Trends in Extreme Weather and Their Implications for Solar-Energy Generation

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IEA Task 13 Report

“Operational and Economic Impacts of Extreme Weather on PV Power Plants”

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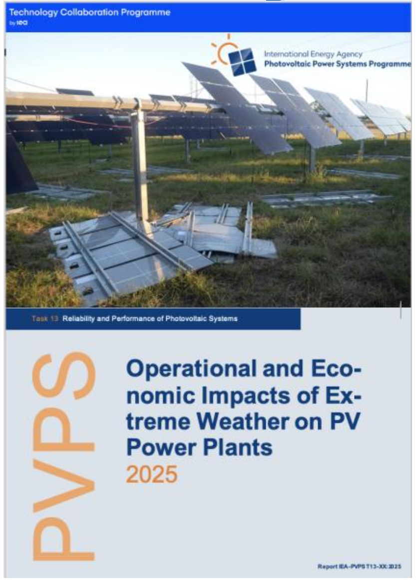

Audience:

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

Why This Report Matters

1. Extreme weather knows no political boundaries; the challenges need to be approached collectively.

2. First collaborative examination of extreme weather patterns and its implications for PV availability and reliability, including failure mechanisms and their root causes

3. Real-world and global perspectives are needed: certification testing is not good enough; our work has the potential to change the *status quo.* We are now a *de facto* community of scholars intent on sharing information on storm-specific risks.

Threat Landscape is Evolving and Expanding

- Extreme weather events are increasing in frequency and intensity (IPCC, NOAA, NASA)* -- 5x-17x above historical projections
- Exponential growth of PV from 2TW to 8TW by 2030): vast majority of new installations are in natural-catastrophe-prone regions
- Economics are a key industry driver (manufacturing and installation)
- Unprecedented technological innovation, but module components are getting large and thinner (more surface area).
- Single-axis tracker systems dominate the market: more joints, more hardware; more vibration.

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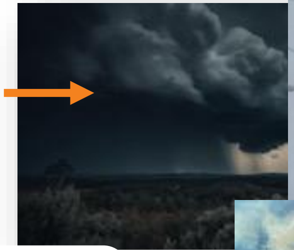
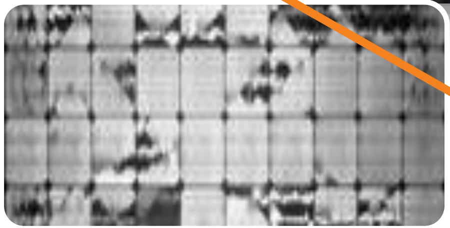
Weather Impacts on PV Systems Are Varied



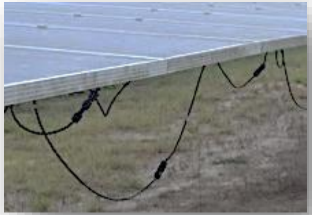
Immediate:

1. Lack of irradiance = reduced power generation
2. Catastrophic destruction = loss of power
3. Sub-catastrophic damage (invisible damages, including cell cracks)



Delayed Manifestation:

1. Module and electrical system reliability
   - Moisture ingress/oxidative stress
   - Crack propagation from further mechanical stress
   - Smoke infiltration of connectors
2. Under-performance and accelerated degradation



Weather Impacts Influenced by Design

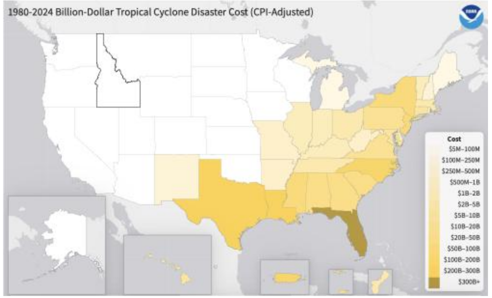
- Single-axis tracker?
- Fixed tilt?
- Module design
- Module orientation
- Balance-of-systems design and installation methods
- Hardware and fastener choice
- Procurement decisions based on cost

