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Dynamics of Workplace Charging for Plug-in Electric Vehicles: How Much is Needed and at What Speed?

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Abstract

This paper presents workplace charging needs from two perspectives: the potential needs based on modelling and the needs based on survey results. These approaches both examine workplace needs from what people need to increase usage of the cars, and what workplace charging they will they actually use. The analysis reveals that for California driving patterns, chargers at the workplace can increase electric vehicle miles travelled (eVMT) by approximately 2%-10% for PHEVs and about 6%-9% for a 60-100 mile battery electric vehicle (BEV). The actual number of chargers used depends on the price charged. Both methods show that workplace charging will increase if charging is free versus a priced scenario with no extra benefit in terms of eVMT. The survey shows that 2 out of 10 vehicles will use workplace charging if it is priced between home electricity and gasoline on a cents per mile basis, while 8 out of 10 vehicles will use it if free on any given day. This corresponds to a 2-4 times increase in “needed” chargers depending on assumptions of how many cars one charger can serve per day. Also investigated was the speed of charging needed at work. Most charging of PHEVs can be accomplished with low power charging and 80% of BEV charging can be accomplished with low power. In general low power charging should comprise 80% or chargers, and charging price should be segmented by charging speed to encourage efficient use of high power chargers – reserving high power level 2 charging for those who need it such as some BEVs and utilizing low power chargers for PHEVs and low need BEVs.

Keywords: workplace charging, price, level 1, level 2, evse

1 Introduction

Plug-in electric vehicles (PEVs) consisting of both battery electric vehicles (BEVs) and plug-in hybrid electric vehicles (PHEVs) are rapidly entering the marketplace and policy makers are

seeking ways to increase their sale and likelihood of use. Increasing the availability of workplace charging has been identified as a one strategy to increase the sale and use of EVs and this effort is represented by the EV Everywhere Workplace Charging Challenge[1]. However, the basic

questions remain: How much is needed, and what is the societal benefit? In the rush to install workplace charging, workplaces may be tempted to simply install a few free high power level 2 chargers without much forethought as to how they will be used and what benefit, if any, they are providing to the usage of electric vehicles. Recent experience in California, one of the most active PEV markets in the world, shows that in the context of a sizeable market, chargers quickly fill up at the workplace. The question becomes, is this usage indicative of success or failure? What is the benefit that is being provided? What is the optimal mix of chargers and speeds? This paper attempts to answer these questions from two different perspectives: surveys and modelling. Modelling shows a longer term perspective on what might happen in the future. Surveys give insight into this modelling and provide guidance on shorter term objectives.

2 Background

There have been a few studies looking at the potential benefit of workplace charging and its potential usage[2,3,4]. Few, however have looked at the effect of pricing on the number of chargers needed and at what power[5,6,7]. Economics, however, suggests that if a resource is free then it will be used more than an equal service that is not free. In the case of EV charging, the choice is often between a home charger at home electricity prices, and a work charger for free. If the work charger is used more often, then more work chargers will be “needed” or at least wanted. To help answer the question of needs versus wants, we asked respondents in a survey how often they would use workplace charging under different pricing scenarios.

Because some charging simulations[5,6] show that low power charging should be sufficient at work for the majority of users, we also asked opinions about low power charging in the survey. The ramifications of the acceptance of low power charging is explored in terms of infrastructure needs at work in the context of pricing.

3 Modelling Results

Modelling the benefit of workplace charging was carried out on travel on data taken from the 2001 Caltrans travel survey[8]. This travel survey asked respondents (driving gasoline vehicles)

where they went throughout the day. We then model how these trips could be completed in a PEV using a combination of home and work charging. The PEVs modelled include BEVs with ranges of 60, 80 and 100 miles and PHEVs of 10, 20, 30, 40, 50, 60, 70, 80, 90, and 100 miles. The benefit of workplace charging is then assessed in terms of percentage increase in eVMT. A more complete model description and expanded results is available in a paper by Nicholas et al.[6]

