kWh analytics

# SOLAR RISK ASSESSMENT

2024

# Executive Summary

The sixth annual Solar Risk Assessment highlights the remarkable progress and resilience of the solar industry in the face of rapidly evolving risk management challenges. As we reflect on the past year, it's clear that our industry's ability to collaborate and innovate remains one of our greatest strengths. Over the years, the Solar Risk Assessment has grown in its role as a platform for thought leaders to share data-driven insights into emerging risks that help the industry progress toward a resilient renewable energy future. This year, for the first time, we are expanding our analysis to include Battery Energy Storage Systems (BESS) and international contributors, recognizing the increasingly critical role that storage plays in the global energy transition.

In 2024, the solar and BESS industries continued their rapid growth trajectory, fueled by the Inflation Reduction Act and increasing demand for clean energy. The fast adoption of BESS has been a key driver, but this growth has not been without its challenges. Extreme weather events are becoming more frequent and severe, testing the limits of deployed renewables and risk management strategies. Operational risks, including equipment failures and maintenance challenges, can lead to unexpected downtime and reduced energy production. Battery storage systems introduce new risks related to fire safety, thermal management, and system integration.

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

- Advanced risk management strategies and accurate insurance modeling are essential to accurately assess and mitigate the growing threat of extreme weather events on solar and storage assets, while technological advancements and best practices in module design and operation enhance resilience.
- Comprehensive O&M planning, including proactive maintenance scheduling, resource allocation, and effective soiling mitigation strategies, is crucial to minimize system downtime, optimize performance, and reduce the impact of seasonal variations on energy production.
- Rigorous safety and quality control measures, such as regular inspections and preventive maintenance, are essential to ensure the safe and reliable operation of PV systems and mitigate risks.
- Accurate P50 forecasting remains a critical factor in reducing the likelihood of extreme downside scenarios, while portfolio aggregation can help diversify and mitigate underperformance risks.
- The rapid growth of Battery Energy Storage Systems (BESS) necessitates a strong focus on fire safety, thermal management, and system integration to address the unique risks associated with these deployments and ensure their long-term viability.

Overcoming these challenges will require ongoing collaboration and innovation among industry leaders. In this dynamic landscape, asset owners play a critical role in protecting renewable energy investments by securing comprehensive insurance coverage and seeking multiple quotes from brokers to ensure accurate protection. Insurers have the opportunity to play an equally important role by offering transparent feedback and helping inform best practices for designing, building, and maintaining resilient assets. We hope the insights and recommendations resonate with industry stakeholders as we work together to advance renewable energy and the planet toward a sustainable future.

Sincerely,

Jason Kaminsky,
CEO, kWh Analytics

# 2024 Contributors

Climate Insurance Provider

Lab Testing

Module Manufacturer

Insurance Brokerage

Asset Performance Optimizer

Asset Management Software

Field Operations Software

Solar Resource Data

Global (Re)insurance Marketplace

Battery Manufacturer

Fire Safety Solutions Provider

Tracker and Software Provider

Developer, Owner, and Operator

Cover photo image courtesy of

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# Extreme Weather Risk

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Industry standard modeling assumptions can under-estimate solar project losses by 300+%

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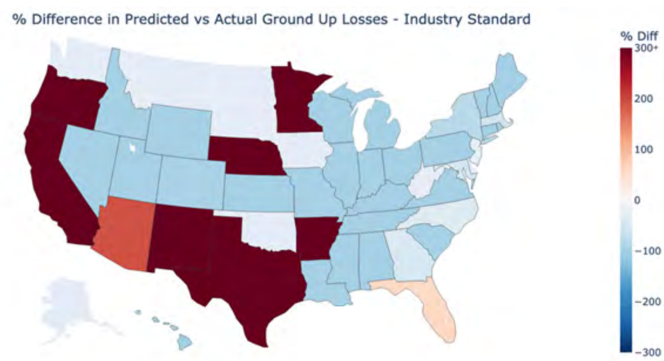
# Industry standard modeling assumptions can underestimate solar project losses by 300+%

By: Nicole Thompson, Sr. Data Science Manager, kWh Analytics

As the solar industry grows and evolves both technologically and geographically, accurately assessing the risks associated with solar projects has become increasingly critical, particularly for insurance purposes. Traditional modeling assumptions fail to capture the unique characteristics and risks of solar photovoltaic (PV) systems. This can lead to significant discrepancies between predicted and actual physical damage, with recent backtesting by kWh Analytics revealing that standard assumptions can underestimate losses due to physical damage by over 300% in some regions. This inaccuracy could have serious implications: incorrect or unreliable models can drive insurers to have outsized reactions to natural catastrophe losses (decreasing capacity and increasing insurance premiums for solar), while pushing investors to seek higher levels of insurance limits due to their inability to accurately quantify the risk.

**Figure 1. Results of backtesting industry standard modeling assumptions for PV against kWh Analytics' loss database**




Existing models can mispresent the risks. As PV is a relatively new asset class, natural catastrophe models typically used to size insurance premiums often rely on proxy structures to estimate losses. However, PV systems possess distinct physical characteristics that give rise to distinctive damage mechanisms, setting them apart from the commonly utilized proxies. Understandably, a 2mm or 3.2mm glass sheet facing the sky, or a set of large format modules mounted on metal racking, will fare differently than a building in different perils. Additionally, PV systems enabled with trackers can assume various configurations in the event of a storm which could alter the system's susceptibility to wind forces or reduce the impact energy of hailstones – leading to unique "secondary modifiers" in the modeling process. These are only a few examples of the many distinctive features of PV that lead to both resiliency and vulnerabilities that are not adequately captured by standard models.

Some modeling decisions can over or under-estimate loss. The sheer size of utility-scale PV arrays introduces significant intra-project topographic variability. The average size of sites within the USGS's US Large-Scale Solar Photovoltaic Database (USPVDB) is approximately 86 acres, in contrast to an average of 57 acres in 2016, indicating a trend towards larger and larger sites. Key loss factors, such as flood risk and wind exposure, can vary substantially across an array. Further, modeling the entirety of site values concentrated at a single point fails to account for the inherently distributed nature of solar projects, where a portion of the site can have a catastrophic loss while the remainder of the site continues to operate.

To address these drawbacks associated with industry standard modeling assumptions, kWh Analytics has developed a novel modeling approach that leverages significant loss data, combined with satellite imagery and NREL's panel-segmentation algorithm for granular, PV-specific loss estimation. By identifying the specific solar panel locations, and overlaying a predetermined resolution of grid points, this approach captures intra-project variability and site-specific risks, and enables a more accurate representation of the unique risks faced by solar PV systems due to their spatial extent (see Figure 2).

**Figure 2. Modeling a site as a set of grid points more accurately portrays how values are geographically distributed**


The solar industry is poised for significant growth in the coming years, with installed capacity projected to reach 1 TW globally by 2030. However, this growth could be hindered if insurers continue to rely on inaccurate industry standard models that underestimate the true risks associated with solar projects. By adopting advanced, PV-specific modeling methodologies like those developed by kWh Analytics, insurers can more effectively assess and price risk, ensuring the financial viability and sustainable growth of the solar industry. Ultimately, the transition to more accurate, data-driven risk modeling will benefit all stakeholders in the solar ecosystem, from project developers and asset owners to insurers and investors.

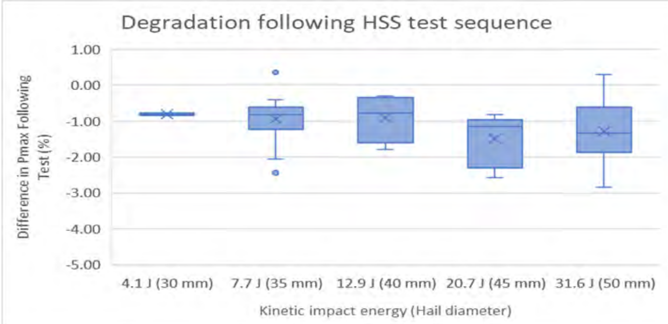
# Broken cells shouldn't break the bank: no module experienced power loss >3% following Kiwa PVEL's hail stress sequence

By: Todd Karin, VP of Technical Operations and Tristan Erion-Lorico, VP of Sales and Marketing, Kiwa PVEL

While Kiwa PVEL's extended reliability test results are often nuanced and difficult to generalize, some good news has emerged: modern modules don't lose significant power even when the cells are severely damaged by hail.

