It's Not Always Sunny in California: Strategies to Increase Our Reliance on Solar Generation

Kevin Novan and Benjamin Dawson

Meeting California's goal of a 100% carbon-free electric grid will require an increased reliance on solar energy. To absorb the growth in solar, storage capacity must expand to shift output to hours when the sun is not shining. Consumers must also be charged time-varying rates that shift consumption to hours when the sun is shining.

California's solar production has increased from 0.4% to 22% of the market between 2010 and 2020.

American Public Power Association

In 2010, less than 0.4% of the electricity produced in California came from solar. Driven by declining solar photovoltaic (PV) costs and plenty of government support, solar rapidly grew to account for over 22% of California's electricity production in 2020—with roughly two-thirds coming from large-scale solar farms and the remainder from smaller units (e.g., rooftop solar).

Going forward, California's growth in solar production will be even more dramatic. With the passage of AB 100 in 2018, the state mandated that 60% of the electricity supplied to the grid must come from renewable sources by 2030, and 100% must come from carbon-free sources by 2045. Solar is expected to supply a large share of this clean output.

These efforts to create a cleaner grid are the key to achieving the state's ambitious greenhouse gas reduction targets. While the electric sector only accounts for 15% of California's greenhouse gas emissions, the state is working to shift the transportation sector away from oil and towards electricity and to move buildings away from natural gas to electricity for heating. By powering the state's transportation sector, buildings, and industries with a clean electric grid, policymakers are striving to dramatically reduce carbon emissions.

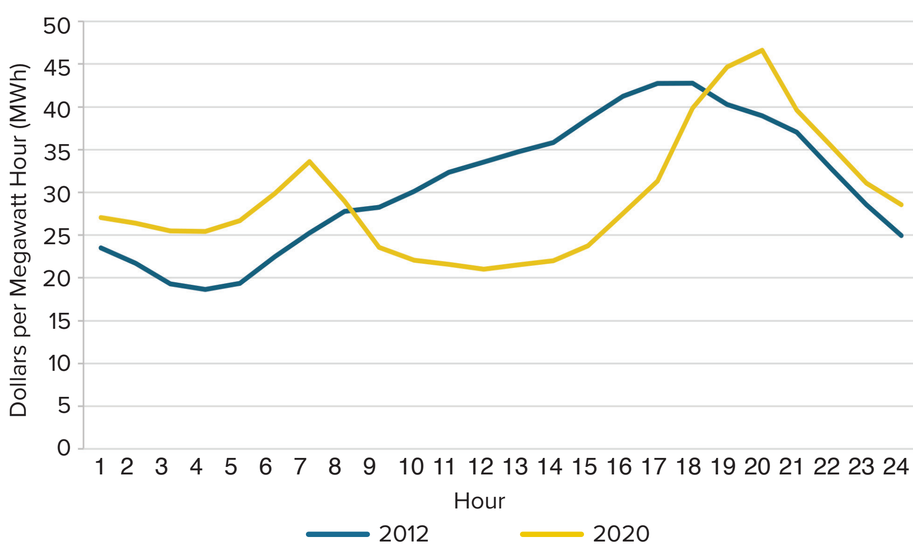
Pushing California's electric sector to become more reliant on solar requires overcoming solar's key shortcoming—all of the output is supplied when the sun is shining. This poses two challenges. First, electricity is still consumed when the sun is not shining. Indeed, in California, consumption peaks in the evening when solar generation is unavailable. Second, California's midday solar output already frequently exceeds what the grid can accommodate, resulting in solar output being reduced, or curtailed.

This article highlights what must occur for renewables, and in particular solar, to account for a substantially larger share of California's energy consumption. First, growth in storage capacity will be required to shift the surplus solar generation to hours when the sun is not shining. Second, the prices that consumers pay for electricity will need to meaningfully change. In particular, consumers will need to be charged time-varying prices that provide strong incentives to shift consumption to the middle of the day.

Market Impacts of Solar

In California, generators compete to supply electricity through markets overseen by the California Independent System Operator (CAISO). The

Figure 1. Average Hourly CAISO Day-Ahead Market Price, 2012 vs. 2020



Source: California Independent System Operator (CAISO).

outcomes in this market have already been reshaped by solar.

Figure 1 (on page 5) displays the average hourly prices in CAISO's day-ahead market in 2012 and 2020. In 2012, the minimum average prices occurred during the low-demand, early morning hours. In contrast, during 2020, the abundance of solar generation depressed midday prices to the point that the lowest average price occurred at noon.

