Let’s Talk About BIPV Resilience

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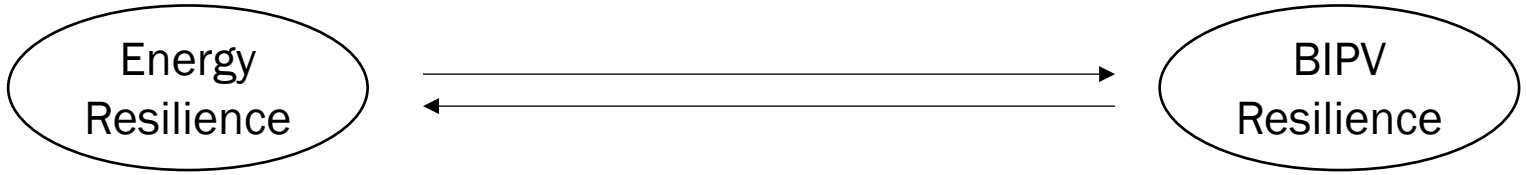
Overview

- 00:00 - 00:30 Introduction
- 00:30 - 03:00 What is BIPV Resilience and Why it's Important
- 03:00 - 06:00 State of Art
- 06:00 - 09:00 Imaging Techniques
- 09:00 - 10:00 Challenges and Opportunities

What is BIPV resilience



Extreme weather scenario

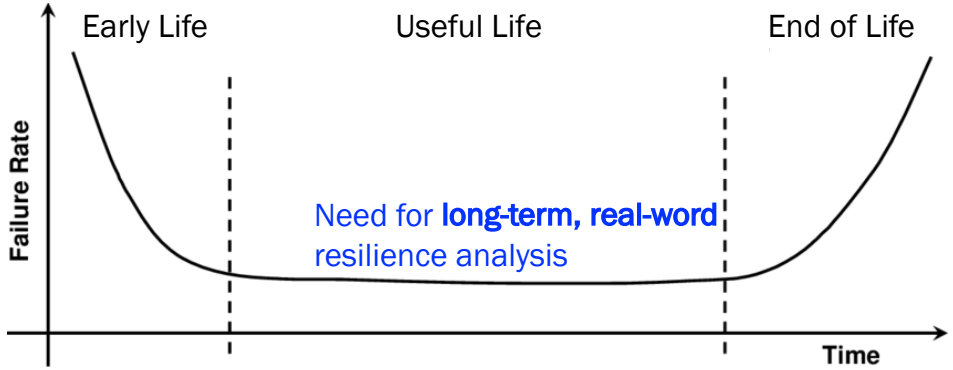
- BIPV can improve community energy resilience, by providing power, particularly during the response and recovery period
- Challenge of severe weather
  - Wind
  - Hail
  - Hurricane
  - Fire
  - Heavy snow
  - Cold & Heat shock

Normal weather scenario

- BIPV modules – only effective when deployed in direct sunlight
- Inherently harsh service environment
  - Damaging solar radiation (especially UV)
  - Heat
  - Humidity
  - Biological factors (mildew, algae, bird's dropping…)
  - Mechanical factors (sand abrasion, hail …)

What is BIPV resilience analysis

Combining **long-term field inspection** and **lab degradation characterizations** to perform a multi-scale **qualitative** and **quantitative** analysis to understand the BIPV behavior (degradation pathway) as both a **building material** and **PV system**

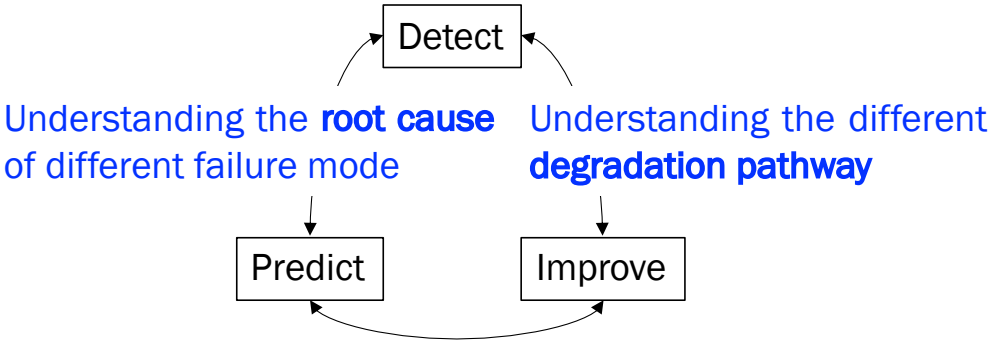


BIPV vs. BAPV vs. BIPVT ⇌ PV

Least integrated (Open rack-mounted PV)

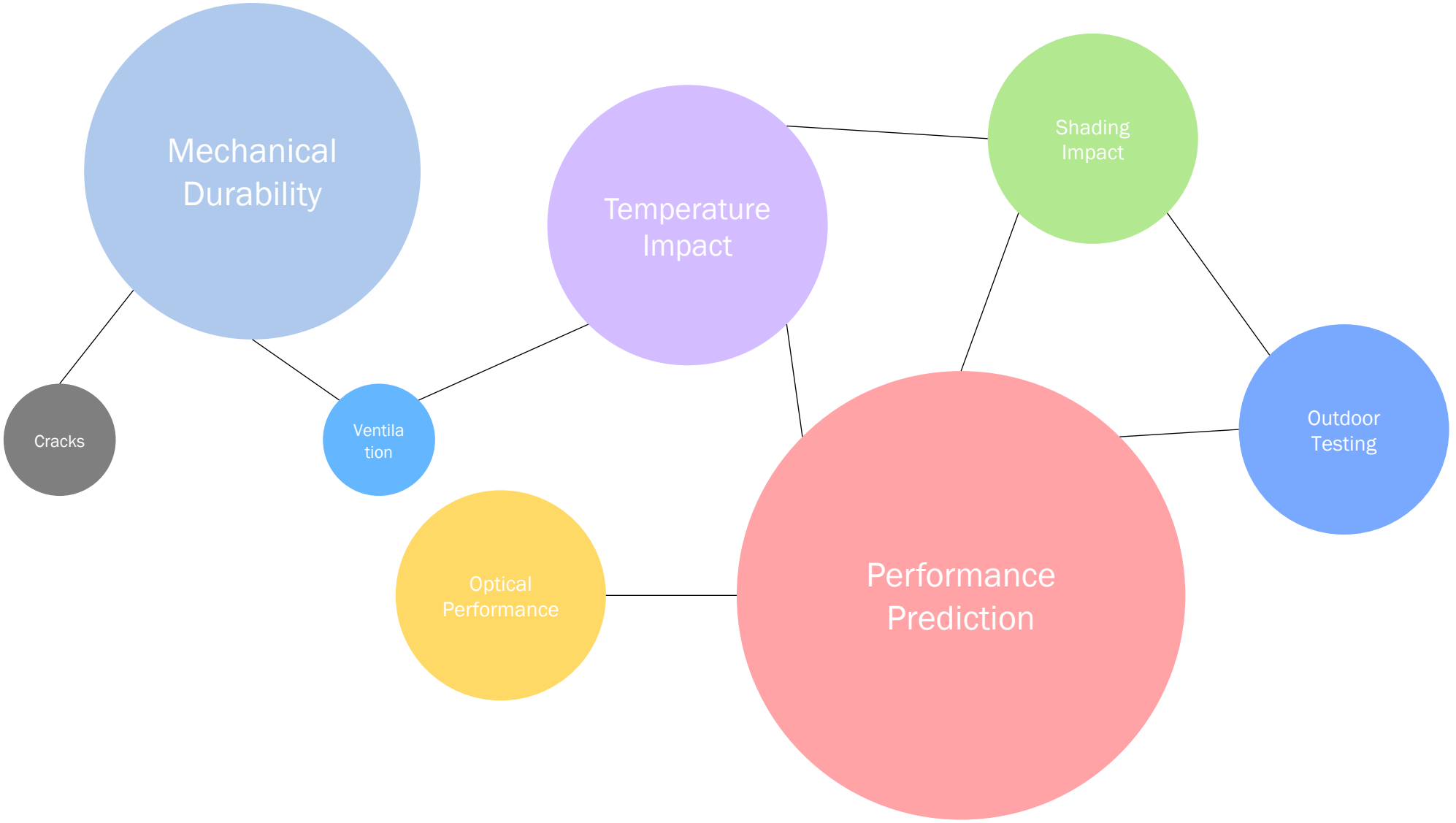
More integrated (Close roof rack-mounted PV)

Fully integrated (Direct-mounted BIPV, multifunctional)

