Growing **ideas** through **networks**

Solar Photovotoltaic Systems Degradation

…and long-term performance

Alessandro Virtuani[1,2], Malta, October 14th 2019

1 École Polytechnique Fédérale de Lausanne (EPFL), Neuchatel, Switzerland
2 Officina del Sole (O'Sole), Milan, Italy

cost EUROPEAN COOPERATION IN SCIENCE & TECHNOLOGY

Funded by the Horizon 2020 Framework Programme of the European Union

PEARL PV

Outline

1. Solar Photovoltaics (PV) in the global electricity mix

2. Definitions

   Failure, lifetime, reliability, durability ….

3. Long-term performance of PV systems (modules)

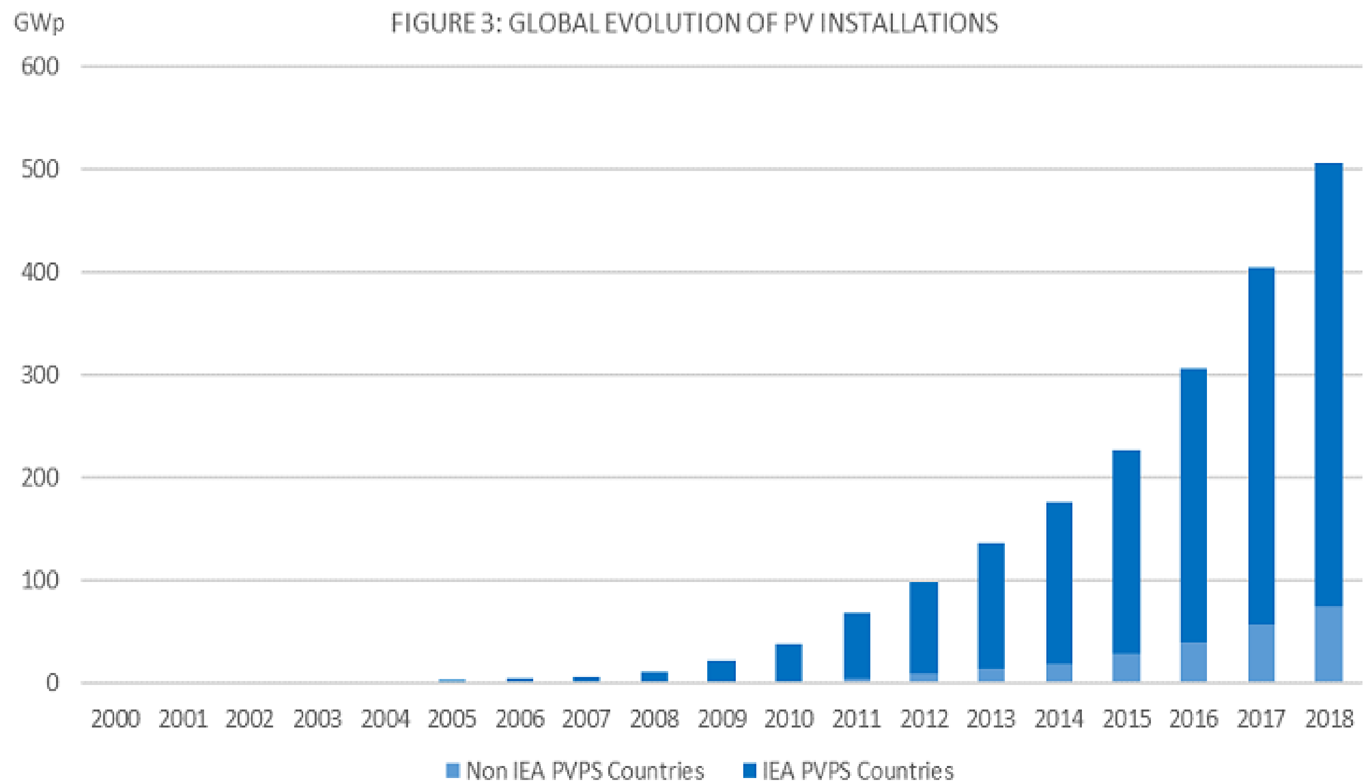
   Two examples:

   a. recent study in Germany (systems)
   b. the TISO-10-kW PV plant - 35 year of PV

4. How to design «reliable» & «durable» PV systems?

   a short journey trough Africa & Europe

Global evolution of PV installations



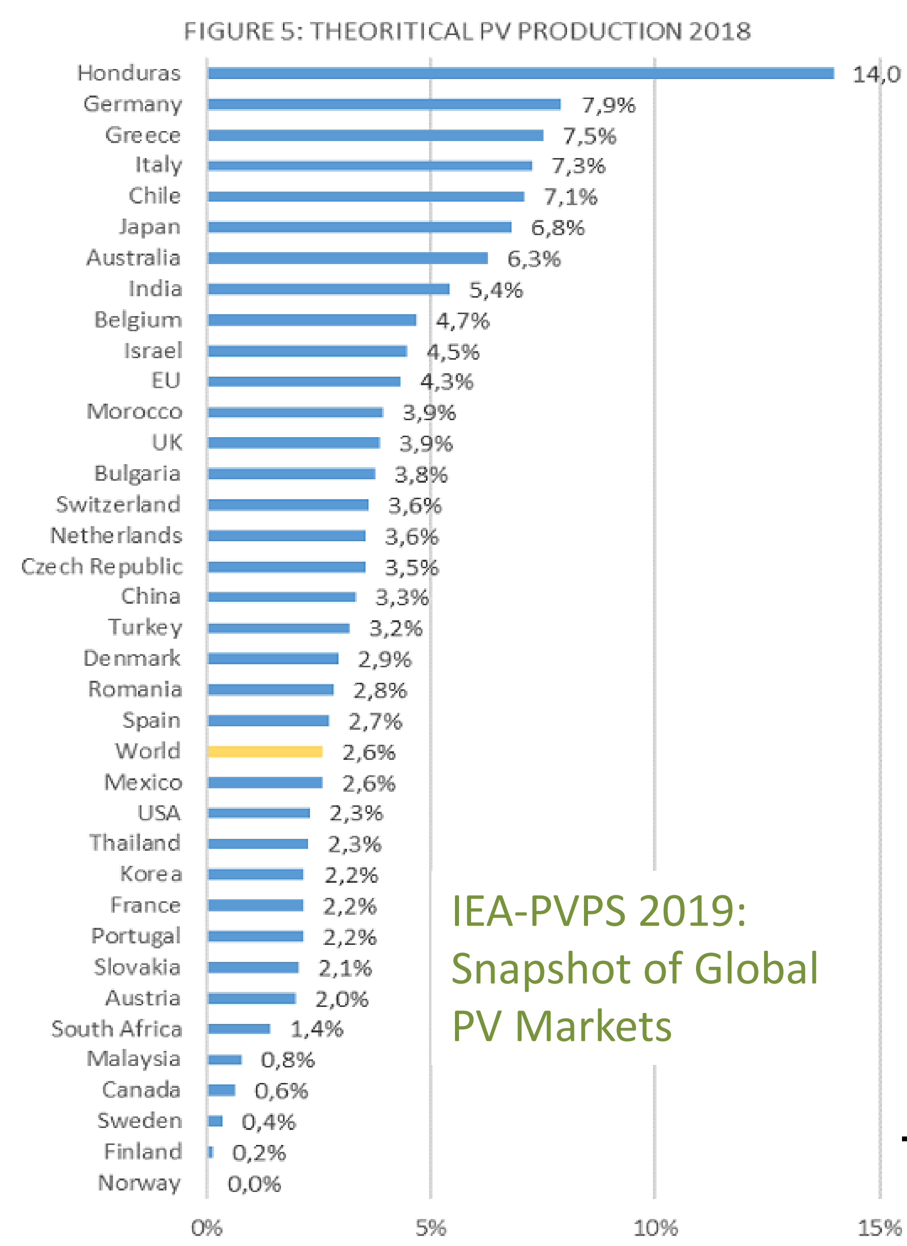
2019: ~115 GW (est.) newly added capacity
~615 GW (est.) cumulative capacity

IEA-PVPS 2019: Snapshot of Global PV Markets

Share of PV in the electricity consumption - selected countries

1) Honduras, Chile, Germany, Greece, Italy, Japan, Australia, India and Morocco have enough PV capacity to produce more than 5% of their annual electricity demand with PV (2018)

2) PV represents around 2,6 % of the global electricity demand and 4,3 % in Europe (2018)



IEA-PVPS 2019: Snapshot of Global PV Markets

Solar PV into the global electricity mix (2)

PV starts to be perceived as one key ingredient of the global electricity mix.

[Intermittency and storage are main issues].

Can we rely on solar PV?

- Evidence tells us that PV can be a reliable power source;
- The technology is evolving rapidly (pros/cons);
- Half of the global PV capacity has been installed in the last 4 years >> no long-term feedback.

Outline

1. Solar Photovoltaics (PV) in the global electricity mix

2. Definitions

Failure, lifetime, reliability, durability ….

3. Long-term performance of PV systems (modules)

Two examples:

a. recent study in Germany (systems)

b. the TISO-10-kW PV plant - 35 year of PV

4. How to design «reliable» & «durable» PV systems?

a short journey trough Africa & Europe

Definitions (1)

In reliability engineering (IEC 60050-191):

the **lifetime** (or useful life) of a product is:
the "time interval from first use until user requirements are no longer met, due to economics of operation and maintenance, or obsolescence".

For **PV modules**, a common practice: 80% of initial power (arbitrary definition!).

Failure is "the loss of ability to perform as required".

Creating a consistent definition of failure for a **PV module/system** is challenging as its aging is often characterized by a gradual degradation rather than a catastrophic event determining a complete interruption of its performance.

IEC 60050-191: International Electrotechnical Vocabulary (IEV) - Part 191: Dependability and quality of service

Definitions (2)

Reliability is defined as the ability [**of a system/component**] to perform as required, without failure, for a given time interval, under given conditions“.

Reliability is described by a probability function, R (t), called the **reliability function**, that expresses the probability that a product performs properly (or “survives”) by time t . Survival is the complementary event to failure.

Reliability at time t is therefore given by:
$R(t) = 1 - F(t)$

where F (t) is the cumulative failure distribution function (i.e. the probability that the product fails by time t).

Definitions (2)

The **durability** of a system/component is the "ability to perform as required, under given conditions of use and maintenance, until the end of useful life".

Durability is often measured as a time (e.g. years or cycles) and can be thought of as the expected value for the useful life.

Whereas a **reliability test** is performed with the aim of reproducing failures in order to fix the issues and improve the device design, a **durability test** is performed to determine the length of the maximum failure-free period.

A. ZIELNIK, Validating photovoltaic module durability tests, Solar America Board for Codes and Standards, (2013).

Outline

1. Solar Photovoltaics (PV) in the global electricity mix

2. Definitions
   Failure, lifetime, reliability, durability ….

3. Long-term performance of PV systems (modules)
   Two examples:
   a. recent study in Germany (systems)
   b. the TISO-10-kW PV plant - 35 year of PV

4. How to design «reliable» & «durable» PV systems?
   a short journey trough Africa & Europe

Degradation rates (%/yr) for PV systems/modules (1)

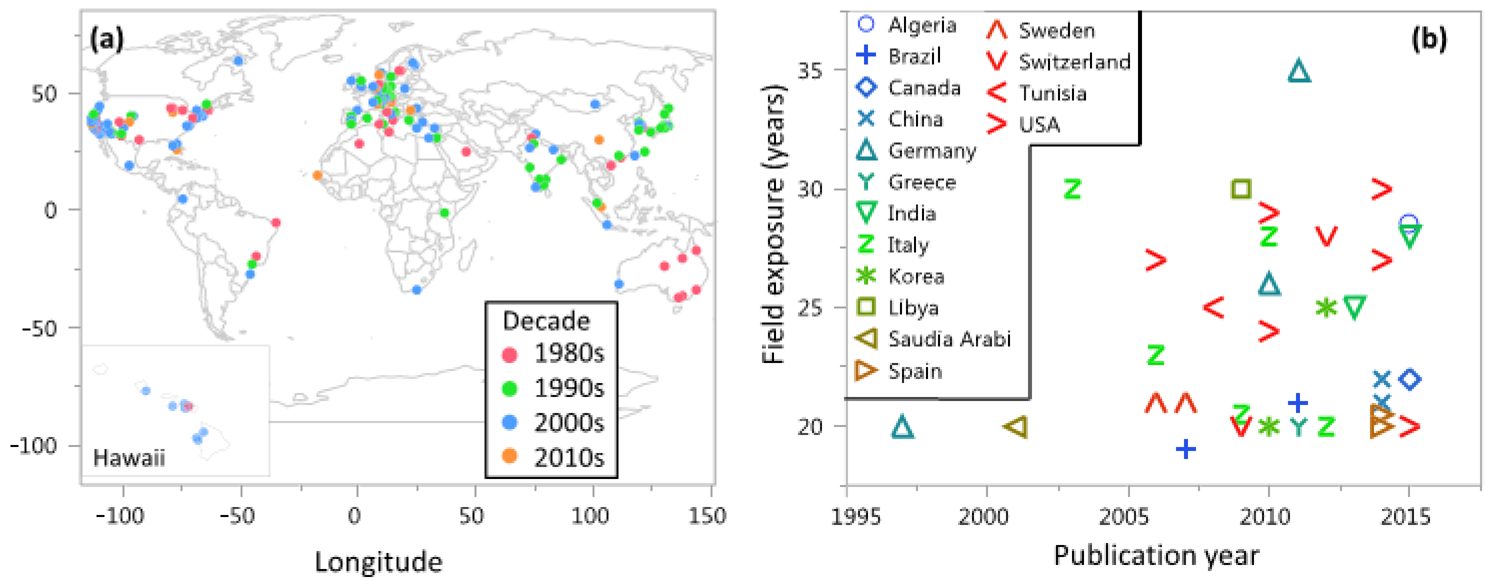


Figure 1. Worldwide reported degradation rates colored by the decade of installation (a) and system reports exceeding 20 years by publication year (b).

