36th International Electric Vehicle Symposium and Exhibition (EVS36)
Sacramento, California, USA, June 11-14, 2023

A Qualitative Investigation into Charging Management Strategies in Workplace Environments

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Executive Summary

This research investigates charging management strategies at workplaces in California. These strategies increase charging station utilization, which allows an optimized number of vehicles to charge. After 40 semi-structured interviews with California PEV drivers in 2018, we detected several approaches to managing charging at work. The interviews revealed three styles of workplace charging management: authoritative, collective, and unmanaged. If the use of workplace chargers is poorly managed, one charger may serve just one plug in electric vehicle (PEV) per day. If workplace charging is unmanaged, the resource is often congested, resulting in underutilization of chargers. More than half reported rules from their employer or developed by employees. Employer introduced strategies included digital queuing, time limits with pricing, and valet serviced charging. Employee introduced strategies included time limits, day restrictions, and email lists. All approaches resulted in higher utilizations of chargers.

Keywords: charging, electric vehicle supply equipment (EVSE), electric vehicle (EV), user behavior, workplace

1 Introduction

In attempts to curb light-duty-passenger vehicle emissions, former California Gov. Jerry Brown signed an executive order targeting 5 million zero emission vehicles by 2030 and 250,000 electric vehicle charging stations by 2025 [1]. Furthering the commitment, California has mandated by 2035 all new passenger cars, trucks and SUVs sold in California will be zero emissions [2]. While the majority of charging events occur at home, some drivers depend on, or want to charge away from home for several reasons including convenience, price, inability to charge at home, long distance travel, and a desire to drive the vehicle on electricity. Workplace charging is the second most used charging location after home and having access to charging at work is important for those considering purchasing or leasing a plug-in electric vehicle (PEV) [3], [4]. A PEV can be either an all-electric battery vehicle (BEV) or a plug-in hybrid electric vehicle (PHEV).

The aim of this paper is to uncover workplace charging management strategies that are being used to increase utilization of chargers. To build context around this issue we also explore the charging behavior of

interviewees. As more people adopt PEVs, workplace charging could become congested especially as more consumers who cannot charge from home purchase PEVs. By understanding charging management strategies, as defined below, we can recommend improved techniques to maximize the utilization of charging infrastructure at work. By managing how people charge at work, more people can use the installed electric vehicle supply equipment (EVSE) per day, meaning fewer chargers are needed to support a larger number of PEVs, and more vehicles can be driven on electric miles. Some workplaces may experience charging station stagnation if there is no motivation to move the vehicle when it's done charging. Conversely, if there was higher turnover of vehicles per day, fewer EVSE would be needed to meet demand. Workplaces who are considering installing EVSE can use this research to plan charging stations locations with maximum benefits for charging vehicles and minimizing charging congestion. Compared to home-based charging, workplace charging stations can support a higher number of PEVs with a lower amount of stations which can reduce infrastructure investment costs.

1.1 Introduction to Charging Management Strategies

Here we define three terms used throughout the paper, these are charging congestion, charging station stagnation, and charge management strategies. Charging congestion is defined as a greater number PEVs wanting to charge than available electric vehicle chargers for those vehicles. This generally means PEV owners are unable to charge or must wait to access a charger. Charging station stagnation is when a PEV plugged into the EVSE has completed charging and the owner has not made the charger available to other PEV owners, either due to not moving their vehicle or unplugging the charge outlet. This can exacerbate the issue of charging congestion and can lead to chargers being underutilized. Finally, charging management strategies are any rules aimed at reducing stagnation and congestion, which results in higher utilization of chargers. These rules could be formal or informal, and may include time restrictions, pricing, formalized queuing, or anything else.

2 Literature Review

Maximizing workplace charging use is important since it is the most commonly used charging location outside of the home [3], [5], [6]. It is especially vital for PEV drivers who live in multiunit dwellings (MUDs) who have been found to charge at work with higher frequency than those who live in detached-single family houses [3]. This is most likely due to MUD drivers having less control over parking at their residence. BEVs overall have been found to charge at work with higher frequency than PHEVs and are more willing to charge even with a cost associated to charge, but PHEVs may chose not to charge and complete their commute on gas [3], [4]. For BEV drivers charging at work can be important to complete a commute [7].