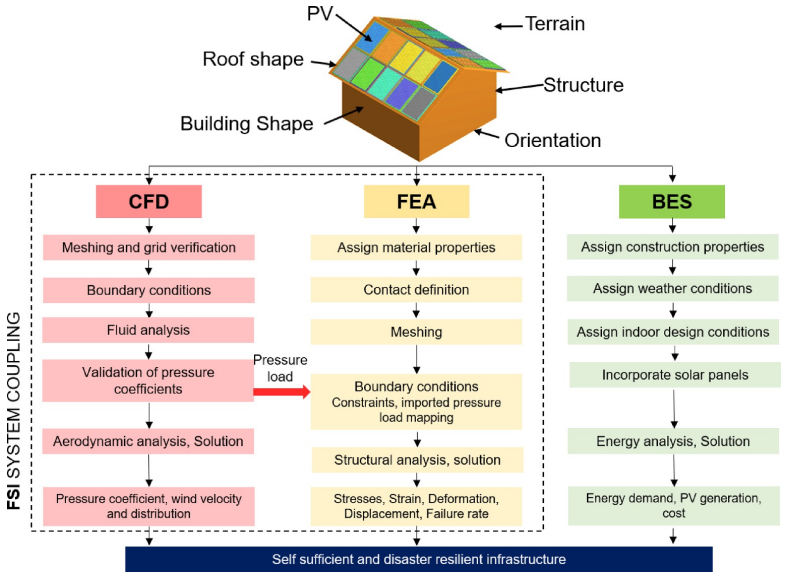


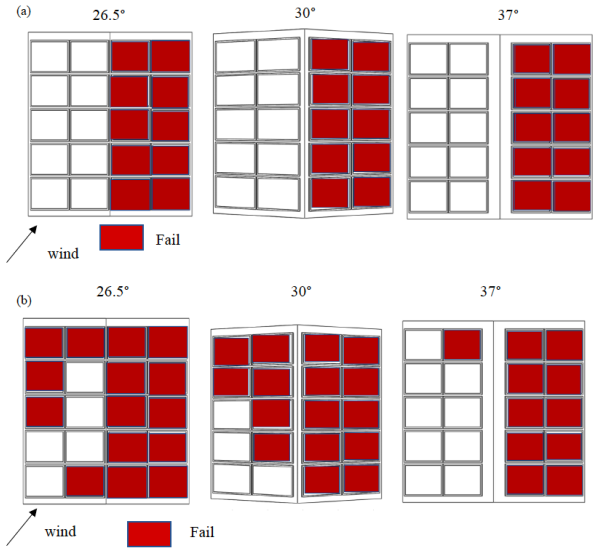
Improving **accuracy** of energy yield prediction, degradation rate calculation and provide input for techno-economic analysis, ultimately **de-risk** the investment and support **market growth**