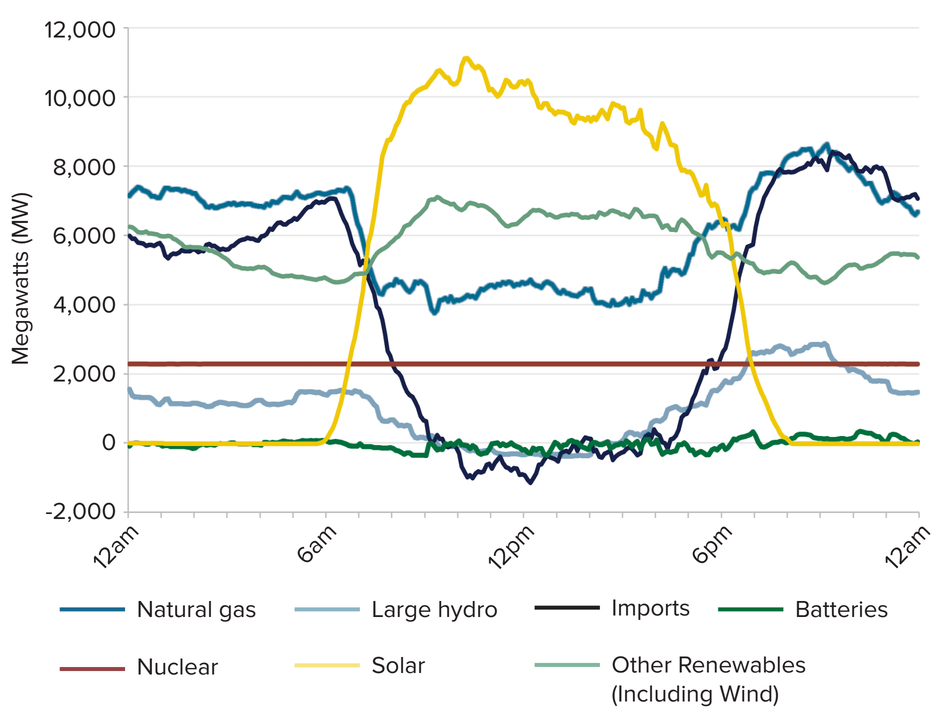
The impact of solar is also evident in the daily pattern of supply. Figure 2 displays the quantity supplied to the CAISO market on May 21, 2021. This pattern of supply represents what is becoming a typical spring weekday in the CAISO market.

In-state natural gas generation was the largest source of supply (26% of the daily consumption), while solar (19%) was the second-largest source. However, because the solar output was concentrated in less than half of the day, solar supplied half of the midday output.

While solar spikes midday, demand in the CAISO market does the opposite. On the day displayed in Figure 2, demand reached a morning peak of 24,000 megawatts (MW) at 9 a.m., then fell to 21,000 MW by noon before steadily climbing back up to 26,000 MW at 9 p.m. This drop in midday demand in the CAISO market is driven in part by regular patterns in consumption and in part by the growth in behind-the-meter solar capacity (e.g., rooftop solar) that reduces the amount of generation needed from the CAISO market.

Because CAISO demand does not increase with solar output, there must be sharp reductions in the midday supply from other sources to accommodate the solar output. Figure 2 highlights how imports from the regions surrounding California plummet from roughly 7,000 MW prior to sunrise to below zero midday (i.e., CAISO begins exporting the surplus production that exceeds midday demand in California).

Figure 2. CAISO Supply by Source (May 21, 2021)



Source: California Independent System Operator (CAISO).

Similarly, output from large hydroelectric plants falls from close to 2,000 MW prior to sunrise to become negative as energy is used to pump water back up into the reservoirs to be used to produce electricity at a later point in time. There is also a limited amount of battery storage capacity within CAISO. Figure 2 highlights how these units were, on net, charging up during the middle of the day.

Figure 2 also reveals that in-state natural gas generation, the dominant source of CAISO's supply, is cut in half during the daylight hours. However, there are limits to how far the gas generators can reduce supply without needing to shut down. When these units shut down, there are sizable costs to starting back up as well as limits to how fast they can ramp back up.

Until there is sufficient supply from alternative sources (e.g., more storage capacity) to meet demand in the evening when solar output disappears, gas units will continue to stay online and operate midday, albeit at lower levels of output.

