Solar Risk Assessment: 2022

Quantitative Insights from the Industry Experts

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Executive Summary

"In God we trust, all others must bring data." - American Statistician W. Edwards Deming

2021 marked the third year in a row that solar represented the largest share of new generation capacity in the United States. We should be proud of this feat, but our work remains cut out for us; continued supply chain constraints, tariff investigations, and inflationary markets all pose uncertainty to development pipelines in 2022. The solar industry is no stranger to adversity. Previous dips in the “solarcoaster” have trained our industry to exercise muscles of creativity and collaboration. Those muscles will be critical this year to identify new solutions to industry challenges.

This year’s Solar Risk Assessment is another testament to the willingness of industry’s leading experts on measurement and management of solar risk to collaborate and leverage data and science to move our industry forward.

Designed intentionally for the non-technical solar financing community, this report has been and will continue to be refreshed every year to provide the latest insights on the evolution of solar risk.

In our fourth annual report, we highlight objective industry research on financial, operating, and natural catastrophe risks. We found:

1. Capital expenditure costs in solar development are increasing for the first time in decades. A combination of commodity prices, supply chain constraints and inflationary markets are tightening margins across the value chain. Equity owners and lenders are forced to scrutinize their assumptions and protect their interest.
2. Solar projects continue to underperform. New research on the verified performance of system degradation, inverter availability, and PV modeling indicate that the industry has significantly overestimated our expectations of these assets. The industry will need to reckon the realities in the field with the assumptions we use on paper.
3. The climate crisis continues to reveal itself through increased frequency and severity of catastrophes that impact our ability to finance, insure and maintain solar assets. Both insurers and insureds must work together to find data-driven solutions to manage and mitigate these risks.

Overcoming these challenges to ensure sustainable growth and investment of capital into solar is in our collective interest and will subsequently require a concerted industry effort. We hope these key takeaways resonate with you and we look forward to the shared work of advancing our solar industry.

Cover Photo Credit: Photo Courtesy of Cypress Creek Renewables O&M and Raptor Maps

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FINANCIAL MODELING RISK

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- **CapEx trends**
- **AD/CVD impacts**
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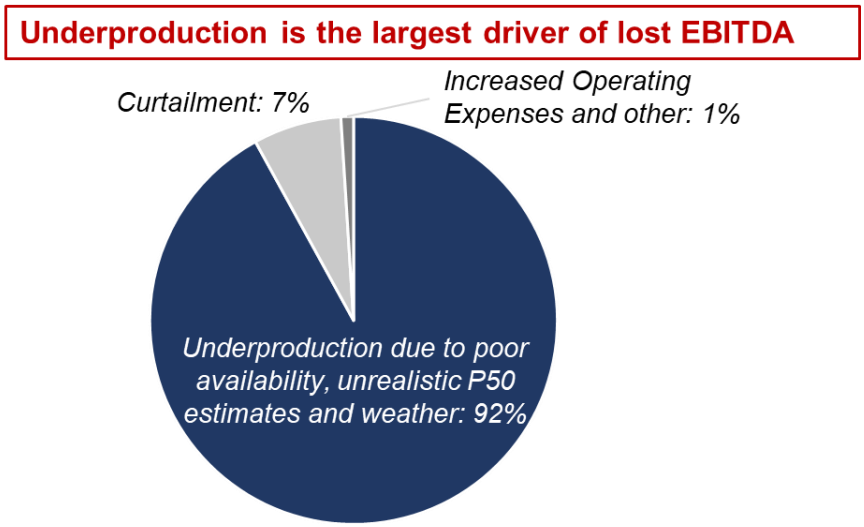
- **Irradiance results**

92% of lost EBITDA is due to underproduction, dwarfing all other sources of risk

By: Ali Afzal, Project Finance Manager

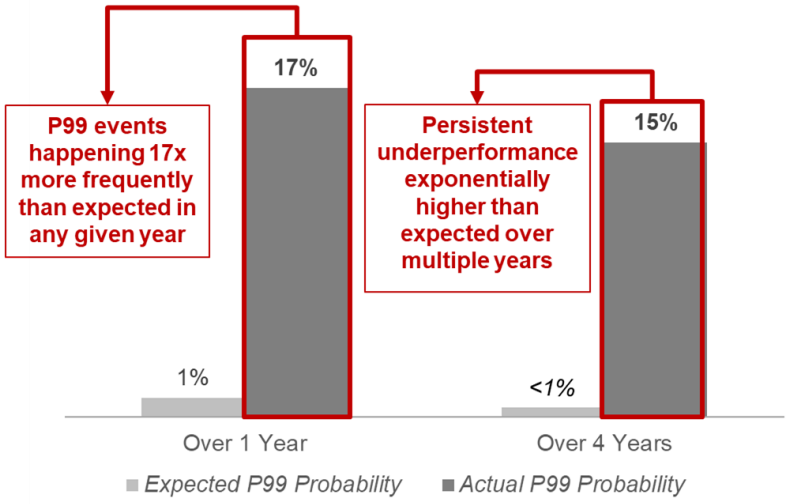
Underproduction continues to be the greatest source of EBITDA volatility. Conceptually, the two biggest risks in any solar loan is a loss of revenue or an escalation in operating expenses. However, an analysis of our database (covering >30% of the US operating fleet) reveals that the average project has not experienced a material increase in total operating expenses compared with the budgeted amount at financing. Meanwhile, widespread underproduction is the largest cause of EBITDA shortfalls, with 92% of all lost EBITDA caused by poor availability, unrealistic production forecasts, and lower-than-expected irradiance.

Figure 1. The average difference between actual and expected EBITDA



Last year's 2021 Solar Risk Assessment (SRA) report revealed that solar projects are experiencing P99 events once every 6 years instead of once every hundred years, 17x more often than expected. In an ongoing review of the data, we see these trends mostly continuing unabated. In addition to yearly underperformance, 1-in-7 projects are persistently underperforming their P99 over multiple years, highlighting that underproduction risk remains exponentially greater than expected.

Figure 2. 1-in-7 assets are continuously underperforming their P99 over multiple years. Figure below shows the expected vs. actual P99 probabilities over a 1 year and 4 year period



New build solar capital expenditures have increased by 8% for a typical 100 MW PV system compared to 2021

By: Sagar Chopra, Research Analyst

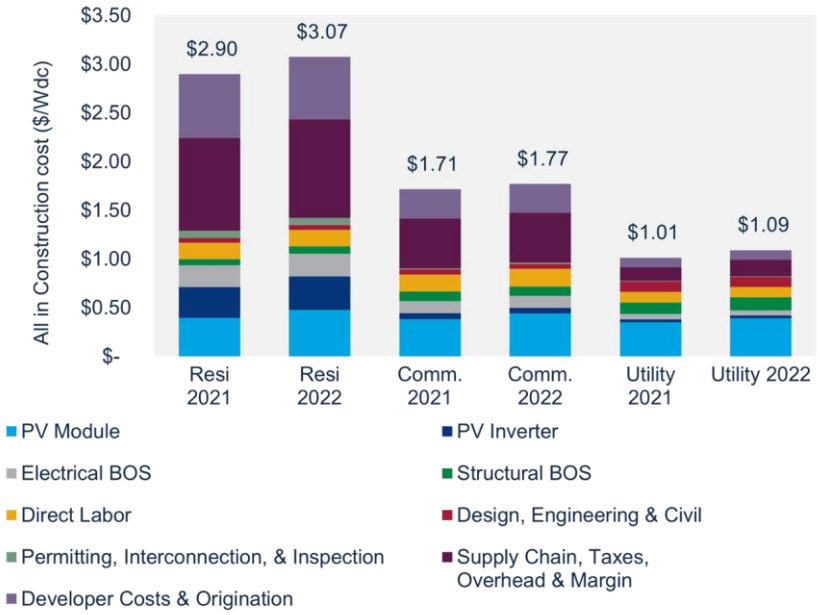
PV system prices continue to remain high through the first half of 2022 as supply chain constraints and policy uncertainties create a high-risk environment for development. However, improvements in module technology and the adoption of large format modules will provide some relief via amortization of both component and soft costs.

The pandemic heavily disrupted the global PV supply chain, leading to increased freight costs and longer lead times. Elevated commodity prices, such as steel, aluminum, and copper −which will be prolonged due to the Russia/Ukraine conflict − continue to squeeze already-tight developers' margins. Labor shortages driven by the 'Great resignation' from 2021 will drag on 2022 and increase development costs. Other soft costs, such as profit margins, contingencies, insurance costs, and project management fees have also increased due to the risks associated with project development in this uncertain environment.

