Solar Generation Index:

Quantitative Insights from Leading Asset Owners

2021 Volume

kWh analytics

Executive Summary

The solar industry has matured tremendously in a few short years. Our asset class has now generated over a decade of data that can be harnessed to guide sustainable growth and yet, there is a scarcity of information about how well solar assets have performed against initial estimates. kWh Analytics -- as the Insurer for the Energy Transition and the owner of the largest database of operating renewable energy assets (over 350,000) -- filled this gap by publishing its inaugural Solar Generation Index ("SGI") report in 2020, the industry's first solar asset performance index.

This year, we are proud to release our second annual SGI in collaboration with 15 of the 20 largest asset owners. Like the inaugural study, the aim of the annual report is to monitor and quantify the industry's asset performance compared to each project's base case ("P50") production estimate. Similar to indices in the U.S. equity market, asset owners and financiers use the SGI results to track trends, benchmark performance reporting, and improve investment decisions. Specifically, the tracking of actual solar generation against performance estimates underpins the financial health of assets, so it is critical to monitor the relationship between the two numbers. Improved accuracy in our modeling and reduced uncertainty in financial returns will help drive the asset class towards more efficient financing, while also supporting the long-term financial health of individual assets and our industry.

Results

This year we expanded the analysis to show weather-adj. average performance by vintage and by operating year between 2011 - 2020 and identified the following trends:

- **Weather-Adj. Performance by Vintage**: When looking at performance by vintage, the analysis showed that average weather-adjusted performance (actual production compared to P50 estimates) of utility-scale solar assets trended downwards from 2011 - 2020, meaning that P50 estimates have become less accurate. At the same time, the variance in performance has decreased, meaning that P50 estimates have become more precise. This indicates that while production modeling tools have become more sophisticated over time, there is still a level of subjectivity in the development of P50 estimates.
- **Weather-adj. Performance by Operating year:** When looking at performance by operating year, performance declined overall likely due to a combination of the less accurate P50 estimates as well as extreme weather. Additionally, we found that there is significant variance in performance on a regional basis.

Executive Summary (continued)

Where do we go from here?

The results are clear: P50 estimates are becoming more precise but are still subject to incentives of stakeholders generating these numbers. As a result, the gap between actual asset generation numbers in relation to these estimates has widened over time. There are simple ways our industry can course-correct:

- **Indices & Benchmarks:** We, as an industry, can leverage indices and benchmarks that utilize real-world data to inform our financial decisions and improve certainty in returns.
- **Collaboration:** This report represents an example of how industry collaboration can improve transparency for everyone. Joining industry working groups, like our Solar Performance Management Collaborative, increases knowledge sharing and improves our collective understanding of best practices.
- **Risk Mitigation:** Long-term asset owners, equity owners, and financiers are the most exposed to inaccurate energy forecasts, so they should seek out risk mitigation solutions to protect themselves. In the near-term, equity investors should seek out solutions to mitigate their exposure to overly-aggressive production forecasts. Examples include procuring insurance, reviewing financial model assumptions, and vetting modeling vendors closely.

We continue to share this index to promote transparency and discussion within the industry. We hope you use the results to inform your work and look forward to the shared work of improving the solar industry.

Regards,

Richard Matsui
Founder & CEO, kWh Analytics

Introduction

As the need to mitigate emissions and address climate change grows more urgent, solar will play an increasingly critical role in the international energy mix. Solar now comprises the largest base of newly installed generating capacity and the United States is expected to double its installed solar capacity over the next five years.[1]

The solar industry has continued to attract new forms of capital to meet the voracious capital needs of building out a new energy paradigm. Solar developers, the industry's "front line workers" in the creation of new solar projects, have laboriously and over time, attracted long-term equity capital for these projects from a variety of sources. Our industry's continued success is predicated upon its ability to reliably deliver the results promised to its investors.

