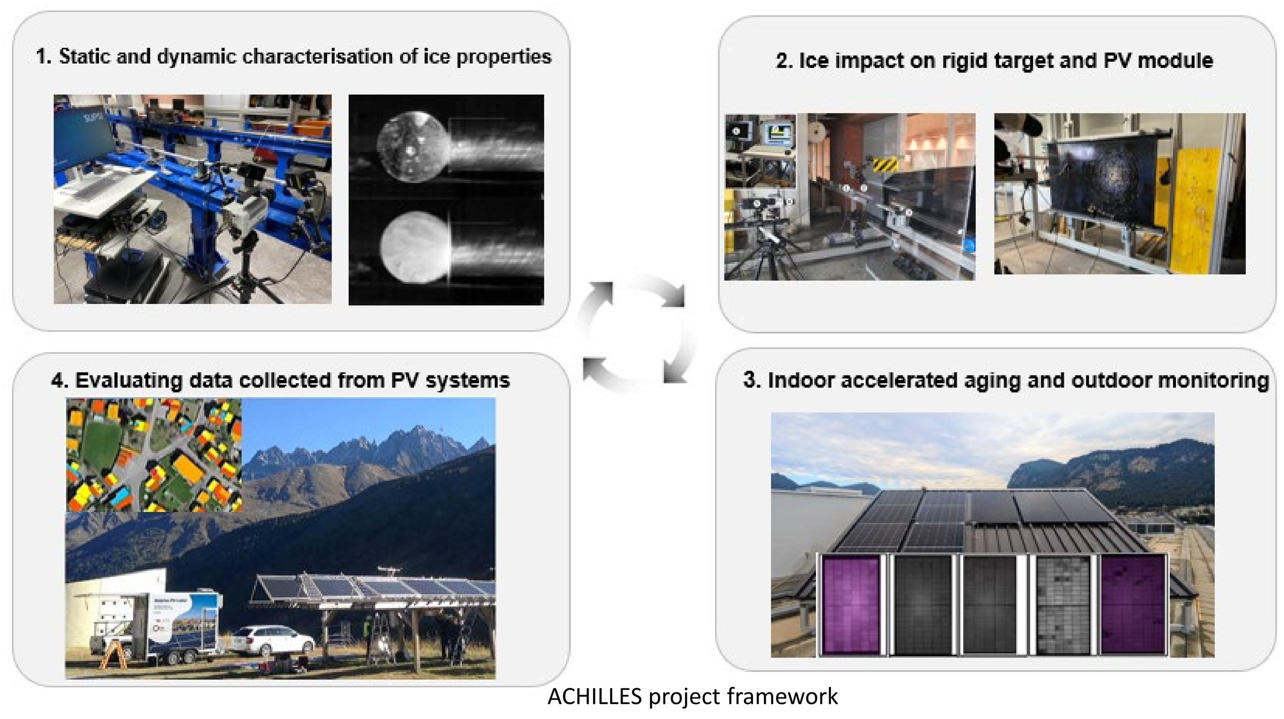
University of Applied Sciences and Arts
of Southern Switzerland
SUPSI

Improving Post-Hail Damage Assessment of Photovoltaic Modules and Systems

Dominika Chudy [1], Evelyn Bamberger [3], Andreas Bohren [3], Mauro Caccivio [1], Ezio Cadoni [2], Daniele Forni [2]
1-University of Applied Sciences and Arts of Southern Switzerland – SUPSI PVLab, Via Flora Ruchat-Roncati 15, Mendrisio, 6850, Switzerland
2-University of Applied Sciences and Arts of Southern Switzerland –DynaMat SUPSI Laboratory, Via Flora Ruchat-Roncati 15, Mendrisio, 6850, Switzerland
3-Eastern Switzerland University of Applied Sciences, Institute for Solar Technology, Gebäude 8, Oberseestrasse 10, CH-8640 Rapperswil-Jona, Switzerland
Contact: dominika.chudy@supsi.ch

Motivation

The rapid deployment of photovoltaic systems increases their cumulative exposure to extreme weather events such as hail. Observational data from Europe indicate a strong increase in large and very large hail events in recent years, particularly after 2018 [1], which directly translates into a higher likelihood of hail-induced damage in PV systems.
Current post-hail inspection practices are predominantly based on visual assessment, which does not reliably detect internal defects such as cell cracks or interconnect damage.
As a result, damage may remain undetected and lead to long-term reliability issues [2].
The **ACHILLES project** addresses this gap by developing advanced, evidence-based guidelines for the comprehensive assessment of post-hail damage in PV systems.

