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Investigations on the Main Causes for Reduced Performances during the Early Stage of Life of Rooftop PV Systems

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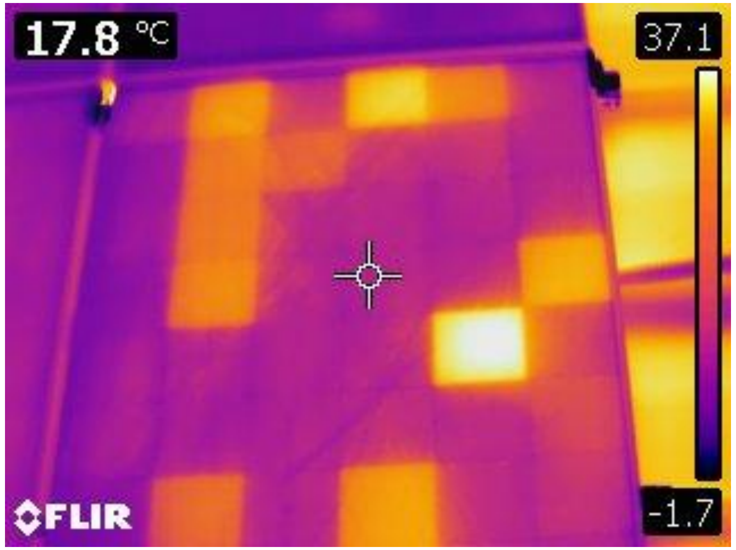
Summary

