Curtailment mitigation with energy storage

A revenue recovery case study

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Imagine this

You're driving through the Midwest on a beautiful, windy day and see a sprawling wind farm on the horizon. You notice that about half of the turbines aren't spinning, and ask yourself, why?

Although some of the turbines may be under maintenance, it's more likely that there isn't enough demand for the electricity being produced at that moment. It's also possible that there isn't enough transmission capacity available to deliver the power where it's needed. Unless the wind farm can store that energy, some turbines will have to temporarily shut down. Intentionally reducing the amount of renewable energy a facility can deliver is called curtailment.

As the United States continues to accelerate the development of renewable energy generation to combat climate change, we have seen an increase in the over-supply of electricity in some areas, leading to increased curtailment. That's because renewable energy generators are intermittent resources — sometimes the wind blows and the sun shines when the grid doesn't need more power. Since intermittent resources cannot be dispatched similarly to traditional generators, they can't ramp up when demand peaks; in fact, the sun usually sets just before power demand peaks. As we seek to transition the grid to a 100% emissions-free future, there is a growing need to "smooth the curve" — store surplus power and dispatch it later when it's needed most. This is where battery energy storage systems (BESS) come into play.

BESS as a solution: An introduction

Energy storage devices, particularly BESS, are some of the most versatile and flexible assets for managing intermittent renewable generation. Their quick response rate and ability to store both renewable output and grid energy allow them to rebalance power flows, reducing the frequency and magnitude of potential curtailment. However, before we can fully understand the benefits of BESS as a curtailment reduction tool, let's look at how quickly renewable energy is growing in the United States and how much is being curtailed.

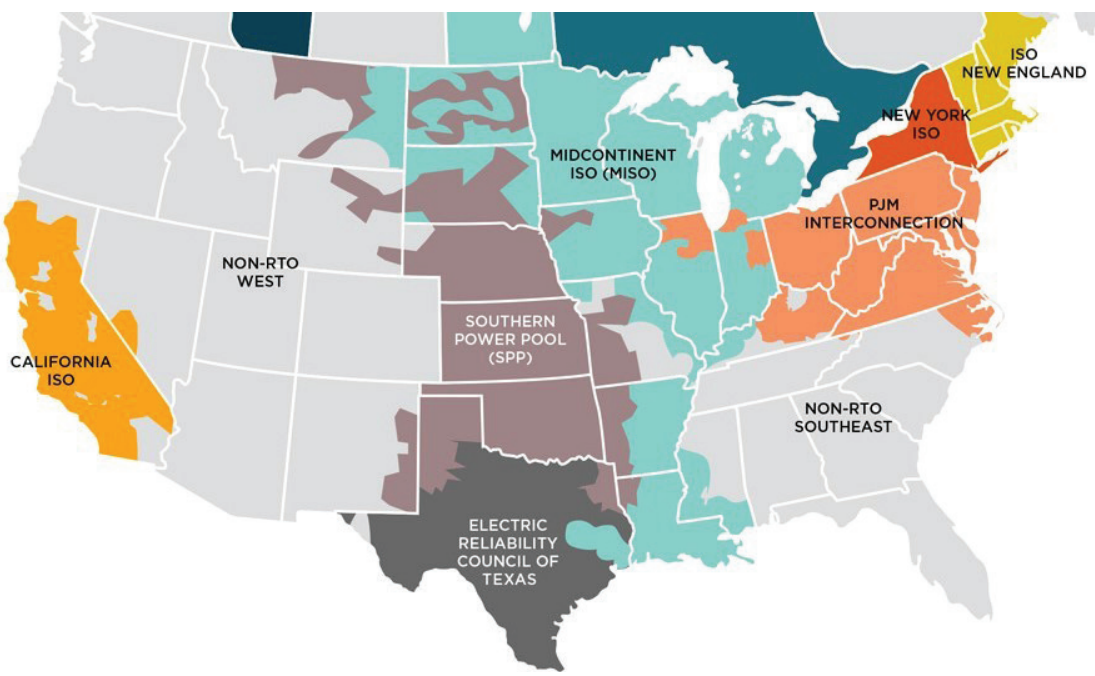
The rise of intermittent generation

In 2023, renewable energy generation has grown to serve about 1/5 of total power needs in the U.S., more than doubling over the last decade as wind and solar developments continue at a breakneck pace.[1] Solar power accounted for nearly half of U.S. generating capacity additions in 2022.[2] Although reducing greenhouse gas emissions is important, the rapid inclusion of intermittent resources has led to significant supply/demand imbalances in certain areas of the grid, often leading to curtailment. So why do certain areas experience more curtailment than others?

