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The Potential for Energy Storage to Provide Peaking Capacity in California under Increased Penetration of Solar Photovoltaics: Report Summary

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Report Background and Goals

Opportunities to provide peaking capacity with low-cost energy storage are emerging. But adding storage changes the ability of subsequent storage additions to meet peak demand. Increasing photovoltaic (PV) deployment also affects storage's ability to provide peak capacity. This study examines storage's potential to replace conventional peak capacity in California.

<u>Study Goals</u>

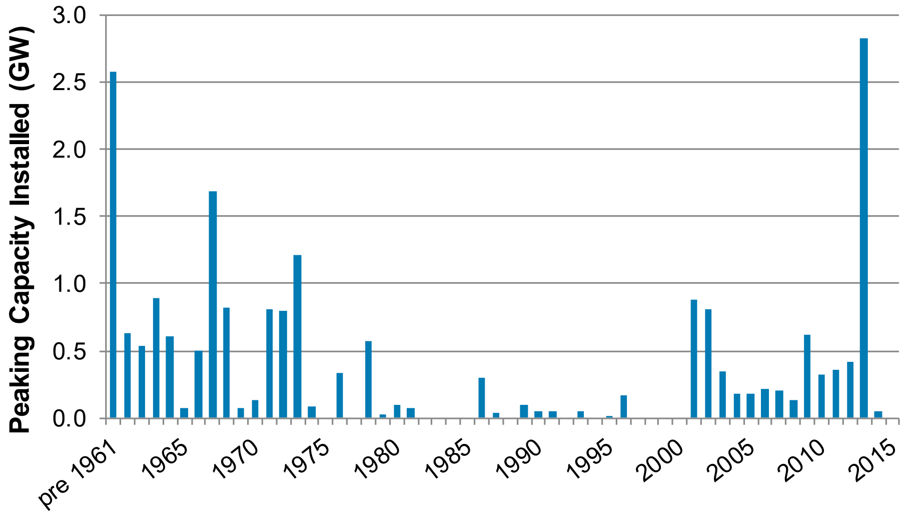
1. Analyze storage's changing potential to meet peak demand at various storage and PV deployment levels

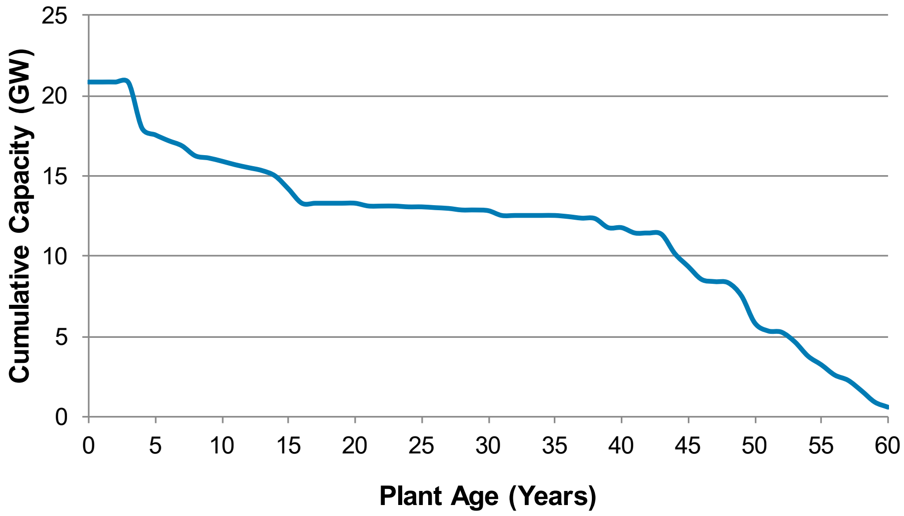
2. Provide timely information to California's energy storage and PV deployment efforts

3. Increase knowledge available to all system planners who might consider deploying significant storage, PV, or both

The Potential Market for Peaking Capacity

- Most recent utility-scale storage deployment has been for ancillary services such as frequency regulation, a small market.
- Peaking capacity is a much larger market for energy storage.
- About 13 GW of California's peak capacity could retire over the next 20 years, based only on age.

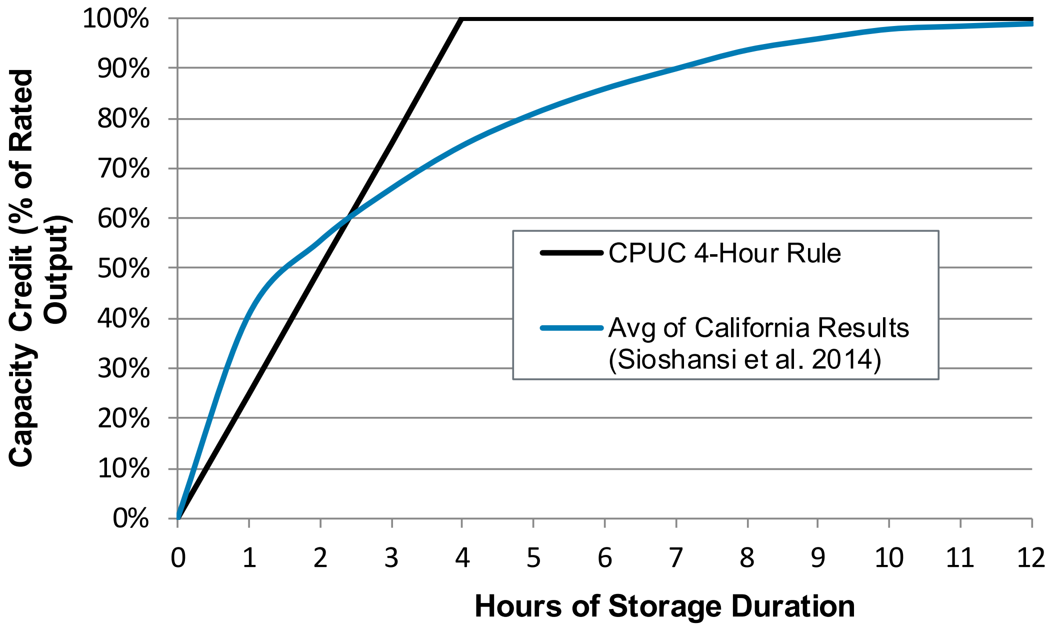




Installation date (left) and cumulative capacity by age (right, as of summer 2017) for peaking capacity in California. About 12 GW of capacity are at least 40 years of age.