- Introduction
- Purpose of the project
- Overview
- Results
- Conclusions

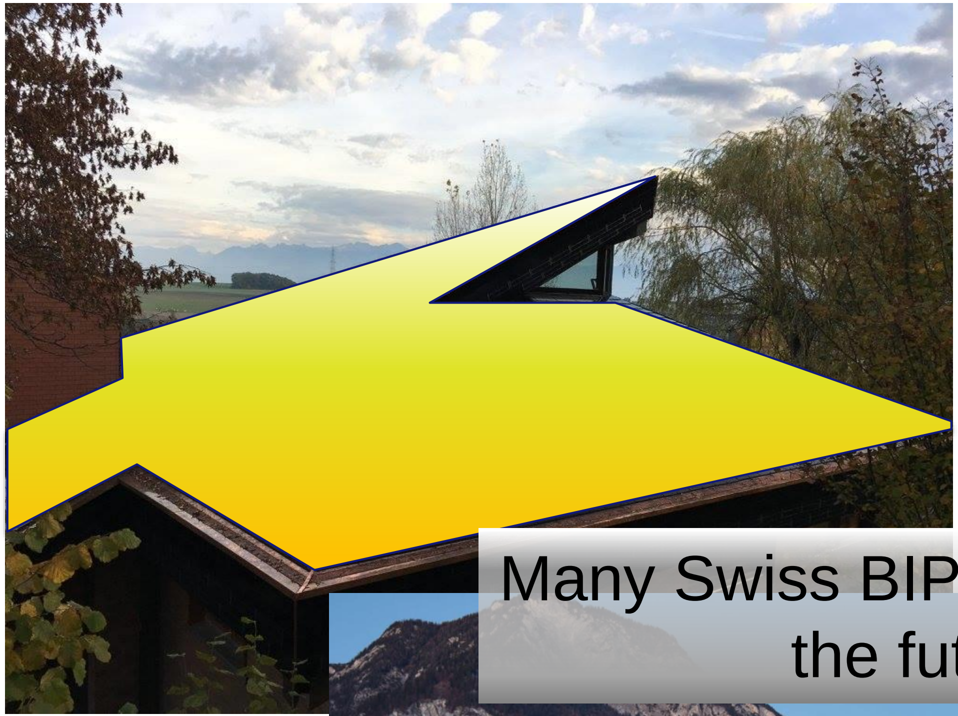


Source: SUPSI

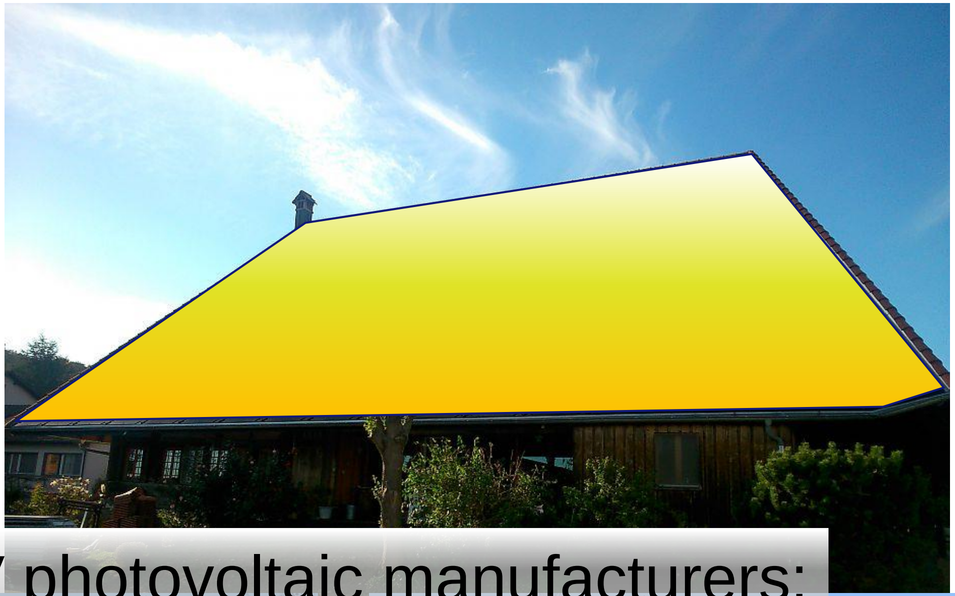
Introduction

Source: tesla.com

Introduction



Source: freesuns.ch



Source: 3s-solarplus.ch

Many Swiss BIPV photovoltaic manufacturers: the future is bright ! But…

Source: .solararchitecture.ch

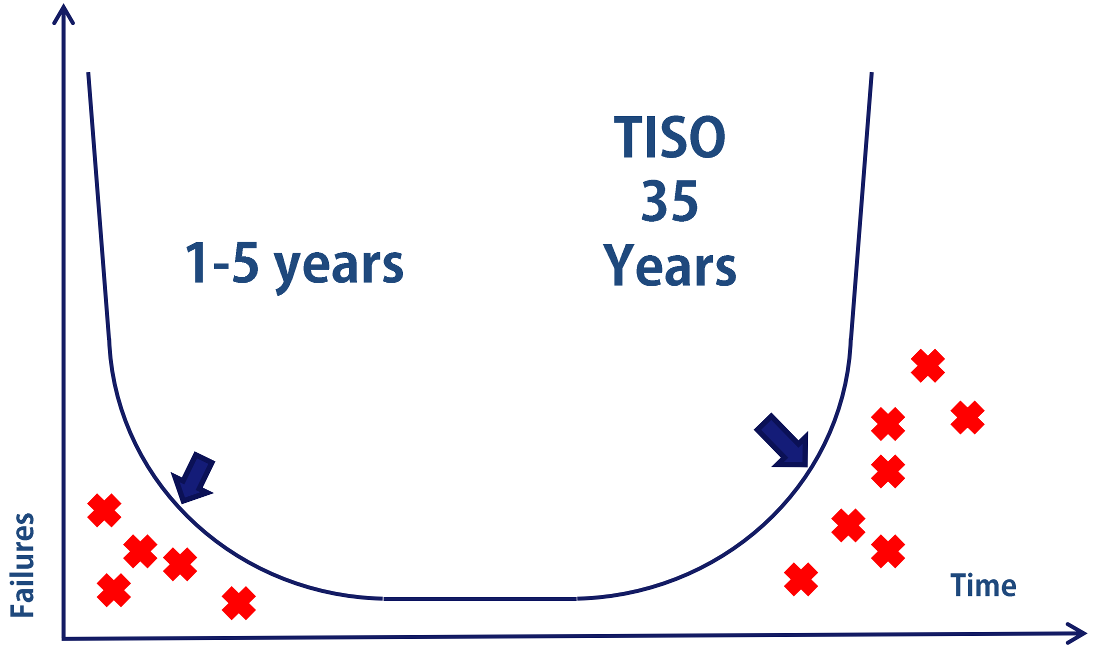
Source: .sunstyle.ch

Introduction

TISO PV Plant, first grid connected PV in Europe in 1982. Source: supsi.ch

Purpose

- **Several PV systems with poor energy production**
  - The lifespan of a rooftop PV plant can be estimated **around 25-30 years**, while the oldest plant in Europe, installed at SUPSI, has exceeded 35 years of life.
  - As in any system, defects and problems typically occur in the early years and at the end of life of the system itself.
- **What are the main causes for reduced performance ?**



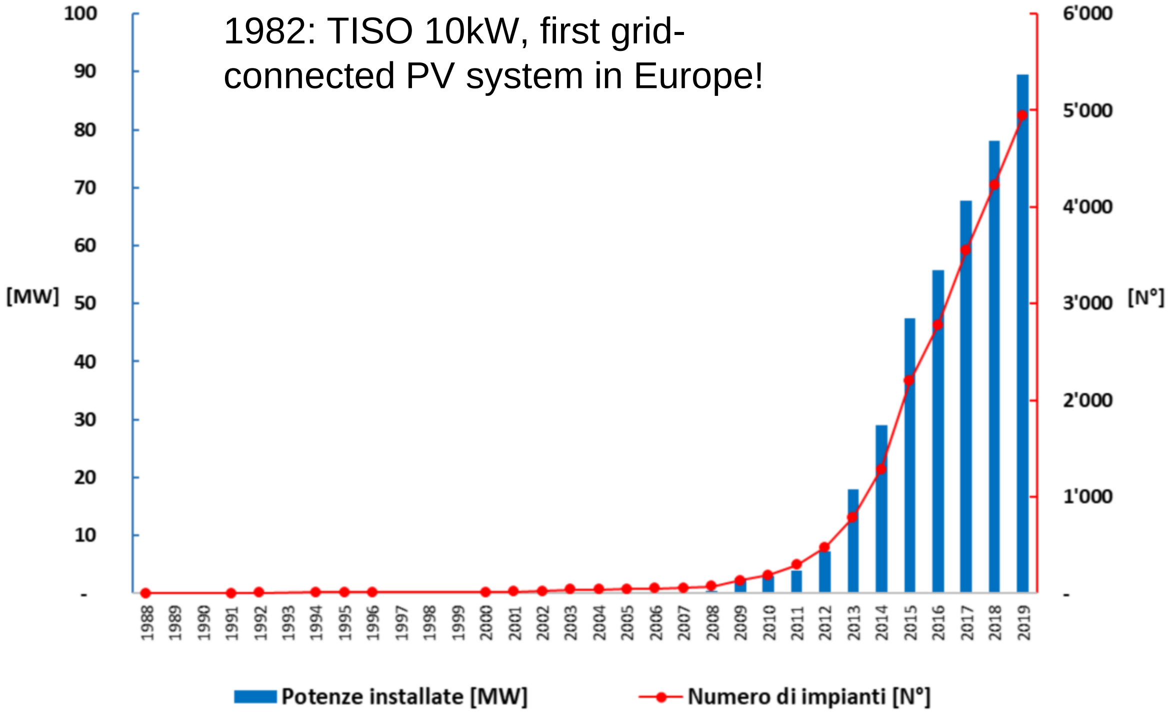
The objectives of the project were manifold:

- Identify, classify and prevent defects that emerge **after the first years of operation** (≤ 5 years).
- Correlate them with power at the beginning of life.
- Improve knowledge of observed early stage defects in order to **reduce costs and risks** for both systems' owners and installers.

Actions:

- Risk reduction, both for existing and newly installed plants.
- Improve the quality, lifespan and reliability of photovoltaic systems in ticino
- Improve system level performance
- Accelerate the return on investment

Purpose: framework



Classi [kW]	N° impianti a fine 2019		Potenza a fine 2019 [kW]	
0-10	3'535	*(71.5%)*	24'043	*(26.9%)*
10-30	1'134	*(22.9%)*	19'919	*(22.3%)*
30-100	158	*(3.2%)*	9'300	*(10.4%)*
100-1000	114	*(2.3%)*	30'162	*(33.7%)*
>1000	4	*(0.1%)*	6'033	*(6.7%)*
Totali	**4'945**	***(100%)***	**89'456**[4]	***(100%)***

Where:

- Ticino, South of Switzerland
- 350’000 inhabitants

- > 5000 PV systems installed
- ≈ 90MW power (STC)
- **260W / inhabitant**

Goal: > 330 MW (out of 880MW possible on rooftop)

Subsidies for PV Systems and renewables energy:

- Swiss subsisies +
- Regional subsidies:
  - **FER: Renewable Energy Fund**
- **FER control of the injected energy**

Purpose: durability and reliability, focus points

Durability and reliability of photovoltaic systems depend on many factors:

- Quality of components (modules, but not only, also: inverters, connectors, etc.)
- Quality of dimensioning and design
- Quality of installation execution
- Quality of maintenance
- Climatic conditions
- Neighborhood conditions

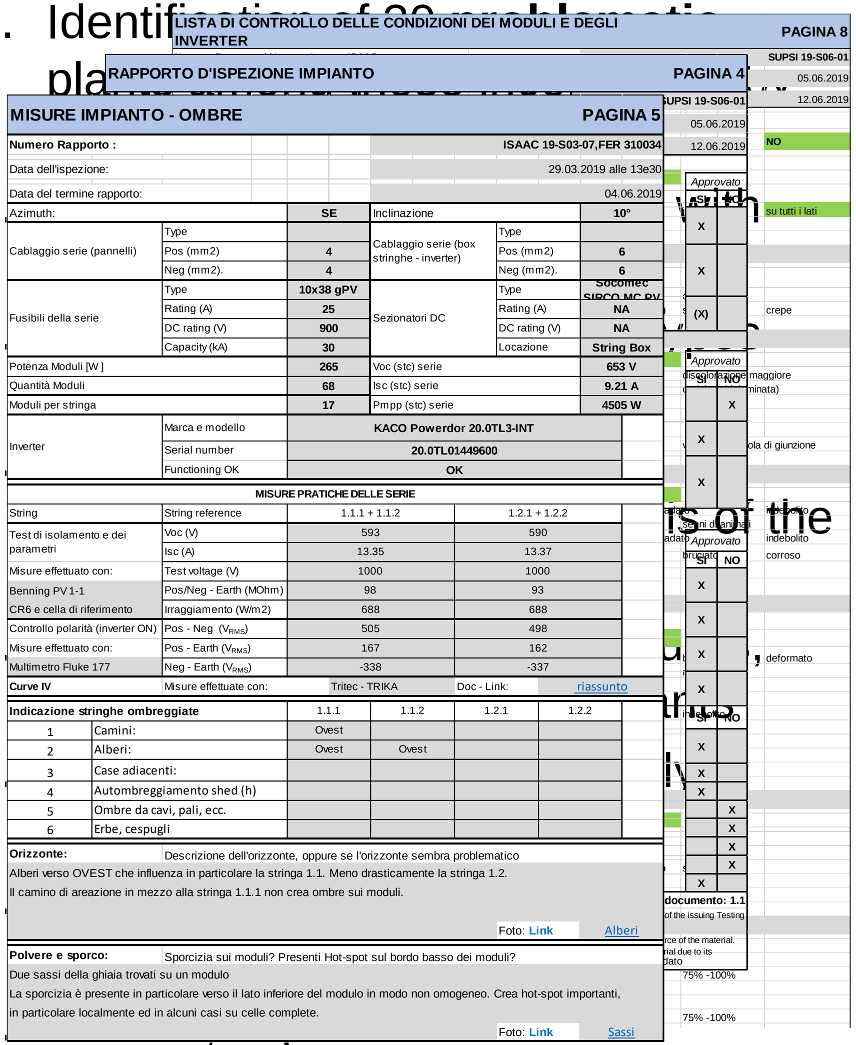
Main topics for the rapid adoption of the PV:

- Drastic cost reduction
  - New technologies adopted
  - New installation systems
- Rapid growth of number of PV installations
  - Lack of knowledge of technologies
  - Lack of monitoring and controls

Quality affects different stakeholders in the value chain:

- Module and inverter and other components' manufacturers
- PV system installers
- Investors
- Owner of PV systems

Overview: method


MISURE IMPIANTO - OMBRE — PAGINA 5

Numero Rapporto :				ISAAC 19-S03-07,FER 310034	
Data dell'ispezione:				29.03.2019 alle 13e30	
Data del termine rapporto:				04.06.2019	
Azimuth:		SE	Inclinazione		10°
Cablaggio serie (pannelli)	Type		Cablaggio serie (box stringhe - inverter)	Type	
	Pos (mm2)	4		Pos (mm2)	6
	Neg (mm2).	4		Neg (mm2).	6
Fusibili della serie	Type	10x38 gPV	Sezionatori DC	Type	Socomec SIRCO MC PV
	Rating (A)	25		Rating (A)	NA
	DC rating (V)	900		DC rating (V)	NA
	Capacity (kA)	30		Locazione	String Box
Potenza Moduli [W]		265	Voc (stc) serie		653 V
Quantità Moduli		68	Isc (stc) serie		9.21 A
Moduli per stringa		17	Pmpp (stc) serie		4505 W
Inverter	Marca e modello	KACO Powerdor 20.0TL3-INT			
	Serial number	20.0TL01449600			
	Functioning OK	OK			

MISURE PRATICHE DELLE SERIE

String	String reference	1.1.1 + 1.1.2	1.2.1 + 1.2.2
Test di isolamento e dei parametri	Voc (V)	593	590
	Isc (A)	13.35	13.37
Misure effettuato con:	Test voltage (V)	1000	1000
Benning PV 1-1	Pos/Neg - Earth (MOhm)	98	93
CR6 e cella di riferimento	Irraggiamento (W/m2)	688	688
Controllo polarità (inverter ON)	Pos - Neg (V_{RMS})	505	498
Misure effettuato con:	Pos - Earth (V_{RMS})	167	162
Multimetro Fluke 177	Neg - Earth (V_{RMS})	-338	-337
Curve IV	Misure effettuate con: Tritec - TRIKA	Doc - Link:	riassunto

Indicazione stringhe ombreggiate		1.1.1	1.1.2	1.2.1	1.2.2
1	Camini:	Ovest			
2	Alberi:	Ovest	Ovest		
3	Case adiacenti:				
4	Autombreggiamento shed (h)				
5	Ombre da cavi, pali, ecc.				
6	Erbe, cespugli				

Orizzonte: Descrizione dell'orizzonte, oppure se l'orizzonte sembra problematico
Alberi verso OVEST che influenza in particolare la stringa 1.1. Meno drasticamente la stringa 1.2.
Il camino di areazione in mezzo alla stringa 1.1.1 non crea ombre sui moduli.
Foto: Link Alberi

Polvere e sporco: Sporcizia sui moduli? Presenti Hot-spot sul bordo basso dei moduli?
Due sassi della ghiaia trovati su un modulo
La sporcizia è presente in particolare verso il lato inferiore del modulo in modo non omogeneo. Crea hot-spot importanti, in particolare localmente ed in alcuni casi su celle complete.
Foto: Link Sassi

