SOLAR OPERATIONS LANDSCAPE

ABSTRACT

Over the past decade, utility-scale solar photovoltaic (PV) generation has grown strongly to become a core component of global power systems. The sector has benefitted from declining capital costs, supportive policy frameworks, and strong investor appetite for long-duration contracted assets. However, as the amount of data related to the existing installed base of operational solar PV assets has increased, a gap has emerged between expected and realised performance in almost all geographies.

The reasons for the gap are varied, and often specific to the region or country in which the assets are located. In general, the gap reflects unforeseen issues that were not fully accounted for within forecasts of solar generation. Overall, actual solar asset performance has lagged forecast assumptions. For example, kWh Analytics estimates in its 2025 solar risk report that across all US operating portfolios, solar PV has underperformed weather-adjusted production (P50) estimates by an average of approximately 8.6%[1]. Raptor Maps estimates in their 2025 global solar report that in 2024 solar installations globally experienced an average of 5.8% underperformance due specifically to module and other project equipment outages[2].

Underperformance relative to forecast assumptions is generally attributable to factors such as poor O&M subcontractor performance, maintenance deficiencies and delays, and grid related issues including curtailment. Whilst irradiance variances have also been observed, forecasting tools for solar are generally more accurate than those used for other technologies such as wind, resulting in an overall lower incidence of this type of underperformance.

As the price of solar on a per MW basis is now significantly below that of conventional generation technologies, including new nuclear and combined cycle gas, and broadly comparable with other onshore renewables[3], there appears to be headroom for these issues to be accommodated within power prices without compromising the relative cost advantage that solar has over other forms of generation. However, this will increase the overall price required by solar asset owners when compared to current prevailing prices that have been predicated based on historic generation and cost assumptions. This is most readily achievable for new assets and for existing assets when they are re-contracted during their operating life. For the owners of underperforming and fully contracted assets, persistent underperformance is likely to translate into downward pressure on asset valuation.

This whitepaper examines the drivers of solar underperformance, highlighting factors that may need to be included in future generation forecasts and operating assumptions, and considers how these dynamics are likely to influence pricing.

[1] kWh Analytics, 2025 Solar Risk Assessment Report, Industry Reports - kWh Analytics
[2] Raptor Maps, Global Solar Report: 2025 Edition, Global Solar Report 2025
[3] US Energy Information Administration, Annual Energy Outlook 2025 – Levelized Cost of New Generation Resources, April 2025, Levelized Costs of New Generation Resources in the Annual Energy Outlook 2025

1. ISSUES RELATED TO OPERATIONS AND MAINTENANCE (O&M) FIRMS

Globally, prior to 2022, more than a decade of sustained capacity additions led to an increasingly competitive solar O&M market. A growing number of regional providers and a number of international firms offered broadly similar service packages, with consolidation providing some scale benefits. It was generally expected that, as a result of the increased competition, there would be downward pressure on pricing. This environment also conditioned asset owners to expect O&M costs to stay flat or decline over time for a set level of performance[4]. More recently, inflationary pressures, skilled labour shortages, and a rapidly changing political outlook for many O&M firms have driven higher costs and reduced competitiveness, as fewer firms remain available to provide O&M services. This has been exacerbated by bankruptcies, including firms such as SunPower, and Blue Ridge Power, as well as the withdrawal of others from solar markets, including Huawei, Eaton, and Ingeteam.

Ownership of many solar O&M platforms has shifted from solar strategics, often affiliated with developers, EPCs, or equipment suppliers, to private equity and other financial ownership. This transition appears to have altered strategic priorities across much of the solar O&M sector. Whereas O&M services were previously positioned to support broader corporate objectives such as equipment sales, turnkey development solutions, long-term customer relationships, or brand positioning, the focus has increasingly shifted toward maximising standalone profitability, cash generation, and value creation[5].

O&M firms are operating in an industry that has rapidly grown and matured, while cost pressures relating to both labour and materials have intensified and many core products and services have become increasingly commoditised. For example, while solar module prices have declined on average over the past year, total installed system costs have increased by approximately 10%, driven by inflation in other electrical components (including racking costs increasing by approximately 50% year-on-year), and installation & repair labour costs increasing by approximately 15% year-on-year[6]. Growth in labour costs is particularly impactful, with a recent study indicating approximately 70% of solar O&M service costs are attributable to labour[7].