PV CAPEX across market segments

Utility-scale projects coming online in 2022 had the most significant impact on procurement due to all the supply-chain related challenges, driving costs up by 8% for an average 100 MWdc system.

Figure 1. Modeled US national average system prices by market segment, 2021 and 2022 (US$/Wdc)



Average residential system: 8 kWdc rooftop system with mono PERC modules and microinverters

Average Commercial system: 500 kWdc rooftop system with mono PERC modules and three-phase string inverters.

Average Utility system: 100 MWdc ground-mount system with bifacial modules, central inverters and 1P single-axis tracking

Expected relief in the future?

Widespread adoption of large format modules provides relief against the cost headwinds. The climate provisions under the Build Back Better act propose ITC extensions beyond 2026 and additional tax credits for domestic content. An extension of Section 201 tariffs on mono PERC modules continues to create pricing pressure, but the exclusion of bifacial modules could provide some relief for the next 4 years.

As industries and businesses return to normal, Wood Mackenzie expects long-term prices to decline by 2026-2027, but the pending AD/CVD tariff investigation on Southeast Asian module imports, which for now has been deferred by executive order for the next two years, could prove to be a headwind against that forecast.

Probable tariff exemption will allow US solar to exceed 24GW this year, but supply constraints remain

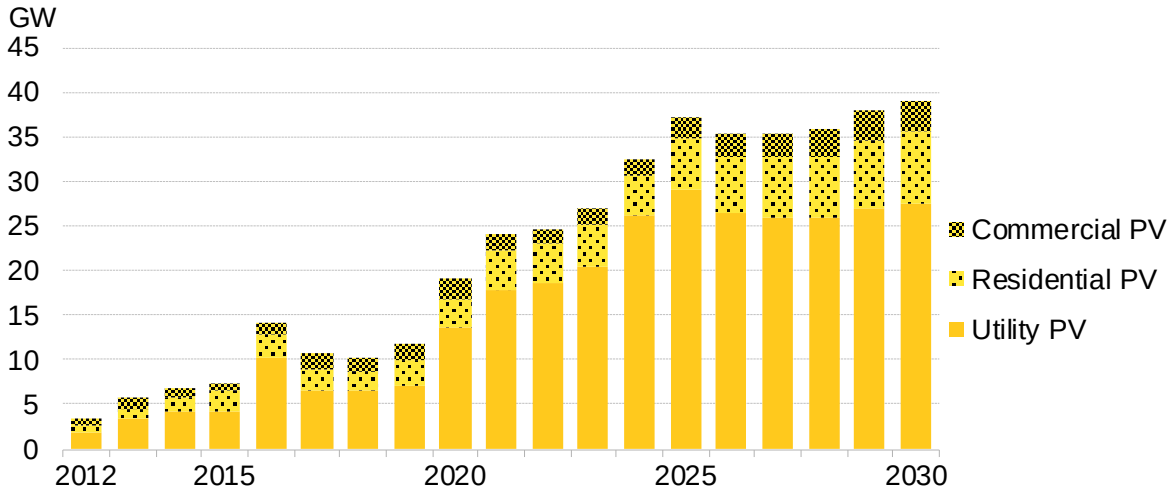
By: Pol Lezcano, Research Analyst

The US Department of Commerce said earlier this year that solar silicon cells made in Malaysia, Vietnam, Thailand and Cambodia may be subject to new antidumping and countervailing duties. More than 85% of module imports in the US last year and roughly half of the cells came from the targeted countries in the tariff proposal. Without knowing the level of potential tariffs and because they may be retroactive, major module makers halted shipments to the US.

But on June 6, most of the US solar industry breathed a sigh of relief after the White House effectively granted Commerce the authority to hold off for two years on imposing new duties on solar cells and modules from Southeast Asia. The exemption would hold even if Commerce finds duties to be applicable in its preliminary results expected in the next few months. Citing a 1930 law and concerns over short-term grid reliability, the move appears to bring at least a temporary end to disruptive tariff uncertainty that delayed dozens of solar projects.

Earlier this year, BNEF lowered its US solar forecast for 2022 by 7.8GW due primarily to module availability concerns. Although there are still considerable supply constraints besides the tariff case, we have slightly increased our solar forecast for the US due to the newly introduced exemption. We now expect the US to add 24.7GW in 2022, up from 22.7GW, and 27GW in 2023, up from 24GW.

Figure 1. Annual US Solar Installations[1]



The Biden administration's decision comes as a big relief for US solar developers. We expect developers to pile up modules in the next two years, following the example of Indian buyers who collectively stockpiled almost a year's worth of build before a new tariff kicked in on April 1, 2022. That said, US module buyers would be wise to keep a close eye on the courts. Auxin or another party could sue the federal government over the 24-month exemption, arguing that it acted unlawfully. The administration appears to have applied the 1930 Tariff Act in a novel way.

Module makers in Southeast Asia have had alternative markets to serve this year. While the US remains a high-value market, shipping constraints will slow delivery of new modules and it may take months for US projects to receive product. If the exemption is successful, BNEF expects prices could remain high next year as well, as buyers hoard modules to use once the potential tariffs kick in.

[1] BloombergNEF. Note: Capacity reported in direct current (DC) terms.

1-in-3 solar assets under development are overstating P50 estimates by >5%

By: Sarath Srinivasan, Vice President, Head of Product

The rapid growth of the solar industry is underpinned by solar's reputation as a low-risk asset class with predictable and stable long term cash flows. Continued market confidence in the accuracy of production estimates is fundamental to solar's cash flow predictability and thus its access to low-cost capital. Unfortunately, the 2021 Solar Generation Index (SGI) report revealed that asset performance has deteriorated in recent years.

Figure 1. Average Annual Weather Adjusted Performance by Region and Operational Year (2011-2020)

Region	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	% YOY [19-20]
Southwest											2%
Southeast											0%
West											-13%
Northeast											-4%
Mid-West											-2%
Mid-Atlantic											-12%
Northwest											1%
National Average	87%	95%	93%	93%	94%	93%	92%	92%	91%	92%	-4%

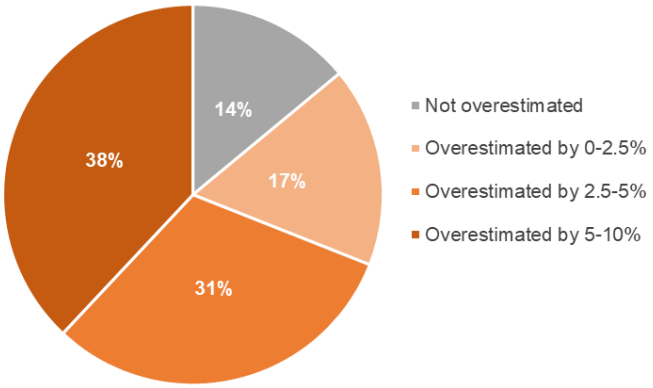
Weather-Adj. Performance Index 111% 82%

Source: *kWh Analytics Solar Generation Index: Quantitative Insights from Leading Asset Owners, 2021 Volume*

We've now insured over 2.5 GW of solar assets with the Solar Revenue Put protecting lenders and investors from production risk. To take on this risk, we've built a best-in-class model that's trained and tested on the industry's leading solar asset performance database. This model, calibrated to our real-world production data, allows us to accurately predict the real P50, P90, and P99 for any project or portfolio, and price the risk of underperformance.

In 2021, we reviewed production estimates on close to 9 GW of potential new build utility scale solar projects distributed geographically across all parts of the US In this representative sample, we've seen that an overwhelming majority of the projects (85%) had aggressive P50 estimates. Furthermore, for 1 in 3 projects, the P50 forecast was between 5-10% higher than our model predicted. For the median project in this category our model predicted a production forecast that was 7.2% lower than the P50 estimate. This equates to equity investors locking in returns 30-40% lower than expected, significantly impairing the equity values of these investments. When the P50 production is aggressive, this also directly implies that P99 events will occur more frequently than estimated - once in every 6 years instead of once every 100 years, exposing lenders to a higher risk of default.

Figure 2. P50 Overestimation



To enable continued growth and access to low cost of capital, the industry needs to use data driven approaches to accurately estimate production to ensure the asset class performs as advertised and delivers long-term stable cash flows to investors.

