What is the Residential Value of Resiliency? The Answer May Lie in the Shadows.

Jean Shelton, William Marin, Mike Rufo, Lauren Robinson, Verdant Associates, Berkeley, CA

ABSTRACT

In recent years, California has experienced the deadliest and most destructive wildfires in its history. In response to the tragic wildfires, California utilities dramatically expanded the scope of planned grid outages (Public Purpose Power Shutoff, or PSPS events), which are intended to pre-empt the risk of sparking wildfires. In response to increased reliability and resiliency concerns, nearly 15 thousand California residential customers have installed energy storage systems pared with solar PV. Cost-effectiveness analysis indicates that the payback period for PV systems paired with storage increases by about five years relative to standalone PV systems. Results suggest that pairing energy storage with solar PV is not more cost-effective than installing a standalone PV system. Additional market characterization research indicates that the primary driver for installing energy storage systems is resiliency, not increased bill savings.

We quantified the gap between a customer's purchase price and the incremental bill savings from energy storage and used the difference between the two as the shadow price of resiliency or value of lost load (VLL). Based on our analysis, the average VLL for residential storage customers is $23.31/kWh. This analysis suggests one of two outcomes: current energy storage adopters are very affluent and place a considerable premium to uninterrupted energy supply, or they are early adopters that are adopting energy storage for non-economic reasons such as perceived environmental benefits.

Introduction and Motivation for Study

Over the last decade, California has experienced increased, intense, and record-breaking wildfires in Northern and Southern California. These fires have resulted in a devastating loss of life and billions of dollars in property and infrastructure damage. Electric utility infrastructure has historically been responsible for less than 10% of reported wildfires. However, fires attributed to power lines consist of roughly half of California history's most destructive fires. With the continuing threat of wildfire, utilities may proactively cut power to electrical lines that may fail in certain weather conditions. Such power cuts reduce the risk of their infrastructure to cause or contribute to a wildfire. In California, these power cuts are called Public Safety Power Shutoffs (PSPS). PSPS events, however, can leave communities and essential facilities without power, which brings its own risks and hardships, particularly for vulnerable communities and individuals. From 2013 through the end of 2019, California experienced over 57,000 wildfires (averaging 8,000 per year) and 33 IOU PSPS de-energizations evens.

As customer expectations for potential electricity disruptions increase, utilities, regulators, and other market actors are increasingly seeking to understand a customer's willingness to pay for avoided service interruptions to better assess potential public expenditure on hardening the grid and/or providing funding for other forms of customer resiliency. The value of lost load (VLL) is a useful metric for estimating the amount that customers would be willing to pay to avoid an interruption in their electricity service such as a PSPS event. Researchers have leveraged survey data to estimate the VLL by customer segment and interruption duration. Table 1 summarizes estimated interruption costs from a January 2015 Lawrence Berkeley National Lab (LBNL) study.

Table 1. Estimated Interruption Cost per Event, Average kW, and Unserved kWh (U.S. 2013$) by Duration and Customer Class (Adapted from Lawrence Berkeley National Lab).

Interruption Cost	Interruption Duration					
	Momentary	30 Minutes	1 Hour	4 Hours	8 Hours	16 Hours
Medium and Large C&I (Over 50,000 Annual kWh)						
Cost per Event	$12,952	$15,241	$17,804	$39,458	$84,083	$166,482
Cost per Average kW	$15.9	$18.7	$21.8	$48.4	$103.2	$203.0
Cost per Unserved kWh	$190.7	$37.4	$21.8	$12.1	$12.9	$12.7
Small C&I (Under 50,000 Annual kWh)						
Cost per Event	$412	$520	$647	$1,880	$4,690	$9,055
Cost per Average kW	$187.9	$237.0	$295.0	$857.1	$2,138.1	$4,128.3
Cost per Unserved kWh	$2,254.6	$474.1	$295.0	$214.3	$267.3	$258.0
Residential						
Cost per Event	$3.9	$4.5	$5.1	$9.5	$17.2	$32.4
Cost per Average kW	$2.6	$2.9	$3.3	$6.2	$11.3	$21.2
Cost per Unserved kWh	$30.9	$5.9	$3.3	$1.3	$1.4	$1.3

Medium and large commercial and industrial (C&I) customers have the highest interruption costs, but when normalized by average kW, interruption costs are highest in the small C&I customer class. On both an absolute and normalized basis, residential customers experience the lowest costs as a result of a power interruption. According to the LBNL study, household income has a relatively modest impact on interruption costs. Between a household income of $50,000 and $100,000, the difference in interruption costs is only around ten percent for all durations. Interruption costs increase even further for a household income of $200,000.