3.1 Tour Creation and Data Preparation

The basis for analysis was home-based tours. A home-based tour in this case represents the travel done in a vehicle from the time it leaves home to the time it arrives home. This distinction is convenient in that we assume that a charger available at home is a given for analysis. There are of course other charging regimes such as purely workplace charging for those with no home charger, but this possibility is not explored. A typical tour would be: Home to work, work to store, store to home. As a matter of convenience, all tours that involved an alternative mode such as biking and public transit, were excluded from analysis. This resulted in 26,561 individuals of driving age (of 31,898 total) from 15,591 households taking 100,519 trips and 36,006 tours. 7,770 individuals of driving age (9,230 total) did not travel on the survey day. There were 31,074 household vehicles available. An overview of survey travel is shown in Figure 1.



Figure1: Density of statewide travel from the CalTrans 2001 survey.

Tour routes were determined based on a shortest time basis between origins and destinations using speed limits to estimate speed. The calculations were performed with ArcGIS software.

3.2 Charging Model

The tours for the entire state were then modelled as if they had to be completed with a PEV. The workplace BEV charging model had one rule. A vehicle would charge at a workplace if they would go below 5 miles left upon returning home from work. The drivers would only be able to charge the amount of time they were parked at the workplace. Some drivers in the sample did not go to a work location on the survey day and so only home charging was available. Some tours were not possible, and so these tours and the associated miles were placed in the “not served” category. Drivers had perfect knowledge of the charging network and knew if the home could be reached within the mileage limit.

The PHEV charging model was similar to the BEV charging model in that charging was only initiated when the PHEV could not reach home on electricity without charging. However, there was no 5 mile threshold and vehicles were allowed to go to 0 miles left before returning home.

3.3 BEV Model Results

Following the needs-based charging approach and assuming that drivers charge at home as much as possible, we see that workplace charging can provide from 5.7% - 9.4% extra statewide eVMT depending on battery size (Figures 2-4). However, workplace charging is separated in to different speeds of charging ranging from 1.2kW to 6.6kW. High power 6.6kW chargers, which are a common industry standard, are not necessary for most workplace charging. Low power charging of approximately 1.2kW (can be 120V or 200+ volts) was sufficient for about 70% - 80% of workplace

charging.

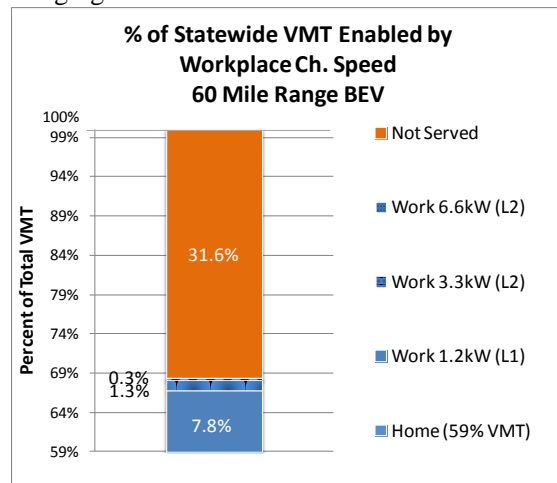


Figure 2: 60 mile range vehicle miles which need charging and workplace charging benefit

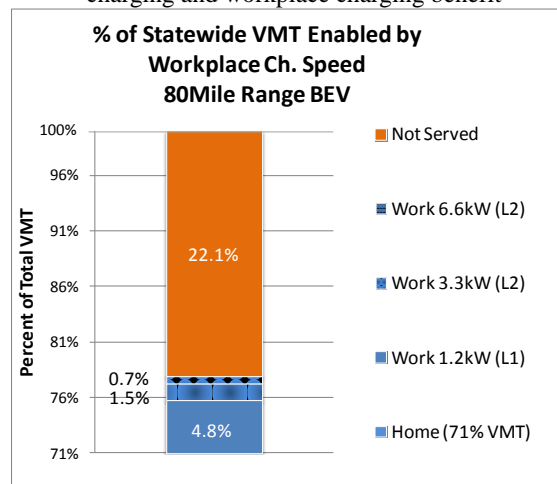


Figure 3: 80 mile range vehicle miles which need charging and workplace charging benefit