One study [4] assumed that one workplace charging station would serve 2 cars/day when modelling an appropriate number of stations needed, but this is not always the case. Nicholas and Tal [4] found that free workplace charging adds unnecessary congestion to the stations as people are substituting home charging for free workplace charging; those findings are corroborated by Chakraborty et al [3]. While free charging at work is known to be a motivating factor for PEV adoption, paid charging may be beneficial as it prevents those who do not need to charge from doing so, and those who need to charge will have more reliable access to the infrastructure [3], [4], [8]. A paper focused on user (the vehicle owner) vs supplier (the vehicle owner's electrical supplier/utility) managed charging at home [9] found drivers had to tradeoff between simplicity and personal control. The themes found in this paper are similar to some found in this study when managing workplace charging. Drivers also feel more comfortable charging away from home if there is a formalized charging etiquette and structure [10].

Management of workplace charging needs to be explored because workplace charging has been found to increase PEV adoption and can increase overall electric miles of the commute, but if it is unmanaged (e.g. when it is free to use) there can be an increase in charging congestion with negative impacts on vehicle purchase decisions and on the use of shorter range BEVs for commuting [3], [4]. Based on a literature search we were unable to identify any studies that investigate this topic. This research aims to address this gap by investigating workplace charging management strategies currently used in California.

3 Methods

The data for this research is from forty semi-structured qualitative interviews that were conducted with PEV drivers across California in the summer of 2018. The interviews explored driver commute information, charging behavior, and experiences with charging etiquette (see Appendix 1 for the topics explored in the interviews). Interviews lasted on average 45 minutes and were conducted at the interviewees' homes. Interviewees were selected based interviewer's availability and the driver's willingness to share their experiences. Forty interviews were conducted because that was when saturation occurred, and no new ideas were being put forth. All interviews were then transcribed and coded in NVIVO.

Interviewees were recruited from an existing study in which PEV owning households had loggers installed in their vehicles. These households were recruited via an online questionnaire survey. The Plug-in Hybrid and Electric Vehicle Research Center sent out a survey to California drivers who purchased or leased a new or used PEV in 2017 or 2018. The new vehicle drivers were those who applied for and received California's Clean Vehicle Rebate Program funds [11], recruitment was via email. Email addresses were provided by the California Air Resources Board. This study also included used PEVs with records obtained from the California DMV. These drivers were mailed a letter with a survey link and requested they complete it. At the end of the new and use PEV surveys, respondents were asked if they would like to participate in future studies.

From the survey results, households were selected to be part of the vehicle logger study, where they would have loggers installed in all household vehicles for one year [12]. The households were selected based on the PEV model they own, their charging behavior, home location, home type, and secondary vehicle characteristics. For PEV model we sampled based on popular vehicle models in California. For charging behavior, we sampled based on the frequency and location where they reported charging (home, work, and public). For home location, we sampled households based on their utility district across the state. For home type, at least 22 MUDs were required for sampling. Finally, for secondary vehicle characteristics we sampled based on yearly mileage, vehicle year, and ability to install the data logger. The project has logged 400 households between 2015-2020. These households were compensated with $350 for their participation in the logger project.

This paper focuses on a subset of forty drivers from the vehicle logger project who were part of the study in 2018 and who agreed to be interviewed.

There is potential for bias in the interviews as interviewees had previously agreed to and completed two other data collection forms. The sample is not intended to be representative of all PEV owning households nor of the general population. However, the diverse sample (geographically, by PEV type, by house type, etc.), shown in Table *1* below, leads us to believe the interviews detect the most common charging management strategies currently employed.

4 Results

4.1 Interviewee Descriptions

The PEVs that were discussed are as followed: four (9%) Nissan Leaf, 15 (35%) Tesla Model S, six (12%) Ford C-Max, three (7%) Ford Fusion, 16 (35%) Chevrolet Volts, and three (5%) other vehicles (one Chevrolet Bolt EV, one Fiat 500e, and one Toyota RAV4EV). There were 22 (47%) BEVs and 25 (53%) PHEVs in the study. There were 11 (28%) MUD drivers and 29 (73%) single-family household drivers. Table 1 below has a full description of the households.