The Need to Analyze Capacity Credit with High Storage and PV

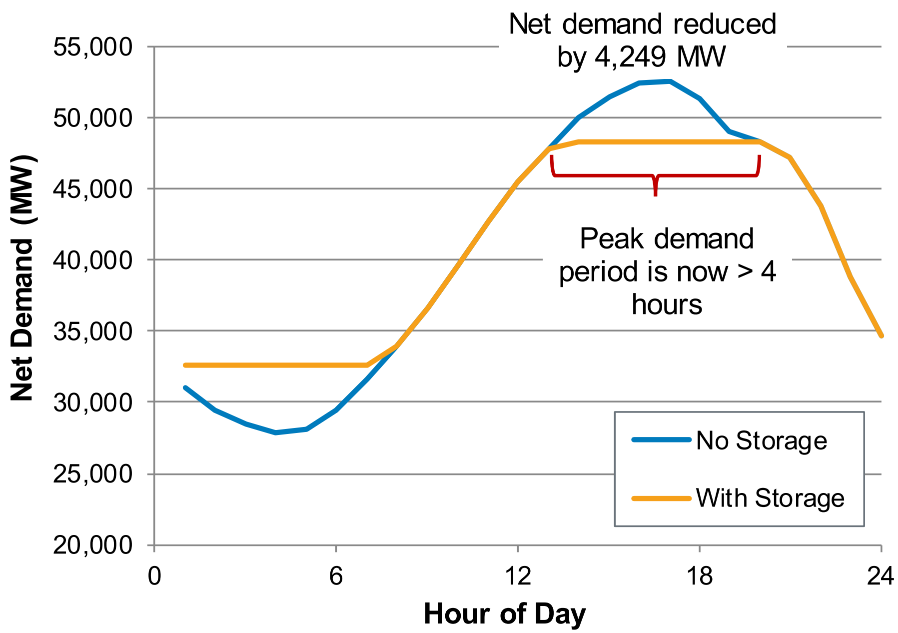
- To provide reliable peak capacity, energy storage must have a high “capacity credit” (ability to provide peak-period energy).
- Additional analysis is needed on the changing capacity credit of shorter-duration energy storage as a function of storage and PV penetration in California.



Capacity credit of storage as a function of hours of storage. Under California Public Utilities Commission (CPUC) rules, eligible storage must have “the ability to operate for at least four consecutive hours at maximum power output”—the "4-hour rule."

Analysis Method

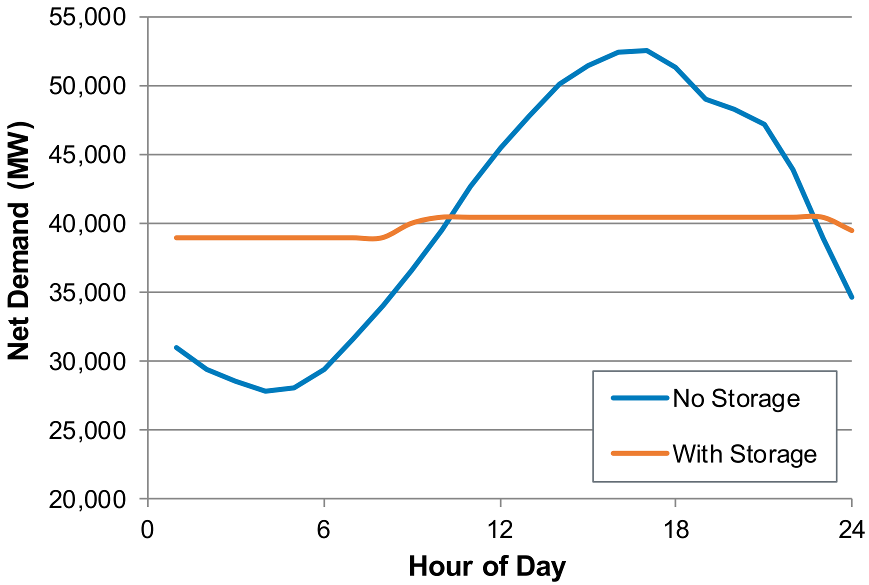
- To approximate capacity credit, storage is incrementally added (assuming full discharge) until adding 1 MW of storage cannot reduce net demand by 1 MW.
- Here 4,249 MW of 4-hour storage reduces peak demand by an amount equal to the power rating (4,249 MW), but more storage has a “peak demand reduction credit” less than 100%.



Impact of 4-hour storage dispatch on net demand on the peak demand day in 2011

Analysis Method

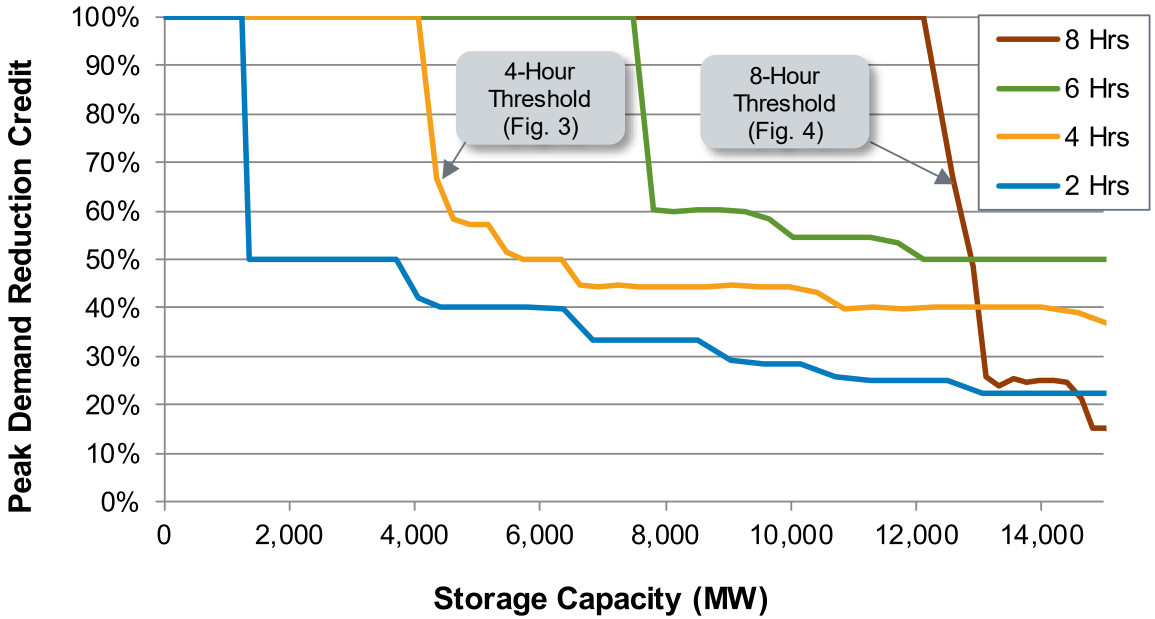
- Longer-duration storage reduces peak net demand further, with limits.
- With 8-hour storage, net demand is almost flat over 24 hours, but reducing peak demand further would require charging during a previous day, requiring much longer-duration storage and the ability to forecast net demand over extended periods.



