SUPSI

New Challenges with latest PV technologies

Insights from SUPSI PVLab R&D projects

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Introduction

Market Trends and PVLab Roadmap

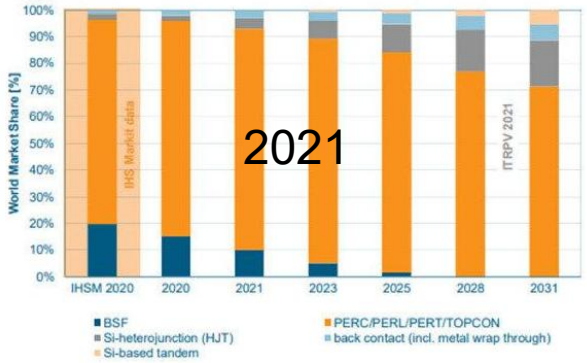
MODULES

SYSTEMS

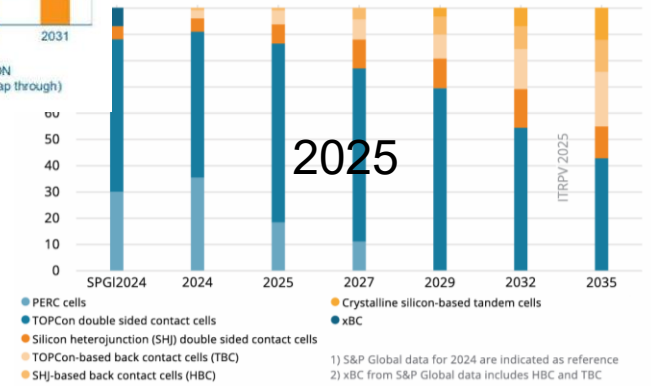
…1982 …1991 … 2007 …2011 …2018 …2021 ……2025

TISO 10 … BIPV … bifacial … Viganello/Trevano

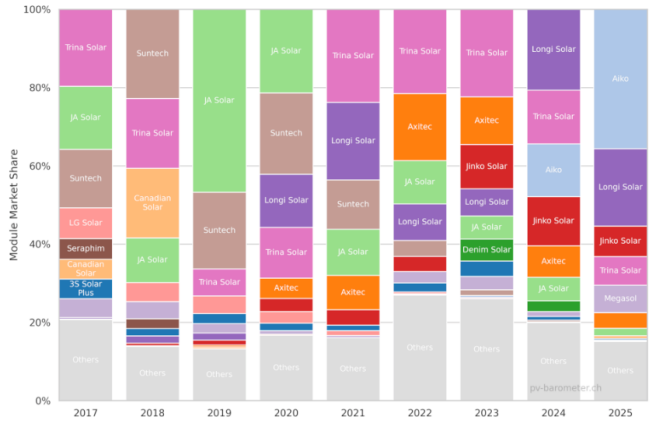
… c-Si modules … thin films … coloured … high efficiency c-Si



World market share of PV technologies [1]



Swiss market share of module manufacturers [2]



1 International Technology Roadmap (ITRPV) 2020/2025

2 Photovoltaik Barometer 2026: Trends und technische Daten aus der Solarbranche

Field Testing at SUPSI

Module technologies under investigation

MODULE TEST FACILITY

- Different configuration (open-rack vs. BIPV)
- Monofacial modules
- Test cycle 14 running and 15 starting
- 16 technologies and 48 modules

Test cycle14 (2021): 4 PERC (2-cut, 3-cut, shingl., diodes), 1 HJT (SW 2-cut), 1 TOPCon BC (full cell), 1 TOPCon (2-cut)

Test cycle15 (2026): 3 HJT, 3 TOPCon, 3 BC NEW

BFE projects: ATTRACT, CREATE

SYSTEM TEST FACILITY

- 132 kWp (+ 16.74 kWp) roof-top system
- Monofacial vs. bifacial modules
- High voltage >1500V vs. low voltage strings
- 7 technologies and 28 reference modules

Viganello (2022): 2 PERC (2-cut), 1 PERC bifacial (shingl.), 1 TOPCon (2-cut), 2 TOPCon bifacial (2-cut), 1 HJT bifacial (SW 2-cut)