The Solar Generation Index (SGI) provides transparency on this topic: it is a comprehensive analysis on how successful and reliable the industry has been in delivering the results promised to investors. The SGI specifically compares baseline P50 production estimates to actual average production. Since revenue for a solar project equals production multiplied by a set price from a Power Purchase Agreement (PPA) or other contract, the delta between the P50 estimates and the actual production figures illustrate how closely actual revenue tracks to estimated revenue.

It is our collective responsibility to ensure that return profiles can be forecasted accurately and projects financed efficiently. So, kWh Analytics and leading solar asset owners compiled our data from the past nine years to conduct this analysis and inform the industry.

Contributors

Lead Author:

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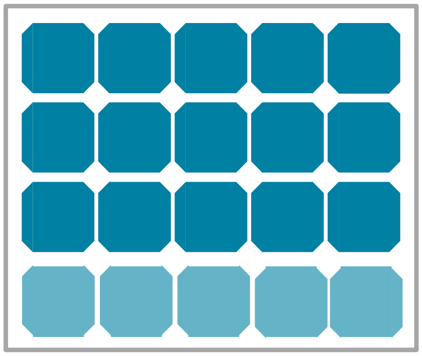
Weather Data:

SolarAnywhere®
powered by Clean Power Research

Performance Data:

Solar Performance Management Collaborative



Data represents 15 of the top 20 largest US asset owners

Our Approach

kWh Analytics collaborated with 15 of the 20 largest solar asset owners in the US to develop this report. We aggregated and anonymized the operating assets from industry contributors with our existing Heliostats solar database to analyze the performance of utility-scale assets (defined as assets that are larger than 1MW) in the United States. In total, the combined dataset included more than 30% of the operating utility-scale projects in the U.S.

We used this data to develop an index, which compares historical actual generation versus the P50 expectations from as-built designs between 2011 and 2020. We used the P50 solar production estimates used at project financing as the basis for our comparison. This number is typically generated by asset developers and Independent Engineers using modeling software and additional assumptions found in the pro forma financial model (e.g. system availability and degradation). Financiers also use this number as the baseline for calculating expected revenue and returns on their investment. As a result, the P50 value is critical to understanding how well solar assets are performing in terms of financial returns and green electrons produced.

In addition to comparing historical generation to actuals, we identified the range of performance against P50 estimates by project vintage (commercial operation date, COD). This part of the analysis aimed to understand how asset performance varies overtime as the sector evolves and matures.

To ensure our comparison accurately reflected financial models, we used the following assumptions:

- **Annual system degradation**: We applied the asset owner's assumed annual degradation factor to the P50 across operational years **or** a -0.5% derate assumption when a degradation factor was not provided.
- **Annual system availability**: We applied the asset owner's assumed annual availability factor to the P50 across operational years or a 99% availability assumption when an availability factor was not provided.
- **Annual curtailment**: We applied the asset owner's assumed curtailment factor to the P50 across operational years, if available.
- **Impact of weather**: We adjusted the results to factor in localized and temporal weather factors by leveraging Clean Power Research's SolarAnywhere® weather database to assess weather anomalies against long-term historical averages for each asset location.

The Appendix provides additional information on our data and methodology.

Results

Our analysis included two results: weather-adj. average performance of solar assets by vintage across the US and weather-adj. average performance of solar assets by operating year by region.

