

Too Much – Too Little. Using Mixed Resource Demand Response to Address Over and Under Supply of Electricity

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ABSTRACT

Demand Response (DR) programs have traditionally focused on providing load reductions during times of critical peak demand, often dispatched only a few times a year. However, increasing penetration of intermittent renewable resources, such as solar, is adding complexity to the balance between instantaneous power supply and demand. In California, there are increasing cases of oversupply of electricity from rooftop solar, often requiring distribution-level solar curtailment. Further, the peak period has shifted to later in the day which coincides with decreases in solar production and contributes to energy imbalances. As the energy transition unfolds, the frequency of energy imbalances will likely increase, and utilities will need to develop programs to rebalance supply and demand.

To address supply and demand imbalances, PG&E worked with Olivine, an implementer, to develop the Intermittent Renewable Resources Pilot in 2010 and the subsequent 2013 Intermittent Management Pilot Phase 2 where aggregators and large customers could participate in wholesale market integrated demand response. These Pilots continued in 2015, renamed as the Supply Side Pilot (SSP). PG&E also initiated the Excess Supply Pilot (XSP) in 2016 to incentivize customer to increase or shift energy usage to periods of excess supply (though the XSP was not integrated with the wholesale market). In February of 2017, The California Public Utilities Commission (CPUC) issued [Decision \(D.\) 17-12-003](#), approving Pacific Gas and Electric Company's (PG&E) request to continue administering these two DR pilot programs from 2018 through 2020 – the Supply Side II DR Pilot (SSP II) and the Excess Supply DR Pilot (XSP). This paper describes findings from an evaluation of the SSP II and XSP DR programs deployed between 2018 and 2020. The SSP II and XSP pilots featured non-traditional DR resources including battery storage, onsite generation, and electric vehicles and had more than 700 dispatches over the course of the pilots' lives. Additionally, the XSP included both traditional load decrease and load increase events.

This paper presents quantitative and qualitative findings from an evaluation of the SSP II and XSP pilot programs. The topics covered will focus on XSP and SSP II event performance; how different DERs, including battery storage and EVs, participate in DR events; differences in load increase and decrease event participation, and participant and load impact challenges surrounding high frequency event participation.

Introduction

The key objectives of the SSP II and XSP Pilots were multi-faceted and were a direct result of PG&E's commitment to utilize and integrate DR resources into the California Independent System Operator (CAISO) market and provide other services, like distribution reliability. These Pilots are also a response to the increasing complexity of the grid, where net

load shapes are impacted by the deep penetration of disruptive end-use technologies, including solar and electric vehicles, that heighten the need for demand response during non-traditional times and intervals. The SSP II and XSP were developed to test various demand response program structures.

The SSP II was a continuation and expansion of two previous DR pilots which studied the feasibility of demand-side resources participating in the CAISO wholesale market as Proxy Demand Resources (PDR). The SSP II expanded on SSP by enabling DR resources to participate in CAISO market-based services, and in 2020, the SSP II called events designed to test the ability of DR to address simulated local distribution reliability issues.

The XSP largely focused on customers' ability to use distributed resources to increase loads during periods of excess supply in 2018 through 2020. In late 2018 the XSP added load decrease events that continued through the end of 2019. In the XSP, a customer could sign up for load increase or load increase and decrease DR events. Load increase events were not bid into the CAISO market as there was not a market associated with increasing consumption of electricity during periods of excess capacity. Load increase compensation was provided exclusively by PG&E using a monthly capacity payment approach with adjustments based on performance.

The XSP-EVCN component of the Pilots was an EV Pilot combining both load increase and decrease opportunities. The XSP-EVCN was designed to provide business and owners of multi-family dwelling unit or site-hosts with incentives to increase the load on their charging networks during periods of excess supply and reduce the usage of their charging networks during periods of grid constraints. The XSP-EVCN Pilot was initiated in 2019. The number of site-hosts enrolled in the XSP-EVCN expanded substantially in 2020, but the COVID pandemic substantially reduced the need for EV charging during this period.

The evaluation of the SSP II, XSP, and XSP-EVCN used process, impact, baseline, and bill and GHG analyses to provide insights into the Pilot programs' impacts. This paper will focus on the process and impact analyses and their findings, while providing highlights of the additional research results. The process evaluation interviewed pilot participants to better assess customers' understanding of the programs and their willingness to participate in demand response over the range of hours necessary for the load decrease and the novel load increase demand response events. A load-impact analysis, using a method consistent with California's Load Impact Protocols (LIP), was undertaken to determine if customers were able to decrease and/or increase their usage over the range of demand response events.