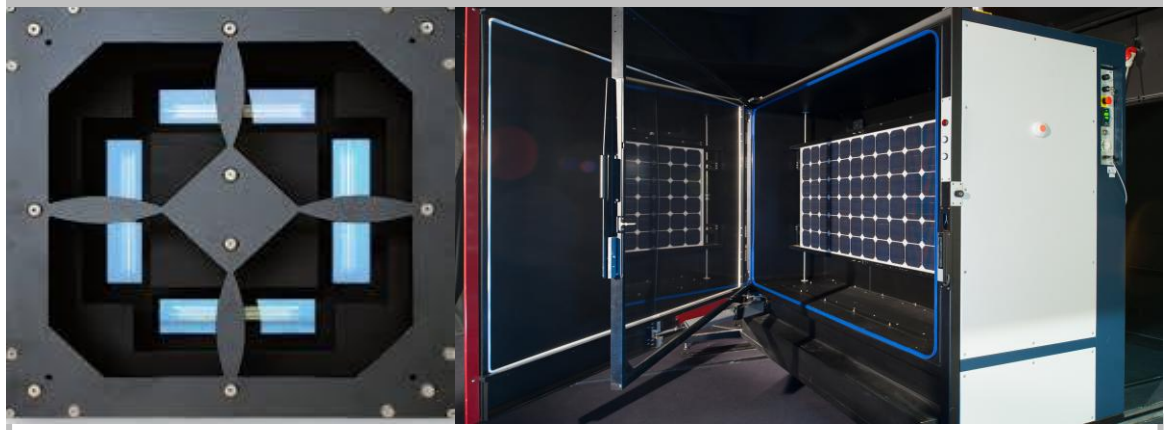
Mendrisio (2023): old TISO10, new low voltage strings

BFE projects: RACONT2050

Testing Equipment (Performance Monitoring)

Latest improvements

LABORATORY TESTING



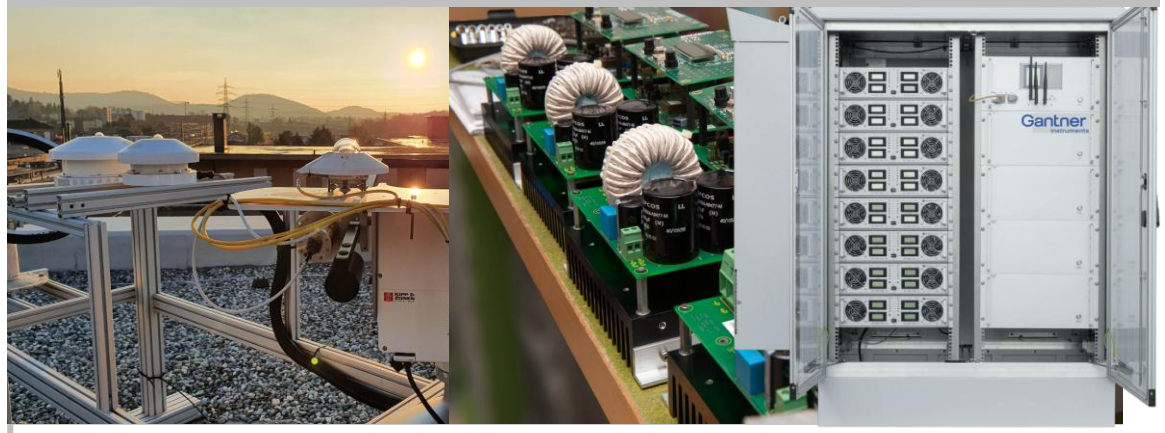
- Pulsed solar simulator (class A++A+A+) NEW
- Light soaking solar simulator (class BBB) NEW
- Thermal control box (15-75 ºC)
- Spectral neutral irradiance filter (100-1100 W/m^2)
- 29 spectral bandpass filters (311-1200nm)
- Rotational rack (0-80º)

best measurement uncertainty at STC

uP_{max}[k=2] = 1.1% & 1.7% without SMM NEW

R&D project: CREATE

FIELD MONITORING



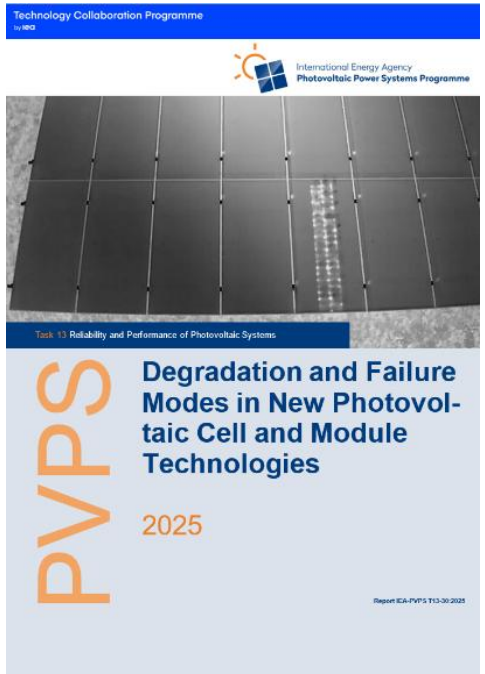
- Module level IV curve tracers + MPP tracker
- Dark I-V measurement (string level monitoring) NEW
- Temperature sensors (PT100)
- Calibrated pyranometers
- Spectrum radiometer (EKO)
- Soiling sensors
- Meteo station

R&D projects: RACONT2050, SOLID-PV

CHALLENGE 1: New Failure modes

Laboratory versus field observations

- UV induced degradation
- TOPCon contact corrosion
- HJT degradation
- Glass breakage



How representative are laboratory degradation mechanisms of field operation?