Annual solar irradiation 10% below long-term average in several US regions

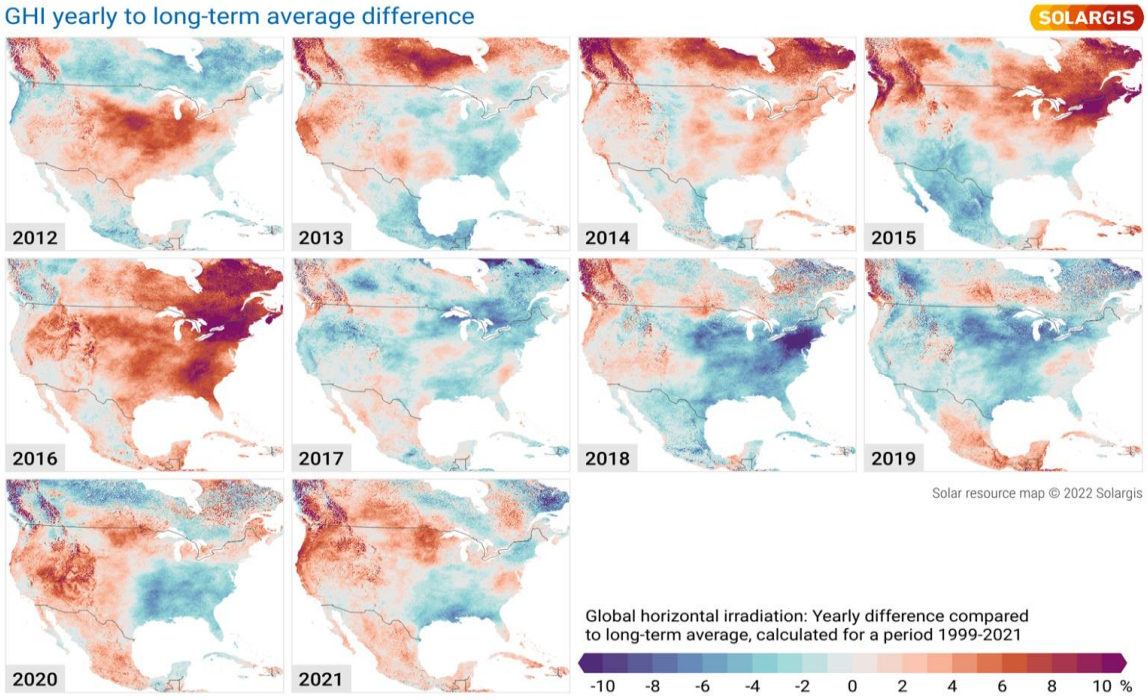
By: Giri Srinivasan, CEO, Americas

Solar resource data company, Solargis, recently conducted an analysis of annual global horizontal irradiation ("GHI") compared to long-term averages, finding significant resource variability in North America over a period of 23 years from 1999 to 2021.

Solargis' solar performance maps illustrate how global horizontal irradiation deviated year-on-year from the long-term average values, which are often used to underpin production estimates and financial models. Significant interannual variability both above and below the average is seen across North America over the past ten years, leading to volatile performance and financial returns for asset owners and investors.

Solargis' data for the last ten years shows annual values up to 10% compared to long-term averages in the North and Southeast. GHI in the Northwest, however, has regularly outperformed the 23-year long-term average by similar margins.

Figure 1: GHI variability across North America compared to 23-years long-term average



High-resolution resource data supports a data-driven approach to solar power generation modeling that reduces uncertainty of financial returns and enables solar asset owners to develop mitigating strategies to variability of weather. Applications of this data today include:

- Financial hedging and insurance products to transfer production and weather risk
- Project development prospecting, optimization of technical configuration and financial modeling
- Extreme weather risk analysis and development of mitigation measures.

With climate change set to bring further uncertainty, the task ahead remains the same – utilize high quality-data to best provide affordable, reliable, green energy while ensuring ample return on investment.

OPERATING RISK

Topics Covered:

- **Inverter OEM and performance data**
- **Terrain impacts**
- **System complexity and quality trends**
- **Degradation rates**

Inverters perform 40% worse during two-year warranty period compared to remaining years of operation

By: Frank Kelly, VP

NovaSource operates 20GW of utility-scale PV systems. Based on its experience and industry knowledge, NovaSource has observed that inverters when covered by their original equipment manufacturer's warranty are underperforming and not meeting proforma availability targets compared to the same inverters when they are operating out-of-warranty.

Inverters are critical components to the performance of PV sites and on average account for ~60% of a site's total lost energy[1]. To measure the performance of inverters, we look at two key metrics: (1) failure rate and (2) mean-time-to-repair ("MTTR"). A lower failure rate and shorter MTTR are key to projects achieving their availability targets.

After reviewing the GWs of inverters we operate, we found that on average, inverter failure incidences that impact generation occur 0.8 to 1.4 times per inverter per year. To quantify the severity and complexity of repairs necessary to bring systems back online, we also review the MTTR associated with inverter failure incidences. While in many cases the complexity to repair is low (e.g. requiring a reset, tightening connections, or replacing parts), other repairs require significant spare parts lead times and technical fixes.

Surprisingly, the NovaSource team identified significant deviation of site technical availability driven by failure rate and MTTR when comparing inverters under warranty (first two years) vs. the same inverters out-of-warranty (plant age 2+). Figure 1 shows that assets within their first two years of operations had the lowest technical availability[2] and began to perform better overtime as inverters fell out of their warranty timelines and constraints. This is corroborated with the review of inverter failure rates and MTTR in Figure 2. Failure rates dropped by ~40% between Year 0 and Year 8 of operations. Similarly, the average MTTR (days) dropped ~45% within the same timeframe.

Figure 1. Technical Availability

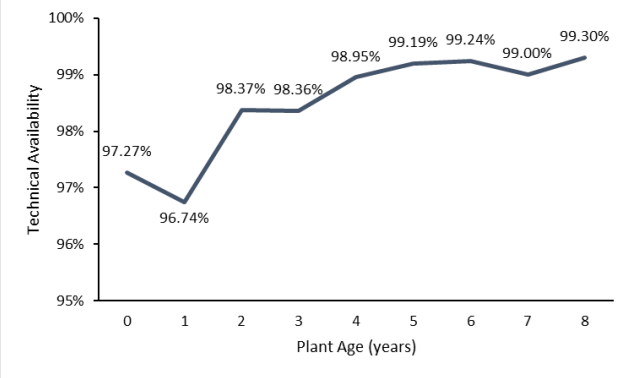
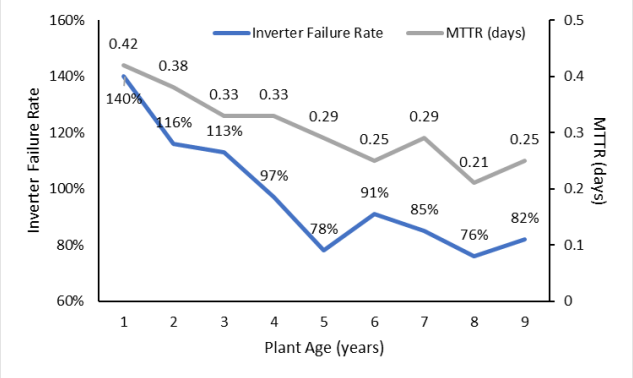


Figure 2. Inverter Failure Rate and MTTR



To help owners improve their asset availability during the warranty period, we recommend owners:

1. **Improve inverter qualification process on new inverters** by performing field tests to confirm performance prior to large scale installation and establish requirements for defect response and remediation times.
2. **Develop a reliable inventory strategy** by establishing inverter inventory onsite or within central inventory to enable next day repairs for medium to high frequency failures. Use OEM recommended spares lists for new inverters and O&M expertise on inverters with operational history.
3. **Align warranty incentives** by enabling O&M providers to perform first responder, level 1, and level 2 repairs and establishing availability and/or time to repair requirements within the warranty.

[1] NovaSource GADS classification of fleetwide downtime events
[2] Technical Availability = Measured Energy / (Measured Energy + Lost Energy)

45% of inverters are “abandoned” (from discontinued manufacturers) just 4 years after construction

By: Noel Myers, Sr. Business Development Manager & Cliff Myers, Co-Founder, Chief Engineering Officer

Based on operational data from 2017-2018, 9,984 MWac of PV capacity was powered using inverters made by discontinued manufacturers. These systems reflect “abandoned inverters” whose Original Equipment Manufacturer (OEM) is no longer in business.

Per NovaSource’s 2021 SRA publication, the O&M company’s research found that solar facilities with equipment from discontinued inverter manufacturers saw average inverters perform at 85% technical availability. In contrast, industry standard aims for 97%-99% power plant availability. Technical availability for a PV power plant is defined as the amount of time a system is producing energy, divided by the total amount of time in that period.

