ELECTRIC VEHICLE CHARGING

Charge Smart Phase B Evaluation

National Grid

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Table of contents

DNV

List of figures

List of tables

DNV

1 EXECUTIVE SUMMARY

This report presents DNV's evaluation results and findings for Phase B of the National Grid Electric Vehicle Charge Smart (CSMA) program. The analysis included in this study is based on data collected from electric vehicle (EV) drivers that opted to participate in the program between January 1, 2022-December 31, 2022. The goal of this research was to identify trends and analyze charging behavior in the following categories:

- Rebates paid to program participants
- Patterns of on- vs. off-peak charging and summer vs. non-summer periods
- Trends in charging based on vehicle type, charging location, and charger type
- Evaluation of potential to shift charging load from on-peak periods to off-peak periods
- Analysis of the greenhouse gas (GHG) emissions associated with EV charging

The sections in this report include detailed descriptions of the overall data generated directly by program participants, crosstab references to identify potential relationships in behavior, DNV-generated parameters to categorize specific equipment, and comparisons with GHG grid metrics. The findings provide valuable information about the current performance of the CSMA program and a strong foundation for additional elements to be introduced for customers in the future.

1.1 Key findings

Finding 1: The program provided more than $81,000 in rebates to program participants.

A total of 2,065,402 kWh was charged during off-peak periods which resulted in a total of $81,592.47 in rebates distributed to the EV drivers.[1] It is notable that approximately $49,000 (60%) of the rebates were earned through charging during summer months when participants received $0.05 per kWh for off-peak charging compared to $0.03 per kWh for off-peak charging during non-summer months.[2]

Finding #2. Most EV charging is done at home.

76% of all charging sessions and volume (kWh) and 85% of all charging hours were completed at the participants' home locations.

Finding #3. Most EV charging takes place during weekday off-peak hours.

A total of 2,065,402 kWh was charged during off-peak periods which represents 82% of total weekday charging. This is a positive sign for the overall performance of the program and shows that rebates are already being delivered to a large part of the market.

Finding #4. Tesla models are the most common type of vehicle in the program.

Tesla models accounted for more charging sessions than any other type of vehicle and make up 75% of the total vehicles in the program. Tesla models recorded the most sessions charged of any vehicle type and each session charged at a higher volume of kWh than other vehicle categories.

[1] Note that ev.energy reported a total $83,273.61 in off-peak rebates paid. The rebate value reported here was calculated by multiplying the total kWh charged off-peak by the seasonal incentive rates. As some kWh charging values were eliminated due to failed QC checks, DNV's reported rebate value is slightly lower than ev.energy's.

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

Finding #5. Level 2 chargers are the most common type of equipment.

A total of 173,869 charging session were recorded in this phase of the program and 128,544 (74%) were completed with a Level 2 charger (this may be a related to the high share of Tesla vehicles in the program). This is notable because Level 2 chargers deliver a higher capacity charge throughout the session and can be equipped with features that provide more functionality than Level 1 chargers.

Finding #6. There is potential to shift some EV charging load from on-peak to off-peak periods.

A total of 35,737 kWh was identified as “technically shiftable” load that could be passively moved to an off-peak period. This represents 2.1% of the total off-peak home charging recorded and roughly 1.3 kWh per eligible session. Future versions of the program may be able to remotely control home charging sessions to maximize the off-peak load.

Finding #7. Typical EV charging times overlap with relatively lower periods of GHG emissions on the grid.

Average charging load profiles show the lowest levels of charging between 7:00 a.m. and 9:00 p.m. which corresponds with periods of high grid emissions. EV charging is highest between 9:00 p.m. and 6:00 a.m. which is consistent with relatively lower (4.06%) GHG emissions on the grid.[3] This is an added benefit of the program and there is evidence indicating that a kWh of charging shifted from on-peak to off-peak will result in a relative reduction in emissions today.

Finding #8. The ev.energy software platform was easy to use and enabled effective analysis of charging data.

The ev.energy team provided a high level of access and visibility to the platform and the overall quality of information met our expectations. The delivery process was smooth, and the staff responded to our questions and requests in a timely manner. Any inconsistencies in the available data were relatively small samples and did not hinder our analysis.

1.2 Recommendations and Considerations

Recommendation 1: Expand the pool of vehicles compatible with the program.

The ev.energy application proved to be a valuable tool to collect information about charging behavior and program performance. However, several vehicle types (including Nissan, Jeep, Hyundai, Ford) had trouble connecting to the software and generating reliable data. This was the first time the ev.energy app was used in this program with National Grid customers and while the connectivity issues did not damage the results of the study, DNV recommends extensive testing and verification with a range of vehicle types before the next version of the program is introduced.

Recommendation 2: Communicate the GHG reduction benefits of charging vehicles during off-peak hours

GHG emissions from EV charging are lower during off-peak periods, which aligns with National Grid’s goals to mitigate emissions while electrifying the vehicle fleet. Participating EV drivers may find value in having more visibility into their charging behavior’s GHG footprint and receiving communications about ways to reduce their emissions profile. This information could be presented through the ev.energy application in a similar format to the total rebates earned by participants to give users another way to interact with the program.

[3] Difference in on- and off-peak GHG is based on a comparison of the 2022 average emission values of time intervals corresponding to on- and off-peak periods

Consideration 1: To support the launch of the “flexible scheduling” initiative planned for Phase 3, conduct research with program participants to understand their appetite and preferences for a direct load control charging pilot to shift charging from on peak to off-peak periods or satisfy other National Grid objectives.

DNV identified on-peak charging intervals that could be moved to off-peak periods with a flexible scheduling charging application or adjusted settings on charging equipment. To design this type of addition to the program, it would be beneficial to gauge user interest and comfort with managed charging to understand the share of the population that would participate and whether additional incentives might be needed to reach a desired level of engagement. This customer research could lead to other insights that would help National Grid understand the benefits and challenges to wider managed charging applications.

Consideration 2: Gather additional information on customer preferences and charging behavior during summer and non-summer months to better understand seasonal habits and evaluate the factors that motivate customers to charge off-peak.

The off-peak charging incentives provided during this version of the CSMA program offered participants a higher rebate for off-peak charging during summer months. From this data set, we were able to detect some seasonal patterns in charging behavior. However, due to the April – May increase in customer enrollment, we did not have a comprehensive year of data to analyze the potential trends in summer and non-summer charging. There may underlying causes for changes in charging behavior that were not visible through the data that is currently available and additional qualitative information would be helpful to determine the potential for seasonal load shifting. DNV suggests additional research on the customer preferences and behavior that may be related to seasonal driving habits, vehicle type, and incentive value. This could include customer surveys and additional behavior metrics.

Consideration 3: Develop incentives for weekend charging.

During Phase B of the CSMA program, weekend charging was not eligible for time-of-use charging incentives. If National Grid would like to influence charging behavior on weekends, developing incentives for targeted charging times may be a useful tool.

Consideration 4: Collect additional information about the capabilities of participants’ home charging equipment and their ability to participate in actively managed charging programs in the future.

To support Phase 3 of the CSMA program, consider collecting more granular data on the installed home charging infrastructure of participants to potentially inform future program design and/or incentive offerings. This would build the capability for National Grid to potentially target offerings like actively managed charging, vehicle-to-grid, and other software-based solutions to customers that have compatible equipment. This information could also be leveraged by National Grid to design incentives for the current Level 1-charging population and address issues with customer accounts that may be using equipment that is currently ineligible with the program.

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2 INTRODUCTION

This section describes National Grid's Massachusetts EV Charge Smart Program ("the CSMA Program") and the evaluation objectives for Phase B, spanning January 1, 2022, through December 31, 2022. DNV was contracted to conduct an independent evaluation of Phase B of the CSMA Program.

2.1 Program overview

The objectives of this evaluation are to understand trends in charging behavior and identify opportunities to optimize the impact that rebates and incentives can have on periods of peak demand. National Grid defines the peak period as 1:00 p.m. to 9:00 p.m. on weekdays, excluding holidays. Charging that occurs during off-peak hours Monday through Friday is eligible to receive charging rebates; charging during the weekend is ineligible for off-peak charging rebates. The off-peak charging rebates are $0.05 per kWh charged off-peak in the summer months and $0.03 per kWh charged off-peak during the non-summer months.[4] Participants also received a $50 sign-up incentive upon their enrollment in the program.[5]

DNV evaluated Phase A of this program and worked with National Grid to conduct a randomized controlled trial (RCT) to test the effect of the rebate on a group of participants. For Phase B, National Grid shifted the charging data collection mechanism from a hardware device installed in participating vehicles to an app-based system that records charging activity from compatible vehicles and/or chargers. Additionally, in Phase B all participants received the off-peak incentives and there was no control group.

2.1.1 Charge Smart Phase B

The Phase B analysis is building on the findings identified in Phase A by conducting a thorough examination of the data generated by the vehicles participating in the study. Data was collected between January and December 2022 and includes 1,870 vehicles, 173,869 charging sessions, and 3,421,249 kWh. The comprehensive level of information involved in the study allowed the DNV team to generate statistics that can help inform National Grid about customer preferences and charging behavior based on the type of vehicle, type of charger, location of charging, typical intensity of charging sessions, and timing (including on-peak vs. off-peak, weekend vs. weekday, and summer vs. non-summer) of charging sessions.

Two additional layers of analysis were added to the study in mid-February 2022 to help support the future evolution of the CSMA program. First, we examined the potential flexibility of charging sessions by identifying the number of home charging sessions that crossed from the on-peak period to off-peak (or vice versa), meaning the vehicle was plugged in, though not necessarily actively charging, during both periods.[6] These sessions are considered potential candidates to further shift charging from on-peak to off-peak via incentives or active load management, taking advantage of the time EVs spend plugged in but not actively charging during the off-peak period. Second, DNV collaborated with National Grid and WattTime to develop a methodology to estimate the greenhouse gas (GHG) emissions impacts of EV charging. The process required the creation of 8760 EV charging load profiles, which were then matched with profiles of marginal and average operating emissions rates (MOERs and AOERs, respectively, measured in lbs. of CO_2 generated per kWh of grid power) provided by WattTime. The 8760 profiles and MOER and AOER figures were then used to produce estimates of the annual average and marginal emissions associated with the charging load.

2.1.2 Program implementation observations

Phase B of the program launched in Fall 2021 and began by transitioning a subset of the Phase A participants over to the new vendor and platform. The goal for this phase was to enroll 1,100 new vehicles in the program and there was a

4 The summer months are June–September and the non-summer months are October–May.

5 Reference: National Grid Charge Smart program description

6 This analysis focused solely on home charging, since National Grid indicated during scoping discussions that they currently do not have plans to manage or control "away" charging.

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coordinated marketing and outreach effort to attract new customers. Table 2-1 shows the range of goals for new vehicle participation in the program from 2022 to 2024.

Table 2-1. National Grid program participation goals (number of vehicles)

Target	2022	2023	2024
Minimum	825	2,750	5,500
Middle	950	4,025	8,250
Stretch	1,100	5,500	11,000

The marketing and outreach strategy included the following six components to distribute information about the program and attract new participants:

- Native ads – This campaign generated targeted awareness of the Off-Peak Charging program to existing EV and plug-in hybrid EV (PHEV) owners in National Grid's MA electric territory.
- Paid search ads – Google Ads designed to connect with EV drivers who have seen Off-Peak ads on other channels or who were searching EV charging terms related to their vehicle.
- Paid social ads – Facebook and Instagram campaign that targeted EV drivers in the high-propensity MA electric territory zip codes. Material was designed for EV drivers who are interested in EVs, energy efficiency, eco-friendly living, etc.
- Paid search – Paid search ads were launched to support the campaign and capture search traffic directed to the Charge Smart landing page.
- Email partnerships – Targeted emails to residential customer segments most likely to own EVs, and customers that signed up during the soft launch period and through partner channels such as Green Energy Consumers Alliance and MOR-EV.
- Events and PR – Promoted the program through a variety of in-person EV events, press events, and webinars.

This series of marketing and communication programs was launched beginning in May 2022 and continued into August. It is notable that the number of vehicles participating in the program increased from 180 in April to 1,416 in August. This increase in membership overlapped with the timing and execution of the National Grid marketing strategy and it is likely that the program reached the 2022 stretch goal because of the marketing efforts.

2.1.3 Data collection by ev.energy

For the CSMA Program, data collection was handled using an application and platform provided by ev.energy. Both participant metadata and charging data were collected by ev.energy, as described below.

- **Participant metadata.** Prospective program participants were directed to the ev.energy platform, where they entered their National Grid account information for eligibility verification; EV make and model; type of home charger; and home address. This information was used to determine participant eligibility based on whether they were a National Grid electric customer and had either a compatible EV or home charger, as determined by ev.energy.
- **Charging data.** Charging data was collected from the EV telematics, or the data collected by an EV's onboard computer systems and transmitted remotely to the automaker; data for a subset of the population was also collected via smart (Wi-Fi connected) Level 2 home chargers, which transmit charging data remotely to the EVSE network provider. To access charging and other data remotely from eligible vehicles and/or chargers, ev.energy integrated with an application programming interface (API) to connect to either the automaker's or EVSE's backend systems to query the following data on a recurring basis:

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- Vehicle description – this field contains data on the vehicle, make, model, trim, battery size, and other specifications
- Vehicle location type ("home" and "away from home")
- Vehicle status (e.g., charging, driving, parked)
- Battery level and status (state of charge, charge rate, etc.)

Only vehicles and/or chargers from automakers and EVSEs with whom ev.energy had an API connection were eligible for the program. Participants who expressed interest but did not have an eligible vehicle and/or charger were prompted to join a waitlist for the program.

Data limitations

As with any dataset, the ev.energy charging dataset has some limitations. We have summarized these in Table 2-2 below, along with (if applicable) how DNV addressed these limitations in the final dataset for this evaluation.

Table 2-2. Limitations of ev.energy charging dataset

Limitation	Description	How limitation was addressed
Tagging locations of charging events	ev.energy indicated that any charging that occurred within 500 feet of the customer-entered home address was tagged as a "home" charging session. While this method is sound, it involves a small risk of tagging "away" sessions occurring near a participant's home as a home session.	DNV did not modify any charging session locational tags.
Faulty API integration	ev.energy indicated that it encountered data quality issues stemming from API integration issues with three automakers– Hyundai, Jeep, and Nissan. These issues resulted in a large number of short, chopped-up charging sessions and occasional inaccurate rebate calculations.	• ev.energy indicated that it agreed with National Grid to disqualify vehicles from these automakers in May 2022, preventing further enrollments for affected vehicles. • DNV flagged and removed all charging data collected from these vehicles in the first half of 2022; this removal affected 35 vehicles and included approximately 34,000 kWh, or less than 1% of all charging conducted in Phase B.
Data polling frequency constraints	ev.energy indicated that some participants with Ford EVs were being temporarily locked out of their FordPass accounts as a result of over-pinging of the API by a third party. As a result, ev.energy reduced its 15-minute data polling frequency to 2 hours to mitigate negative customer impacts.	DNV did not modify, flag, or remove any charging data from Ford EVs for this reason (though standard QC flags were applied to all charging data). While reducing the polling frequency incurs the risk that the queried data will not be as accurate or timely as it would be with more frequent polling, DNV believes that this is an inherent aspect of telematics-based data collection that does not reduce the quality of the Ford data to the point where it should be excluded. Rather, we seek to make National Grid and their stakeholders aware of this potential limitation to telematics data collection so that it can be discussed and potentially addressed in future iterations of the CSMA Program.

2.1.4 Data combination with WattTime

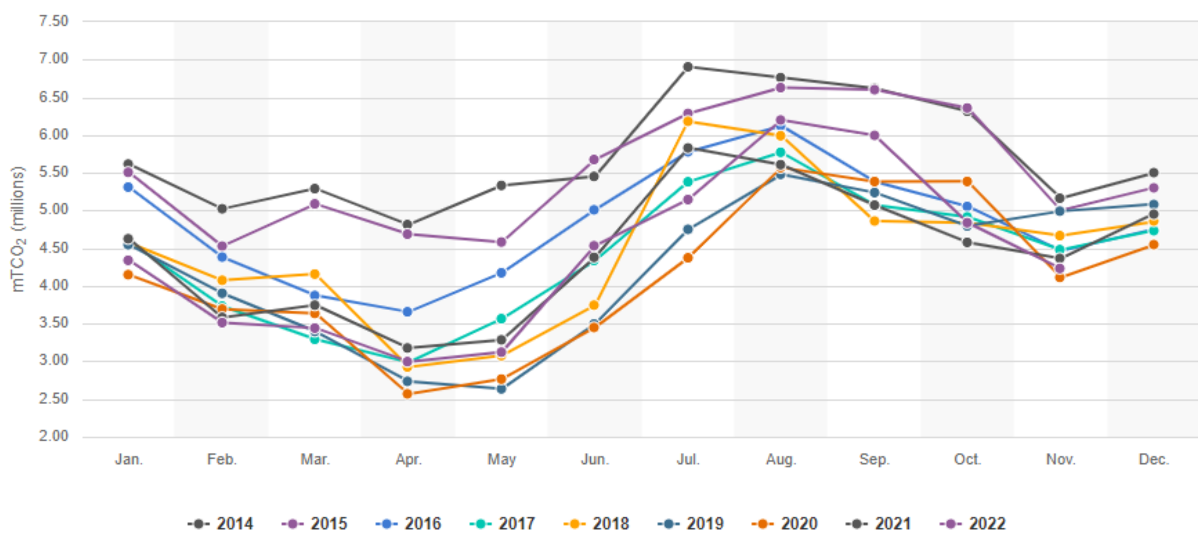
DNV leveraged its existing relationship with WattTime to source MOER and AOER data to support the GHG Emissions Impact analysis. WattTime is a third-party firm that has developed a proprietary data model for quantifying the marginal and average emissions of the electric grid. The model incorporates historical resource load data, weather data, and a wide array of other inputs—including publicly available grid data from the Independent System Operator of New England (ISO-NE)—to predict emissions rates. The data consists of a time series of MOER and AOER values, representing the emissions rate in units of lbs. of CO_2 per kWh of electricity generated. The data was converted to prevailing time (Eastern time zone) and rolled up to hourly resolution for this analysis. MOER data was available for the three ISO-NE Massachusetts load zones (Western and Central Massachusetts, Northeast Massachusetts and Boston, and South-eastern Massachusetts), while AOER data was available at the state level.[7] All emissions data covered January 1, 2022, through December 31, 2022.