→ Field studies remain essential

for…

- validating accelerated testing procedures,
- increasing confidence in emerging technologies,
- strengthening bankability.

"While field studies of degradation are the gold standard for understanding longevity, the findings become less transferable when critical materials change practically every six months"

https://iea-pvps.org/key-topics/degradation-failure-modes-new-cell-module-technologies/
https://iea-pvps.org/key-topics/photovoltaic-failure-fact-sheets-2025/

CHALLENGE 1: New Failure modes

Field observations

- **UV induced degradation**
- Heterojuction degradation
- Glass breakage

Origin

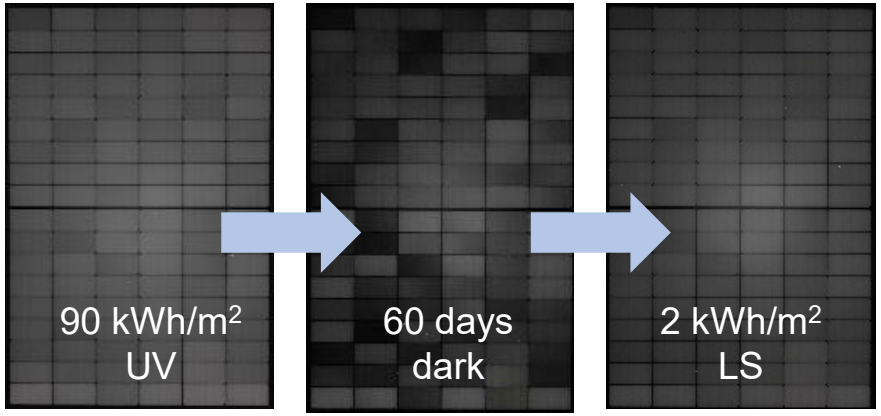
- Damage of cell passivation or interfaces by high-energy photons.
- More frequent in TOPCon and HJT.
- Mostly BOM/manufacturing related.

Observations

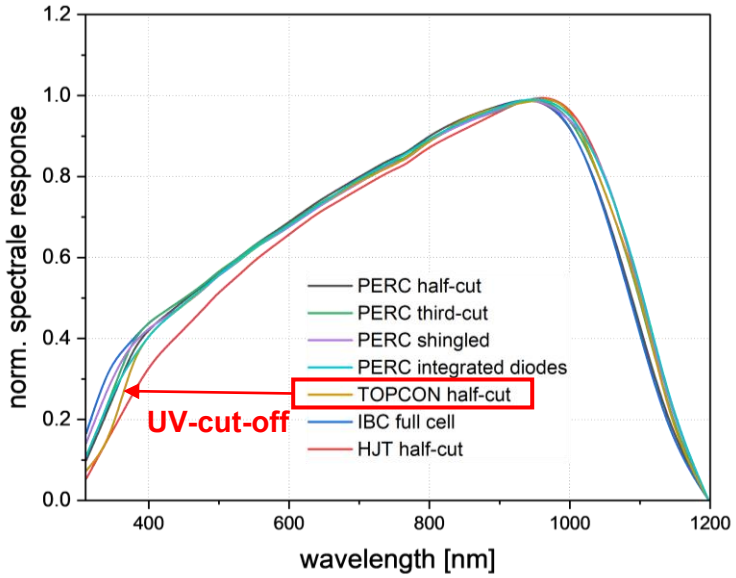
- Visible as checkerboard EL pattern.
- Power loss continues in the dark.
- Partially reversible through short light soaking.

4 out of 14 module types purchased in 2021 shows dark storage degradation suggesting meta-stability caused by light induced degradation effects. Ongoing investigations

Risk of underestimating reference power!



Test cycle 14 (stable TOPCon)