Work in this field is emerging, but no study is currently available that captures the VLL for California customers exposed to PSPS events. For example, the Interruption Cost Estimate (ICE) Calculator is focused on short-duration outages. In California, the Microgrids and Resiliency Proceeding highlighted the Power Outage Economic Tool (POET) under development as a “prototype extension of the ICE calculator” by LBNL and Commonwealth Edison in Illinois. However, this tool will have limited applicability to California customers. Similarly, a recent study in New England (Baik et al., 2020) found residential customers’ stated willingness to pay was $2.3 - $3.3/kWh, or $70 - $100/day to avoid a 10-day winter outage. However, customer energy use and substitution options to meet essential needs (e.g., gas-fired heating) in New England are very different from California. For example, California residential customers consume on average 17 kWh/day. The New England study is based on 30 kWh/day consumption. The VLL is also likely higher for medical baseline customers, customers reliant on air conditioning during life-threatening heatwaves, critical sites servicing communities and providing essential infrastructure, and other vulnerable customers. As California policy evolves to promote fuel substitution and whole home electrification, VLL estimates will increase.

Residential Battery Storage Capabilities

Behind the meter battery storage systems have emerged as one potential solution for customers seeking to mitigate the effects of these lengthy outages. In September of 2019 the CPUC issued D. 19-09-027 establishing the Self-Generation Incentive Program equity resiliency budget. To help deal with critical needs resulting from wildfire risks in the state, D. 19-09-027 establishes a new equity resiliency budget set-aside for vulnerable households located in Tier 3 and Tier 2 high fire threat districts, critical services facilities serving those districts, and customers located in those districts that participate in low-income/disadvantaged solar generation programs.

By December 31st of 2019, the SGIP had provided incentives to 8,875 advanced energy storage systems, installed across multiple customer sectors. As part of our annual impact evaluation of the SGIP, we requested and received electric outage information for all energy storage systems throughout 2019, along with the description of the outage cause. Overall, 288 SGIP participants (9%) experienced at least one PSPS outage throughout October of 2019. We observe a wide variety of storage activity for residential customers:

- For those systems paired with solar PV, we observe the storage system satisfying consumption at the home. We observe consumption very similar to what it was prior to and after the PSPS events, and consumption that appears to be tied to only critical loads. Systems are charging from on-site solar generation, so they can sustain their normal energy consumption behavior for long durations during shutdowns.
- For systems not paired with PV, we observe the storage system discharging, but only at low levels of magnitude – likely to maintain service on a few critical loads.

Figure 1 presents the storage behavior for a sample of customers who lost power during a PSPS event called from 10/26 through 10/28. We observe the net load, PV generation and storage charge (-) and discharge (+) throughout the 3 days. Customer load behaves normally throughout the first day until the power is shutoff in the early evening. The storage system then begins to discharge to satisfy consumption at the homes throughout the remainder of the evening and into the morning. PV generation allows the system to charge again and provide that benefit to the customers on the second day and into the third day. The power is restored in the late afternoon of 10/28.

