Solar + Storage Synergies for Managing Commercial-Customer Demand Charges

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Overview

Demand charges, which are based on a customer's maximum demand in kilowatts (kW), are a common element of electricity rate structures for commercial customers. Customer-sited solar photovoltaic (PV) systems can potentially reduce demand charges, but the level of savings is difficult to predict, given variations in demand charge designs, customer loads, and PV generation profiles.

Lawrence Berkeley National Laboratory (Berkeley Lab) and the National Renewable Energy Laboratory (NREL) are collaborating on a series of studies to understand how solar PV can impact demand charges. Prior studies in the series examined demand charge reductions from solar *on a stand-alone basis* for residential and commercial customers. Those earlier analyses found that solar, alone, has limited ability to reduce demand charges depending on the specific design of the demand charge and on the shape of the customer's load profile.

This latest analysis estimates demand charge savings from solar in commercial buildings when co-deployed with behind-the-meter storage, highlighting the complementary roles of the two technologies. The analysis is based on simulated loads, solar generation, and storage dispatch across a wide variety of building types, locations, system configurations, and demand charge designs.

Data and Methods

The analysis relies on 30-minute weather data spanning a 17-year historical period (1998-2014), sourced from the National Solar Radiation Database. Using those data, we then simulate 30-minute-interval building loads for 15 commercial building types across 15 U.S. cities, relying on the Department of Energy's Energy+ Commercial Reference Building Models. Using the same weather data, we also simulate rooftop PV generation using NREL's System Advisor Model for the same locations and for multiple PV system sizes, ranging from 10% to 100% of each customer's annual energy consumption. Finally, we simulate battery storage dispatch for each pair of load and solar profiles, across battery system sizes ranging from 10% to 100% of each customer's peak load. This process yields 22,500 matched sets of simulated building load, PV generation, and storage charge/discharge profiles. For the purpose of this analysis, we assume batteries have 3 hours of storage and are operated solely for demand charge minimization with perfect foresight.

For each of these matched sets, we calculate the reduction in monthly demand charges (relative to no solar or storage) for solar-alone, storage-alone, and both solar and storage. We estimate demand charge reductions for a basic non-coincident demand charge, where billing demand is based on the maximum 60-minute average demand at any point over the course of the month. We also estimate demand charge savings when based on the maximum demand during various specified peak period windows (12-5 pm, 12-10 pm, and 5-10 pm) and with averaging intervals ranging from 30 minutes to 4 hours.

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Key Findings

We compare demand charge savings across the various permutations of load, solar, and storage profiles and demand charge designs. The principal metric used in the analysis is the percentage reduction in a given customer's average monthly billing demand, over the entire 17-year analysis period, relative to the customer's demand without solar or storage. We also introduce a separate metric, the *cooperation ratio*, which quantifies the degree to which demand charge savings from solar + storage are greater than the sum of the demand charge savings from each technology alone.

Solar + storage exhibit consistent synergies for demand charge management. As one would expect, solar + storage yields greater demand charge savings than either technology alone. However, demand charge savings from co-deploying the two technologies is generally more-than-additive; that is, for nearly every simulation in our analysis, solar + storage together resulted in a greater reduction in billing demand than the sum of what each would achieve alone. For example, across all simulations with a basic non-coincident demand charge (see Figure 1), the median reduction in demand charges was 42% for solar + storage when coupled together, compared to 8% for solar-alone and 23% for storage-alone.

Solar + storage synergies are greater for certain building types and locations. Synergies between solar + storage arise for two distinct reasons. First, for customers with broad daytime peak loads that extend into early morning or early evening hours, solar tends to create narrow peaks in the customer's net load profile that storage can easily clip. Among the simulated building loads in our analysis, hospitals and large

