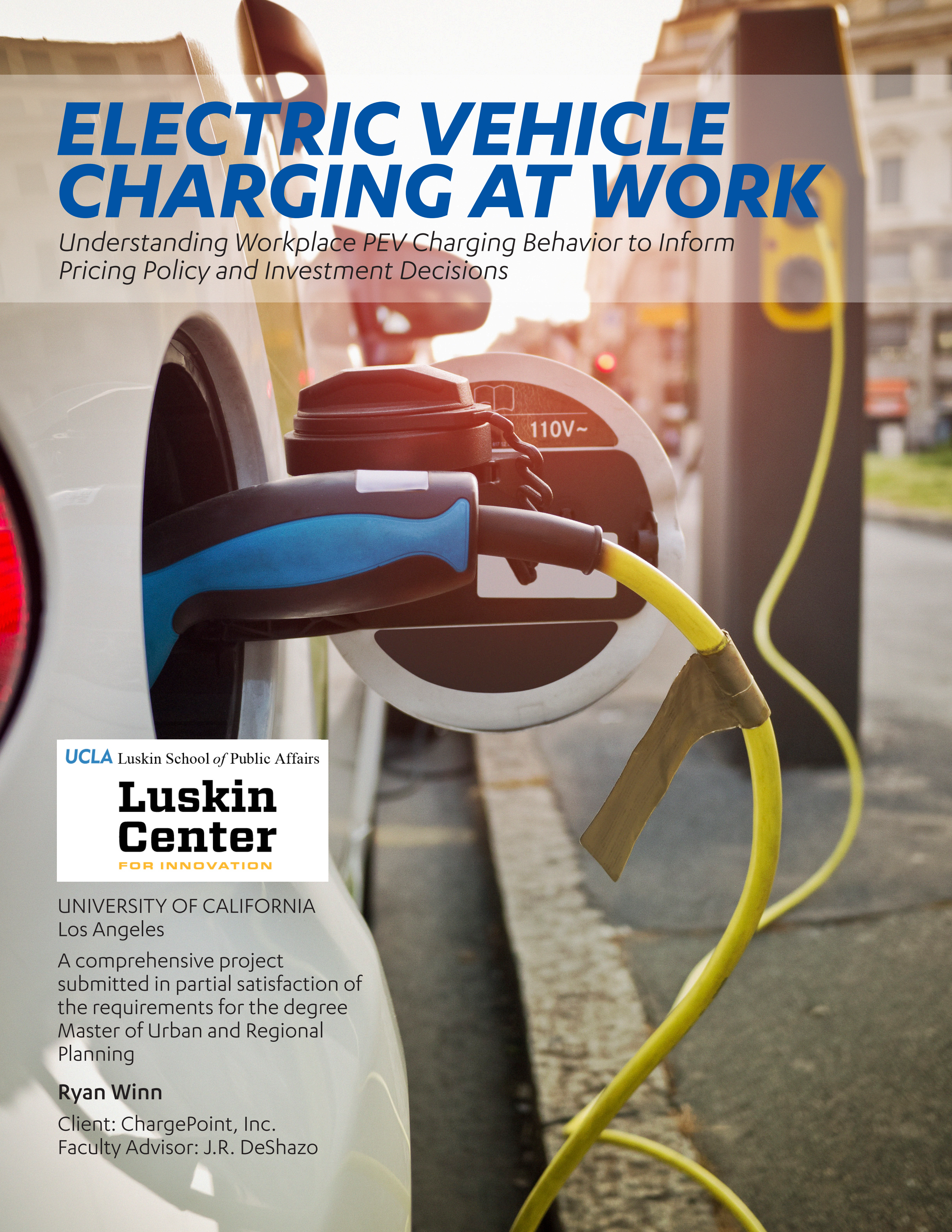


ELECTRIC VEHICLE CHARGING AT WORK

Understanding Workplace PEV Charging Behavior to Inform Pricing Policy and Investment Decisions

UCLA Luskin School *of* Public Affairs

Luskin Center
FOR INNOVATION

UNIVERSITY OF CALIFORNIA
Los Angeles

A comprehensive project submitted in partial satisfaction of the requirements for the degree Master of Urban and Regional Planning

Ryan Winn

Client: ChargePoint, Inc.
Faculty Advisor: J.R. DeShazo

SPECIAL THANKS & ACKNOWLEDGEMENTS

I would especially thank the three people that have helped create, guide, and refine the analysis conducted within this report. David Peterson for helping create this research project by agreeing to be my client representative, allowing me access to the ChargePoint data, and working to develop the analysis, as well as all the support and guidance you have provided over the past few years. J.R. DeShazo for helping guide this research project and granting me access to the Luskin Center for Innovation resources to maximize the potential of this project. And, Sam Krumholz for teaching me STATA and expeditious running of the advanced statistical analyses that added significant depth and support to my research.

DISCLAIMER

This report was prepared in partial fulfillment of the requirements for the Master in Urban and Regional Planning degree in the Department of Urban Planning at the University of California, Los Angeles. It was prepared at the direction of the Department and of ChargePoint as a planning client. The views expressed herein are those of the author and not necessarily those of the Department, the UCLA Luskin School of Public Affairs, UCLA as a whole, or ChargePoint.

CONTACT AUTHOR

Ryan Winn **Email:** ryanwinn77@gmail.com

table of contents

list of figures

list of tables

list of acronyms

AC	Alternating current
CPUC	California Public Utilities Commission
DC	Direct curent
E3	Energy + Environmental Economics
EV	Electric vehicle
EVSE	Electric vehicle supply equipment
GHG	Greenhouse gas
ICE	Internal combustion engine
kW	Kilowatt
kWh	Kilowatt-hour
LADWP	Los Angeles Department of Water and Power
NET	Negligible energy transactions
PEV	Plug-in electric vehicle
SaaS	Software as a Service
SCAG	Southern California Association of Governments
SCAQMD	South Coast Air Quality Management District
SCE	Southern California Edison
SDG&E	San Diego Gas & Electric
TOU	Time-of-use
UCLA	University of California, Los Angeles
V	Voltage

1 EXECUTIVE SUMMARY

Workplace site hosts are investing in plug-in electric vehicle (PEV) charging infrastructure for their employees and tenants, but the impact of their investment decisions on behavior and usage are still not yet fully understood. Insight into the interdependency of pricing, behavior, productivity, usage, and investment decisions can help to achieve a balance between the needs of all three primary stakeholders (PEV drivers, site hosts, and utility providers), each of which have their own objectives interacting with the charging infrastructure. While a PEV driver wants the flexibility to charge when and where they want, utility providers want PEVs to plug in when there is an abundance of renewables and sufficient local capacity. Site hosts have a variety of goals, including maximizing vehicle turnover, operating a cost neutral resource, offering free charging as a building amenity, promoting company sustainability goals, among others. PEVs can be utilized as a grid management resource if drivers are compelled to shift usage patterns through appropriate pricing incentives to times when the marginal cost of supplying energy is lowest. Peak energy periods occur during work hours in the middle of the day when vehicles are parked idle for extended periods of time, and therefore including workplace site hosts in these discussion are critical to provide maximum cumulative benefits and align the interests of all players.

Previous research conducted on workplace charging has been limited to qualitative analyses looking at case studies and best practices to help inform employers more generally on the benefits and drawbacks of free workplace charging. This report instead quantitatively analyzes almost a half million workplace charging sessions over the past five years within Southern California in order to answer the following: How do workplace site hosts' pricing policies and investment decisions influence PEV drivers' behavior, and what are the consequences of their decisions on public policy?

In order to quantify the behavioral and usage effects of how PEV drivers interact with charging infrastructure, this report analyzes charging sessions conducted on ChargePoint's network at Southern California worksites that includes information on session timing, active charging time, energy drawn, and fee charged, among other statistics. From this data, a collection of utilization and performance metrics were derived to describe charging behavior and evaluate the effects of different pricing policy components and investment decisions on charging efficiency and overall usage. Regression analyses were then conducted to isolate the effects of different pricing policy components as well as compare the six most common types of policies observed. These same metrics are then used to analyze usage trends before and after the 27 worksites identified as investing in additional charging stations to determine trends and describe how workplace charging influences PEV adoption rates.

Pricing is the primary tool that can maintain the level and quality of access needed that satisfies the greatest demand for charging. While free charging can encourage high levels of adoption by providing a free amenity and energy costs less than gasoline, it facilitates inefficient use of the charging stations and constrains availability because there is no monetary incentive to move a vehicle once it is done charging. This report shows this effect as well as how various paid pricing policies affect charging behavior. Proper pricing can increase overall productivity by motivating drivers to only consume the resources they require when they need them. Resources include not only the energy required to recharge a vehicle, but also the time needed and physical space occupied during the charging session; this is a divergence from the throughput pricing model of traditional gas stations where the transaction price is heavily dominated by the cost of energy supplied. These space and time elements must be considered when determining a site's pricing policy to curb excessive usage, which can impose a physical constraint on the number of vehicles serviceable per day. This report quantifies the magnitude of the behavioral effects of different pricing policy components and re-investment decisions to provide a better understanding of PEV charging behavior and show that without considering these additional elements, physical resources becoming the limiting factor resulting in a loss of access and productivity to users.

Recently, innovative pricing strategies are being explored by policy makers and utility providers to balance the needs of PEV drivers, grid resources, and site hosts. Time-variable pricing (i.e., time-of-use or dynamic pricing) are being implemented in trials and pilot projects within California to provide different hourly energy prices as a method to manage local electrical grid loads while allowing flexibility for site hosts to personally manage and price their own resource in pursuit of their objectives for providing the resource. While pricing is only beginning to be applied to optimize benefits to the electrical grid, this research shows that pricing can be an effective tool to encourage specific charging behavior that aligns drivers' charging needs with site hosts' and utilities' needs. The magnitude of different pricing policies on distinct behavioral responses by drivers and usage differences by time of day are described herein and can inform policymakers and site hosts how to balance temporal grid conditions with workplace charging and parking objectives. The findings from this report can be used in conjunction with utilities' time-variable pricing to inform current and future EV policy discussions aimed to facilitate the maximum productivity and accessibility benefits to both the electrical grid and PEV drivers.

As more PEVs drive on the road, it is critical to maintain an adequate level of productivity, accessibility, and equity for drivers as unacceptable levels can hinder future PEV adoption. Workplaces are considered a primary driver of PEV adoption because of the network effects of EV-driving employees influencing colleagues, but the extent of this has only been previously discussed in anecdotal evidence. This research isolates the workplace as the primary explanatory variable for adoption to quantitatively show that workplace charging investments do encourage PEV adoption over both the long-and short-term.

As this report will show, drivers are responsive to pricing policies, and specific policy components have the ability to influence particular behavior. While pricing only for the energy consumed results in very inefficient use of the charging infrastructure, including a blended pricing policy that incorporates an initial hourly rate with an increased hourly rate after the first few hours (called "graduated hourly" pricing) result in the most efficient policy; this policy considers the time and physical space occupied during the charging session and penalized those users that occupy the parking space much longer than is needed to charge. This graduated rate effectively curbs excessively long stays as a strong preference was shown for drivers choosing to terminate immediately before this graduated rate kicks in instead of receiving a full 100% charge. If specific pricing policy elements are used in conjunction with utilities' time-variable pricing programs on the worksite level, PEV charging can be shifted from the highest demand period in the morning to when more renewable energy resources come online in the afternoon and when there is also more capacity to absorb charging demand. Afternoon sessions are more commonly initiated to top off a battery until the drivers needs to leave for the day and are defined by shorter overall durations and post-charge dwell times than morning sessions. If managed more efficiently through pricing, afternoon sessions could help balance grid loads while still satisfying the charging needs of drivers and hosts.

2 INTRODUCTION

Workplace site hosts are investing in plug-in electric vehicle (PEV) charging infrastructure for their employees and tenants, but the impact of their investment decisions on behavior and usage are still not yet fully understood. Investment decisions not only include the quantity of electric vehicle supply equipment (EVSE) ports to provide and when to add more, but more importantly encompass the specific pricing policy chosen for that site. A better understanding of the interdependencies of investment decisions and usage patterns can help achieve a balance between the needs of PEV drivers, site hosts' objectives in providing the charging resource, and temporal grid conditions.

The three primary affected stakeholders in related policy discussion include the PEV drivers, utility providers, and the workplace site hosts. PEV drivers want the flexibility to charge when they want or need to, and prefer to get the maximum possible energy whenever they plug in at a fair price. Utilities want PEVs to charge when there is an abundance of renewables and sufficient local capacity to minimize the power required during peak periods. PEVs can be utilized as a grid management resource if drivers are compelled to shift usage patterns through appropriate pricing incentives to times when the marginal cost of supplying energy is lowest. Peak energy periods occur during work hours in the middle of the day when vehicles are parked idle for extended periods of time, and therefore including workplace site hosts in these discussion are critical to provide maximum cumulative benefits and align the interests of all stakeholders. Site hosts manage parking and charging to align with the specific set of objectives for their site (e.g., maximize vehicle turnover, operating a cost neutral resource, offer free charging as a building amenity, promote sustainability goals, etc.); however, an acceptable level of service must be maintained that balances accessibility, productivity and equity for users.

Proper pricing and number of the EVSE charging ports provided can aid in achieving this balance through encouraging PEV charging behavior congruent with the host's goals. Previous research conducted on workplace charging has been limited to qualitative analyses looking at case studies and best practices to help inform employers more generally on the benefits and drawbacks of free workplace charging. This report quantitatively analyzes almost a half million workplace charging sessions over the past five years within Southern California in order to answer the following: How do workplace site hosts' pricing policies and investment decisions influence PEV drivers' behavior, and what are the consequences of their decisions on public policy?

Current EV policy discussions and upcoming pilot programs focus on how to maximize productivity and access while maintaining equity among all stakeholders. Pricing of charging stations is a pivotal piece of this discussion because, as this report will show, different pricing policies affect how users interact with the charging stations. Proper pricing can increase the overall productivity of the charging infrastructure by motivating drivers to only consume the resources they require when they need them. Resources include not only the energy required to recharge a vehicle, but also the time needed and physical space occupied during the charging session; this is a divergence from the traditional throughput pricing model of traditional gas stations where the transaction price is heavily dominated by the cost of energy supplied. These space and time elements must be considered when determining a site's pricing policy to curb excessive usage, which imposes a physical constraint on the number of vehicles able to utilize the charging station per day and negatively impacts equity in terms of access to potential users. This report quantifies the magnitude of the behavioral effects of different pricing policy elements and re-investment decisions to provide a better understanding of PEV charging behavior and show that without considering these additional elements, physical resources are limited resulting in a loss of access and productivity to users.

Innovative pricing strategies are more recently being explored by policymakers and electric utilities to balance the needs of PEV drivers, grid resources, and site hosts. Over the previous few years, some utilities have introduced time-of-use (TOU) rates to incentivize users to shift non-time sensitive charging needs to off-peak times with lower capacity utilization (typically overnight), which have shown some positive grid management effects. More recently, dynamic rates are being analyzed and included in pilot projects that would provide different hourly kilowatt-hour (kWh) prices that vary by location to reflect local grid conditions. The San Diego Gas & Electric (SDG&E) Power Your Drive is a pilot program that provides sites with this dynamic pricing scheme, but require submission of a load management plan to SDG&E if that site wants to impose its own pricing policy consisting of more than just passing along the cost to distribute the energy. The load management plans empower site hosts to develop uniquely tailored solutions that balance their personal site objectives with driver needs and grid management goals through individual pricing policy selection. Understanding the changes that different pricing policy components have on user charging behavior is critical in the selection process to facilitate desirable behavior, but to date, no quantitative research has been conducted to describe these effects.

A diversity of pricing policies exist which are generally based on an hourly rate, cost per kWh of energy dispensed, flat session fee, or a combination of these with a few other optional minor components. The hourly rate can be $0 and therefore the charging station is free to users; and, the hourly rate can increase after a set number of hours to discourage long stays (called "graduated hourly" pricing). Each individual component causes different user behavioral responses, and different pricing mechanisms can be used as tools to encourage or discourage desirable behavior. While pricing is only beginning to be applied to optimize benefits to the electrical grid, this research describes the magnitude that different pricing policies have on distinct behavioral responses by drivers and usage differences by time of day to better inform policymakers and site hosts how to balance temporal grid conditions with workplace charging and parking objectives. While there has been previous qualitative research on the general effects of free versus paid pricing policies, this report examines specific policy components to quantitatively determine the extent of those behavioral reactions as well as usage differences by time of day. The findings from this report can be used in conjunction with utilities' time-variable pricing to inform current and future EV policy discussions aimed to facilitate the maximum productivity and accessibility benefits to both the electrical grid and PEV drivers.

Understanding this connection between pricing effects and resulting behavior is important to all stakeholders because the observed behavioral variations can more creditably inform policy discussions about how to use pricing to influence behavior that promotes equality through accessibility for all users. For site hosts, proper pricing strategies can maximize revenues to recoup operating and maintenance costs while generating some profit, but should be done in an equitable manner that does not diminish productivity or limit access to any potential user of that resource. Maintaining an acceptable level of service for users can be done by making investment decisions that curb excessive usage. Proper pricing can also delay unnecessary capital investment in additional EVSEs by selecting policy components that encourages behavior to maximize vehicle turnover while still satisfying all the charging needs of PEV drivers at that site. Most PEV drivers have options on when and where they can charge their vehicle, so pricing workplace charging competitively with home and public charging options is necessary. Free workplace charging and policies that only charge by the amount of energy dispensed results in inefficient and overuse of the space because there is no incentive to move one's vehicle after it is done charging, nor a penalty for excessive use; but conversely, if the cost is too expensive then drivers will seek cheaper charging alternatives. PEV drivers have their cars parked idle for extended periods during the day at work but must be encouraged through pricing to only consume the resources they require.

For utilities, understanding how drivers interact by time of day can help better manage temporal loads on the grid. The transportation sector has a large impact on energy, and therefore, applying time variable rates to commercial customers (e.g., time-of-use or dynamic rates) can encourage behavior beneficial to load management and in turn reduce rates for all utility customers, reduce costs to drivers, while still maintaining value to utility shareholders. PEVs often have flexibility when and where they can charge as they sit parked for a majority of the day and night; therefore, using innovative pricing policies can incentivize drivers to charge at times and locations that provide the maximum cumulative benefits, such as times with over generation of renewable energies than cannot be absorbed under typical daily non-EV load demand. The analysis within this report describes different usage patterns by time of day to inform discussions with policy makers and electric utilities on PEV driver workplace charging behavior.

Additionally, this research evaluates the usage patterns before and after 27 workplace sites within this data set that invested in additional charging stations at least six month following the site's initial purchase date. At these sites, there were high level of utilization and adoption before and after the re-investment activation date; this reflects how private investment monitors and responds to demand seen at their site. For all usage metrics analyzed on a per available port basis (i.e., sessions, energy dispensed, unique users, and charging hours), it consistently took six to seven months to rebound to pre-installation levels. Additionally, this analysis concentrates on both aggregate usage and the network effects of encouraging PEV adoption among coworkers, as defined by the increase of unique users per site. Workplaces are considered a primary driver of EV adoption because of the system effects of EV-driving employees influencing colleagues. The extent of this driving factor has only previously been discussed in anecdotal evidence, but this research isolates the workplace as the primary explanatory variable for adoption to quantitatively show that workplace charging infrastructure investments do encourage PEV adoption over both the long-and short-term. Beginning with the initial investment and throughout the first few months, the number of unique users per worksite steadily increase; following the re-investment date, unique users per worksite grow at a faster rate illustrating that workplace charging infrastructure investments do encourage PEV adoption at those sites. But, there is a concern that this increased growth in PEV adoption creates a cycle that hinders accessibility by reducing availability of charging stations as more drivers need to access the limited number of charging stations, and policymakers are concerned that limited availability at workplaces can impede adoption.

Pricing is the primary tool that can maintain the level and quality of access needed that satisfies the greatest demand for charging while not impeding access or hindering adoption. Site hosts are stewards of their parking lots and need to ensure that the charging stations are used efficiently to not take up a parking space that could be used by a non-PEV. While free charging can encourage high levels of adoption by providing a free amenity of energy costs less than gasoline, it facilitates inefficient use of the infrastructure and constrains availability because there is no monetary incentive to move a vehicle once it is done charging. A similar trend is seen in pricing policies that only impose a cost per kWh dispensed with no additional pricing components tied to time physically occupying the space.

In order to quantify the behavioral and usage effects of how PEV drivers interact with charging infrastructure, this report analyzes charging sessions conducted on ChargePoint's network at Southern California worksites that includes information on session timing, active charging time, energy drawn, and fee charged, among other statistics. From this data, a collection of utilization and performance metrics were derived to describe charging behavior and evaluate the effects of different pricing policy components and investment decisions on charging efficiency and overall usage. Regression analyses were conducted to isolate the effects of different pricing policy components as well as compare the six most common types of policies observed. These usage metrics are then used to also analyze usage trends before and after the 27 worksites which have been identified as investing in additional charging stations over the analysis period.

This report begins with background information including California's recent legislative history to advance it as the early leader in both EV adoption and planning for the necessary supporting infrastructure, description of different types and locations of charging infrastructure to highlight the importance of focusing on workplace charging, a description of ChargePoint, and an overview of the SDG&E dynamic pricing pilot program. The **Literature Review (p11)** discusses the limited literature and research that has been conducted on workplace charging, especially as it relates behavioral responses to pricing from a quantitative analysis perspective. Also included is the E3 Study that frames the discussion of grid benefits and EVs, which has become a primary reference document in related nationwide policy discussions. **Data Collection and Data Description (p14)** describes the data set provided by ChargePoint in Southern California, assumptions made for the analysis, and potential concerns related to the data. **Data Analysis and Findings (p18)** analyzes the data to answer the research question described above by first illustrating typical usage patterns on a macro-level and how those patterns vary by time of day. The analysis continues by looking at available pricing policies and the specific usage effects of different pricing components on charging behavior. The final piece of data analysis focuses on the worksites which have invested in additional EVSEs at least six months following their initial purchase by analyzing usage patterns before and after a re-investment of EVSEs at a site. **Conclusion and recommendations (p59)** summarizes the findings of each of the three data analysis subsections and offers policy recommendations on pricing and management techniques that can help best achieve the balance between the needs of PEV drivers, workplace site hosts, and utility providers.

3 BACKGROUND

Legislative Action

Just after the turn of the 20th century, EVs held a dominate market share before being overtaken by internal combustion engine (ICE) vehicles, which still control most of the automobile market today. ICE vehicles have major negative environmental externalities that executive and legislative policy actions have only recently begun to remedy, with California leading the way in the re-adoption of EVs onto roadways. The primary benefits of EVs over ICE vehicles include a reduction of dependence on fossil fuels, lower carbon and greenhouse gas (GHG) emissions, and the ability to migrate energy dependence to a more sustainable portfolio of renewable resources (e.g., wind and solar).[1] These environmental benefits are in line with the primary goal and California's broad strategy to reduce GHGs by setting both near- and long-term goals to achieve stringent air quality targets.

Former California Governor Schwarzenegger signed Executive Order S-3-2005 in 2005 that established the target of: "by 2020, reduc[ing] GHG emissions to 1990 levels; [and] by 2050, reduc[ing] GHG emissions to 80 percent below 1990 levels."[2] A year later, the CA Legislature passed Assembly Bill 32, which adopted the 2020 GHG target into statute. It was recognized that a significant portion of GHG emissions were emitted from the transportation section and targeting vehicle emissions would be beneficial in achieving this goal. Alternative fuel vehicles were the first target within the transportation sector due to their inherent lower emissions than their ICE counterparts.

The efforts initiated by Governor Schwarzenegger were continued by Governor Jerry Brown a few years later when he signed CA Executive order B-16-2012 in March 2012 setting state goals to help achieve the 2020 and 2050 reduction targets. This recognized the importance of zero-emission vehicles (ZEVs) in achieving California's aggressive emission goals. Highlights of this Executive Order include:

1. By 2020, infrastructure for ZEVs will be able to support one million ZEVs.
2. Costs of ZEVs will be competitive to traditional internal combustion engine vehicle.
3. By 2025, over 1.5 million ZEVs will be on California roads with expanding market share.
4. California's clean air vehicles will displace at least 1.5 billion gallons of gasoline annually.[3]

In 2013, the ZEV Action Plan was released by the Governor's Office of Planning and Research to identify specific tactics and approaches to meet the Executive Order's goals.[4] Achieving these ambitious goals will take a significant coordinated effort by all affected parties: EV drivers, utility providers, and building and equipment owners.