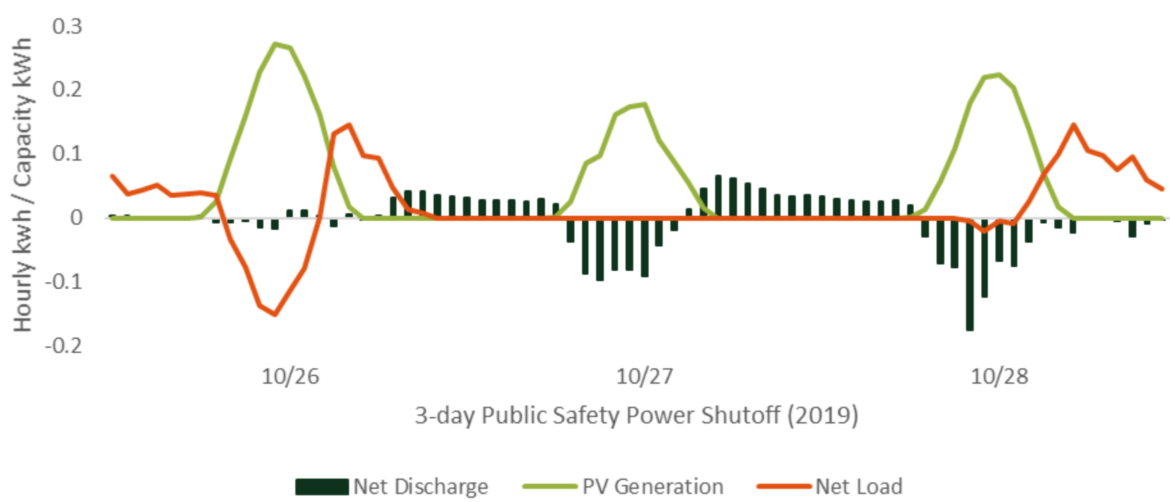

Figure 1. Observed Residential Storage Behavior During PSPS Events (with Solar PV).

Customer Drivers for Purchasing Battery Storage

Host customers were asked the primary reasons they decided to install either standalone energy storage or energy storage paired with solar PV. The question was first asked as an open-ended question to isolate the primary driver they recalled without any prompts, and then followed up with a second close-ended question, that included a pre-defined list of additional potential motivations to capture all the main drivers in their storage decision-making. The top five primary motivations reported by residential customers to the open-ended question were:

- To provide resilient backup power for emergencies or outages (45 percent)
- To save money on their electric bill (31 percent)
- For environmental reasons (19 percent)
- To become less grid dependent (17 percent)
- To respond to TOU price signals (10 percent)

Table 2 presents residential and nonresidential host customers' primary motivations, based on both open and closed-ended responses for installing battery storage in their homes or businesses.

Table 2. Primary Motivations for Installing Battery Storage.

Motivations for Installing Battery Storage	Residential Host Customers	Nonresidential Host Customers
To provide backup/emergency power	90%	11%
To save money on electric bill	77%	89%
To become less grid dependent	68%	21%
To receive the SGIP incentive or federal investment tax credit	61%	53%
To use more of the solar energy we generate	61%	16%
To reduce greenhouse gas emissions	59%	58%
To shift load in response to time-of-use price signals	46%	26%
To help the grid by shifting load from on-peak to off-peak times	46%	42%
To benefit from net energy metering	36%	21%

Customer Economics and Cost-Effectiveness of Battery Storage

The primary motivation for installing storage after resiliency benefits is the ability to save money on the electric bill. Verdant modeled the incremental cost-effectiveness of adding battery to customers who already had solar PV. This incrementality is important as it reflects the cost-effectiveness of the battery relative to a customer that only installs solar PV. Bill savings associated with solar PV systems are large and can confound the overall economics of battery storage.

Figure 2 on the following page presents results of the participant cost test (PCT) for residential energy storage customers under the base case in 2018. We define the residential base case as all residential simulations based on the two residential load shapes (2x), under the two rate types for each electric IOU (6x), with and without the PV charging constraint (2x), for a total of 24 distinct residential simulations. The results are shown including the effect of the SGIP incentive ($0.35/Wh in 2018). Recall that the PCT represents the cost-effectiveness from the perspective of the storage customer. The average 2018 PCT for residential energy storage performing exclusive bill optimization is 0.59. Base case 2018 PCT values ranged from 0.33 to 0.86. From a participant perspective, the only source of bill savings in the base case is TOU arbitrage, suggesting that the bill savings available from TOU arbitrage combined with state and federal incentives (as applicable, including the SGIP incentive) are not enough to overcome the costs of the energy storage system.

