SOLAR RISK ASSESSMENT 2025

kWh ANALYTICS

Executive Summary

The seventh annual Solar Risk Assessment arrives at a pivotal moment for the renewable energy industry. In the past year, we've seen solar and wind energy production overtake coal for the first time in the US energy mix, marking a historic milestone in our clean energy transition. We installed nearly 50GW of solar capacity in 2024 alone, shattering records and expectations. As these clean energy sources become increasingly central to our grid reliability, the resilience and performance of solar, wind, and battery assets has never been more critical to our continued success.

The renewable energy sector faces evolving challenges across multiple fronts. Climate impacts have intensified, with hail damage, flooding, and wildfire becoming more frequent and severe. Operational risks persist as PV assets continue to underperform against forecasts. Battery storage safety concerns have heightened following recent incidents, highlighting the need for better thermal management and early detection systems. Fire losses are significantly driven by overgrown vegetation. Risks can be mitigated by strict vegetation management (especially around inverters, transformers, and combiner boxes), proper wire management and coordination with local fire departments. Meanwhile, cybersecurity threats have grown more sophisticated as our industry becomes increasingly reliant on connected monitoring systems.

This year's report highlights objective industry research on these risks. Key takeaways include:

- Hail continues to represent one of the most severe financial risks. Implementing proper module selection with thicker glass and advanced stow protocols that allow for steeper tilt angles can significantly reduce damage probability during severe storms.
- While the emergence of AI technologies presents powerful opportunities for renewables, improperly trained models can give false results. Data quality will be imperative to incorporating these tools into the industry.
- Cyber threat activity targeting renewable energy infrastructure is growing, necessitating enhanced protection strategies.
- Quality inspections of energy storage systems identify issues with fire suppression systems and thermal management components, highlighting the critical need for improved manufacturing and monitoring.

As renewable energy becomes the backbone of our electrical grid, ensuring system resilience is no longer optional–it is imperative to keep these assets in the ground for 30+ years. Meeting this challenge requires unprecedented collaboration among asset owners, operators, financiers, insurers, brokers, manufacturers, and researchers to establish higher standards for the industry. Through thoughtful risk management and innovation, we can build energy infrastructure that withstands our changing climate and leaves a better world for future generations.

Sincerely,

Jason Kaminsky

CEO, kWh Analytics

2025 Contributors

Climate Insurance Provider

kWh ANALYTICS

Quality Assurance

kiwa

Hail Researcher

CENTRAL MICHIGAN UNIVERSITY

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Table of Contents

Extreme Weather Risk

Operational Risk

Battery Storage Risk

EXTREME WEATHER RISK

Climate impacts intensify as hail, wildfire, and extreme weather events become more frequent and severe, testing the resilience of solar infrastructure.

1. **kWh Analytics**
   Hail Accounts for 73% of Total Losses by Damage Amount, Despite Representing Only 6% of Loss Incidents
2. **Central Michigan University**
   99.27% of PV Plants Have a 10% Annual Chance of Seeing Hail Bigger Than 2 Inches in their Close Proximity
3. **Kiwa PI Berlin**
   Cross-cutting Analysis Reveals Frame to Glass Deviations Exceed 5% of Acceptable Thresholds, Highlighting Needs for Additional Quality Control & Module Testing
4. **60 Hertz**
   Projects Can Experience 6% Revenue Annual Loss From Far Away Wildfire Smoke
5. **VDE Americas**
   Study Shows 100% Hail Stow Success Despite Severe Storm Exposure
6. **kWh Analytics and GroundWork Renewables**
   The risk of inelastic behavior: Physics-based models may be overestimating the benefit of hail stow by 48% for ~3in hail

1 Hail Accounts for 73% of Total Losses by Damage Amount, Despite Representing Only 6% of Loss Incidents

By: Reilly Fagan, Sr. Data Analyst - kWh Analytics

Solar installations face a range of potential hazards, with hail damage emerging as particularly significant. Recent analysis of the kWh Analytics loss database reveals that hail accounts for 73% of total financial losses despite representing only 6% of loss incidents – an 8% incr ease from previous years. Interestingly, 19% of these hail-related losses occurred in North Carolina, an area not traditionally considered high-risk for hail. This geographic spread indicates that while hail events may be relatively rare, their financial impact is disproportionately severe when they do occur. Fire emerges as the second most costly peril, while attritional losses–small, frequent damages– tend to be the least costly per incident.

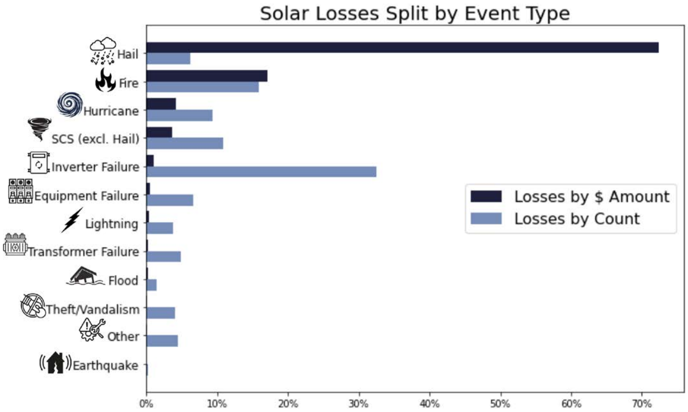


Figure 1: Distributions of loss counts and losses by $ amount incurred, by different event types.

Despite these risks, the outlook for solar remains promising. When evaluating all installed solar capacity in the kWh Analytics database, 23% of sites have experienced at least one partial loss, including both attritional and natural catastrophe losses. However, among those that have incurred losses, 29% have suffered multiple loss events. While attritional losses are expected to occur in multiples, an important finding is that 3% of sites with multiple losses have been affected by more than one natural catastrophe (Nat Cat) event. This raises a crucial question: why do some sites experience repeated losses while others remain untouched?

Several factors influence a site's susceptibility to damage, including location, system age, and resilience-focused design and behavior. Building and operating solar installations with risk mitigation in mind can significantly reduce potential losses.

- Severe Convective Storm damages (which typically include hail, tornado, and straight-line wind) are largely caused by hail, and specifically, breakage to the glass of the panels. To avoid a large hail loss, module selection is key (see Figure 2). Modules with thicker, tempered glass are less likely to have hail damage. Implementing robust stow programs and testing stow protocols is important to ensure the process is working end-to-end.
- Severe winds cause losses through torsional galloping or liberated modules. In regions prone to high winds, fixed mounting or single-axis trackers with wind stow programs, combined with top-tier racking systems, torque audits, and deep pile foundations, can improve stability.
- Fire losses are significantly driven by overgrown vegetation. Risks can be mitigated through strict vegetation management, proper wire management, and coordination with local fire departments.
- Flood-prone sites should ensure that system equipment is elevated above potential flood depths, and have a flood stow protocol in place to elevate the modules above the water.

By implementing these risk-reducing strategies, solar stakeholders can enhance site durability, minimize financial losses, and improve long-term system performance in the face of increasingly severe and frequent natural catastrophe events.

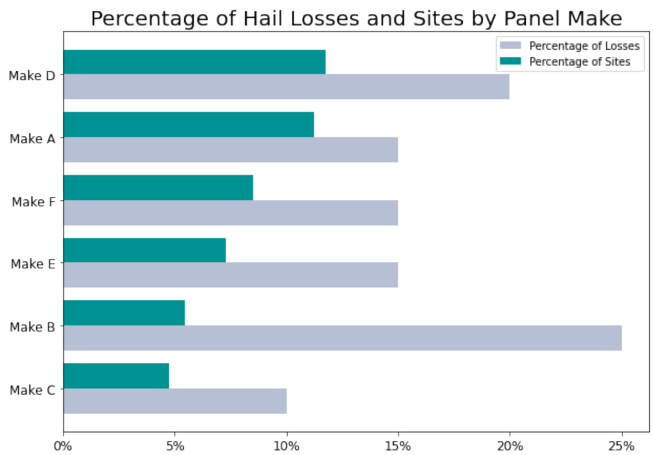


Figure 2: Percent of hail losses and sites in kWh Analytics' loss database by panel make. Modules with disproportionately high losses compared to percentage of sites represented may not be ideal choices in hail prone regions.

1. Hail No! Defending Solar From Nature's Cold Assault, Q4 2023 Report, GCube
*loss history does not cover the lifetime of the site for all sites - the average loss history range we have for a site is 4 years.

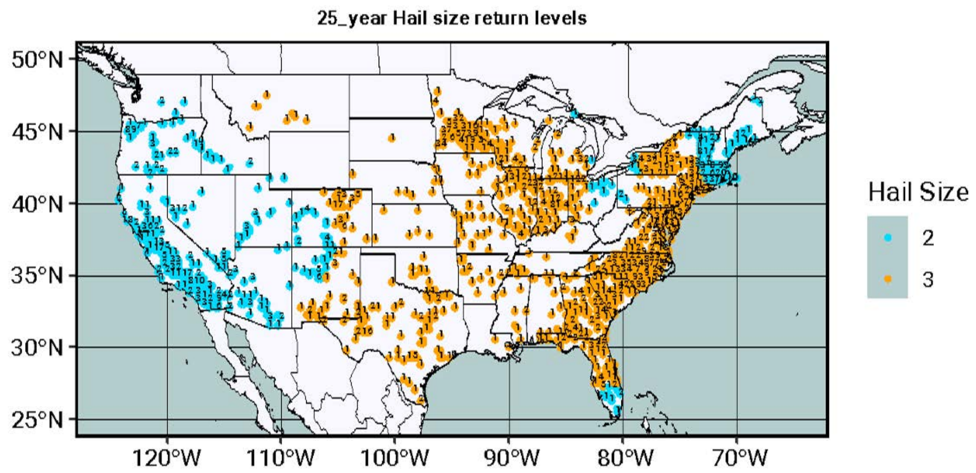
2 99.27% of PV Plants Have a 10% Annual Chance of Seeing Hail Bigger Than 2 Inches in their Close Proximity

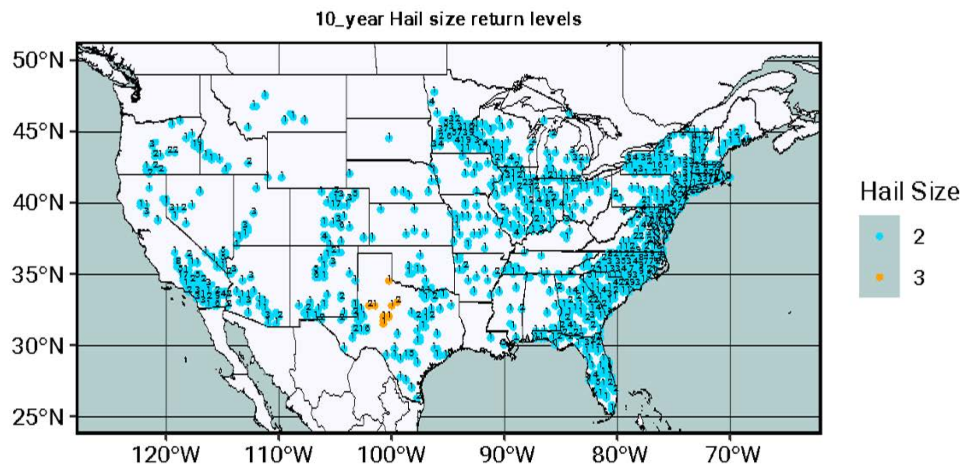
By: Dr. John Allen, Associate Professor and Dr. Subhadarsini Das, Postdoctoral Research Fellow - Central Michigan University

Large hail has been a cause of increasing concern for utility scale PV plants, but until recently, our ability to estimate just how widespread this threat extends has been limited. We asked the question, what portion of utility scale PV (by MW) exists in a region with a 25-year return period of 2-inch or larger hail within 0.25 degrees (~17 miles). Using a new model (Das and Allen 2025, NPJ Natural Hazards) we find that for the 4184 plant locations within the U.S. Large-Scale Solar Photovoltaic Database dataset, 100% of these locations had 25-year return levels greater than 2 inches, and 64.12% have return levels above 3 inches. At the 10-year return level, 91.18% of plants exceed expected 2-inch diameters.