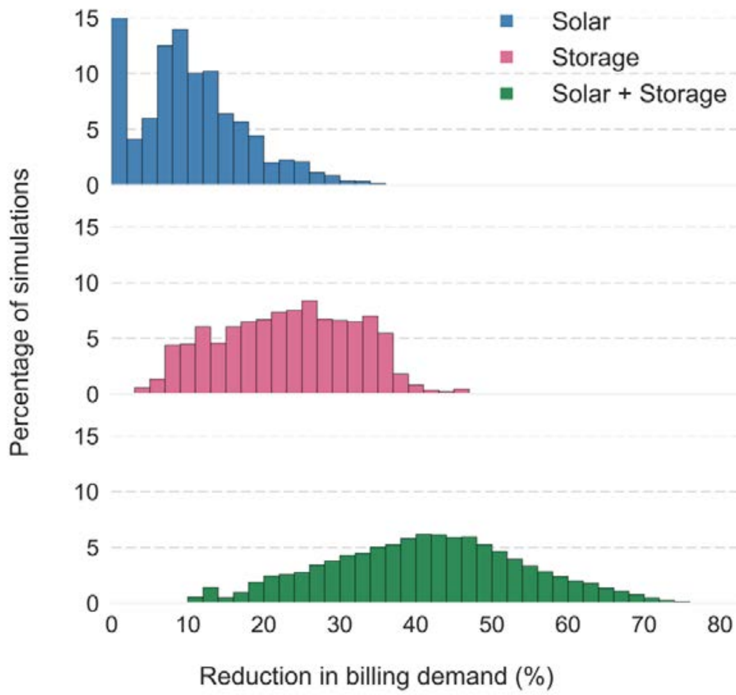

Figure 1. Distributions of average monthly billing demand reductions under a basic non-coincident demand charge

The figures show the distribution of average monthly billing demand reductions across all modeled combinations of commercial building types, locations, solar system sizes, and storage system sizes. These results are based on a demand charge design with a 1-hour averaging interval for measuring billing demand.

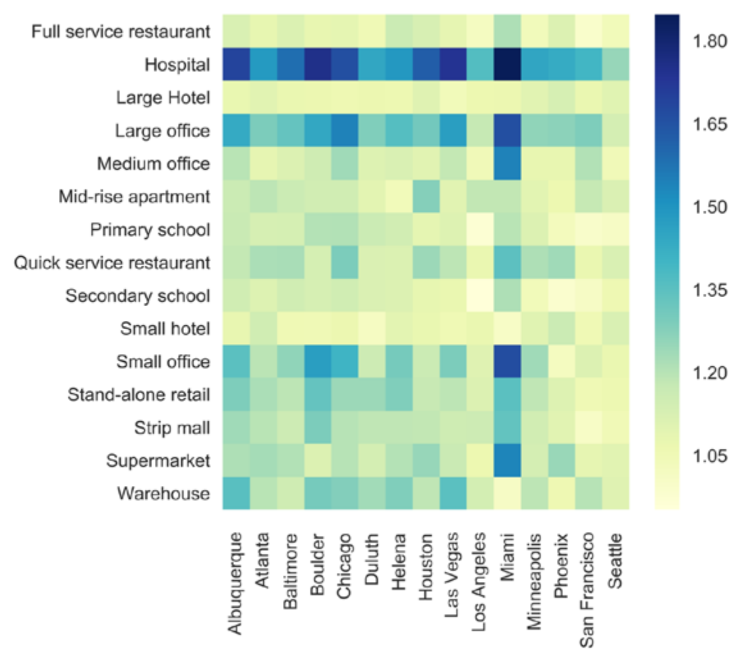

Figure 2. Cooperation ratios for solar and storage

The cooperation ratio is equal to the demand charge savings from solar + storage divided by the sum of the demand charge savings from solar alone and from storage alone. This figure shows cooperation ratios under a basic non-coincident demand charge with a 1-hour averaging interval, PV systems sized to meet 20% of each customer's annual load, and batteries sized to equal 20% of the customer's annual peak demand.

office buildings exhibit this type of load profile, and thus show relatively high cooperation ratios in Figure 2. Second, passing clouds create transient dips in solar production that storage can easily buffer. Solar + storage synergies therefore tend to also be relatively strong in locations with a high degree of intermittent cloud cover; for this reason, Miami shows relatively high cooperation ratios in Figure 2. Important to note, however, is that building types and locations with the greatest synergies do not necessarily have the highest absolute demand charge savings, as evident in the findings below.

