What's in it for me? Understanding the Stakeholder Value of Code-Compliant Residential Batteries

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ABSTRACT

Given the increasing number of battery energy storage system (BESS)-related provisions in building code, there is a need to understand whether true battery operation reflects substantial benefit from following these provisions. This paper presents a comprehensive analysis aimed at understanding the effectiveness of BESSs in managing customer electricity bills, supporting grid harmonization, and reducing carbon emissions for residential homes. As part of this effort, commercially available, California Title 24, Joint Appendix 12 compliant BESSs were deployed in ten homes. Using energy code metrics for quantifying long term system cost and greenhouse gas emissions, the study assessed the incremental benefits of adding BESS systems to homes.

Results from these deployments underline the importance of consistent battery cycling for enhancing solar self-utilization, reducing grid imports, and realizing homeowner value. BESS utilization patterns reveal that effective battery control strategies, particularly those that increase depth of discharge, are important for decreasing electricity consumption from the grid. These strategies must balance a battery's role in providing backup power with its role in enhancing load flexibility. Finally, the increasing prevalence of electric vehicles poses a challenge for code-optimal BESS operation due to high charging demand that significantly alters site load profiles.

The findings emphasize that while specification-driven compliance with code BESS provisions is helpful, it does not guarantee that installed system operation will fully align with policy goals. Achieving policy goals requires not only proper configuration and continuous monitoring of system modes, but also a strategic alignment between customer objectives, ease of use, and distribution-level benefits.

Introduction

In 2018, California enacted Senate Bill 100 (SB-100), committing the state to 100% clean electricity by 2045 (California Senate, 2018). Achieving this goal will require substantial decarbonization across the building sector. In 2020, California also implemented its residential solar mandate, requiring new homes to include photovoltaic systems (Brittan and Hoen, 2023). As PV deployment expands both at the grid scale ("front of the meter") and at the level of individual buildings ("behind the meter"), buildings must become more flexible assets that can interact beneficially with the electric grid rather than exacerbate grid imbalances. There is therefore a growing need to harmonize behind-the-meter PV with grid operations, a need that the current Title 24 energy code seeks to address through behind-the-meter battery systems. In this context, grid harmonization means supporting generation, transmission, and distribution needs across the electric grid.

Title 24 Joint Appendix 12 (JA12) is part of California's Building Energy Code (Title 24) and establishes the qualification requirements for battery energy storage systems that can receive Title 24 compliance credit when paired with solar photovoltaic systems (California Energy Commission, 2024). It sets minimum standards for safety, performance, durability, efficiency, and control capabilities, including requirements for load shifting and grid-responsive operation. JA-12 encourages the adoption of battery storage technologies that store excess renewable energy for later use, increase on-site solar self-consumption, reduce peak electricity demand, and support electric grid reliability and flexibility. By promoting daily battery cycling and demand-responsive controls, JA-12 aims to help advance California's goals for energy efficiency, renewable energy integration, and greenhouse gas reduction.

Residential battery energy storage systems (BESS) are increasingly used to improve resilience, reduce energy costs, and increase the value of distributed solar. When paired with customer-sited solar, BESS can provide homeowners with economic and reliability benefits by increasing solar self-consumption and reducing grid purchases during high-cost peak periods. Under 2025 residential net billing structures, batteries can further increase solar value by storing exported energy for use when it offsets higher-priced grid imports. In addition to bill savings, BESS can provide backup power during outages, a capability that traditional rooftop solar alone typically cannot offer. Solar-plus-storage systems may also benefit the broader electric grid by reducing peak demand and supporting the integration of variable renewable resources. Together, these capabilities make customer-sited DER a potential asset for both households and the grid. However, real-world performance is influenced by manufacturer control strategies, customer-specific settings, and site operating conditions.

Drawing on field deployments from a California Energy Commission (CEC) demonstration project involving ten single-family homes with residential BESS installations in California, this study evaluates how effectively Title 24 JA-12-compliant batteries deliver different value streams. The analysis compares reductions in metrics commonly used to quantify Title 24 performance and customer costs to provide a broader view of the grid, environmental, and customer benefits of the deployed systems. It also examines relationships between common battery performance indicators and broader Title 24-derived metrics to identify design parameters and control modes that best support the intent of Title 24. Finally, the study characterizes the benefits of organic code-compliant battery deployments, in which customers received batteries but were not instructed on how to operate them. Although the sample size is limited, this approach helps characterize battery performance under real code conditions, where builders receive compliance credit for including BESS in their designs, but no specific operating strategy is enforced.

Primary Research Questions and Contribution

The primary research questions explored in this paper are the following:

(a) What are the primary value propositions of behind-the-meter BESS operation? How do these value propositions differ between homeowners, grid operators, policymakers, and other stakeholders? Is there substantial alignment among those stakeholders?
(b) To what extent can residential BESS improve grid harmonization by mitigating duck-curve effects and shifting solar generation to periods of higher grid need, as intended by Title 24 Joint Appendix 12?
(c) What are the limitations of including provisions in building energy codes that are supportive of BESS adoption?

This paper contributes to the body of knowledge surrounding BESS and energy codes by highlighting an analytical framework for better understanding the potential for BESS to improve overall building performance as defined by Title 24, and by relating the relevant performance metrics to battery performance characteristics through illustrative examples.

Study Setup and Methodology

Site Overview

This paper analyzes data from ten homes in the CEC project. Eight are in Department of Energy Climate Zone 3C (Antonopoulos et al., 2022), classified as warm marine (California Climate Zone 2), and the remaining two are in Climate Zone 3B, classified as warm-dry (California Climate Zones 10 and 7).