Limits of 8-hour storage to reduce peak net demand due to limits in charging energy (peak demand day in 2011 shown)

Analysis Method

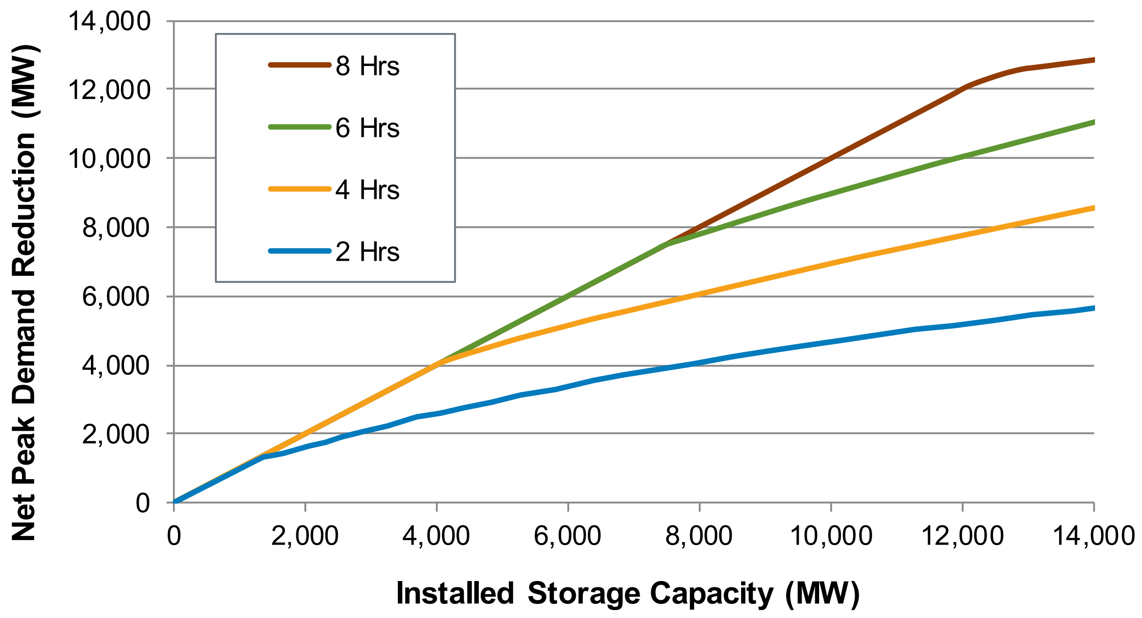
- Process is repeated over various storage power capacities and fixed durations of 2, 4, 6, and 8 hours, with dispatch simulated using NREL's REFlex model (assuming 80% roundtrip efficiency and no storage outages) and hourly load data for 2007–2015.
- In 2011 the 4-hour storage peak demand reduction credit falls below 100% at 4,249 MW; the 8-hour threshold is 12,559 MW.



Incremental peak demand reduction credit vs. storage capacity in California (2011 data)

Analysis Method

- When the peak demand reduction credit is 100%, the relation between net peak demand reduction and installed storage capacity is linear, but below 100% there are diminishing returns.
- Here about 4 GW of 4-hour storage reduce peak net demand by 4 GW, but reducing peak net demand by another 4 GW requires an additional 9 GW of 4-hour storage.

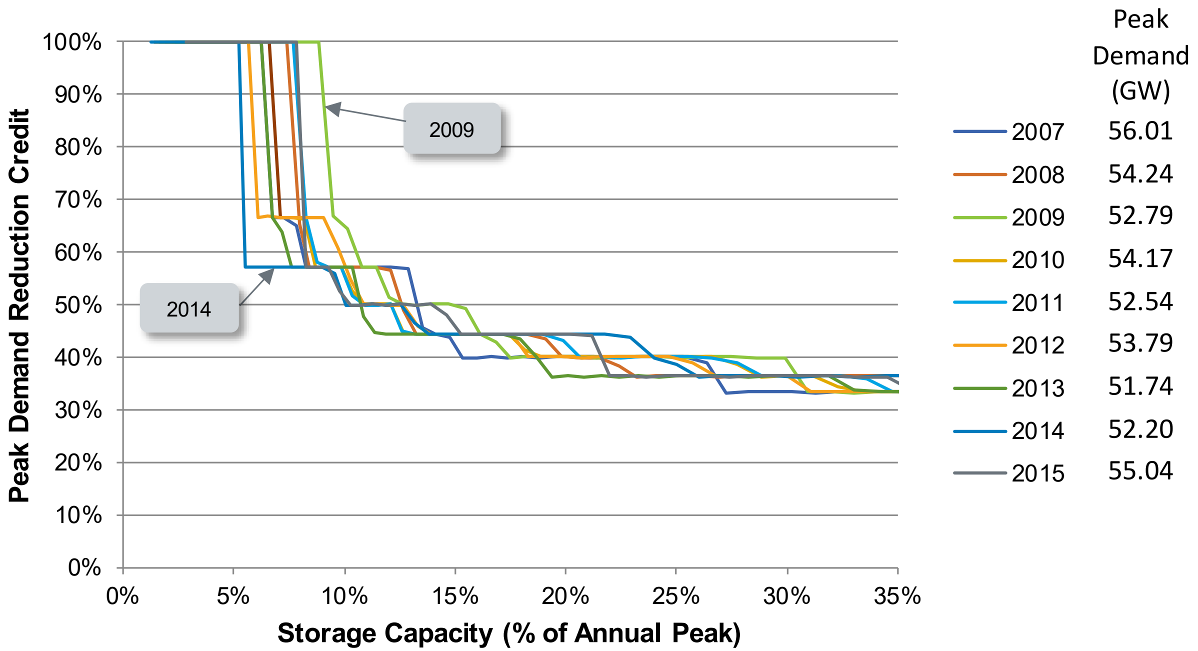


Total net peak demand reduction vs. storage capacity in California (2011 data)

Results with No PV

- Relationships between peak demand reduction credit and installed storage capacity vary by year, e.g., 4-hour storage could reduce annual peak demand by 9% at 100% credit using 2009 data, but only by 6% using 2014 data.

- To estimate storage's potential to meet peak demand in 2020 (~54 GW), the lowest credit values across all years are used.

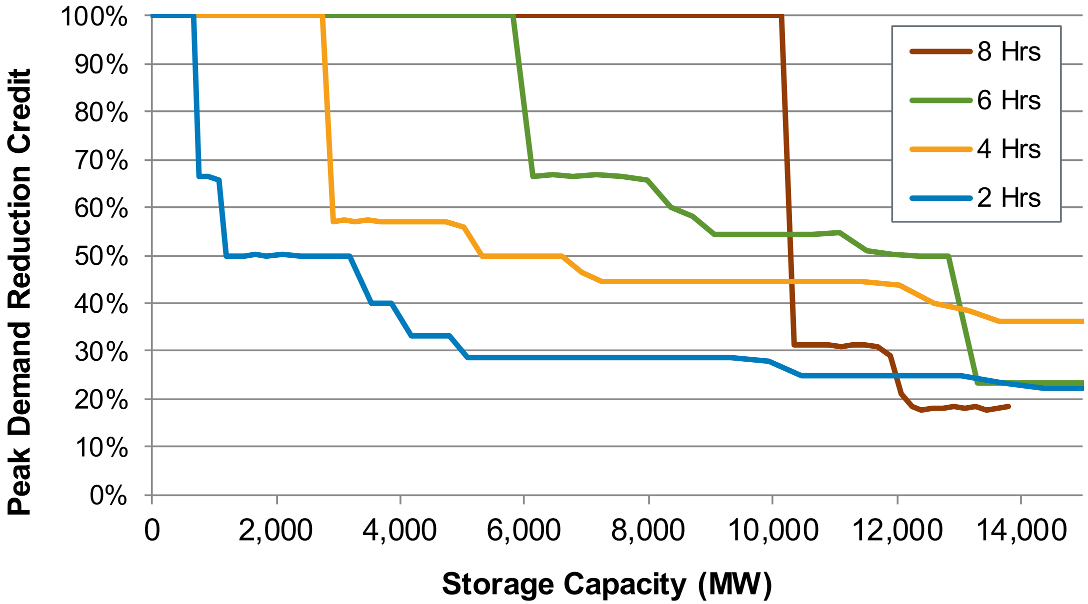


Peak demand reduction credit vs. 4-hour storage capacity in California (2007–2015 data)

Results with No PV

- Projecting incremental peak demand reduction credit vs. storage capacity in 2020 shows the strong dependence on existing storage capacity of storage's incremental contribution to meeting peak demand.