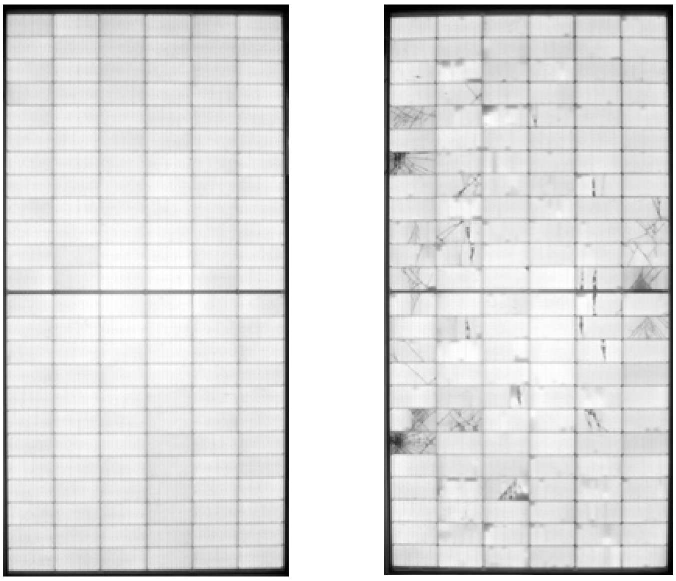
Kiwa PVEL analyzed the power loss following the hail stress sequence (HSS) over the past three years. The HSS tests the hail limits of panels by impacting modules with 11 freezer ice balls with diameters ranging up to 50mm. Modules which do not have broken glass then undergo dynamic mechanical loading and numerous thermal and humidity freeze cycles to emulate environmental factors which propagate cell cracks in susceptible modules. This sequence results in modules reaching their maximum possible power loss, and the results are very encouraging.

**Figure 1. Degradation per kinetic impact energy and hail diameter following Kiwa PVEL's hail stress sequence across the full test population (including both glass//glass and glass//backsheet modules).**




In looking at the results across technology types, we note that heat-strengthened glass//glass modules, which typically suffer higher rates of cracked glass, use a symmetrical design that places the cells in the neutral plane between the glass layers. This protects the cells from compressive and tensile stresses and therefore glass//glass modules tend to not experience cell cracking. And while glass//backsheet modules with thicker tempered glass are more resilient to glass breakage, they are robust against power loss arising from cell cracks due to the use of half-cut, multi-bus bar (MBB) cells. Meanwhile, the industry's collective concerns regarding cell cracking power loss are often based on studies[1] using older two- and three-bus bar (2BB or 3BB) modules, which are susceptible to higher power loss due to larger areas of the cell that can become electrically isolated from a bus bar.

**Figure 2. Left: EL image of a glass//glass module post-HSS using 50 mm hail (0.6% power loss).**
**Right: EL image of a glass//backsheet module post-HSS using 50 mm hail (2.9% power loss).**



While the cell damage caused from hail and other severe storms may be a cause for concern for some industry stakeholders, the end result is likely not as worrisome as the double-digit power loss previously feared. Kiwa PVEL's hail testing shows that module designs from the past few years are less prone to hail-induced cell-cracking-related power loss. For sites hit by hailstorms resulting in cell cracks, rather than expensive EL imaging campaigns and module replacement, we would encourage annual aerial thermal scans to help identify modules that have developed hot spots, as those should be replaced due to the potential fire/ safety risks. Fire risks are most severe in the rare case that a module with a failed bypass diode has cracked cells. The remaining modules should stay put, as the minimal amount of power loss likely does not justify their replacement costs.

1 Köntges et al, The risk of power loss in crystalline silicon based photovoltaic modules due to micro-cracks, Solar Energy Materials and Solar Cells, 2011, https://doi.org/10.1016/j.solmat.2010.10.034

# Modules pass edge-on hail strikes in stow position

By: Neha Sainbhi, Research and Development Manager, Waaree

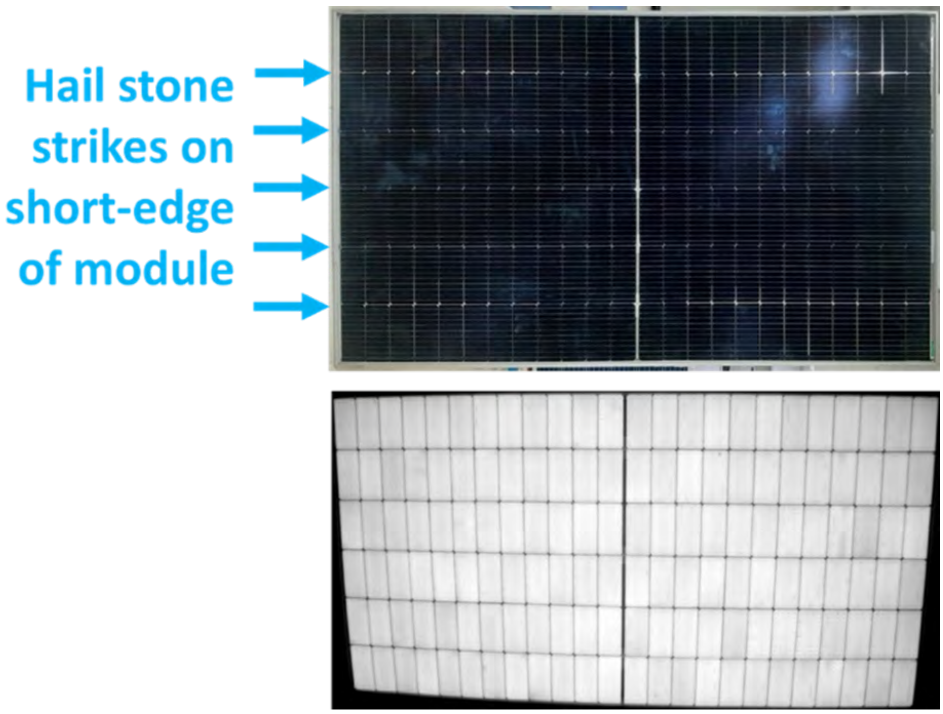
Rising insurance rates and increased replacement costs due to hail loss have become a significant concern for solar asset owners, financiers, and insurers. Demonstrating the efficacy of passive and active hail mitigation measures that can reduce the probable maximum loss (PML) at the photovoltaic (PV) plant is crucial for addressing these issues. In recent years, solar manufacturers are increasingly focused on building "hail resistant" modules, and an increase in white papers and research labs demonstrating how various modules stand up to lab testing has been observed.

Hail testing performed during typical PV module qualification tests (e.g., IEC 61215) shoots hail stones perpendicularly to the module surface to test for module hail resistance. However, PV modules in large-scale plants are commonly installed on single-axis trackers that rotate the modules throughout the day to improve irradiance collection. Modules go into stow at a high degree tilt when there are hail storms to reduce the overall exposed surface area of the modules and reduce the impact energy of hail stones due to a more glancing blow. However, in these situations, the edge of the module becomes even more exposed to hail, where glass is typically more susceptible to breaking from edge-on impacts.

This work goes beyond hail-related conventional module qualification testing to demonstrate durability of modules against hail strikes in field representative conditions emulated in a lab environment. The experiment shot hail stones (45 mm diameter, 30 m/s) parallel to the front surface onto the short frame edge of Glass//Glass Waaree M10 PERC modules with 2.0 mm semi-tempered heat-strengthened front and back glass and standard edge seal and aluminum frame. Five equidistant points marked on the module were targeted by the hail stone.

Visual and electroluminescence imaging showed no signs of damage. Power loss was 0.8%, which is well below the 5% loss allowed in the IEC guideline. The test demonstrated the performance and reliability of Waaree modules against hail strikes when in hail stow position. Testing field relevant conditions are important for continuing to improve modules and, as necessary, updating certifications to reflect the broader geographies in which modules are installed, technology innovations, and potential hazards encountered. Future field relevant lab tests at Waaree will include testing a range of hail stone impact angles to assess potential damage from glancing strikes.

**Figure 1. Visual and Electroluminescence images after 45 mm hail stone strikes parallel to the front surface onto the short-edge frame at five equidistant points. No damage is observed.**



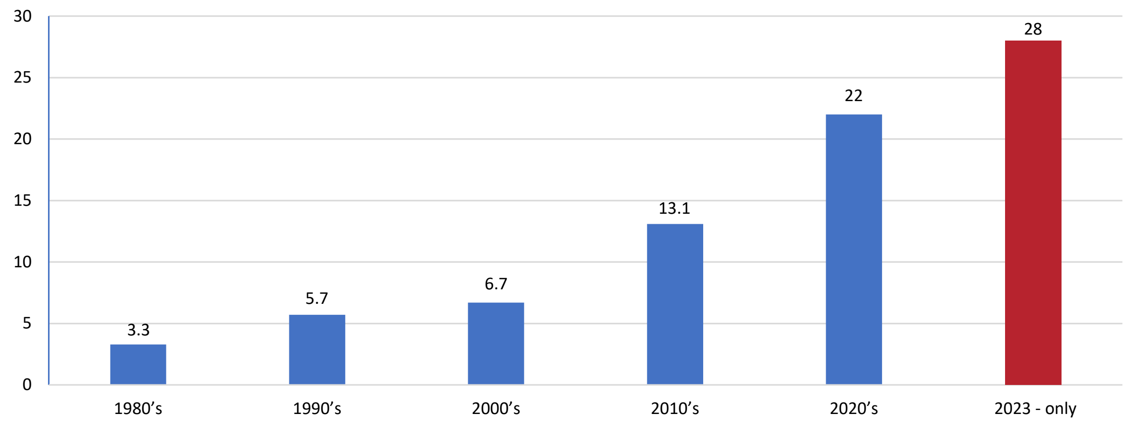
# Can your project financially survive a catastrophic loss? Implementing risk solutions for long-term viability

By: Alex Post, Brendan Fountain and Molly Lovelette, Alliant Power, Alliant Insurance Services

The natural catastrophe events in 2024 have fostered a continued concern amongst renewable project owners, investors and insurers given the location and quantum of recent events. While many in the insurance market are quick to categorize recent events as a "limit loss" - a claim which exhausts the total insurance limits available for a defined insurable event - it does not fully capture the total economic loss of the event faced by the project owners and its investors. Solar project owners who invest in designing, building and maintaining resilient solar sites in combination with bespoke insurance solutions can achieve up to a 50% reduction on rate loads for highly exposed natural catastrophe zones.