Using operational data from 2017-2018, Solar Support estimates that **PV plants operating with abandoned inverters lost between 1.9 million and 2.7 million MWh** in production per year, costing investors **$97m - $174m in missed revenue**[1]. Unfortunately, the lost revenue is unrecoverable due to production limits in interconnect agreements.

Owners who are exposed to PV assets powered by abandoned inverters face tremendous pressure to make operational decisions that triage current and future losses. Without active and ongoing inverter OEM help, PV power plants fail to receive sufficient technical support, and battle to find and procure replacement parts as old equipment fails. **Of all sites that were operating in 2018, 45% are powered with inverters made by manufacturers who are now discontinued.**

Figure 1. Inverter Market Share by OEM

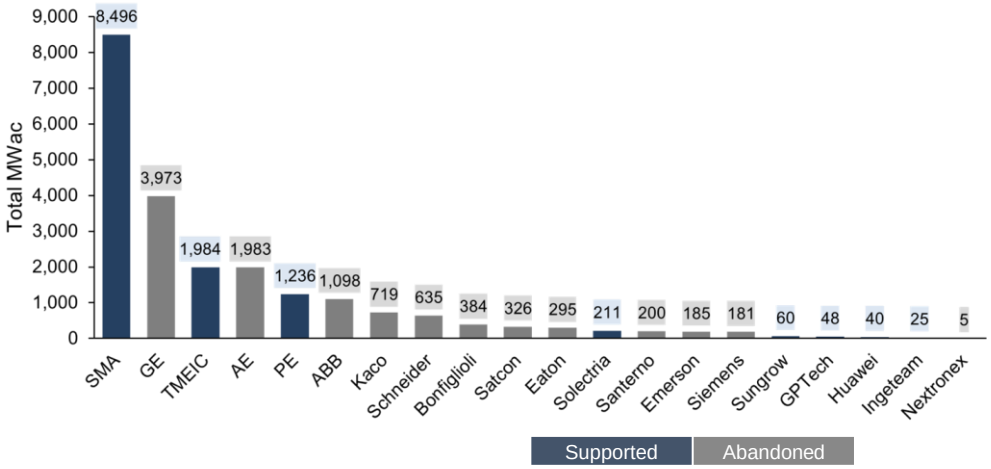
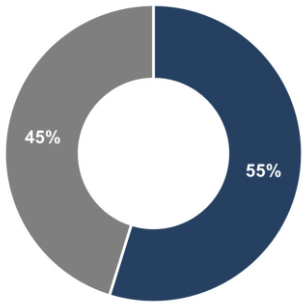


Figure 2. Inverter OEM Status



Solar repowering - the process of removing old PV technology and replacing it with new - is increasingly becoming the best long-term solution for investors exposed to sites with abandoned inverters. By developing business cases and performing engineering analyses, strategic asset owners are beginning to implement repowering projects through finance and partnership with experienced repowering Engineering, Procurement, Construction (EPC) teams.

As solar PV fleets age and inverter OEMs continue to go out of business, asset owners are forced to develop and deploy new solutions. Industry thought-leaders are refining solutions for the lowest-cost and least-disruptive methods for boosting plant performance. Repowering is now a proven method for addressing discontinued products and project stakeholders have a great opportunity to capitalize on the lost production but acting quickly is paramount before aging Power Purchase Agreements expire.

[1] Model evaluated five scenarios: 1) high production x high PPA price; 2) low production x high PPA price; 3) high production x low PPA price; 4) low production x low PPA price; 5) average production x median PPA price. Solar Support estimated 1800 MWh per MW per year high production; 1300 MWh per MW per year low production; 1550 MWh per MW per year average production; $150 high PPA price; $40 low PPA price; $75 median PPA price.

Uneven terrain driving up to 6% of performance losses; new tracking tech and modelling software help assets recover

By: MinWah Leung, Senior Engineer, Mark Mikofski, Principal Engineer, & Anat Razon, Head of Solar IE & Tech

In the 2021 SRA, DNV reported from a validation study of 20 sites that uneven terrain at solar projects had caused up to 6% losses compared to preconstruction estimates. Previously, the impact of uneven terrain was not a significant concern because for many years US solar projects were sited on relatively flat terrain. However, DNV has observed increased development in regions with hilly topography. Luckily, several leading tracker manufacturers have deployed advanced backtracking algorithms that claim to substantially reduce uneven terrain losses. In response to these new tracker technologies, DNV has developed a modeling method that predicts both uneven terrain losses and the possible recovery by using an advanced backtracking algorithm.This methodology is designed to accompany PVsyst, the industry-standard solar energy modeling software, which doesn't fully accommodate modeling of these variables.

As reported by M. Leung et al.[1], DNV has developed a proprietary method to calculate losses from complex terrain and the expected benefit of deploying advanced tracking algorithms. The method has been validated with operational data provided by tracker manufacturers as well as publicly available data from a DOE funded site. DNV has further compared the methodology against results from DNV's proprietary SolarFarmer solar energy assessment software, which does enable three-dimensional modeling of trackers on any terrain with either standard or user-specified advanced backtracking algorithm. Table 1 summarizes results comparing the two methods and shows agreement in production gains and losses for the site analyzed in the article.

Table 1. Comparison between DNV uneven terrain method and SolarFarmer

Gain/Loss	DNV uneven terrain method	SolarFarmer
Uneven terrain loss	-3%	-4%
N-S gain	+1%	+2%
Net terrain effect	-2%	-2%
Advanced backtracking	-0.5%	-1.5%
Recovery	+2.5%	+2.5%
Net advanced backtracking effect	**+0.5%**	**+0.5%**

In summary, losses attributable to terrain will be higher for sites with more complex topography and will be a key point of investigation for project developers who wish to evaluate the cost versus benefit of implementing advanced backtracking algorithms for their projects. DNV implemented the methodology for complex terrain evaluation in early 2021 as part of its baseline methodology.

[1] "Tracker Terrain Loss Part Two," in IEEE Journal of Photovoltaics, vol. 12, no. 1, pp. 127-132, Jan. 2022

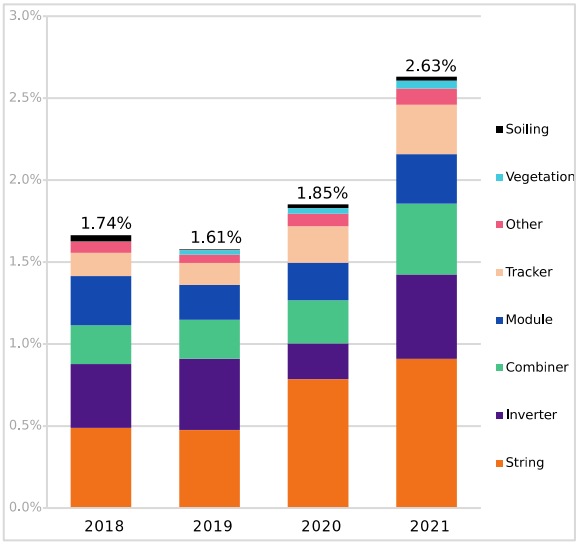
Complex installations and BOS anomalies increased total affected power to 2.63% in 2021 from 1.85% in 2020

By: Nikhil Vadhavkar, CEO, Eddie Obropta, CTO, & Shane Carey, Marketing Specialist

As the solar industry rapidly expands, PV systems are becoming increasingly anomalous. Over the last 4 years, Raptor Maps has built digital twins for 53 GW of solar PV assets spread across 40 countries. The 2021 dataset spans 20.24 GW of utility, commercial, and industrial PV systems across 32 countries, captured from 2,943 aerial inspections.

Overall power affected - as a percentage of nameplate capacity - increased from 1.74% in 2018 to 2.63% in 2021 (Figure 1). The upward trend in 2021 is largely driven by increases in several balance of system (BOS) anomalies associated with strings, inverters, combiners and trackers in addition to module and sub-module level issues.

Figure 1. Power Affected by Anomaly[1]

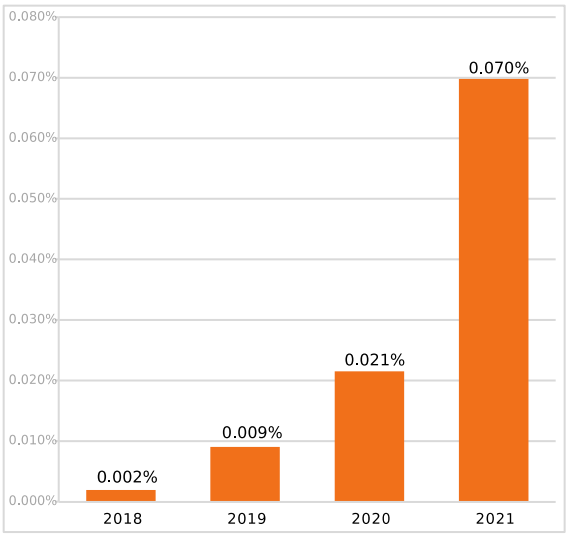


String anomalies, which stayed constant at 0.5% of total power affected in 2018 and 2019, increased in 2020 and 2021 to 0.8% and 0.9% respectively. The next four most common anomalies were inverters, combiners, module level anomalies, and trackers. Together in 2021, these five categories contributed 2.5% of lost power production as a percent of power inspected.