These changes have the potential to create knock-on effects for asset owners, including higher service costs and reduced service quality. In the near term these changes have translated into stricter contract interpretations by O&M contractors, reduced proactivity and greater rigidity in the delivery of defined scopes of service, greater pass-through of cost increases from solar component suppliers, less budget discipline in relation to variable/non-fixed O&M items, and more onerous monitoring requirements for asset owners seeking to manage performance effectively.

In the US, significant changes in federal policy during 2025 have created an uncertain outlook for many solar O&M providers. Pressures created by the “One Big Beautiful Bill” (OBBB) are expected to drive a pronounced surge in new solar deployment over the next two to four years as

[4] Origis / Wood Mackenzie, “The True Cost of Solar O&M is Increasing”, 2022, The True Cost of Solar O&M—Is Increasing - Origis Energy

[5] Bain & Co., “A Private Equity Lens on the Energy Transition”, February 2023, A Private Equity Lens on the Energy Transition | Bain & Company

[6] SEIA/Wood Mackenzie Power & Renewables U.S. Solar Market Insight Q4 2025, Solar Market Insight Report Q4 2025 – SEIA, Interstate Renewable Energy Council, National Solar Jobs Census 2024, Census Solar Job Trends - Interstate Renewable Energy Council (IREC)

[7] Origis / Wood Mackenzie, “The True Cost of Solar O&M is Increasing”, 2022, The True Cost of Solar O&M—Is Increasing - Origis Energy

developers accelerate projects to capture remaining renewable tax credits[8]. In the short term, this build-out is creating additional opportunities for O&M providers. However, in the medium term, as tax credits are phased out, the expected slow-down in renewable deployment could stall or even reverse that growth, creating a strategic dilemma for O&M firms. In response, many O&M firms appear to be pursuing higher margins to support an annuity-style business model capable of sustaining operations through the forecast slow-down in new solar installations.

As further discussed below, solar component suppliers have expanded their control over equipment maintenance by introducing subscription-based services. This has reduced asset owners' ability to self-maintain acquired equipment and increased dependence on solar component suppliers, limiting the range of services that independent O&M providers can perform. For example, whereas it was previously common industry practice for solar inverter manufacturers to train third-party O&M technicians to service their equipment, certain component suppliers have now restricted or withdrawn such programs. As a result, even routine interventions, such as equipment resets following site-wide utility outages, may require direct involvement from supplier personnel. This has narrowed competitive differentiation and reduced the ability of O&M providers to resolve performance issues quickly and efficiently and increased both costs and response times for asset owners.

Collectively, this shift has meaningful implications for the quality and cost of O&M services, and operational performance of solar assets. A typical feature of solar projects is the pairing of long-term revenue contracts with shorter term, or mutually terminable contracts for the O&M of the assets. The requirement to periodically recontract O&M services, or to absorb pricing changes over time, can lead to variations in profit margins.

2. CHANGES IN THE SOLAR SUPPLY CHAIN

Solar systems are comprised of solar modules (panels) and balance-of-plant (racking, trackers, inverters, combiner boxes). Changes to global trade policy and regional industrial policy have created a complicated outlook for both module suppliers and manufacturers of other components.

Solar module suppliers continue to invest in new manufacturing capacity in response to sustained demand and ongoing deglobalisation of supply chains[9]. By contrast, balance of plant equipment manufacturers, including inverter suppliers, are adopting more measured approaches to capacity expansion[10]. Comparable dynamics are evident in the solar tracker market, where major suppliers are expanding order backlogs rather than making meaningful investment in new manufacturing capacity[11].