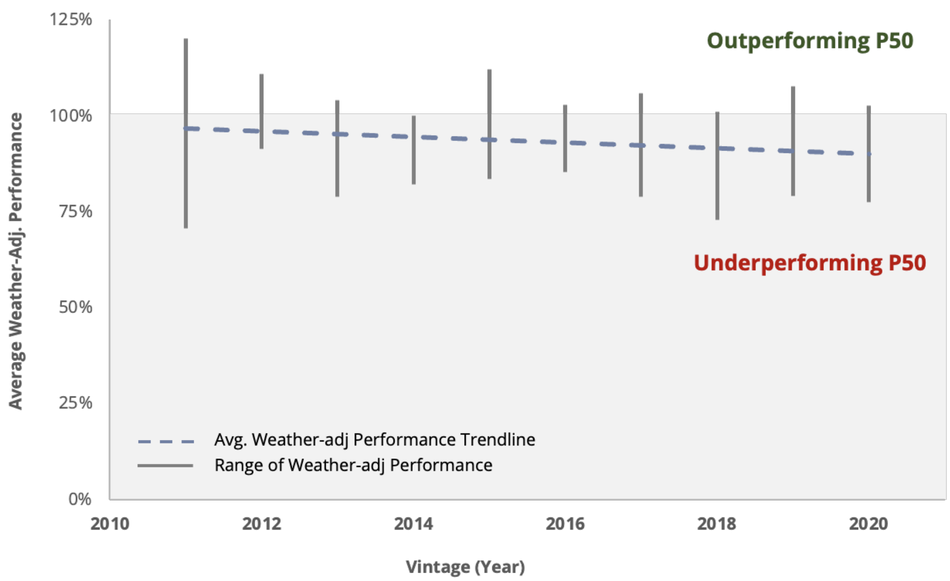
Weather-adj. Average Performance by Vintage

kWh Analytics calculated average annual performance from 2011 - 2020 by vintage as well as annual performance variance by vintage, as shown in Figure 1. kWh Analytics defines vintage based on an asset's commercial operation date (COD), or the date that the asset is placed into service. This analysis was added to the 2021 analysis to provide a deeper understanding of how an asset's development date impacts performance.

The results indicate that assets commissioned in the early 2010s (2011 - 2016) have performed significantly better than those commissioned in the late 2010s (2017 - 2020). As a result, performance variance by vintage has decreased overall. These trends suggest that P50 estimates have become more precise but less accurate over time.

In particular, earlier vintages had higher accuracy -- performing closer to their P50 -- but less precision with a wider range of estimates. This fact makes sense, given independent engineers and developers used unsophisticated modeling approaches and were likely more conservative in their estimates for the first assets financed. Later vintages see the opposite trend. Those vintages had less accuracy -- performing further from their P50 -- but more precision with a narrower range of estimates. Once more, the improved precision makes sense given a decade of experience/knowledge of PV systems, higher quality weather files, and improved modeling tools. However, this does not explain the reduced accuracy. This latter trend illustrates that P50 estimates can still be subjectively developed, even with better modeling.

Figure 1. Avg. Weather-adj Performance Trend & Variance by Vintage (2011 - 2020)



Results (continued)

Weather-adj. Average Performance by Operational Year

In addition to weather-adj. average performance by vintage over time, kWh Analytics calculated weather-adj. average performance by operational year by region from 2011 - 2020, as shown in Table 1 and Figure 2 below. kWh Analytics defined operational year as any year an asset was in service.

Table 1 shows that performance has worsened over time for operating assets, particularly in the past five years. Notably, several regions performed at or above their P50 estimates during the 2011 - 2015 period, while most regions performed below their P50 estimates from 2016 - 2020. Importantly, the trend holds across all regions, except for the Mid-Atlantic region in 2019, indicating an industry-wide shift. This shift may be caused by more aggressive P50 estimates for newer vintage assets as well as more extreme weather events throughout the country.

Systems underperformed their P50 estimates by 5-13% from 2011 to 2020

Table 1. Avg. Annual Weather Adj Performance by Region & Operational Year (2011 - 2020) [2,3]