Average emissions rates

The average GHG emissions rate (or average emissions rate, MOER) represents the load-weighted (by MW contribution) average GHG intensity of all grid resources that contribute to the supply stack. While the average emissions can be calculated at a single point in time (e.g., at 1:00 p.m. on a given day, by quantifying the emissions associated with power generation and dividing by the power generated), this calculation provides little direct insight into how that intensity would change if demand for power increased or decreased. Average emissions rates are most often used to measure and compare the carbon intensity of the grid over time, on a monthly, seasonal, or annual basis.

For example, Figure 2-1, from the California Independent System Operator (CAISO), shows that average carbon intensity varies both month-to-month within a year and year-over-year. Monthly variation is the result of different grid resources being called upon to meet seasonal load variation, with more carbon-intense resources typically being relied on more in the summer, when loads are highest. Measured annually, the grid has gotten “cleaner” over time as more low-carbon resources have come online.

Figure 2-1. CAISO year-over-year variation in average carbon intensity[8]



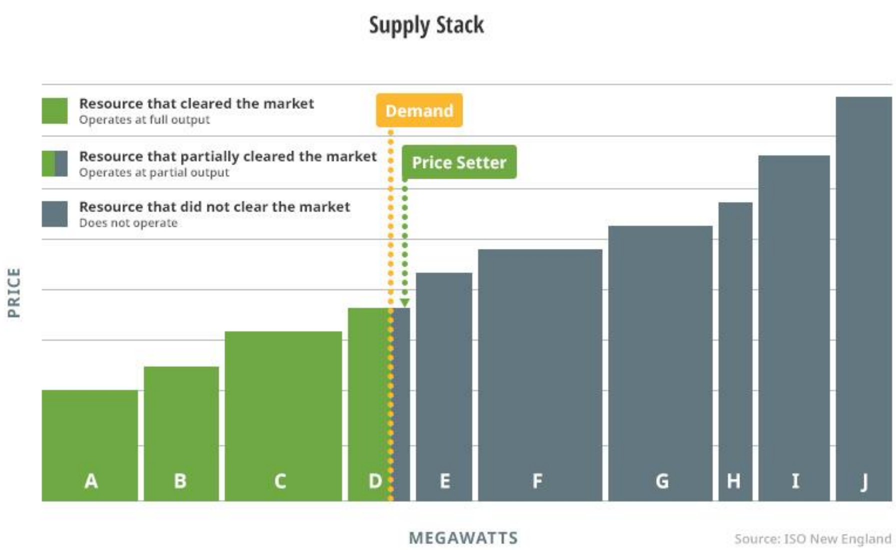
Marginal emissions rates

To understand the concept of the marginal GHG emissions rate (or marginal emissions rate, MOER), it is first helpful to understand the concept of marginal resources in detail. The “marginal resource” is the resource that would supply the next megawatt (MW) of load to the grid if demand were to increase by 1 MW; per the ISO-NE’s economic dispatch model, the

[7] Due to the similarity of the MOER profiles across load zones within MA, only the Northeast Massachusetts and Boston (NEMA) dataset was leveraged in this analysis.
[8] Source: CAISO Historical CO_2 trend

marginal resource is determined by identifying the resource able to supply the next MW to the grid at least cost. In many cases, multiple resources are simultaneously considered “on the margin” due to constraints on the grid and transmission system that prevent the next cheapest MW from reaching the location where load is increasing on its own. In these cases, a mix of resources is identified that can collectively supply the next MW at least cost. Figure 2-2 illustrates the market-clearing process and the concept of marginality.

Figure 2-2. Market-clearing process and marginality



Here, the y-axis represents supply bids from various resources in $/MWh; this is the price at which the individual generators are willing to supply power. Resources A, B, C, and a portion of D “clear” the market, are dispatched by ISO-NE to generate a certain amount of power and make up the “supply stack.” Resource D is “on the margin” and, as the marginal resource, sets the price of power that is paid to all dispatched generators. Resource D would be called upon to generate more power if needed and would turn down its output if demand fell in the next time interval.

The marginal GHG emissions rate (or marginal emissions rate, MOER) represents the load-weighted (by MW contribution) average GHG intensity of all resources that are on the margin at a given point in time. As discussed above, the “marginal resource” is the grid resource (or collection of resources) that would supply the next unit of load to the grid if demand were to increase; conversely, it would also be the next resource to reduce its output if demand were to decrease. The MOER is often taken into account in EV managed charging and demand response (DR) programs to support decision-making around when to add or reduce load on the grid given its relative MOER at different times throughout the day. As an example, when designing a managed charging program with a GHG emissions component, the design team might look to historical MOER data to determine when the program’s off-peak period should begin; because the marginal resource would be the only grid resource to increase output as EVs plug in, the associated emissions impact would be based only on the carbon intensity of the marginal resource.

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3 METHODOLOGY

DNV analyzed the charging data collected through Phase B of the Program to identify trends in charging behavior based on descriptive information about the vehicle type, charging session start time and duration, charger type, seasonal charging, potential flexibility of charging sessions, and GHG emissions from EV charging. The scope of this analysis includes charging data recorded from January 2022 through December 2022. DNV completed the following activities: Data cleaning and quality control, program performance analysis, and 8760 load profile development, which are described below.

3.1 Data cleaning and quality controls

The first phase consisted of the following steps:

1. **Filtering for participant eligibility.** As noted above, National Grid partnered with ev.energy to implement Phase B of the charging program. DNV filtered out data for any participants listed with incompatible hardware or with unknown vehicle makes. Participants with incompatible hardware are not eligible for the program under ev.energy's implementation. Participants with unknown vehicle makes have likely dropped out of the program since initial enrollment, and DNV would be unable to classify vehicle type without make information. Of the 2,128 vehicles listed, 311 vehicles (or 14.6%) were removed due to incompatible hardware or unknown vehicle makes. These 311 vehicles accounted for only 3.6% of all charging intervals.
    a. Additionally, in mid-2022, ev.energy encountered difficulty with Hyundai, Nissan, and Jeep data collection and ruled those makes incompatible. DNV was unable to determine when those makes were officially removed from the program as data reporting continued through December 2022. As a result, DNV filtered out all 2022 data for Hyundai, Nissan, and Jeep vehicles. Of the 2,128 vehicles, 35 vehicles (1.6%) were removed due to this issue.
2. **Quality control.** DNV also 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, charge rates that exceeded a given EV model's maximum charge acceptance rate (kW), charging sessions with durations greater than 10 days, and charging intervals with less than 0.05 kWh charged (likely a signifier of phantom charging when the vehicle was nearly fully charged). Of the over 4 million charging intervals analyzed for compatible participants, 97% of intervals passed QC.
3. **Filtering for eligible data.** As stated above, the team filtered the data to remove all charging intervals that failed QC.

3.2 Initial analysis

DNV conducted an initial analysis to quantify high-level program statistics and develop charging load profiles with 30-minute resolution.[9] Only data that met the above criteria was included in this analysis, which included the following steps:

- DNV calculated vehicle-level and program-level statistics, including total kWh charged and number of charging sessions by month, group, and vehicle type.
- Per-vehicle average charging load profiles were constructed with 30-minute resolution and aggregated by vehicle type; load profiles were further segmented by month and day type (weekday vs. weekend).
- To assess the program's continued 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.

[9] Note that Phase A of the program included load profiles with 15-minute resolution. In Phase B, however, ev.energy's data was collected at 30-minute resolution, so DNV developed load profiles at the provided resolution.

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4 PROGRAM SUMMARY STATISTICS

In 2022, the Charge Smart program provided a total of $81,592 in off-peak charging rebates to program participants. Table 4-1 shows that these rebates were generated by more than 2.6 million kWh in off-peak charging during the year. The incentive rate during the summer months ($0.05/kWh) was 66% higher than the incentive rate during winter months ($0.03/kWh) and the program paid a total of $16,560 more in incentives during the summer months.

Table 4-1. Total incentivized off-peak charging rebates

Season	kWh	Rebate value	
		Overall	Per vehicle
Non-summer month off-peak	1,083,883	$32,516.48	$23.50
Summer month off-peak	981,520	$49,075.99	$56.40
Total off-peak	**2,065,402**	**$81,592.47**	**$79.90**

Note that the overall rebate values are calculated by multiplying the seasonal incentive levels by the total kWh charged in each season. Some differences are to be expected when compared to figures published in program scorecards given that not all kWh data passed QC for this analysis, which slightly lowers the overall rebate value estimates in Table 4-1. Note also that the per-vehicle rebate value estimates are based on the average number of active participants who provided charging data in each season, which accounts for the initial slow buildup in program enrollment figures (during which time proportionally less charging took place) and the possibility that some participants dropped out of the program early.

Table 4-2 shows the total vehicle counts, charging sessions, and kWh charged for each vehicle type (PHEV, Non-Tesla BEV, and Tesla BEV). Tesla models accounted for more charging sessions than any other type of vehicle and make up 75% of the total vehicles in the program. Tesla’s also consume more energy. The average Tesla consumed 1,029 kWh per year more energy than non-Tesla BEV and 1,575 kWh more energy than PHEV categories.

Table 4-2. Participating vehicles, number of charging sessions, and total charging (kWh)

Vehicle type	Vehicle count		Number of charge sessions		kWh charged	
	Total	% of vehicle type	Overall	Per vehicle	Overall	Per vehicle
PHEV	153	8%	10,906	72	85,539	559
Non-Tesla BEV	319	17%	19,093	61	352,446	1,105
Tesla BEV	1,398	75%	143,870	104	2,983,265	2,134
All	**1,870**	**100%**	**173,869**	**94**	**3,421,249**	**1,830**

Figure 4-1 shows the number of vehicles in the program and the cumulative energy used for charging throughout the year. There was a large increase in the number of participating vehicles between May and July when the count of vehicles jumped from 295 to 1,340. As previously described, this period overlaps with an increase in sales and marketing material associated with the program.

Figure 4-1. Program summary of charging (kWh) by vehicle type

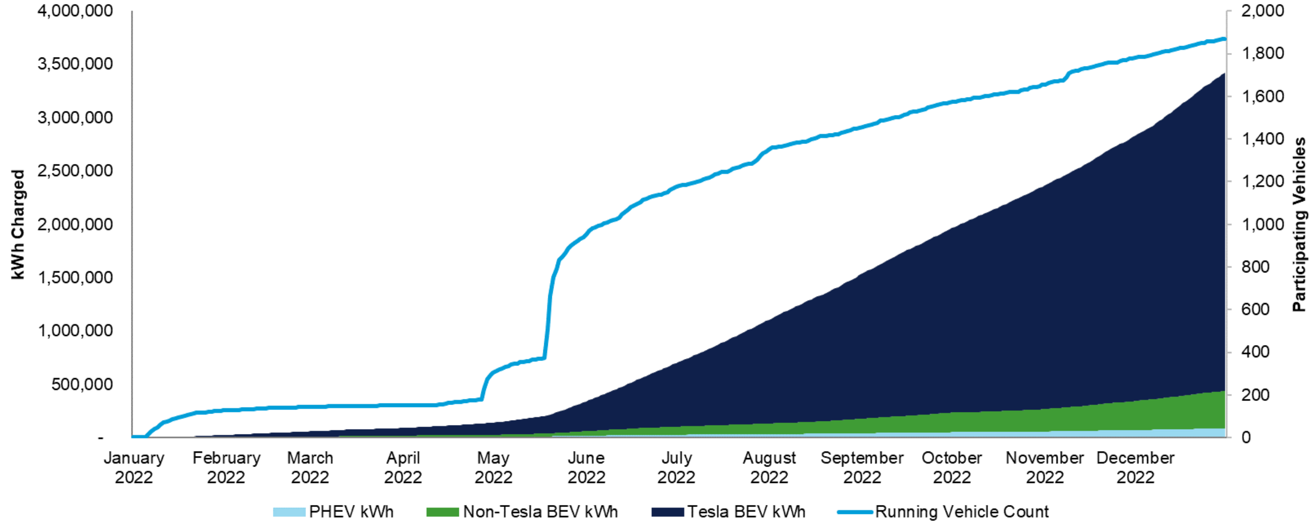
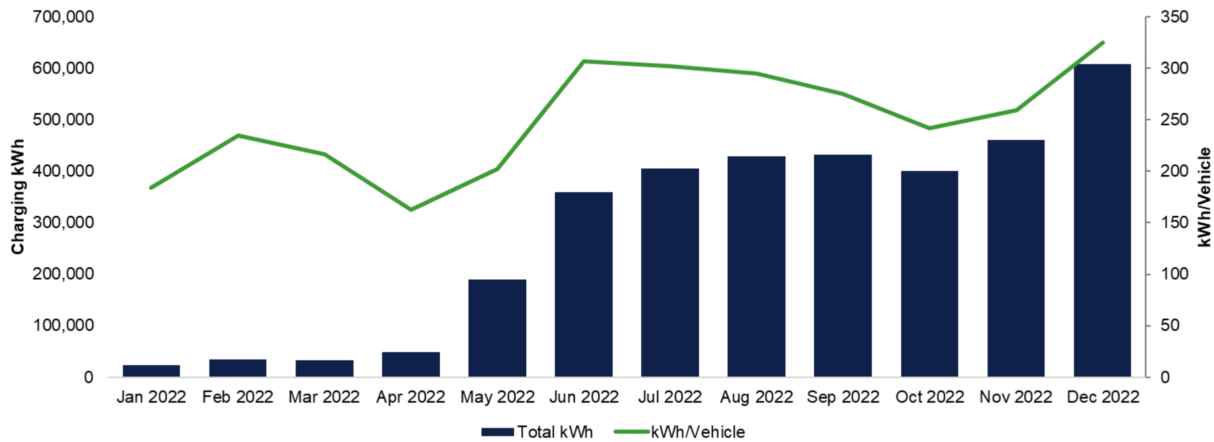


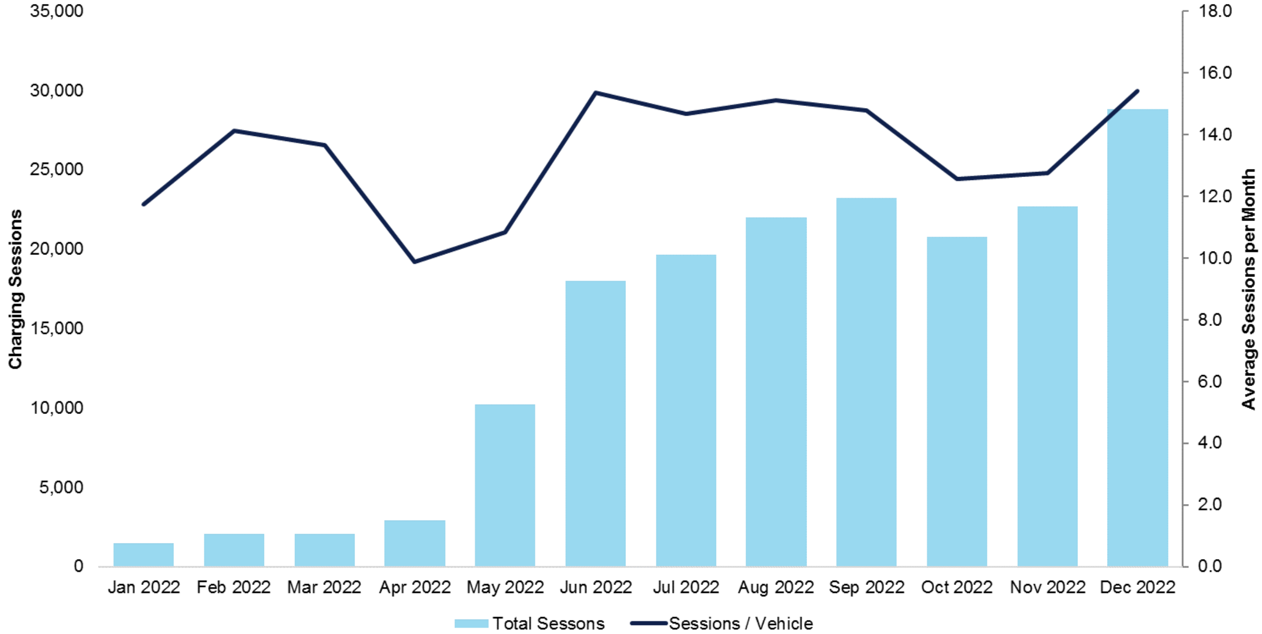
Figure 4-2 shows the progression of the program. In January 2022, Charge Smart included 127 vehicles that recorded 23,369 MWh of total charging volume resulting with an average of 185 kWh per vehicle. In December, the program had grown to include 1,870 total vehicles (+1,372%) that charged more than 600,000 kWh (+2,502%) and average monthly charging per vehicle increased to 325 kWh (+77%).

