Smart and Grid-Interactive Buildings: A utility works to incentivize customers to install dispatchable storage in their homes.

Chelsea Liddell, DNV
Cynthia Austin, Sacramento Municipal Utility District

ABSTRACT

Central to many utilities' decarbonization goals are demand flexibility and distributed resources, which may include battery energy systems in residential customers' homes. Sacramento Municipal Utility District (SMUD) is rolling out a program providing incentives in exchange for direct control of customers' residential battery energy systems. Batteries are dispatched during times of day when system load is highest, particularly on days with especially high loads. SMUD's hope is that program incentives will also make residential battery installations more affordable and more common. The program goal is to enroll 1,460 battery storage units to enable 10.2 MW of controllable load capability before 2026.

DNV, a consulting firm, is collaborating with SMUD to evaluate the impact of this program relative to two different baselines, serving two different SMUD goals. The first of these goals is determining the impact of program battery control compared to customers' operation of batteries without a program. The second goal is to determine, when the utility calls a battery dispatch event, how much grid load reduction they can expect relative to a day without an event.

In this research, we primarily discuss the tradeoffs of the two different baselines in the experimental design. This includes the validity, potential biases, and logistical challenges of each. We also give a high-level report on the level of impacts that can be expected from this kind of program. This is helpful to program administrators considering residential battery programs, for evaluation design and sense of potential impact magnitude.

Introduction

Sacramento Municipal Utility District (SMUD) is a community-owned, not-for-profit municipal utility serving electricity to over 1.5 million people in California's capitol region. Facing the climate emergency, SMUD's elected board of directors adopted a goal of zero carbon emissions from its electricity portfolio by 2030. Achieving reduction of the last 10% of emissions elimination will be driven by new technologies and business models, including an estimated 165 MW of demand flexibility, which reduces peak demand, lowering pressure on grid infrastructure and enabling a better match between electrical load and renewable generation (SMUD 2021).

One opportunity for demand flexibility comes from batteries installed in residential customers' homes. These batteries can charge from solar during the day (usually from customer-sited solar) and dispatch during peak afternoon hours when demand is highest. SMUD has been exploring how to effectively use residential-sited batteries to serve peak load since 2019, starting with pilot programs called Commitment to Operate and Smart Energy Optimizer (Huang 2019) . In 2023, SMUD launched a full-scale automated residential battery program, called My Energy Optimizer™ Partner+ (Partner+).

In the Partner+ program, SMUD will have access to up to 80% of a customer's battery capacity on a near real-time, around-the-clock basis with a maximum of 30 peak-hour discharge events per month in summer (June 1 - Sept. 30) and 15 events per month in winter (other months).[1] Participants receive an up-front incentive of $250/kWh battery capacity (up to $2,500) and ongoing performance payments. Tesla Powerwalls, the most common residential battery type in SMUD territory, are eligible for Partner+ and there are plans to add other manufacturers. SMUD is partnering with a battery program implementation company ("the implementer") to directly control the batteries. The program goal is 1,460 enrolled batteries by 2026.

Enrollment in the program is made more complex by SMUD's transition from the net energy metering (NEM) export rate to the new Solar and Storage Rate (SSR), which went into effect in March 2022. The lower export rate of SSR was adopted by SMUD's elected Board of Directors with support from the community and industry because it continued SMUD's support for customer sited renewable energy through battery storage financial incentives. These incentives can cover up to a quarter of the cost of battery energy storage installations if the customer agreed to participate in the Partner+ program.

Partner+ is inherently tied to the SSR. Customers who installed solar and/or storage before the effective date of SSR are grandfathered into the NEM rate but must switch to SSR to enroll in Partner+. Enrollment requires these existing NEM customers to make a complex financial choice, weighing the large Partner+ incentive and ongoing capacity payments against a different net metering agreement which reduces income on electricity sent back to the grid (by about 50-80%, depending on time of day and year).

As of March 2022, new solar and/or storage customers are automatically enrolled in the Solar and Storage Rate and pay an interconnection fee of $475 or $900, depending on system size. A secondary goal of the Partner+ incentive is to encourage adoption of battery energy storage alongside residential solar. This incentive will mitigate the reduction in income from solar sent back to the grid. Additionally, non-event day battery operation should allow customers to use more of the electricity generated by solar to offset their own grid energy draw (during non-solar, peak-electricity-price[2] hours), further increasing the value of the solar generation. Both Partner+ event-day dispatch and the offsetting of customer peak-hour load will also benefit SMUD.