Homes and Battery System Configurations

The ten homes used commercially available battery energy storage solutions with different energy and power capacities:

- **Homes 1, 2, and 3:** 10 kWh / 3.84 kW battery systems.
- **Homes 4, 5, and 6:** 13.6 kWh / 5.0 kW battery systems.
- **Homes 7 and 8:** 10 kWh / 7.68 kW battery systems.
- **Home 9:** 13.5 kWh / 7.60 kW battery system.
- **Home 10:** 27 kWh / 11.5 kW battery system.

The batteries analyzed came from several manufacturers that collectively represented over 60% of the U.S. residential BESS market in 2026. Manufacturer names and model details are omitted because they are not relevant to the analysis. Table 1 provides additional information on the study homes, including floor area, solar PV capacity, BESS energy capacity, BESS power capacity, and location.

Table 1. Description of the ten homes modeled and measured in this report

Home	Area (sq. ft.)	Solar PV (kW)	BESS Energy Capacity (kWh)	BESS Power Capacity (kW)	EV Present	Location
1	2855	2.32	10.00	3.84	Yes	Rohnert Park, CA
2	2549	4.32	10.00	3.84	Yes	Rohnert Park, CA
3	1888	4.32	10.00	3.84	No	Rohnert Park, CA
4	2855	2.32	13.60	5.00	No	Rohnert Park, CA
5	1412	2.32	13.60	5.00	No	Rohnert Park, CA
6	1214	2.32	13.60	5.00	No	Rohnert Park, CA
7	2494	2.32	10.00	7.68	No	Rohnert Park, CA

8	2855	2.32	10.00	7.68	No	Rohnert Park, CA
9	2214	2.32	13.50	7.60	No	Vista, CA
10	1890	4.32	27.00	11.50	No	San Marcos, CA

Data Analysis Methodology Overview

Data collection spanned a full year of operation (January-December 2025). To obtain a holistic view of how BESS perform, two classes of metrics were assessed: Techno-Economic Performance Metrics, and Battery Operational Metrics. Table 2 summarizes the two sets of metrics. Techno-economic performance metrics evaluate the overall economic and environmental outcomes of the energy system, such as long-term system cost (LSC), long-run marginal greenhouse gas (GHG) emissions, and customer utility bills. These metrics capture the value and impacts of the system from a broader grid, societal, or customer perspective over time. In contrast, battery operational metrics, such as solar self-consumption efficiency and state of charge (SOC), measure the battery's day-to-day performance, utilization, and operational behavior in managing energy flows.

Table 2 Summary of Performance and Operational Metrics

Techno-Economic Performance Metrics	Battery Operational Metrics
• Long-Term System Cost (LSC) • Long-Run Marginal Greenhouse Gas (GHG) Emissions • Customer Utility Bills	• Solar Self Consumption Efficiency • State of Charge

These performance metrics are assessed relative to three scenarios, two fictitious and one representative of observed operation.

Scenarios Under Consideration

This study evaluates three scenarios to assess how distributed energy resources affect the energy performance of the participating homes. Two scenarios are hypothetical and use measured home data modified to represent specific DER configurations; the third reflects the actual on-site configuration. Together, these scenarios help evaluate how changes in BESS control modes influence environmental, technical, and financial performance, while identifying patterns and relationships for further investigation.

- **Scenario 0 (Fictitious):** No DER. This scenario assumes that the whole site load is met through grid imports. In this scenario, home energy performance is assessed based on the site load collected through OEM instrumentation systems.

$$Imports = Site$$

- **Scenario 1 (Fictitious)**: PV Only. This scenario assumes that excess generation is exported immediately. For this analysis, PV generation is subtracted from the site load, with the formula for grid imports given by:

$$Net\ Import = Imports - Exports = Site\ -\ Generation$$

- **Scenario 2 (True-to-life):** PV + BESS, as deployed in field. This scenario assesses performance based on net electricity imports, as given by:

$$Net\ Imports = Imports - Exports = Site - Generation + Charge - Discharge$$

Scenario 2 was assessed with the actual, real-world battery operation. Under Scenarios 1 and 2, timesteps that show a net export are important to discuss. Under NEM 2.0 (which was replaced by the Net Billing Tariff in 2023), the net export is assessed at the retail rate. Conversely, it is assessed according to the Avoided Cost Calculator (Energy and Environmental Economics, 2024) under the Net Billing Tariff (NEM 3.0). This distinction is important to emphasize for purposes of assessing the impacts of BESS dispatch on customer costs. Treatment of solar exports is further discussed in the next subsection of the methodology. Table 3 summarizes the scenarios in a simplified fashion.

Table 3: Analysis scenario breakdown and comparison

Scenario	Home Consumption	Solar PV Generation	BESS Dispatch
0	Measured	None	None
1	Measured	Measured	None
2	Measured	Measured	Measured

In total, three configurations are assessed, all of them using measured real-world case study data pulled directly from the vendors' monitoring systems, inverters, and online platforms.

Techno-Economic Performance Metrics

Long Term System Cost (LSC)

Long-Term System Cost (LSC) is an hourly metric used in California to estimate the societal value of energy. Before the 2025 edition of Title 24, this metric was known as Time Dependent Valuation (TDV). LSC values are provided for electricity, natural gas, and propane for each hour of a modeled year, totaling 8,760 hours (Energy and Environmental Economics, 2016). Total annual long-term system cost is computed by multiplying energy use at every hour by the fuel-specific LSC multiplier for that hour. This study focuses only on electricity-based LSC because other fuels, if present in the homes, were not monitored. LSC assigns higher value to energy saved during peak periods and lower value to energy saved during off-peak periods, reflecting factors such as grid congestion, market demand, marginal emissions from incremental energy use, and transmission and distribution costs. A heat map of LSC is shown in Figure 1, depicting the average LSC multiplier for every combination of month and year.