Participant and Event Information

The pilots included aggregators and customers. The customers are the entity whose load is modified by their participation while aggregators help customers join together, nominate, and bid capacity into the CAISO market (for SSP II) or into the XSP program. For XSP-EVCN, the aggregator is the customer's EV service provider (EVSP), the customer is the EV charging network's site host (EVCN), and the EV driver is the entity whose EV charging behavior the Pilot is attempting to shift. As of 2020, 90 customers were participating in the SSP II, XSP, and XSP-EVCN pilots. These customers were using traditional DR end uses, like reducing air conditioning usage during DR load reduction events, and non-traditional DR end uses including EVs, battery storage, water chillers, and distributed generation curtailment including solar and bio-gas generators.

Unlike a traditional DR program, the number and timing of SSP II and XSP load increase events were not determined by PG&E. The aggregators nominated capacity and helped their customers bid into the CAISO market. Aggregators nominated capacity throughout the year, not just during the traditional DR summer months. The number of load decrease events experienced by a customer depended on their bid being accepted or being at or lower than the market price. Given the dependence of being called to shed load (an event) on the customer's bid amount, the number of events differed by aggregator. Some aggregators and customers experienced only a few events during a month while other customers experienced up to 28 events in a month with the number of days with winning bids exceeding 200 in 2018. The number of XSP load increase and XSP-EVCN events was determined by PG&E.

Customers in the SSP II and XSP Pilot Programs participated in events on more than 400 days between 2018 and 2020. As a result, there are too many events to describe in detail. However, the count of SSP II event days by month and year and the count of XSP event days by month, year and event type are in Table 1 and Table 2 respectively.

Table 1: Count of SSPII Event Days by Year and Month

Month	Event Days in 2018	Event Days in 2019	Event Days in 2020
January	16	-	-
February	17	9	-
March	20	24	2
April	-	17	-
May	20	-	5
June	23	2	7
July	12	3	7
August	31	8	16
September	6	6	11
October	29	11	9
November	22	28	5
December	26	29	-

Table 2: Count of XSP Event Days by Year, Month, and Event Type

Month	Event Days in 2018		Event Days in 2019		Event Days in 2020	
	Event Curtailment Type					
	Load Increase	Load Decrease	Load Increase	Load Decrease	Load Increase	Load Decrease

January	20	-	12	7	9	-
February	12	-	8	19	10	-
March	19	-	8	21	9	-
April	23	-	15	22	8	-
May	11	-	11	27	8	-
June	3	-	13	25	8	-
July	4	-	12	23	8	-
August	9	-	11	25	4	-
September	9	13	9	24	4	-
October	8	28	10	26	4	-
November	9	20	10	18	7	-
December	8	22	10	22	3	-

The XSP-EVCN events were called by PG&E or their implementor, Olivine. Between October 2019 and the end of 2020, there were events called on more than 150 days. Table 3 below lists the number of event days by year and month for the XSP-EVCN.

Table3: Count of XSP-EVCN Event Days by Year and Month

Month	Event Days in 2019	Event Days in 2020
January	-	9
February	-	10
March	-	7
April	-	7
May	-	8
June	-	9
July	-	10
August	-	19
September	-	13
October	10	12
November	15	11
December	9	3

The frequency of events, non-summer events, load increase events, the bidding of resources into the wholesale market, and the use of distributed energy resources for load increase and load decrease events differentiate the SSP II, XSP, and XSP-EVCN from traditional DR programs in California.

Participant Experience

The participant experience was assessed based on interviews with PG&E, Olivine (the program implementor), aggregators, and customers. The interviews collected information on aggregator and customer motivations to participate, their satisfaction, and ability to respond to the many Pilot events.

Table 4 lists the number of unique aggregators and customers that participated in the Pilots. For the purposes of this table, the number of customers and aggregators is consolidated to the number of unique contacts provided by PG&E. If the customer or aggregator participated across multiple sites, buildings, or parking lots (EVCN), the company is consolidated into a single observation for the purpose of the data presented in Table 4. If a company acted as both the aggregator and the customer, the company is recorded as both.

The number of aggregators and customers in the Pilots can be confusing as four unique customers participated in both the SSP II and XSP. Aggregators also participated in both programs during the Pilot implementation period. For interview purposes, one of the customers who had participated in both the SSP II and XSP was interviewed, but the customer chose to discuss their experience in the XSP pilot and they are only listed as an XSP interview. The aggregator chose to discuss both their XSP and SSP II experiences and are listed in both the XSP and SSP in Table 4.