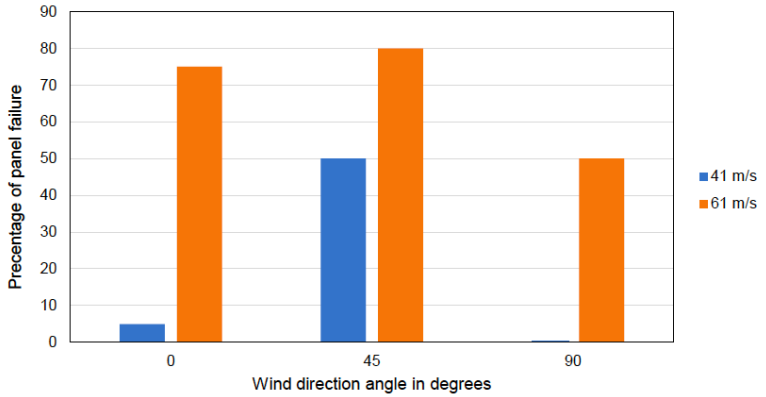
State of Art - Overview

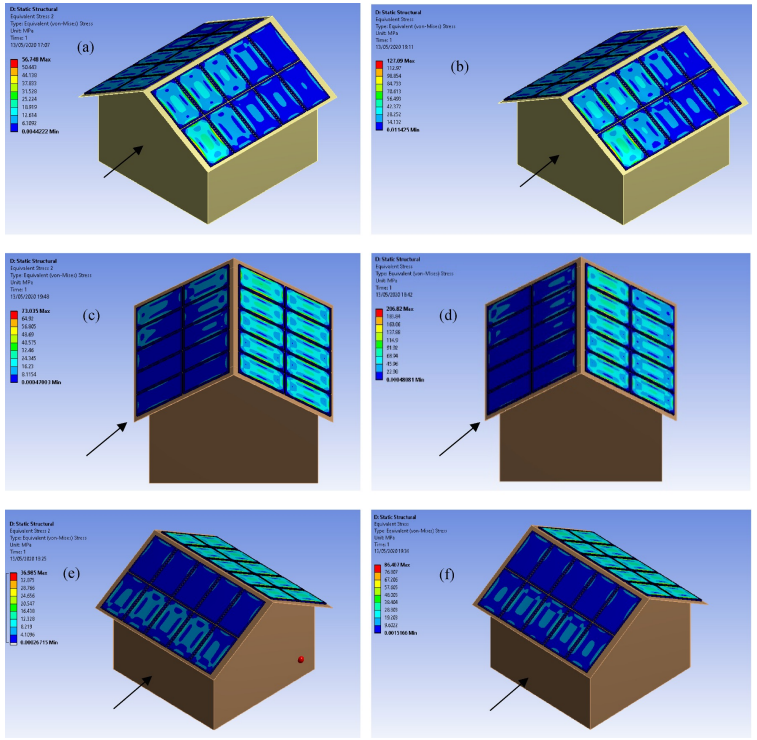


State of art – Mechanical durability

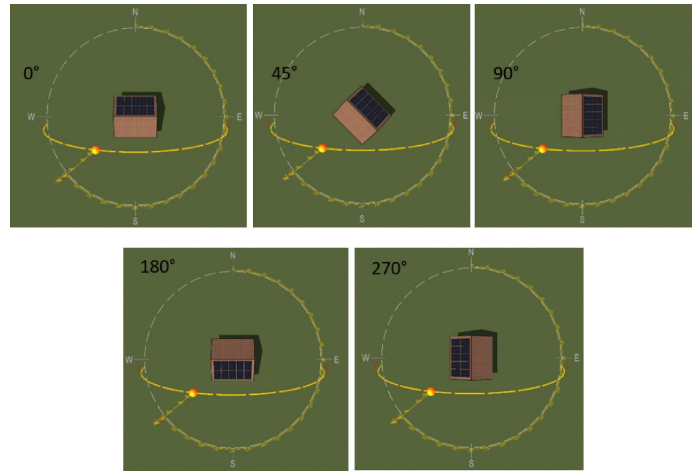


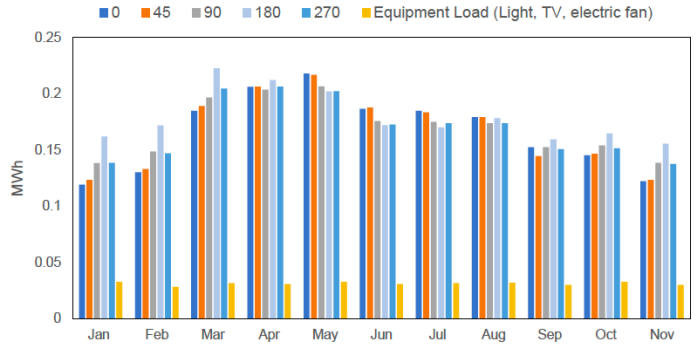






2021 C. A. J. Pantua *et al.*

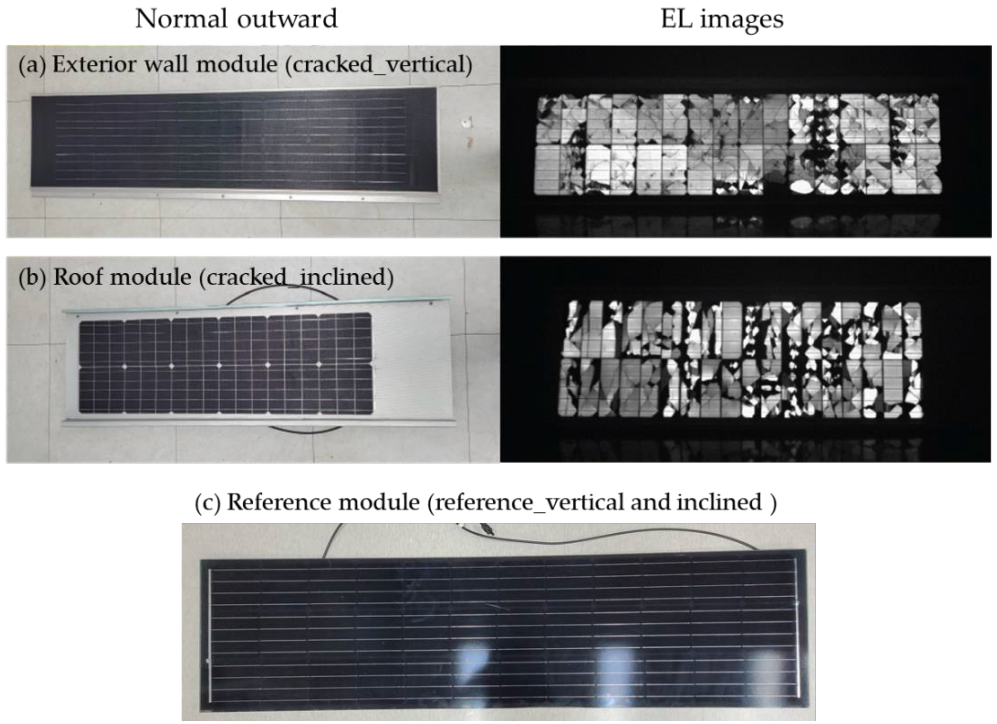


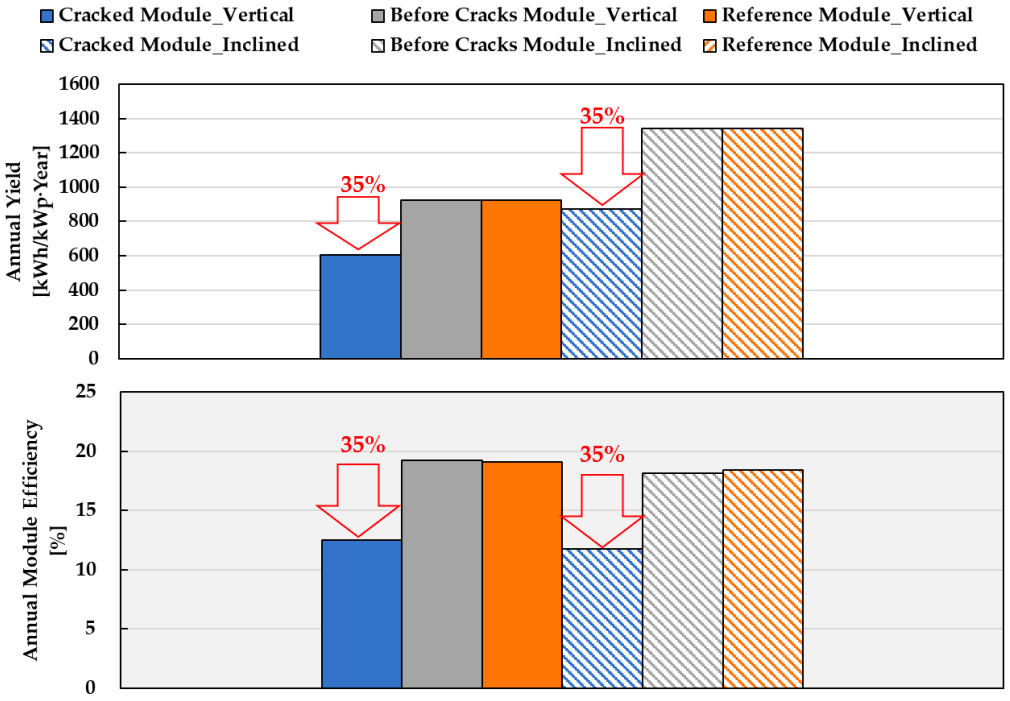


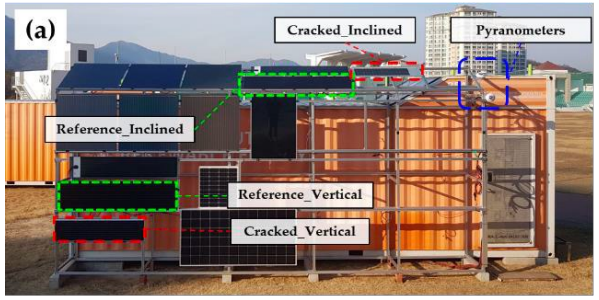
C. A. J. Pantua *et al*. Sustainability and structural resilience of building integrated photovoltaics subjected to typhoon strength winds, *Applied Energy*, 2021. https://doi.org/10.1016/j.apenergy.2021.117437

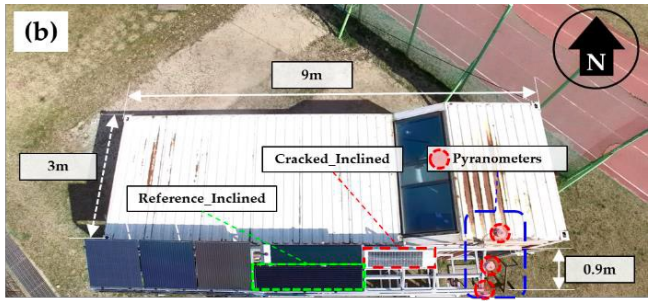
State of art - Mechanical durability

2021 K. Lee *et al.*









K. Lee et al., The Impact of Cracks in BIPV Modules on Power Outputs A Case Study Based on Measured and Simulated Data, energies, 2021. *https://doi.org/10.3390/en14040836*

State of art – Colored BIPV

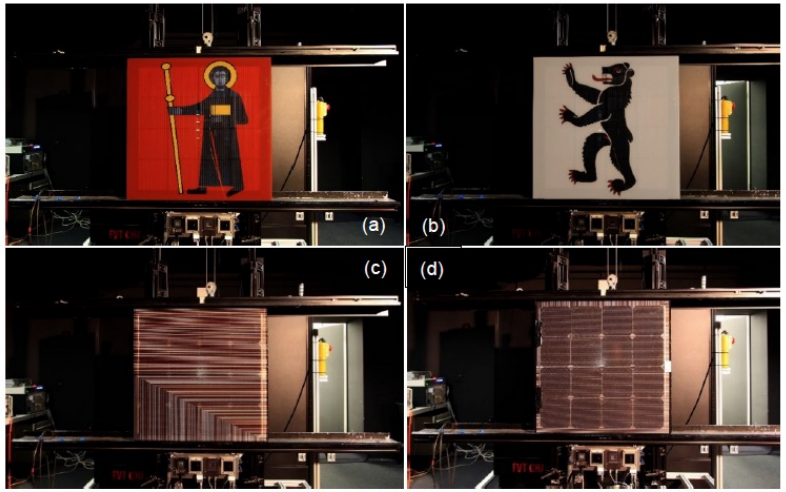


Figure 1: PV modules coloured by ceramic digital printing technology: (a) C13-A1, (b) C13-B1 and (c) & (d) front and rear side of module C13-C1.

Figure 3: Two different PV modules with terracotta appearance: (left) C13-F1 module with prismatic glass and (right) C13-I1 module.

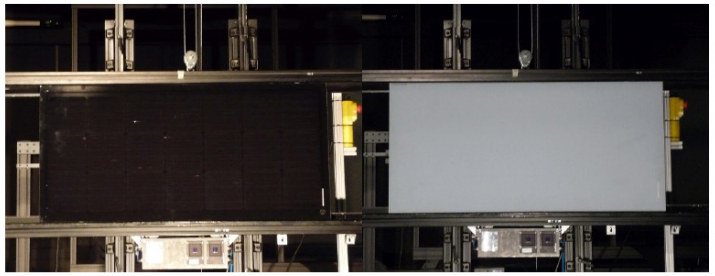
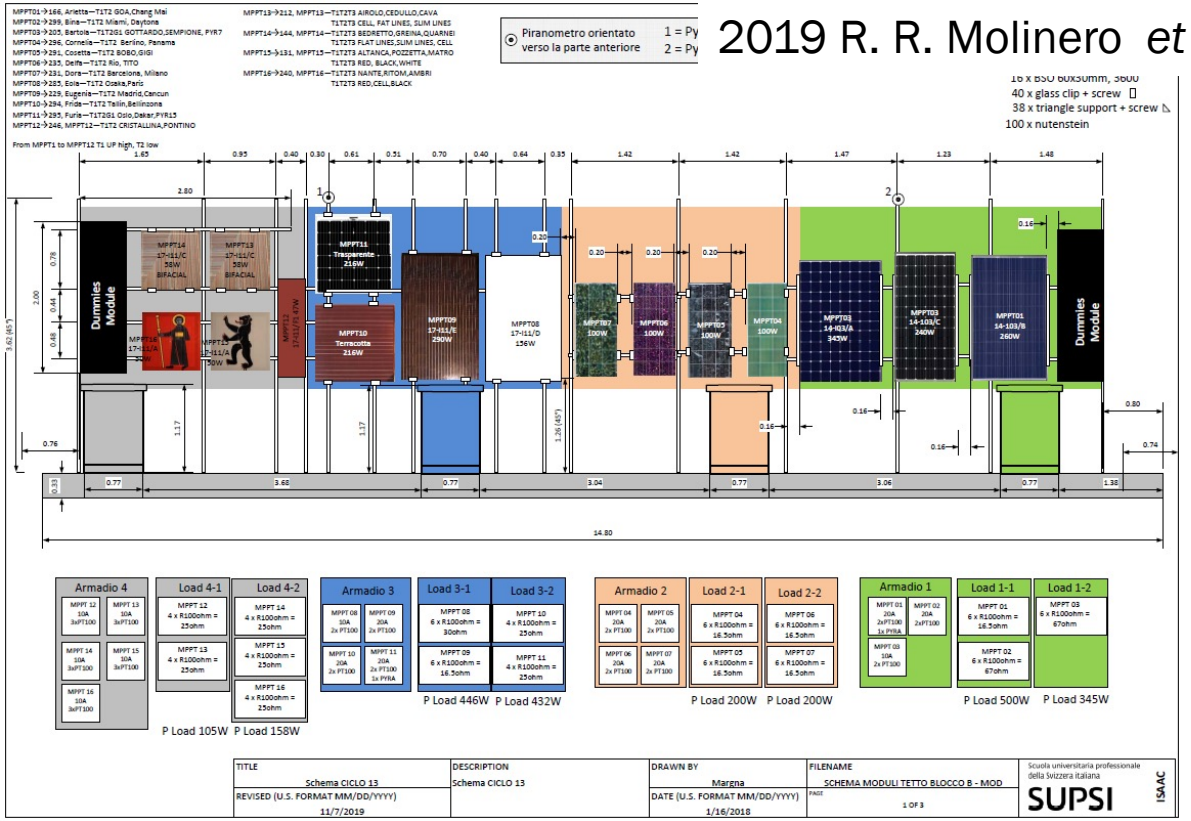
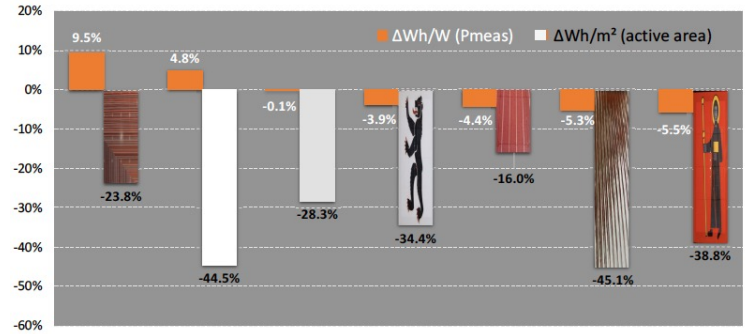


Figure 4: PV modules with full-surface printing with UV-resistant and translucent special inks: (left) C13-SA2 reference module and (right) C13-SC2 light grey module.