[8] SEIA/Wood Mackenzie Power & Renewables U.S. Solar Market Insight Q4 2025, Solar Market Insight Report Q4 2025 – SEIA

[9] SEIA/Wood Mackenzie Power & Renewables U.S. Solar Market Insight Q4 2025, Solar Market Insight Report Q4 2025 – SEIA

[10] For example, despite strong growth in global solar deployment over the past decade, leading European solar inverter manufacturer SMA Solar Technology initiated a company-wide restructuring plan in late 2024 in response to "a persistently challenging market environment" seeking to reduce costs and improve production efficiency across the company. In China, a similar retrenchment has been observed. In mid-2025 the Chinese government directed major solar companies to undertake a sector-wide restructuring in response to what it characterised as "disorderly" competition and "irrational" pricing. The stated objectives were to stabilie pricing, improve product quality, and remove excess capacity from the system. Sources: SMA Solar Technology AG, "SMA initiates company-wide restructuring and transformation program", 25 September 2024, SMA initiates company-wide restructuring and transformation program | SMA Solar; PV Magazine, "China moves to curb solar overcapacity, stabilize pricing", July 2025, China moves to curb solar overcapacity, stabilize pricing – pv magazine International

[11] See for example Nextracker Q2 FY2026 Shareholder Letter, Nextracker_ShareholderLetter_Q2-FY2026_Final.pdf

A consequence of these trends has been demand growth exceeding supply growth, resulting in longer order lead times for component parts, including for inverters, transformers, trackers, and other balance-of-plant equipment. For operational assets, this directly impacts the availability and replacement timelines of critical parts, highlighting the importance of diligent spare parts management[12].

In conjunction with the tightening of supply chains, equipment manufacturers, particularly inverter suppliers, are increasingly seeking to capture higher margins from their existing installed equipment base by "locking in" customers. In recent years there has been a significant rise in the introduction of subscription-style services and the requirement to have maintenance agreements. These include annual fees for extended equipment warranties, or additional payments to secure "priority access" to spare parts. A major factor in the ability for equipment manufacturers to request these additional fees is tighter controls over proprietary software and systems including software locks and other encryption to prevent non-component supplier staff interacting with their equipment. Higher fees for training and reduced availability of training and certification programs for third-party technicians has led to an increased reliance on component supplier technicians. Similar tactics have been observed in other industries, such as agricultural machinery, where manufacturers have sought to restrict asset owners' abilities to quickly self-repair equipment and increase reliance on component suppliers[13].

Given these new developments and aggressive pricing models that are being introduced, asset owners increasingly facing a choice between paying materially higher fees to maintain asset performance at target levels, or accepting longer outages, higher corrective maintenance costs and the risk of sustained underperformance.

3. COMPONENT FAILURE RATES

With respect to solar modules, reliability studies undertaken by quality assurance firm Kiwa PVEL indicate that the depth of expertise for the successful design and manufacturing of solar modules has increased substantially over the past decade. In its 2025 testing programme, Kiwa PVEL identified 50 solar module suppliers as "Top Performers", versus only 8 in 2016[14].

Despite this recent analysis by Raptor Maps indicated that solar underperformance due to module and other project equipment outages increased to 5.8% in 2024, up from 5.0% in 2023. Based on 2024 data, inverters continued to be the largest cause of underperformance, responsible for 37% of total power losses. String faults and combiner faults, both component parts of the electrical system transferring power from the modules to the inverters, contributed 22% and 18% of losses respectively.[15] The remaining 23% of losses were attributed to tracker faults, module faults, and other issues.