Demand reductions from solar + storage vary across commercial building types, though all see some level of savings. For standalone solar, demand reductions are greatest for buildings with distinct afternoon peak loads that coincide well with the timing of solar generation (e.g., schools and strip malls, as shown below in Figure 3). For the same reason, these building types also generally see the greatest demand reductions from solar + storage. However, unlike standalone solar, where some building types see virtually no benefit in terms of demand reductions, solar + storage systems generate demand reductions across all commercial building types simulated in this analysis. This is for the simple reason that storage systems can generate demand reductions for all building types. Demand reductions from solar + storage nevertheless vary across building types, though the differences are somewhat less pronounced than for standalone solar. In large part, this is because those building types that perform most poorly for standalone solar—namely, apartments and hotels—happen to perform best for standalone storage, as they have relatively narrow peak loads that storage is well suited to clip. Figure 3 also helps to illustrate the significance of solar + storage synergies for hospitals, which have relatively low demand reductions for both standalone solar and standalone storage, but substantial solar + storage synergies that allow for demand reductions much greater than the sum of what each technology achieves alone.

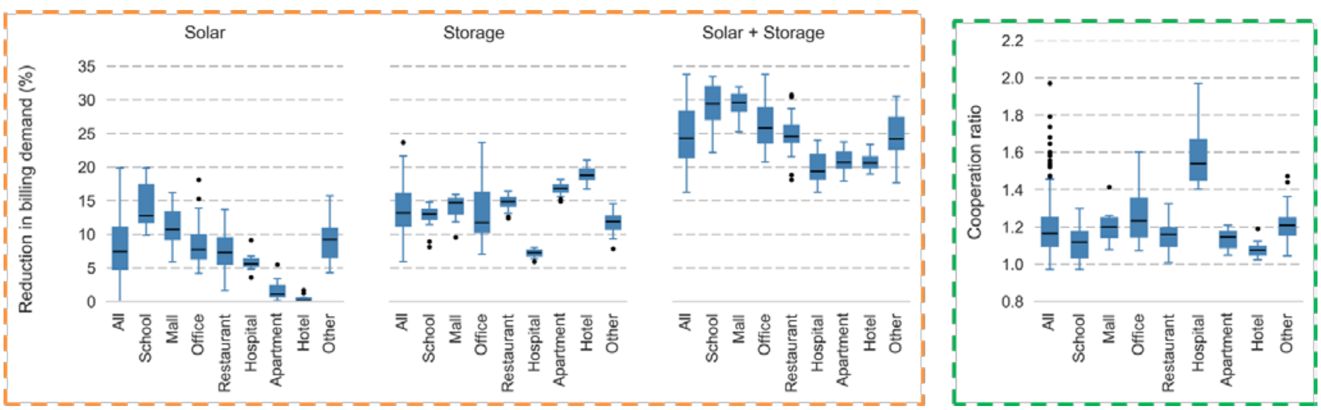

Figure 3. Demand reduction and cooperation ratio across commercial building types

The figure shows distributions in billing demand reductions for each building type (horizontal lines are median values; boxes are the first and third quartiles; whiskers are 1.5x the interquartile range). These results are based on a basic non-coincident demand charge with a 1-hour averaging interval, PV systems sized to meet 20% of each customer's annual load, and battery sized to equal 20% of the customer's annual peak demand.

Demand reductions from solar + storage are location-dependent. The width of the error bands in Figure 3 reflect locational differences in demand reductions for each building type. As shown, demand reductions from standalone solar vary significantly across locations, while demand reductions from standalone storage are considerably less variable across locations for most building types. When solar + storage are co-deployed, demand reductions continue to vary by location, as they do for standalone solar, though to a slightly lesser degree. As is the case with standalone solar, demand reductions tend to be greatest in locations such as Phoenix and Albuquerque, with the strongest solar resource and least amount of cloudiness. Additional details on these locational differences are provided in the full briefing.