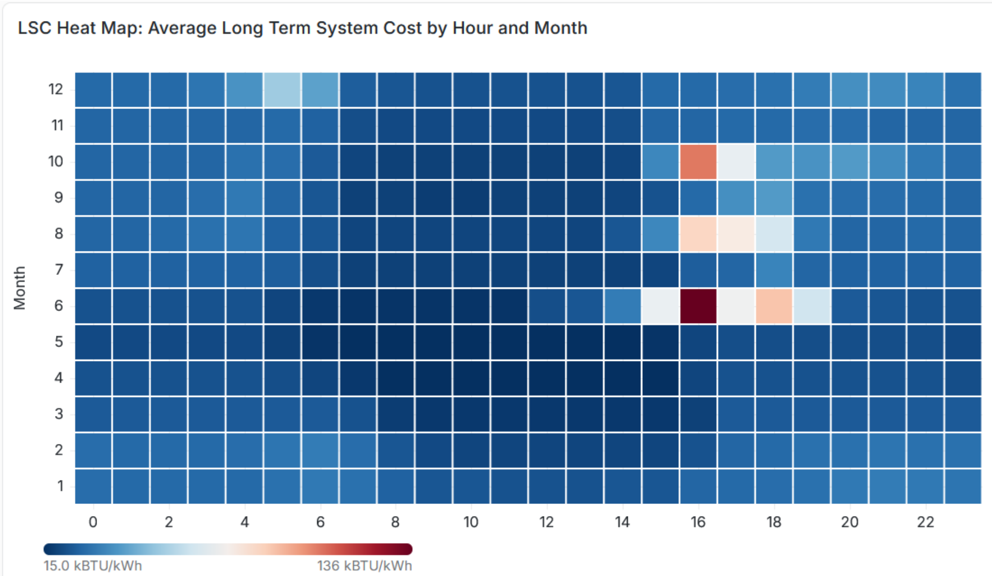

Figure 1 Average Long-Term System Cost by Hour and Month

Marginal Greenhouse Gas Emissions

Over a building's lifetime, greenhouse gas emissions, often referred to as carbon emissions, occur at different points in the energy supply and use chain. For operational energy analysis, these emissions are commonly grouped into the following scopes:

- **Scope 1:** Direct emissions from on-site fossil fuel combustion, such as water heating, space heating, or cooking.
- **Scope 2:** Indirect emissions from producing energy consumed on site, such as natural gas used by a peaker plant to generate electricity during periods of high demand.

Together, Scope 1 and Scope 2 emissions represent operational carbon. This study focuses on operational carbon because it is most relevant to energy performance analysis and Title 24 compliance.

Before 2022, Title 24 compliance did not explicitly account for marginal greenhouse gas emissions, which are emissions associated with incremental building energy use. The 2022 edition introduced Hourly Source Energy (HSE), a metric intended to approximate the annual emissions impact of building energy consumption (Energy and Environmental Economics, 2016). Although HSE is not a direct greenhouse gas emissions estimate, it serves as a proxy for emissions from commonly used fuels in California. Like LSC, HSE uses hourly multipliers that vary by fuel type and time of use (Energy and Environmental Economics, 2016). Because this study focuses on customer-sited DERs as a decarbonization strategy, the analysis considers only electricity-related emissions, or Scope 2 emissions. While compliance calculations use HSE, the California Energy Commission also provides hourly multipliers that estimate marginal greenhouse gas emissions for common fuels. A heat map of GHG multipliers by month and hour is shown in Figure 2.

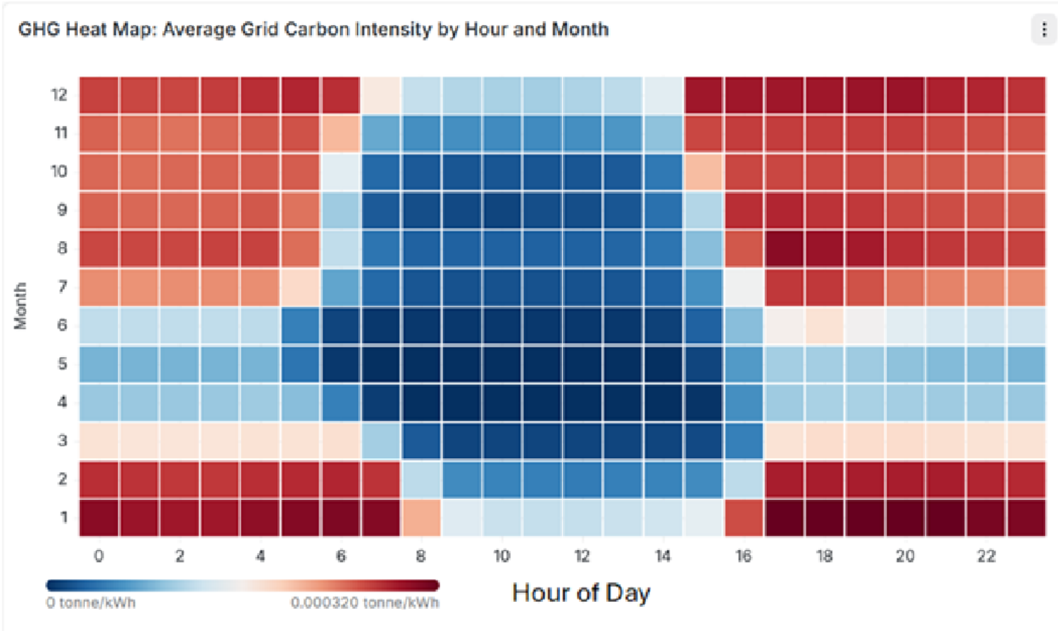

Figure 2 Average Grid Carbon Intensity by Hour and Month

Utility Costs and Tariff Assumptions

Utility costs are a core component of the present techno-economic analysis because they represent the homeowner's economic benefit from the presence of a BESS system. Under time-of-use (TOU) rate structures, electricity prices vary by time of day and season; therefore, the timing of household consumption, solar generation, and battery dispatch has a substantial effect on long-term costs.