PEV Recharging vs. Traditional Gas Stations

Charging infrastructure for PEVs is fundamentally different than the established refueling infrastructure for ICE vehicles, and therefore encourages different usage patterns. Refueling an ICE vehicle occurs at a commercial gas station and usually when the driver is near empty; however, EVSEs do not need to be at a standalone commercial establishment and PEV drivers will more likely charge their vehicle even if they are not near empty. A full charge is not necessary every day or night, but is often charged just to replenish the

[1] Faruqui, Ahmad, Ryan Hledik, Armando Levy, and Alan Madian (2011)
[2] Gov.ca.gov (2015)
[3] Gov.ca.gov (2015)
[4] 2012 ZEV Action Plan

electricity used during the day prior to alleviate any range anxiety the next day. Due to the shorter range of EVs than gas-powered vehicles, PEV drivers must be more conscious of their state of charge when planning a trip. Additionally, re-charging EVs takes significantly longer than gasoline refueling (even with the fastest available type of infrastructure) and therefore time occupying the parking space associated with the charging station should be considered into the cost of recharging, where applicable.

Types of Charging

There currently exists three types of EVSEs that can be installed at a variety of locations. The most common is alternating current (AC) level 1 charging and is available whenever an ordinary 120 volt (V) electricity outlet is. Level 1 charging has minimal barriers to entry as no additional upgrades to a standard outlet are needed; however, the primary limitation to level 1 charging is the low power delivered and therefore can only be used in non-time-sensitive scenarios, such as over-night charging.[5] Due to the slow charging nature of level 1, each hour of charge corresponds to approximately four to five additional electric miles that can be driven.

AC level 2 charging is available for those users who are willing to invest in more energy intensive, but faster charging. Level 2 charging uses a dedicated EVSE for faster charging at a higher power of 240V, which is the level that large home appliances utilize, such as electric dryers, stoves, ovens, and air conditions. Level 2 investment typically ranges from one to a few thousand dollars and can double the voltage delivered, quadruple the amperage, and greatly improve the power delivered to PEVs over level 1 charging.[6 7] These are improvements over level 1, but level 2 charging is still time consuming and would take several hours to fully charge a depleted battery. Level 2 does provide benefits at locations that expect to have visitors staying for only an hour or two for a partial recharge (e.g., malls, museums, restaurants, and libraries) as each hour of charge can add 11 to 22 electric miles.[8 9] For those drivers investing in a PEV and have a dedicated parking space at their residence, a level 2 charger could also be a wise investment to relieve some of the anxiety associated with the limited range of PEVs as a level 2 charger will allow a faster charge than level 1 infrastructure at a relatively affordable price.

Direct current (DC) fast charging can be installed at a much greater cost than Level 2, but provides a significantly faster charge; however, only some existing EVs can accept DC Fast charging and therefore not many DC Fast chargers have been built to-date. Their price tag can reach up to $100,000 that includes both the installation and charging equipment.[10] Whereas level 1 and level 2 charging is typically used when time is not a primary factor, DC fast charging stations are purposely built to greatly decrease charging time; for example, a depleted Nissan Leaf battery can be replenished to 80% charge in 30 minutes to travel about 67 miles.[11] Until an extensive network of inter-city DC Fast chargers has been developed, long distance travel is not a reasonable option in a PEV.

Location of Charging Stations

Each of the levels of charging infrastructure (AC level 1, AC level 2, and DC fast charging) can be placed in different locations (i.e., home, workplace, intracity, medium-distance intercity, and long-distance interstate), with each type of EVSE having inherent benefits and restrictions based on its location. **Figure 1** displays these categories of charging infrastructure and the importance of each location based

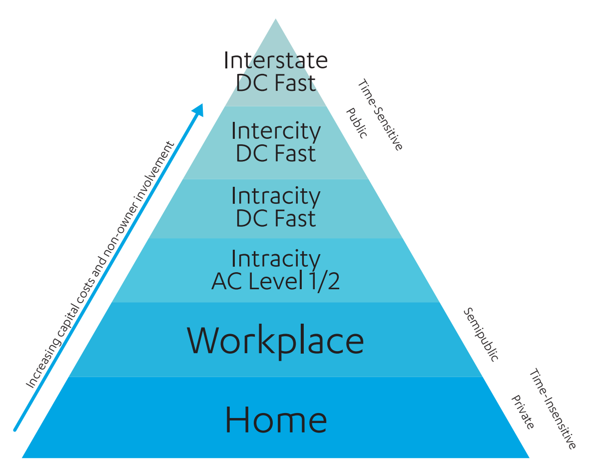


Figure 1: PEV Charging Infrastructure Categories and Priorities[12]

[5] Nicholas, Michael, Gil Tal, and Justin Woodjack (2013)
[6] Nicholas, Michael, Gil Tal, and Justin Woodjack (2013)
[7] "Overcoming Barriers to Deployment of Plug-in Electric Vehicles" (2015)
[8] "Overcoming Barriers to Deployment of Plug-in Electric Vehicles" (2015)
[9] Nicholas, Michael, Gil Tal, and Justin Woodjack (2013)
[10] "Overcoming Barriers to Deployment of Plug-in Electric Vehicles" (2015)
[11] "Overcoming Barriers to Deployment of Plug-in Electric Vehicles" (2015)
[12] "Overcoming Barriers to Deployment of Plug-in Electric Vehicles" (2015)

on a hierarchy.[13] The following sections describe the two most prevalent types of charging infrastructure: home and workplace charging.

Home Charging

Home charging is the current primary method of charging and a near-necessity for drivers of any type of PEV. As shown in **Figure 1** above, home charging has the biggest share and importance to PEV deployment, especially as it is the cheapest and has the least barriers for construction.[14] Vehicles are parked at home most of the day and PEVs can be charged during the least time-sensitive periods, particularly overnight.[15] The convenience of being able to arrive home and plug in your vehicle makes home charging attractive to PEV drivers. Home charging is also typically the cheapest way to charge one's vehicle, assuming away-from-home charging (i.e., work place and public) is not free. Especially if PEV drivers take advantage of the TOU rates recently adopted by utilities throughout the state to incentivize charging PEVs overnight when electricity demand and prices are lowest.[16]

While home charging is a critical factor for PEV deployment, some issues arise for home charging not occurring at single family homes. In multi-family dwellings, not everyone will have a dedicated parking spot and/or an electrical outlet within accessible reach to charge their vehicle; therefore, this can represent a significant barrier to PEV deployment if drivers are uncertainty about their home charging.[17] Furthermore, in multi-family buildings, issues about the ownership, responsibility, liability, and control of the charging infrastructure arise. Especially in rental apartment buildings, tenants are not incentivized to upgrade to level 2 charging as they might leave at the end of their lease or before the lifespan of the EVSE expires; similarly, building owners are not incentivized to upgrade charging infrastructure on their property unless they can charge tenants a premium to use the EVSE to recoup their capital and operating expenses.[18] For these reasons, workplace charging has become increasing prevalent as EV drivers who only have level 1 or limited available level 2 EVSEs at their residence can charge at work when their cars are sitting idle during most of the workday.

Workplace Charging

Workplace charging is the next most important charging infrastructure piece as many vehicles are parked for most of the day at work. Level 1 is available at any parking space that is adjacent to a regular outlet, but often businesses that promote EVs will invest in at least one level 2 EVSE. This charging resource acts as an added amenity to attract and retain employees or distinguish themselves as a green company through supporting sustainability objectives.[19] In Southern California, workplaces with over 250 employees are required to meet designated emission reduction targets by the Southern California Air Quality Management District (SCAQMD). SCAQMD Rule 2202 provides a menu of emission reduction strategies to meet these targets, including installing charging stations to mitigate vehicle emissions from employee vehicles and any company fleets.[20]

By providing an additional place for long-period charging, PEVs can essentially double the electric vehicle mileage per day by charging both overnight at home and during the day at work; in effect, this greatly increases the feasible length of commute distance by PEVs to lower the barrier to entry for drivers which have both available.[21] Workplace charging also enables drivers without accessible home charging (e.g., due to living in a multi-family dwelling without access to an outlet) to fully charge their batteries during the workday.

[13] "Overcoming Barriers to Deployment of Plug-in Electric Vehicles" (2015)
[14] "Overcoming Barriers to Deployment of Plug-in Electric Vehicles" (2015)
[15] "Overcoming Barriers to Deployment of Plug-in Electric Vehicles" (2015)
[16] Kurani, Kenneth, Jennifer Tyree, Hageman, and Nicolette Caperello (2013)
[17] "Overcoming Barriers to Deployment of Plug-in Electric Vehicles" (2015)
[18] "Overcoming Barriers to Deployment of Plug-in Electric Vehicles" (2015)
[19] "Overcoming Barriers to Deployment of Plug-in Electric Vehicles" (2015)
[20] SCAQMD Rule 2022
[21] "Overcoming Barriers to Deployment of Plug-in Electric Vehicles" (2015)

ChargePoint, Inc.

ChargePoint provides network services (SaaS – software as a service) to drivers, charging station operators and electric utility companies. They design, manufacture and sell charging stations for a variety of uses, including residential, workplace, commercial, and public land uses. The expanding network of ChargePoint stations allows more access to a greater number of EV drivers to charge at different destinations throughout each day. As this network grows, it makes driving an EV more sensible in pursuit of their social goal: driving a better way.

For individual drivers, ChargePoint offers a free mobile app, special driver discounts, and integration with automakers to support EV drivers by offering connected charging wherever they work, shop, eat, and play to create a seamless driving and charging experience. In addition to having access to charging stations around town, ChargePoint Home is available to those users wanting to invest in fast, convenient, and intelligent home-based EV charging.

For businesses, ChargePoint offers everything a company requires to provide and manage EV charging for employees, customers, visitors, and residents. Every charging station is individually owned by the site host to provide the greatest control for business owners to manage their investment, including establishing their specific pricing policy. The ChargePoint commercial service plan includes a variety of flexible management tools, data analysis, payment process, and driver support; while they provide the services and support for commercial EVSEs, they allow the site host to set the their own pricing policy by time, session, energy dispersed, or any combination thereof to meet the objectives of the business providing the resource. Detailed reports are easily available from the dashboard to monitor and manage the resource over time.

ChargePoint's vision for the future includes a world where EV charging is seamlessly woven into the fabric of everyday life by having EV charging readily available at any location around town: at home, office, running errands around town, or inter-city travel. Their growing network can alleviate range anxiety for existing and new EV drivers by providing a smart, easy, and convenient system to charge at a diversity of destinations.

SDG&E Power Your Drive Pilot Program

The San Diego Gas & Electric (SDG&E) Power Your Drive Pilot Program is the first utility program approved to offer dynamic pricing to users. Dynamic pricing is a time-variable rate that provides drivers and/or site hosts different hourly energy prices that vary by location to reflect local grid conditions. Site hosts have the option to either (1) pass the exact cost through to the driver, or (2) receive that rate themselves and impose their own access and pricing policy that align with that site's specific objectives of providing and managing the charging resource. In order to pursue option (2) and obtain the flexibility of selecting a specific pricing policy greater than the cost to deliver the energy, the site host must submit a load management plan to SDG&E which is consistent with the Guiding Principles set forth in the Proposed Settlement. These eleven principles are aimed to support California's PEV adoption and infrastructure goals, encourage increased productivity and accessibly to charging equipment, encourage integration of renewable energy resources to deliver overall grid benefits, protect ratepayers from excessive charges, and provide equitable deployment of services.[22] The load management plans empower site hosts to develop uniquely tailored solutions that balance their personal site objectives with driver needs and grid management goals through individual pricing policy selection. The Power Your Drive Pilot Program was approved in January 2016 by the California Public Utilities Commission (CPUC) and is expected to be fully implemented by the end of the year.

[22] SDG&E and California Public Utilities Commission (Rulemaking 13-11-007) (February 2016)

4 LITERATURE REVIEW

The following section looks at the limited literature and research conducted regarding workplace charging stations as well as a study on coordinating PEV charging stakeholders to maximize grid benefits. The previous research has concentrated only on qualitative analysis using case studies and surveys of workplaces which have invested in charging infrastructure. Research on the pros and cons of free workplace charging is better documented, but only looks at general effects of free and paid policies instead of individual components of different pricing policies. Because the PEV market is consistently evolving, looking only broadly at pricing can result in limited conclusions as PEV drivers become more accustomed to this emerging industry. This report analyzes actual usage of workplace charging stations to better understand charging behavior and provide insight on the effect of specific pricing policies on usage and behavior. The discussion can also provide insight into the adequacy of the existing qualitative research using quantitative analysis based on southern California workplaces as an example.

Qualitative Workplace Case Studies and Best Practices

The research conducted and published regarding workplace EV charging has been limited to qualitative research and has consisted of surveys and specific case studies to inform best practices when operating and planning for workplace charging.

In November 2013, the California Plug-in Electric Vehicle Collaborative released Amping Up California Workplaces which looked at twenty case studies of employers throughout California covering all sizes of workplaces as well as both private and public entities. Surveys were sent to more than the twenty workplaces and data is provided for the total of 79 respondents on the type of facilities, reasons for installing charging stations, top challenges to installing, breakdown of types of chargers, and general pricing policies. This study found that the most common reason for installing charging stations was promoting a green and sustainable image, followed by requests from employees; whereas, equity in terms of employee benefits was only minimally stated.[23] The two top challenges were far and away the costs of installation and the cost of equipment, which seems intuitive due to the high price tag associated with installing EVSEs.[24] Federal and (in some areas) local tax incentives are available to reduce the installation costs and lower the barrier to entry for these workplaces choosing to take advantage of them. The Amping Up California Workplaces survey also found that 87% of the responding organizations reported that the availability of charging stations encouraged other employees to purchase PEVs.[25]

The primary difference between the analysis within this report and the Amping Up California Workplaces survey and report is the unit of analysis. The survey looked at workplaces from a broader and more qualitative perspective to describe their specific decision making processes, pricing policies, workplace charging challenges, and employee benefits. My analysis reports on the individual workplace charging sessions that were conducted at a much more granular level. All workplace names were removed from my data set so that I could unbiasedly study the behavior of how people use workplace charging infrastructure void of any preconceived notions about a specific employer or the industry for which they conduct work in.

CALSTART released Best Practices for Workplace Charging in September 2013 that highlights the

[23] California Plug-in Electric Vehicle Collaborative (2013)
[24] California Plug-in Electric Vehicle Collaborative (2013)
[25] California Plug-in Electric Vehicle Collaborative (2013)

importance of workplace charging (to employees, to employers, air quality benefits, and encouraging PEV adoption). Additionally, the CALSTART report provides information regarding costs, power requirements, installation, and ways to evaluate a program for decision-makers contemplating investing in workplace charging stations. Case studies and survey results are also included in the Best Practices for Workplace Charging, and collectively provide a valuable resource for employers and employees seeking to launch a workplace charging program.[26]

My analysis is focused on after implementation of a workplace charging program and real usage patterns of those charging stations. Although the external reports listed above provide survey results after usage, the findings are based on the respondents' observations of usage at their workplaces, instead of actual quantitative usage data collected by the EVSE on a per-session basis.

Workplace Charging Pricing Policies

The pricing policies of workplace charging can have a major effect on usage and potential future adoption rates. While employers that offer free workplace charging are providing a monetary benefit to their employees, the resulting charging behavior with free versus paid charging infrastructure differs and can limit the potential efficiency of charging stations.

The case studies analyzed in this literature review suggested that PEV-only parking spaces have been underutilized at many workplaces during the initial growth of PEVs over the previous few years due to free pricing policies. Adding a workplace charging station takes away a parking space from a non-PEV and therefore, some companies, such as Cisco, implemented a policy to only increase "the number of workplace charging stations in proportion to the number of employees who express interest in using them" which has already shown positive feedback and has encouraged other employees to purchase PEVs.[27] Other firms have chosen not to provide workplace charging because of equity concerns that dedicating parking spaces for PEVs only benefits a small number of employees, especially during initial deployment.[28] On the other hand, offering free workplace charging can lead to over usage of the EVSEs; drivers will plug in or just use the parking space even if they do not additional charge to complete their daily trips.

Nicholas and Tal (2013) argue that workplace charging should be priced higher than home electricity rates, but lower than gasoline costs in order to create dependability of available stations by relieving congestion at stations.[29] They reason that if workplace charging is too cheap than people will shift all their charging needs to work and increase the number of charging sessions needed to satisfy demand that could be managed by other means. In general, pricing PEV charging encourages more efficient use of the resource. This supports the "tragedy of the commons" theory describing that when a resource is free, it will be used more than an equal service that not free and will become overused because there is no incentive to individuals to use it efficiently. It should be noted that Nicholas and Tal do not consider any parking costs in their recommendation of a pricing model and only base their recommendation on units of energy dispensed. This is a core difference between traditional gasoline stations which operate as a throughput model compared to PEV charging which requires a parking aspect for the long durations required to charge. Surveys they conducted found that at workplaces offering free charging, 38% of users reported limited availability of those stations at least once per week.[30] Free workplace charging encourages vehicles to plug in and charge, even when they may not need to recharge because it is a favorable spot and available. This takes up an EV parking space that could be better utilized by a PEV that needs to charge there during the day.[31] [32] Congestion at workplace stations creates a barrier to PEV adoption if drivers depend on workplace charging but are uncertain about availability each day.

[26] CALSTART (2013)
[27] "Overcoming Barriers to Deployment of Plug-in Electric Vehicles" (2015)
[28] "Overcoming Barriers to Deployment of Plug-in Electric Vehicles" (2015)
[29] Nicholas, Michael and Gil Tal (2013)
[30] Nicholas, Michael and Gil Tal (2013)
[31] Nicholas, Michael and Gil Tal (2013)
[32] Kurani, Kenneth, Jennifer Tyree, Hageman, and Nicolette Caperello (2013)

Engaging Utilities and Regulators on Transportation Electrification

This study by Energy + Environmental Economics (E3) explains the benefits that PEVs could have on utility customers, shareholders, and vehicle drivers, but emphasizes the need for innovation in utility practice and regulatory policy to achieve these benefits. It continues to describe the potential economic benefits to all stakeholders of more efficient grid management, especially if time-variable rates are used to help control demand.[33] Electricity production is built to satisfy absolute peak demand, but real-time demand varies drastically based on time and is a factor of time of year, day of week, and time of day. Utilities providers generally charge a higher blanketed price per kWh than needed at most times to recoup the costs modeled to deliver energy during daily peak demand. Recently, some utilities have introduced TOU rates to incentivize users to shift non-time sensitive charging needs to off-peak times in an effort to balance electrical loads on the grid. This method provides cheaper electricity rates to consumers who take advantage of these TOU rates and help redistribute the energy loads by spreading out demand from peak periods to times with the lower capacity utilization, typically overnight. Similarly, dynamic rates have been considered recently that would adjust prices in real-time to incentivize customers to charge during daytime periods where the marginal cost of supplying energy is the lowest. U.S. energy generation mix is shifting towards more renewable energy (i.e., solar and wind), but these outputs are both variable and uncertain due to fluctuating weather conditions day-to-day. For solar, this irregularity can limit reliability on a cloudy day or cause over-generation on a sunny day when more energy is produced than can be absorbed.[34] Dynamic rates can help balance this over generation by incentivizing PEV drivers to charge during the day when parked for extended time periods at work.

[33] Ryan, Nancy and Luke Lavin (2015)
[34] Ryan, Nancy and Luke Lavin (2015)

5 DATA COLLECTION & DATA DESCRIPTION

Data Collection

Data has been provided by ChargePoint that includes details of the charging sessions (or transactions) on their network. The data has been geographically limited to workplaces within the six counties in the Southern California Association of Governments (SCAG) region. The time period covered in this analysis is five years, between January 1, 2011 and December 31, 2015.

The relevant information provided includes the following:

- Location:
  - Station name (randomized to protect client identity and avoid any analysis bias)
  - Zip code location
- Type of Infrastructure:
  - Port type (i.e., level 1, level 2, or DC Fast)
  - Port number and connection type
- Session Timing:
  - Start date and time
  - End date and time
  - Transaction date and time
  - Total duration (time plugged in)
  - Active charging time (time drawing electricity)
- Energy:
  - Energy dispensed (in kilowatt-hour)
- Per Session Transactional Data:
  - Anonymous user ID (used to determine frequency of unique individual users)
  - Transaction fee price
  - How the session was terminated
  - Driver postal code associated with that user ID

Unit of Analysis

The unit of analysis will be the individual sessions on each port on the EVSE in the provided ChargePoint data set. An EVSE can have up to two ports each. Every charging session transacted on the ChargePoint network from 2011 to 2015 at the workplaces within the SCAG region is included in the data set.

Assumptions

The following assumptions were made in order to focus the analysis on typical workplace charging behavior.

Level 2 EVSEs Only

Only Level 2 EVSEs were used in the analysis. All transactions that were Level 1, DC Fast, or not reported were removed in order to keep a consistent analysis throughout. This report aims to provide insight on charging behavior for the most common type of charging infrastructure. Level 2 transactions accounted for 98.7% of all transactions over the five-year period and therefore are primarily representative of workplace sessions. Level 1 and DC Fast sessions were excluded from the analysis as they only accounted for 1.0% and 0.2% of all transactions, respectively. The remaining less than 0.1% of data points did not have a port type listed and were therefore not included due to reporting errors. The non-Level 2 charging types were only minimally represented in the data set and therefore not included in order to focus the analysis herein to the typical workplace behavior that explains almost 99% of all work-based charging sessions.

Work Week-only Transactions

This analysis is aimed to provide insight on typical workplace charging behavior and therefore only the standard workweek (Monday through Friday) was analyzed. All Saturday and Sunday sessions were removed as there was less demand-side constraints during these times, including less energy demand on the grid and fewer employees at the workplace competing for charging stations and/or parking spaces.

"Faulty" Transaction

The data set included every transaction on the ChargePoint network in the SCAG region, but not all transactions represent a productive charging session. Sometimes a driver will plug in and start a session incorrectly and therefore cancel it within a few minutes. In order to not ignore those users who purposely only get a quick charge while running an errand, sessions that meet both of the following criteria have been eliminated from the analysis:

- Power delivered: less than 0.15 kWh
- Total duration time: less than 5 minutes

Negligible Energy Transactions

A negligible energy transaction (NET) is one that the driver utilizes the prioritized EV parking space, but does not charge his/her vehicle. These are categorized by negligible energy being drawn but non-negligible session durations. The thresholds used in this analysis for a NET are less than 0.3 kWh of energy delivered with a total duration of over 15 minutes. These thresholds were chosen as they are much less than the expected 0.83 kWh of energy for a 15-minute session using a 3.3 kW level 2 charger (and 1.65 kWh for a 6.6 kW level 2 charger). The kWh mileage equivalent for a NET is less than a single mile of charge. These transactions are meant to capture those users who quickly plug in to start a session but are already at a near-full state of charge so their vehicle immediately stops drawing power in order to utilize the priority EV parking space for an extended period of time.

Typical Commute

The average "typical commute" in the SCAG region was derived to compare different pricing policies and scenarios based on the same set of parameters, particularly for the analysis in **Behavior of Specific Pricing Policies (p29)**. This typical commute assumes a PEV is fully charged and travels a distance of 10 miles with an average fuel economy of 0.32 kWh/mile (average of Leaf, Prius, Volt, and Model S). The charging power of the EVSE is assumed to be 3.3kW. Most of the sessions in the data set were conducted by PEVs which charge at this power, but some recent models are able to charge at 6.6kW. The typical commute used within this report uses the simplified 3.3KW as most vehicles on the road at the time of the data collection use 3.3KW. Vehicles will take longer to charge so the parking factor can be discussed more than if only short durations were assumed.