After six months of testing, SMUD began full operation of the Partner+ program in November 2023. As of June 2024, around 60 customers are enrolled.

DNV is working with SMUD to evaluate the impacts of this program. In this paper, we explain our impact evaluation strategies for this program, focusing on the selection of an accurate and useful baseline. We also describe the outputs that SMUD will use to evaluate the program's effectiveness and present early results.

Methods

The impact evaluation of this program includes three components. The first of these is a rapid-feedback battery performance dashboard. The second and third are different baseline impact analyses.

---

[1] Events are currently called by program staff as the program is being tested. In the future, grid operators will call events on days with high peak load and/or expensive or carbon-intensive peak generation.

[2] The majority of SMUD's customers are an opt-out time-of-use rate, with peak hours from 5-8 pm on non-holiday weekdays

Rapid-Turnaround Dashboard

For newer technologies, DNV and SMUD have found that it is essential to create mechanisms for rapid feedback on program performance. While an extensive impact evaluation is important and necessary for accurate and in-depth program assessment, for many load flexibility programs, a simple visualization of hourly load shapes, comparing event days with non-event days, can show whether the program is working as intended. For this program, DNV is creating a dashboard that shows each battery's average charge and discharge on event days and non-event days. Batteries working incorrectly can usually be easily identified, SMUD can coordinate with the implementer, and problematic algorithms[3] can be identified and fixed, resulting in improved program impacts going forward.

Impact Baselines

For the full impact analysis, DNV compared event-day battery operation to two different baselines to serve two different information needs. Before describing the baselines that were included in this evaluation, we discuss those that were not. A secondary goal of the program incentives was to encourage more residential battery installs, and more solar systems with storage. However, the primary goal was to successfully control the batteries (and many program batteries were installed before the program began), so we focused on baselines with batteries. That means that no-battery and no-solar/no-battery baselines were not considered in this study.

The first baseline that was used for evaluation controlled in-program batteries to battery operation had there been no program. This allows SMUD to understand the impact and cost-effectiveness of the program relative to other ways of providing peak capacity or load curtailment, whether the program needs to change, and whether it should be continued.

For this "no program" counterfactual, the most ideal baseline would be a control group of battery owners willing to sign up for a battery control program, but who were not enrolled. While this type of randomized control trial design would provide the most accurate program impact estimates, it requires customer enrollment limitations. Since SMUD's Zero Carbon Plan requires rapid battery deployment, SMUD decided against a randomized control trial due to its added complexity, the delay in maximum peak load curtailment, and potential issues with customers feeling excluded from the program, which has been widely advertised as available to all. Additionally, because of additional Partner+ goals of continuing to encourage solar (with storage) adoption, it would be counterproductive to deny program participation to some customers.

In some load management evaluation contexts, DNV is able to find a matched comparison group with similar load characteristics as participants, to use as a pseudo-control group. However, in this case, that is both impractical and unnecessary. First, the population of battery owners is still very small, so finding nonparticipating battery owners with similar load profiles as battery owners could be challenging. Additionally, battery telemetry data is only available from program participants, so an evaluation using a matched comparison group would have to be done with AMI data, which would add large daily variation and noise to impact results (relative to an impact calculation using battery telemetry). Third, battery operation, unlike

[3] For example, in other battery programs, some batteries have not responded to event-day discharge signals. In Partner+, the dashboard has shown that this is not an issue, but we have seen that batteries occasionally discharge more in some hours and less in others, which may be worth investigating.

some other devices used for demand management (say, thermostats or electric vehicles), varies relatively little from day-to-day.[4] Most batteries charge up as solar begins to produce energy in the morning, and discharge in the afternoon/evening (with discharge patterns depending on battery settings). Because of this, DNV chose to use participant battery telemetry data for the year[5] preceding the program as the no-program baseline.

The second type of important information for SMUD is that grid operators understand how much load curtailment will occur when an event is called. Expectations for the grid, without an event, will be based on recent grid operation on non-event days. Therefore, when grid operators choose a resource mix to provide reliable electric service, they will need to know how much load will change compared to recent energy usage. For this "no event" baseline, we used data from participant non-event days, but excluded days immediately before or immediately after events. This is because the events are likely to affect battery operation on those days. On days immediately before events, the implementer may control batteries to reduce discharge amounts, ensuring that the maximum possible charge is available for event hours the following day. On days immediately following events, batteries may begin with lower states of charge than usual and need to charge more during the day.