Some areas experience higher wind speeds than others, while some areas are exposed to more solar irradiance than others. Developers want their facilities to operate at the highest possible capacity factor. Since solar irradiance is plentiful in the Southwestern United States, the California Independent System Operator (CAISO) has the highest solar photovoltaic (PV) penetration of any ISO, with utility systems making up 62% of the total capacity and 23% of the total load served in 2021.[10] Since wind speeds are highest in the central United States, the Southwest Power Pool (SPP), the Electric Reliability Council of Texas (ERCOT) and the Midcontinent ISO (MISO) have built the most wind capacity, with penetrations reaching 38%, 32.4%, and 16% of load served in 2022, respectively.[4]

Although increasing renewable penetrations on the grid can lead to increased curtailment, they are not directly related; some areas have more transmission capacity than others, meaning they can facilitate more intermittent power flows. So which region is curtailing the most?

U.S. electricity markets



Curtailment of renewable energy

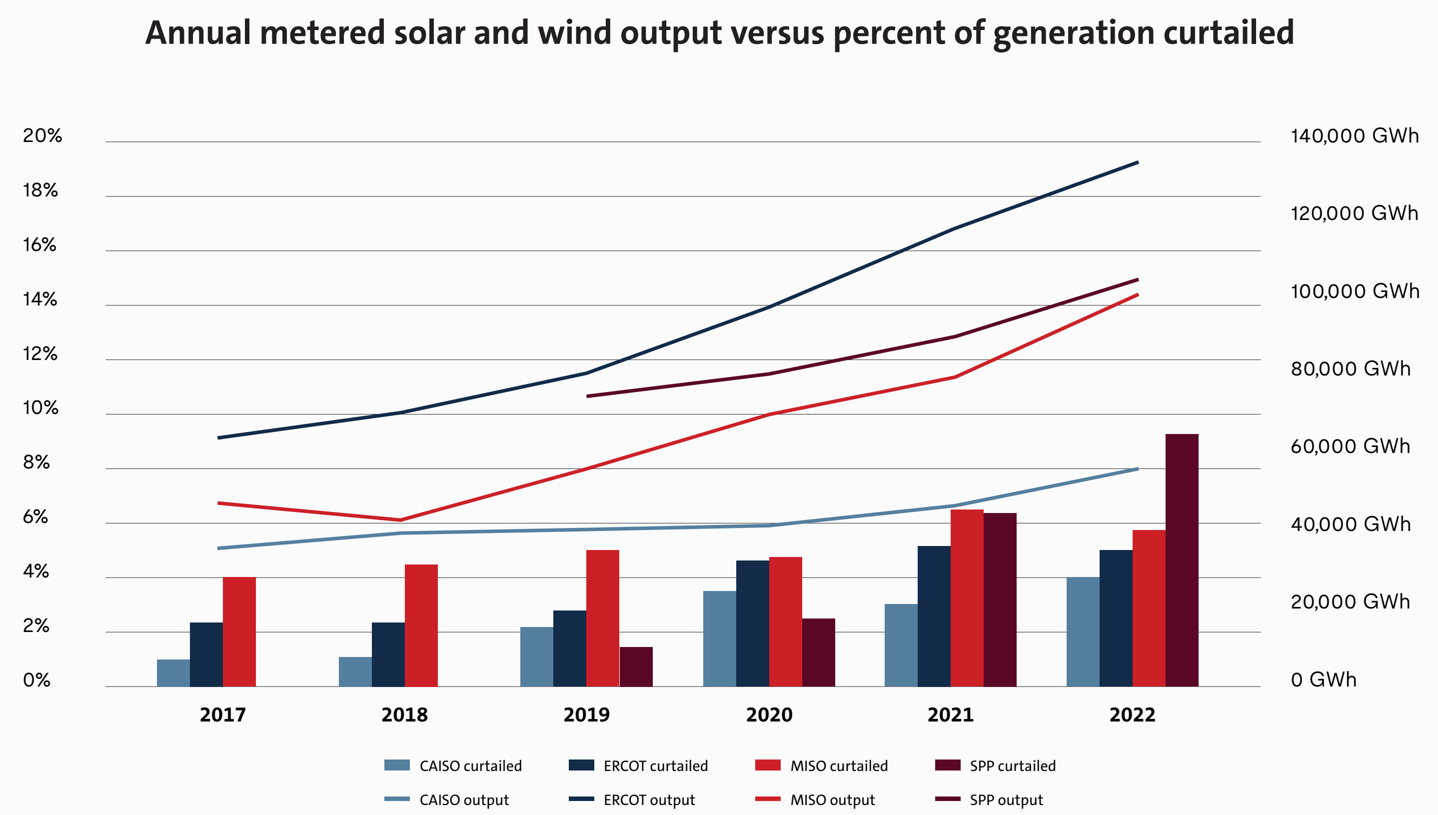


Figure 1
Total Wind and Solar Production by ISO vs. Percentage of Curtailed Output; sources: [3, 4, 5, 6, 7, 8, 9, 13]

By comparing the metered power output of solar and wind facilities to the percentage of total renewable generation curtailed, we can see that renewable energy curtailment is steadily increasing. This is particularly true in California, where curtailments have grown steadily from just 1% to nearly 4% in 2022 as solar energy takes a greater share of the supply mix. And with SPP rapidly expanding its wind generation capability over the past 5 years relative to demand, total curtailments surpassed 9% of total generation in 2022.