Table 1: Summary of Interviewee Information

Interview	Total # cars	# of PEVs	PEV	Vehicle Style	# ICEs	MUD	Gender	Age	Region
1	1	1	Chevrolet Volt	PHEV	0	1	Male	19-29	Bay Area
2	2	1	Ford Cmax	PHEV	1	0	Male	30-39	Bay Area
3	2	1	Nissan Leaf	BEV	1	0	Male	40-49	Bay Area
4	1	1	Tesla Model S	BEV	0	0	Male	40-49	Bay Area

5	3	1	Tesla Model S	BEV	2	0	Male	50-59	Bay Area
6	1	1	Chevrolet Volt	PHEV	0	1	Male	19-29	Bay Area
7	3	1	Tesla Model S	BEV	2	0	Male	60-69	Bay Area
8	1	1	Chevrolet Volt	PHEV	0	0	Male	30-39	Northern California
9	2	1	Nissan Leaf	BEV	1	0	Male	30-39	Bay Area
10	2	1	Chevrolet Volt	PHEV	1	1	Male	30-39	Bay Area
11	2	2	Tesla Model S / Chevrolet Volt	BEV / PHEV	0	0	Male & Female	30-39; 30-39	Bay Area
12	2	1	Ford Fusion	PHEV	1	0	Male	40-49	Sacramento Area
13	1	1	Chevrolet Volt / Fiat 500e	PHEV / BEV	0	0	Male	50-59	Bay Area
14	1	1	Chevrolet Volt	PHEV	0	1	Male	30-39	Bay Area
15	1	1	Chevrolet Volt	PHEV	0	1	Male	30-39	Los Angeles Area
16	3	1	Tesla Model S	BEV	2	0	Male	40-49	Los Angeles Area
17	2	1	Tesla Model S	BEV	1	0	Male	50-59	Los Angeles Area
18	2	2	Ford Cmax / Chevrolet Volt	PHEV / PHEV	0	0	Male	30-39	Los Angeles Area
19	2	1	Chevrolet Volt	PHEV	1	1	Male	30-39	Los Angeles Area
20	2	2	Chevrolet Volt / Nissan Leaf	PHEV / BEV	0	0	Male & Male	40-49; 50-59	Los Angeles Area
21	1	1	Tesla Model S / Toyota RAV4EV	BEV / BEV	0	0	Male	40-49	San Diego Area
22	2	1	Chevrolet Volt	PHEV	1	0	Male	50-59	Bay Area
23	2	1	Tesla Model S	BEV	1	0	Female	50-59	Bay Area
24	1	1	Chevrolet Volt	PHEV	0	1	Male	40-49	Los Angeles Area
25	3	1	Tesla Model S	BEV	2	0	Male	50-59	San Diego Area
26	1	1	Chevrolet Volt	PHEV	0	1	Female	40-49	Los Angeles Area
27	2	1	Tesla Model S	BEV	1	0	Male	40-49	Los Angeles Area
28	2	1	Ford Fusion	PHEV	1	0	Male	30-39	San Diego Area
29	2	2	Nissan Leaf / Chevrolet Bolt	BEV / BEV	0	1	Male & Female	50-59; 40-49	San Diego Area
30	2	2	Chevrolet Volt / Ford Fusion	PHEV / PHEV	0	0	Male	50-59	San Diego Area
31	2	1	Tesla Model S	BEV	1	0	Male	40-49	Los Angeles Area
32	1	1	Tesla Model S	BEV	0	0	Male	70-79	Sacramento Area
33	2	1	Tesla Model S	BEV	1	0	Female	60-69	Northern California
34	1	1	Tesla Model S	BEV	0	1	Male	30-39	Bay Area
35	4	1	Chevrolet Volt	PHEV	3	0	Female	19-29	Sacramento Area
36	1	1	Ford Cmax	PHEV	0	0	Male	19-29	Sacramento Area
37	2	1	Ford Cmax	PHEV	1	0	Male & Female	50-59; 40-49	Bay Area
38	1	1	Ford Cmax	PHEV	0	1	Male	30-39	Bay Area
39	2	1	Ford Cmax	PHEV	1	0	Male	40-49	Bay Area
40	4	1	Tesla Model S	BEV	3	0	Male	50-59	Bay Area

4.2 Charging Behavior

Interviewee charging behavior is discussed below because of its relevance to workplace charging management. First, we explore home charging, followed by public, and then workplace charging. Then we discuss workplace charging management in detail.

4.2.1 Home Charging

Thirty-five people charge their vehicles at home, ten are unable to, and two chose to not charge at home (Figure 1). The interviewees who charge at home cite convenience and low refueling cost as their main reasons behind this choice. Of those that live in MUDs, eight (73%) are unable to charge at home. The drivers

who live in a MUD noted the nuisances of not having a garage or access to electricity at their parking spot. Of those who choose to not charge at home (a Tesla Model S and Nissan Leaf), the Tesla Model S charges exclusively at work, and the Nissan Leaf has no issues relying solely on public charging. The quotes below outline reasons why interviewees don't charge at home.

