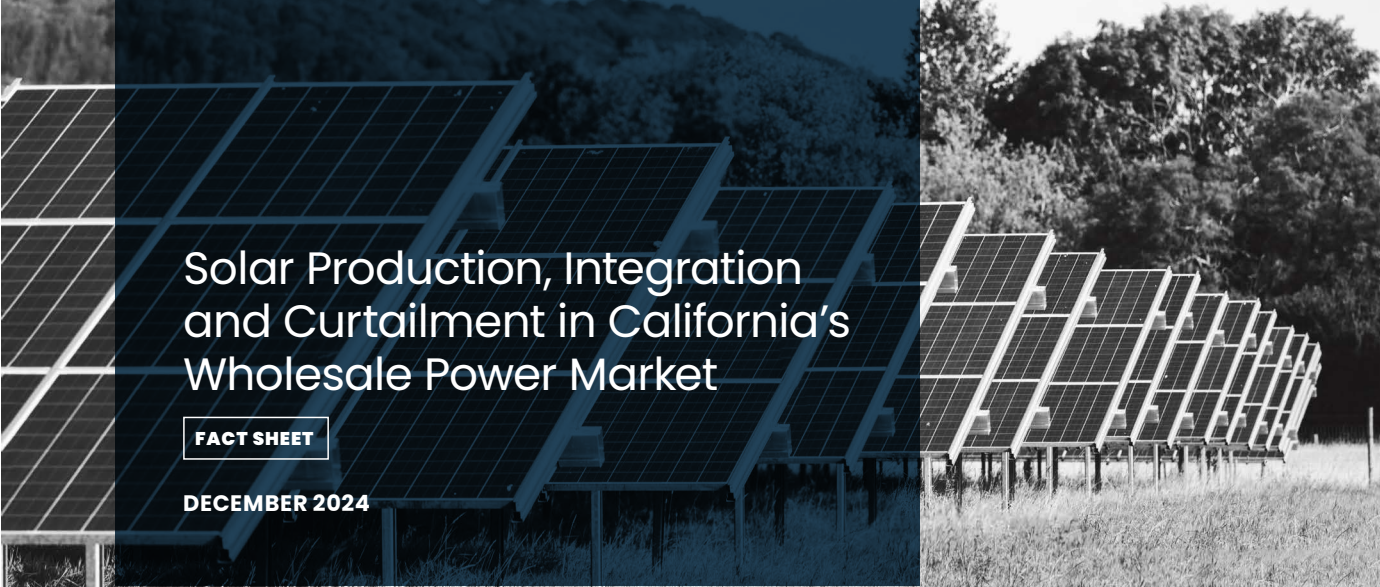




Solar Production, Integration and Curtailment in California's Wholesale Power Market

FACT SHEET

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How much solar power capacity is available in the wholesale power market managed by the California Independent System Operator?

According to the California Independent System Operator (CAISO) as of 11/07/2024 there were 19,853 megawatts (MW) of solar generation connected to the CAISO grid. As of 7/01/2019 there were 12,049 MW of solar connected to the CAISO system. This represents a growth rate of nearly 65% in just five years.

How much electricity is generated by grid-connected solar installations?

According to the California Energy Commission (CEC), 41,344 gigawatt (billion-watt) hours (GWH) of electricity was produced by solar power plants located in California in 2023. This represents 19.2% of all the electricity generated in California in 2023. In 2012 solar power only accounted for 0.9% for the electricity generated in California. Through October 31, 2024 according to the CAISO solar accounted for 23.8% of all California electrical generation. There is a significant amount of additional solar generation that occurs on customers' premises behind-the-meter. The behind-the meter solar generation is not directly controlled by the CAISO. However, with the addition of batteries there is the potential to create virtual power plants that can respond to grid needs.

How much electricity is imported from other states into California?

According to the CEC, 31,399 GWH of electricity were imported into California in 2023, representing 23.3% of all of the electricity consumed in California. In 2012 California imported 34.1% of the electricity consumed in the state. With the introduction of large amounts battery storage, imports are expected to decline significantly in 2024

How much solar electricity is imported from other states into California?

According to the CEC, 6,525 GWH of the power that was imported was from solar power plants located in neighboring states, primarily Arizona and Nevada. Solar accounted for 10.0% of all imported power in 2023.

How is solar energy integrated into California's wholesale electric markets?

Solar is integrated into California's wholesale electric markets through competitive bidding processes for electricity generation. The CAISO markets uses three main market intervals to balance electricity supply and demand. They are the integrated forward market (IFM), the hour-ahead scheduling process (HASP) and the real-time market (RTM).

The markets optimize the dispatch of power generation through competitive bidding processes. Generators, including solar generators, offer power for each hour of the following day in the integrated forward market. The CAISO uses an optimization algorithm to determine the most cost-effective schedule to meet forecasted demand while maintaining reliability on the transmission system.

The day-ahead hourly schedule is later refined into 15-minute intervals to re-optimize the schedule to account for changes in demand, resource availability, and grid conditions. The real-time market is based on 5-minute dispatch intervals. The CAISO continuously monitors grid conditions and issues dispatch instructions to generators every 5 minutes to maintain system balance which assures reliability. The CAISO also manages ancillary services in real-time to respond to grid disturbances.