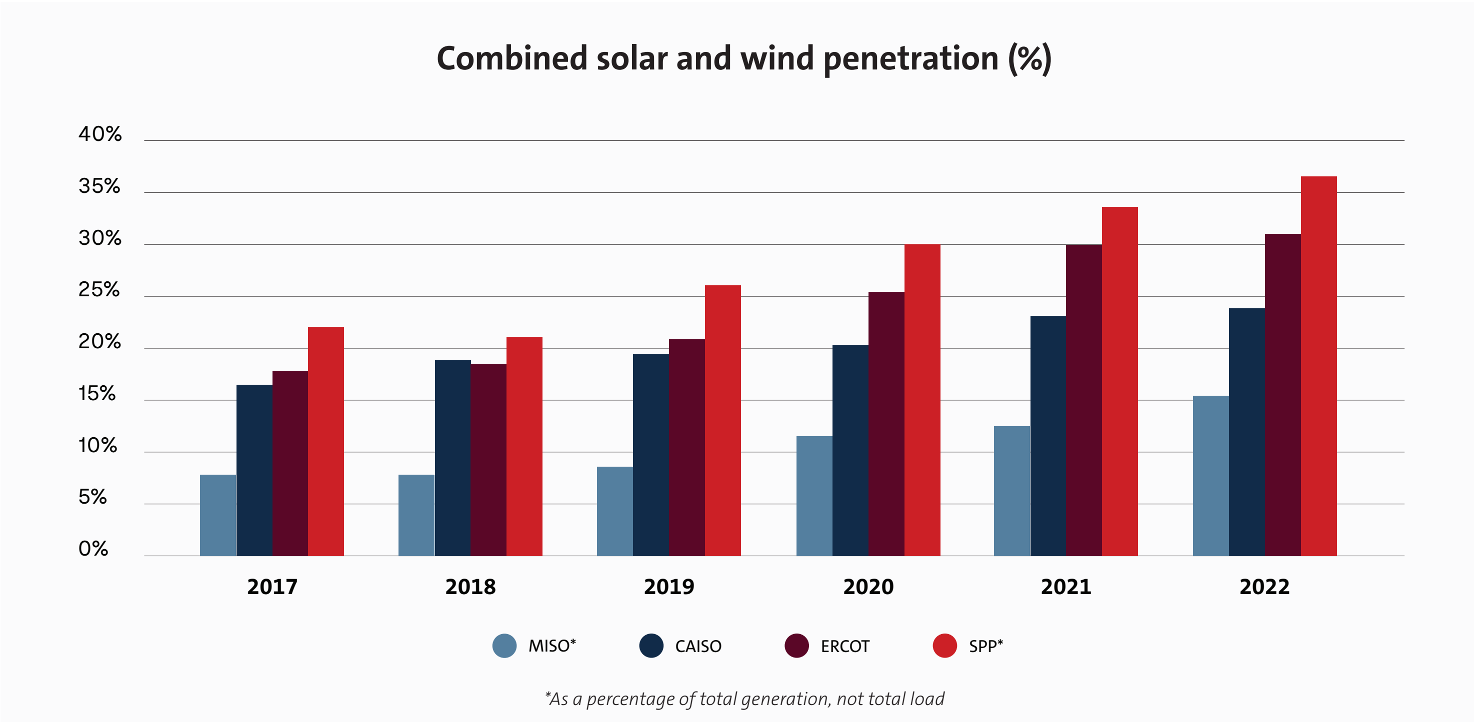


Figure 2
Combined Solar and Wind Penetration by Market

Although only a fraction of annual production is being curtailed, it's important to understand that curtailments can be more aggressive in specific areas and during specific times of the year. For instance, on April 20, 2022, in California, more than 40% of system-wide PV output in California was curtailed due to system constraints. Across the entire year, 80% of all economic curtailments were due to localized constraints resulting from pockets of overgeneration, usually during periods of weak system demand.[3] Since curtailment is obviously a highly complex issue, how do we know it will continue to present challenges moving forward?

A changing landscape

In August of 2022, the Biden administration signed the largest piece of climate legislation in U.S. history: the Inflation Reduction Act (IRA). This legislation extended the timeframe for eligible renewable energy projects to collect investment tax credits (ITC) of up to 30% or production tax credits (PTC) of at least $0.026 (USD)/kWh through 2032. Additionally, the IRA expanded ITC eligibility to stand-alone BESS and interconnection upgrades and even allows the transfer of the ITC to a third party in exchange for cash, which can simplify financing for private owners.[18] These changes position the renewable energy industry for massive growth over the coming decade, increasing the need for energy storage, all while BESS energy density, manufacturing capacity and affordability are on the rise.

HOMER Front case study