Increasing BOS anomalies are correlated with solar installations becoming increasingly large and complex, with wider varieties and greater numbers of parties involved in their design, construction, and maintenance. On average the number of unique contributors shared on an aerial inspection report grew from 22 in 2020 to 27 in 2021. Faulty BOS components can affect power production (e.g., defective fuses causing string outages) and can also be subject to installation issues (e.g., miswiring) that can go unnoticed at commissioning without a thorough inspection. The 2.5 GW of commissioning inspections that occurred within an asset's first operating year found that 1.2% of power was affected primarily due to combiner, string, inverter, and module anomalies.

With regards to module-level anomalies, the prevalence of cracking has been increasing since 2018 (Figure 2). There was a 3X increase in 2021 compared to 2020. Cracking has several root causes such as mishandling of modules during transportation or installation, debris from vegetation management, or weather events such as hailstorms. The significant increase in 2021 is suspected to be correlated with increased utility-scale solar PV in regions where hailstorms are more common.

Figure 2. Total Power Affected by Year[2]



Inspection data in this report was collected with unmanned aerial vehicles (aka UAVs or drones) and manned aircraft (aka planes) with high-resolution color (RGB) and infrared (thermal) cameras. Raptor Maps' open-source data collection methods are recorded at a range of 3 cm/pixel, 5.5 cm/pixel, and 15.0 cm/pixel depending on inspection level. Power figures in this report are based on manufacturer rated power (or nameplate capacity). JinkoSolar, First Solar, Trina Solar, Canadian Solar, and JA Solar were the five most common module manufacturers.

[1] Raptor Maps 2022 Global Solar Inspection Report
[2] Raptor Maps database

Commercial and utility-scale PV systems are degrading at -0.75%/yr after accounting for availability issues

By: Dirk Jordan, Senior Reliability Engineer

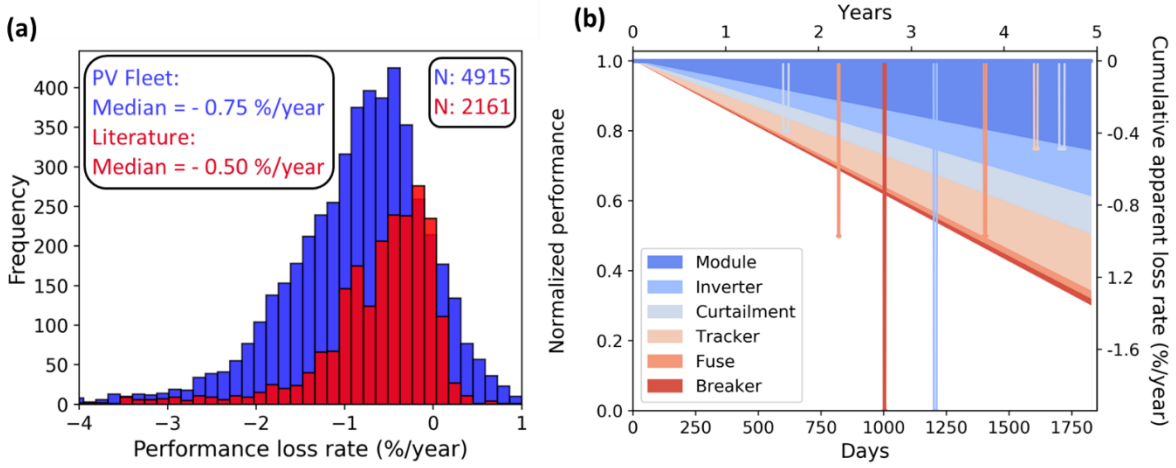
The long-term gradual performance loss of PV technologies is of great financial importance. Many studies have focused on this topic, yet, confusion often surrounds the subject because of module versus system and recoverable versus nonrecoverable losses.

In the PV Fleet initiative, high frequency data from a large number of commercial and utility-scale systems is collected. To date, more than 1,700 sites, with ca. 19,000 individual inverter data streams provide a high-level perspective of the long-term performance of PV systems. The total monitored capacity has surpassed 7.2 gigawatts (GW) or roughly 6% of the entire commercial and utility market in the US.

The open-source freely available software package RdTools[1] is used to determine the performance loss rate (PLR) of the system in the database. The aggregated PLR distribution from the entire fleet is displayed in blue in Figure 1 (a) with a histogram of individual inverter-level PLRs. The median PLR for the fleet is found to be -0.75 %/year based on 4,915 inverters passing automated data quality checks[2].

This is lower than other recent publications (e.g. Bolinger 2020)[3] that have established higher system PLR values around 1 %/yr. Because of our high frequency data we are better able to account for availability issues. It is also possible that a difference in the portfolio or makeup of systems could include faster degrading systems. In addition, soiling deposition can contribute to annual performance loss even if cleaning events bring the system back up to full production. Identifying and isolating soiling performance loss trends remains an active area of work for the PV Fleet initiative.

Figure 1. System PLR (blue) and predominantly module degradation (red) (a) and example illustration of module versus system losses (b)



A second histogram is shown in red displaying previously published literature values from our 2016 degradation summary paper. The vast majority of the data points in that previous study were based on module-level degradation and did not present system loss. The example in Figure 1 (b) illustrates how recoverable (fixable) losses such as inverter outages, stalled trackers, outages due to fuses, breaker or even curtailment, can explain a higher PLR than module-level degradation. Because of the high-fidelity of our data, we can now better account for availability issues and obtain a more accurate estimation of system losses. **It is essential to differentiate between module and systems losses and use the appropriate number for the most accurate financial models.**

[1] RdTools: https://github.com/NREL/rdtools
[2] Jordan DC, Anderson K, Perry K, et al. Photovoltaic fleet degradation insights. Prog Photovolt Res Appl. 2022;1-10. doi:10.1002/pip.3566
[3] Bolinger M, Gorman W, Millstein D, Jordan D, J. Renewable Sustainable Energy 12, 2020.

PVEL's 2022 results show 5x increase in median degradation rates following damp heat tests for mono PERC modules

By: Tristan Erion-Lorico, VP Sales & Marketing

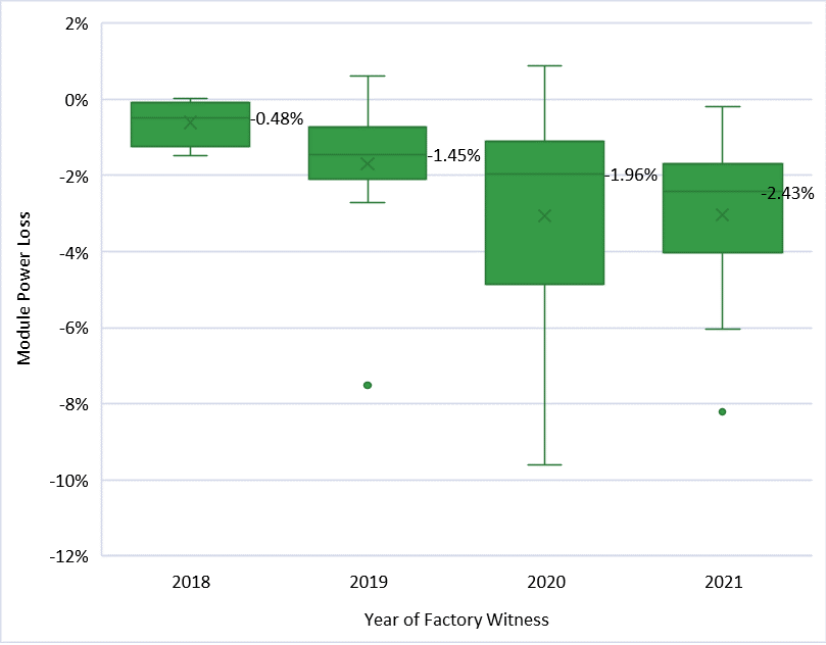
For the past decade PV Evolution Labs ("PVEL") has subjected PV modules to our Product Qualification Program ("PQP"), a series of extended-duration reliability and performance tests that help address the gap between module certification and the due diligence needs of the sophisticated PV site developer and investment community. During that time, we have tested over 500 different bill of material ("BOM") combinations from more than 50 PV module manufacturers.