Getting to this question is somewhat challenging for many existing models, as producing this type of extreme value model requires careful application of all available observational data, leveraging well observed locations to the greatest benefit, and using a combination of Bayesian modeling and machine learning.

In reading this statistic you may be concerned – a 10% annual chance of a potentially damaging hail event (>2 inches) certainly should elicit a response. But recognize that this statistic applies to a larger area than the scales of a typical utility-scale PV asset. However, it does suggest that hail mitigation through stowing or module hardening should be a key part of the plans for PV resilience in the future. These results imply that damaging hail is occurring regularly in the nearby vicinity of many PV sites across the country, and so to ignore hail is rolling the dice.





1. Das, S., Allen, J.T. Bayesian estimation of the likelihood of extreme hail sizes over the United States. npj Nat. Hazards 1, 47 (2024). https://doi.org/10.1038/s44304-024-00052-5

3 Cross-cutting Analysis Reveals Frame to Glass Deviations Exceed 5% of Acceptable Thresholds, Highlighting Needs for Additional Quality Control & Module Testing

By: Thomas Weber, Senior Project Manager and Don Cowan, Director of Sales and Marketing - Kiwa PI Berlin

Glass breakage rates are on the rise, according to the National Renewable Energy Laboratory. Kiwa PI Berlin has investigated solar photovoltaic (PV) plant failures and have discovered glass failures contributing to up to 10% of identified failures. Factors such as increasing module sizes, thinner glass, reduced frame dimensions, and inadequate manufacturing controls are all factors based on the industry's current understanding of the multitude of potential causes. Kiwa PI Berlin has performed advanced inspections and destructive testing studies, revealing that potential quality control failures are one of the many factors contributing to higher breakage rates.

Following reports of breakage, Kiwa PI Berlin conducted a field failure analysis on a project portfolio of 55 MW across five sites in Germany during 2024. The observed failure rate was 1.2%, with glass cracks primarily originating near the modules' mounting clamps. The investigation began with material quality assessments and module assembly inspections to identify potential contributors to glass breakage on a 3.2 mm tempered glass module with a backsheet. After the site investigation showed a trend of cracks originating from the clamps, additional root cause analysis steps were conducted, including surface compressive stress tests and cross-section cutting analysis performed in the lab.

The surface compressive strength of the glass was first evaluated to determine whether it fell within industry standards (~120 MPa). The results ranged from 112 MPa to 142 MPa, with an average of (124 ± 8) MPa, indicating that glass strength was likely not the primary cause. This led to further analysis of the module's construction, particularly surrounding the breakage areas.

Cross-section analysis was conducted at multiple points within the module to assess deviations in manufacturing assembly as shown in Figure 1. The findings revealed significant variations in the glass-to-frame distance, with deviations ranging from 2.3 mm to 0.2 mm (approximately 5% over the common tolerance of +/- 1mm). Figures 2 and 3 are photographs of these cuts highlighting inconsistent framing resulting in variations in silicon thickness, and unintended metal-to-glass contact. Such deviations increase failure risk when static and dynamic operational loads are applied to the module.

To mitigate future failures, enhanced quality control is crucial during production, including the frame assembly stage. Verifying module dimensions (length, width, and diagonal alignment) can help detect misalignment issues. Failures can be identified during production or by operators in-field post-installation as part of a root cause investigation. In addition, batch-based cross-section analyses during production can provide further insights into potential assembly risk. Implementing these efforts can help protect against one of the multitudes of potential causes the industry is seeing related to glass breakage to improve PV module reliability.

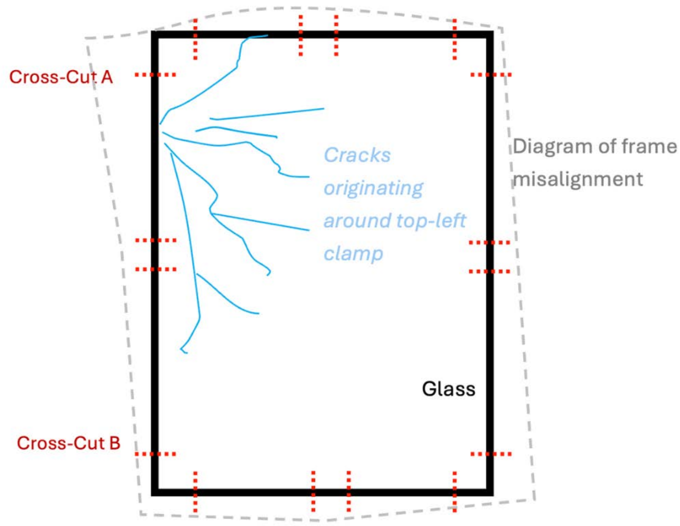
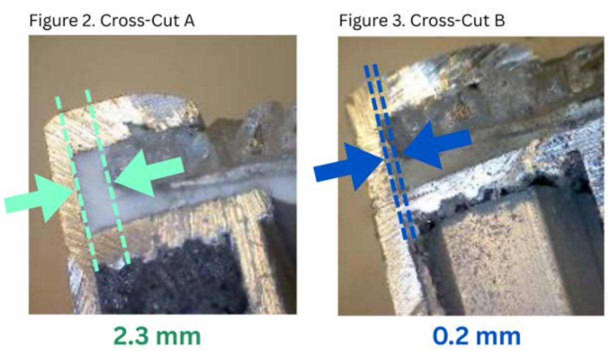


Figure 1: Diagram of frame misalignment



Common tolerance of glass-to-frame is +/- 1mm, the above images show a 2.1 deviation, which is ~5% above the acceptable threshold.

4 Projects Can Experience 6% Revenue Annual Loss From Far Away Wildfire Smoke

By: Piper Foster Wilder, Founder and CEO - 60Hertz Energy

Solar assets can lose up to 6% of annual revenue from major smoke events, even when fires occur hundreds of miles away, according to new NOAA-funded research by 60Hertz Energy. This finding doubles previous loss estimates published in the 2022 Solar Risk Assessment. 60Hertz Energy's wildfire algorithm, FLARE (Fire Linked Asset Risk Evaluation), analyzes empirical site-specific data to model both smoke and ash impacts on generation.

This study utilized the FLARE model to examine 40 sites with 1.2 Gwh of capacity to determine the impact of particulate matter (PM) on solar generation as measured by Aerosol Optical Depth and proprietary ash deposition and smoke plume models. In May 2025, almost 700 wildfires and prescribed burns were active across the US. Contrary to popular assumptions, 65% of these fires are burning in the Midwest, Northeast and Southeast: fire is not just a threat for Western sites.

The results revealed acute impacts at sites exposed to smoke for multi-day smoke events, with some developers seeing 60% of their national portfolios lose double-digit generation values during various two-week windows of impact. This amounted to 6% of annual site revenue on average among the subset of sites with generation loss from the 40 locations analyzed (from Western, Southeast, and Northeast regions). Fire-weather days have increased nationwide with sites in the Southwest and West by 23 -37 additional days per year, with wind speed, humidity, and temperatures that meet the definition of fire weather. The 2023 Canadian wildfires in our research show smoke impacts hundreds of miles away.

To address these challenges, 60Hertz Energy developed an algorithm that accurately predicts site-specific losses; input came from Lightsource bp, Clean Capital, SunShare, FracSun, SolarUnsoiled and others. The tool helps asset owners quantify lost generation, determine necessary soiling mitigation, measure underperformance, and predict energy availability during smoke events.

This research is productized as a callable API and a cones-of-risk map that provides site-specific insight on smoke and ash. For the public interest, the tool is available free of charge during the current product development period.

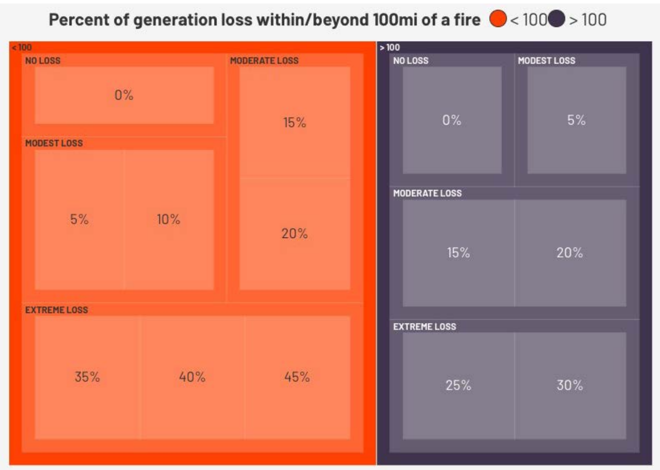


Figure 1: This treemap illustrates how solar sites far from active fire zones still experienced significant generation losses, underscoring the wide-reaching impact of smoke and particulate matter.