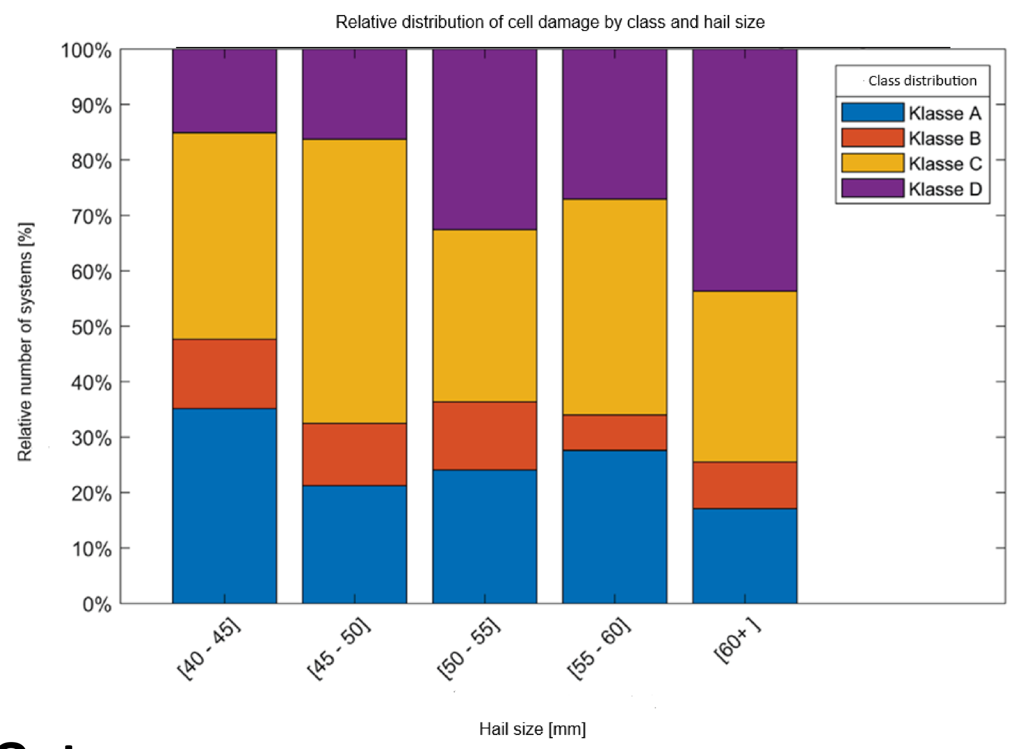


ACHILLES project framework

Evaluating data collected from PV systems

Aim: Multi – method field assessment

Field inspection of 300 of hail-affected PV modules using **damage classification (A–D)** based on observed cell defects, supported by electroluminescence imaging and visual assessment, combined with hail intensity data at system locations.
Parameters: Hail size [mm]; damage class (A-D); cell damage (cracks, inactive areas); tilt angle [°]; orientation [°].



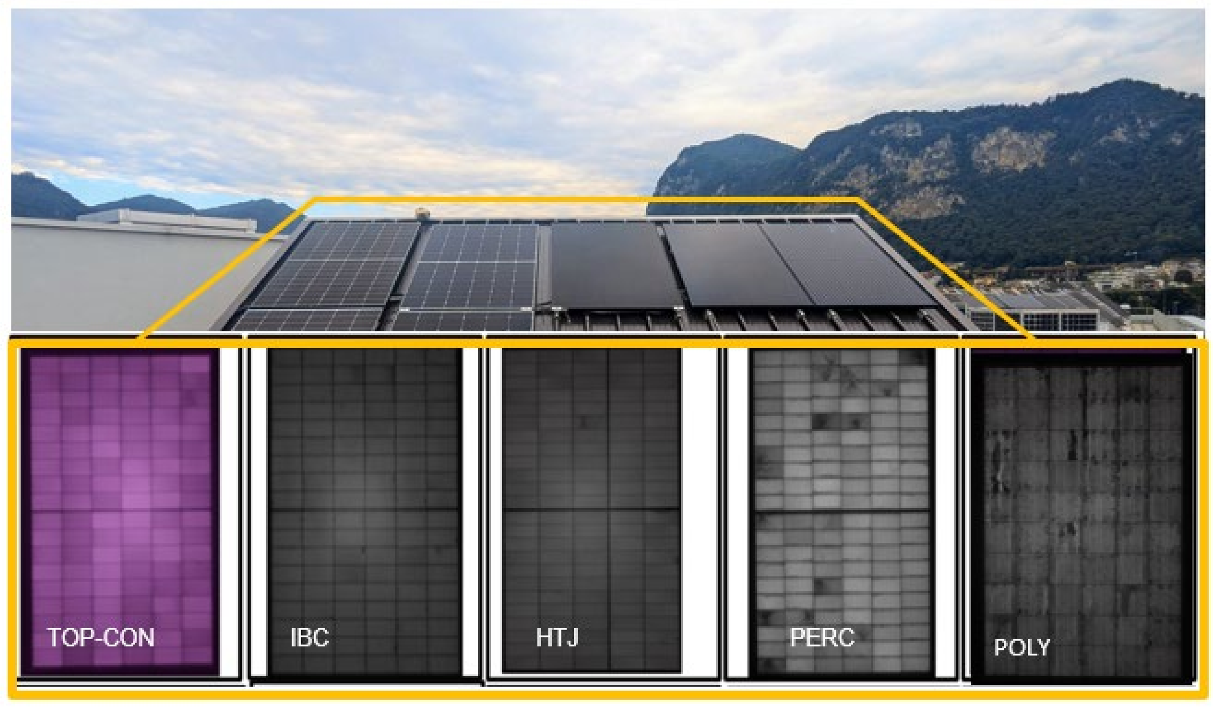
Damage classes
Class A → Negligible defects
Class B → Minor defects, small cell cracks
Class C → Moderate defects, larger cracks, partially inactive regions
Class D → Severe defects, extensive cracking, inactive regions

