NATIONAL GRID SMARTCHARGE MASSACHUSETTS EVALUATION

Full Phase A Final Report

National Grid

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Table of contents

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1 EXECUTIVE SUMMARY

This report presents the evaluation results and findings from Phase A of National Grid's Massachusetts Electric Vehicle (EV) Off-Peak Charging Program (also known as the SmartCharge ["SCMA"] Program and referred to throughout this report as "the Program"). The data and insights presented here include all charging data collected from the program launch in September 2020 through October 31, 2021.

The program, which is split into two phases, aims to understand current electric vehicle (EV) charging behaviors and the impact of price signals on participant charging behavior. The first phase, Phase A, began in September 2020. Data was collected through October 31, 2021, though the program ran through January 2022 to allow customers time to transition to a new data platform. Data collected during this phase was used to study the effects of off-peak charging price signals, as well as to develop a baseline and to understand current EV charging behavior. The second phase, Phase B, is scheduled to run from 2022 through late 2024, during which National Grid plans to integrate additional charging technologies to open the pool of participants. Data collected during both phases will help National Grid develop future rates and new load management techniques and mechanisms.

National Grid and Geotab Energy (Geotab), vendor for Phase A, recruited EV drivers in Massachusetts to participate in this program. Participants received EV charging data collection devices from Geotab that they installed in their vehicles to record all EV charging activities. DNV assisted National Grid in allocating participants into control and treatment groups on a rolling basis and structured the allocation process to include a baseline data collection period for all vehicles. The baseline period for all participants extended from the date of each participant's program enrollment through late March 2021. Starting in late March 2021, all participants received emails communicating the availability of the information dashboard and, for the treatment group, their eligibility to earn rebates for charging off-peak.

Note that all EV charging data collected for this evaluation occurred during the COVID-19 pandemic, which may have caused some participants to adjust their travel, commuting, and driving habits, with possible impacts to their charging behavior. However, it was not possible to directly assess the effects of COVID-19 on the observed charging behavior due to a lack of pre-pandemic charging behavior data for the participant population.

DNV completed the following evaluation activities for this effort:

- Allocated participants to vehicle type-stratified control and treatment groups using participant tracking data
- Assessed the initial observed EV charging behavior and effect of the program through an interim analysis and accompanying memo, completed in March 2021
- Assessed the overall effect of the program, including the following activities:
  - Conducted quality control (QC) on interval EV charging data from over 180,000 charging sessions
  - Assessed high-level program statistics describing aggregate EV charging behavior across 535 vehicles
  - Developed segmented EV charging load profiles by vehicle type and group
  - Conducted statistical regression analysis to assess the effectiveness of the off-peak charging rebate in shifting EV charging load off-peak

The key findings, recommendations, and considerations from this analysis are as follows:

Finding #1: Off-peak charging rebates work to increase off-peak charging. The SCMA off-peak charging rebates had a statistically significant positive effect on off-peak charging behavior, resulting in a shift of both kWh charged and charging sessions initiated to off-peak hours. The effect varied across vehicle types and was greatest for non-Tesla BEVs, followed by Tesla BEVs and PHEVs.

- Across all vehicle types, the treatment group charged 5.6% more of their kWh and initiated 3.3% more of their charging sessions off-peak than the control group (both statistically significant).
- Treatment group non-Tesla BEVs charged 10.5% more of their kWh off-peak than the control group (statistically significant). PHEVs and Tesla BEVs charged 1.5% and 4.0% more of their kWh off-peak than the control, respectively (not statistically significant).
- Treatment group PHEVs, non-Tesla BEVs, and Tesla BEVs initiated 1.1%, 4.4%, and 4.0% more of their charging sessions off-peak than the control group; however, none of these observations were statistically significant.

Finding #2: The off-peak rebate resulted in more weekday charging. Treatment group participants charged 3.1% more of their kWh during the week than the control group after being notified of their eligibility to earn off-peak charging rebates. This statistically significant trend is further evidence of the program working and appears to be a response to the program design, which rewards participants for charging off-peak during the week.

- **Consideration:** While this weekday shift is unlikely to represent a sizable increase in load (kWh) at current EV adoption rates, National Grid should consider the potential grid impacts of greater weekday charging under a future high EV adoption scenario and weigh the costs and benefits of incentivizing off-peak charging only during the week vs. on all days of the week as it develops future program offerings and time-of-use rates.

Finding #3: A majority of away-from-home (“away”) charging happens off-peak across all drivers. The majority of away charging took place off-peak – between 9 p.m. and 1 p.m. the next day on weekdays –with roughly 58% of control group and 63% of treatment group away weekday charging occurring off-peak.

- The average away charging session was 69% more energy intense than home charging (10.3 kWh/session vs. 6.1).
- Across all EV charging data collected in Phase A, 70% of kWh were charged at home and 80% of charging sessions occurred at home.
- Away charging peaks at 10 a.m. on weekdays and does not exhibit an evening increase in charging, which is consistent with workplace charging behavior. Most weekday away charging occurred between 8 a.m. and 5 p.m.

- **Consideration:** National Grid should consider collecting and integrating charging location data from current and future program offerings to assess on- and off-peak and location-based charging trends over time. As the EV charging network in Massachusetts continues to grow, EV adoption increases, and larger and more diverse types of vehicles, including fleet vehicles, begin electrifying at scale, it will be key to understand not only when charging occurs but where EVs are charging to model potential local grid impacts and support planning processes.

The remainder of this report presents a summary of the SCMA Program, DNV’s evaluation methodology, and details regarding results, findings, and recommendations.

2 INTRODUCTION

This section describes National Grid's Massachusetts EV Off-Peak Charging Program ("the Program") and the evaluation objectives for Phase A, spanning September 2020 through October 31, 2021. DNV (formerly ERS) was contracted to conduct an independent evaluation of Phase A of the SCMA Program.

2.1 SmartCharge Massachusetts Program overview

The Program aims to understand EV charging patterns and the effect of rebates in shifting EV charging from on-peak to off-peak hours. Participants' charging activity is measured by a Geotab monitoring device (C2 device), which plugs into a vehicle's onboard diagnostics port and records data while the vehicle is actively charging. National Grid defines the peak period as 1 p.m. to 9 p.m. on weekdays. Charging that occurs during off-peak hours from Monday through Friday is eligible to receive charging rebates; charging during the weekend is ineligible for off-peak charging rebates.[1] The off-peak charging rebates are 5 cents per kWh charged off-peak in the summer months and 3 cents per kWh charged off-peak during the non-summer months.[2] All participants also received $50 for installing their C2 device and recording their first charge, as well as an additional $50 for each year they keep the device plugged in.

To evaluate this program and determine the effects of rebates on participant charging behavior, DNV, National Grid, and Geotab conducted a randomized controlled trial (RCT). An RCT is a rigorous experimental approach commonly used in the medical and social science fields to test the effect of a treatment on a group of participants, minimizing bias by randomly allocating participants across treatment and control groups. The two groups receive different treatments during the experimental period, enabling assessment of the treatment on the outcome being measured. The program's intended experimental design is summarized in Table 2-1. Further details regarding the observed implementation of the program and the impact on the experimental design are provided in Section 2.1.1.

Table 2-1. Intended experimental design for SCMA Program Phase A evaluation

Participant Group	Baseline (rolling based on enrollment date; earliest start date is 9/1/20)	Intervention (rolling start date beginning after two full months of baseline data collection for each participant; ends on 10/31/21)
Control Group	Baseline period: participants are recruited, enroll, are activated in the program, and receive incentive for installing device. All participants receive access to the baseline dashboard.[3]	Participants receive access to an updated version of the program dashboard that provides additional insights into their driving and charging behavior.
Treatment Group		Participants receive notice of their eligibility to earn rebates for charging off-peak as well as access to an updated version of the program dashboard that provides additional insights into their driving and charging behavior. The notice of off-peak charging rebate eligibility includes the off-peak hours and rebate levels.

[1] Per the off-peak period definition (9 p.m. to 1 p.m. weekdays only), charging done from 12 a.m. Monday to 1 p.m. Monday is considered off-peak, as is charging done from 9 p.m. until midnight (12 a.m.) on Friday. These periods ensure that weekend charging is not eligible for off-peak charging rewards, even if completed between the hours of 9 p.m. and 1 p.m. the following day. For Monday (9 p.m. and later), Tuesday, Wednesday, and Thursday, the off-peak period is defined as 9 p.m. until 1 p.m. the next day.

[2] The summer months are June–September and the non-summer months are October–May.

[3] See Appendix A for a screenshot of this dashboard.

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2.1.1 Program Implementation Observations

During the implementation of the program, the communications notifying treatment group participants of their eligibility to earn off-peak charging rebates were not sent via email on the timeline outlined in Table 2-1. Following the delivery of the interim program evaluation memo in March 2021, which showed minimal effects through the first several months of data collection, the program team discovered that the emails had not been sent and subsequently notified all treatment group participants of their eligibility to earn off-peak charging rebates via email on March 24, 2021. In discussions immediately following this discovery, DNV recommended that an email should also be sent to all control group participants to maintain parallel messaging and similar communications timelines between the two groups; that email was sent two days later, on March 26, 2021. Both emails referred to the online dashboard and included a link to it, though no reference was made to the fact that the dashboard had been updated from the initial baseline dashboard all participants saw. Screenshots of these emails are included in Appendix B.

National Grid confirmed two additional details during these discussions:

1. Treatment group participants began earning off-peak charging rebates on the planned timeline, though they were not made aware of the rebates at that time
2. The updated dashboards were implemented on the planned timeline for both groups, though, as planned, no communication was sent to participants notifying them of these changes

Table 2-2 outlines the observed program implementation.

Table 2-2. Observed experimental design for SCMA Program Phase A evaluation

Participant Group	**Baseline** (rolling based on enrollment date; earliest start date is 9/1/20)	**Pre-Intervention** (rolling start date based on enrollment date; ends on 3/24/21[4] for all participants)	**Post-Intervention** (3/24/21–10/31/21)
Control Group	Baseline period: participants are recruited, enroll, are activated in the program, and receive incentive for installing device. All participants receive access to the baseline dashboard.[5]	Following a two-month baseline data collection period, participants receive access to control group version of online dashboard **but <u>are not notified</u> via email or sent a link.**	Participants receive an email on 3/26/21 containing a reminder of dashboard availability, with a link to the dashboard.
Treatment Group		Following a two-month baseline data collection period, participants receive access to treatment group version of online dashboard as well as off-peak charging rebates **but <u>are not notified</u> via email of rebate eligibility, rebate levels, or off-peak period definition.**	Participants receive an email on 3/24/21 notifying them of their eligibility to earn “additional rewards for charging during off-peak hours,” outlining the off-peak hours, rebate levels, and average potential monthly earnings, and reminding them of the dashboard availability (with a link).

Additional details on the three periods identified in Table 2-2 are included below.

Key program notes:

- During the baseline period, participating vehicles were randomly assigned to either the control or treatment group. The first random allocation occurred in November 2020, and additional allocations continued monthly through February 2021 as more vehicles enrolled in the program and met the group assignment eligibility criteria. As part of this allocation process, DNV ensured that the two groups were appropriately representative of the participating vehicles in the study

[4] For ease of implementation in the evaluation analysis, the 3/24/21 date on which treatment group participants were notified of the off-peak charging rebates was used as the end of the pre-intervention period for all participants.

[5] See Appendix A for a screenshot of this dashboard.

and balanced across vehicle types (see Table 4-1 for group breakdown). During the baseline period, all participants received access to the same dashboard containing basic information on their individual charging behavior.

- Following the baseline period – which extended for two months from each participant's enrollment and thus ended at different times for different participants – all participants received access to a group-dependent dashboard containing slightly different levels of information[6]. Treatment group participants also began earning rebates for charging off-peak at this time. However, contrary to what was intended in the initial program design, email communications notifying participants of the new level of dashboard access and, if applicable, rebate eligibility were not sent at this time.
- Following the discovery that email communications had mistakenly not been sent to program participants when intended, all participants received an email communication from the program team between March 24 and March 26, 2021, depending on their group:
  - Control group participants received emails reminding them about and containing a web link to the program dashboard.
  - Treatment group participants received emails notifying them of their eligibility to earn off-peak charging rebates. These emails defined the off-peak hours, rebate levels, and average potential monthly earnings and reminded participants of and contained a link to the program dashboard.

2.2 Evaluation objectives

The evaluation objectives are as follows:

1. Understand the charging behavior of EV drivers under current electricity pricing, including variation by geography, time, and vehicle characteristics
2. Assess the impact of the introduction of off-peak charging rebates on charging behavior, including measurement of the load shift from on-peak to off-peak and variation by geography, time, and vehicle characteristics

[6] The treatment group's dashboard, for example, shows an indication of the off-peak charging rewards earned as well as estimates of greenhouse gas emissions reductions and vehicle fuel efficiency. The control group's dashboard contains the same off-peak charging rewards panel, but the rewards are always "zero." See Appendix A for screenshots of these dashboards.