Figure 4-2. Aggregate charging (kWh) and average charging (kWh) per vehicle



Through the first four months of the program, the total number of charging sessions was between 1,400 and 3,000 per month. However, in May, the total number of sessions increased to 10,255 and the total number of sessions in December nearly reached 30,000. While the total number of sessions increased steadily throughout the year, Figure 4-3 shows that the average number of sessions per vehicle never dipped below 10 and never went above 15.6.

Figure 4-3. Total charging sessions per month and average sessions per vehicle



5 ANALYSIS BY TIMING OF CHARGING SESSION

DNV studied the data generated by each charging session to identify trends in on-peak vs. off-peak charging,[10] weekend vs. weekday charging, seasonal charging behavior,[11] and trends in charging based on the charger type. As noted, the number of vehicles participating in the program increased substantially between April and July which represents the seasonal transition from non-summer to summer months. To account for this change in participation, the charging data was analyzed both at an aggregate level to show total number of charging sessions and kWh across each month and at an average vehicle level to show the typical number of sessions and kWh needed for a single vehicle. These results served as a basis to develop our approach and expectations for a deeper study of charging session flexibility and to identify opportunities to optimize charging times.

5.1 On-peak vs. off-peak charging

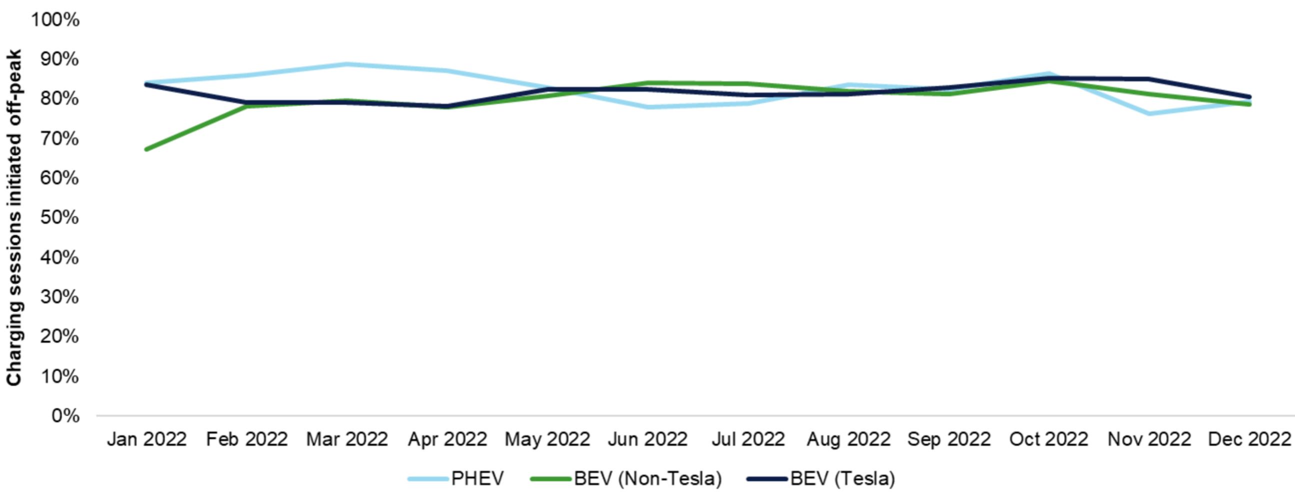
In 2022, most weekday charging took place during off-peak hours. Data in Table 5-1 shows that participating vehicles recorded 2,512,896 kWh charged off-peak which represents more than 82% of the total kWh charged on weekdays.

Table 5-1. Comparison of weekday on peak and off-peak charging (kWh) by vehicle type

	On-Peak		Off-peak		Total for vehicle type
	kWh	% Overall kWh	kWh	% Overall kWh	
PHEV	12,224	0.5%	51,917	2.1%	64,140
BEV (Non-Tesla)	49,193	2.0%	210,515	8.4%	259,708
BEV (Tesla)	386,077	15.4%	1,802,971	71.7%	2,189,048
Total weekday	**447,494**	**17.8%**	**2,065,402**	**82.2%**	**2,512,896**

Reinforcing this finding, Figure 5-1 shows that the percent of weekday charging sessions that are initiated during off-peak hours is consistently between 60% and 70% for each vehicle category. Based on this result, there does not appear to be a significant difference in charging behavior based on the type of vehicle participating in the program.

Figure 5-1. Percent of weekday charging sessions initiated off-peak by vehicle type



[10] Per the off-peak period definition (9:00 p.m. to 1:00 p.m. weekdays only), charging done from 12:00 a.m. Monday to 1:00 p.m. Monday is considered off-peak, as is charging done from 9:00 p.m. until midnight (12:00 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 9:00 p.m. and 1:00 p.m. the following day. For Monday (9:00 p.m. and later), Tuesday, Wednesday, and Thursday, the off-peak period is defined as 9:00 p.m. until 1:00 p.m. the next day.

11 The summer months are June–September and the non-summer months are October–May.

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More granular data in Table 5-2 shows the monthly trends in weekday kWh charged during off-peak periods. Across each vehicle category, the total kWh charged increases throughout the program and the share of off-peak charging consistently represents between 75% and 85% of kWh charged on weekdays in a given month. This indicates that most charging is done during off-peak windows and that off-peak charging consistently delivers a higher volume of kWh to the vehicle. Additional analysis of on- and off-peak charging session length is provided in Section 9 (Charging session flexibility analysis).

Table 5-2. Monthly comparison of weekday on peak and off-peak charging (kWh)

Month	PHEV			BEV (Non-Tesla)			BEV (Tesla)		
	On-peak	Off-peak	% Off-peak	On-peak	Off-peak	% Off-peak	On-peak	Off-peak	% Off-peak
Jan-22	206	1,078	84%	983	2,018	67%	2,210	11,164	83%
Feb-22	202	1,234	86%	709	2,552	78%	4,203	15,989	79%
Mar-22	200	1,586	89%	731	2,832	79%	4,048	15,351	79%
Apr-22	290	1,964	87%	848	2,969	78%	6,095	21,695	78%
May-22	973	4,680	83%	3,121	13,094	81%	19,851	92,416	82%
Jun-22	1,727	6,062	78%	3,903	20,522	84%	41,571	194,641	82%
Jul-22	925	3,450	79%	2,646	13,625	84%	49,630	211,625	81%
Aug-22	1,002	5,079	84%	5,037	22,901	82%	53,996	234,569	81%
Sep-22	1,277	5,995	82%	6,936	29,888	81%	48,289	233,162	83%
Oct-22	628	3,992	86%	2,718	14,769	84%	38,327	219,908	85%
Nov-22	2,523	8,101	76%	8,622	37,534	81%	44,351	249,569	85%
Dec-22	2,270	8,694	79%	12,940	47,808	79%	73,505	302,882	80%
Total	**12,224**	**51,917**	**81%**	**49,193**	**210,515**	**81%**	**386,077**	**1,802,971**	**82%**

5.2 Weekend vs. weekday charging

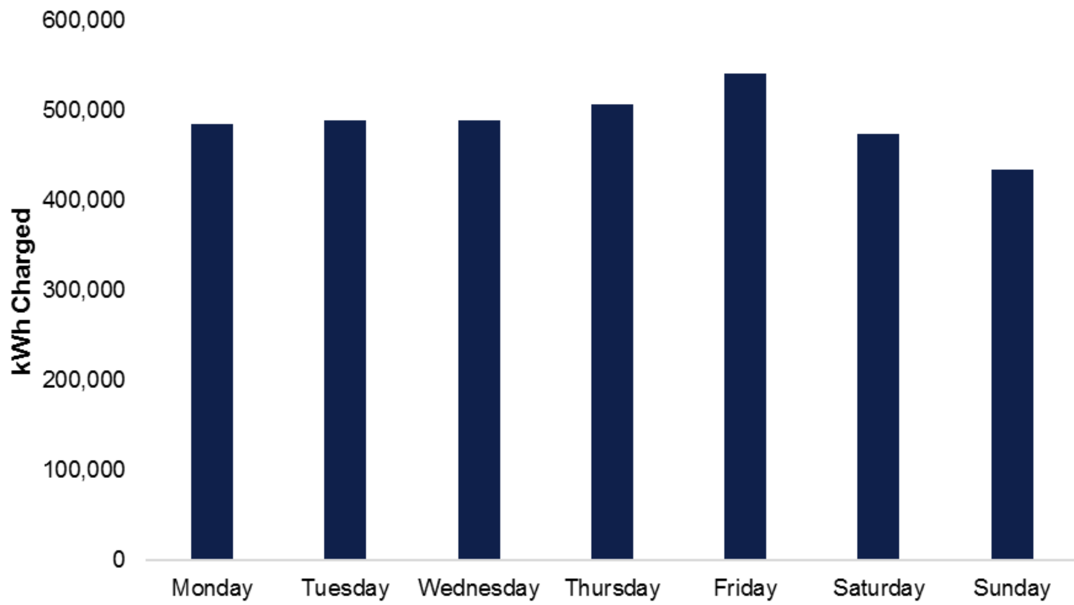
In 2022, weekday charging accounted for more than 2.5 million kWh and 73 percent of total kWh delivered to vehicles. Table 5-3 shows that vehicle type did not account for any significant differences in charging behavior as PHEV, BEV, and Tesla models each recorded between 73% and 75% of total annual charging on weekdays.

Table 5-3. Comparison of total weekend and weekday charging (kWh) by vehicle type

Vehicle type	Total kWh on weekdays	% kWh on weekdays	Total kWh on weekends	% kWh on weekends	Total kWh
PHEV	64,140	75.0%	21,399	25.0%	**85,539**
BEV (Non-Tesla)	259,708	73.7%	92,738	26.3%	**352,446**
BEV (Tesla)	2,189,048	73.4%	794,217	26.6%	**2,983,265**
Total	**2,512,896**	**73.4%**	**908,354**	**26.6%**	**3,421,250**

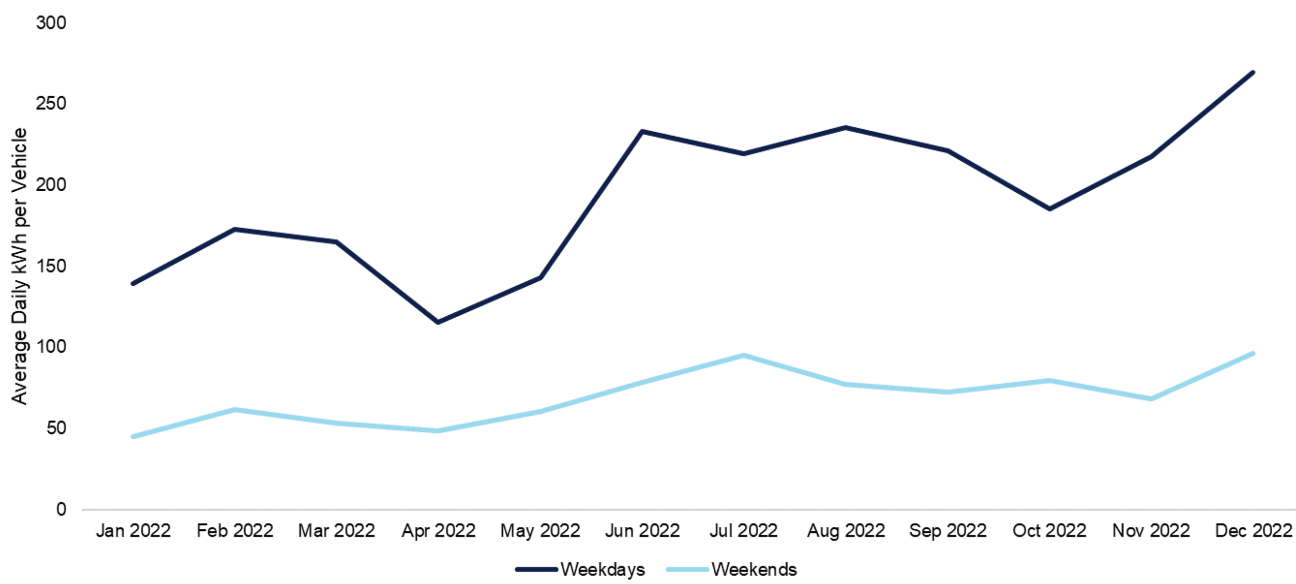
As seen in Table 5-3 above, weekday charging accounts for approximately 74% of total charging across vehicle types. As uniform charging across all days would result in 5/7, or 71.4% of weekday charging, this result signifies relatively uniform daily distribution.Figure 5-2, below, supports this implication while showing slightly higher charging totals on Fridays and slightly lower totals on Sundays.

Figure 5-2. Total charging (kWh) by day of week



The average daily kWh per vehicle on both weekdays and weekends increased substantially from January to December. At the start of the year, weekday charging was less than 150 kWh per vehicle on weekdays and less than 50 kWh on weekends. By the end of the year, weekday charging increased to just under 300kWh and weekend charging reached about 100 kWh. A spike in daily kWh per vehicle occurred between April and June. This period overlaps with a large increase in the number of vehicles participating in the program and is likely a result of roughly 1,000 additional vehicles joining the Charge Smart program. Most of these new vehicles were Tesla models, which typically have higher volume (kWh) charging sessions and could have contributed to this change in average daily charging on both weekdays and weekends.

Figure 5-3. Daily kWh charged per vehicle



5.3 Summer vs. non-summer charging

Charging volume was closely split between summer (1.6 million kWh; 47.5%) and non-summer months (1.8 million kWh; 52.5%).[12] This aggregate charging volume was affected by the increase in number of vehicles participating in the program after April 2022 and charging during non-summer months is likely underrepresented in these results.

Table 5-4. Comparison of total seasonal charging (kWh)

Season	PHEV	BEV (Non-Tesla)	BEV (Tesla)	Total
Summer	33,776	141,757	1,447,927	**1,623,459**
Non-summer	51,763	210,689	1,535,338	**1,797,790**
Total	**85,539**	**352,446**	**2,983,265**	**3,421,249**

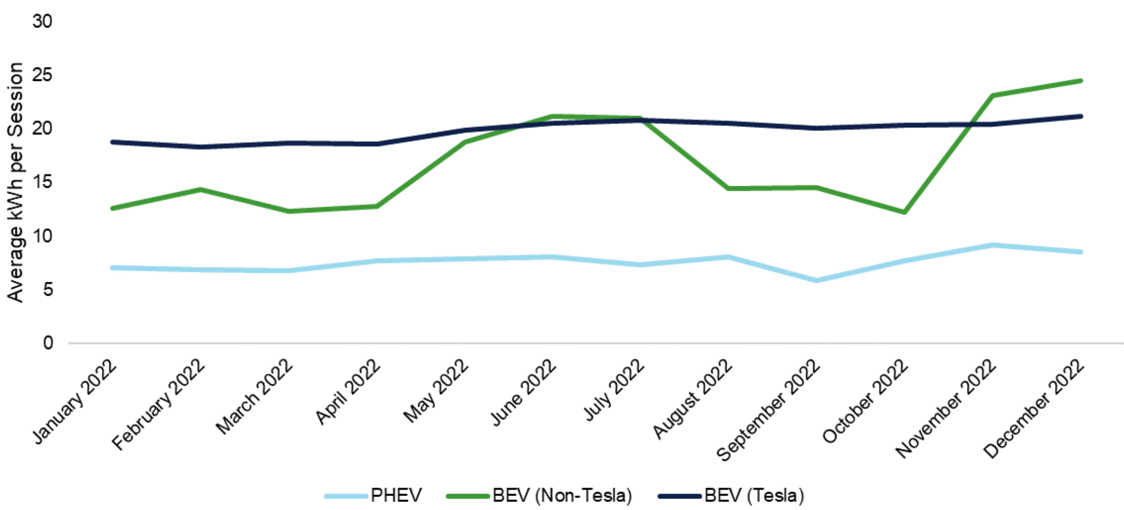
To identify opportunities in seasonal charging behavior, we first analyzed the average kWh delivered in summer and non-summer months for each vehicle type. These results are displayed in Table 5-5. The average volume (kWh) delivered in each session was relatively consistent for both Tesla and PHEV models in summer and non-summer months.

Table 5-5. Average seasonal charging (kWh) per session

Season	PHEV	BEV (Non-Tesla)	BEV (Tesla)
Summer	7.3	17.8	20.5
Non-summer	7.7	16.3	19.5

However, the average kWh per session for non-Tesla BEV models was more volatile throughout the year. Figure 5-4 demonstrates that from January to April (non-summer), this category averaged less than 15 kWh per session. From May to July, the average volume per session increased to nearly 20 kWh before dropping back to 15 kWh. Finally, the average volume delivered to non-Tesla BEV models during the last two months of the year was the highest of any vehicle type. There are several factors that could have influenced this data including: an increase in the number of non-Tesla BEVs, variation of charger type, variation of home vs. away charging.