Dirk C. Jordan, NREL 2016
„Compendium of photovoltaic degradation rates“ & related works.

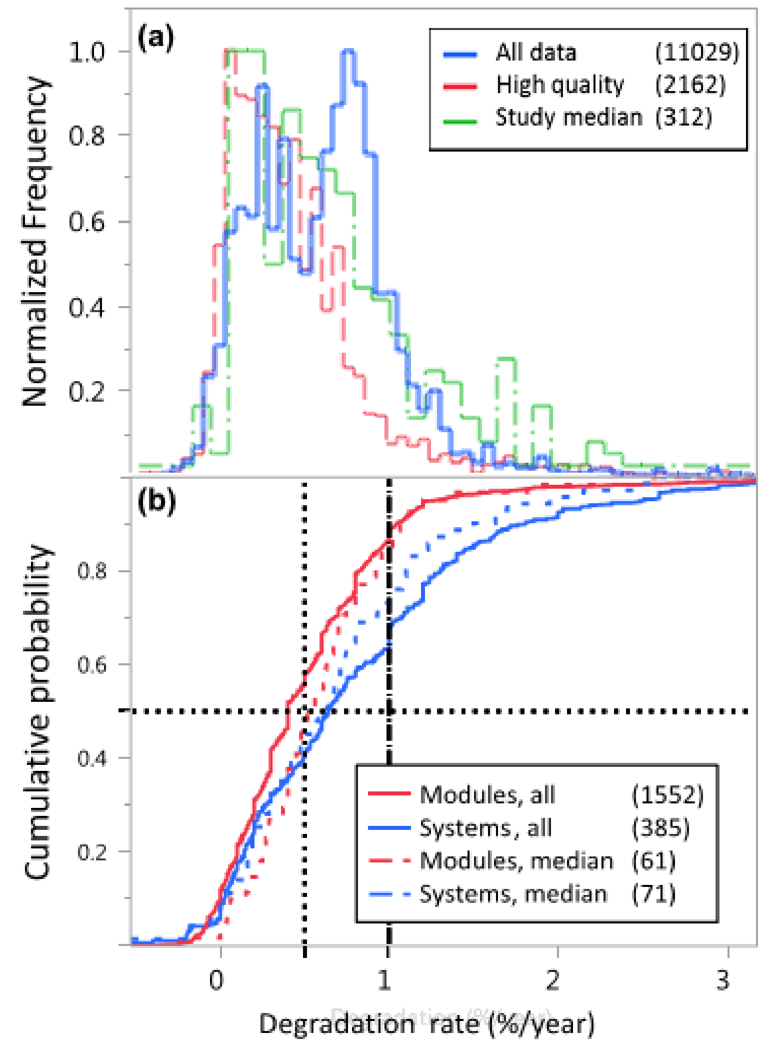
Data for PV systems/modules from an extensive literature survey

D. Jordan et al., Prog.Photov. 2016; 24: 978-989

Degradation rates (%/yr) for PV systems/modules (2)

Histograms of all data, high quality data and the median per study and system presented as the normalized frequency.

Cumulative distribution functions for high-quality x-Si systems and modules



“ We found mean degradation for c-Si technologies in the - 0.8–0.9%/year range”

D. Jordan et al., Prog.Photov. 2016; 24: 978-989

Degradation rates (%/yr): caveats

1. Several data published in the literature for PV system/module degradation;
2. Most work on PV system report degradation rates for modules (not systems!);
3. In both cases, **data quality is often low:**
   - Data are often not consistent over time;
   - System data (Performance Ratio, PR) depend on irradiance data, monitoring system, cleaning/re-calibration of irradiance sensors;
   - System (PR) and modules data come we a great uncertainty;

4. To compute degradation rates, what initial value do we use?

   Are initial values available?

   Are measurements traceable over time?

   Do we use name-plate values for modules?

   How were name-plate values measured? Tollerances?

Modules: measured power vs nameplate power

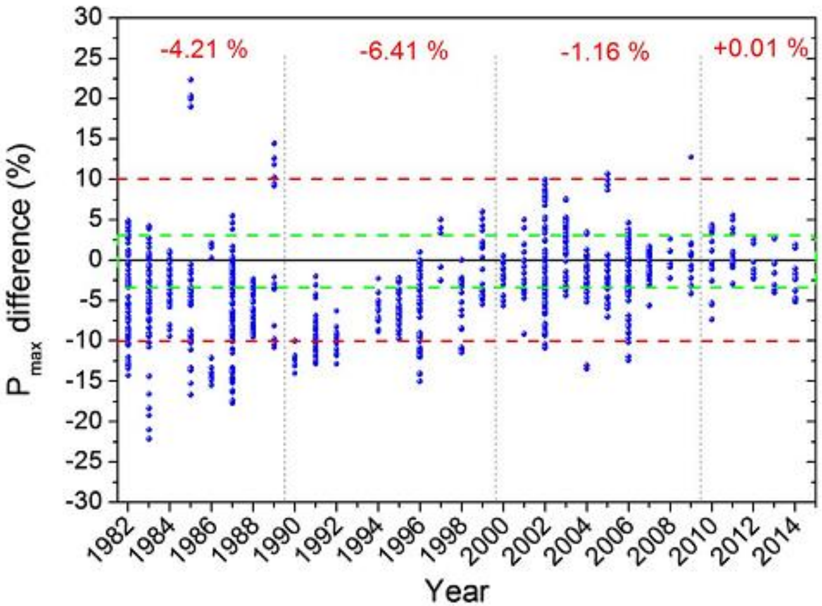


Fig. 1. Difference between P_{max} measured and P_{max} from label.

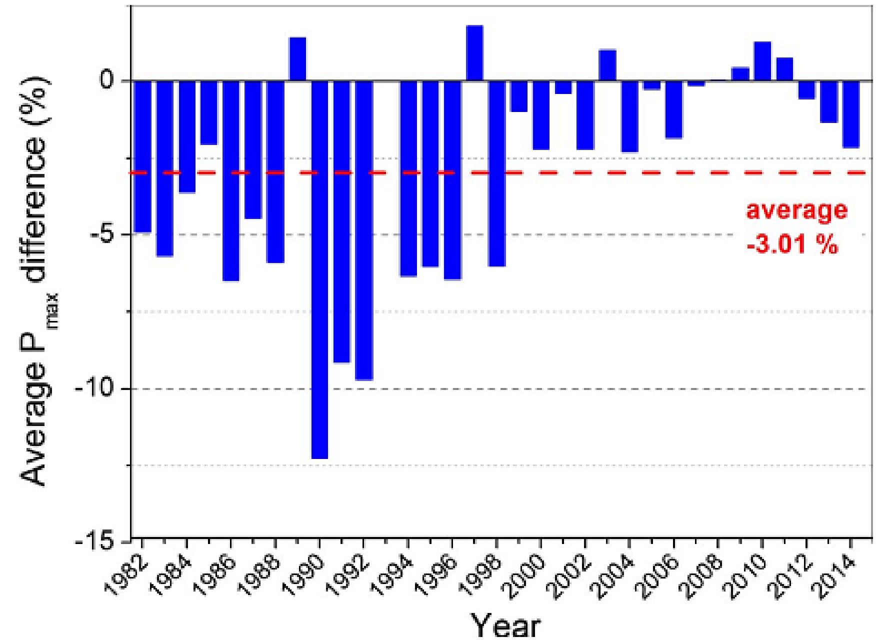


Fig. 8. Average difference between P_{max} measured and P_{max} from label.

JRC/ESTI (Ispra) study: deviation in measured power vs power declared by the manufactures (nameplate).

Tollerances:

- ± 10% in the 80s & 90s;
- Reduced then to ± 5% and ± 3%
- Today -0/+3% is quite common

J. Lopez-Garcia, T. Sample,
Solar Energy 160 (2018) 252–259

Example 1

DEGRADATION IN PV POWER PLANTS
THEORY AND PRACTICE

Klaus Kiefer, Boris Farnung, Björn Müller
Fraunhofer-Institut für Solare Energiesysteme ISE

EU PVSEC 2019
Marseille, September 2019

Klaus Reinartz, Igor Rauschen, Christian Klünter
POHLEN SOLAR

Fraunhofer ISE

K. Kiefer et al., EUPVSEC 2019 (Marseille)

Degradation in PV Power Plants
Practice

The PV power plants we have investigated

- are in the power range from 500 to 1500 kWp
- are located at different locations in Germany
- with a total of 200,000 PV modules
- With 80 central and 800 decentral inverters

K. Kiefer et al., EUPVSEC 2019 (Marseille)

Example 1

From all sites we have

- Continuous independent monitoring data with over 99.5 % availability
- Regular and traceable calibrations of the irradiation sensors

➢ Initial, regular and traceable module power measurements

➢ ~10 years of data

⇨ High quality data set!

Example 1

- The average solar irradiance **increased** by **1.1 %** per year compared to the initial value
- Yields **increased** by an average per year of **0.3 %**

But

- The average annual PRloss rate is - 0.7 %

[Definitions]

- **Performance Ratio (PR**) [%] (daily, monthly, annual)
- PR does not depend on location and insolation. Yf does.

$$\mathrm{PR}_d = \frac{E_d / P_{\mathrm{STC}}}{H_d / G_{\mathrm{STC}}} = \frac{\eta_{\mathrm{en}}}{\eta_{p\_\mathrm{STC}}}$$

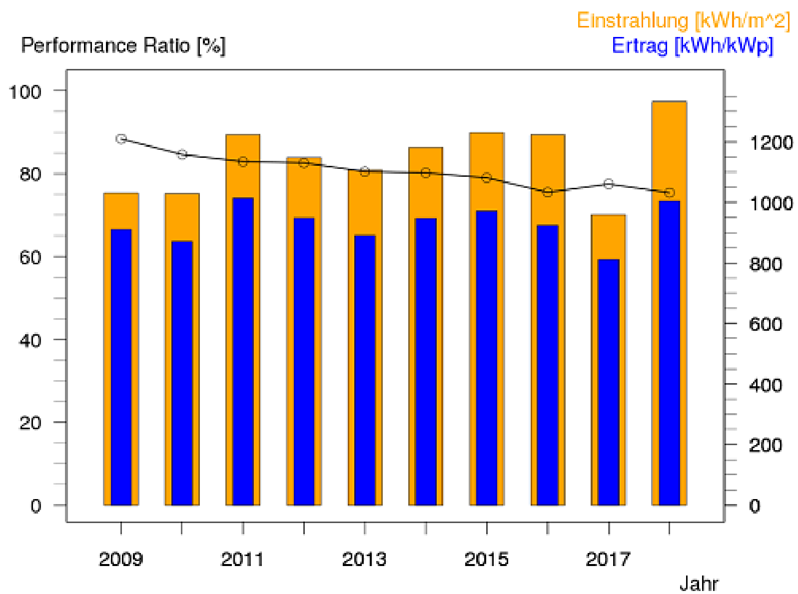
- **Final yield**

$Y_f = E_d / P_{STC}$ [kWh / kWp]