Solar and several other types of generation, including wind and must-run power plans like nuclear and geothermal are usually price-takers in wholesale power markets. They typically bid into the markets at a zero price and are then compensated at the market clearing price for each interval. This type of competitive bidding results in very high utilization of solar power generation with approximately 94% all potential power being delivered to the grid in 2024.

How does "excess" solar power get marketed to neighboring states?

"Excess" solar power is sold to neighboring utilities (balancing area authorities) through the Western Energy Imbalance Market (WEIM), a real-time energy market managed by the CAISO. In the WEIM each utility monitors its electricity supply and demand. When there is a mismatch they have an "imbalance."

Utilities with imbalances submit bids and offers to the WEIM. Those with excess energy offer to sell, while those needing energy submit bids to buy. The CAISO uses an algorithm to find the most cost-effective way to resolve all the imbalances across the entire system, which covers much of the Western United States and parts of Canada. The CAISO considers factors like transmission constraints, generator availability, and energy prices in its market optimization process. Every 5 minutes, the WEIM sends dispatch instructions to generators, telling them how much to increase or decrease their output. This ensures that supply and demand are balanced across the entire region.

WEIM helps integrate variable renewable resources (solar and wind) by providing a mechanism to balance their fluctuations across a broader market. This real-time optimization process helps lower energy costs for California and the other participants in the WEIM.

Why is the power from solar power plants curtailed at times?

The two main reasons for curtailment are 1) oversupply of available power generation during certain intervals of time and 2) congestion on specific transmission lines due to their thermal ratings. According to the CAISO, overall curtailment resulted in a "loss" of potential

power from solar power plants of 6.3% through October 31, 2024. Most of the curtailment (5.8%) was due to local congestion on power lines. Curtailment is the highest during months where electricity demand is low (March, April and May).

What are the solutions to reduce the amount of solar curtailment in the future?

One solution is to install more battery storage on the electric grid. This is being done aggressively in California. As of November 2024, according to the CAISO, there were 10,522 megawatts of battery storage connected to the grid. The batteries typically charge during the mid-day when solar is abundant and discharge after the sun sets and into the nighttime hours. Battery storage has been growing rapidly. Battery capacity was just 2,595 megawatts in January 2022.

The other solution to lessen curtailment is to increase transmission capacity in locations where there is congestion. As part of its annual Transmission Planning Process, the CAISO conducts production cost modeling to determine the cost-effectiveness of expanding the power grid to limit congestion and expensive re-dispatch of power.

The CAISO is currently evaluating the impacts of future resource portfolios for 2034 and 2039. A preliminary assessment shows growing congestion between the PG&E and SCE systems (Path 26), on the backbone high voltage grid running through the Central Valley (Path 15) and on transmission lines from the Central Valley into the Greater Bay Area. It is likely that upgrades will be required to economically limit the amount of curtailment from solar power plants in the future.

How much solar power is available to consumers through behind-the-meter solar projects?

The CEC estimates that at the end of 2023 there were approximately 1,950,000 solar systems installed on residential or commercial properties in California. These systems are often referred to as behind-the-meter (BTM) solar since only exported power is measured at the meter. The rest of the power is used to meet the customer's electricity needs.

According to the CEC the AC capacity of the BTM systems in the CAISO footprint was 15,723 megawatts. Unfortunately, there is no precise estimate as to how much power the BTM solar systems produce. This is largely because BTM solar is decentralized and occurs at the individual consumer level, making it difficult to track in real-time.

How is behind-the-meter solar integrated into California's wholesale energy markets?

BTM solar reduces the overall demand from the grid, especially during hours when solar production is highest. This lowered demand affects the wholesale market by decreasing the amount of electricity that needs to be scheduled and dispatched by the CAISO.

California's net metering policy allows BTM solar customers to sell excess electricity back to the grid. These exports influence the wholesale market by injecting more renewable energy into the system during certain periods.

Some BTM solar customers participate in structured demand response programs, where they can be compensated to reduce their consumption or export stored solar power during peak demand periods. However, this is still a very small proportion of solar customers.

The variable nature of solar generation and the increasing penetration of BTM solar make it important for grid operators to accurately forecast net electricity demand. Uncertainty about demand can contribute to curtailment. Investments in advanced forecasting tools, energy storage systems, and improved transmission infrastructure, are crucial to mitigate curtailment and effectively integrate growing amounts of both BTM and utility-scale solar.

Is there a “glut” of solar power and what are the consequences?

Glut is a subjective and somewhat pejorative term. Speaking factually, there has been a rapid increase in solar generation in California over the last decade. From a consumer perspective this increase has been beneficial by introducing a source of electricity that has no variable fuel costs. The near-zero operating costs of solar has had a dampening effect on prices on the wholesale power market by pushing out less efficient gas-fired generation from setting the clearing price for each interval.

Solar has also provided a hedge against droughts which periodically occur in California and the West. Solar generation in California has reduced the amount of imported power coming into the state from the Pacific Northwest and the Southwest.

From the perspective of the owners of gas-fired generation increased solar production has reduced revenues from the California energy market. Since some gas-generation, for the time-being, is needed to maintain system reliability during peak periods they often obtain additional revenue in California’s bilateral resource adequacy market. However, those revenues are also being reduced by the rapid introduction of battery storage systems.

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