Olivine, Inc.

Vehicle-Renewable Integration Report for BMW Total Charge Management

Optimizing Electric Vehicle Charging using Renewable Energy Excess Supply

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ABSTRACT

The vehicle-renewable integration report describes the benefits of using renewable energy excess supply signals to shift electric vehicle charging patterns. Use cases included vehicle charging optimization, at home and away from home, and load increase demand response events with day-ahead dispatch. Several new functions of Olivine's vehicle-grid-integration optimization engine were explored through these use cases, which were executed from October 15, 2018 to November 10, 2018, using Pacific Gas and Electric Company's excess supply data feed.

The results of comparing optimized and baseline vehicle charging patterns show that charging based on the excess supply signal has the potential to provide benefits to the grid, such as better balance of demand and renewable energy supply. The benefits were highest for at-home charging for those participants not on time-of-use rates. Financial benefits could be achieved from shifting vehicle charging to times of day with negative wholesale market pricing. New incentive mechanisms or improved pricing signals for electric vehicle drivers may help realize the benefits associated with shifting electric vehicle load to grid-friendly periods, including by better aligning electric vehicle charging load with excess generation from renewables.

Keywords: renewable energy excess supply, renewable-vehicle integration, vehicle-grid integration, VGI, optimization, PG&E excess supply pilot, XSP, real-time pricing, time-of-use rates, TOU

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CHAPTER 1: Vehicle-Renewable Integration Overview

The Vehicle-Renewable Integration Report is a deliverable from Olivine, Inc. reporting on results of optimizing electric vehicle (EV) charging, at home and away from home, using a forecast of renewable energy excess supply. Olivine developed this report on behalf of BMW of North America as a deliverable under the California Energy Commission's EPIC grant for *Total Charge Management (TCM): Advanced Charge Management for Renewable Integration* (EPC-15-084).

The implementation of the vehicle-renewable integration use cases builds upon previous work by the research team that enabled and assessed optimization of vehicle charging patterns based on day-ahead locational marginal price (LMP) and renewable (RE) supply mixture. The vehicle charging patterns are optimized using Olivine's vehicle-grid integration (VGI) optimization engine, which is part of the Olivine DER platform. The results of the earlier use cases are described in the *Charging Behavior Optimization Report*.

For the current use cases, the research team incorporated a day-ahead forecast from Pacific Gas and Electric Company (PG&E) that provides an hourly forecast of the probability of excess renewable generation. This data is also used for PG&E's Excess Supply-Side Pilot (XSP). This data feed is sometimes referred to as renewable energy *overgeneration*. For the purposes of this report, it is referred to as *excess supply*.

The vehicle-renewable integration use cases demonstrate the use of renewable energy excess supply signals to shift EV charging patterns, on a daily basis through charge schedule optimization, and on an event basis through day-ahead dispatches. New functionality in Olivine's VGI optimization engine was explored during this use case period, which was executed from October 15, 2018 to November 10, 2018.

Results from implementation of these use cases were analyzed and are presented in this report. The remainder of this report is organized as follows:

- Chapter 2 describes PG&E's excess supply data
- Chapter 3 describes vehicle charging optimization results, for both at home and away from home charging
- Chapter 4 describes load increase event results
- Chapter 5 summarizes lessons learned from the vehicle-renewable integration use cases

CHAPTER 2: Renewable Excess Supply Data Source

The implementation of the vehicle-renewable integration use cases was enabled by a data feed from PG&E that is also used for the excess supply pilot (XSP) program. PG&E provides a day-ahead hourly forecast of the probability of renewable energy excess supply. By using this data source for optimizing vehicle charging, the research team anticipated being able to shift vehicle charging from periods with low probabilities of excess supply into periods with high probability of excess supply. The benefit to the grid would be to shift vehicle charging into times when excess renewable energy – primarily solar and wind generation – can be absorbed and stored in the vehicles.

PG&E's excess supply probability forecast is based on day-ahead forecasts of both renewable generation and "net load" – defined as the portion of customer load not served by renewables. When renewable generation exceeds customer load, the result is an excess supply of renewable generation on the grid. When this happens, system reliability may be challenged by a supply-demand imbalance, and this can lead to negative pricing in real-time wholesale energy markets. Though an analysis of the predictive power of the excess supply forecast is outside of the scope of this report, analysis by PG&E suggests that the forecast provides a good indication of when excess supply events occur, especially in those months when excess supply is most likely.

Figure 1 shows PG&E's 2018 hourly average excess supply forecast by month. For comparison, Figure 2 shows the 2018 hourly average of net load. Net load is positive when customer load exceeds renewable generation and negative when renewable generation exceeds customer load. As shown in Figure 1, September, April, and May had the highest average excess supply probability forecast in 2018. These are the only months in which the average probability exceeded 50 percent at some hours during the day. Higher probabilities of excess supply in these periods are consistent with lower average net load shown in Figure 2, and reflect the combined effect of longer days (resulting in higher solar generation, on average) and/or lower temperatures (resulting in lower weather-sensitive load, from air conditioning, for example).

Figure 1: Average Hourly Excess Supply Probability Distributions by Month (2018)

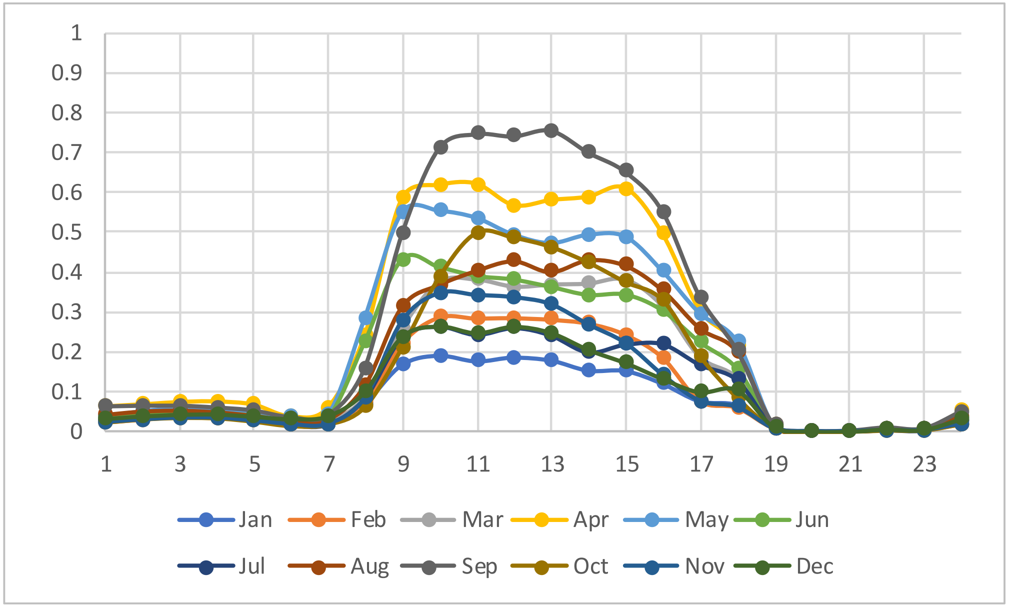


Figure 2: Average Hourly Net Load as Percent of Total By Month (2018)

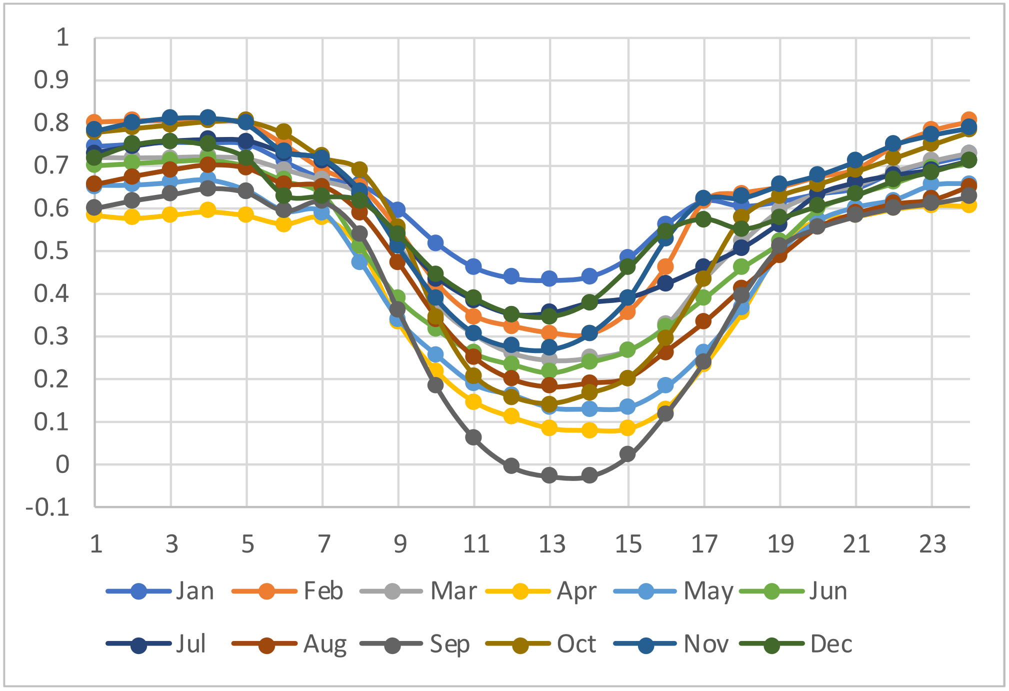
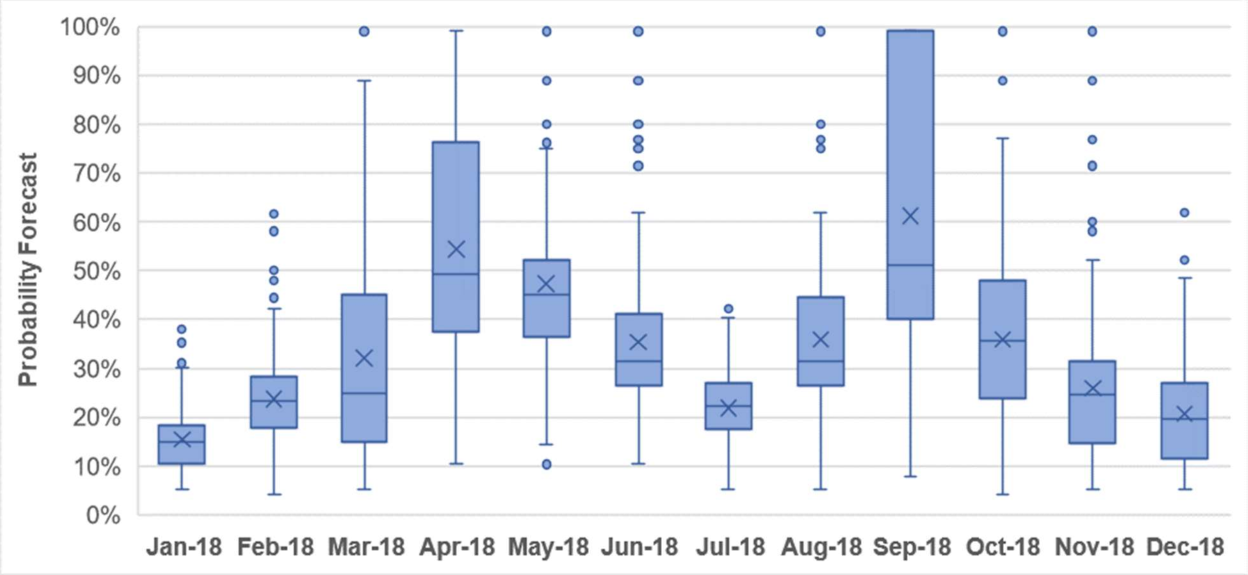


Figure 3 shows the distribution of the excess supply probabilities for hours from 8 AM to 4 PM by month in 2018. The hours from 8 AM to 4 PM are selected because PG&E's XSP pilot focuses on these hours for program dispatches. This data representation in Figure 3, known as a box and whisker chart, is useful for making direct comparisons across categories when presenting large amounts of data. The data are presented in quartiles: the bottom of the box shows the first quartile (i.e., 25th percentile), the middle line shows the second quartile (i.e., 50th percentile or median), and the top of the box shows the third quartile (i.e., 75th percentile). The "X" inside the box shows the mean value, and the lines extending above and below the box (the *whiskers*) show the top and bottom quartiles, respectively, excluding outliers. Data points are classified as outliers if they are greater than 1.5 times the interquartile range. Outliers show up as dots above or below the whiskers.

