The Future of PV Systems in a World Increasingly Defined by Extreme Weather

Ulrike Jahn, Task Manager of IEA PVPS Task 13 / Laurie Burnham, Sandia Labs, USA

Outline

1. What is IEA-PVPS?
2. Risks to PV power plants created by extreme weather
3. Mitigation strategies and O&M guidelines for PV power
4. Recommendations and Take-Home Messages

1. What is IEA PVPS?

The IEA Photovoltaic Power Systems Programme (IEA PVPS) is one of the **Technological Collaboration Programmes (TCP)** established within the International Energy Agency (IEA). Since 1993, international participants have collaborated on a diverse range of joint projects, all aimed at **advancing the application of photovoltaic technology** for the conversion of solar energy into electricity.

The IEA PVPS Executive Committee 2023

9 Research Tasks are currently operational

340 Individuals from all over the globe are participating in PVPS

175 Scientific reports have been published since 1998

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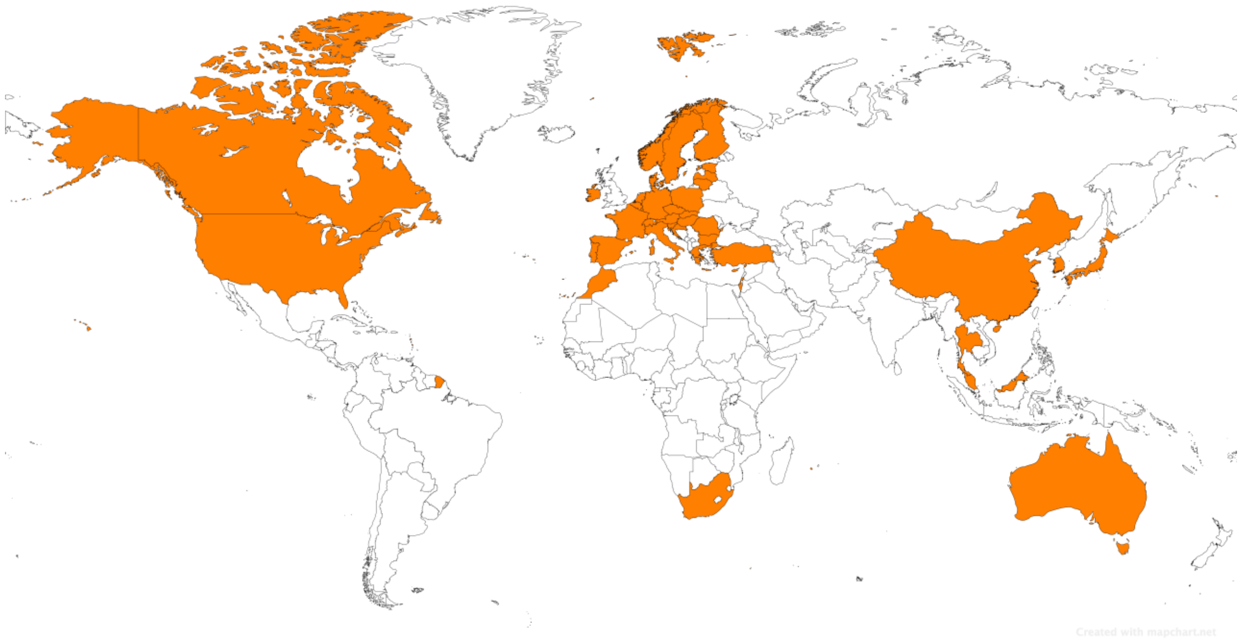
1. Our members



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- United States

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1. PVPS Task 13: Subtask on Extreme Weather

Title: "Extreme Weather and its Impacts on PV Power Plants: Risks, Failure Mechanisms, Mitigation Strategies and Costs"

Co-leaders: Laurie Burnham (USA) and Tadanori Tanahashi (Japan)

Contributors:
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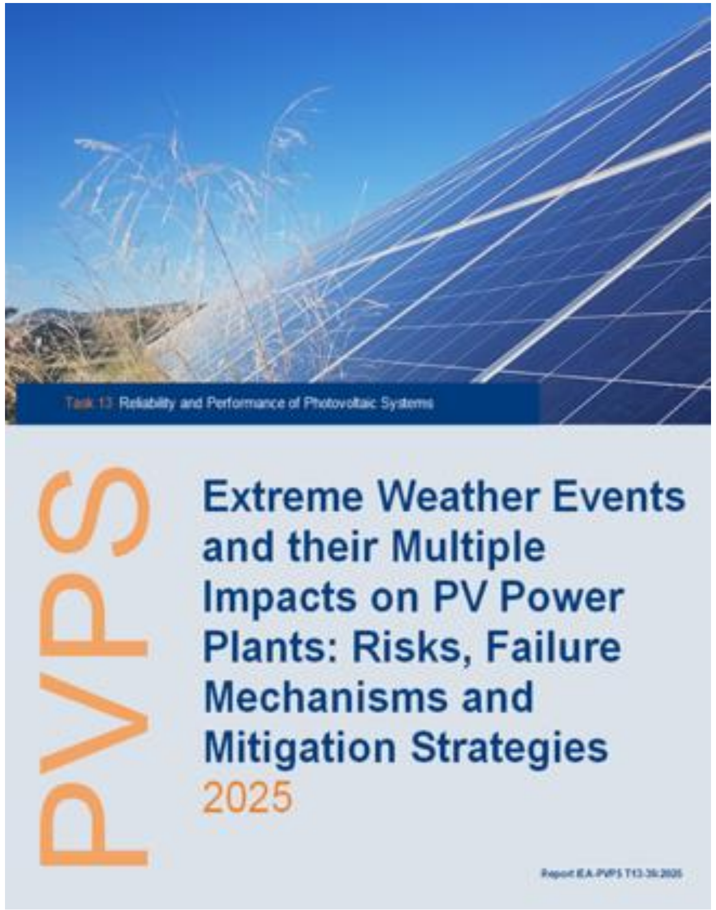