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3 METHODOLOGY

DNV analyzed the charging data collected through Phase A of the Program to determine the extent to which charging behavior was affected by the program. The scope of this analysis includes charging data recorded from September 2020 through October 2021. DNV completed the following activities: Data cleaning and quality control, initial analysis, and regression analysis, which are described in the sections below.

3.1.1 Data cleaning and quality control

The first phase consisted of the following steps:

1. **Participant group allocation.** During Phase A, DNV worked with National Grid and Geotab to randomly assign participating vehicles to either the control or treatment group. Random allocations were conducted from late November 2020 through February 2021.
    a. As part of the allocation process, the team ensured that the two groups were appropriately stratified so as to be representative of the participating vehicles in the study and balanced by vehicle type. National Grid's initial program enrollment efforts targeted a participant pool consisting of 35% Tesla BEVs, 35% non-Tesla BEVs, and 30% PHEVs.
    b. Participants did not initially receive any instruction, messaging, marketing, or price signal indicating when they should charge their EVs. During the allocation process, vehicles were considered eligible for allocation once they had met several eligibility criteria, including having recorded their first charge and having been in the program for at least two months. Upon enrollment, participants received access to an online dashboard showing a basic level of information about their charging behavior.
    c. Data was provided for a total of 546 vehicles during the analysis period; of those, 5 vehicles were never assigned to a group because they either swapped out their vehicle or withdrew from the program prior to assignment. DNV removed an additional 6 vehicles from the analysis because all their data failed quality control (QC), leaving a total of 535 vehicles whose data was eligible for inclusion in this analysis. There were 36 homes with multiple EVs in the study. Together, these homes accounted for 77 EVs, or 15% of the participating vehicles.
2. **Quality control.** DNV performed QC checks to ensure that blank, invalid, and inaccurate data was flagged for removal from the analysis. Examples of data the team omitted from the analysis include negative kWh or kW data and charge rates that exceeded a given EV model's maximum charge acceptance rate (kW). Of the over 1.8 million charging intervals analyzed across over 180,000 charging sessions, 93% of data points passed QC.[7]
3. **Filtering for eligible data.** As stated above, the team filtered the data to remove all charging intervals that failed QC.

3.1.2 Initial analysis

DNV conducted an initial analysis to quantify high-level program statistics and develop charging load profiles with 15-minute resolution. Only data that met the above criteria was included in this analysis, which included the following steps:

1. DNV calculated vehicle-level and program-level statistics, including total kWh charged and number of charging sessions by month, group, and vehicle type.
2. Per-vehicle average charging load profiles were constructed with 15-minute resolution and aggregated by vehicle type and group (treatment vs. control); load profiles were further segmented by month and day type (weekday vs. weekend).

[7] Some amount of out-of-bounds or blank data is typically expected with remote data collection equipment such as Geotab's C2 device; the QC process is designed to remove suspect data so as not to bias the analysis results.

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3. To assess the program's effectiveness, the percentage of kWh charged off-peak by month for each vehicle was calculated. A similar metric representing the percentage of charging sessions initiated off-peak by month for each vehicle was calculated to identify potential differences in observed behavior with that metric.

3.1.3 Statistical regression analysis

DNV developed two linear regression models[8] to test the effect of several independent variables on two separate dependent variables representing off-peak charging performance: 1) the per-vehicle monthly percentage of kWh charged off-peak (kWh model), and 2) the per-vehicle monthly percentage of charging sessions initiated off-peak (session start time model). Both metrics provide valuable insight into how Massachusetts EV drivers charge their vehicles.

- The kWh model reflects the program design of rewarding drivers who shift charging off-peak; however, the timing of when a vehicle consumes kWh is a function of several factors, including the plug-in time, the state of charge at plug-in, the battery size, and the level, or kW output, of the charger.
- The session start time model focuses on when charging sessions are initiated and more directly captures how participants have internalized the intent of the off-peak charging rebate.

DNV developed a difference-in-differences (DID) regression analysis designed to measure the effect of the price signal (off-peak charging rebates) plus the online dashboard on the treatment group's charging behavior relative to that of the control group, which received access to the online dashboard but did not receive off-peak charging rebates. Though the primary objective of the evaluation is to assess the effect of rebates on off-peak charging, DNV structured the regression analysis as a DID to control for any effect on off-peak charging behavior observed due to the introduction of the dashboard for both groups.

During the regression analysis, DNV iteratively introduced variables to determine the impact they had on the estimator values and the statistical significance of each estimator. The observations fed into these models represented the monthly percent of off-peak charging (both percent of kWh charged off-peak and percent of charging sessions initiated off-peak) for each vehicle in the program. The models control for charging behavior changes that occur over time or due to factors outside the scope of the experiment in order to fully capture the effect of the interventions and minimize the potential for bias in the results. Random assignment of the control and treatment groups also minimizes bias.

DNV structured the regression analysis to measure the effect on off-peak charging behavior of the communication of the treatment group's eligibility to earn off-peak charging rebates in late March 2021, which coincided with communications being sent to all participants reminding them of (and providing a web link to) the program web dashboard, where they could access insights regarding their individual charging behavior. Though the implementation of each group's planned interventions occurred several months earlier – with all participants receiving access to the correct dashboard for their group, and treatment group participants beginning to earn off-peak charging rebates, as each participant's two-month baseline period ended – participants' off-peak charging behavior was not expected to shift in response to these interventions without the participants being made aware of them. As such, the regression features two periods:

- **Baseline period,** which includes all data recorded prior to April 1, 2021
- **Post-intervention period,** which includes all data recorded on and after April 1, 2021

These models have the following structure, where T is a dummy variable for the treatment group; P is a dummy variable for the period following the email communication being sent to all participants in late March 2021 ("post-intervention period")[9];

[8] DNV selected a linear model over other types of models (e.g., the logit model) because the behavior being modeled could take any value between 0% and 100%. Had the observed behavior gravitated toward either end of that spectrum, suggesting that most drivers tended to charge either all on-peak or all off-peak, the logit model would have been more appropriate, as it is designed to model such pass/fail events.

[9] The "post-intervention period" starts April 1, 2021, to capture the first full month of charging data after the interventions were communicated to participants. The "baseline period," conversely, includes each participant's data from their first charge through March 31, 2021.

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and *T x P* is the interaction of the treatment and post-intervention period variables (treatment group participants in the post-intervention period):

$$y = \beta_0 + \beta_1 T + \beta_2 P + \beta_3 (T \times P)$$

The coefficients represent the modeled incremental per-vehicle percentage of off-peak charging introduced by “turning on” the respective variable:

- β_0 represents the level of off-peak charging for the control group in the baseline period (base case),
- β_1 represents the incremental off-peak charging of the treatment group in the baseline period,
- β_2 represents the incremental off-peak charging of all participants during the post-intervention period[10],
- β_3 represents the incremental off-peak charging of the treatment group during the post-intervention period.

[10] While this variable is technically defined to describe only the control group's charging behavior (consistent with the definition of β_0), per the DID model specification it is assumed that any exogenous/time-dependent effects experienced by the control group are experienced equivalently by the treatment group. As such, it is appropriate to define this variable as summarizing the observed effect on “all participants.”

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4 RESULTS AND FINDINGS

DNV conducted a full analysis covering all Phase A charging data in November 2021 to evaluate the effectiveness of the off-peak price signal in shifting EV charging load to off-peak hours. As part of these efforts, the team cleaned and analyzed the charging data to characterize the vehicles participating in the program, developed average charging load profiles across multiple time horizons, and assessed the prevalence and timing of both on-peak and off-peak charging to determine the impact of the off-peak charging rebate.

Note that all EV charging data collected for this evaluation occurred during the COVID-19 pandemic, which may have caused some participants to adjust their travel, commuting, and driving habits, with possible impacts to their charging behavior. However, it was not possible to directly assess the effects of COVID-19 on the observed charging behavior due to a lack of pre-pandemic charging behavior data for the participant population.

This section presents the Phase A evaluation results and findings for the SCMA Program, which include program summary statistics, charging load profile analysis, statistical regression results, and key findings.

4.1 Program statistics

DNV analyzed the overall program charging activity recorded during Phase A, summarized in Table 4-1 below. Table 4-1 summarizes charging behavior from September 2020 through October 2021. The SCMA Program is available for both battery electric (BEV) and plug-in hybrid electric (PHEV) vehicles, with three mutually exclusive vehicle types, or strata, used during the random allocation process. These vehicle types were selected to provide a representative view of the EV pool in Massachusetts. Initial program enrollment efforts targeted a participant pool consisting of 35% Tesla BEVs, 35% non-Tesla BEVs, and 30% PHEVs. The vehicle strata presented in this analysis reflect the allocation of participating vehicles into the control and treatment groups as individuals enrolled in the program. Tesla BEVs are defined as any Tesla vehicle – Model S, Model 3, Model X, or Model Y – while non-Tesla BEVs are defined as any non-Tesla all-electric vehicle. This distinction among BEVs was made to capture the fact that Tesla has the highest market share among EV manufacturers and its vehicles have exclusive access to its proprietary Supercharger network of direct-current fast chargers (DCFC), sometimes at subsidized or zero cost.[11] PHEVs are vehicles that have both an electric battery and an internal combustion engine.

Table 4-1. Program summary statistics

Group	Vehicle Stratum	Vehicle Count*		kWh Charged**		Charge Sessions‡	
		Total	Percent of Group	Overall	Per Vehicle	Overall	Per Vehicle
Control	PHEV	93	35%	135,601	1,458	37,077	399
	Non-Tesla BEV	90	34%	166,419	1,849	20,046	223
	Tesla BEV	79	30%	285,936	3,619	34,236	433
Total	**All**	**262**	**100%**	**587,956**	**2,244**	**91,359**	**349**
Treatment	PHEV	96	35%	145,408	1,515	36,239	377
	Non-Tesla BEV	92	34%	194,980	2,119	22,673	246
	Tesla BEV	85	31%	335,040	3,942	31,463	370
Total	**All**	**273**	**100%**	**675,429**	**2,474**	**90,375**	**331**
Overall Total		**535**		**1,263,385**	**2,361**	**181,734**	**340**

* DNV ran a Chi Square Test to test the equivalency of the control and treatment groups. With a p-value of 0.969, the test indicates there is no statistically significant difference in the groups' composition.

[11] Direct-current fast charging (DCFC) is the fastest type of commercially available EV charging. It typically features charging speeds of at least 50 kW and can restore approximately 80% of an EV's charge in as little as 15-30 minutes.

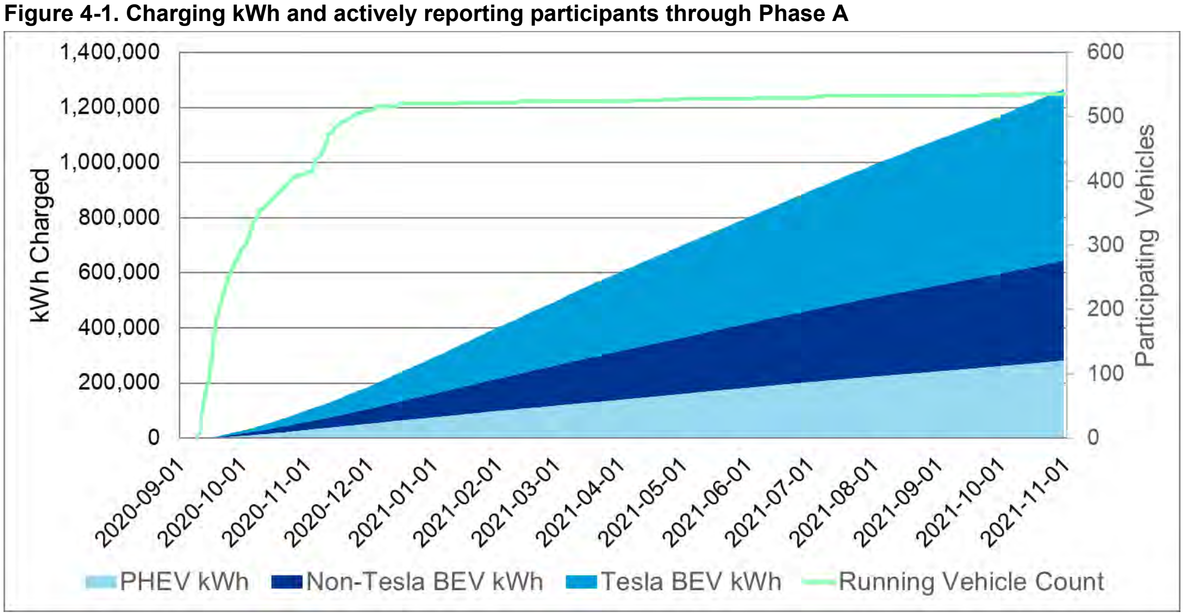
** DNV ran an independent samples t-test to assess the statistical significance of differences in the amount of kWh charged per vehicle. Across all vehicle types, the differences observed between the control and treatment group were not found to be statistically significant, which indicates that the drivers in each group behave similarly in terms of the overall volume of charging they do (though, as will be discussed later, the timing of that charging differs significantly between the two groups).
‡ DNV ran an independent samples t-test to assess the statistical significance of differences in the number of charge sessions per vehicle. Across all vehicle types, the differences observed between the control and treatment group were not found to be statistically significant, which indicates that the drivers in each group behave similarly in terms of how often they plug in (though, as will be discussed later, the timing of those charging sessions differs significantly between the two groups).