2019 R. R. Molinero *et al.*

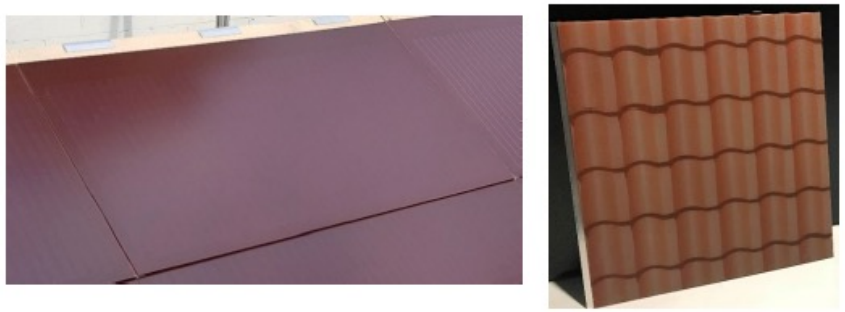




R. R. Molinero *et al*. Enhance next generation photovoltaic performance, 2019.

State of art - Colored BIPV

2020 M. Pelle *et al*.



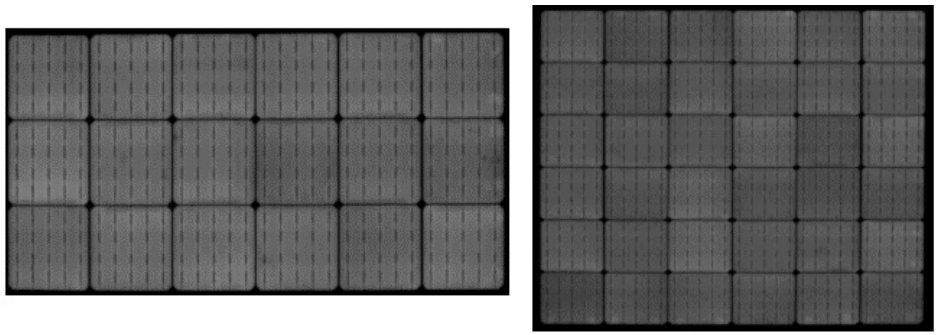
(a) (b)

Figure 4. Tested modules samples: Suncol® Tile-Terracotta Simil RAL 8015 (a); and Suncol® Tile-Texturing Simil roof tile (b).

Table 2. Detail of the two tested modules typologies.

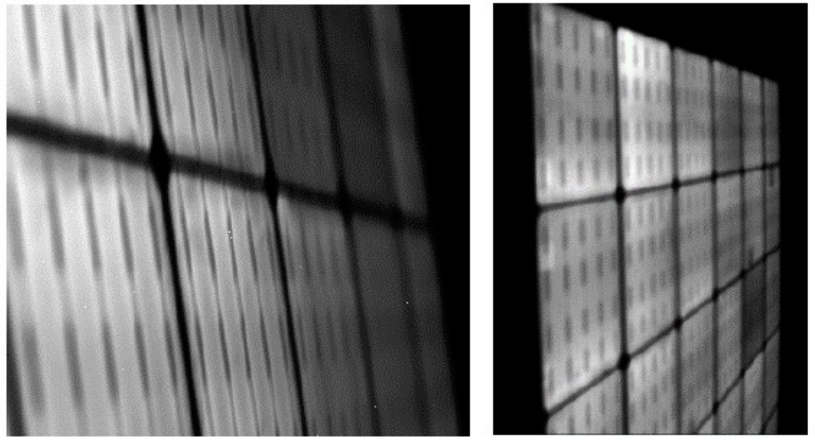
	Suncol® Tile-Terracotta	Suncol® Tile-Texturing
Solar tempered front glass	Simil RAL 8015	Simil roof tile
Active layer	18 monocrystalline cells	36 monocrystalline cells
Solar tempered back glass	Black printed	Black printed
Dimensions [m × m]	1 × 0.575	1 × 1.05

(a) (b)



(a) (b)

Figure 8. Electroluminescence images obtained at normal incidence shooting for: (a) Terracotta; and (b) Texturing Roof Tile.



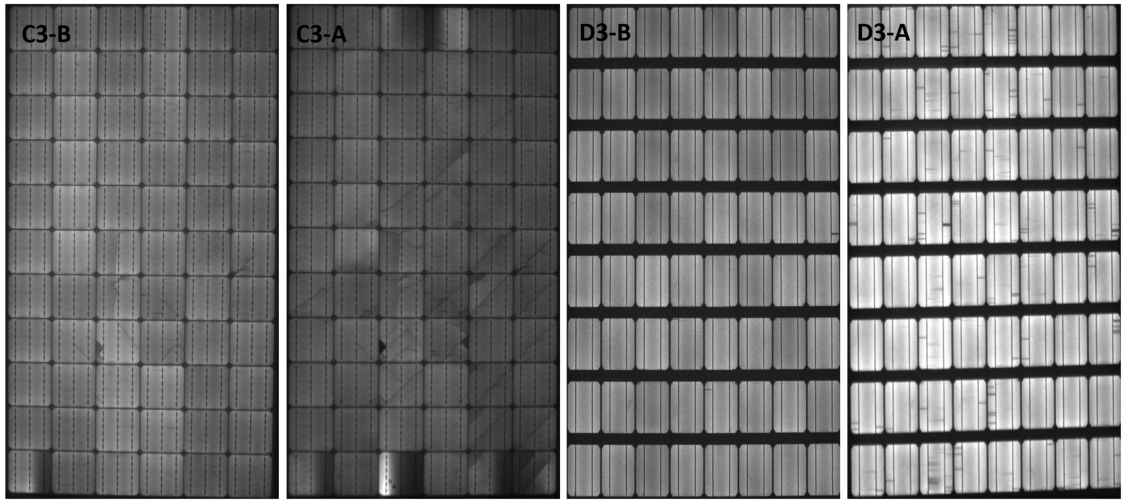
(a) (b)

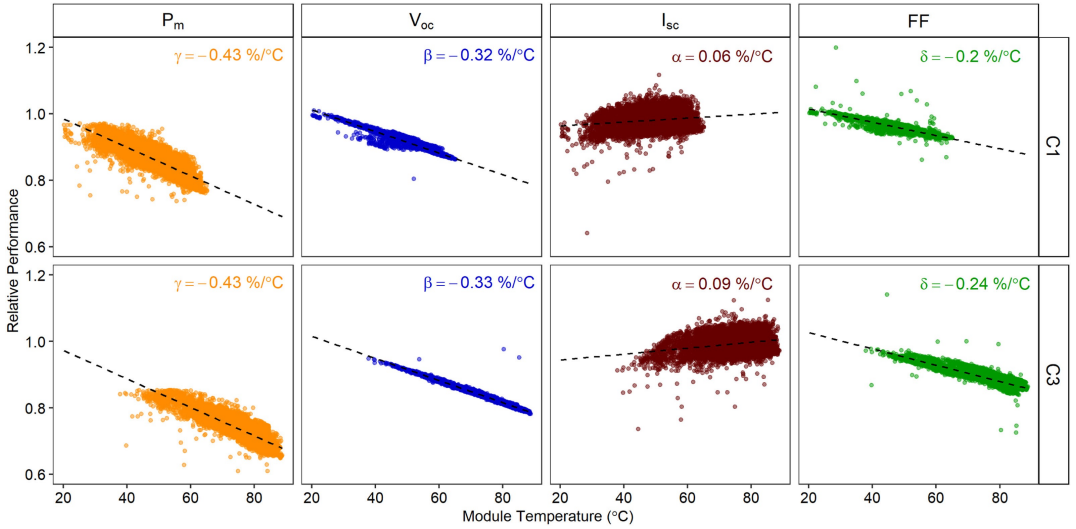
Figure 9. Electroluminescence images obtained at small incidence shooting for: (a) Terracotta; and (b) Texturing roof Tile.