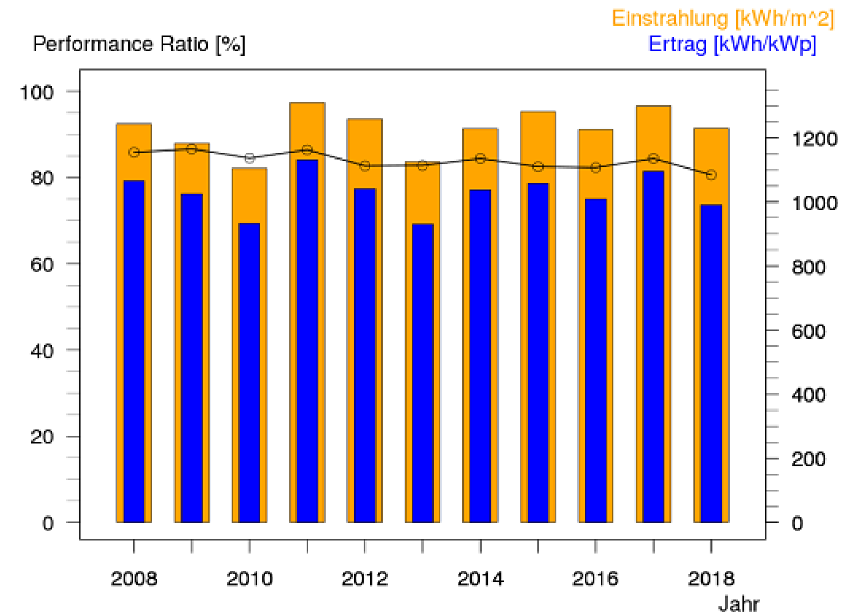
E_d [kWh] daily en. production,
H_d [kWh/m2] daily insolation,
P_{STC} [kWp] power at STC,
G_{STC} [kW/m2]at STC,

Degradation in PV Power Plants
Examples

- Rinteln: (PR = 80.7% +/-5.1%) near Hannover
- PR loss per year: 1.72%



- Roth (PR = 83.9% +/- 2.2%) near Nürnberg
- PR loss per year: 0.16 %



K. Kiefer et al., EUPVSEC 2019 (Marseille)

Degradation in PV Power Plants

Example: Rinteln (PR fluctuation +/-5.1%, PR loss per year: 1.72%)

Reasons for the negative PR trend

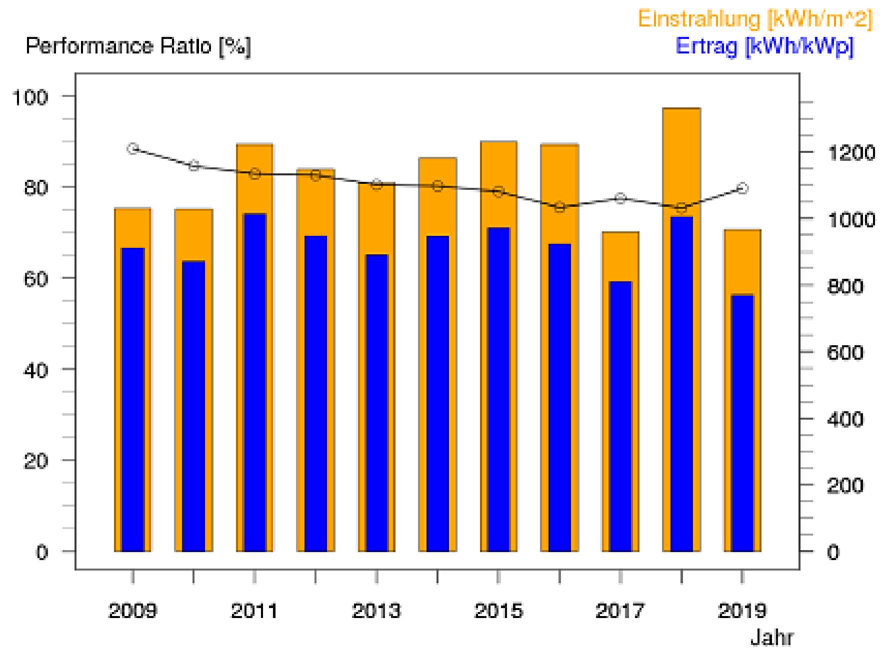
- Failures of inverters and fuses
- Soiling of the PV Modules

In 2018

- Repair of all defects was done
- PV Modules were cleaned

PR increase of 5% in 2019 compared to 2018

PR loss rate is partly reversible !

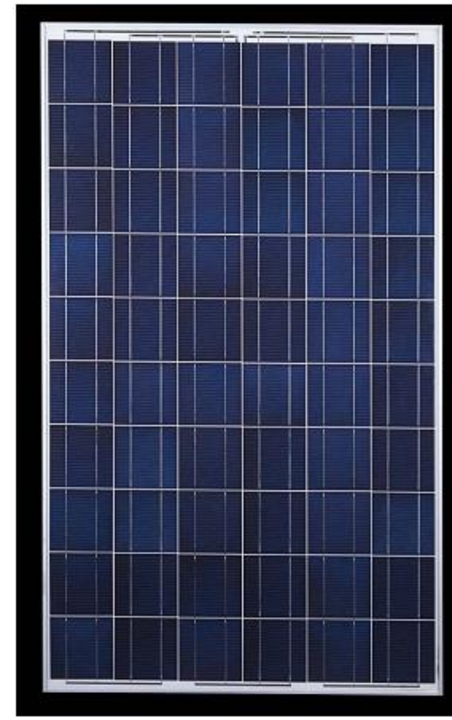


K. Kiefer et al., EUPVSEC 2019 (Marseille)

Degradation in PV Power Plants

Comparison of PR loss System/ P loss Module

Location	years	PRloss/year	Pmloss/ year
Dormagen	8	-0.30%	-0.19%
Hedemünd	10	-0.50%	-0.24%
Kerpen	9	-0.50%	-0.13%
Bingen	10	-0.40%	-0.08%
Aichtal	8	-0.67%	-0.09%
Altenstadt	12	-0.60%	-0.08%
Average	**9.5**	**-0.50%**	**-0.14%**



Conclusion

- Power loss of PV Modules contributes only slightly to Performance loss rates

K. Kiefer et al., EUPVSEC 2019 (Marseille)

Degradation in PV Power Plants
Conclusion

- PV Modules showed **very small Power loss** after 10 years of operation
- The **PV Modules** are **very stable** and **reliable**
- **Inverter failures** have the most effect on **Performance loss rates** on system level
- Almost all of the observed Performance loss are reversible
- The loss rate depends very much on the speed of troubleshooting

Location	Pnom	PR	Spread	PRloss/year
	kWp	%	%	%
Eschweiler	999	90.2	1.9	+0.17
Mülheim	984	85.9	2.2	0.05
Kircheim	1001	88.8	1.6	0.09
Murr	293	86.1	1.5	0.13
Greven	999	90.6	1.2	0.15
Dormagen	1003	90.0	3.7	0.33
Großbeeren	910	88.3	1.8	0.37
Butzbach	1002	91.4	1.6	0.37
Langensebold	988	86.4	1.8	0.52
Raunheim	999	89.6	2.4	0.59
Kerpen	542	87.1	2.7	0.61
Lahr	595	87.1	1.8	0.66
Eching	829	86.5	2.8	0.71
St. Augustin	999	88.5	3.0	0.75
Sevetal	555	88.4	2.5	0.89
Köln	713	87.5	3.1	0.91
Ketsch	595	89.0	2.8	1.03
Bargtheide	998	86.8	2.6	1.16
Aichtal	553	81.3	3.2	1.23
	14558	87.7	2.4	0.59

K. Kiefer et al., EUPVSEC 2019 (Marseille)

Example 2

35 years of PV
The Tiso-10-kW Solar Plant: Lessons Learned In Safety And Performance

Alessandro Virtuani[1], Eleonora Annigoni[1] & Christophe Ballif[1]
Mauro Caccivio[2], Gabi Friesen[2] & Domenico Chianese[2]
Tony Sample[3]

École Polytechnique Fédérale de Lausanne (EPFL), Neuchatel, Switzerland
SUPSI, Lugano, switzerland
Joint Research Centre (JRC), Ispra, Italy

35th EU PVSEC 2018
35th European Photovoltaic Solar Energy Conference and Exhibition

The TISO 10 kW PV plant – a unique of its kind

- The TISO (Ticino Solare) PV plant is the first grid-connected plant of Europe (May 1982);
- Installed in Lugano (46°N, 8°57'E), temperate climate:
  insolation 1243 kWh/m^2/y, min/max air T 1.1-20.8° C, min/max RH 57-80 °C (avg values)
- The history of the plant (**35 years**) is very well documented

A history of changes (1)

- The plant underwent a number of configuration changes and a major refurbishment/repowering in 2010;

- Major changes:

  - Siting: 2 roofs
  - Inverter: 5
  - Electrical layouts & cabling: 5
  - System voltages: 3
  - Monitoring systems: 4

- No change in the original set of 288 c-Si modules

  > some refurbishment: terminals, j-Boxes, by-pass diodes, etc.

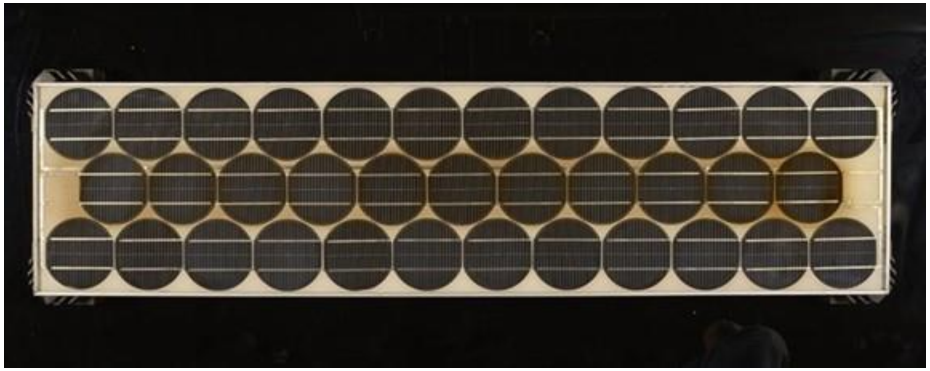
A history of changes (2)

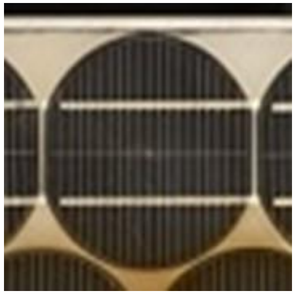
YEAR	# modules	Tilt angle	# strings / modules	# arrays	Inverters
1982 – 1989	288	65°	24 / 12	3	ABACUS 10 kW
1989 – 1991	288	65°	24 / 12	1	SOLCON – experimental
1992 – 2003	252	55°	12 / 21	3	ECOPOWER
2003 – 2008	288	55°	4 / 24	3	3 x Sunny Boy 2500 SMA
2009 – 2010	*Disassembling – characterization, relocation & new design (18 month)*				
Since 2010	288	22°	24 / 12	6	6 x Sunnyboy 1200 SMA
2017 – 2018	*Disassembling & characterization*				
2019 ?	Possibly: new installation of a sub-set of modules				

The Arco-Solar ASI 2600 module (1)

- Modules (35 cells) manufactured in 1981
- **Cells**: c-Si (mono), 4'' wafers, thickness 320-330 μm, 2 ribbons
- **Encapsulant**: PVB (we exclude presence of EVA, even if manufacturing soon swithched to EVA)
- Module **sealing** is **quite solid**:

  3-mm glass, backsheet: Tedlar/steel/Tedlar, edge seal, J-box closed on all sides





The Arco-Solar ASI 2600 module (2)