"I don't have a garage, so I have to do street parking and that ultimately means I don't charge my car when I'm at home" (Interview 01, Chevrolet Volt)

"With the free options there didn't really seem to me to be much need for that, um, and it's not inconveniencing me at the moment to do it the way I'm doing it. Umm so, yeah I haven't seriously considered the charging at home" (Interview 03, Nissan Leaf)

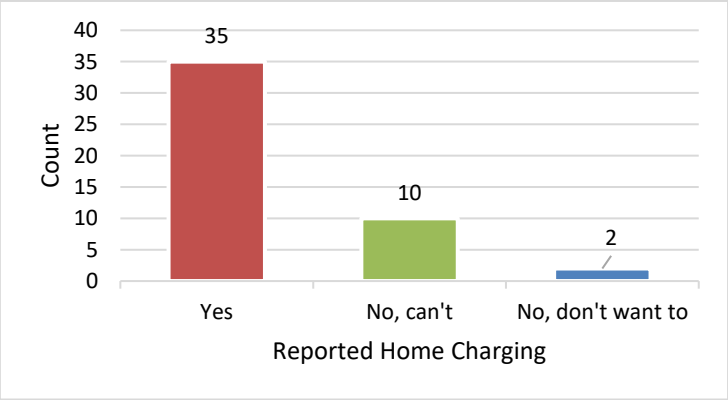

Figure 1. Interviewees reported home based charging (N=47)

4.2.2 Public Charging

Public charging is classified as charging that is not at home or while at work, as defined by [6]. The frequency of charging in public is broken down by always, frequently, occasionally, rarely, and never (Figure 2).

Seven drivers reported always charging their vehicles when available in public. The vehicles include two Nissan Leafs, three Chevrolet Volts, one Chevrolet Bolt, one Ford C-Max, and two Tesla Model S. Of those seven, three are unable to charge at home. A few participants also brought up that charging was a determining factor of where they travel.

"I also charge when I go shopping at the mall or the park, wherever there's a charging station… [charging] actually kind of skews on where I watch a movie, so … I just look at which one has more availability on charging stations and then that's where I go." (Interview 24, Chevrolet Volt)

Seven interviewees reported charging in public frequently. This was defined as those who would charge in public more likely than not when they go out. They may check the local EVSE they know for availability and may not mind adjusting their parking patterns to charge their vehicles. The vehicles in this category are two Chevrolet Volts, one Ford Fusion, one Ford C-Max, and three Tesla Model S. A few mention the secondary perks of charging in public such as parking priority or saving money.

"Whenever we go out if there's a charger available well try to, to get it and just park there and you know, even if we have to walk a little extra we'll do that" (Interview 08, Chevrolet Volt)

Sixteen drivers charge in public occasionally; from this sample, this is the largest segment. Occasional public charging interviewees were defined as those who know their routine charging stations, but do not seek out additional stations. As one interviewee put it, "I don't really search for them. If they're there, they're there" (Interview 02, Ford C-Max). If it is convenient for them, they will charge their vehicle. The vehicles in this grouping are seven Chevrolet Volts, two Ford C-Maxes, five Tesla Model S, and two Nissan Leafs.

"I generally just try to charge it when I can when it's convenient for me. I don't want to go out of my way" (Interview 14, Chevrolet Volt)

Ten interviewees rarely charge in public. Five Tesla Model S, one Ford Fusion, three Chevrolet Volts, and one Ford C-max are part of this group. These drivers only use public charging as a last resort or very infrequently.

"Public chargers are literally for emergency use cause especially since I have it at home, like I just don't need to use public chargers" (Interview 27, Tesla Model S)

One interviewee with a Ford C-Max does not charge in public. He cited the hassle of charging compared to home charging and time to charge as preventing him from seriously considering using it.

"I don't go that many places where I would have time to charge my car" (Interview 37, Ford C-Max)

Irrespective of public charging frequency, seven drivers only charge in public when it is free (Figure 2). This is an additional grouping and is not a category of charging frequency. It contains two Ford C-Maxes, three Chevrolet Volts, and two Tesla Model S. Paying for charging is not always a disincentive for drivers to charge.

"I will only use a public charger if it's available and they're free" (Interview 23, Tesla Model S)

"There's a lot of them that are like paid um I don't usually bother using those um because we can do it at home and get the electricity from the solar panels" (Interview 34, Tesla Model S)

Some drivers had no problem paying to charge their vehicle or had a maximum amount they would pay to charge in public. Some find it useful to have a payment system to increase the chance of finding a vacant charging station. A few PHEVs mention the emissions offset from driving on electric while others want to support the EVSE companies by charging when they can.