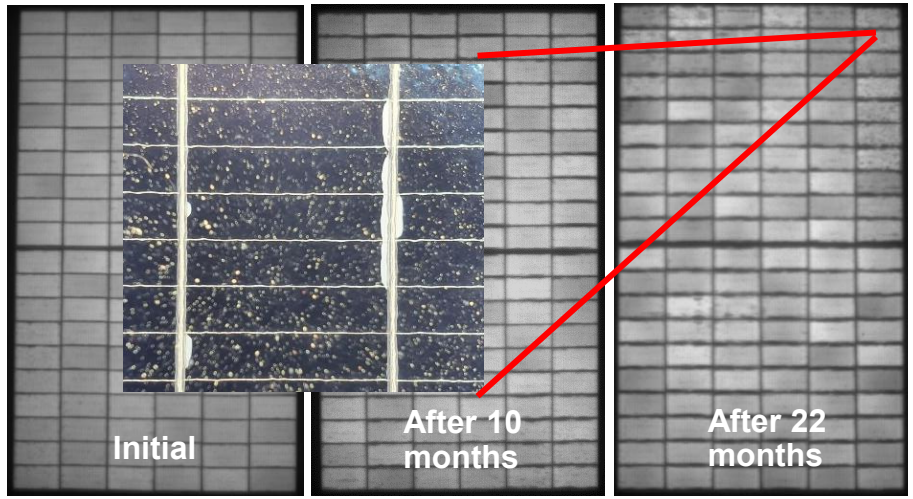
See presentation Ebrar Özkalay

CHALLENGE 1: New Failure modes

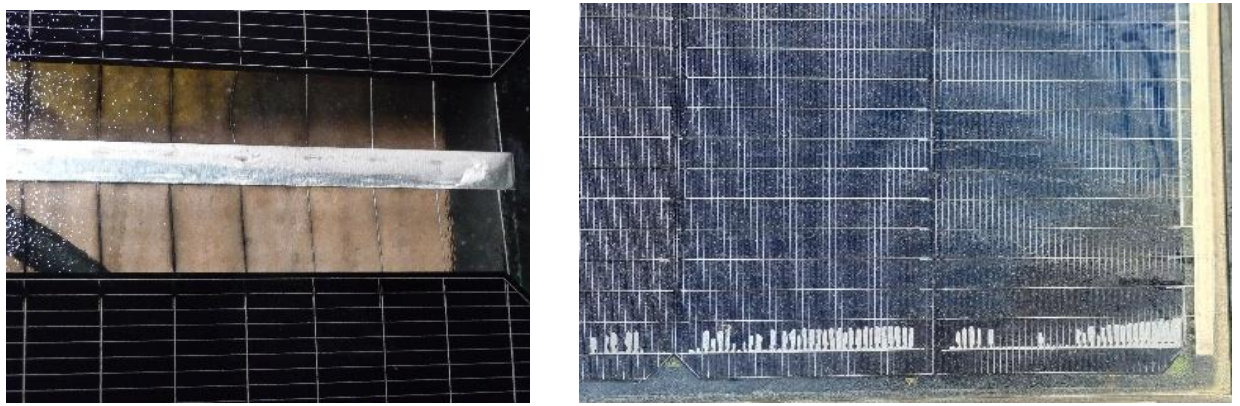
Field observations

- UV induced degradation
- **Heterojuction degradation**
- Glass breakage

- SHJ cells are sensitive to moisture and heat.
- More sensitive due to the use of low-temperature metallization/ contacting technologies.
- Degradation is strongly tied to module packaging quality and contacting technology.



Test cycle 14: HJT glass/backsheet module without moisture barrier.



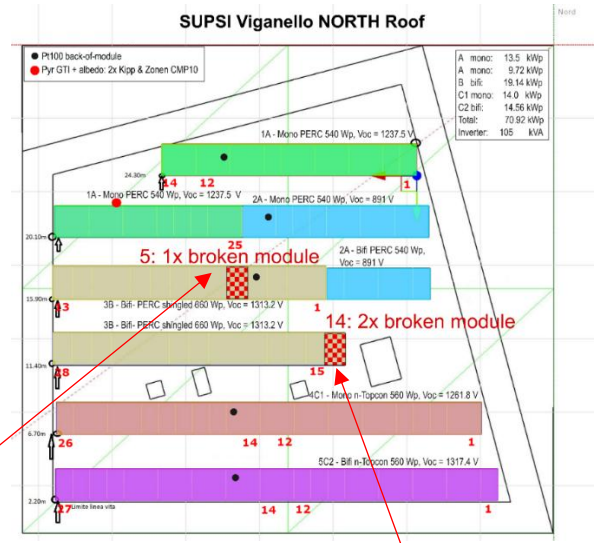
Viganello: HJT glass/glass module showing darkening of the contacts and delamination of fingers at the module border