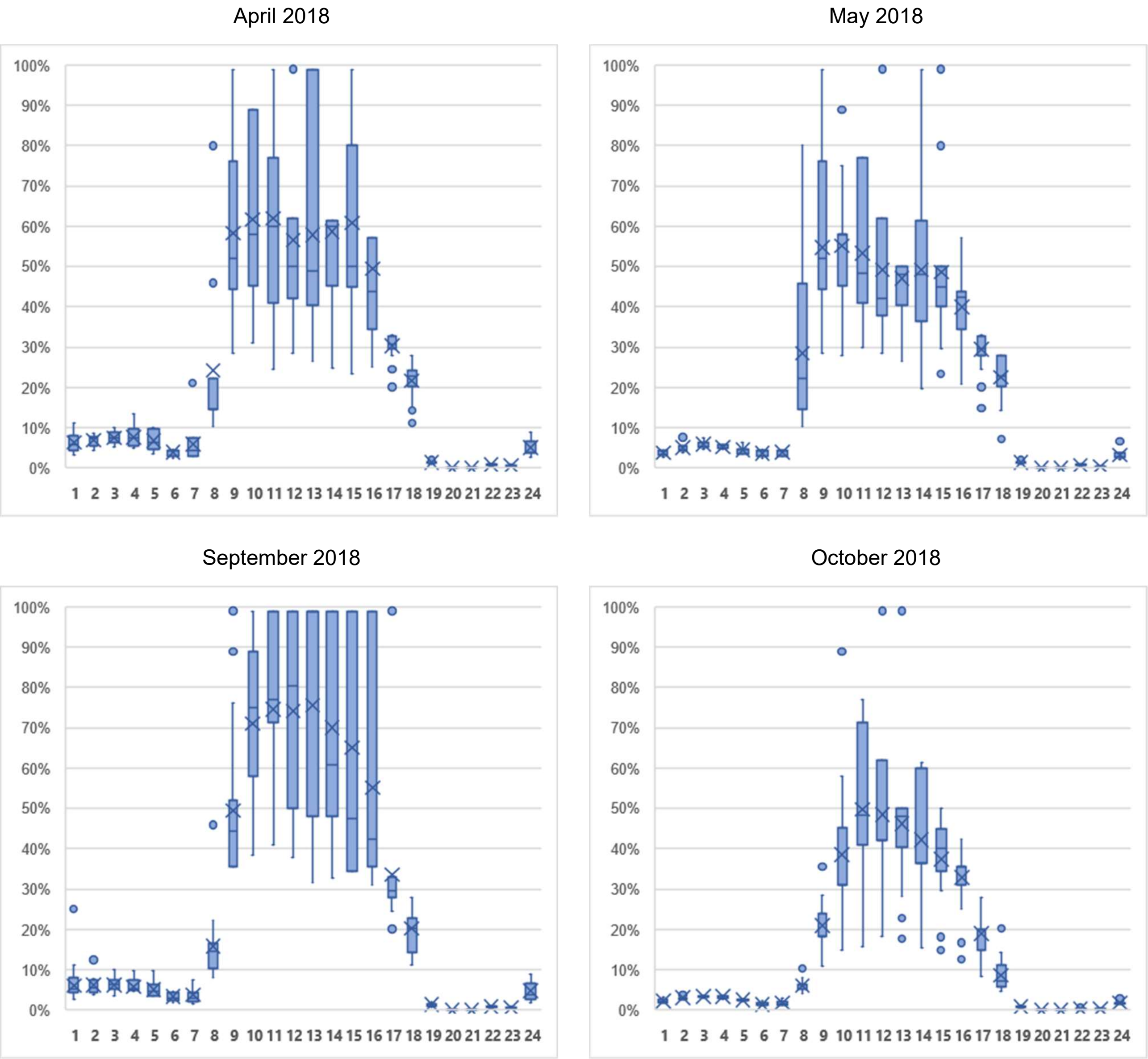
Figure 3: Distribution of Excess Supply Probabilities from 8 AM to 4 PM by Month (2018)



As previously shown in Figure 1, Figure 3 shows that the shoulder months of April, May and September have the highest average probability of renewable excess supply (average values marked by "X"). As described earlier, higher probabilities of excess supply in shoulder months reflect the combined effect of longer days and lower temperatures. Figure 3 also shows the distribution of excess supply probabilities, with September and April having the higher dispersion of excess supply hours than other months. Also notable in Figure 3 is the presence of excess supply probability outliers exceeding 70% in many months (i.e., data points above the whiskers in March, May, June, August, October, and November). The outliers suggest the occurrence of specific yet significant events of excess supply on the grid, which can potentially present opportunities for day-ahead dispatch of load increase events. Vehicle charging can be managed to respond to these events either through ongoing optimization or through day-ahead dispatch, as described in the following chapters.

In addition to varying by time of year, the probability of renewable energy excess supply varies by time of day. Figure 4 shows the distribution of hourly probabilities of excess supply in April, May, September, and October of 2018. As also seen in Figure 1, Figure 4 shows that, consistent with a typical solar profile, the probability of excess begins to pick up at around 8:00 AM, peaks right before noon, and remains relatively high throughout midday and early afternoon. This hourly pattern for the excess supply signal suggests that electric vehicle charging during the middle of the day could be valuable for consuming renewable energy excess supply, particularly in the shoulder months.

Figure 4: Hourly Excess Supply Probabilities, Selected Months (2018)



The vehicle-renewable integration use cases were designed to take advantage of periods when the probability of excess supply is high. This included enabling optimizations for away-from-home charging and calling load increase events based on day-ahead forecasts of excess supply. The following chapters present the results.

CHAPTER 3:
Vehicle Optimization Using Excess Supply

This chapter presents the results of the vehicle charging optimizations using PG&E's excess supply data feed for both at home and away from home charging. The implementation of the vehicle-renewable integration use cases builds upon previous work by the research team that enabled and assessed optimization of vehicle charging schedules using locational marginal price (LMP) and renewable (RE) supply mixture on the grid. The results of the earlier use cases are described in the *Charging Behavior Optimization Report*.

Optimization Approach

The vehicle charging optimization approach for the vehicle-renewable integration use case was similar to that described in the *Charging Behavior Optimization Report*. For the earlier use cases, the research team used day-ahead locational marginal price (LMP) and renewable (RE) supply mixture signals to derive optimal vehicle charging schedules. For the vehicle-renewable integration use cases, the research team enabled optimizations using the excess supply signals described in Chapter 2. The research team also enabled away from home charging during this period.

For those vehicles enrolled in BMW's TCM program, the process works as follows: when a vehicle owner plugs in and sets a target departure time for their vehicle, a request for an optimized charging schedule is triggered. That request is transmitted to Olivine DER, and in response, Olivine DER uses data from several sources to derive the optimal vehicle charging schedule. The optimal schedule takes into account the vehicle's charging location and applicable rate schedule, in order to maximize value to the grid without adversely affecting the cost of charging for the vehicle owner. The charging schedule is sent back to the vehicle from Olivine DER through the protocols defined with BMW and Sulzer, a partner on the EPIC BMW TCM project. For a more detailed description of this process, refer to the *Charging Behavior Optimization Report.*

Key variables used in the optimization include:

- Vehicle plug-in time
- Vehicle target departure time
- Vehicle remaining charge time
- Applicable rate schedule, whether time-of-use (TOU) or flat rates; away-from-home charging defaults to a flat rate schedule
- Vehicle location indicator to flag whether charging at home or away from home
- Optimization type, of which LMP, RE, and Excess Supply are currently enabled
- Hourly day-ahead forecasts, which differ for each optimization type

- Any special optimization rules. In the case of excess supply optimizations, a tie-breaker was implemented using LMP to address situations in which the excess supply signal alone did not yield one optimal schedule (e.g., during periods when the probability of excess supply is zero or one for multiple consecutive hours). Also, the weekday hours from 3:00 PM to 9:00 PM were de-prioritized in the optimization to avoid increasing load during the evening ramp.

The scope of this report is to describe the results of optimizations based on PG&E's renewable energy excess supply forecast. These optimizations were conducted over a four-week period starting on Monday, October 15, 2018 and ending on Saturday, November 10, 2018.

Optimization Participation

Of the 279 cars enrolled for TCM optimizations during this period, 172 vehicles (62%) opted in for at least one optimized charging session during the study period. The count of vehicles by vehicle type, categorized by all-electric models and plug-in hybrid electric models (PHEV), is shown in Table 1. Of the 279 active TCM participants during the study period, 224 are all-electric vehicles and 55 are PHEVs. Optimization participation rates were similar across these two vehicle types (62% for electric compared to 60% for PHEV).

Table 1: Optimization Participation Rates by Vehicle Type

	Electric	(%)	PHEV	(%)	Total	(%)
Opt-In Vehicles	139	(62%)	33	(60%)	172	(62%)
Opt-Out Vehicles	85	(38%)	22	(40%)	107	(38%)
Active Vehicles	**224**	**(100%)**	**55**	**(100%)**	**279**	**(100%)**

For those 172 vehicles that opted in during the study period, the total number of *optimized charging sessions* was 1,631 over the study period, as shown in **Error! Reference source not found.**. An optimized charging session is triggered when a TCM participant plugs a vehicle in and sets a target departure time. Of the 1,631 optimized charging sessions, 75 percent were fulfilled by all-electric vehicles and 25 percent by PHEVs.

Table 2: Optimization Charge Sessions by Vehicle Type

Charge Location/Rate	Electric	(%)	PHEV	(%)	Total	(%)
At Home	742	(45%)	322	(20%)	1,064	(65%)
TOU rate	592	(36%)	170	(10%)	762	(47%)
Non-TOU rate	150	(9%)	152	(9%)	302	(19%)
Away from Home	488	(30%)	79	(5%)	567	(35%)
Total Optimized Charge Sessions	**1,230**	**(75%)**	**401**	**(25%)**	**1,631**	**(100%)**

The algorithm for optimized charging takes into account a vehicle's location and applicable electricity rate. If the vehicle is charging away-from-home, the optimization defaults to a non-TOU rate structure. Thus, this report presents results for three optimization categories: At

Home – TOU; At Home – Non-TOU; and Away from Home. Table 2 shows that 47 percent of optimized charging sessions occurred at home under a TOU rate, 19 percent at home under a non-TOU rate, and 35 percent away from home. Roughly two-thirds (65 percent) of the optimized charging sessions took place at home.

Using a box and whisker chart and a cumulative distribution function, Figure 5 further explores the diverse number of optimized charging sessions for those vehicles that participated in excess supply optimizations during the study period. The electric vehicles had an average of nine optimized charging sessions with half of the vehicles having between four and twelve optimized charging sessions. The PHEV vehicles charged more frequently than the all-electric vehicles, with an average of twelve optimized charging sessions and with half of the vehicles having between four and seventeen optimized charging sessions. The box and whisker chart identifies some outliers, with a maximum of 42 optimized charging sessions from a single vehicle in the study period.

Figure 5: Distribution of Vehicle Optimization Requests by Vehicle Type

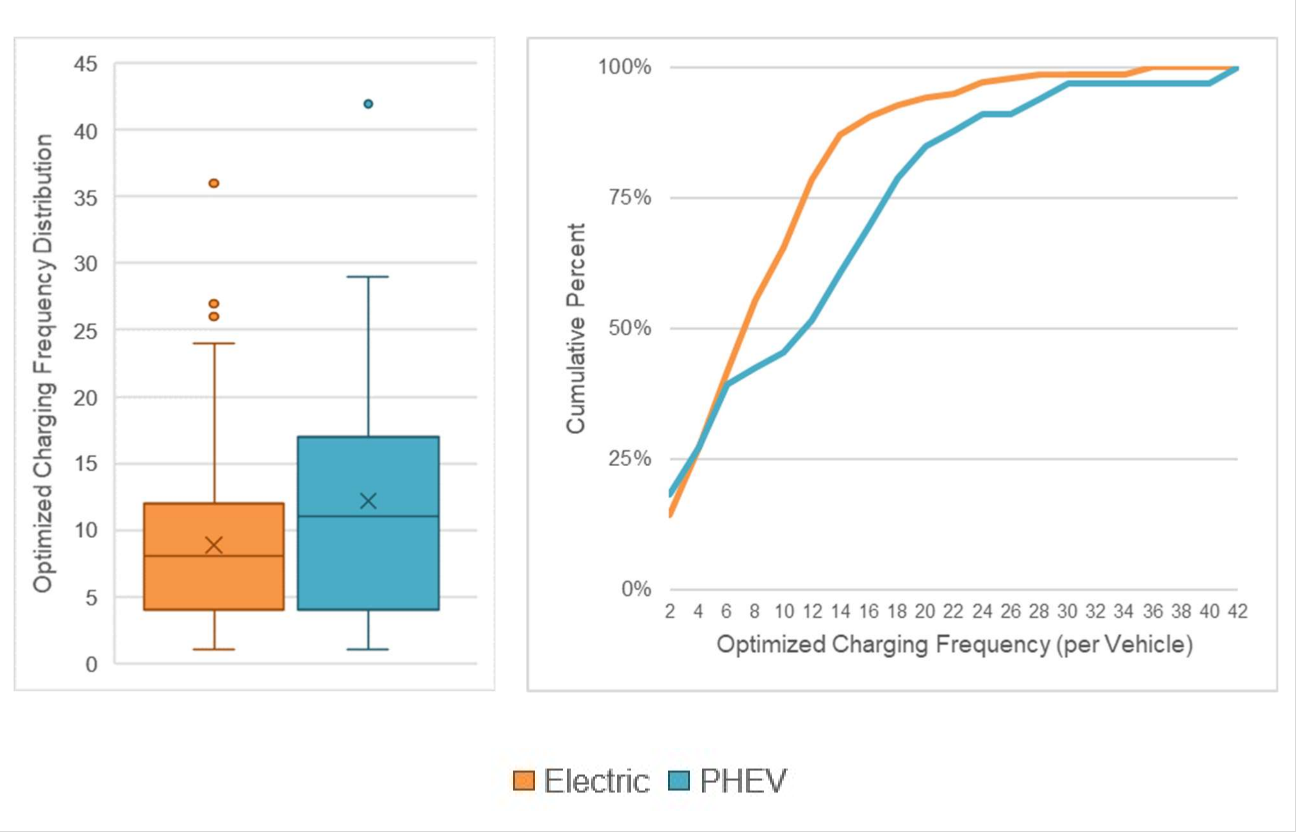


Figure 6 shows how the number of optimized charging sessions for the vehicles are distributed by charging location and rate. The frequency of optimized charging is similar for vehicles charging at home, whether on TOU or non-TOU rates. Both populations had an average of about eight optimized charging sessions, with over half of the vehicles at home having between three and twelve optimized charging sessions. In contrast, that number of away from home optimized charging sessions was lower, with an average of six, and with half of the vehicles having between two and eight optimized charging sessions.