Additional Drivers of Impact Differences

While batteries often operate similarly day-to-day, there is some predictable variation, and different batteries will have different charge/discharge profiles. To allow SMUD better understanding of how program impacts will change with season, battery settings, and customer battery size, the methods for this evaluation include examining each factor.

Program impacts will change by season because of differences in charging as sunlight varies, and differences in discharging as air conditioning loads change.

Battery settings are key to understanding program impact. Tesla Powerwalls have two primary settings for battery operation (outside of direct control on SMUD program event days): backup reserve percentage and operational mode. Backup reserve percentage defines the lowest percentage state of charge that the battery can reach in its normal operations – that is, unless there is a power outage. Operational mode determines how the battery will discharge its power down to that backup percentage, during normal operation. There are two primary operational modes. The first, called 'time-based control,' discharges the battery as much as possible during peak price hours (assuming the battery is set to be able to export to the grid). The second, called 'self-powered' mode, discharges the battery just to power the customer's home, for as long as possible. Under SMUD's solar and storage rate, customers will receive a much higher financial benefit powering their own home (and reducing their draw from the grid, 'self-powered' mode), rather than sending electricity back to the grid (even during peak price hours, 'time-based control' mode).

Both of these modes affect the baseline for calculating program impacts relative to event days when batteries are directly controlled to dispatch during event hours. A higher percent backup reserve means less energy available for discharge on baseline days, leading to a lower baseline discharge, and higher program impacts. The time-based-control setting would result in

[4] We discuss exceptions to this and evaluation strategies for addressing them below.
[5] Where available; some participants did not have their battery for a year before joining the program, and, going forward, more and more participants will join the program at the same time they purchase a battery.

more battery discharge during SMUD peak hours, which are also usually program event hours, increasing the baseline discharge, and reducing program impacts.

Finally, battery size has a clear impact on dispatch amount. Most batteries are either 5 kW/13.5 kWh or 10 kW/27 kWh, meaning the smaller batteries could output 5 kW for a little over 2.5 hours, whereas the larger batteries could output double that for the same amount of time (if dispatched from 100% to 0%). If the enrolled battery size mix changes, the program impact could change drastically.

Remaining Baseline Challenges

While these baselines provide the best impact estimates possible, there are still potential challenges with the results they provide. These should be kept in mind as results from this type of evaluation are presented.

The biggest of these is that this is a new technology, so results represent a population that are both early adopters of the technology and early adopters of the program. They also represent a segment of the population that has enough resources to purchase a battery for their home, but for whom this level of incentive matters enough that they'll allow external control of that battery on more than half of the days of the year.

It can be challenging to predict how early program adopters will be different than later program adopters. If early adopters are different than later adopters, event day battery behavior may be very similar because the implementer is optimizing the battery. However, both short- and long-term impacts are likely to be different because baseline behavior may be different. Observed baseline behavior, both in the pre-program period baseline and non-event day baseline, varies across currently enrolled batteries. There could be systematic differences in that baseline behavior between early and later adopters. For example, later adopters could be less engaged, and more likely to leave batteries on factory default settings rather than using customized settings.

Early technology adopters are likely to be different than later adopters because of both their level of engagement with batteries – they could be more likely to use customized settings – but also because public knowledge about how to program batteries will expand with time. For example, for SMUD customers, it is now most financially advantageous to set batteries to self-powered mode, but currently many customers have their batteries set to time-based control mode, which was best under SMUD's previous net energy metering rate. This difference in operational mode changes the baseline, which changes the impact of the program.

Another important factor that could affect future baselines (and, potentially, event day impacts), is whether a summer season in California sees large fires and/or rolling blackouts. In that scenario, customers may set their batteries to have 100% backup reserve, which would mean that on non-event days, they are not discharging during peak evening hours. If events happen as intended, then event impacts would be relative to a zero baseline, and much larger.