CHALLENGE 2: New Failure modes

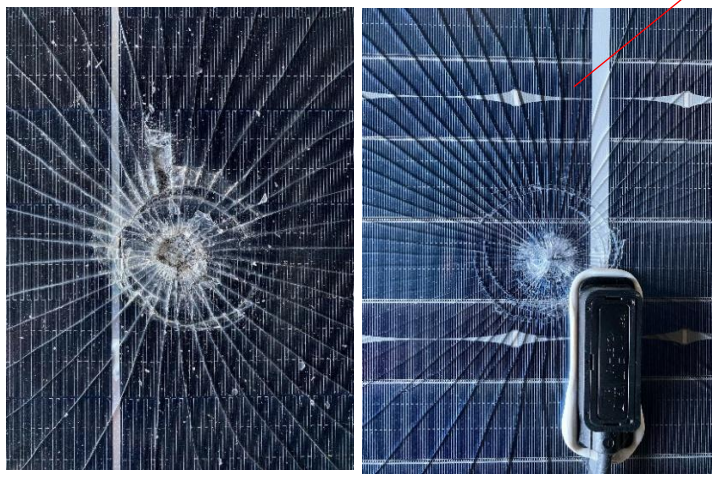
Field observations

- UV induced degradation
- Heterojuction degradation
- **Glass breakage**

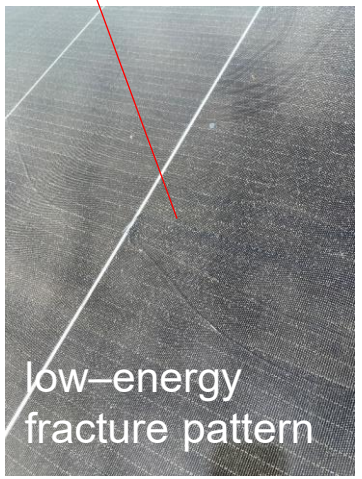
- The transition to large size thin glass/glass modules increased the risk of glass breakage.
- Potential causes: external impact, thermal stress, mounting induced stress, module design.



Viganello: bifacial 2x2mm PERC shingled modules



External impact: stone dropped by birds?



Repeated damage in same position: Shading induced?

CHALLENGE 2: Degradation rates

Field observations

- Warranty declarations
- Degradation rates
- Performance ratio

Key questions

- How do emerging failure modes translate into field degradation?
- Are current manufacturer warranties realistic?
- What are the real long-term energy yield gains of emerging PV technologies?