Figure 6: Distribution of Vehicle Optimization Requests by Charging Location and Rate

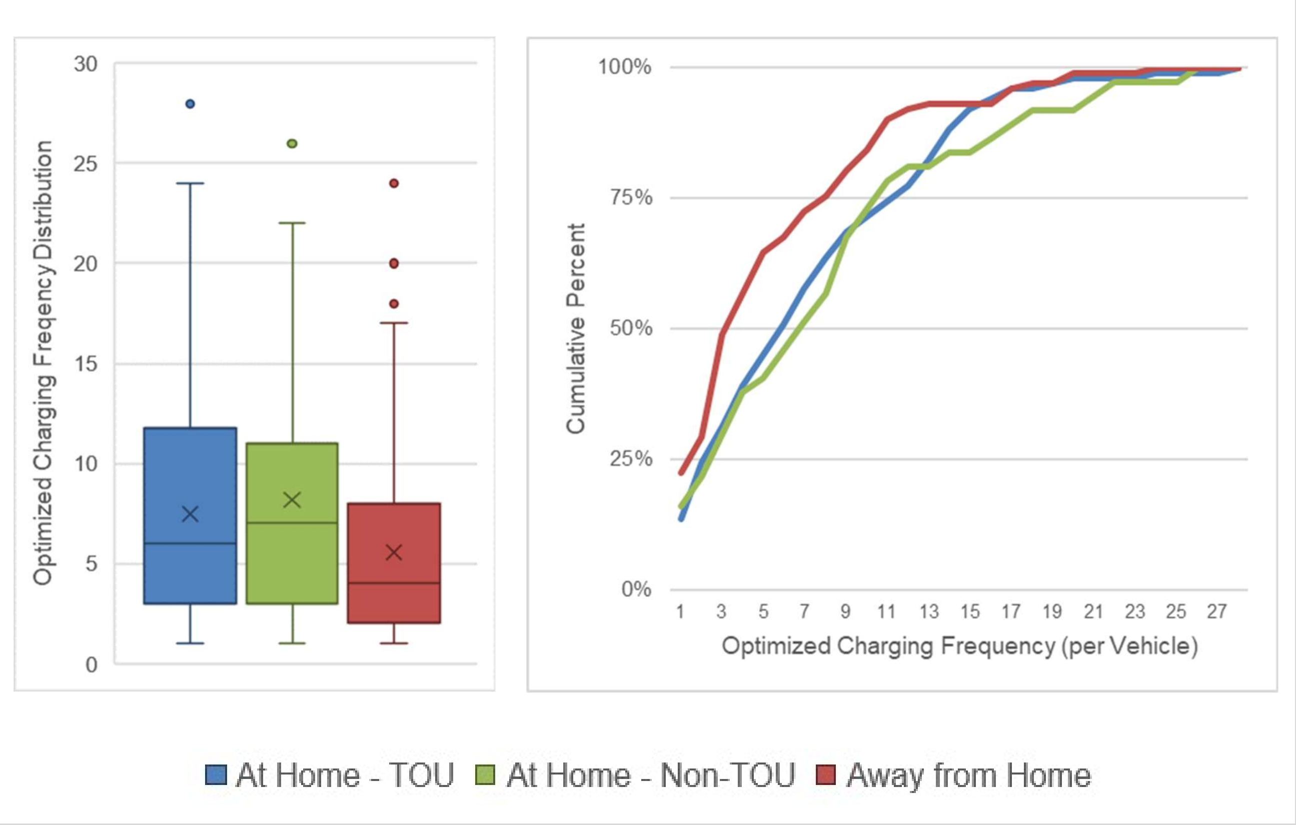


Figure 7 and Figure 8 show the distribution of plug-in time and target departure time, with Figure 7 showing the times for at-home charging and Figure 8 showing the times for away-from-home charging. The plug-in times represent measured data, captured by Sulzer US when the vehicle plugs in, and sent to Olivine DER. The pattern for plug-in times aligns with expectations. For both home and away-from-home charging, people primarily plug in at home in the evening hours (6:00 PM peak) and they plug in away from home during the day (8:00 AM peak).

The target departure times represent user-provided inputs set through a phone application (*app*). Vehicle owners use their phone app to identify when they will need their vehicle to be fully charged; they can set these schedules in advance and they do not need update the target time each time they plug in. To better understand charging behaviors, in Figure 7 and Figure 8 the target times have been divided into two groups: same-day target time (where plug-in date equals target date) and next-day target time (where target date is greater than plug-in date).

At-home charging behavior aligns with expectations: most vehicles are plugged in during the evening and target departures are primarily set for the next morning (7:00 AM peak). Away-from-home target departure times appear to be approximately evenly split between same-day and next-day target times. In fact, over half (58 percent) show target times for the next day (8:00 AM peak) and the next-day charging pattern resembles at-home charging. This suggests that when plugging in away from home, many vehicle drivers are not updating the default target departure time in their phone app to reflect expected departure times from the away-from-home charging station. It is possible that vehicle drivers are choosing to keep departure times for the next day knowing that they have enough range to meet their mobility needs until their next set departure time; however, further analysis is needed to confirm this hypothesis.

Figure 7: Distribution of Vehicle Plug-In and Target Times – At Home

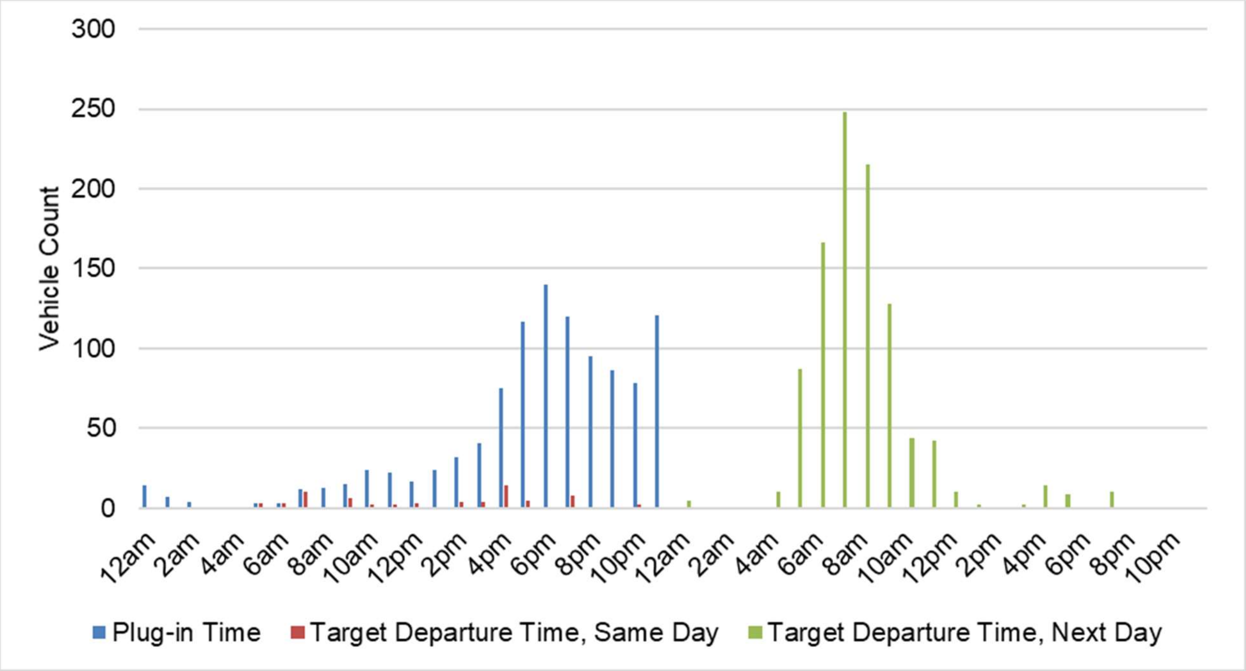
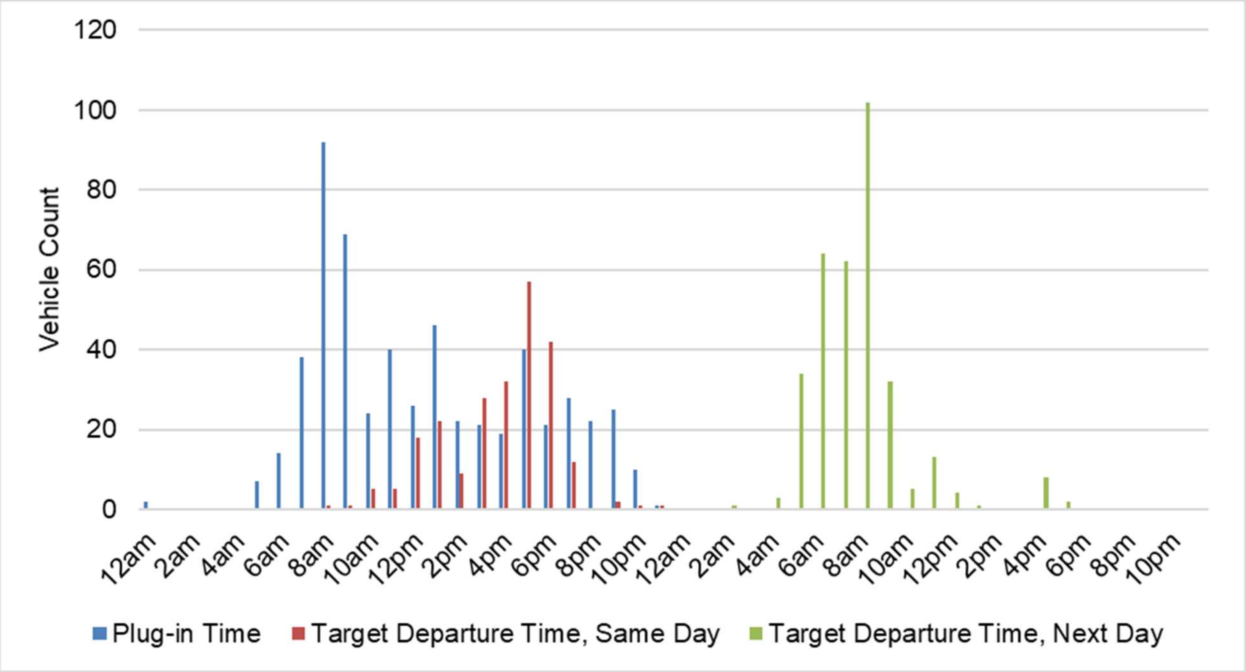


Figure 8: Distribution of Vehicle Plug-In and Target Times – Away from Home

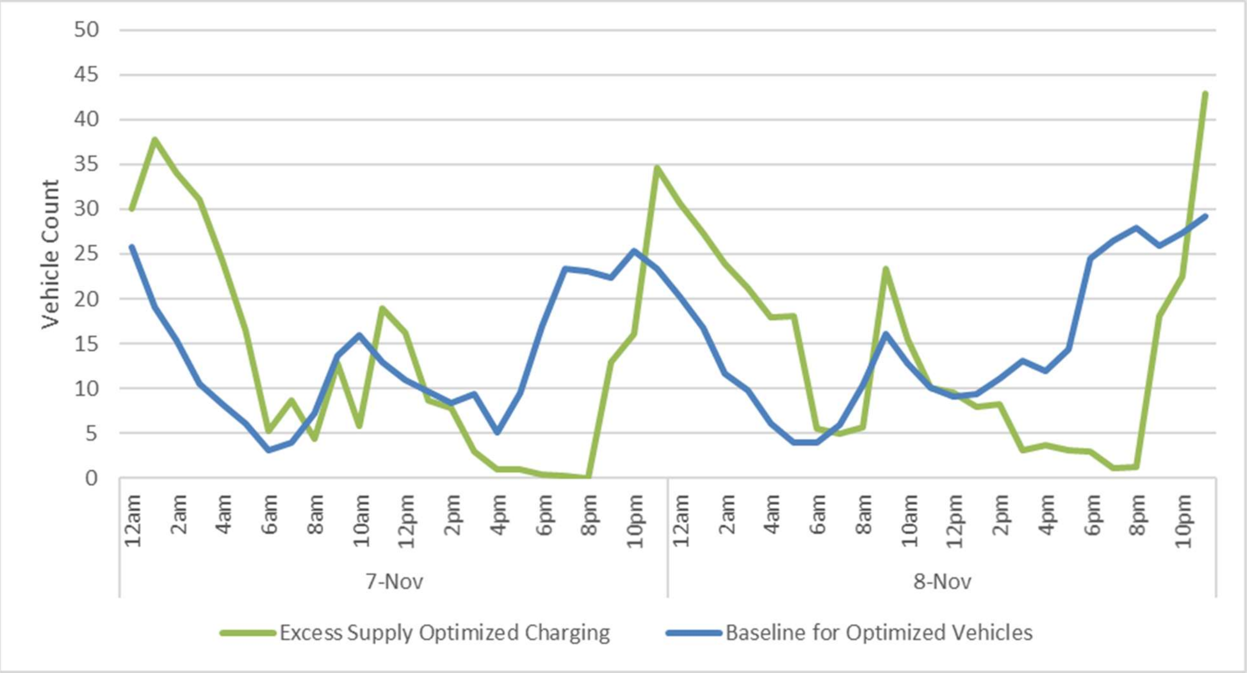


Optimization Results

Hourly charging profiles were derived to show the optimized vehicle charging patterns in response to the excess supply signal. To determine the impact of optimized charging, the research team compared the optimized charging schedule with a baseline charging schedule that was derived based on the assumption that, if not for requesting an optimization, the vehicles would have started charging immediately after plugging in. For baseline (non-optimized) charging, the charging start time is assumed to be the plug-in time and the stop time is assumed to be the start time plus the remaining charge time.