"If you have to pay, then there's better turnover. And I can usually find a place to charge." (Interview 12, Ford Fusion)

"We always have gas but I hate oil. So we try to avoid it as much as we can." (Interview 38, Ford C-Max)

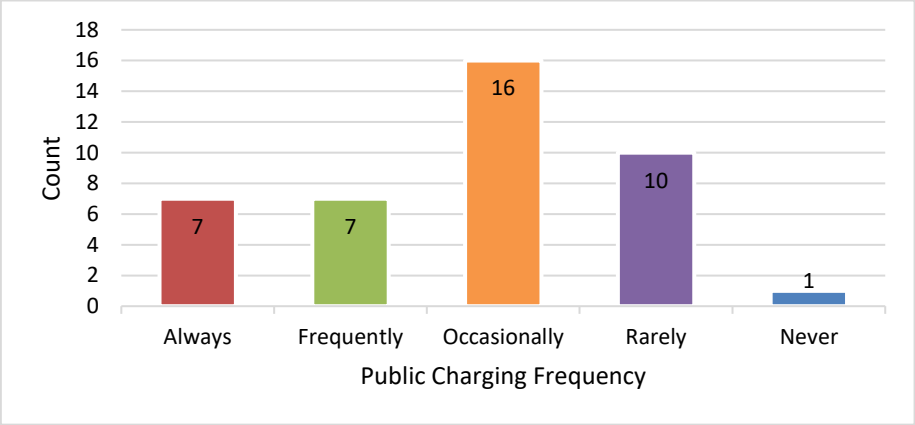

Figure 2. How often interviewees reported charging their vehicles in public (N=40).

4.2.3 Workplace Charging

Workplace charging is defined as where people charge while they are working. Some workplace charging locations are in public lots; interviewees perceive this as workplace charging as it is where they park their car while at work. This definition is consistent with Lee et al. [6]. Seventeen interviewees reported always charging their vehicle at work, six charged sometimes, five had the option to charge at work and chose not to, and seven had no access to charging at work. An additional nine interviewees were either retired, did not commute, or had an irregular driving schedule with no regular commute location so they cannot charge at work (Figure 3).

Seventeen interviewees reported charging their vehicles at work whenever there is an available charging station. The vehicles are ten Chevrolet Volts, two Ford C-Maxes, two Tesla Model S, one Ford Fusion, one Nissan Leaf, and one Chevrolet Bolt. The main motivator to charge at work was cost-savings and

convenience. Free workplace charging meant that some interviewees prioritized charging at work over charging at home. Ten MUD drivers (of 11 interviewed) always charge at work. Some drivers reported wanting to charge every day but were unable to because of charging station congestion. Some reported driving in earlier or later (after lunch when others would move their vehicle) to ensure they would be able to access a charging station.

"It was kind of in the middle of a big parking garage that was a little bit further away, um but that was totally fine" (Interview 10, Chevrolet Volt)

"I charge at work because it's free. It's convenience." (Interview 11, Tesla Model S)

Six interviewees in the sample charged at work sometimes. These interviewees include two Tesla Model S, one Nissan Leaf, one Ford Fusion, one Ford C-Max, and one Toyota RAV4EV owning households. These drivers used workplace charging as secondary to home charging. They would sometimes charge at work because they needed additional charging because they forgot to charge at home or drove additional miles beyond their normal routine. Some interviewees reported charging at work because the parking space was in a better location than the non-charging spaces.

"The reason we'd charge at work is that someone forgets to plug it [the household's BEV] in it at night. That's the primary reason like, "oh!" Or if she's running errands during the day and just needs a quick charge to get home." (Interview 09, Nissan Leaf)

Five interviewees do not charge at work; the vehicles owned by these interviewees are three Tesla Model S, one Nissan Leaf, and one Ford C-Max. Some drivers find workplace charging inconvenient because the EVSE was too far from their office, due to cost, or because the charging management strategies did not align with their schedule. One PHEV driver chose not to charge at work to keep the spaces open for BEVs owners who may need to charge.

"[Work] has charging stations, but it's a dollar an hour, and you have to move your car every 2 hours so that's very inconvenient." (Interview 33, Tesla Model S)

Seven interviewees reported being unable to charge at work. These include those who own the following vehicles: one Fiat 500e, three Chevrolet Volts, two Ford C-Maxes, and one Tesla Model S. Reasons for this include having no charging infrastructure installed or parking being too much of a luxury to dedicate to charging at their workplace.