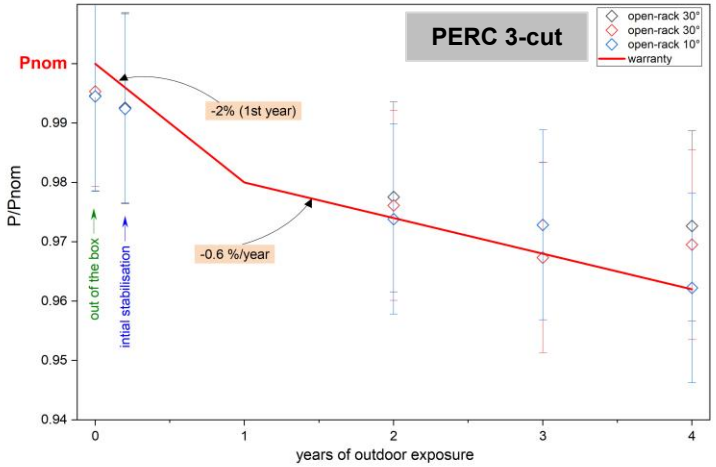
→ Field studies remain essential

CHALLENGE 2: Degradation rates

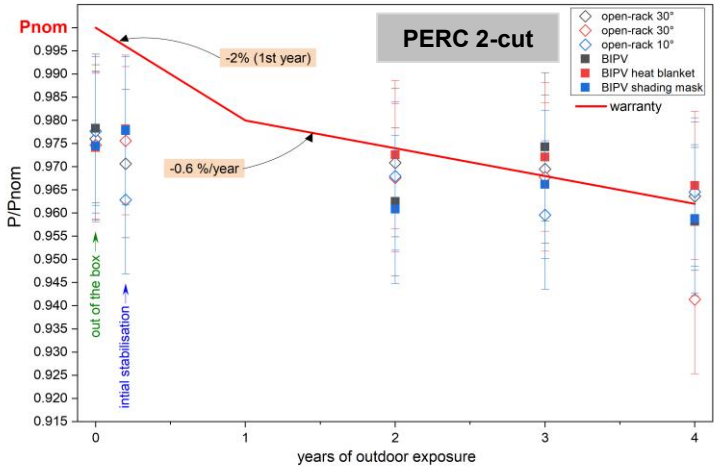
Field observations

- **Warranty declarations**
- Degradation rates
- Performance ratio

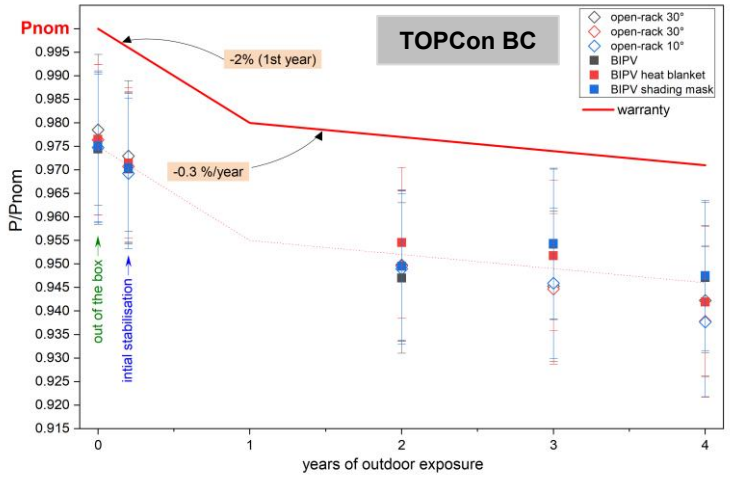
Conform to warranty



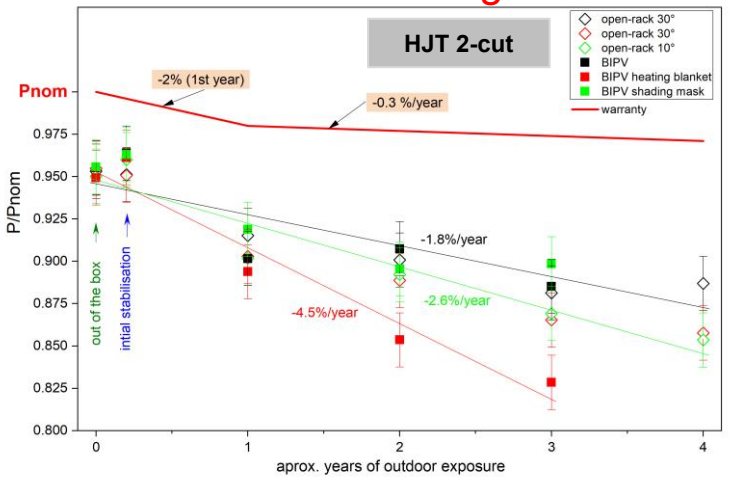
Overestimated annual degradation



Underrating



Underestimated degradation



Error bars: PVlab P_{max} uncertainty ±1.7% (without SMM)

CHALLENGE 2: Degradation rates

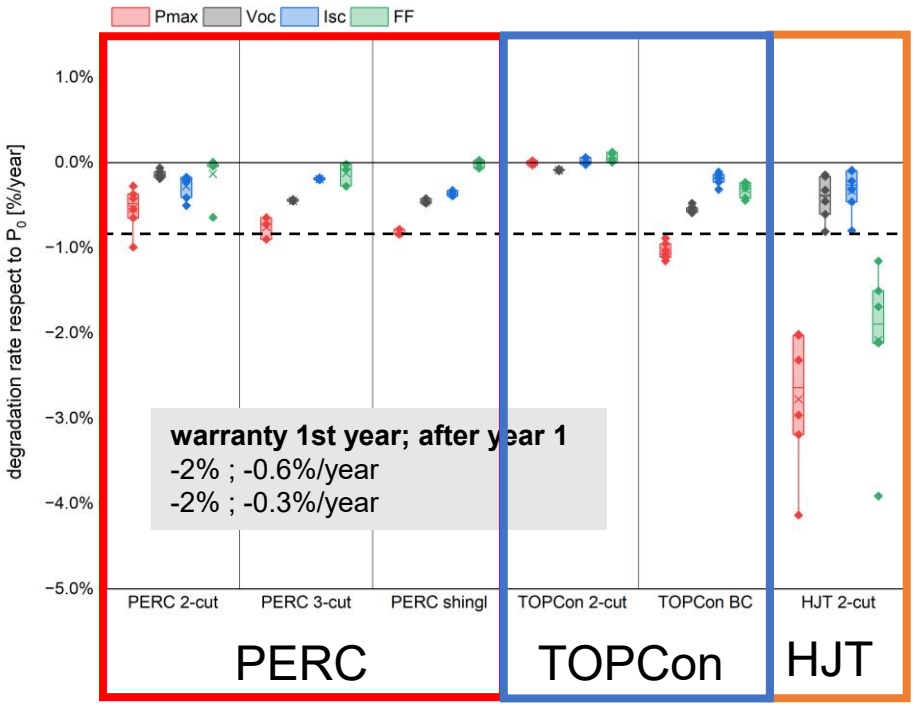
Field observations

- Warranty declarations
- **Degradation rates**
- Performance ratio

Degradation rates in %/year respect to initial (out of the box) STC values (P0)