Using BESS, developers can mitigate curtailment at new and existing wind and PV facilities by storing excess electricity and dispatching it later, when there is more demand or market prices are higher. Recognizing the importance of independent engineering and revenue-grade dispatch modeling to secure financing for utility-scale projects, UL Solutions developed HOMER Front, a techno-economic modeling tool designed specifically for utility-scale systems. Using HOMER Front, UL Solutions performed a case study on an existing 200 MW wind facility in Texas during the 2021 extreme weather event that caused generator outages and derates for five straight days in ERCOT. The outages spanned across 25 Texas counties and peaked at 51 MW of unavailable capacity on Feb. 16, 2021.[16] In 2021, the 200 MW wind farm generated 407 GWh of energy, 199 GWh of which was curtailed. That means almost half of the facility's generation was not utilized that year due to curtailment. Our analysis compared the addition of a 200 MW BESS to the wind farm at one-hour, two-hour and four-hour durations. To explicitly capture the curtailment benefits adding BESS can offer, the case study considered only the wind facility's curtailed energy during the simulation. This means the BESS was charging from otherwise excess electricity that would have been wasted, and the revenue shown in the results is solely from shifting curtailed energy. Additionally, the HOMER Front model included a 200 MW interconnection limit, the 2021 real-time market locational marginal pricing (LMP) from ERCOT with 100% allocation into the real-time market, and a bonus depreciation tax incentive of 28.75% of eligible capital costs. Excluding the winter storm from Feb. 13-18, the 2021 LMP for this wind facility averaged approximately $45 (USD)/MWh. During the five-day winter storm, the grid prices spiked massively and peaked at $9,349 (USD)/MWh.

