



Assessing Risks for Photovoltaic Modules: Environmental Conditions, Extreme Weather, and Regional Capacity

Norman Jost^{1,*}, Elizabeth C. Palmiotti², Jarett Zuboy², Dirk C Jordan², Jennifer L. Braid¹ and Teresa M. Barnes²

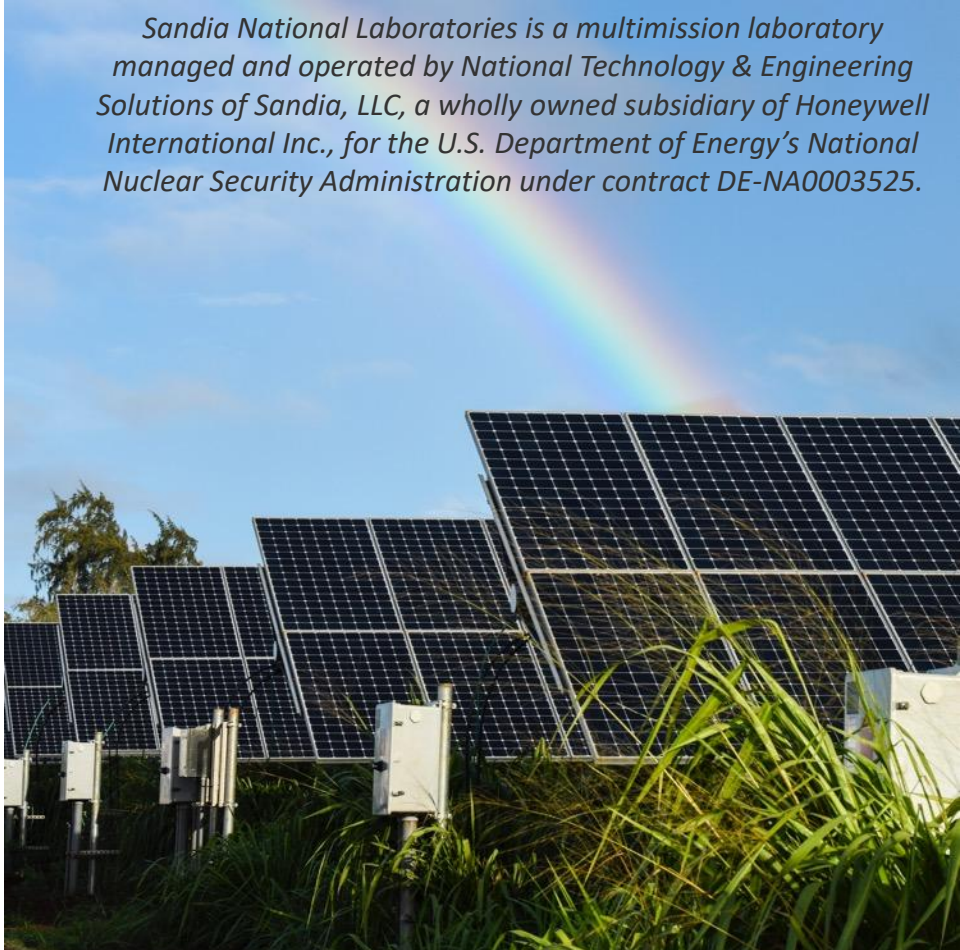
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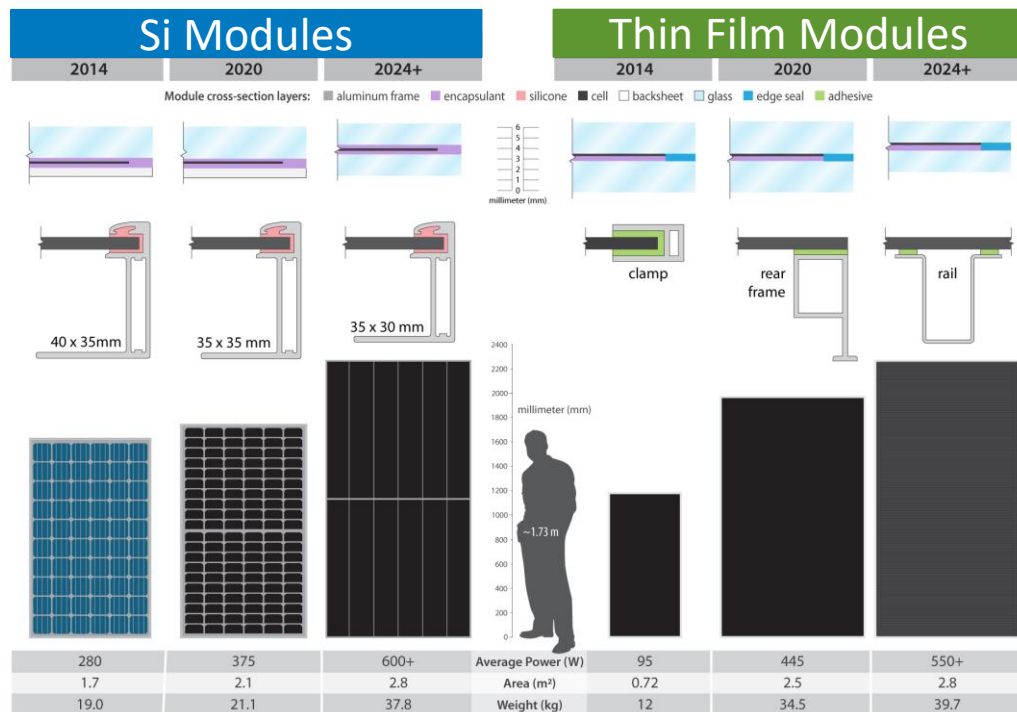
SAND2026-22541C

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DuraMAT Technology Scouting

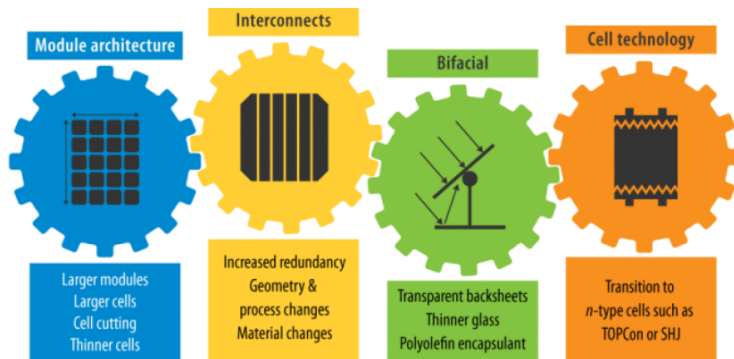
- Track technology changes that could affect PV reliability
- Assess changes in PV reliability risks over time
- Identify the need for new research related to reliability



Tech Scouting To Date

Getting Ahead of the Curve: Assessment of New Photovoltaic Module Reliability Risks Associated With Projected Technological Changes (2024)

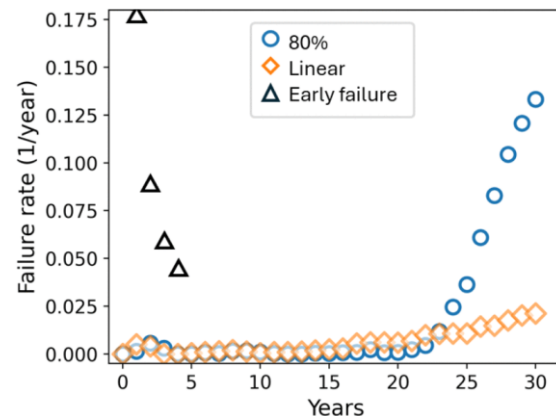
Jarett Zuboy, Martin Springer, Elizabeth C. Palmiotti, Joseph Karas, Brittany L. Smith, Michael Woodhouse, Teresa M. Barnes



