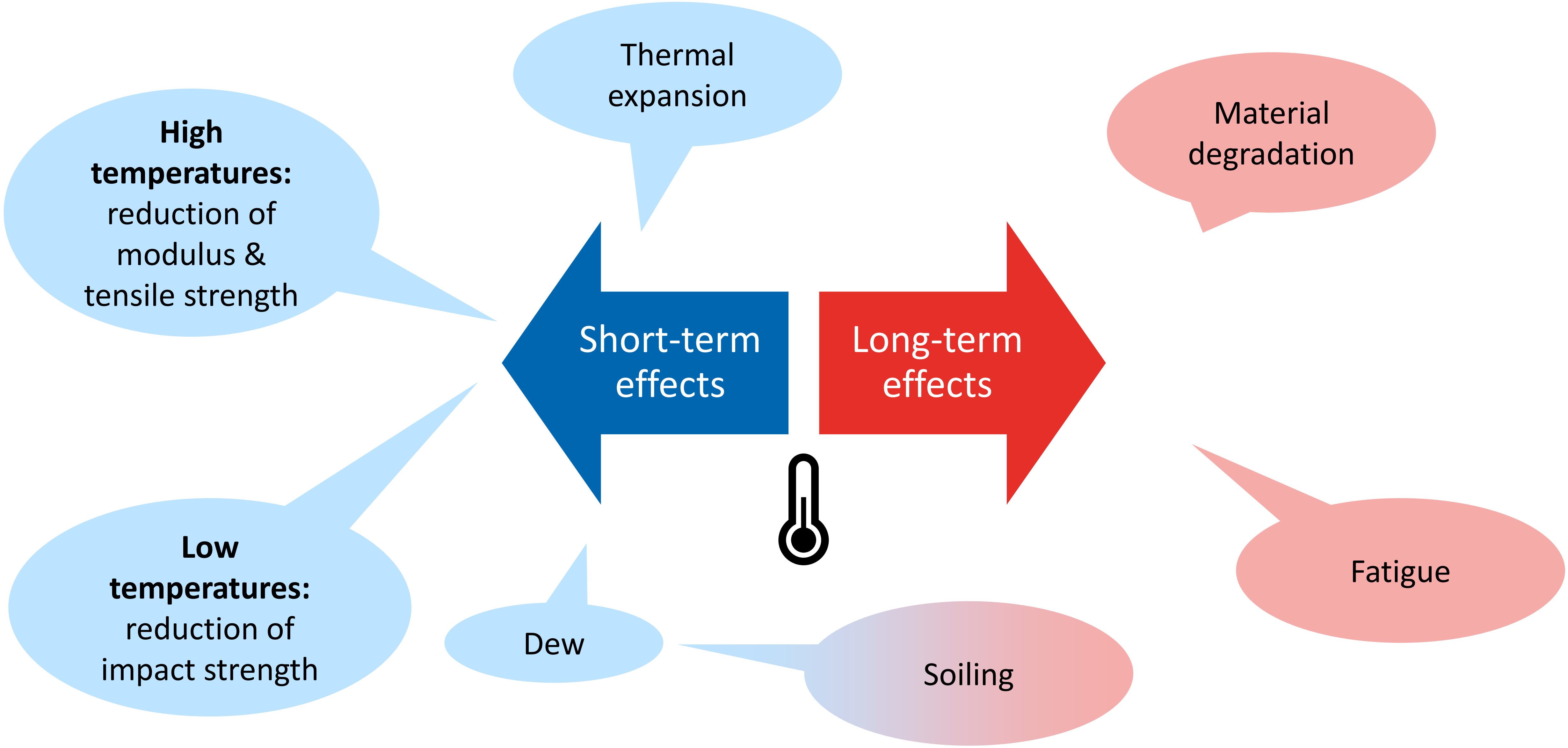
- Lines are coloured to discern line crossings
- Thick black lines to the left of the "component" and "effect" are there to indicate the termination of the connector from the previous point in the flow diagram
- Thick coloured lines to the right indicate branching
- Dotted lines indicate when failure results in a new stressor