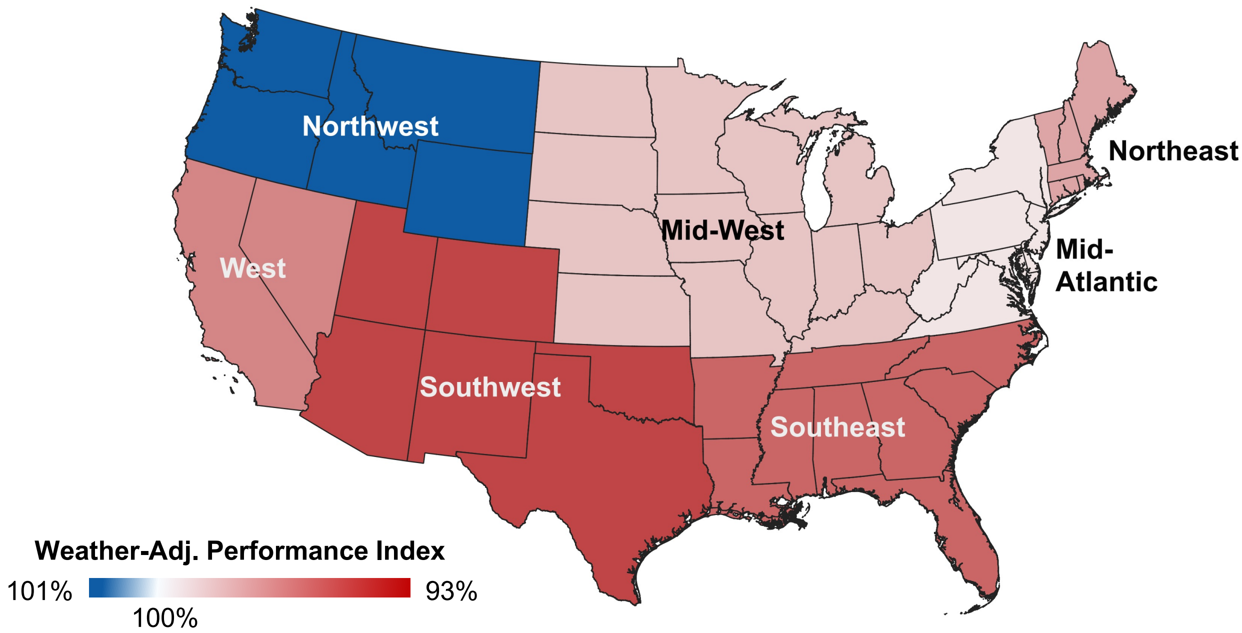
Region	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	% YOY [19-20]
Southwest											2%
Southeast											0%
West											-13%
Northeast											-4%
Mid-West											-2%
Mid-Atlantic											-12%
Northwest											1%
National Average	87%	95%	93%	93%	94%	93%	92%	92%	91%	92%	-4%

Weather-Adj. Performance Index 111% 100% 82%

When aggregating performance data across the study period by operational year, the Northern regions (Northwest, Mid-West, Mid-Atlantic, and Northeast) outperform the Southern regions (West, Southwest, Southeast), as shown in Figure 2. The Northern regions performed at or below their P50 estimates by one to four percent. In contrast, the Southern regions performed below their P50 estimates by five to seven percent. It's unclear what is driving regional performance differences, although kWh Analytics plans to investigate this further in future reports.

Results (continued)

Figure 2. Avg. Weather-adj Performance by Region & Operational Year (2011-2020)



Summary

In summary, our analysis yielded three critical takeaways, described below.

- **Weather-Adj. Average Performance by Vintage:** Newer vintage assets tend to underperform their P50 estimates compared to older vintage assets across the 2011 - 2020 study period, although the variance in estimates is narrower. This means P50 estimates have become more precise, but less accurate with estimates getting more aggressive over time, indicating that subjectivity may play a role in the development of P50 estimates.
- **Weather-Adj. Average Performance by Operating Year:** Overall, assets tended to underperform their P50 estimates from 2016 - 2020. The underperformance trend is likely caused by the declining accuracy of P50 estimates for newer vintage assets in addition to the impact of more extreme weather events. For instance, Clean Power Research conducted an analysis on the impact of wildfire smoke on solar production in 2020 and found that production dropped 30% below the summer average.[4]
- **Geographic Variability in Weather-Adj. Performance by Operating Year**: Unsurprisingly, there is significant performance variation in assets based on the climate zone and subsequent weather patterns at the location. This indicates that asset owners and independent engineers need to adjust operating measures and performance assumptions to accurately anticipate these geographic differences. We expect this variability to worsen over time as the effects of climate change produce more severe weather.