Many procurement misconceptions have been literally put to test by PVEL, and the results have repeatedly shown that country of origin and manufacturer size is not an indicator of module reliability; relying on module certification alone will not protect the module purchasers' long-term interests; and seemingly minor changes to the BOM can have major impacts on test results[1].

Another trend observed in recent results is that changes to proven technology may result in unintended consequences. This is evidenced in recent damp heat ("DH") results, particularly for mono PERC glass backsheet modules. The PQP damp heat test places modules in a climate chamber at +85°C and 85% relative humidity for 2,000 hours, followed by a 48-hour stabilization step. This test reveals corrosion and/or delamination in susceptible modules. For the last few years most of the power loss seen in mono PERC modules following DH was erased during the stabilization step, as cells were doped using boron.

The switch from boron to gallium dopant has been widespread across the population of PQP-tested mono PERC modules, and has solved previous destabilization concerns. It has also resulted in record low light-induced degradation rates, as stated in the 2022 PV Module Reliability Scorecard. However, in gallium-doped mono PERC modules across multiple manufacturers PVEL is now seeing higher rates of DH power loss that is not recoverable during stabilization. Research is ongoing to determine if this is related to the gallium dopant, a change in cell metallization, or other module properties.

Figure 1. Mono PERC Module Degradation Post-DH



Technology in our industry moves fast, and while changes to what may be considered mature products bring potential benefits, they also present inherent risks. Buyers need to exercise caution and ensure the products they are procuring have been properly vetted.

[1] PVEL, "Minute differences in raw materials impact system performance by up to 5%", SRA 2021

Frequency of high-risk quality concerns found in module purchase contracts has increased 20x from ‘20H1 to ‘22H1

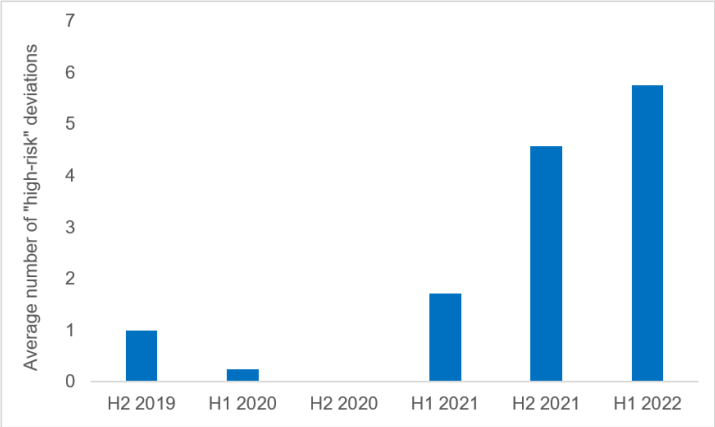
By: Frederic Dross, VP Strategic Development

The PV quality assurance community is witnessing an “earthquake” of module quality issues. The number of high-risk deviations requested by suppliers during the contracting process has gone up by a factor of 20 in the last two years. These requests by module suppliers intend to waive quality controls from their module purchase agreement with buyers. As a result, it is hard to imagine that there will be no impact on field degradation and failure rates over the next few years; The question remains: will this “earthquake” trigger a tsunami, or just a little ripple on the slowly rising sea of risks taken by developers today?

During contract negotiations, STS advises procurement teams through a diligent risk assessment process. STS has established “best practice” quality requirements (STS-STD-PVM1 Standard) and records the deviations away from this safe zone, labeling each risk as “low”, “medium” or “high” based on the nature of the risks, their probability, severity and detectability (Risk Priority Number). While in the first half of 2020, the number of high-risk deviations requested by suppliers was on average of 0.25 per contract (one every four contracts), this average reaches 5.75 high-risk deviations per contract in the first half of 2022; a 20 times increase compared to two years ago. These additional high-risk deviations may have a significant impact on the performance of the modules in the field. For instance, modules with more cracks or more soldering defects (which happen to be the two main high-risk deviations observed recently), are more likely to develop hotspots, which require immediate replacement, and expose owners to safety risks.

Because of the current “seller’s market” conditions, some manufacturers have lowered the quality specifications of their products. STS clients are made aware of the additional risks associated with these deviations and may therefore push back. Many other developers, however, may end up at an increased risk of purchasing low quality items.

Figure 1: Average number of “high-risk” deviations requested by manufacturers during the negotiation of the module purchase contracts[1]



Today’s supply chain situation parallels the shortage between 2010 and 2012. The PV module industry demand was growing faster than the supply of materials, cornering manufacturers into using new, unproven materials in their modules. Quality checks were dropped, and risks were taken to quench the thirsty demand. One example is the Isovoltaics AAA backsheet. Used in an estimated 12GW worth of modules, this backsheet had an 88% failure rate in the field at the 10-year mark.

Unfortunately, the story seems destined to repeat itself, and the quality assurance community is bracing for what may be the next module quality tsunami, unless developers are able to course correct by introducing more rigorous inspection plans to the procurement process.

[1] STS 2022

EXTREME WEATHER RISK

Topics Covered:

- **Property insurance trends**
- **Hail mitigation strategies**
- **Soiling impact from wildfire**
- **Irradiance impact from wildfire**

Property insurance market experience beneficial, yet limited reprieve from last year's 10%+ rate increases in premiums

By: Darryl Harding, Senior Underwriter

Insurance in the renewable industry has gained significant attention for lenders and project developers. Insurance carriers have experienced significant losses recently and the market has shifted in response. Premiums, limits, deductibles, and the ability to obtain coverage have all been impacted by this shift. For some, there are signs that this shift is ending, but for others, the shift has not slowed down.

Insurance Premium Rates and Terms

kWh Analytics surveyed leading insurance brokers to learn about the latest trends. Overall, projects that are less exposed to extreme weather are getting more favorable terms. Many projects that experienced 10%+ rate increases year-over-year in 2021 and 2020 are now approaching renewal rates with no increase at all. However, projects with exposure to extreme weather will continue to see higher rates and restrictive terms from carriers, especially for projects exposed to hail, severe convective storm, and wildfire risk.

Per Alex Post, SVP at Lockton Power, *"Insurance carriers have higher confidence levels in traditional NAT CAT exposures (earthquake, hurricane, and flood). Non-traditional NAT CAT perils including severe convective storm, and wildfire, are more challenging as various risk models are not as mature and results range widely between models. It is challenging for insurers or lenders consultants to have a high degree of confidence especially in regions like Texas following recent large loss events."*

Placing Coverage with Carriers

Carriers are also shifting their risk appetite and taking a larger share of each insurance contract despite limiting the maximum amount of risk they hold. For developers, this could mean your broker can find the same level of coverage for your project with fewer carriers involved.

One secondary effect of this is that the time needed for placing coverage has decreased about 15%. As different approaches to renewables have been tested for a few years, lenders are getting more comfortable with the language and policy terms being offered. As consistency is being found in the insurance market, renewal policies are seeing only mild changes, requiring less time to quote and bind policies. As term standardization increases, the number of exceptions needing to be approved for loans are down about 5% from last year.

Although the industry is constantly evolving, some things remain the same. Large projects still require multiple carriers to provide coverage, carriers are not offering full limits, and deductibles are still high across all perils. Todd Burack, insurance broker with McGriff Insurance Services, Inc., stated, *"When the US renewable marketplace has approximately 300 million in gross written premiums, yet you have several significant, high-dollar losses, you quickly realize the conservatism being expressed by insurers."*

Innovations in equipment manufacturing and asset management help mitigate risk, however, incumbent carriers are not recognizing changing technology and resilient designs nor are they providing rates and terms to reflect the mitigated risk. Alistair Barnes of AMWINS Group, Inc shared that, *"Different insurers have different approaches to site specific hardware and design with some insurers providing no credit for superior physical attributes and few providing more than 15% credit. Insurance carriers need to become better educated and reward those efforts to incentivize the development of a more resilient and sustainable sector."* New entrants to the markets are beginning to disrupt the underwriting process by rewarding owners with well managed risk with favorable policies. Traditional carriers are taking a larger portion of the risk, but they are struggling to underwrite individual projects rather than view each project as "average" for the industry. The renewable and insurance industries will benefit long term from resilient and well-maintained projects which is why smart carriers should incentivize such behaviors. Regardless of your view of insurance, the renewables industry needs insurance to allow investment and growth.