Figure 9 contrasts optimized charging (green line) with baseline charging (blue line) for all vehicles that were optimized on 11/7/2018 and 11/8/2018. These days were chosen to illustrate how the excess supply optimization shifts daily charging patterns. Any two consecutive dates could have been selected to provide an illustration of how optimized charging shifts the charging from early evening hours into the late evening and early morning hours. The lines show the vehicle count by hour over the 48-hour period. The green line represents the actual aggregate charging pattern of the vehicle population, based on optimized charging schedules that were sent to individual vehicles. The blue line is a hypothetical aggregate baseline, illustrating what would have happened had the vehicles started charging immediately upon plugging in. In general, vehicle charging patterns in this chapter are presented as vehicle counts. Olivine DER does not have information on vehicle charging energy use. To translate vehicle counts into energy use, an estimate for average energy use per hour for vehicle charging could be applied.

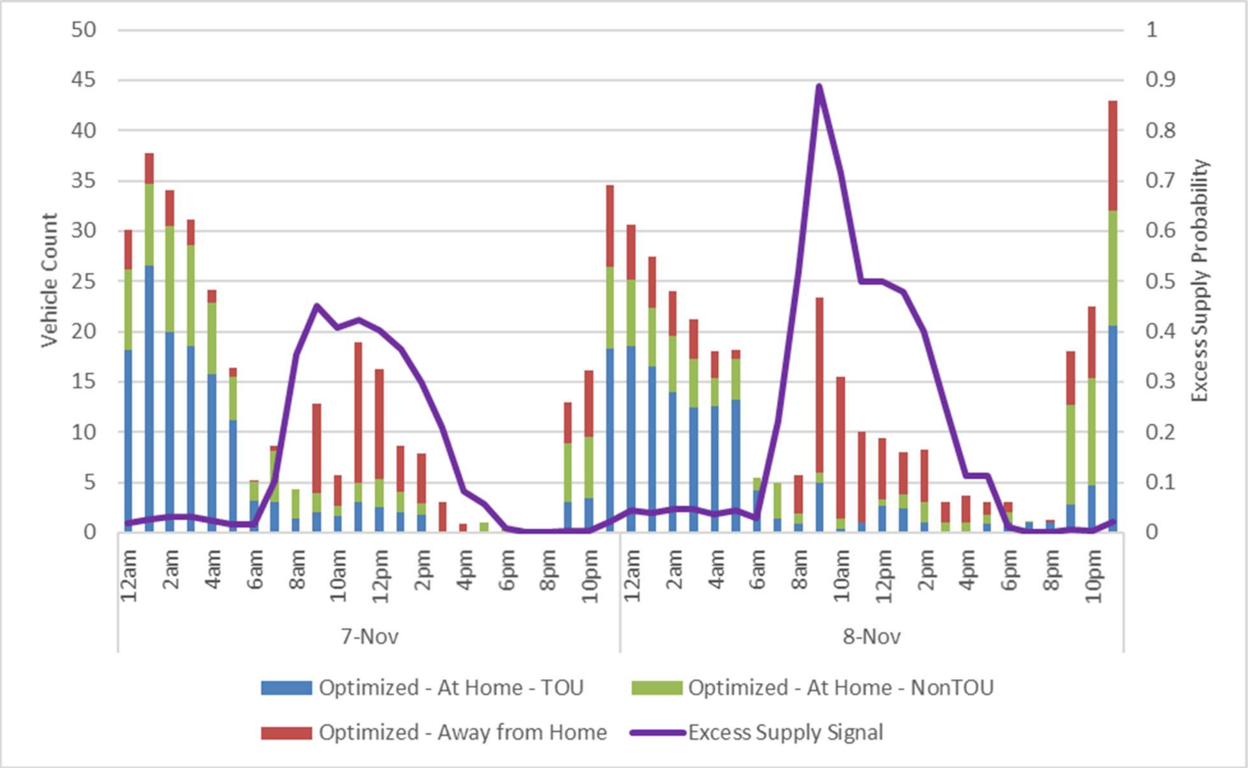
Figure 9: Optimized versus Non-Optimized Charging Patterns



In Figure 10, a stacked bar chart shows optimized charging, with the blue portion showing home charging on TOU rates, the green portion showing home charging on non-TOU rates, and the red portion showing away-from-home charging. The left axis shows the vehicle counts associated with optimized charging. Note that the stacked bar charts in Figure 10 correspond with the green line in Figure 9 depicting total optimized charging on these dates. In Figure 10, the optimized charging is overlaid with the excess supply probability curve (purple line with values displayed on the right axis). This figure shows how charging patterns are influenced by choosing excess supply for the optimization. Again, 11/7/2018 and 11/8/2018 were chosen to illustrate how the profiles differ on a day-by-day basis.

The data shows that using excess supply for optimization is primarily influencing charging patterns from around 8:00 AM to around 2:00 PM and that vehicles are charging both away from and at home during this period. The presence of away-from-home charging in the middle of the night (i.e., the red portion of the bars from 11:00 PM to 5:00 AM) illustrate the challenge described earlier when vehicle drivers use default next-day target times for away-from-home charging. The analysis in this report was structured using data available from the Olivine DER VGI optimization engine, which relies upon vehicle plug-in times, target times, and remaining charge times to identify optimal charging schedules.

Figure 10: Charging Optimized for Excess Supply



The goal of the vehicle-renewable integration optimization is to shift vehicle charging from periods when the probability of renewable excess supply is low to periods when excess supply is high. The approach for calculating optimization impacts is to compare what would have happened had the vehicle started charging immediately upon plugging in (i.e., baseline) with the optimized charging schedule that was sent to the vehicle.

To quantify increased charging during periods of renewable excess supply, a weighted excess supply curve is derived by multiplying the vehicle count (per hour per day) and excess supply probability (per hour per day). This value is calculated for the baseline and optimized charging profiles to determine the percentage increase (or decrease) from optimized charging. The percentage change between the baseline and optimized weighted excess supply curves provides a consistent metric for how much charging was shifted from periods of low excess supply to periods of high excess supply.

$$Weighted\ Excess\ Supply\ (Baseline)_t = Excess\ Supply\ Signal_t\ \times \#\ vehicles\ (Baseline)_t\ , \qquad t = 1 - 24\ hours$$

$$Weighted\ Excess\ Supply\ (Optimized)_t = Excess\ Supply\ Signal_t\ \times \#\ vehicles\ (Optimized)_t\ , \qquad t = 1 - 24\ hours$$

As shown in Figure 11, the comparison of baseline to optimized charging using the excess supply signal resulted in a 16 percent increase for all vehicles optimized during the study period. This increase shows that the optimizations successfully shifted charging to periods when excess supply is high. The largest impacts are seen from 10:00 AM to 2:00 PM (i.e., where the red curve exceeds the purple curve).

also shows a period from 3:00 PM to 6:00 PM during which benefits for optimized charging are lower than the baseline (i.e., where the purple curve exceeds the red curve). This is attributable to a rule implemented in the optimization logic to de-prioritize hours between 3:00 PM and 9:00 PM to avoid ramping hours. Because some relatively high renewable excess supply probabilities occur in the afternoon (as previously seen in Figure 3), this imposed optimization rule lowers the impact of using excess supply signal for optimization. Going forward, grid value could be increased by using a signal that combines grid constraints with probability of excess supply to capture all available value.

Figure 11: Benefit of Shifting Charging to Match Excess Supply

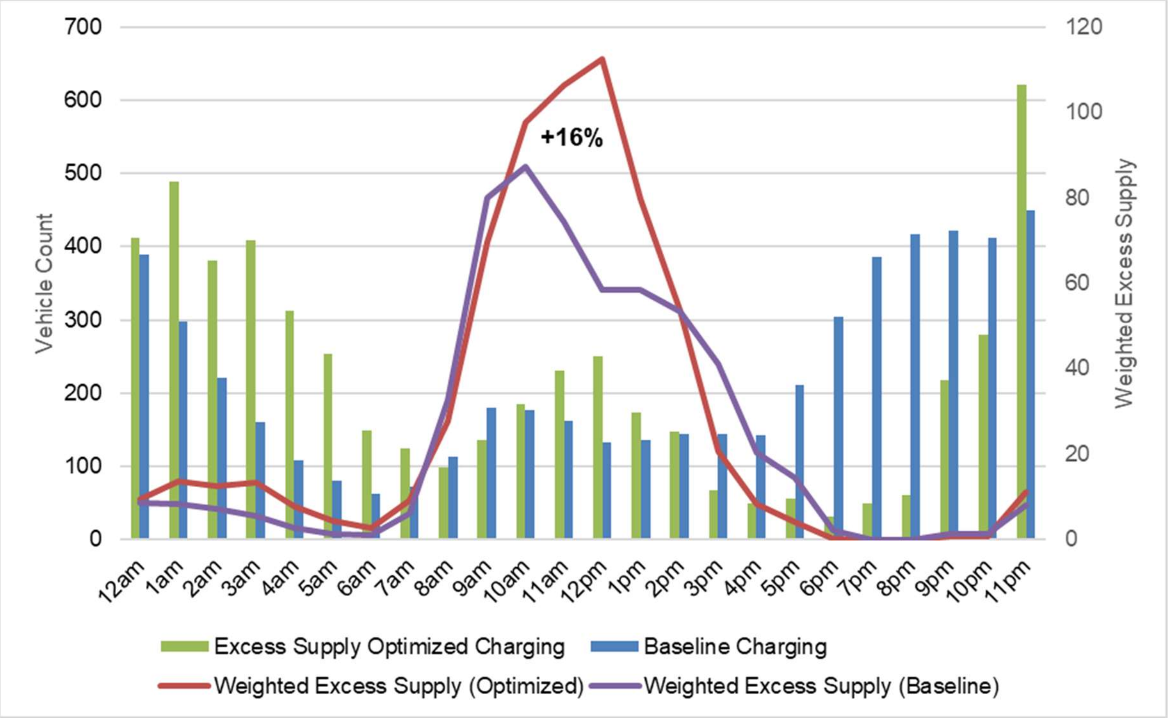


Table 3 summarizes the incremental relative benefits from the vehicle-renewable integration optimization use cases by charging location and rate type, whether TOU or other. As seen previously, the increase was 16 percent for all vehicle charging sessions over the study period. The values of incremental relative benefits range from a high of 48 percent for non-TOU participants charging at home, to a low of 6 percent for charging away from home.

Table 3: Use Case Benefits by Charging Location and Rate Type

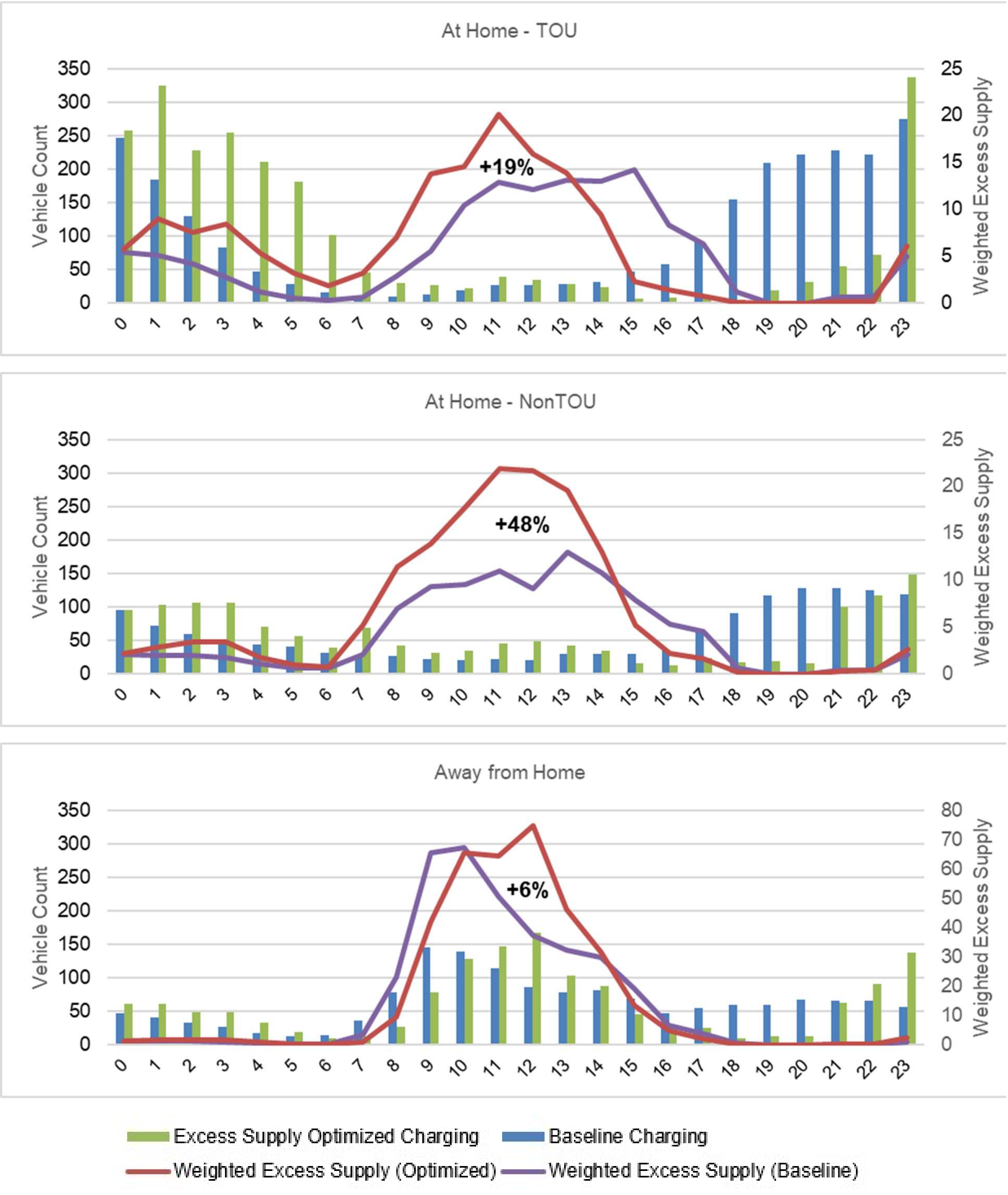
	Increase (%)
At Home (All)	32%
At Home – TOU	19%
At Home - Non-TOU	48%
Away from Home (All)	6%
Overall Benefit	16%

Relative to their respective baselines, non-TOU participants realize the most incremental benefit because the optimization does not factor in TOU peak- and off-peak periods for these participants. As a result, vehicle charging can be shifted into high excess supply periods without adversely affecting electricity bills. Away-from-home charging results in the least incremental benefit because the baseline profile is already quite favorable to excess supply, given the pattern of plugging in during the morning hours, as previously shown in Figure 8. These different charging patterns and their influence on the benefits of the excess supply optimization are illustrated in Figure 12.