"We don't have any outdoor outlets on our building. And even if we did, you would have to drape the cord across sidewalks and planters, across parking lots, so, um, it's just not practical and not worth it." (Interview 22, Chevrolet Volt)

Nine interviewees do not commute, have an irregular commute, or are retired. These people are excluded from the workplace sample because their travel patterns do not allow them to charge at a workplace.

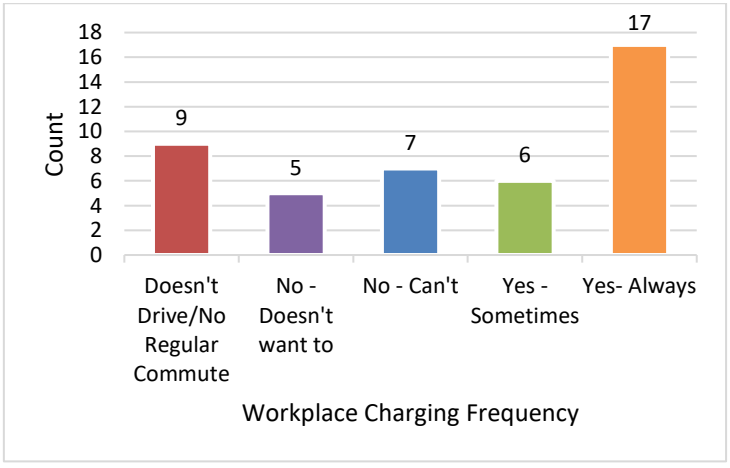

Figure 3. Break down of interviewee's work charging patterns and availability. Nine interviewees did not have a regular commute or were retired. (N=44)

4.3 Workplace Charging Management Strategies

Twenty-three (58%) interviewees reported charging at work either every day or sometimes while five people said they have the option to charge at work, but do not (Figure 4). Twenty-six of these 28 interviewees provided information on charging management strategies at their workplace charging location. From these interviewees, three categories of approaches were detected. We refer to these as 'authoritative charging management strategies', 'collective charging management strategies', and 'unmanaged charging'.

4.3.1 Authoritative Management Strategies

Twelve interviewees reported having a set of rules enforced and created by their workplace, which we call 'authoritative charging management strategies'. These are rules that have been applied to workplace charging by the company, without input from the charging station users.

Reported authoritative management strategies include: digital queuing, rotation, a time limit with pricing, and valet charging. Digital queuing occurs when one vehicle is charging and a second parks next to it waiting to charge. This required having more parking sports surrounding the EVSE than there were ports. The driver of the second vehicle taps a card (in this case a ChargePoint card) against the reader to get in the virtual queue to use the charging station. When the first vehicle has finished charging, the second driver is notified via email that they can unplug the first vehicle and plug in their vehicle. Rotation is defined as the company forcing the driver to move their vehicle after a time limit or the vehicle has completed its charge; this information is usually conveyed in the form of signs or digital messaging. Non-compliance can lead to a penalty. These are not independent strategies: one workplace could employ multiple strategies.

"[There is] a rotation system where you, since there are more cars than there are charging spots, park next to charging station and you badge in and then whenever the car next to you is fully charged you get notified and then you go down and you switch the charger." (Interview 01, Chevrolet Volt)

Time limit with pricing is when the system is set up to be free or very low cost, and after a set number of hours, the price ramps up significantly.

"If you keep your car charged for longer than 3 hours, then they uh start charging you like 5 bucks an hour. So that's ah, it's a real- it's a strong incentive to move your car and let other people use it." (Interview 19, Chevrolet Volt)

Valet charging was observed in workplaces that already had valet parking for their employees with EVSE in the lot. The valets are responsible for charging the vehicles and rotating them as necessary. The two interviewees who had workplace valet charging were less aware of how their vehicle's charging was being managed because they were not physically involved in the charging process. These interviewees were indifferent about how their vehicle was charged so long as it was ready for them upon leaving work. For workplaces in this sample who had valet parking for their employees, the charging was managed by the valet, and was paid.

"Valets are good about rotating the cars around, so everybody gets a charge and like, I'm usually charged up full by the time I go home" (Interview 18, Ford C-Max)

Eighteen (64%) workplaces required joining a charging network company before being able to charge. Requiring employees to have an EVSE membership (e.g. ChargePoint) does not qualify as authoritative management because no mechanisms to increase charger utilization were in place.