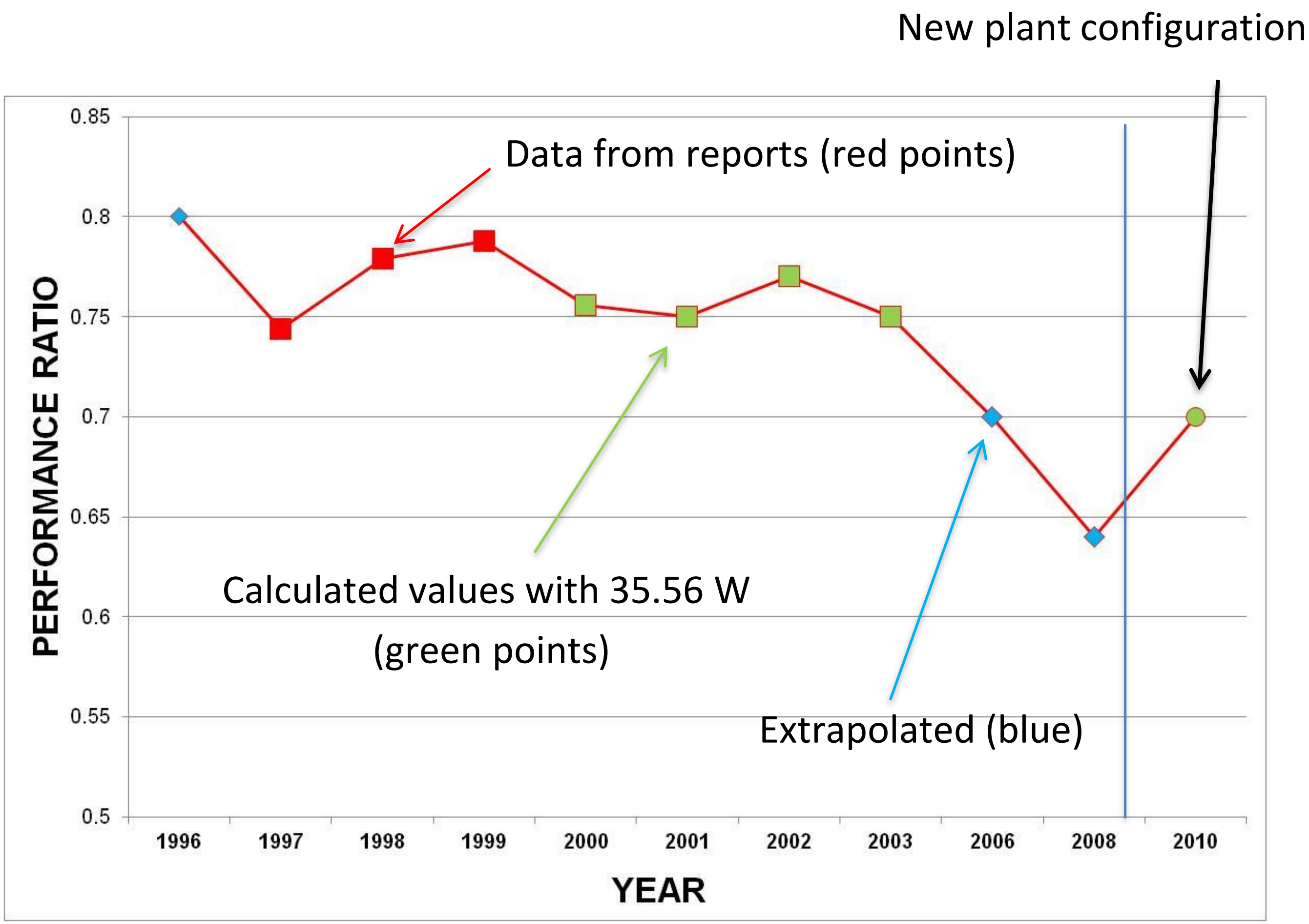
Power /efficiency (nameplate)	**37 W ± 10% (1000 W/m² and 25°C)** **η = 10 % (total area)** **Voc = 21.5 V, Isc = 2.55 A, FF = 68%**
Cells	4'' wafers (∅ 102.5 mm), mono-c Si (Czochralski) 2 ribbons /cell, Thickness: 320-330 μm
Module size	Area: 121.9 x 30.5 = 3'718 cm^2 Depth: 3.8 cm (w. frame), Weight: 4.9 kg
Electrical layout	35 cells in series
Front glass	3—mm tempered
Encapsulant	PVB
Backsheet	Tedlar®/metal-plate/Tedlar®
Junction box	Weatherproof plastic box, hosting by-pass diode
Edge seal	Hot melt Butyl
Frame	Full perimeter Al- frame

Performance ratio (PR) of TISO 10 kW plant: 1996-2010

PR(dc) decreased 20% from 1996 to 2008.

PR decrease correlated to module degradation.

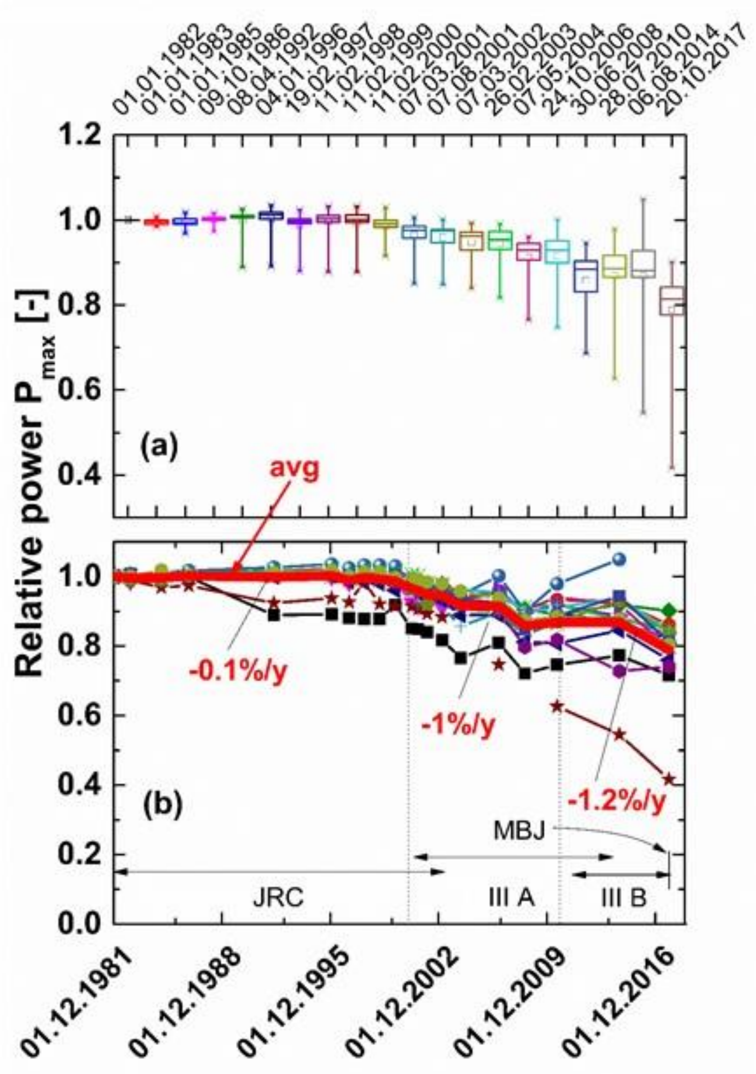
After plant maintenance (2010) the PR increased 10% due to sorting and repairs.



T. Friesen et al., EUPVSEC 2012 (Frankfurt)

Traceability of measurements and link to original

1982 measurements



Set of **18 «reference» modules** (part of the plant >> exposed) and characterized at regular intervals over the years:

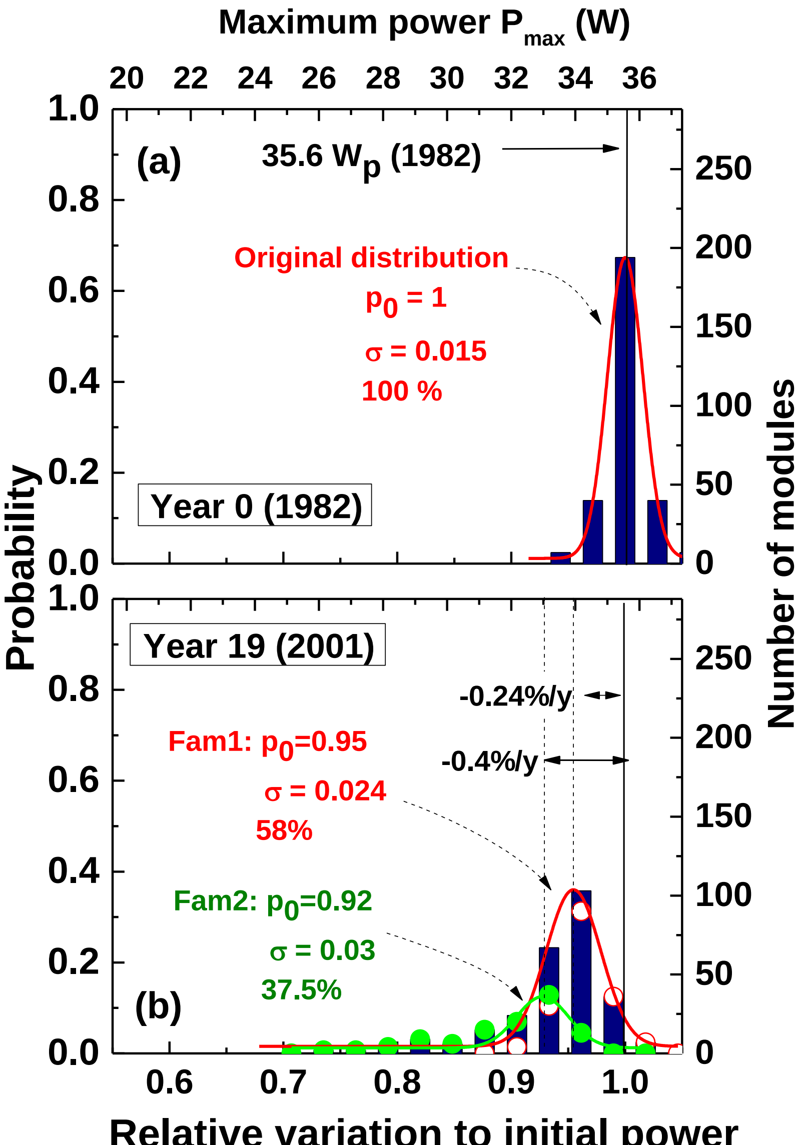
1982 – 2003 (& 2018) ESTI-JRC (Ispra, Italy)
>> accredited calibration lab

2000 – 2018 at SUPSI (Lugano, CH)
>> accredited testing lab

2017: MBJ mobile lab (all 288 modules)

2018: validation of MBJ measurements
at ESTI&SUPSI on 18 ref. modules

Long-term degradation rates and probability distribution functions (PDF) for the full set of 288 modules



Original 1982 measurements (JRC)

- Performed on 18 reference modules
- Distribution for 288 modules extrapolated

>> Gaussian: mean **35.56 Wp,**
$\pm$ 0.67 W STD 1-σ ($\pm$ 1.88%)

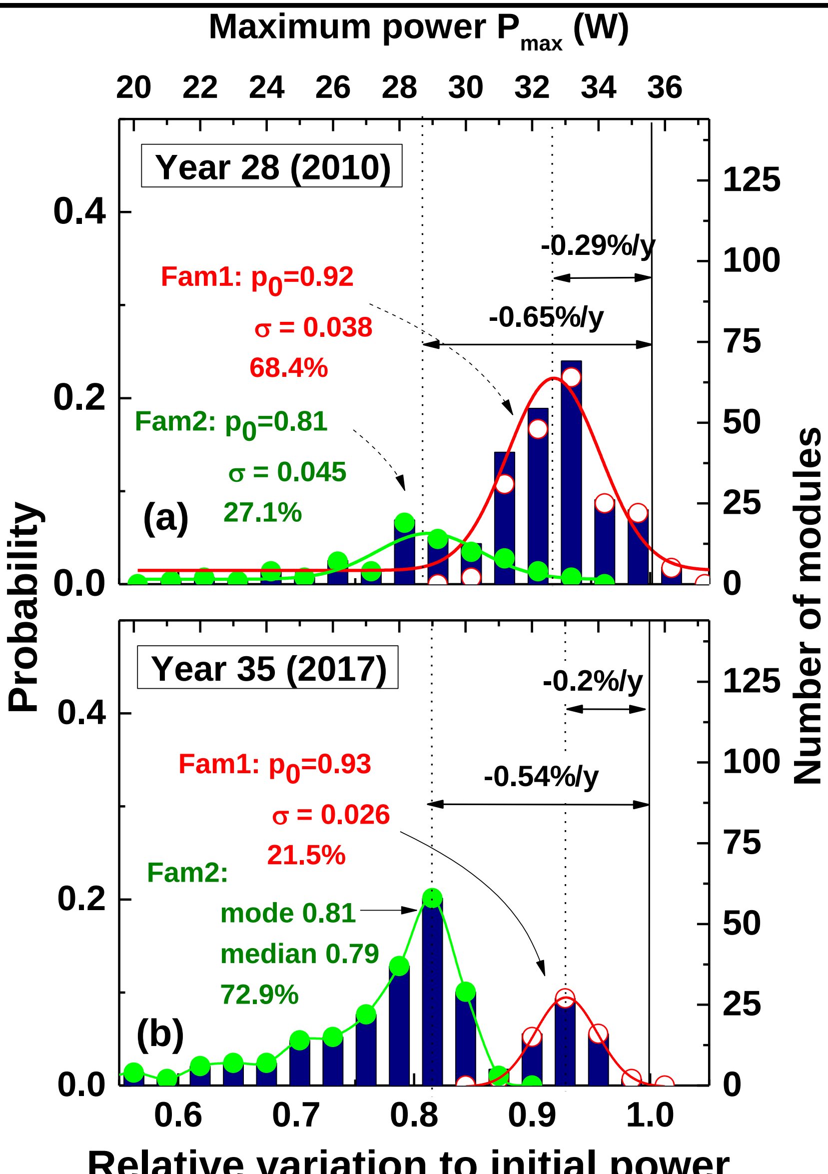
(value used later to compute degradation rates for all modules)