Figure 5-4. Comparison of average charging (kWh) per session



[12] Summer months are June–September and non-summer months are October–May

6 ANALYSIS BY LOCATION

The next area of focus was to identify trends in charging behavior at different locations. Each session is recorded as being completed at the vehicle's "home" location or "away" from home. The statistics reveal that of the total 173,869 sessions recorded, 131,752 (76%) took place at home and these sessions accounted for more than 1,429,880 hours (85%) of charging time and 2,588,689 kWh (76%). This indicates that drivers are more likely to charge their vehicles at home and that home charging accounts for a higher energy volume (kWh) than away charging.

Table 6-1. Total sessions, hours, and kWh charged at each location

Location	Total sessions		Total hours		Total kWh	
	Number of sessions	% Total	Number of hours	% Total	kWh	% Total
Home charging	131,752	76%	1,429,880	85%	2,588,689	76%
Away charging	42,117	24%	253,476	15%	832,561	24%

Building on this analysis, average charging session length and intensity metrics were developed to study locational charging behavior. In this case, the average session intensity was approximately 19.7 kWh at both locations, but, on average, home charging sessions were nearly 5 hours longer than away charging sessions. This indicates that away charging sessions deliver the same amount of energy, but in less time than home sessions. This is likely caused by the difference in charging equipment as DCFC chargers deliver a higher charge rate and are only available for away charging sessions.

Table 6-2. Average session length and intensity by charging location

Location	Average session length (hours)	Average session intensity (kWh)
Home charging	10.9	19.7
Away charging	6.0	19.8

Finally, Figure 6-1 shows monthly values for the number of charging sessions per vehicle enrolled in the program. It is evident that home charging makes up the majority of sessions charged in every month of 2022. However, there is slight seasonal variation in home versus away behavior. In summer (June-September), there are approximately 2.9 times more home charging sessions than away charging sessions. In non-summer (October-May), there are approximately 3.4 times more home charging sessions than away charging sessions. Hence, away charging makes up a slightly higher proportion of total sessions charged in the summer months. Still, April 2022 shows the highest proportion of away charging sessions for any month of the year.

Figure 6-1. Monthly number of charging sessions per vehicle

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7 ANALYSIS BY CHARGER TYPE

The statistics described in the sections above were generated directly from the data collected through the ev.energy program and provide a foundation for additional analysis. Our next layer of analysis focused on identifying trends in charging behavior based on the type of equipment used. To distinguish the charger type, DNV created the following criteria that allowed each charging session to be flagged as either Level 1 charging (L1), Level 2 charging (L2), or DC fast charging (DCFC).

Table 7-1. Charger level criteria

Level 1 charging	Level 2 charging	DC fast charging
Peak session capacity < 2 kW	Peak session capacity: 2 kW – 20 kW	Peak session capacity > 20 kW

It is valuable to understand the specific characteristics associated with each charging level because the equipment categories deliver power to the vehicle batteries at different rates and have distinct capabilities, including options to schedule the session start and end time, adjust charging capacity, and provide data back to the user about the status of the battery.

There are also locational characteristics and limitations of these charger types. For example, the high cost and high-power demand of DCFCs makes them unsuitable for residential locations, meaning all DCFC charging takes place away from home. Additionally, EV drivers may select a home charger or prefer public chargers with a power output proportional to the charge acceptance rate (kW) or battery size (kWh) of their vehicle. As a result, PHEVs – which have smaller batteries and often lower charge acceptance rates and can more easily recharge with a Level 1 charger in a reasonable amount of time – charge with an L1 charger more often than BEVs, while all-electric models (including Tesla and Non-Tesla BEVs) with larger batteries are more likely to leverage Level 2 and DCFC chargers to take advantage of higher charge rates to reduce charge times. (Tesla drivers also have access to the Supercharger DCFC network when away from home, though access to this historically closed network is opening to non-Tesla EVs.[13])

- Below are several key takeaways from this analysis; these are also summarized in
- Table 7-2:
- Over the course of the program, most vehicle charging was completed with Level 2 equipment. It is notable that 74% of the total sessions and 85% of the total kWh were delivered through Level 2 chargers.
- The average session length of Level 1 chargers (12.9 hours) was more than 40% longer than the average Level 2 session (9.2 hours) while delivering 64% less energy on average (8 kWh per Level 1 session compared to more than 22 kWh per Level 2 session).
- DCFC charging accounted for the fewest total sessions and lowest share of charging energy. DCFC charging sessions had the shortest average duration (0.5 hours) and highest energy intensity, delivering more than 32 kWh per session.

Table 7-2. Comparison of charger type

Charger type	Sessions		kWh		Average session duration (hr.)	Average kWh per session
	Number of sessions	Percent of Total	kWh charged	Percent of Total		
Level 1	38,811	22.3%	312,094	9.1%	12.9	8.0
Level 2	128,544	73.9%	2,896,055	84.6%	9.2	22.5
DCFC[14]	6,514	3.7%	213,100	6.2%	0.5	32.7

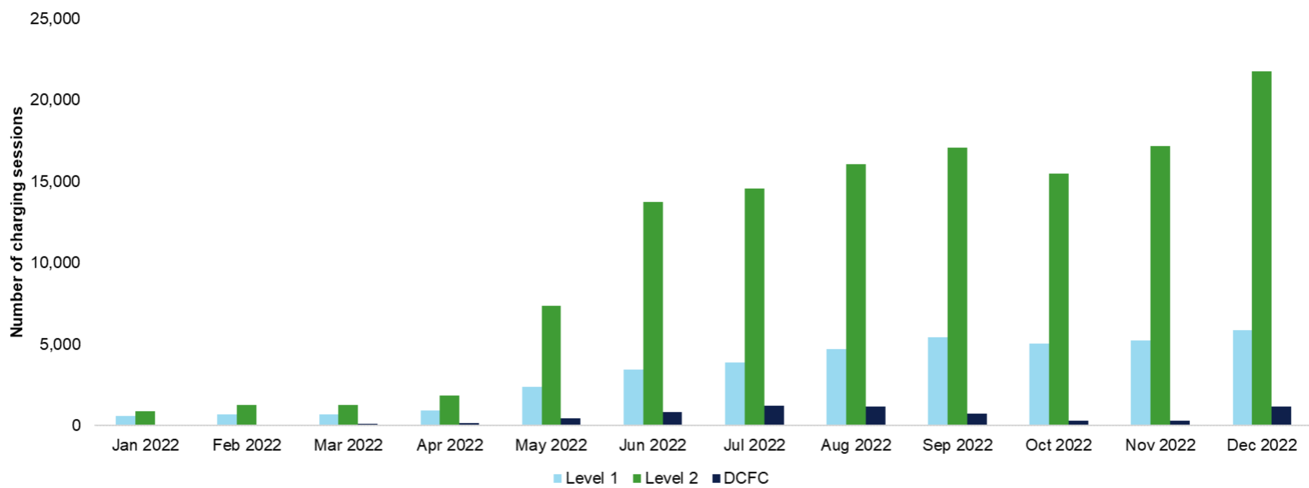
[13] Source: Tesla Supercharger network

[14] QC parameters applied to the charging data to classify charger types based on session peak kW resulted in 14 home charging sessions being errantly classified as "DCFC." Those data points are included in this table but are not representative of home charging.

Charger type	Sessions		kWh		Average session duration (hr.)	Average kWh per session
	Number of sessions	Percent of Total	kWh charged	Percent of Total		
Total	**173,869**		**3,421,249**		**7.5**	**19.7**

Analysis of the number of charging sessions shows a trend consistent with the increase in the number of vehicles participating in the program between April and June. The notable aspect of Figure 7-1, below, is the pronounced increase in the number of L2 charging sessions over time, indicating significant growth in overall program engagement and total charging. There is also a decrease in both L2 and DCFC charging in October, while the number of L1 sessions remained relatively constant. This is consistent with the drop in monthly kWh charged that was observed in October (Figure 4-2), suggesting a possible decrease in overall driving and charging activity; however, without additional data, it is not possible to determine the cause of this drop.

Figure 7-1. Monthly number of charging sessions by charger type



7.1 Comparison of charger type and location

The location-based data described in Section 6 indicated that home charging is more common than away charging. Overall, 76% of both charging sessions and total kWh charged took place at home, while 24% took place away. It has also been established that L2 is the most common type of charger used. Table 7-3 provides additional visibility into the prevalence of charging types used at home, showing that L2 chargers account for 77% of home charging sessions and 91% of the kWh delivered in residential charging. This is one of the clearest demonstrations of the difference in charging capability between L1 and L2 charging.

Table 7-3. Home charging sessions and volume (kWh) by charger type and location

Charger type	Sessions		kWh	
	Number of sessions	% Total	kWh charged	% Total
Level 1	30,663	23.3%	243,277	9.4%
Level 2	101,075	76.7%	2,344,774	90.6%
DCFC[15]	--	0%	--	0%

[15] QC parameters applied to the charging data to classify charger types based on session peak kW resulted in 14 home charging sessions being errantly classified as "DCFC." Those data points are not representative of home charging and have been removed from this table.

Charger type	Sessions		kWh	
	Number of sessions	% Total	kWh charged	% Total
Total	**131,738**	**100%**	**2,588,051**	**100%**

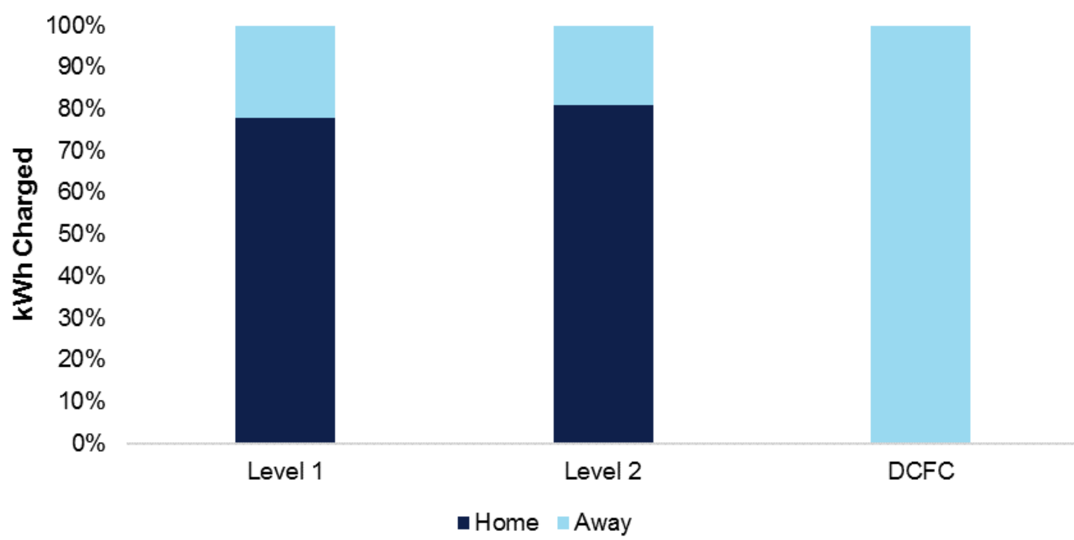
Table 7-4 shows that L2 equipment is also the most common option for charging away from home. Of the total 42,117 away charging sessions, more than 65% were completed with L2 chargers. All 6,500 DCFC sessions were completed at away locations, accounting for roughly 15% of away sessions and more than 25% of the energy charged. This split between DCFC's share of away sessions and away kWh is consistent with the higher energy intensity of DCFC charging, which is primarily used for quick recharging.

Table 7-4. Away charging sessions and volume (kWh) by charger type

Charger type	Sessions		kWh	
	Number of sessions	% Total	kWh charged	% Total
Level 1	8,148	19.4%	68,817	8.3%
Level 2	27,469	65.2%	551,281	66.2%
DCFC	6,500	15.4%	212,463	25.5%
Total	**42,117**	**100%**	**832,561**	**100%**

Figure 7-2 shows the percentage of home and away charging volume by charger type. The majority of Level 1 (77.9%) and Level 2 (81.0%) charging take place at home while DCFC charging takes place exclusively away from home.

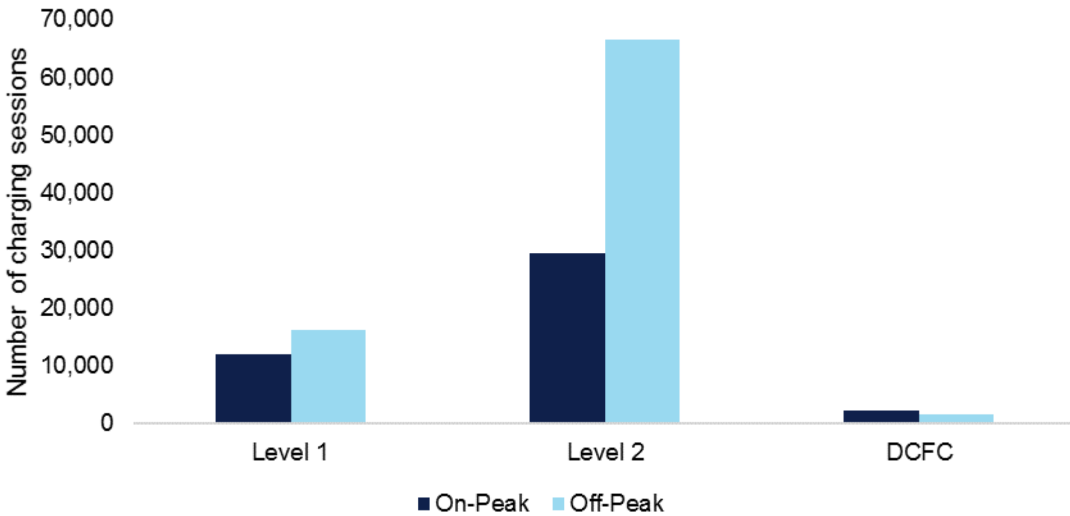
Figure 7-2. Percent of home and away charging volume (kWh) by charger type



7.2 Comparison of charger type and charging period

The next goal was to parse the data for trends in on peak and off-peak charging behavior related to charger type. Figure 7-3 provides a visual comparison of the number of charging sessions completed with each charger type and clearly shows the prominence of off-peak L2 charging over the course of the program.

Figure 7-3. Comparison of number of charging sessions charged on-peak and off-peak by charger type



Consistent with previous findings, Table 7-5 shows that L2 chargers are the most common charger type during on peak and off-peak periods. A key finding is that nearly 70% of weekday L2 charging sessions were initiated during off-peak hours which was the largest share of off-peak sessions of any charger type. Conversely, most of the weekday DCFC sessions took place during on-peak periods and accounted for 57% of the sessions in this category. A total of 28,348 weekday charging sessions completed with L1 equipment were recorded and 57% of these were initiated off-peak.

Table 7-5 Weekday on-peak and off-peak sessions by charger type

Charger type	On-Peak Sessions	% On-Peak by Charger Type	Off-Peak Sessions	% Off-Peak by Charger Type	Total
Level 1	12,143	43%	16,205	57%	28,348
Level 2	29,566	31%	66,545	69%	96,111
DCFC	2,258	57%	1,723	43%	3,981
Total	**43,967**	**34%**	**84,473**	**66%**	**128,440**

7.3 Comparison of charger type and vehicle type

The final level of charger type analysis focused on identifying trends in behavior based on vehicle type. Figure 7-4 shows the number of charging sessions per-vehicle by charger type across the entire program year. Hence, results show the yearly average number of charging sessions for a single vehicle with the given charger type. The figure illustrates the clear pattern for Tesla charging to be completed with L2 equipment, but there were also a substantial number of sessions that used L1 and DCFC equipment. PHEV charging is evenly split between L1 and L2 charging, and most non-Tesla BEV charging used L2 equipment.

Figure 7-4. Normalized comparison of number of charging sessions by charger type and vehicle type

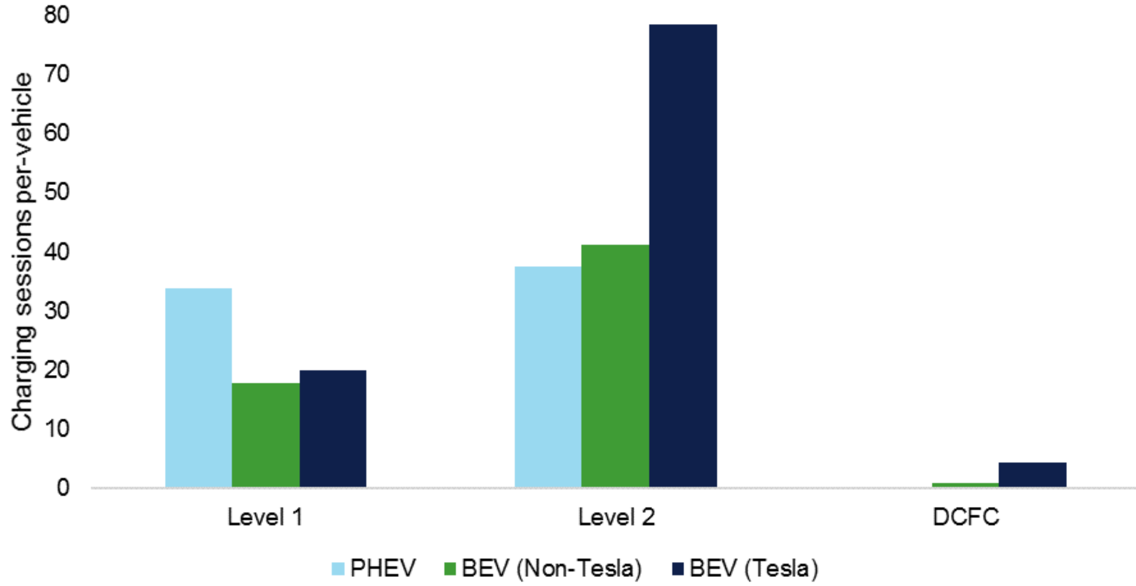


Table 7-6 provides additional granularity of PHEV charging. While there is little difference in the number of L1 and L2 sessions, the kWh delivered through L2 chargers accounted for 69.5% of total charging in this category.