<https://ieeexplore.ieee.org/document/10347402>

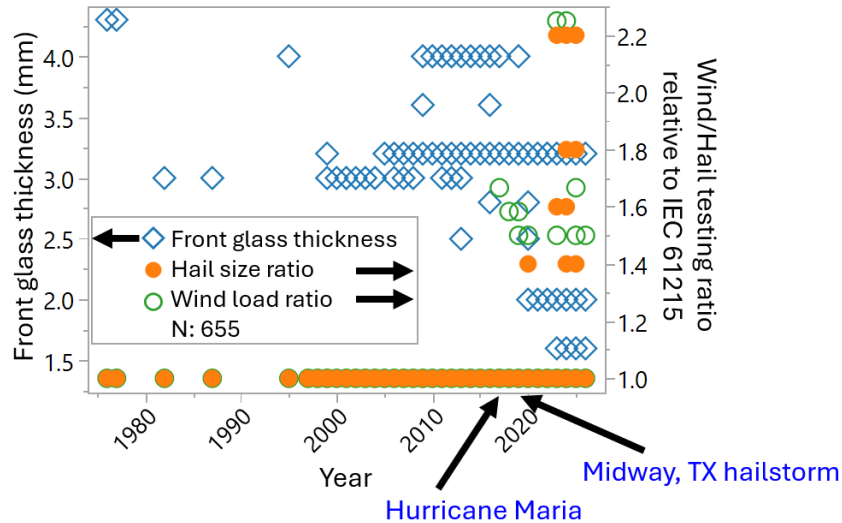
Growing Panes: Investigating the PV Technology Trends Behind Frequent Early Failures in Modern Glass–Glass Modules (2025)

Elizabeth C. Palmiotti, Martin Springer, Jarett Zuboy, Timothy J. Silverman, Jennifer L. Braid, Dirk C. Jordan, Salil Rabade, Teresa M. Barnes



<https://ieeexplore.ieee.org/document/10847304>

Tech Scouting 3.0: Market-Specific PV



PARADEA

HIGH EFFICIENCY BI-FACIAL GLASS-GLASS PV MODULES



SUPERIOR HAIL TEST PERFORMANCE

- ø 45mm hail test passed from third party laboratory with impact velocity up to 27m/s

Hi-MO 5 Ice-Shield

Certified up to 65mm hailstone
Withstand up to 3600Pa wind load

EAGLE® G6X



Vertex S+

Superior weather resistance,
effortlessly handling extreme wind
with a +5400/-5400Pa load
capacity and 45mm hail resistance.

PURE-R

Guaranteed better durability

- Withstands up to 7000 Pa
- Better protection against harsh weather

TOPBiHiKu6 Anti-Hail
N-type Bifacial TOPCon Technology



Tested up to ice ball of 55 mm diameter
according to IEC 61215 standard

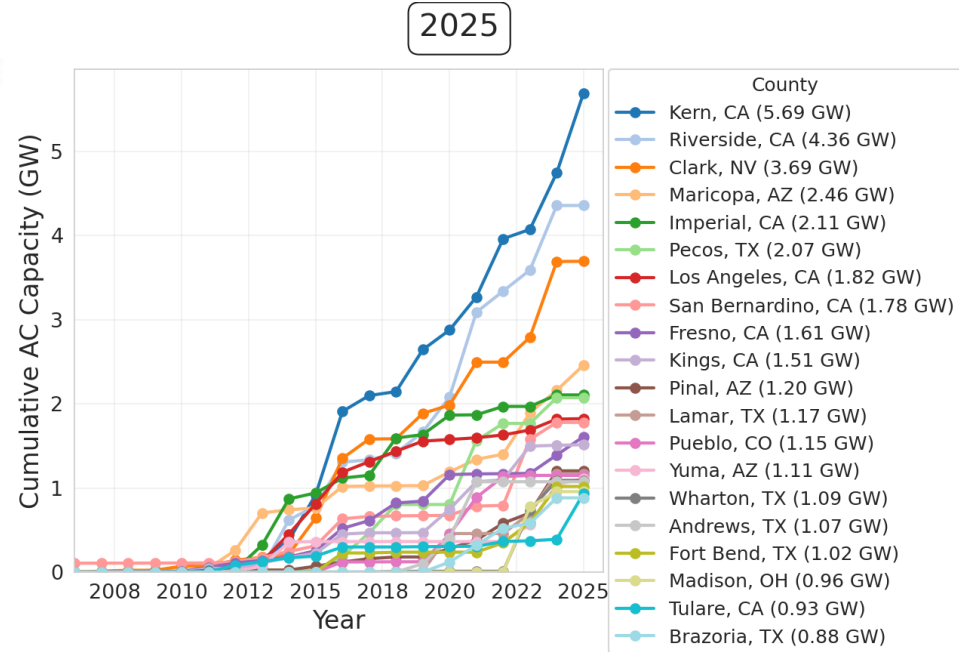
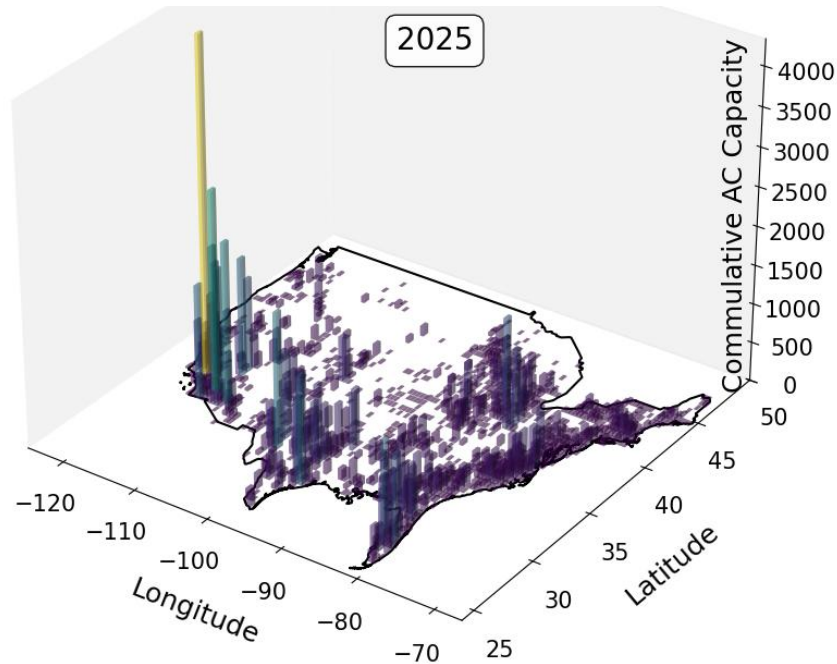
- What combinations of environmental and extreme weather stressors should be addressed for US markets now and in the future?
- What is the best approach for durability/reliability of modules in different environments now and in the future?