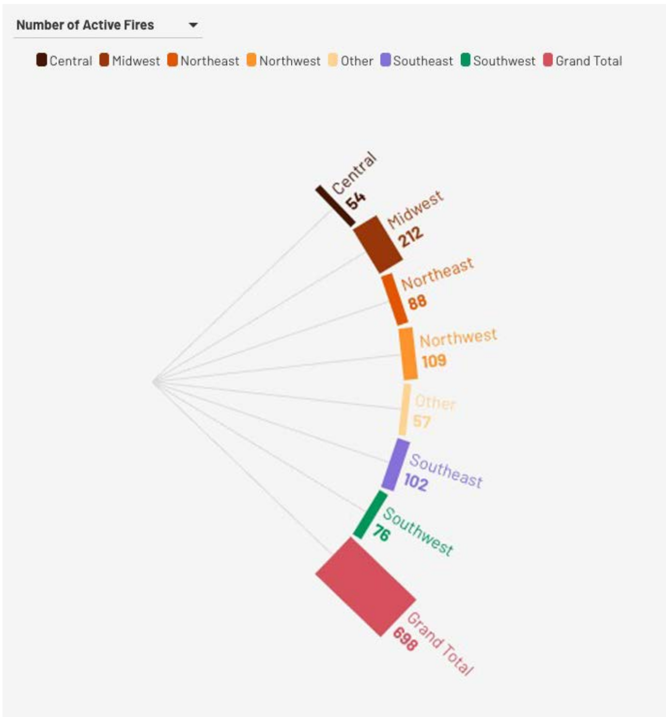


Figure 2: This radial chart reveals the regional distribution of nearly 700 active fires on a single day in May, and prescribed burns, dispelling the myth that wildfire risk is confined to the West

1. Climate Central, "Longer, More Intense Fire Weather Seasons"

5

Study Shows 100% Hail Stow Success Despite Severe Storm Exposure

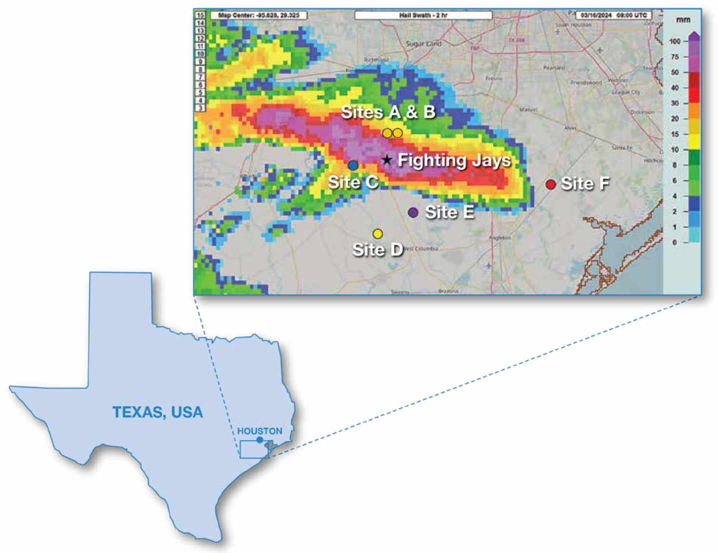
By: Jon Previtali, Senior Principal Engineer - VDE Americas

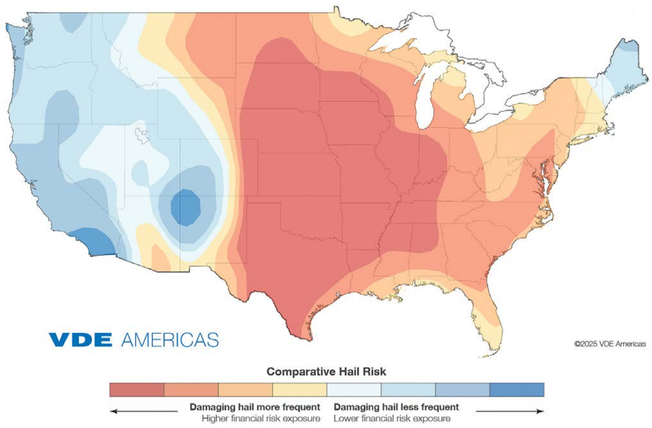
Last year's hailstorm may have decimated Fighting Jays, but it also provided the opportunity to demonstrate the effectiveness of hail stow to prevent hail damage. In Fort Bend County, TX, within 10 miles of Fighting Jays, three solar projects– Site A, Site B, and Site C, as labeled in Figure 1– successfully weathered the same hailstorm system in March 2024.[1] The first major storm struck on March 15 at about 5:00 p.m. with wind gusts up to 51 mph and hailstones from 30–75 mm as estimated by NOAA's MESH (Maximum Estimated Size of Hail) radar data. A second, more severe storm hit around 2:30 a.m. March 16 with wind gusts up to 31 mph and hailstones up to 100 mm. While radar does tend to overestimate ground-level hail size, in this case it still indicates the potential for very large and damaging hail.

VDE Americas interviewed project operators to understand the outcomes. Site A stowed to the nearest extreme angle (likely west) and defended against radar-estimated 40–50 mm hailstones without damage. Site B, under construction and already in hail stow (likely east), was hit by radar-estimated 50–75 mm hailstones with no damage. Site C went into hail stow and was hit by radar-estimated 75-100 mm hailstones, suffering only minor damage due to flying debris and a known tracker motor issue that prevented one set of rows from stowing properly. The hail damage at Site C helps prove that hail stow worked–unstowed modules sustained hail damage, while stowed modules did not. All hail stow angles were 52° and all projects have 2.0-mm/2.0-mm dual glass panels.

These sites highlight the value of best practices with respect to stow. Namely, hail stow should be used on sites with return intervals (RI) for ≥45-mm hail of less than 100 years (this area's RI was 25–50 years for reference). Operators should use a two-tier hail alert system for hail greater than 25 mm (1 in.) based on regional National Weather Service (NWS) alerts, and project-specific private alerting services. The NWS issued a warning of golf-ball sized hail for this area at 3:30 p.m., about 1.5 hours before the first storms. Other recommendations include stowing early and stowing often, prioritizing hail stow over other stow types, and implementing redundancies to ensure stow works.[2]

Insurance companies are starting to offer premium differentiation to owners who prove the reliability of hail stow systems by documenting stow protocols, events, and tests.[3] For premium differentiation, the industry needs more success stories like Fort Bend County to prove hail stow works. We typically only hear about big losses above deductibles. To this end, we've collaborated with NREL, FM, and CAC Specialty to create a crowd-sourced hail data repository, the [NREL DuraMAT Hail Forensics Database.]





1. Sincere thanks to Array Technologies for supporting the Fort Bend County, TX study.
2. See our tech memo "Best practices for hail stow of single-axis tracker-mounted solar projects".
3. See the Hail Stow and Risk Evaluation Form for a summary of relevant data requirements.

6 The risk of inelastic behavior: Physics-based models may be overestimating the benefit of hail stow by 48% for ~3in hail

By: Nicole Thompson, Sr. Manager, Data Science - kWh Analytics and
Colin Sillerud, Director, Reliability Testing - GroundWork Renewables

Testing data from GroundWork Renewables combined with kWh Analytics' hail stow model reveals standard physics-based models used to derive the value of high degree tilt may be overestimating the hail risk reduction by 48% in some cases. Hail stow is a protective measure where solar trackers rotate PV modules to a high-degree tilt angle during hail events to reduce the impact energy of hailstones and minimize damage.

Simple kinetic energy models used to quantify the benefit of stow assume that hail impacts are elastic collisions (where the total kinetic energy of the objects before collision equals the total kinetic energy of the objects post-collision). In reality, real hailstone collisions have an inelastic component associated with them (where kinetic energy is transformed into other forms of energy, such as energy associated with deformation of the module or rotational energy of the hailstone). Lab testing reveals that this inelastic component is non-negligible when accounting for angled impacts: the simple elastic kinetic energy model $1/2\ mv^2 \cos^2 \theta$ underestimates the energy delivered to a sensor (used for measuring impact in a lab setting) under angled impacts by up to 69% at 75° (Figure 1). This is because the simple model assumes that all the energy received by the sensor follows the $\cos^2 \theta$ relationship, whereas in reality, only a portion of it does. Also, that portion may change with impact angle: previous studies on rock-falls have noted that the inelasticity of the collision increases with increasing impact angle[1].

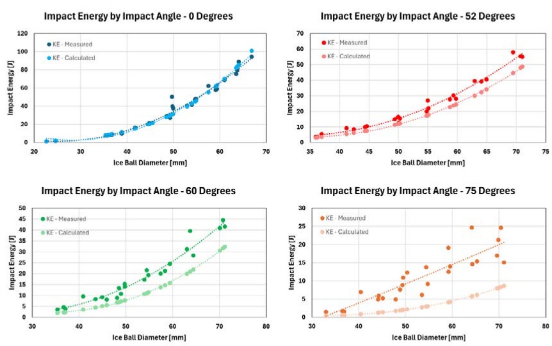


Figure 1: Impact energy by impact angle shows higher deviation from the simple KE model as angle increases.

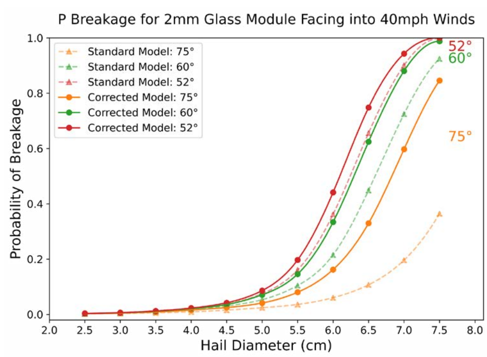


Figure 2: Probability of glass breakage shows large variability between the simple KE model and the corrected model.

Taking these corrections for inelasticity into account, kWh Analytics derived an increase in the probability of module breakage of up to 48% for 7.5cm (~3") hail when compared to the simple elastic model (Figure 2).

Using a traditional physics-based model that does not account for inelasticity, a 2mm glass module has approximately a 36% chance of breakage at 7.5cm hail under 40mph winds when stowing at 75°. When you include inelasticity into modeling assumptions, the probability of breakage jumps to approximately 84%. Note that one way to reduce the probability of breakage is to stow away from the wind, and this analysis uses an into-the-wind assumption. Probabilities of module breakages are courtesy of RETC Solar Risk Assessment 2023.

This analysis indicates that while stow is a useful mitigant against hail damage, it may not provide the scale of benefit the industry hopes for. However, the industry's shift towards hail-resilient modules, particularly the promising 3.2mm/2mm glass/glass construction, offers reassurance. GroundWork's preliminary tests on this new module architecture found that they require a much higher impact energy to break, withstanding around 1.7x more impact energy than a 3.2mm glass/polymer backsheet module.