Graduated Hourly Rate Pricing and Threshold Hour

A graduated hourly rate is a pricing policy element that increases the hourly rate after a set number of hours to discourage long sessions and extended post-charge dwell times. For example, a policy with a graduated hourly pricing rate component might begin the cost of the charging session at $1 per hour for the first four hours but then increase to $5 per hour for every subsequent hour (or part thereof) of session duration. Therefore, a four hour session would cost $4 total, but a five hour session would cost $9 total. The hour at which the increased rate begins is considered the “threshold hour”. As most PEVs can receive a full charge within four hours under level 2 EVSEs, the additional cost associated with the graduated pricing is tied to physically occupying the space. This graduated hourly pricing policy is also sometimes referred to as an occupancy penalty rate pricing.

Possible Data Issues

The provided data set only includes those workplaces that are on the ChargePoint network within the SCAG region, which limits the scope of this report to Southern California workplaces. While there is a high rate of PEV adoption within Southern California, this area also has unique driving preferences and longer average commute distances and times than throughout the country which could impact typical behavior.

Additionally, no information is included in the vehicles' state of charge when the session is initiated, which can greatly influence charging behavior. If a battery is near depleted, then the urgency to charge is greater and will likely be charging for a longer period of time, compared to a driver with a nearly-full state of charge who knows that they only need to top-off their battery or plug in just to access the priority parking space. Some pricing policies discourage these inefficient uses, which are discussed later in the report.

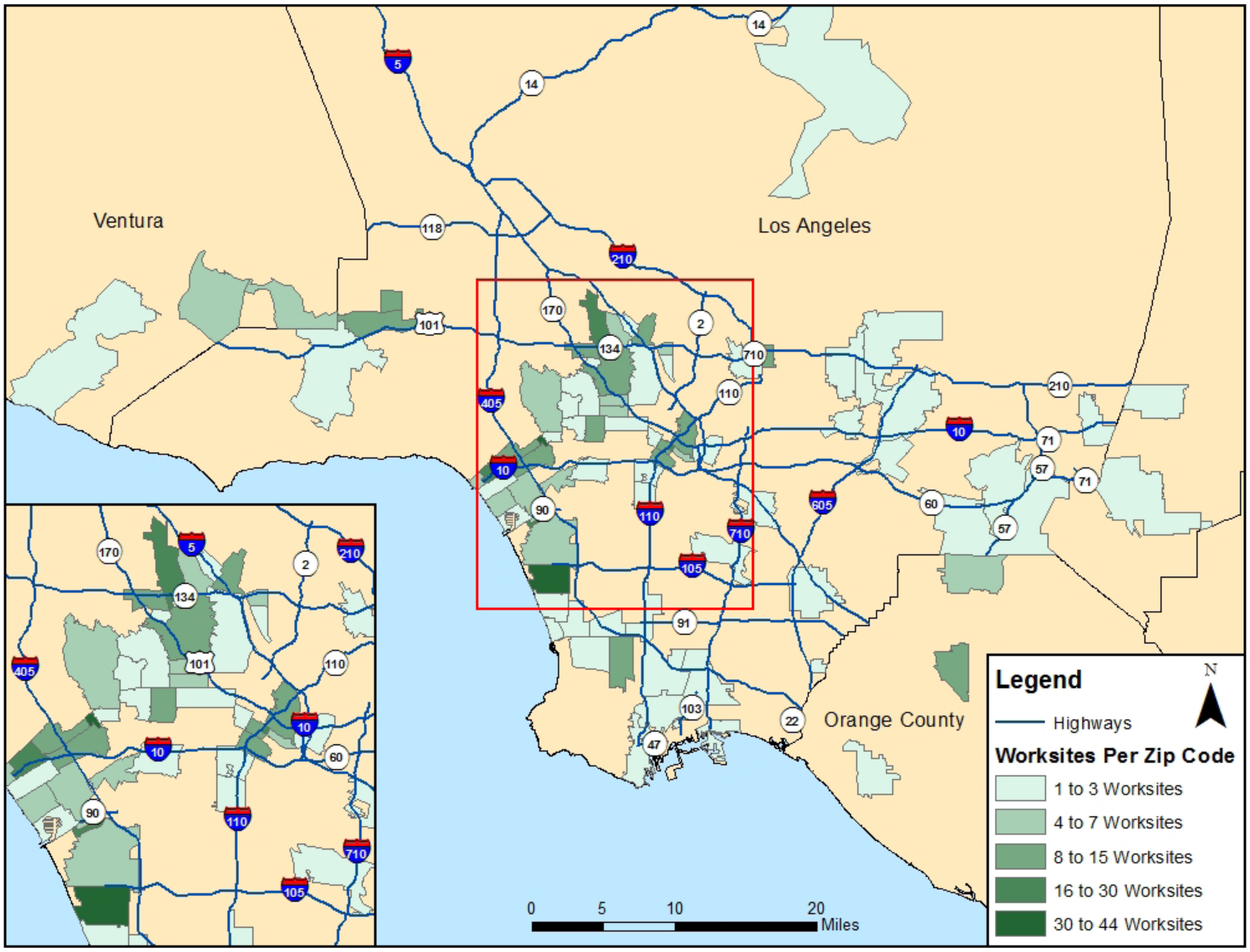
Descriptive Statistics

Using the assumptions made above, the following statistics describe the data set used for analysis within this report:

Transactions in the data set:	417,302
Workplace sites:	247
EVSEs:	477
Ports:	850
Zip Codes Covered:	88

The data covers a range of workplaces throughout the SCAG region. **Figure 2** shows the number of workplaces per zip code covered in the analyzed data set.

Figure 2: Worksites per Zip Code



6 DATA ANALYSIS & FINDINGS

Typical Workplace Usage by Time of Day

This section explores how workplace charging usage differs throughout the day (based on the session start time) to describe the macro trends of usage and behavior of workplace charging to inform discussions on how to maximize the potential effects of time-variable pricing (e.g., time-of-use or dynamic pricing) while balancing the needs of site hosts, PEV drivers, and utilities. The general effects of paid versus free charging on behavior will also be discussed in this chapter to inform analysis later in this report on specific pricing policy components. The research questions guiding this section of analysis include:

- What are the typical behavior and usage patterns of workplace charging and how do they differ throughout the day?
- What general effects do free vs paid charging sessions have on this behavior?

Furthermore, understanding time of use differences throughout the work day can inform future policy decisions related to smart charging and energy grid resource management (i.e., power curtailment), in addition to the recommendations for employers' best practices on maximizing the efficiency of workplace charging. As more dynamic pricing programs are studied and implemented by electric utilities (like the SDG&E Power Your Drive Pilot Program), more thorough comprehension how current PEV drivers interact with charging infrastructure by time of arrival can facilitate more efficient local grid management by both the utilities and site hosts.

Methodology

Segmenting by Time of Day

In order to analyze behavior by different time periods throughout the day, the frequency distribution based on time of arrival was evaluated to determine where the most natural breaks in the data occur that represent different commuting times and workplace uses. The typical workday across most industries is approximately 8AM to 6PM, but a more granular time analysis is needed to determine how PEV drivers' charging behavior varies based on the time of arrival. Therefore, the typical workday was divided into four different segments between two and four hours each; an additional three time segments were included to represent the remainder of the day.

Table 1 displays the categories for the time periods used in the analysis, including the number of transactions and percentage of all the transactions by time period. Segmenting the data by these time periods provided a relatively even distribution throughout the regular work day hours, but with the most transactions occurring in the 8AM to 10AM Morning time period lining up with the beginning of a typical workday.

Table 1: Time of Day Categorizations and Number of Sessions

Category	Time of Day	Number of Sessions	% of All Sessions
Early Morning	5 AM - 8 AM	84,929	20.4%
Morning	8 AM - 10 AM	111,240	26.7%
Late Morning	10 AM - 12 PM	56,443	13.5%
Early Afternoon	12 PM - 2 PM	63,559	15.2%
Afternoon	2 PM - 6 PM	74,931	18.0%
Evening	6 PM - 12 AM	22,336	5.4%
Overnight	12 AM - 5 AM	3,864	0.9%

Metrics used in the Analysis

Table 2 describes each of the behavioral and usage metrics derived from the available data to best describe and understand workplace charging behavior. These metrics are summarized in **Table 3** by the time of day categories identified above.

Table 2: Usage Metrics Used in Time of Day Analysis

Metric	Description
Number of sessions	
Total Sessions	The total number of charging sessions per time period.
Percent of All Sessions	The proportion of sessions per time period to total daily sessions.
Sessions per Hour	The average number of sessions beginning per hour in that time period.
Free Sessions	The total number free sessions in that time period.
Percent Free Sessions	The percentage of that time period's sessions that are free.
Timing and Energy	
Duration	The total duration of the session.
Active Charging Time	The time the EV is actively drawing energy from the EVSE.
Post-Charge Dwell Time	The time after the EV is no longer drawing energy from the EVSE but is still connected until the session is terminated.
Percent of Time Charging	The ratio of active charging time to total duration.
Energy Dispersed (kWh)	The average energy dispensed by the EVSE, in kilowatt-hours (kWh).
Power Delivered (kW)	The average power dispensed by the EVSE, in kilowatts (kW).
Fee Analysis	
Average Fee (All Sessions)	The average fee amount per session across all sessions (paid and free).
Average Fee (Paid Only)	The average fee amount per session across paid sessions only.
Effective Fee per kWh (All Sessions)	The average effective fee paid per kWh of energy delivered across all sessions (paid and free), including all components of the pricing policies.
Effective Fee per kWh (Paid Only)	The average effective fee paid per kWh of energy delivered across paid sessions only, including all components of the pricing policies.
"Negligible Energy Transactions" (NETs)	
Total NETs	The number sessions that are longer than 15 minutes in duration, but drawn negligible energy (less than 0.30 kWh).
Percent of NETs	The percentage of NETs to all sessions in that time period.
Duration of NETs	The average duration of a sessions meeting the NET criteria.
Number of Free NETs	The number of sessions that are both free and meet the NET criteria.
Efficiency	
Total Inefficient Sessions (<75%)	The number of sessions that were actively charging for under 75% of the total session duration; this represents an inefficient use of the EVSE resource (or, more than 15 minute of dwell time per hour charged).
Percent Inefficient Sessions	The percent of inefficient sessions in that time period.
Total Inefficient Sessions (<75%)	The number of sessions that were actively charging for over 98.33% of the total session duration; this represents a super-efficient use of the EVSE resource (or, less than 1 minute of dwell time for every hour charged).
Percent Super-Efficient Sessions	The percent of super-efficient sessions in that time period.

Table 3: Summary Table of Time of Day Analysis

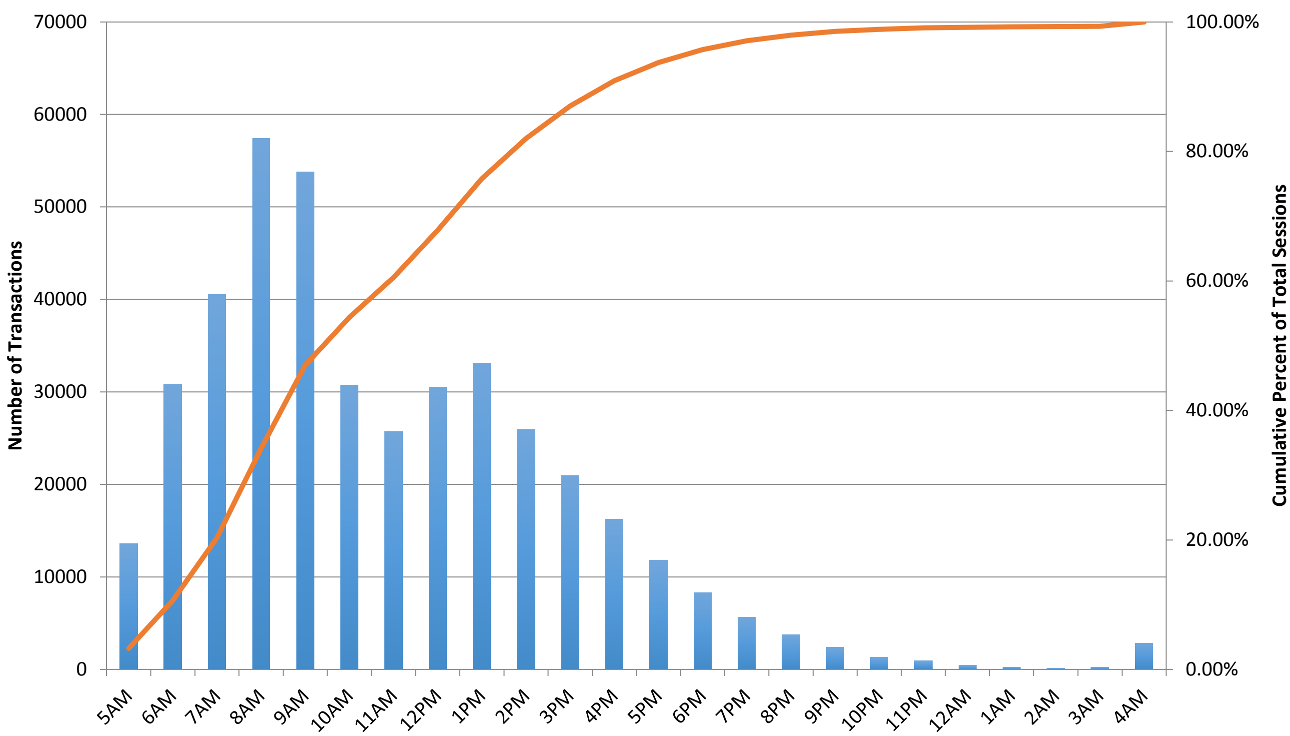
	Units	Early Morning (5AM-8AM)	Morning (8AM-10AM)	Late Morning (10AM-12PM)	Early Afternoon (12PM-2PM)	Afternoon (2PM-6PM)	Evening (6PM-12AM)	Overnight (12AM-5AM)
Counts								
Total Sessions	Transactions	84929	111420	56443	63559	74931	22336	3864
Percent of All Sessions	% of total transactions	20.4%	26.7%	13.5%	15.2%	18.0%	5.4%	0.9%
Sessions per Hour	Transactions	28310	55620	28222	31780	18733	3723	773
Free Sessions	Free Transactions	33657	45189	27668	28441	35694	12593	1197
Percent Free Sessions	% of total transactions by time period	39.6%	40.6%	49.0%	44.7%	47.6%	56.4%	31.0%
Timing and Energy								
Duration	Minutes	224	223	193	182	156	168	229
Active Charging Time	Minutes	157	147	137	131	113	108	168
Post-Charge Dwell Time	Minutes	67	76	56	51	43	60	61
Percent of Time Charging	% (Ratio of Charging to Duration)	79.0%	75.6%	79.8%	79.5%	82.5%	82.6%	82.2%
Energy Dispersed (kWh)	Kilowatt-hour (kWh)	9.68	9.13	8.58	8.27	7.23	7.11	11.38
Power Delivered (kW)	Kilowatt (kW)	3.62	3.62	3.66	3.68	3.72	3.91	4.00
Fee Analysis								
Average Fee (All Sessions)	$	$1.90	$2.06	$1.63	$1.53	$1.22	$1.00	$2.29
Average Fee (Paid Only)	$	$3.14	$3.48	$3.19	$2.78	$2.33	$2.28	$3.32
Effective Fee per kWh (All Sessions)	$ per kilowatt-hour (kWh)	$0.23	$0.45	$0.17	$0.26	$0.47	$0.04	$0.03
Effective Fee per kWh (Paid Only)	$ per kilowatt-hour (kWh)	$0.38	$0.75	$0.33	$0.47	$0.89	$0.09	$0.04
"Negligible Energy Transactions" (NETs)								
Total NETs	Transactions	31	46	83	95	143	25	1
Percent of NETs	%	0.04%	0.04%	0.15%	0.15%	0.19%	0.11%	0.03%
Duration of NETs	Minutes	91	98	105	109	84	81	45
Number of Free NETs	Transactions	20	27	68	73	103	23	1
Efficiency								
Total Inefficient Sessions (<75%)	Transactions	26940	42051	17453	20857	20187	5771	1045
Percent Inefficient Sessions	%	32.0%	38.0%	31.0%	33.0%	27.0%	26.0%	27.0%
Total Inefficient Sessions (<75%)	Transactions	24452	32317	21593	24070	37070	12010	1206
Percent Super-Efficient Sessions	%	29.0%	29.0%	38.0%	38.0%	49.0%	54.0%	31.0%

Time of Day Analysis

Number of Sessions

As shown in **Figure 3**, the highest number of sessions begin in the 8AM and 9AM hours as most employees begin their work day during these two hours and will plug in their vehicle upon arriving at work. However, there are a considerable amount of workplace sessions that occur before 8AM for those EV drivers that arrive earlier to work. Following this period of high usage in the morning (until 10AM) is a considerable drop in the number of sessions conducted between 10AM and noon. A slight increase in the number of sessions occur between noon and 2PM. From 2PM to 6PM, there is a steady decrease in the number of sessions as most employees have already charged their vehicle earlier in the day, but still some users will replenish their charge during the afternoon until they leave for the evening.

Figure 3: Total Number of Transactions per Hour



After 6PM, the number of workplace transactions continues to rapidly decline and therefore all evening sessions after 6PM were grouped together. Additionally, there were some transactions in the data set that occurred overnight (beginning between midnight and 5AM). These sessions could be worksites that have EV fleets and choose to charge overnight; or, if the station is available to the general public outside of business hours, nearby residents taking advantage of this neighborhood resource, but are not considered a significant aspect of workplace charging. These two off-peak time periods cover 11 hours of the day (6PM through 5AM) but only represent a little over 6% of the total transactions.

The largest number of sessions occur in the morning between 8AM and 10AM as a typical employee arrives at work, plugs in his/her vehicle, and begins the workday. These two hours account for 26.7% of all transactions. Early Morning sessions in the three hours leading up to 8AM account for the next most amount of transactions (20.4%), but cover three hours instead of two. On a number of sessions per hour basis, the Early Morning time period is more similar to the Late Morning and Early Afternoon periods, whereas the Morning time period has approximately double the amount of transactions per hour than any other time period. Therefore, the highest level of demand for charging stations occurs in the morning. Overall, approximately 47% of all analyzed transactions occur before 10AM, a total of almost 61% of transactions before noon, and 76% cumulatively before 2PM.

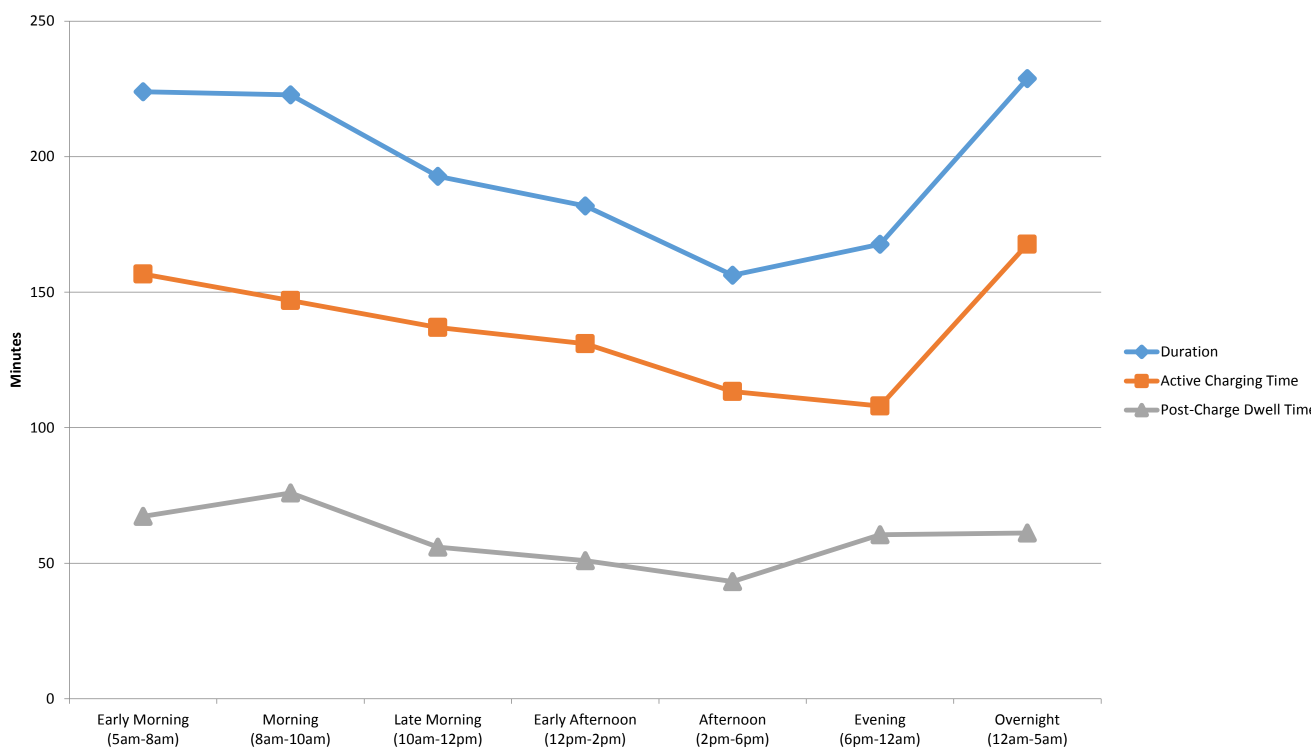
Not including overnight charging, the lowest percentage of free transactions occurs in the Early Morning and Morning time periods at approximately 40% of all sessions transacted over the five-year period. These morning hours have the highest levels of user demand for charging stations and therefore should be paid to encourage efficient use of the EVSE resource. Currently, specific pricing policies do not vary price by time of day and the 40% free transactions is in absolute number of sessions, but as session durations are longer in the morning than afternoon, it can be inferred that there is less turnover at free stations morning hours than in the afternoon.

Time and Efficiency

Figure 4 displays the average duration, active time charging, and post-charge dwell time by time period. The average total duration is the highest for the morning commuters and stays constant between the Early Morning and Morning time period at 223-224 minutes. However, the active charging time drops from 157 minutes to 147 minutes between these two time periods, which corresponds to drivers letting their vehicle dwell for 10 minutes longer after charging is complete if they arrive before 8AM than after.

Although the morning has the highest demand, users are typically less time sensitive then knowing they have all day to charge their vehicle and therefore will leave their vehicles plugged in longer in the morning. Discussed more in depth later in **Behavior of Specific Pricing Policies (p29)**, some policies have occupancy penalty rates that will greatly increase the cost of using the charging station after 3 or 4 hours to influence behavior (i.e., graduated hourly pricing). When a session is initiated in the afternoon, these penalty thresholds are reached less often than when beginning in the morning as noted by the declining average duration throughout the workday.

Figure 4: Average Duration, Active Charging Time, and Post-Charge Dwell Time



The average session duration rapidly declines after the Morning time period throughout the rest of the workday to a minimum of 156 minutes for the Afternoon time period. While the active charging time for sessions beginning during this time period is shortest, these sessions also have the highest percentage of drivers vacating the parking space shortly after their vehicle has completed it charge. At an average of 82.5% of time actively charging, drivers plugging in after 2PM utilize the charging stations most efficiently. The high efficiency in the Afternoon can be partially explained by drivers plugging in and charging right up until they need to leave for the day as nearly half (49.5%) of all sessions beginning in the Afternoon time period are actively charging for at least 98.33% of the session duration (or, one minute of post-charge dwell time for every hour of session duration). Conversely, only 29% of sessions surpass this super-efficient charging threshold in the Early Morning and Morning time periods.