Objectives:

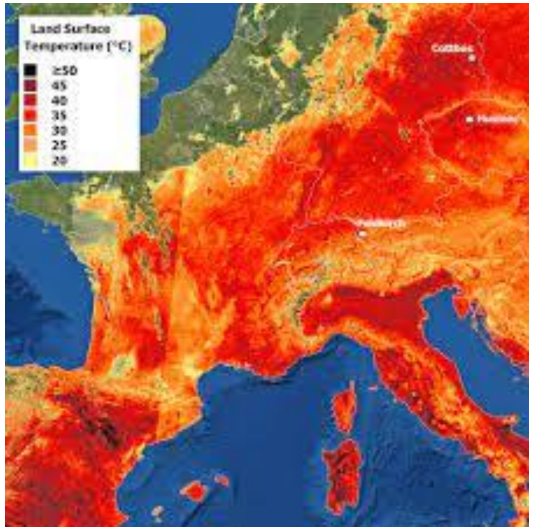
- Create framework for quantifying and qualifying the risks posed by specific storm threats.
- Assemble global data on failure mechanisms and their root causes.
- Disseminate strategies for designing, siting and managing storm-resilient PV systems

Audience:

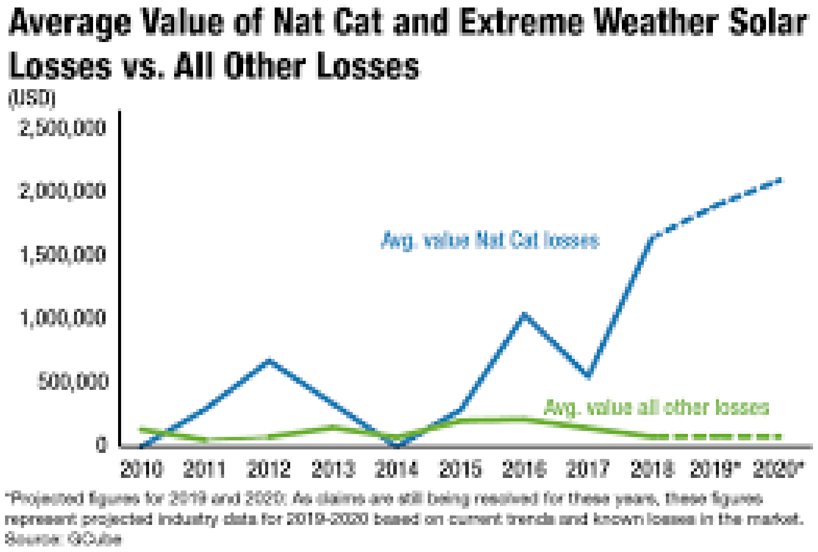
- EPCs, asset owners, insurers, investors, utility planners, disaster responders