PCT results in Figure 2 are color coded by residential rate type – traditional TOU (i.e., default TOU rates available to all residential IOU customers) rates are shown in gray and EV TOU rates are shown in green. In general, the lowest PCT ratios are for customers on traditional TOU rates. Residential customers performing TOU arbitrage on PG&E's E-TOU B rate have the lowest participant cost test ratios. In contrast, EV TOU rates tend to produce the highest PCT ratios – residential customers on SDG&E's EV-TOU 5 rate have the highest PCT ratio. This is to be expected as EV TOU rates tend to have larger TOU price differentials relative to the traditional TOU rates. Note that EV rates are not always available to energy storage customers who do not also own an EV.

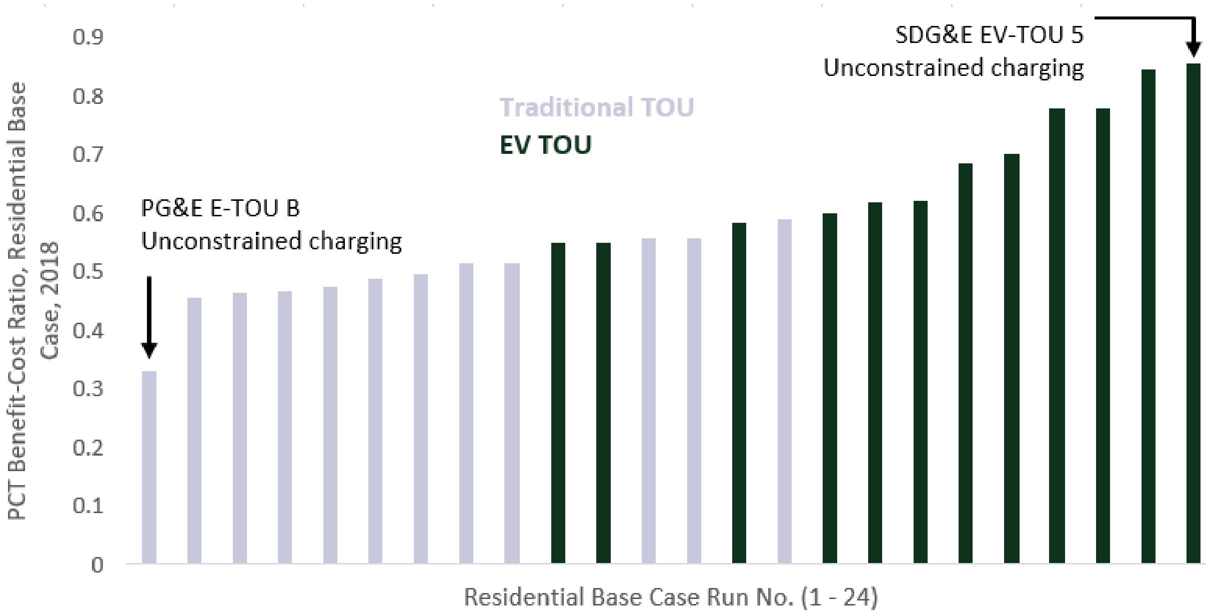

Figure 2. Residential Participant Cost Test Results.

Using Cost-Effectiveness Modeling to Determine Shadow Value of Lost Load

Having established that residential customers primarily adopt battery storage for resiliency benefits and that battery storage systems are not yet cost-effective to the participant, we hypothesize that the cost-effectiveness "gap" is filled by the value the customer assigns to the resiliency benefits of the storage system. When Verdant modeled battery backup, the energy storage system is forced to discharge during three distinct events throughout the year, each lasting four hours. For cost-effectiveness purposes, under this scenario, customers are initially assigned a benefit value of $1.4/kWh for backup. This value represents the inflation adjusted national average VLL for a four-hour outage during 2018. The VLL benefit is reported as a bill savings in the model output as the product of the VLL and the kWh discharged by the energy storage system during the outage. Effectively, the backup value is credited as a benefit in the participant test. On average, the PCT increases slightly from 0.59 to 0.61 when modeling use cases that include backup. During outage events, the participant receives benefits from avoiding the outage equal to the storage energy delivered multiplied by the VLL ($1.40/kWh).