- These results are of limited use without considering the impact of PV deployment, which is evaluated next.



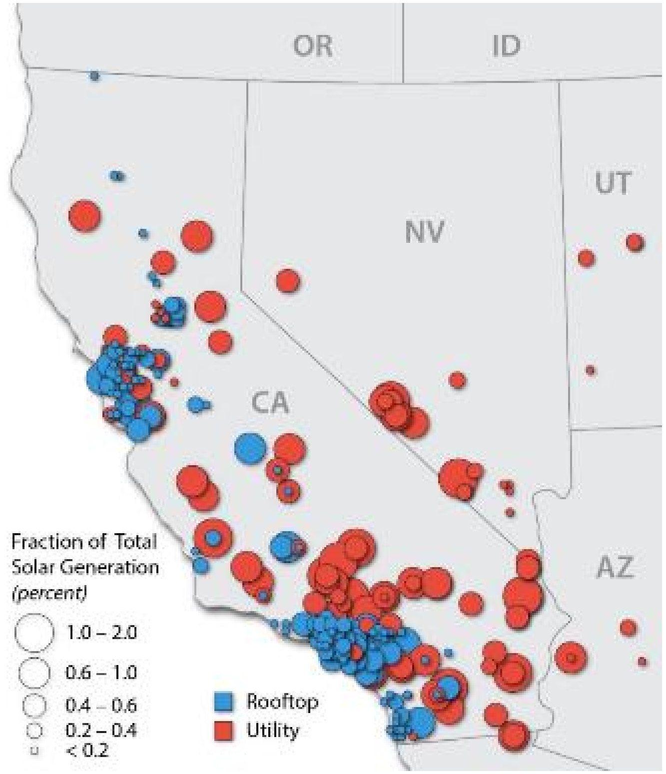
Estimated technical potential of energy storage to provide peak capacity in California in 2020

Adding PV

- In 2017, California already provided about 11% of total electricity demand with PV

- PV energy penetrations up to 30% are simulated for 2007–2015.

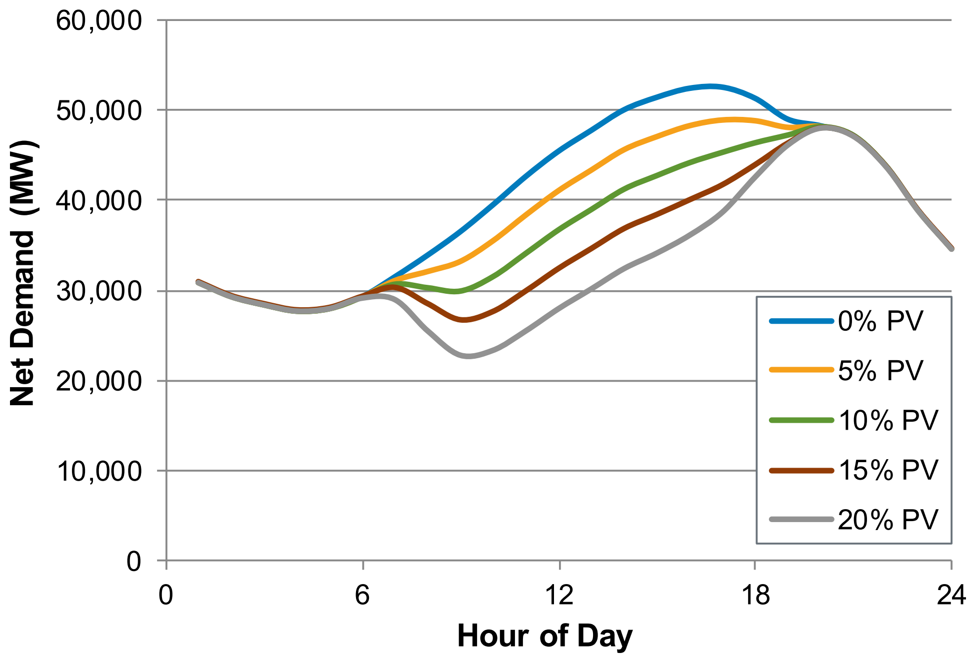
- Generation profiles were simulated using NREL's System Advisor Model assuming a mix of utility-scale and rooftop PV



Distribution of simulated PV sites

Results with PV

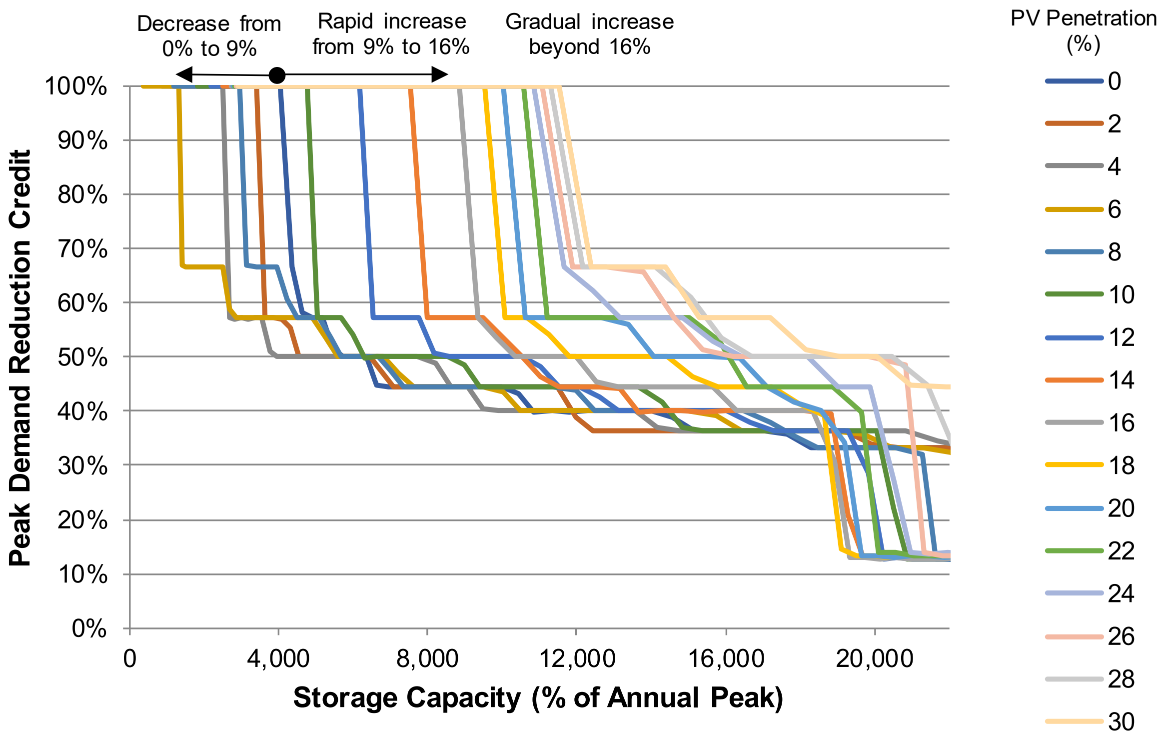
- Increasing levels of PV change the net load shape: at low penetration, PV reduces and flattens the peak demand. As PV penetration increases, PV's impact on reducing peak demand diminishes, while it increases the "peakiness" (narrows the width) of the net peak demand.