2. PVPS Task 13: Weather Challenges to PV Power Plants

Hurricane Fiona in Puerto Rico



Heat wave in Europe



Flooding in Pakistan

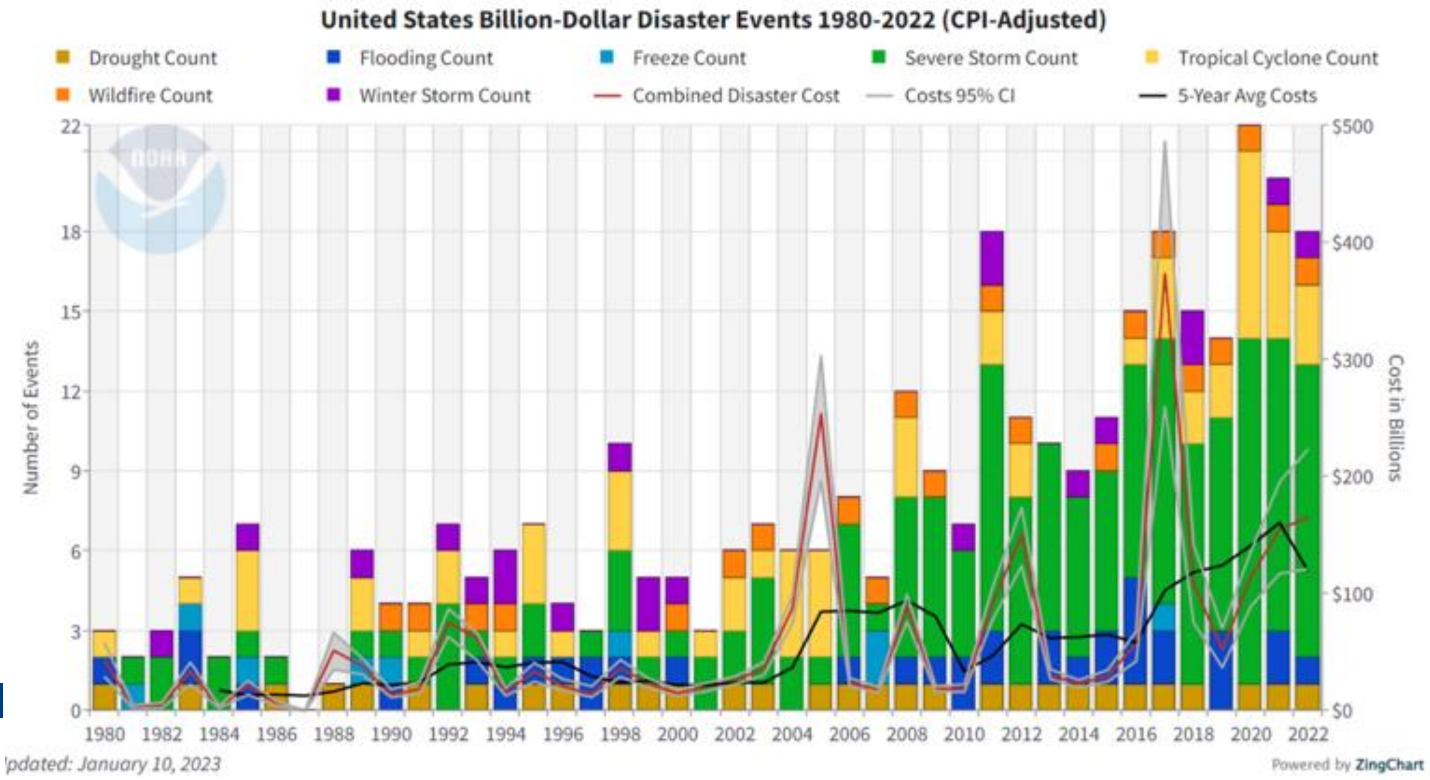
Hurricanes in the US

Wildfires in Italy

2. Why Extreme Weather Events Matter

Threat landscape is evolving and expanding:

- Extreme weather events are increasing in frequency and intensity [IPCC, NOAA, NASA*: 5x-17x above historical predictions.
- Exponential growth of PV of 75 TW needed to decarbonize the grid by 2050.
- Vast majority of solar sites globally are located in natural-catastrophe exposed areas.
- Downward cost pressures on the industry, both on the manufacturing and installation sides.
- Rapid technological innovation: module and cel technologies tending toward larger and thinner.
- Predominance of single-axis tracker systems that are vulnerable to vibration and resonance.



Other ways to define extreme weather:

1. Recurrence interval or probability (P99 event);
2. Highest or lowest 5% or 10% of historical measurements;
3. Distance from the mean.

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** Hausfather, Z., Drake, H. F., Abbott, T.,& Schmidt, G. A. Geophysical Research Letters, (2020).*

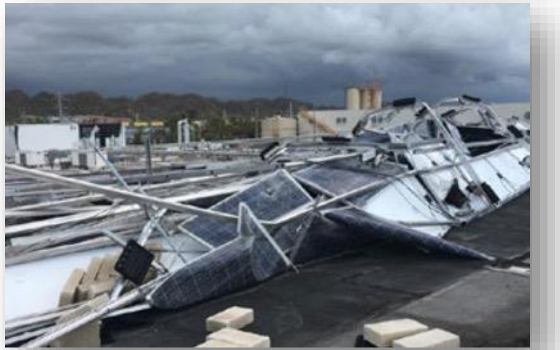
2. Impact of Extreme Weather on PV Power Plants

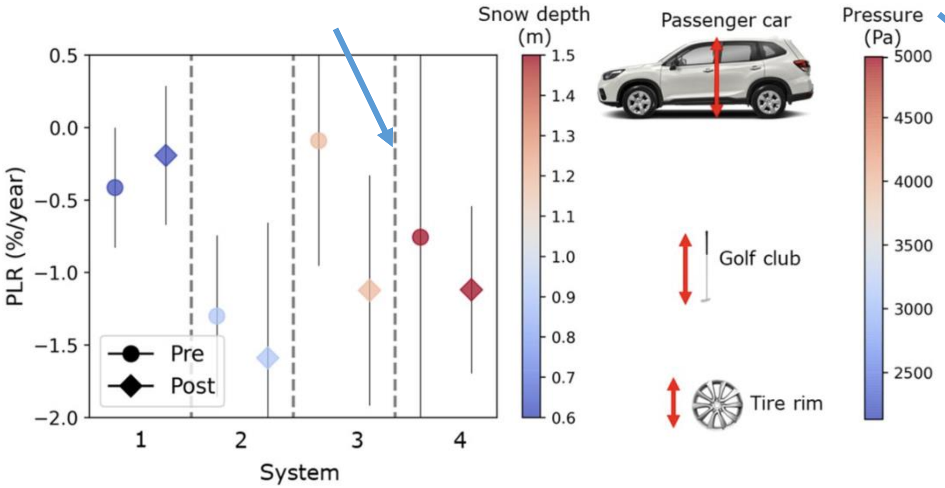
Immediate:

1. Reduced power generation = lack of irradiance
2. Total loss of power = site destruction

Delayed Manifestation:

1. Reliability of modules and balance-of-system components
2. Under-performance and accelerated degradation





Jordan, D., et al. *PV Tech,* 2023

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2. Why this Topic is Challenging

- Extreme weather is a global phenomenon; PV is a global commodity…
- Yet little data is available:
  - No centralized repository for reporting damages,
  - No standardized methodology for systematically recording loss and damage; no common vocabulary
  - No comprehensive studies on the long-term impacts on LCOE and performance

IEA Task 13 could play a role in the above; our report on Extreme Weather will cover:

- **Overview:** definition of extreme weather event, geographic distribution and projected change in frequency and intensity
- **Equipment damage and failure mechanisms** (include catastrophic damage vs performance and equipment degradation)
- **Economic impacts** (lost generation, repowering, insurance costs, impact on future developments)
- **Diagnostic tools** for module and BOS failures; O&M for long-term performance monitoring
- **Mitigation Strategies**
- **Key Take-Aways** and Recommendations (standards, best practices).

2. Extreme Weather Events Covered in the IEA PVPS Report

1. High wind events: hurricanes, typhoons, etc.
2. Convective storms
3. Snowstorms and blizzards
4. Dust storms
5. Heat waves
6. Floods
7. Wildfires

2. Hurricanes

CATEGORY	WIND SPEED MPH	KM/H	KNOTS	DAMAGE POTENTIAL MULTIPLIER
1	75	121	65	1x
	80	129	70	1.6x
	85	137	74	2.9x
	90	145	78	4.3x
	95	153	83	6.6x
2	100	161	87	10x
	105	169	91	15x
	110	177	96	21x
3	115	185	100	30x
	120	193	104	43x
	125	201	109	60x
4	130	209	113	82x
	135	217	117	110x
	140	225	122	147x
	145	233	126	195x
	150	241	130	256x
	155	249	135	333x
5	160	257	139	429x
	165	266	143	549x
	170	274	148	697x
	175	281	152	879x
	180	290	156	1101x
	185	298	161	1371x
	190	306	165	1696x

Hurricane Damage Potential

Potential damage increases logarithmically from category 1 to Category 5, so small increases in wind strength can dramatically increase damage. E.g., doubling of windspeed from 121 km/h to 241 km/h results in a 256 times increase in damage. *Source:* NOAA.gov

Damage to Photovoltaic Systems

- Mechanical loading can cause structural deformation and cascading failures.
- Modules can break apart when winds exceed 241 km/h.
- Airborne debris can destroy the front glass.
- Flooding also occurs and can submerge parts of the power plant.

Mitigation Strategies

- Improved stow strategies
- Ground mounted fixed-tilt
- More robust fasteners (e.g., through-bolts) and torque specs
- Smaller format modules

Photo: D. Valentín, *et al.*, *Engineering Failure Analysis*, 2022, https://doi.org/10.1016/j.engfailanal.2022.106137.

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2. Severe Convective Storms: Hail, Tornadoes and Straight-line Winds

Case Studies, Failure Modes, and Event Severity

- **Hailstorm loss events:** Netherland, USA, and Switzerland
- **Windstorm loss events:** Australia, USA

Economic Impacts of Convective Storm Damage

- **Insurance:** 54.2% of claims value (total incurred costs)

Hail Damage

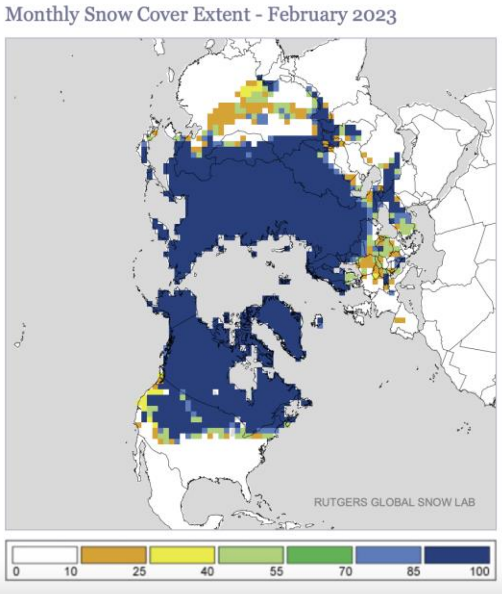
- Hail damage is randomly selective; not all panels are impacted
- Damage is immediately apparent if front glass is broken
- Damage, if glass is intact, much harder to diagnose and assess
- Increase in hail events and geographic distribution is big insurance concern

Mitigation Strategies for Hail and Wind

- Advanced stow algorithms for trackers
- Hail-resilient solar modules:
  - Thicker front glass (3.2mm+)
  - Smaller form factor (less surface area)
  - High upload resistance to wind

Though hail loss events are infrequent,[??] the magnitude of the resulting damages compromises the viability of renewable energy insurers' books, erodes ClimateTech investor confidence, and threatens global climate risk mitigation goals. Strong statement and I am not sure I agree.