Despite the reductions in midday natural gas and hydroelectric generation, the switch from CAISO being a net importer to a net exporter, and the use of storage, there was still more midday solar output than could be absorbed by the grid. That is, the quantity of electricity being supplied simply exceeded the quantity of electricity demanded. As a result, on the day displayed in Figure 2, 17% of the solar output from large-scale solar farms had to be curtailed (i.e., not utilized).

While the curtailment required on the day displayed in Figure 2 is currently on the high-end, Figure 3 highlights how solar curtailment has been steadily increasing as solar capacity has grown. Solar curtailment is now exceeding 300 gigawatt hours (GWh) during some months. To put that in perspective, 300 GWh of curtailed output in a month is equal to the monthly consumption of 538,000 households.

Increasing Trade

For California's grid to accommodate dramatic growth in solar capacity, several key changes must occur to avoid ever-increasing curtailment. First, with increased transmission capacity and coordination between CAISO and the surrounding regions in the western United States, surplus midday solar generation can be more effectively exported out of California.

Indeed, substantial progress has already been made to facilitate increased trading. In 2014, the Western Energy Imbalance Market (EIM) began coordinating real-time trading between CAISO and several utilities in the surrounding western United States. The EIM currently includes 15 entities, and by 2023, 8 additional entities are expected to join. This will ultimately bring over 80% of the electricity consumed across the western United States and Canada under the EIM's coverage.

The EIM is estimated to have already achieved over $1.7 billion in cost savings by more efficiently using the regional transmission system. In 2020 alone, it is estimated that 16% of potential CAISO solar curtailments were avoided due to EIM facilitated trading.

There are, however, limits to what increased coordination of trade can accomplish. For one, there is limited transmission capacity connecting CAISO and the surrounding markets. Moreover, California is not the only state that is pushing for increased renewables. For example, Nevada has mandated that 50% of its utilities' electricity comes from renewables by 2030. As solar production increases in the markets surrounding California, there will be less scope for exporting CAISO's midday glut of solar production.

Growth in Storage

While increased trade can help cost-effectively absorb greater levels of solar production throughout the western United States, exporting solar will not ultimately help California reach its goal of satisfying in-state consumption with 100% carbon-free energy. Instead, much of the renewable output will need to be consumed in California.

To accomplish this goal, there are effectively two options: 1) excess renewable output can be stored and used to meet demand when the sun is no longer shining or 2) consumption can be shifted to the middle of the day.

Historically, pumped hydroelectric has been the dominant form of storage. Going forward, batteries will be taking over. Between 2015 and 2019, the capital costs for large-scale battery units fell by 72%.

Consequently, investment is now beginning to take off. While CAISO's large-scale battery power capacity was only 500 MW at the end of 2020, there is already 4,000 MW of planned capacity additions over the next three years, the majority of which will be co-located with solar farms.

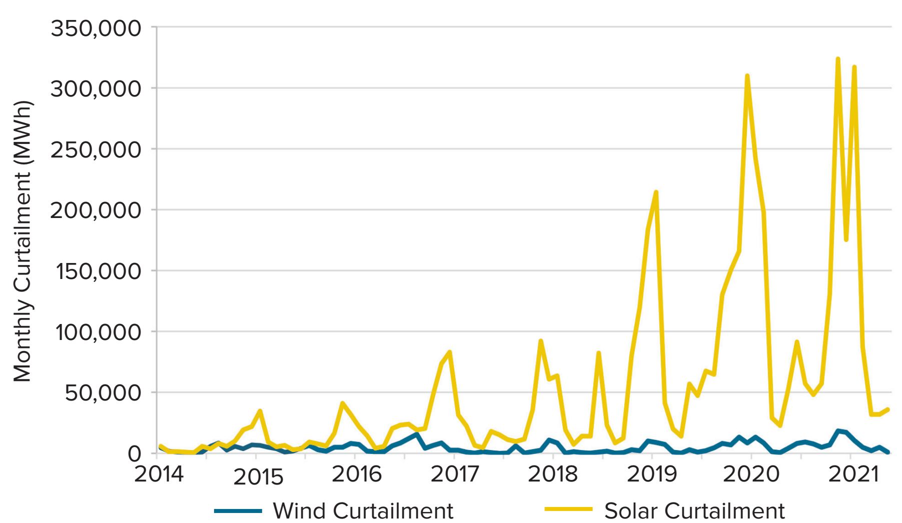
Over the coming decades, battery storage technologies are poised to dramatically alter the electric sector. Not only will the storage be vital in storing renewable output to meet demand when the sun sets and the wind dies down, but it will also play an important role in maintaining the stability of the electric grid by providing a range of important services currently dominated by fossil fuel units (e.g., frequency regulation). However, in the near term, the amount of battery storage capacity available will continue to pale in comparison to the amount of renewable output being curtailed.