It is important to note that the results (percentages) in Table 3 cannot be directly compared across the different participant groups to assess the overall (absolute) grid impact. This is due to two reasons. First, the number of participating vehicles is different for the different groups. Second, charging patterns and profiles are quantified in terms of vehicle count, not total charging capacity; the latter may differ across the participant groups due to different charging rates.

When considering the results for the TOU participants, one question is what the charging behavior would have been if not for the optimization. This analysis assumes that the vehicle would have started charging immediately upon plugging in, regardless of whether the plug-in time was during a peak, partial-, or off-peak period. It could be more realistic to assume that TOU customers would respond to TOU rates and schedule vehicle charging to minimize their electric bills. Identifying the most accurate baseline for TOU participants is noted as an area for future research.

Figure 12: Excess Supply Benefits by Charging Location and Rate Type



CHAPTER 4:
Load Increase Demand Response Events

Using the excess supply hourly probabilities, day-ahead load increase events of one-hour duration were called on seven days over the study period. Table 4 shows the load increase event hours and the probabilities of excess renewable supply associated with those hours. The event dates were selected in advance by the BMW project manager. Using the excess supply data feed from PG&E, on days when the maximum probability of excess supply was forecasted to be 50 percent or greater, the event hour was selected based on the hour with the highest value. On days when no probability value exceeded 50 percent or when no data were provided by PG&E before 5:00 PM, a default event time of 11:00 AM was selected.

Table 4: Load Increase Events Details

Date	Day of Week	Event Start Time	Event End Time	Excess Supply Probability
10/20/2018	Saturday	10 a.m.	11 a.m.	0.7692
10/27/2018	Saturday	11 a.m.	12 p.m.	0.6190
10/30/2018	Tuesday	12 p.m.	1 p.m.	0.5000
11/1/2018	Thursday	11 a.m. (default)	12 p.m.	0.3116
11/3/2018	Saturday	11 a.m. (default)	12 p.m.	0.4222
11/6/2018	Tuesday	9 a.m.	10 a.m.	0.5806
11/8/2018	Thursday	9 a.m.	10 a.m.	0.8889

As seen in Table 4, the event time defaulted to 11:00 AM on two of the seven event days. Three additional days were originally selected for load increase events but are not included in the analysis for reasons explained in APPENDIX A: Data Validation.

Load Increase Dispatch Approach

The load increase dispatch approach for the vehicle-renewable integration use case was similar to that described in the *Size and Categorization Report (#1)*. Enrollment in TCM required a customer to enroll one or more vehicles as well as to register their household for CAISO market participation under the Proxy Demand Resource (PDR) model. The households with current registrations in CAISO's Demand Response Registration System (DRRS) were included in the analysis for the load increase event use case.

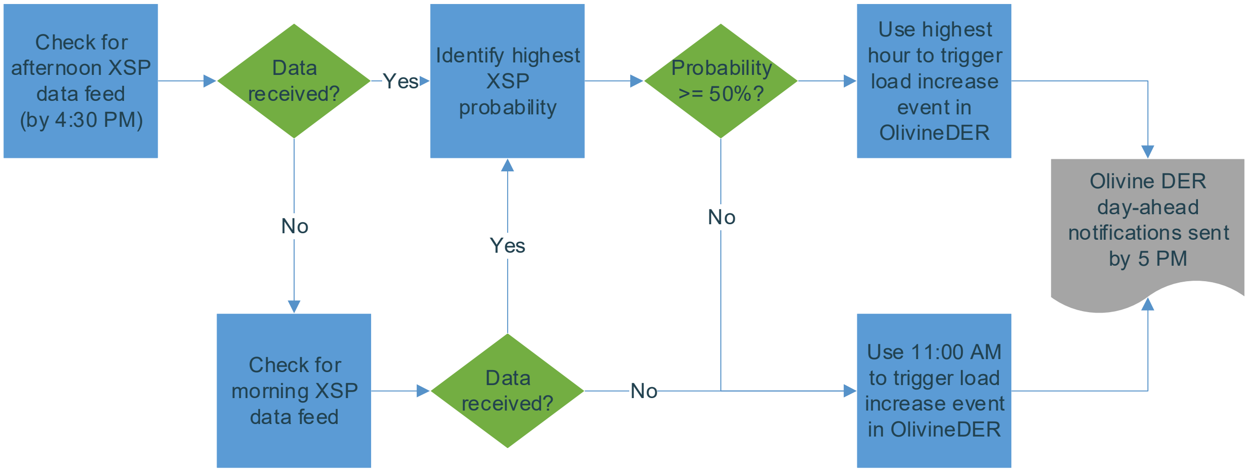
In contrast to the 279 vehicles included in the optimization analysis, the number of households included in load increase analysis was 241. The difference is due to 38 households being dropped from the load increase analysis dataset for the reason listed in Table 5. As shown, TCM participants include 25 vehicles that have a DRRS status that precludes participation in CAISO market programs (22 are flagged as "Optimization only"; 3 are flagged "Resolvable"). An additional 13 households were excluded from the load increase analysis due to insufficient information provided on their status during the events (3 of these were not in the listing of email addresses notified of the event; 10 were not included in the dataset that identified vehicle status at the time of the event).

Table 5: Explanation for Exclusion from Load Increase Analysis

Vehicle Count	Explanation for Exclusion
22	DRRS Status = Optimization only
3	DRRS Status = Resolvable
3	No match in DR email notification list
10	No match on vehicle status at event time
38	Total Households Excluded from Analysis

During the use case period, the pool of TCM vehicles participated in event-based demand response (DR) modeled after PG&E Excess Supply Pilot (XSP) program, which provides incentives for increasing load during periods of excess supply on the grid. As indicated above, BMW provided a list of days on which to call events. The process for identifying event hours and dispatching events is shown in Figure 13. The notification from Olivine DER to BMW's contacts resulted in an alert being sent to all participating vehicle drivers through the phone app.

Figure 13: Load Increase Event Dispatch Steps



Olivine generally receives two XSP data files from PG&E each day – a preliminary file, which typically is available by 11:00 AM, and a final file, which typically is available by 4:30 PM. In the *happy path* in Figure 13, Olivine would receive the afternoon XSP data feed from PG&E no later than 4:30 PM each day and the probabilities included in the file would determine the event hour. Note: the *happy path* is defined as the one in which handling of exceptions to the preferred logic would not be required.

Four out of seven of the load increase events analyzed in this report followed the happy path. The three exceptions were:

- As noted earlier, and seen in Table 4, the event time defaulted to 11:00 AM on 11/1/2018 and 11/3/2018, and this was due to generally low excess supply probability forecasts for those days, with none greater than or equal to 50 percent.
- For the event on 10/30/2018, the 12:00 PM event hour (with probability of 50 percent) was selected using the morning XSP data file since the afternoon file was not available by 4:30 PM. If the afternoon file had been available in time, the 10/30/2018 event would have been dispatched for the hour beginning at 10:00 AM instead (which had a 71 percent excess supply probability forecast).

Load Increase Event Participation

The load increase events were assessed using premise-level metered data from the 241 eligible TCM participant households. In order to get a better understanding of what was happening within the household with the vehicle, the vehicles were segmented into categories for each of the seven event hours based on the following questions:

- Was the vehicle at home? (Yes or No)
- Was the vehicle plugged in? (Yes or No)
- Was the vehicle charging? (Yes or No)
- Did the vehicle have an optimized charging schedule? (Yes or No)

All TCM vehicles that are charging at home and away from home are able to respond to DR events via the BMW vehicle telematics system. Using vehicle telematics, it is possible to document whether, when, and how a vehicle modified its charging behavior in response to DR events, regardless of location. Due to current CAISO constructs for PDR participation and performance measurement, however, vehicles that were away from home during the DR events were not included in an aggregation.

For the analysis presented in this section, aggregations were created in the Olivine DER platform for vehicles that were at home during each event for the purpose of calculating performance using CAISO’s 10-in-10 non-event day baseline methodology (described here: http://www.caiso.com/Documents/Section4-Roles-Responsibilities-asof-Nov6-2018.pdf). The households were segmented into the following four aggregation categories for the purposes of analyzing premise-level performance during the event:

1. Plugged in, Charging, Optimized
2. Plugged in, Charging, Not Optimized
3. Plugged in, Not Charging
4. Not plugged in

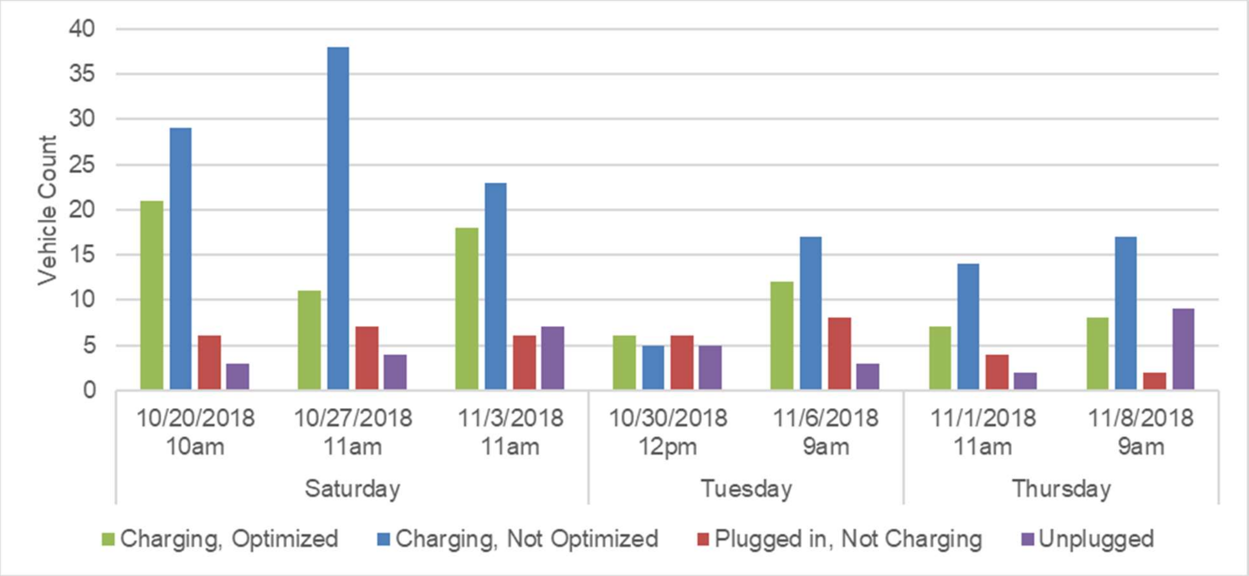
Table 6 shows the numbers of vehicles in each category for each of the seven events.

Table 6: Status of Vehicles During Load Increase Events

Status During Event Hour	**Sat 10/20**	**Sat 10/27**	**Tue 10/30**	**Thu 11/1**	**Sat 11/3**	**Tue 11/6**	**Thu 11/8**
At Home, Plugged In, Charging, Optimized (1)	21	11	6	7	18	12	8
At Home, Plugged In, Charging, Not Optimized (2)	29	38	5	14	23	17	17
At Home, Plugged In, Not Charging (3)	6	7	6	4	6	8	2
At Home, Not Plugged In (4)	3	4	5	2	7	3	9
Total	**59**	**60**	**22**	**27**	**54**	**40**	**36**

Figure 14 shows the number of vehicles by segment and event date, with the event dates clustered by day of week. For the vehicles that are at home during these events, non-optimized charging is consistently the largest segment, with the exception of Tuesday, October 30th, the date that had the lowest overall participation and was the only event to be scheduled for 12:00 noon. The Saturday events had the most participation, which is likely due to the increased likelihood that people are at home. The weekday events occurred during typical working hours when many people are likely to be away from home.

Figure 14: Vehicle Charging Status at Home for Load Increase Events



Load Increase Event Results

Table 7 shows the results from load increase events. The results are displayed for each event date and for each aggregation, which were configured after the events to reflect vehicle status during the event. The overall performance (based on the 10-in-10 non-event day baseline methodology) for the aggregations is reported along with vehicle count. These metrics are used to derive a per vehicle increase (or decrease) associated with the events.