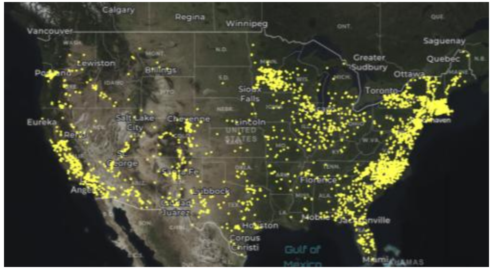
Other Impact Considerations

1. Project Development Stage

Plants under construction are most vulnerable

2. Probability of Risk





State ranking by cumulative solar capacity

1. California - 49,421 MW
2. Texas - 34,907 MW
3. Florida - 16,865 MW
4. North Carolina - 9,698 MW
5. Arizona - 8,934 MW
6. Nevada - 7,644MW
7. Georgia - 6,147 MW
8. New York - 6,125 MW
9. Virginia - 5,799 MW
10. New Jersey - 5,434 MW

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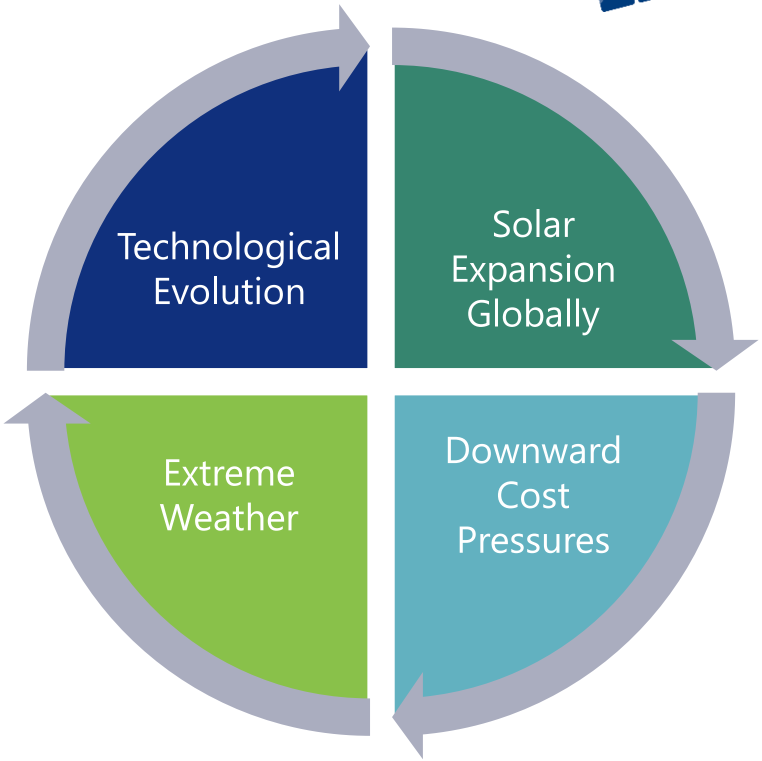
A Perfect Storm?

Four Intersecting Trends:

- Extreme weather events are increasing; damages reflected in insurance payouts
- Solar deployment is accelerating, notably in high-risk areas
- Downward cost pressure remains a key driver of growth
- Technological “advances” introduce additional risk



Is the Sky Falling…Literally, on Solar?

Or Maybe Not?

"Information from multiple sources shows that during 2012 hurricane Sandy, virtually all PV systems received no damage by the storm and, if not disconnected, produced electricity following the storm."

--V. Fthenakis, "The resilience of PV during natural disasters: The hurricane Sandy case" PVSC, *2013 IEEE 39th PVSC*, Tampa, FL.

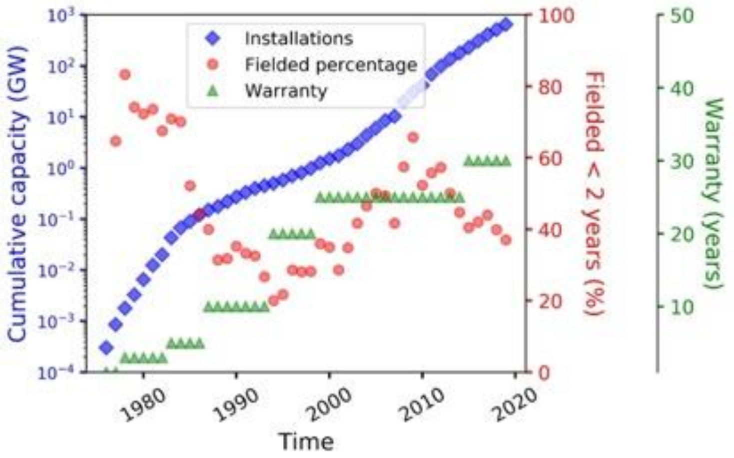
Why It Is Hard to Know

- Little data available (most is confidential related to plant value and litigation):

“National databases significantly under-report damage losses because the complete picture is hard to obtain (federal agency data, private sector date, confidentiality, litigation, etc.)”