2. Snowstorms and Blizzards



Global snow distribution Feb 2023

Snow is ubiquitous

- Every winter, snow covers 50M km^2 (>50% of the northern hemisphere)
- PV and snow an emerging issue: in 2021, **31%** of **US PV capacity** was located **above 40° N***

Power losses are significant

- Snow shading of modules causes significant power losses throughout winter months

Snow takes PV offline (resource challenges)

- Blizzards can sweep across a continent, resulting in zero solar generation

Heavy snow loads can collapse racking, damage modules

Wintry climates have unique stressors

- Snow is repetitive and always accompanied by cold temperatures

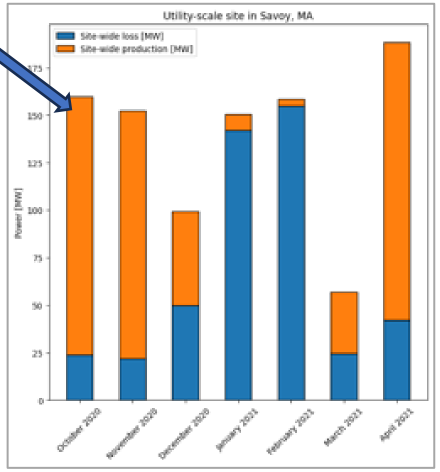
Design optimization is a big unknown

Mitigation Strategies

- Stow strategies
- High tilt angles; vertical orientation
- Frameless modules; steel frames
- Snow-phobic coatings; low-roughness AR coatings/glass