Please note that data collection and analysis are ongoing. While the industry currently models hail impact energies using kinetic energy, it is possible that a momentum basis is more accurate and will be explored. Additionally, while the impact dynamics with a sensor differ from those with a PV module, we believe this analysis offers a directionally accurate approach to adjusting for stow angle. Further, it was noted that the data from the hail sensor transitions from non-linear to nearly-linear as the impact angle is increased. This likely results from the hail sensor's limited surface distance of ~14". Using high speed photography, it was observed that the ice travels along the surface of the sensor during angled impacts and that 14" may not capture the full duration of the impact, thus reducing the measured energy at high angles. Work with solid projectiles is underway to better characterize this behavior.

Overall, the point stands that the combination of highly resilient modules and steep stow is crucial to module survival, giving assets the best chance of survival in hail-prone regions.

1. Wang, Yanhai, et al. "Effects of the Impact Angle on the Coefficient of Restitution in Rockfall Analysis Based on a Medium-Scale Laboratory Test." Natural Hazards and Earth System Sciences, Copernicus GmbH, 19 Nov. 2018, doi.org/10.5194/nhess-18-3045-2018.

OPERATIONAL RISK

Performance gaps persist across the industry as equipment reliability challenges impact long-term asset viability.

7 **kWh Analytics**
PV Sites Around the Country are Underperforming by 8.6% on Average

8 **Radian Generation**
Cybercriminals Targeting Solar's Rapid Growth: Persistent Threats Demand Action

9 **Zeitview**
Hot Spot Prevalence on Sites Increased from 0.24% in 2023 to 0.81% in 2024: A Sample of Newly Commissioned Sites in North America

10 **Clean Power Research**
Future Climate Models Suggests Potential -4.9% Impact to PV Production

11 **kWh Analytics**
AI Models Misclassify Up to 20% of Solar Operational Issues Without Domain-Specific Training

7 PV Sites Around the Country are Underperforming by 8.6% on Average

By: Phoebe Hwang, Data Engineer - kWh Analytics

The solar industry has expanded rapidly over the past decade, with an average annual growth of 26%, according to the Solar Energy Industries Association (SEIA)[1]. Understanding production trends is vital for evaluating photovoltaic (PV) sites' ability to meet generation expectations, as these are imperative to project financing and equity returns. This study analyzes performance data from over 34,000 system-months spanning 2015 to 2023 from kWh Analytics' extensive production database of monthly operating reports (MORs), providing insights into long-term performance trends.

Performance was assessed using a performance index (PI), defined as the ratio of actual generation to industry P50 expectations. P50s are used as the baseline for financial models and loan agreements. The PI is adjusted for insolation using Global Horizontal Irradiance (GHI) data from the Clean Power Research® SolarAnywhere® database. The resulting weather-adjusted PI (WA PI) was analyzed across different climate regions (as defined by NOAA) and operational months.

The results indicate a nationwide underperformance of 8.6% below P50 estimations, validating results found in the 2022 Solar Generation Index. As presented in Table 1, a gradual decline in performance can be observed throughout the analyzed years. Seasonal trends reveal significant underperformance in winter. However, MOR data lacks sufficient detail to pinpoint the root cause of this underperformance trend. Possible contributing factors include underestimated losses (e.g., extreme weather, shading, curtailment, DC health issues, and sub-hourly clipping losses), overly optimistic availability assumptions[2], and financial incentives that encourage inflated P50 estimates. On the other hand, the Southwest leads in PV site performance, as seen in Fig. 1. At the same time, the Southern United States exhibits the most significant underperformance, particularly in recent years, regardless of the month. The phenomenon may be attributed to curtailment[3]. Installing more battery storage systems could help mitigate this problem.

This study emphasizes the need for improved data granularity and model accuracy in solar performance forecasting. Accurate P50s are imperative for the industry as they are key to determining stable cash flow projections and risk management. Aligning financial models with real-world performance could help mitigate long-term financial risks, boost investor confidence, and support the sustainable growth of the solar industry.

Avg. WA PI by Year & Month

Year	Month 1	2	3	4	5	6	7	8	9	10	11	12
2015	87.2%	84.3%	94.7%	99.5%	100.6%	100.5%	101.8%	98.4%	96.1%	97.5%	99.3%	91.2%
2016	89.4%	94.3%	97.3%	106.5%	95.6%	97.0%	95.3%	94.6%	94.1%	94.7%	97.2%	90.4%
2017	87.3%	93.1%	94.0%	95.6%	96.1%	95.2%	93.1%	93.7%	95.6%	96.4%	94.3%	85.1%
2018	88.5%	91.2%	94.2%	94.2%	92.8%	93.7%	92.0%	91.3%	87.7%	90.6%	90.1%	87.3%
2019	90.3%	90.8%	92.7%	94.1%	93.3%	93.5%	93.6%	92.9%	88.7%	91.5%	90.7%	85.3%
2020	91.1%	91.8%	94.3%	94.0%	92.2%	91.6%	91.4%	90.0%	93.7%	90.0%	90.0%	86.7%
2021	87.6%	78.8%	95.8%	94.1%	94.8%	98.0%	94.5%	91.1%	93.0%	90.4%	92.2%	83.5%
2022	83.4%	85.7%	91.2%	91.7%	90.2%	89.9%	87.8%	87.3%	90.5%	91.3%	90.3%	79.7%
2023	79.0%	89.9%	91.2%	90.2%	91.8%	91.2%	87.3%	89.5%	89.8%	88.6%	91.2%	85.7%

Table. 1. The weather-adjusted solar performance index averaged by operational years and months from 2015 to 2023. Performance has declined over the years, with winter months experiencing the most significant underperformance.

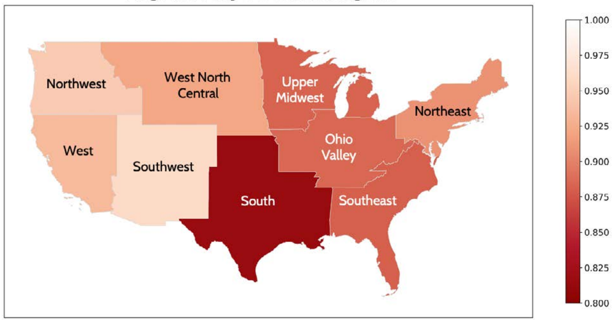


Fig. 1. The weather-adjusted solar performance index averaged by NOAA-defined US climate regions. The Southwest leads in performance, while the South experiences the worst, which stems from curtailments in the region. Underperformance in the Upper Midwest, Ohio Valley, and Northeast is primarily attributed to winter weather conditions.

1. Solar Energy Industries Association (SEIA), "Solar Market Insight Report Q4 2024," Dec. 4, 2024.
2. H. Rasmussen and kWh Analytics, "Bringing solar availability assumptions back down to earth: the case for adjusting to 97%," Jul. 1, 2024. [Online]. Available: https://kwhanalytics.com/bringing-solar-availability-assumptions-back-down-to-earth-the-case-for-adjusting-to-97/
3. D. Warady, T. Hodge, and L. Aramayo, "As Texas wind and solar capacity increase, energy curtailments are also likely to rise," U.S. Energy Information Administration (EIA), Jul. 13, 2023.

8 Cybercriminals Targeting Solar's Rapid Growth: Persistent Threats Demand Action

By: Michael Dockins, Senior Cybersecurity Manager and Adib Abdulzai, VP of OT & Security - Radian Generation

As solar and storage assets expand their role in the modern energy grid, cybercriminals are taking notice. Check Point Research reported[1] a 70% increase in cyberattacks on U.S. utilities in 2024, enabled by the rapid deployment of highly-connected assets and advanced monitoring systems aimed at improving efficiency and performance. Bottom-line: the continued rise of solar PV, battery storage, and hybrid systems interconnected to transmission and distribution systems has dramatically expanded the grid's threat surface.

Solar and storage systems offer multiple attack surfaces, spanning traditional IT equipment–such as firewalls, switches, and servers– to industry-specific devices like inverters, SCADA interfaces, and third-party integrations. The integration of diverse systems needed to operate these assets further increases exposure, as any improperly secured devices or communication creates vulnerabilities that attackers may exploit. Additionally, the global nature of solar supply chains adds risk, with compromised components expanding the threat landscape.

Many cyberattacks focus first on reconnaissance to identify weaknesses for future exploitation. Port scans, simple threat probes, and login attempts are routinely seen on Internet-connected devices. Attackers may ultimately seek to disrupt operations (as seen in Ukraine's 2015 grid hack) or steal sensitive data (as in the SolarWinds breach).

These trends are reflected in a historical cross section of Radian Generation's service portfolio, where daily threat activity highlights the persistent risk facing the industry. Even sites with strong security controls may identify and block hundreds of threat events per day. (See Figure 1)

Credential-based attacks are a parallel concern. VPN login failures, often tied to credential stuffing or brute-force attempts, reinforce the need for a uniform and proactive security posture. Sites that implemented geolocation filtering and IP blocking of suspected threat actors saw a substantial drop in login attempts, underscoring the value of layered defenses. (See Figure 2) Multifactor authentication for remote access further strengthens protection.

As clean energy deployments accelerate and the power ratings of independently managed units rise, operators must prioritize cybersecurity with the same urgency as physical asset management. While compliance with regulations like NERC CIP is an important foundation, truly effective risk mitigation requires owners and their partners to go further–implementing robust security controls in both the design and operation of sites to protect the grid and their investment. The future of the grid will depend not just on how much clean energy is deployed, but on how resilient and secure the infrastructure behind it remains.

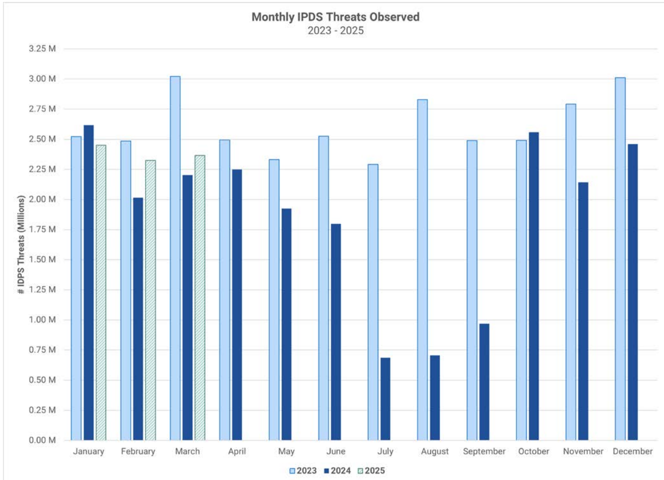


Figure 1. Monthly IDPS Threats Observed (2023–2025). Daily threat activity targeting clean energy infrastructure remains persistently high across years. The steady cadence of threat probes, port scans, and reconnaissance attempts highlights the ongoing cyber risk facing even well-defended solar and storage sites.