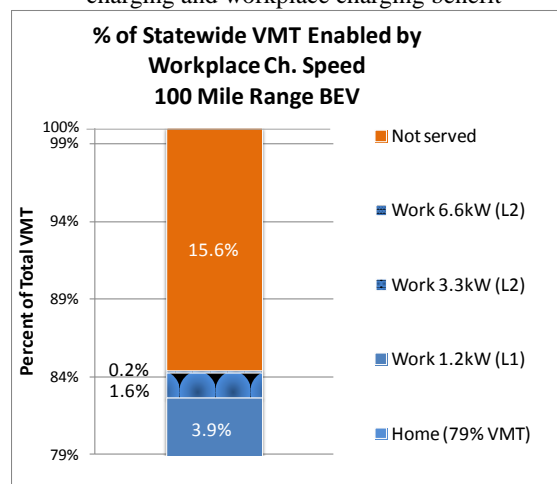


Figure 4: 100 mile range vehicle miles which need charging and workplace charging benefit

The bottom of the y axis in Figures 2-4 represents the limit to which home charging can provide travel. For example, 59% of miles in the state

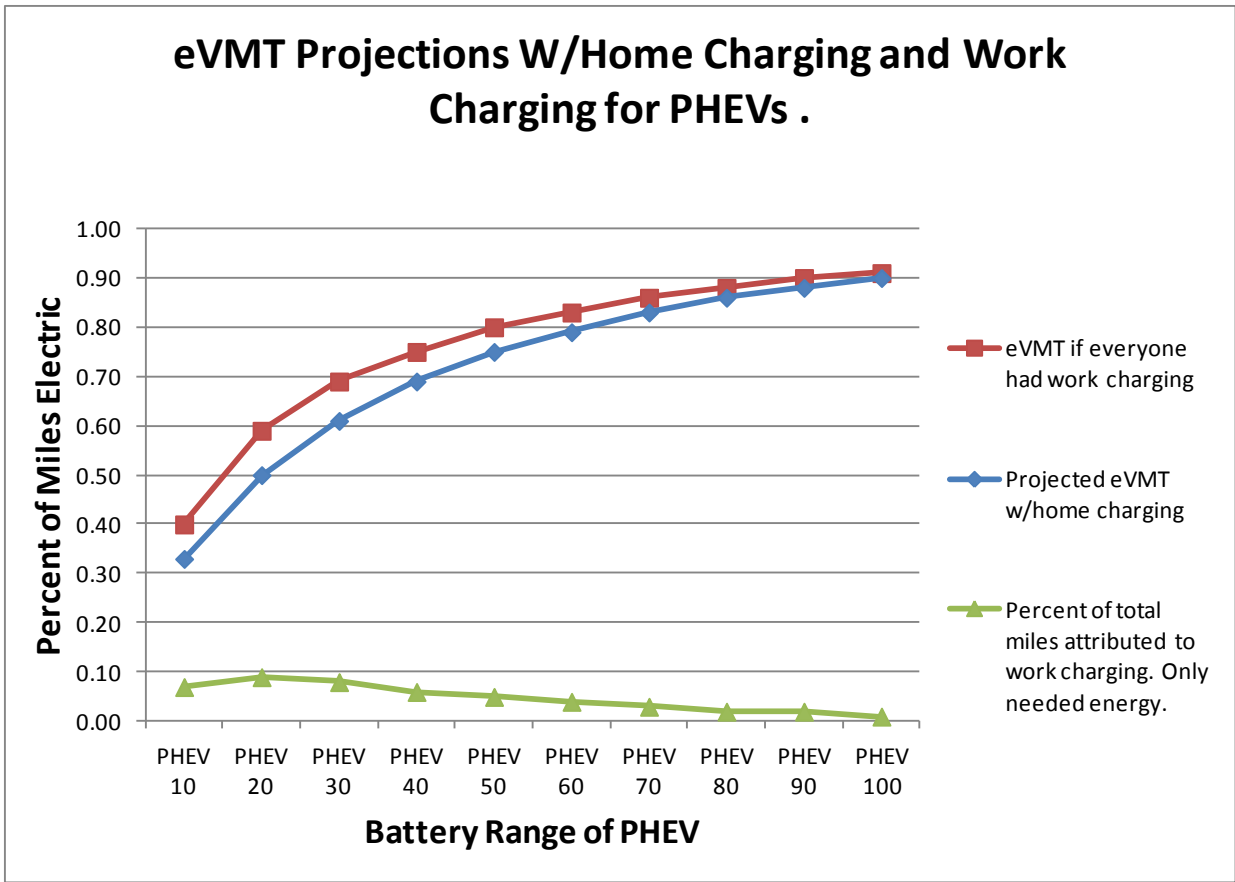


Figure 5: Proportion of total electric miles travelled possible using home and workplace charging with PHEVs of various battery sizes

could be accomplished with home charging alone if everyone in the state drove a 60 mile range vehicle, leaving 41% of miles that need charging. Of this 41%, 9.4% can be provided by workplace charging. Surprisingly, providing higher power chargers for 60 mile BEVs did not prove more useful than providing it for higher range BEVs. This counterintuitive result is due to the long parking durations at work and the fact that small batteries reach full capacity faster. The range of the vehicle seems to be the limiting factor in how useful high power 6.6kW chargers are.

3.4 PHEV Model Results

The PHEV model was slightly different in that vehicles were allowed to run out of charge if the charging infrastructure did not allow them to travel all-electric. However it was similar in that it was a needs-based model where vehicles only charged at work when needed. Figure 5 shows the home based eVMT of PHEVs of different battery sizes. The benefit is greatest for 20 mile PHEVs with an increase of 9% statewide eVMT

attributable to workplace charging. Even though 10 mile PHEVs need charging more often, the battery capacity is not big enough to store much energy and the battery fills up before there is enough energy to get home. Larger battery sizes such as a 40 mile PHEV actually need less charging from work when looked at statewide and workplace charging only accounts for 6% extra eVMT.