4.3.2 Collective Management Strategies

Four interviewees stated they and their fellow co-workers created rules for charging at work, known here as 'collective management strategies'. These systems are organized by the employees who drive and charge their PEVs at work. These interviewees' workplaces did not have any formal rules in place (i.e. Unmanaged Charging). Examples of collective charging management strategies include day restrictions (e.g. only being able to charge on Mondays and Wednesdays), time of day restrictions (e.g. a 4-hour limit on charging), messaging an email group when your vehicle is done charging, and well-maintained spreadsheets of vehicle

owner contact information which could be used to request someone to move their vehicle. The vehicles in this category are two Chevrolet Volts and two Nissan Leafs.

Collective charging is only functional if there is a strong sense of commitment and leadership to get everyone's vehicle charged with a shared resource. One interviewee reported that their office's "leader" left the company, and it was proving difficult to pick up the pieces of their charging patterns. This technique only arises when there is unmanaged charging at work, and the collective wants to do something about it.

"I'm part of that google doc, so you know you have to coordinate with another person, go down and meet them, swap cars, um you know and then you have to check the doc cuz someone may say I want it when you're done." (Interview 20, Nissan Leaf)

One interviewee (quoted below) stood out because they were collectively charging off of an 110V outlet. Due to the inefficient time required to charge at this power level, it was it was unexpected that co-workers would justify time to create a schedule for them all to charge. This interviewee does live in an MUD without home-based charging, so this is one way he is able to charge his Chevrolet Volt.

"We just kind of had a meeting and said okay how can we best handle this without fighting for it?" (Interview 24, Chevrolet Volt)

4.3.3 Unmanaged Charging

Ten (38%) drivers reported no organization or rules for charging at work; we have classified these as 'unmanaged charging.' Drivers report there is often competition to charge and sometimes cannot charge if they arrive at work too late in the day. Two interviewees recently changed jobs and went from an authoritative management strategy to unmanaged workplace charging. They both reported frustrations with the lack of management for the EVSE. One even asked HR for some sort of managed charging but had not heard back.

"It's just like, you grab it, and it's yours all day. If you're going to be really nice you could move the car out and like, move to a different spot, but I usually don't have time during the day to do that." (Interview 10, Chevrolet Volt)

"Over the course of the past few years, as more electric vehicles have come to [work], it's become a little bit more challenging to make sure you get charge" (Interview 40, Tesla Model S)

Five interviewees report that they charge by bringing their own charging cord to plug into an 110V or 240V outlet at the workplace. Five people have charging at work with installed charging infrastructure that has no rules. Vehicles here include two Chevrolet Volts, three Tesla Model S, one Ford Fusion, one Nissan Leaf, one Bolt EV, and two Ford C-Maxes.

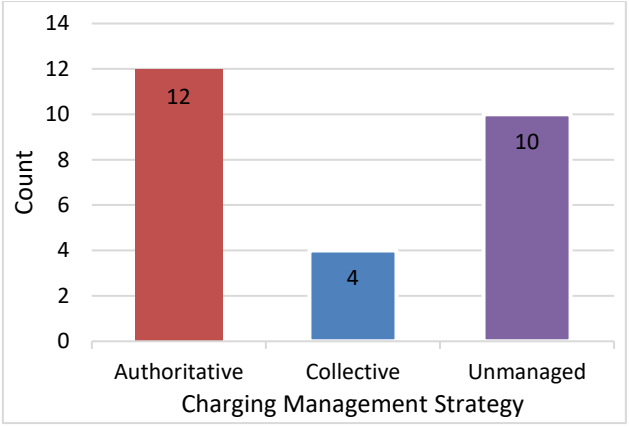

Figure 4. Three interviewees did not go into enough detail about their workplace charging management strategies to categorize (n=26)

5 Discussion and Conclusion

Charging management strategies appear to be effective in increasing vehicle turnover at workplace EVSE. With higher turnover, more people can use the stations thus increasing utilization of them. This allows more PEVs to charge and reduce the number of EVSE a workplace may need to install. The majority of interviewees liked their workplace's authoritative charging management strategies. However, four BEV owners chose to not charge at work. One has a collective (move vehicle when done charging), one has authoritative (priced charging), and two did not give enough detail to classify. This may at first seem negative, but those households were able to complete their travel without using the chargers. The rules for those charging stations have had the intended effect of increasing availability of chargers for those that really need them. These strategies are a successful deterrent and could allow vehicles that need to charge or are willing to go through the extra effort to charge.

Interviewees who were part of collective charging management systems also reported positive experiences. They liked designing their own rules to fit the needs to the drivers. These systems also increased the number of vehicles that could be serviced by the limited number of EVSE.

For those without any charging management rules in place, drivers may not always be able to charge when they want or need. These workplaces may have underutilized charging stations, not necessarily due to high charging congestion, but a high charging station stagnation as the drivers have no incentive to move their vehicle when charging is complete.