The frequency and severity of natural catastrophe events continues to grow. In 2023, more than 50% of global insured property losses came from North American severe convective storms.

**Figure 1. NOAA Billion Dollar Weather Events per year (CPI Adjusted to 2024)**




2023 had a record year for billion-dollar weather events in a single year (28) and the record for most billion-dollar severe thunderstorm losses (19).

*The numbers in the chart are economic impacts from these events and not specific to just renewable projects.

Over the past five years, insurers have been managing their exposure by increasing premiums and deductibles while reducing limits to ensure future sustainability. The challenge for project owners is the exposure is shifting from the insurer to the project owner's balance sheet.

Renewable project growth in storm prone states, such as Texas which added 6,500 MW of solar in 2023, has led many to forecast a continued gap between insurance availability and potential economic loss to project owners.

To close the gap amid this challenging risk transfer environment requires the greater sophistication of industry stakeholders to differentiate project reliability and resiliency. Despite the concern from insurers, Alliant have seen projects impacted by material hailstorms with no expected losses to the insurance market due to the following.

## Technology Capabilities

Spurred by the proactive demands of market-leading renewable energy owners, original equipment manufacturers are improving operating thresholds of critical equipment, including equipment specifically designed for significant hail. For instance, selecting thicker, heat-tempered panels and trackers that enable hail stow (high degree panel tilt) can protect against hail loss.

## Prudent Operational Practices

Utilizing technology effectively is critical to minimizing the impact of severe storm events to the balance sheets of project owners and insurers. Proving that a site has hail stow technology and uses it proactively in the face of a storm is key.

## Effectively Managing Risk

Closing the potential economic loss to projects through more sophisticated risk transfer solutions is paramount. The combination of captives, parametric solutions and managing insurer capacity can better position project owners to reduce their overall cost of risk.

More sophisticated renewable energy insurers can differentiate projects that are prioritizing technology selection and operating procedures. Implementing these strategies and working with your specialized power insurance broker to effectively communicate them to the insurer market allows owners to save up to 50% on reduced rate loads imposed by carriers for projects in highly exposed natural catastrophe zones. It pays to take the time to differentiate your project and select highly qualified partners when it comes to risk and insurance.

# Hail Case Study:
# 75 Degree Tilt Can Decrease PV Asset Damage Probability by 87%

By: Michael Alvarez, COO & Co-founder, Longroad Energy and Alex Au, Chief Technology Officer, Nextracker

On June 1, 2022, a large hailstorm impacted West Texas. Longroad Energy had completed construction on its 710 MWdc projects Prospero I and II in 2020-2021 with single-axis trackers and thin-film modules, putting extensive hail safety protocols in place. The installed hail sensors, advanced weather forecasting service, and dedicated onsite staff and Renewable Operations Center (ROC) in Maine were all put to the test during the hailstorm.

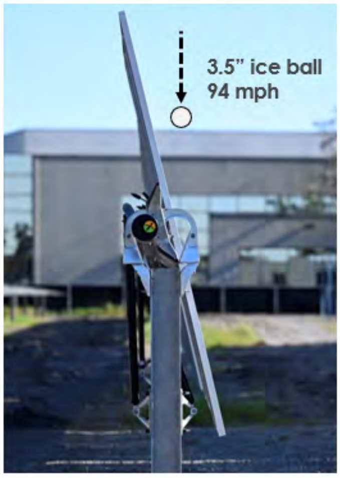
Longroad's ROC responded as the storm approached and set the trackers to the maximum tilt: 60 degrees. When the storm arrived, it created white-out conditions with large hail stones and shifting winds. Locations that were hit the hardest saw 5,000 to 8,000 impacts of 2-to-3-inch hail stones per square meter.

Longroad's hail protocol performed as anticipated, stowing the modules 28 minutes ahead of the storm. Module damage was minimal in areas where the size of the hail stones stayed under two inches. In regions that were hit with bigger hail stones, around one-third of the stowed modules experienced damage. These results were remarkably in accordance with Longroad's expectations based on the available lab data.

After the fact, VDE Americas analyzed this hail event, using simulated hail strike lab data from Nextracker and the Renewable Energy Test Center. Under conditions of 3.5" hail size, no wind, and thin-film modules, VDE concluded that a steeper stow angle of 75 degrees would have reduced the probability of module damage at Prospero from 8% to 1% (an 87% risk reduction).

Based on the modeled results at the Prospero sites, trackers with 75-degree stow capability can be an important tool for hail-exposed sites. While big hail events cannot be avoided in some regions, damage can be minimized with proper preparation and careful technology selection.

**Figure 1. 3.5" ice balls, vertically falling single strike, First Solar S6+ panels, 87% decrease in breakage probability.**

| | 50° stow | 60° stow | 75° stow |
|---|---|---|---|
| Tracker angle stow conditions at test site |  |  |  |
| Effective Kinetic Energy | 121 J | 73 J | 20 J |
| Est. Breakage Probability | 33% | 8% | 1% |

Sources: RETC, Nextracker.

# Operational Risk

*Optimizing system performance requires addressing equipment-related downtime, voltage collapse, inverter failures, and soiling through comprehensive O&M planning and accurate forecasting.*

**kWh Analytics**
Aggregating portfolios of 4 or more sites can cut the risk of extreme downside scenarios by 50%, but overly optimistic P50's remain the largest driver of under-performance

**Solarlytics**
Voltage collapse can reduce production by more than 20%

**Univers**
O&M corrective action statistics show a 14% surge in winter compared to summer in 2023

**SolarGrade**
Safety problems requiring partial or total de-energization found in 11% of PV systems inspected by auditors

**Clean Power Research**
Unmitigated soiling of PV systems can reduce annual energy production by 50%

**kWh Analytics**
Inverters cause 59% of lost energy, but DC distribution issues last 2.2x longer than they're worth

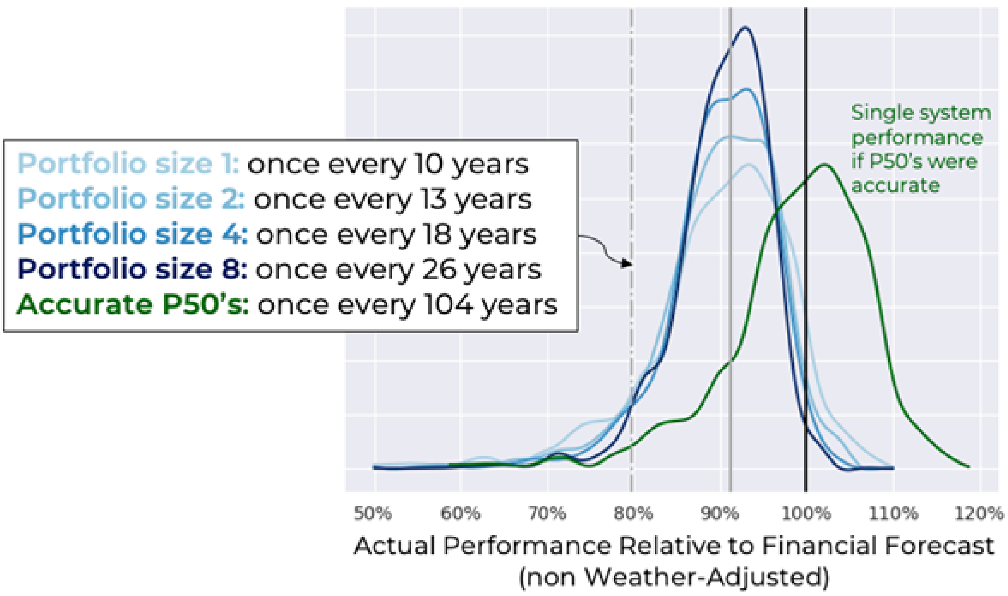
# Aggregating portfolios of 4 or more sites can cut the risk of extreme downside scenarios by 50%, but overly optimistic P50's remain the largest driver of under-performance

By: Veronica Anderson, Sr. Data Scientist, kWh Analytics

In previous releases of the Solar Risk Assessment, kWh Analytics have shown that most financial forecasts under-estimate the risk of extreme downside scenarios. Extreme underperformance at the forecasted P99 level that should occur once every 100 years is occurring as frequently as every 6 years, mainly due to over-optimistic P50 forecasts. One possible way to mitigate the risk of extreme downside scenarios is to aggregate portfolios of projects for financing – the distribution of risk increases the likelihood that a poorly performing site will be balanced by a better one within the portfolio. The team sought to quantify the impact of portfolio aggregation on extreme downside scenarios and determine if this is a viable strategy for reducing financial risk due to underperformance.