2001 (19 years) measurements (SUPSI)

All 288 modules
3 families (f):

2 gaussians (f1 & f2)
13 modules (4.5%) at 0 W (f3)

Long-term degradation rates and PDF for all modules (2)



2010 (28 years) measurements (SUPSI)

3 families (f):

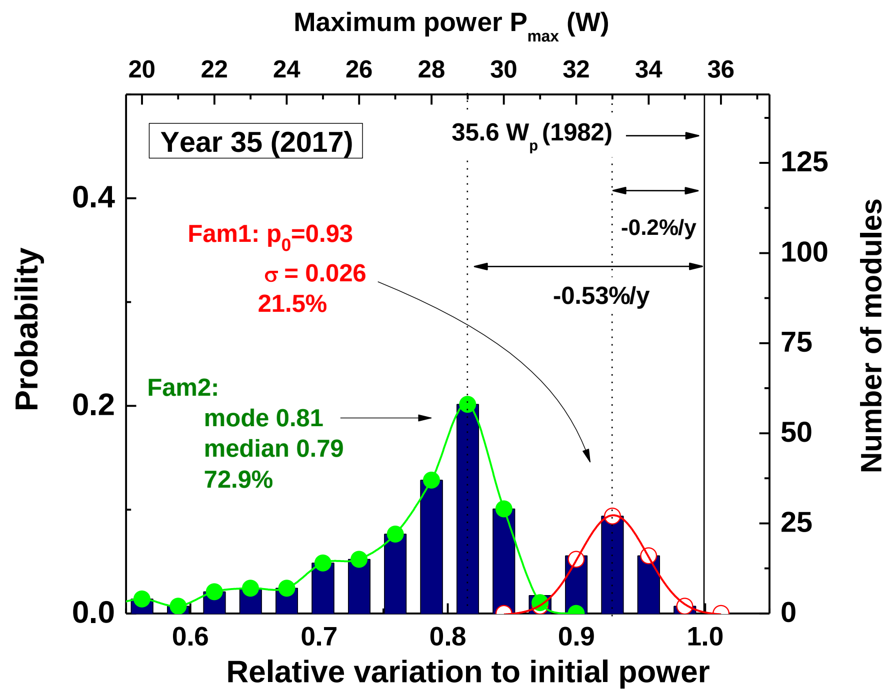
2 gaussians (f1 & f2)
13 modules (4.5%) at 0 W (f3)

2017(35 years) measurements (MBJ)
>> acceleration in degradation

3 families (f):

1 gaussian (f1), 1 negatively-skewed PDF (f2)
15 modules (5.2%) at 0 W (f3)

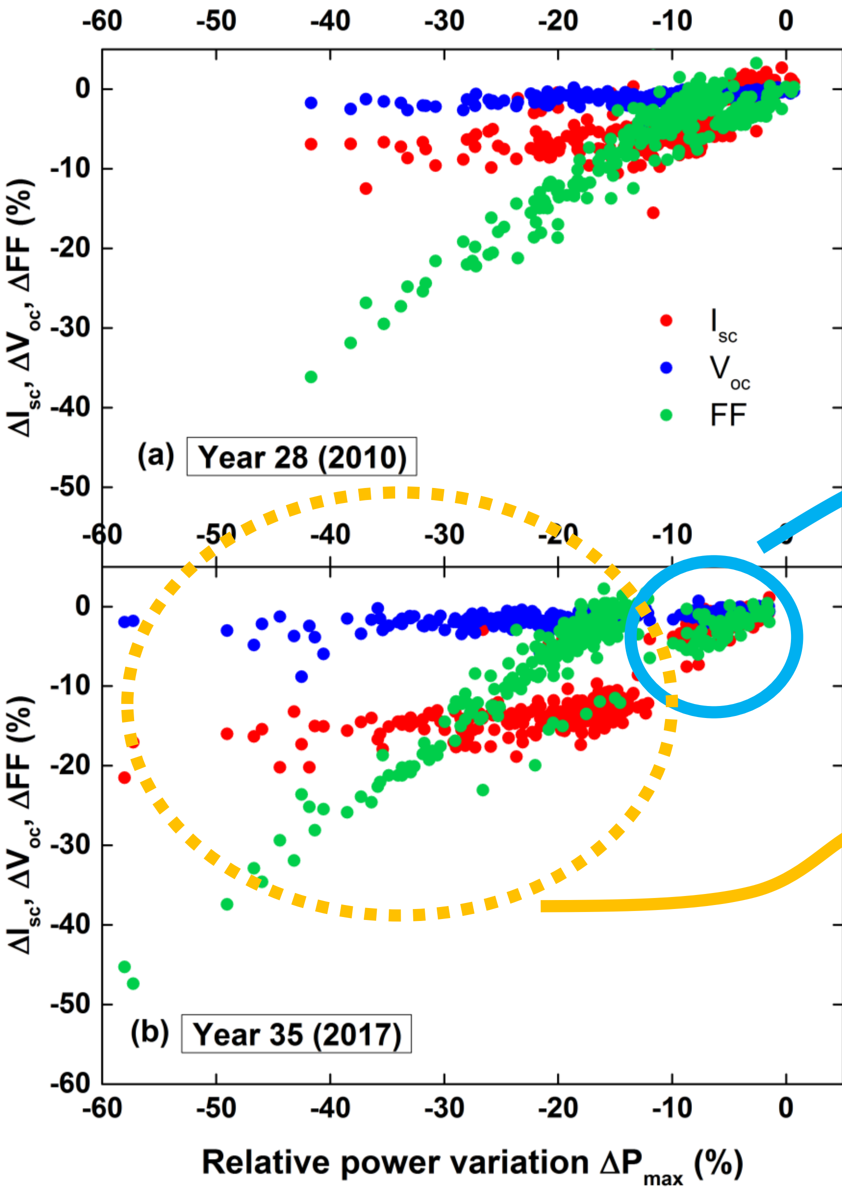
Life-time & warranties ?



After **35 yrs of operation in a temperate climate**, **70%** of the modules (considering a ± 3% measurement uncertainty) would still satisfy a criterium set by a **performance warranty** that module manufacturers are presently considering to apply to the PV technology of tomorrow:

i.e. 35 years of operation with a performance threshold set at 80% of the initial value.

Loss in: Pmax vs (Voc, FF, Isc) 2010/2017



2017(35 years)

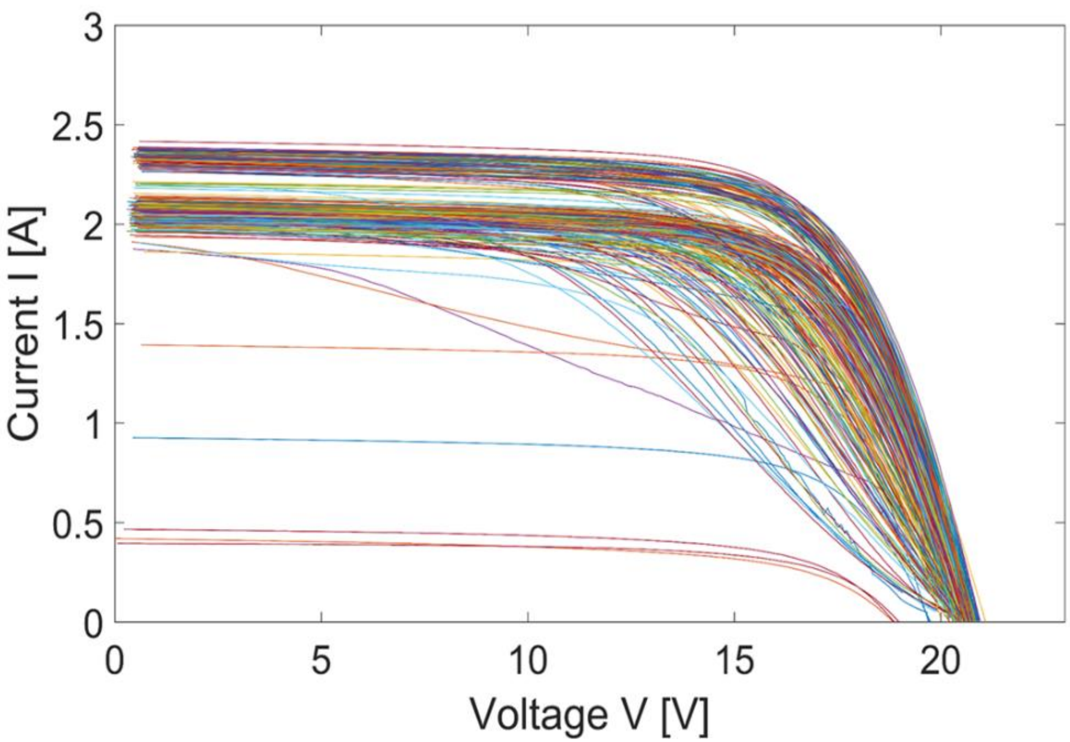
Family 1 (gaussian)

- modest losses in FF & Isc

Family 2 (negatively-skewed)

- losses in Isc (off-set)
- losses in FF (strong correlation)
- combined losses in Isc & FF

2017: IV curve measurements for all 288 modules



2017(35 years)

Family 1 (gaussian)
- modest losses in FF & Isc

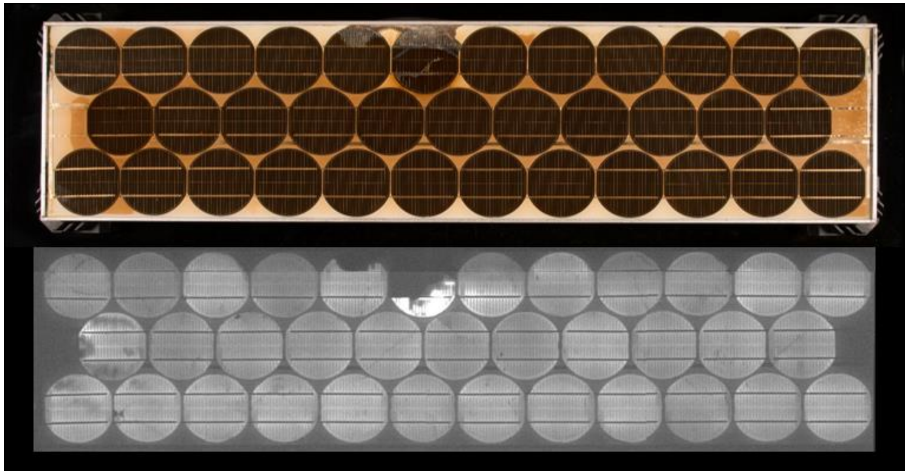
Family 2 (negatively-skewed)
- losses in Isc (offeset)
- losses in FF (strong correlation)
- combined losses in Isc & FF

Can we found a **clear correlation** between loss in performance and failure modes ?

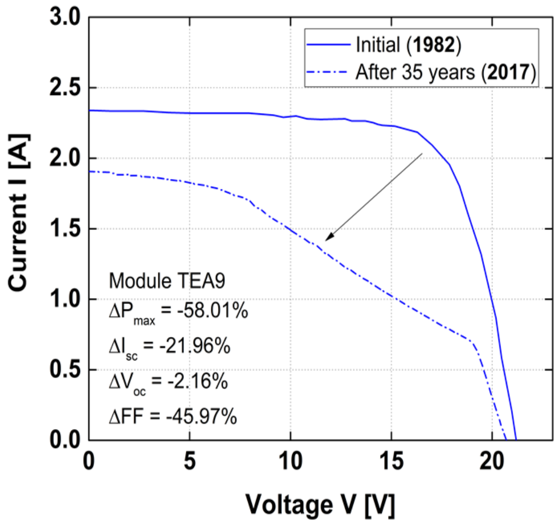
>>> Sometimes yes & sometimes no .....