We find that, on average, the assumed VLL of $1.40/kWh based on a national average of residential customers does not increase the PCT to at or above 1.0. However, based on the survey research described earlier in this paper, we know that current SGIP energy storage participants are more affluent than the average California residential customer. It's likely that the VLL for current SGIP participants is higher than the national average. Current SGIP customers likely value uninterrupted energy supply higher than the average California residential customer, perhaps due to a critical medical condition, working from home, or living in a region subject to increased risk of wildfires.

As the VLL increases, the PCT also increases. Market research findings shown earlier in this paper suggest that customers find energy storage cost-effective based on the outage protection benefits that storage provides. Figure 3 illustrates the effect of increasing VLL on the PCT ratio for a representative SCE customer. We find that the PCT increases linearly as a function of the VLL. In this case, the breakeven VLL for a specific SCE customer is $22.50/kWh, considerably higher than the national average of $1.40/kWh used earlier. Based on our modeling, this prototypical SCE customer must value their loss of load at this rate for the energy storage system investment to be cost effective in 2018 given the assumed twelve hours of outage. This breakeven VLL is at least an order of magnitude above the national average, suggesting that the customer has a very high VLL, or the customer is an early adopter and is not making an economic decision when purchasing storage. Figure 4 below expands the breakeven VLL analysis to all base case simulations.

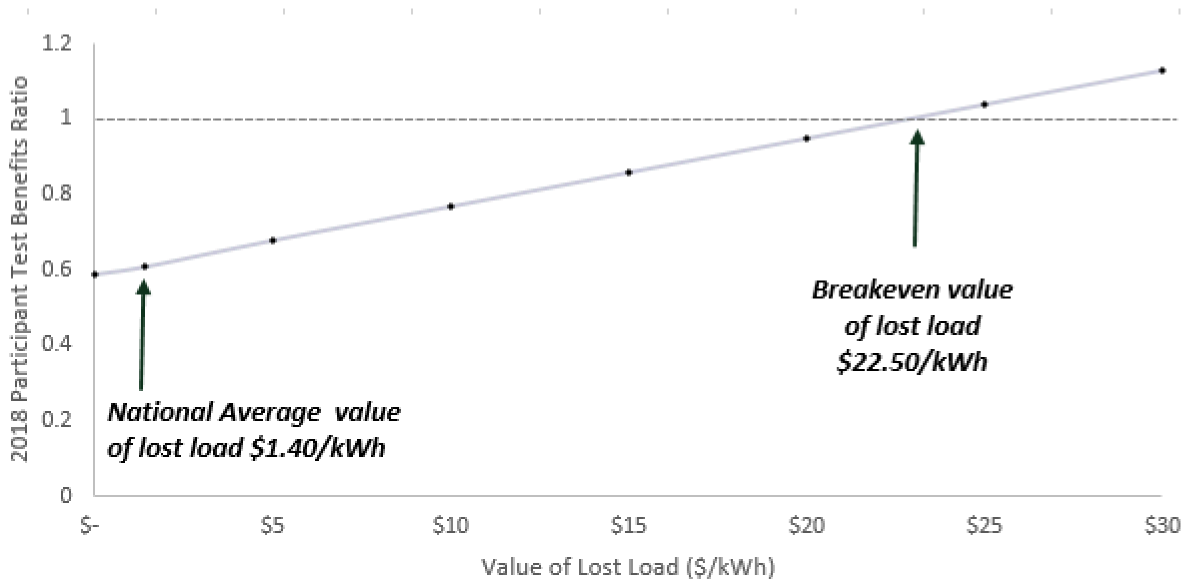

Figure 3. Effect of Value of Lost Load on Participant Cost Test, SCE Residential TOU Customer, Base Case, With Incentive.