Solar + storage systems are more effective at reducing demand charges that are based on peak period demand. Demand charges may be based on maximum demand during a pre-defined peak period, rather than on a customer's maximum non-coincident demand. As shown in Figure 4, solar + storage systems generate greater demand charge reductions under these designs. The greatest reductions occur when the peak period is restricted to afternoon hours, as is the case for standalone solar, due to the concentration of solar generation in afternoon hours. However, solar + storage systems also perform better with evening peak period designs, though in those cases demand reductions are almost entirely derived from the storage component. Demand reductions from solar + storage under the wide, 10-hour transition peak period are lower than under the other peak period demand charge designs, both with 5-hour peak periods. As a general matter, storage systems—whether paired with solar or deployed on a standalone basis—are better able to reduce billing demand when restricted to a limited set of hours.

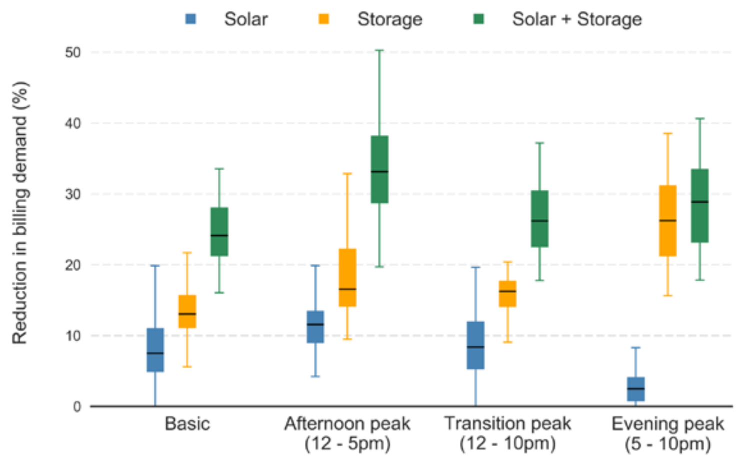

Figure 4. Demand reductions under a basic non-coincident demand charge and "peak period" demand charge designs

The figure compares billing demand reductions between a basic non-coincident demand charge and several variants of a peak-period demand charge. The distributions reflect variation across building types and locations. All simulations used in this figure are based on PV systems sized to meet 20% of each customer's annual load and batteries equal to 20% of the customer's annual peak demand. See Figure 3 notes for explanation of box-and-whiskers plot.

Solar + storage systems are generally more effective at reducing demand charges the shorter the averaging interval for measuring billing demand. Demand charges are typically based on measurements of customer demand averaged over some interval of time—often between 15 and 60 minutes, though potentially longer intervals could be used. Longer averaging intervals smooth out short-duration peaks, in effect performing the same function as storage. Consequently, demand reductions from solar + storage tend to be lower under demand charge designs with longer averaging intervals (see Figure 5). One implication of these results is that preceding figures, which are based on 1-hour averaging intervals, will tend to understate demand reductions from solar + storage, given that most demand charge designs currently in place rely on shorter averaging intervals (15-minute intervals are likely the most-common). Notably, the trend shown here for solar + storage is the

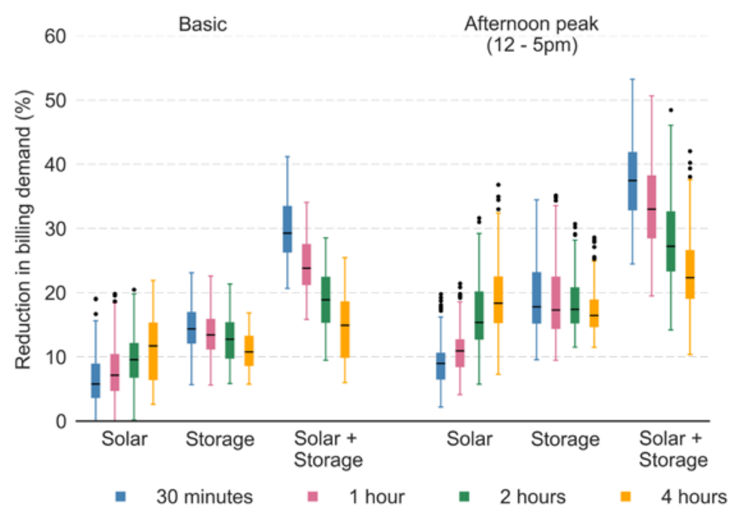

Figure 5. Demand reductions under varying averaging intervals

The figure compares billing demand reductions for averaging intervals ranging from 30 minutes to 4 hours. The distributions reflect variation across building types and locations. All simulations used in this figure are based on PV systems sized to meet 20% of each customer's annual load and batteries equal to 20% of the customer's annual peak demand. See Figure 3 notes for explanation of box-and-whiskers plot.