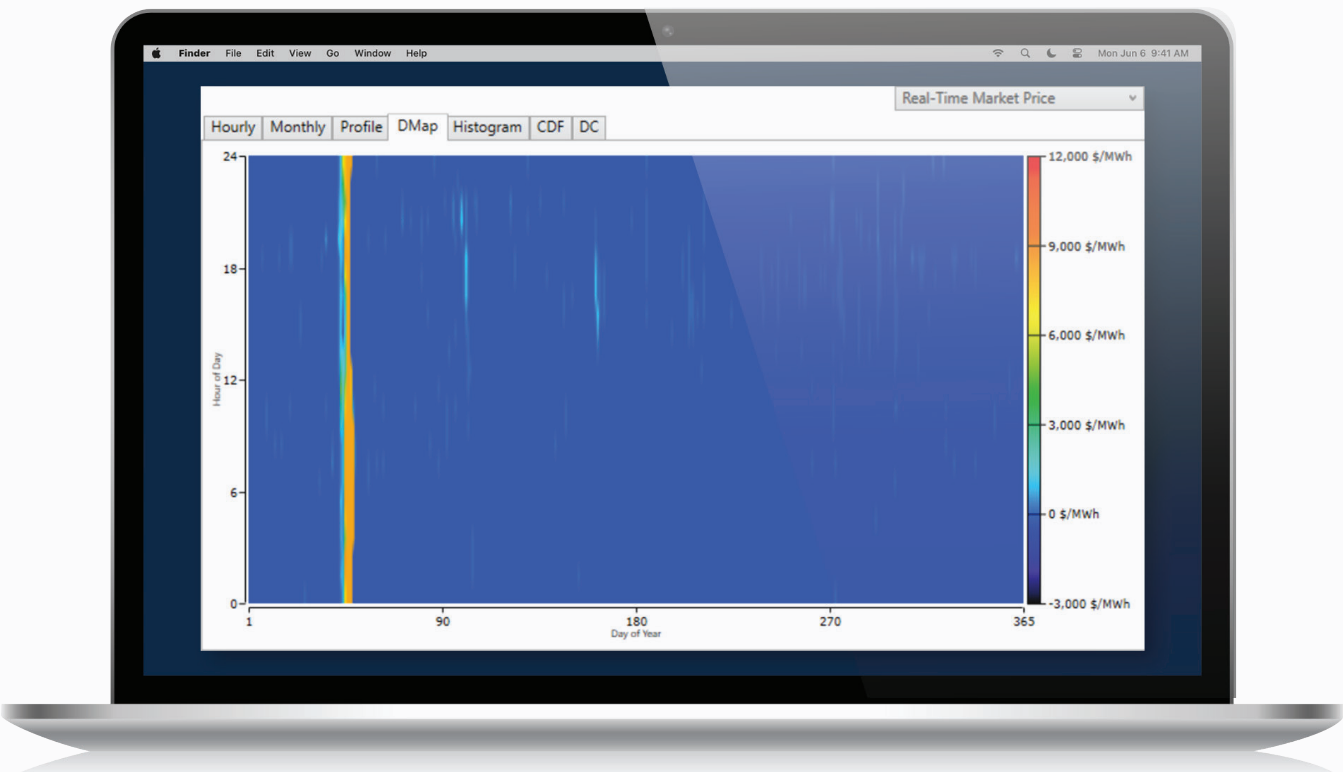


Figure 3
2021 Real-Time Market LMP Price Strip in ERCOT

The results

HOMER Front's dispatch strategy is to maximize the value of the front-of-the-meter revenue through strategic dispatch of the BESS. Therefore, during each timestep of the annual simulation, HOMER Front makes dispatch decisions for each component in the system with the goal of generating as much revenue as possible over the project's lifetime. In this case, HOMER identifies the amount of wind generation available in the system, the LMP grid price and the battery's state of charge each hour to decide whether to cycle the battery into the real-time market.