Table 7-6. Charger type for PHEV sessions and volume

Charger type	Sessions		kWh	
	Number of sessions	Percent of total	kWh charged	Percent of total
Level 1	5,176	47.5%	26,097	30.5%
Level 2	5,730	52.5%	59,442	69.5%
DCFC	0	0.0%	0	0.0%
Total	**10,906**	**100%**	**85,539**	**100%**

Table 7-7 gives a closer look at non-Tesla BEV charging. Most of the charging sessions (68.8%) and volume (88%) were completed with L2 equipment. There were very few DCFC sessions.

Table 7-7. Charger type for non-Tesla BEV sessions and volume

Charger type	Sessions		kWh	
	Number of sessions	Percent of total	kWh charged	Percent of total
Level 1	5,668	29.7%	32,238	9.2%
Level 2	13,142	68.8%	310,241	88.0%
DCFC	283	1.5%	9,967	2.8%
Total	**19,093**	**100%**	**352,446**	**100%**

The data in Table 7-8 follows previously described patterns in Tesla charging and shows the majority (76.2%) of sessions and volume (84.7%) completed with L2 equipment. L1 charging accounted for nearly 20% of total sessions, which indicates that these drivers still rely on L1 charging in many cases. While DCFC charging recorded the fewest sessions (6,231), Tesla models conducted the vast majority (96%) of all DCFC charging.

Table 7-8. Charger type for Tesla BEV sessions and volume

Charger type	Sessions		kWh	
	Number of sessions	Percent of total	kWh charged	Percent of total
Level 1	27,967[16]	19.4%	253,759	8.5%
Level 2	109,672	76.2%	2,526,372	84.7%
DCFC	6,231	4.3%	203,133	6.8%
Total	**143,870**	**100%**	**2,983,264**	**100%**

The consolidated results of charging sessions and volume are described in Table 7-9**,** below. A notable data point is that 63% of the total sessions and 73.8% of total volume was recorded through L2 chargers connected to Tesla vehicles. This indicates that targeting this segment of the market with additional incentives or opportunities to optimize charging behavior will have the greatest impact on overall grid conditions that result from EV charging.

Table 7-9. Consolidated comparison of charger type and vehicle model

Charger type	Vehicle type	Sessions		kWh	
		Number of sessions	Percent of total	kWh charged	Percent of total
Level 1	PHEV	5,176	3.0%	26,097	0.8%
	BEV (Non-Tesla)	5,668	3.3%	32,238	0.9%
	BEV (Tesla)	27,967	16.1%	253,759	7.4%
Level 2	PHEV	5,730	3.3%	59,442	1.7%
	BEV (Non-Tesla)	13,142	7.6%	310,241	9.1%
	BEV (Tesla)	109,672	63.1%	2,526,372	73.8%
DCFC	PHEV	0	0.0%	0	0.0%
	BEV (Non-Tesla)	283	0.2%	9,967	0.3%
	BEV (Tesla)	6,231	3.6%	203,133	5.9%
Total		**173,869**		**3,421,249**	

[16] Note that while Tesla Level 1 charging is possible, it is somewhat unexpected. However, there were 27,967 Tesla sessions with a charge rate less than 2 kW, signifying a Level 1 charging session. These sessions may be a consequence of Level 1 home chargers, Level 1 public charging, or occasional Level 2 sessions that were ramping up but did not reach the charger's maximum rate of charge before being disconnected and were thus classified as Level 1. Future investigation of individual Level 1 sessions could highlight the cause of this unexpected result.

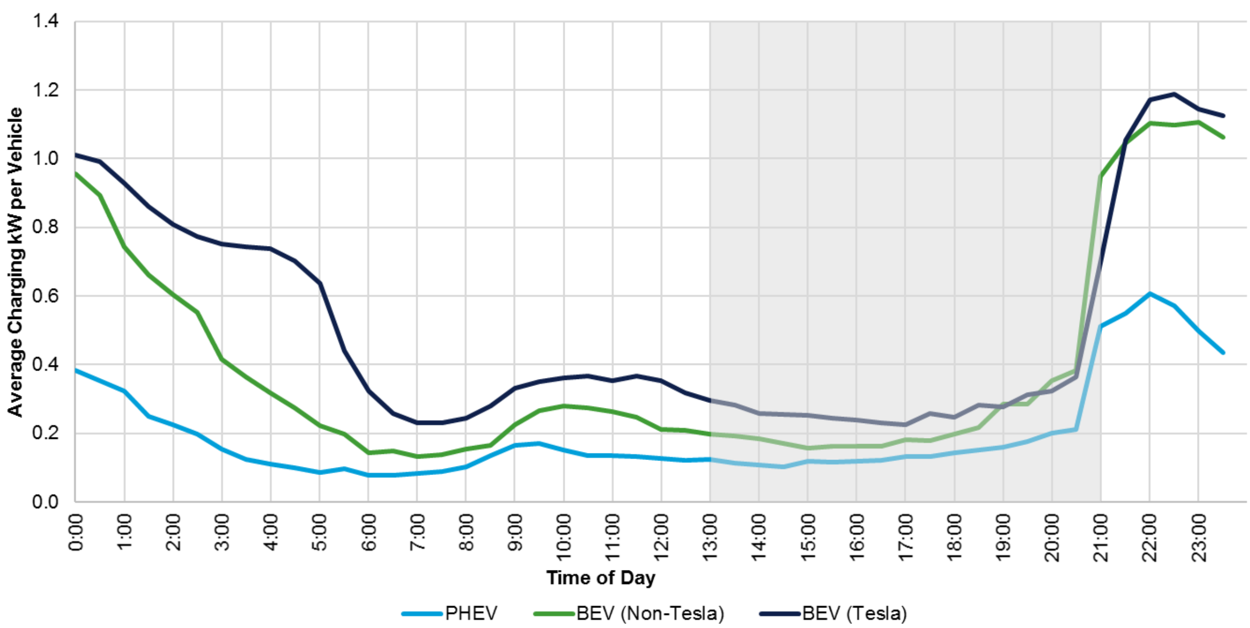
8 AVERAGE LOAD PROFILES

DNV developed 24-hour charging load profiles with 30-minute resolution for different vehicle types and charging days using the following method:

- For each vehicle included in the analysis, DNV calculated a full charging load profile (kW) spanning the vehicle's first charge date through December 31, 2022 (the end of Phase B); 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 enrolled after January 1, 2022.
- 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, weighting every vehicle equally, to identify differences in charging behavior by vehicle type.

Note that in each of the load profiles in this section, the shaded box represents the on-peak window of 1:00 p.m. to 9:00 p.m., ending slightly before the 9:00 p.m. interval to indicate that charging occurring at and after 9:00 p.m. *on weekdays* is classified as off-peak, per the program definition. Figure 8-1 shows the weekday charging profile for each vehicle type to highlight peak-affected behavior.

Figure 8-1. Average 24-hr weekday load profile by vehicle type



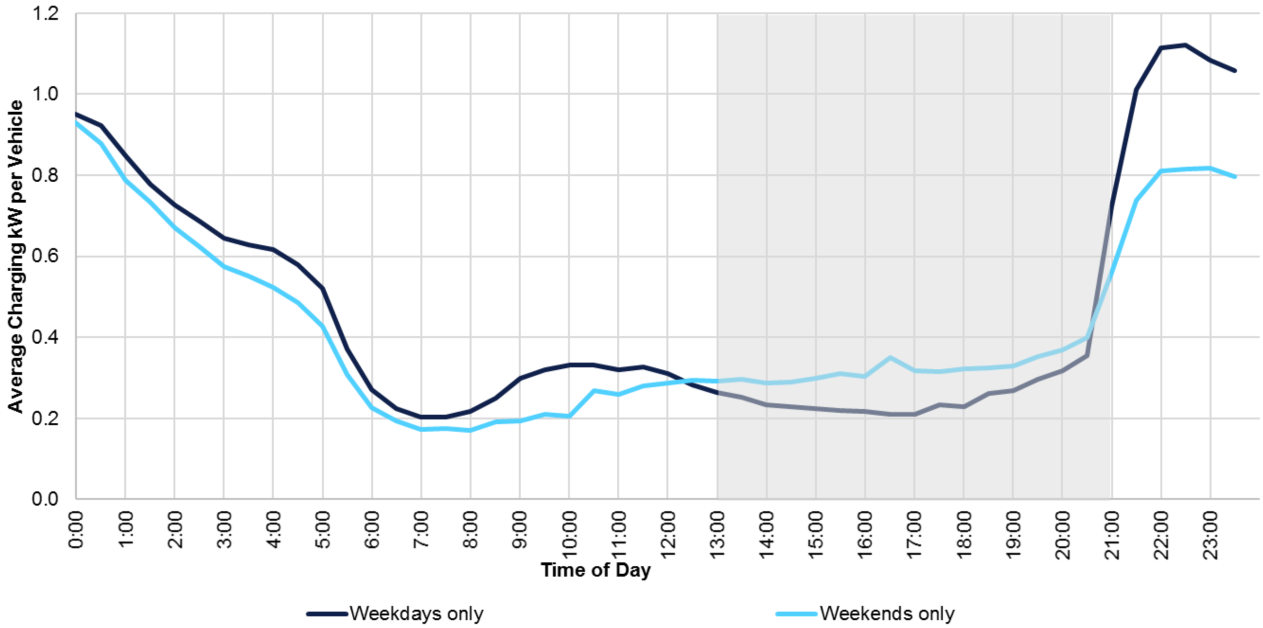
The results shown in Figure 8-1 are consistent with DNVs expectation that the maximum average kW for PHEVs is substantially lower than the maximum average kW for non-Tesla and Tesla BEVs. These results also illustrate that charging for each vehicle type is very low during the peak period and then ramps up quickly at 9:00 p.m. This matches the timing of the program's incentive window and is a positive sign for the effectiveness of off-peak rebates. It is worth reiterating that the $81,592.47 rebates provided to program participants resulted from charging activity that took place during the unshaded sections of the graphic above. The peak period continues to positively affect charging behavior, with all three groups showing sharp upticks in charging at 9:00 p.m.

Charging for all groups appears relatively consistent from 6:00 a.m. to 9:00 p.m. This may be a result of drivers coming home from work, waiting to charge until the off-peak period, charging their vehicles overnight, and unplugging in the morning.

An interesting finding is that these load profiles are illustrative of peak-affected behavior and there do not appear to be major differences in charging period start and end times between vehicle groups.

DNV also developed load profiles for weekday versus weekend charging. Note that the shaded box in Figure 8-2 represents the weekday on-peak window of 1:00 p.m. to 9:00 p.m. Weekends have no classification of on/off-peak.

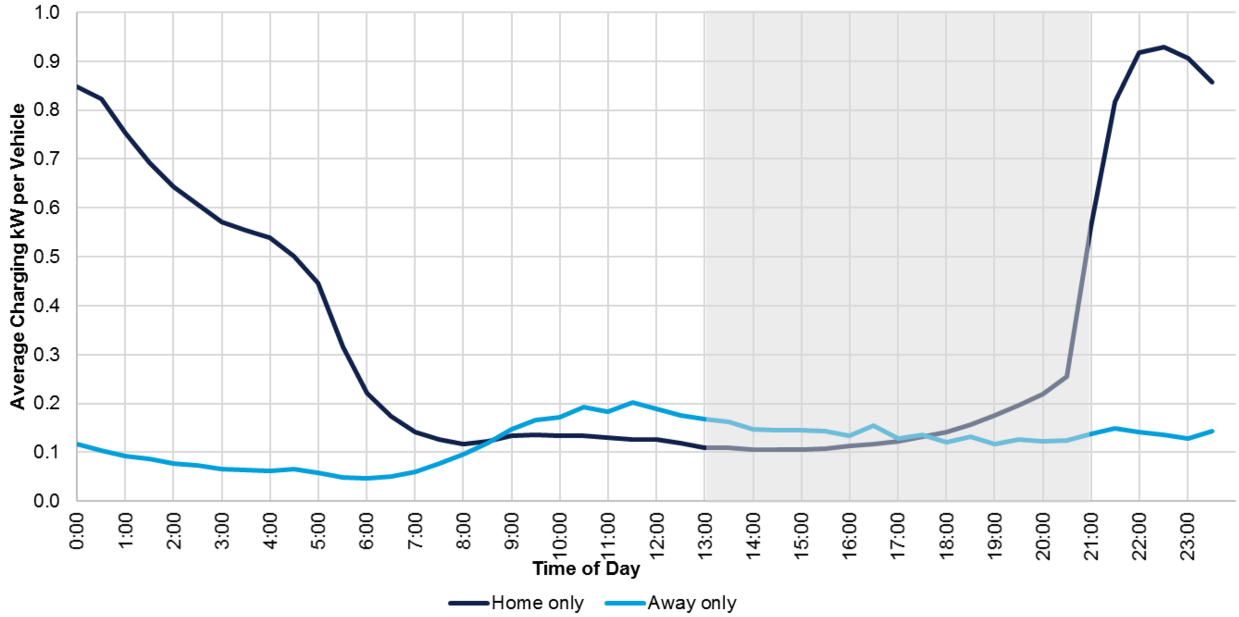
Figure 8-2. Average 24-hr load profile of weekday vs. weekend charging



Important takeaways from Figure 8-2 include the following:

- The weekday and weekend profiles track each other closely and most charging occurs overnight in both scenarios.
- It appears that some participants continue to delay charging until after 9:00 p.m. on the weekends (resulting in the post-9:00 p.m. spike). This may be the result of EVs adhering to a charging schedule that remains in effect on weekends.
- Weekends show a slightly higher on-peak kW. This is consistent with the incentive schedule because participants receive rebates only for charging during off-peak periods on weekdays and there are no on/off-peak incentives on weekends. However, the magnitude of this difference is relatively small and should not necessarily be interpreted as a significant result without further investigation.
- There is a small “bump” in weekday charging around 9:00 a.m. which may be evidence of charging at work since the weekend charging profile does not show a similar trend. This is supported by the away charging profile shown in Figure 8-3 below.

Figure 8-3. Average 24-hr load profile of home vs. away charging



The results shown in Figure 8-3 are consistent with DNV's expectation of an increase in away charging from 9:00 to 11:00 a.m., that is likely a result of workplace charging. While the home charging profile shows high levels of overnight charging and alignment with the off-peak period, the away charging profile reaches its maximum value in mid-morning. Additionally, the variation in away charging behavior and overall lower frequency of away charging causes the maximum away charging kW value to be much lower than that for home charging.

9 CHARGING SESSION FLEXIBILITY ANALYSIS

To study the potential to shift additional charging load from on-peak to off-peak periods, DNV analyzed the charging data to satisfy three objectives:

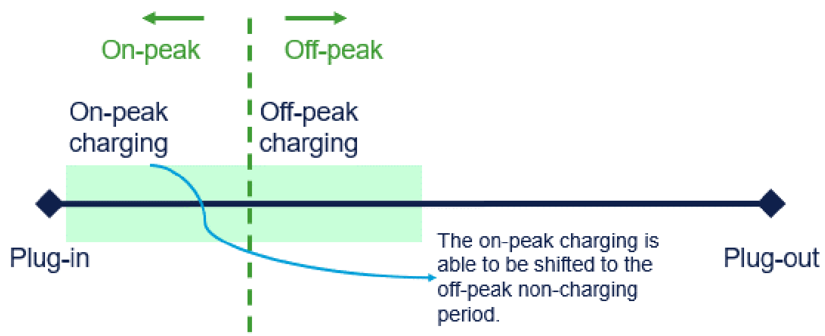
- To better understand the flexibility of charging behavior and the charging characteristics of distinct vehicle types
- To estimate the potential additional off-peak charging that could be achieved via load flexibility
- To inform National Grid's strategies for optimizing charging times to incrementally increase the prevalence of off-peak charging

In this section, "load flexibility" is defined as the technical ability to shift on-peak charging to off-peak periods when an EV is plugged in but not actively charging, which frequently happens when an EV battery reaches a full state-of-charge but is not unplugged for a period of time. We note that this analysis only quantifies the *technical potential* for shifting further charging off-peak and we do not consider how this incremental load flexibility would be achieved. We recognize that most approaches to shifting further charging load will be unable to achieve a 100% success rate (that is, shifting all of the technically shiftable load off-peak) in practical applications.