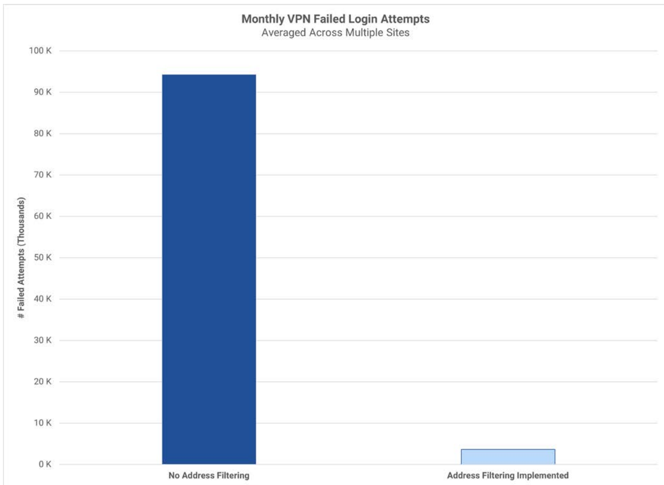


Figure 2. Monthly Failed VPN Attempts (average). Data from before and after implementation of address filtering shows implementation of geolocation filtering and banning known and suspected threat actors dramatically reduces undesirable login attempts.

1. Zeba Siddiqui and Christopher Bing, "Cyberattacks on U.S. Utilities Surged 70% This Year, Says Check Point," Reuters, September 11, 2024. https://www.reuters.com/technology/cybersecurity/cyberattacks-us-utilities-surged-70-this-year-says-check-point-2024-09-11/

9 Hot Spot Prevalence on Sites Increased from 0.24% in 2023 to 0.81% in 2024: A Sample of Newly Commissioned Sites in North America

By: Fan Zhang, Alfredo Spagnuolo, Devon Nishimura, Thomas Amsuess - Zeitview

Solar project development continues to accelerate across North America with increased construction activity in both utility-scale and distributed solar assets. Hot spots, or over-proportional heating of a small region of the module (Figure 1), are a critical concern in photovoltaic (PV) systems, causing up to 30% power loss per module, and long-term damage or degradation. Hot spots can result from cell mismatch, internal defects, or physical damage, which may be caused by equipment quality issues, poor installation, or weather events, respectively.

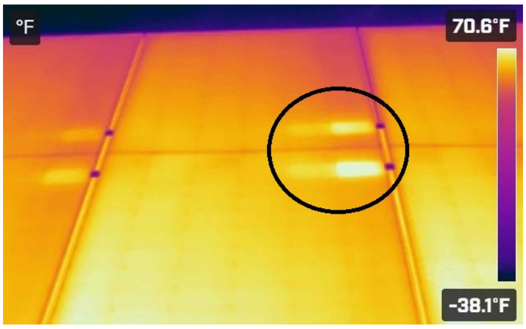
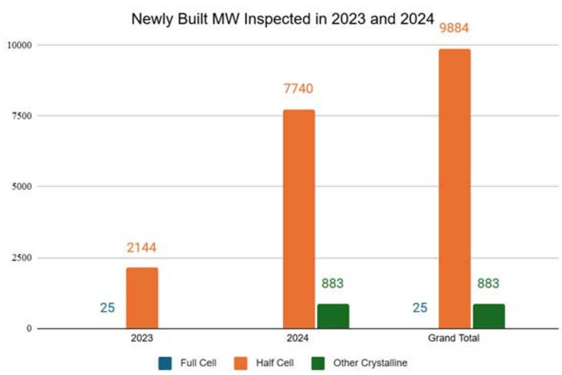
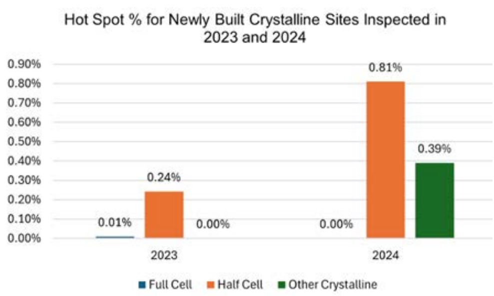


Figure 1: Infrared imagery of hot spots (circle) identified in a half-cell module.



Graph 1: Newly Built utility-scale PV systems (in MW) in North America in 2023 and 2024, comparing crystalline module technology installed on site.



Graph 2: Hot Spot prevalence and development (in % of modules affected) on newly built, utility-scale crystalline PV systems in North America, in 2023 and 2024

Overall, hot spot occurrences increased from 2023 to 2024 in newly commissioned sites. Half-cut modules consistently reported the highest hot spot rates in both years, with a notable spike in 2024. The data may indicate that real-world operating conditions or manufacturing inconsistencies are undermining the intended benefits of half cell modules.

Multiple factors are likely contributing to the uptick in hot spot occurrences, especially on half cell and other crystalline technologies, in which modules are composed of silicon crystalline cells but not classified as full cell or half-cell modules.

- Glass Cracks: Subtle glass cracks on the front or rear of modules allows moisture to ingress, leading to cell degradation. As module sizes increase, larger surface areas and thinner glass may be more vulnerable to stress from strong winds or storm events, particularly around the clamps. Across the utility scale solar assets from 2023 and 2024, the majority of modules trend towards larger dimensions, with widths exceeding 2 meters and some approaching 2.5 meters.
- Clamp Design: Smaller, centrally positioned clamps can concentrate stress along the module's long edge, increasing the risk of localized damage. Wider grip or more robust clamp design help distribute stress more evenly across the frame, reducing peak stress concentrations. Additionally, certain clamp designs may introduce minor shading along the module during certain times of day and season, leading to performance losses or hot spot formation over time.
- Cell Mismatch: Half Cell modules may be especially susceptible due to the increased likelihood of cell mismatch across the split-cell configuration, particularly if there are inconsistencies during manufacturing or string assembly.

As solar deployment continues to accelerate, the industry can't afford to ignore the compatibility of system components. Early identification of systemic issues, industry-wide collaboration, continued field monitoring, and long-term performance analysis will be critical to maintaining long-term asset performance.

1. Of assets of 100MWdc or more compared to the SEIA data base

10 Future Climate Models Suggests Potential -4.9% Impact to PV Production

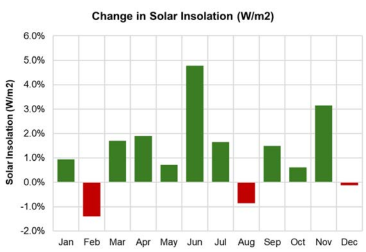
By: Hang Bui, Lead Product Manager - Clean Power Research

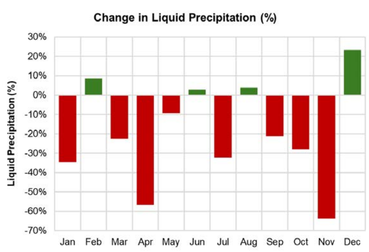
Modeling climate change impacts to PV projects is a complex subject and the solar industry has not reached a consensus on method. However, the SolarAnywhere team at Clean Power Research is developing a clearer framework on this topic to inform long-term investments. The conventional approach to evaluating solar project return involves production modeling using a typical meteorological year (TMY) dataset, which normally reflects historical weather and irradiance observations for the last 30 years. However, some large-scale solar developers are beginning to consider extreme weather and climate change in their prospecting efforts, considering potential future projections from years 2030 to 2100. Extreme risks can be represented in what is known as an extreme metrological year (XMY)[1] dataset that selects for the severe deviations like sustained heat wave events (HWE) rather than averages, or identified by simulating the entire timeseries of data.

To quantify potential risks, we completed a case study at an example site in Europe and compared production output from simulations of typical years created purely from historical data versus extreme years created from established climate change models.

The results show an estimated 4.9% power loss over 30 years from the modeling using projected datasets when compared to modeling using the historical TMY dataset, pointing to the detrimental effects of climate change on production. Interestingly for this asset, climate modeling actually shows increases in sunny days, but those production benefits are outweighed by the negative impacts. Namely, sustained high temperatures and lower rainfall increase risks for soiling and asset degradation (if left unmitigated by equipment design or maintenance).

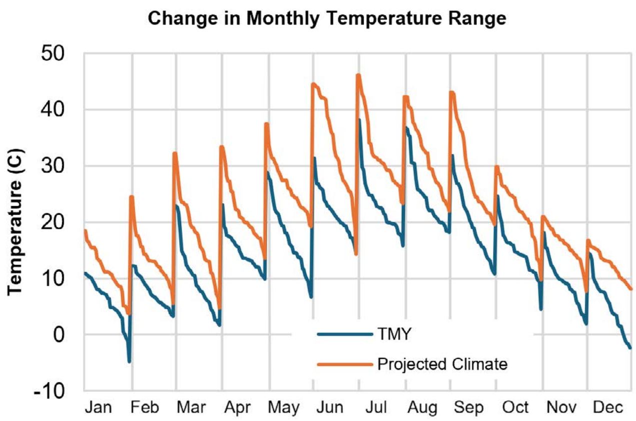
Example of Climate Change Impact to PV Production





These results suggest that climate change can negatively impact PV production and such consequences should be considered alongside conventional project evaluation. However, practical and technical barriers exist in widespread adoption of this type of analysis, which include complex data access and low native resolution of models. To counter this, Clean Power Research is developing advanced downscaling techniques to adopt these generalized, coarse-resolution data sources specifically to solar development. We are also fine-tuning methods for irradiance estimation, which due to local meteorological forces, are more challenging to forecast than parameters like air temperature.

Combined, these novel approaches can quantify the risk to PV production in the future. With the effects of climate change leading to real financial impacts, this full probabilistic modeling will be required for accurate financial predictions, as opposed to the simple P50 analyses heavily utilized today.