M. Aghaei *et al* 2022 Renewable and Sustainable Energy Reviews 159, 112160, https://doi.org/10.1016/j.rser.2022.112160

Material response

Material response to stressors – temperature



Temperature dependent behavior of polymers

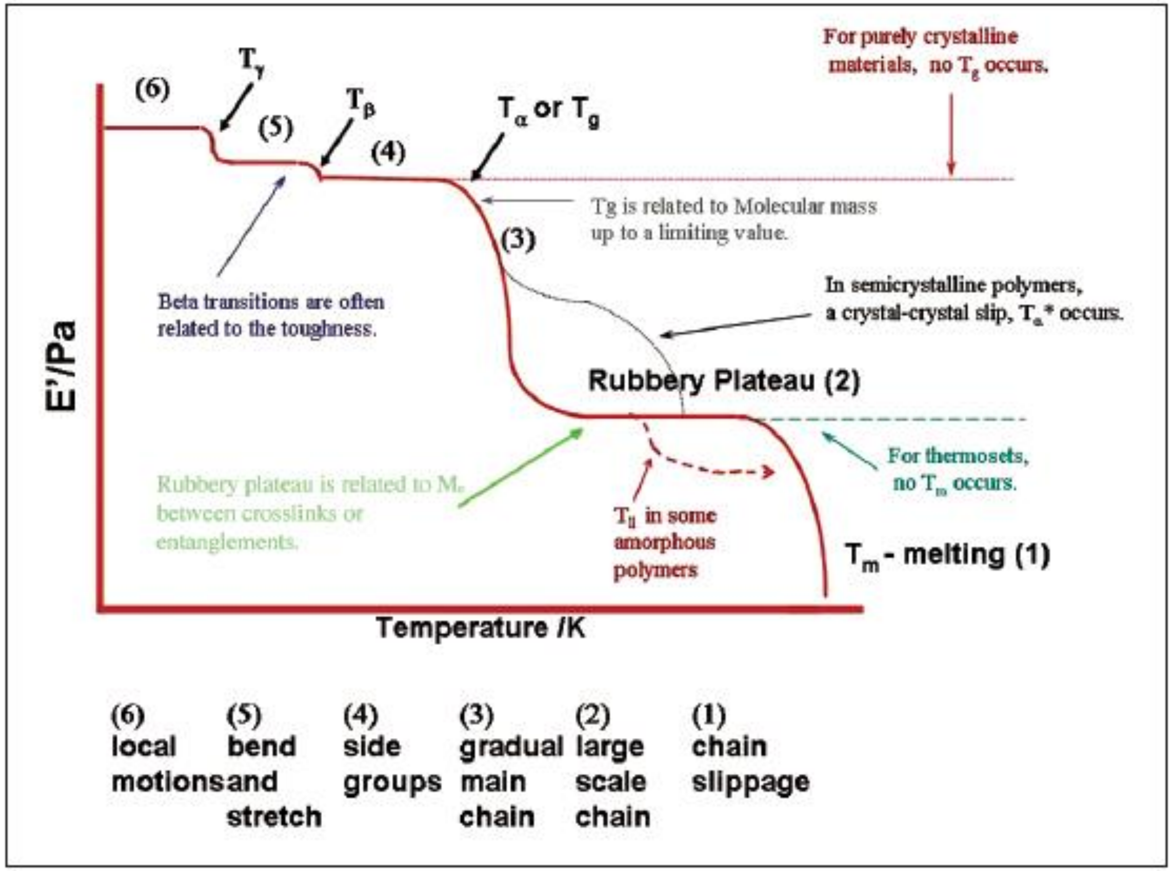
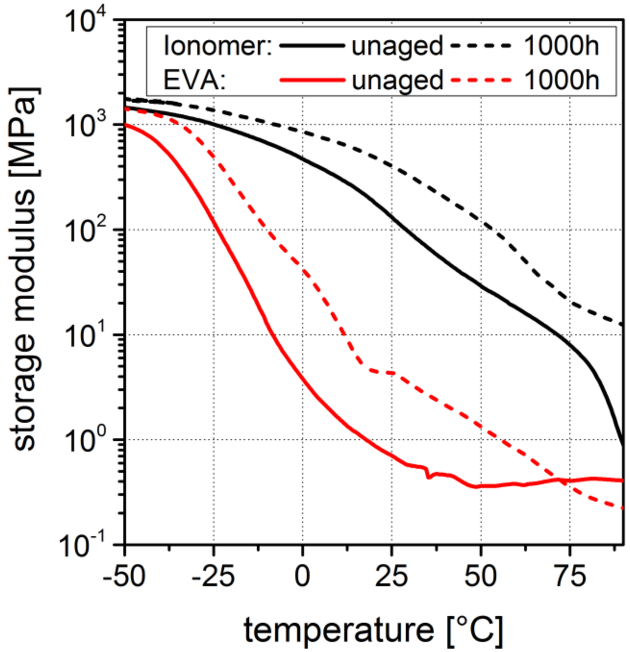


Figure 3. Modulus values change with temperature and transitions in materials can be seen as changes in the E' or tan delta curves.

https://resources.perkinelmer.com/corporate/cmsresources/images/44-74546gde_introductiontodma.pdf