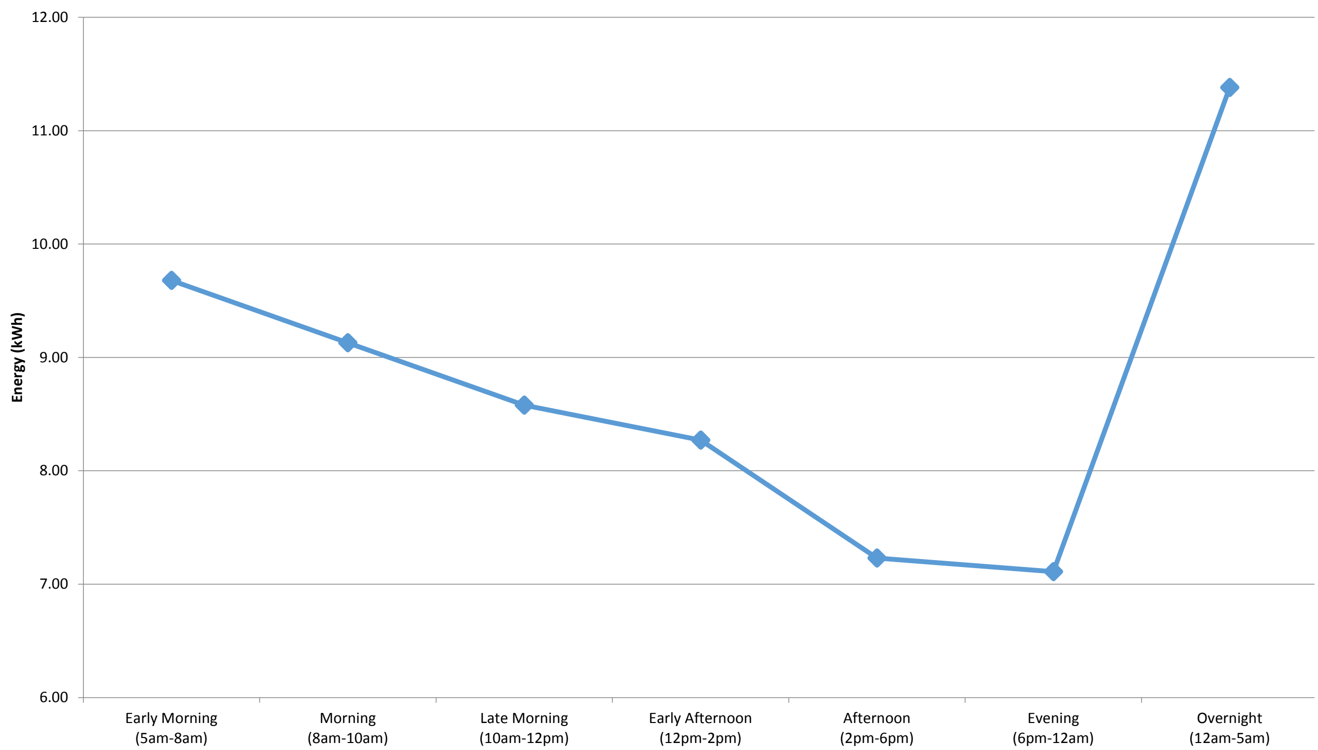
This behavior of longer durations beginning earlier in the day and more efficient sessions later in the workday can be expected. Drivers with long commutes that deplete most of their vehicle's battery driving to work will need to charge for an extended period of time so that they have enough battery power to return home at the end of their day. To alleviate range anxiety for these drivers, they likely choose to plug-in in the morning so their vehicle is ready whenever they need to leave throughout the day. If they wait until the afternoon and there are no available charging ports or an unexpected circumstance occurs requiring them to leave before they routinely do so, they may not have enough battery power to make it to their destination. Furthermore, EV drivers wanting to ensure their battery is fully charged before leaving work for the day will begin a session in the Afternoon to charge up until they need to leave, as shown by this time period having the largest percentage of super-efficienct transactions.

Comparing sessions that are actively charging for under 75% of the total duration, there are 8% more sessions below this threshold that are free than paid. The Afternoon time period is characterized by the high amounts of super-efficient transactions (49.5%) and some of the least amounts of low-efficiency transactions (26.9%). In general, free workplace pricing policies do not incentivize users to utilize the EVSE efficiently as the marginal cost is zero to stay longer than needed to charge; whereas, a paid pricing policy can encourage vehicle turnover because each additional minute occupying the charging station costs the driver money that can saved by moving their vehicle after charging is completed. This effect is magnified for policies with an occupancy penalty rate after a couple of hours (i.e., graduated hourly rates). **Behavior of Specific Pricing Policies (p29)** discusses the behavioral responses of particular pricing policies in more depth.

Energy Dispensed

As shown in **Figure 5** below, the highest energy per transaction (in kWh) occurs in the mornings (excluding overnight charging) and slowly but gradually decreases through the work day. The average kWh delivered per sessions being 12% and 6% higher in the Early Morning (9.68 kWh) and Morning (9.13 kWh) time periods, respectively, compared to the daily average (8.61 kWh). With the exception of overnight charging that accounts for only 1% of all workplace sessions and have the longest duration, all other time periods analyzed draw lower than average kWh. The average power delivered (in kW) stays consistent at approximate 3.6-3.7 kW as most of the existing PEV fleet charges at 3.3kW with some recent PEVs and battery electric vehicles able to charge at 6.6kW on Level 2 EVSEs.

Figure 5: Average Energy (kWh) by Time of Day



Negligible-Energy Transactions

As listed in the assumptions in **Data Collection, Assumptions (p14)**, a NET is one that the driver chooses to utilize the prioritized EV parking space, but does not actively charge. These NETs are represented in the data set as those with durations greater than 15 minutes, but drawn less than 0.30 kWh of energy (equivalent to less than one mile of travel for the average PEV). Although these type of sessions only are a small portion of the data, they are representative of extremely inefficient sessions and can show when users are exploiting the charging station for a prior parking space.

The Afternoon time period has most of NETs and account for 0.19% of all transactions; however, these Afternoon sessions are also the shortest in duration. As explained above, this is likely because drivers plug their vehicles in the afternoon until they need to leave, regardless of the state of charge. Conversely, the least amount of NETs by time period occur in the morning hours when drivers have a greater need to charge.

Transaction Fee and Effective Price per kWh

This section gives a broad overview based on the total transaction price and effective price paid per kWh, regardless of that site's specific pricing policy. The effective price per kWh is the total transaction price divided by the amount of energy dispensed and therefore also includes any built-in parking costs or session fees.

The average fee transacted (including both paid and free transactions) is $1.68 with a standard deviation of $2.68, showing that the fee is highly variable. The highest average fee during the workday occurs in the Morning time period ($2.06) and decreases through the day to an average of $1.00 per transaction in the Evening.

The average effective price paid per kWh across the data is $0.31, but varies throughout the workday from $0.17 per kWh in the Late Morning to $0.45 and $0.47 per kWh in the Morning and Afternoon time periods, respectively (as shown in **Figure 6**). These average prices are driven by specific pricing policies that can charge by time occupied, energy dispensed, per session, or a combination of multiple pricing elements.

Therefore, it should be noted that there are additional costs besides energy included in these average transaction prices, most notably parking and occupancy costs encompassed in many specific pricing policies. **Behavior of Specific Pricing Policies (p29)** describes the different possible pricing policies and the resulting behavior of individual policy components.

Figure 6: Effective Price per kWh by Time of Day

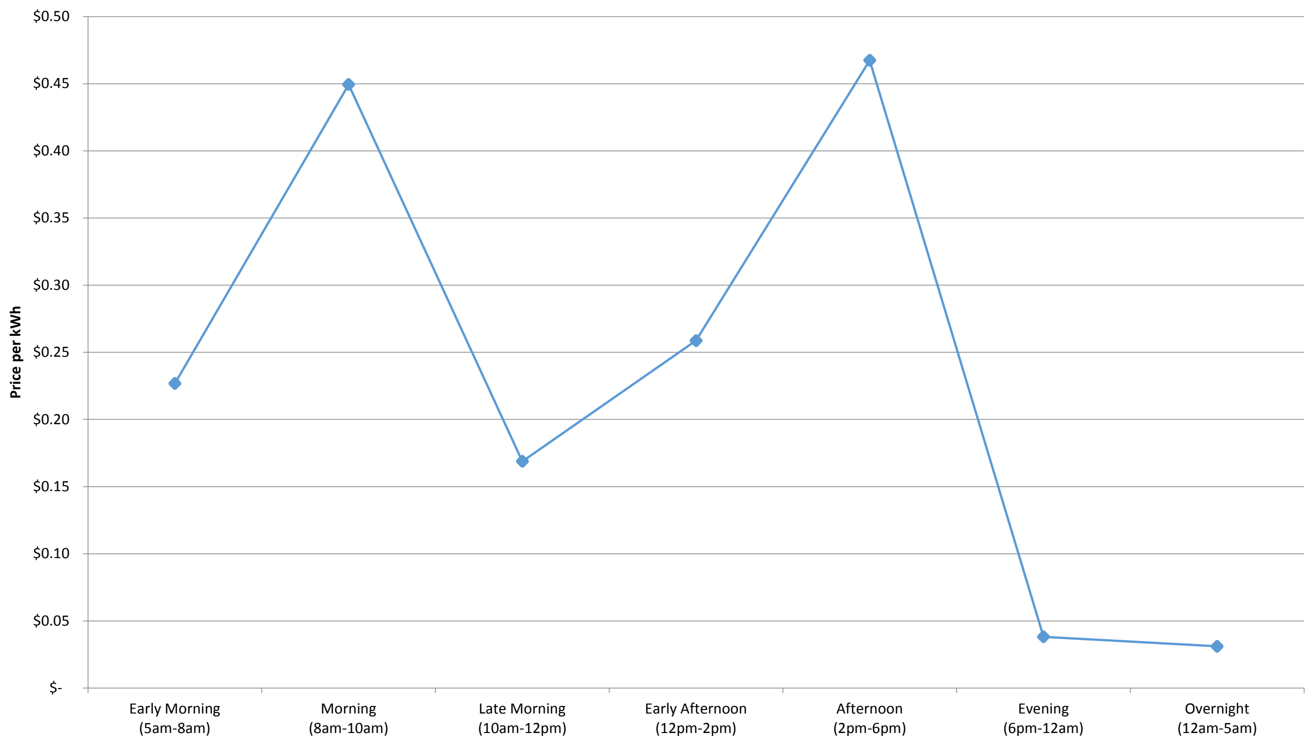


Figure 7 below shows that the highest frequency of sessions pay an effective rate of $0.31 per kWh with the next highest frequency occurring at $0.19 per kWh. **Table 4** displays the TOU rates introduced by Southern California Edison (SCE) and Los Angeles Department of Water and Power (LADWP) for charging EVs at non-residential sites. While it is unknown which utility provider the worksites in the dataset are operating under, these rates are used to provide an overview of time-variable pricing rates to understand the cost site hosts pay to the utilities to receive the energy, and the difference in the resulting effective price per kWh paid by the PEV driver that incorporates the other factors (i.e., time and space occupied by the PEV). Although the cost the site host pays to receive this energy is usually less than $0.31 per kWh, the host chooses a pricing policy that is aligned with their goal of providing the resource and is more often charges by time occupied than solely based on energy dispensed. These additional time and space factors must be considered when pricing charging stations in order to maintain an acceptable level of productivity, access, and equity among PEV drivers.

Figure 7: Effective Price Paid per kWh Dispensed

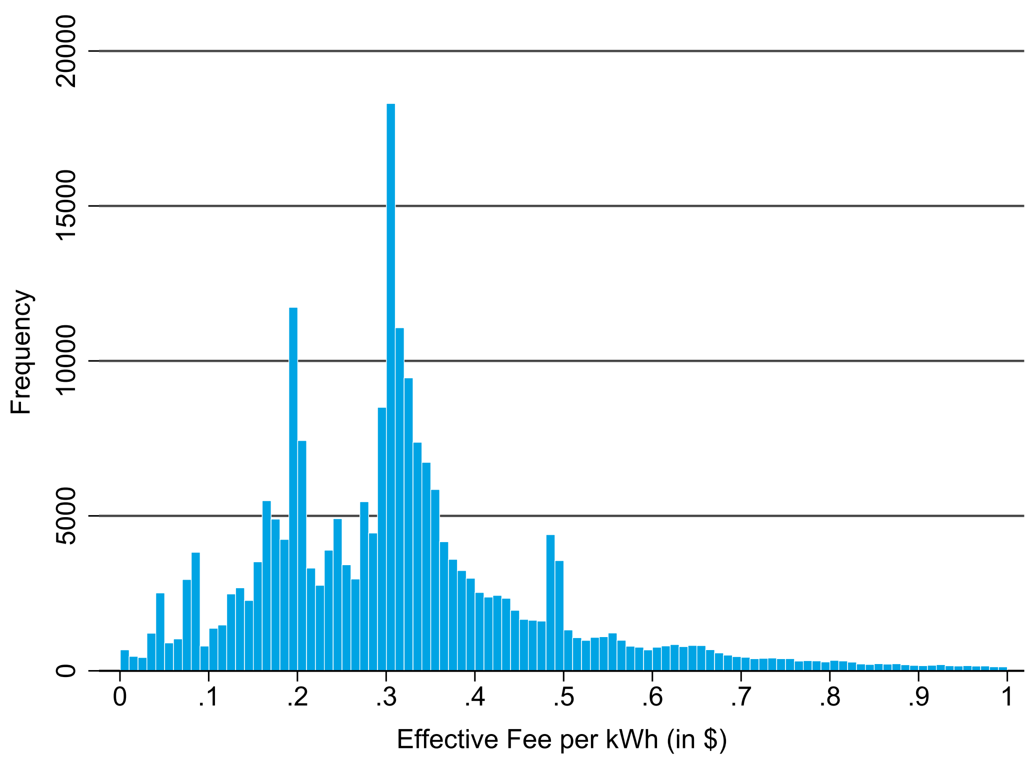


Table 4: Los Angeles Utilities' TOU rates

	Summer ($/kWh)	Winter ($/kWh)
SCE: TOU-EV-3-A Rate Schedule (Smaller Worksites) [35]		
On-Peak (Noon to 6PM)	$0.36	$0.16
Mid-Peak (8AM to noon; 6pm to 11PM)	$0.17	$0.14
Off-Peak (All other hours)	$0.09	$0.10
SCE: TOU-EV-4 Rate Schedule (Larger Worksites) [36]		
On-Peak (Noon to 6PM)	$0.29	$0.11
Mid-Peak (8AM to noon; 6pm to 11PM)	$0.12	$0.09
Off-Peak (All other hours)	$0.05	$0.06
LADWP: Small Commercial TOU Rate-B [37]		
High Peak (1PM to 5PM)	$0.209	$0.104
Low Peak (10AM to 1PM; 5PM to 8PM)	$0.148	$0.104
Note: There are also facility related demand charges, customer charges, and commercial adjustment factors with each of these tiers that effectively raise the costs to the sites very slightly over those prices listed, but vary between sites.		

[35] SCE Electric Car Rate Options; rates effective 1/1/15 to end of analysis period
[36] SCE Electric Car Rate Options; rates effective 1/1/15 to end of analysis period
[37] LADWP Small Commercial Time-of-Use Rate B; rates effective 7/1/13 to end of analysis period

When analyzing **Figure 6** and **Table 4** comparatively, the highest effective price paid per kWh occurs in Morning and Afternoon time periods. Afternoon high prices are driven by the increased TOU rate imposed to the host, especially during the summer hours; whereas, the high effective price paid during the Morning hours is due to a combination of balancing demand through hourly pricing policies and longer average durations, but more time-specific pricing could be utilized to facilitate shifting site demand to the Late Morning in a more effective manner. The Late Morning time period has the lowest workday energy costs from the utilities (i.e., low- or mid-peak pricing) and half the charging sessions beginning then compared to the Morning peak, therefore, there is physical capacity to shift some of these sessions if the PEV is incentivized to plug in for the day after 10AM, or turnover an Early Morning vehicle completing its charge before noon instead of waiting to move the vehicle after lunch.

Overview of Free vs Paid Charging Effects

This subsection shows an overview of paid versus free charging sessions on an aggregate level over the five-year period of analysis. If any fee amount is recorded, then it is considered a paid session, regardless of the magnitude. Macro-level trends are described here and the behavioral responses to specific pricing policies are described later in **Behavior of Specific Pricing Policies (p29)**.

The effect of paid vs free transactions on timing variables is shown in **Table 5**. On average, paid charging sessions result in shorter session durations by 9 minutes, longer active charging times by 20 minutes, and shorter post-charge dwell time of approximately 29 minutes across the entire day. The largest effect is on the post-charge dwell time as this metric decreases by 29 minutes for paid transactions, when the overall duration only decreases by 9 minutes, on average. This demonstrates that charging stations are utilized in a more efficient manner when the driver is required to pay for at least part of the transaction. Pricing for workplace charging barely affects the variance of the active charging time, but does have a large effect on both the post-charge dwelling time and overall duration.

Table 5: Overall Effects of Free Transactions on Session Timing Metrics

Variable	Average (mean)			Std. Dev		
	Combined	Paid	Free	Combined	Paid	Free
Duration (in minutes)	198	194	203	138	115	163
Active Charging (in minutes)	137	146	126	73	71	73
Dwell Time (in minutes)	61	48	77	116	89	141
Percent Charging	69.2%	75.3%	62.0%	--	--	--

The difference in average duration, average dwell time, average percentage of time actively charging, and average energy drawn for paid versus free pricing policies by time of day is shown below in **Table 6**.

Table 6: Session Timing Differences between Free and Paid Sessions by Time of Day

	Early Morning (5AM-8AM)		Morning (8AM-10AM)		Late Morning (10AM-12PM)		Early Afternoon (12PM-2PM)		Afternoon (2PM-6PM)		Evening (6PM-12AM)	
	Paid	Free	Paid	Free	Paid	Free	Paid	Free	Paid	Free	Paid	Free
Duration (mins)	215	238	215	234	195	191	181	183	150	163	150	182
Dwell (mins)	50	93	59	100	47	66	41	63	32	56	43	74
% Charging	83.2%	72.7%	79.1%	70.6%	82.5%	77.0%	81.7%	76.8%	85.1%	79.6%	85.9%	80.0%
Energy (kWh)	10.35	8.65	9.82	8.11	9.51	7.63	9.02	7.34	7.74	6.67	7.20	7.05

As shown in **Table 6** above, free vs paid policies affect the efficiency of the transactions. In all workday time periods except the Late Morning, the effect of paying for a session results in shorter durations and much shorter dwell times, and therefore greater percentage of time actively charging. The greatest difference is in the Early Morning time period when the presence of paid transactions shortens the average duration by 23 minutes and the post charge dwell time by 43 minutes (or 86% shorter dwell times).

Findings

The analysis and figures above demonstrate that the highest demand for workplace charging occurs in the morning hours (up to 10AM) and then decline throughout the remainder of the day. Overall, approximately 47% of all analyzed transactions occur before 10AM, a total of almost 61% of transactions before noon, and 76% cumulatively before 2PM. Many drivers will plug-in their vehicle upon arriving to work and therefore the longest session durations occur during these the morning hours. Afternoon sessions charge for more of their overall duration as drivers will plug in until they need to leave for the day, with approximately half of all transactions charging for their entire session duration. With more active incentives to shift charging patterns, there is room to shift charging demand from the Morning to Late Morning time period when there are less physical constraints on charging.

On average, paid charging sessions result in shorter session durations by 9 minutes, longer active charging times by 20 minutes, and shorter post-charge dwell times of approximately 29 minutes across the entire day. This corresponds to increased charging efficiency of 13.3% when sessions are not free. Free workplace pricing policies do not incentivize users to utilize the charging resource efficiently as the marginal cost is zero to stay longer than needed to charge.

Summary of Findings:

- The highest demand for workplace charging occurs in the morning hours (up until 10AM) as nearly twice as many sessions per hour begin during this time, but with capacity to shift some of this demand to the Late Morning time period when TOU rates are still low but have less physical constraints on the charging stations.
- The average session duration declines throughout the workday, as efficiency increases. The Afternoon period (2-6pm) has the shortest durations, but highest percentage of time actively charging as drivers plug in their vehicles until they need to leave at the end of the day. Half of all Afternoon sessions charge for nearly the entire duration.
- On average, paid charging sessions result in shorter session durations by 9 minutes, longer active charging times by 20 minutes, and shorter post-charge dwell times of approximately 29 minutes across the entire day.
- Free workplace pricing policies do not incentivize users to utilize the EVSEs efficiently as the marginal cost is zero to stay longer than needed to charge.

Behavior of Specific Pricing Policies

Understanding the typical behavior of PEV charging, as described above in previous section, can help inform a site host's decision on the most effective pricing policy to achieve the specific site objectives of that host. Each workplace site host establishes its own pricing policy under the possible options and pricing variations that can be administered under the available ChargePoint software. While some worksites offer free charging as an amenity for employees, other sites offer much more complex pricing structures depending on the hosts' objectives of providing and pricing the resource. However, each type of pricing policy can provoke different types of behavioral responses from the users depending on the monetary penalty (or lack thereof) for excess use of the charging resource.

The PEV charging market is still relatively nascent and growing at an exponential rate every year. Because of the developing nature of this market, there has been minimal quantitative research conducted to inform pricing policy discussions on usage patterns and possible time-variable pricing. Understanding the behavioral implications of specific PEV charging policies will help recognize other factors besides energy costs that must be included when pricing charging stations. This report helps to bring to light these differences and guide best practices moving forward that can align drivers' behavior with site hosts' goals while maintaining an acceptable level of equity for users at their sites.

This section explains the various possible inputs into different pricing models, displays a snapshot of the workplace pricing policies included within the entire dataset, analyzes specific usage metrics resulting from the most common types of pricing policies, and provides recommendations for effective pricing policies.

Methodology

The pricing policy analysis begins by describing the process in which each site host chooses their initial pricing policy. The possible options for pricing policies are categorized into four base policies with an additional six pricing component options to supplement one of the base policies. A snapshot of the distribution of base policies with applicable options are summarized and discussed for the 239 sites that had reliable policy information at the time of this writing to determine the most common policies. These were then regrouped into the six most common policies derived from the four base categories and common components, primarily concentrating on free, hourly, and energy policies with and without graduated rates. A graduated rate is a pricing policy element that increases the hourly rate after a set number of hours to discourage and penalize long sessions and extended post-charge dwell times. For example, a policy with a graduated rate component might begin the cost of charging session at $1 per hour for the first four hours but then increase to $5 per hour for every subsequent hour of session duration. The hour at which the increased rate begins is considered the "threshold hour". As most PEVs can receive a full charge within four hours with a Level 2 EVSE, the additional cost associated with the graduated pricing is tied to physically occupying the space.

To ensure sites had consistent policies over the period of analysis, only pricing policies enacted before July 1, 2015 with consistent policies between July 1 and December 31, 2015 were used. Historical pricing policy data was not available and therefore the focus of this specific analysis concentrates on the most recent six-month period available in the data set with reliable pricing policy information. A total of 167 work places were retained for the statistical analysis. The following usage and pricing metrics are then described for each of these six policies:

- Average kWh per session
- Weekly sessions per site
- Average weekly sessions per available charging port
- Average sessions duration (hours)
- Average active charging time (hours)
- Average dwell time (hours)
- Percent actively charging
- Average weekly attach rate (ratio of unique users to available charging ports)
- Average fee per session
- Average effective price paid per kWh
- Price for the typical commute

These usage and pricing metrics are used throughout the remainder of this chapter to compare different pricing policies and components.

To isolate the effect of the occupancy penalty under graduated hourly pricing, session duration graphs are plotted relative to the threshold hour. The threshold varies between specific pricing policies, but is typically after 3 or 4 hours. The bunching effect of sessions terminating right before or immediately after the threshold hour are analyzed to determine the effect of graduated hourly rates on session duration and efficiency based on the magnitude of the graduated hourly rate.

As a proxy to price elasticity, PEV drivers' response to price change is analyzed based on the standardized typical commute (defined above in **Data Collection, Assumptions (p14)**). Scatterplots with best fit regression lines are used to explain the response effect of different usage metric on the price for the typical charging session. A regression analysis on the typical commute on the listed usage metrics was also conducted to describe PEV drivers' price elasticity.