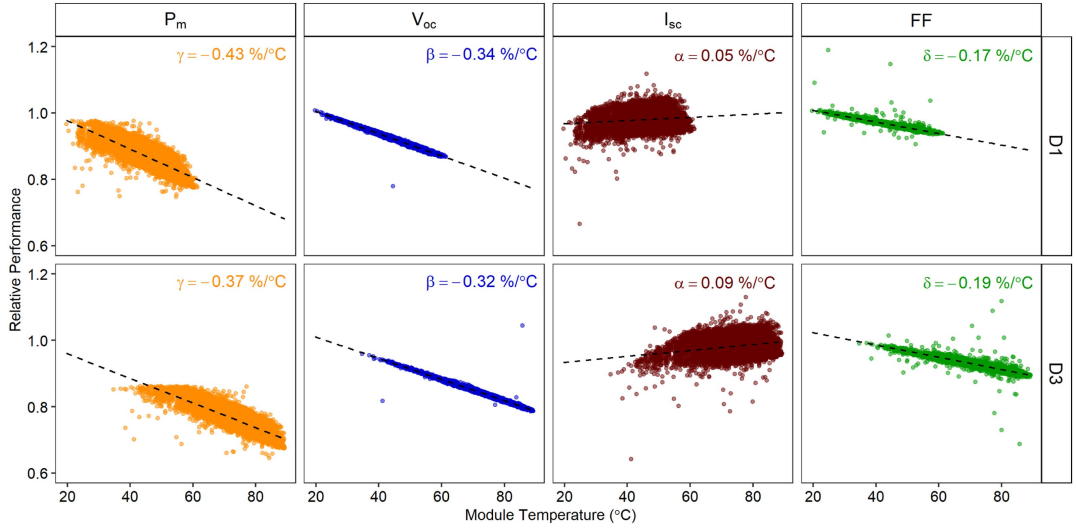
M. Pelle *et al*. Coloured BIPV Technologies- Methodological and Experimental Assessment for Architecturally Sensitive Areas, *Energies*, 2020. doi:10.3390/en13174506

State of art – T impact

2020 A. Gok *et al.*



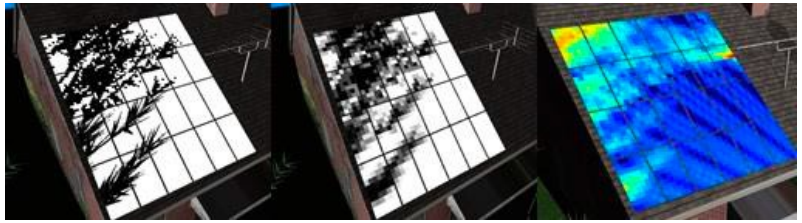




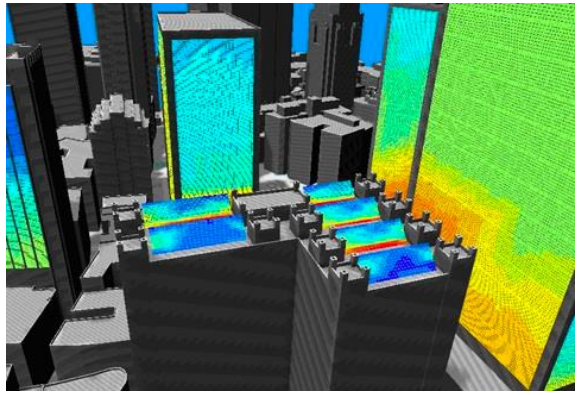
A. Gok *et al*. The influence of operating temperature on the performance of BIPV modules, *IEEE JPV*, 2020. 10.1109/JPHOTOV.2020.3001181

State of art – T impact, shading

Shading analysis



2019 IEA Task 15



Temperature effect

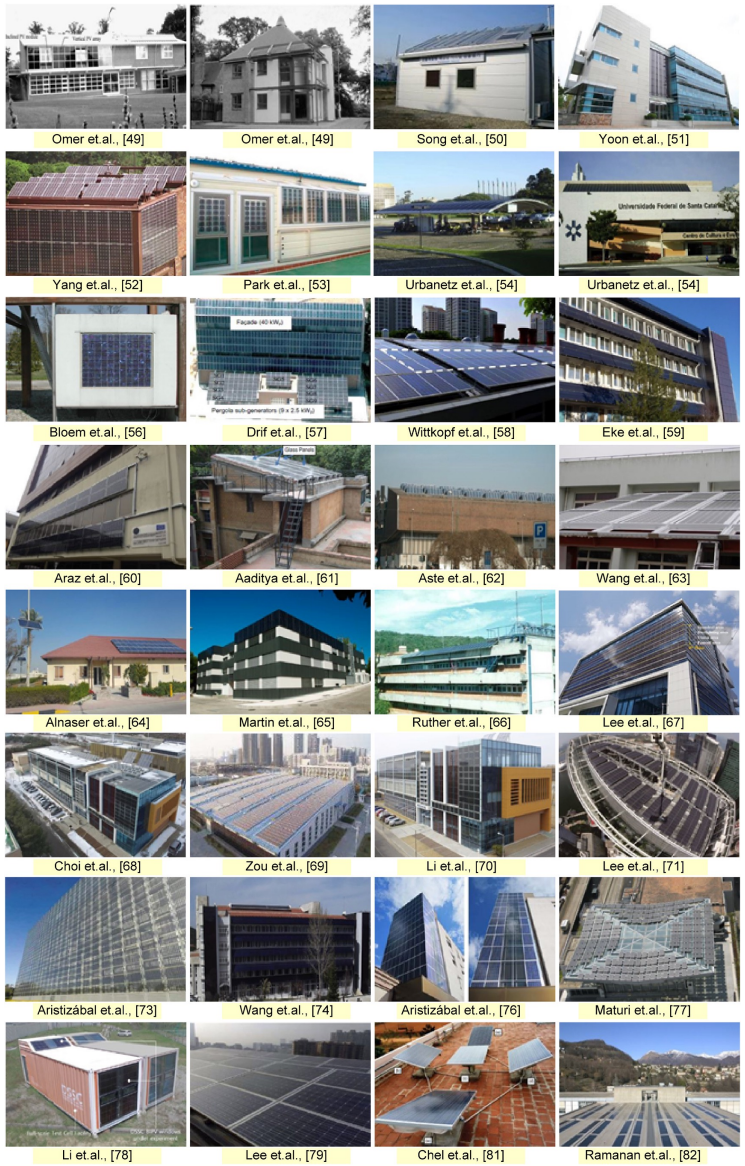
Type of tested property	Tested property	Property testing level (Module/ System)	BIPV feature to be considered	Recommended tests/procedures (including references to existing ones)
5. Durability and reliability	Thermal cycling	Module	Frequent shading	Increase number of cycles compared to standard IEC tests
5. Durability and reliability	Thermal stress	Module	Frequent partial shading (by close and distant objects)	Adapted IEC hot-spot test to new boundary conditions
5. Durability and reliability	Thermal stress	Module	Frequent partial shading (by close and distant objects)	Make IEC 62979 (bypass diode thermal runaway) mandatory if frequent shading may occur

Type of tested property	Tested property	Property testing level (Module/ System)	BIPV feature to be considered	Recommended tests/procedures (including references to existing ones)
1. Electrical	Module defect identification	Module	Inhomogeneous surface coverage	Electroluminescence testing - Mask back surface with opaque material
1. Electrical	Module defect identification	Module	Inhomogeneous surface coverage	IR imaging (problems with IR-transmissive materials like thin polymers)
1. Electrical	PID	Module	Module decoration	PID test, See Section 3.1.2.1
1. Electrical	Rated module power output	Module	Bifacial modules	Refer to IEC standardisation work on bifacial modules: Define BIPV-relevant illumination conditions for I-V measurement.
1. Electrical	Rated module power output	Module	Curved modules	Test under natural sunlight to achieve a realistic variation of incidence angles
1. Electrical	Rated module power output	Module	Large module dimensions	Test "representative-size" modules and apply extrapolation procedures; Outdoor testing; measure IV curves of individual strings within module separately
1. Electrical	Rated module power output	Module	Modules of many different dimensions	Testing "representative-size" modules and interpolation procedures
1. Electrical	Rated module power output	Module	Frequent partial shading (by close and distant objects)	Adapt IEC hot-spot test to BIPV-relevant boundary conditions
1. Electrical	Rated module power output	Module	Module decoration causing mismatch within module	Area-weighting; Optical modelling; I-V measurement
1. Electrical	Annual electricity yield	System	Treatment of front glass surface, e.g. structured, anti-reflective, anti-glare	Simulation, taking correct angular dependence of electrical data into account