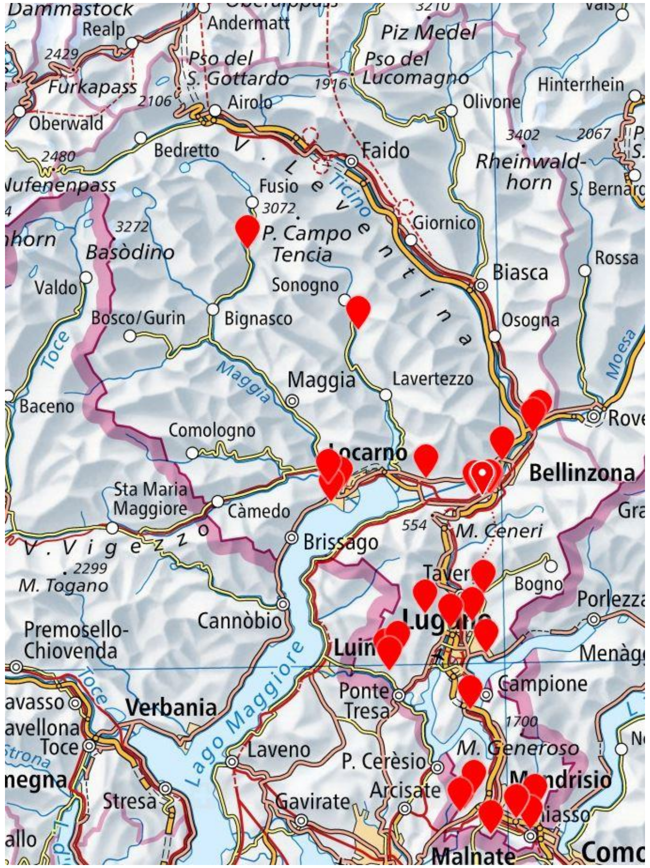
Checklist measurements:

- Measurement of the I-V characteristic of the string (I-V tracer); extrapolation to STC.
- Measurement of insulation (Riso), Voc and Isc.
- Polarization measurement (i.e. PID)
- Thermographic analysis (where possible)
- Visual analysis of the PV modules (where possible)
- Partial shadow analysis
- System and BOS analysis (inverters, string boxes, connectors, cables,….)
- Documentation

An energy production analysis is not carried out!

Overview: approach and limits

- 30 rooftop PV systems were tested (out of a total of approx. 4200 plants in Ticino)
- **Only 1.4%** of the installed power in Ticino in 2018
- built in the last 5-7 years.
- Measurements and checklist in accordance to international standard



30 rooftop PV systems examinated in Canton Ticino, South of Switzerland

Limits of the project:

- Only PV plants with FER control of the energy fed into the grid
- Not an exhaustive statistic
- Self-consumption does not always allow a correct preliminary analysis
- Limited measurement and analysis time available
- Access to roofs not always possible

Overview: measurements

- A total of 560 strings were checked (I-V curve measurement, insulation measurement, visual inspection, etc.).
- 360 pictures with **infrared thermography** (IRT) were taken on half of the PV plants (14 out of 30 PV plants).
- The **visual inspections** were carried out directly or with the help of a drone.
- The traceability of defects was limited by the difficulty in accessing the roofs, in particular the pitched ones (limits in detailed visual inspection and infrared thermography).

- About 560 I-V curve with HALM and TRIKA IV curve tracers
- About 560 insulation measurement with Benning PV 1-1

Overview: 30 PV systems - 1.1MW measured

- **29** systems inpected **less than 5 years old**
- **1** system inpected 22 years old
- **Power classes:**
  - < 5kW: 4
  - < 15kW: 7
  - < 30kW: 8
  - > 30kW: 11
  - TOTAL: 1.1 MW
    - (1.4% of the 79MW installed up to the end of 2018)

  2/3 are small PV systems
- **Type of roof:**
  - Pitched roof: 14
  - Flat roof: 15
  - BIPV: 0
  - Field: 1 (the 22 years old system)
- **Cell types:** sc-Si and mc-Si with 2BB or 3BB, one system with half-cut cells.
- **Type of plant:** on-grid, in self-consumption
- **Inverter type:**
  - Central Inverter with one or more MPPTs: 26
  - String Inverter: 3
  - Optimiser: 1
- Number of **strings** per plant:
  - Mean: 9.8
  - 1 to 42 (96)
- Number of inverters per plant:
  - Mean: 1.7
  - 1 to 6 (16)

RESULTS

Types of defects / errors / system failures found

The types of defects, errors or faults encountered during the analyses can be grouped into four different areas:

1. Errors in the **design** of the system
2. Plant or component **construction** errors (wiring, cables and connectors, modules, inverter ...)
3. **Maintenance** problems (soiling, fault traceability, lack of monitoring...)
4. **Aging** defects (faults, hot-spots, burns or oxidations in cells or connectors, ...)

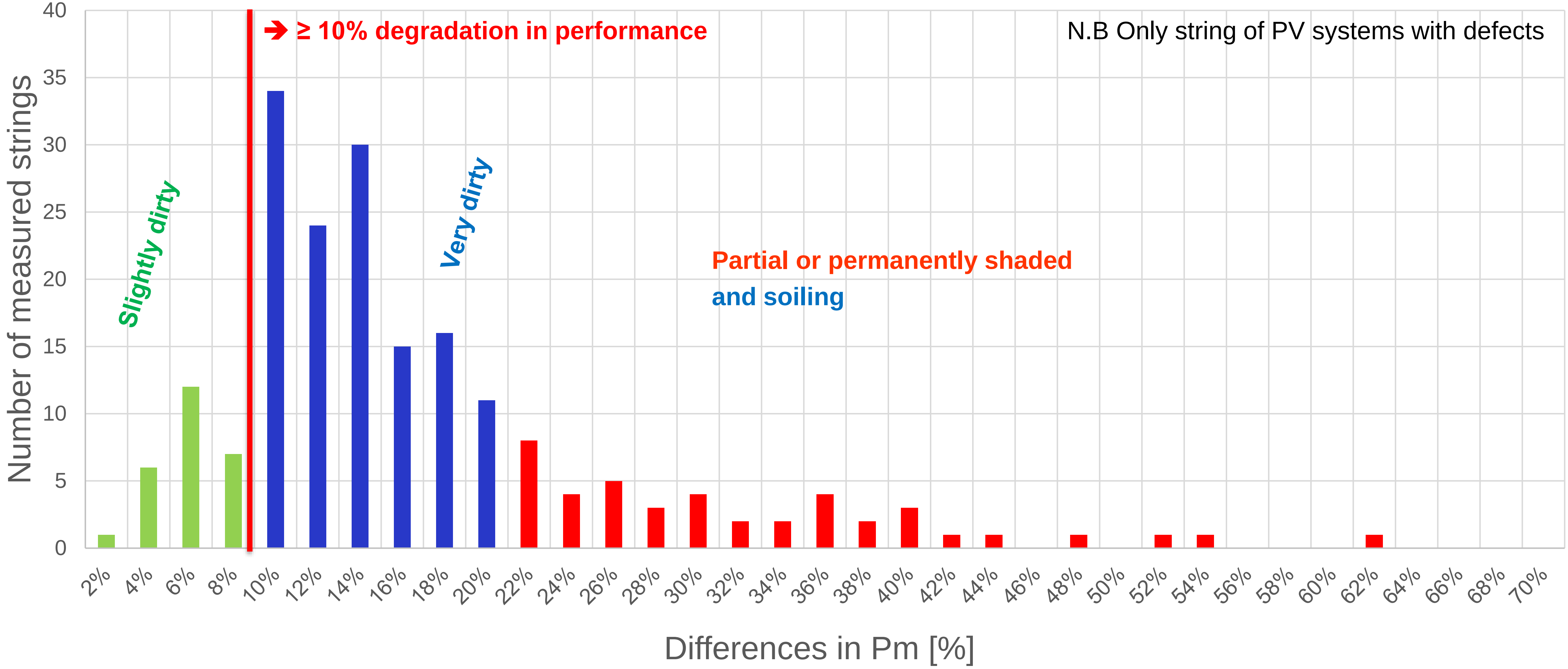
Occurence of defects / errors / failures:

- **Soiling** is by far the most frequent problem encountered
  - 24 dirty plants
  - 3 clean plants
  - 3 n.a.
- Temporary partial shadows
  - Present in more then **50%** of the plants
- Permanent partial shadows
  - **In 16.7 % of the plants**
- Strings disconnected: **3 out of 203**

	Defects/Errors/Failures in strings	
1	Power Degradation (STC)	96.5 %
2	Soiling on modules	88.9 %
3	Partial shadows	53.3 %
4	Permanent partial shadows	16.7 %
5	Defects / dirt in the inverter	10.0 %
6	Broken glass	3 modules
7	Strings disconnected	1.4 %

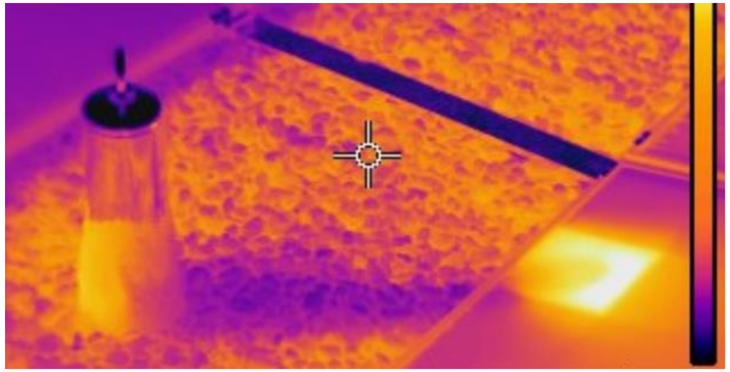
Note: Thermography was not possible to systematically analyze the presence of hot spots in all plants.

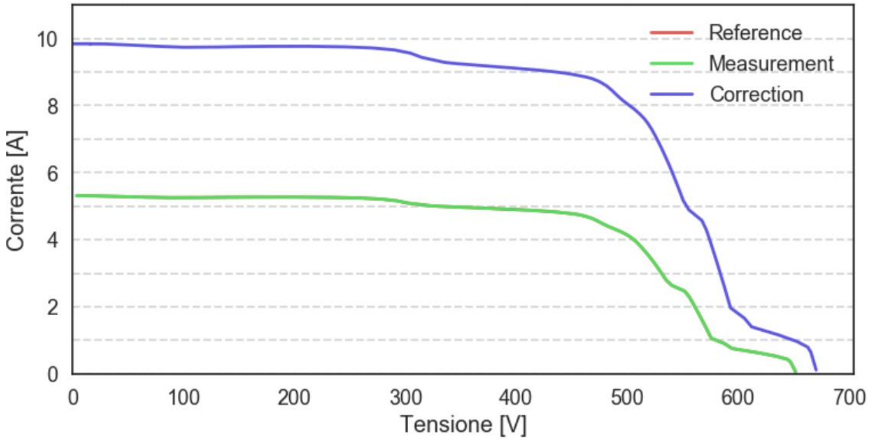
Power differences, Pmax_measured (STC) vs. Pmax_nominal (STC)



Design issues

- **Permanent** partial shadows!
  - Mutual shadows
  - Chimneys
- **Temporary** partial shadows**:**
  - Chimneys
  - Trees
  - Poles
  - Antennas
- and corresponding **electrical wiring**





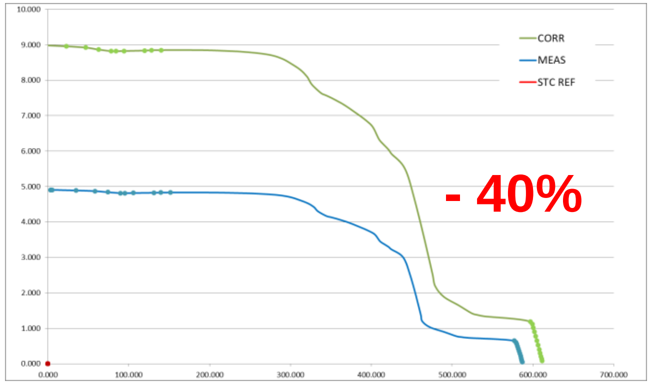
I-V curve with module permanently shaded (measure and STC)