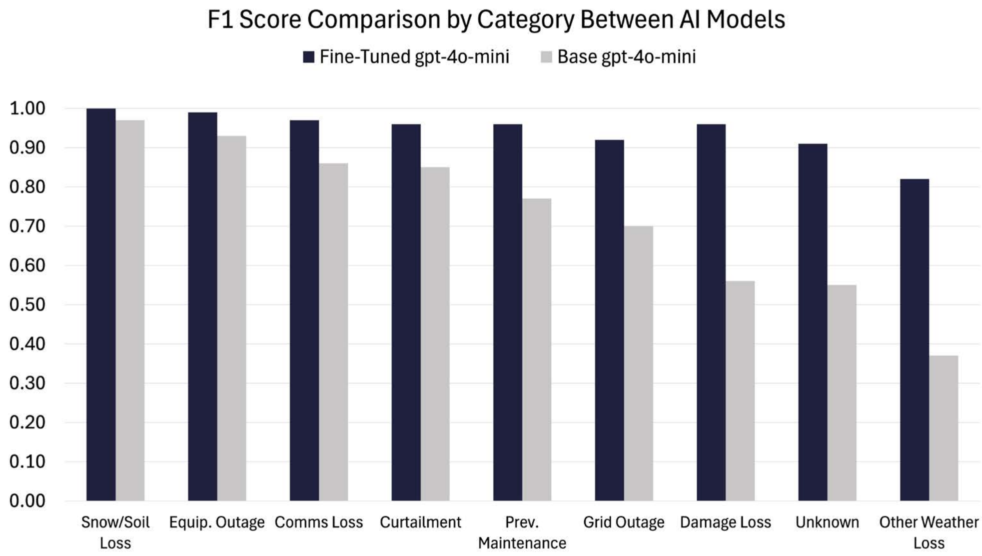


Parameter	Description	Yearly Production Impact Low %	High %
Heat Wave Events Annual Degredation	25 days > 40 C versus 0 previous	-0.50%	-1.20%
Solar Resource	More sunny days	3.20%	9.50%
Precipitation Soiling	Up to -13.70% lower rainfall; dry months	-5.70%	-8.70%
Simulated 30-Year Impact to Power		**-2.5%**	**-4.9%**

1. The inclusion of XMY datasets is a concept in urban planning and building design. Machard, A., Salvati, A., P. Tootkaboni, M. et al. Typical and extreme weather datasets for studying the resilience of buildings to climate change and heatwaves. Sci Data 11, 531 (2024). https://doi.org/10.1038/s41597-024-03319-8

11 AI Models Misclassify Up to 20% of Solar Operational Issues Without Domain-Specific Training

By: Mike Mousou, Data Engineer - kWh Analytics



As artificial intelligence (AI) continues to experience explosive growth, the solar industry increasingly seeks to leverage these tools for rapid assessment of operational risks. However, deploying AI without proper validation introduces significant financial and operational risks.

Highlighting this, kWh Analytics investigated the application of using LLMs to classify solar operational losses described by Operations & Maintenance (O&M) logs into multiple root causes, testing both out-of-the box models as well as a fine tuned model. To achieve this, a manually labeled dataset of 10,000+ logs was split into a training and a validation set using an 80/20 statified split. When evaluating the GPT-4o-mini model without fine-tuning against the 2,000 data point validation set, the overall F1-score was 87%, compared to 98% for the same model fine-tuned with the 8,000 data points in the training set. F1-score is a commonly used accuracy metric for classification problems, combining both precision and recall accuracies[1].

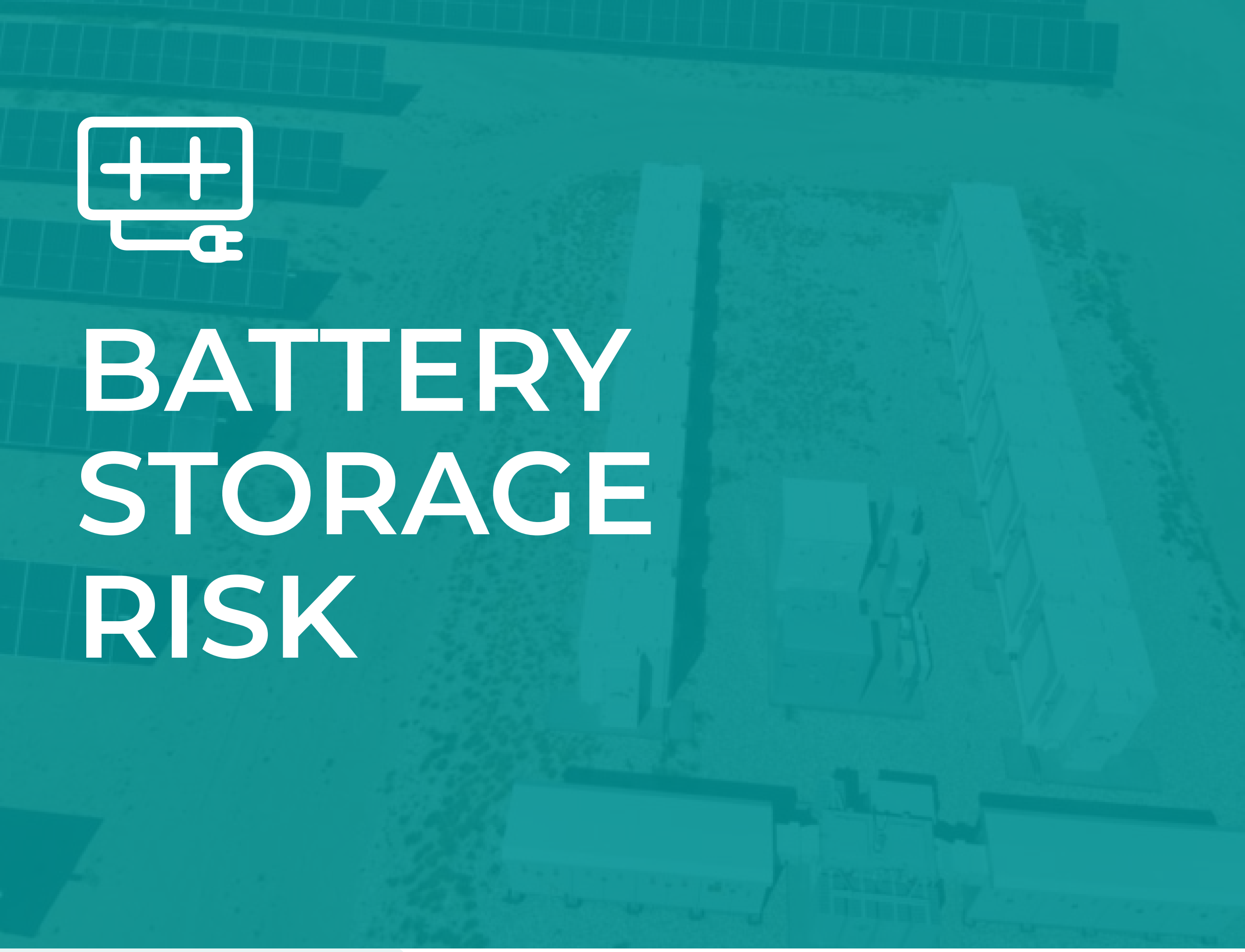
For each root-cause category, the model without domain-specific training consistently misclassified approximately 15-25% of solar loss events in frequent and common categories such as curtailment, communication loss, and preventative maintenance. Additionally, we found the out-of-the-box model struggled especially with critical categories such as weather-related and damage losses, misclassifying these events upwards of 40-50% of the time.

Conversely, the same GPT-4o-mini model achieved significantly improved accuracy across all categories when fine-tuned using the training dataset. This enhanced accuracy significantly reduces uncertainty, lowering operational risk and directly impacting financial outcomes by providing trustworthy, actionable trends and insights.

For instance, fine-tuned AI models can swiftly pinpoint actual damage loss or grid outages that out-of-the-box model commonly misclassify as "unknown" or incorrectly attribute to other categories. More precise classification could lead to rapid, accurate intervention, allowing stakeholders to better understand asset performance issues and act accordingly. However, fine-tuning isn't a one-time task. Continuous updating with fresh, representative data is necessary to maintain model effectiveness amid evolving solar technologies and operational conditions. Additionally, the reliability of these AI predictions hinges on data quality; biased or inaccurate data severely degrade predictive accuracy, underscoring the importance of rigorous data governance.

Ultimately, while AI can dramatically improve risk assessment and management in solar operations, unchecked reliance on out of the box models without any fine tuning poses a significant risk. Implementing AI responsibly demands ongoing model validation, transparent application practices, and high-quality data curation to ensure these powerful tools deliver accurate and reliable benefits to the solar industry.

1. Precision measures the accuracy of positive predictions, calculated as the ratio of true positives to the sum of true positives and false positives. Recall measures the model's ability to find all positive instances, calculated as the ratio of true positives to the sum of true positives and false negatives. F1-score is the harmonic mean of precision and recall, considering both false positives and false negatives. .



BATTERY STORAGE RISK

Rapid BESS deployment brings new safety and operational challenges that require enhanced quality control and risk management strategies.

12 **Clean Energy Associates**
28% of Energy Storage Systems Show Fire Suppression Issues during 2024 Factory Inspections

13 **EPRI**
To date, 72% of BESS failures Have Occurred Within the First 2 Years of Installation

14 **ACCURE Battery Intelligence**
State of Charge (SOC) Estimation Errors for LFP Batteries can Exceed 15%

15 **TWAICE**
Lost in Translation? O&M Teams See up to 2x More BESS Issues Than Asset Managers

12 28% of Energy Storage Systems Show Fire Suppression Issues during 2024 Factory Inspections

By: Leo Chen, Senior Engineer, Energy Storage - Clean Energy Associates

CEA's factory quality inspections revealed that 28% of energy storage systems exhibited issues in the fire suppression system and 15% in the thermal management system. Fortunately, the issues are typically easy to rectify when identified during factory testing.

Battery energy storage systems (BESS) play a critical role in integrating renewable energy into power grids , but manufacturing defects pose risks to safety and reliability. In 2024, Clean Energy Associates (CEA) conducted 330 comprehensive factory inspections in BESS manufacturing facilities worldwide, covering 29 gigawatt-hours of lithium-ion battery systems.

CEA's inspections revealed that quality issues in the fire suppression system were among the most frequent, observed in 28% of the audited units. These quality issues included non-responsive smoke detectors, malfunctioning fire suppression actuators, and incorrectly wired alarm systems, all contributing to heightened safety risks. There are many opportunities to catch these problems, including production audits, factory acceptance tests, and during commissioning.

Auxiliary circuit panel defects affected 19% of systems, with issues like exposed wiring, improperly installed circuit breakers, and wiring mismanagement that could lead to electrical failures, unexpected system downtime and safety risks.

Thermal management system failures were found in 15% of audited BESS units, typically manifesting as coolant leaks from poorly secured pipes, faulty temperature sensors, or malfunctioning circuit boards. These issues increase the risk of overheating, potentially leading to thermal runaway–a hazardous condition that can cause battery fires.

Common reasons for the observed quality issues include non-conforming materials, poor installation workmanship, and insufficient internal quality control.

As global BESS manufacturing continues to expand, these findings highlight the urgent need for improved quality assurance. Without stricter oversight, these defects could lead to costly system failures, increased insurance liabilities, and safety risks that threaten the industry's long-term viability. With proper oversight, these issues can be easily solved. BESS manufacturers, developers, and investors must prioritize quality control measures to protect their assets and ensure the safety, reliability, and financial viability of energy storage projects worldwide.