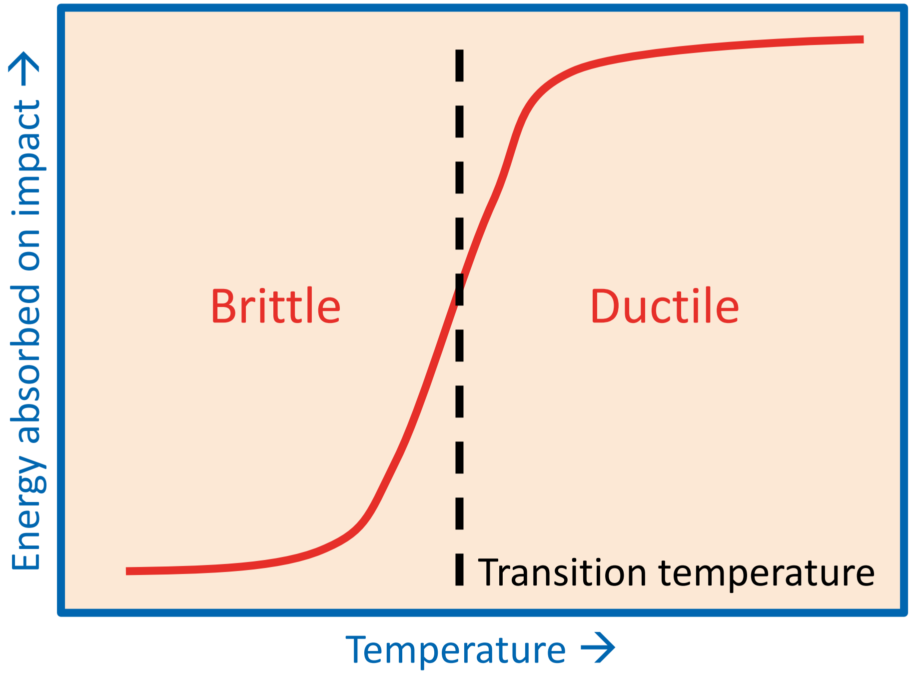


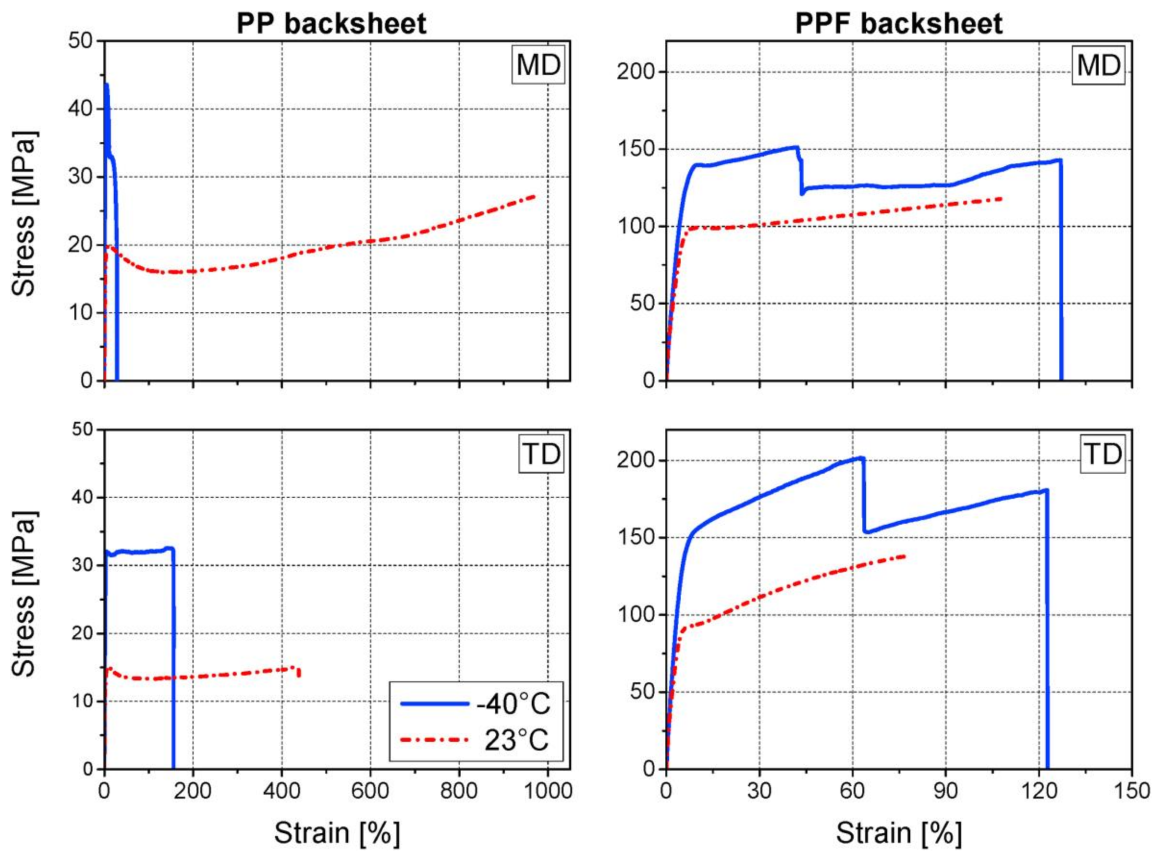
At low temperatures encapsulant materials like EVA are significantly stiffer (Factor up to of 10^3) than at typical PV module operating temperatures