Low power charging at 1.2 kW was also considered as opposed to higher power 5.7kW chargers (Table 1).

Table 1: Benefit of increasing power levels at workplace chargers for PHEVs

eVMT Benefit of 5.7 kW vs. 1.2 kW Charging at Work	
PHEV 10	0%
PHEV 20	1%
PHEV 30	1%
PHEV 40	0%
PHEV 50	1%
PHEV 60	1%
PHEV 70	1%
PHEV 80	1%
PHEV 90	1%
PHEV 100	1%

As shown by Table 1, for PHEVs, increasing the power of chargers did not help increase the eVMT of PEHVs greatly. Therefore low power chargers are mostly sufficient for workplace charging of PHEVs.

3.4.1 Charging Price for PHEVs

Three scenarios were run for charging at work: free, equal to home electricity and double the price of home electricity. In terms of behaviour, in the free scenario everyone who arrives at work plugs in, in the equal price scenario, everyone who needs to plug in to get home on electricity plugs in and stays plugged in throughout the day, and in the double price scenario, people who need to plug in to get home do, but unplug as soon as there is enough electricity to get home. The three scenarios are shown in Figure 6 for a 40 mile PHEV.

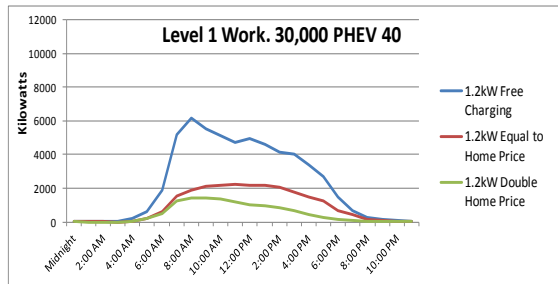


Figure 6: Modelled results of workplace charging under free and priced scenarios for a 40 mile PHEV

All three scenarios result in the *same* eVMT. There is no societal benefit to everyone plugging in whether they need it or not. However, under free charging the number of kilowatts dispensed triples for a 40 mile PHEV and the number of vehicles charging more than triples due to the short charging duration of many people who are using the charging but don't need it.