Non-uniform shading and surface differences impact performance

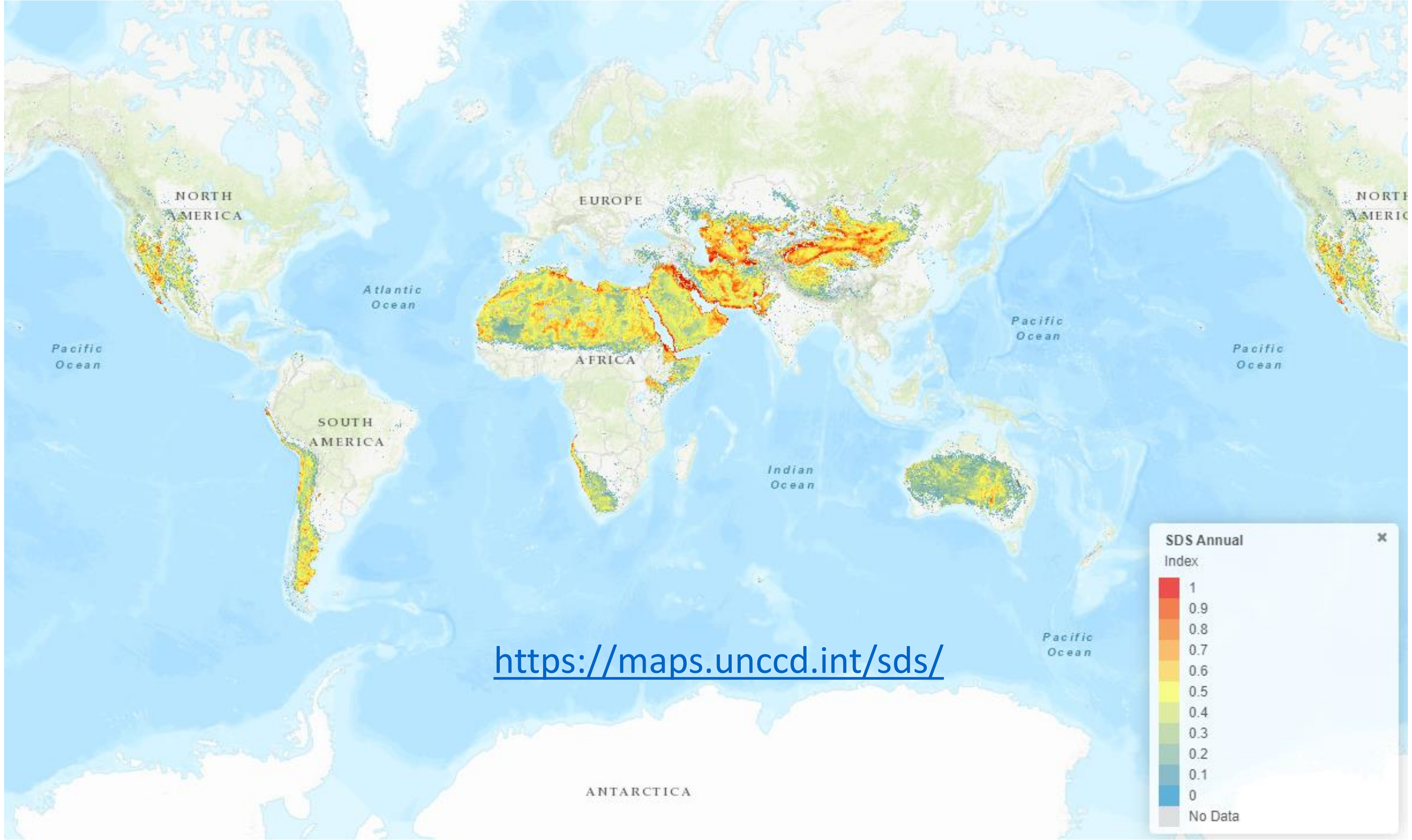
Snow damage in Japan, 2022



Snow losses in winter exceed 90% at utility-site in the US

* *From the U.S. EIA, Annual Generator Report,* EIA-860A/860B//////

2. Dust storms



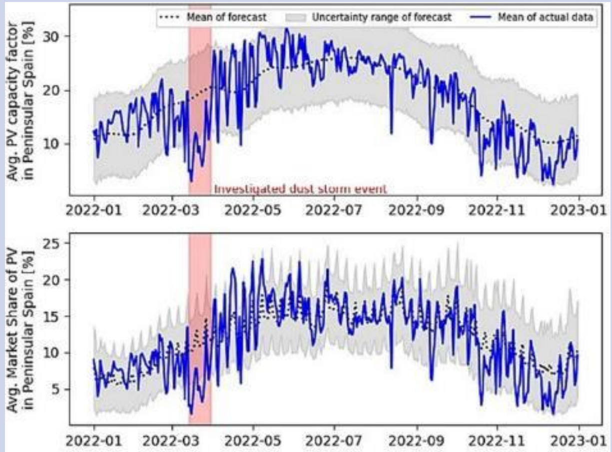
https://maps.unccd.int/sds/

Dust storms are particularly intense across the southern Asia and the Middle East but occur in desert areas around the world, including the USA, Chile and Australia.

Impact of Dust Storms on Performance

Absorption, reflection and scattering of the sunlight caused by the suspended dust particles

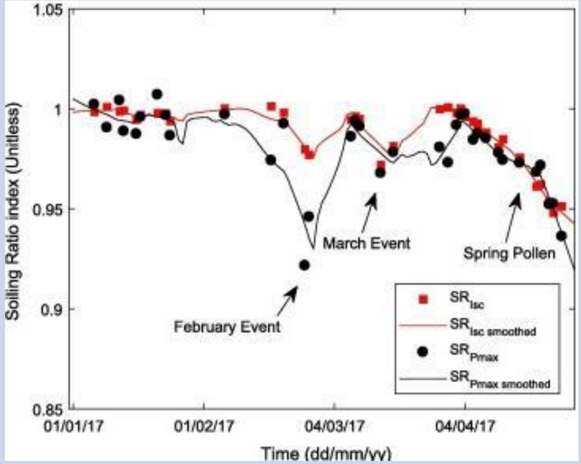
Dust storms can have prolonged effects over large areas



Dust storm in 2022 halved the PV capacity in Spain for 2 weeks.

Increased accumulation of dust particles (soiling)

Dust storms cause most soiling losses in Europe.



Power losses as high as 8% after storm in 2017 in Portugal.

Dust storms can also abrade anti-reflective and anti-soiling coatings

Mitigation Strategies

- Extraordinary and regular cleanings
- Upside-down positioned modules during storms
- “Dust walls“

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2. Flood-Prone (Monsoon) Regions

Flood Damage

- Force of flowing water can damage racking and other hardware
- Erosion of the support structure and foundations can occur, destabilizing the system
- Moisture ingress into electrical components can increase electrical resistance, resulting in generation losses, post-flooding
- Moisture increase can also cause arc faults and fires