Gernot Oreski, Bettina Ottersböck, Antonia Omazic, 6 - Degradation Processes and Mechanisms of Encapsulants, Editor(s): Hsinjin Edwin Yang, Roger H. French, Laura S. Bruckman, In Plastics Design Library, Durability and Reliability of Polymers and Other Materials in Photovoltaic Modules, William Andrew Publishing, 2019, Pages 135-152, ISBN 9780128115459,
https://doi.org/10.1016/B978-0-12-811545-9.00006-9

Impact of low temperature

Ductile brittle transitions of polymers





https://doi.org/10.1016/j.solmat.2021.110976

- Reduction of ductility at low temperatures
- Reduction of impact strength increase chances of mechanical damage

- Some backsheets show different behavior at low temperatures, e.g.
  - ✓ *PP backsheets have a ductile-brittle transition*
  - ✓ *Delaminations at low temperature*

Impact of low temperature

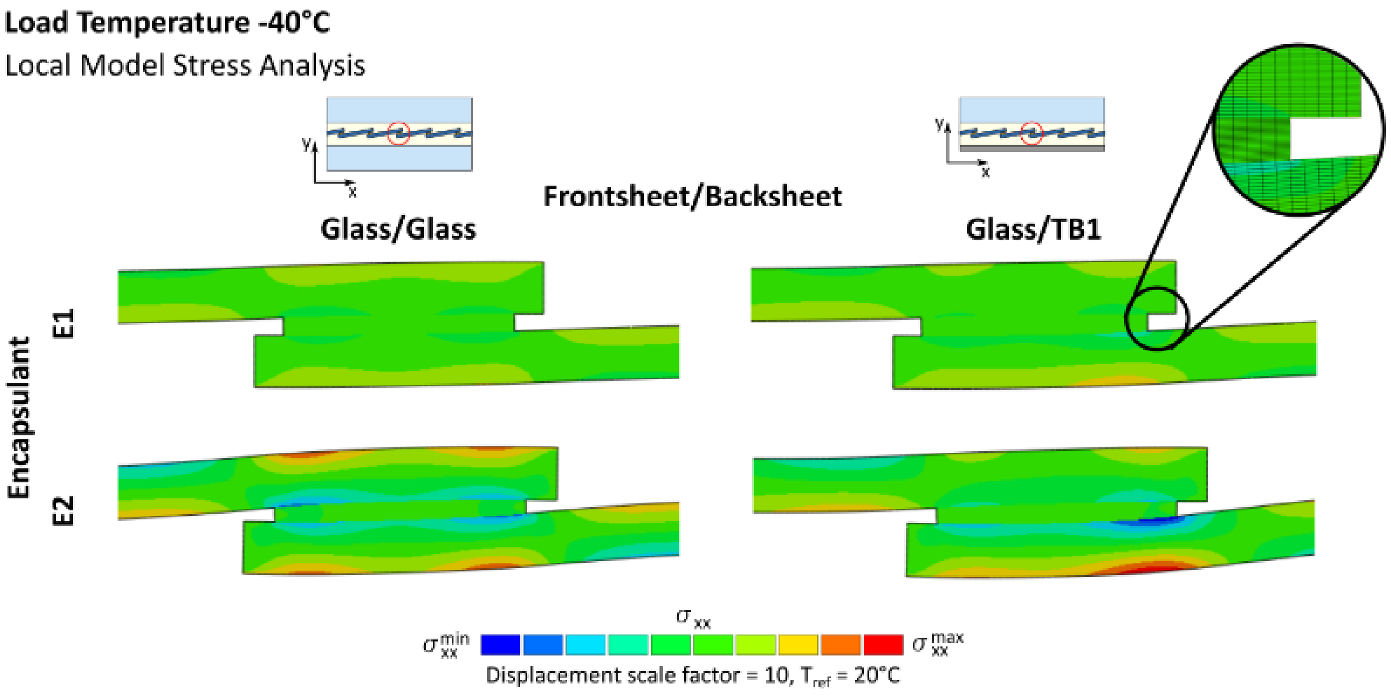
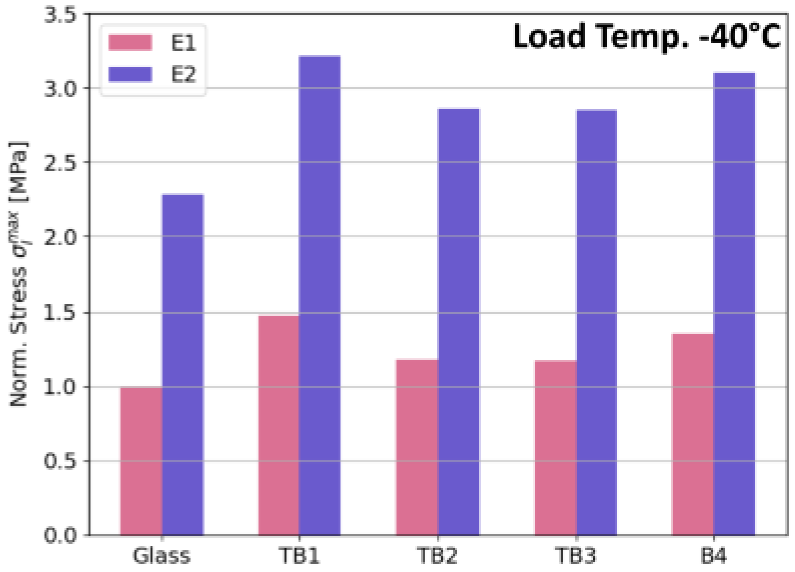