Additionally, we define a charging session in which the vehicle is plugged in on-peak and unplugged off-peak, or vice versa – regardless of when charging occurs – as a "cross-peak session." We focused on these sessions for this analysis because any session that occurs entirely off-peak would not benefit from further load flexibility, while sessions whose plug-in and plug-out times are entirely on-peak cannot, in this analysis, achieve an incremental off-peak shift thanks to load flexibility improvements.

Figure 9-1 illustrates the load flexibility analysis covered in this section.

Figure 9-1. Illustration of load flexibility concept



9.1 Analysis approach

For each charging session conducted in Phase B in 2022, DNV assessed the following:

- Charger type (Level 1, Level 2, or DCFC)
- Session location (home vs. away)
- Vehicle type
- Session plug-in and plug-out timestamps
- Session charge-start and charge-end timestamps
- Total session energy (kWh) and duration (hrs.)
- Energy charged on-peak vs. off-peak
- Duration of off-peak non-charging period (this was the window into which on-peak charging was eligible to be shifted)

An important note is that each charging interval represents a 30-min period of activity, and each charging session is made up of individual intervals that occur between the same plug-in/plug-out period.

Table 9-1. Flexible criteria

Category	Criteria
Cross-peak session	Plug-in time stamp recorded during on-peak hours and plug-out time stamp recorded during off-peak hours (or vice-versa)
Charging interval	Vehicle is connected to charger and power is flowing to EV battery
Non-charging interval	Vehicle is connected to charger, but power is not flowing to EV battery

First, we filtered to remove all away and DCFC charging sessions, since National Grid indicated that they were currently focused on the potential load flexibility for home charging. Then we classified each 30-minute interval as charging or non-charging during the session by using standard power level assumptions by charger type – about 1.8 kW for Level 1 and 6-12 kW for Level 2. Intervals whose power level fell below a defined threshold – 0.2 kW for Level 1 (or about 10% of the assumed charge rate) and 2 kW for Level 2 (or about 16-33% of the assumed charge rate) – were classified as non-charging intervals. This approach allowed for some in-session power fluctuations and near-end-of-session tapering, which is a common feature of EVs to optimize battery health and minimize battery degradation, to be accurately tagged as charging intervals.[17] We then quantified the number of both charging and non-charging intervals occurring on-peak and off-peak to determine what portion of the on-peak charging intervals could be shifted to off-peak non-charging intervals. Finally, we multiplied the portion of shiftable intervals by the overall session kWh to quantify the technically shiftable energy impact.

Table 9-2 Charging and non-charging interval power levels by charger type

Charger Type	Charging Interval Power Level	Non-Charging Interval Power Level
Level 1	Peak session power greater than 1.8 kW and less than 3 kW	Less than 0.2 kW
Level 2	Peak session power in the range of 6 – 12 kW	Less than 2 kW

9.2 Analysis results

The load flexibility analysis was structured to calculate three key metrics designed to understand:

- How common cross-peak sessions were in Phase B
- How much of the charging in cross-peak sessions happened on-peak vs. off-peak
- How much additional charging could technically be shifted to off-peak intervals

The following subsections provide results from each of these components of the analysis.

[17] For Level 1 sessions, we classified non-charging intervals as intervals in which the power level was below 0.2 kW – or roughly 10% of a typical Level 1 charging level of 1.8-2 kW. For Level 2 sessions, we classified non-charging intervals as intervals in which the power level was below 2 kW – or between 16-33% of a typical home Level 2 charging level of 6-12 kW.

9.2.1 Cross-peak session analysis

We first quantified the number of cross-peak sessions by vehicle type to gain an understanding of how prevalent these types of charging sessions were in Phase B. This analysis is summarized below in Table 9-3.

Table 9-3. Summary of cross-peak charging session counts

Vehicle type	Home charging sessions	Cross-peak charging sessions	Percent of cross-peak sessions
PHEV	8,969	1,477	16%
BEV (Non-Tesla)	13,602	2,260	17%
BEV (Tesla)	108,494	24,339	22%
Total	**131,065**	**28,076**	**21%**

This table shows that cross-peak sessions are fairly prevalent, representing 21% of all home charging sessions. This suggests that there may be an opportunity to take advantage of load flexibility to shift further charging load off-peak. Across all vehicle types, Tesla's have the highest share of cross-peak sessions (22%), compared to similar shares (16-17%) for PHEVs and Non-Tesla BEVs.

Analysis of Cross-Peak Session On-peak vs. Off-peak Charging

After quantifying the number of cross-peak sessions by vehicle type, we estimated the relative share of on-peak vs. off-peak charging (kWh) within these sessions. The results are shown in Table 9-4, below.

Table 9-4. Average On- and Off-peak Charging Within Cross-peak Sessions

Vehicle type	Percent On-peak Charging	Percent Off-peak Charging	Percent Weekend Charging
PHEV	35%	62%	3%
BEV (Non-Tesla)	30%	66%	4%
BEV (Tesla)	22%	74%	4%
Total	**29%**	**67%**	**4%**

These results indicate that for the average cross-peak session, the majority – between 62% (PHEVs) and 74% (Tesla BEVs) – of charging activity already takes place off-peak. This limits the amount of on-peak charging that might technically be shiftable to an off-peak non-charging period. However, the fact that most home charging occurs off-peak within cross-peak sessions is further indication of the positive off-peak shifting effects of the program as a whole.

Note that a small share of charging for all vehicle types occurs on weekends, which are not classified as on- or off-peak; these result from sessions that spanned part of a weekday but either began on or ended on a weekend day.

"Technically Shiftable" Home Charging kWh

To complete this analysis, DNV quantified the technical potential for load flexibility ("technically shiftable kWh"), which is summarized in Table 9-5, below. For each cross-peak session, the technically shiftable potential was calculated by determining the lesser of the number of on-peak charging intervals and the number of off-peak non-charging intervals. This value was then multiplied by the average per-interval charging energy consumption. For example, if there were two hours' worth of on-peak charging intervals and four hours of off-peak non-charging intervals, two hours' worth of on-peak charging (in this case 100%) was found to be shiftable off-peak (Example A in Figure 9-2 below); however, if there had only been one hour of off-peak non-charging intervals, then only half of the two on-peak charging intervals (50%) were determined to be shiftable off-peak (Example B in Figure 9-2). This approach was then applied across all home cross-peak charging sessions to estimate, at the program-level, how much additional charging load could potentially be shifted off-peak, both in aggregate (total kWh) and relative to the amount of charging already occurring off-peak through the program.

Figure 9-2. Illustration of "technically shiftable" charging example

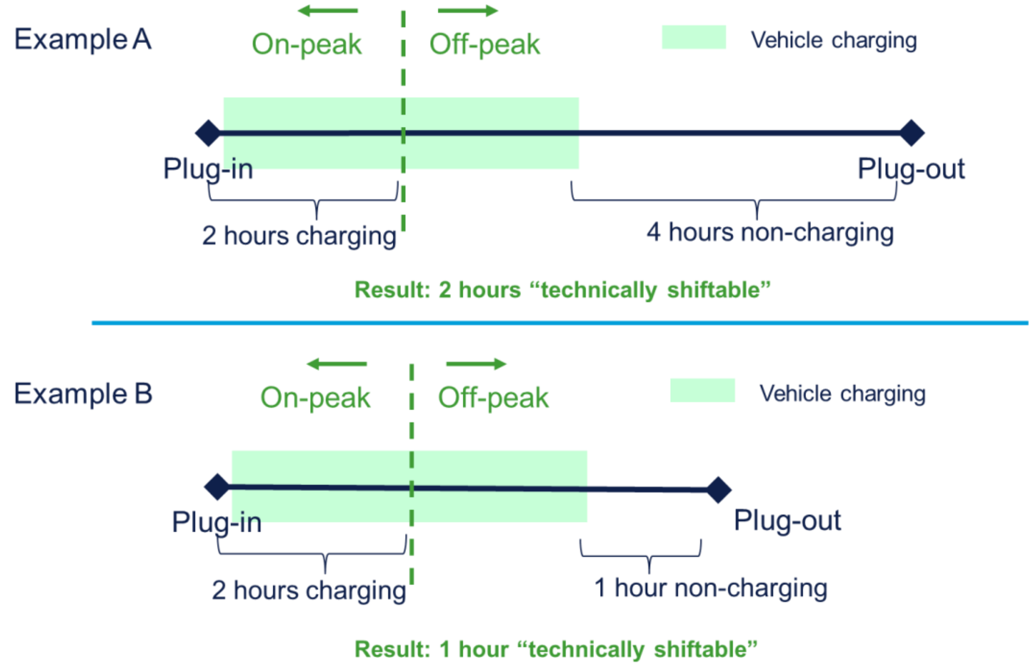


Table 9-5. Technically Shiftable kWh Summary

Vehicle type	Home Off-peak kWh Charged in Phase B	Technically Shiftable kWh	Percent Shiftable kWh	Technically Shiftable kWh per Cross-peak Session
PHEV	41,917	1,207	2.9%	0.8
BEV (Non-Tesla)	167,812	2,591	1.5%	1.1
BEV (Tesla)	1,482,709	31,940	2.2%	1.3
Total	**1,692,439**	**35,737**	**2.1%**	**1.3**

Our analysis shows that a further 2.1% increase in off-peak charging (relative to the amount of off-peak charging already occurring as a result of the program) could technically be achieved if National Grid were able to shift the on-peak charging in cross-peak sessions to off-peak non-charging periods. It is important to note that this result depends not only on the number of cross-peak sessions and the average amount of on-peak charging taking place within those sessions, but also on the average non-charging off-peak time within a cross-peak session. This time depends on several factors, including the EV state of charge at plug-in, the level of home charger (Level 2 chargers will fill a battery faster, potentially resulting in more non-charging time), the time spent charging compared to the overall plug-in event duration, and whether a driver employs scheduling or other controls to shape their charging behavior.

These results indicate that Tesla BEVs have the most potential for shifting additional kWh off-peak in aggregate terms (31,940 kWh) and per-session (1.3), followed by Non-Tesla BEVs and PHEVs. This may be a result of the high prevalence of Level 2 charging among Tesla's, which results in faster charging times and longer non-charging periods into which on-peak charging can be shifted. Meanwhile, PHEVs have the highest share of technically shiftable kWh relative to their off-peak charging already conducted through the program. This result is likely a combination of the fact that a relatively high share of their cross-peak charging occurs on-peak (35%), so there is more to shift, paired with the fact that, due to their small batteries, PHEVs are more likely than BEVs to reach a full state of charge earlier in a charging session, leaving a longer non-charging period.

The additional technically shiftable kWh could potentially be achieved by active load management approaches that involve the utility taking control of the timing of EV charging in exchange for an incentive to participating customers. This approach could help National Grid achieve higher levels of off-peak charging and would also offer opportunities to smooth aggregate EV charging load to mitigate timer peaks or other negative grid impacts of simultaneous charging by EV drivers. Efforts like this are being piloted around the country and typically require two-way communication protocols to not only receive charging data but also to send charging and/or curtailment signals to participating EVs and smart chargers over-the-air. By moving to a telematics-based managed charging solution for Phase B, National Grid is moving in the right direction to unlock additional off-peak charging potential in future managed charging efforts.

10 GHG EMISSIONS ANALYSIS

To calculate the greenhouse gas (GHG) emissions associated with EV charging, DNV created 8760 load profiles of each vehicle type and matched them with data points provided by WattTime[18] that represent corresponding grid emissions (both average and marginal). This is a valuable process because the goal of the Charge Smart program is to shift EV charging to off-peak hours and the state of Massachusetts has set targets to reduce GHG emissions. The expectation is that off-peak EV charging periods overlap with relatively low-emissions conditions on the grid.

This analysis summarizes the emissions impact of off-peak vs. on-peak charging and summer vs. non-summer charging. This approach seeks to generate high level emissions profile data based on the information provided through the Charge Smart program and future versions of this analysis can be designed to create additional levels of granularity.

10.1 Emissions summary

DNV examined two aspects of emissions generated by EV charging. The first calculation identified the average emissions (CO_2 lb./kWh) associated with each kWh of EV charging. This metric provides a benchmark of existing grid and market conditions based on the EV charging load recorded in 2022.

The second calculation measured the marginal emissions (CO_2 lb./kWh) associated with each additional kWh of charging. This metric indicates the way that total emissions will change as demand from vehicle charging increases. These data points are useful for forward looking analysis and program design.

Table 10-1. GHG Calculations

Calculation Methodology and Formulas	
Aggregate Emissions	Actual total charged energy [kWh] * WattTime [CO2lb/kwh]
Per-kWh Emissions	Aggregate emissions [CO2lb] / 8760 [kWh]

Based on average emissions rates (MOERs), the vehicles participating in the Charge Smart program generated a total of 1,633,918 lbs. of CO_2 emissions.

When calculated based on the marginal emissions rate (MOER) associated with EV charging, the vehicles accounted for 3,125,153 lbs. of CO_2 emissions. In Table 10-2 the marginal calculations indicate a much higher level of emissions because this approach is based on the additional generation resources needed to supply power for the additional volume. In many cases, the marginal generation resource in ISO-NE territory is fossil fuel-based and has a higher emissions intensity than the average grid mix, which includes a range of fuel types including nuclear power, renewables, and hydro power.

Table 10-2. Total emissions by location based on average and marginal grid calculations

Location	Total emissions based on Average (CO_2lb)	Total emissions based on marginal (CO_2lb)
Home	1,219,211	2,357,286
Away	414,707	767,866
Total	**1,633,918**	**3,125,152**

Next, DNV analyzed the seasonal trends in GHG emissions; Table 10-3 shows that the average per-kWh emissions were higher in summer months than in non-summer months. However, the marginal per-kWh emissions were lower in summer months than in non-summer months. This indicates that the grid's average carbon intensity is higher during the summer

[18] See Program Overview for background and description of WattTime data

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which is consistent with the need for more carbon-intense resources to come online to meet increased summer demand. However, marginal summer resources have a lower emissions intensity than marginal winter resources. Values presented below represent CO_2 lbs. emitted per kWh charged.

Table 10-3. Summer and non-summer emissions profiles[19]

Season	Average per-kWh Emissions (CO_2lb/kWh)	Marginal per-kWh Emissions (CO_2lb/kWh)
Summer	0.521	0.910
Non-Summer	0.453	0.921

Finally, DNV studied the emissions associated with on- vs. off-peak charging. Table 10-4 confirms the expectation that on-peak periods tend to have higher emissions levels than off-peak periods. Both the average and marginal CO_2 lb./kWh metrics were higher during the on-peak periods. This result is encouraging, as it indicates that the program goal of shifting EV charging to off-peak periods also results in decreased overall emissions.

Table 10-4. On and off-peak emissions profiles[20]

Period	Average per-kWh Emissions (CO_2lb/kWh)	Marginal per-kWh Emissions (CO_2lb/kWh)
On-Peak	0.518	0.942
Off-Peak	0.476	0.912
Off-Peak percent reduction	8.1%	3.2%

10.2 Emissions factors by location

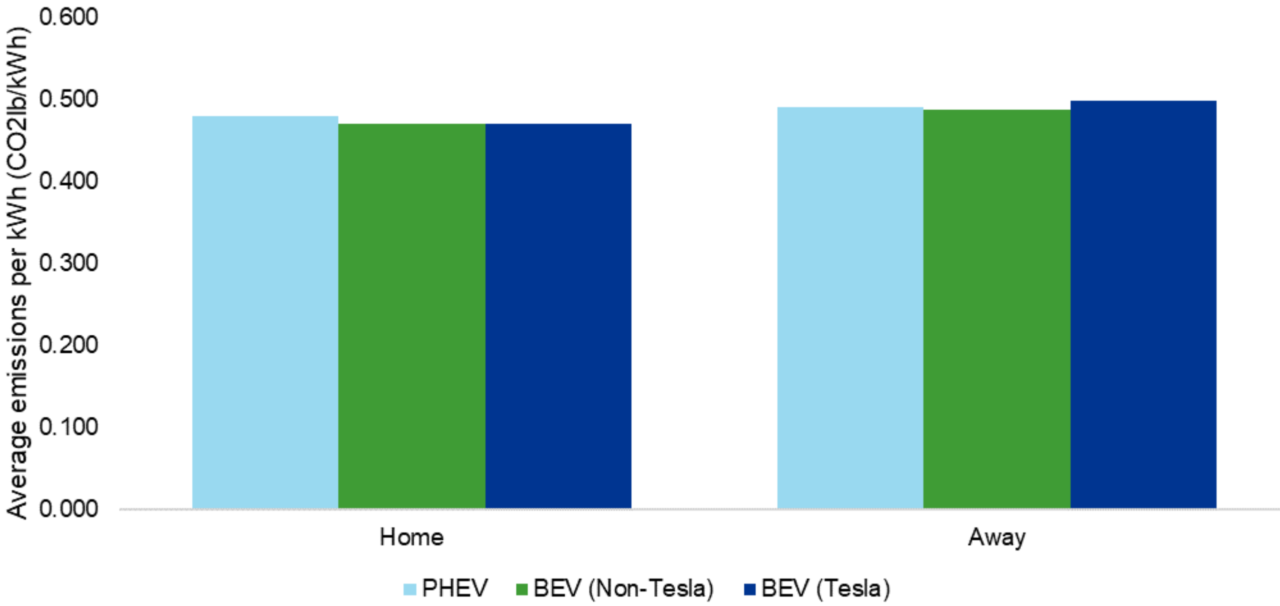
As previously described, home charging made up 76% of total kWh charged and thus resulted in higher total emissions. A deeper analysis of locational per-kWh emissions by vehicle type in Figure 10-1 shows that PHEVs have the highest per-kWh average emissions when charging at home. Notably, non-Tesla BEVs recorded the lowest per-kWh average emissions for both home and away charging while Tesla models recorded the highest per-kWh emissions for away charging.[21]