Table 4: Unique Program Aggregators and Customers and Interviews Completed

Program	Number of Aggregators	Number of Customers with Unique Contact Information	Number of Aggregators Interviewed	Number of Customers Interviewed
Supply Side Pilot II (SSP II)	2	6	2	1
Excess Supply Pilot (XSP)	2	8	2	1
Excess Supply Pilot – Electric Vehicle Charging Network	5	23	1	5

Verdant also interviewed Olivine, the program implementor. Olivine described the Pilots as the first DR program in California to enable third parties to participate in the wholesale market. They reported that the level of participant understanding of the Pilot requirements and performance metrics was mixed, Olivine remarked that “one size fits all doesn’t fit most.” Olivine stated that customers with extensive traditional DR experience were better prepared for the Pilots than those with less experience. Olivine also felt that aggregators and customers didn’t fully understand how frequent participation could negatively impact their baseline calculations and capacity payments.

SSP II customers and aggregators were asked why they participated and their satisfaction with the pilots:

- Aggregators and customers reported that they participated to take advantage of a potential revenue stream and to help the grid.

- The aggregators and customers stated that they understood the nomination and bid process. Though there was a desire for additional information, education, and training and potentially an interactive dashboard illustrating baselines, nominated capacity, and achieved capacity.
- One of the aggregators felt that the Pilot had excessive administrative burden. The aggregator chose to discontinue participation in 2020.
- Neither customer felt that there were too many events. The aggregator with frequent event participation preferred frequent events. The high frequency of events, however, negatively impacted their baselines and program compensation.

XSP customers and aggregators were also asked why they participated and their satisfaction with the pilot:

- Aggregators and customers again reported that they participated to take advantage of a potential revenue stream, to help the grid, and because they were interested in participating in a load increase DR program.
- The aggregators and customers reported little training. The use of solar and bio-gas generation curtailment to increase customer load implied that these customers often increased rather than shifted load. Changing the timing of water chilling and using battery storage enabled customers to shift the timing of their load. Increasing load, rather than shifting load, can have implications for customer's demand charges and utility bills.
- One aggregator felt that the Pilot had excessive administrative burden while the second aggregator was satisfied with the Pilot.
- One of the aggregators felt that the XSP was best suited to large customers with loads that were easily shifted.

The XSP-EVCN customers were businesses and multi-unit dwelling site-hosts who had installed EVCNs with PG&E's support. The XSP-EVCN was one of the two load management plans available to EVCN. Customers who did not enroll in the XSP-EVCN were required to charge individuals who used their chargers based on PG&E's TOU rates. The XSP-EVCN was a way for site-hosts to opt-out of charging their EV users based on TG&E's TOU rates. The load increase events for the XSP-EVCN could occur from 8AM to 1PM and the load decrease event could occur from 4PM to 9PM. For the participant experience, one EV service provider (EVSP, the aggregator) and five EVCN (the customers) were interviewed. During the 2019 no customers were able to increase or decrease load such that they achieved an incentive. Requirements to receive incentives were substantially lowered in 2020 but only \$250 in incentives were paid out across all participant customers.

XSP-EVCN aggregators (EVSP) and customers (site-hosts) were also asked why they participated and their satisfaction with the pilot:

- The EVSP stated that their participation in XSP was required as part of their participation in the EVCN program. Participation in XSP was not a goal but managing more EVCNs was a goal of their business model.
- The interviewed EVSP felt that the Pilot was not well designed to change the charging behavior of EV owners. The XSP-EVCN was not designed such that EV

owners always knew of events or received a financial benefit from changing their behavior.

- The XSP-EVCN customers joined the pilot to lead by example or they did not want to be mandated to charge their employees PG&E's TOU rates.
- Only one of the five site-hosts interviewed stated that they notified the EV owners if an event was occurring. None of the other site-hosts believed that they, or the EVSP, did anything to increase charging during load increase events. The EVSPs slowed charging during load decrease events.

Load Impacts

Regression models consistent with the California Load Impact Protocols (LIP) were used to determine event impacts. The analysis used a set of aggregated models for aggregators with more than one customer and customer-specific models for aggregators with only one customer.