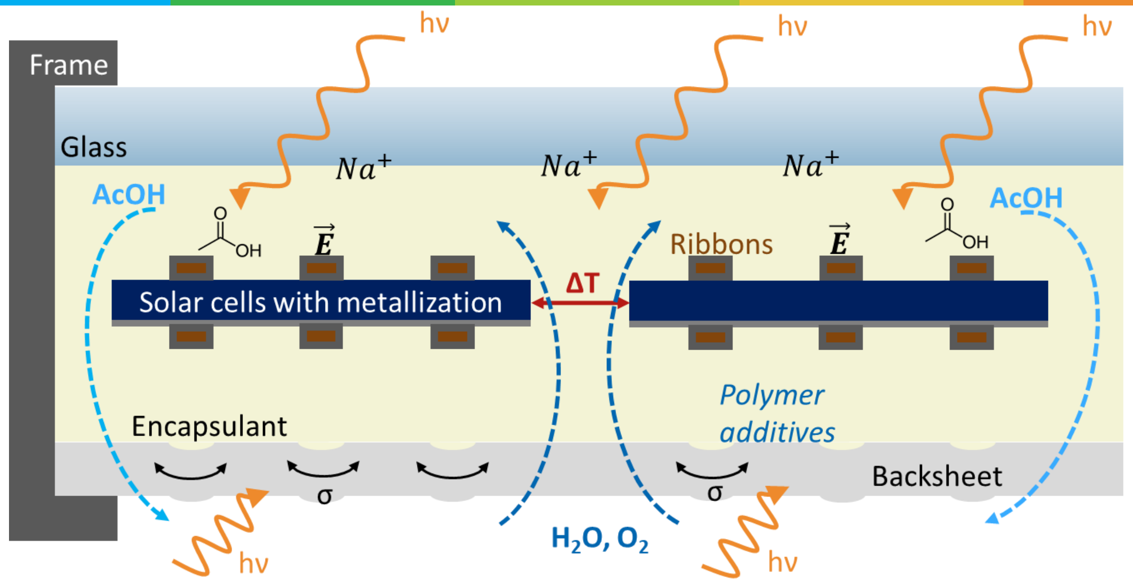
Figure 2: Deformation figure of shingle joint and adjacent silicon cells for different combinations of frontsheet/backsheet and different encapsulants. A contour plot of the stress component in x-direction is overlaid to indicate the maximum (tensile) and minimum (compression) location of the stress component. A detail of the finite element mesh used for the local model is shown.



https://doi.org/10.1063/5.0126221

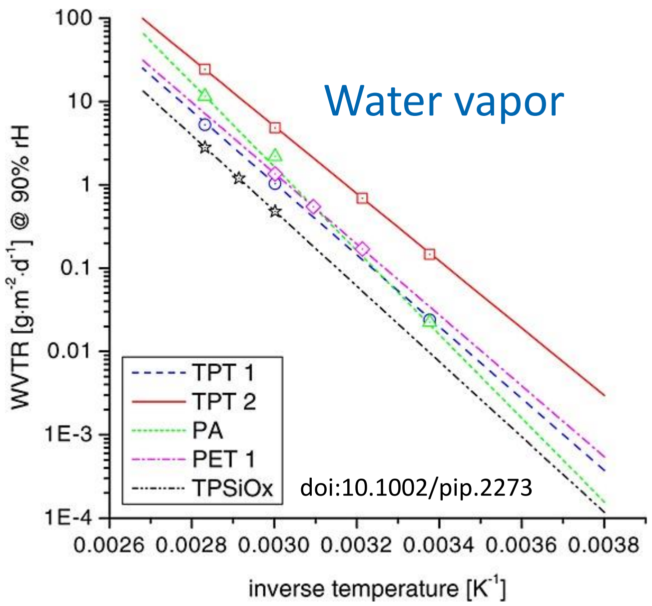
- Higher stiffness of the encapsulant will lead to higher stresses in cell and interconnection
- Potential fatigue loads due to temperature changes