Tech Scouting 3.0 Contributions



USPV Database

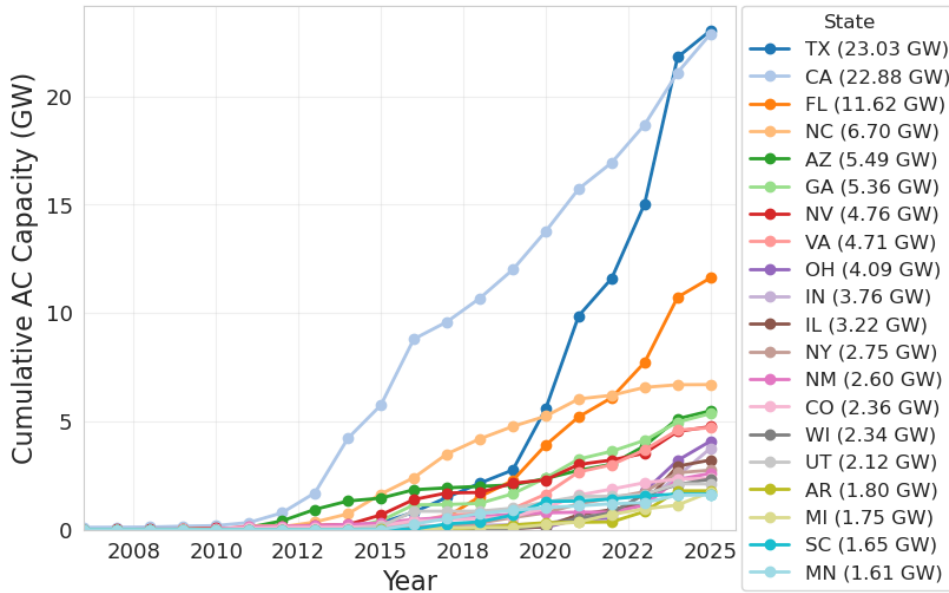
- LBNL US PV Location database v4 April 14th (energy.usgs.gov/uspvdb/)



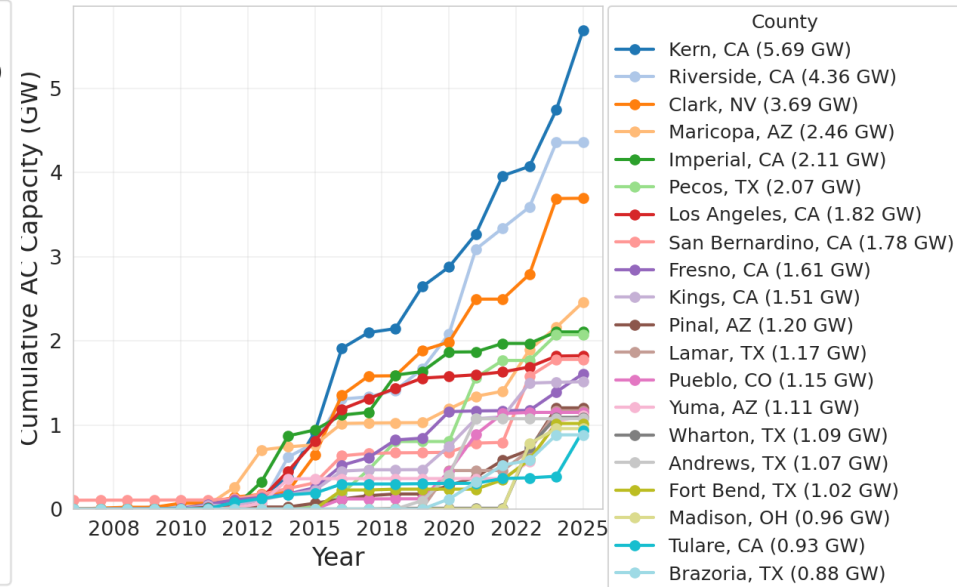
USPV Database

- Cumulative AC capacity PV in the US

2025

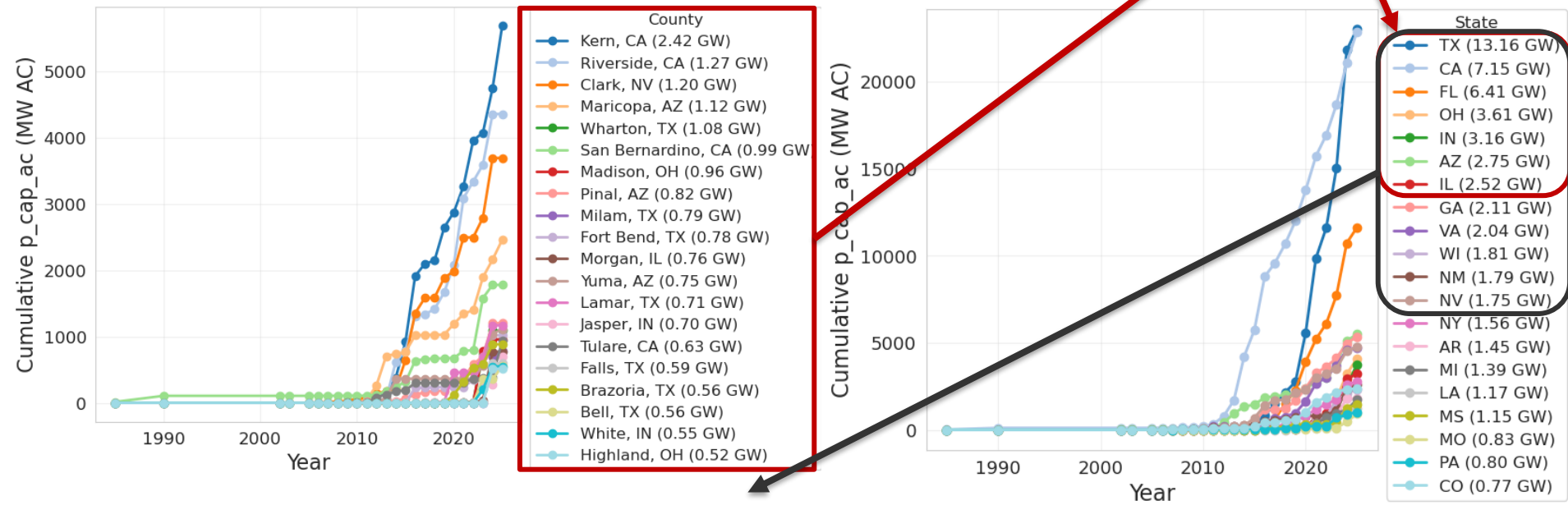


2025



USPVDb “Hot Spots”

- We use the cumulative of the last 3 years

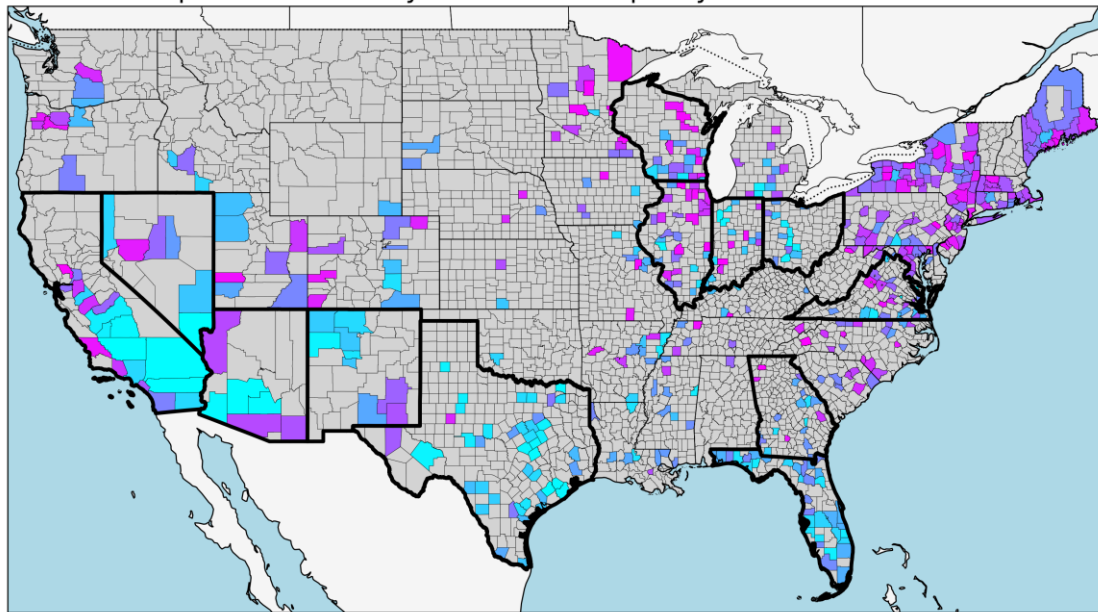


Top 12 States: TX, CA, FL, OH, IN, AZ, IL, GA, VA, WI, NM, NV each over 1.75GW

USPVDb “Hot Spots”