Where do we go from here?

The results are clear: P50 estimates are becoming more precise but are still subject to incentives of stakeholders generating these numbers. As a result, the gap between actual asset generation numbers in relation to these estimates has drastically widened over time. This reality ripples across the industry and jeopardizes investors' financial returns and the industry's credibility, impacting our ability to achieve sustainable growth. However, there are simple ways our industry can course-correct:

- **Indices & Benchmarks:** The lack of accepted standards means that production forecasts can vary dramatically depending on who is running the model, as evidenced by the wide variance in P50 estimates in the past few years. Given these variances, we, as an industry, should leverage indices and benchmarks that utilize real-world data to inform our financial decisions and improve certainty in returns.
- **Collaboration:** This report represents an example of how industry collaboration and data sharing can improve transparency for everyone. There are several industry groups, such as kWh Analytics' Solar Performance Management Collaborative, that promote data and knowledge sharing. These forums increase knowledge sharing and improve our collective understanding of best practices.
- **Risk Mitigation:** Long-term asset owners, equity investors, and financiers are the most exposed to inaccurate energy forecasts. In the near-term, equity investors should seek out solutions to mitigate their exposure to overly-aggressive production forecasts, including procuring insurance, reviewing financial model assumptions, and vetting vendors closely.

Endnotes

[1] Gabbatiss, Josh, Wind and solar capacity will double over the next five years globally and exceed that of both gas and coal, according to a new International Energy Agency (IEA) report, CarbonBrief, October 11, 2020, https://www.carbonbrief.org/iea-wind-and-solar-capacity-will-overtake-both-gas-and-coal-globally-by-2024.

[2] kWh Analytics provided regional average numbers exclusively to Solar Performance Management Collaborative participants. For more information on how you can participate, please go to www.kwhanalytics.com/spm.

[3] The national average reflects the average of all system performance in a given year. It does not reflect the average of the regional averages. kWh Analytics used this methodology to provide a more accurate perspective on average national performance.

[4] U.S. Energy Information Administration, Smoke from California wildfires decreases solar generation in CAISO, September 30, 2020, https://www.eia.gov/todayinenergy/detail.php?id=45336.

Appendix:

Detailed Data & Approach

Detailed Data

kWh Analytics sourced the data for this analysis from the Solar Performance Management Collaborative and Heliostats, our proprietary database of renewable energy assets. This database is the largest repository of operating renewable energy assets in the world. Each data point from the Collaborative and Heliostats represents revenue-grade meter production numbers directly from asset owners, equity owners, and financiers.

The data for the analysis included over 350 utility-scale systems and over 1,400 system years across a nine-year period. The tables below provide the exact number of systems for each performance year analyzed.

With over 1,400 project-years in the analysis, the Solar Generation Index is the most comprehensive performance validation study in the US.

Table A1. Detailed Data Metrics

Analysis Metrics	
Number of solar assets	**350+**
Number of operating years	**1,400+**
Average operating years per project	**3.7**
Maximum operating years per project	**10**
Total installed capacity [GWdc]	**10+**

Detailed Approach

Using the data above, our team developed a consistent analysis methodology to replicate this report over time. Specifically, it involves:

1. Selecting solar assets from our HelioStats database and portfolios submitted by asset owners to include U.S. utility-scale assets that are greater than 1MWdc, have system design and operating data availability and completeness, and P50 production estimates used by financiers.
2. Projecting the P50 production estimate for each system for every subsequent year in the analysis after the commercial operation date (COD) by applying the system's degradation, availability, and curtailment assumptions. For systems with no data available for these parameters, we applied the following standard factors -0.50%, 99%, and 0%, respectively.
3. Calculating the weather adjustment factor for each system and each operating month using Clean Power Research's SolarAnywhere software to account for the monthly weather anomaly against the long-term historic average at each system's location.
4. Calculated the weather-adj Performance Index (PI) for each project annually, using the following calculation:

Weather-adj PI = Actual Production / P50 Estimate * Weather Factor