Simulated change in California net load shape due to PV on a peak demand day in September 2011

Results with PV

- Peak demand reduction curves are generated for various PV penetrations (4-hour storage, 2011 load and PV patterns below).
- PV penetration has major impact on storage threshold, which decreases between 0% and 6% PV and increases beyond 8%.

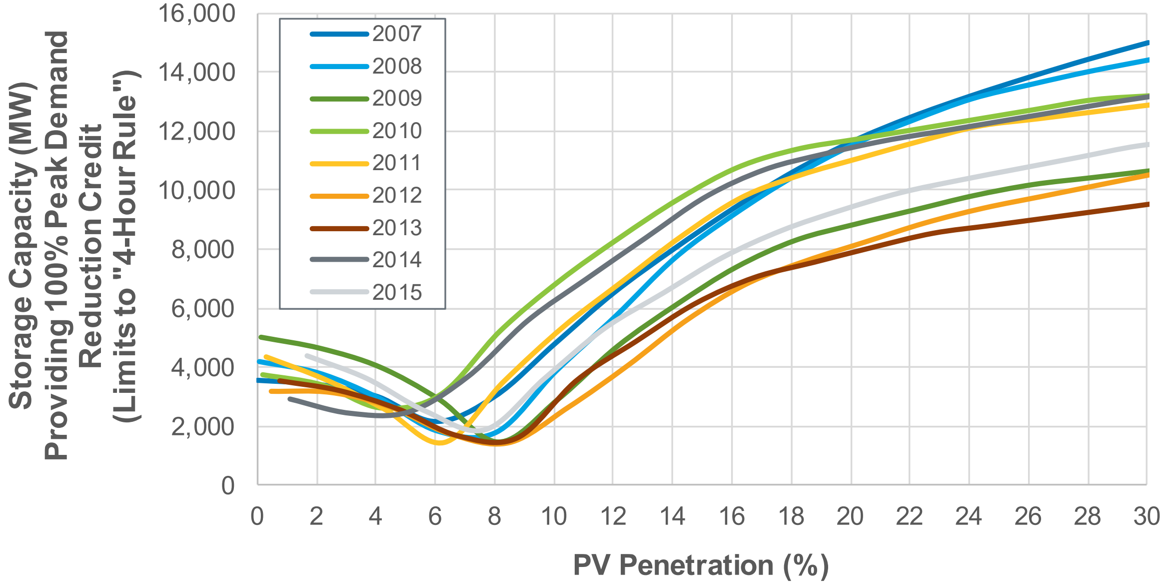


Peak demand reduction credit for 4-hour storage vs. storage capacity in California (2011 load and simulated PV patterns)

Results with PV

- For all years, from zero to about 5%–8% PV there is a decline in storage capacity that can receive a 100% peak demand reduction credit owing to the “flattening” effect of PV.

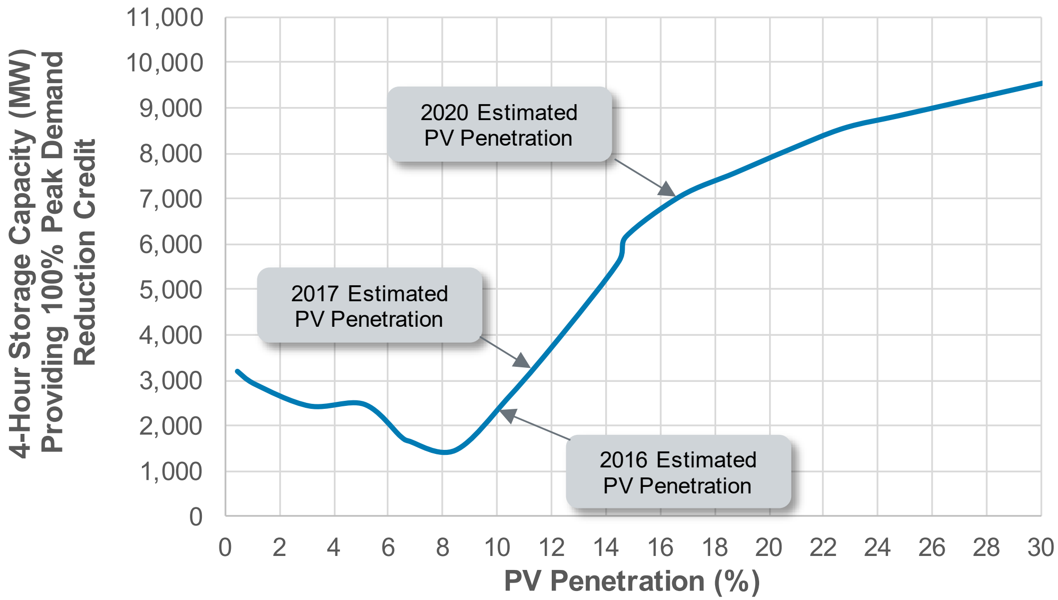
- At 5%–8% PV, the net peak demand begins to narrow, and at 7%–11% PV the storage capacity providing 100% peak demand reduction credit increases past its value at zero PV.



Threshold values for 100% peak demand reduction credit for 4-hour energy storage in each year, 2007–2015 (assuming a peak demand of 54 GW)

Results with PV

- Using the lowest credit values across all years, at 11% PV penetration optimally dispatched 4-hour storage could reduce California's net peak demand by about 3,000 MW, with full peak demand reduction credit—about the same as at zero PV.
- Assuming a 2020 PV penetration of 17%, the full-credit 4-hour storage capacity rises to 7,000 MW.



Threshold values for 100% peak demand reduction credit for 4-hour energy storage in 2020 (assuming a peak demand of 54 GW)

Conclusions

- **Storage's ability to reduce peak demand decreases with increasing installed storage capacity**. In a “no PV” case, 4-hour storage reduces peak demand at full rated capacity up to about 3 GW of installed storage capacity (assuming 2020 peak demand of 54 GW), beyond which the ability of an incremental unit of 4-hour storage to reduce peak demand drops.

- **Adding PV changes storage's ability to meet peak demand**. Below 11% PV energy penetration, the potential of 4-hour storage is lower than with zero PV; above 11% PV, it is higher. At 17% PV penetration (projected for California in 2020), the storage that can provide full capacity under the 4-hour rule more than doubles compared with the no-PV case—to 7,000 MW.