Outcome:
- Damage severity increases with hail size.
- Severe damage (Classes C–D) becomes dominant for hail sizes >50 mm.
- Post-hail assessment requires a multi-method field approach rather than a single diagnostic technique.

Outdoor monitoring

Aim: Outdoor monitoring of PV modules following hail events

Long-term monitoring of performance and degradation of PV modules collected after hail events, representing five different module technologies, under outdoor conditions at two test sites (Mendrisio and Rapperswil).
Monitoring timeline: September 2024 – 2028

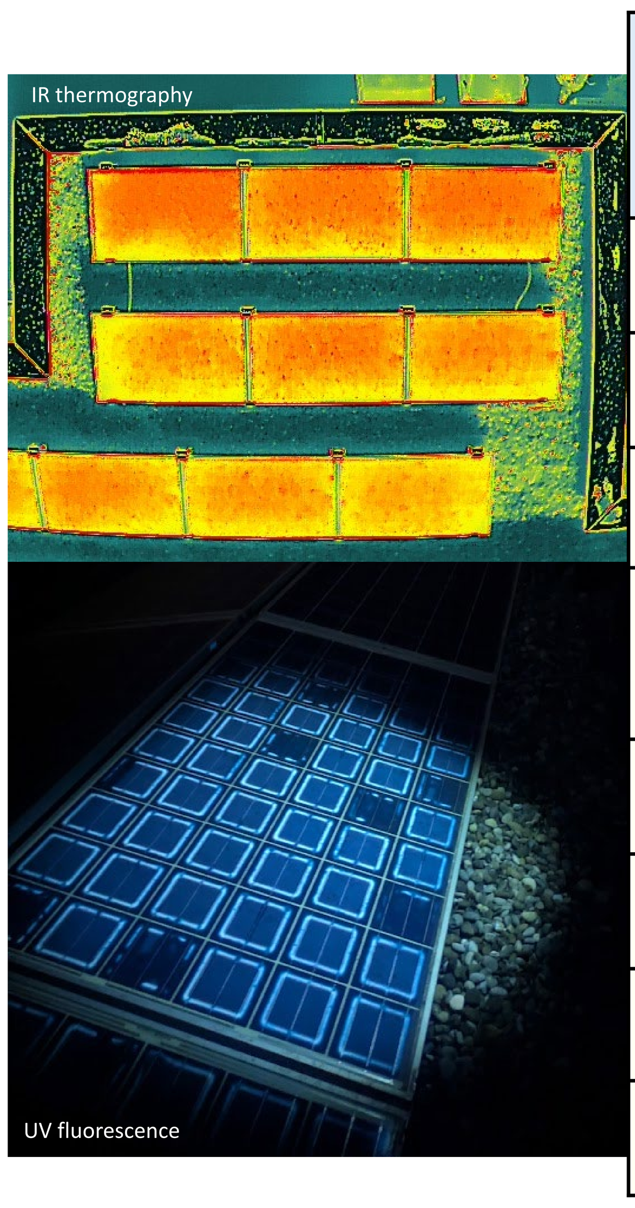


Monitoring parameters
Modules were collected after severe hailstorm in the Locarno area.
Top row shows hail-damaged PV modules, while the bottom row presents corresponding new reference modules of the same technology.
Installed on a corrugated roofing system solution.