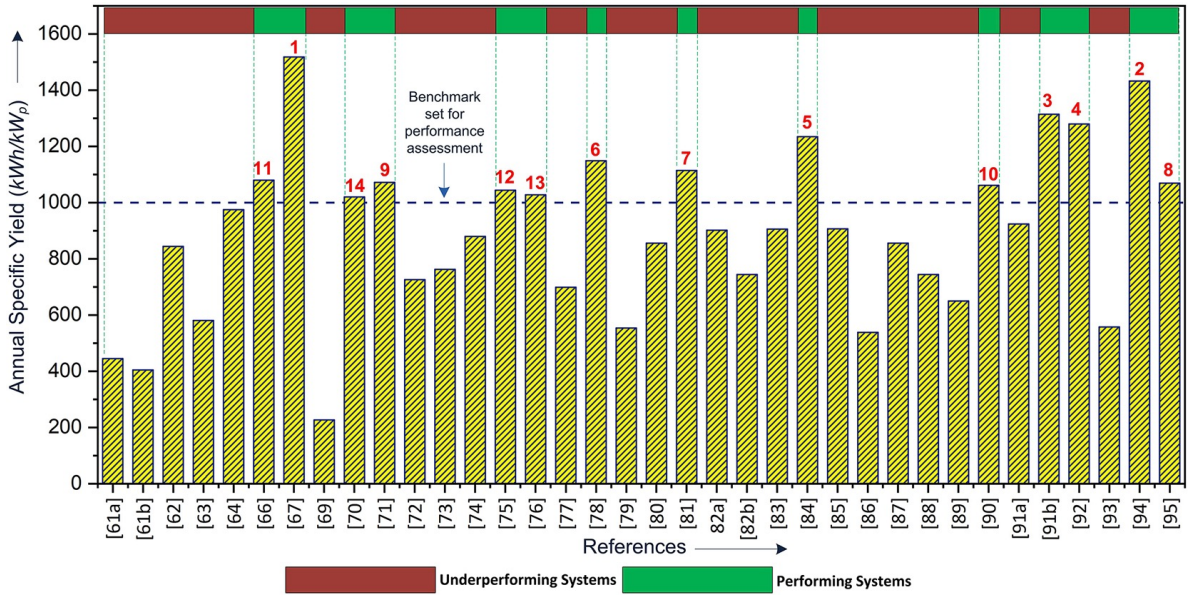
2020 IEA Task 15

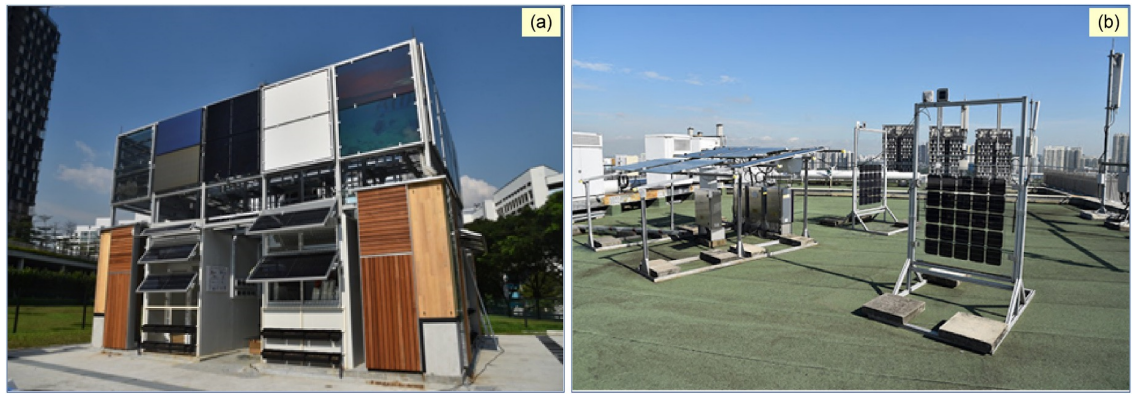
IEA Task 15: Multifunctional characterisation of BIPV - proposed topics for future international standardisation activities, 2020.

State of art - Performance



2022 D. S. Pillai *et al*.

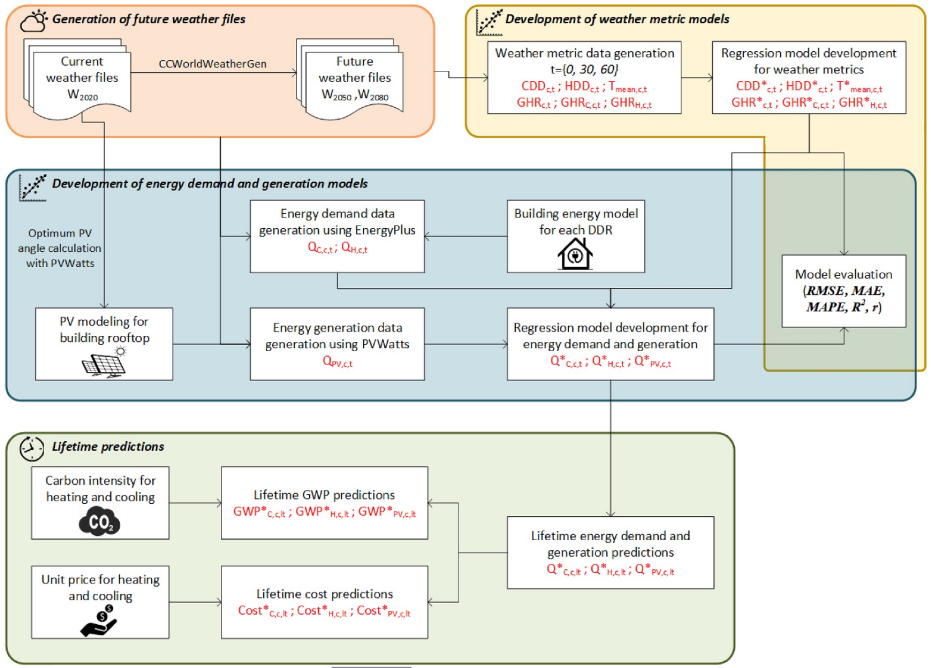


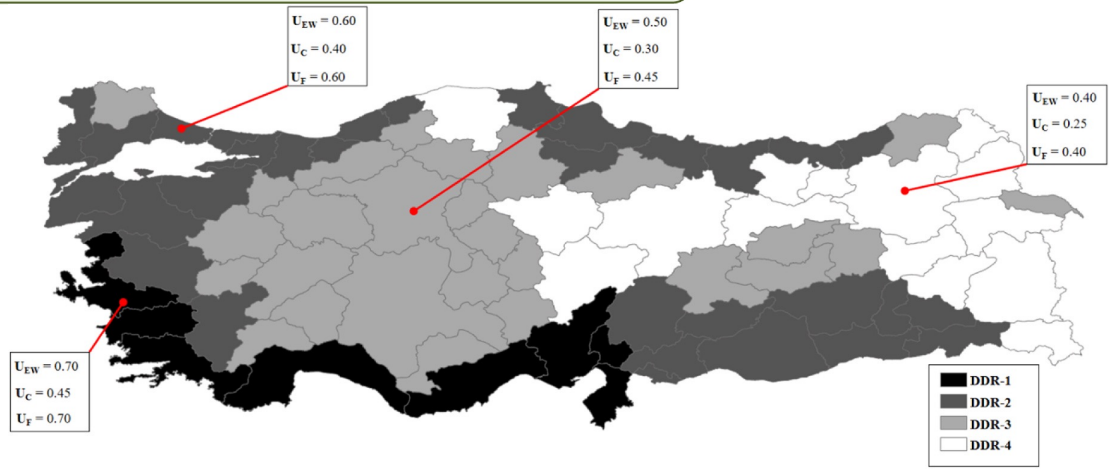


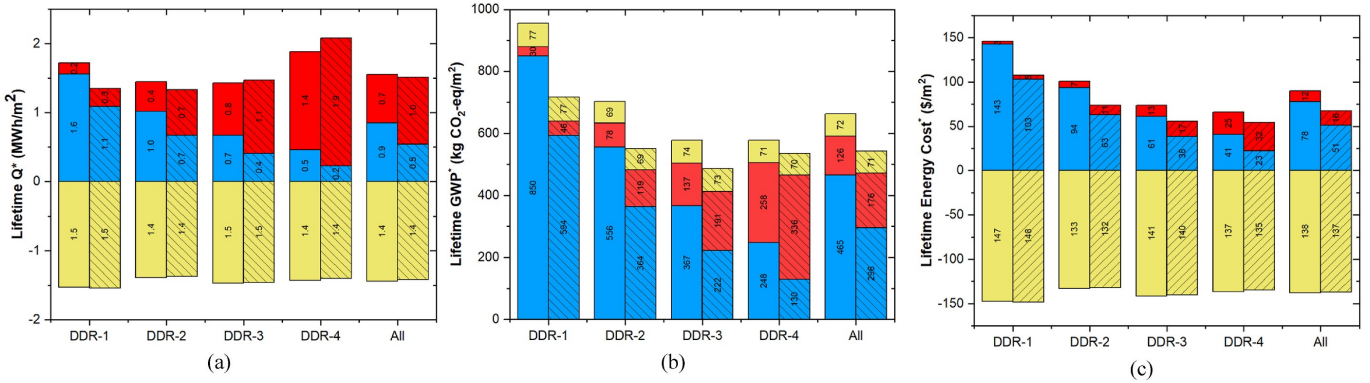
D. Pillai et al., A comprehensive review on building integrated photovoltaic systems Emphasis to technological advancements, outdoor testing, and predictive maintenance, *Renewable and Sustainable Energy Reviews*, 2022. https://doi.org/10.1016/j.rser.2021.111946

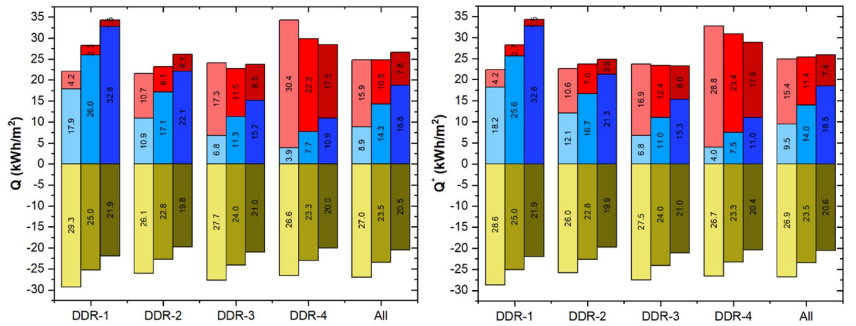
State of art - Performance

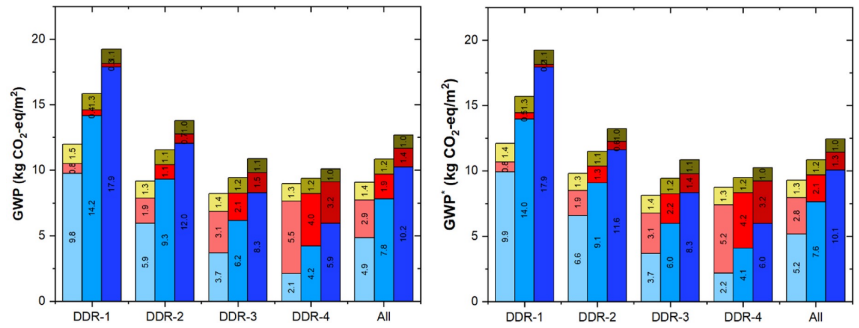
2022 T. Tamer *et al.*











T. Tamer et al., Data-driven, long-term prediction of building performance under climate change- Building energy demand and BIPV energy generation analysis across Turkey, *Renewable and Sustainable Energy Reviews, 2022.* https://doi.org/10.1016/j.rser.2022.112396