4 Survey Results

The survey results support the modelling results for the requirements of workplace charging. UC Davis and the California Center for Sustainable Energy (CCSE) partnered on a survey conducted in May-June 2013 of PEV owners revealing some of the most recent usage of and opinions on workplace charging by vehicle type and follows another paper by the authors [9]. Figure 7 shows the prevalence of workplace charging and Figure 8 shows the pricing of current workplace charging based on the results of this survey.

Figure 8 shows that there are some areas that do have paid charging, and those light blue shaded areas have exclusively free workplace charging. Although not specifically asked in the survey, most paid workplace charging is likely in public lots near the workplace rather than lots owned by the workplace.

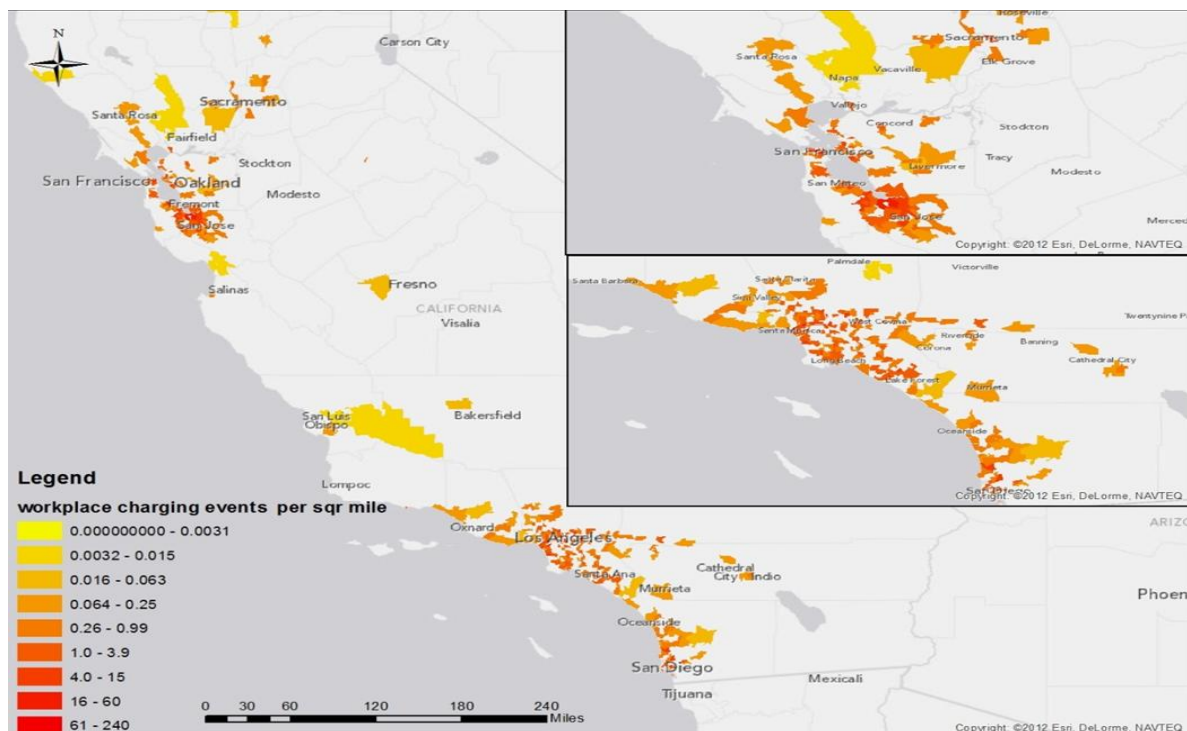


Figure 7: Density per square mile of workplace charging events with a minimum of 5 respondents per zip code.