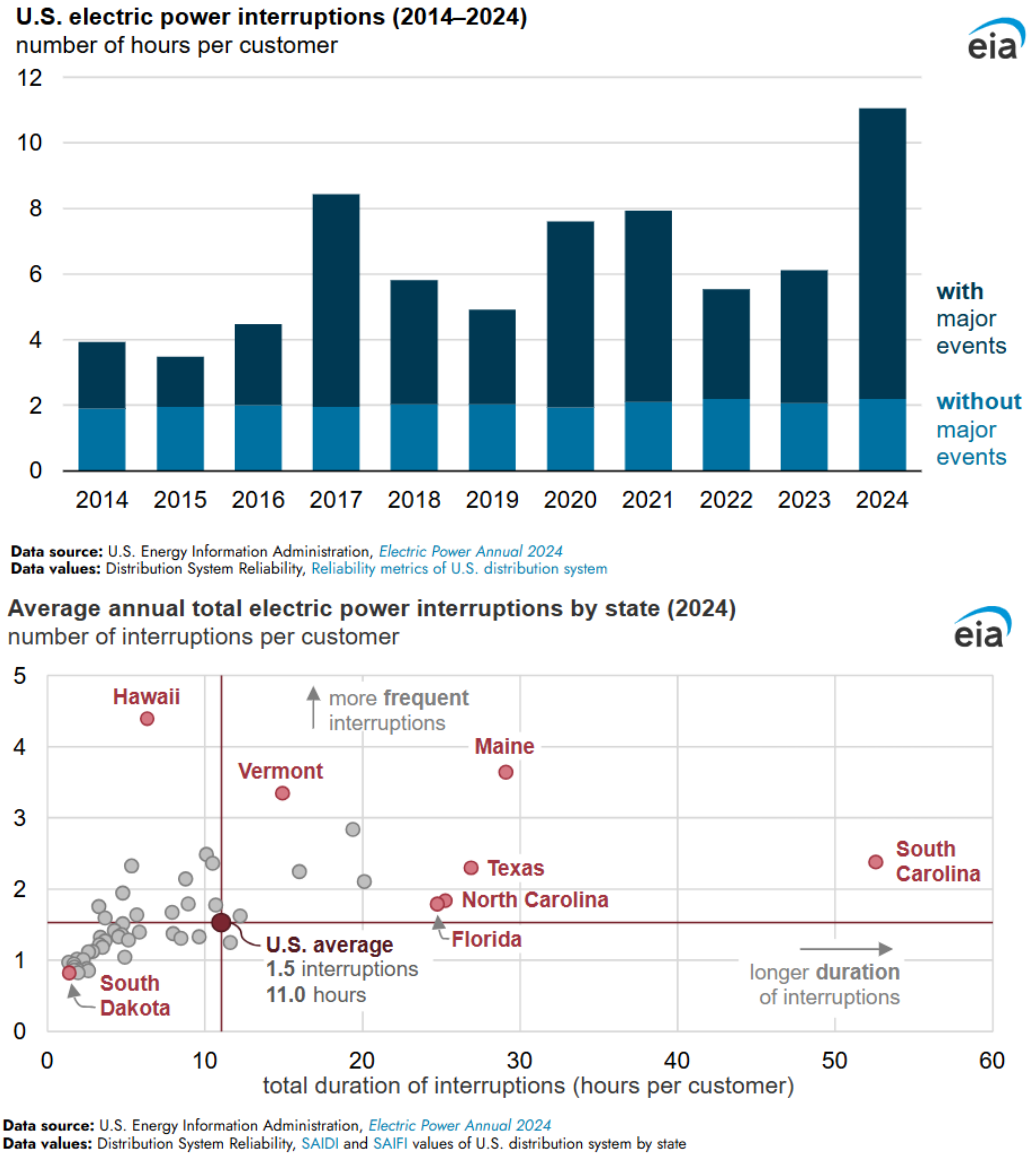
4. GROWING EXPOSURE TO UTILITY GRID OUTAGES AND CURTAILMENT RISK

A growing risk to on-budget generation performance for solar PV assets (and other generation assets) arises from the increasing rate of utility grid outages. In Europe, for example, physical

[12] Raptor Maps, Global Solar Report: 2025 Edition, Global Solar Report 2025
[13] See for example Federal Trade Commission, re Deere & Company, January 2025, FTC, States Sue Deere & Company to Protect Farmers from Unfair Corporate Tactics, High Repair Costs | Federal Trade Commission
[14] Kiwa PVEL, 2025 PV Module Reliability Scorecard, 2025_Scorecard_Summary.pdf
[15] Raptor Maps, Global Solar Report: 2025 Edition, Global Solar Report 2025

constraints within existing transmission and distribution networks are resulting in increasing curtailment of solar and wind assets. In Germany, 3.1% of total solar generation was curtailed in 2025, up from 1.4% in 2024, according to data from regulator Bundesnetzagentur (BNetzA)[16]. These outages are largely outside the control of the asset owners and in many cases, are not compensated, resulting in lost generation and revenue. While discussions of solar performance have historically focused on site-level and equipment-related factors, grid reliability and availability have emerged as a material and growing source of lost generation and revenue.