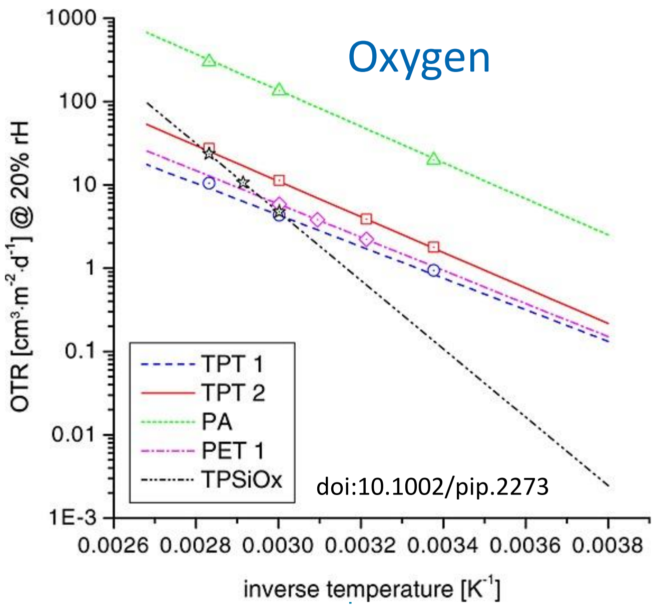
Effect of temperature



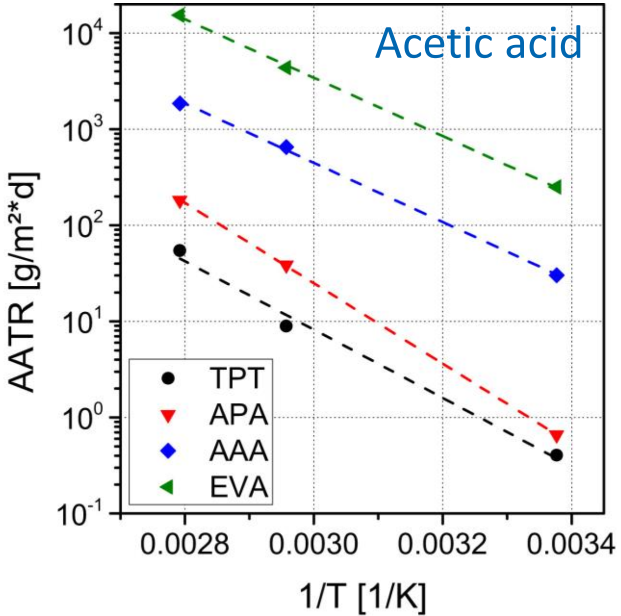
- Polymers used in PV modules enable mass, heat and stress transfer to other components
- Temperature influences transfer properties

Empirical "Van't Hoff" rule:
An increase of temperature of 10K leads to an increase in the reaction rate by a factor of 2 to 3.