The Verdant team developed a set of candidate models consisting of parameters designed to estimate event impacts as well as establish the counterfactual baseline on event days. While each model specification varied, a general model specification form is presented below in Equation 1. The general model specification below includes the various types of parameters that were included in the analysis but does not include the numerous interaction terms generated from these parameters.

Equation 1: General Model Specification

$$\begin{aligned} Net_kWh_{d,h} = & \alpha + \beta_{1e,h}EventDay_eHour_h + \beta_2TempVar_h + \beta_3SolarIrr_h + \beta_{4,h}Hour_h \\ & + \beta_{5,m}Month_m + \beta_{6,d}Wday_d + \beta_7Monday_d + \beta_8Friday_d \\ & + \beta_9MorningLoad_d + \varepsilon \end{aligned}$$

Table 5: General Form Model Specification Parameters

Parameter	Description
$Net_kWh_{d,h}$	The Net Load on day d in hour h
α	The intercept of the regression model
$EventDay_eHour_h$	An interaction between the event day dummy and hour. Its coefficient, $\beta_{1e,h}$, yields the impact of an event on event day e during hour h
$TempVar_h$	A temperature variable in hour h. Temperature variables used for modeling included CDH65, CDD60, HDH55 and HDD55
$SolarIrr_h$	A variable representing the global horizontal solar irradiance in hour h
$Hour_h$	A dummy variable for each hour h
$Month_m$	A dummy variable for each month m
$Wday_d$	A dummy variable indicating the day of the week d
$Monday_d$	A dummy variable indicating whether day d is a Monday
$Friday_d$	A dummy variable indicating whether day d is a Friday
$MorningLoad_d$	A variable indicating the average morning load on day d
ε	The regression error term

Across the model specifications, there are three general model types used to develop baselines. These include:

- **Weather Sensitive Models** which include weather and calendar effects.
- **Solar Irradiance Sensitive Models** which include solar irradiance and calendar effects. These types of models were only used for XSP and XSP-EVCN modeling and if the aggregation contained a stream of negative net load.
- **Non-Weather and Non-Solar Irradiance Models** which include calendar effects and, in most cases, average morning load as a load adjustment variable.

XSP and SSP II events occurred on weekdays, weekends, and holidays. Weekday events were modeled separately from weekend and holiday events due to differences in energy usage on these day types.

Model Selection

After developing the set of candidate models, each model was used to estimate net load on the set of out of sample proxy event days for each reporting group. The set of proxy days used included five weekday proxy days and three weekend days for each aggregator and quarter. Weekday proxy days were used to model performance on weekdays, whereas weekend proxy days were used to test model performance on weekend and holidays. The proxy days included a set of days based on maximum temperatures, maximum solar irradiance, and randomly selected days. Model performance was assessed on all three of these proxy day selection types. Ultimately, proxy days selected based on the maximum temperatures were used for selecting the final SSP II models and proxy days based on maximum solar irradiance were used for XSP and XSP-EVCN model selection. Figure 1 presents example load shapes from each model tested on out of sample proxy event days for quarter two and three of 2019.