- Cumulative of the last 3 years mapped out

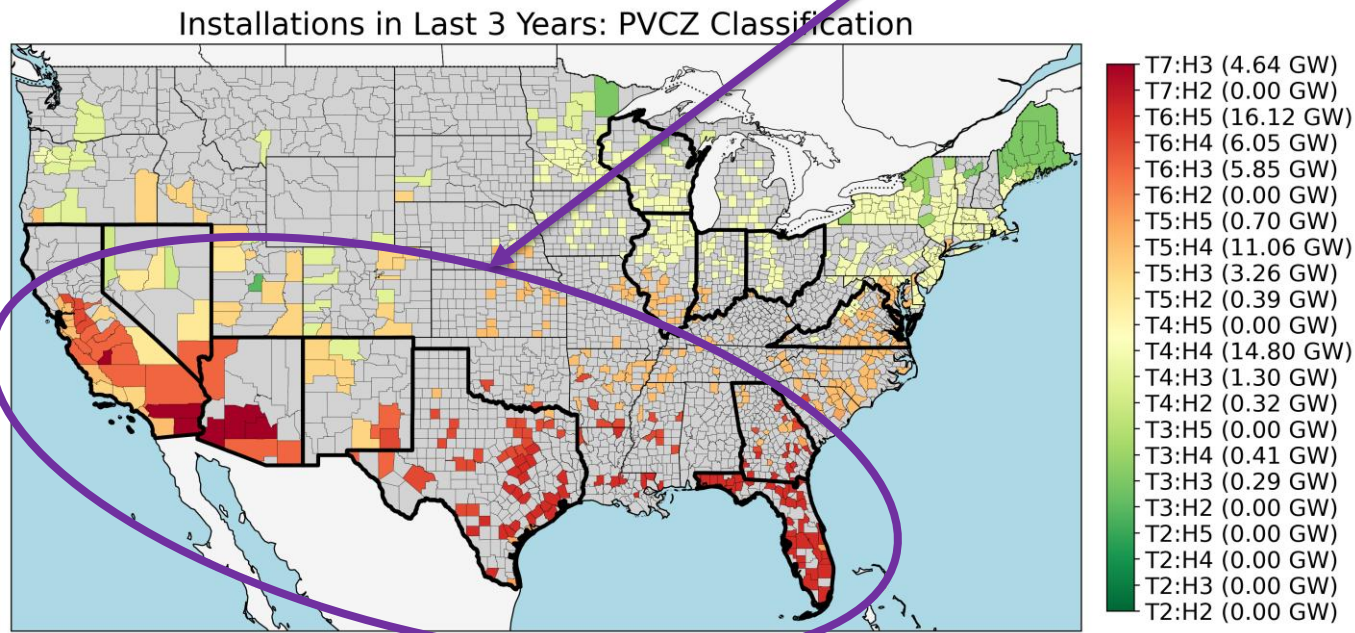
Top 500 Counties by PV Installed Capacity in the Last 3 Years



PV Climate Zones

- PVCZ [1] are added to the analysis
- Colorbar takes T and H level
- Top PV installations across counties

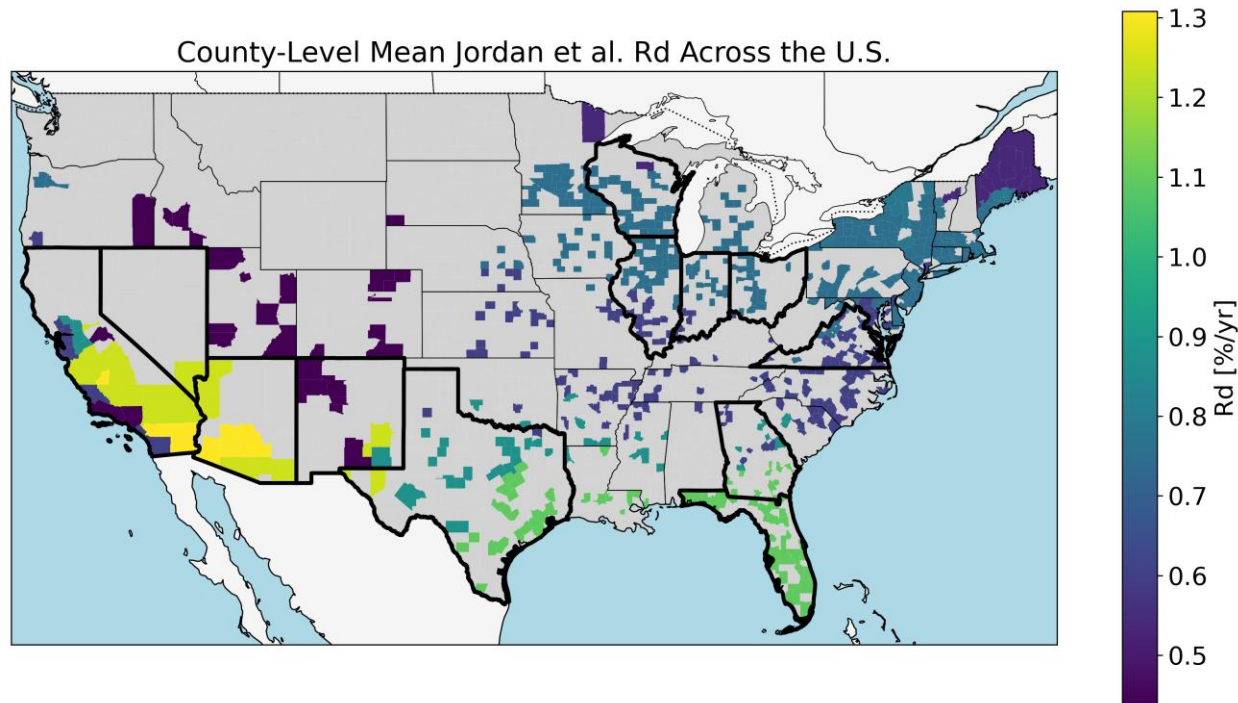
>40 GW AC



[1] T. Karin [10.1109/PVSC40753.2019.8980831](https://doi.org/10.1109/PVSC40753.2019.8980831)