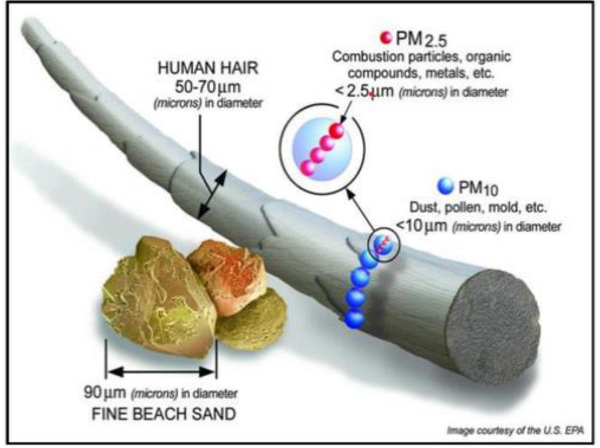
Mitigation Strategies

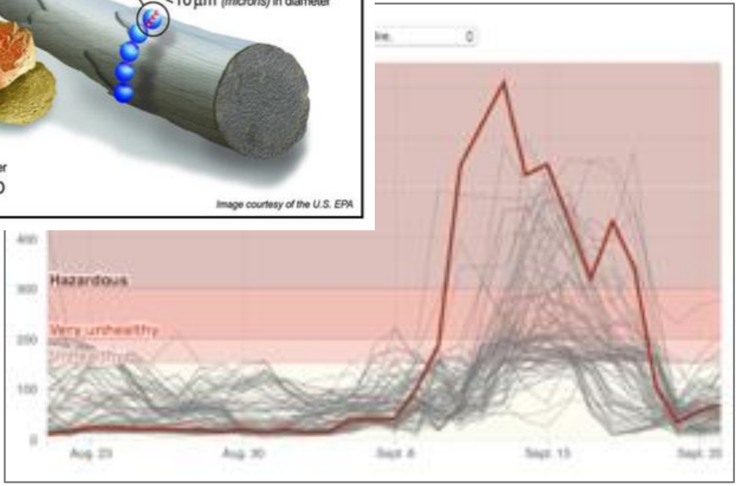
- Site selection, to avoid flood zones, is critical
- The height of the system, including height of the inverters, should reflect risk of flooding
- Proper installation of connectors and cables is essential.
- Post-event O&M should include visual inspections of all components and thermal/electrical measurements of panels and electrical system.

2. Wildfires

Global occurrence of wildfires threatens PV in three ways:

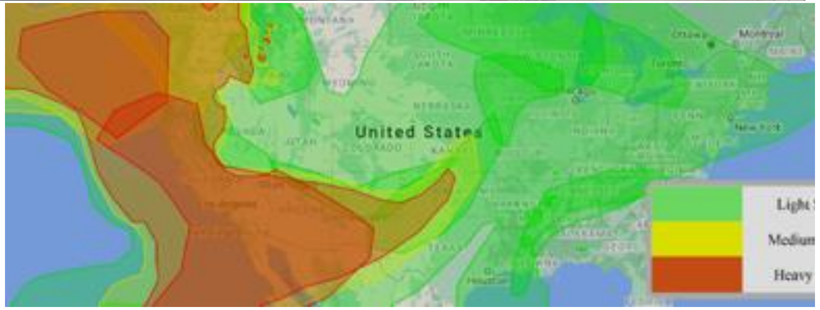
1. Catastrophic destruction
2. Generation losses from reduced irradiance
3. Smoke exposure from proximal fires: caustic ash, electrically conductive nano-particles
4.





Wildfire particulates

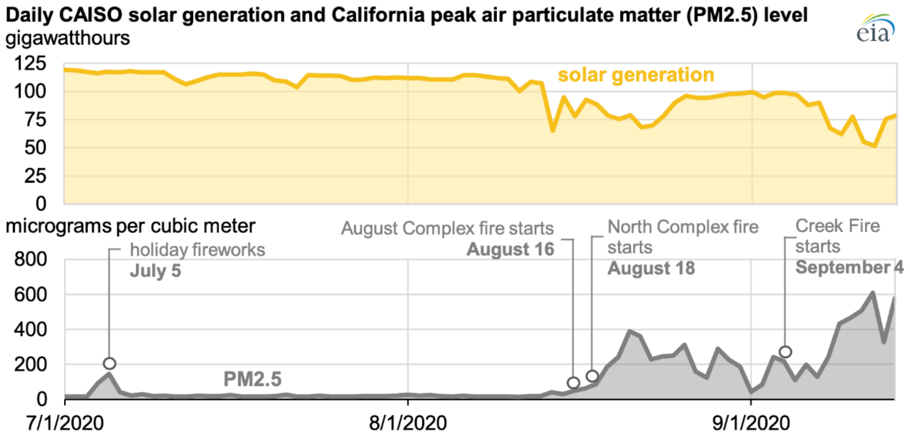
Juxtaposition of wildfires and PV power plants in California, 2020



Distribution of wildfire smoke on 9/9/2020

SEPTEMBER 30, 2020

Smoke from California wildfires decreases solar generation in CAISO



Source: U.S. Energy Information Administration, Hourly Electric Grid Monitor; California Air Resources Board, Air Quality and Meteorology System