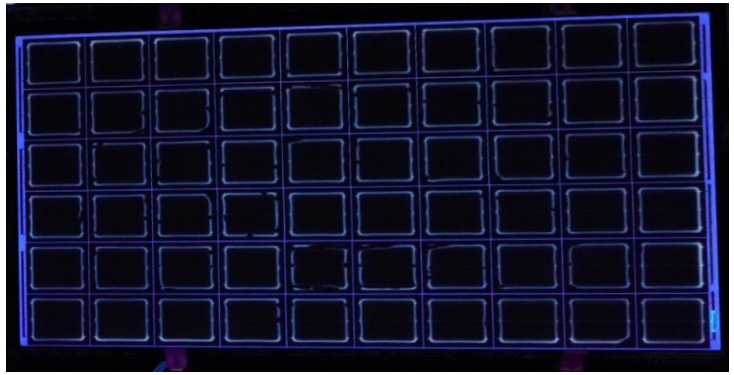
Imaging Techniques

What information we can get from images?

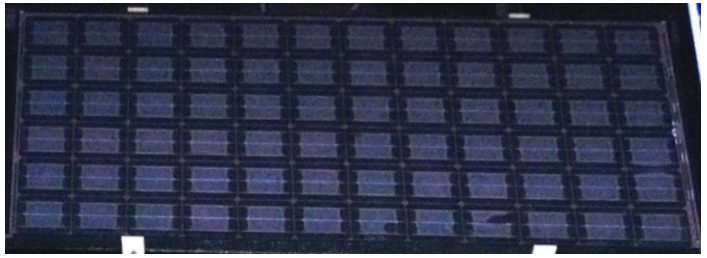
Degradation Analysis – UVF imaging

Mono AlBSF, System age = 4 years

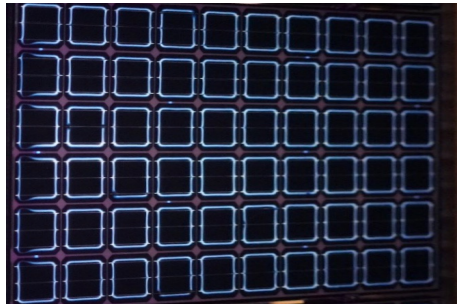
Multi AlBSF, System age = 4 years



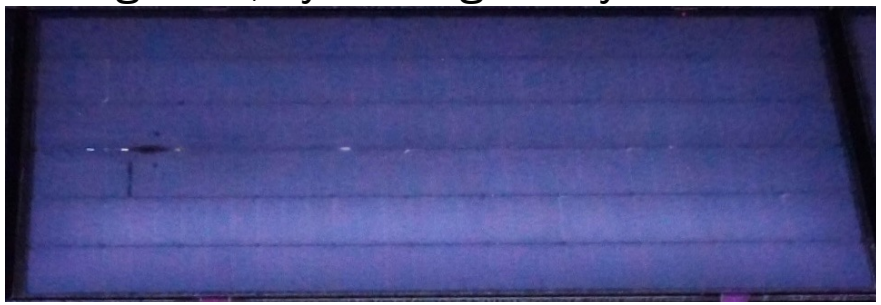
HIT, System age = 4 years



Mono AlBSF, System age = 10 years

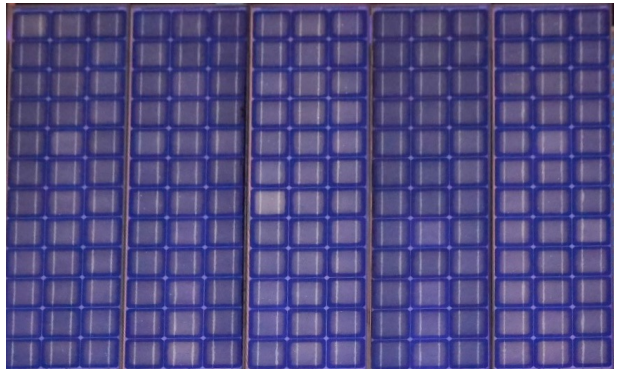


Shingle HIT, System age = 6 years

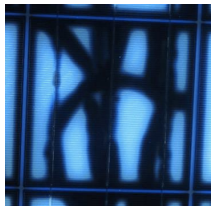


Mono PERC, System age = 4 years

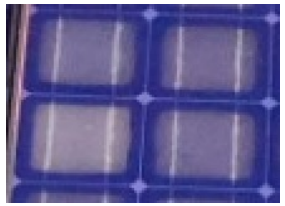
Mono AlBSF, System age = 20 years



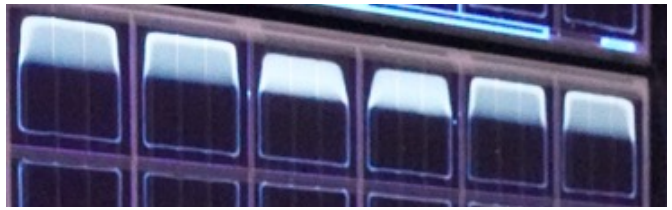
- Cracks



- Hot cells

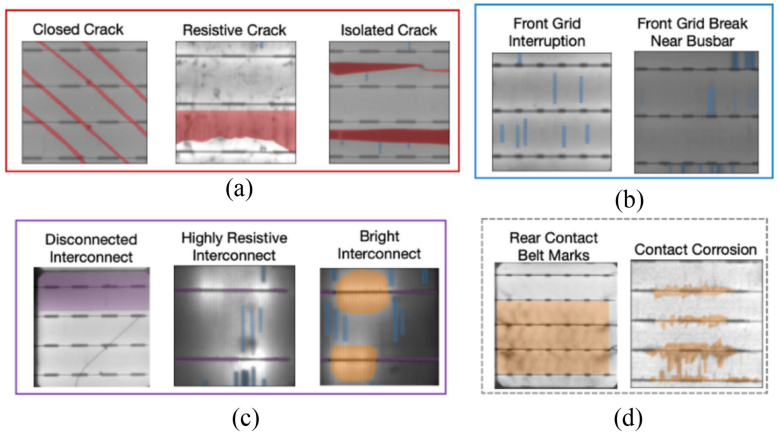


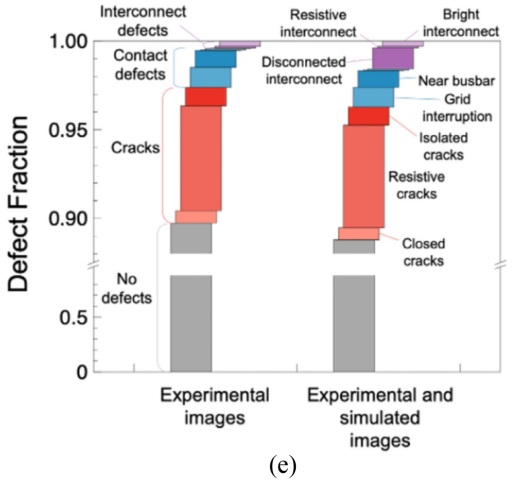
- Different BOM



UCF

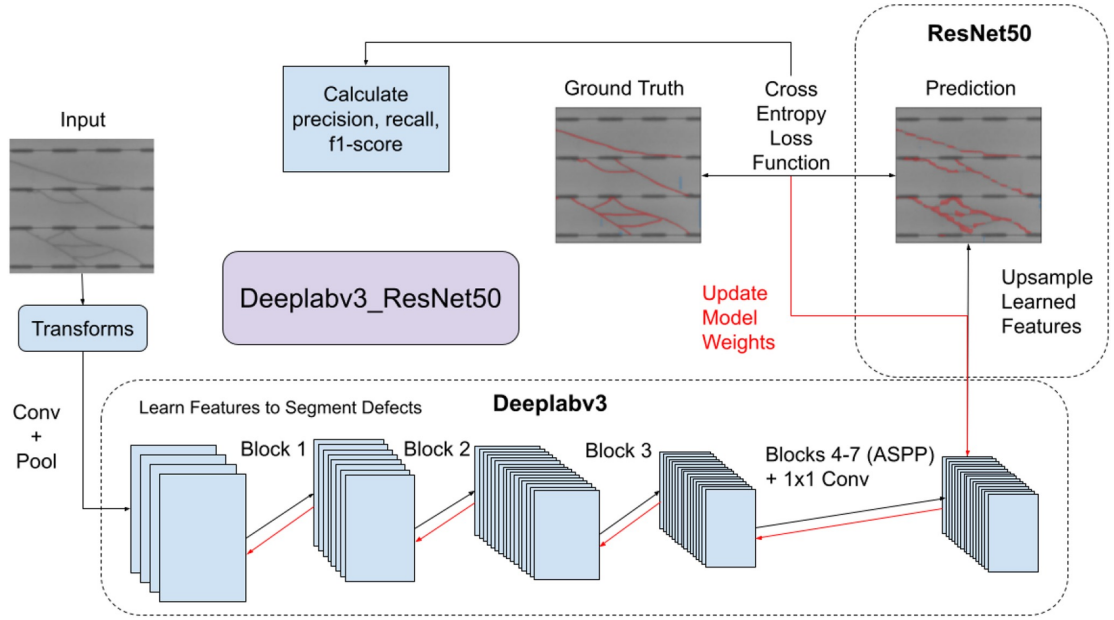
Degradation Analysis – EL imaging





Automatic defect detection using semantic segmentation

- Input of module EL images
- Indexing each individual cells within the module
- Output percentage of cells with certain type of defect