Using a dataset of non weather-adjusted production data and P50 estimates provided by asset owners for 301 utility-scale sites, covering 935 years of production from 2017-2022, we simulated the performance of synthetic portfolios of varying sizes and compared the results to single systems.

**Figure 1. Frequency of outcomes at different portfolio sizes**




kWh Analytics found that the median performance across all portfolio sizes was 91%, indicating that forecasts remain overly optimistic relative to actual performance. An asset owner would need to aggregate at least four systems in order to cut in half the likelihood of including a year where the portfolio performs below 80% of its initial forecast. While portfolio aggregation can be an important tool to reduce risk, the magnitude of the effect is dwarfed compared to the effect of using more accurate forecasts. Improving P50 forecast accuracy with realistic, data-driven availability estimates has the potential to decrease the occurrence of extreme downside scenarios by as much as a factor of 10.

# Voltage collapse can reduce production by more than 20%

By: Rhone Resch, Thomas Mart, John Abe, Solarlytics

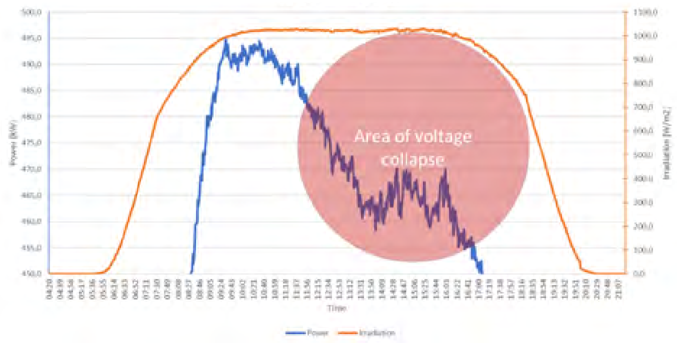
Voltage collapse, a significant decline in voltage levels within the DC field, is a fast-growing performance problem that affects the financial viability of many solar installations. As the voltage collapses below the inverter operating range, it hinders the inverter's ability to match the DC field voltage resulting in energy losses. In advanced cases, voltage collapse causes the inverters to frequently trip, leading to energy losses that exceed 20%.

Voltage collapse is caused by various environmental factors. Systems designed for cold weather climates require shorter strings to perform on cold days. But when these systems face the warm weather of summer, the string voltage drops below the inverter range, affecting the efficiency of the inverter. Exacerbating the problem are soiling, module degradation and the fact that we are deploying more solar in areas with extreme temperature fluctuations. As global temperatures increase, voltage collapse is becoming a systemic problem. Based on our work with leading US asset owners, Solarlytics estimates that more than 30% of all utility scale plants in the US suffer from voltage collapse. The amount of lost energy and revenue depends on the project specifics and can exceed 20% of yearly energy.

## Data and Example

This is an illustration of a typical voltage collapse experienced at a site in Central California. The graph depicts the AC power output of a 500 kW inverter, represented by the blue line. Throughout the day, irradiation levels remained high and stable, as indicated by the orange line. The bubble on the graph highlights the area where power loss occurred as a result of the voltage collapse.

**Figure 1. Power and Irraditaion**



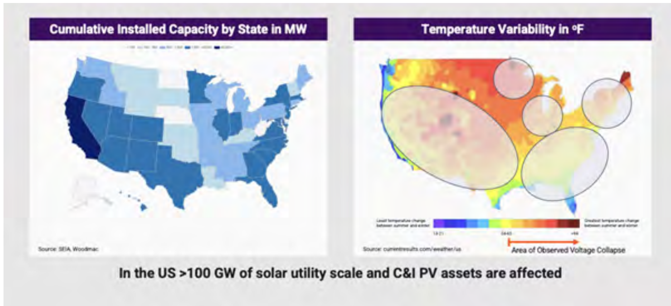

## Voltage Collapse Affects Assets Throughout the US

There are several solutions that asset managers can take to eliminate voltage collapse:

1. **Technical Solutions:** Use an advanced string-level monitoring and optimization system to provide a real-time view of system performance and predictive analytics to anticipate and mitigate voltage collapse events. These systems also allow the O&M manager to increase and maintain the voltage from the strings to ensure maximum inverter efficiency when there is the potential for a voltage collapse.
2. **Proper Design and Maintenance:** Verifying proper system sizing, inverter configuration, and regular predictive and preventative maintenance are essential to mitigating voltage collapse stressors.
3. **Continuous Monitoring:** High-frequency monitoring of system performance allows for early detection of voltage sagging and enables prompt corrective actions.

Effectively addressing voltage collapse with technology, monitoring and maintenance are key to maximize efficiency and performance of solar PV systems. Every asset owner, investor, and O&M company must take steps to understand and manage this rapidly growing issue to ensure optimal energy production and to improve the reliability of plant returns.

**Figure 2. Voltage collapse occurs in all states with high installed solar PV Capacity**



# O&M corrective action statistics show a 14% surge in winter compared to summer in 2023

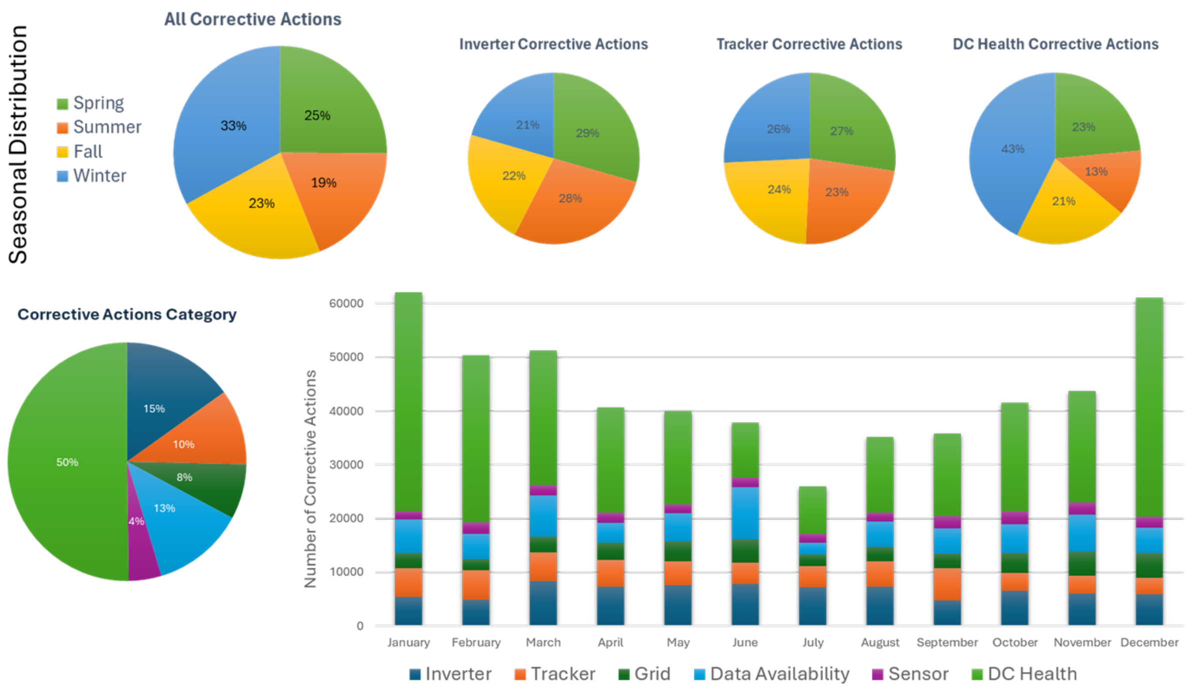
By: Anjie Jiang, Senior Staff Product Engineer, Julián Ascencio-Vásquez, PhD, Head of Solar Advanced Analytics, Univers

With the rapidly increasing number of solar assets under operation, the field workforce demand also grows to maintain an optimal asset state. Thus, Operation and Maintenance (O&M) planning becomes increasingly critical to optimize the performance and longevity of solar installations, minimize downtime and ensure consistent energy production with minimized OPEX costs. Analyzing corrective action patterns allows O&M teams to allocate resources efficiently over the year, boost system reliability, and proactively implement preventative measures.

Data-driven analytics tools, such as Univers Solar Advanced Analytics (AA), plays a pivotal role in providing data-driven recommendations for corrective actions for PV projects. Analyzing all corrective actions throughout 2023 for a fleet of +300 sites, +28000 devices and +11GW, Univers have discerned distinct seasonal patterns across various categories of corrective actions, including inverters, trackers, DC health, sensors, grid and data availability.