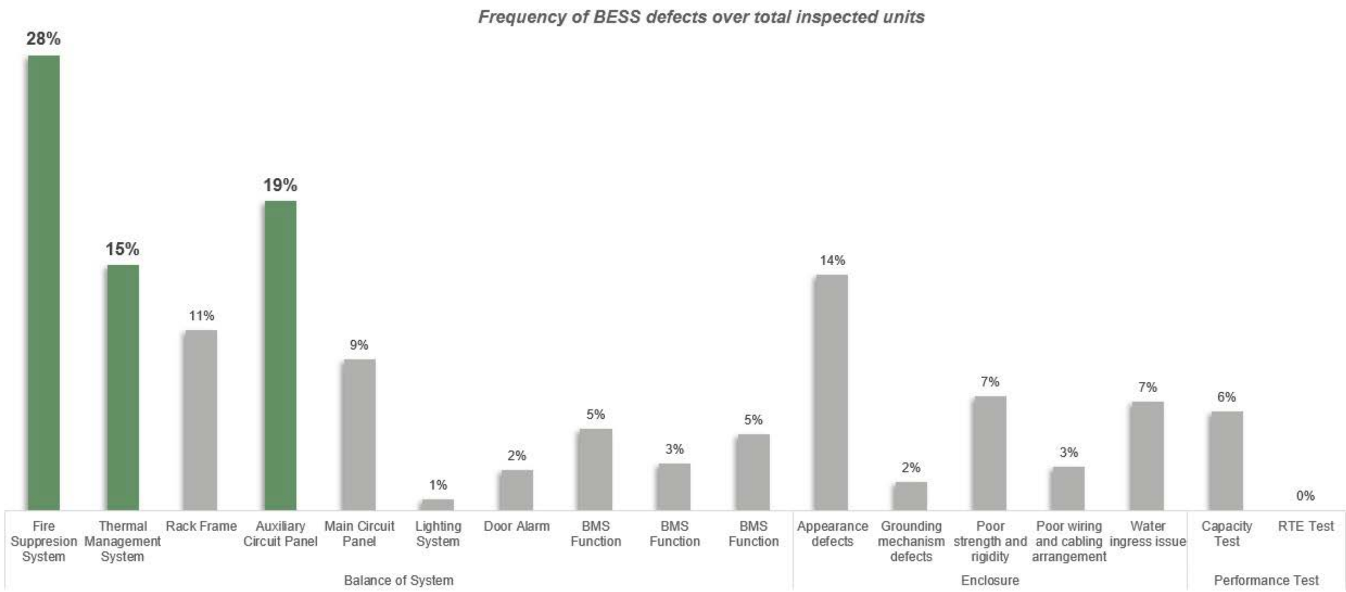


Figure 1: Frequency of BESS manufacturing defects over total inspected units

13 To date, 72% of BESS failures Have Occurred Within the First 2 Years of Installation

By: Eula Billaut, Project Engineer, Lakshmi Srinivasan, Principal Team Lead, Stephanie Shaw, Senior Technical Executive - EPRI

Over the last six years, global deployment of grid-scale battery energy storage systems (BESS) has dramatically increased from 11 GWh to over 300 GWh. 78% of the fleet was installed in the last two years, and commissioning is a key phase for reducing risk in new BESS projects. While recent BESS fires received significant media attention, the overall rate of incidents has sharply decreased, dropping 98% from 2018 to 2024.

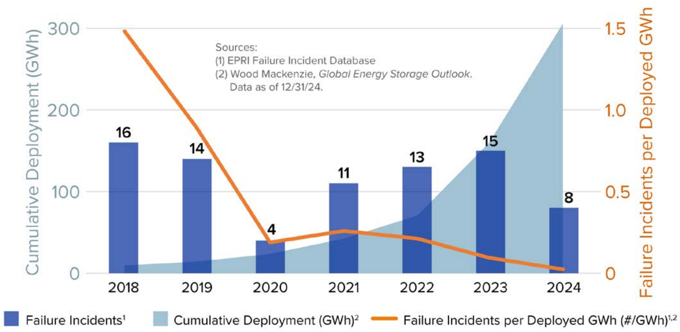


Figure 1: Global Grid-Scale Storage Deployment and Failure Statistics

Root Cause Analysis Results

Last year, EPRI published the industry's first aggregate failure root cause analysis to better understand failure causes and to inform prevention and mitigation measures. The analysis was based on EPRI's BESS Failure Incident Database, which compiles utility-scale and commercial and industrial BESS failure incidents. A failure incident is defined as an event which results in thermal runaway or fire, caused by BESS system or component failure.

Of the 81 failure incidents recorded at the time of publication, only 26 had sufficient information to determine root cause, and 64 incidents had a known system age at failure. Some incidents may not be captured by the database as it relies on public reporting.

Most failures (72%) oc curred within two years of installation. Nine incidents between 2018-2023 occurred before the BESS became operational. In several cases, monitoring and communications were not yet online, allowing leaks or isolation failures to cascade into large-scale fires. However, there are few systems older than 5 years; most systems were installed within the last 2 years. It is essential to continue safety monitoring and maintenance as deployed systems age.

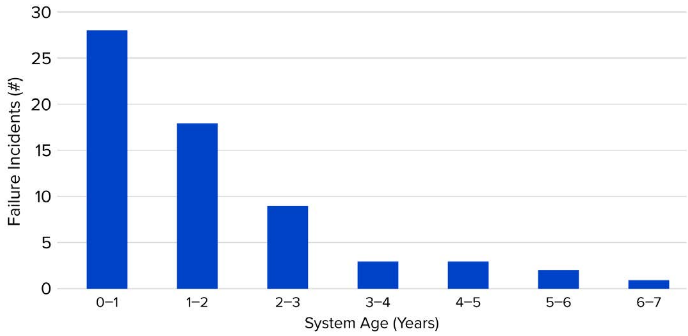


Figure 2: System Age at Failure

The results also showed that Integration, Assembly, & Construction is a critical phase to prevent failures originating in the balance-of-system (any component besides the cell/module or the controls system, such as thermal management, enclosure, external wiring, etc.). Integration-related failures have become more common, with the vast majority of these failures related to poor build quality in the balance-of-system, whether it is AC or DC wiring, coolant systems, or safety systems such as water suppression piping.

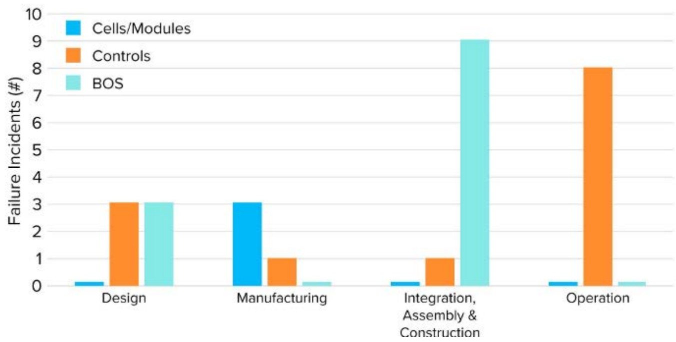


Figure 3: Biaxial Failure Classification: Relationships between Root Cause and Failed Element

There are well-understood engineering solutions to reduce or prevent balance-of-system failures, such as component design studies, factory acceptance testing, and integrated product testing. Workforce training and quality checks during installation and commissioning can further support safety. EPRI continues to lead BESS safety research and calls upon industry to provide more transparency on details of BESS failures to inform improved designs and ensure safe operation of BESS facilities.

14 State of Charge (SOC) Estimation Errors for LFP Batteries can Exceed 15%

By: Dr. Georg Angenendt, CTO & Co-founder - ACCURE Battery Intelligence

Within just a few years, lithium iron phosphate (LFP) batteries have taken the energy storage industry by storm, accounting for more than 80% of new grid-scale storage developments[1]. These batteries offer significant cost benefits and impressive longevity. However, they also come with a unique challenge: it can be surprisingly difficult to accurately estimate their state of charge (SOC).

Traditional battery management systems rely on two primary methods to estimate State of Charge (SOC): coulomb counting and the voltage-based method. Coulomb counting uses current sensors to track charge flow in and out of the battery. However, these sensors are prone to errors that accumulate over time, leading to a significant reduction in the accuracy of SOC estimates. Voltage-based methods are often applied to recalibrate SOC and correct this error, but this is particularly ineffective for LFP batteries due to their flat open circuit voltage (OCV) curve, making it difficult to translate voltage readings into accurate SOC values. In fact, ACCURE's database of over 12 GWh of battery data reveals that LFP systems commonly display SOC estimation errors of ±15%, with outliers exceeding 40%– figures that few in the industry would suspect.

For battery energy storage system (BESS) operators, these inaccuracies introduce both financial and operational risks. Because trading decisions hinge on SOC estimates, errors can lead to missed market opportunities, non-compliance fines, and unnecessary stress on the battery that worsens degradation. Some operators, aware of these pitfalls, resort to using wide safety margins to avoid overselling power. The downside is a reduction in usable capacity, directly curbing revenue potential.

Until recently, a reactive strategy–accepting SOC inaccuracies or operating with conservative buffers–was the only practical option. The emergence of advanced analytics technologies in this field curbs this risk by utilizing data from millions of battery cells worldwide to better predict state of charge. Some advanced analytics solutions can correct SOC errors, enabling SOC estimates as accurate as ±2% of the true value.

In practice, operators leveraging these insights can confidently optimize their assets and trading strategies to maximize revenue. This means capitalizing on all the benefits LFP batteries offer, while minimizing the risks and inefficiencies of inaccurate SOC calculations. Through advanced analytics, LFP technology can truly deliver on its promise, supporting a more reliable and profitable energy storage ecosystem.

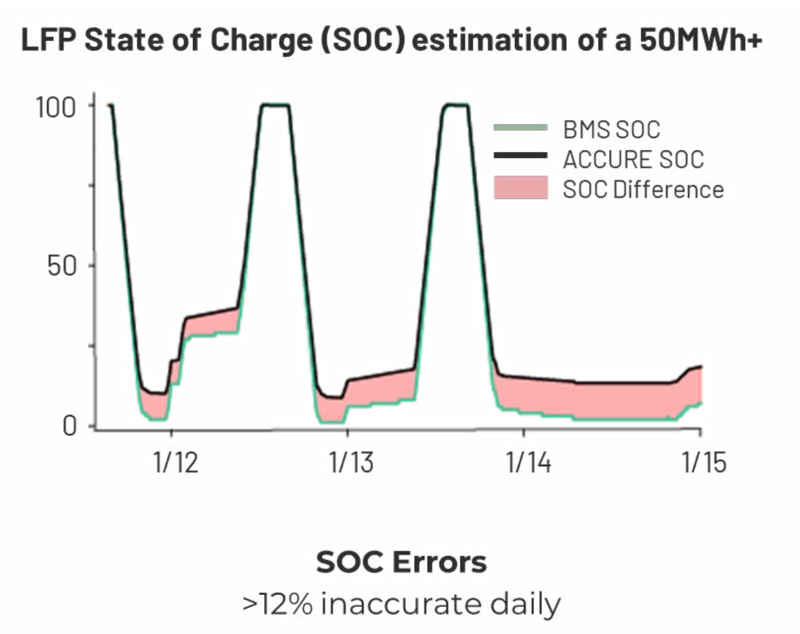


Figure 1: A comparison of BMS-reported SOC (green line) and ACCURE's SOC estimates (black line) using advanced data analytics over the course of 3 days. The BMS deviated from the true SOC value by more than 12% daily.