Informed hail mitigation strategies reduce probable maximum loss by up to 80%

By: John Sedgwick, President

Last year Texas led the nation in utility scale PV installations. As development in the state rapidly expands, so does the risk of exposure to extreme weather events. In response to the increased number of hail-related claims, the insurance market has hardened. Premiums have increased and hail risk is subject to significant sub-limits and deductibles, pushing more risk onto owners and investors. How do owners and investors assess the risk and the value proposition of mitigation measures for setting insurance strategy and optimal financial performance?

Utility scale PV development in severe hail prone regions has been limited to date, yielding a small sample of PV actuarial loss data. At the same time, module technology is evolving rapidly. This makes the task of projecting financial impact due to hail difficult. Fortunately, there is another approach, a “bottom-up” risk assessment based on engineering and science considering the multiple factors which drive Probable Maximum Loss (PML) – the maximum value an insurer is expected to lose – in a given time period and Average Annual Loss (AAL) due to hail, two values which are used today not just for risk analysis, but which also play a critical role in the pricing of insurance premiums.

Risk Assessment

A “bottom-up” model of hail risk includes two primary components:

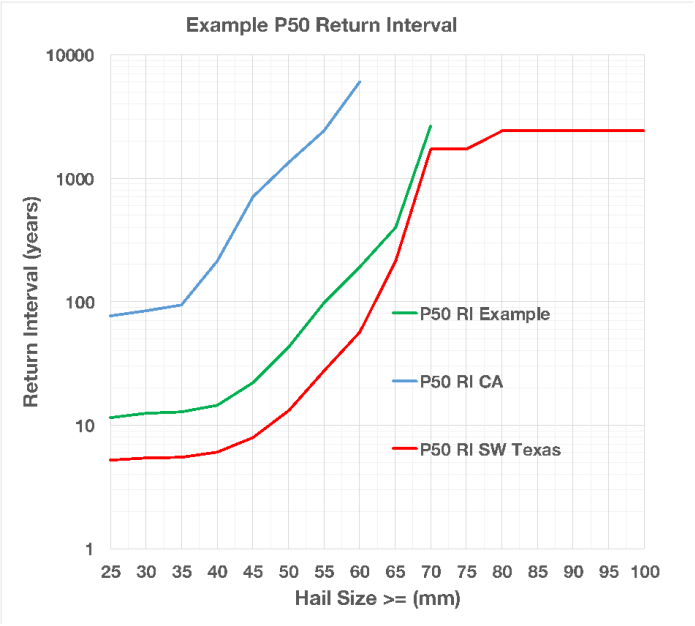
1. **High Quality hail frequency and severity data.** As shown in Figure 1, depending on hail diameter, the Return Interval of hail can vary significantly from one location to another. Even from one location in Texas to another the frequency of hail can vary by a factor of two and compared to an example location in California itn can vary by an order of magnitude or more.
2. **Detailed physical modeling.** Best in class loss estimation recognizes that some modules are more resilient than others depending on glass thickness and temper. Losses also depend heavily on the ability of trackers to move to a mitigating tilt angle ahead of an imminent severe hail event.

Risk Mitigation

VDE estimates that, at a typical Texas location, module resilience (thickness and temper) can influence losses by 30%. However, the single most important mitigation action an owner can take is to tilt modules away from the horizontal, reducing estimated losses by up to 80%. Advanced tracking technology is required as well as warnings of impending severe weather. To ensure movement without compromise, operators must also consider hail stow movement in relation to other safety stow protocols such as wind stow.

Using the above methodology, investors, operators, suppliers, insurers and their advisors can evaluate the risk of hail specific to the location and estimate the PML and AAL for a given system design and operation. This enables specific quantification of the value proposition of selected equipment and chosen sub-limits based on the 500-year PML, while the AAL informs the component of premium based on hail risk.

Figure 1. Comparison of Return Interval by Hail Size for three sample sites



Wildfires caused up-to-3% annual soil–related performance losses at solar PV sites in California between 2018 and 2020

By: Stephen Lightfoote, Technical Director

Wildfires have major detrimental effects on the performance of solar PV arrays in nearby areas in two ways. They make atmospheric conditions smokier or hazier; and they also deposit particulates on the solar PV panels, known as 'soiling'. This reduces the sunlight reaching the panels.

Research from Power Factors shows that the wildfires in 2020 led to excess soiling-related performance losses of between 1% and 3% annually at affected sites. We learned this by analyzing data from 150 solar PV arrays that represent 1.3GW of AC capacity in California from 2018 to 2020. Operators can clean the panels to mitigate the effects of soiling, but they need accurate project performance data to know when this makes financial sense.

Degraded Performance

Operators can decide when it makes sense to clean soiled panels using the degraded performance methodology of Power Factors. This looks at the actual performance of solar PV projects compared to their theoretical performance, and shows operators when projects are underperforming.

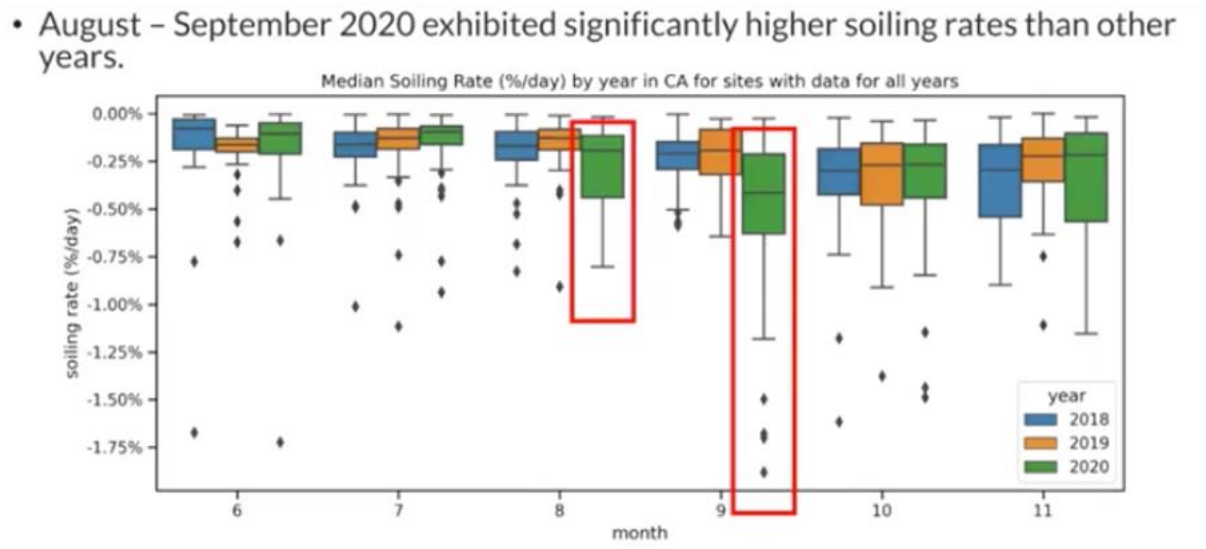
Further analysis can show operators the likely reasons that the projects are underperforming, by comparing their performance to signatures that show how four common types of degradation affect project performance.

For example, underperformance caused by dirt, dust or ash will result in steady drops in project performance over time until panels are cleaned. It is a different profile to underperformance caused by snow, combiner outages and stalled trackers. This shows when soiling causes losses.

Wildfire Impacts

Our research showed that soiling rates were significantly worse in 2020 during months when wildfires were at their worst (Figure 1). It shows a clear correlation between wildfires, soiling, and underperformance. The research showed that projects most affected by soiling were in counties in California most affected by wildfires, such as Kern County.

Figure 1: Soiling Rate by Month



Wildfires are likely to become more common and more severe as a result of climate change. By better understanding this trend, operators can mitigate their losses in the years ahead.

Days where wildfire smoke impacted solar doubled in 2020, 2021 compared to historic wildfire years of 2017, 2018

By: Patrick Keelin, Lead Product Manager

According to a new analysis by Clean Power Research, California's solar potential was down 17% in September 2020—the peak of the worst wildfire season in recent history—relative to the long-term average for the month. Smoke clouds and aerosols from wildfires block sunlight and thus reduce PV output. Across California, resulting losses were 27 kWh/kW_{DC}. Increased PV soiling from soot and ash also reduced yield (Clean Power Research estimates a median loss of 3% based on models utilizing concurrent particulate matter and precipitation data). Total impacts exceeding 30% were seen in regions surrounding large fires (Figure 1).