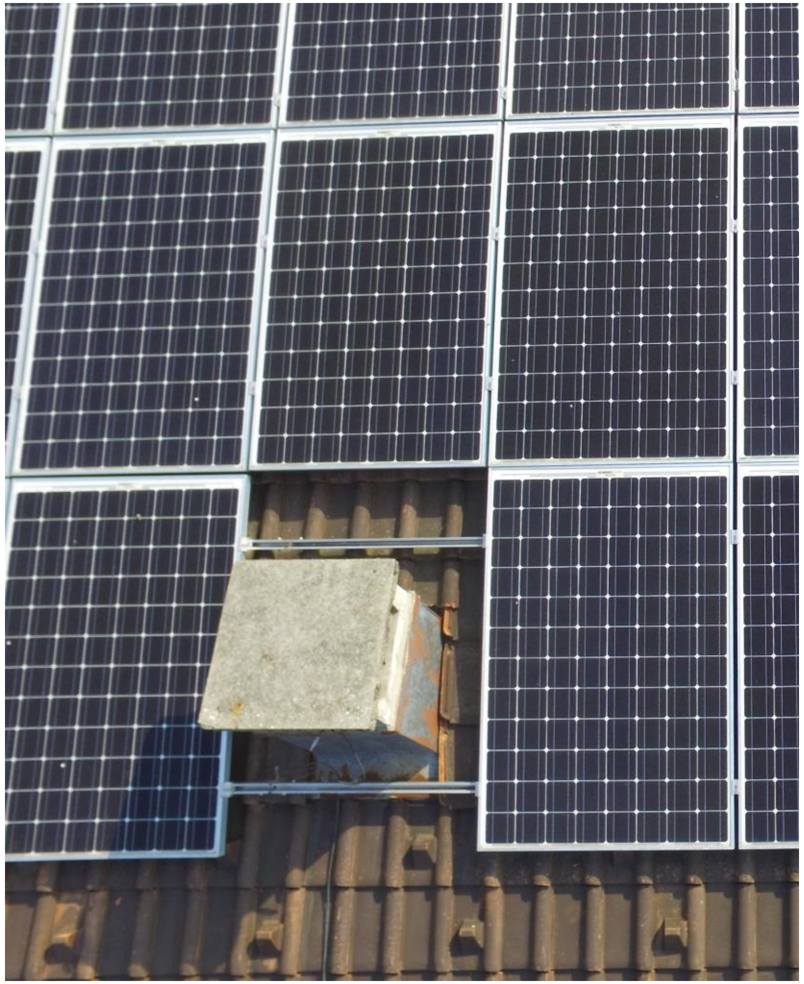
Design issues, some examples:

Mutual shadows

Tree shadows

Near building shadows

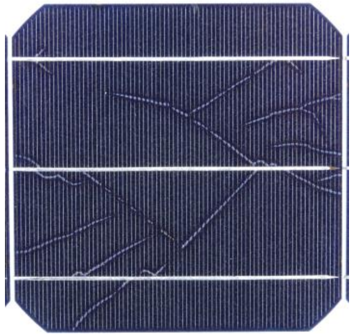




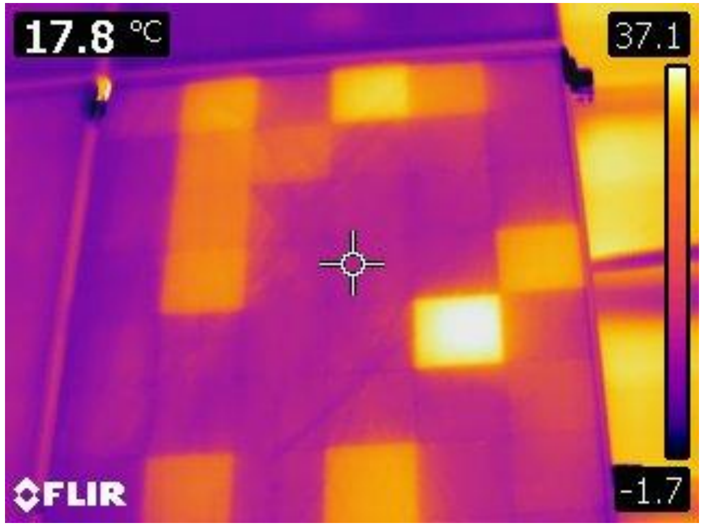
Chimney shadows

Construction and wiring defects and errors

- Incorrect number of modules in the string
- Changes in layout or position of the modules
- Incorrect wiring of dummy (spare) modules



Cell defects



Dummy module in Isc instead Voc

Layout and wiring error

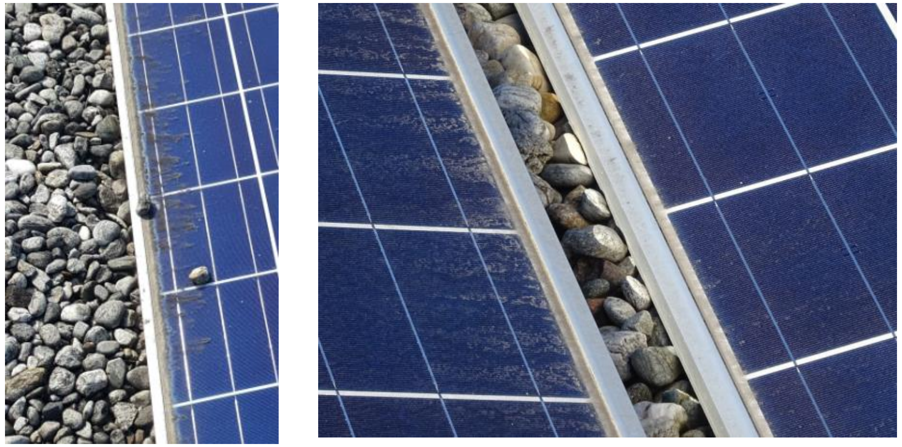
Poor wiring

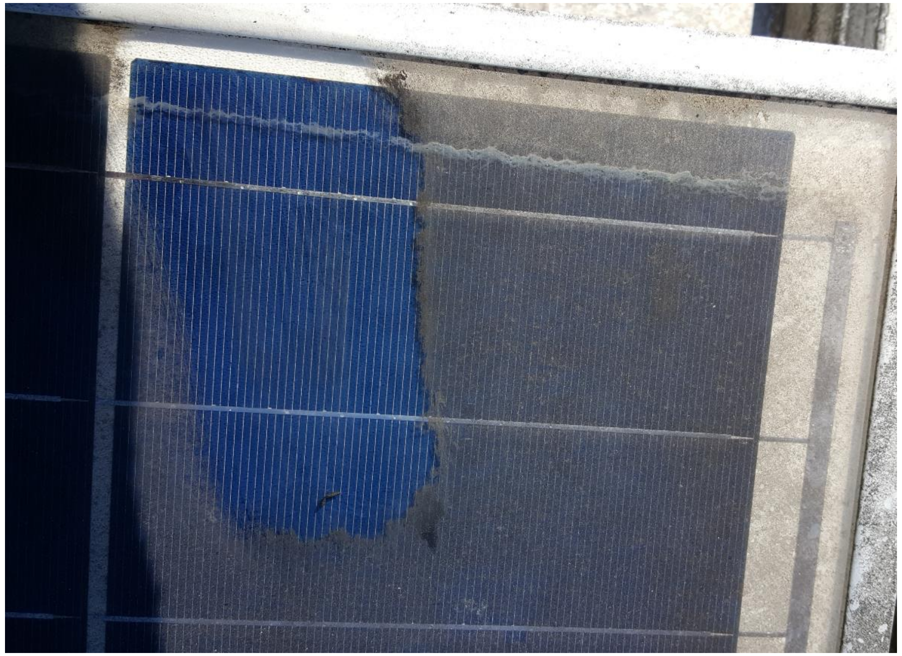
Only few construction or wiring defects

Maintenance issues: examples

Dirty Inverter filter: derating in power

Soiling on bottom edge in proximity to the ground:

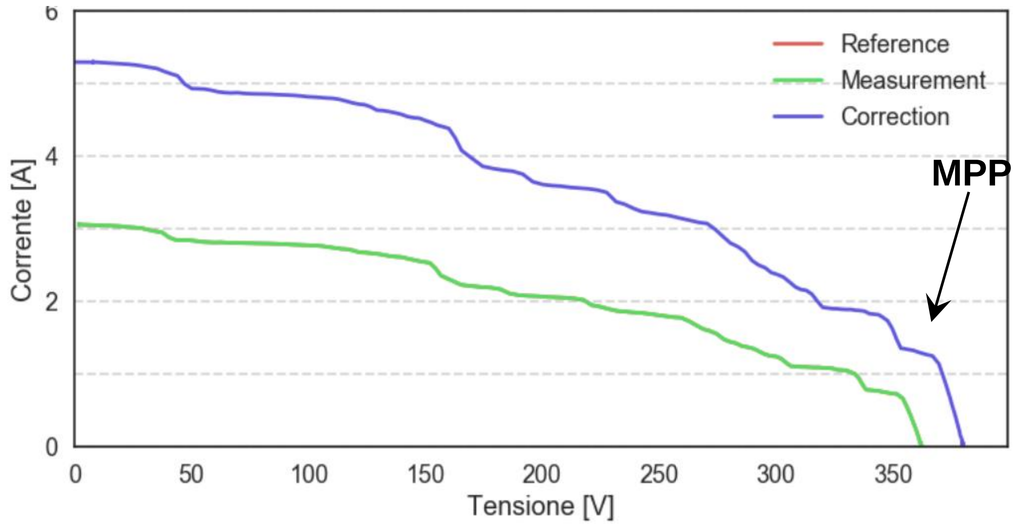




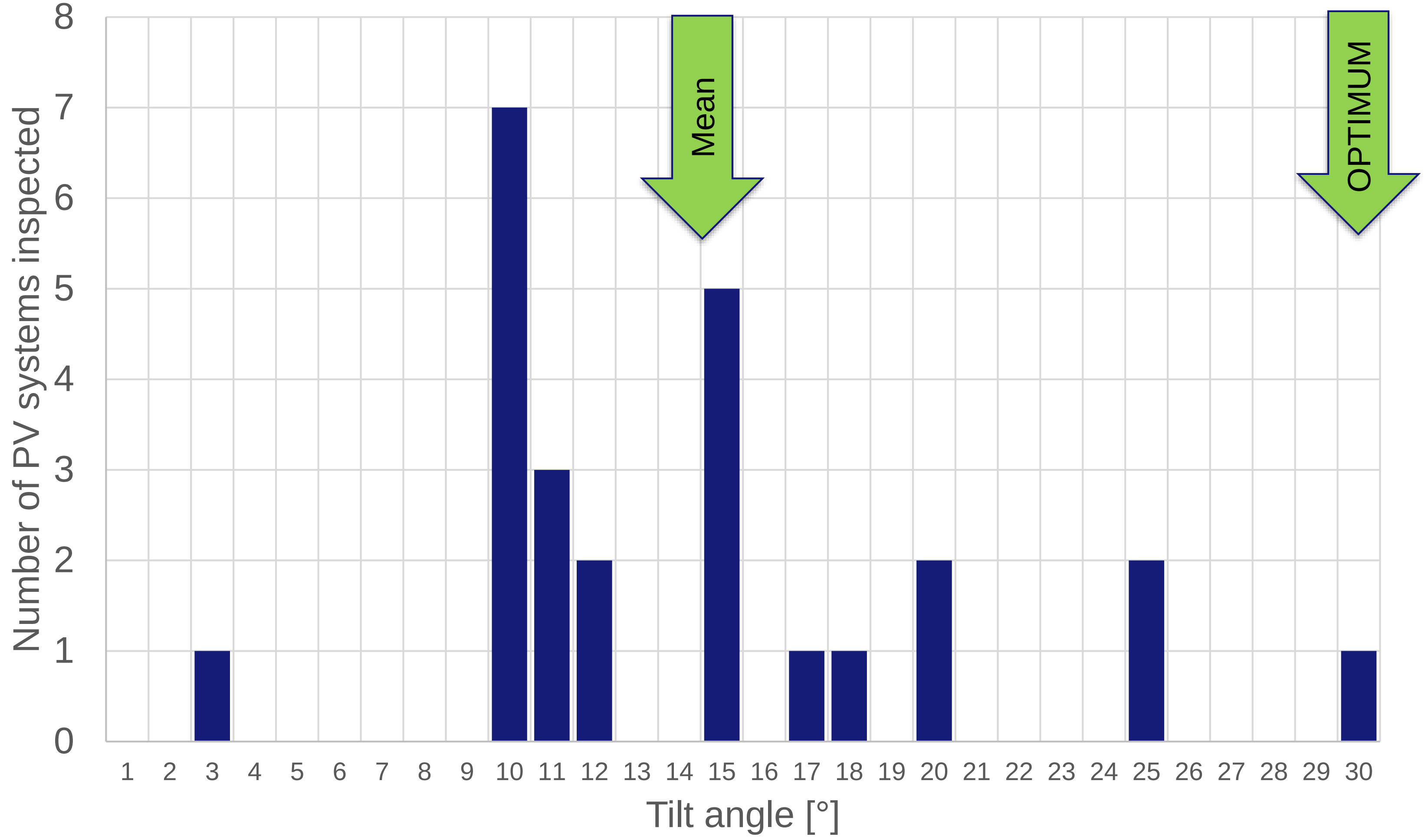
Soiling on the bottom edge of the modules can cause hot spots

Maintenance issues: soiling

- No hot-spot but lower performance (e.g. -30%)
- Soiling is not always uniform but heterogeneous: it can accumulate in some parts of the modules or of the strings
- Farms and agriculture are more sensitive