Including utility costs in the analysis makes it possible to characterize whether and how solar and storage work in unison improve customer bill outcomes by shifting consumption away from on-peak periods, increasing the use of lower-cost energy, and reducing high-priced grid imports. TOU rates also enable distributed energy resources (DERs) to create value through behavioral and automated flexibility, such as scheduling battery discharge during expensive peak periods. This analysis uses the actual utility TOU rate plans assigned to the participating homes. For homes located in Rohnert Park, the impact of BESS and PV deployments on customer bills is assessed using PG&E's TOU-D rate (PG&E, 2026). For homes in SDG&E service territory (Vista and San Marcos), SDG&E's TOU-ELEC rate is used (SDG&E, 2026). Both of those time-of-use rates feature evening on-peak price bands, from 5 to 8 pm for PG&E and from 4 to 9 pm for SDG&E.

Tariff structures such as Net Energy Metering (NEM) and net billing directly influence the homeowner value of solar and solar-plus-storage systems. Historically, NEM provided bill credits for excess electricity exported to the grid, often at or near the retail rate, which made solar financially attractive even without storage. Under NEM 2.0, California maintained a retail-based crediting structure aligned with time-of-use rates, allowing exported solar energy to offset consumption at nearly a one-to-one value.

In April 2023, California adopted NEM 3.0, also known as the Net Billing Tariff (Barbose et al., 2024). This policy shifted export compensation from retail rates to avoided-cost-based rates, which are often much lower during solar-saturated midday hours. As a result, battery storage can increase system value by storing lower-value midday solar generation and discharging during higher-value evening periods.

The shift from net metering to net billing is becoming more common as utilities and regulators respond to higher solar penetration and evolving grid needs. There is a notable trend of states moving away from traditional full retail export crediting (North Carolina Clean Energy Technology Center, 2025). This transition is reshaping residential solar economics and making battery storage increasingly important for maximizing customer value.

Net billing is included in the present analysis to reflect the current financial environment for solar-plus-storage systems. Export values directly affect annual bill savings and the relative economic benefit of storage compared with solar-only configurations. Considering California NEM 3.0-like conditions helps capture the long-term cost-effectiveness of customer-sited DERs under modern policy conditions, where storage increasingly supports the economic value of residential solar investments.

Battery Operation Metrics

State of Charge and Solar Self-Consumption Efficiency were computed to assess typical battery dispatch patterns and characterize the extent to which batteries were changing the utilization of solar generation in the homes under study.

State of Charge

The state of charge (SOC) of a BESS provides critical information in understanding how a battery is being used, cycling patterns, dispatch schedules, depth of discharge (DoD), and overall energy capacity utilization. This information provides insight into the extent to which the battery is leveraged to meet two primary goals: save generated electricity and lower grid imports by providing power to site loads. In the present paper, the primary focus is to understand the diurnal patterns of state of charge variation for the deployed batteries, to ultimately be able to draw conclusions regarding typical times of charging and discharging, as well as effective state of charge floors and depths of discharge.

Solar Self-Consumption Efficiency

The Solar Self-Consumption Efficiency of a solar plus storage installation is calculated by dividing the amount of solar energy that was used on site, either via coincident load or shifting solar energy use later with a storage system, by the amount of solar energy that could have been used on site.

Solar self-consumption efficiency measures the share of available solar energy used on site, either directly by coincident load or later through battery discharge.

Although the metric appears simple, its calculation is piecewise:

- When the amount of energy consumed by the home is less than the amount of energy generated by on-site solar, then any energy import from the grid is excess import and lowers the solar self-consumption efficiency.
- When the amount of energy consumed by the home is greater than the amount of solar energy generated, then only the energy imported from the grid that exceeds the energy deficit (the amount of energy needed to be supplemented from the grid to satisfy all home loads) lowers the solar self-consumption efficiency.

This metric emphasizes maximizing on-site solar utilization by using locally generated energy on site. For additional details on how solar self-consumption efficiency is calculated in this study, see two interim reports published by the research team (Giarta et al., 2024; EPRI, 2026).

Results and Analysis

Grid Harmonization and Customer Cost Metrics

Long-Term System Costs

Figure 3 summarizes Long-Term System Cost results by home and scenario. The long-term system cost for each home appears to substantially improve with deployment of DERs. The most substantial incremental improvement comes from adding on-site rooftop solar PV. From comparing Scenario 2 to Scenario 1, the data shows incremental improvements from adding a residential BESS. However, there is considerably variability in the magnitude of improvement. For certain homes (notable, Homes 1, 2, and 3), it appears that the measured incremental benefit of adding a residential BESS to an existing solar PV installation is relatively small. Across the ten homes, PV accounts for roughly 84–100% of the total improvement, while the battery contributes roughly 0% to 15%. This suggests that for certain homes, battery dispatch may are not materially shift solar power utilization towards heavily weighted hours under this metric. These are the times when utility system costs are high, thus conserving energy would be beneficial.