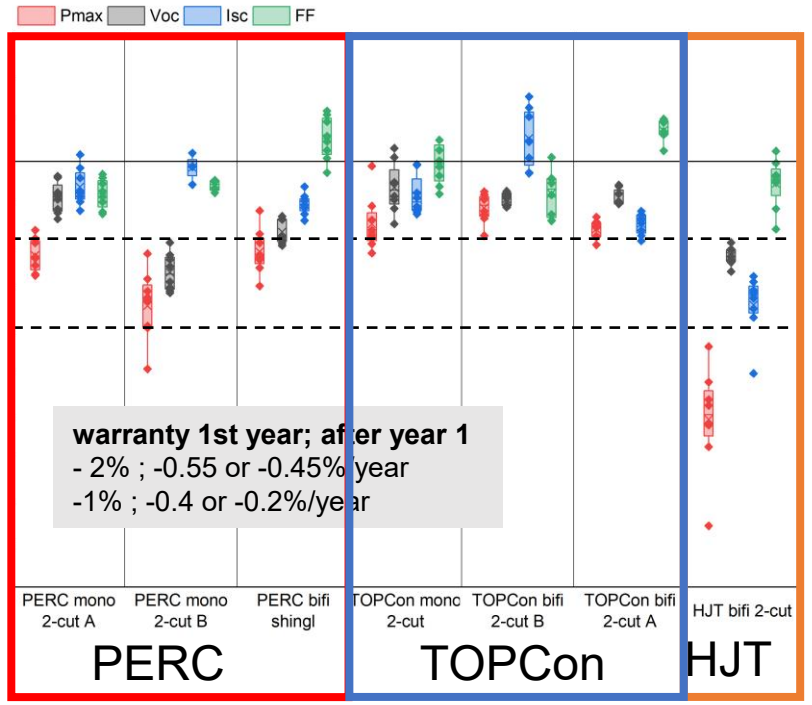
Mendrisio (test cycle 14)

after **3-3.6** years of field exposure



Viganello (PV system)

after **0.8-1.2** years of field exposure

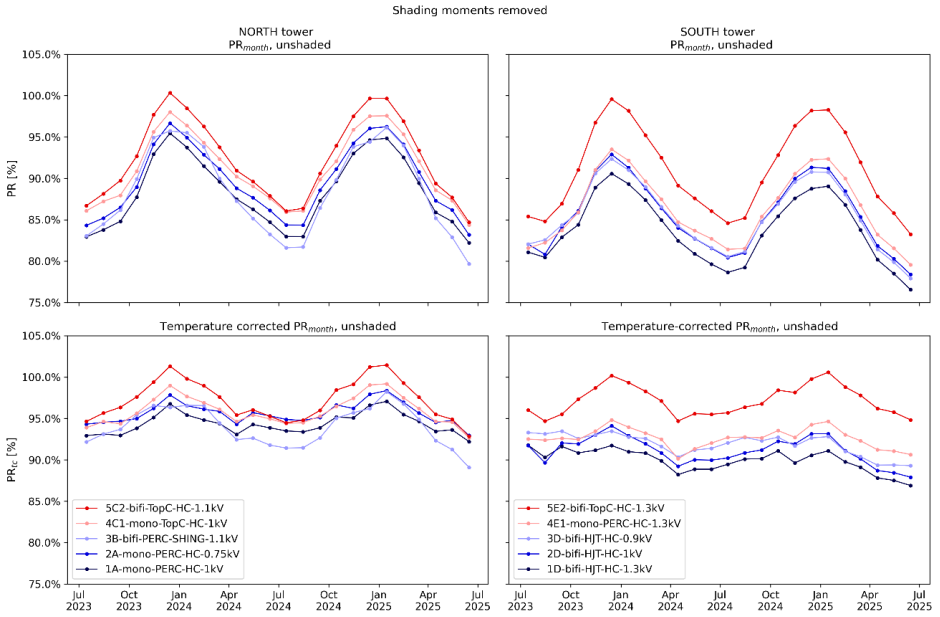


CHALLENGE 2: Degradation rates

Field observations

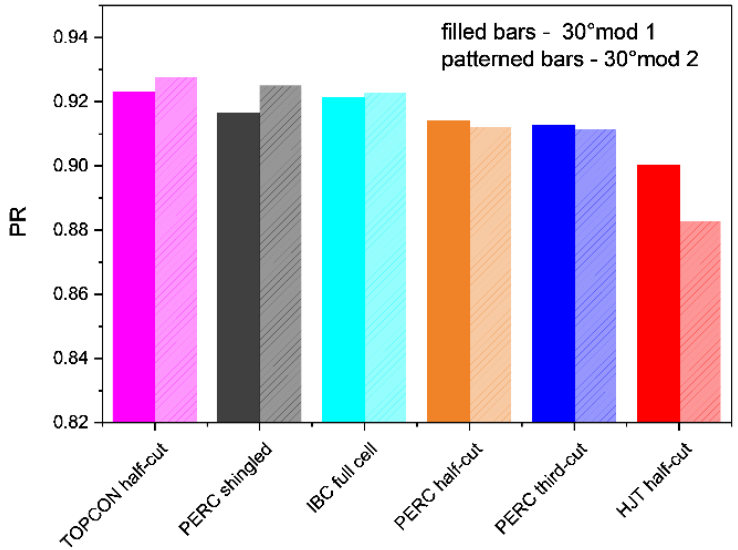
- Warranty declarations
- Degradation rates
- **Performance ratio**

Viganello system (south and north roof)



	TOPCon	PERC	HJT
Monofacial	89.1%	86.0%	
Bifacial	89.1%	86.0%	82.9%
All	89.1%	86.0%	82.9%
Δ TOPCon		**-3.1%**	**-6.2%**

Test cycle 14 (open-rack 30° modules) after 17 months



Updated data (after 3.6 years) will be available soon!