With all three BESS configurations compared in the analysis, HOMER Front found the addition of BESS to the existing wind facility favorable. For this site, HOMER Front found the system with the lowest BESS duration at one hour yielded the highest internal rate of return (IRR) at 12.1%. Adding a one-hour BESS to the wind facility allowed the system to shift 35 GWh of the 199 GWh of curtailed energy the wind facility experienced in 2021. The added revenue from storing this curtailed energy in BESS, then ultimately selling it once the grid becomes operational, pays back 17.1% of the BESS capital costs in the first year alone. If this were to occur every year, the simple payback of adding the BESS would only be approximately 7.9 years. While an extreme winter storm is not likely to occur every year, BESS is an extremely flexible asset capable of providing capacity and various ancillary services, like frequency regulation and operating reserves. These facts highlight the need to optimize the BESS using HOMER Front to maximize revenue and performance in all situations, including periods of curtailed renewable energy.

After simulating the addition of three different BESS configurations in HOMER Front, the results were as follows:

HOMER® Front case study results

Configuration	Wind generation curtailed (MWh/yr)	% reduction in total curtailment (%)	BESS CAPEX (USD)	BESS simple payback (years)
Wind only	199,245	0	0	0
200 MW/200 MWh	164,180	17.6	65,000,000	7.9
200 MW/400 MWh	140,431	29.5	126,000,000	9.1
200 MW/800 MWh	109,700	44.9	244,000,000	11.8

Conclusion

This study has shown that adding energy storage to a new or existing intermittent generating facility can significantly reduce curtailment from extreme weather events and grid congestion. By shifting energy from periods of oversupply to periods of undersupply, BESS can help avoid potential generation shortfalls, maximizing the project's environmental benefits while providing additional value to the grid and the project with other capacity and ancillary services.

Whether you are pursuing energy storage for a new or existing facility or just looking to explore your options, HOMER Front's advanced dispatch modeling and our industry-leading team of subject matter experts and independent engineers can help.

Learn more at UL.com/energystorage.

Endnotes

1. https://www.eia.gov/totalenergy/data/browser/index.php?tbl=T07.02B#/?f=M
2. https://www.eia.gov/todayinenergy/detail.php?id=50818
3. http://www.caiso.com/informed/Pages/ManagingOversupply.aspx
4. https://www.energy.gov/sites/default/files/2022-08/land_based_wind_market_report_2202.pdf
5. https://www.energy.ca.gov/media/7311
6. https://www.ercot.com/gridinfo/generation
7. https://www.misoenergy.org/markets-and-operations/independent-market-monitor2/#nt=%2Fimmtype%3AAnnual%20State%20of%20the%20Market%20Report&t=10&p=0&s=FileName&sd=desc
8. https://www.eia.gov/electricity/gridmonitor/dashboard/electric_overview/US48/US48
9. https://www.spglobal.com/marketintelligence/en/news-insights/research/as-ira-drives-renewables-investment-attention-turns-to-transmission-upgrades
10. https://emp.lbl.gov/solar-capacity-and-generation
11. https://ftp.puc.texas.gov/public/puct-info/industry/electric/reports/ERCOT_annual_reports/2021annualreport.pdf
12. https://www.energy.ca.gov/data-reports/energy-almanac/california-electricity-data/california-electrical-energy-generation
13. https://cdn.misoenergy.org/20220622%20Markets%20Committee%20of%20the%20BOD%20Item%2004%20IMM%20State%20of%20the%20Market%20Report625261.pdf
14. https://www.spp.org/documents/67104/2021%20annual%20state%20of%20the%20market%20report.pdf
15. https://energyinnovation.org/wp-content/uploads/2019/06/US-RTO-ISO-markets-via-SustainableFERC.jpg
16. https://energy.utexas.edu/research/ercot-blackout-2021
17. https://www.spp.org/documents/69330/2022%20annual%20state%20of%20the%20market%20report.pdf
18. https://www.energy.gov/femp/overview-inflation-reduction-act-incentives-federal-decarbonization
19. https://www.ercot.com/gridinfo/load/load_hist

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