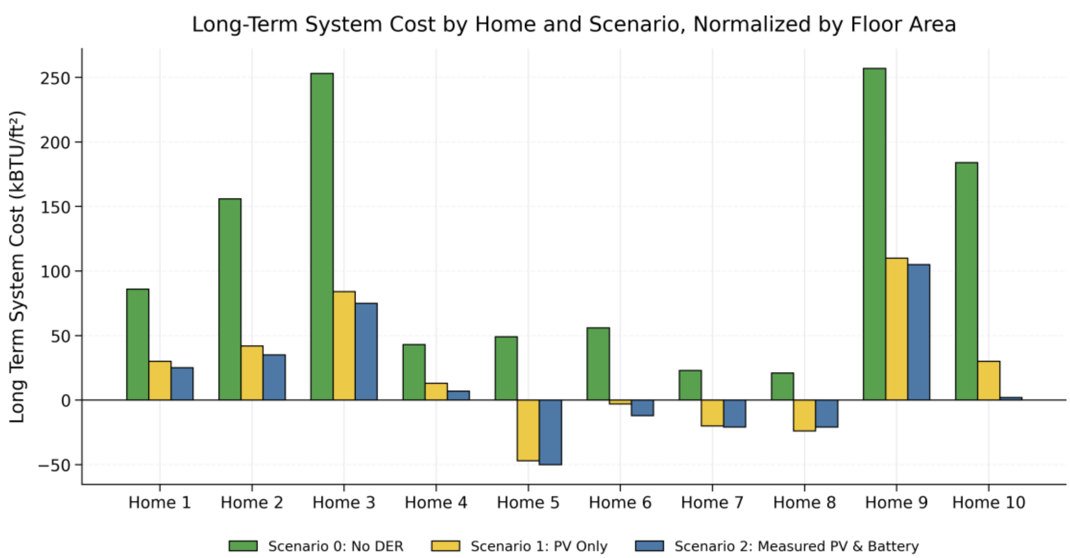

Figure 3: Long-term system costs by home and scenario, normalized by square footage.

Long-Run Greenhouse Gas Emissions

Figure 4 compares electricity-related greenhouse gas emissions across the three analysis scenarios, including the measured PV-plus-BESS case. Across the study sample, emissions are lower in both DER scenarios relative to the no-DER baseline.

Although PV accounts for most of the reduction in long-term system cost, battery storage contributes a larger share of the observed greenhouse gas reductions. Averaged across the analyzed homes, PV accounts for approximately 60% of the emissions reduction relative to the no-DER case, while battery operation accounts for the remaining approximately 40%. In several homes, the battery contribution approaches one-half of the total emissions reduction.

Under the Title 24 interpretation used in this analysis, electricity consumed during the low-emissions "trough" of the duck curve is treated as having negligible marginal greenhouse gas emissions. As a result, exporting behind-the-meter solar generation during high-solar midday periods produces limited additional marginal emissions benefit. This reflects the prevalence of low-carbon utility-scale solar generation during these hours, when additional behind-the-meter solar exports are less likely to displace higher-emitting marginal generation.

On-site BESS can improve the emissions value of behind-the-meter solar by storing generation produced during low-marginal-emissions periods and discharging it later, when grid-supplied electricity is more likely to be associated with higher marginal emissions.

This temporal shifting enables stored solar energy to serve on-site loads during more carbon-intensive hours, subject to the battery's available state of charge, power rating, and control strategy.

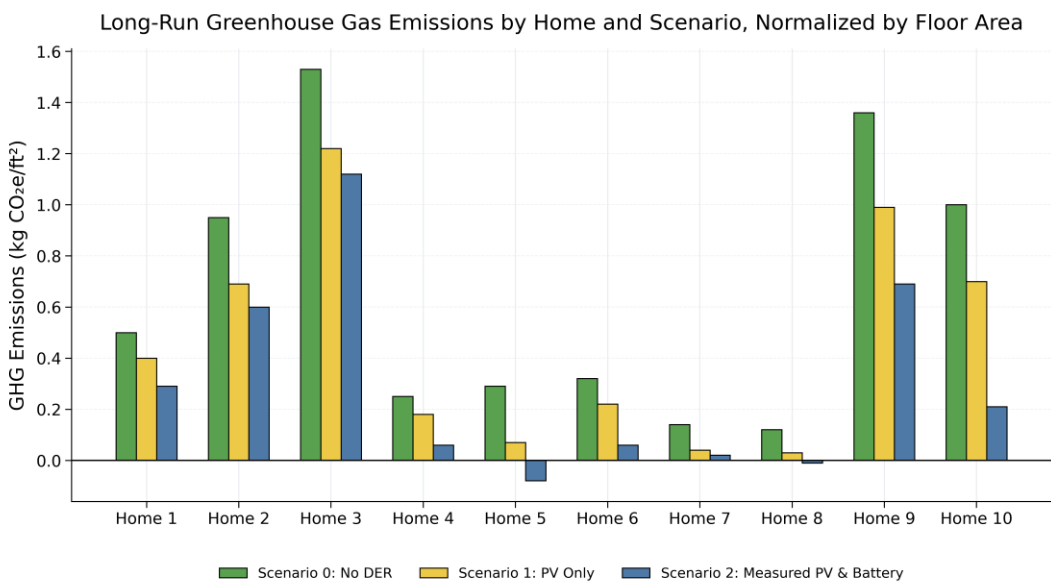

Figure 4: Long-run greenhouse gas emissions by home and scenario, normalized by square footage.

Energy Costs

Energy cost variation patterns across the different scenarios, shown in Figure 5, tend to match those observed for long-term system costs and greenhouse gas emissions. Adding solar leads to a significant reduction in energy costs. For energy costs, PV remains the primary source of savings, typically providing about three-quarters of the total reduction relative to the no-DER case. However, battery storage plays a substantially larger role than it does in long-term system cost reduction, accounting for roughly one-quarter of the total energy-cost benefit on average, with several homes deriving 40–45% of their total savings from battery operation.