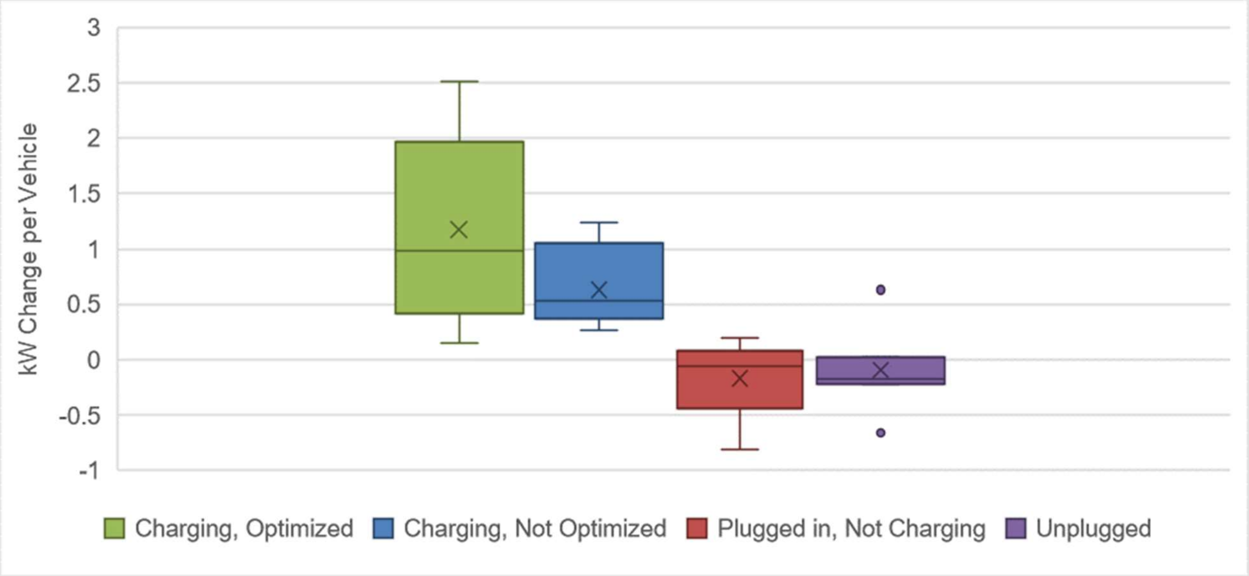
Table 7: Load Increase Event Performance, At Home by Vehicle Charging Status

Date	Day of Week	Hour	Vehicles Charging at Home (Count)	Average per Vehicle Increase /Decrease (kW)	PDR Event Performance (kW)
Charging, Optimized					
10/20/2018	Saturday	10:00 AM	21	1.54	32.42
10/27/2018	Saturday	11:00 AM	11	2.51	27.60
10/30/2018	Tuesday	12:00 PM	6	0.98	5.88
11/1/2018	Thursday	11:00 AM	7	0.41	2.87
11/3/2018	Saturday	11:00 AM	18	0.66	11.79
11/6/2018	Tuesday	9:00 AM	12	1.97	23.59
11/8/2018	Thursday	9:00 AM	8	0.15	1.18
Charging, Not Optimized					
10/20/2018	Saturday	10:00 AM	29	0.38	10.99
10/27/2018	Saturday	11:00 AM	38	0.54	20.35
10/30/2018	Tuesday	12:00 PM	5	0.55	2.77
11/1/2018	Thursday	11:00 AM	14	1.24	17.36
11/3/2018	Saturday	11:00 AM	23	1.05	24.14
11/6/2018	Tuesday	9:00 AM	17	0.26	4.45
11/8/2018	Thursday	9:00 AM	17	0.37	6.36
Plugged in, Not Charging					
10/20/2018	Saturday	10:00 AM	6	-0.81	-4.85
10/27/2018	Saturday	11:00 AM	7	-0.13	-0.93
10/30/2018	Tuesday	12:00 PM	6	0.08	0.47
11/1/2018	Thursday	11:00 AM	4	0.19	0.76
11/3/2018	Saturday	11:00 AM	6	-0.44	-2.62
11/6/2018	Tuesday	9:00 AM	8	-0.06	-0.48
11/8/2018	Thursday	9:00 AM	2	0.00	0.01
Unplugged					
10/20/2018	Saturday	10:00 AM	3	-0.66	-1.98
10/27/2018	Saturday	11:00 AM	4	-0.17	-0.68
10/30/2018	Tuesday	12:00 PM	5	-0.22	-1.12
11/1/2018	Thursday	11:00 AM	2	0.63	1.26
11/3/2018	Saturday	11:00 AM	7	-0.21	-1.46
11/6/2018	Tuesday	9:00 AM	3	-0.04	-0.12
11/8/2018	Thursday	9:00 AM	9	0.02	0.18

The PDR event performance values presented in Table 7 are calculated for each aggregation using household-level metered data and approved CAISO baseline methodologies. Households with unplugged vehicles also have performance values that reflect electricity increase or decrease compared to the baseline period.

Figure 15 summarizes the per vehicle event performance data from Table 7 using a box and whisker plot. This figure clearly shows that households with optimized vehicle charging had the greatest overall increase during the load increase events, with an average increase of 1.17 kW per household. Households with non-optimized vehicle charging during the event also showed an increase during the events, with an average increase of 0.63 kW per household. For those households where charging was not taking place during the load increase event, results show some small decrease in usage (negative values) at the household level with average values close to zero. The variation in load in these households can be attributed to normal variation in household energy usage patterns.

Figure 15: Per Vehicle Load Increase Event Performance Results



To assess the overall impact of the load increase events for both at-home and away-from-home charging, the average per vehicle kW increase results for at home vehicle charging were applied to vehicles that were charging away from home during the events. This assumes that charging rates and participation patterns are similar on average between at-home and away-from-home charging. BMW telematics data could be used to test this assumption and further analysis will be shared in subsequent reports.

Table 8 shows the number of vehicles that were charging away from home, segmented by whether charging was optimized or not optimized. As shown in Table 8, the number of vehicles charging away from home with non-optimized schedules far exceeds the number charging with optimized schedules. To estimate the load increase event performance associated with away-from-home charging, the number of vehicles was multiplied by an average load increase amount (1.17 kW for optimized charging; 0.63 kW for non-optimized charging). The at-home performance for the load increase events was added to the calculated away-from-home performance to determine overall event performance for both optimized and non-optimized vehicles. The total impact of load increase events – across optimized/non-optimized and at-home/away-from-home vehicles – was calculated and shown in Table 8 (see column entitled *Total Load Increase*).

Table 8: Load Increase Event Performance, including Away from Home

Date	Day of Week	Hour	Vehicles Charging Away from Home (Count)	Avg Load Increase (kW)	Away from Home Performance (kW) - Calculated	At Home Performance (kW) - Actual	Total Load Increase (kW)
Charging, Optimized							
10/20/2018	Saturday	10:00 AM	2	1.17	2.35	32.42	34.77
10/27/2018	Saturday	11:00 AM	3	1.17	3.52	27.60	31.12
10/30/2018	Tuesday	12:00 PM	14	1.17	16.43	5.88	22.31
11/1/2018	Thursday	11:00 AM	8	1.17	9.39	2.87	12.26
11/3/2018	Saturday	11:00 AM	1	1.17	1.17	11.79	12.96
11/6/2018	Tuesday	9:00 AM	7	1.17	8.21	23.59	31.81
11/8/2018	Thursday	9:00 AM	6	1.17	7.04	1.18	8.22
Charging, Not Optimized							
10/20/2018	Saturday	10:00 AM	28	0.63	17.57	10.99	28.57
10/27/2018	Saturday	11:00 AM	23	0.63	14.43	20.35	34.78
10/30/2018	Tuesday	12:00 PM	24	0.63	15.06	2.77	17.83
11/1/2018	Thursday	11:00 AM	27	0.63	16.94	17.36	34.30
11/3/2018	Saturday	11:00 AM	21	0.63	13.18	24.14	37.32
11/6/2018	Tuesday	9:00 AM	25	0.63	15.69	4.45	20.14
11/8/2018	Thursday	9:00 AM	34	0.63	21.34	6.36	27.69
Charging, Total							
10/20/2018	Saturday	10:00 AM	30		19.92	43.42	63.34
10/27/2018	Saturday	11:00 AM	26		17.95	47.95	65.91
10/30/2018	Tuesday	12:00 PM	38		31.49	8.65	40.14
11/1/2018	Thursday	11:00 AM	35		26.33	20.23	46.56
11/3/2018	Saturday	11:00 AM	22		14.35	35.93	50.28
11/6/2018	Tuesday	9:00 AM	32		23.90	28.04	51.94
11/8/2018	Thursday	9:00 AM	40		28.38	7.54	35.92

Figure 16 shows the results from the load increase event by day (grouped by day of week). The figure shows a high value of approximately 66 kW on Saturday, 10/27/2018 and a low value of approximately 36 kW on Thursday, 11/8/2018. Generally, the load increase results are highest on Saturdays, when more vehicles were using optimized charging at home. Further, based on BMW charging profiles for the TCM project, there is generally more charging at the beginning of the week and people do not charge every day. Of note, during the one DR event called for noon on a weekday (10/30/2018), the data show the highest number of vehicles using optimized charging away from home.

Figure 16: Overall Load Increase Event Performance – All Charging Vehicles

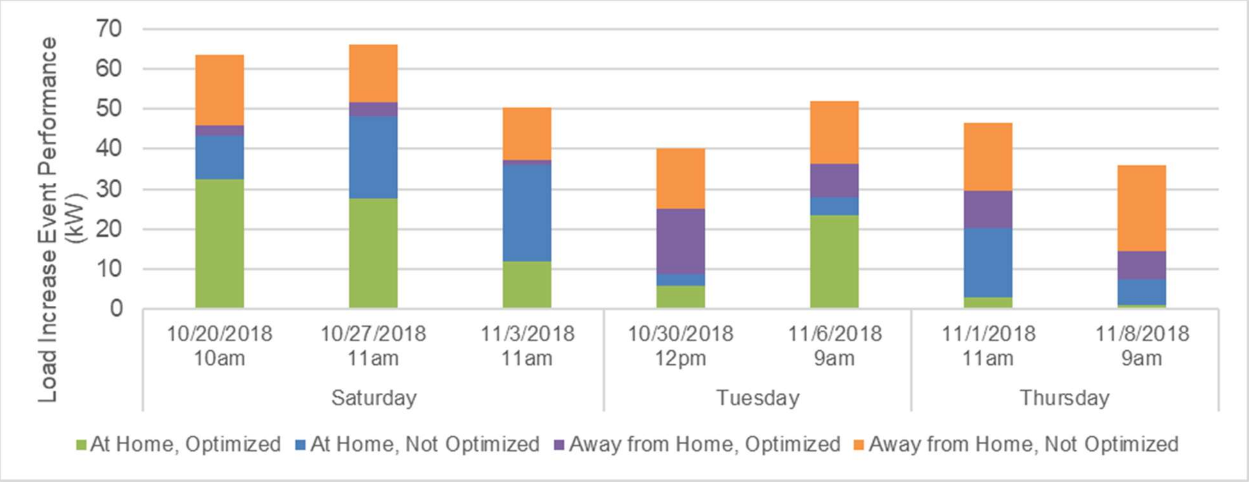


Figure 17 and Figure 18 show some representative performance results for vehicles at home, from the highest performance weekend day (Saturday, 10/27/2018) and the highest performance weekday (Tuesday, 11/6/2018). For each of the four aggregation types, the graphs depict the metered hourly load profiles and the baseline hourly load profiles (derived using CAISO's 10-in-10 baseline methodology). The event time is signaled by a light gray bar. Load increase magnitudes are shown in purple and load decrease magnitudes are shown in orange. These figures are included to illustrate how the load increase results are derived using household metered and baseline data. Results like these were calculated for seven event days and four aggregation types. To review charts for all days and aggregation types, refer to APPENDIX B: Load Profiles.