Several observations can be drawn by examining the high-level program charging data. This analysis was conducted to provide an overview of aggregate charging behavior and to allay concerns that the groups are fundamentally unbalanced, which could hinder drawing conclusions throughout the rest of the analysis.

- Per-vehicle charging volume and frequency reflect differences in vehicle strata composition.
  - Tesla BEVs charged the most kWh/vehicle, followed by non-Tesla BEVs and PHEVs, in both groups
  - Conversely, PHEVs (treatment) and Tesla BEVs (control) had similarly high charging session per vehicle metrics
  - In general, these trends reflect differences in EV technology, battery size, and driving behavior across vehicle types, with PHEVs requiring more frequent charging due to their small batteries and Tesla BEVs tending to be driven, and thus charged, more due to their large battery sizes
- The overall amount of charging (kWh) is statistically equivalent between the control and treatment groups across all three vehicle types when normalized by the count of vehicles in each group.
  - The control group charged 2,244 kWh/vehicle and the treatment group charged 2,474 kWh/vehicle, a delta of around 9.3%.
  - This confirms that there are no statistically significant differences between the two groups that would hinder direct comparisons of their off-peak charging performance.
  - This observation is also consistent with the program goal of shifting when charging occurs, rather than the amount of charging taking place.

Figure 4-1 provides another view of the program activity through Phase A; it highlights the simultaneous growth of the charging load and the number of assigned program participants. Note that, because group assignments were conducted monthly, the participant count did not increase smoothly.

Figure 4-1. Charging kWh and actively reporting participants through Phase A



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4.1.1 Rebate Analysis

A total of $11,591 in off-peak charging rebates were earned by the treatment group, based on a total of 202,644 kWh charged off-peak during non-summer months and 110,234 kWh charged off-peak during the summer months. Per the program's off-peak definition, only weekday charging was included in this analysis. Table 4-2, below, provides a breakdown of the average rebates earned per-vehicle per-month over the course of Phase A.[12]

Table 4-2. Breakdown of average monthly off-peak charging rebates earned by vehicle type and period

Program period	PHEV	Non-Tesla BEV	Tesla BEV
Non-summer	$1.67	$2.51	$4.64
Summer	$3.27	$4.71	$9.45
Total	**$2.16**	**$3.19**	**$6.12**

Table 4-3, below, provides a breakdown of the average per-vehicle rebates earned per session for Level 1 and Level 2 charging sessions, which are the most common type of charging session and the two types of charging that occur at home.

Table 4-3. Breakdown of average per-session off-peak charging rebates earned by vehicle type and session type

Session type	Period	PHEV	Non-Tesla BEV	Tesla BEV
Level 1	Non-summer	$0.08	$0.08	$0.07
	Summer	$0.21	$0.15	$0.11
Level 2	Non-summer	$0.23	$0.40	$0.47
	Summer	$0.35	$0.71	$0.84

This analysis shows that the average per-session earnings tend to vary by session type and vehicle type. For Level 1 sessions, the average non-summer per-session rebate is between $0.07 and $0.08 per session across all vehicle types. In the summer, PHEVs earn the most per session, followed by non-Tesla BEVs and Tesla BEVs; this is because PHEVs conduct more Level 1 charging than the other vehicle types. The opposite is true for Level 2 sessions, with Tesla BEVs earning the most per-session in all months, followed by non-Tesla BEVs and PHEVs. This trend corresponds directly to the average kWh charged per session.

4.1.2 Charging behavior over time

In addition to calculating high-level program statistics, DNV developed higher resolution statistics to evaluate time-varying EV charging behavior.

4.1.2.1 Monthly charging behavior analysis

Figure 4-2 provides a month-by-month view of the average kWh charged per vehicle throughout Phase A.

[12] This analysis excluded data from September 2020 because it was a partial data collection month during which vehicles were enrolling in the program.

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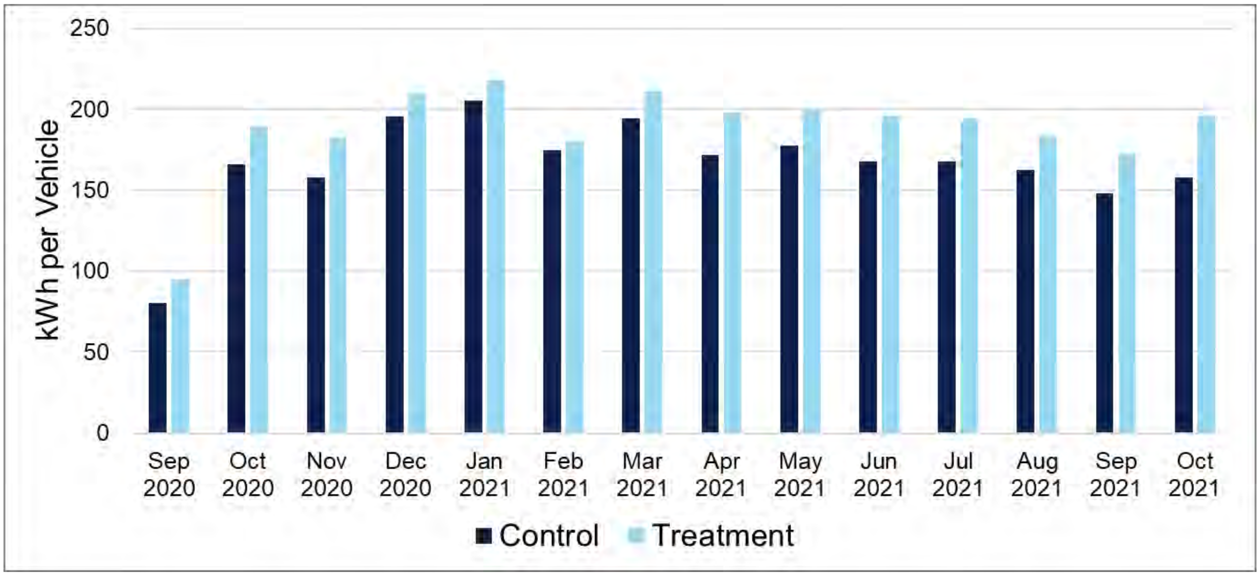
Figure 4-2. Monthly kWh per vehicle for Phase A



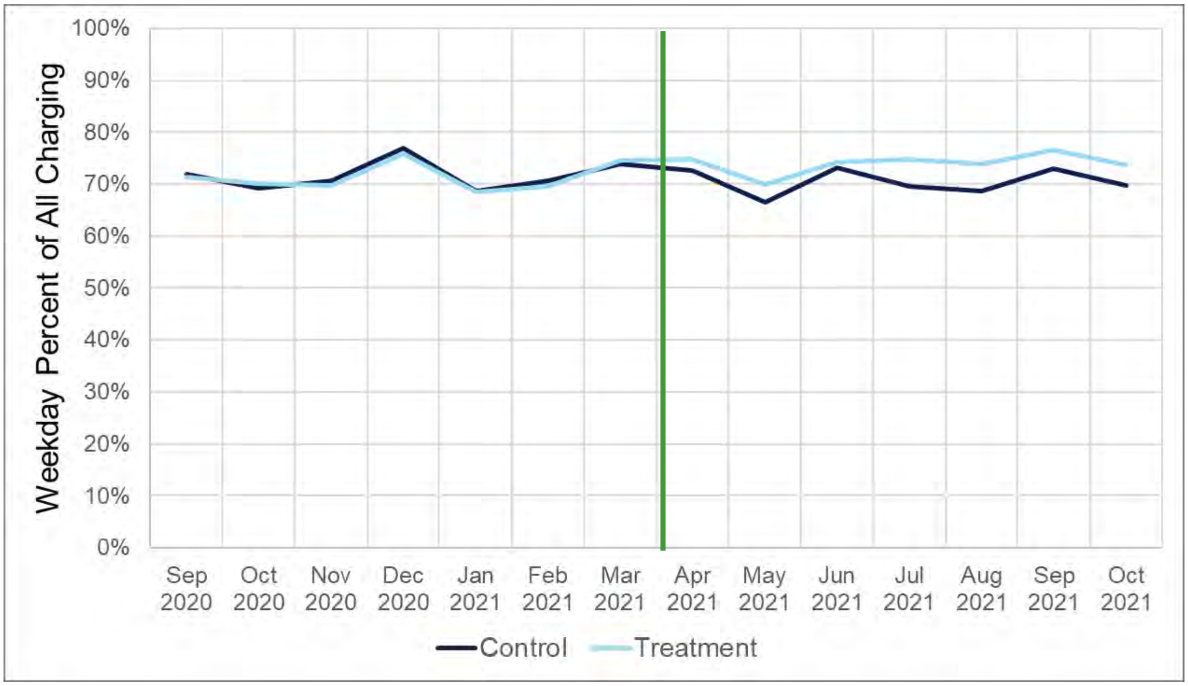
The data recorded to date shows that the per-vehicle monthly charging load peaked in January 2021, dropped in February (likely due to the short month), and bounced back in March before declining steadily until September 2021, at which point the amount of charging per vehicle increased for both groups in October 2021. The control group's October 2021 charging activity was 5% lower than the activity observed a year prior, in October 2020; the treatment group's charging activity was 3.5% higher. This relative similarity in year-over-year charging activity across both groups suggests a potential seasonal trend, with the amount of charging increasing in the winter due to a combination of increased driving activity and less efficient energy consumption. Changes in driving activity could result from schedule changes, increased holiday travel, or other factors, while reduced EV efficiency would be driven by increased energy requirements to maintain comfortable interior cabin conditions and the energy demands of the battery thermal management system. Note also that the September 2020 charging load is lower than the other months due to the program rolling out mid-month and the first participants beginning to enroll and install their C2 devices; it is a partial data collection month. Note also that it was not possible to determine the possible effect of the COVID-19 pandemic on monthly per-vehicle charging behavior due to the lack of pre-pandemic charging data for the program.

4.1.2.2 Weekly charging behavior analysis

DNV also assessed participant charging behavior across day type to assess any trends that emerged following the introduction of and communication of the treatment group's eligibility to earn off-peak charging rebates. Because the program's peak period definition rewards participants for charging off-peak during the week but not on the weekend, DNV hypothesized that the treatment group might begin to shift more charging toward the week to maximize their earnings. The team also considered the possibility that the treatment group's weekend proportion of charging would not change significantly, especially if they seemed to employ a "set it and forget it" approach to scheduling their charging either in-vehicle, through a smart home EV charger, or through another application, in which case they might not differentiate between weekdays and weekends. In that scenario, National Grid could potentially reap the benefits of shifting weekend EV charging to off-peak hours while minimizing its total spend on rebates to achieve that result.

The results of this analysis are shown in Figure 4-3, which highlights the proportion of weekday charging month-by-month for the control and treatment groups. The green line highlights the point at which the treatment group was made aware of its eligibility to earn off-peak charging rebates; the first full month following those communications was April 2021.

Figure 4-3. Proportion of weekday charging by group and month



As shown above, the proportion of weekday charging conducted by the two groups tracked closely from September 2020 through March 2021. Starting in April 2021 – the first full month following the communication of the treatment group's eligibility to earn off-peak charging rebates – the treatment group's weekday charging increased relative to the control group's and remained higher for the remainder of Phase A. The largest delta between groups occurred in July and August 2021, when the treatment group conducted an average of 5.3% more charging during the week than the control group did. On average over the months from April to October 2021, the treatment group charged 3.5% more kWh during the week, compared to conducting 0.3% *less* kWh during the week from September 2020 through March 2021. It is also worth noting that from September 2020 through March 2021 the delta between the groups was less than 1%, which supports the conclusion that the two groups behaved similarly prior to April 2021.