- **Synergy exists between storage and PV deployment**. Beyond 11% PV, more PV enables use of more shorter-duration/lower-cost storage. By 2029, 11,000 MW of California's capacity is expected to retire owing to once-through-cooling requirements, much of it peaking capacity. Substantial capacity could be replaced with 4-hour storage assuming continued storage cost reductions and PV growth. The additional storage could capture more otherwise-curtailed PV generation and discharge it as needed by the system.

Future Work

- Explore how results are impacted by relaxing the assumptions of optimal storage dispatch and perfect forecasts for load and PV generation. Improving storage scheduling under uncertainty will improve assessment of storage's realistic ability to meet peak demand reliably.

- Explore how behind-the-meter storage and PV present additional opportunities or challenges. Existing tariff structures may not send proper signals; thus, if behind-the-meter storage and PV are not dispatched to reduce net demand at the system level, their ability to provide resource adequacy capacity may be diminished.

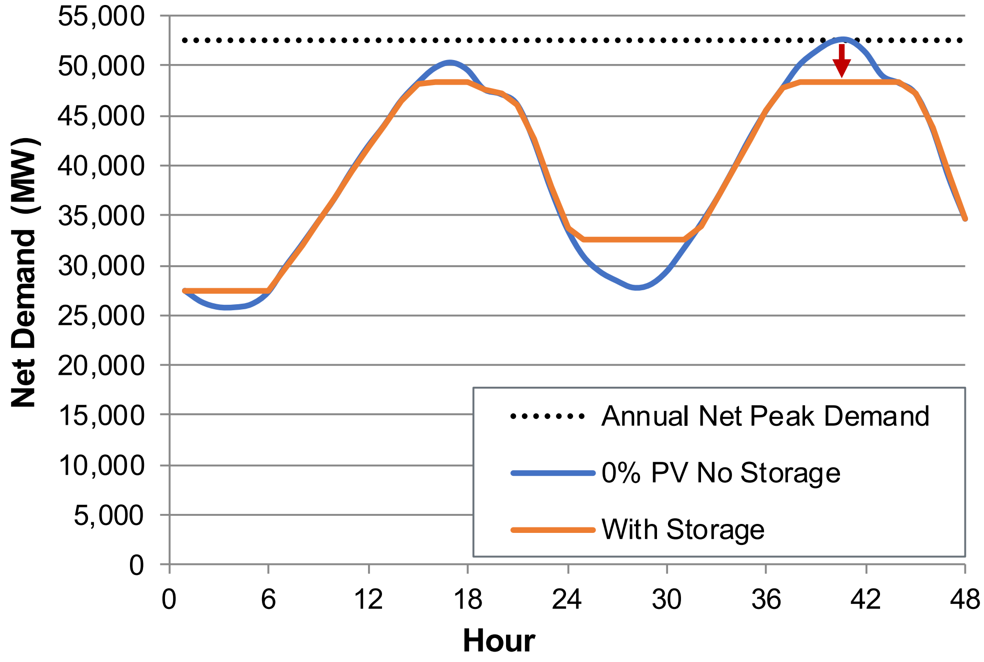
- Clarify how future load shapes are likely to evolve given increased electric vehicle deployment, increased use of demand response and energy efficiency, climate change, and other factors.

Appendix Material

Supplement: Impact of PV on 4-Hour Storage

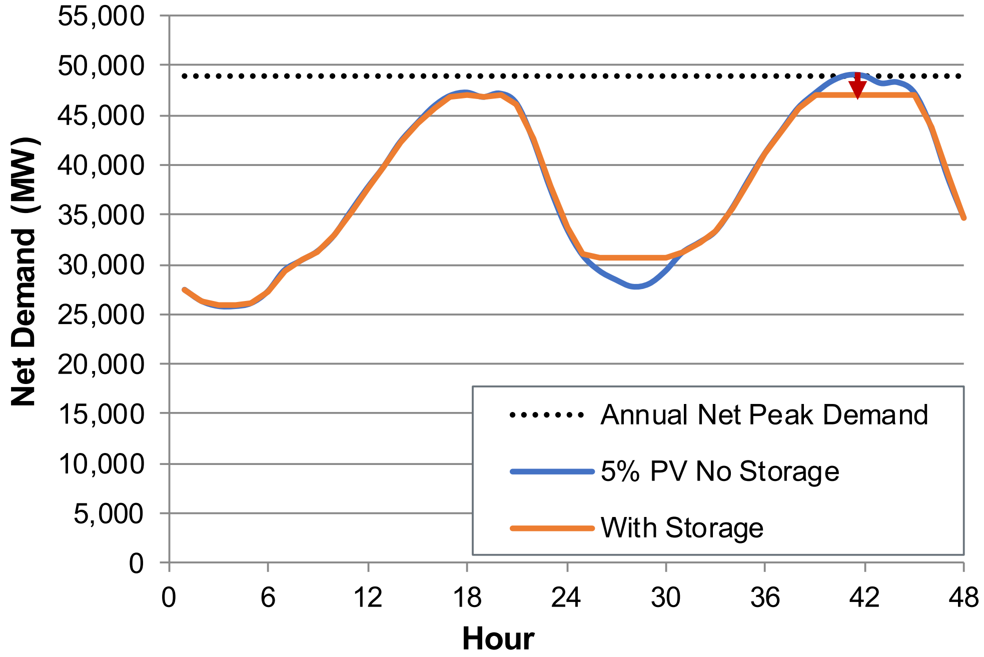
- Here we show the impact of increasing levels of PV deployment on the ability of 4-hour storage to reduce the net peak demand. The following images show this progression from zero to 20% PV in 5% increments. Each panel shows the results for two days (September 5-6, 2011), which includes the day with the highest peak demand (Sept. 6). The figures show the net demand before and after the addition of storage, and the amount of storage that can be added before the incremental peak demand reduction credit falls below 100%.

Supplement: Peak Day With and Without Storage (0% PV)