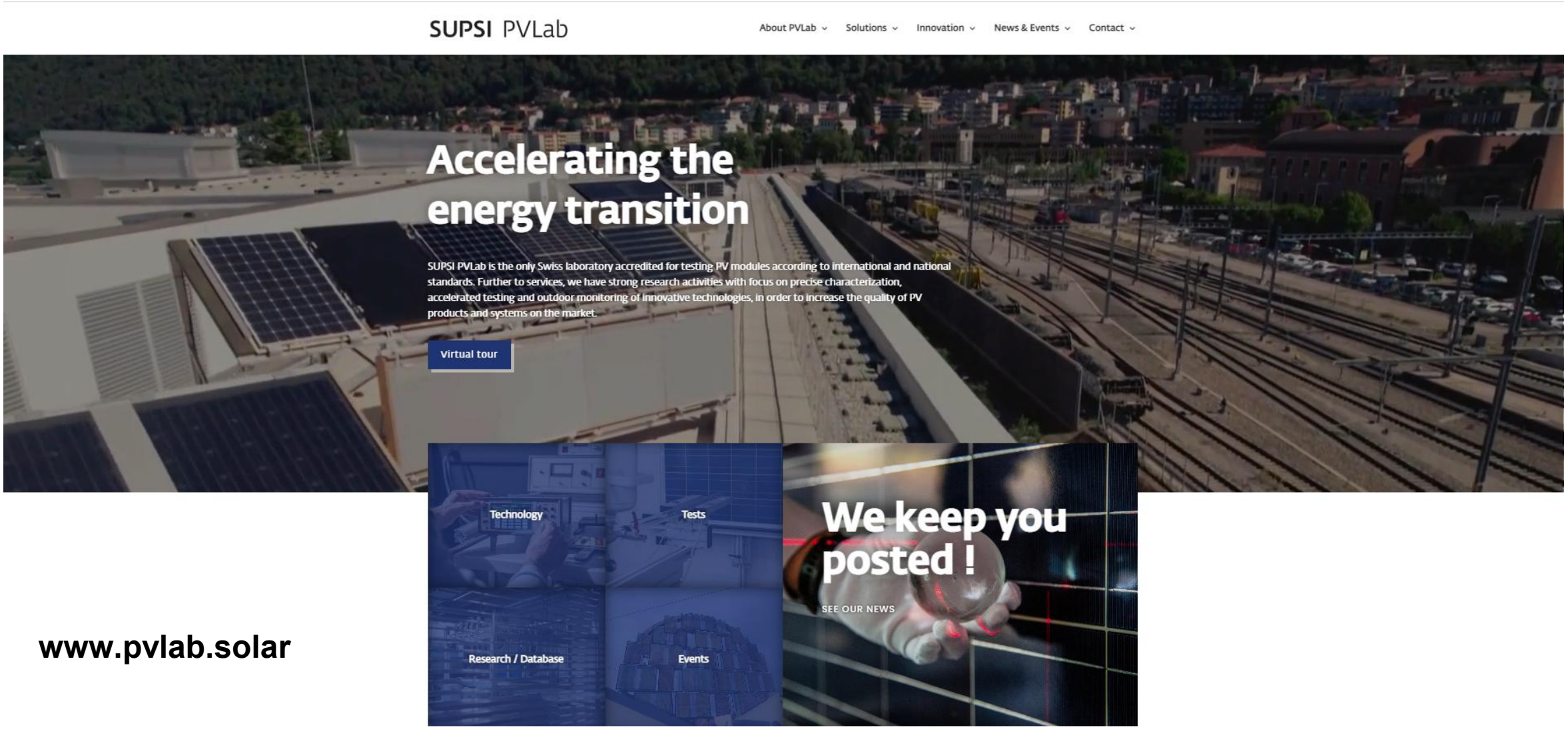
Conclusions & Outlook

Conclusions

- **Good news:** TOPCon technology currently delivers the best overall performance, confirming the ongoing technological shift in photovoltaics.
- **Some modules show higher early degradation and reliability risks:** degradation is determined by BOM and manufacturing more than cell technology.
- **Metastabilities increases the uncertainty of performance and yield assessments:** Cost effective, field representative and repeatable testing procedures are needed.

Next steps

- Analyse long term degradation rates >4 years.
- Continue study on dark storage and fast recovery procedures.
- Understand origin of glass breakage in Viganello modules.
- Testing of more HJT and TOPCon (including BC) within test cycle 15 (higher efficiencies and current).



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Thank you for your attention!