DNV ran a regression analysis to determine the statistical significance of the delta. This analysis showed that the treatment group had a statistically significant 3.0% higher weekday charging rate than the control group between April and October 2021; from September 2020 through March 2021, the two groups charged on weekdays at statistically equivalent rates. The team did not observe a statistically significant increase in weekday charging during the summer months relative to non-summer months, despite summer rebate levels being higher. This relatively small shift suggests that the potential to earn rebates for charging off-peak during the week spurred participants in the treatment group to shift charging to weekdays to maximize their earnings. While the weekday shift is unlikely to represent a sizable increase in weekday load (kWh) given current levels of EV adoption, National Grid should consider the potential grid impacts under a future with high EV adoption and weigh the costs and benefits of incentivizing off-peak charging only during the week vs. on all days of the week as it develops future program offerings and time-of-use rates.

4.1.3 Charging location insights analysis

DNV also conducted an analysis of charging activity by location, using data provided by Geotab that indicated whether a charging session took place at a participant's home address ("home charging") or away from home ("away charging"). This analysis of the geospatial charging data shows that just over 70% of kWh are charged at home, while 80% of charging sessions occur at home. Figure 4-4 and Figure 4-5 show the proportion of home charging by group over time, focusing on kWh charged and charging sessions, respectively.

Figure 4-4. Proportion of kWh charged at home by group and month – Phase A

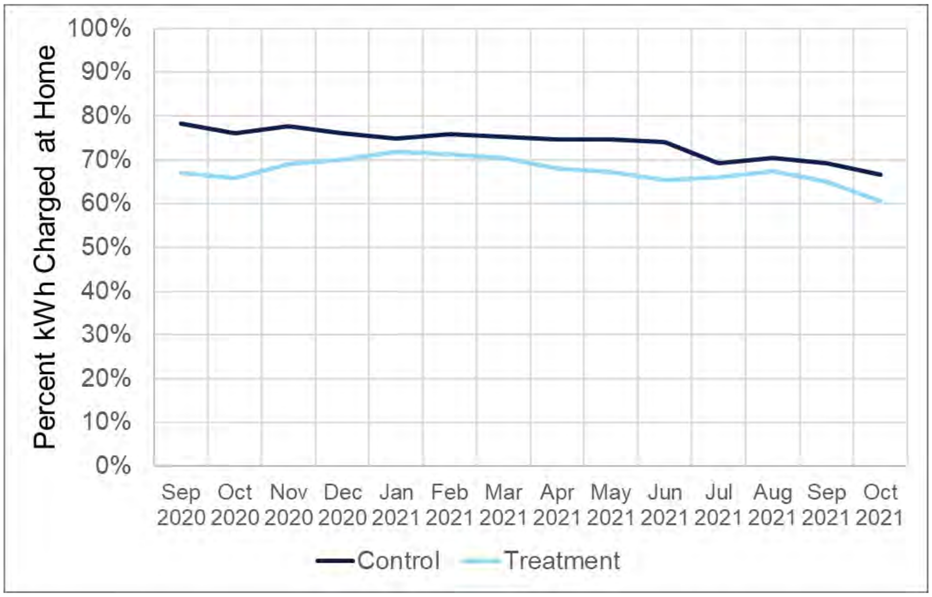
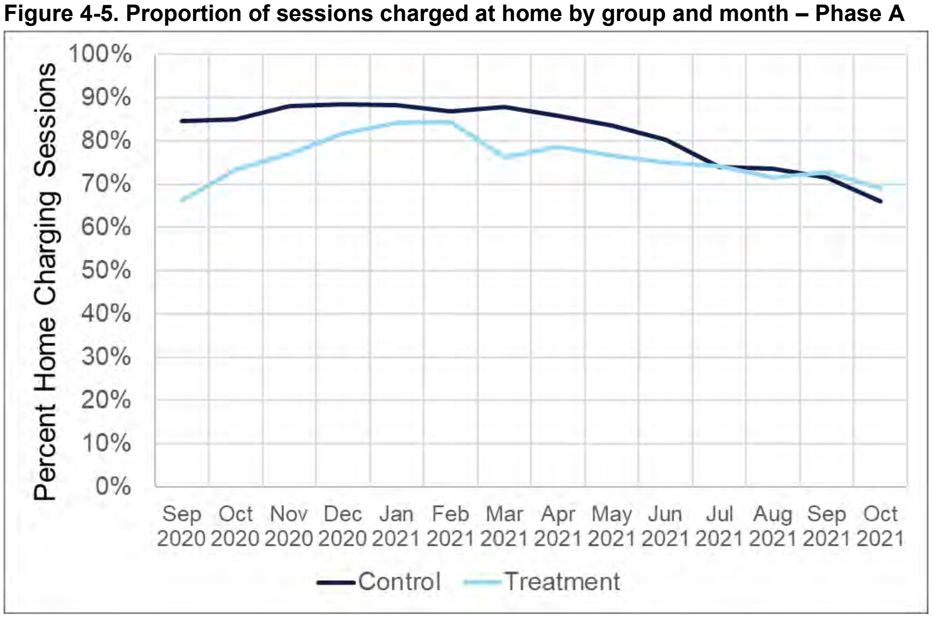


Figure 4-5. Proportion of sessions charged at home by group and month – Phase A



While home charging accounted for more charging sessions overall – 80% across both groups and all of Phase A – it only accounted for 70% of kWh charged, indicating that away charging sessions deliver proportionally more energy per session.

Further analysis into the charging intensity for home and away sessions shows that the average home charging session intensity is 6.1 kWh/session, while the average away charging session intensity is 10.3 kWh/session. Away charging sessions thus typically result in about 69% more charging delivered per session. This is not a surprising finding, per se, since high-powered DCFC charging occurs outside the home and has power ratings ranging from 50 kW up to 250 kW, thus delivering more kWh per unit of time and per charging session. However, since only 1.8% of charging sessions recorded in Phase A are estimated to have occurred at DCFC stations, it is not likely that DCFC charging alone is driving these figures. It is also possible that non-residential Level 2 charging stations in the region have higher power ratings than participants' home chargers. Additional research would be needed to assess the average charge rates of the regional public charging network.

There are two other trends worth noting: the month-to-month variation in home vs. away charging rates and the consistent delta between the control and treatment group. Over the course of Phase A, more charging sessions took place at home during winter 2020-2021 across both groups, peaking at 88.5% for the control group in December 2020 and 84.5% for the treatment group in February 2021. The proportion of home charging consistently dropped for both groups from April to October 2021, dropping from 86% to 66% of sessions for the control group and 79% to 69% of sessions for the treatment group. It is possible that this shift to more frequent away charging was driven by a combination of changing temperatures (seasonality) and the changing intensity of the COVID-19 pandemic throughout 2021; however, without pre-pandemic charging data, it is not possible to determine a specific driver of this observed behavior. Additionally, the control group tended to charge more at home than the treatment group throughout the majority of Phase A, with control group participants charging more kWh at home in all months and recording more charging sessions at home for 11 of 14 months. However, this trend was not statistically significant when looking at aggregate home and away charging behavior across all vehicle types and all data collected during Phase A.

Table 4-4 summarizes the home vs. away charging statistics to date for charging kWh and charging sessions, by group and month.

Table 4-4. Proportion of home charging by group and month – multiple metrics

	Percent of kWh Charged at Home		Percent of Home Charging Sessions	
Month	**Control**	**Treatment**	**Control**	**Treatment**
Sep 2020	78.4%	67.0%	84.6%	66.4%
Oct 2020	76.1%	65.8%	85.0%	73.5%
Nov 2020	77.7%	68.9%	88.2%	77.2%
Dec 2020	76.0%	70.0%	88.5%	81.7%
Jan 2021	74.9%	71.8%	88.3%	84.3%
Feb 2021	75.9%	71.3%	86.9%	84.5%
Mar 2021	75.3%	70.5%	87.8%	76.2%
Apr 2021	74.6%	68.1%	86.0%	78.8%
May 2021	74.6%	67.2%	83.6%	76.6%
Jun 2021	74.1%	65.5%	80.4%	75.2%
Jul 2021	69.2%	65.9%	74.0%	74.2%
Aug 2021	70.5%	67.4%	73.5%	71.7%
Sep 2021	69.1%	65.0%	71.7%	72.8%
Oct 2021	66.7%	60.5%	66.2%	69.2%
Total	**73.6%**	**67.6%**	**82.8%**	**77.3%**

DNV also assessed the timing of home and away charging for both groups over the course of Phase A. Figures 4-6 through 4-9, on the next two pages, present 24-hour histograms showing the total hourly kWh charged for each group for both away and home charging; Figures 4-6 and 4-7 represent weekday charging and Figures 4-8 and 4-9 represent weekend charging. All Phase A data is included in these figures, including data recorded both before and after the communication of the treatment group's eligibility to earn off-peak charging rebates. The two sets of graphics are set to the same y-axis value to highlight the relative prevalence of home and away charging on both weekdays and weekends as well as the hourly trends for charging at each location.[13]

[13] That is, Figures 4-6 and 4-7 are on the same axis as each other and Figures 4-8 and 4-9 are on the same axis as each other.