Source: Science for Disaster Reduction (US inter-Agency Working Group)

- 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



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Inspection Data: Single-Axis Tracker Site (60 MW)

50% Damage

Bracket that holds rails to torque tube

1. Washers loosen and purlins pull from mounting plate

2. Purlins rip apart before bolts fail

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Pre-Storm: Fixed-Tilt system (15 MW)

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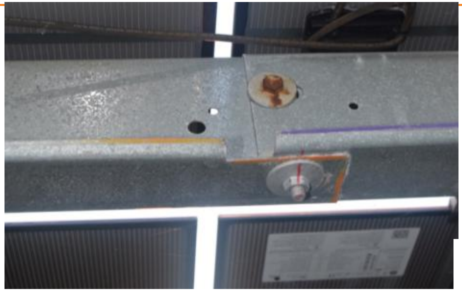
Post-Storm Fixed Tilt

Brace bolts fail



Rails insufficient for load

Purlins deform under load

Clips loosen,,,

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Wind Damages – 2MW Fixed Tilt in Northeast

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Not Yet Operational

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Storm Categories

Storm Type	Destructive Risk	Mitigation
Tropical Cyclones	Wind loading; torsional galloping of modules on SATs; bolt and fastener failures	Robust system design (hardware); installation protocols (e.g., bolts torqued to spec); automated stow strategy
Hail	Module destruction (glass breakage); cell cracking without glass damage.	Glass/glass modules with minimum of 3.2mm glass on front); automated stow strategy (high-tilt angle; away from wind) executed when risk is perceived to be high
Floods	Erosion and destabilization of racks; infiltration of combiner boxes and other electrical components	Stow strategy to reduce loading on modules; raise systems
Snow	Heavy loading on modules and systems, that can result in module breakage and racking collapse	System design options include high tilt-angle; portrait orientation; ; frameless modules (if an option). Stow strategy for SATs that increases the tilt angle and faced modules away from wind

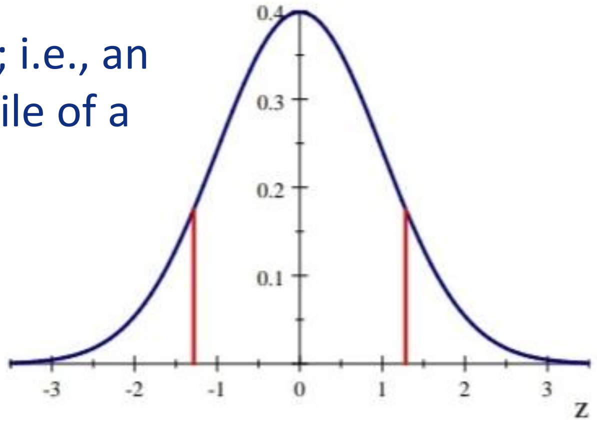
Lessons Learned

- Most PV is-–or could be—made resilient to structurally-threatening storm events (i.e., high wind vs heat and dust).
- But industry appears to be consistently defined by low-cost (manifested in cheap materials and poor quality installations).
- Not just about the module; system approach is needed.
- Follow-on O&M is important.
- Location matters: risk mapping needs to be incorporated into every development plan.
- Full cost accounting is needed to drive change.

Thank You!

What is Extreme Weather?

- Events that are ‘rare at a particular place and time of year”; i.e., an occurrence that falls at or beyond the 10th or 90th percentile of a probability distribution.” (IPCC)
- Economic impact (> $1B)
- Probability of recurrence (100-year event)
- Intensity relative to historic measurements (cat 6 hurricanes)



The $10th$ and $90th$ percentile of the standard normal distribution.

Categories Most Often Recognized:

1. Tropical Cyclones
2. Hail*
3. Snow
4. High heat
5. Dust storms

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