To isolate individual pricing components, additional regression analyses were conducted on the following four major components (parking charge, graduated hourly rate, energy cost, and minimum fee). These were represented as dummy variables in the analysis to trigger whether they existed in specific policies to separate the effects of various components. This chapter concludes with regression analyses comparing usage of a "Free at all Times" policy to the other five most common policies. All regressions were conducted both with and without zip code fixed effects. The regressions with zip code fixed effects only compare those sites located within the same zip code, whereas without these fixed effects compare statistics between all 167 sites. The closer the coefficients are between the with and without zip-code fixed effects, it can be assumed the reported number without this effect is near the true average. Numerous zip codes only have one to three sites and therefore when including the zip-code fixed effects, some coefficients could be heavily influenced by the specific commuting characteristics of that zip code, which could not be further controlled for in this analysis. Therefore, the without zip code fixed effects have been bolded and are used as the primary result for the regression analyses. The with zip code fixed effects is provided as a reference.

Overview of Pricing Policies

Gasoline Refueling vs. PEV Recharging

The PEV charging industry is in an emerging and educational state. PEV recharging systems are not parallel with traditional fueling systems of the past, typically done at a gas station. Understanding this difference and incorporating a time-related element into EV charging is crucial to establishing the PEV charging marketing.

PEV charging pricing policies are fundamentally different the conventional gasoline refueling pricing that drivers are accustomed to. The unit of gasoline dispensed is in gallons of gasoline compared to kWh for PEVs. Kilowatt-hours are used as the most general and fair unit of energy as different vehicles all draw power (in kilowatts) at varying rates, and therefore standardizing it to a unit of time creates equity among dissimilar vehicles. The time aspect is the most important distinction between traditional gasoline stations and EVSEs, and this discrepancy must be understood as it has a major effect on how pricing should be administered. The extended time required to charge a vehicle compared to the couple of minutes spent at a gas station is the key factor that should be included in the charging price. This extra time needed for PEVs results in the vehicle occupying a parking space for multiple hours at a time, and therefore only a limited amount of vehicle turnover per day can be reasonably expected, putting a physical constraint on charging resources. Because of this important distinction, gasoline and EV charging should not be priced on an equivalent gallon of gasoline versus kWh energy consumption basis. PEV charging should include some form of parking cost associated with vehicles occupying the space for an extended time period as that parking space is removed from use for another driver.

Pricing Policy Selection Process

To select a pricing policy, the ChargePoint sales team engages in discussions with the site host to inform and demonstrate the breath of capabilities that can be provided through their software to the host. A review of the variety of pricing options and case studies of other sites are used to help educate the host on picking a policy to fit their site's specific needs; however, most hosts view their site as individually and unrelated to all other sites and will therefore price their charging infrastructure at their own discretion.

Every host has a set of goals they wish to achieve through providing charging stations to their employees or tenants. Specific goals can include providing a benefit to employees, operating a cost-neutral resource, generating a minimal profit, promoting a sustainable image of the company, attracting new tenants or employees, and/or maximizing the number of vehicle turnover at the charging stations. While EVSEs can be priced to generate a marginal profit, seeing a significant return on investment should not be expected as that would require prices to be unacceptably high to consumers and they will find alternative places to charge. Most sites aim to be at least cost-neutral and will pick a policy that will generate enough revenue to recoup both the energy and associated maintenance costs.

The educational process conducted between ChargePoint and the site host is included in the overall implementation process to help inform those property managers who are setting their pricing policy. Whether they realize it or not, site hosts are effectively establishing the new EV charging market rates, and therefore it is necessary to understand all the elements included in the recharging process (especially a time factor) to price adequately. ChargePoint assists these hosts by providing informational materials and case studies to the hosts to encourage pricing policies that maximize utilization of charging stations. As many site hosts receive all this information then act independently and set their own prices, ChargePoint provides various tools to monitor the usage and analyze behavior through the dashboard within their software, as well as have their analysts generate usage reports for the host.

The recommendations and case studies provided support the most efficient use of resources, which includes pricing it in some form or another. Free pricing all the time typically results in over and inefficient use, as shown in the analysis later in this section. Including a graduated hourly rate is an important element to consider in order to minimize the number of long duration stays, especially after vehicles are done charging and unnecessarily occupying the parking space. Additionally, a combination of hourly rate and cost per kWh (called "taxi" pricing) is often endorsed as an effective pricing policy as the fairest way to incorporate both the energy costs and parking costs associated with each session; however, not many hosts choose this option as they view it as too complex to administer and therefore choose a more straight forward policy.

Pricing Policy Options

PEV charging pricing policies come in a large variety of different options. For those included at worksites within the data set, the assorted policies have been grouped into four base pricing categories with six optional elements that can be used in coordination with the base categories. In general, the policies are based on an hourly rate, amount per energy dispensed, flat session fee, or a combination of these. The hourly rate can be $0 and therefore the charging station is free to users. Additionally, the hourly rate can increase after a set number of hours to discourage long stays and encourage turnover of the charging station to other drivers, called graduated hourly pricing.

Using the rules above, pricing policies have been subdivided into the following four base categories:

1. **Free**: these stations are free at all times
2. **Hourly rate**: these stations charge an hourly rate from the beginning of the session
3. **Fee per kWh dispensed**: these stations charge a flat fee per unit of energy (in kWh) dispersed
4. **Flat fee per session**: these stations charge a flat fee per session

Many policies include a combination of two or more pricing policy components. To create a mixed rate, one or more of the following six elements can be added to a base category.

1. **Fee per kWh dispersed**: stations can be a straight fee per kWh or can have a kWh rate in addition to another base pricing policy
2. **Graduated hourly rate**: after an established period of time, the hourly rate can increase
3. **Minimum**: stations can have a minimum fee per session
4. **Maximum**: stations can have a maximum fee per session
5. **Flat fee per session**: stations can be a flat session fee or have a fee per session in addition to another base pricing policy

6. **Preferred discounts**: some stations offer a cheaper or free rates for preferred members (i.e., management or specific tenants commuting especially long distances) and this can be enacted on an individual user basis

Policies within the Entire Data Set

Table 7 displays a cross table overview of the 239 worksites within the data set that had reliable pricing policy data as of March 2016. The total number of sites utilizing each base category is summed on the left, and the number of sites utilizing each of the pricing options available in coordination with each base category are shown in blue boxes. Each pricing category can have multiple options assigned to it and therefore the bottom row totaling the policies will be greater than 239. For example, there are 98 sites that use the "Hourly" base category, but have a mix of different types of policy options that can be applied in conjunction with the hourly rate. Note that **Table 7** displays a snapshot of pricing policies in the SCAG region for reference of the distribution of policies enacted at the time of this writing, but are not the same distribution of policies used later in the regression analyses.

Table 7: Overview of All Pricing Policies

	Total	kWh	Graduated Rate	Session Fee	Preferred Discounts	Min Fee	Max Fee
Free	66	0	0	0	0	0	0
Hourly	112	8	72	1	21	36	36
Fee per kWh dispensed	56	56	33	5	1	15	4
Session flat fee	5	0	0	5	0	0	0
TOTAL	239	64	105	11	22	51	40

Hourly rates are the most common at 47% of the analyzed work sites, including those with and without a graduated/penalty rate. This also includes fourteen sites that are free for the first few hours before a graduated hourly rate begins. For the other 98 sites that remain at a constant hourly rate regardless of duration time, the flat hourly rates ranges from $0.25 to $1.50 per hour, with an average (mean) hourly rate of $0.92 and mode of $1. This straight forward type of pricing is observed often as it is the simple to for drivers to understand and hosts to administer, but does not encourage the most efficient use of the charging resource because there is no penalty for occupying the parking space longer than needed to recharge a vehicle.

Approximately 44% of work sites in the SCAG region have a graduated hourly rate to help discourage excessively long durations and increase turnover throughout the day. Of those 105 sites, fourteen of them begin completely free for between two and five hours before the increased rate begins, with the most common policy under this structure being free for the first four hours. For those policies that begin with an initial hourly rate before a graduated rate is applied, the initial rate begins between $0.55 and $3.60 per hour. The remaining sites with a graduated rate included it their policies, the primary fee for usage is based on kWh dispensed (with no additional parking costs) for the first few hours before the graduated rate goes into effect.

Policies based on straight kWh energy consumption account for 23% of work places in the SCAG region. For policies that only charge a straight fee per kWh dispensed, the average fee is $0.280 per kWh, compared to $0.265 per kWh for all sites that include some form of energy pricing. Seventeen of the 56 sites only charge a straight fee per kWh charge of $0.30 or $0.31 and 33 of the sites only charge a per energy rate for the first few hours before a graduated hourly rate is enforced.

Per session pricing policies are the least common, especially as a stand-alone policy. Although it is the most straight forward policy, it provides the least behavioral responses (as shown later in the regression analysis). Sessions fees only range from $0.50 to $1.00 per transaction, regardless of length of session and therefore do not encourage efficient use of the resource.

Work sites that offer entirely free EV charging as a benefit to their employees and visitors account for 28% of the sites analyzed. The motivation behind this policy is providing an amenity to attract people to the site. There is no penalty for excessively using the EVSE, either on a time occupying the space or drawing energy. As described above in **Typical Workplace Usage by Time of Day (p18)**, the general effects of pricing anything for a PEV charging session results in shorter session durations of 9 minutes, shorter post-charge dwell times of 29 minutes, and longer active charging time of 20 minutes. The presence of having to pay anything for a charging session increases the efficiency of charging sessions and therefore should be encouraged to deter exploitation of the charging stations and associated parking space.

Analysis of Pricing Policies and Pricing Components

The following analysis only includes worksites that had the listed policy enacted before July 2015. The outcomes from July 1 through December 31, 2015 were used to ensure that these 167 worksites all had consistent policies over period of analysis. Historical pricing policy data was not available and therefore the focus of this specific analysis is concentrated on the most recent six month period available in the data set with reliable pricing policy information.

Comparison of the Most Common Pricing Policies

For the 167 sites with continuous pricing policy data between July 1 and December 31, 2015, the six most common types of policies were identified to compare the effects of each pricing policy on a variety of usage metrics and how these usage metrics are affected compared to free charging stations. **Table 8** explains these most common combinations of policies, but additional options could be included (i.e., minimum, maximum, or per session fee). These options are not expected to drive behavior significantly and therefore not called out individually to limit the number of scenarios tested to a reasonable amount for comparison. Individual pricing policy components are discussed in the regression analyses. **Table 9** displays the average values of each metric for all six pricing policies.

Table 8: Most Common Pricing Policies for Analysis

Policy Name	Description
Free at all Times	Free charging at all times
Free with Penalty (Graduated Hourly) Rate	Free charging for the first few hours before a graduated hourly rate begins
Hourly Rate	Fee is based on time occupying the charging station
Hourly with Penalty (Graduated Hourly) Rate	Fee is based on time occupying the charging station and increases after a few hours with a graduated hourly rate
Straight kWh	Fee is based on amount of energy dispersed
kWh with Penalty (Graduated Hourly) Rate	Fee is based on amount of energy dispersed, but after a few hours a graduated hourly rate begins

Table 9: Usage and Pricing Metrics for Each Common Pricing Policy

	Free	Free + Penalty	Hourly	Hourly + Penalty	Straight kWh	kWh + Penalty
Number of Sites Analyzed	50	9	36	38	14	20
Number of Session Analyzed	28883	12582	28941	19433	3791	13947
Usage Metrics						
Average kWh per session	8.27	7.71	9.63	9.72	8.29	9.38
Weekly sessions per site	22.2	53.8	30.9	19.7	10.4	26.8
Average weekly sessions per available charging port	8.9	13.0	8.7	6.3	3.9	7.5
Average session duration (hours)	3.35	2.54	3.20	2.79	4.02	3.26
Average active charging time (hours)	2.14	2.08	2.45	2.31	2.23	2.44
Average dwell time (hours)	1.22	0.46	0.75	0.48	1.79	0.82
Percent actively charging	61.7%	81.3%	76.4%	83.1%	58.5%	75.2%
Unique users per site	181	553	385	239	120	317
Average weekly attach rate	2.7	5.4	4.4	3.1	1.7	3.5
Pricing Metrics						
Average fee per session	--	$0.70	$2.48	$4.03	$2.20	$3.52
Average effective price paid per kWh	--	$0.08	$0.30	$0.44	$0.28	$0.41
Price for the typical commute	--	--	$0.90	$1.39	$0.84	$1.08

Price for the Typical Commute

Sites offering free workplace charging at all times have very long session durations at an average of 3 hours and 21 minutes, but are only actively charging for 62% of the time. There is no incentive to end the transaction and turnover the charging station and therefore free charging work sites have an average post-charge dwell time of 1 hour and 13 minutes. This results in decreased dependability of available EVSE ports as vehicles occupy the charging station longer than they need to and therefore limit the number of possible sessions and users per day. The number of average unique users per site is ranked towards the bottom because of the limited availability of stations with free charging. PEV drivers that know that they have free workplace charging will try to maximize their state of charge whenever possible, which is represented by having low average energy per session and low percent of time actively charging metrics.

Free with Penalty (Graduated Hourly) Rate

Although this common policy has the least amount of sites, they are bigger sites and represent 12% of all transactions analyzed in this part of the analysis. These sites have the lowest average energy dispersed as drivers can use the EVSE for free as long as they move their vehicle before the graduated hourly rate begins. As most of these sites have a penalty rate initiating after three hours, the average duration is less than the three hours. The dwell time is the shortest as drivers must be conscious of their time if they do not want to pay anything for the charging session, which explains the high percent of time actively charging. This policy encourages a large amount of users to utilize the EVSE as the unique users per site, average weekly attach rate, and average weekly sessions are the highest of all policies.

Hourly Rate

Policies that charge based on time occupying the charging station are the most straight forward approach to pricing that includes a parking cost. The average session duration is 3 hours and 20 minutes and dwell time of 45 minutes, corresponding to 76.4% of the session duration time actively charging. The average energy dispersed per session is high at 9.63 kWh as users are not paying for the energy drawn but only for time occupied.

The average price per session is only $2.48 as the average charge hourly parking cost is $0.92 (and only ranges from between $0.25 to $1.50). Although these policies do not charge for energy, the average effective price paid per kWh is $0.30 which is on the cheaper end of the common paid policies. Similarly, the price for a typical commute is second cheapest as only about an hour of charge is needed to replenish the typical 3.2 kWh used with no additional cost per unit of energy.

Hourly with Penalty (Graduated Hourly) Rate

Introducing an increased hourly rate after a few hours increases the efficiency of transactions, by limiting long post-charge dwell times. The average session duration drops beneath 3 hours, decreases the dwell time to under 30 minutes, and increases the average percentage of time actively charging to the very high rate of 83%.

This policy has the highest associated prices with an average session fee of over $4, but encourages the most efficient use of charging stations. Sites that enact this policy choose to charge users a greater amount per hour than those under just the Hourly pricing policy (without graduated rates). The average initial hourly rate is higher and more variable than the previous category at $1.41 and ranging from $0.55 to $3.60; the average graduated penalty rate increases the price per hour to an average of $5.00 and ranges from $1.50 to $20 with most policies increasing to between $3 and $5. These parking costs are included from the beginning of the transaction and then increase over time by means of the graduated hourly rate for users who choose to utilize the parking space longer than needed. Therefore, there is a monetary penalty for this behavior throughout the entire transaction as there is a marginal cost for every minute parked at the station regardless of whether the vehicle is drawing power. This policy has the highest price for the average typical commute as it includes the highest average parking costs from the session initiation and charges a long-term occupancy penalty.

Straight kWh

Workplace pricing policies that are driven by only charging a straight fee per amount of energy dispensed have some of the lowest utilization metrics of any of the common policies, including free sites. This pricing policy has no connection to occupying the parking space and only charges per kWh delivered. Session durations are by far the longest at over 4 hours but are only actively charging for 58.5% of the time. Similar to free workplace charging, there is no disincentive to staying in the parking space longer than required to receive a full charge. Knowing that it is cheap to top off one's battery and stay parked, drivers are more likely to begin a session to take advantage of the priority parking space for an extended period of time. As a result, this policy has the longest post-charge dwell time (1 hour and 47 minutes) at approximately a half hour longer than free pricing policies.

The average price per session of this policy is the lowest of all the common policies that enact a charge beginning when the session commences at $2.20. These sites charge an average of $0.26 per kWh dispensed, but the average effective price paid per kWh is $0.02 more due to a couple of sites having a $1 minimum transaction price.

kWh with Penalty (Graduated Hourly) Rate

Introducing a penalty rate to the straight kWh pricing policy greatly increases the usage efficiency of the charging stations and consistently ranks in the middle of the common pricing policies for all metrics analyzed. Session durations are reduced by 45 minutes, dwell times are over cut in half, and percent of time actively charging increases to 75% with the introduction of a penalty rate to include a cost tied to parking. The average active charging time is still under 3 hours, but the presence of knowing they cannot leave their car parked for an extended period of time results in much more efficient usage.

The average price per session is high at $3.52 due to a combined occupancy and energy rate included within this policy. These sites charge an average of $0.29 per kWh dispensed with an average effective price paid per kWh of $0.41.

Graduated Hourly Pricing and Bunching Effect

A major reason for site hosts choosing to include a graduated hourly (or penalty) rate as part of a pricing policy is to encourage turnover of vehicles throughout the day and allow the maximum number of tenants or employees to utilize the charging stations. Graduated rates typically kick in after three or four hours, but have been observed to be as quick as two hours to as long as five hours. Most PEVs using level 2 charging only require three to four hours to become fully charged from a very low state of charge and therefore utilizing the parking space longer than three hours is usually unnecessary for charging purposes. To prove the benefits of implementing a graduated hourly rate, the analysis within this subsection looks at those pricing policies with graduated rates and the bunching effects of charging durations and percentage of time actively charging relative to the threshold hour.

Table 10 shows the frequency distribution for the magnitude of the graduated hourly rate at the 105 sites with this policy option and **Figure 8** shows the overall distribution of session durations with graduated pricing relative to the penalty threshold time of each specific site's policy. As shown in the figure, the highest frequency of transactions terminate immediately before the graduated rate begins with a very steep decline immediately following this threshold. This demonstrates that most drivers are conscious of when the graduated rate goes into effect and choose to end their charging session to avoid the increased fee and make the parking space available for another driver. **Figure 9** through **Figure 11** graphically reveal the effect of the magnitude of the graduated rate (under $4, between $4 and $5, and over $5, respectively) on bunching and immediate decline following the increased hourly rate. As the monetary penalty increases, bunching effects increase immediately before the graduated rate begins, and the rate of which sessions are terminated shortly after this threshold time rapidly declines.

Table 10: Frequency Distribution of Graduated Rates

Graduated Rate	$1	$2	$3	$4	$5	$6	$7-$9	$10	$20
Frequency	1	11	34	14	37	1	0	5	2

Figure 8: Session Duration Relative to Penalty Threshold

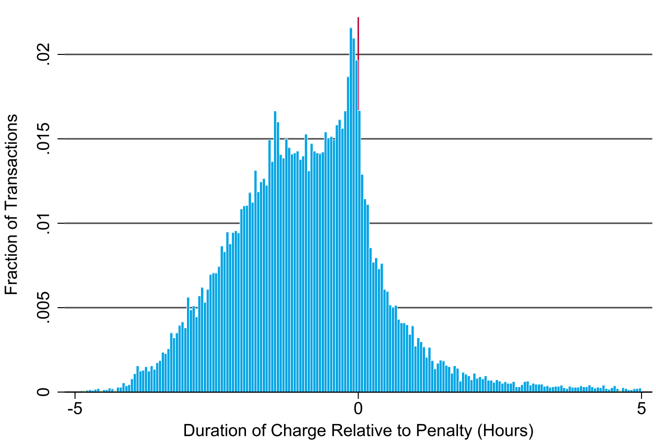


Figure 9: Session Duration Relative to Penalty Threshold (under $4)

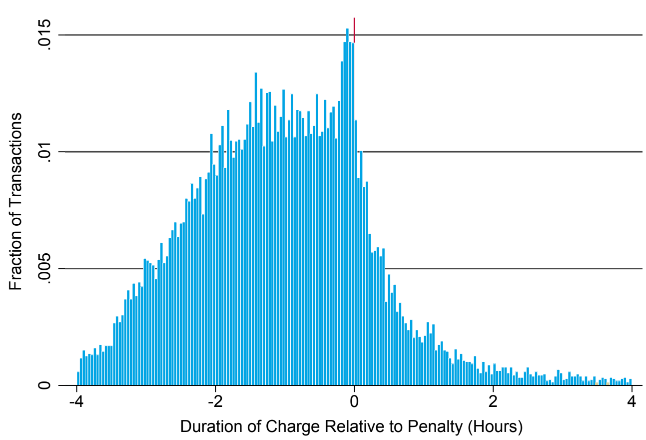


Figure 10: Session Duration Relative to Penalty Threshold (between $4 and $5)

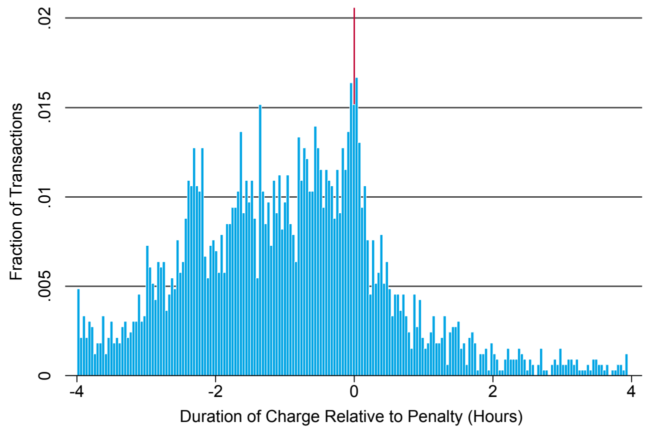
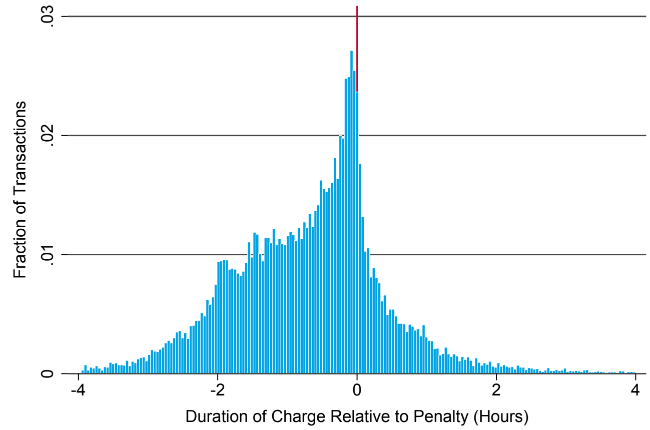


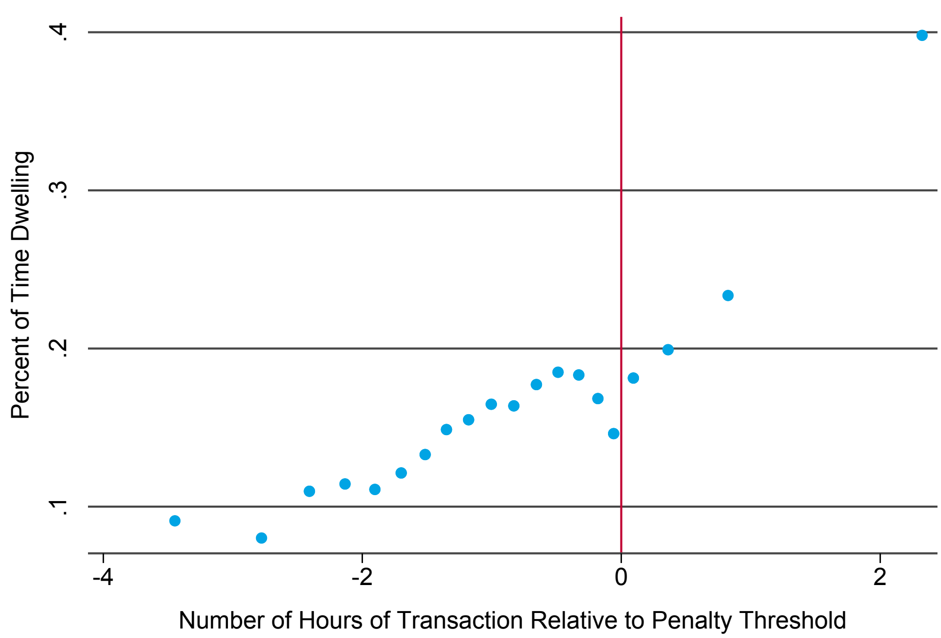
Figure 11: Session Duration Relative to Penalty Threshold (over $5)



The sharpest peak of sessions terminating immediately before (and after) the graduated rate begins are those sites with the largest graduated rate of greater than $5 per hour (as shown in **Figure 11**). A very immediately and severe drop off occurs after the penalty threshold. Conversely, the bunching effect for graduated rates of less than $4 per hour have a minor peak before the occupancy penalty threshold with a much more gradual ascension, but still show a drop off following when the graduated hourly rate kicks in (as shown in **Figure 9**). The most common range of a graduated rate (between $4 and $5) shows more sporadic usage before the penalty rate, but still has a high percentage of transactions terminating immediately before the penalty threshold and decline after this point (as shown in **Figure 10**).