Figure 4-6. Hourly breakdown of weekday away charging by group – Phase A

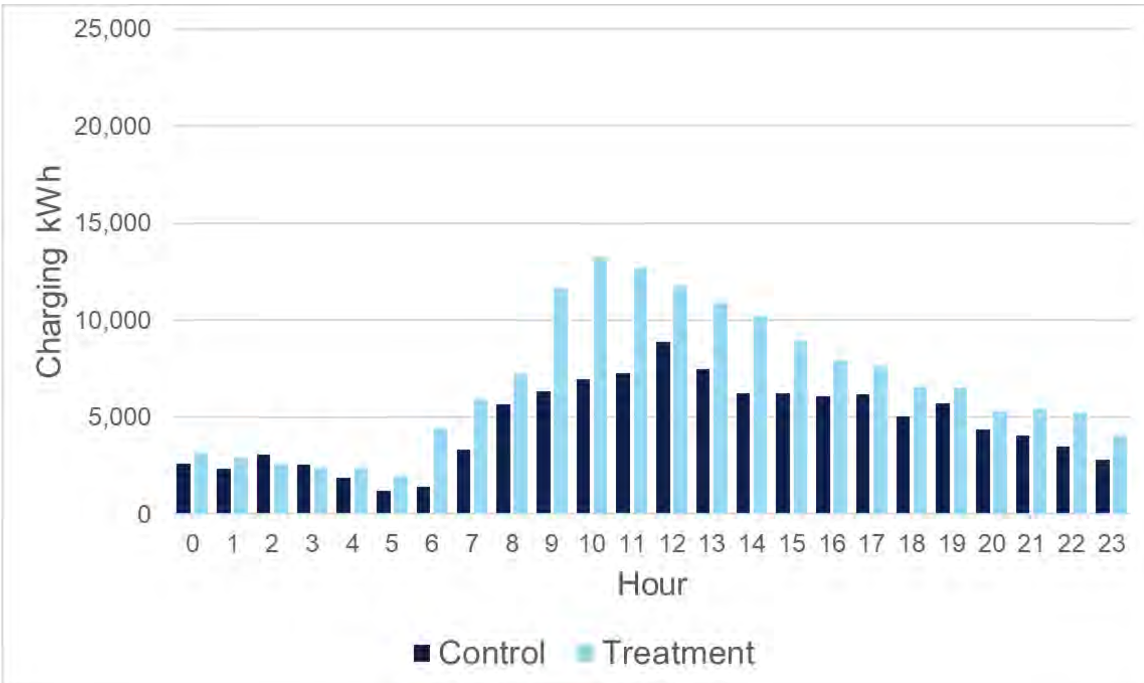


Figure 4-7. Hourly breakdown of weekday home charging by group – Phase A

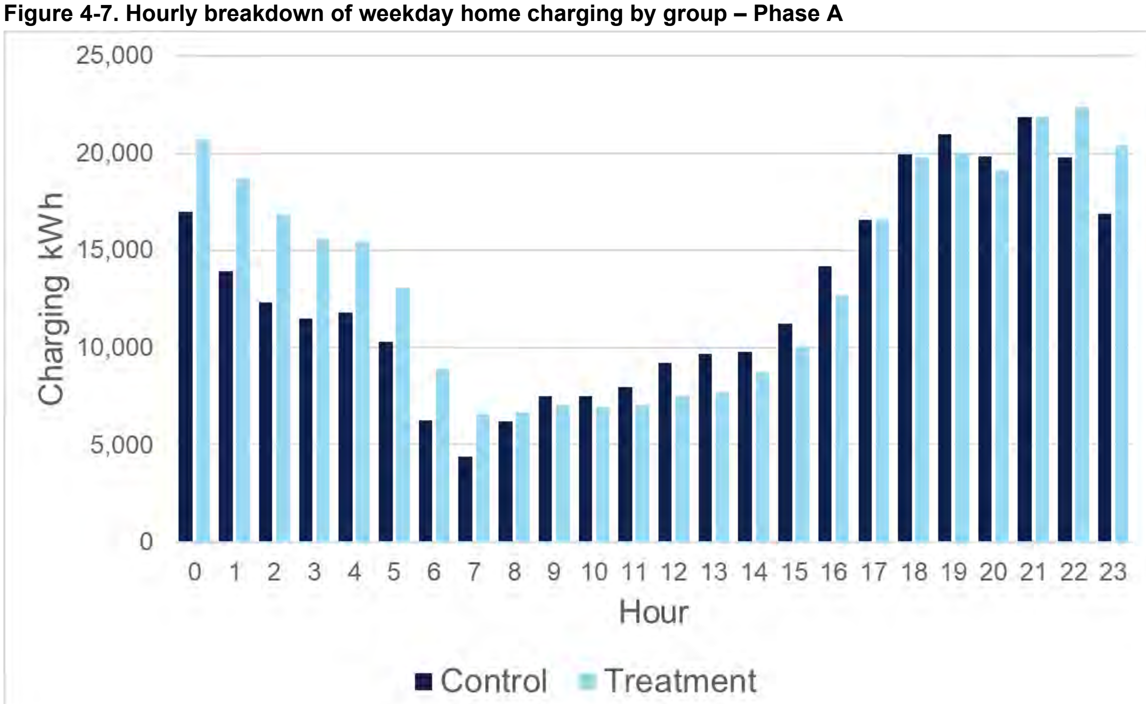


Figure 4-8. Hourly breakdown of weekend away charging by group – Phase A

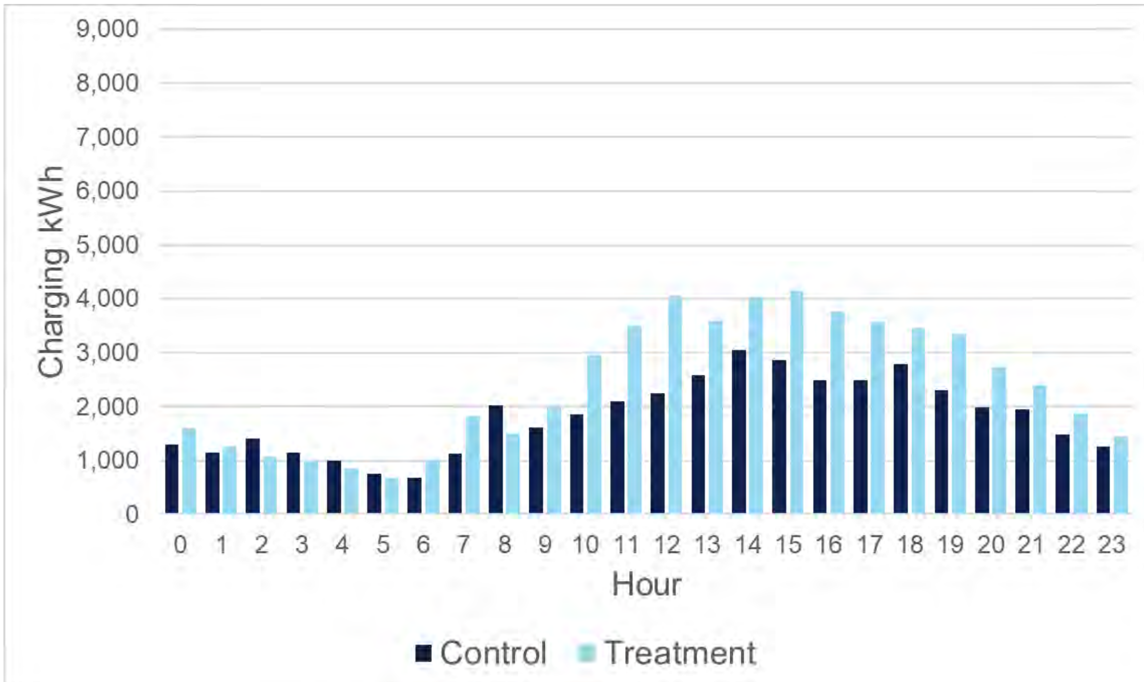
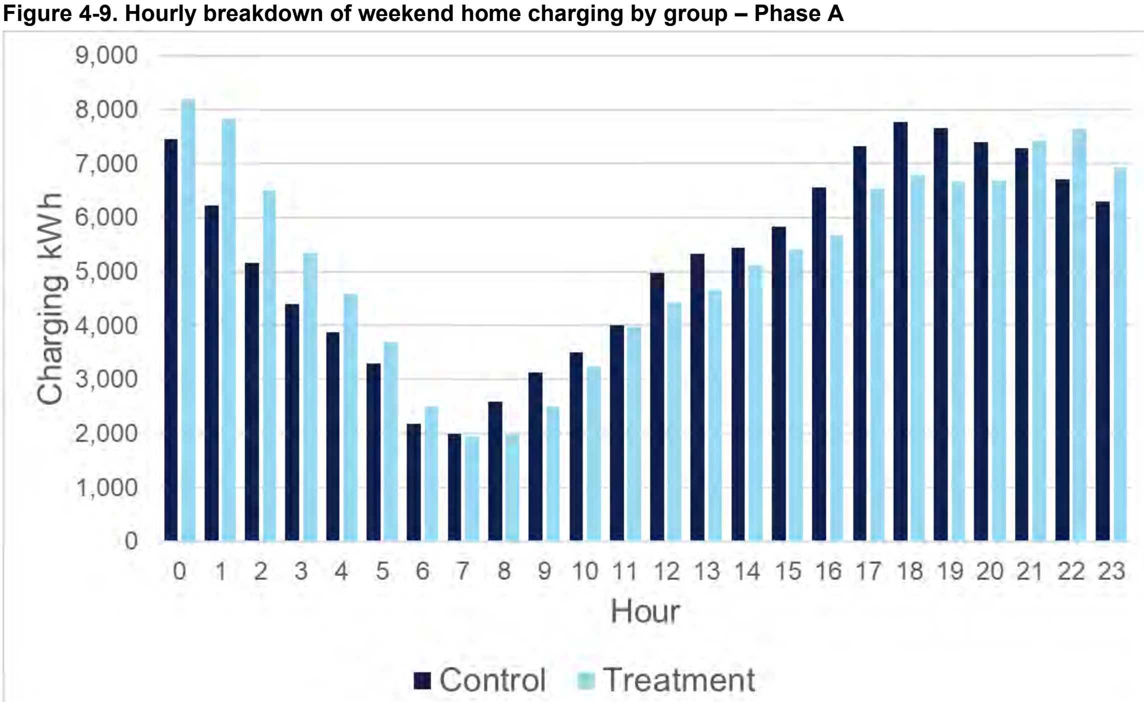


Figure 4-9. Hourly breakdown of weekend home charging by group – Phase A



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These figures show a clear distinction between when home and away charging occur throughout the day and on different day types. The observations from this analysis are summarized below.

- Weekdays:
  - Weekday away charging ramps up between 6 and 7 a.m., peaking at approximately 10 a.m. before steadily decreasing throughout the rest of the day. Notably, there is no evening bump in away charging, and overnight charging occurs at low levels. This behavior is consistent with workplace charging, with participants plugging in their vehicles as they arrive at their office to charge up.
  - Weekday home charging ramps up throughout the day, beginning around 8 a.m. and beginning to plateau around 6 p.m. The midday ramp is not steady, however; it begins slowly and then accelerates between 3 and 6 p.m. The evening load, from 6 p.m. until midnight, remains relatively high before falling off overnight as batteries hit full charge.
  - Significantly more weekday charging occurs at home.
- Weekends:
  - Weekend away charging begins to ramp between 7 and 8 a.m. and plateaus between approximately 12 and 3 p.m. before falling off throughout the evening and early morning hours. Notably, the weekend away charging peak occurs several hours after the weekday peak, which is consistent with altered weekend schedules and a lower likelihood that participants are using workplace chargers.
  - Weekend home charging also begins to increase around 8 a.m. and peaks around 6 p.m., similar to weekdays. However, there is a steady increase in weekend charging throughout the afternoon compared to the slow-then-fast ramp observed on weekdays. This behavior is consistent with altered weekend schedules as well as the fact that off-peak charging rebates cannot be earned for weekend charging, reducing the incentive for participants to avoid charging during the afternoon.
  - As with weekday charging, significantly more weekend charging occurs at home.

Finally, DNV also assessed the on-peak vs. off-peak coincidence of home and away charging for both groups over the course of Phase A. Table 4-5 summarizes the results of this analysis, which included only weekday charging, per the program's peak period definition. Note that the treatment group data includes all of Phase A, including data recorded both before and after the communication of this group's eligibility to earn off-peak charging rebates.

Table 4-5. Crosstab of on-peak vs. off-peak coincidence of home and away charging by group – kWh charged

		On-peak	Off-peak	Total	Percent Off-peak
Control	Home	164,312	143,900	308,211	46.7%
	Away	47,081	65,379	112,460	58.1%
	Control Subtotal	**211,392**	**209,279**	**420,671**	**49.7%**
	Control - Percent Home Charging	**77.7%**	**68.8%**	**73.3%**	
Treatment	Home	159,097	173,155	332,251	52.1%
	Away	59,235	103,392	162,627	63.6%
	Treatment Subtotal	**218,332**	**276,547**	**494,878**	**55.9%**
	Treatment - Percent Home Charging	**72.9%**	**62.6%**	**67.1%**	
	Overall Total	**429,724**	**485,826**	**915,550**	

This crosstab shows the following:

- For the control group:
  - The majority of home charging is conducted **on-peak**, with only 46.7% of home kWh charged occurring off-peak.
  - The majority of away charging – 58.1% – is conducted off-peak.
- For the treatment group:
  - The majority of home charging – 52.1% – is conducted **off-peak**.
  - The majority of away charging – 63.6% – is conducted off-peak.
  - This analysis shows that the treatment group charges more off-peak for both home and away charging than the control group. Section 4.3 focuses on the regression analysis conducted to assess the impact of the program on each group's off-peak charging performance.

The fact that away charging, which is 69% more energy intense than home charging, occurs off-peak is positive from a grid management standpoint. However, it will be critical to assess this trend over time, particularly as the EV charging network in Massachusetts continues to grow, EV adoption increases, and larger and more diverse types of vehicles, including fleet vehicles, begin electrifying at scale. Understanding when, where, and at what power level EVs are charging can be used to support the modeling of grid impacts and grid planning processes.

4.2 Charging load profile analysis

DNV developed 24-hour charging load profiles with 15-minute resolution for several combinations of the control and treatment groups during different periods of the program using the following method:

- For each vehicle included in the analysis, DNV calculated a full charging load profile (kW) spanning the vehicle's group assignment date through the end of Phase A; for participants who withdrew or vehicles that were swapped out mid-program, the last day they provided data was used as their endpoint. This approach considers periods during which data was not available because the vehicle was not charging (as having 0 kW of charging load) and ensures that the average load profile is not diluted for vehicles that were assigned to a group after the Phase A start date of September 1, 2020.
- The team then calculated an average hourly charging load profile (kW) for each vehicle, weighting every hour and day in the analysis period equally.
- DNV constructed average charging load profiles by vehicle type and group, weighting every vehicle equally, to identify differences in charging behavior driven by the availability of the off-peak pricing signal as well as vehicle type.

Note that, in each of the load profiles in this section, the shaded band around each load shape highlights the margin of error (MOE) at the 90% confidence level, and the shaded box represents the on-peak window of 1 p.m. to 9 p.m., ending slightly before the 9 p.m. interval to indicate that charging occurring at and after 9 p.m. *on weekdays* is classified as off-peak, per the program definition.

4.2.1 Control vs. treatment group load profile comparison

Figure 4-10 shows a comparison between the control and treatment group load profiles across all vehicle types for April 2021 through October 2021, including the margin of error (MOE) at the 90% confidence level. Note that the shaded box in the following figures represents the on-peak window of 1 p.m. to 9 p.m., ending slightly before the 9 p.m. interval to indicate that charging occurring at and after 9 p.m. is classified as off-peak.