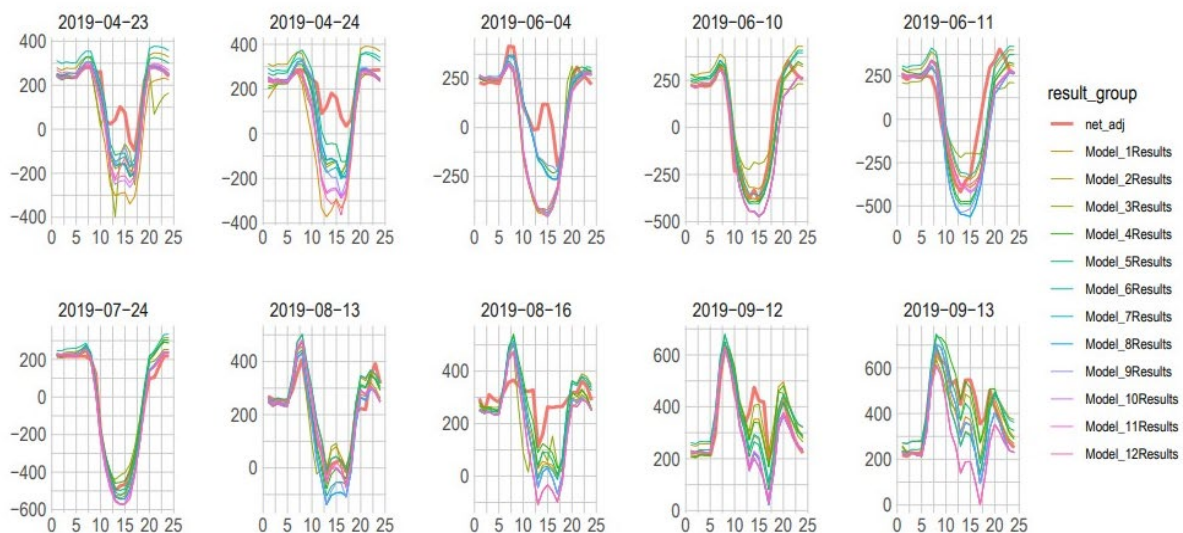


Figure 1: Example of Models Tested on Proxy Event Days

The performance of each model was assessed using a variety of performance metrics. The “best” model for each event day type (weekday and weekend/holiday) for an aggregator in a specific quarter was selected based on the minimum average CV(RMSE) during likely event hours on respective proxy event days. In some cases, CV(RMSE) was not an eligible metric due to presence of zero load in the observed variable. In those cases, $RMSE \left(\sqrt{\frac{1}{n} \sum_{i=1}^n (y_i - \hat{y}_i)^2} \right)$ was used to select the best model. As a result, an aggregator could have up to eight different model specifications if they had events in all four quarters and on weekends and weekdays/holidays in a given year. Table 6 presents the average performance metrics of models selected for final estimating impacts.

The SSP II models performed with a high degree of accuracy across all years and generally were more accurate than models specified for the XSP and XSP-EVCN programs. SSP II participants tended to have higher levels of customer aggregation for modeling counterfactual load shapes. This helps smooth out any idiosyncrasies in individual customer event loads and to produce a more consistent daily load shape, which in turn makes it easier to estimate predicted loads. Especially when compared with XSP and XSP-EVCN models, which relied on customer specific regression models or an aggregation of a few service points.

On average, the accuracy of XSP models decreased between 2018 and 2019 model estimation. This is largely the result of a customer with a high degree of season load variability and inconsistent use of an onsite biogas generator. Additionally, XSP-EVCN model accuracy decreased from 2019 into 2020, which is due to decreased usage of EV chargers following the implementation of COVID-19 restrictions.

Table 6: Average Performance Metrics by Program and Year on Proxy Days used for Selection

Program	Year	Aggregator	Accuracy	Precision	
			NMBE	NMAE	CV(RMSE)
SSP	2018	All	-0.0047	0.0142	0.0159
SSP	2019	All	-0.0032	0.0162	0.0179
SSP	2020	All	-0.0029	0.0104	0.0118
XSP	2018	All	-0.0229	-0.0048	-0.0089
XSP	2019	All	-0.6344	0.4164	0.4167
XSP	2020	All	0.6549	-0.2574	-0.2215
XSP-EVCN	2019	All	0.0501	0.1225	0.1568
XSP-EVCN	2020	All	0.4823	0.5539	0.6240

The selected models were used to estimate “fake” event impacts on the proxy event days during likely event hours. If models were accurately estimating baselines and impacts, then the parameter values associated with event impacts should not be statistically different from zero. If the chosen model was consistently producing statistically significant impacts on proxy days, then the model was re-examined, and another specification was chosen. The estimated baseline loads

were also visually examined for large discrepancies in actual and predicted loads profiles and to ensure that estimated load profiles looked reasonable compared to the actual load on a given day. If visual inspections identified odd load increases or decreases, then the model's specifications were updated to account for these effects.

Impact and Baseline Estimation

Once the final set of models were selected, each event day's hourly impacts were modeled using a dataset including the event day of interest and the non-event weekdays or weekend/holidays. Depending on the event day type, days chosen were within 100 days before the event and 45 days after the event. These bounds were selected to ensure enough non-event days close to the event day were included in the models. In some cases, these bounds were expanded when there were not enough non-event days available for modeling impacts. The models generate event day impacts for each hour of an event day since impacts from an event can exist before and after the event window. For example, a customer may shift battery charge and discharge behavior or precool a facility prior to the event. Modeled impacts were then added back into the observed load to generate the 24-hour counterfactual loads.