Figure 17: Load Increase Event Performance Results, Saturday 10/27/2018 11 AM

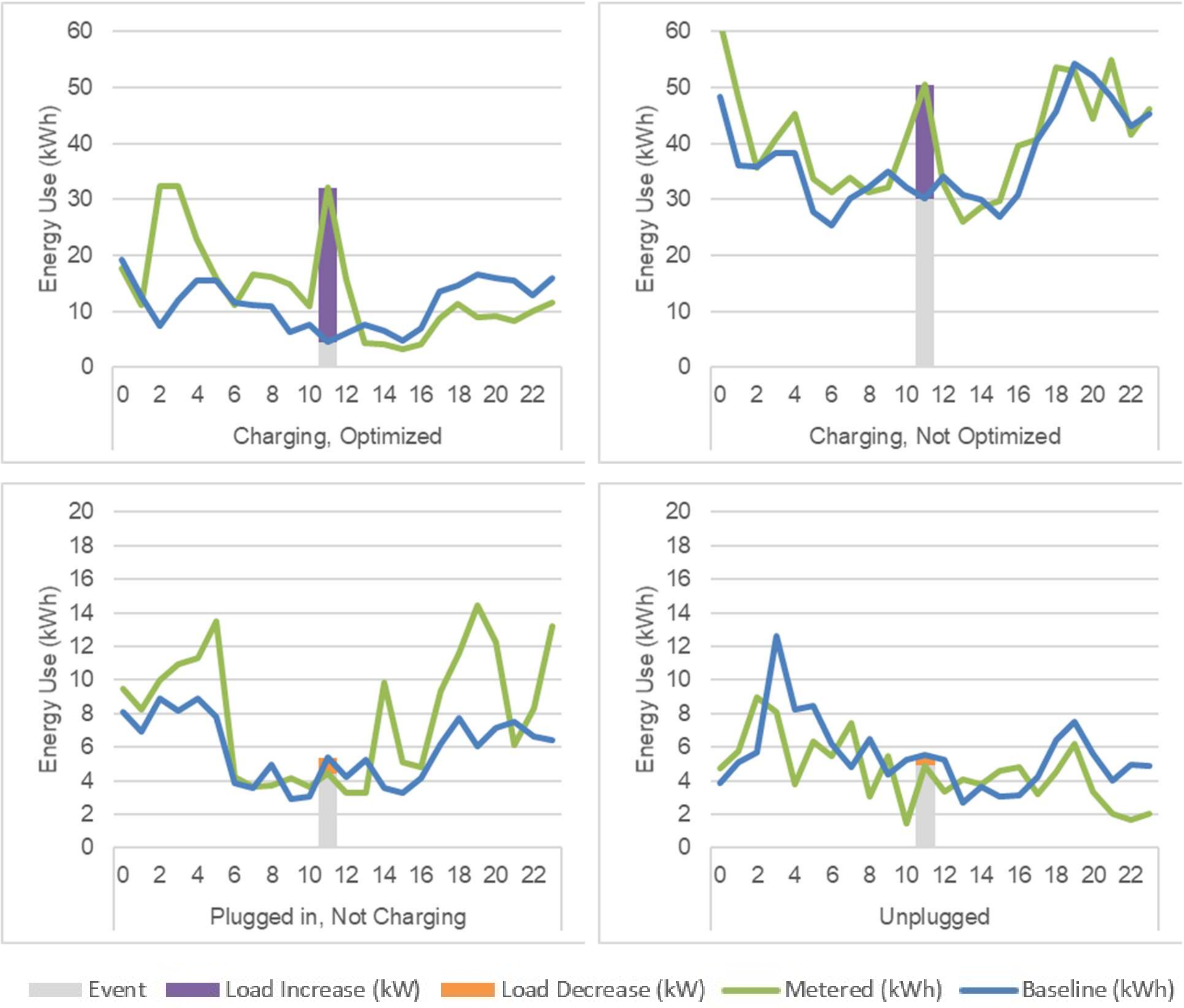
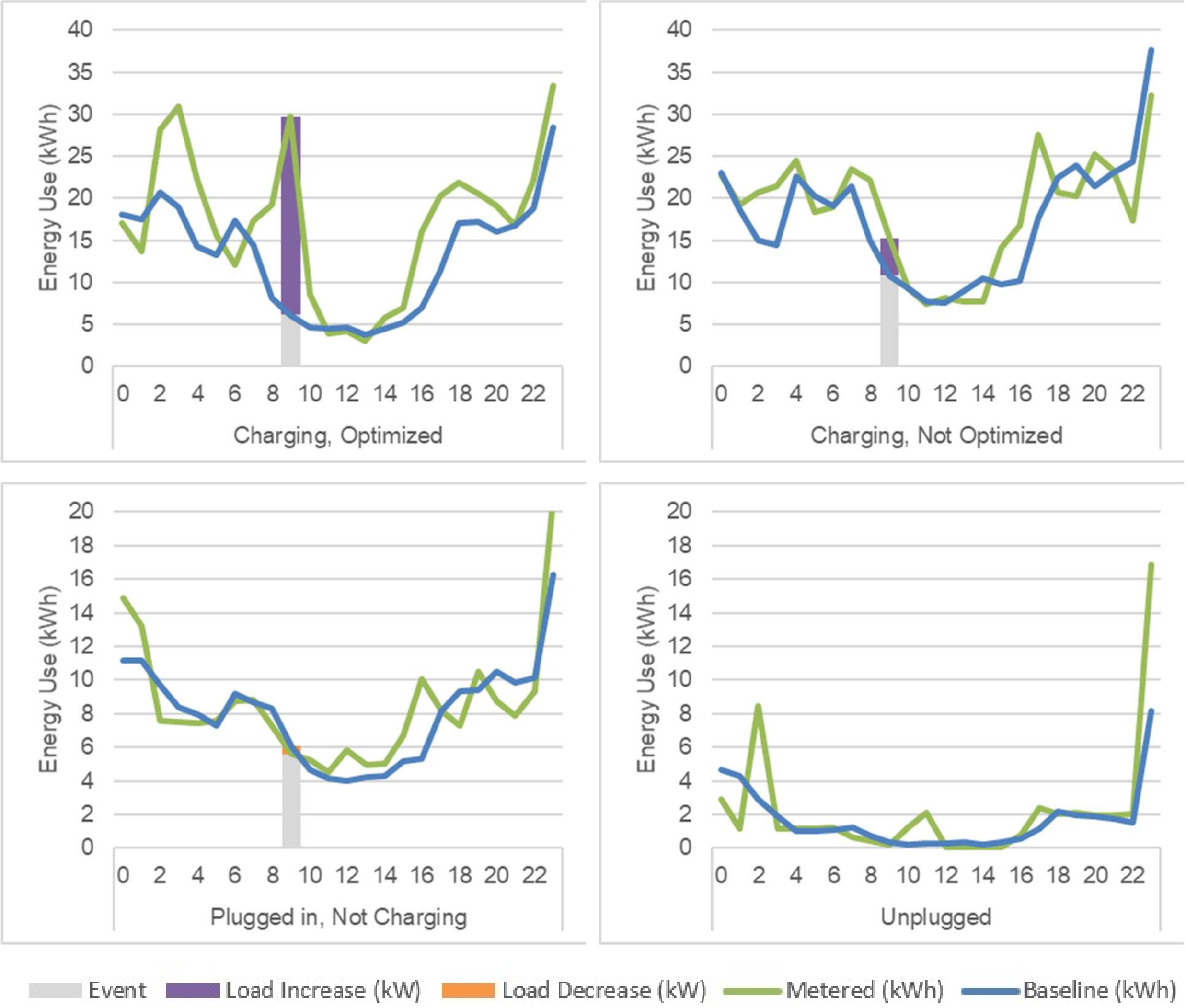


Figure 18: Load Increase Event Performance Results, Tuesday 11/6/2018 9 AM



CHAPTER 5:
Summary of Findings and Lessons Learned

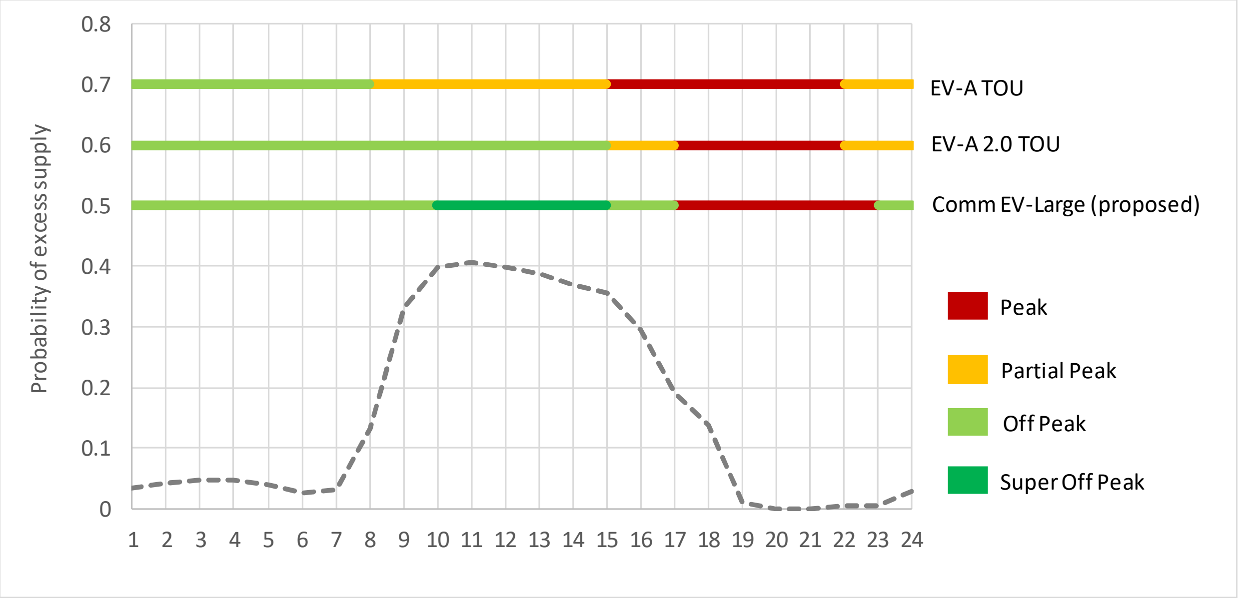
Excess supply from renewables will likely become increasingly significant in the future. As a partially flexible load, EV charging can be shifted to better align with excess supply of renewables, which has the potential to provide value.

The results of comparing optimized and baseline vehicle charging patterns show that charging based on an excess supply signal has the potential to provide benefits to the grid, such as better balance of demand and excess renewable energy.

Relative to the participating groups' respective baseline performance, the incremental benefits were highest for at-home charging by those participants not on time-of-use rates. Given the flat rate structure, those participants did not incur higher costs to charge during daytime hours when excess supply probability is high.

New incentive mechanisms or improved pricing signals may help realize additional benefits. As shown in Figure 19, new (planned or proposed) changes in PG&E TOU rates ensure progressively better alignment of pricing signals for EV charging with excess generation from renewables. Ultimately, EV rate design and smart, managed charging can complement one another to capture the full value of balancing several important considerations, including and beyond excess renewable generation, such as energy cost and carbon intensity, transmission and distribution grid conditions, equity, and customer behavior.

Figure 19: TOU Periods Contrasted with Hourly Average Probability of Excess Supply



The results from reviewing household performance in response to day-ahead dispatch of load increase events suggests that vehicle owners, under the right conditions, respond to these events. As expected, the best performance is seen with those vehicles that are charging using optimized schedules. On average, performance was about twice as high for optimized charging compared to non-optimized charging. This suggests that grid benefits would be increased by identifying ways to obtain more accurate departure time data for individual drivers.

During the analysis and reporting on data from these use cases, the study team identified several areas for additional research:

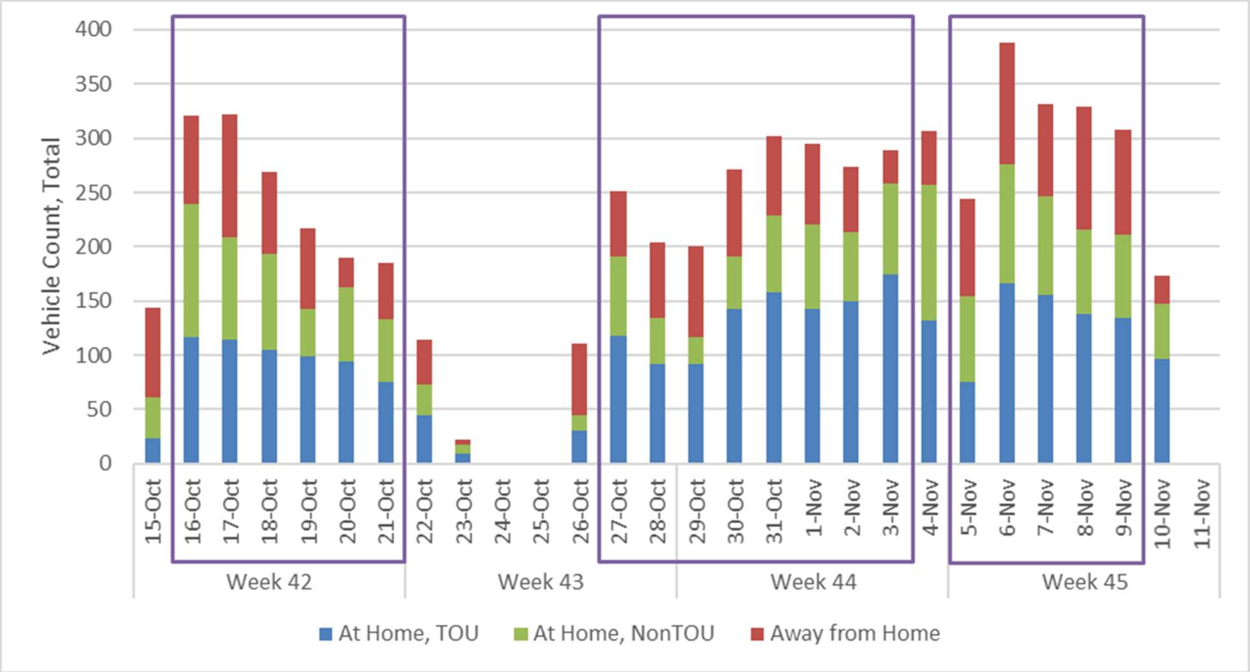
- Capture additional data on energy use and charging rates associated with charging optimization, in order to translate the vehicle counts presented in Chapter 3 into energy impacts.
- Incorporate additional data to reflect actual charging patterns in response to optimized schedules (e.g., use actual unplugged times instead of target times).
- Incorporate additional data on energy use and charging rates in the workplace, in order to better evaluate the performance for load-increase events.
- Explore how TOU participants are charging when they do not request optimizations. Do they follow TOU rates on their own? If so, update baseline assumptions for impact calculations.
- Refine the phone app interface for away-from-home charging to get better information on planned target departure times.
- Continue collaborative efforts with utilities and other stakeholders to explore the value and feasibility of new incentive mechanisms and/or pricing signals that can better align vehicle charging with grid needs and conditions, including the state of excess renewables.
- Continue collaborative efforts with utilities and other stakeholders to explore potential mechanisms for proper verification and compensation of EV participation in providing grid services, especially when the EV, EVSE, and the meter do not belong to the same customer account,

APPENDIX A: Data Validation

Vehicle Optimization Analysis

The study period for the vehicle-renewable integration optimizations started on October 15, 2018 and ended on November 10, 2018. Figure 20 shows the number of optimized vehicle-charging sessions by date over this time period. The purple boxes show the analysis dates that were included for the purposes of calculating the benefit of shifting charging using the excess supply signal. The 19 days included are: 10/16/2018 to 10/21/2018; 10/27/2018 to 11/3/2018; 11/5/2018 to 11/9/2018. The remaining dates were excluded due to a variety of issues described below.