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Figure 4-10. Control vs. treatment weekday load shape, post-intervention period – all vehicle types

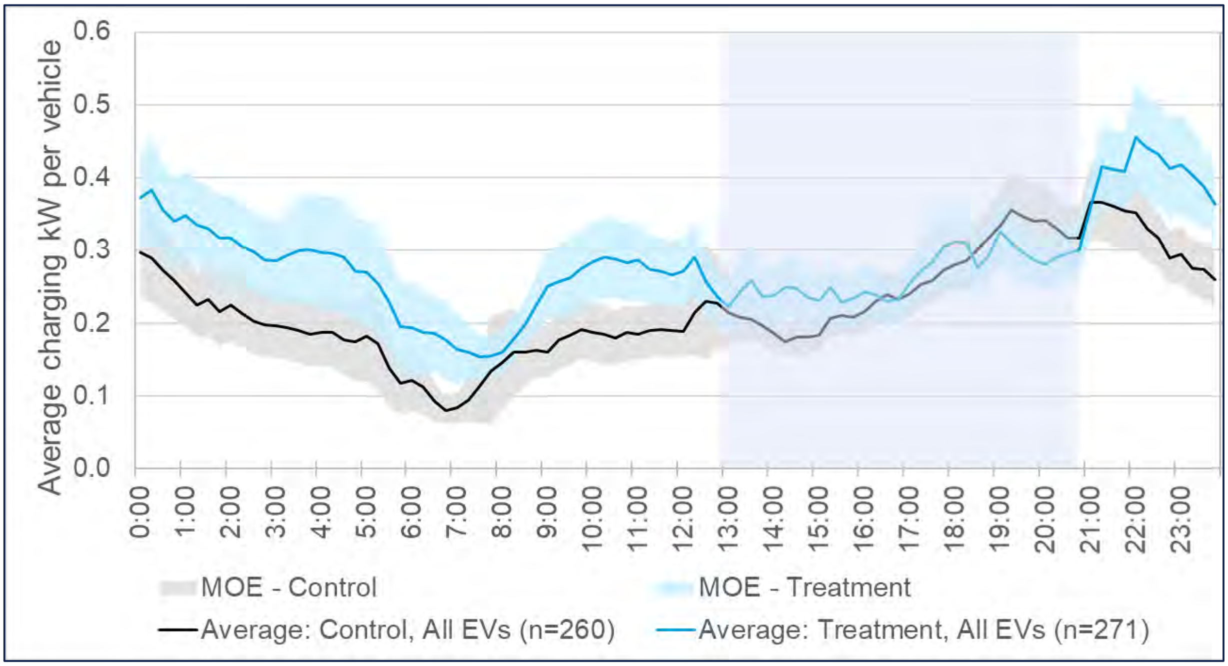


Figure 4-11 through Figure 4-13 show comparisons between the control and treatment group load profiles broken out by vehicle type. In each figure, the shaded box represents the on-peak window of 1 p.m. to 9 p.m., ending slightly before the 9 p.m. interval to indicate that charging occurring at and after 9 p.m. is classified as off-peak. The shaded bars in these figures also represent the margin of error (MOE) at the 90% confidence level.

Figure 4-11. Control vs. treatment weekday load shape, post-intervention period – PHEVs

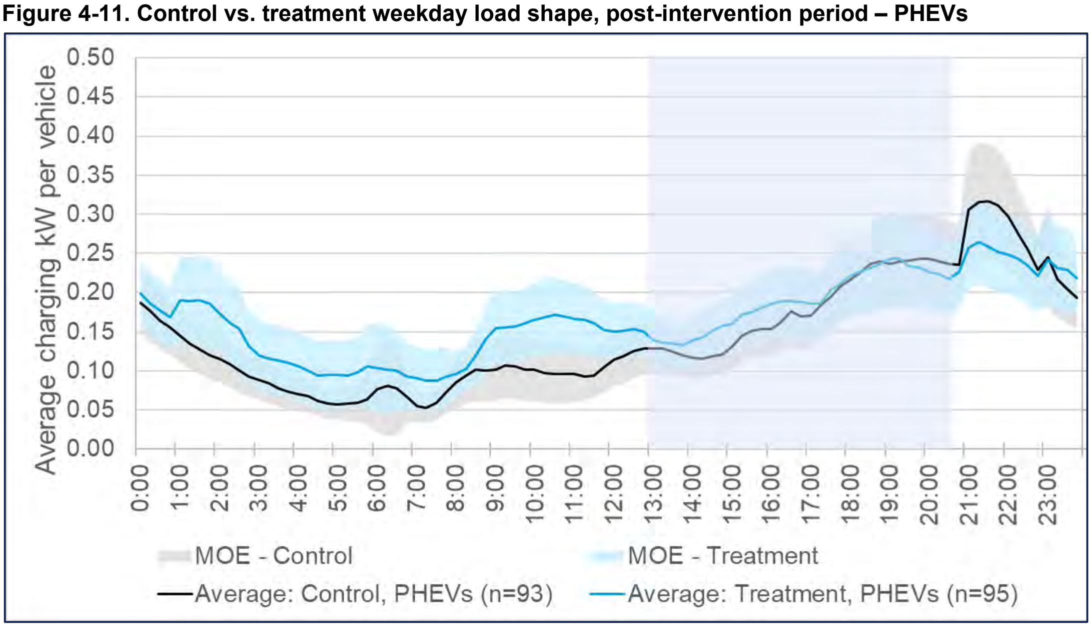


Figure 4-12. Control vs. treatment weekday load shape, post-intervention period – non-Tesla BEVs

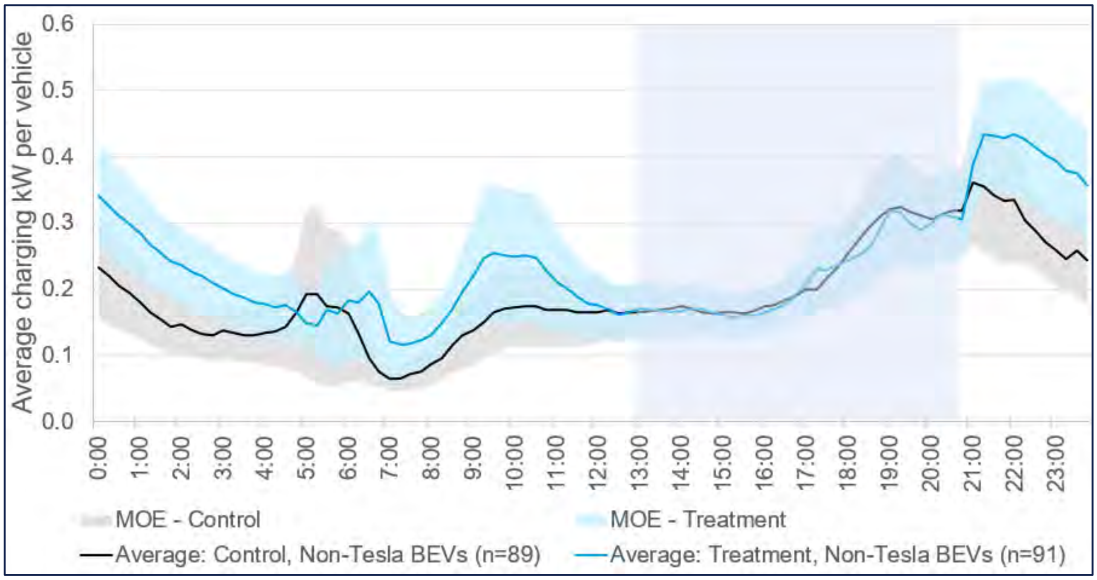
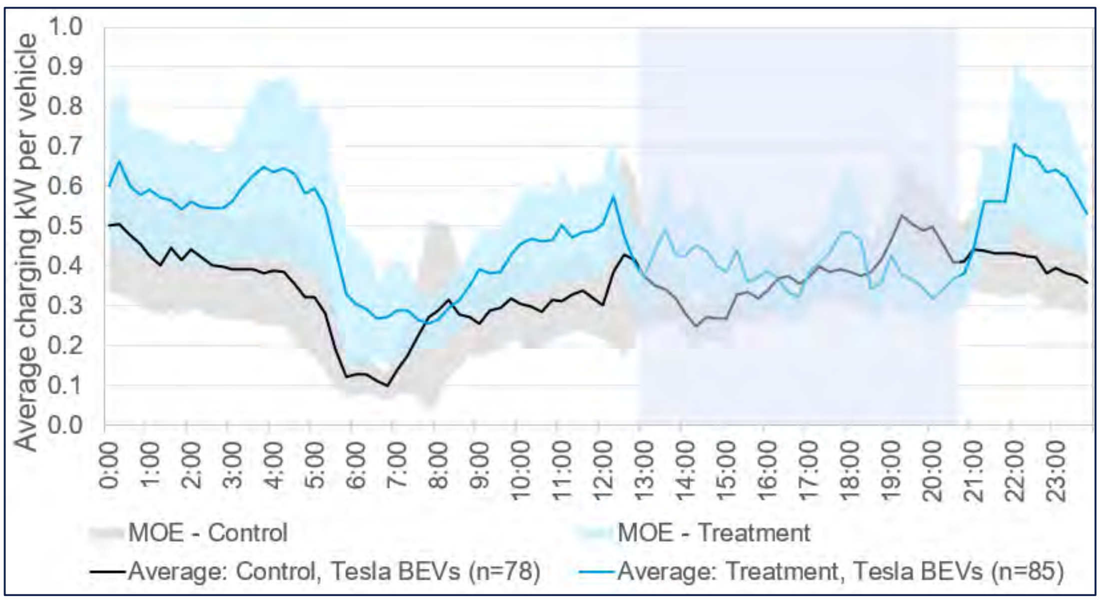


Figure 4-13. Control vs. treatment weekday load shape, post-intervention period – Tesla BEVs



The figures above reveal a number of observations regarding the weekday charging behavior of the control and treatment groups during the post-intervention period, from April through October 2021. Notably, there is not a consistently visible difference in on-peak charging load between the control and treatment groups. There are, however, some consistent trends in how charging changes throughout the day:

- All three vehicle types show a morning uptick between approximately 7 a.m. and 9 a.m., which likely corresponds to workplace charging. This is observable for both groups, as expected.
- Charging load ramps up during the on-peak period for both PHEVs and non-Tesla BEVs. Tesla BEVs, however, exhibit jagged on-peak charging behavior that does not increase consistently throughout the peak period.

- A sharp uptick in charging occurs at 9 p.m. for non-Tesla and Tesla BEVs in the treatment group, with little to no observable uptick for the control group. PHEVs, however, exhibit the opposite behavior, with a much larger increase in charging load at 9 p.m. for the control group than for the treatment group.
  - It is unclear why this would occur for control group PHEVs, given that this group is not eligible to receive off-peak charging rebates and has not received any communication regarding charging off-peak
  - It is also unclear why this would be observed for PHEVs but not for non-Tesla and Tesla BEVs
- Between approximately midnight and 5 a.m., charging tends to drop off smoothly, with a few notable exceptions:
  - One or more treatment group PHEVs appear to have set a charging schedule for around 1 a.m., causing a consistent charging bump at that time
  - Tesla BEV charging is higher at midnight than it is at 11 p.m., for both groups, and remains relatively flat overnight until about 5 a.m., at which point it drops sharply.

Table 4-6 shows the average demand reduction by vehicle type across the entire peak period (1 p.m.–9 p.m.) as well as the second half of the peak (5 p.m.–9 p.m.). The average demand reduction is calculated as the control group average load minus the treatment group average load. Also included is the size of the demand reduction over the given hours relative to the control group's average charging demand over the same hours (akin to a percent demand reduction).

Table 4-6. Average demand (kW) reduction per vehicle by vehicle type – Phase A

Vehicle Type	Peak Period Demand Reduction, 1 - 9 p.m. (kW/vehicle)	Peak Period Demand Reduction Relative to Control Group Load, 1 - 9 p.m.	Peak Period Demand Reduction, 5 - 9 p.m. (kW/vehicle)	Peak Period Demand Reduction Relative to Control Group Load, 5 - 9 p.m.
PHEV	-0.009	-5.2%	0.005	2.2%
Non-Tesla BEV	0.004	1.7%	0.008	2.8%
Tesla BEV	-0.022	-5.8%	0.031	7.3%

The treatment group's average load is higher than the control group's during the full peak period for both PHEVs and Tesla BEVs, resulting in a negative demand reduction. Over the 5 p.m.–9 p.m. window, the treatment group's charging load is lower than the control group's for all vehicle types, but only slightly. The demand reduction is negligible for PHEVs (2.2%) and non-Tesla BEVs (2.8%) and still small for Tesla BEVs (7.3%).

DNV tested the statistical significance of the above data and found that the difference between the average control group peak period demand and the average treatment group peak period demand was not statistically significant (p-value > 0.05) over both the 1 p.m.–9 p.m. window and the 5 p.m.–9 p.m. window. This indicates that the program is not achieving a statistically significant reduction in on-peak charging. The regression analysis discussed in Section 4.3 provides additional detail on the observed off-peak shift due to the program.

4.2.2 Weekday vs. weekend load profile comparison

Figure 4-14 shows a comparison between the weekday and weekend charging profiles for the treatment group.[14] This load profiles includes all vehicle types and includes data from April 2021 through October 2021. Note that the shaded box in the following figures represents the on-peak window of 1 p.m. to 9 p.m., ending slightly before the 9 p.m. interval to indicate that charging occurring at and after 9 p.m. is classified as off-peak.