19 Based on average emissions values of all vehicle types

20 Based on average emissions values of all vehicle types

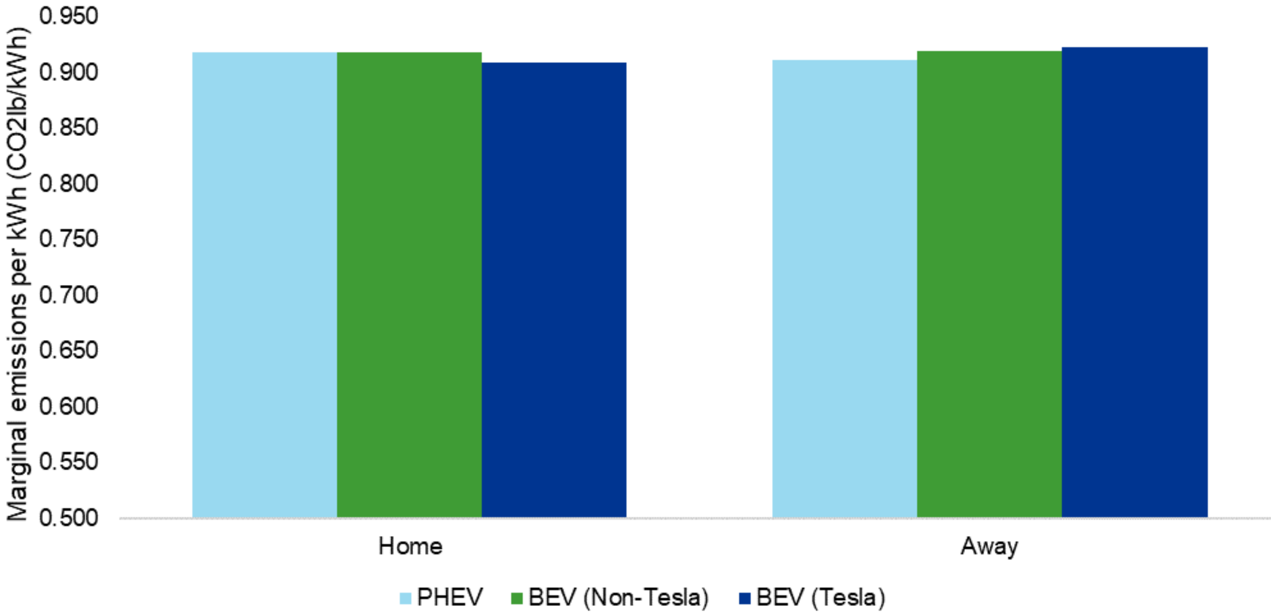
21 DNV considered all “away” sessions to be completed within the same grid emissions profile as “home” charging sessions

Figure 10-1. Average emissions per kWh by location and vehicle type



The marginal emissions analysis followed a similar trend, with Tesla models producing the lowest home per-kWh emissions and the highest away per-kWh emissions. Higher away charging emissions for Tesla's may be a result of the higher share of charging done with DCFC equipment (seen in Table 7-9) as DCFC chargers place higher demand (kW) on the grid.

Figure 10-2. Marginal emissions per kWh by location and vehicle type



10.3 Emissions factors by on peak and off-peak behavior

Consistent with previous findings, Figure 10-3 shows that on-peak home charging results in higher average per-kWh emissions than off-peak home charging. Though the difference is small, average per-kWh emissions are noticeably higher on-peak than off-peak, with Tesla charging showing the largest difference between the two.

Figure 10-3. Comparison of average emissions profile of home charging during on- and off-peak periods

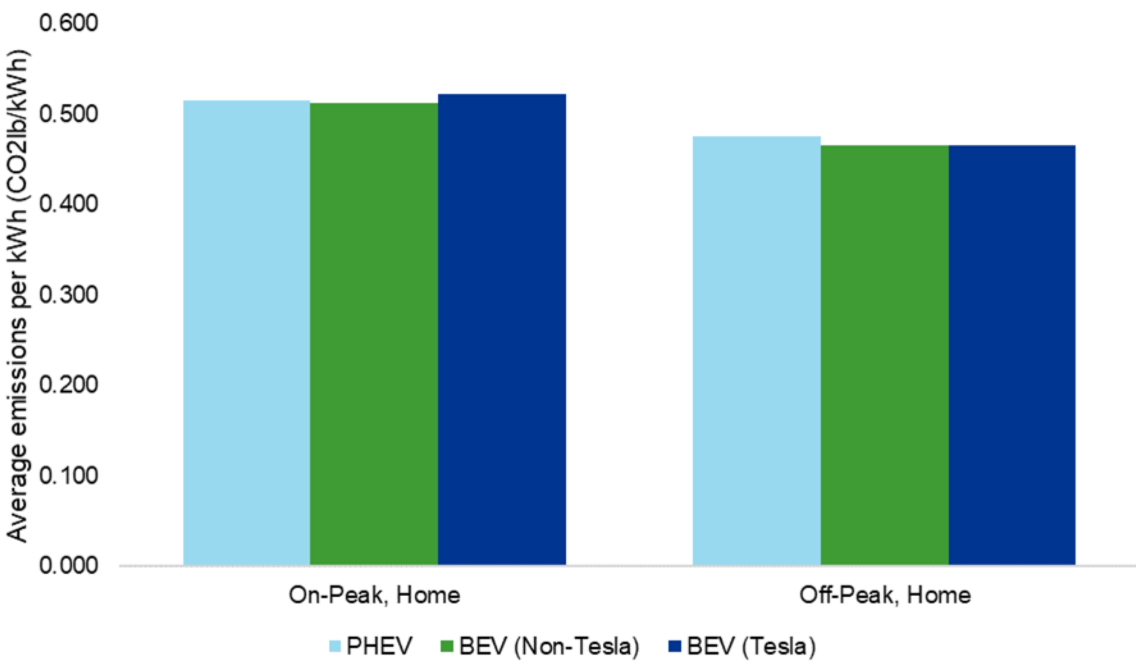
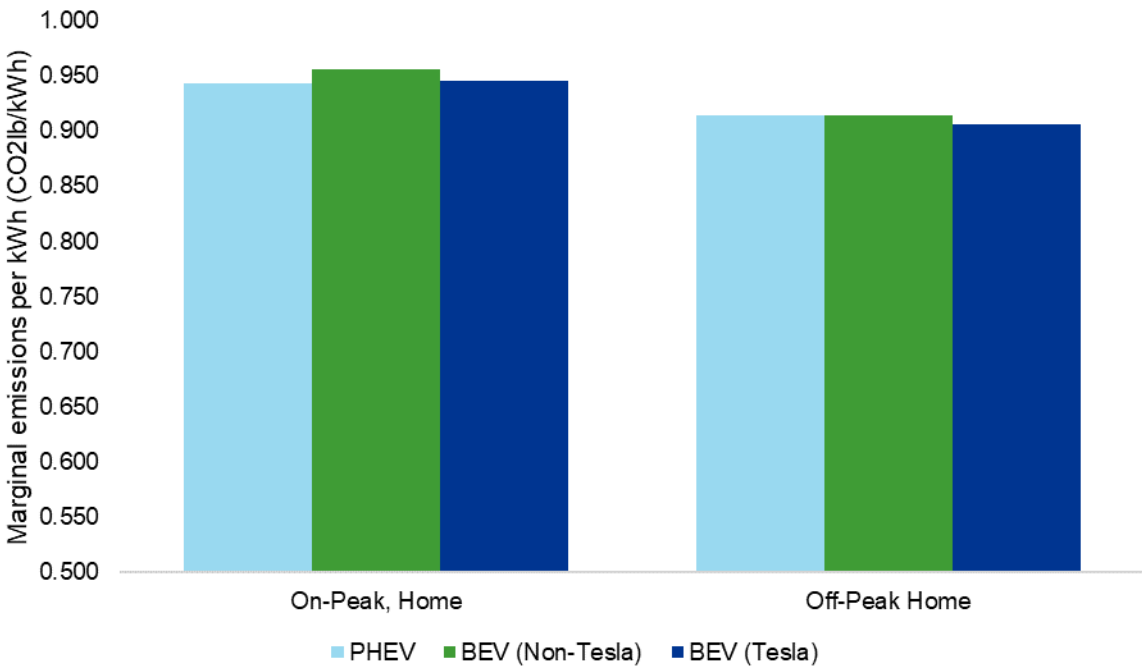


Figure 10-4 reinforces that off-peak home charging has lower marginal emissions impacts as well, highlighting the benefit of shifting any additional charging to off-peak periods. In this case, the difference in marginal per-kWh emissions on-peak and off-peak is largest for non-Tesla BEVs. This indicates that a kWh of charging shifted from on-peak to off-peak for non-Tesla BEV models will result in a larger emissions reduction than either of the other vehicle types.

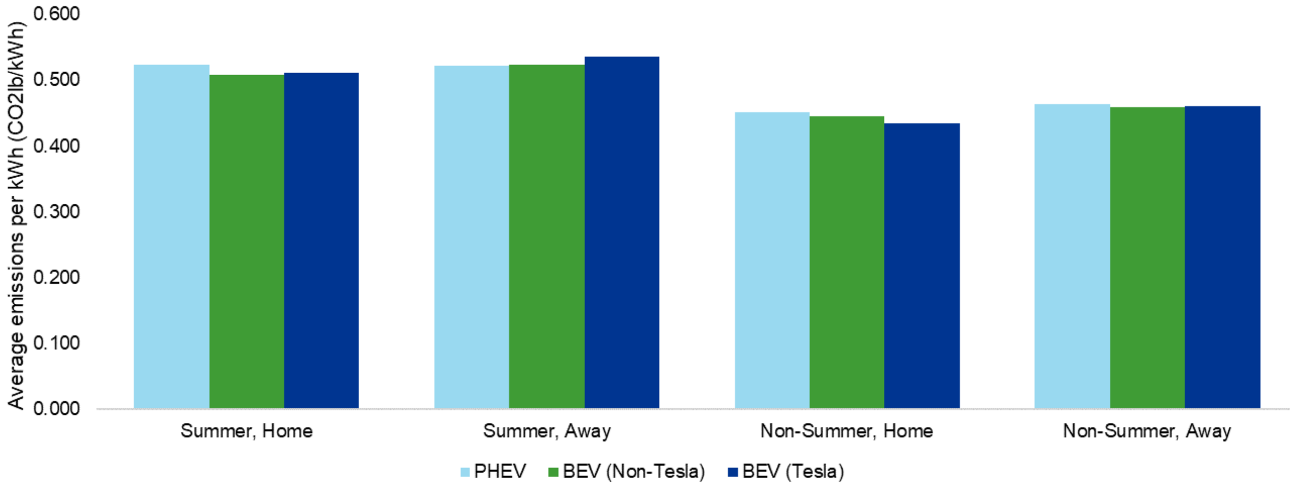
Figure 10-4. Comparison of marginal emissions from home charging during on- and off-peak periods



10.4 Emissions factors by season

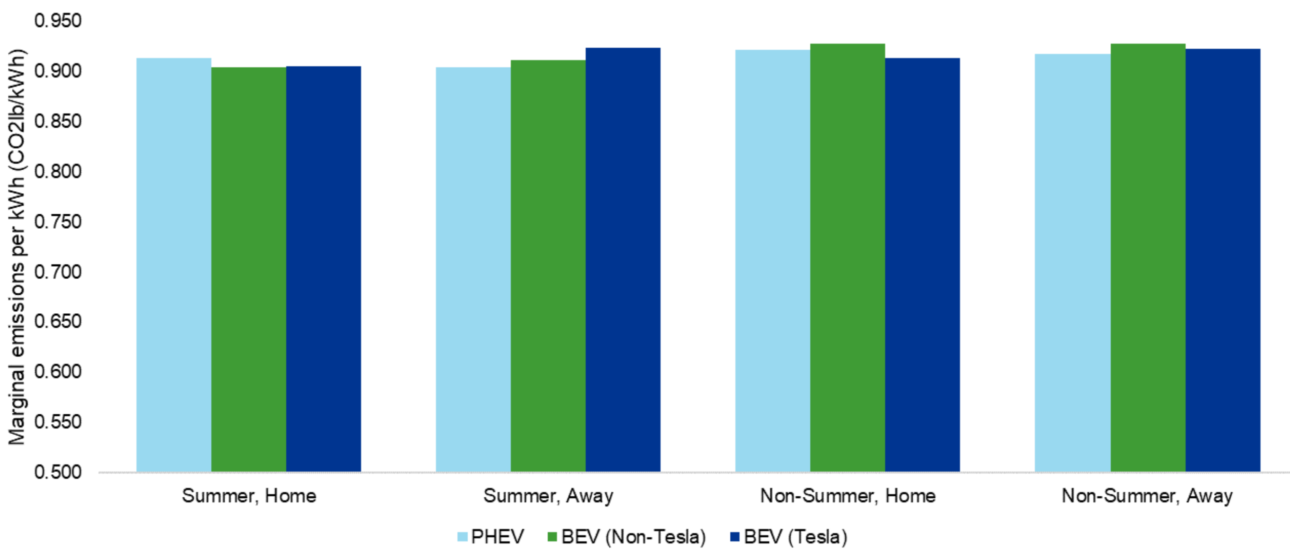
Figure 10-5 highlights differences in average per-kWh emissions during summer and non-summer periods and shows the average per-kWh emissions factors were highest during the summer months for both home and away charging. While solar production may be higher in summer months, it likely is not a large enough portion of Massachusetts's grid makeup today to result in lower average summer emissions factors.

Figure 10-5. Summer and non-summer average emissions factors by location and vehicle type



While difficult to draw seasonal conclusions from the results shown, it is notable from the data in Figure 10-6 that Tesla charging in summer months has a lower home emissions factor (0.511 CO_2 lb./kWh compared to 0.509 CO_2 lb./kWh for non-Tesla BEVs and 0.524 CO_2 lb./kWh for PHEVs), but the highest away emissions factor. Again, this may be a result of Tesla owners' higher utilization of DCFC away charging.

Figure 10-6. Summer and non-summer marginal emissions factors by location and vehicle type



10.5 Daily charging and emissions profiles

The final step in this emissions analysis involved overlaying the average and marginal emissions profiles with the average charging profile of the program's entire vehicle population. The charging profile (discussed in Section 8) demonstrates that daily charging load typically ramps up after 9:00 p.m. and tapers off around 7:00 a.m. Importantly, the period of high charging load aligns with the period of relatively low grid emissions in both the average (Figure 10-7) and (Figure 10-8) analysis. This is an encouraging result, as it indicates that off-peak charging aligns with lower emissions factors and that efforts to shift charging to the off-peak period will help decrease greenhouse gas emissions caused by EV charging.

It is important to note the scale of the secondary y-axis on both figures below. To show the variation in emissions of individual vehicle charging, it is necessary to zoom in to a tighter range of CO_2 lb./kWh. With this understanding, the charts show that there is a difference in emissions generated by charging at different times of the day. As the number of EVs that rely on grid power for battery charging increases, the total emissions attributed to vehicle charging will scale accordingly.