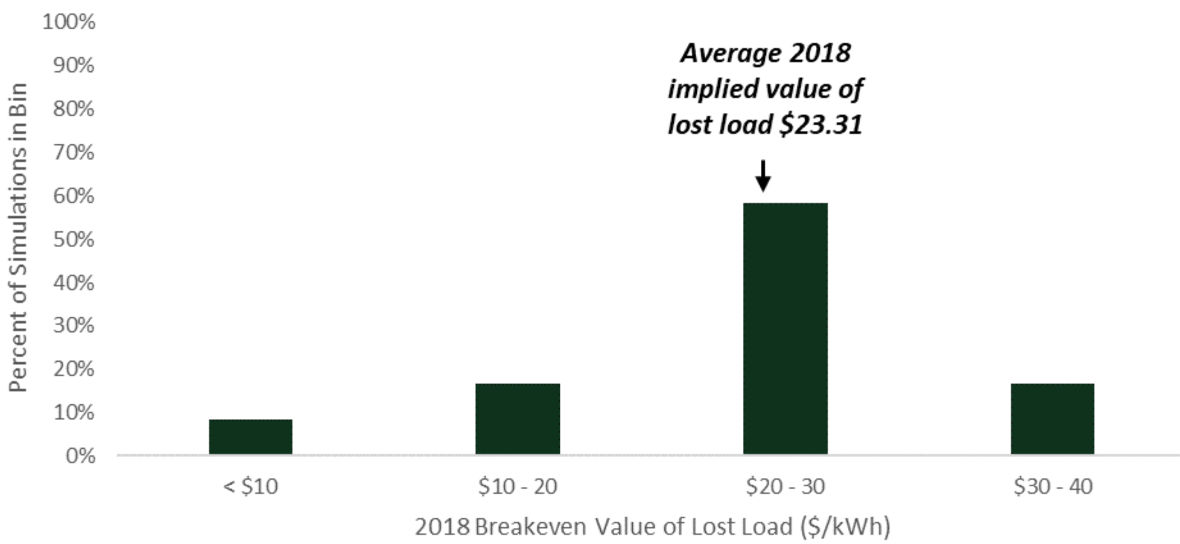

Figure 4. Breakeven Value of Lost Load for Participant Cost Test, with Incentive, all IOUs.

For each case, we solve for the VLL that would achieve a PCT of 1.0. The breakeven VLL will be the highest for cases that are least cost-effective without backup, and lowest for the most cost-effective cases. The average breakeven VLL is $23.31/kWh for base case simulations run in 2018. This suggests that for SGIP participants that installed energy storage in 2018, the breakeven value of lost load is almost 17-times greater than the national average of $1.40/kWh. Breakeven VLL ranges from a minimum of $8.48/kWh to a maximum of $39.29/kWh.

Increasingly, customers are installing battery storage without the support of SGIP incentives. Figure 5 shows the implied values of lost load under a no-incentive scenario. In this case, the average breakeven value of lost load is $32.95/kWh. Under the no-incentive scenario, the VLL ranges from a minimum of $20.91/kWh to a maximum of $52.01/kWh.