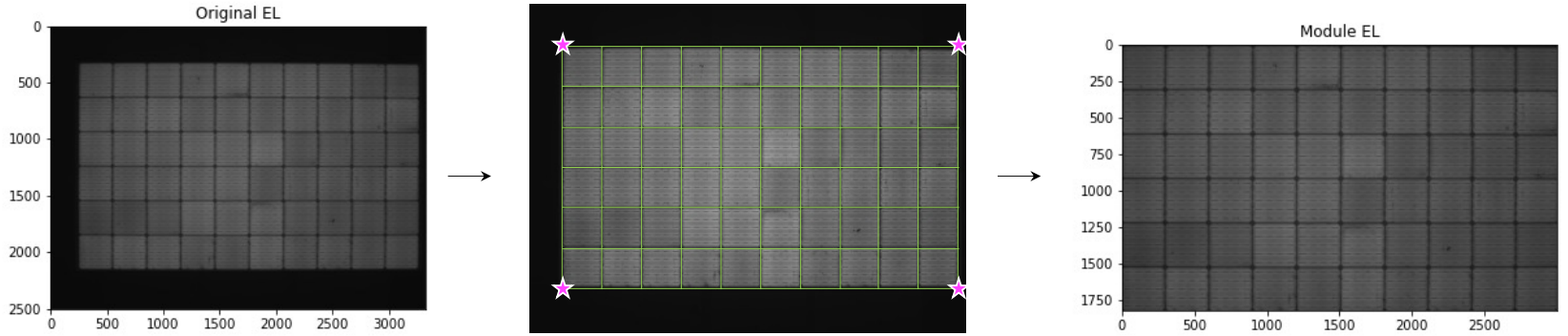
Defect	Modules with Defect	Percent of Total
Backsheet bubbling	2	1.3
Front delamination	156	100
Backsheet burn marks	10	6.4
Backsheet bumps	27	17.3
ARC corrosion	80	51.3
Snail trails	30	19.2

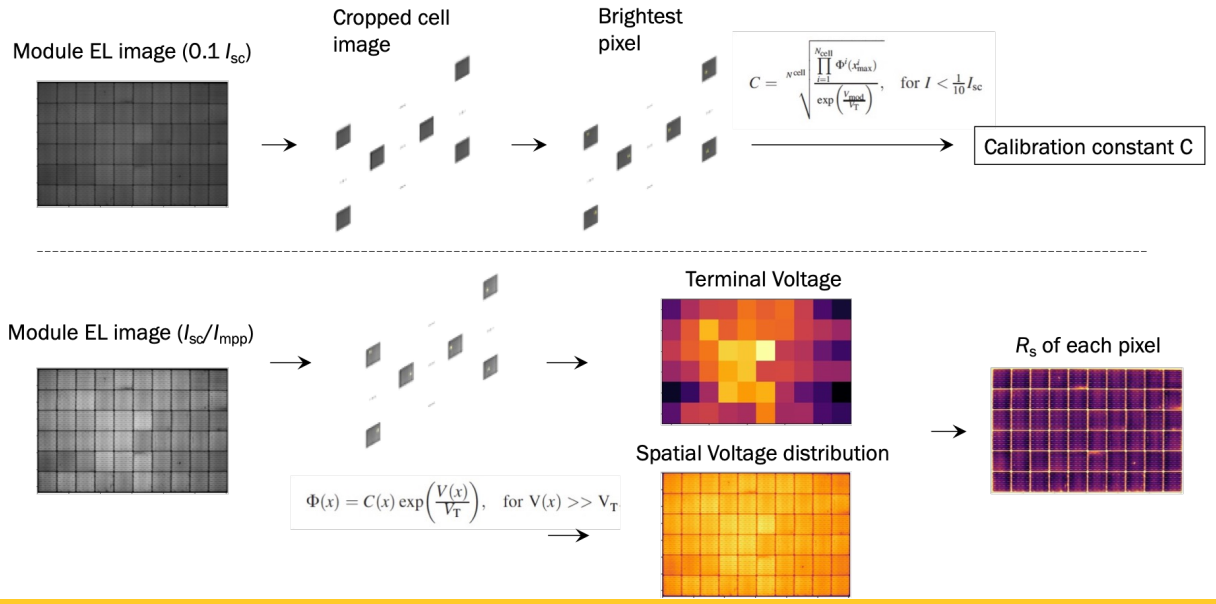
J. Fioresi, D. Colvin, R. Frota, R. Gupta, **M. Li**, H. Seigneur, S. Vyas, M. Shah, K. O. Davis, "Automated Defect Detection and Localization in Photovoltaic Cells using Semantic Segmentation of Electroluminescence Images",*IEEE Journal of Photovoltaics*, vol. 12, issue 1, pp. 53-61, 2021.

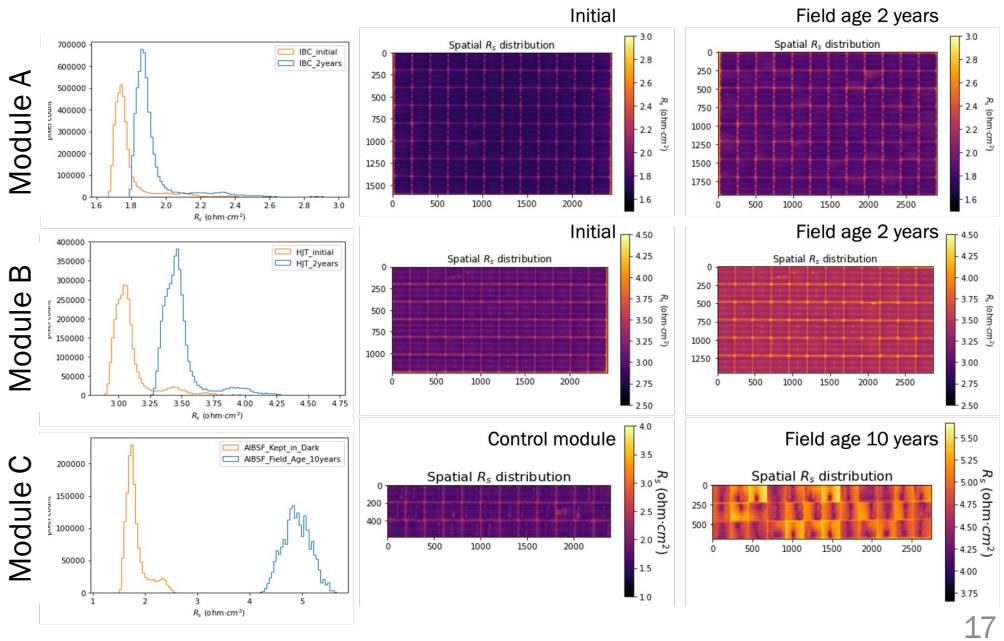
Degradation Analysis – EL imaging

Streamline series resistance imaging

- Input of minimum of 2 EL images
- Automatically calculate terminal voltage and spatial voltage distribution at pixel level
- Output module R_s images



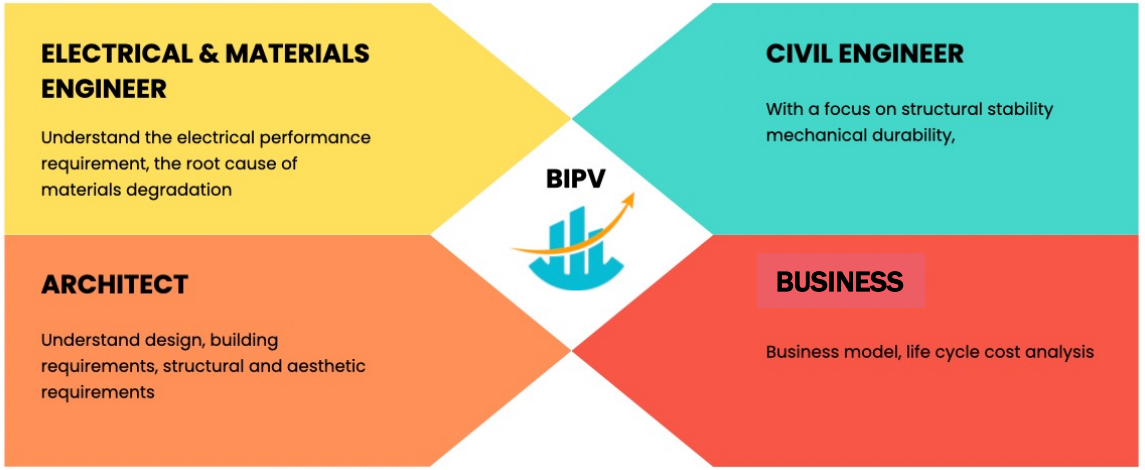




https://github.com/ucf-photovoltaics/PVRs

Challenges and Opportunities

- Different BIPV products
  - Foil
  - Tile
  - Module
  - Shingles
  - Glazing



- Difference between BIPV and PV
  - No specific standards for BIPV
- Understanding root cause vs. global degradation rate estimation
- Challenge with long-term field testing

Thanks! Questions?

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