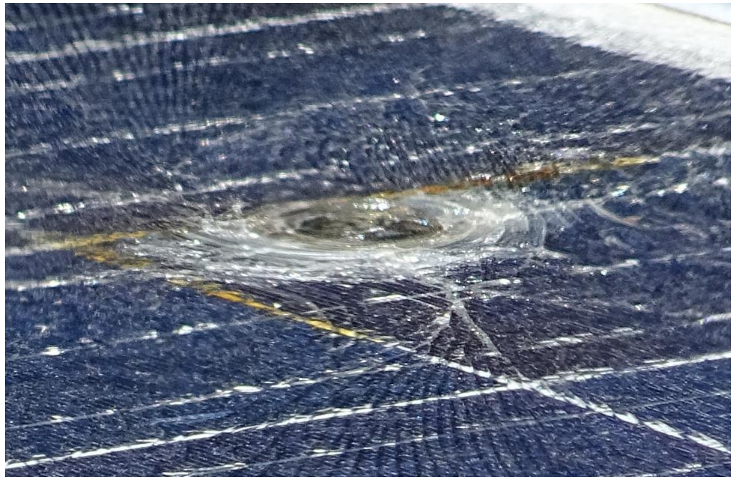
Maintenance: modules tilt angle on flat and pitched roofs



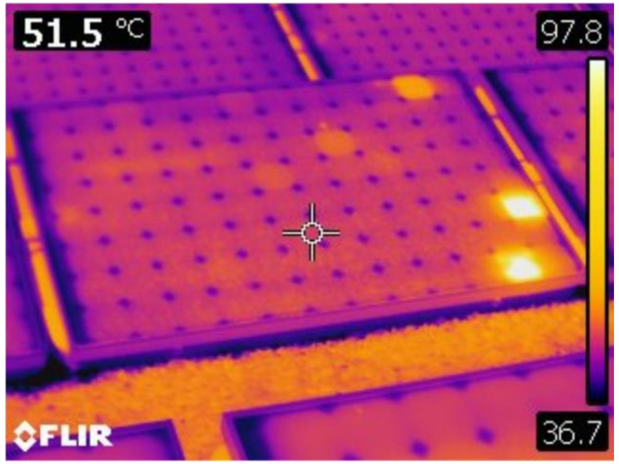
- Modules tilt angle:
  - Mean: 14.2°
  - Min: 3°
  - Max: 30°
- The decrease in tilt angle, increases soiling problem

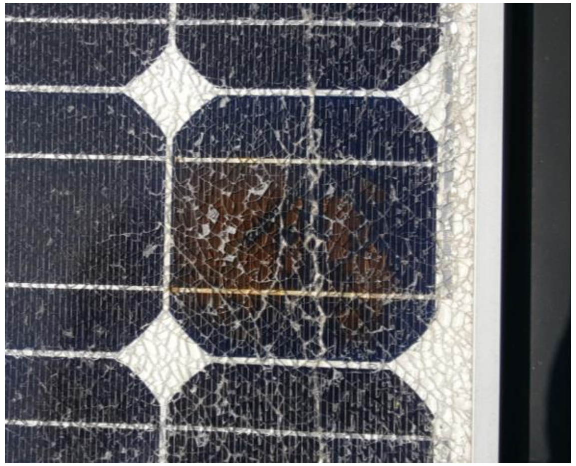
Aging defects or glass breakage: examples

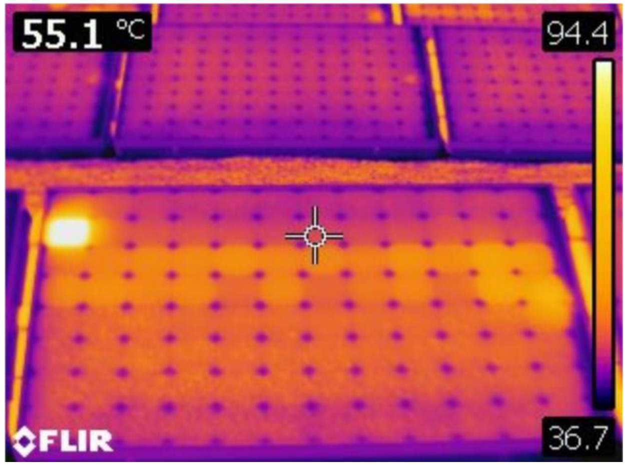
- Damage to the cell or glass (browning, broken glass, delamination , etc …)
- Loss of power (transparency of the glass, current, …)
- Activation of the by-pass diode
- Hot-spots

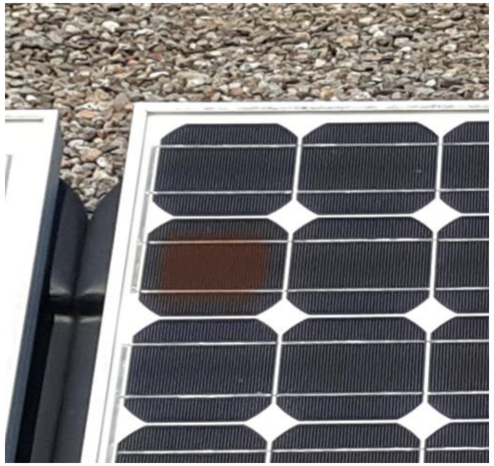


Short circuit / lightning or hot spot ?









Hot spots can cause broken glasses

…and browing cells

Conclusions

- The **30 PV plants** (1.4% of the power installed in Canton Ticino, Switzerland), were chosen from those with reduced production or already with indications of defects, built in the last 5-7 years: **2/3 less then 30kW**

- 4 different types of defects, errors or faults found: errors in the **design** of the system / Plant or component **construction** errors / **maintenance** problems / **aging** defects

- **«Design»** and **«Maintenance»** are the two main causes of functional defects in plants and lower performance.

- **«Soiling»** is by far the most frequent problem encountered. It is a maintenance issue but also a design issue (tilt angle).

Conclusions/Suggestions

Source: swissolar.ch

The **installer** should care for:

- Limit partial shadows
- Avoid permanent shadows
- Increase knowledge in design

The owner should care for:

- Monitoring (monthly values but at least annual value)
- Comparing (with expected simulated performance)
- Annual maintenance (cleaning modules and inverter filters, cutting trees and hedges)

Thanks to:

- Cantone Ticino, Fondo Cantonale FER
- Ufficio dell'energia del cantone Ticino

- Energieschweiz

energieschweiz
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- Team PVLAB - ISAAC: Gabi Friesen

Questions