Figure 1 shows the monthly distribution of different categories of corrective actions, showcasing notable trends across seasons. Remarkably, winter (December to February) exhibits a 14% increase in total corrective actions compared to summer (June to August). Specifically, January and February stand out with the highest corrective action counts, surpassing 60,000 corrective actions monthly. Notably, DC Health accounts for approximately 50% of the total corrective actions, primarily attributed to the substantial presence of DC-level components in the PV system. Following closely is the category of Inverter corrective actions, comprising 15% of the total, signifying its significance in system maintenance and optimization. Data Availability actions rank third, representing 13% of the total corrective actions. 43% of DC health corrective actions occur during winter, indicating the influence of winter environmental conditions such as low temperatures, reduced irradiance, and snow cover on DC inputs and strings. In contrast, inverters are prone to experiencing corrective actions more frequently during warmer seasons (spring and summer) because elevated temperatures can lead to cooling system failure and decreased inverter efficiency. Additionally, corrective actions for trackers exhibit relatively consistent distribution across seasons, suggesting less pronounced seasonal impacts on trackers.

**Figure 1. Corrective Actions Monthly Distribution and seasonal distribution for the main components in PV systems (Inverter, DC components and trackers)**




These insights underscore the importance of comprehending seasonal variations in corrective action patterns. Anticipating a rise in corrective actions, particularly on DC health during winter, O&M providers should allocate resources for manpower and inventory of spare components during this season. They should strategize to address a higher volume of DC health issues per truck roll. Moreover, O&M providers need to be mindful of potential inverter performance issues in summer and should set aside replacement cooling components accordingly. This understanding facilitates enhanced O&M planning, enabling targeted interventions and resource allocation to mitigate environmental challenges and optimize system performance throughout the year.

# Safety problems requiring partial or total de-energization found in 11% of PV systems inspected by auditors

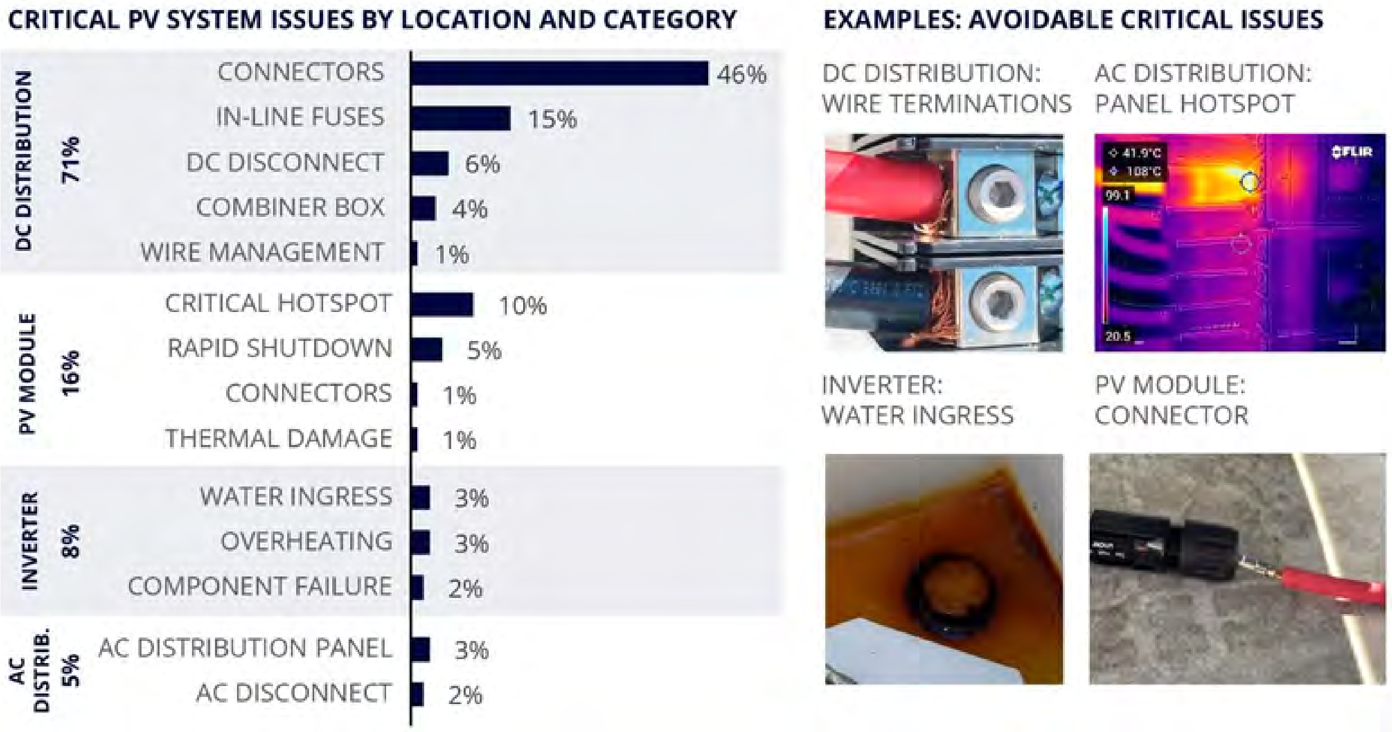
By: David Penalva, CEO and Co-Founder, SolarGrade

Critical issues were found in 11% of U.S. solar projects in a study of inspections conducted from January 2023 to March 2024. The critical severity level is only used for issues that are likely to cause catastrophic failure before the next maintenance event. These safety problems always result in financial losses due to lost energy yield and remediation costs. To protect personnel and property, partial or total de-energization of the PV system is required until corrective action is taken.

**In almost all cases, critical issues can be avoided with third-party QA/QC, proactive preventative maintenance, and organized, geo-referenced fieldwork records.**

The chart below summarizes critical issues in nearly 300 C&I and DG projects with an average system size of 8.4 MWdc. The data was collected with SolarGrade, a fieldwork and asset management software platform. Additional findings will be released in the 2024 SolarGrade PV Health Report.

**Figure 1. Critical PV System Issues by Location and Category**




## Connectors and Safety

The most common critical issues are in DC connectors, especially field-made connectors and homeruns. When these connectors are installed improperly, cross-mated, or exposed to environmental elements, they are prone to dangerous DC arcing and overheating.

Unsafe connectors are relatively common due to (1) complex installation requirements and tooling, (2) pervasive myths around MC4 compatibility, and (3) lack of field team training. This has driven widespread but improper installation techniques that result in improperly seated electrical contacts, compromised connector integrity, and increased susceptibility to accelerated degradation. For more information, read the SolarGrade Connector Safety Guide.

## Defining Risk

Not all risks are equal. Risks that threaten property and human life must be neutralized immediately and remediated quickly – and then measured so they can be avoided in future.

Yet the solar industry lacks universal standards for quantifying risks, although several models have been explored[1].

**As the market matures, consistent metrics to quantify and compare technical risks are essential to safe, profitable, and reliable solar operations.**

1 Quantifiation of Technical Risks in PV Power Systems 2021. International Energy Agency: Photovoltaic Power Systems Programme. Report IEA-PVPS T13-23:2021.

# Unmitigated soiling of PV systems can reduce annual energy production by 50%

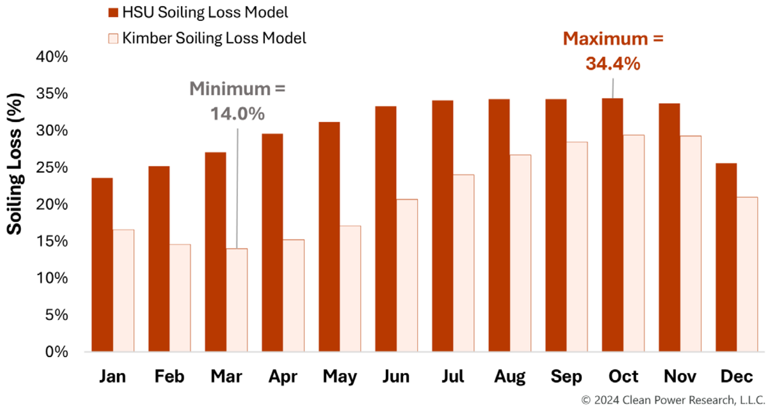
By: Evan Kyte (Product Manager), Hang Bui (Product Manager), Clean Power Research ®

Soiling—the accumulation of dirt, dust, and other particulates on solar panels—may appear minor, but its impact on photovoltaic (PV) system performance can be significant. According to NREL, soiling can cause annual energy losses of up to 50% in specific regions[1]. Our study investigates two common models for estimating soiling-related energy impacts. By analyzing these models at a 1 km spatial resolution, incorporating typical PV system parameters, and leveraging SolarAnywhere ® V3.7 datasets, Clean Power Research aims to highlight model variation and the importance of accurate inputs to minimize PV performance uncertainty.

## Understanding Soiling Model Variations

The Humboldt State University (HSU) and Kimber soiling loss models are the top two prevailing models in the industry. While the HSU model relies on particulate matter ($PM_{2.5}$, $PM_{10}$) and rain accumulation as core input parameters,[2] .the Kimber model relies on user-applied assumed soiling loss rates and cleaning frequency.[3] To simply compare the two, the HSU model is more dependent on observed weather data while the Kimber model is more dependent on empirical data and industry practice.