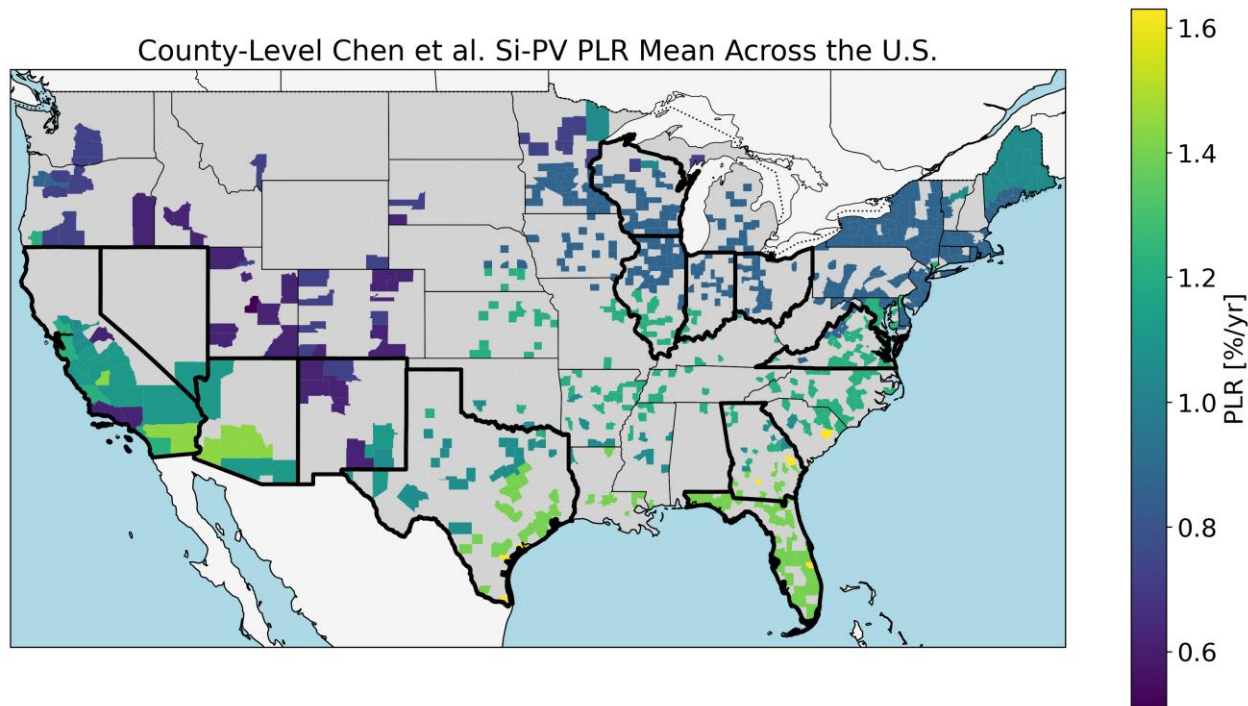
PVCZ: Degradation

- Matching degradations for PVCZ for most 3 year cumulative PV
- Jordan et al. Module level Rd
([10.1002/pip.2744](https://doi.org/10.1002/pip.2744))



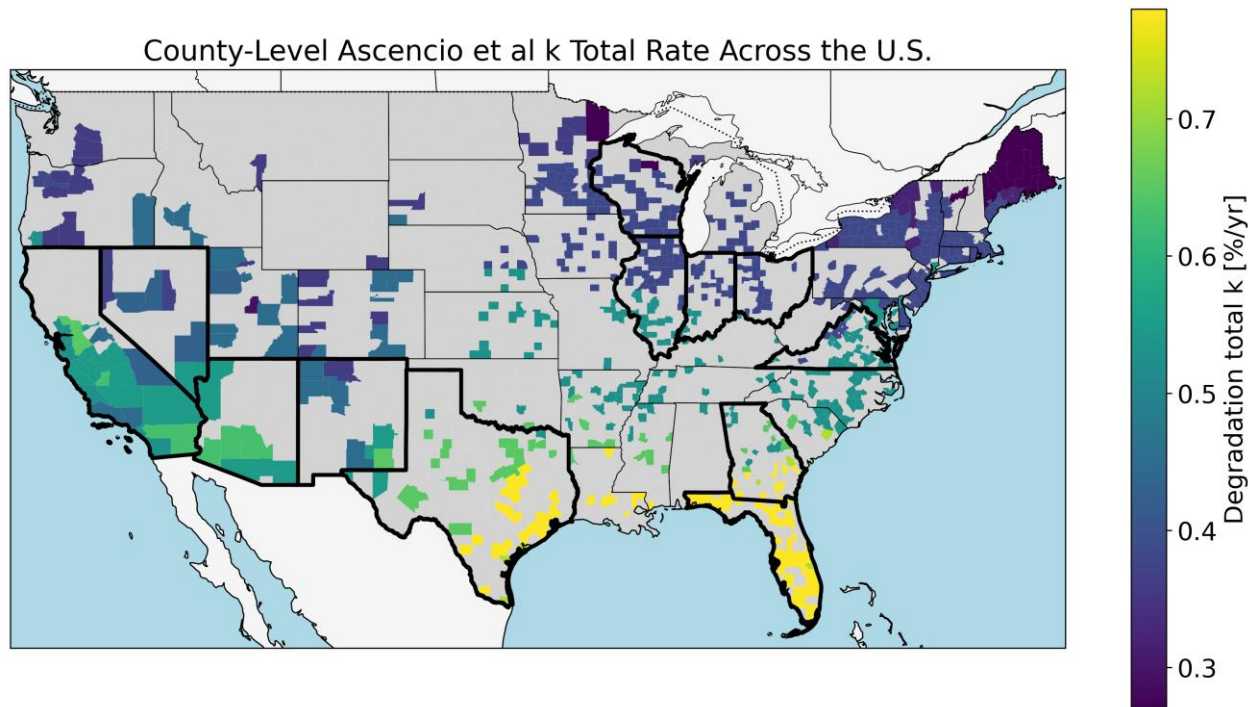
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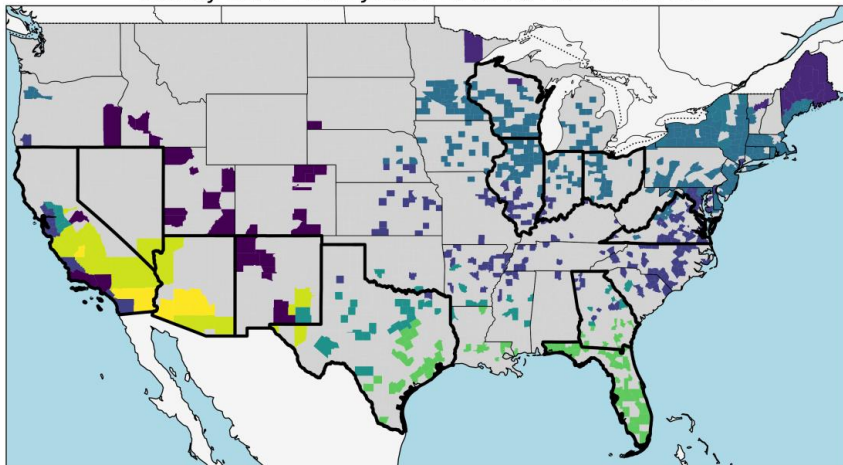
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- Ascensio et al simulated module degradation
([10.3390/en12244749](https://doi.org/10.3390/en12244749))



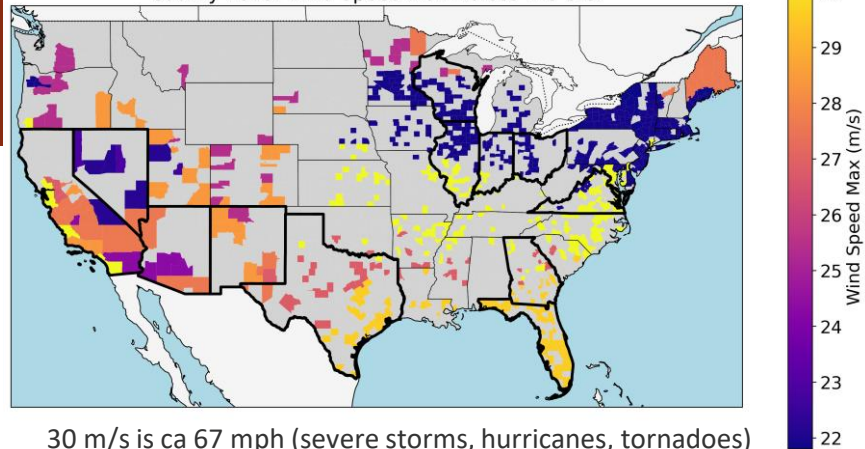
PVCZ Degradation stressors

- Reminder top PV installation 3 years
- Jordan et al. results
- Wind, UV?