Further supporting this behavioral reaction to the presence of a graduated hourly rate is that amount of post-charge dwell time around the time of the increased hourly rate beginning. Relative to when the graduated rate begins, **Figure 12** shows the average (mean) percentage of the total session duration that is dwell time compared to the total session duration. The percentage of dwell time steadily increases until about 30 minutes before when the graduated rate begins and then makes a rapid decline until the threshold hour. After the threshold hour, there is a rapid increase in the percentage of dwell time to total session duration as most vehicles complete their charge.

Figure 12: Percent Dwell Time Relative to Penalty Threshold



This drop off confirms that users are terminating their sessions right before the graduated hourly rate commences, and that drivers prefer to not pay an increased parking occupancy rate over getting a full 100% charge. When a driver chooses to unplug his/her vehicles right before the penalty rate, it is likely that the vehicle was still charging as the increasing dwell time trend compared to duration length in **Figure 12** continues to increase through the threshold hour (with the exception of 30 minutes before the beginning of the graduated hourly rate). Therefore, the drop off in average percentage of dwell time right before threshold hour is a result of sessions being terminated while still (or just completed) charging (i.e., negligible dwell time).

PEV Drivers Response to Price Changes

Price per kWh Compared to Transaction Cost

This subsection demonstrates that the price charged per unit of energy is not a good indicator of how much users spend at workplace charging stations. **Figure 13** through **Figure 15** display scatterplots comparing the price charged per kWh and the average price (across all 159 worksites) for a 5-, 10-, and 15-mile commute, respectively. As shown in the figures, the average price is greatly variable implying that transaction price is dominated by other pricing policy elements (i.e., hourly and/or graduated hourly rates) instead of just energy price. This supports the concept that EV charging is conceptually different than traditional gasoline refueling because for each given price per kWh, the session fee charged varies and is not solely dependent on the price per unit of energy.

Figure 13: Average Transaction Price Compared to Price per kWh (5-mile commute)

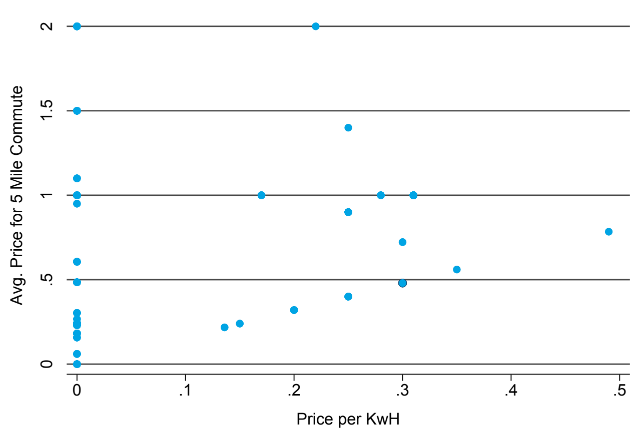


Figure 14: Average Transaction Price Compared to Price per kWh (10-mile commute)

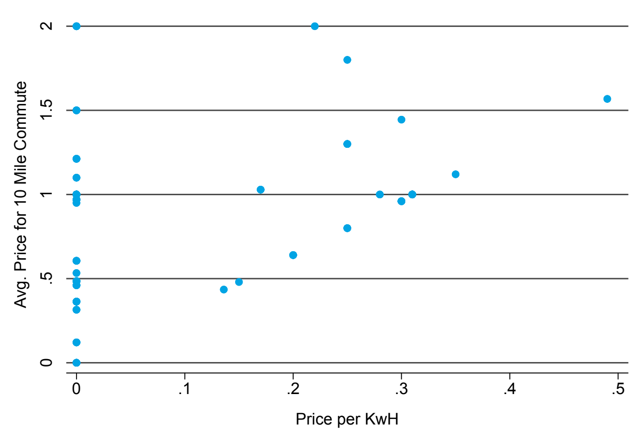
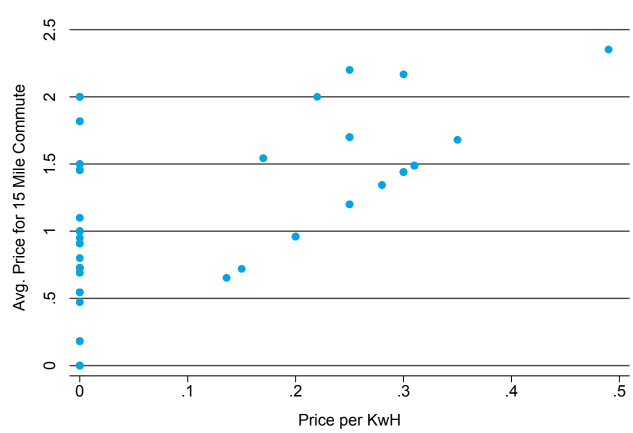


Figure 15: Average Transaction Price Compared to Price per kWh (15-mile commute)



Drivers Response to Price Changes

To analyze how responsive PEV drivers are to price, the typical commute (as described above in **Data Collection, Assumptions (p14)**) is used to standardize a typical charge and compare like cases across the different policies and work sites. The following graphs display the effects that the average typical commute price variable has on total sessions, total worksite duration hours, total worksite charging hours, weekly transactions per available port, and weekly attach rate. Cumulatively, these graphs show workplace EVSE usage responds negatively to an increase in transaction price.

Figure 16 shows that as the pricing policies increase the typical charging session price, the number of sessions per work site decrease. This demonstrates that aggregate usage negatively is affect by an increase in price.

Figure 16: Total Sessions per Site Response to Price Change

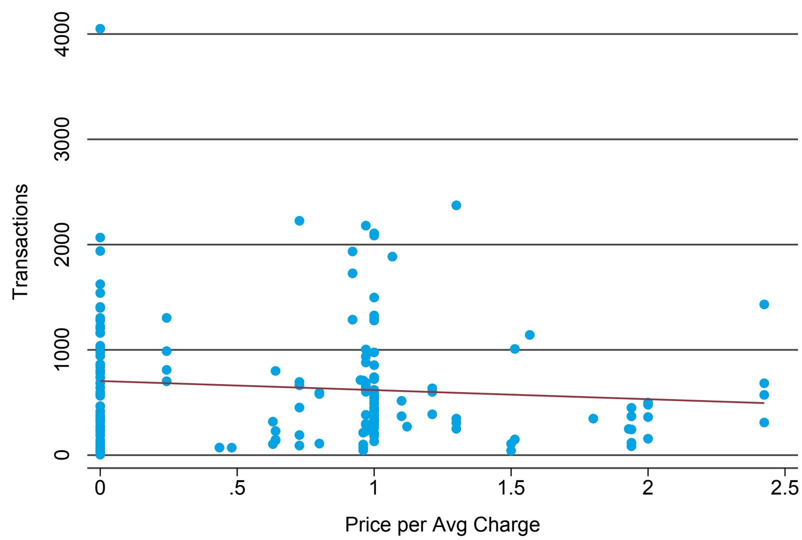


Figure 17 and **Figure 18** display the effect that the price for the typical charging under each pricing policy has on the number of total session hours and total charging hours. Both variables are negatively associated with a change in price for the typical commute demonstrating again that usage decreases as price increases.

Figure 17: Total Session Hours per Site Response to Price Change

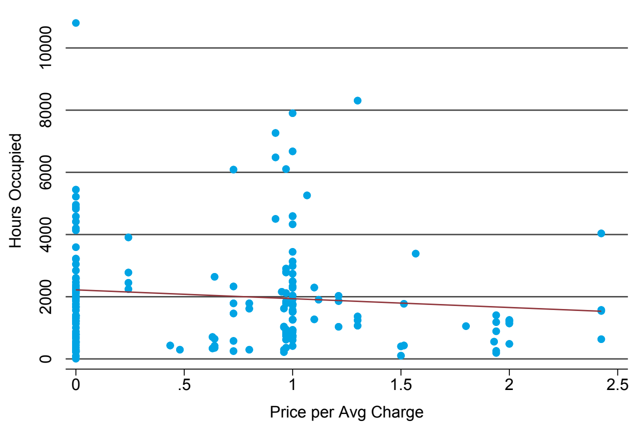
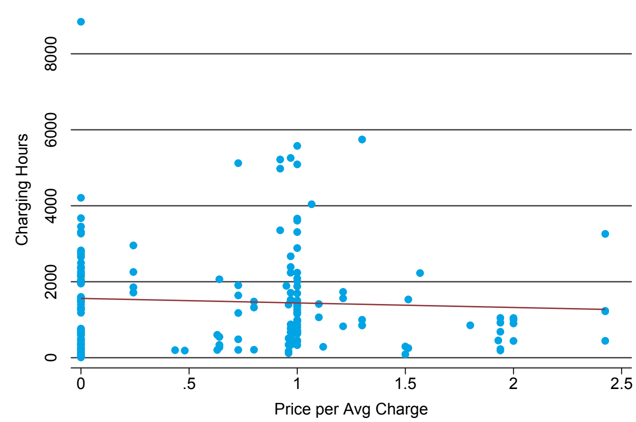


Figure 18: Total Charging Hours per Site Response to Price Change



As shown in the figures above, the typical commute price is negatively associated with all the main outcome variables, suggesting that drivers are responsive to price. These were found to be robust when considering the zip-code fixed effects of only comparing worksites within the same zip code to one another. The specific quantitative effects on the regressions lines are discussed in the next subsection.

Regression Analysis of Pricing Effects

Table 11 shows the individual regression analyses of increasing the transaction price by $1 on each variable.

Table 11: Price Change Regression Coefficient

Variable	Regression Coefficients	
	Without Zip Code Fixed Effects	With Zip Code Fixed Effects
Average session duration (minutes)	**-29.6*** **	-18.2
Average session active charging time (minutes)	**+3.7**	+9.66
Average session dwell time (minutes)	**-36.7*** **	-28.2**
Percentage of duration actively charging	**+7.7%*** **	+7.8%**
Total sessions per site per week	**-3.33**	-1.47
Sessions per week per available port	**-1.86** **	-1.56
Total session hours per site per week	**-10.9**	-6.17
Total active charging hours per site per week	**-4.59**	-0.19
Total dwell hours per site per week	**-6.42*** **	-6.00
Average transaction fee	**+2.32*** **	+2.46***
Average energy (kWh) dispersed per session	**+0.719** **	+1.178**
Effective fee paid per kWh	**+0.257*** **	+0.259***
Total unique users	**+14.59**	+62.69
Attach rate (unique users : available ports)	**+0.02**	+0.59
Notes: *** Statistically significant at the 99% level ** Statistically significant at the 95% level		

Price effects on the average session metrics (duration, active time charging, dwell time, and percentage of duration actively charging) demonstrate that increasing the price at charging stations results in more efficient use of the infrastructure. Increasing the cost to use workplace EVSEs has the greatest effect on decreasing the post-charge dwell time. Overall session durations also decrease by the presence of a greater fee charged, but active charging time increases. This combination results in PEVs actively charging for approximately 8.6% more of the session duration, which is statically significant at the 99% level. These effects are consistent with the overall effects of paid vs free charging stations previously discussed in **Typical Workplace Usage by Time of Day (p18)**.

Price effects on the weekly aggregate usage metrics (total sessions, total session hours, and total active charging hours) are all negatively associated demonstrating the PEV drivers are responsive to price effects. For every $1 increase in average transaction price, approximately 3 less charging sessions per week are conducted at each worksite. Resulting from less weekly charging sessions is a corresponding decrease in the total number of session hours and hours actively charging per worksite. As the decrease is much greater for total session hours than active charging hours, the largest effect is the decrease in dwell hours.

Price effects on energy metrics show a positive relationship. This can be expected as a higher price usually means more energy dispensed to the vehicle. For every $1 increase, the effective average price per kWh is increased by between $0.27 and $0.32 which include a combination of both energy and parking costs.

Regression Analyses of Individual Pricing Policy Components

The following subsections discuss the impact of individual pricing policy elements on the major usage metrics. The components analyzed include whether or not the following components are in the pricing policy: parking charge (i.e., hourly and/or graduated hourly rate), graduated hourly rate only, charging for energy dispersed, and a minimum fee.

Parking Charge Policy Effects

For this regression analysis, the effects of having any inclusion of a parking charge has on the usage metrics are analyzed. A parking charge consists of either an initial hourly rate and/or a graduated rate included in the pricing policy. This aspect of a policy is important as a parking charge incorporates the extended period of time occupying the space instead of just charging on a per unit of energy basis (as is done in traditionally gasoline refueling).

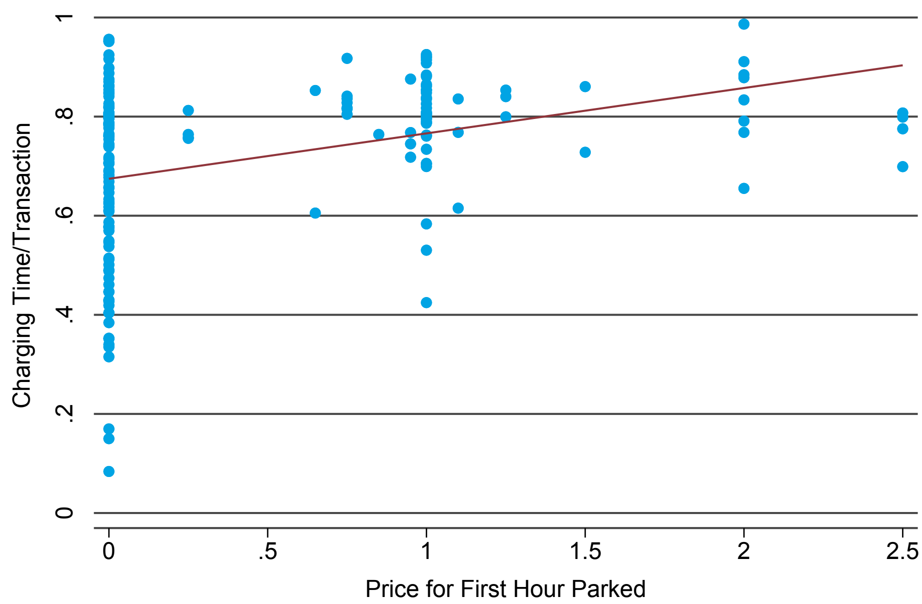
Table 12: Parking Charge Policy Regression Coefficients

Variable	Regression Coefficients	
	Without Zip Code Fixed Effects	With Zip Code Fixed Effects
Average session duration (minutes)	**-44.6*** **	-8.0
Average session active charging time (minutes)	**+5.0**	+4.9
Average session dwell time (minutes)	**-54.1*** **	-13.5
Percentage of duration actively charging	**+10.5%*** **	+2.8%
Total sessions per site per week	**+5.7**	+12.2
Sessions per week per available port	**-0.03**	-1.10
Total session hours per site per week	**+16.7**	+42.2
Total active charging hours per site per week	**+20.0**	+36.1
Total dwell hours per site per week	**-3.5**	+6.1
Average transaction fee	**+1.51*** **	+1.60**
Average energy (kWh) dispersed per session	**+0.86** **	+0.43
Effective fee paid per kWh	**+0.21*** **	+0.23***
Total unique users	**+172.5*** **	+291.8**
Attach rate (unique users : available ports)	**+1.65** **	+1.22
Notes: *** Statistically significant at the 99% level ** Statistically significant at the 95% level		

Including a parking charge has a statistically significant effect on decreasing both the duration and dwell time, and as a result, increasing the percentage of time actively charging by 10.5% on average. Overall usage is also increased from having a parking charge included in the pricing policy as there is an additional 5.7 transactions per week at each site (or more than 1 extra charge per day). A parking charge also has a large effect on the number of unique users utilizing the worksite implying that a parking charge does increase overall usage and helps encourage other employees to use these stations.

Figure 19 display the positive relationship between the parking cost of the first hour (as measured by the initial hourly rate with or without a graduated rate) and the percentage of the session actively drawing power. This further shows that incorporating a parking cost increases the efficiency of the charging sessions, and as the parking costs increases, the charging stations are used in a more efficient manner.

Figure 19: Percent Time Charging as Function of Parking Price



Graduated Hourly Rate Policy Effects

To isolate the effects on graduated hourly pricing policies on the usage metrics, a regression analysis was run to determine the effect of having a graduated rate included in the pricing policy on the same usage metrics. The regression coefficients are shown in **Table 13**.

Table 13: Graduated Hourly Rate Policy Regression Coefficients

Variable	Regression Coefficients	
	Without Zip Code Fixed Effects	With Zip Code Fixed Effects
Average session duration (minutes)	**-71.6*** **	-53.82**
Average session active charging time (minutes)	**-1.3**	-2.5
Average session dwell time (minutes)	**-75.0*** **	-52.0***
Percentage of duration actively charging	**+17.4%*** **	+14.7%***
Total sessions per site per week	**-5.9**	-1.2
Sessions per week per available port	**-2.60** **	-1.78
Total session hours per site per week	**-27.5** **	-15.3
Total active charging hours per site per week	**-10.6**	-0.9
Total dwell hours per site per week	**-17.0*** **	-14.4**
Average transaction fee	**+3.34*** **	+3.13***
Average energy (kWh) dispersed per session	**+1.23*** **	+1.13
Effective fee paid per kWh	**+0.37*** **	+0.35***
Total unique users	**+17.5**	+120.0
Attach rate (unique users : available ports)	**+0.19**	+1.15

Notes:
*** Statistically significant at the 99% level
** Statistically significant at the 95% level

The presence of a graduated hourly rate has a large and statistically significant effect on decreasing the average session duration and active dwell time per transaction at 72 and 75 minutes, respectively. There is only a very minimal effect on the active charging time. This shows the strong influence that a monetary penalty has on limiting the overuse of the EVSE longer than needed to charge. Furthermore, policies with this occupancy penalty rate increase the percentage of the session actively charging by over 17% which can partially be explained by the bunching effect when drivers will terminate the session right before the penalty rate begins but have not received a full charge, as described above in the bunching effect subsection.

There is a small but negative effect that graduated hourly rates have on weekly usage as the presence of this occupancy penalty reduces the amount of weekly sessions by an average of 5.9. On a per port basis, the number of weekly sessions decrease by 2.6. The average hours per week the charging stations are used also decreases because of a graduated hourly rate, driven by the large decrease in average session duration.

The average transaction fee increases by $3.34 with the presence of a graduated hourly rate, which is greater than the only $1.51 increase for any type of parking charge. The presence of this rate therefore has the greatest effect on increasing revenue generated by the site host.

Charge for Energy Policy Effects
Table 14 summarizes the effect that having a charge for energy dispensed included in a pricing policy has on overall usage. As described above, the average fee dispensed is $0.265 per kWh across all sites that include an energy pricing component.

Table 14: Energy Charge Policy Regression Coefficients

Variable	Regression Coefficients	
	Without Zip Code Fixed Effects	With Zip Code Fixed Effects
Average session duration (minutes)	**-12.1**	+47.0
Average session active charging time (minutes)	**+1.8**	+18.0
Average session dwell time (minutes)	**-18.0**	+28.9
Percentage of duration actively charging	**+2.2%**	-7.8%
Total sessions per site per week	**-5.9**	-2.8
Sessions per week per available port	**-2.6****	-3.0
Total session hours per site per week	**-17.6**	+2.0
Total active charging hours per site per week	**-11.0**	-2.8
Total dwell hours per site per week	**-6.7**	+4.8
Average transaction fee	**+2.16*****	+2.00***
Average energy (kWh) dispersed per session	**+0.06**	+0.06
Effective fee paid per kWh	**+0.28*****	+0.31***
Total unique users	**+18.3**	+51.5
Attach rate (unique users : available ports)	**+0.11**	+0.27
Notes: *** Statistically significant at the 99% level ** Statistically significant at the 95% level		

Including an energy component in specific pricing policies has a less significant but negative effect on overall usage. Session durations only decrease by an average of 12 minutes and percentage of time actively charging only increases by 2.2%, displaying the minimal effect on efficiency. Aggregate usage does decrease by 5.9 weekly sessions per site. As pricing per energy is commonly included with other types of policies, the presence of an energy charge may not be driving this usage but instead the aggregate usage is led by other policy elements.

The average energy dispensed per session stays relative even with and without the presence of an energy pricing component and only increases the average kWh by 0.06 kWh. This policy element does encourage some additional unique users, but not nearly as much as the parking charge.

Minimum Fee Policy Effects

For this regression analysis, the effects on the usage metrics of having a minimum session fee included in the pricing policy are analyzed.

Table 15: Minimum Fee Policy Regression Coefficients

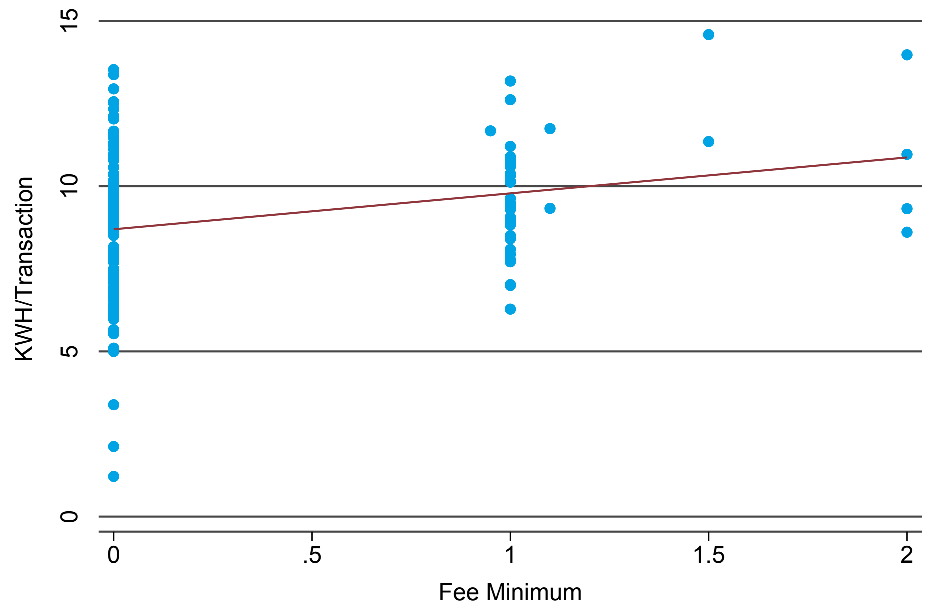
Variable	Regression Coefficients	
	Without Zip Code Fixed Effects	With Zip Code Fixed Effects
Average session duration (minutes)	**+1.5**	-16.0
Average session active charging time (minutes)	**+8.4***	+10.2
Average session dwell time (minutes)	**+7.1**	-26.3
Percentage of duration actively charging	**+1.3%**	+6.7%
Total sessions per site per week	**-2.2**	-8.6
Sessions per week per available port	**-0.7**	-0.5
Total session hours per site per week	**-3.0**	-26.1
Total active charging hours per site per week	**-3.1**	-18.3
Total dwell hours per site per week	**+0.02**	-7.87
Average transaction fee	**+1.13*****	+1.00
Average energy (kWh) dispersed per session	**+0.82****	+1.19
Effective fee paid per kWh	**+0.11*****	+0.07
Total unique users	**-45.7**	-124.4
Attach rate (unique users : available ports)	**-0.43**	-0.29

Notes:
*** Statistically significant at the 99% level
** Statistically significant at the 95% level
* Statistically significant at the 90% level

The presence of a minimum fee in the pricing policy has a near negligible effect on a per-session usage, but does increase the average time actively charging per session by 8.4 minutes. Aggregate usage show a similar minimal effect by only reducing the number of weekly sessions per site by 2.2. There is an increase in the average transaction fee and amount of energy dispersed per session as a minimum fee disincentives minimal usage transactions because users will be paying a minimum fee of approximately $1, even if they only use the station for a very short period of time and draw negligible energy.