1. IEA. (2024). Batteries and secure energy transitions (Executive Summary). International Energy Agency. https://www.iea.org/reports/batteries-and-secure-energy-transitions/executive-summary

15 Lost in Translation? O&M Teams See up to 2x More BESS Issues Than Asset Managers

By: Olivia Willson, Senior Product Marketing Manager - TWAICE

Battery Energy Storage Systems (BESS) are vital for grid stability and integration of renewable energy. Yet the technical challenges they present are often perceived differently by those maintaining systems day-to-day and those overseeing financial performance. This discrepancy in perspectives can lead to a gap in understanding and addressing technical issues, posing a hidden risk for asset optimization and long-term profitability.

Data from the TWAICE BESS Pros Survey[1], which surveyed 83 industry professionals – including engineers, technicians, and asset managers – revealed that 73% of O&M staff encounter technical issues[2] at least monthly, compared to only 53% of asset managers. Moreover, 40% of O&M staff reported issues weekly - double the rate seen by asset managers.

This discrepancy points to a disconnect between technical performance and financial oversight. While engineers typically understand the technical dynamics at play, asset managers may only grasp their importance when tied to tangible financial impact. If these operational issues are overlooked, organizations risk making decisions based on incomplete or misleading data, leading to increased downtime, unaddressed underperformance, and financial losses.

For instance, system imbalances, such as uneven cell discharging, can significantly degrade battery performance. When a single cell discharges prematurely, it can limit the usable energy of the entire system. In one customer's case, this imbalance resulted in a daily loss of 18 MWh, translating to approximately $1 million in annual losses – all from a single cell.

This is where a strong data strategy and BESS analytics becomes essential. By making technical shortcomings visible and quantifiable across teams, organizations can ensure that everyone has a shared understanding of operational risks and their financial implications.

BESS produce billions of data points, which, when used in the right way, can be incredibly valuable. Teams responsible for developing and managing BESS projects should think about how they will access and use BESS data as soon as they start planning a project. Once operational, data and insights should be shared across the organization to ensure that all relevant stakeholders are aware of how technical BESS issues directly impact financial outcomes.

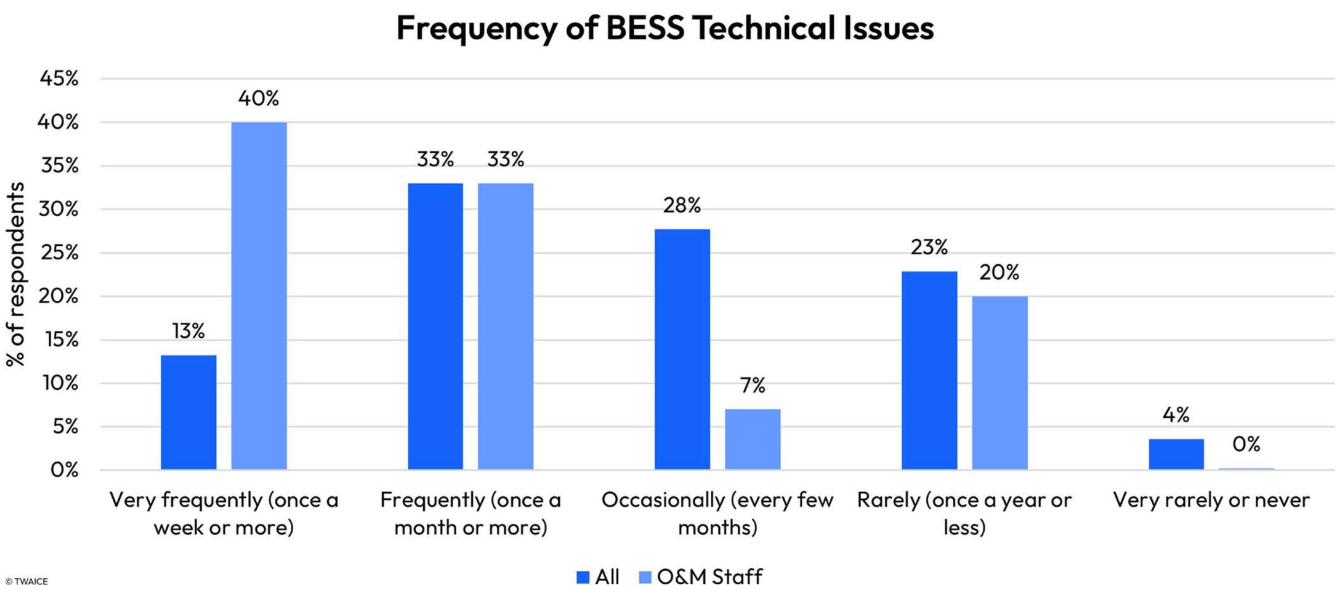


Figure 1: The frequency of technical issues greatly varies across job functions.

1. Survey group represents 8-10% of US/Europeanasset owners and operators found in Rho Motion's database.
2. The numbers do not differentiate between severities of technical issues. Issues could range from minor software glitches to data outages, unexpected downtime or severe safety incidents. Importantly, industry data shows that failures are not spread evenly over a BESS's lifetime but are concentrated in the first two years of operation, reflecting early-stage reliability challenges.

2025 Contributors

kWh Analytics, a leading Climate Insurance provider, underwrites property insurance and revenue firming products for renewable energy assets. Our proprietary database of 300,000+ zero-carbon projects and $100B in loss data fuels advanced modeling and insights, enabling precise underwriting decisions. This data-driven approach incorporates resiliency measures in risk evaluation, promoting sustainable practices in the renewable energy sector. Website

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Dr. John Allen is an Associate Professor of Meteorology at Central Michigan University, and independent consultant on severe weather risk. He is a leading expert in hail science, global severe weather observations and modeling, links between severe weather and the larger climate system, machine learning and statistical prediction of severe weather, and providing community and cross-disciplinary relevant risk and hazard resilience information. Website

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Kiwa PI Berlin provides expert technical diligence, procurement, and quality assurance services for a wide range of solar installers, integrators, project developers, utilities and investors. We enable our clients to manage technical risk associated with the investment or procurement of PV equipment. We leverage direct relationships with PV module, inverter and battery manufacturers, apply our expertise to qualified manufacturers and independently verify quality, reliability, and performance. Website

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60Hertz Energy is a Computerized Maintenance Management System software company with integrations to most DAS and monitoring brands. Founded in 2017, 60Hertz is a Woman Owned Small Business that serves more than 2000 utility scale, C&I and emerging market renewable energy plants. The platform enables maintenance from basic site inspections, to complex PM planning to ROC operations. The company is a recipient of NOAA Small Business Innovation Research Phase I and Phase II awards. Website

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VDE Americas provides technical advisory and risk mitigation services to equipment manufacturers and those who develop, finance, construct, own, operate, and insure large-scale solar power generation and energy storage facilities. The company's products and services have facilitated the financing of over $15 billion in operating renewable energy assets. VDE Americas is the world's leading expert in solar project hail risk intelligence and loss prevention. Website

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GroundWork Renewables is the leading provider of high-quality meteorological (MET) data and ISO-accredited PV lab testing to give solar plant owners complete situational awareness of planned and operating assets. GroundWork's solar intelligence helps reduce uncertainty, improve modeling and forecasting, and mitigate risk to increase value across plant lifecycle phases. As a certified B Corporation, GroundWork is committed to innovation, sustainability, and supporting the global transition to renewable energy. Website

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Radian Generation, founded in 2013, is a leader in renewable energy asset management, NERC compliance, cybersecurity, and software solutions. Supporting a diverse portfolio of solar, wind, and battery storage projects, Radian delivers full lifecycle support through its Radian Digital platform. Its integrated services help owners and operators optimize performance, maintain compliance, and strengthen cybersecurity, empowering the clean energy transition with scalable, data-driven tools. Website

2025 Contributors

Zeitview is the leading global provider of automated inspections and analysis for renewable energy and high-value infrastructure, providing businesses with actionable, real-time insights through a single-source solution to recover revenue and reduce liability risk. Zeitview is the trusted, go-to data management platform for worldwide enterprise customers spanning industries such as solar and wind energy, retail, cloud computing, transportation, insurance, telecommunications, construction, real estate, and critical infrastructure. Website

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Clean Power Research is a trusted partner of leading utility and energy enterprises. We are a team of professionals passionate about clean energy and committed to transforming the global energy landscape using software for a clean-powered planet. SolarAnywhere is a product of Clean Power Research, a global software and data provider for the solar industry, delivering solutions for asset development and operations. Website

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Clean Energy Associates (CEA) helps buyers and long-term owners of solar and energy storage equipment buy the right products and ensure they are properly manufactured and installed. CEA offers investment confidence to project developers, EPCs, IPPs and financial institutions by providing insights into supply chains and project execution. CEA's global team has executed over 260 GW of solar and 55 GWh of storage projects in 85+ countries. CEA is a subsidiary of Intertek Group plc. Website

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EPRI, founded in 1972 is the world's preeminent independent, non-profit energy research and development organization, with offices around the world. EPRI's trusted experts collaborate with more than 450 companies in 45 countries, driving innovation to ensure the public has clean, safe, reliable, affordable, and equitable access to electricity across the globe. Website

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ACCURE Battery Intelligence helps companies reduce risk, improve performance, and maximize the business value of battery energy storage. Our predictive analytics solution makes batteries safer, more reliable, and more sustainable. By combining cutting-edge artificial intelligence with expert knowledge of batteries, we bring clarity to energy storage. Website

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TWAICE has led predictive battery analytics since 2018, optimizing BESS safety, availability, and profitability. Its advanced software improves BESS operation by combining AI with deep battery expertise. Unlike Battery Management System and Energy Management System providers, TWAICE goes beyond basic monitoring, uncovering hidden patterns to improve performance and lifespan. As an independent third party, it delivers unbiased insights, free from ties to insurers, manufacturers, or vendors. Website