Challenges occurred when developing LIP based impacts. These challenges generally focused on two issues; the frequency of event participation for specific customers and the persistence of intervals with zero loads. Regression-based impacts rely on modeling usage on a set of non-event days that represent typical load profiles given various calendar and weather specific effects and then testing various models on event like non-event days. However, some SSP II and XSP load decrease customers bid and won events on the majority or all days for a given quarter and year. For example, a customer won their bid for events on 120 weekdays out of 128 from June through December of 2019. This essentially makes event days the baseline. In these situations, event impacts are modeled using a model specification that performed the "best" on other quarter's proxy event day, rather than a seasonal specific model. We are not aware of a methodology for estimating event baselines when there is this high a volume of event days. A customer bidding into, and winning, events on 120 out of 128 days may more appropriately need/want to participate in a permanent load shifting program than a demand response program.

Regression modeling relies on variation in the dependent variable to estimate relationships with the independent variables. The presence of an excess amount of zero load intervals dilutes the relationship between the calendar and weather effects. As a result, the effects of these independent variables may not be accurately represented. This type of challenge occurred frequently with XSP-EVCN impacts after March of 2020.

Figure 2 below illustrates the average load impact for the SSP II program in 2018. Similar illustrations were developed for 2019 and 2020. The average LIP impacts for SSP II generally look similar to other DR impact illustrations. The technologies used for the 2018 SSP II include HVAC and battery storage. The observed load during the event day is less than the estimated reference load and the estimated impacts are positive or an increase in energy available for the grid.

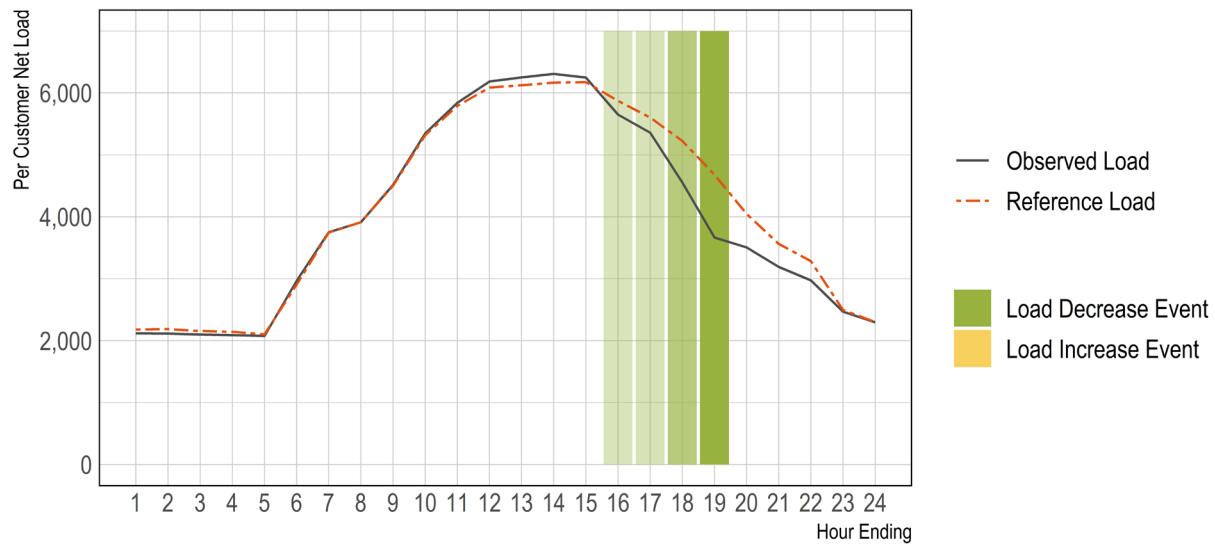


Figure 2: Example of Average LIP Event Table for SSP II

Figure 3 below illustrates the average event impacts from the XSP for 2018. The LIP includes both load increase events from 5-7 AM and 9AM to 4 PM and load decrease events from 4-9 PM. The early morning load increase events and the evening load decrease events are not statistically different from zero while the load increase in the morning and afternoon hours are statistically significant. The resources included in the mid-morning and afternoon hours include solar curtailment, biogas generation curtailment, and water chiller shifting load from evening to early morning. Battery storage was used for the early morning load increase and the evening load decrease events.