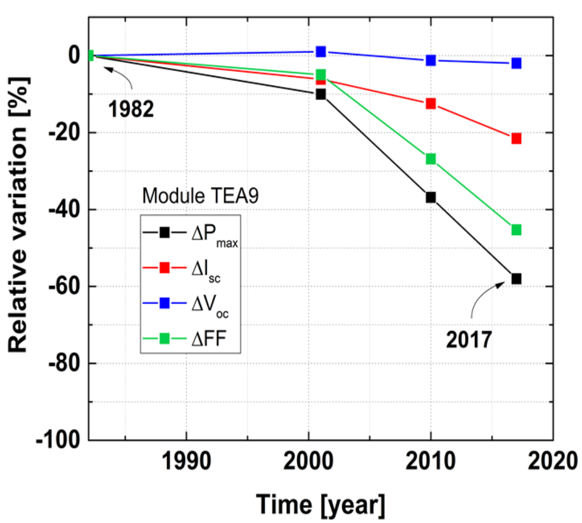
A. Multiple failure modes

Sometimes no: reference module (TEA 9) is affected by multiple failure modes

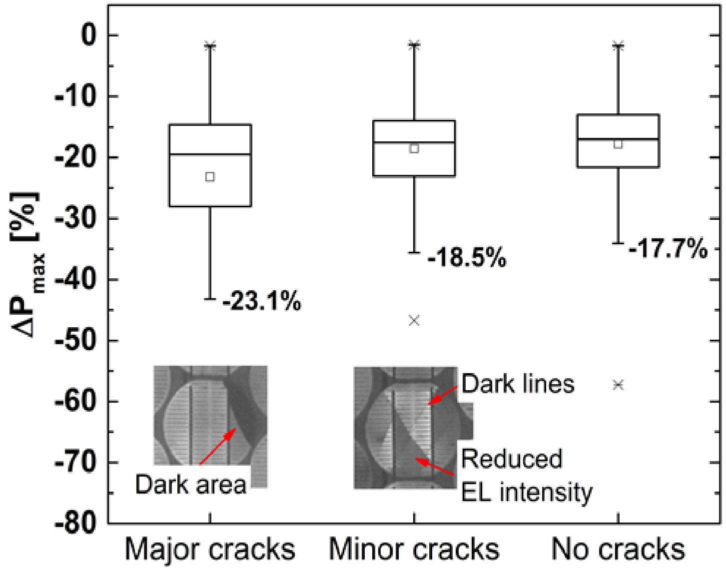


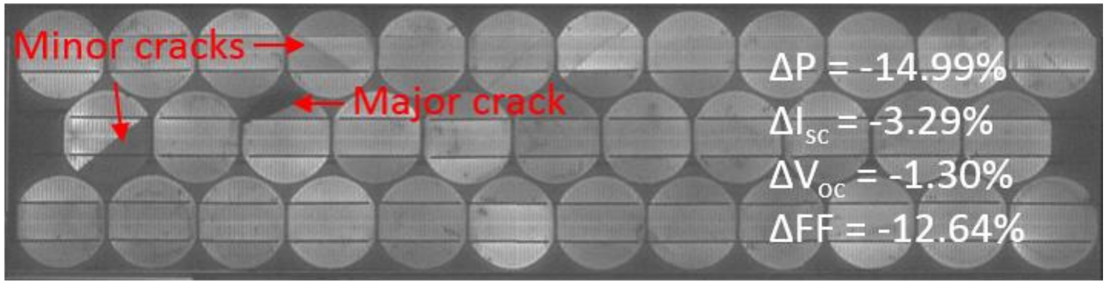
- Hot-spots
- Major front delamination
- Browning
- Burn marks,
- Interconnection (IC) discoloration





B. Cell cracks

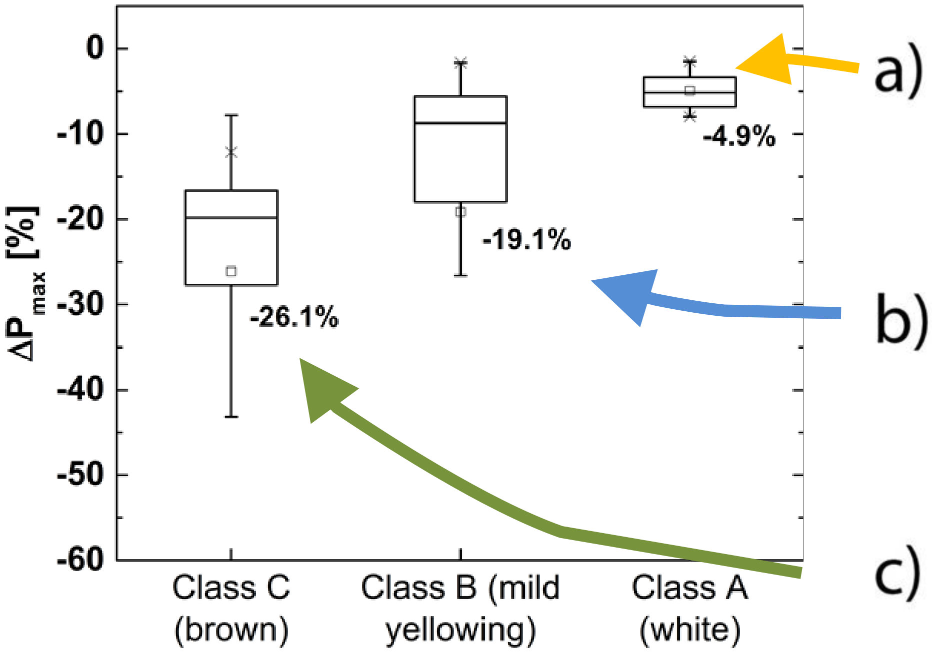


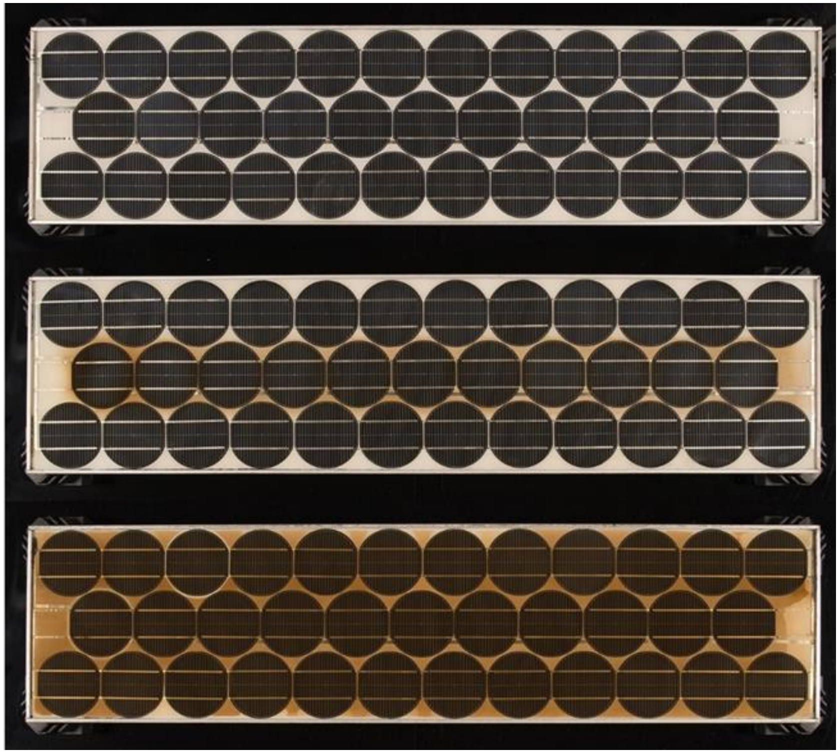


Power variation (2017 vs 1982) for modules belonging to the 3 different classes: **no cracks, minor cracks, major cracks**: moderate correlation.

Major cracks may evolve in hot spots and other safety threats.

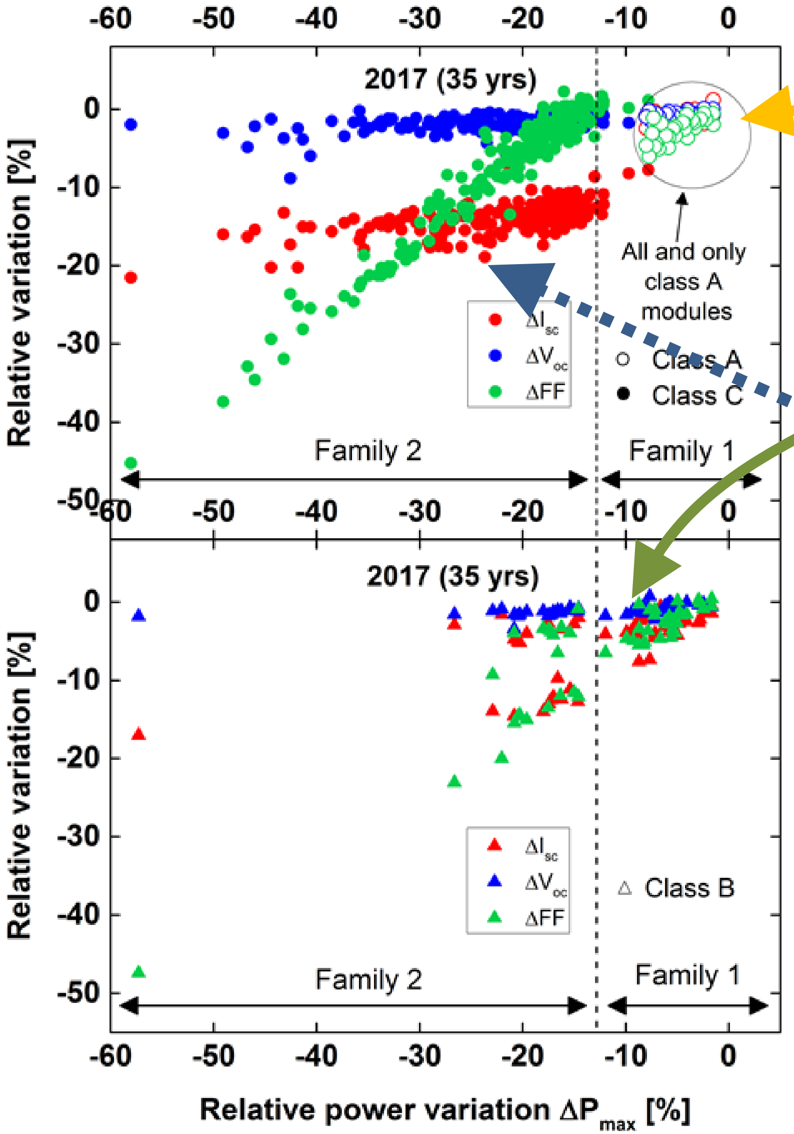
C. Discoloration of encapsulant: yellowing & browning (1)

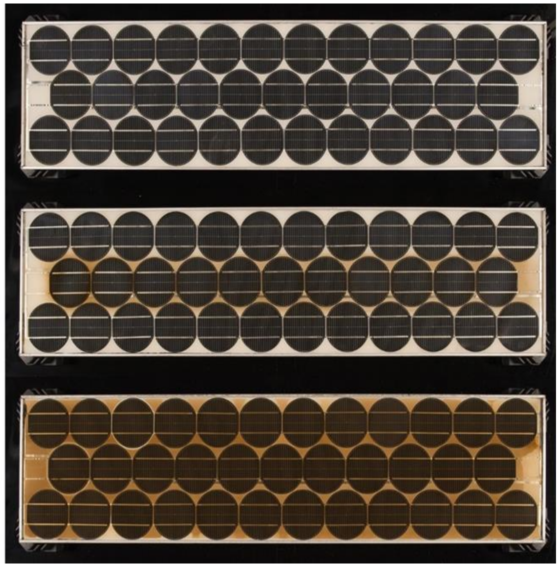




Power variation (2017 vs 1982) for modules belonging to the three different classes based on different encapsulant discoloration levels.