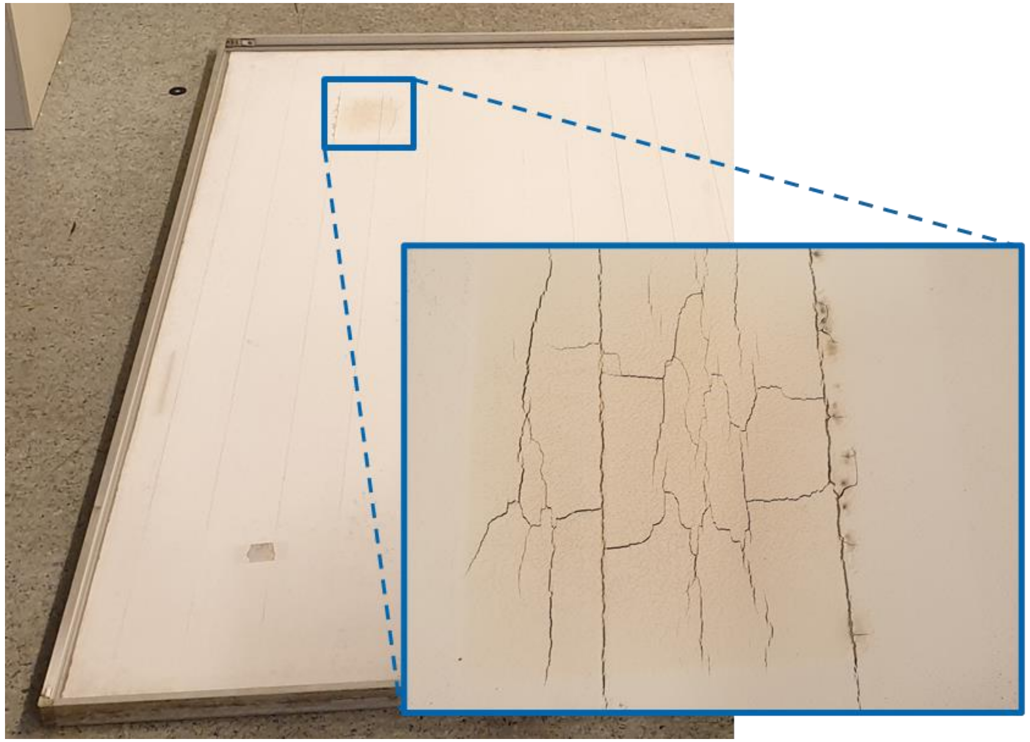


https://doi.org/10.1016/j.polymertesting.2017.04.025



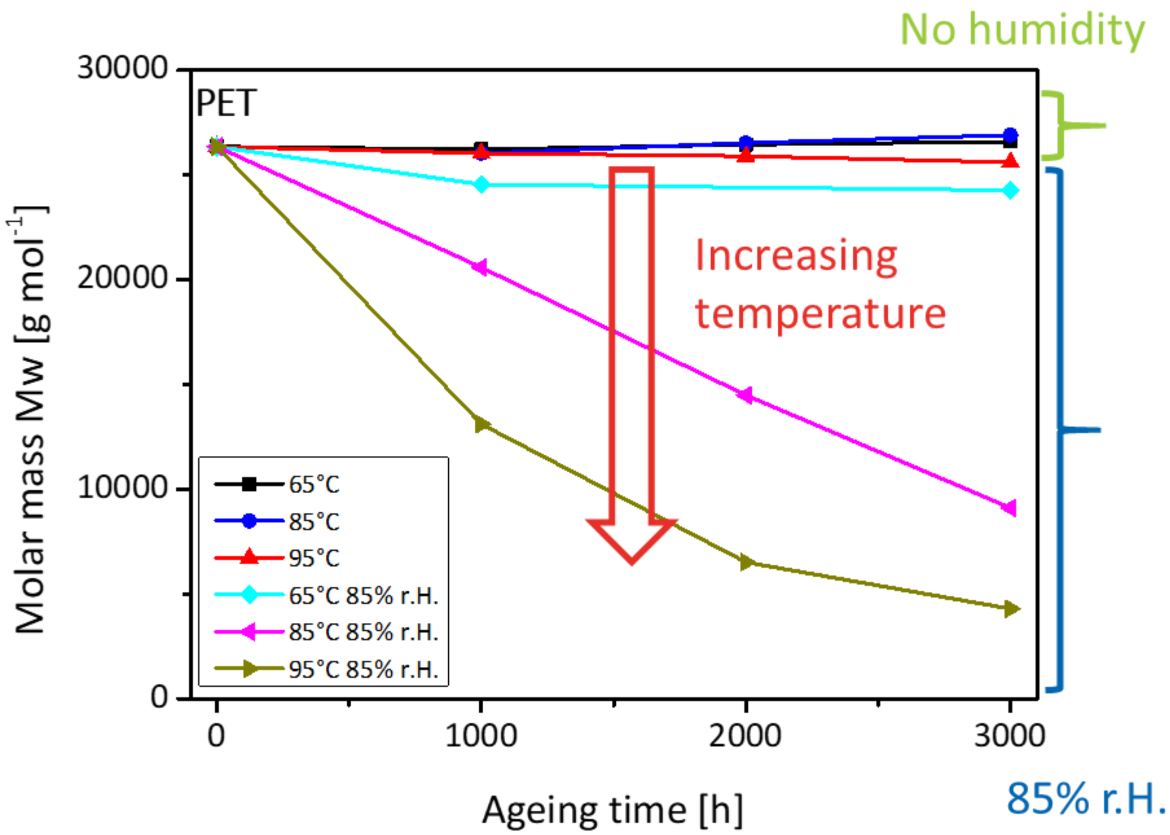
Effect of temperature

Hotspot in PV module



- **Short circuit due to broken cell or interconnect:** Electricity of whole string converted to heat
- Elevated temperature leads to **faster degradation** than rest of the module (Increased yellowing and multiple cracking)