County-Level Mean Jordan et al. Rd Across the U.S.

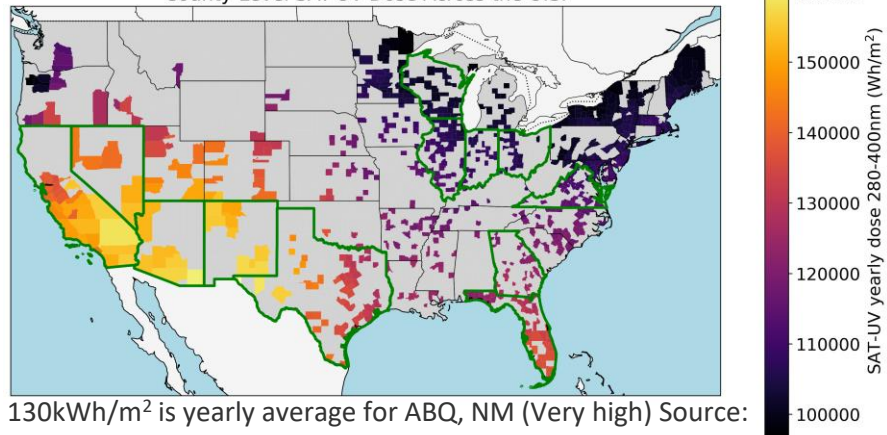


County-Level Wind Speed Max Across the U.S.



30 m/s is ca 67 mph (severe storms, hurricanes, tornadoes)

County-Level SAT-UV Dose Across the U.S.

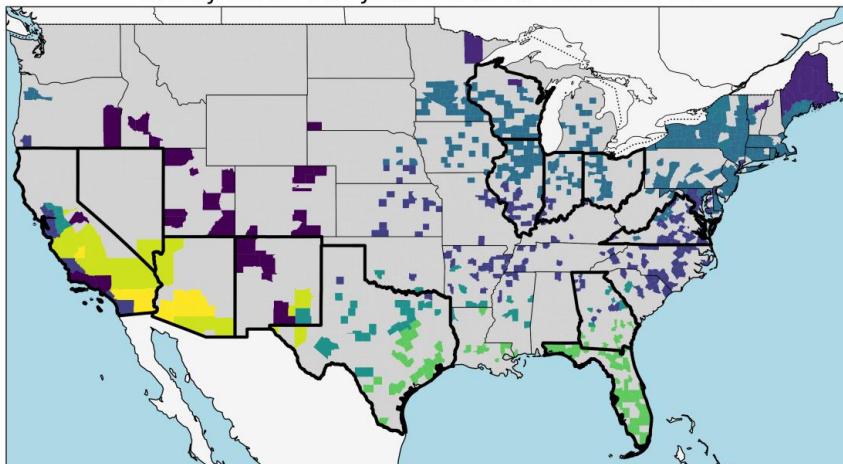


130kWh/m² is yearly average for ABQ, NM (Very high) Source: National Environmental Public Health Tracking Network

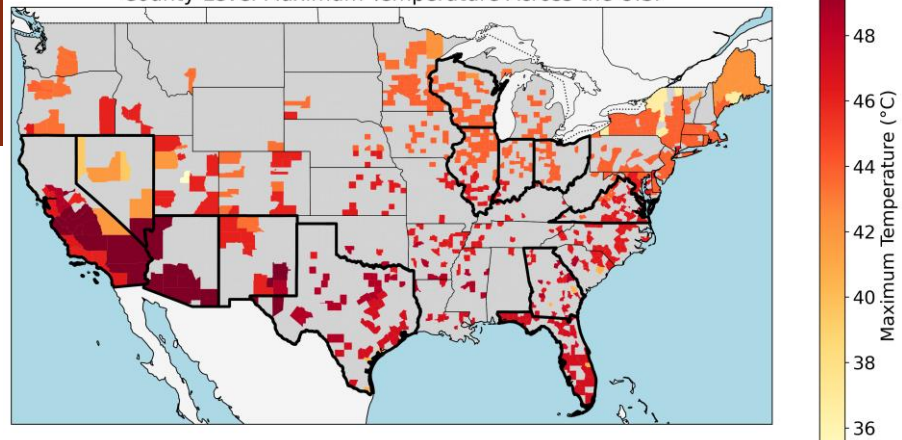
PVCZ Degradation stressors

- Reminder top PV installation 3 years
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- Humidity, Temperature?

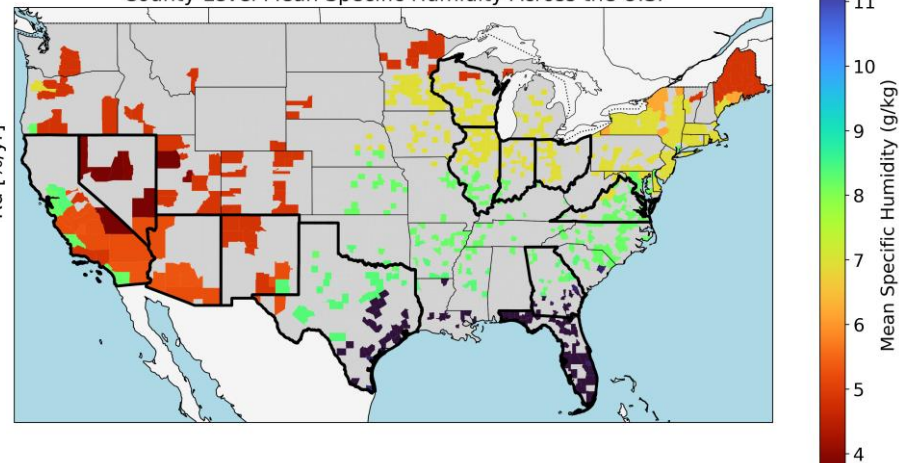
County-Level Mean Jordan et al. Rd Across the U.S.



County-Level Maximum Temperature Across the U.S.



County-Level Mean Specific Humidity Across the U.S.