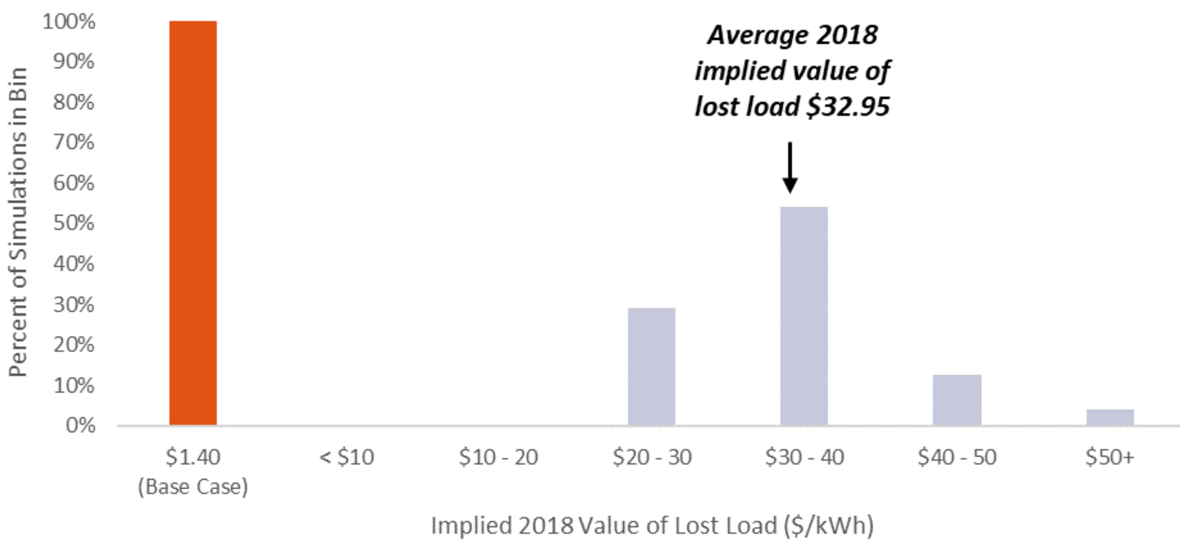

Figure 5. Breakeven Value of Lost Load for Participant Cost Test, no Incentive, all IOUs.

Key Takeaways and Opportunities for Further Research

This paper combines the results of impact evaluation, market assessment, and cost-effectiveness analysis to propose a novel approach to estimate the implied value of lost load (VLL). National efforts suggest an average VLL of $1.40/kWh for residential customers. In California, SGIP impact evaluations have demonstrated that battery storage can reliably provide backup benefits for several days. Market research suggests that the primary reason for battery storage adoption by residential customers are resiliency benefits. Finally, cost-effectiveness analysis suggests that while battery storage systems can provide bill savings through TOU arbitrage, these savings over the life of the system are less than the costs associated to acquire and finance a residential battery storage system.

We modeled the cost-effectiveness of battery storage including resiliency benefits. The energy storage system is forced to discharge during three distinct events throughout the year, each lasting four hours. Using the national average VLL of $1.40/kWh increases the PCT benefit cost ratio from 0.59 to 0.61. This approach is further extrapolated – rather than calculating the PCT benefit cost ratio from a certain VLL, we instead calculate the necessary VLL in order to achieve a “break even” PCT benefit cost ratio. This effectively calculates the implied shadow value of lost load for customers who purchase battery storage systems. Using this approach, we arrive at an average implied VLL of $23.31/kWh. This value represents the implied value of lost load for customers who install battery storage in California and receive an incentive from the Self-Generation Incentive Program. If we expand the analysis to consider customers who adopt energy storage outside of the SGIP, the implied value of lost load increases to $32.95/kWh. The implied VLL ranges from $8.48/kWh with incentives to $52.01/kWh without incentives.

Opportunities for Future Research. This analysis of implied value of lost load is largely based on the revealed preference of California customers who installed battery storage. For many customers it's possible that the value of resiliency is even higher than the amount they paid for the battery storage system. Additional market research could reveal a higher willingness to pay for resiliency.

References

Itron. 2019. "2019 SGIP Energy Storage Market Assessment and Cost-Effectiveness Report". Submitted to Pacific Gas and Electric SGIP Working Group. https://www.cpuc.ca.gov/-/media/cpuc-website/files/legacyfiles/2/6442463457-2019-sgip-energy-storage-market-assesssment-ce-report-2019.pdf

Public Safety Power Shutoff History. https://www.cpuc.ca.gov/psps/

Sullivan, Michael J., Josh Schellenberg, and Marshall Blundell. 2015. "Updated Value of Service Reliability Estimates for Electric Utility Customers in the United States". Ernest Orlando Lawrence Berkeley National Laboratory, LBNL-6941E.

Sullivan, Michael J., Myles T. Collins, Josh Schellenberg, Nexant, Inc. and Peter H. Larsen Lawrence Berkeley National Laboratory. 2018. "Estimating Power System Interruption Costs: A Guidebook for Electric Utilities". Office of Electricity Transmission Permitting and technical Assistance Division U. S. Department of Energy.