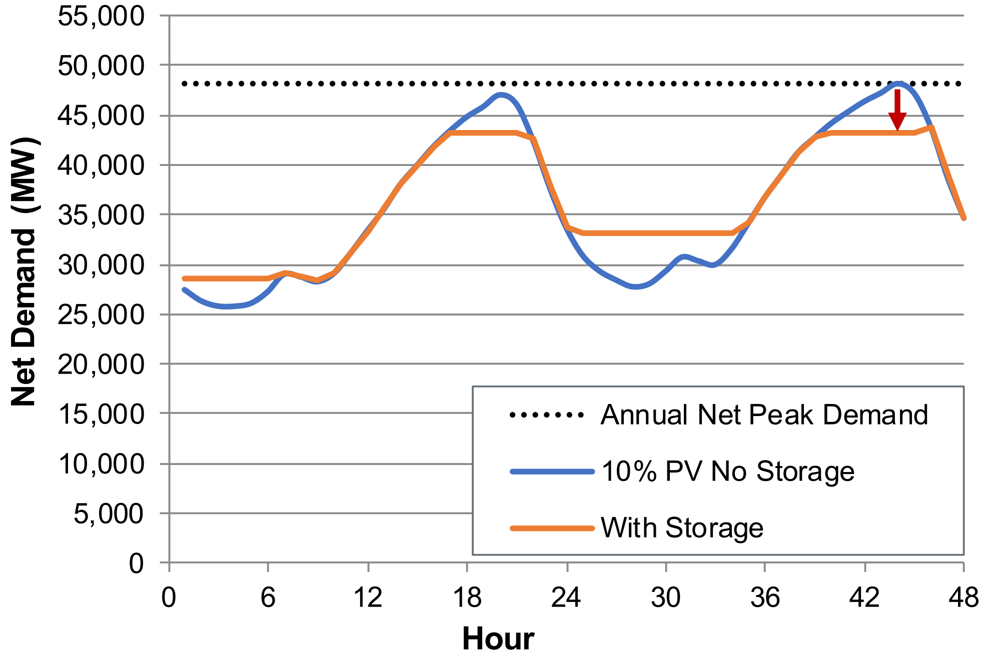
Zero PV. Peak demand occurs on September 6 (day 2) and is 52,540 MW. Peak demand reduction with 4-hr storage at 100% credit is 4,249 MW. Annual net peak demand is reduced to 48,292 MW. Storage is not completely utilized on day one so could have had additional charge/discharge for greater price arbitrage.

Supplement: Peak Day With and Without Storage (5% PV)



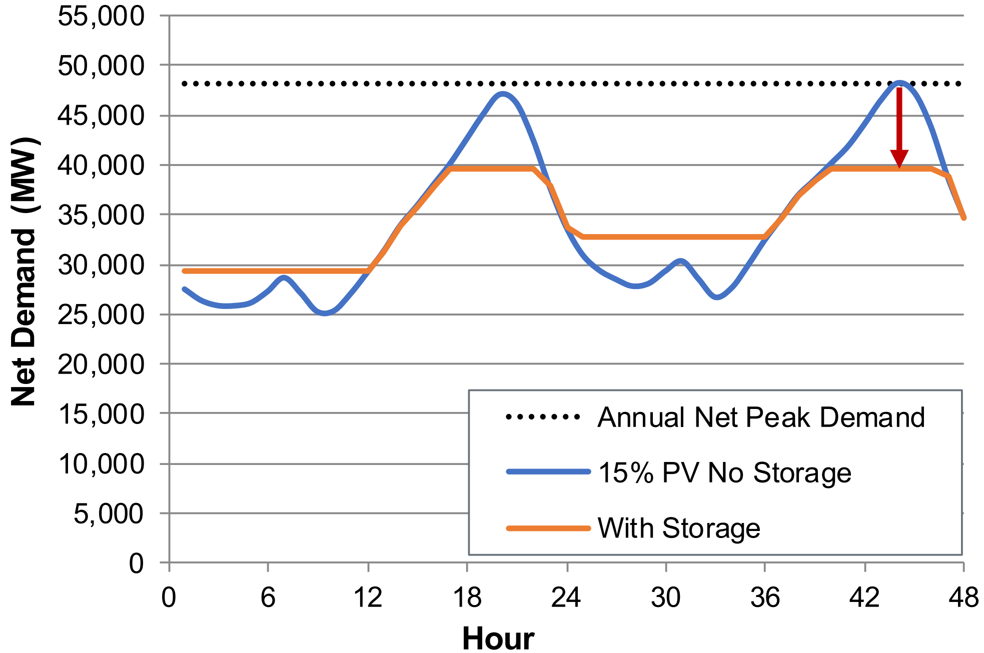
5% PV. PV generation has reduced net peak demand has been reduced to 48,940 MW. The peak shape is clipped (flattened) compared to zero PV case. Peak demand reduction of 4-hr storage at 100% credit is 1,937 MW (less than with zero PV).

Supplement: Peak Day With and Without Storage (10% PV)



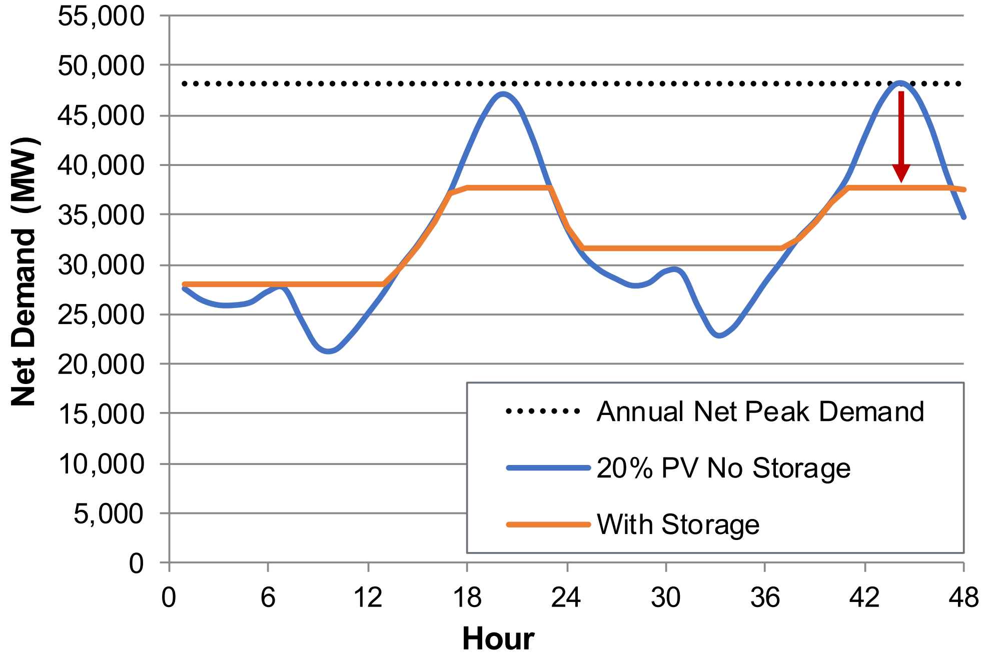
10% PV. PV generation has reduced net peak demand has been reduced to 48,172 MW. Peak demand shape has been narrowed relative to previous cases. Peak demand reduction with 4-hr storage at 100% credit has increased to 4,935 MW, a small increase relative to the zero PV case.

Supplement: Peak Day With and Without Storage (15% PV)



15% PV. PV generation has reduced net peak demand has been reduced to 48,123 MW. Net demand peak now occurs during period of low solar output and incremental capacity credit of PV is approaching zero. Peak shape has been significantly narrowed. Peak demand reduction with 4-hr storage at 100% credit is 8,462 MW, or about double the zero PV case.

Supplement: Peak Day With and Without Storage (20% PV)



20% PV. PV generation has reduced net peak demand to 48,117 MW. Essentially zero incremental capacity credit of PV. The peak continues to narrow. Peak demand reduction with 4-hr storage at 100% credit is 10,372 MW.