6 Recommendations

The charging management strategies presented in this research can be a good starting place for companies who want to offer charging for their workforce. Without enforced charging, stagnation and congestion can occur at the charging stations reducing the number of PEVs that charging stations can support. This in turn increases the number of EVSE that a workplace would need to install, which can increase costs substantially.

When designing the infrastructure layout, digital queuing should be kept in mind. We recommend having more parking spaces around the EVSE and charge cords that can reach multiple parking spaces. This coupled with an electronic queue means drivers do not have to move the PEV when it's done charging, and others can plug their vehicle in when one is finished. A rotational system like this can reduce congestion and allow more vehicles throughout the day to charge. Locating chargers away from the front of the building can solve the issue of PEV owners charging just to get a good parking location. Keeping the stations visible, however, can help create awareness of the available charging infrastructure.

Another EVSE layout is to install slower charging stations in the front of the building and faster charging stations farther away; this can create an additional soft barrier from charging to save the charging stations for people who may need to charge for a longer time or have a larger battery to refuel. An alternative is to install costly faster chargers in the front of the building, and many free slower charging stations toward the back of the lot. People who need to refuel quickly can spend the money to charge swiftly and maintain a nice parking spot, but those who are just taking advantage of free electricity can choose to park further back.

For workplaces with existing unmanaged charging, we recommend adding enforceability, cost, and/or idle fee components to the EVSE to spur vehicle turnover. Adding a reasonable cost to charging vehicles may help alleviate congestion from vehicles which otherwise could charge at home. A reasonable rate, such as a few cents over the cost of electricity in the area (at home), would in theory not dissuade MUD drivers who rely on workplace charging, since the electricity price would be cost comparable to what they would pay if they had access at home. It is useful to make charging strategies so those who cannot charge at home can instead charge at work due to the long dwell time at the workplace. The threat of banning people from charging if the rules are not followed may also be a strong motivator to honor the guidelines. Idle fees or a steep fee increase when the car is done are very useful turnover techniques because the driver would be monetarily charged when not receiving any electrical charge.

There are a few key principles to keep in mind for workplaces considering installing charging: evaluating charging needs, selecting the right equipment, and managing the charging program. To evaluate charging needs, the employer should understand the current and potential charging infrastructure needs. This can be

accomplished by surveying employees' level of interest and identify any potential barriers to adoption. The number and type of charging stations needed will depend on the demand for workplace charging and the available space. The findings outlined in this paper can serve as a starting point for managing workplace charging.

It is also a good idea to understand existing resources for employers and employees interested in installing workplace charging. One such program is CALSTART and Forth's national workplace charging program, Charge@Work. The Department of Energy's (DOE) national workplace charging program Charge@Work is meant to provide employees and their employers with the tools and education necessary to advocate for and commit to the installation of EV charging stations at work. The goal is to increase awareness, availability, and accessibility of charging at work. More information is available at [13].

Above all, making sure any charging strategy design is simple and easy for the drivers to use is important.

7 Appendix 1 – Interview Topics

- Who uses the car? How do you use it?
- Where do you charge? When and why?
- What is your experience with public charging? Do you charge in public even when you have sufficient range to get home?
- Do you know how to read the blink pattern of other vehicles to know what their approx. SOC is? Do you move your car or unplug it when it is done charging?
- How would you feel if you someone unplugged your vehicle? Would you be upset if a PHEV unplugged you? A BEV? Would/have you ever unplugged a stranger? Someone at work? Ever leave a note or seen someone leave a note? Ever come back to your car and find a note?
- What does charging etiquette mean to you?
- Do you think you have good charging etiquette? How could you be incentivized to improve?
- PHEV: How often does your engine turn on for increased power?
- PHEV: How much is your engine on? Do you know of anything to do to prevent the engine from starting?

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Acknowledgments

We would like to thank our wonderful team of undergrad research assistants (past and present): Nathanial Kong, Mounika Bodagala, Thomas Bradas, Scott Begneski, Eric Racadag, Marcelo Steinkemper, Melissa Ng, Alexa Monserret, Ethan Khoe, Noam Baharav, Courtney Carroux, Noh Kahsay, and Jade Ogunmayin for their efforts in transcribing and travelling around the state to assist in data collection. Thank you to Claire Sugihara and Vaishnavi Karanam for sanity checks. Thank you NVivo for having an affordable Student Edition. Funding for this research came from the California Air Resources Board, and we thank them for that.

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