Figure 20: Excess Supply Use Case Charging Sessions – Analysis Dates



Due to uncertainty on how charging patterns could be affected, vehicle charging sessions from dates with partial data are not included in the impact analysis. The dates that were excluded and the reasons for excluding them are listed in Table 9.

Table 9: Dates Excluded from Optimization Impact Calculations

Date	Day of Week	Reason
10/15/2018	Monday	Olivine detected and resolved an issue in the optimization code for the excess supply optimization approach.
10/22/2018 to 10/26/2018	Monday to Friday	Optimization requests to Olivine DER unexpectedly stopped on Monday, 10/22/218 5:17 PM. Sulzer detected and resolved an issue in their system and optimization requests started flowing again on Friday, 10/26/18 around 7:00 AM.
11/4/2018	Sunday	Olivine did not receive data from PG&E with the renewable excess supply signal.

Table 10: Dates Excluded from Load Increase Events

Date	Day of Week	Reason
10/18/2018 11:00	Thursday	Olivine identified an issue with how the first event was entered into the system
10/23/2018 10:00	Tuesday	Sulzer’s system was not generating optimization requests during this time
10/25/2018 12:00	Thursday	Sulzer’s system was not generating optimization requests during this time

Load Increase Event Analysis

BMW provided a list of 282 email addresses to identify those TCM participants who received day-ahead notifications of load increase events via push notification. In order to receive the push notification, customers must have the BMW ChargeForward pilot app downloaded and operating on their smart phone device. The study team compared the email address list to the list of current participants, as identified in a list jointly maintained by BMW and Olivine to identify enrollment status. Only those vehicles located in households with current registrations in CAISO's Demand Response Registration System (DRRS) were included in the analysis for the load increase event use case. 241 vehicles were included out of the 282 in the email list. Table 11 shows how the study team arrived at the final list of 241 vehicles based on matching to several different data sources.

Table 11: Vehicles Included in Load Increase Events

Explanation	**Vehicle Count**
Number of emails in notification list	282
Number that did not match active participant list (matched on email)	14
Remaining emails	268
Status is "Optimization Only" or "Resolvable" or "Closed"	20
Remaining emails	248
No vehicle match in Data Team files (to identify vehicle status during event)	7
Remaining Vehicle IDs (included in analysis)	241

APPENDIX B: Load Profiles

Figure 21: Load Increase Performance – Optimized Charging

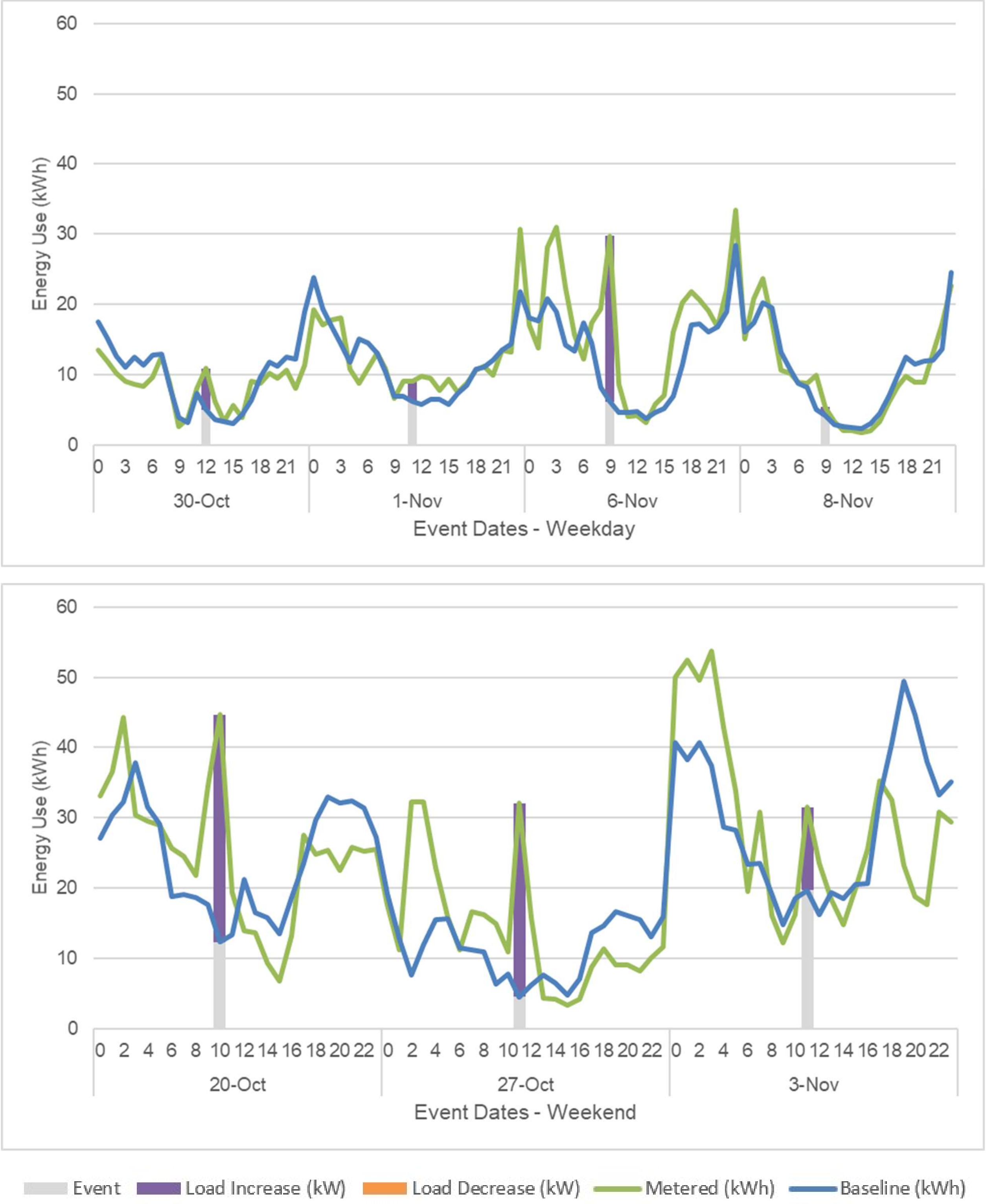


Figure 22: Load Increase Performance – Non-Optimized Charging

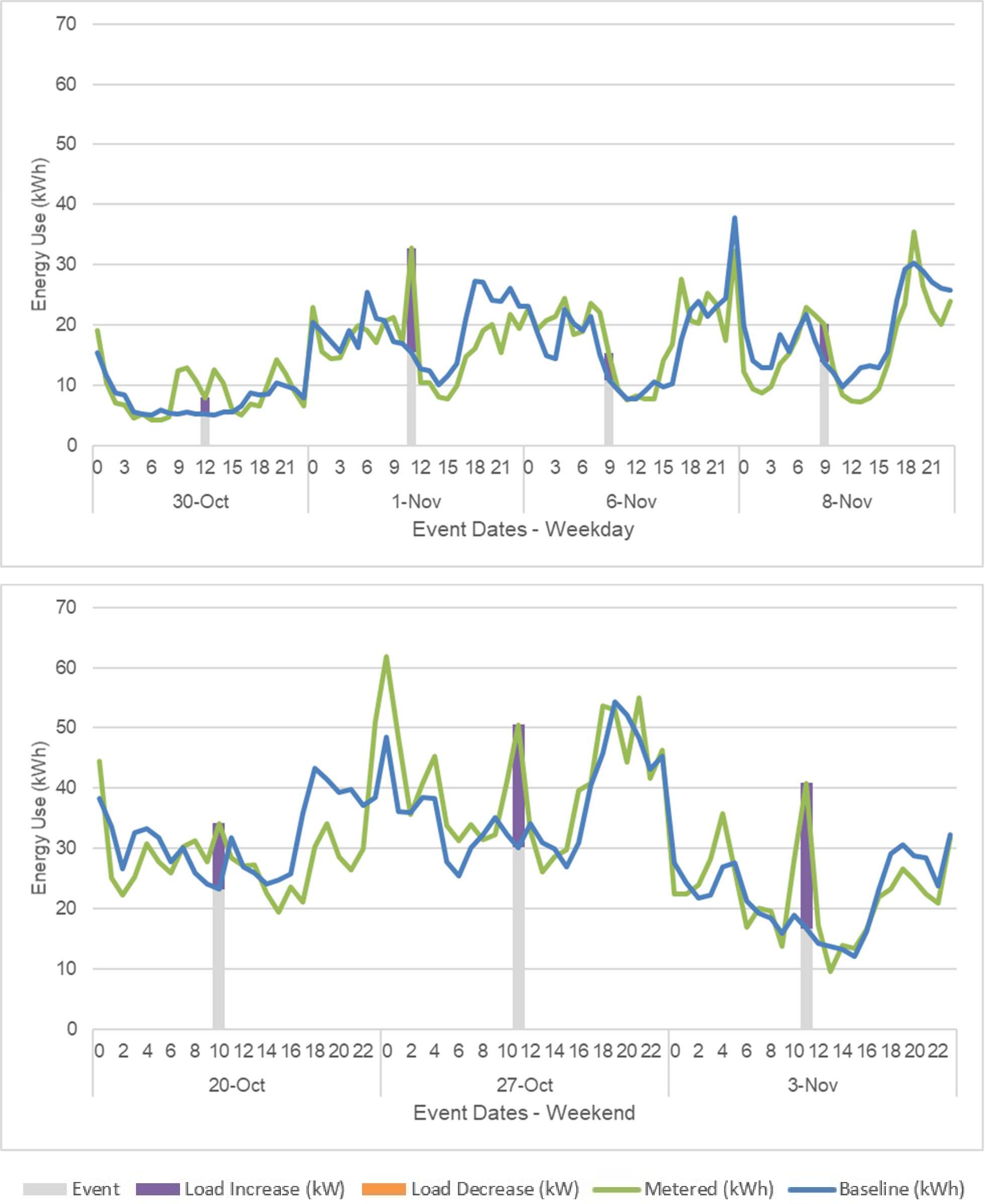


Figure 23: Load Increase Performance – Plugged In, Not Charging

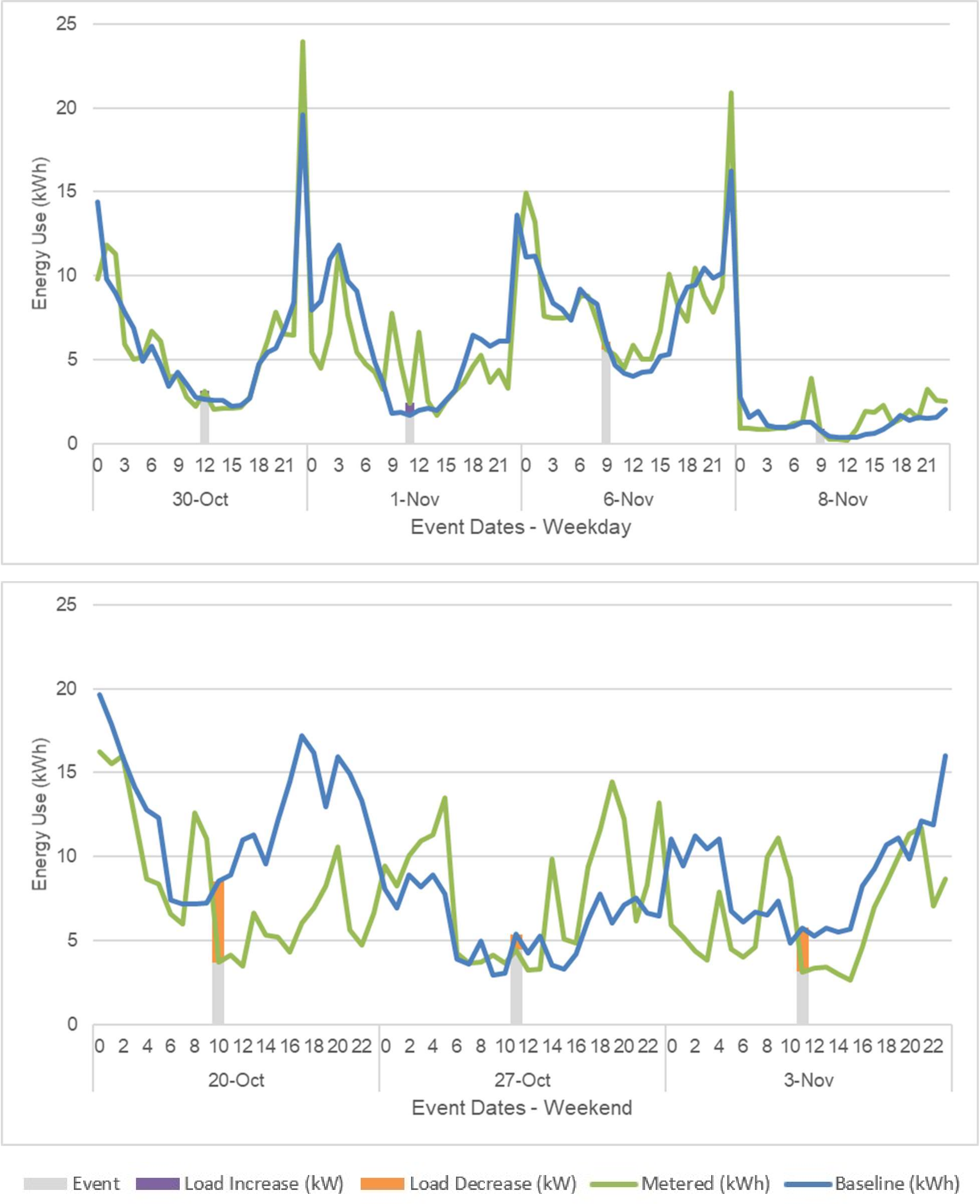


Figure 24: Load Increase Performance – Unplugged