Figure 1. September 2020 PV yield relative to long-term average for September (%)[1]

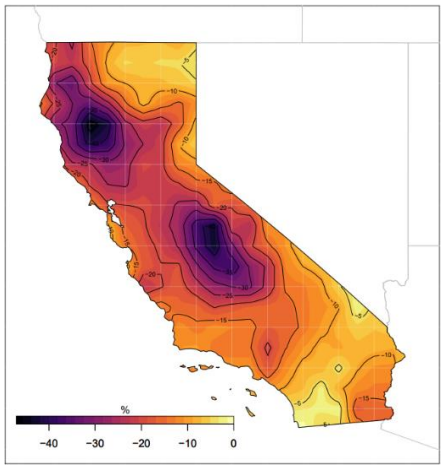
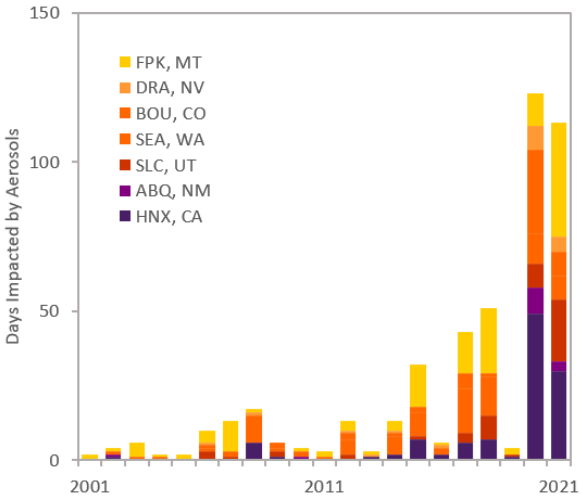


Figure 2. Number of days impacted by aerosols[2]



The 2020 wildfires were extreme by historical standards: September 2020 yield across California was nearly three standard deviations from the long-term average (i.e., < P99). Unfortunately, hotter, drier conditions are increasing US wildfire risk.

If further proof was needed that 2020 was an indication of things to come, 2021 provided it. The 2021 wildfires burned 7.1 million acres and caused $10.6 billion of damages in the United States (10.2 million acres burned in 2020). The number of days where aerosols dimmed sunlight more than doubled in 2020 and 2021 compared to historic wildfire years of 2017 and 2018 (Figure 2).

For stakeholders needing to forecast solar yield and asset value, observations from recent years provide new information on the risks to solar projects. First, some locations will be more impacted by smoke than others. Intuitively, proximity to wildfire fuel increases risk. But in addition, it's been observed that smoke traps itself in valleys by blocking sunlight and air circulation, creating a self-reinforcing temperature inversion. The effect is apparent in the California Central Valley, the Columbia River Basin, the Po valley in Northern Italy and the Sichuan Basin in China, for example.

Second, there is increased risk to solar-powered generation during wildfire season throughout Western North America. Interestingly, annual deviations for both 2020 and 2021 were moderated by unusually sunny spring weather. A shift in the seasonal yield profile is possible.

NOAA's seasonal outlook predicts that June – August 2022 will be hot and dry. The stage is set for another active fire season. While we will hope for the best, stakeholders must prepare for the possibility that wildfires will materially impact solar assets for the foreseeable future.

[1] Deviations show the impact of wildfire smoke and soiling
[2] Days considered impacted if clear sky DNI was at least 35% below 2001-2015 averages

Contributors

kWh Analytics: kWh Analytics is the market leader in solar risk management. By leveraging the most comprehensive performance database of solar projects in the United States (30% of the US market) and the strength of the global insurance markets, kWh Analytics' customers are able to minimize risk and increase equity returns of their projects or portfolios. Website

BloombergNEF: BloombergNEF (BNEF) is a strategic research provider covering global commodity markets and the disruptive technologies driving the transition to a low-carbon economy. Our expert coverage assesses pathways for the power, transport, industry, buildings and agriculture sectors to adapt to the energy transition. We help commodity trading, corporate strategy, finance and policy professionals navigate change and generate opportunities. Website

Clean Power Research: Clean Power Research has delivered award-winning cloud software solutions to the solar industry and utilities for more than 20 years. Our SolarAnywhere®, PowerClerk® and WattPlan® product families allow customers to make sense of and thrive amid the energy transformation. Website

DNV: DNV provides assurance to the entire energy value chain through its advisory, monitoring, verification, and certification services. As the world's leading resource of independent energy experts and technical advisors, the assurance provider helps industries and governments to navigate the many complex, interrelated transitions taking place globally and regionally, in the energy industry. DNV is committed to realizing the goals of the Paris Agreement, and supports customers to transition faster to a deeply decarbonized energy system. Website

NREL: The National Renewable Energy Laboratory (NREL) is the nation's primary laboratory for renewable energy and energy efficiency research and development (R&D). NREL develops technologies and practices, advances related science and engineering, and transfers knowledge and innovations to address the nation's energy and environmental goals. NREL has forged a focused strategic direction to increase its impact on the US Department of Energy's (DOE) and our nation's energy goals by accelerating the research path from scientific innovations to market-viable alternative energy solutions. Website

Novasource Power Services: Novasource Power Services is a diversified national solar services company, delivering unparalleled expertise to the nation's distributed generation infrastructure. We provide safe, professional, and reliable operations and maintenance services enabling the growth of C&I (Commercial and Industrial) and Residential renewable energy sectors. Website

PowerFactors: Power Factors develops software that accelerates the global energy transition by empowering all renewable energy stakeholders to collaborate, automate critical workflows, and make the best decisions. Power Factors fights climate change with code. Power Factors has incorporated its three flagship solutions Drive, Greenbyte, and BluePoint to build an integrated suite of open and smart apps. These apps are purpose-built for asset management, field service optimization, and performance optimization. Leveraging the domain expertise and machine learning-based advanced analytics within these apps, customers can maximize the value of their renewable assets in order to stay competitive. Power Factors' renewable energy software platform is the most extensive and widely deployed solution in the market with more than 50GW of wind, solar, hydro, and energy storage assets managed worldwide. Website

Contributors Cont.

PV Evolution Labs: PV Evolution Labs (PVEL) is the leading independent lab for the downstream solar and energy storage industry and a member of the Kiwa Group. As a bankability testing pioneer, PVEL has accumulated more than a decade of measured reliability and performance data for PV and storage equipment. Today, PVEL provides developers, investors and asset owners with a suite of technical services for mitigating risk, optimizing financing and improving system performance throughout the project lifecycle. Website

Raptor Maps: Raptor Maps offers advanced analytics, insights and productivity software for the entire solar lifecycle. The Raptor Solar software platform features a digital twin of your solar sites, aerial thermal inspections, data standardization and normalization, serial number mapping, warranty claim features, equipment records, mobile tools and more — all powered by their industry-leading data model. Website

SolarGIS: Solargis is a data and software architect for bankable solar investments. Solargis works with solar stakeholders throughout the lifetime of their projects and portfolios, reducing risk and creating transparency with the most accurate and reliable solar data on the market. Solargis data and software platform helps the industry to simplify the process of an energy assessment, maximize asset performance, and forecast long and short-term production and returns. Solargis data have helped develop several GW of assets worldwide and are also used for monitoring and forecasting solar power plants. Website

Solar Support: Solar Support is the single-source engineering services company that delivers peak performance. Through expert equipment knowledge and plant reliability solutions, Solar Support helps boost uptime, cut costs, and maximize production. With over 50 years of combined industry experience, we fuse operations and maintenance expertise with deep inverter knowledge and project management acumen to resolve complex performance issues. Website

STS: Founded in 2010 French solar veterans, STS is an independent ISO17020-accredited Inspection Body specialized in the photovoltaics and energy storage industry. The company supports solar and storage developers' procurement efforts through supplier evaluation, manufacturing site audit, inspection and quality control, and technical due-diligence services. STS is the global market leader for PV modules Pre-Shipment Inspection services. Present in 9 different countries globally with operational focus in Asia, STS enjoys the largest inspector fleet in the industry and conducts more than 200 quality assessment projects per year for clients in more than 30 countries including leading EPCs, developers, independent power producers and utility companies. Website

VDE Americas: VDE Americas is a wholly-owned subsidiary of VDE. Our goal is to advance the deployment of clean energy projects that are bankable, investable and insurable. We support this goal by offering technical due diligence and engineering advisory services in addition to providing neutral 3rd-party product certification and testing. We provide value for our customers by maximizing quality and reducing technical risks at both the system and equipment level. Website

Wood Mackenzie Power & Renewables: Wood Mackenzie Power & Renewables delivers actionable insight into the state and the future of the global electricity sector, from wind and solar to power markets and grid edge technology. Wood Mackenzie research is backed by exclusive relationships with industry partners, proprietary models, and an ever-expanding executive network. Website