**Figure 1. Comparison of Soiling Loss Models**

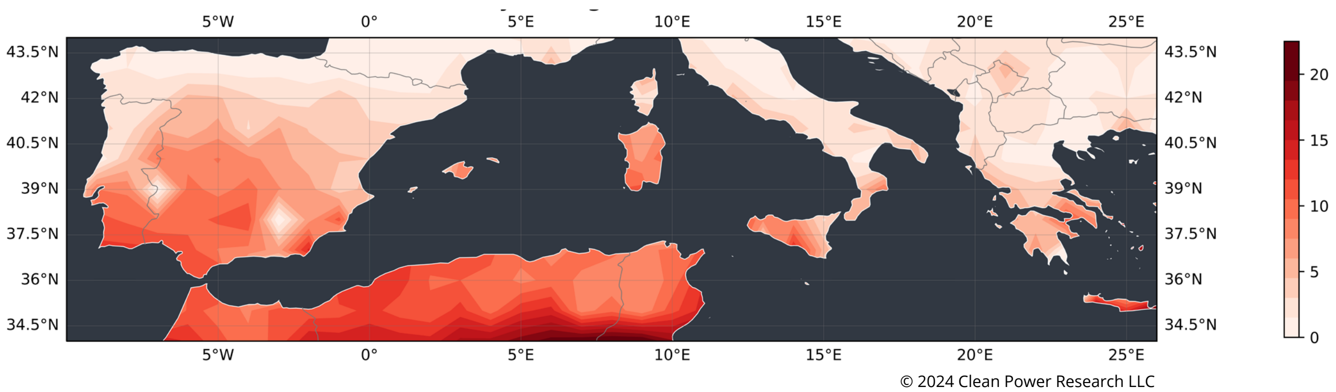



In the high-soiling location of Harad, Saudi Arabia the HSU model predicts an annual energy loss of 31.0% while the Kimber model estimates 21.6%. Monthly energy losses from soiling ranged from 14.0% to 34.4% when compared to a perfectly clean system. While both models have the same order of magnitude for loss estimation they vary significantly in absolute power impact.

The figure below depicts the HSU model's projected maximum monthly soiling loss over a large area.

The estimated soiling-losses exhibit considerable variability, dependent upon location, model selection, and input parameters. However, one fact remains evident: unmitigated soiling can pose significant impacts to PV performance. By employing various soiling loss models, coupled with accurate model inputs and reliable irradiance data from SolarAnywhere, industry experts can establish effective strategies to minimize performance uncertainty when modeling PV systems in complex climate conditions.

**Figure 2. Maximum Percent Monthly Soiling Loss (%)**




1 Hicks, W. (2021, April 1). Scientists Studying Solar Try Solving a Dusty Problem. News. National Renewable Energy Laboratory (NREL)

2 M. Coello and L. Boyle, "Simple Model For Predicting Time Series Soiling of Photovoltaic Panels," in IEEE Journal of Photovoltaics. DOI: 10.1109/JPHOTOV.2019.2919628

3 "The Effect of Soiling on Large Grid-Connected Photovoltaic Systems in California and the Southwest Region of the United States," Adrianne Kimber, et al., IEEE 4th World Conference on Photovoltaic Energy Conference, 2006, DOI: 10.1109/WCPEC.2006.279690

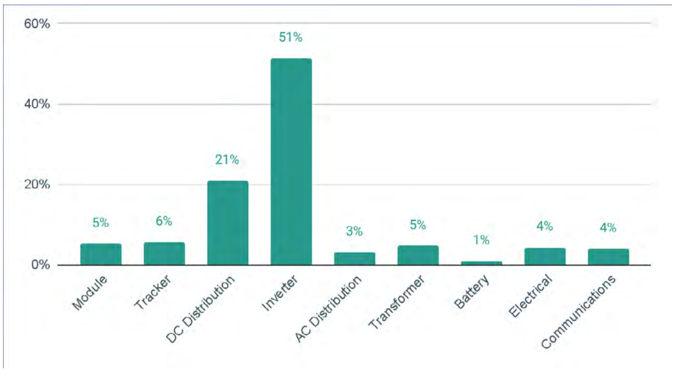
# Inverters cause 59% of lost energy, but DC distribution issues last 2.2x longer

By: Charity Sotero, Data Scientist, kWh Analytics

Solar photovoltaic (PV) systems are designed to last for 35 years or more, but the various components that make up these systems often fail much sooner. This premature failure can lead to costly repowering and replacement expenses, making it crucial for asset owners to develop a well-designed spare parts strategy. However, with limited onsite storage, it can be challenging to determine which components should be prioritized.

Operations and Maintenance (O&M) logs in the solar industry hold a rich potential for data on equipment failure, energy loss, and time to replace. kWh Analytics, in collaboration with Sandia National Labs and the National Renewable Energy Laboratory and with support from the Department of Energy, have developed a PV specific language dictionary and Natural Language Processing (NLP) model to decipher O&M logs and derive valuable insights.

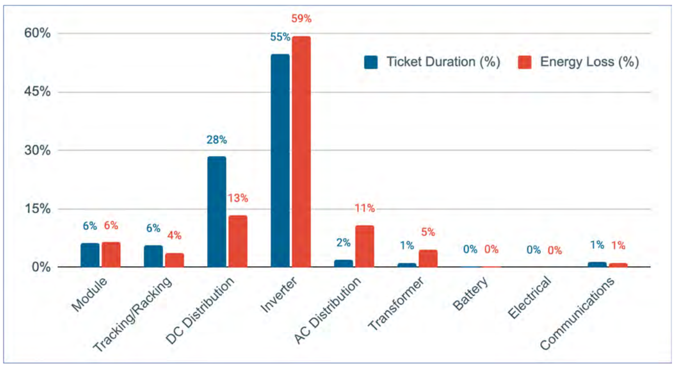
**Figure 1. Proportion of O&M Records (%), by Equipment Type**




The analysis of O&M logs revealed that the most frequent cause of corrective maintenance issues, or maintenance in response to a significant loss event were inverters (51%), followed by DC distribution equipment (including, but not limited to: connectors, combiners, wiring) (21%).

These results may vary from other studies done analyzing O&M records, possibly due to differences in the underlying data set. We analyze event records from largely utility-scale PV systems (average age 3.7 years) spanning 2005-2024, from 75+ data providers. All event records are unlabeled, and labels are the result of text pre-processing and NLP modeling (accuracy score of 83.91%).

**Figure 2. Proportion of O&M Ticket Impact (%), by Equipment Type**




When looking at average impact, inverter failure causes both the highest time to resolution (55% of O&M ticket duration) and the highest energy lost (59% of energy lost). Inverters issues are most often resolved with a repair attempt, and are composed of many sub-components. Their impact and design suggest that inverters benefit the most from an O&M spare parts strategy.

The most frequently-occuring key terms in inverter-specific O&M tickets are: controller, fan, and logic board. While these terms are not necessarily the most common failure modes, they may be useful in determining spare parts priority, with the caveat that the dataset is largely driven by utility-scale systems with central inverters. Asset owners should vary their spare parts strategy most suited to their technology and operating budget.

DC distribution issues have a significantly outsized impact on O&M time and labor (28%), which may be overlooked due to their relatively lower energy loss (13%). DC distribution issues are largely driven by connector mismatch issues, and so having the correctly-rated DC distribution components on hand is recommended.

The findings of this study provide valuable insights for asset owners looking to optimize their spare parts strategy. By prioritizing spare inverter sub-components, such as controllers, fans, and logic boards, and correctly-rated DC components, such as connectors, owners can minimize system downtime and reduce maintenance costs. The conclusion of this DOE-funded study will be to develop a “safe driver discount” for renewable energy insurance, further incentivizing the adoption of best practices.

# Battery Risk

*As BESS deployments grow, addressing risks related to fire safety, thermal management, and system integration is essential for ensuring their safe and reliable operation.*

**Lloyd's London**
Global role of battery energy storage systems poised for 13x growth

**Powin**
Conventional state of charge measurements are error-prone and can result in an average error of 7% in estimation of energy available for dispatch

**SEVO IFP**
Industry leading survey highlights 26% of energy storage systems face fire-detection and fire-suppression challenges