[14] The control group is not shown because they were not made aware of the off-peak charging rebates, which reward off-peak charging during the week but not on the weekend. Hence, we would not expect to see a meaningful difference between weekday and weekend charging for this group.

Figure 4-14. Weekday vs. weekend load shape, post-intervention period – treatment, all vehicle types

The following can be seen from Figure 4-14:

- The weekend load in this profile begins to increase later in the day than the weekday profile, likely due to a combination of reduced workplace charging on the weekend and altered schedules.
- The two mid-day on-peak ramps track each other closely.
- It appears that some participants continue to delay charging until after 9 p.m. on the weekends, though at a much lower rate than during the week. This may be the result of EVs simply being plugged in at 9 p.m. and adhering to a charging schedule that remains in effect on the weekend.

4.3 Statistical regression results

DNV developed multiple linear regression models to test the effect of several independent variables on two separate dependent variables representing off-peak charging performance: 1) the per-vehicle monthly percentage of kWh charged off-peak (kWh model), and 2) the per-vehicle monthly percentage of charging sessions initiated off-peak (session start time model).[15] Both metrics provide valuable insight into how Massachusetts drivers charge their EVs.

- The kWh model reflects the program design of rewarding drivers who shift charging off-peak; however, the timing of when a vehicle consumes kWh is a function of several factors, including the plug-in time, the state of charge at plug-in, the battery size, and the level of the charger.
- The session start time model focuses on when charging sessions are initiated and more directly captures how participants have internalized the intent of the off-peak charging rebate.

[15] DNV selected a linear model over other types of models (e.g., the logit model) because the off-peak performance behavior being modeled could take any value between 0% and 100%. Had the observed behavior gravitated toward either end of that spectrum, suggesting that most drivers tended to charge either all on-peak or all off-peak, the logit model would have been more appropriate, as it is designed to model such pass/fail events.

4.3.1 Regression model design

DNV structured the regression analysis to measure the effect on off-peak charging behavior of the communication of the treatment group's eligibility to earn off-peak charging rebates in late March 2021, which coincided with communications being sent to all participants reminding them of (and providing a web link to) the program web dashboard, where they could access insights regarding their individual charging behavior. This regression features two periods:

- **Baseline period,** which includes all data recorded prior to April 1, 2021[16]
- **Post-intervention period,** which includes all data recorded on and after April 1, 2021

As discussed in Section 2.1, the communication of the program interventions occurred on March 24, 2021. Though the implementation of each group's planned interventions occurred several months earlier – with all participants receiving access to the correct dashboard for their group, and treatment group participants beginning to earn off-peak charging rebates, as each participant's two-month baseline period ended – participants' off-peak charging behavior was not expected to shift in response to these interventions without the participants being made aware of them. It is possible that some participants visited the updated program dashboard without prompting from the program and that some treatment group participants ascertained the intent of the program upon receiving a monthly rewards summary email and associated rebates. However, DNV did not review data regarding participants' interactions with the dashboard or the rewards emails. The team considered the two-stage model design to most accurately reflect the participant experience during Phase A and will focus on the results from this model in the following subsections.

To verify whether participants did respond to the implemented program interventions prior to the March 24 communication, DNV also tested whether there was any statistically significant observable effect on charging behavior between the end of the baseline period and April 1 ("pre-intervention period"). This three-stage regression included the following periods:

- Baseline period, including all data recorded during each participant's baseline period
- Pre-intervention period, including all data recorded between the end of each participant's baseline period and March 31, 2021
- Post-intervention period, including all data recorded after April 1, 2021

For both the charging load (kWh) and session start time models – and across all vehicle type-specific models – the three-stage regression did not result in a statistically significant off-peak shift for the treatment group during the pre-intervention period, confirming the expectation that the uncommunicated interventions would not have a significant impact on off-peak charging behavior. Because these regressions did not show statistical significance, they are not discussed further in this section. However, verifying the lack of a statistically significant increase in off-peak charging during the pre-intervention period was important to validate the choice to use the two-stage regression discussed below.

Sections 4.3.2 and 4.3.3 contain more details and discussion on the outputs of the two-stage regressions. As discussed above, we consider the two-stage regression to more accurately capture the effect of the program on participant off-peak charging behavior.

4.3.2 Regression Analysis – kWh Model

The final model developed for estimating the percentage of kWh charged off-peak takes the following form:

$$y = \beta_0 + \beta_1 T + \beta_2 P + \beta_3 (T \times P)$$

[16] The April 1, 2021, cut-off date between the baseline and post-intervention periods was chosen to align with the analysis design, which takes monthly per-vehicle off-peak charging performance data as input. April was the first full month following the communication of the off-peak charging rebate eligibility.

Table 4-7 summarizes the results of the overarching kWh model, which excludes vehicle type as a variable. The unstandardized coefficients, presented as percentages, represent the percent of kWh charged off-peak by the corresponding group of participants either before or after the start of the post-intervention period on April 1, 2021.

Table 4-7. Charging load (kWh) model – all vehicle types

Coefficient Symbol	Variable	Unstandardized Coefficient	P-value (statistical significance)	Standard Error
β_0	Base case; control group, baseline period	53.1%	0.00	0.7
β_1	Treatment group, baseline period	2.1%	0.04	1.0
β_2	Post-intervention period, all participants	5.7%	0.00	1.0
β_3	Treatment group in post-intervention period	5.6%	0.00	1.4

Table 4-8, Table 4-9, and Table 4-10 summarize the results of the vehicle type-specific kWh models, which focus individually on PHEVs, non-Tesla BEVs, and Tesla BEVs, respectively. A discussion of the model results is included following Table 4-10.

Table 4-8. Charging load (kWh) model – PHEVs

Coefficient Symbol	Variable	Unstandardized Coefficient	P-value (statistical significance)	Standard Error
β_0	Base case; control group, baseline period	49.7%	0.00	1.2
β_1	Treatment group, baseline period	1.4%	0.40	1.7
β_2	Post-intervention period, all participants	7.7%	0.00	1.7
β_3	Treatment group in post-intervention period	1.5%	0.53	2.4

Table 4-9. Charging load (kWh) model – non-Tesla BEVs

Coefficient Symbol	Variable	Unstandardized Coefficient	P-value (statistical significance)	Standard Error
β_0	Base case; control group, baseline period	56.4%	0.00	1.2
β_1	Treatment group, baseline period	-2.6%	0.13	1.7
β_2	Post-intervention period, all participants	1.9%	0.26	1.7
β_3	Treatment group in post-intervention period	10.5%	0.00	2.4

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Table 4-10. Charging load (kWh) model – Tesla BEVs

Coefficient Symbol	Variable	Unstandardized Coefficient	P-value (statistical significance)	Standard Error
$\boldsymbol{\beta_0}$	Base case; control group, baseline period	53.3%	0.00	1.3
$\boldsymbol{\beta_1}$	Treatment group, baseline period	8.3%	0.00	1.8
$\boldsymbol{\beta_2}$	Post-intervention period, all participants	7.4%	0.00	1.8
$\boldsymbol{\beta_3}$	Treatment group in post-intervention period	4.0%	0.10	2.5

This model leads us to several initial findings regarding how participants' charging behavior changed following the program communications sent to all participants on March 24, 2021:

- Participants in the control group, across all vehicle types, charged about 53.1% of their kWh off-peak prior to the communication of the program intervention:
  - This *baseline* off-peak charging rate varied across vehicle types in the control group, with the highest value being observed for non-Tesla BEVs (56.4%) and the lowest for PHEVs (49.7%).
  - Despite efforts to achieve balance across the new groups, treatment group participants charged a statistically significant 2.1% more off-peak in the baseline.
  - Of note, treatment group Tesla BEVs charged a statistically significant 8.3% more kWh off-peak *in the baseline* than control group Tesla BEVs, while differences between the control and treatment groups in the baseline period were small and negative for PHEVs and non-Tesla BEVs, respectively, and not statistically significant for either.
- There is a 5.7% increase in off-peak charging across all participants (statistically significant) following the communication of the program intervention. This shift affected all participants.
  - Notably, both PHEV and Tesla BEV drivers exhibited a statistically significant shift off-peak between the baseline and post-intervention periods of 7.7% and 7.4%, respectively.
  - Non-Tesla BEVs did not exhibit a statistically significant off-peak shift between the two periods.
- Across all vehicle types, there is a statistically significant 5.6% increase in off-peak charging due to the communication of the treatment group's eligibility to earn off-peak charging rebates.
  - Non-Tesla BEVs exhibited the largest effect, a statistically significant 10.5%off-peak shift.
  - The effect is smaller, though still positive, and not statistically significant for PHEVs and Tesla BEVs.
  - The large and significant delta between treatment and control group Tesla BEVs in the baseline period may explain the relatively low, and not statistically significant, off-peak shift of Tesla BEVs in the post-intervention period

4.3.3 Regression analysis – session start time model

The final model developed for estimating the percentage of kWh charged off-peak takes the following form:

$$y = \beta_0 + \beta_1 T + \beta_2 P + \beta_3 (T \times P)$$

Table 4-11 summarizes the results of the overarching session start model, which excludes vehicle type as a variable. The unstandardized coefficients, presented as percentages, represent the percent of charging sessions started off-peak by the corresponding group of participants either before or after the start of the post-intervention period on April 1, 2021.

Table 4-11. Session start time model – all vehicle types

Coefficient Symbol	Variable	Unstandardized Coefficient	P-value (statistical significance)	Standard Error
β_0	Base case; control group, baseline period	51.0%	0.00	0.7
β_1	Treatment group, baseline period	3.6%	0.00	1.0
β_2	Post-intervention period, all participants	0.9%	0.40	1.1
β_3	Treatment group in post-intervention period	3.3%	0.02	1.5

Tables 4-12, 4-13, and 4-14, below, summarize the results of the vehicle type-specific session start time models, which focus individually on PHEVs, non-Tesla BEVs, and Tesla BEVs, respectively. A discussion of the model results is included following Table 4-**11.**

Table 4-12. Session start time model – PHEVs

Coefficient Symbol	Variable	Unstandardized Coefficient	P-value (statistical significance)	Standard Error
β_0	Base case; control group, baseline period	46.6%	0.00	1.3
β_1	Treatment group, baseline period	4.8%	0.01	1.8
β_2	Post-intervention period, all participants	0.7%	0.71	1.8
β_3	Treatment group in post-intervention period	1.1%	0.68	2.5

Table 4-13. Session start time model – non-Tesla BEVs

Coefficient Symbol	Variable	Unstandardized Coefficient	P-value (statistical significance)	Standard Error
β_0	Base case; control group, baseline period	52.1%	0.00	1.3
β_1	Treatment group, baseline period	1.1%	0.55	1.8
β_2	Post-intervention period, all participants	-2.3%	0.22	1.8
β_3	Treatment group in post-intervention period	4.4%	0.09	2.6

Table 4-14. Session start time model – Tesla BEVs

Coefficient Symbol	Variable	Unstandardized Coefficient	P-value (statistical significance)	Standard Error
β_0	Base case; control group, baseline period	54.8%	0.00	1.2
β_1	Treatment group, baseline period	5.1%	0.00	1.7
β_2	Post-intervention period, all participants	4.2%	0.02	1.7
β_3	Treatment group in post-intervention period	4.0%	0.10	2.4

This model leads us to several initial findings regarding how participants' charging behavior changed following the program communications that were sent to all participants on March 24, 2021:

- Participants in the control group for this intervention started 51.0% of their sessions off-peak prior to the communication of the program intervention:
  - This *baseline* off-peak session start rate varied across vehicle types, with the highest value being observed for Tesla BEVs (54.8%) and the lowest for PHEVs (46.6%).
  - Despite efforts to achieve balance across the new groups, treatment group participants started more of their charging sessions – a statistically significant 3.6% – off-peak than control group participants. This baseline period delta was driven by PHEVs (4.8%) and Tesla BEVs (5.1%), both of which were statistically significant.
- There is no statistically significant increase in off-peak session start percentages following the communication of the program intervention. This stands in contrast to the kWh model, which showed a statistically significant shift off-peak for all participants in the post-intervention period.
- There is a statistically significant 3.3% increase in off-peak session starts due to the rebates. This effect is positive, but not statistically significant, across each vehicle type.
  - The large and significant delta between treatment and control group PHEVs and Tesla BEVs in the baseline period may explain the relatively low, and not statistically significant, off-peak shift of PHEVs and Tesla BEVs in the post-intervention period