As shown in the chart below, disruptions to the US electric system have trended upward over the past decade[17].



Source: US Energy Information Administration. See footnote 17.

[16] Ember Energy Research, "European Electricity Review 2026", January 2026, EER_2026

[17] US Energy Information Administration, Today in Energy – 1 December 2025, Hurricanes in 2024 led to the most hours without power in the United States in 10 years - U.S. Energy Information Administration (EIA)

Utilities have increasingly implemented preventative system outages to mitigate certain risks. Major wildfires in recent years, particularly in California (including the Camp Fire in 2018 and the Los Angeles wildfires in early 2025) and Hawaii (including the Maui wildfires in 2023), have highlighted the significant financial and legal exposure utilities face when fires are linked to utility-owned equipment[18]. In response, many US utilities, including utilities outside of California such as PacifiCorp and Xcel Energy, have expanded the use of "public safety power shutoffs" (PSP) protocols to pre-emptively deenergise electric infrastructure during periods of elevated wildfire risk[19]. Given the strong incentives for utilities to demonstrate that reasonable preventative steps are being taken, PSP programs are generally applied conservatively and, in some cases, over increasingly broad geographic areas during wildfire seasons.

In parallel, utilities are facing mounting challenges arising from deferred maintenance and bottlenecks in expanding existing networks to support ongoing load growth. Aging transmission and distribution infrastructure, combined with prolonged permitting timelines, supply-chain constraints, and workforce shortages, has slowed the pace at which new grid capacity can be built or upgraded[20]. As a result, congestion, forced outages, and extended maintenance windows are becoming more common, particularly in regions experiencing rapid load growth or renewable interconnection backlogs.

From the perspective of solar asset owners, all types of grid outages have the same economic impact: solar assets that are available to generate power are unable to deliver electricity to the grid and therefore receive no revenue, while also receiving no compensation from the grid operator for lost output in most cases.

5. ELEVATED RISK OF PROPERTY DAMAGE AND THEFT AT REMOTE SOLAR FACILITIES

An additional, often underappreciated, risk facing solar asset owners at present is the growing incidence of property damage at project sites resulting from the theft of copper wiring used on-site. US copper prices have risen strongly over the past 12-24 months in response to strong demand from data centres and other electrical infrastructure demand, concerns over tightening US domestic supply, and tariff uncertainty. US copper prices recently reached record highs of approximately $6/lb and increased by approximately 42% in 2025[21]. Elevated copper prices are driving increasing incidences of copper wire theft across the country, with targets including streetlighting, telecommunications cables, and copper looms in transit on trucks and at logistics centres[22]. Recent examples of such activity include, in Las Vegas and its surrounding suburbs, more than 970,000 feet of copper wiring went missing from streetlights from 2022 to 2024, in mid-2024 thieves impersonating a trucking firm using stolen identification documents intercepted a $135,000 shipment of copper wire near Cincinnati, Ohio, and in April 2025 two employees of a

[18] Stanford University, Woods Institute for the Environment, "Fire Ready?" Whitepaper, June 2025, Fire Ready?: White paper finds many U.S. power utilities unprepared for wildfire risk | Stanford Woods Institute for the Environment
[19] Stanford University, Woods Institute for the Environment, "Fire Ready?" Whitepaper, June 2025, Fire Ready?: White paper finds many U.S. power utilities unprepared for wildfire risk | Stanford Woods Institute for the Environment
[20] Grid Strategies, "Fewer New Miles", July 2024
[21] Wall Street Journal, "Copper Extends Rally, Bursting Through $13,000 a Ton", 6 January 2026, https://www.wsj.com/finance/commodities-futures/copper-extends-rally-bursting-through-13-000-a-ton-9e66c958
[22] Wall Street Journal, "Copper Thieves are Wreaking Havoc Across America", 29 November 2025, https://www.wsj.com/business/telecom/copper-thieves-are-wreaking-havoc-across-america-9135906f

JFK Airport contractor stole 1,100 feet of copper cable valued at approximately $70k from an airport warehouse[23].