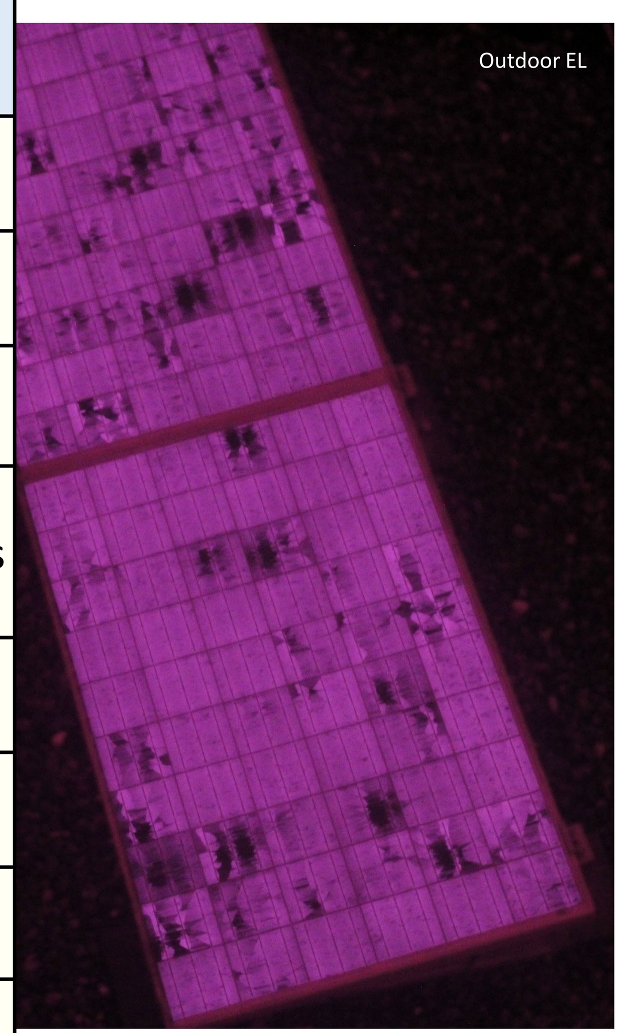
Outcome:
- After one year of monitoring, laboratory power measurements indicate less than 5% Pmax degradation in hail-damaged modules.
- The monitoring campaign is ongoing.

Field-based methods for post-hail PV system assessment

Assessment guideline document is being developed to identify the most suitable methods for in-field inspection of PV systems after hail events. The guideline provide a screening of available diagnostic techniques and highlight that a combination of complementary field methods is required for post hail damage assessment.



Evaluation method	In-field feasibility	Hidden damage detection	Advantages	Limitations	Application
Visual inspection	✅	❌	Fast, simple	Misses internal damage	First screening
Drone-based visual inspection	✅	❌	Rapid mapping	Surface-only	Plant overview
Infrared thermography (IR)	✅	🟠	Fast, scalable	Misses inactive defects	Screening
Outdoor electroluminescence imaging (EL)	🟠	✅	Detects cracks	Logistically complex	Targeted diagnosis
Daylight EL	🟠	✅	Field-capable luminescence	Complex processing	Advanced inspection
Photoluminescence (PL)	🟠	✅	Contactless	Limited deployment	Advanced diagnosis
UV fluorescence (UVF)	✅	🟠	Material insight	Indirect electrical link	Complementary
SCADA monitoring	✅	❌	High availability	Low sensitivity	Sudden event detection



Summary and Outlook

- PV systems are increasingly exposed to severe hail conditions, with significant damage observed for hail sizes >50 mm.
- Damage severity correlates with hail size, with higher classes (C–D) dominating at large hail diameters.
- Initial monitoring results show limited power degradation (<5% Pmax) after one year, despite visible and hidden defects.
- Individual diagnostic methods provide only partial information; multi-method field assessment is essential.
- Results support the development of practical, field-applicable guidelines within the ACHILLES project.

Acknowledgment: The ACHILLES project is funded by the Swiss Association of Cantonal Fire Insurance (ACFI).
References: [1] Púčik, T., Groenemeijer, P., Rädler, A., Tijssen, L., & Nikulin, G. (2019)
Future changes in European severe convection environments in a regional climate model ensemble.
[2] Mannino, G., et al. (2026) *Large hail impacts on photovoltaic systems: A review of damage, testing, and mitigation.*

Swiss Photovoltaic Conference 2026 – 31-03 -01.04 2026 - Bern, Switzerland