opposite of what is shown for solar-only, where demand reductions are greater for *longer* averaging intervals. For solar + storage systems with much larger solar and/or much smaller storage system sizes than assumed in Figure 5, the trends can invert and more closely resemble those for standalone solar.

Solar + storage systems exhibit diminishing returns to scale. Solar and storage each, on a stand-alone basis, exhibit diminishing returns to scale in terms of incremental demand reductions with increases in system size. In the case of solar, this occurs because larger system sizes progressively push the customer's net peak load further toward non-daylight hours. In the case of storage, this occurs because larger system sizes lead to progressively wider peak loads. Not surprisingly, then, solar and storage, when deployed together, also exhibit diminishing returns to scale, as shown in Figure 6. However, those diminishing returns are mitigated to some extent by greater synergies between solar and storage for larger system sizes. This occurs because larger solar systems create progressively narrower and taller peaks, which are progressively easier for storage systems to clip.

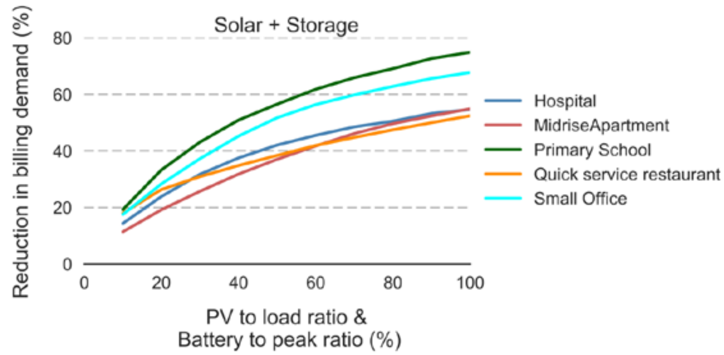

Figure 6. Demand reductions from solar + storage across system sizes (Albuquerque)

The figure shows the average billing demand reduction under a basic non-coincident demand charge, for solar + storage systems installed at a select set of commercial building types in Albuquerque, New Mexico, with solar and storage system sizes varying across the full set of modeled sizes. PV system sizes are denominated in terms of a percentage of the customer's annual load, and battery storage system sizes are denominated in terms of a percentage of the customer's annual peak demand.

Conclusions

The preceding analysis is based on simulated building load, PV generation, and storage dispatch profiles that reflect a number of simplifying assumptions. It should also be clear that this analysis considers only one aspect of a much broader set of issues related to the costs and benefits of solar + storage. Notwithstanding those limitations, we offer several general conclusions based on the preceding findings:

- **Solar and storage are mutually beneficial.** Though one might anticipate that solar + storage could "cannibalize" demand reduction opportunities for the other, this analysis shows the opposite: namely, that each technology incrementally reduces demand charges by a *greater* amount when deployed with the other than on its own. Some of the most economic opportunities (from the customer perspective) for storage may therefore be in facilities that already have solar, and vice-versa.
- **Demand charge savings from solar + storage are highly customer-specific.** Demand reductions from solar + storage systems vary substantially from customer to customer, depending on commercial building type, location, and system sizes (albeit to a somewhat lesser degree than for standalone solar). Identifying market opportunities for solar + storage may therefore require fairly specialized targeting.
- **Demand charge design matters for the economics of solar + storage.** This analysis examines two aspects of demand charge design: non-coincident demand charges vs. peak-period demand charges and the averaging interval over which demand is measured. The results show clearly that these details can significantly impact the level of demand reduction from solar + storage systems, though not always in the same manner as for each technology individually. Understanding those interactions will be important as utilities continue to refine demand charge designs.

For More Information

Download the full briefing, published in slide-deck form

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