Results

Early results from this evaluation show promising per-battery average impacts during event hours. As a reminder, the two goals of this evaluation are (1) to examine how program event days impact the grid relative to battery operation without a program, and (2) to examine how event days impact the grid relative to non-event days. We do not focus on differences in impact by battery setting, because we are interested in actual expected impacts for a utility, given the real-world mix of battery settings and the effectiveness of those settings.[6] Similarly, while non-event-day discharge, and therefore impacts, can depend on weather and customer load, this study focuses on the overall mix in the study, and does not analyze specific impacts of those factors.[7]

Figure 1 shows 'long term' impacts, or the effect of the program relative to a no-program baseline. This means that, for each hour, the average battery charge/discharge in the pre-period is subtracted from the average battery charge/discharge on event days, leaving the additional kW that the program delivers as the impact shape shown. This is the marginal kW provided by direct program control of batteries, relative to a baseline with batteries but no program.

Figure 2 shows 'short term' impacts, or the effect of program event days relative to non-event days. Again, for every hour, the average battery charge/discharge on non-event days is subtracted from the average battery charge/discharge on event days, leaving the additional kW that is delivered on event days (relative to non-event days) as the impact shape shown. This is the marginal kW that grid operators can expect when an event is called, relative to days without an event.

For both long-term and short-term impacts, we see a clear difference in impact by battery size, as expected. The 10 kW batteries have about twice the program impact as the 5 kW batteries. They also have slightly different impact shapes, especially for the short-term impacts. These larger batteries are more likely to operate according to the time-based-control mode on non-event days, dispatching all their power during the first hour or so of SMUD's time-of-use rate (which has the same hours as the events that have been called so far). This means that the program has less impact during these hours, relative to this time-of-use based discharge.

Short-term impacts are slightly smaller than long-term impacts, indicating that program enrollment has affected battery operation on non-event days, moving it slightly closer to event-day operation. That is, after enrolling in the program, batteries are more likely to discharge during event hours, even on non-event days. This means that SMUD grid operators should expect a slightly smaller kW program-hour impact from non-event to event days (relative to a comparison with no-program batteries) because enrolled batteries are already providing a higher event-hour impact.

[6] Battery setting is not always recorded, so for the pre-program period, we only have algorithmically-determined settings, not real settings. For the post-period, the setting is recorded monthly, but the daily or hourly setting is still unknown. The correspondence of recorded settings and expected behavior under a given setting is mixed. Additionally, program participants are supposed to set their batteries to self-powered mode upon entering the program, but compliance to this expectation appears to also be mixed.

[7] All customers could export energy to the grid, so this was not an influencing factor on program impacts.

Figure 1: Long-term, or no-program baseline, impacts per program enrollee, for two battery sizes. 5 kW batteries shown in blue, and 10 kW batteries shown in black. Event hours are shaded pink. Information from all 60 batteries is included in the plotted data.