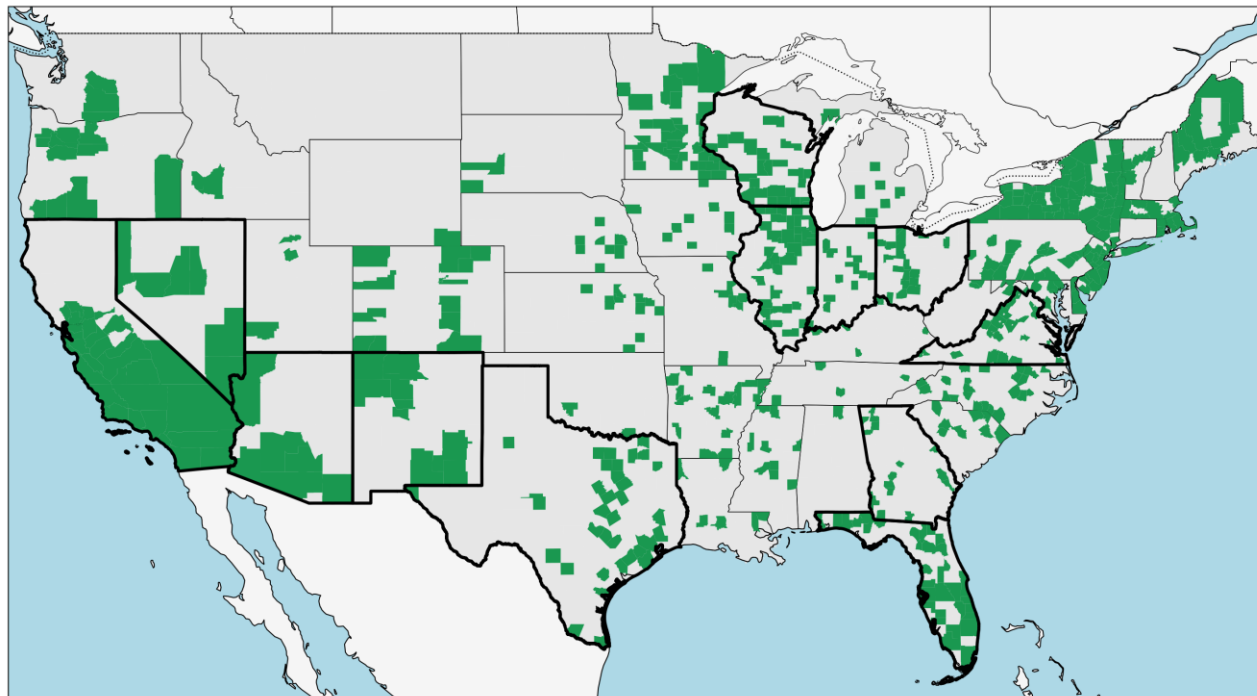
FEMA Hazard Index

[1] [fema.gov/flood-maps/products-tools/national-risk-index](https://www.fema.gov/flood-maps/products-tools/national-risk-index)

- Classification of hazards by annual loss, social vulnerability and community resilience [1]
- We attach to each county the list of extreme weather events
- Result is a list with most common events

Extreme Weather Event	County Count	Installed Capacity (GW AC)	Expected Impact
InlandFlooding	555	52.8	Total or light damage
Lightning	464	42.1	Minor if properly surge protected
Tornado	384	36.7	Total damage in path and high wind module/tracker damage
StrongWind	449	36.5	Module tracker damage
ColdWave	342	31.5	Ice can cause strain
WinterWeather	396	30.8	Snow and ice cause strain on modules
HeatWave	225	29.5	Accelerated degradation, power loss due to temperatures and fire risk if vegetation
Hail	245	28	Glass and cell break
Drought	190	27.3	Minor, fire risk if vegetation is present
Wildfire	129	21.5	Total damage
IceStorm	184	14.1	Mechanical strain
Earthquake	95	13.6	Damages to multiple components
Hurricane	115	13.5	Total damage
Landslide	43	7.7	Total damage
CoastalFlooding	90	5.9	Severe or total damage

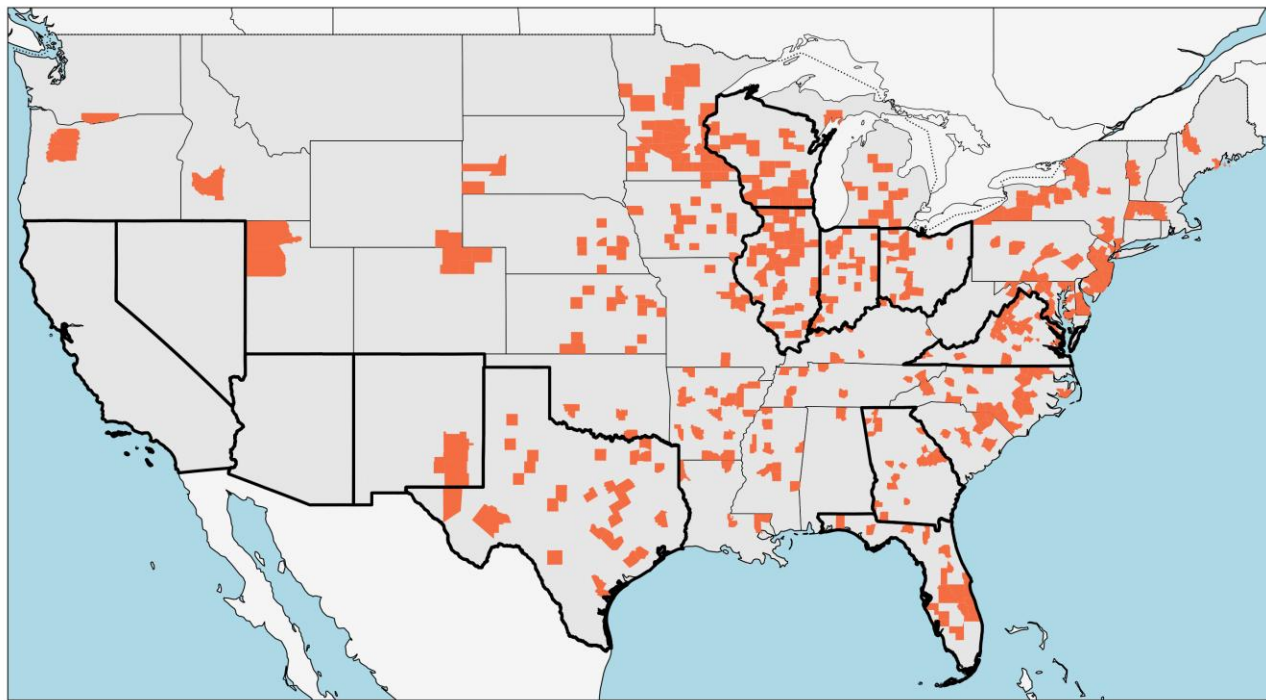
FEMA Hazard Index



Events

- **InlandFlooding**
555 counties, 52.77 GW AC
- StrongWind
449 counties, 36.46 GW AC
- WinterWeather
396 counties, 30.80 GW AC
- Hail
245 counties, 27.98 GW AC
- HeatWave
225 counties, 29.54 GW AC
- Wildfire
129 counties, 21.49 GW AC