C. Yellowing & browning (2)



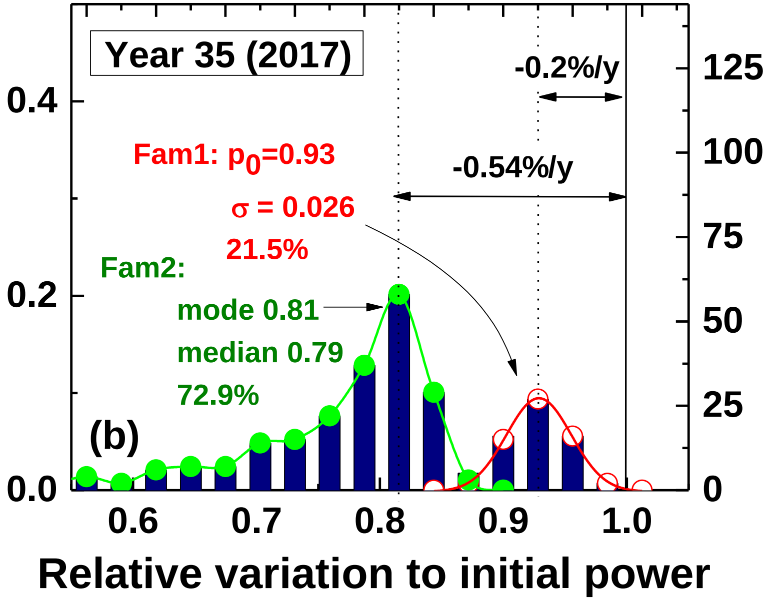


Class A: transparent: modest degradation

Class B: localized mild yellowing: modest/medium degradation (more dispersed (Isc and/or FF)

Class C: uniform browning: medium/high degradation (Isc, and Isc & FF)

C. Yellowing & browning (3)

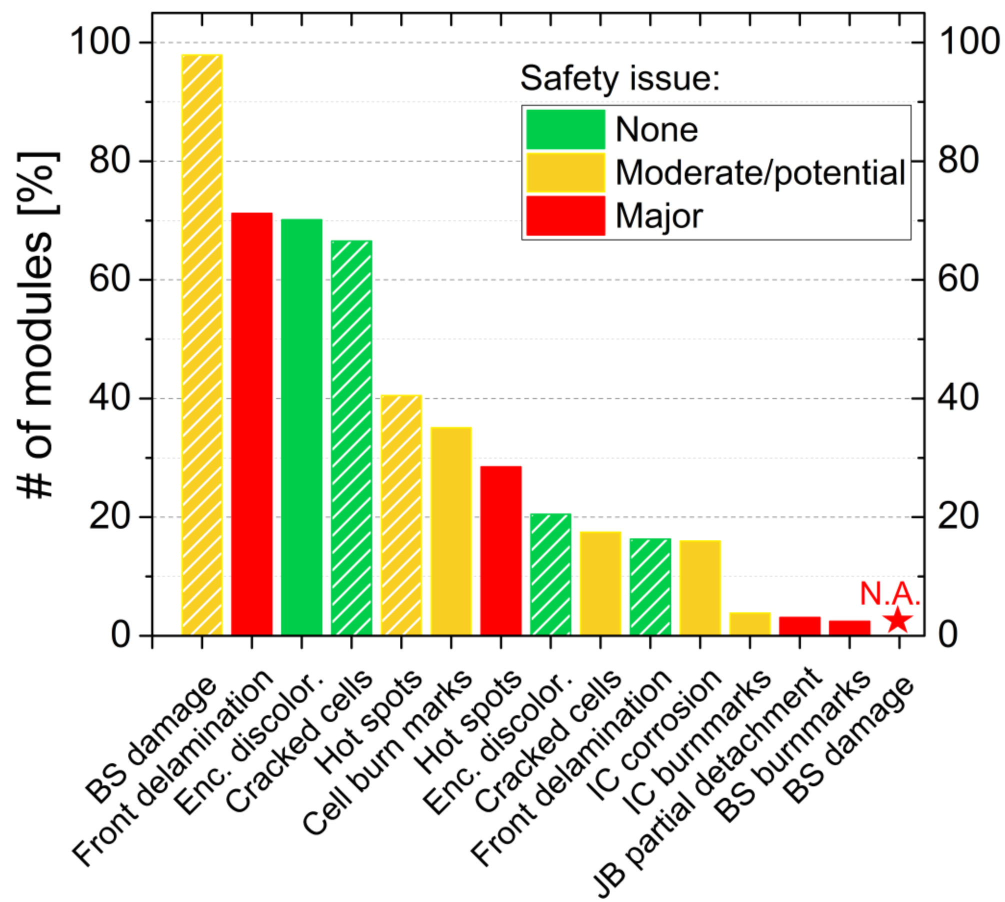


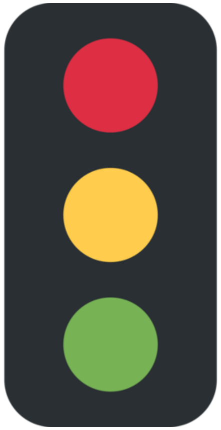
		Class A Transp.	Class B Local./mild yellowing	Class C strong browning
Fam. 1 66 mod.	# mod.	27	33	6
	Share [%]	40.9	50.0	9.1
Fam. 2 222 mod.	# mod.	0	26	196
	Share [%]	0.0	11.7	88.3

Encapsulant:

- **PVB,** but……Arco Solar switched production to EVA in those years (**EVA?);**
- Chemical/optical analysis confirm that all modules are laminated with **PVB**: **3 different formulations** >>> 3 different suppliers;
- Two formulations of PVB allowing modules to obtain excellent long-term performance after 35 years in a temperate climate.
- **Class A**: (~10% of total) >> no remarkable degradation in P_{max}, FF, Isc, Voc

Occurence of main failures modes





Obtained by combining Visual Inspection, EL & IR imaging;
Several modules experience multiple degradation modes

Tiso-35: conclusions

- **70% (**considering a $\pm$ 3% uncertainty) of modules experience a degradation of ≤ 20% and would still be covered by a 35-yrs-long warranty set at 80% of initial power.

- We note an acceleration of degradation rates in the last 7 years.

- We see that a strong correlation exist between degradation rates and the encapsulants used in manufacturing.

- Most likely all modules were manufactured with **PVB**, using three different formulations (different additives).

More details?

RESEARCH ARTICLE

WILEY PROGRESS IN PHOTOVOLTAICS

35 years of photovoltaics: Analysis of the TISO-10-kW solar plant, lessons learnt in safety and performance—Part 1

Alessandro Virtuani[1] | Mauro Caccivio[2] | Eleonora Annigoni[1] | Gabi Friesen[2] | Domenico Chianese[2] | Christophe Ballif[1] | Tony Sample[3]

Part 1: Prog Photovolt Res Appl. 2019;27:328–339

Part 2: Prog Photovolt Res Appl. 2019;27:760–778

Outline

1. Solar Photovoltaics (PV) in the global electricity mix

2. Definitions

   Failure, lifetime, reliability, durability ….

3. Long-term performance of PV systems (modules)

   Two examples:

   a. recent study in Germany (systems)
   b. the TISO-10-kW PV plant - 35 year of PV

4. How to design «reliable» & «durable» PV systems?

   a short journey trough Africa & Europe

O'SOLE
OFFICINA DEL SOLE
TESTING | ANALYSIS | SOLUTIONS

IFC | International Finance Corporation
WORLD BANK GROUP

Solar Electricity In Africa:

Overcoming Barriers And Lessons (Which May Be) Learnt From Previous Experiences in Europe

Alessandro Virtuani, Luca Parini
Officina del Sole (O'Sole), Milan, Italy

Guido Agostinelli
International Finance Corporation IFC, Washington

www.o-sole.eu

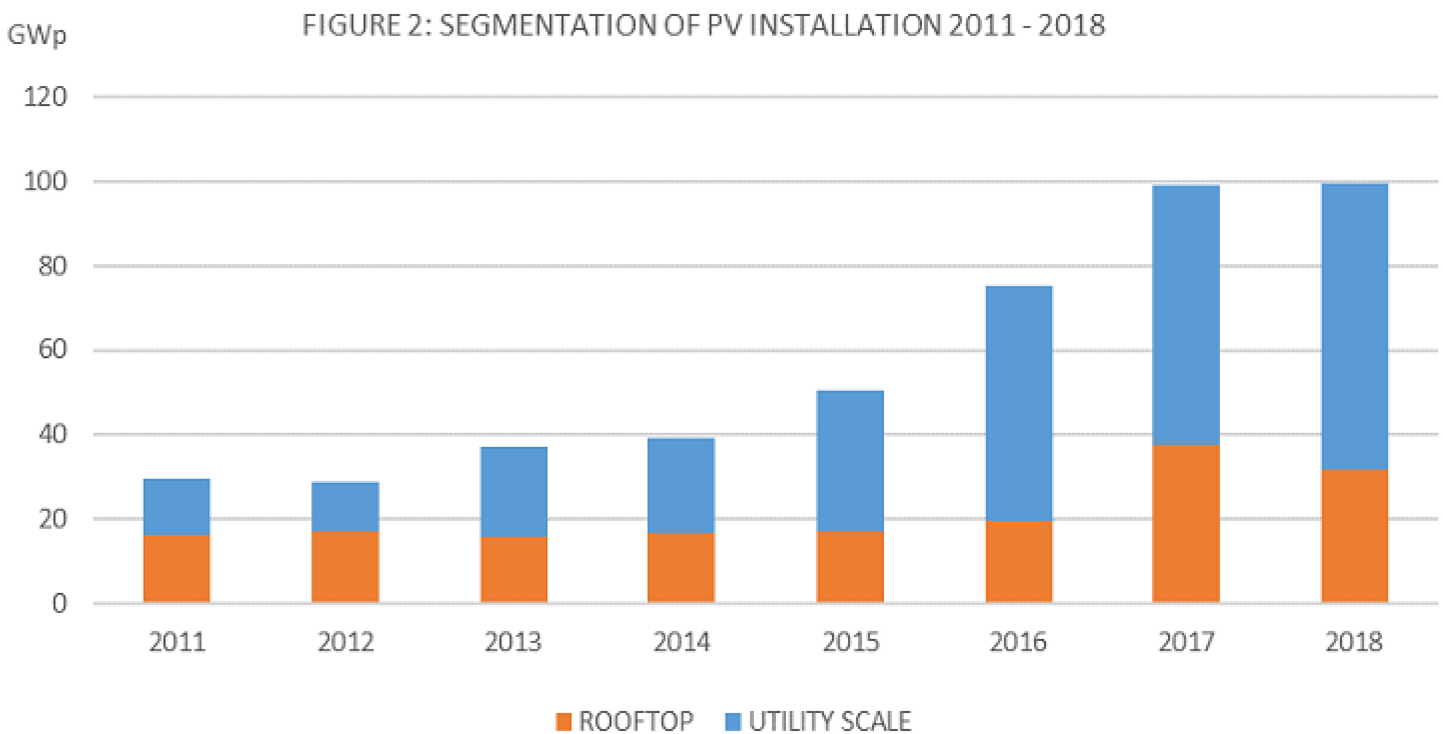
35th EU PVSEC 2018
35th European Photovoltaic Solar Energy Conference and Exhibition

Rooftop vs utility-scale PV

Villanueva Mexico 0.754 GW
Largest PV plant in the Americas
[courtesy of Enel Green Power]

Cape-Town (SA):
Commercial roof-top 300 MW [AV]

Market segmentation: rooftop vs utility-scale PV



IEA-PVPS 2019: Snapshot of Global PV Markets

Outline

1. Great **potential** for solar in Africa

2. Main **barriers** to deployment of solar

3. **Lessons learnt in Europe** in the booming years (2000-2013) when overgenerous incentives were often promoting unhealthy market dynamics

4. We drive a **parallel** between the situation ~10 years ago in Europe and today in Africa

5. The quest for **quality**: «easy» recipes for ***bankable* solar projects**

Introduction (2)

Focus in this work on:

1. **Rooftop solar systems** (residential & commercial/industrial, 1 kWp – 5 MWp);

2. **Africa**

However, most findings/observations may apply to:

a. other markets segments (including μ-solar, street-lightning, ground-mounted installations & utility-scale);

b. fast developing markets in SUN-BELT countries.