Figure 20 shows that as the minimum fee of a site gets larger, the average energy dispersed per session increases. This implies that sites with a pricing policy including a minimum fee, users more often will plug in to receive a substantial charge rather than plugging to just top off a charge. The minimum fee discourages drivers from plugging in for a quick charge to top off their battery as they will be paying a high rate if drawing minimal energy or staying for a short duration that monetarily equates to less than the minimum charge.

Figure 20: Energy Dispensed per Session as a Function of Minimum Fee



Comparing Pricing Policies Relative to Free Charging

This subsection compares the six different common pricing policies. **Table 16** displays the effect that each common policy has on the same set of usage metrics used above relative to the sites with a Free all the Time policy.

For the usage metrics on a per-session basis, all common policies except Straight kWh result in shorter average session durations by at least 52 minutes. The same pattern is shown for the decrease in the average dwell time per session as the Free then Penalty and Hourly then Penalty at over an hour and half shorter dwell time on average compared to free charging stations. The highest increase in efficiency is the Hourly then Penalty by increasing the percentage of time actively charging by 21.4%, which is statistically significant at the 99% level.

Work site aggregate usage varies from policy to policy. Free then Penalty results in the biggest increase in aggregate usage compared to a Free all the Time policy. As the average session duration also shows the largest decrease, it can be inferred that this increase in aggregate usage is from a larger quantity of short transactions to top-off one's battery when they know they will not be occupying the space long enough to activate the graduated hourly rate and therefore the session will be free. This is also supported by a high change in the percent of time actively charging. Conversely, the largest decrease in weekly sessions per site is with the Straight kWh policy. There is no penalty for extended occupancy under this policy and therefore results in an increase in average dwell time and a decrease in percentage of the session actively charging.

All the priced policy clearly show an increase in the average session fee. The greatest difference is for the Hourly then Penalty policy at over $4 per session, demonstrating this policy is the largest revenue generating policy. In conjunction with the largest increase in overall efficiency, the Hourly then Penalty policy has the greater overall behavioral policy reaction. Charging an hourly rate does increase the amount of energy dispersed per session greater than those policies charging based on kWh (with and without graduated hourly rates).

Table 16: Comparing Different Pricing Policy Effects Relative to Free Pricing

Metric	Free then Penalty		Hourly		Hourly then Penalty		Straight kWh		kWh then Penalty	
	No ZCFE	ZCFE	No ZCFE	ZCFE	No ZCFE	ZCFE	No ZCFE	ZCFE	No ZCFE	ZCFE
Average session duration (minutes)	-99.3***	-49.9*	-56.7***	-35.4*	-85.0***	-72.1***	+25.9	+116.4*	-52.6***	-10.0
Average session active charging time (minutes)	-10.86*	+1.0	+11.3*	+12.8	+2.3	+0.2	+7.6	+47.6***	+14.2**	+19.7
Average session dwell time (minutes)	-94.9***	-51.3**	-74.2***	-49.1**	-93.8***	-73.1***	+12.8	+68.9	-73.3***	-30.5
Percentage of duration actively charging	+19.6%***	+12.1%*	+14.7%***	+11.8%**	+21.4%***	+20.3%***	-3.2%	-12.7%	+13.6%***	+34.0%***
Total sessions per site per week	+31.6**	+37.2	+8.7*	+9.3	-2.5	-1.8	-11.8***	+22.9	+4.6	-1.8
Transactions per week per available port	+4.0**	-1.3	-0.3	-1.5	-2.6**	-1.9	-5.0***	-5.1	-1.4	-1.3
Total session hours per site per week	+62.3	+95.5	+24.6*	+29.0	-19.5*	-20.9	-32.5**	+79.9	+13.0	-6.0
Total active charging hours per site per week	+64.2**	+82.9	28.3**	29.5	-2.1	-3.0	-24.4***	+59.8	+17.8	-3.9
Total dwell hours per site per week	-2.2	+12.6	-3.8	-0.5	-17.5***	-17.9**	-8.3	+20.1	-5.0	-2.2
Average session fee	+0.70***	+0.94***	+2.48***	+2.88***	+4.03***	+3.84***	+2.20***	+3.66***	+3.52***	+2.79***
Average energy (kWh) dispersed per session	-0.56	-0.56	+1.4***	+1.2*	+1.5***	+1.2	+0.02	+1.6*	+1.1**	-0.17
Effective fee per kWh	+0.08***	+0.11***	+0.30***	+0.35***	+0.44***	+0.42***	+0.28***	+0.43***	+0.41***	+0.38***
Total unique users	+373***	+502**	+204***	+255**	+58	+111	-61	+323*	+136**	+48

Notes:
ZCFE: Zip Code Fixed Effects
*** Statistically significant at the 99% level
** Statistically significant at the 95% level
* Statistically significant at the 90% level

Findings

Understanding the differences between pricing components and the behavioral effects of each component can inform policy selection to help site hosts choose a policy that is congruent with their personal site objectives.

It is important to understand that the PEV charging network is a paradigm shift from the traditional gasoline refueling stations drivers are accustomed to, and should not be priced the same way. Gas stations are based on a throughput model compared to PEV charging stations which operate under a parking model; therefore, the additional time and physical space occupied when charging must be factored into the charging price. This is accounted for in the difference between the observed average effective price per kWh charged at 31 cents and the cost to supply that energy. The difference between these prices represent these additional time and space resources consumed that limit access to other drivers, not entirely profit for site hosts; these associated costs are related to providing and maintaining the EVSEs at an acceptable level of service with reliable accessibility to users.

Including a graduated hourly rate in the pricing policy facilitates turnover of vehicles by charging for excessive usage. There was a significant observed bunching effect of charging sessions that terminated immediately before the threshold hour demonstrating that there is a clear preference to save money by avoiding the increased hourly rate over receiving a 100% charge. The bunching effect becomes greater as the magnitude of the penalty rate increases. The regression analysis on the effect of including a graduated hourly rate shows the largest decrease in average session duration and dwell time at 71.6 and 75.0 minutes, respectively. The graduated hourly rate has a negligible effect on active charging time and therefore implies that graduated rates primary impact is to curb excessive usage after a PEV is done charging.

PEV drivers' usage patterns are responsive to changes in price, especially as it relates to excessive usage. A $1 increase in transaction price reduces average session duration by approximately a half hour, but has the largest effect on decreasing average post-charge dwell time. Overall, the regression analysis shows that a $1 price increase raises the efficiency of transactions by 7.7%, as measured by percentage of duration actively charging. Price increases also has a negative effect on the amount of aggregate charging sessions at a site, and as a result, decreases total hours spent using the charging stations.

The most inefficient paid pricing policy is only charging on a straight kWh dispensed, with no additional components. There is no monetary penalty for remaining in the parking space longer than is needed to charge and therefore limits the number of PEVs that can access the charging station each day. This encourages drivers to remain parked at the EVSE and priority parking space all day, even if a charge is not needed.

Summary of Findings:

- The EV fueling network is new and different than the traditional refueling stations. Pricing policies should be based on a parking model to incorporate all resources consumed (i.e., time, physical space, and energy)
- Straight price per kWh results in most inefficient usage of the paid policies. There are no associated parking costs so drivers will plug in and leave their vehicle because no monetary penalty is enforced for excessively using the charging station. Also, solely evaluating the price charged per kWh is not a good indicator of how much people spend at workplace EVSEs.
- Bunching effects occur with policies including graduated hourly rates near the threshold hour and should be used as a motivator to curb excessive usage. When a graduated rate is in effect, users prefer to terminate their charging session right before the increased hourly rate begins. There is a clear preference to save money by avoiding the increased hourly rate over receiving 100% charge.
- Drivers are elastic in their response to price as an increase in transaction cost will decrease overall

usage at work; this could be a shift to charging at home or other locations.

- Hourly then Penalty policy encourages the most efficient usage of the EVSE and generates the most revenue for the site host.
- Regardless of the base pricing policy, minimum fees can be used to disincentive very inefficient transactions by discouraging users to occupy the space if they have a near-full state of charge.

Usage Trends Before and After Additional EVSE Investments

After choosing to invest in workplace charging infrastructure and selecting a pricing policy that satisfies the goals of the site host, the other major decision is determining if and when to invest in additional EVSEs to meet existing and expected future demand. This section concentrates on the 27 worksites within the data set that have made subsequent investments in additional charging equipment for their employees and/or tenants. The analysis herein can inform hosts on the typical usage patterns following investments relative to existing usage. Based on their known demand and specific site objectives, the host can decide whether an investment would be beneficial to them and their users.

If site hosts do not proactively monitor the demand at their charging stations, a physical constraint on resources can occur that will dissuade potential PEV adopters because they perceive limited charging availability at work. This can hinder adoption rates if these potential users forgo purchasing a PEV for this reason. Furthermore, as demand increases at worksites, the supply of EVSEs should grow proportionally to maintain the levels of productivity and access PEV drivers expect.

Methodology

In order to analyze the effects of the 27 worksites identified to have invested in additional charging infrastructure over the five-year period in the data set, a series of indicator variables were plotted before and after the date of investment to identify trends and evaluate the effectiveness of additional charging stations. The indicators were computed on both a weekly and monthly basis at each of these individual worksite to analyze both the immediate and longer term effects. The graphs included within this section then aggregated these variables relative to the number of weeks or months before and after the date of re-investment at each site. The weekly trends shown concentrate on the 12 weeks before and after the investment date, whereas the monthly trends shown concentrate on the year before and year after the investment date.

The key indicator variables used in this analysis include the following and calculated on a per week, per month, and average per session basis (where applicable):

- Number transactions
- Number of unique users
- Energy dispersed (in kWh)
- Hours of time actively charging
- Hours of post-charge dwell time
- Percentage of time actively charging out of total session duration

Additionally, regression models including twelve indicators based on those listed above as well as an average transactions per user were analyzed. Each regression included a variety of variables calculated on a weekly (or monthly) basis and average per session basis. The weekly models analyzed were conducted at both the individual worksite level and at the zip code level looking at (1) the effect of adding one more EVSE on average weekly outcomes for the entire period post-installation, and (2) the trends right around the activation date of new the EVSEs. The monthly model evaluated these same effects but only at the worksite level. **Table 17** through **Table 19** at the end of this section display the results of the regression analyses.

Analysis

Aggregate Sessions

A primary reason worksites chooses to invest in additional EVSEs is due to existing capacity constraints on the existing infrastructure. An indicator of a needed and effective investment is an immediate increase in the number of sessions per week beginning right after the new infrastructure is activated. This signals that there was a latent demand that the new charging stations helped fill. **Figure 21** displays relative change in the number of sessions per week before and after the investment dates. Furthermore, this same pattern is seen when looking at a longer horizon at the monthly scale. As shown in **Figure 22**, there is a large immediate jump in the number of transactions that continues to gradually increase over the following year.

Figure 21: Change in Aggregate Sessions (Weekly)

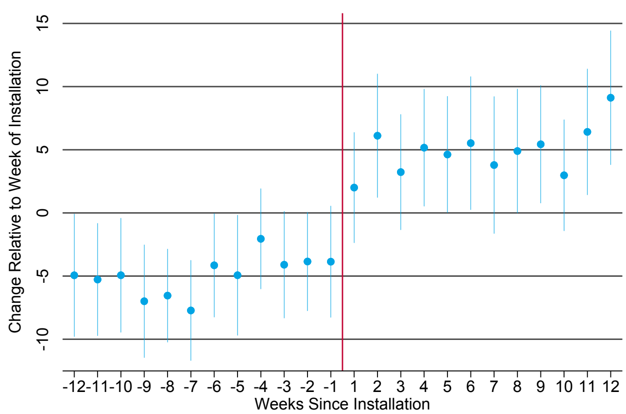
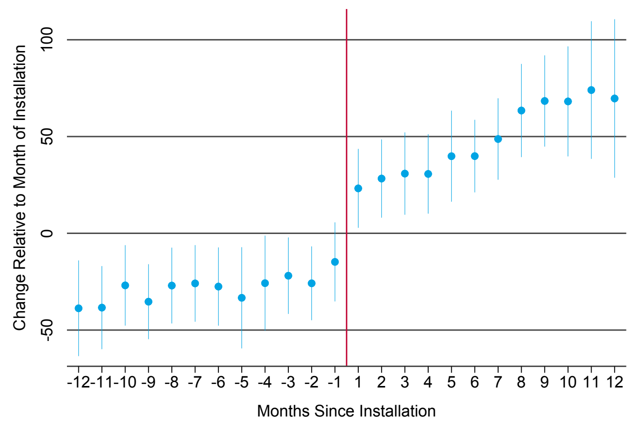


Figure 22: Change in Aggregate Sessions (Monthly)



These graph demonstrates that the introduction of additional worksite charging stations has an effect on immediately increasing the number of sessions conducted at those sites which have re-invested. Assuming capacity constraints were the driving factor for adding EVSEs, this trend can be expected as the supply was increased to meet the high demand. From the regression analysis, adding one EVSE results in an additional 10.2 transactions per week at the worksite level and 13.9 transactions per week at the zip code level; similarly, adding one EVSE results in an additional 44.8 transactions per month at the worksite level.

If the reasoning for additional investment was driven by adding convenience for existing users instead of additional commuters needing charging infrastructure, the number of total transactions would not jump this drastically, especially immediately after installation (as seen in **Figure 21**). This finding is further supported by the increase in the number of unique users per week and month; **Figure 23** and **Figure 24** show that there is a steady increase in the number of unique drivers utilizing the charging infrastructure before and after the investment date. This is encouraging as it demonstrates that workplace charging stations do encourage PEV adoption among employees because a greater number of unique drivers are initiating more charging sessions after the investment date. Further supporting this trend is the two yearlong continual increase shown in the monthly graph implying that the presence of workplace charging helped encourage PEV adoption even before additional investment, and the additional charging stations increased the rate at which more unique employees charged.

Figure 23: Change in Unique Users (Weekly)

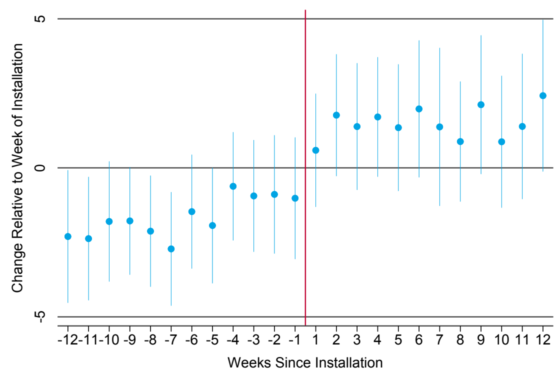
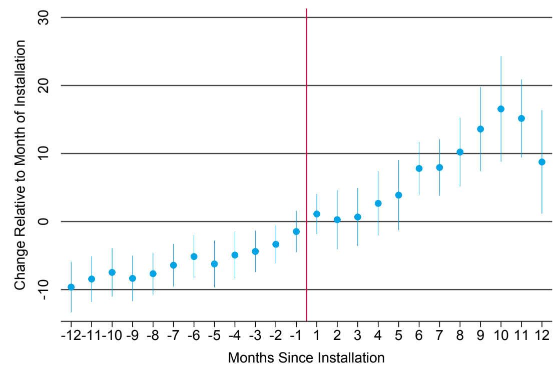


Figure 24: Change in Unique Users (Monthly)



Sessions per Available Port

A more standardized statistic than overall sessions to evaluate capacity constraints is the number of sessions per available EVSE port. Although there is an initial jump in the number of weekly transactions, the aggregate session figures above show that this metric continues to increase for the following year. On the activation date of the new EVSEs, the number of available ports instantaneously jumps by the amount of additional ports added. Even with existing capacity constraints, investments are usually made in excess of the existing demand in anticipation of increasing demand in the future; otherwise, the employer would need to immediately consider installing even more ports on the activation date. Therefore, the number of sessions per available port will initially decrease relative to before the investment, but then increase to at least the same level of utilization over the upcoming months. If the investment is timed in coordination with a pricing policies to better manage the charging resource (e.g., a graduated hourly rate to encourage turnover), then this metric could increase from before the activation date. **Figure 25** illustrates this trend increasing month after month aggregated over the 27 worksites. As shown in the figure, it takes at least 6 months to rebound to pre-installation levels of transactions per available port. Similarly, a time period of six to seven months was consistently needed to reach pre-installation levels on a per port basis for the following metrics: energy dispensed, unique users, and charging hours (see **Figure 26** through **Figure 28**).

Figure 25: Change in Sessions per Port (Monthly)

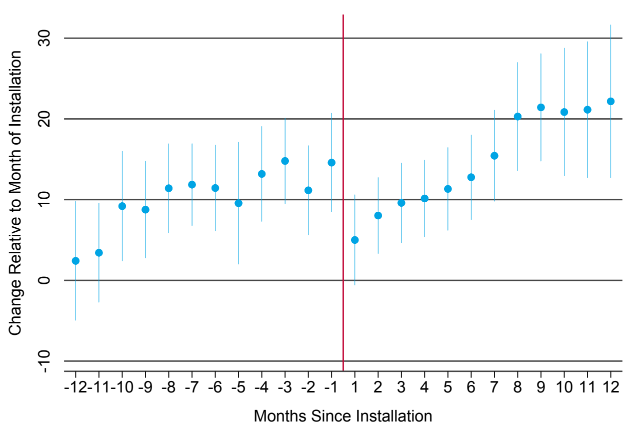


Figure 26: Change in kWh Charged per Port (Monthly)

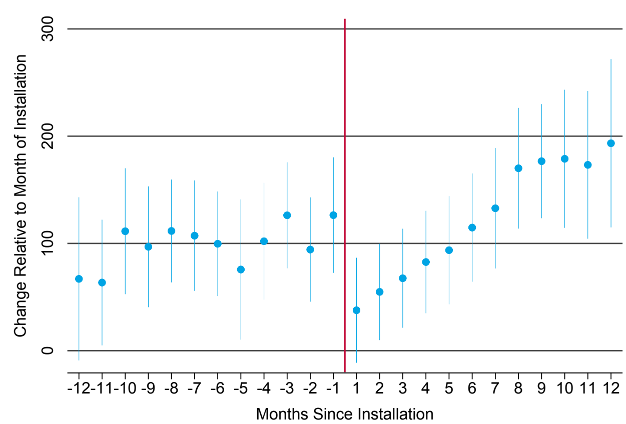


Figure 27: Change in Unique Users per Port (Monthly)

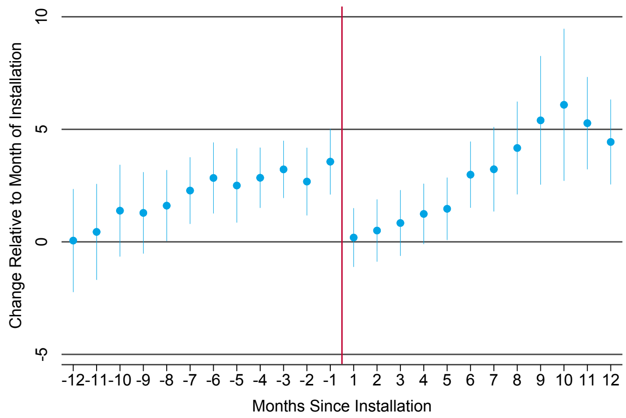
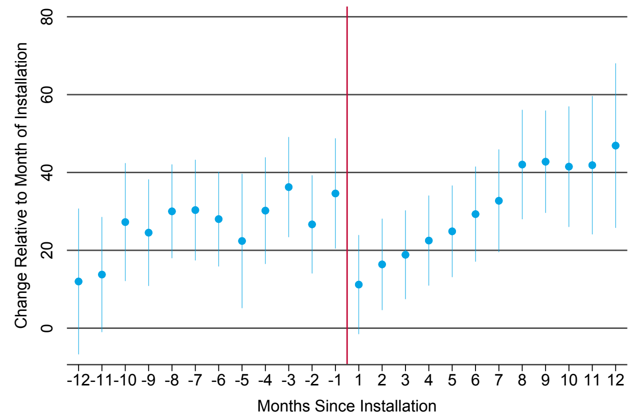


Figure 28: Change in Charging Hours per Port (Monthly)



Timing and Energy

Figure 29 through **Figure 31** below show the weekly effects of total number of charging hours, dwell hours, and total energy dispensed at worksite. All of these usage variables increase instantly following the investment week as they are driven by the overall increase in the total number of transactions following the investment (as shown above in **Figure 21**). More sessions result in more energy usage as more vehicles are being charged throughout the work day at that site.

Figure 29: Change in Total Charging Hours (Weekly)

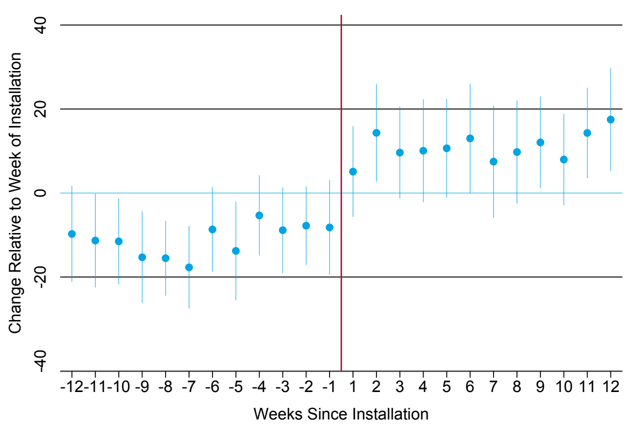


Figure 30: Change in Total Dwell Hours (Weekly)

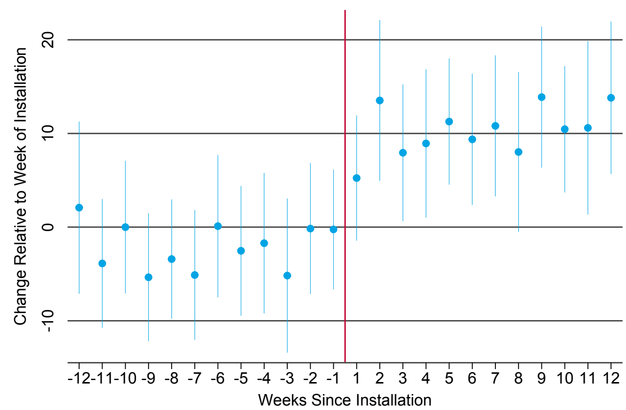
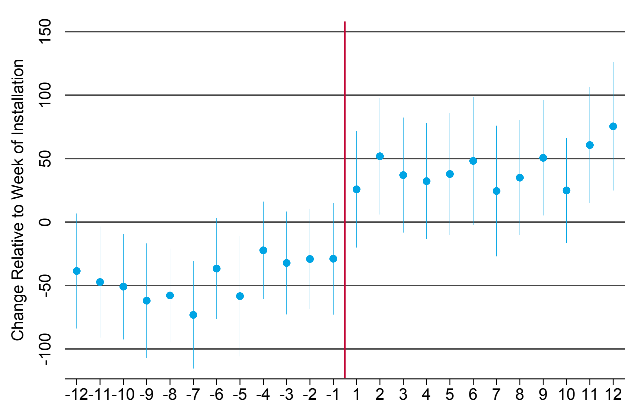


Figure 31: Change in Total Energy Dispersed (Weekly)



There is a clear association between these usage variables increasing following the re-investment week as all values before the investment date have negative relative values and after the investment have positive relative values. The regression model shows that adding an additional worksite charging station results in 25.7 hours of additional charging per week, 8.8 hours of dwell time per week, and 108.1 kWh dispensed per week. As expected, more sessions per week corresponds to increased usage. These variables are on the weekly aggregate level by worksite, but the analysis below further explores these variables on a per session basis to determine how individual's behavior is or is not altered after additional EVSE investments.