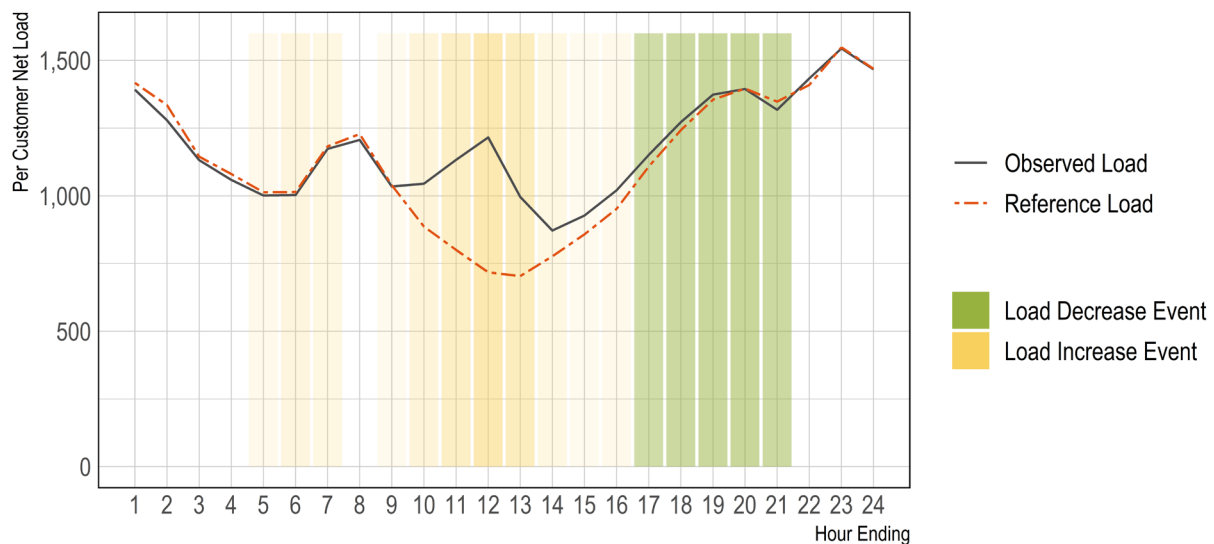


Figure 3: Example of Average LIP Event Table for XSP

Figures 4 and 5 below illustrates the average event impacts from the XSP-EVCN for 2019 and 2020, respectively. The models include both load increase events from 9AM to 1PM and load decrease events from 5-7 PM in 2019 and 5-9PM in 2020. The load increase events in 2019 are associated with a statistically significant increase in load while the early evening load decrease events in 2019 are not statistically significant. The 2020 events illustrate the substantially lower average charging loads in 2020 on business and multi-unit dwelling EVCN and the “events” are generally associated with impacts of incorrect signs.