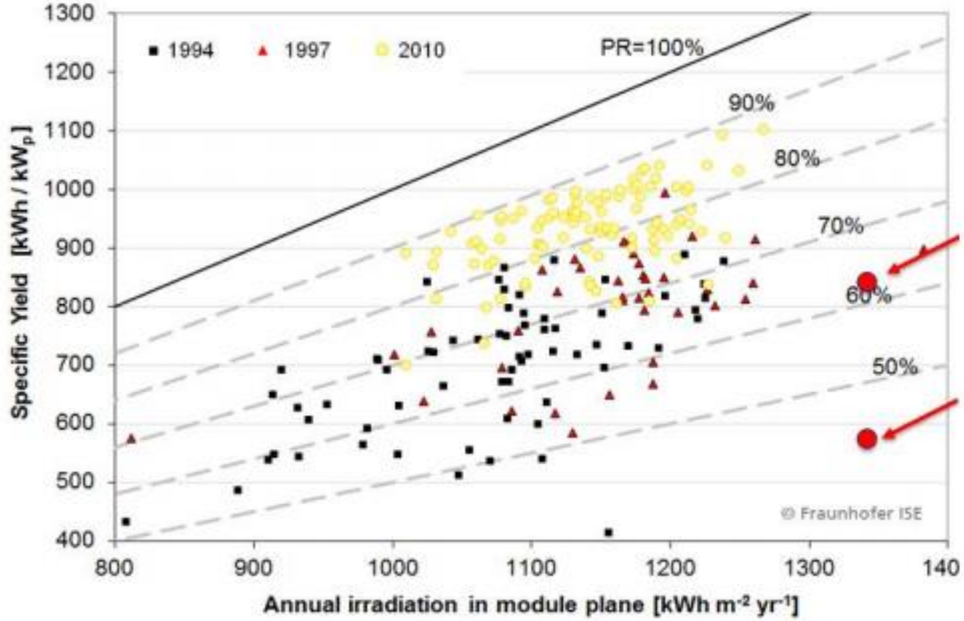
Credits: SolarMate, Lagos Nigeria

Solar PV as a learning process

O'SOLE

OFFICINA DEL SOLE
TESTING | ANALYSIS | SOLUTIONS

Learning processes:
Good training is critical to develop skills, expertise and know-how



N. Reich et al.,
Prog. Photovolt: Res. Appl.2012
(& EU-PVSEC 2011)

PR as a function of year of installation (Germany)

Specific Yied Yf (and Performance Ratio PR) as a function of plane-of-array irradiance for a selection of PV systems installed in 1994, 1997, and 2010

(1000-Roofs Program, Germany)

IFC International Finance Corporation WORLD BANK GROUP

The quest for «**quality**»

Availability

Long-term performance

Reliability

Durability

Safety in operation

Should start from:

a) Selection of state-of-the art components (modules, inverters, BOS, batteries)

b) State-of-the-art system design & planning

c) Installation & commissioning

d) Operation and maintenance (O&M)

e) Safety in operation

O'SOLE OFFICINA DEL SOLE TESTING | ANALYSIS | SOLUTIONS

a. Components (e.g. modules)

In Africa evidence exists that:

1. Sub-standard components are sold in African markets;
   >>> modules with no-traceability, no certification

2. Some countries are preferential destinations for modules stolen in Europe

PV modules available for sale at a local >>>> market (Marché Sandaga) in Dakar, 2017

Source: Annigoni et al. EUPVSEC 2017

O'SOLE a. Components (Europe) - Modules: most often certified products….

Italy, 2016-2018:
module origin: I, D, J, NL, CN
(short selection)

Credits: Luca Parini

a. Components Europe (other components)

b. System design (Europe)

Milan, Italy, 60 kW plant

Small shadows, big losses …

- Shadows on rows
- No open horizon

(plant surrounded by buildings on all sides)

Particularly in heavily urbanized areas **shading losses** are a significant loss mechanism.

For a correlation of PR at province level in Italy with residential/building density see:

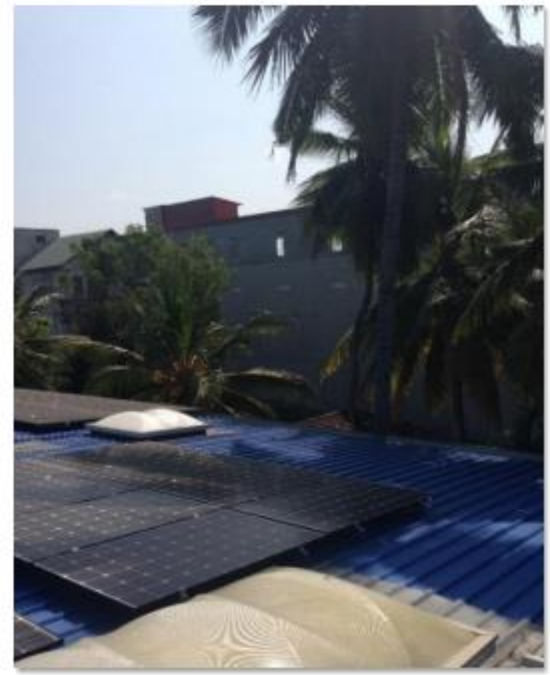
Virtuani, Betak, Skoczek, this conference (6DV.1.21, Thursday 13:30 - 15)

b. System design

Small shadows,
big losses …

Credit: R. Meyer, GeoSun Africa

Johannesburg, SA: ~20 kW, strong shading losses in winter (why portrait?)



South East Asia, retail shop, 350kWp rooftop: too much faith in power optimizers

IFC International Finance Corporation
WORLD BANK GROUP

b. System design (or poor selection of components)

Africa, Coastal Areas, 900kWp canopy, corrosion after less than a year of operation

Credit: R. Meyer, GeoSun Africa

Oudtshoorn, South-Africa 20 kW, (2017), non rigid mounting structure

c. Installation & commisioning

Stepping on solar modules….

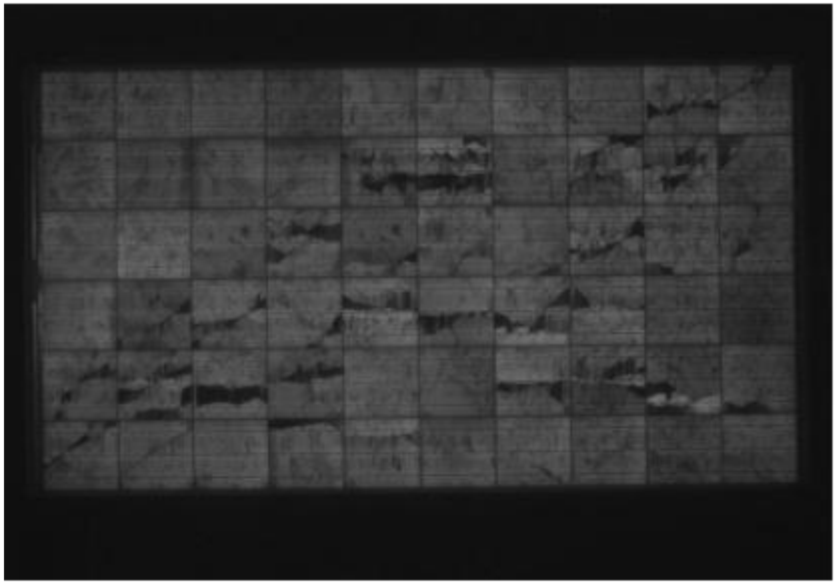
Old habits die hard!

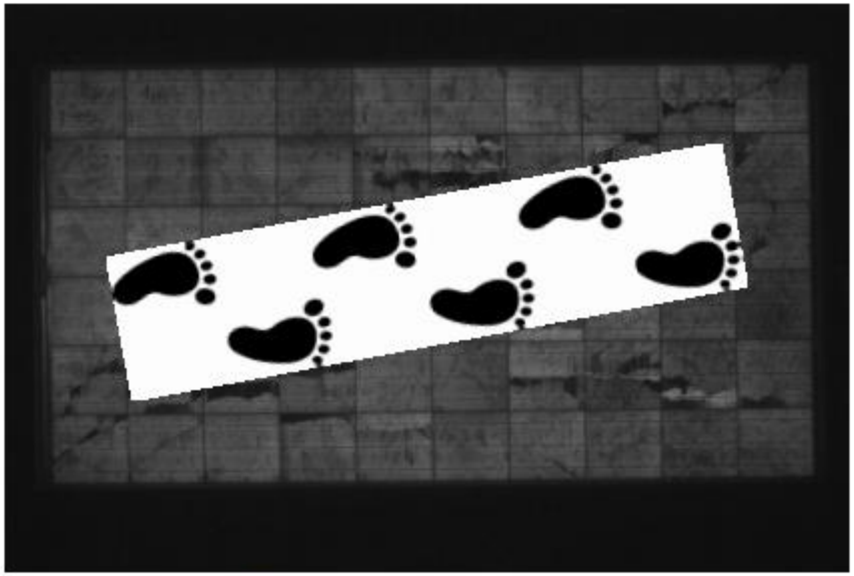
Lagos, Nigeria, 2016

Central Asia, 2017 - video

c. Installation & commisioning (Europe)

Electro-luminescence (EL) imaging:
makes visible defects not visible to the human eye



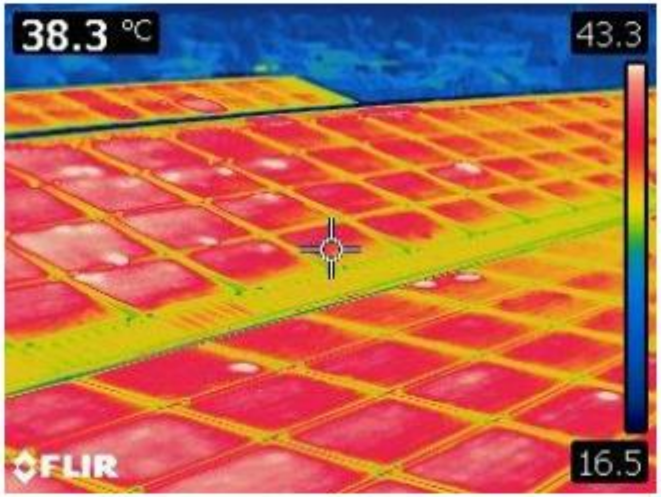


Switzerland, 5 kW plant, 2013

c. Installation & commisioning (Europe)

Infra-red (IR) imaging:
makes visible defects not visible to the human eye

Como, Italy, 200 MW (2018)



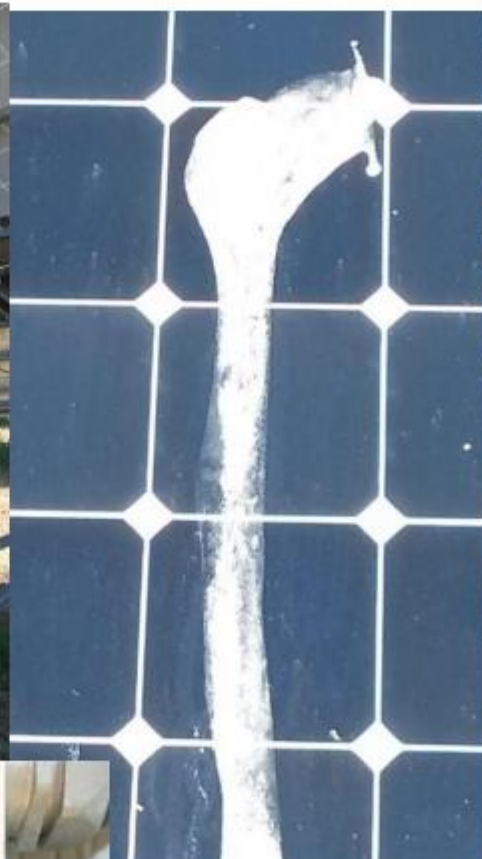
Credits: L. Parini (O'Sole)

Solar Plant owner, May 2018:
«Installers were literally running on the modules, saying….. *modules are tested for this*».

IFC International Finance Corporation WORLD BANK GROUP

c. O&M (Europe)

OFFICINA DEL SOLE
TESTING | ANALYSIS | SOLUTIONS


Credits:
A. Virtuani, L. Parini
(O'Sole)

c. O&M (Africa)

Middle-east, 2016

Stellenbosch, SA (2018)

Credit: R. Meyer, GeoSun Africa

Abudja Airport (Nigeria), street-lightning PV (2016)

Example 1 & 2: Conclusions (1)

Extended lifetime of PV systems is possible but requires:

1. Training / experience (learning process)
2. Selection of quality components
3. Excellent design
4. Monitoring
5. Operation and Maintenance (O&M)

O&M strategies and timely interventions have a strong impact on loss rates of PV systems.

This include:

a. Monitoring / inspections to detect failures;
b. Substitution (or repair) of fault components;
c. Prompt intervention;
d. Labor-intensive activities: e.g. module cleaning

-

Example 1 & 2: Conclusions (2)

Hardware-related issues are dominated by:

- **Inverters**:

  lifetime of inverters: 15 years (10 years in the past) if proper O&M in place (including availability of spare parts)

- **Fuses or other electrical components** requiring replacement;
- **Modules:**

  - evidence exist that modules can make it to 30-35+ years in temperate climates (!);

  - not all modules: quality is still a big issue, as well as the deployment of PV in different climates (hot-humid, desert, ...)

  - technology evolving rapidly (pros/cons)

- **Batteries (off-grid)**: lifetime 3-4 years low-quality; 6-8 (?) higher quality;

[see as well: D. Jordan & S. Kurtz, EUPVSEC 2014 (Paris)]

Thank you for your attention!

PEARL PV

Acknowledgments

All colleagues at EPFL/PV-Lab & O'Sole.

Contacts:

alessandro.virtuani@epfl.ch

alessandro.virtuani@o-sole.eu