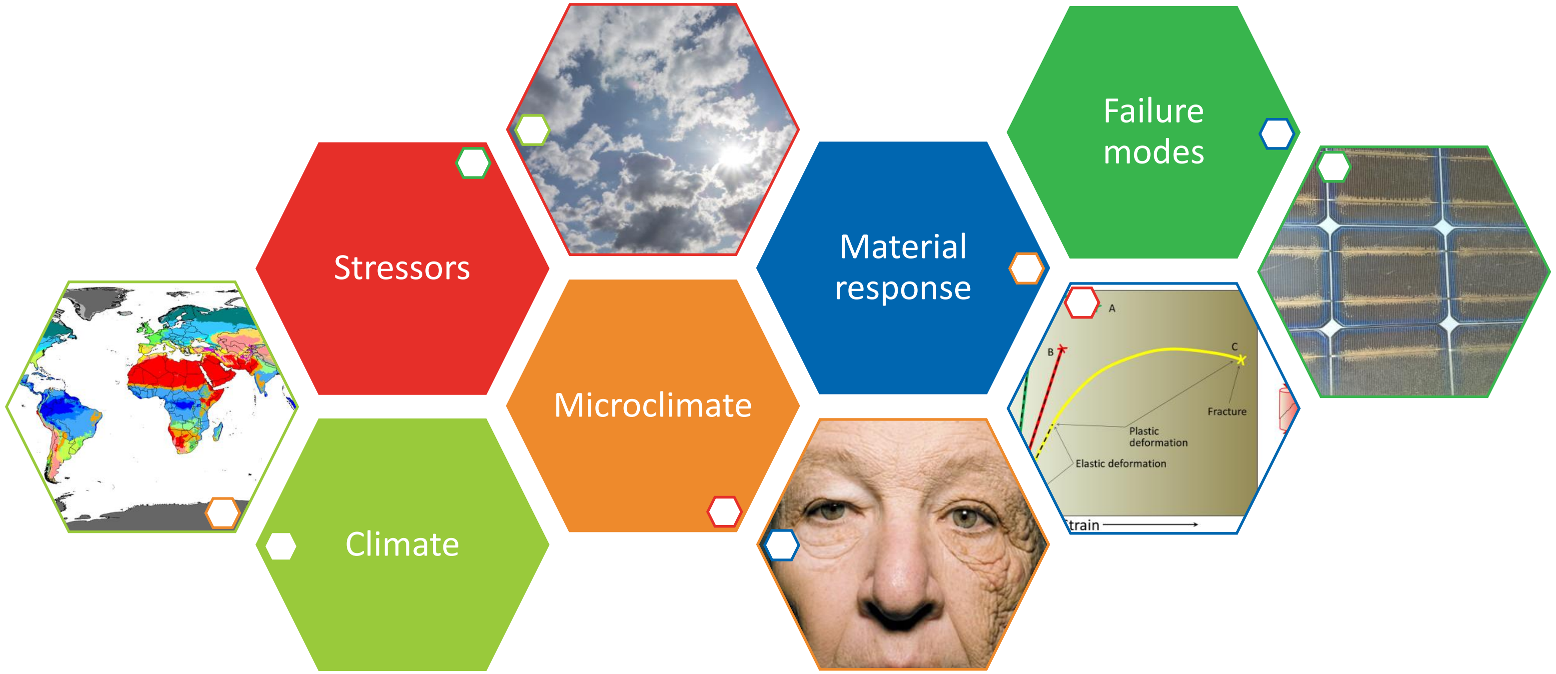
Temperature effect on hydrolysis



- **No PET hydrolysis** at typical PV module operating conditions

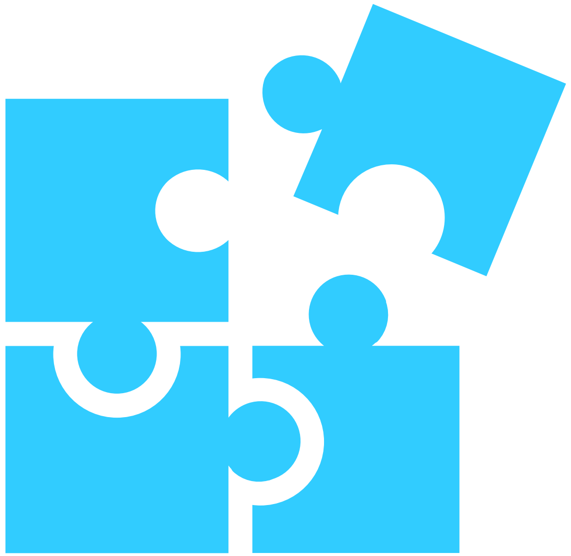
How to adapt modules?

What do we need to know in order to adapt PV module design for harsh climatic conditions?



Do you understand all of this?

Let´s puzzle



Module design for harsh climates

Cell

- Cell technology selection based on local climatic conditions
- Sensitivity to LID, LeTID, UVID, humidity
- Temperature coefficient

Module design

- Size
- Design type (GG vs. GB; Edge seal)
- Cell & bypass diode layout
- Interconnection technology

Module components

- Load dependent material selection (stability, UV protection, mass transport etc.)
- Material & component compatibility
- Functional layers (Anti soiling, anti glare, AR etc.)

Summary & Conclusion

PCCL
Polymer Competence Center Leoben

How do we build resilient PV modules?

There is no simple solution - we need to know about

- the climate of the location of the PV system
- the resulting microclimate of the modules
- the interaction between microclimate and module design and module bill of materials
- the interaction of module materials & components

We know how to build resilient modules

- There are plenty of examples of modules operating for 30 and more years with minimum power loss
- However, these modules where much more robust and practically "overengineered"

What do we need for adapting modules to harsh climates?

- Transparency of module design and bill of material
- Traceability of all module components
- Comprehensive qualification procedures for module design and composition