Figure 10-7. Comparison of daily charging load and average emissions

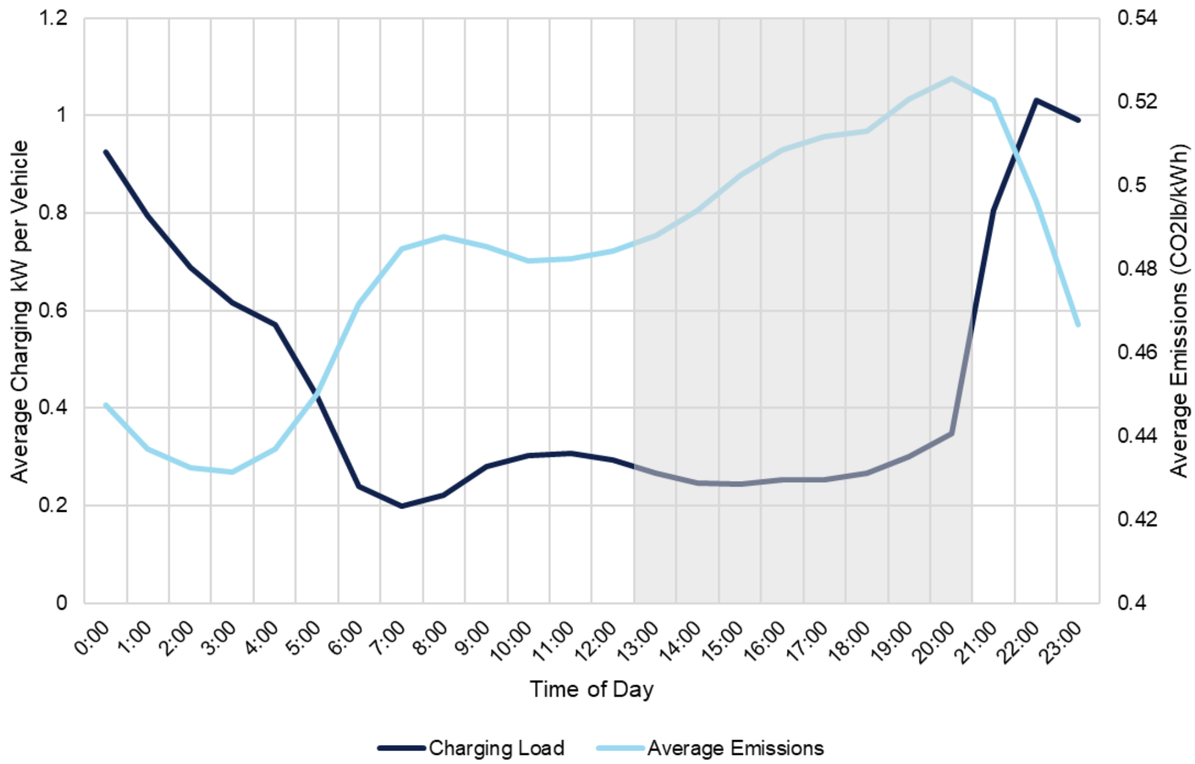
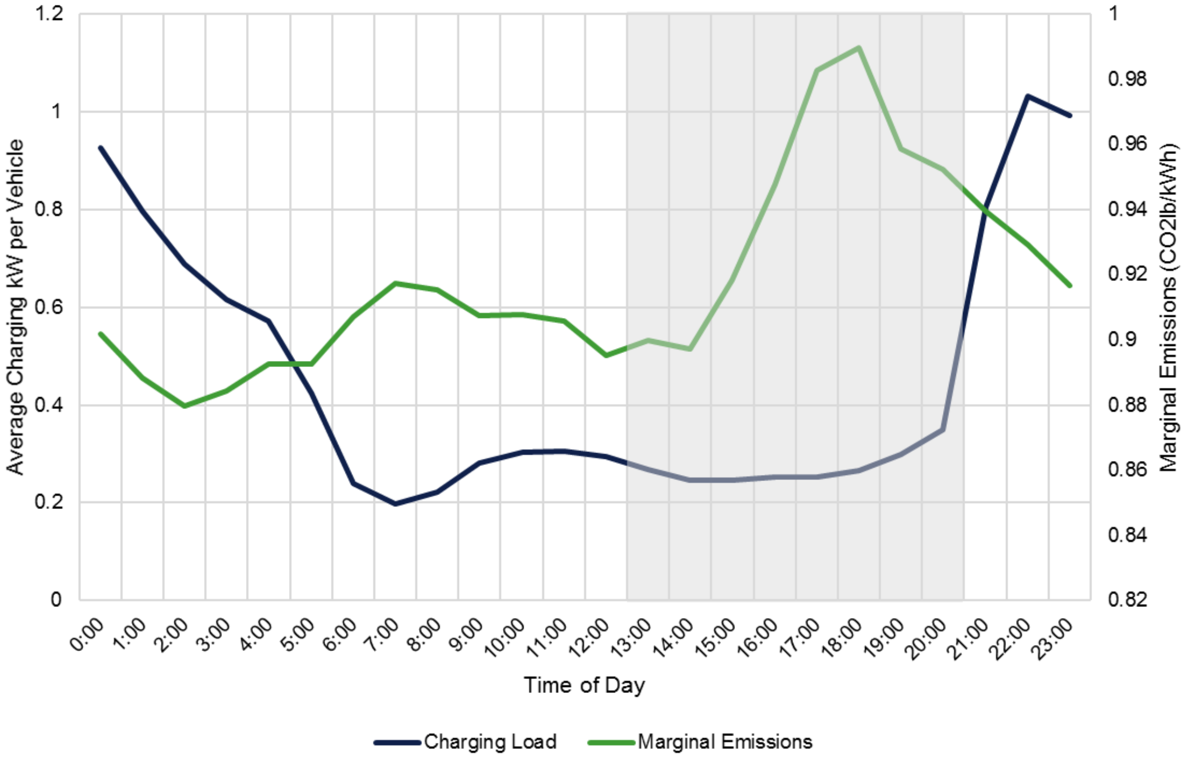


Figure 10-8. Comparison of daily charging load and marginal emissions



APPENDIX A. MARKETING MATERIAL CALENDAR

Media Flow Chart:

Figure 10-9. Off-peak launch media flow chart

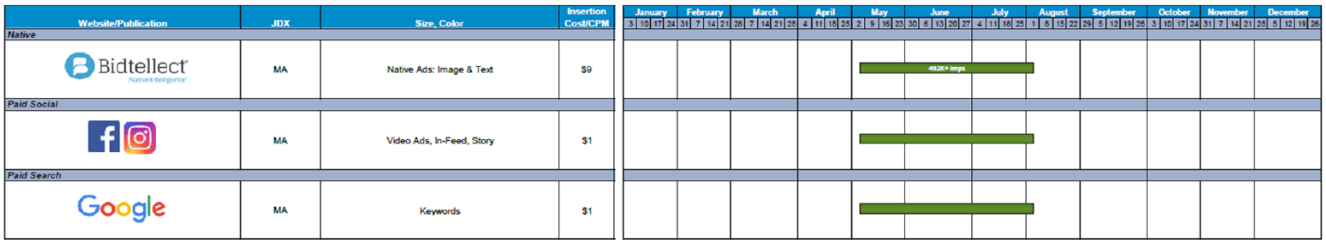
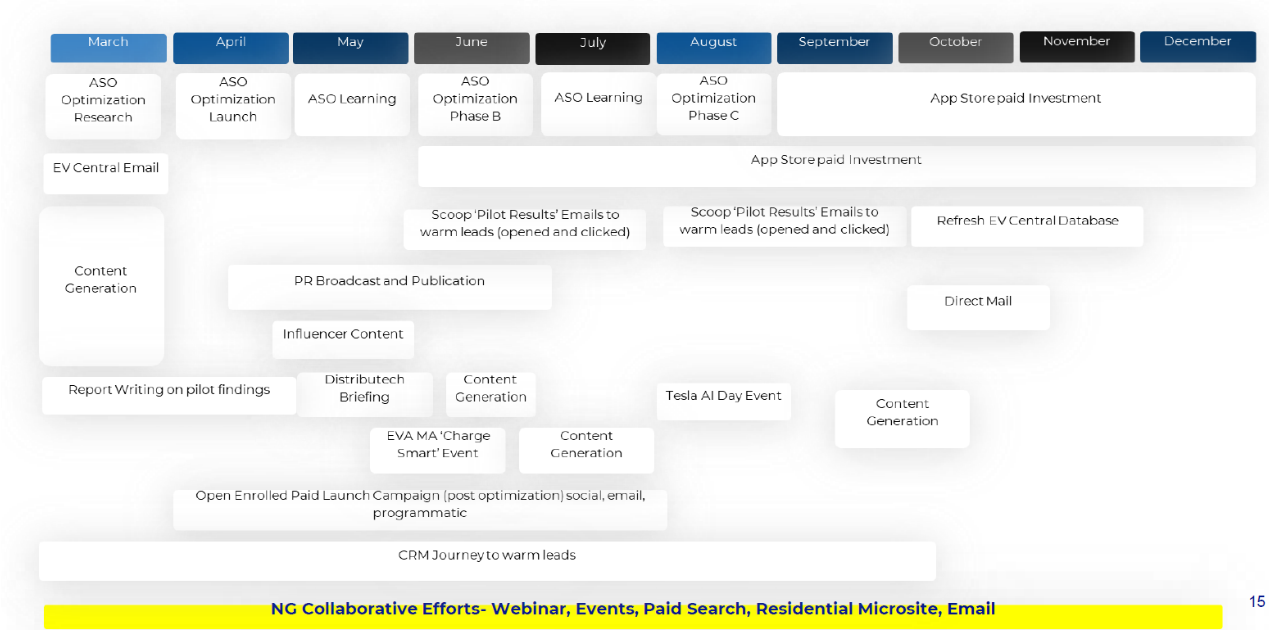


Figure 10-10. Off-peak marketing calendar



APPENDIX B. EV.ENERGY APPLICATION EXAMPLES

Figure 10-11. Onboarding and welcome screen

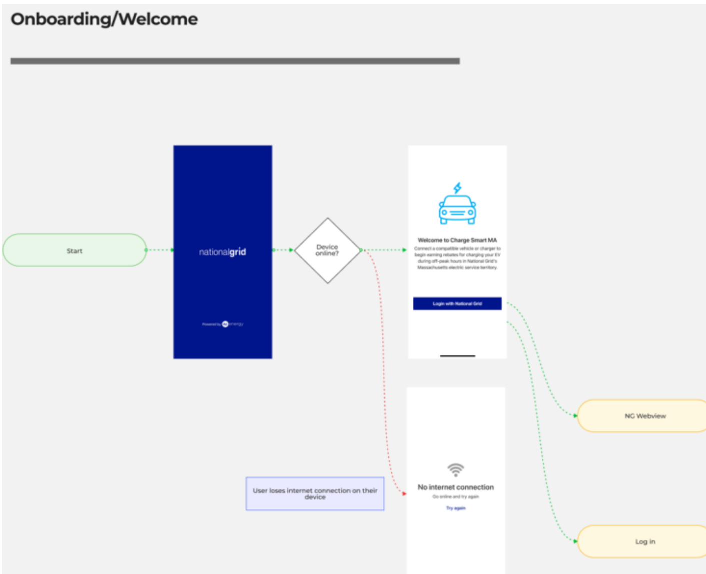


Figure 10-12. User statistics screen

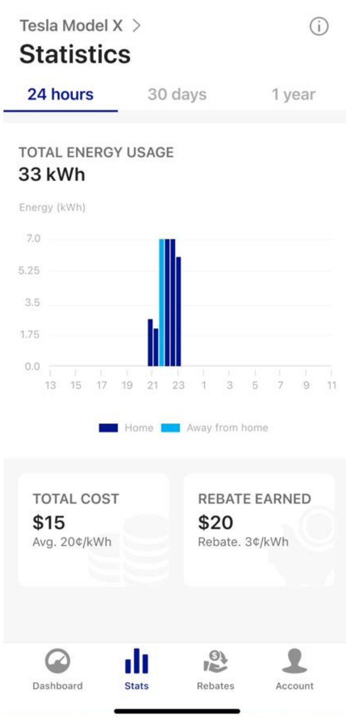
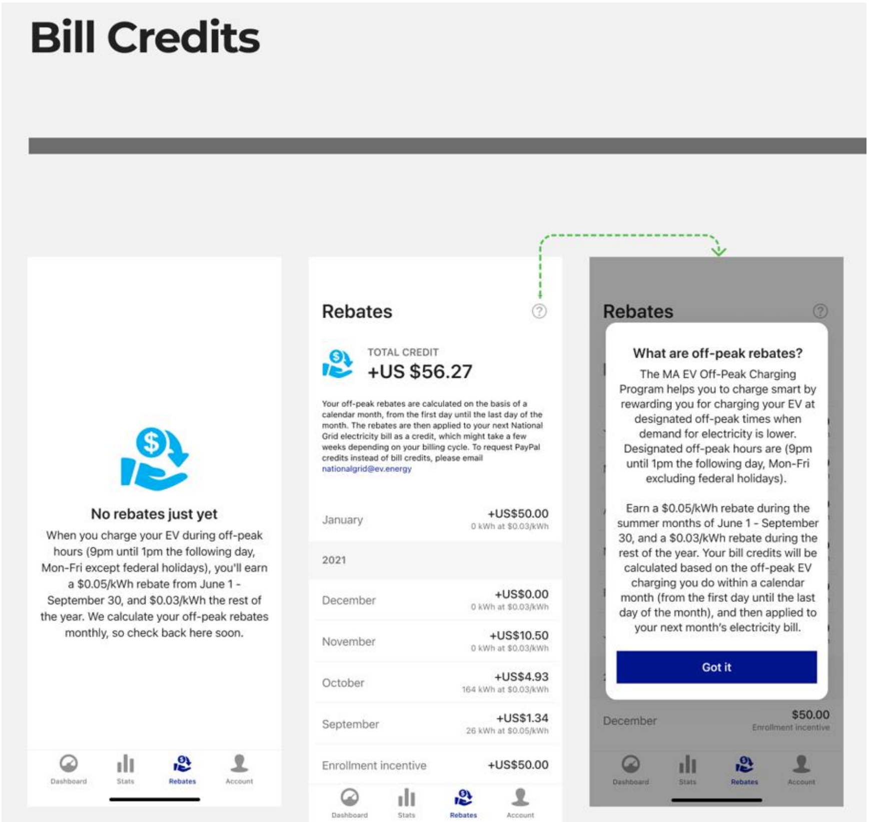


Figure 10-13. Bill credit screen



APPENDIX C. CHARGING PROFILE EXAMPLES

Figure 10-14. Level 1 charging sample

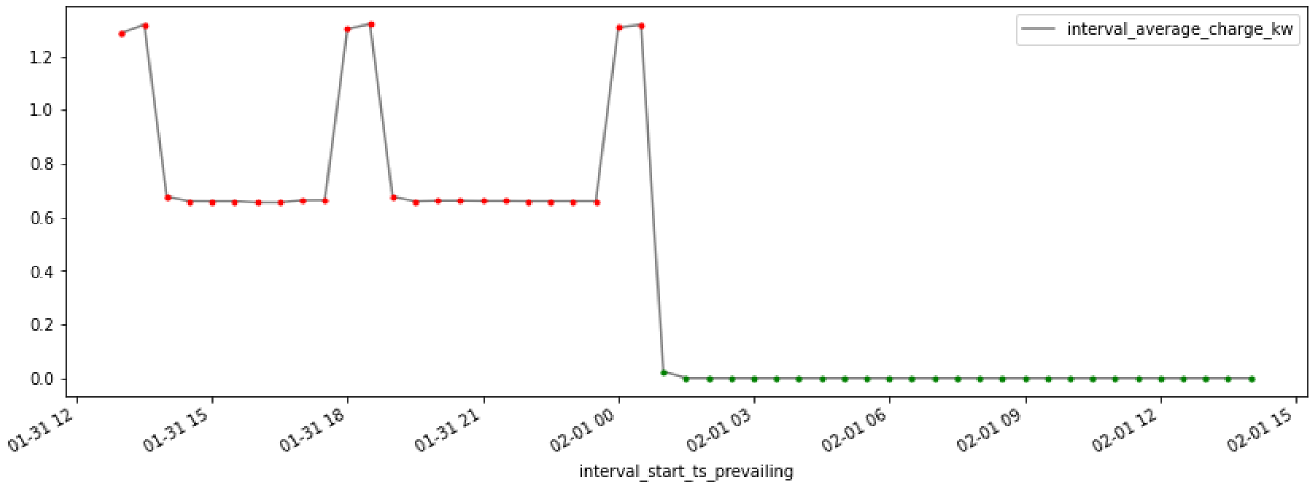
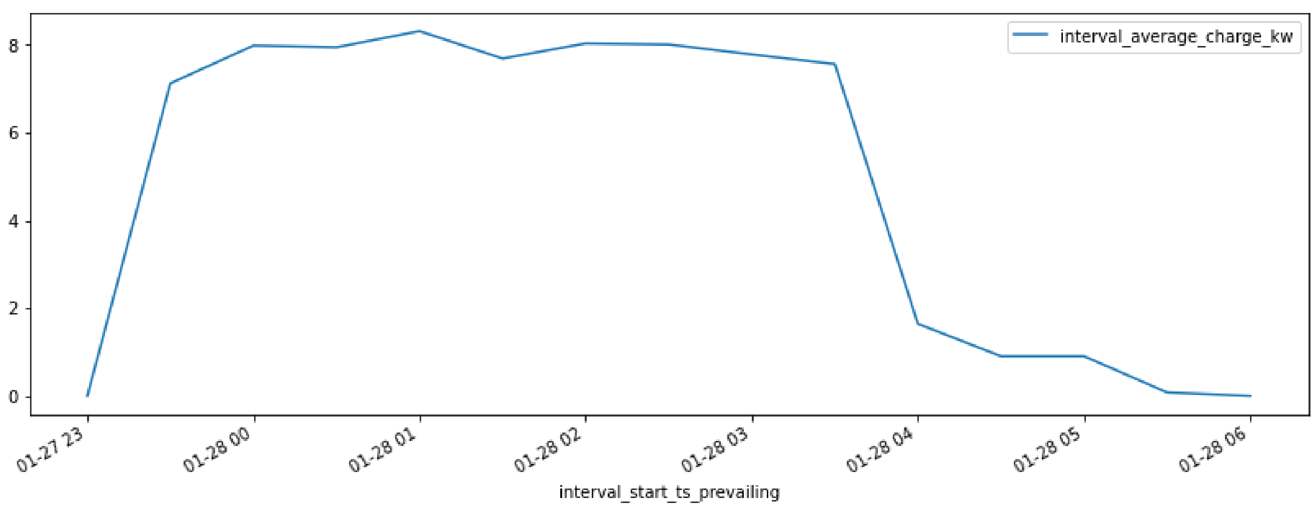


Figure 10-15. Level 2 charging sample



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