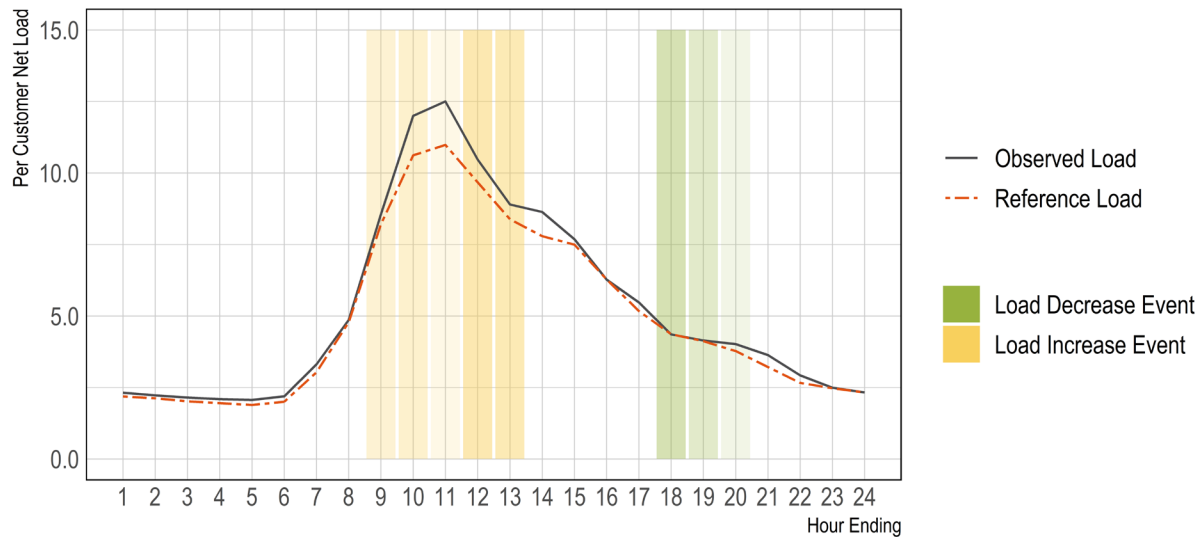


Figure 4: Example of Average LIP Event Table for XSP-EVCN in 2019

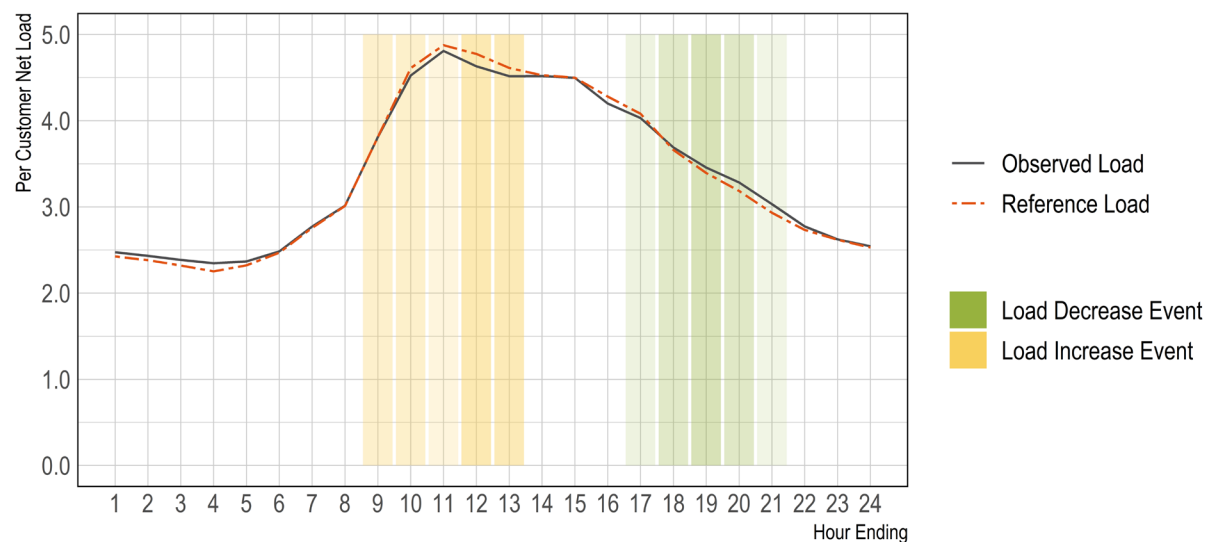


Figure 5: Example of Average LIP Event Table for XSP-EVCN in 2020

The XSP-EVCN impacts from 2019 illustrate that EVCNs may be potential sources of increased load to help consume excess morning and middle of the day capacity associated with the high penetration of solar PV. But the Pilot results found no reduction in charging in the early evening during event days. The site-hosts remarked that on most days, nearly all cars have disconnected and/or left for home by the 5 PM start of load reduction events. While the XSP-EVCN programs was also available to multi-unit dwellings, the largest share of participants were business charging locations.

Findings and Conclusions

The main finding in the evaluation of qualitative and quantitative findings from the XSP and SSP II evaluations include:

- Aggregators and customers were able to participate in wholesale markets for load decrease events
- Customers were capable of responding to frequent events during traditional and non-traditional DR seasons
- Frequent events can negatively impact baselines, regression models, and program compensation
- The participates were able to use DERs to increase load during load increase events but curtailment of distributed generation at the customer level may have undesirable impacts on customer utility bills. Load shifting measures may provide preferred economic outcomes
- The XSP-EVCN illustrated the hope program planners place in the ability to use EVCN to help increase load during periods of excess supply and decrease loads during periods of constraint while also showing that additional refinement is needed to realize this hope.

These Pilot programs succeeded at showing customer ability to participate in the wholesale markets, respond to frequent events, and demonstrated both load increases and load decreases. Participation in an excessive number of events, however, make baseline and impact calculations difficult and may signify the need to enroll some resource types in permanent load shifting programs instead of event-based DR. Several large customers were enrolled in the XSP load-increase events, but more study is needed to identify customers with resources and loads that can shift during events, provide load increase during periods of excess capacity, and provide the customer with positive economic returns.

As the number of EVs grows dramatically in California, the need to manage the demands they place on the grid and the desire to use them to help manage the grid also grows. The XSP-EVCN Pilot attempted to encourage EVCN site-hosts and their EV drivers to increase load during periods of excess capacity and decrease load during periods of constraint. Additional thought, however, needs to go into the design of managed charging programs to provide drivers with the information and incentives needed to help modify charging behavior.