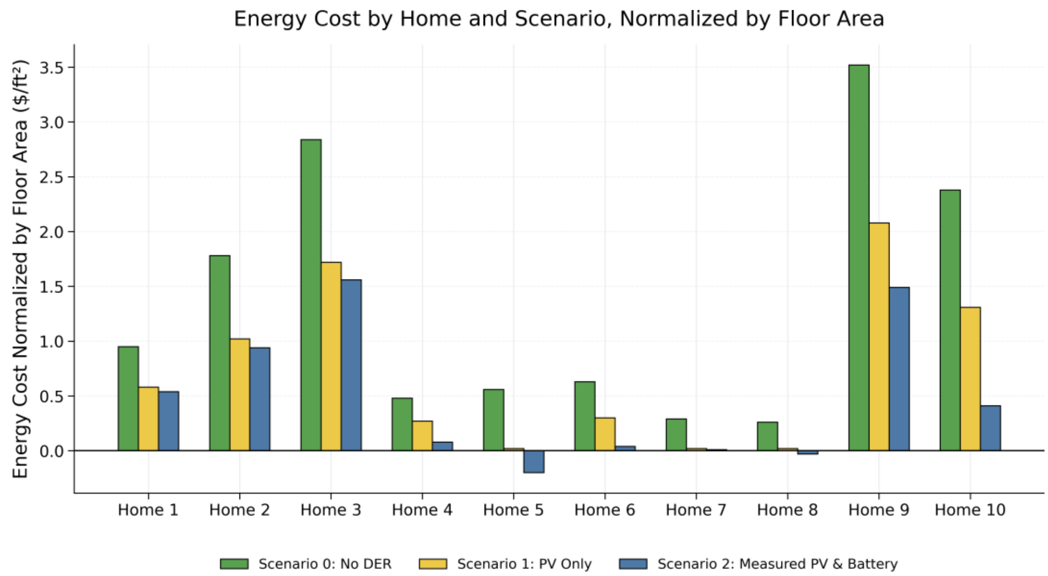

Figure 5: Energy cost by home and scenario, normalized by square footage.

Across all three metrics, PV is the primary driver of performance improvements. The addition of battery storage provides secondary benefits whose magnitude depends on the metric considered. For the long-term system-performance metric, battery storage typically contributes only a small fraction of the total improvement beyond PV. The battery contribution is larger for energy-cost reduction and largest for greenhouse-gas reduction. Across all homes, Home 7 appears to be an outlier that shows near zero benefit from the addition of a battery.

Battery Operation Metrics

State of Charge

Figure 6 shows the average measured state of charge by hour of day for all ten homes. Home 7 very quickly emerges as a clear outlier, maintaining near full charge. This anomaly would explain the minimal battery impacts previously discussed for this home. If the battery is not cycling, then it cannot improve solar self-consumption in a way that meaningfully reduces cost or emissions. The other homes all exhibit the same directional pattern: charging ramps up in conjunction with solar production, and the batteries begin to discharge as solar production subsides. The speed with which stored charge is released is then a function of (a) how aggressively controls are set to discharge during peak hours, and (b) the battery's rated power capacity, which imposes a physical limitation on battery dispatch. A strategy that prioritizes on-peak energy use above all other considerations would therefore potentially see the battery's State of Charge drop as much as its power rating would allow. Figure 6 also implies that for several of the homes in the dataset, depth of discharge was not very pronounced. Similarly, it can be seen that for seven out of the ten homes under study, average state of charge always remains above 50%. This pattern suggests that for certain batteries, there may be "unused" capacity that may be put to use towards different purposes, of which solar self-consumption may only be one. Multiple participants in the study signaled that they wanted to purchase a BESS for resilience purposes, rather than to optimize their energy bill and improve their solar self-consumption. Depth of discharge can be informative in that sense as it can give a sense of "practical capacity" for load flattening and potentially other types of grid services. Documentation of typical cycling behavior across a larger sample size may also provide grid planners with enhanced visibility into the behavior of behind-the-meter distributed energy resources. Notable homes that warrant further discussion include Home 2, which exhibits a relatively elevated depth of discharge but showed modest improvements in the previously discussed performance metrics (LSC, GHG, Utility Cost) and Home 10, which sits at a lower average state of charge than the other home, though that may be a function of its substantially larger BESS.