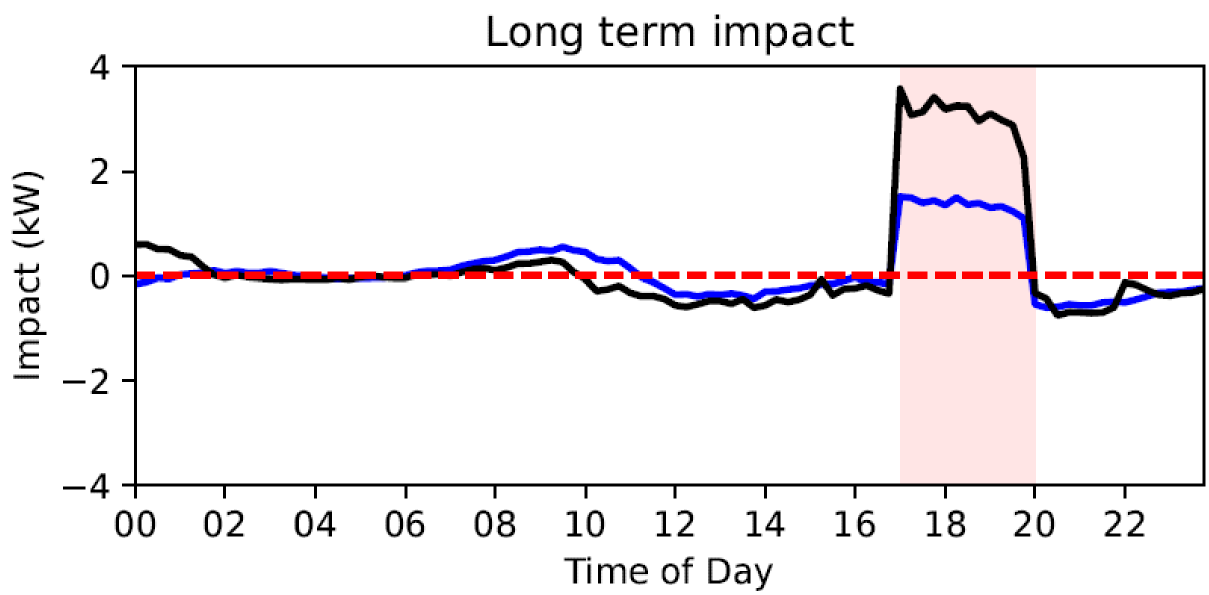
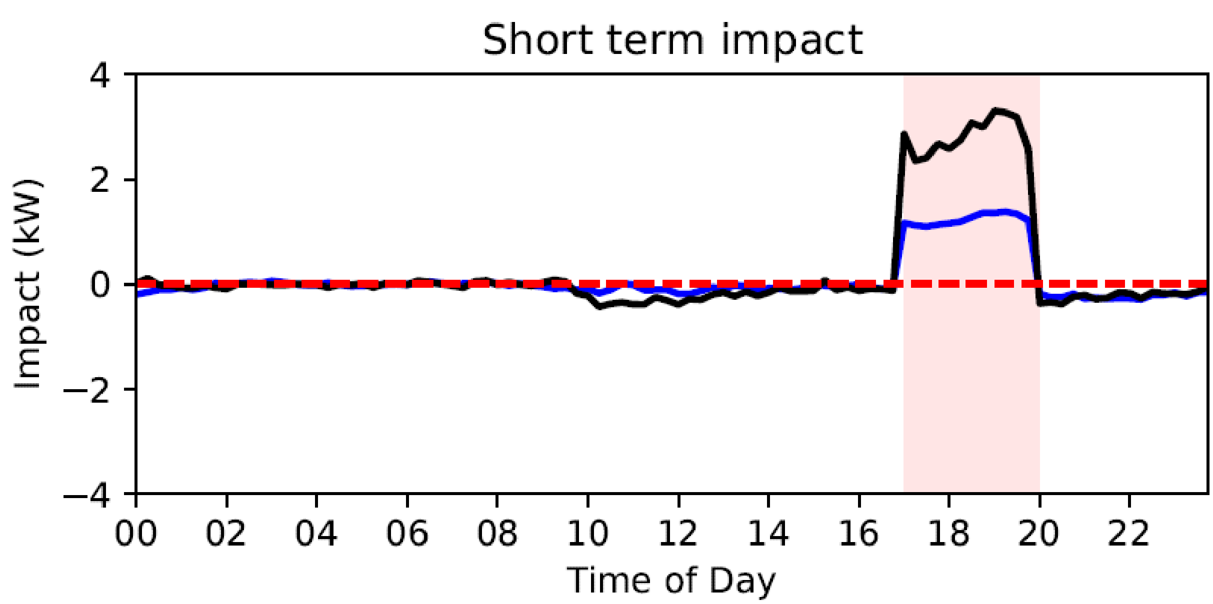


Figure 2: Short-term, or non-event day baseline, impacts per program enrollee, for two battery sizes. 5 kW batteries shown in blue, and 10 kW batteries shown in black. Event hours are shaded pink. Information from all 60 enrolled batteries is included in the plotted data.



Conclusions

In designing this evaluation and looking at early results, we see that this type of program holds huge promise and evaluation methodologies need to be considered carefully. Quick visualizations of battery operation can lead to improved implementation and a much more successful program. Different baseline methodologies are important for different utility stakeholders. Program designers and managers want to know if the program is successful and cost-effective relative to a no-program alternative. Grid operators want to know how much curtailment they can rely on to minimize generation and energy procurement costs, as well as maintain grid reliability.

While batteries do operate similarly day-to-day, seasons and battery settings can cause differential program impacts. These are especially important for our awareness for fast-growing programs with new technologies, because how customers set up their batteries is likely to continue to evolve.

References

R. Huang. 2019. "SMUD's Carbon Reduction Strategies: Smart Homes, Strategic Electrification, and Energy Storage." Clean Energy States Alliance. https://www.cesa.org/wp-content/uploads/ESTAP-webinar-slides-12-5-19.pdf

Sacramento Municipal Utility District (SMUD). "2030 Zero Carbon Plan." April 2021. www.smud.org/-/media/Documents/Corporate/Environmental-Leadership/ZeroCarbon/2030-Zero-Carbon-Plan-Technical-Report.ashx