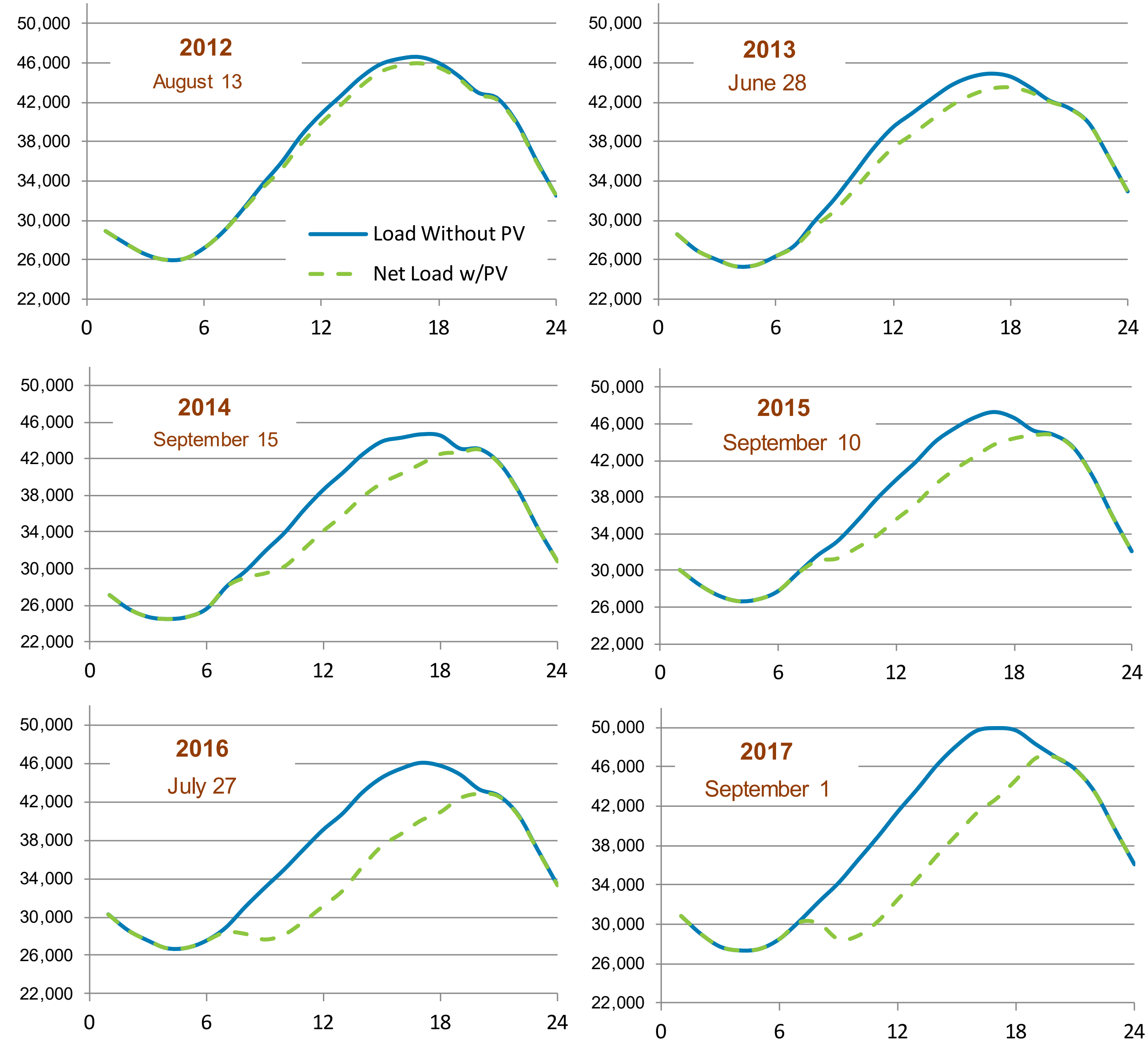
Supplement: Comparison to Measured PV Data

- We use simulated PV data to enable analysis using 9 years of load data.
- This amount of measured PV performance data does not yet exist.
- However there are a few years of measured PV data that enable comparison to simulated PV data.
- We use data from 2012–2017 for the California Independent System Operator (CAISO), which serves about 80% of California. Our previous analysis simulates nearly all of California.
- Results using measured PV data are very similar to those using simulated PV data

Supplement: Comparison to Measured PV Data

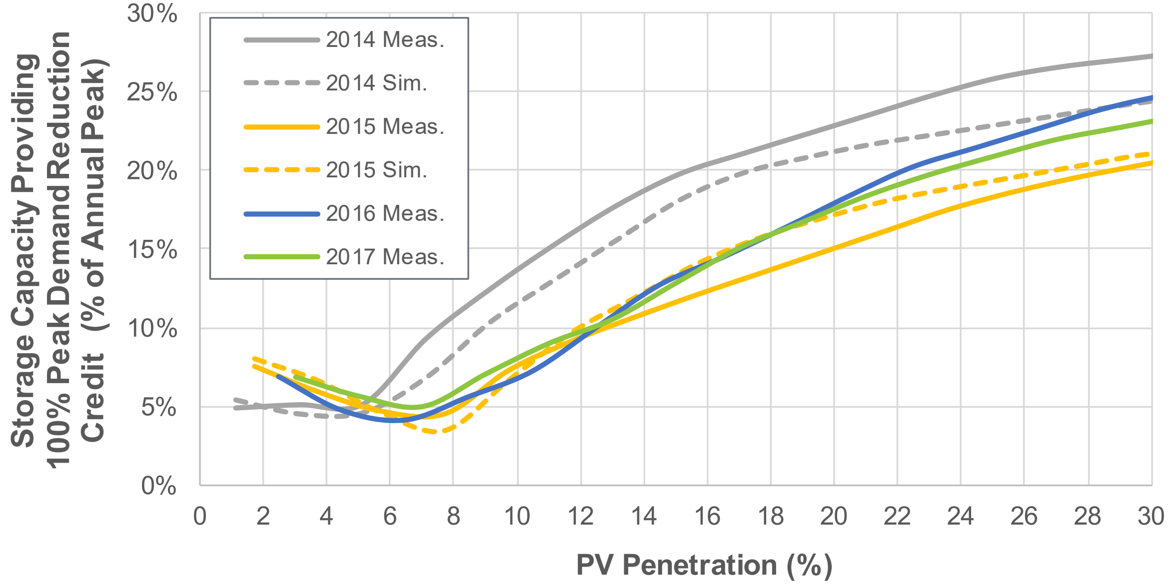
Net CAISO load during the peak demand day, 2012–2017 (x-axis is hour of day, y-axis is net demand in MW)

Measured profiles show net load becoming peakier over time as PV penetration increased in California



Supplement: Comparison to Measured PV Data

- Simulating the impact of storage on net peak demand using the measured CAISO PV data (scaled to 0%–30% PV) yields results similar to those using simulated PV data.
- Lines generally track, and storage has less ability to reduce net peak demand in 2015 than in 2014 based on both the measured and simulated PV data (under most PV penetrations).



Threshold values for 100% peak demand reduction credit for 4-hour energy storage in each year, 2014–2017 (normalized to annual peak) using measured vs. simulated PV data

For More Information

Download the report:

https://www.nrel.gov/docs/fy18osti/70905.pdf

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