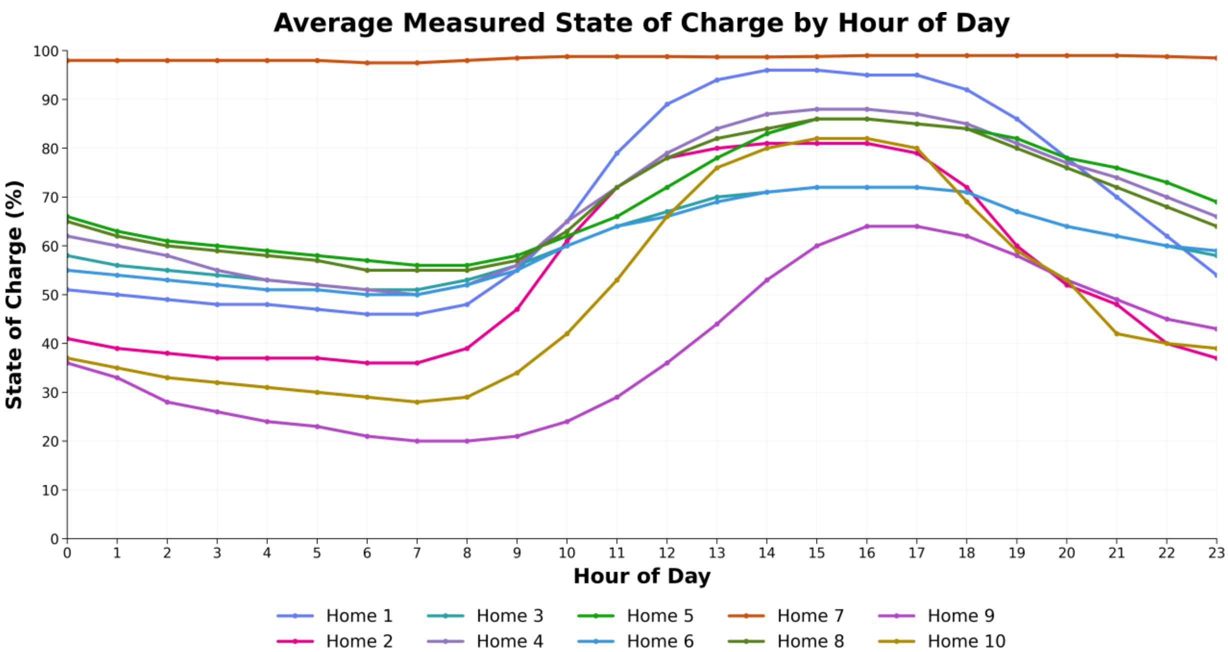

Figure 6 Average Measured State of CHarge by Hour of Day

Solar Self-Consumption Efficiency

All of the homes under study, with the exception of Home 7, show substantial improvement in solar self-consumption efficiency when a BESS is added, as depicted in Figure 7. Improvements ranged from 10 to 50 percentage points, with most homes experiencing gains of 20–35 percentage points. The largest increase was observed in Home 4, where self-consumption efficiency rose from approximately 40% to 90%, while Homes 1, 6, 9, and 10 also demonstrated substantial improvements. Overall, the results indicate that integrating BESS can dramatically enhance the utilization of on-site solar generation, reducing reliance on grid exports. Another observation of note is that the final self-consumption efficiency for Homes 1, 2, and 3 remains relatively low compared to the self-consumption efficiencies achieved for homes 4 through 10. Homes 1,2, and 3 have considerably lower power capacities than the other homes. For example, Homes 1,2, 3, 7, and 8 all have an energy capacity of 10 kWh, but B, C, and D only have 3.68 kW of power capacity. This means that where high power loads are present, even if they only run for a brief period and there is enough energy stored in the battery to serve it, power must still be imported from the grid. The specific case of Home 2 is explored in the next session. Finally, while batteries can drive substantial improvements in solar self-consumption, understanding the underlying load is critical for gauging the potential for a BESS to improve solar self-consumption, and other metrics of interest.

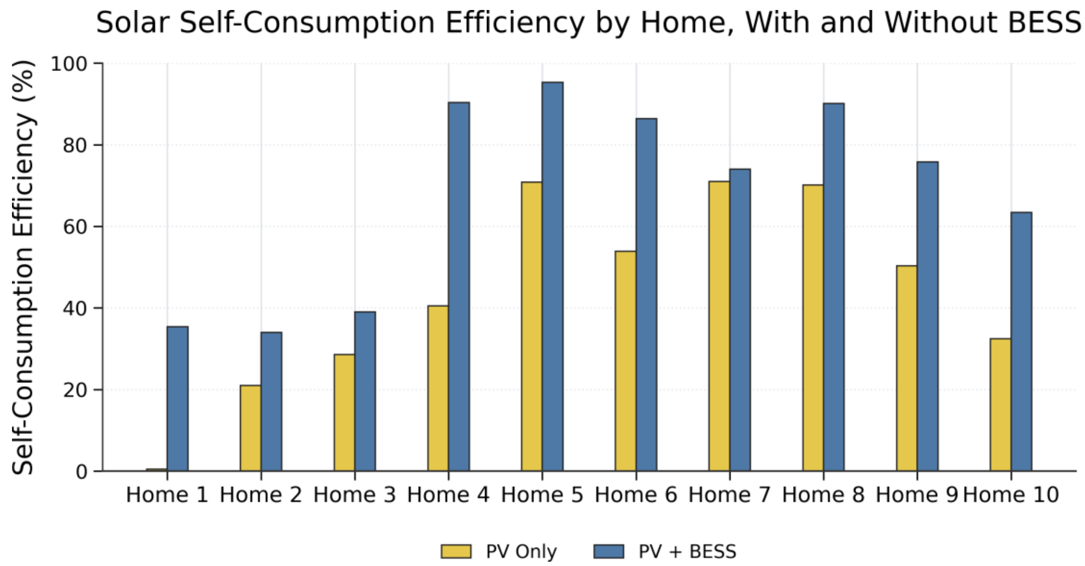

Figure 7 Solar Self-Consumption Efficiency, Scenarios 1 and 2

Selected Load Profiles: Homes 2 and 10

Figure 8 shows the average daily net load profile for Home 2. Home 2 is an interesting home to look at for multiple reasons: (a) It showed considerable improvement in solar self-consumption from the addition of a BESS, yet (b) it showed modest improvements in the three techno-economic performance metrics; and (c) the residents have an electric vehicle that they charge on site. Figure 8 provides some clarity regarding these observations. The site load without any DER's (Scenario 0) appears to be dominated by a 1 a.m. peak, potentially due to nighttime EV charging. This nighttime peak is double the more "code-targeted" evening peak. The addition of a PV system (Scenario 1) results in a typical "duck curve" load profile, with ample exports during the generation window, and minor change outside of it, namely a slight reduction in evening peak. The addition of the BESS (Scenario 2) drastically reduces solar exports, while also reducing evening energy demand. Yet, the BESS does not meaningfully reduce the nighttime peak. The nighttime peak occurs during a time of relatively high marginal emissions (Figure 2), which may explain the lower reductions in GHG that this home exhibits compared to the rest of the sample. Overall, Home 2's net load profile under the three different scenarios underlines the importance of understanding the underlying site load when designing and assessing the prospective benefit of residential BESS systems.