Shifting Consumption

While storage will certainly play a vital role in increasing the share of consumption supplied from intermittent renewable sources, there is a much more immediate, and much less costly, strategy for increasing the share of consumption met by renewables: we can shift more of our consumption to the periods of the day when renewable output is being supplied.

Historically, there has been no incentive for households to shift consumption across hours in response to variations in wholesale market prices.

Figure 3. Monthly Curtailment of CAISO Solar and Wind



Source: California Independent System Operator (CAISO).

Until recently, the vast majority of consumers have paid a constant price for electricity, regardless of when they use it. This is now changing.

Customers in Sacramento and San Diego have already been transitioned to default time-of-use (TOU) prices that vary across periods of the day. During the "peak" evening hours when wholesale prices are at their highest levels, customers face a higher price per kilowatt hour (kWh). Pilot studies have demonstrated clear potential for these TOU rates to reduce consumption during peak periods, which can provide huge cost savings.

By the end of 2022, customers served by the two largest investor-owned utilities, Pacific Gas & Electric (PG&E) and Southern California Edison (SCE), will also be transitioned to default TOU pricing. Customers will have the option to opt-out of the new TOU rates, but those that do not elect to do so will begin paying time-varying rates.

To begin, the default TOU rate structures have been kept incredibly simple. There will be only two different rates within a day: 1) a peak price for electricity consumed between 4 p.m. and 9 p.m. and 2) an off-peak price for electricity consumed outside of these hours. Moreover, the spread between these peak and off-peak prices has been kept quite small.

For example, from June through September, PG&E's default residential TOU rates will charge low-consuming households (i.e., those consuming less than 100% of their monthly baseline allowance) a peak price of 34 cents per kWh from 4–9 p.m. and an off-peak price of 28 cents per kWh during all other hours. For high-consuming households, the peak and off-peak rates jump up to 42 cents and 36 cents, respectively.

From October through May, the peak versus off-peak price difference is even less pronounced. For low-consuming households, PG&E's peak price will only be 2 cents per kWh more than the off-peak price. For high-consuming households, the peak price will only be 1 cent per kWh above the off-peak price.

Initially, the default TOU rates will be kept incredibly simple to increase customer acceptance and to shift as many customers as possible to TOU rates. Going forward, to achieve the full potential benefits from time-varying retail prices, the differences in prices across different parts of the day will need to increase to reflect the variation in wholesale prices.

For example, as Figure 1 highlights, wholesale market prices now reach their lowest levels during the middle of the day. As solar capacity continues to expand, the gap between midday prices and morning and evening prices will only continue to increase. To incentivize customers to shift more of their consumption specifically to these midday hours, when surplus solar output is regularly being curtailed, the TOU programs will need to meaningfully reduce midday retail rates relative to the morning and evening rates.

While more pronounced time-varying rates cannot concentrate all consumption to the daylight hours, there is certainly scope to shift more of our consumption to the middle of the day. For example, customers who are home during the day could save money by drying their clothes and charging their electric vehicles midday. Moreover, customers who are not home midday can take advantage of increased automation—e.g., using programmable thermostats to pre-cool their homes prior to returning home in the evening. Ultimately, by shifting a larger portion of energy consumption to the middle of the day, solar will be able to supply a larger share of California's electricity consumption without requiring the same dramatic growth in storage capacity.

Conclusion

Solar capacity in California will continue to climb as the state drives towards a 100% carbon-free electric grid. To cost-effectively absorb the growing midday solar output, changes will need to be made on the supply-side—e.g., increased coordination of trade and expansions in storage capacity.

There will also need to be a change on the demand side of the market. In particular, consumers will need to be charged retail prices that meaningfully vary across periods of the day. Importantly, the retail rates must not be designed solely to reduce consumption during peak hours. They must also incentivize consumption to move to the periods of the day when wholesale prices are the lowest—which is now in the middle of the day when the sun is shining.

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Authors' Bios

Kevin Novan is an associate professor and Benjamin Dawson is a Ph.D. student, both in the Department of Agricultural Resource Economics at UC Davis. Dr. Novan can be reached at knovan@ucdavis.edu.

For additional information, the authors recommend:

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