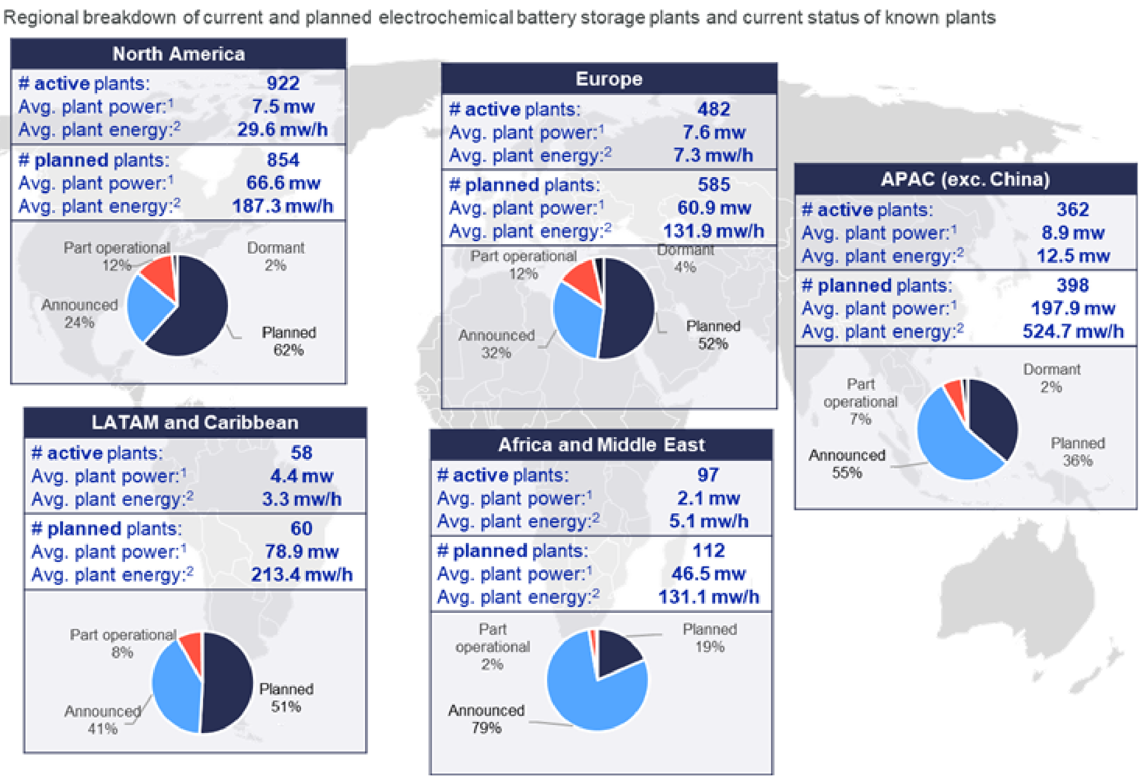
# Global role of battery energy storage systems poised for 13x growth

By: Alain Caplan, Head of Research & Strategic Partnerships, Lloyd's of London

The energy transition is driving deep and irreversible change in the power and energy markets. As renewable generation increases, energy storage will become more critical in balancing supply and demand and helping combat system stability issues.

The global battery energy storage systems (BESS) sector saw a 60% increase in installed capacity of grid-scale batteries between 2020 and 2021. There is currently about 15GW of installed capacity around the world, with an additional 181GW either under construction or planned, equivalent to nearly 13x the current capacity[1].

**Figure 1. Regional electrochemical BESS plant size and status**




Understandably, BESS projects are also gaining traction and interest among the insurance community, with underwriting appetite for risk and capacity growing. Any emerging technology like BESS brings new risks, and insurers are paying close attention to the risk of battery failure, thermal runaway and the failure of control systems, including from cyber attacks. Extreme weather such as floods or heatwaves are also a key consideration, depending on the location of the BESS asset.

As insurers develop their offering, the growth of new BESS technologies, as well as the limited availability of performance data from original equipment manufacturers can make it more difficult to stay on top of developments.

The establishment of minimum global standards and greater visibility around loss data can help underwriters gain confidence around the risks involved.

As investment grows, and BESS operators expand the number of planned plants globally, the insurance industry must remain agile, responding innovatively to technological change and working with clients to navigate the challenges of project deployment. Global marketplaces like Lloyd's that act as a clearinghouse for insurance risks will play an important role in the energy transition.

1 GlobalData

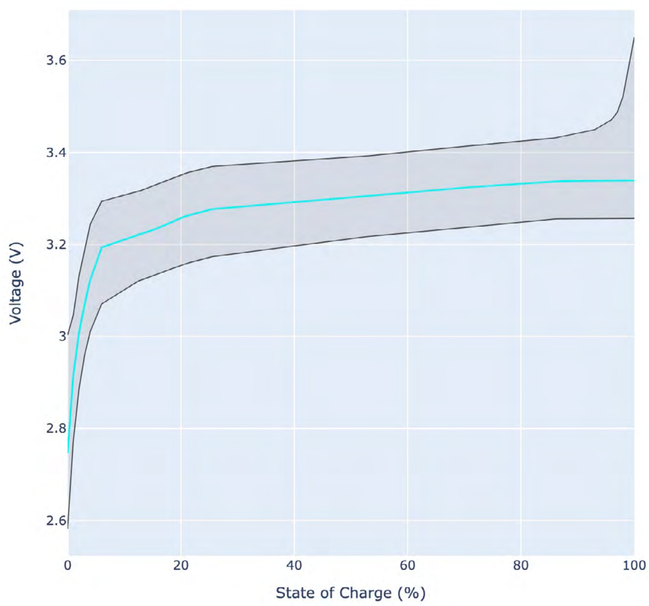
# Conventional state of charge measurements are error-prone and can result in an average error of 7% in estimation of energy available for dispatch

By: Kyle Smith, Monique Wong, Eric Stone, Powin

State of Charge (SOC) represents a Battery Energy Storage System's (BESS) available energy for discharge, making this an important metric for managing electric grid stability and reliability. SOC is critical in predictably committing to dispatch schedules and can lead to penalties if commitments for delivery of grid services cannot be fulfilled due to insufficient energy/capacity. Unfortunately, poor SOC estimation is common. Lithium Iron Phosphate (LFP) cells exhibit a flat voltage-SOC curve (Figure 1), making accurate estimations based on voltage alone nearly impossible between 20-95% SOC. The specific electrical architecture connecting thousands of cells further complicates the problem and reduces SOC certainty at the site level.

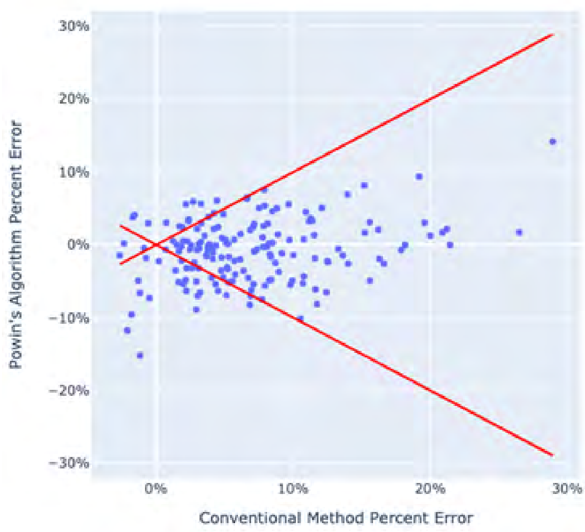
The conventional method of calculating SOC is referred to as "Coulomb Counting". This method is prone to accumulating error since it relies on accurately measuring charge / discharge current over time and an accurate initial SOC reading. Conventional SOC algorithms do not correct for sensor error, nor do they account for the electrical architecture connecting cells into a BESS. Powin has measured up to an average of 7% SOC error using conventional methods.

**Figure 1. Voltage vs. SOC Relationship for LFP cells (an example)**




Powin addresses these issues with an advanced SOC algorithm that leverages terabytes of cell-level data from Powin's operational fleet. The advanced SOC algorithm combines Coloumb Counting with data-driven state estimations to adjust for sensor error, temperature, and the effects of current on voltage. At the string level (individual unit/rack with capacity of around 230-375 kWh), this algorithm achieves an average error of only 3%, based on more than 6 months of operational studies (Figure 2).

**Figure 2. SOC Error - Conventional Method vs Powin's Algorithm**




In summary, accurate State of Charge (SOC) estimations are essential for the reliable operation of BESS assets and their ability to provide grid services effectively. Powin's advanced SOC algorithm increases the accuracy of estimated energy available for discharge, a necessary update to current technology as the industry works to improve the energy and power availability of all BESS systems with the goal of increased operational and financial reliability.

# Industry leading survey highlights 26% of energy storage systems face fire-detection and fire-suppression challenges

By: Illy Logu, Director, Business Strategy, SEVO IFP

A recent survey conducted by Clean Energy Associates (CEA) revealed that 26% of audited energy storage systems have deficiencies in their fire detection and suppression capabilities and 18% had issues with their thermal management systems. These findings highlight the lack of proper fire safety and its potential consequences to the future of the energy transition. The increasing deployment of Energy Storage Systems (ESS) globally is driven by the need to integrate renewable energy into the grid. However, safety concerns, particularly regarding fire safety, hinder progress, impacting public perception and regulatory approval. To address these concerns, a comprehensive approach is needed, covering risks from cell to site level.

Addressing these risks requires an approach tailored to each specific hazard. This involves adopting a micro to macro strategy to ensure proper protection. It is recommended to divide the process into two separate focuses; 1) addressing risks associated with batteries and 2) focusing on risks related to all other hazards in a container. Regarding batteries: It's about thermal management, not just fire protection.