Average Usage per Session

As shown above, workplace charging usage increases following an additional EVSE investment, but what is the connection between overall workplace usage and individual behavior? Analyzing individual behavior on a per session basis will inform if drivers are altering how they interact with charging infrastructure when stations are added, or if typical behavior remains consistent but at a greater frequency.

The average time charging and post-charge dwell time per session immediately before and after a site's investment date does not show a significant effect as a result of the investment, as shown in **Figure 32** and **Figure 33**. The average length of time actively charging slightly decreased three weeks after the investment date, but over the following month leveled out to its average at the time of investment and beforehand. Similarly, the average dwell time per session stayed fairly consistent before and after a site's investment with no discernible pattern. The monthly analysis shows similar patterns over a longer period of time, with even a slight decrease in the average session charging duration, see **Figure 34**. This slight long-term decrease could be explained by new pricing and/or management policies that more effectively operate the EVSEs.

Figure 32: Change in Average Active Charge Time per Session (Weekly)

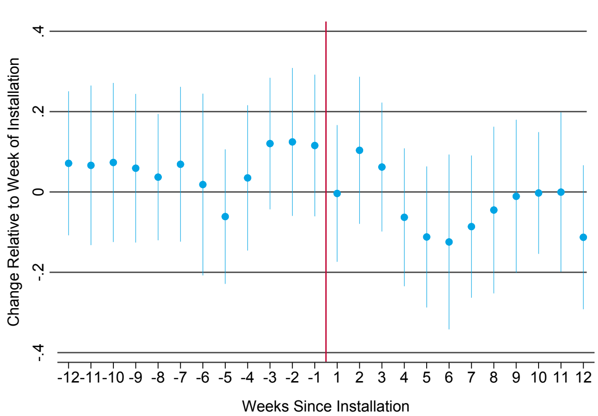


Figure 33: Change in Average Dwell Time per Session (Weekly)

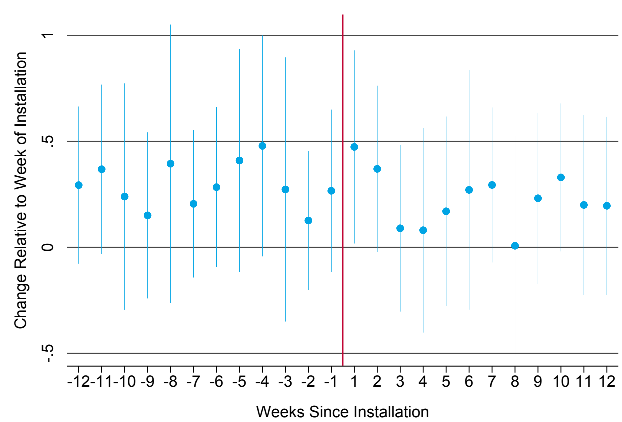
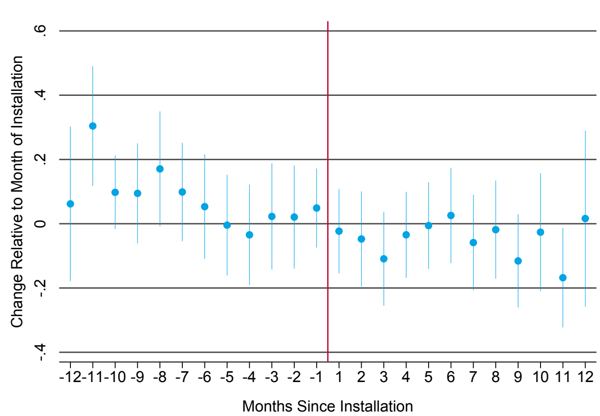


Figure 34: Change in Average Active Charge Time per Session (Monthly)



While the overall energy dispersed per worksite shows a significant increase, there is a negligible difference when evaluating the average energy dispersed per session. The weekly average kWh dispersed per session is shown in **Figure 35** and monthly average kWh dispersed per session is shown in **Figure 36**. The weekly graph shows that there is not an immediate change on a per session basis for the energy that vehicles draw immediately. The presence of added EVSEs has no influence on the amount of energy a vehicle needs to charge; therefore, it makes sense that the average energy dispensed per transaction does not significantly change as drivers will still need to charge their vehicles while they are at work. The monthly graph (**Figure 36**) further shows that there is no significant change in the average kWh per session for a year before and after the investment date, which is supported by the regression analysis and a corresponding R^2 value of only 0.51 and is not statistically significant.

Figure 35: Change in Average kWh per Session (Weekly)

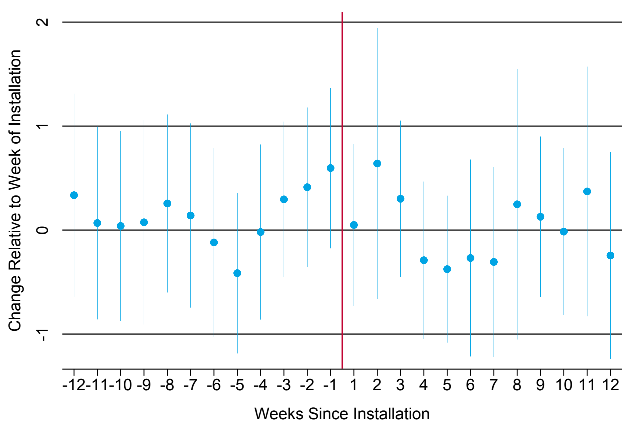
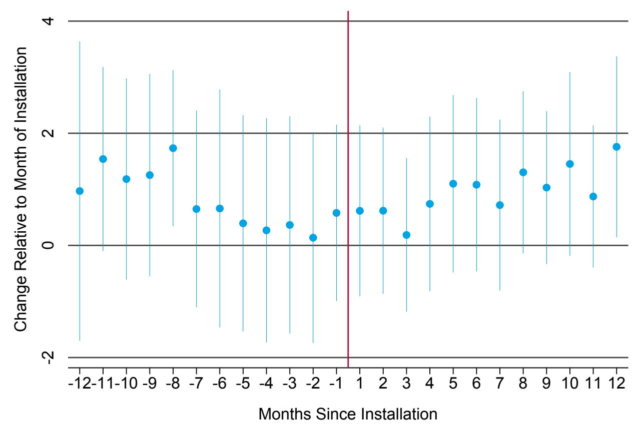


Figure 36: Change in Average kWh per Session (Monthly)



Findings

The analysis and figures above demonstrate that adding charging stations does increase aggregate usage at worksite, but does not alter individual behavior at those stations. While there was a clear increase in the aggregate usage metrics following a site's investment date, there was a negligible effect on charging behavior, as shown in the per session figures. This implies that older users before the investment date are not changing their behavior following the introduction of more charging stations, and new users typically follow the same behavioral patterns as the older users. Additionally, it takes six to seven months to rebound to pre-installation levels for metrics conducted per available port (i.e., sessions, energy dispensed, unique users, and charging hours)

Furthermore, the increased aggregate usage, constant per-session behavior, and PEV adoption at these sites collectively suggest that most of the change in usage is derived from new users rather than increased intensity from previous users. If the aggregate numbers were instead driven by increased intensity from existing users, the per session usage metrics would increase proportionally with the aggregate numbers and there would be a lesser or minimal effect with regards to PEV adoption. As this is not the case, it can be inferred that an increase in the number of EVSEs at a worksite does not significantly affect individual charging behavior.

These findings are additionally supported by both the weekly and monthly regression analyses conducted using twelve variables that include both the aggregate and per session metrics. The five variables found to be statistically significant at the 99% level on the number of EVSEs at a worksite are (1) charging hours per week/month, (2) dwell hours per week/month, (3) energy dispensed (in kWh) per week/month, (4) total sessions per week/month, and (5) unique users per week/month. All variables conducted on a per session basis were found to not be statistically significant, even at the 90% level. See **Table 17** through **Table 19** for regression analysis results. Furthermore, the weekly regressions conducted at both the worksite and zip code level result in similar coefficients suggesting that the increased usage arising from the addition of new EVSEs is not removing usage from other nearby ChargePoint stations, but instead represents organic growth within each worksite.

Summary of Findings:

- Immediately following an investment, usage increases (as defined by the total number of transactions conducted) and results in the growth in total session hours and total energy dispensed.
- The presence of additional charging stations do not alter individuals' behavior. At the 27 worksites that have invested in additional EVSEs, there was an increase in the number of unique users, implying PEV adoption among employees. These new drivers behaviorally interact with the charging infrastructure similarly to previously existing users.
- It take approximately six to seven months to rebound to pre-installation levels for metrics conducted per available port (i.e., sessions, energy dispensed, unique users, and charging hours).
- At worksites that have invested in additional EVSEs, the presence of charging infrastructure has encourage additional users even before the investment date, and the rate of additional users increased following the activation date.
- The usage growth resulting from additional charging stations is organic instead of cannibalizing from other nearby ChargePoint worksites.

Table 17: Regression Coefficients at the Worksite Level (Weekly Analysis)

Variables	Weekly Charging Hours	Weekly Dwell Hours	Weekly kWh	Weekly Sessions	Weekly Unique Users	Percent Time Charging	Average Sessions per User	Median Sessions per User	Mean kWh per Session	Mean Hours Charged per Session	Mean Dwell Hours per Session	Mean % Time Charging per Session
Number EVSE	25.68* (5.324)	8.838* (1.810)	108.1* (19.9)	10.15* (2.501)	3.52* (0.68)	-0.009 (0.012)	0.0377 (0.241)	0.113 (0.328)	0.0867 (0.256)	-0.0165 (0.0246)	0.0946 (0.0992)	-0.00861 (0.0122)
Constant	-39.55* (11.52)	-12.18* (3.663)	-172.2* (44.4)	-16.50* (5.420)	-7.85* (2.28)	0.789* (0.041)	0.219 (0.971)	0.388 (1.073)	7.469* (0.649)	2.412* (0.122)	0.911^ (0.353)	0.792* (0.0432)
Observations	21,234	21,234	21,234	21,234	21,234	19,864	19,869	19,869	19,869	19,869	19,783	19,783
R-squared	0.808	0.703	0.799	0.798	0.823	0.574	0.821	0.803	0.411	0.435	0.593	0.604

Notes:
Robust standard errors in parentheses
* Statistically significant at 99% level (p<0.01)
^ Statistically significant at 95% level (p<0.05)

Table 18: Regression Coefficients at the Zip Code Level (Weekly Analysis)

Variables	Weekly Charging Hours	Weekly Dwell Hours	Weekly kWh	Weekly Sessions	Weekly Unique Users	Percent Time Charging	Average Sessions per User	Median Sessions per User	Mean kWh per Session	Mean Hours Charged per Session	Mean Dwell Hours per Session
Number EVSE	34.52* (2.336)	10.82* (0.705)	132.1* (9.528)	13.91* (0.986)	5.764* (0.616)	0.00123 (0.0022)	0.119 (0.142)	-0.0287 (0.0422)	0.0554 (0.0283)	0.0148^ (0.0071)	0.00673 (0.0218)
Constant	-67.35^ (26.80)	-9.231 (8.414)	-272.6* (102.3)	-38.93* (13.06)	-13.2^ (6.015)	0.484* (0.0500)	-1.073 (1.490)	0.989 (0.962)	15.02* (0.542)	4.936* (0.166)	8.844* (0.401)
Observations	9,569	9,569	9,569	9,569	9,569	8,886	8,888	8,888	8,888	8,888	8,828
R-squared	0.908	0.857	0.901	0.891	0.903	0.587	0.610	0.626	0.410	0.411	0.620

Notes:
Robust standard errors in parentheses
* Statistically significant at 99% level (p<0.01)
^ Statistically significant at 95% level (p<0.05)

Table 19: Regression Coefficients at the Worksite Level (Monthly)

Variables	Weekly Charging Hours	Weekly Dwell Hours	Weekly kWh	Weekly Sessions	Weekly Unique Users	Percent Time Charging	Average Sessions per User	Median Sessions per User	Mean kWh per Session	Mean Hours Charged per Session	Mean Dwell Hours per Session	Mean % Time Charging per Session
Number EVSE	113.3* (25.73)	36.54* (8.546)	479.5* (95.15)	44.83* (12.13)	4.928* (1.155)	-0.00636 (0.0143)	0.00747 (0.258)	0.0445 (0.311)	0.132 (0.276)	-0.00311 (0.0313)	0.0883 (0.109)	-0.00748 (0.0143)
Constant	-147.3* (51.50)	-41.40^ (16.28)	-661.8* (198.7)	-60.69^ (23.76)	-20.7* (6.506)	0.789* (0.0428)	1.043 (0.922)	0.968 (0.974)	7.483* (0.621)	2.435* (0.196)	0.772^ (0.306)	0.786* (0.0446)
Observations	5,006	5,006	5,006	5,006	5,006	4,882	4,883	4,883	4,883	4,883	4,877	4,877
R-squared	0.828	0.762	0.823	0.817	0.835	0.667	0.871	0.864	0.514	0.526	0.681	0.684

Notes:
Robust standard errors in parentheses
* Statistically significant at 99% level (p<0.01)
^ Statistically significant at 95% level (p<0.05)

7 CONCLUSION & RECOMMENDATIONS

Conclusion

The findings within this report can inform policy makers on balancing the needs of PEV drivers, site hosts, and utility providers by better understanding usage and behavior of how drivers interact with charging infrastructure based on various investment decisions. This report focused on southern California workplaces for the five-year period between 2011 and 2015 to describe typical behavior by time of day, the effect of specific pricing policies on usage and behavior, and how subsequent investments in charging stations affect usage and encourage adoption among employees at those sites. The findings from this report can be used in conjunction with possible time-variable pricing to inform current and future EV policy discussions aimed to maximize productivity and accessibility benefits to both the electrical grid and PEV drivers.

The time of day analysis in **Typical Workplace Usage by Time of Day (p18)** describes how charging behavior based on time of arrival. As more utilities explore innovate pricing policy structures (such as SDG&E's Power Your Drive dynamic pricing pilot program), understanding how to balance temporal grid loads with drivers' needs and site host objectives is an important part of the overall policy discussion. Currently, the greatest demand for charging stations occurs in the morning hours and diminishes throughout the day as charging efficiency increases. However, this does not line up with when renewable energies come online throughout the day. Incentivizing users to charge their PEVs when there is an abundance of solar energy being produced can alleviate over-generation issues on the grid and provide better energy management.

Behavior of Specific Pricing Policies (p29) evaluates different pricing policies and the effects of individual components on behavior and usage. It is important to understand that the PEV charging network is a paradigm shift from the traditional gasoline refueling stations drivers are accustomed to, and should be priced to encourage the most efficient use of resources. Resources include not only the energy delivered to the PEV, but also the time and physical space occupied during the charging session. In policies that do not consider these factors (i.e., free charging and straight kWh pricing), much longer post-charge dwell times were observed which limited accessibility to drivers because there is no monetary incentive to vacate the parking space after the vehicle is done charging. Graduated hourly rates show a strong incentive to turn over the charging station by increasing the monetary penalty for excessive usage. The strong bunching effect of sessions terminated immediately before the threshold hour demonstrates that users are extremely responsive to this pricing component. Additionally, the discontinuity in the dwell time immediately before the threshold hour proves users have a preference of avoiding the increased hourly rate following the threshold hour over receiving a 100% charge.

The final area of analysis in **Usage Trends Before and After Additional EVSE Investments (p50)** analyzes the before and after effects of adding additional EVSEs to a workplace. Re-investing in new charging stations does increase aggregate usage at worksites, but does not alter individual behavior of the people charging at those stations as the per-session metrics remained relatively constant before and after the re-investment date. Additionally, an increase in the number of unique users was shown at these worksites implying that there was PEV adoption among coworkers; the rate at which more unique users accessed the charging stations increased following the re-investment date demonstrating that investing in workplace charging sites has a beneficial impact on encouraging adoption. Utilization factors at these worksite on a per-EVSE port basis immediate drop following the re-investment date due to the additional ports installed, but rebound to pre-installation levels after six to seven months and then continue to increase (but at a slower rate) following that time.

Recommendations

The policy recommendations included within this section build off the findings described throughout this report in an effort to provide a more comprehensive understanding of the interdependencies of investment decisions and usage patterns. Considering these recommendations can help achieve a balance between the needs of PEV drivers, site hosts' objectives, and managing grid conditions.

Recommendation 1: Workplace EVSE pricing should be based on a parking model
The workplace PEV charging network is something new and should not be priced the same way as traditional refueling stations, even if the administration of the pricing policy is more complex to administer. Pricing EVSEs should be based on a parking model instead of a throughput model, as is currently implemented for traditional gas stations. Charging stations are a physically constrained resource and therefore a parking model incorporates all the resources consumed (i.e., time, space, and energy) instead of exclusively considering the amount of energy dispensed. The most simplistic parking model charges an hourly rate, but could also include a graduated hourly rate to discourage excessively long durations. Furthermore, workplace charging station pricing should not be based only on energy dispersed as it is the least efficient base policy and results in long durations; some drivers will park to use the parking space knowing they have a near-full charge so will only pay to draw minimal energy but can occupy the priority parking space for an extended period of time for free.

Recommendation 2: Graduated hourly rates should be used to limit excess usage
Graduated hourly rates that increase the cost per hour after a set number of hours should be included in pricing policies at worksites to encourage vehicle turnover and curb excessive usage. Most charging needs can be accomplished within three hours with level 2 EVSEs, and therefore the threshold hour is recommended to be set at three hours to facilitate maximum accessibility to users, but should be no more than four hours to allow for more flexibility because not all employees are able to leave in the middle of the day to move their car. This will encourage PEV drivers to more proactively monitor their charging behavior and encourage smarter management of resources.

Recommendation 3: Resource management techniques
Two resource management techniques are proposed to align site hosts' objectives with drivers' needs. First, a valet service could be implemented at sites with sufficient demand that want to maximize turnover of vehicles. This promotes equity and accessibility by allowing the greatest number of drivers to use the charging resource in the most efficient manner. The PEV valet attendant would move the vehicle once it has completed charging and replace it with another vehicle that requires charging to provide minimal dwell times. Second, a software service can be developed that automatically alerts the driver via email or text message when their charge is completed (or near completed) to suggest the driver to move their vehicle. This would serve the same objectives as the valet service at a lower operating cost, but would function at a slightly less efficient manner as the driver would have the option to act upon the alert or continue to pay for parking services after the charge is complete.

Recommendation 4: Explore time-variable pricing at worksites to maximize grid benefits
As shown throughout the report, pricing is a tool that can be used to influence behavior and usage at worksite. Further exploration into a dynamic pricing policy at the individual worksite level should be conducted to encourage PEV drivers to shift their charging times to maximize cumulative benefits. This can include encouraging drivers to plug in when renewable energy is more abundant, such as the afternoon hours when there is currently less demand than morning hours. Similarly, shifting some morning charging sessions from before 10AM to after 10AM when TOU rates are still considered low- to mid-peak could benefit drivers and site host as these are cheaper times to charge and there is less demand for charging stations. Dynamic pricing has begun on the utility-level in the SDG&E Power Your Drive Pilot Program, but

should be explored further in upcoming studies on a more granular level at specific worksites that have high levels of utilization. Site hosts should be able to change pricing by the hour to incentivize shifting usage patterns to spread out local demand at that workplace. The usage by time of day descriptions within this report can help inform the upcoming discussion as there is capacity for charging in the late morning and afternoon hours that can be shifted through pricing incentives from the morning peak charging demand.

Recommendation 5: Reserve ports for drivers with extended commutes

In an effort to promote equity among drivers commuting different distances, a proportional number of charging ports should be reserved for those commuters traveling long distance to work in order to ensure availability. If these drivers do not perceive there to be available charging stations, they will be much less likely to invest in a PEV due to the anxiety of not being able to charge at work and therefore potentially not having enough energy to return home.

8 WORKS CITED

"2012 ZEV Action Plan" Office of Governor Edmund G. Brown Jr. (2012). September 2012. Available at: http://opr.ca.gov/docs/Draft2012ZEVActionPlan(09-21-12).pdf

"Amping Up California Workplaces." California Plug-in Electric Vehicle Collaborative, November 2013. Available at: http://www.pevcollaborative.org/workplace-charging

"Application of SAN DIEGO GAS & ELECTRIC COMPANY (U902E) for Approval of its Electric Vehicle-Grid Integration Pilot Program." Public Utilities Commission of the State of California, February 2016. Rulemaking 13-11-007. Available at: https://www.sdge.com/sites/default/files/documents/461232896/VGI%20FD.PDF?nid=17366

"Best Practices for Workplace Charging." CALSTART, September 2013. Available at: http://www.calstart.org/projects/Workplace-Charging.aspx

"Electric Car Rate Options" Southern California Edison (SCE). Accessed May 22, 2016. Available at: https://www.sce.com/wps/portal/home/business/rates/electric-car-business-rates/!ut/p/b1/hc9Ba4NAEAXg35KDx7jP3ZJqbyuIrpVao6S6l6LFbgTj BmMr-fcxIT1E0nZub_gezBBJciK78rtR5dDormzPWa7eLdvngUghbNexIdzny LMiijhlEygmgF-G47_-G5EzkvnemcDZvFKWcToH_vqRQoQbL4pdi-LhBzg-vCCMJ5AlDIIleEk5Z8DqCv44MiRStbq6PFzw rmK2IrKvP-u-7s2vflpvh2F_ eDJgYBxHU2mt2tr80DsD9ypbfRhIfivJfpejEUtZHcfFCb4ibhg!/dl4/d5/L2dBISEvZ0FBIS9nQSEh/

"Electric Rate Schedules: Small Commercial Time-of-Use Rate B." Los Angeles Department of Water and Power (LADWP). Accessed May 22, 2016. Available at: https://ladwp.com/ ladwp/faces/ladwp/aboutus/a-financesandreports/a-fr-electricrates/a-fr-er-electricrateschedules?_afrWindowId=null&_afrLoop= 93804293903110&_afrWindowMode=0&_adf.ctrl-state=1clkn3h5oo_4#%40% 3F_afrWindowId%3Dnull%26_afrLoop%3D93804293903110%26_afrWindowMode%3D0%26_adf.ctrl-state%3D1df5reluxi_17

Faruqui, Ahmad, Ryan Hledik, Armando Levy, and Alan Madian (2011). "Will Smart Prices Induce Smart Charging of Electric Vehicles?" The Brattle Group, July 2011.

Gov.ca.gov. (2015). Office of Governor Edmund G. Brown Jr. - Newsroom. Retrieved 6 November 2015, from https://www.gov.ca.gov/news.php?id=17472

Kurani, Kenneth, Jennifer Tyree, Hageman, and Nicolette Caperello (2013). "Potential Consumer Response to Electricity Demand Response Mechanisms: Early Plug-in Electric Vehicle Drivers in San Diego, California." University of California, Davis, Institute of Transportation Studies, September 2013.

Nicholas, Michael, Gil Tal, and Justin Woodjack (2013). "California Statewide Charging Assessment Model for Plug-in Electric Vehicles: Learning from Statewide Travel Surveys." University of California, Davis, Institute of Transportation Studies, January 2013.

Nicholas, Michael and Gil Tal (2013). “Charging for Charging at Work: Increasing the Availability of Charging Through Pricing.” University of California, Davis, Institute of Transportation Studies, October 2013.

“Overcoming Barriers to Deployment of Plug-in Electric Vehicles.” Committee on Overcoming Barriers to Electric-Vehicle Deployment; Board on Energy and Environmental Systems; Division on Engineering and Physical Sciences; Transportation Research Board; National Research Council, 2015.

“Rule 2022 – On-road Motor Vehicle Mitigation Options Employee Commute Reduction Program Guidelines.” South Coast Air Quality Management District (SCAQMD), February 5, 2016.

Ryan, Nancy and Luke Lavin. “Engaging Utilities and Regulators on Transportation Electrification.” Energy + Environmental Economics, March 2015.