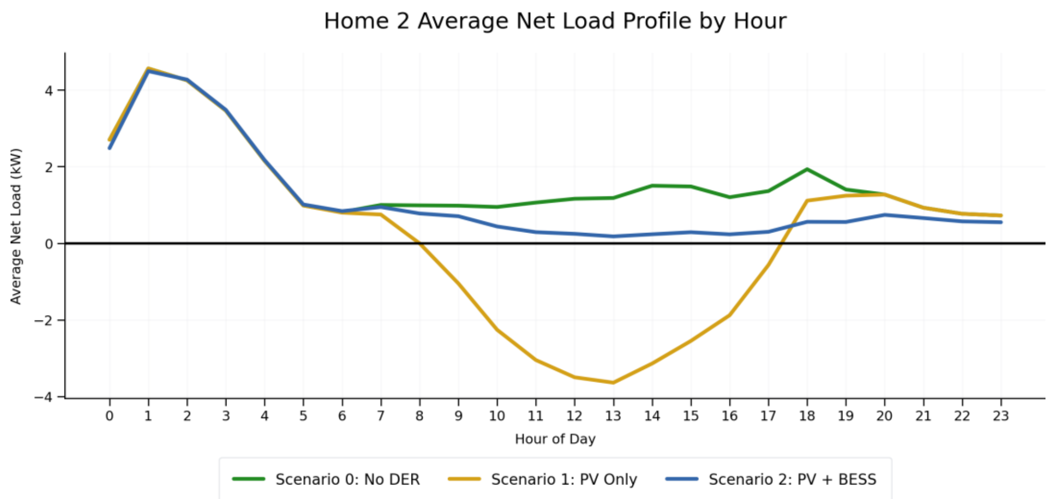

Figure 8 Average Net Load by Scenario, Home 2

Figure 9 shows the average net load profile by scenario for Home 10. Home 10 is interesting to look at because (a) it sees substantial benefits across all three performance metrics,

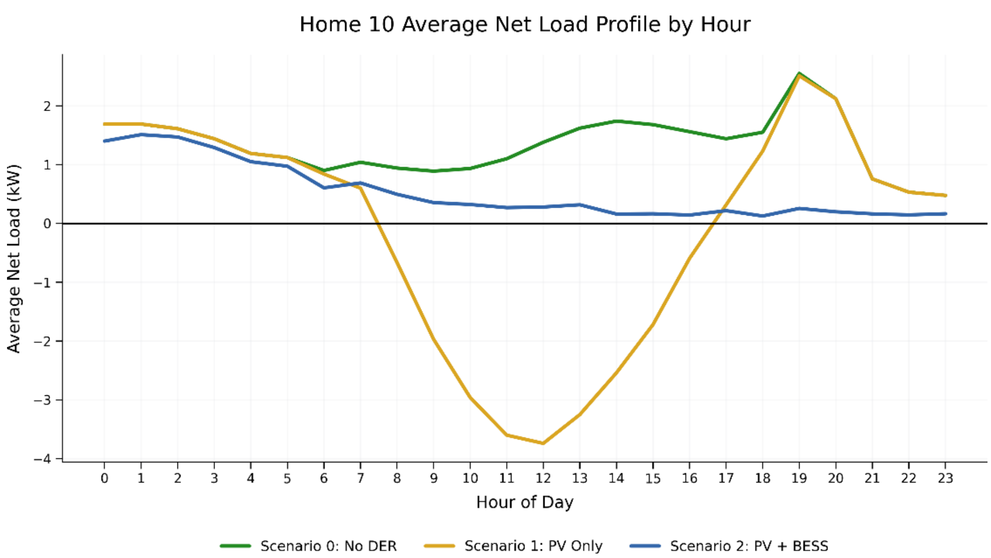

Figure 9 Average Net Load by Scenario, Home 10

(b) in contrast to most other homes, it performs better under LSC than under GHG, and interestingly, (c) it has a very similar load profile to Home 2, albeit without the 1 am, presumed EV-driven peak. The introduction of the different DER's shows similar patterns to those observed for Home 2: the introduction of PV creates a load profile reminiscent of the duck curve, while the addition of a BESS flattens the load profile and eliminates the evening peak. In the absence of a nighttime peak, this pattern results in important savings across all metrics. As mentioned, Home 10 performs better under LSC than under GHG emissions. Heavily weighted LSC hours tend to be concentrated in the 5 to 8 pm window, as shown in Figure 1, while GHG weighting tends to be dictated by the presence of utility-scale solar generation (Figure 2) and thus is more spread from the late evening to the late morning, with a midday trough. Thus, the limited reductions observed in the morning may be limiting GHG reductions, while LSC may be reduced effectively through the elimination of the evening peak.

Conclusion

The data presented in the present paper supports the following key takeaways:

(a) **Adding BESS to a PV system can increase benefits, with caveats:** Overall, adding BESS to a PV system can substantially increase solar self-consumption and reduce LSC, GHG emissions, and customer utility costs. However, the magnitude of these benefits depends on several factors, including site load, battery and PV sizing, control mode, and depth of discharge.

(b) **Stakeholder benefits appear directionally aligned in California, though magnitudes vary:** Customer, grid, and environmental benefits appear to align directionally in California. Similar alignment may occur in other jurisdictions where duck-curve dynamics are present. However, prior research indicates that retail electricity rates are not always well aligned with system costs outside California (Daher et al., 2025). Additional research is therefore needed to assess the broader potential for incorporating customer-sited BESS into energy codes to increase the value of PV.

(c) **More data are needed to improve BESS predictability:** This project illustrates useful data streams and potential benefits of Title 24-regulated BESS deployments, but the small sample size limits how broadly the findings can be applied. The analytical framework and observed patterns, including relatively high SOC floors and site-specific load factors such as EV charging, can inform future research aimed at improving the predictability of code-specified BESS deployments. Greater predictability would support more effective integration of these assets into grid planning.

Beyond codes and standards, the data collected as part of this study can be valuable for future work exploring the real-world performance of residential solar PV and battery energy storage systems (BESS). In particular, the findings can support research on optimizing battery sizing and control strategies to improve cost-effectiveness, evaluating system performance across different building types, utility service territories, and geographic regions, and assessing the impacts of alternative utility rate designs on battery utilization and customer value. The dataset may also inform studies examining the role of residential batteries in virtual power plant (VPP) programs and the incentives needed to support meaningful participation.

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