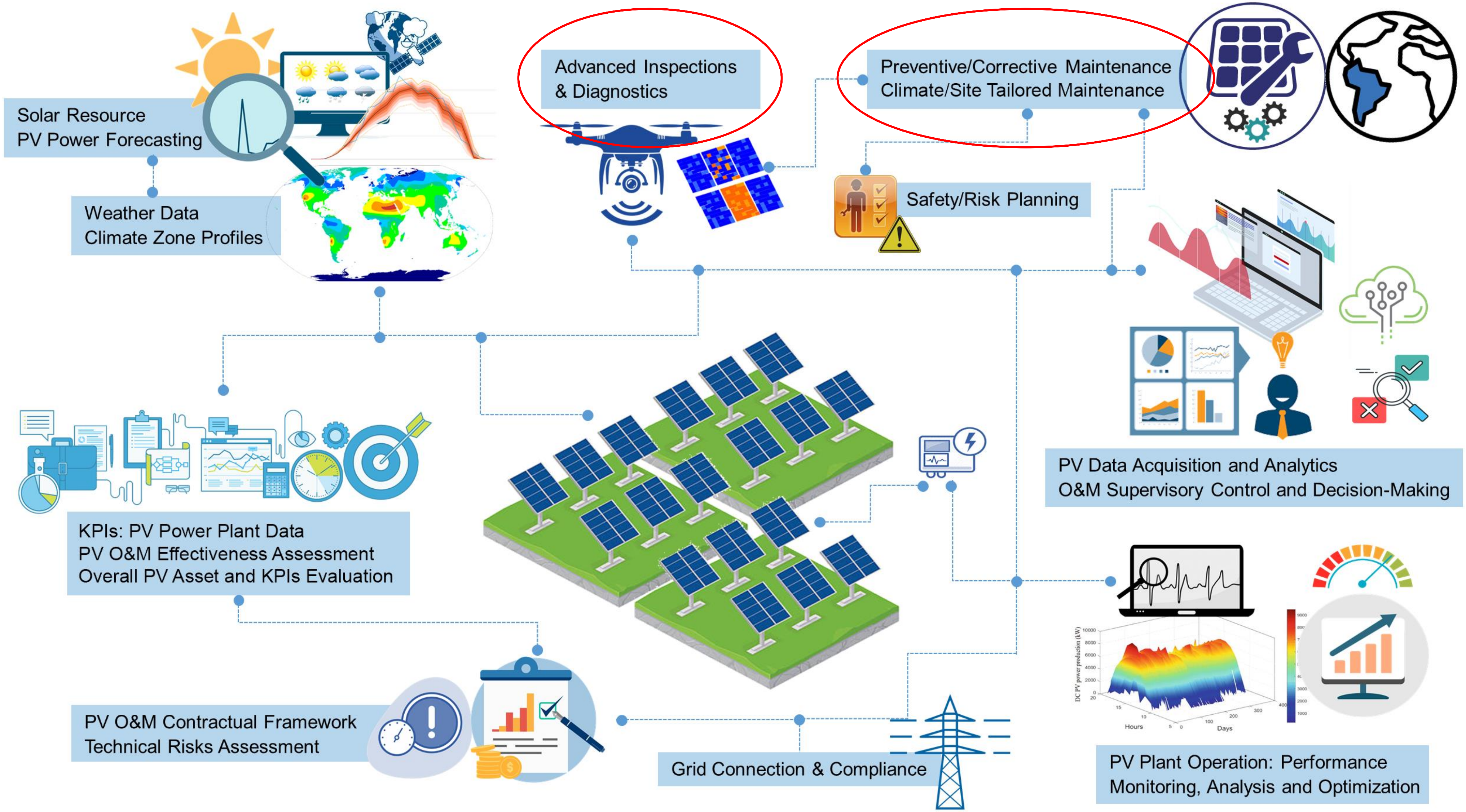
Note: CAISO=California Independent System Operator.

In September 2020, average solar-powered electricity generation in California dropped nearly 30% from the July 2020 average.

2. Insurance and Risk Management Challenges

- Little data is available; no centralized repository for reporting the types of damages incurred, their cost, their long-term impacts on LCOE, performance degradation.
- Geographic diversification of solar PV and unleashing of new technologies, including thinner cells and larger surface: frame ratios, resulting in a broader range in claims.
- Hail claims some of the largest – predominately in the US, where geographic risk is expanding.
- Also extreme weather events can be compounded by poor installation practices.
- Upshot is that in some cases premiums doubled; policies are becoming more restrictive; deductibles also increasing.
- Need to provide greater insurance-cost certainty for CAPEX and OPEX finance models.
- Also bad weather occurs not just during the operations phase but during construction.
- Probable maximum losses => estimates of worst-case scenarios: the value of the largest loss that could result from a natural disaster.
- Need to reduce risk by identifying in advance the points of failure and mitigating against them.

3. Guidelines for Operation and Maintenance of PV Power Plants in Different Climates



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Report IEA-PVPS T13-25:2022, October 2022

4. Recommendations and Take-Home Messages for Utility-Scale PV

- Storm activity is projected to increase in different parts of the world.
- PV systems need to be designed and built, not as one-size-fits-all power plants but designed to withstand local risks, from heat waves to blizzards to hurricanes.
- Storm impacts can be highly localized within a plant; within a region. Examples are hail and hurricanes in the US, in Puerto Rico and in Japan => highest human and economic toll.
- Zero component failures are impossible to achieve.
- Importance of regional and global cooperation; information sharing around failure mechanisms and frequency of failure.
- Complexities of changing weather are not well understood.
- Skilled labor is increasingly important – from installation to advanced diagnostics of PV power plants.

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[Task 13 Report: Reliability and Performance of Photovoltaic Systems - IEA-PVPS]

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Head of PV Energy Systems at EURAC Research, Italy
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Jaione Bengoechea Apezteguia
Head of Photo-Electric and Photovoltaic Innovation and Technological Development Area, CENER, Spain

Ulrike Jahn
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Thank You, Task 13 Team!

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PVPS Task 13 Collaboration: 185 experts from 25 countries