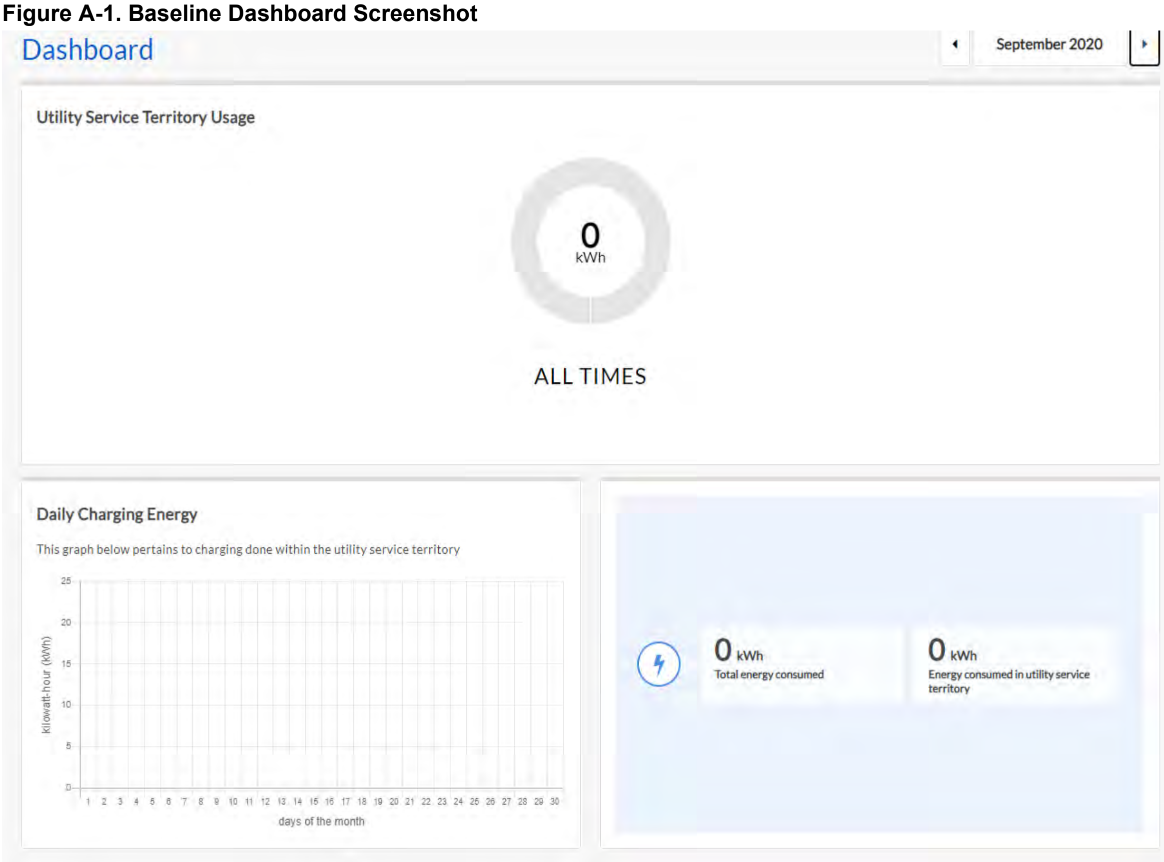
APPENDIX A

Appendix A contains screenshots of the three dashboards that were available to participants over the course of the program.

Baseline Dashboard

The baseline dashboard, shown in Figure A-1 below, was shown to all participants during the baseline period. It contains a basic level of information about participants' level of charging activity.

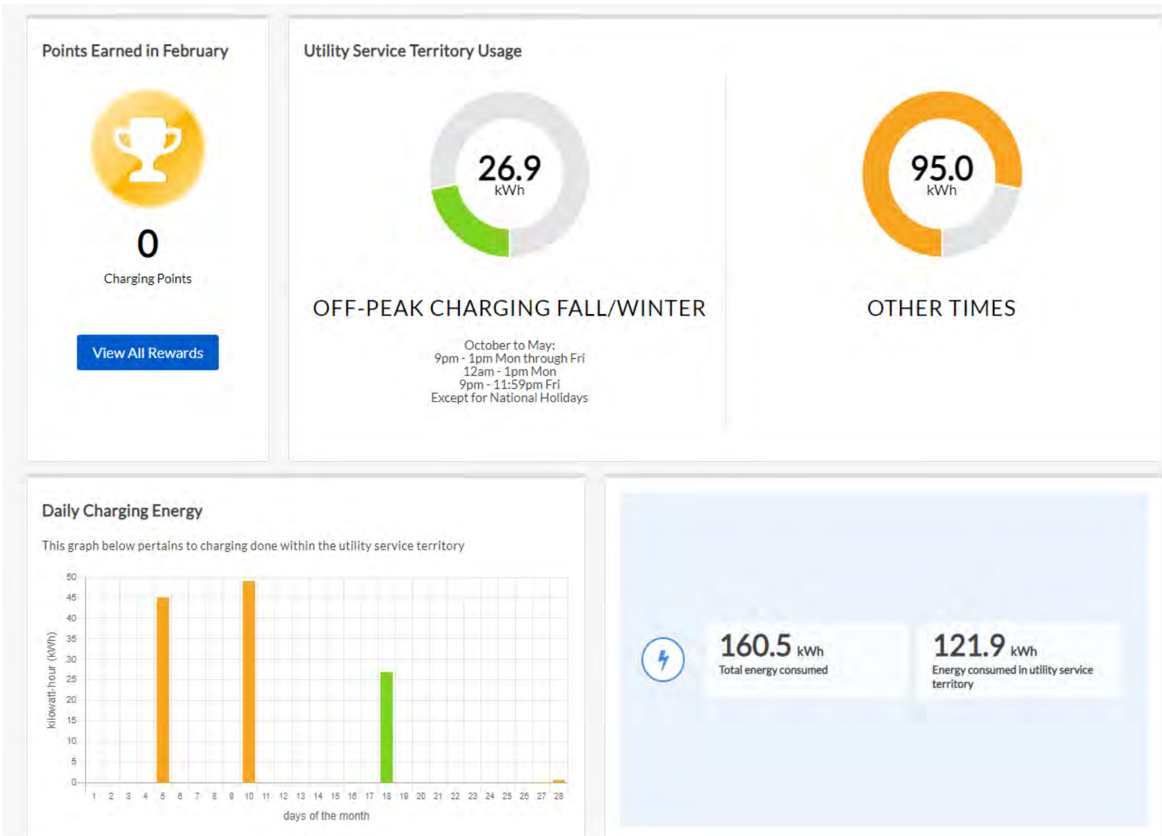
Figure A-1. Baseline Dashboard Screenshot



Control Group Dashboard

The control group dashboard, shown in Figure A-2, was shown to control group participants following the completion of their two-month baseline period. It contains more information than the baseline dashboard. The “Points Earned in *Month*” field always showed zero for the control group.

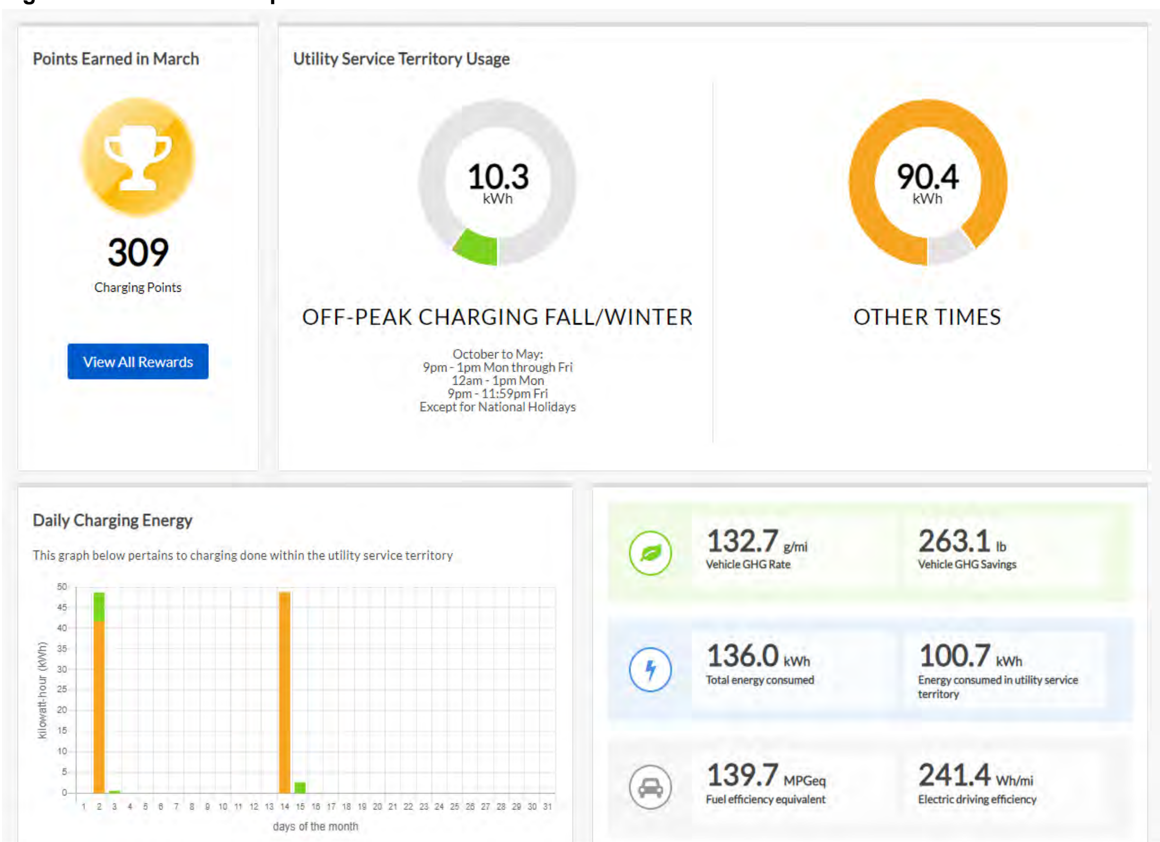
Figure A-2. Control Group Dashboard Screenshot



Treatment Group Dashboard

The treatment group dashboard, shown in Figure A-3, was shown to treatment group participants following the completion of their two-month baseline period. It contains more information than the baseline dashboard. The “Points Earned in *Month*” field was updated monthly to reflect the off-peak charging rewards earned by the participant.

Figure A-3. Control Group Dashboard Screenshot



APPENDIX B

Appendix B contains screenshots of the emails that were sent to control and treatment group participants in late March 2021.

Figure B-1. Screenshot of email sent to control group on 3/26/21

SmartCharge Massachusetts

Thank you for participating in **SmartCharge Massachusetts**. We're already seeing great changes in Massachusetts, and you're helping us improve system planning and EV charging across the state.

We wanted to remind you of a great tool at your disposal. You're able to view your daily charging patterns and behaviors when you log in to the SmartCharge web portal: https://smartchargemassachusetts.fleetcarma.com/login.

Thank you again for being a member of **SmartCharge Massachusetts**, and for making a difference to all Massachusetts residents.

For more details or questions please contact, smartcharge@fleetcarma.com or you can reach us via phone at 1-800-975-2434.

Happy charging,
The SmartCharge Team

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Figure B-2. Screenshot of email sent to treatment group on 3/24/21

fleetcarma.

SmartCharge Massachusetts

Ready for more rewards?

Thank you for participating in **SmartCharge Massachusetts**. We're already seeing great changes in Massachusetts, and you're helping us improve system planning and EV charging across the state.

On top of the $50 incentive you received for getting started in the program, you may have noticed you can now earn additional rewards for charging during off-peak hours.

When you charge during off-peak hours throughout Massachusetts, including Nantucket, you'll receive a rebate of $0.03 per kWh (October - May) and $0.05 per kWh during the summer months (June -September). The more you charge your EV off-peak, the more you'll earn. Off-peak hours are 9pm-1pm Monday - Friday.

On average, participants earn $7-10 per month for charging their EV during these hours of lower electricity demand ("off-peak").

You're able to view when you've charged as well as the rewards you've earned when you log in to the SmartCharge web portal. You will also receive an email with the rewards you have earned.

Thank you again for being a member of **SmartCharge Massachusetts**, and for making a difference for all our customers.

For more details or questions please contact, smartcharge@fleetcarma.com or you can reach us via phone at 1-800-975-2434.

Happy charging,
The SmartCharge Team

About DNV

DNV is a global quality assurance and risk management company. Driven by our purpose of safeguarding life, property and the environment, we enable our customers to advance the safety and sustainability of their business. We provide classification, technical assurance, software and independent expert advisory services to the maritime, oil & gas, power and renewables industries. We also provide certification, supply chain and data management services to customers across a wide range of industries. Operating in more than 100 countries, our experts are dedicated to helping customers make the world safer, smarter and greener.