Copper wiring used extensively at solar facilities is also a viable target for theft given solar facilities are frequently located in sparsely populated areas with limited (if any) on-site staff, multi-acre solar sites are difficult to fully secure, and stolen wire is very difficult to trace once offsite making them inherently vulnerable to vandalism and theft. Theft events can result in immediate outages, extended repair timelines, safety hazards, and higher insurance premiums, as well as the potential for repeated incidents once a site is identified as a target. While it can be challenging to fully secure multi-acre solar facilities, there are various monitoring and intervention strategies that solar asset owners can implement to mitigate these theft risks, albeit at higher costs to the effected assets.

CONCLUSION

The factors discussed in this paper highlight a common theme, that many of the issues that are currently impacting generation performance have historically not been accommodated or have been insufficiently reflected in forecasts. As the solar industry matures and the operational record of existing assets lengthens, these realities are becoming increasingly visible to investors, lenders, and service providers.

Over time, the cumulative impact of these risks will be reflected in the pricing and structuring of renewable energy. Higher operating cost expectations, greater performance variability, and increased uncertainty around grid availability and equipment support will ultimately translate into higher required returns and, in turn, higher PPA prices.

Evidence supporting this repricing thesis can already been seen in recent trends and outcomes for renewable PPA prices. In recent years, US solar PPA pricing has grown at a much faster rate than the installed costs for such assets[24], while remaining meaningfully cheaper than offtake pricing for gas generation[25]. A recent example from the UK, where the most recent round of offshore wind auctions cleared at approximately GBP91/MWh far higher than the GBP 57.50 clearing price in 2015 shows how prices have started to rise. This auction, however, was concluded by the UK Government to be approximately 40% cheaper than the offtake price would be for new gas generation[26]. These results indicate that there is headroom for renewable PPA prices to increase to accommodate higher operating costs and greater performance variability, while remaining cost competitive against other forms of generation.

Existing solar projects with long-term, fixed-price revenue contracts are likely to face the greatest pressure. Projects that locked in PPAs during the 2021–2022 period, when competition was intense, capital was abundant, cost assumptions were optimistic, and inflation was accelerating, are particularly exposed. These assets must absorb escalating operating costs and performance risks while revenues remain largely fixed, compressing margins and eroding expected returns.

[23] Wall Street Journal, “Thieves Target Copper by the Truckload as Prices Rise”, 10 July 2025, https://www.wsj.com/articles/thieves-target-copper-by-the-truckload-as-prices-rise-b4120aa9; Forbes, “Here’s Why Higher Copper Prices Usually Lead to More Crime”, 9 July 2025, Here’s Why Higher Copper Prices Usually Lead To More Crime

[24] LevelTen Energy, PPA Price Index Q3 2025, go.leveltenenergy.com/2025_Q3_PPI_Exec_Summary

[25] Norton Rose Fulbright, “The Shift Back to Gas”, 1 August 2025, The Shift Back to Gas | Norton Rose Fulbright - August 2025

[26] UK Government, “Record breaking auction for offshore wind secured to take back control of Britain’s energy”, 14 January 2026, Record breaking auction for offshore wind secured to take back control of Britain's energy - GOV.UK

While current M&A valuations for renewable energy assets may not yet fully reflect these factors, awareness of these issues is increasing amongst seasoned market participants. We believe that evolving market dynamics, including OBBB-led changes to renewable energy development, discount rate changes driven by base rate movements, and constraints on new generation supply amid rising demand, remain greater influences on transaction outcomes.

Over the longer term, market fundamentals suggest that these risks will be reflected in project economics and priced in future contracts and contract renewals. Higher power prices, improved risk allocation, and different operating assumptions are likely to emerge as the sector recalibrates. Effective asset management will be critical in bridging this transition, preserving value in existing portfolios while positioning asset owners to benefit from more sustainable pricing and contract structures in future development cycles.

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