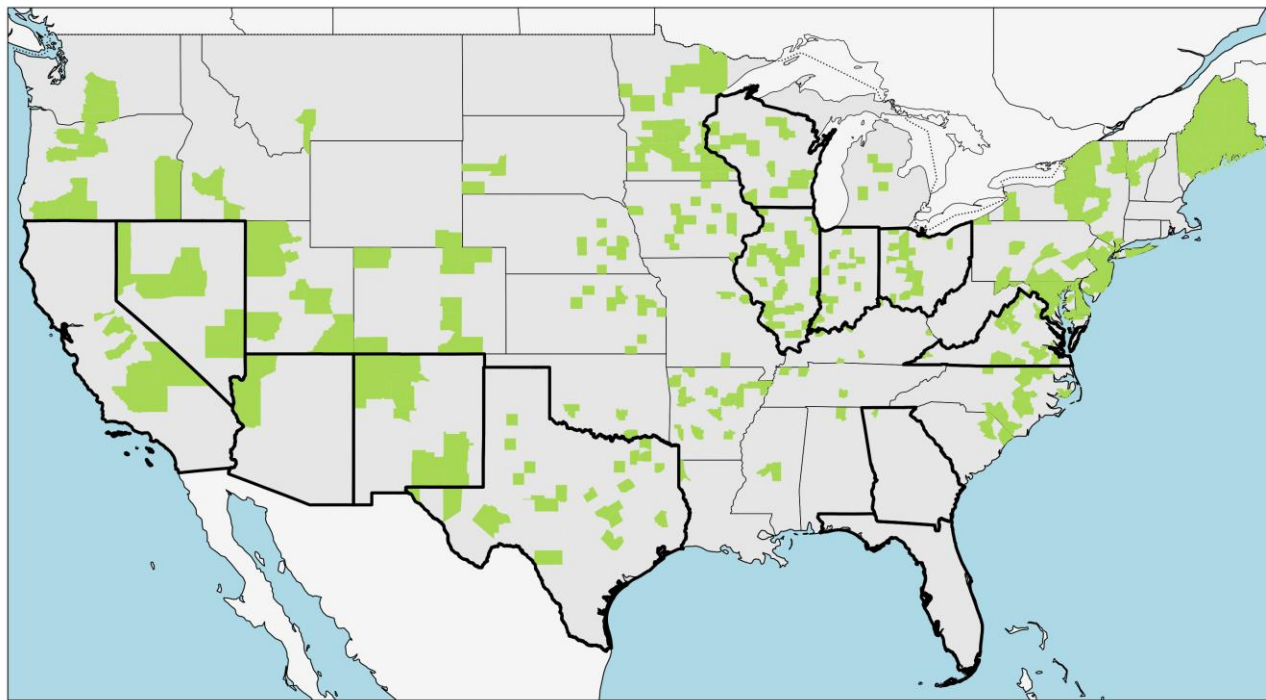
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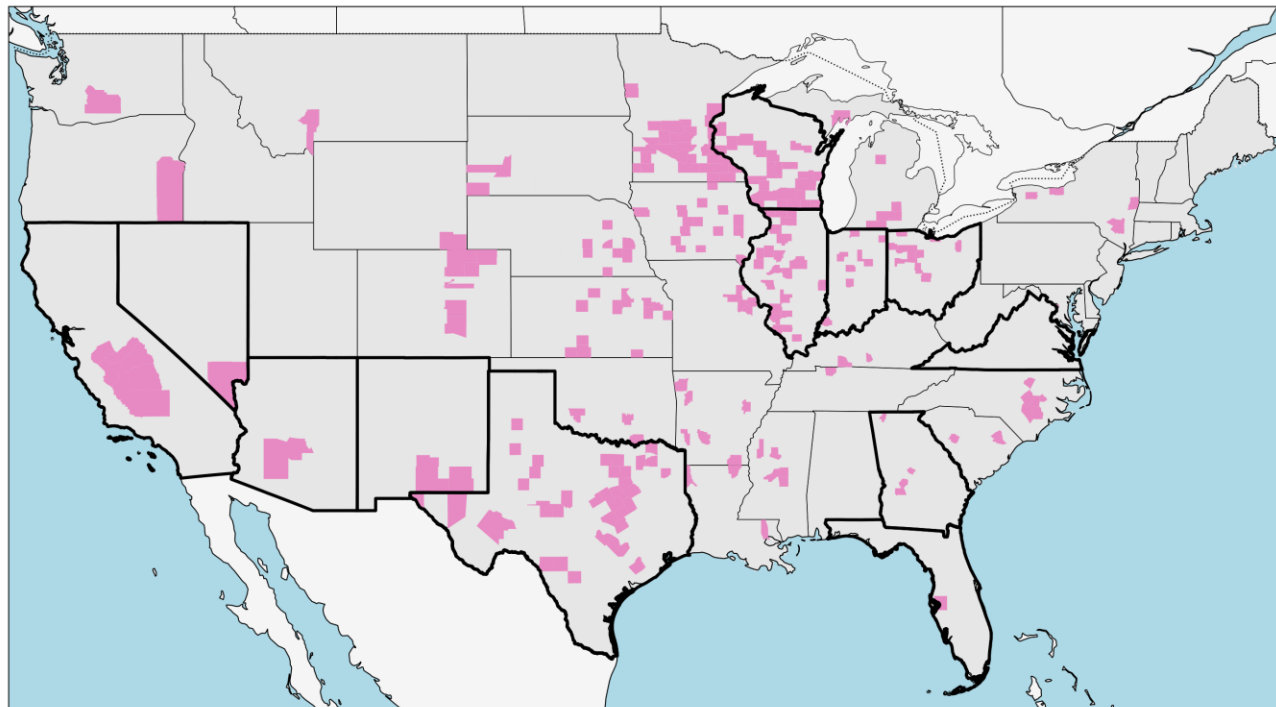
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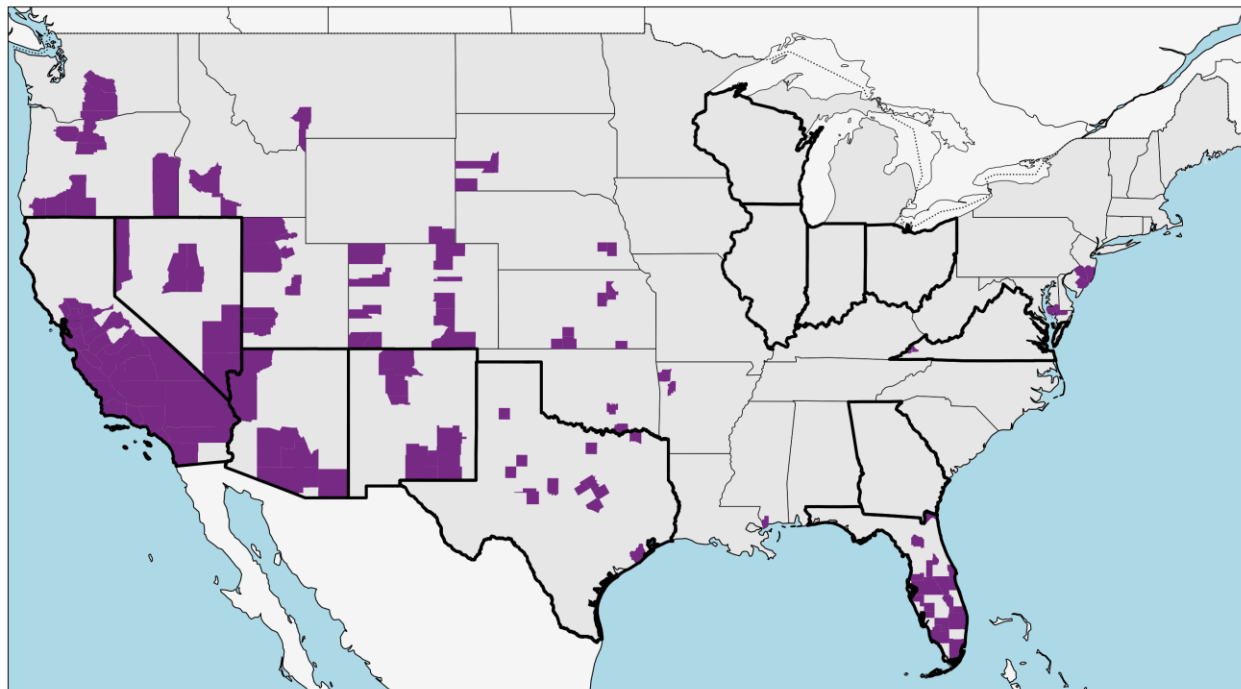
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Tech Scouting 3.0 Contributions



Market-specific modules and systems

**Survey results.
Looking for more
participants!**

- Hail and wind drawing attention due to field failures
- Both module and system-level design improvements are needed
- Possible solutions
 - Thicker glass
 - Taller frames
 - Wider mounting
 - Improved stow strategies
 - More secure connections
- Module and system changes will be driven by insurers and banks
- Improvements in tests and standards are needed for current and future products

Conclusions

- Modules manufacturing more flexible to address specific needs
- A lot of PV is deployed in regions that show high degradation and extreme weather events
- Survey results emphasize importance of mechanical failures
- **Looking for more participants for our survey, please talk to us or reach out: nrjost@sandia.gov or elizabeth.palmiotti@nlr.gov**

Thanks for your attention...

Thanks to DuraMAT and US DOE IESO for funding this work.

Contact us about this work: nrjost@sandia.gov, elizabeth.palmiotti@nlr.gov & jlbraid@sandia.gov