1. Use reliable and thoroughly tested technologies and procure quality products.
2. Employ battery thermal management systems to prevent cascading thermal runaway, that is, uncontrolled cell to cell heat transfer. Various methods exist to prevent thermal runaway, each with unique efficiencies. The proof is in the data. Refer below for testing on cell direct injection fluid immersion as just one of the ways to prevent cell to cell propagation.
3. Install early detection mechanisms such as off-gas, hydrogen, and smoke detection to provide early warnings in case of failure.
4. Design containers to prevent explosions caused by toxic and flammable gases released during a thermal runaway event.
5. In case of a fire, activate emergency plans and allow fire departments to handle the situation, noting that most suppression systems are ineffective against battery fires.
6. Once a risk mitigation plan from the cell to container is in place, attention should shift to the site level. Implementing a risk-based approach to container-to-container fire propagation minimizes exposure to major economic distress and a potential catastrophic event.

As grid resiliency increasingly depends on ESS, there is a serious need for proactive risk mitigation strategies. The industry needs to collaborate to tackle these challenges. To that end, educating stakeholders on the risks spanning from battery cells to ESS sites is important to improve comprehension of relevant terminology, increase quality control measures, and promote heightened vendor quality control standards. The findings from the CEA survey serve as a reminder of the urgency in addressing fire-related vulnerabilities and implementing proper risk mitigation strategies. It is important that we make high safety standards a non-negotiable part of innovation and growth to safeguard the integrity of the sector as a whole.

**Figure 1. Cell to Cell Thermal Runaway - No Protection**

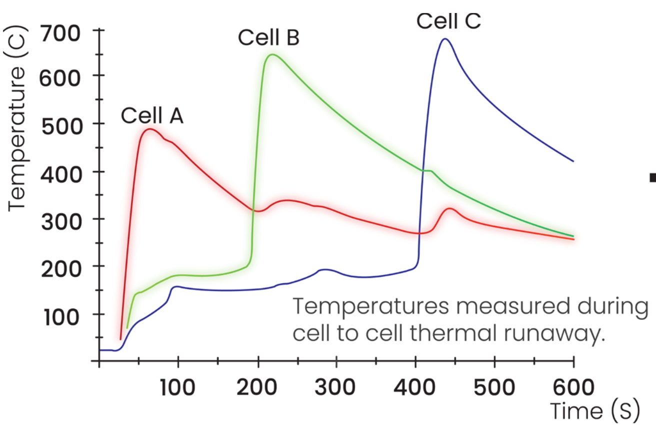
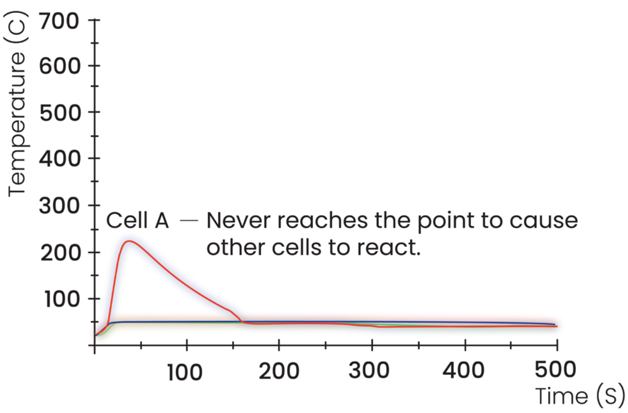



**Figure 2. Cell to Cell Thermal Runaway - Immersion Protection**




Meyring, Lu, Johnson, 3M Company, Application of Fluid Immersion for Increased Safety and Efficiency of Lithium-Ion Battery and Electronic Devices, SFPE International North America Conference and Expo, April 2014

# Contributors

**kWh Analytics:** kWh Analytics is a leading provider of Climate Insurance for zero-carbon assets. Utilizing their proprietary database of over 300,000 operating renewable energy assets, kWh Analytics uses real-world project performance data and decades of expertise to underwrite unique risk transfer products on behalf of insurance partners. **Website**

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**Kiwa PVEL** is the leading reliability and performance testing lab for downstream solar project developers, financiers, and asset owners around the world. As part of the larger Kiwa Group, Kiwa PVEL's integrated services for the solar supply chain offer technical solutions for mitigating risk, optimizing financing and improving solar and energy storage systems performance throughout the project lifecycle.

For over a decade, Kiwa PVEL's Product Qualification Program (PQP) has been globally recognized for replacing assumptions about PV module performance with quantifiable metrics. Related data and consulting services offered by Kiwa PVEL provide vital procurement intelligence to a network of downstream solar buyers. Visit kiwa.com/pvel and kiwa.com/solar to learn more. **Website**

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**Waaree** Energies Limited ("WEL") was founded in 1990. WEL is India's largest manufacturer of solar PV modules with the largest aggregate installed capacity of 12 GW, as of June 30, 2023. WEL commenced operations in 2007 focusing on solar PV module manufacturing with an aim to provide quality, cost-effective sustainable energy solutions across markets, and aid in reducing carbon footprint paving the way for sustainable energy thereby improving quality of life. As of June 30, 2023, WEL operated four solar module manufacturing facilities in India with international presence. Waaree is building a 3 GW of solar module manufacturing plant near Houston, Texas, USA which is expected to be operational by August 2024. In 2025 manufacturing capacity expansion of 3 GW of solar cell manufacturing and 5GW of solar module manufacturing is planned to be operational. For more information, please visit Waaree.com **Website**

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**Alliant** Power is the specialized national group within Alliant Insurance Services, comprised of a team of 56 power brokers, claims advocates and engineers solely dedicated to the power generation and renewables sector. Led by Rob Bothwell, Alliant Power represents 156+ GW of independent power assets and 62+ GW of renewable power assets with a total insured value exceeding $100B. Our market size and power and utility specific expertise uniquely position Alliant Power to deliver a comprehensive portfolio of risk and insurance solutions with world-class service. **Website**

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**Solarlytics** is a Silicon Valley based manufacturer of high-tech power electronics and artificial intelligence software designed to maximize solar energy production. Our technology eliminates voltage collapse caused by string imbalance, module misalignment, high temperatures and aging inverters. Our BOOST Platform digitizes solar assets and uses machine learning algorithms to analyze performance data and provide asset owners with predictive maintenance and actionable insights to optimize production. Solarlytics is defining the future of solar energy performance by partnering with industry leaders and innovating new solutions for maximizing clean energy production. **Website**

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**Univers** leads global decarbonization with a comprehensive system spanning IoT, renewables, energy storage, carbon management, and electric mobility. Our advanced technologies—Artificial Intelligence, Machine Learning, and sophisticated analytics—empower users to analyze past, present, and future scenarios. With 568GW managed energy assets and 500+ global clients, Univers is a trusted partner in sustainable energy transformation. Visit univers.com for more information. **Website**

# Contributors cont.

**SolarGrade** is an award-winning software platform that helps EPCs, O&Ms, and asset owners standardize, digitize, and analyze on-site work at renewable energy projects. The software turns construction reports and O&M logs into business intelligence and cuts labor costs by 30%. SolarGrade is developed by HelioVolta, an independent technical advisory that provides tech-enabled site inspections focused on project safety and reliability. **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, a product of Clean Power Research, is a global software and data provider for the solar industry, delivering solutions for asset development and operations. **Website**

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**Lloyd's** is the world's leading marketplace for insurance and reinsurance. Through the collective intelligence and expertise of the market's underwriters and brokers, we're sharing risk to create a braver world. The Lloyd's market offers the resources, capability, and insight to develop new and innovative products for customers in any industry, on any scale, in more than 200 territories. **Website**

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**Powin** is advancing the next frontier of energy and changing the way we power our daily lives by ensuring access to clean, resilient, and affordable power. As a global energy platform provider, we offer fully integrated battery storage solutions, software, and services to optimize grid performance, enabling the transition to cleaner energy sources. Powin has over 17,000 MWh of energy storage systems that have been deployed or are under construction worldwide. To learn more visit Powin.com. **Website**

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**SEVO IFP** is a vertically integrated special hazard fire and life safety company that leads in solutions for mission critical facilities, specializing in the Energy, Aviation, Defense, Data, and Industrial fields. With over 20 years of leadership, we pioneer sustainable solutions and set industry standards globally. Our solutions for ESS are deployed worldwide, ensuring the highest level of safety. **Website**

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**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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**Nextracker** is a leading provider of intelligent, integrated solar tracker and software solutions used in utility-scale and ground-mounted distributed generation solar projects around the world. Our products enable solar panels power plants to follow the sun's movement across the sky and optimize plant performance. With power plants operating in more than 30 countries worldwide, Nextracker offers solar tracker technologies that increase energy production while reducing costs for significant plant ROI. For more information, please visit www.nextracker.com. **Website**

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**Longroad Energy** Founded in 2016, Longroad Energy Holdings, LLC is focused on renewable energy project development, operating assets, and services. Longroad has developed or acquired 4.9 GW of renewable energy projects across the United States and has raised over $12.8 billion of equity, debt, and tax equity to support completion of its portfolio. Today, Longroad owns over 3.1 GW of wind, solar, and storage projects and operates and manages a total of 5.0 GW on behalf of Longroad and third parties. Longroad is owned by the NZ Superannuation Fund, Infratil Limited, MEAG MUNICH ERGO Asset Management, and Longroad Energy Partners, LLC. **Website**