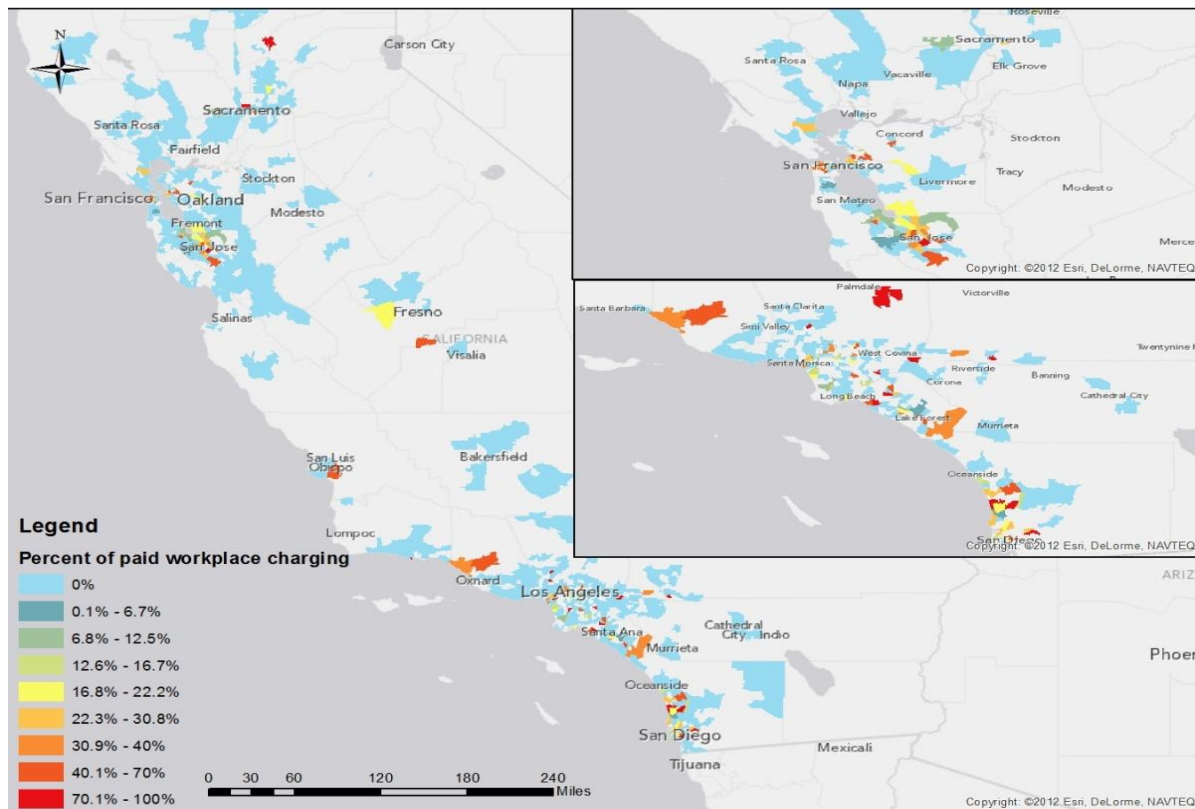


Figure 8: Zip codes where workplace charging was present (no minimum number) and the percent of which was paid and free

The survey indicates that there is already congestion at work chargers and 38% of those who report workplace charging availability report congestion at chargers at least one day a week. For example, in the San Jose area (Figure 4) on many days people reported not finding chargers reliably at work. Interestingly, the location of the paid charging in Figure 8 in many places is correlates with the congestion shown in Figure 9. What may be happening is a maturation of the charger market and that a strategy to deal with congestion is paid charging. The implication is that if congestion requires paid charging, policy steps may be taken in advance of congestion to improve charger dependability.

Figure 9 shows that charging cannot be depended on reliably at work in many areas. Those who need charging may not be able to find it. In the sections below, further details about the survey and its relation to work charging are presented.

4.1 How Much Charging is Needed and Price Sensitivity

The number of chargers that will be used at the workplace depends on the price that is charged. Similar to the modelling there is a distinction between usage and need. We asked owners of Plug-in Priuses (PHEV 11), Chevy Volt (PHEV 35), and the Nissan Leaf (BEV 73) questions about workplace charging usage under three pricing scenarios: Free, same price as home electricity, and double the price of home electricity Figures 10-12.

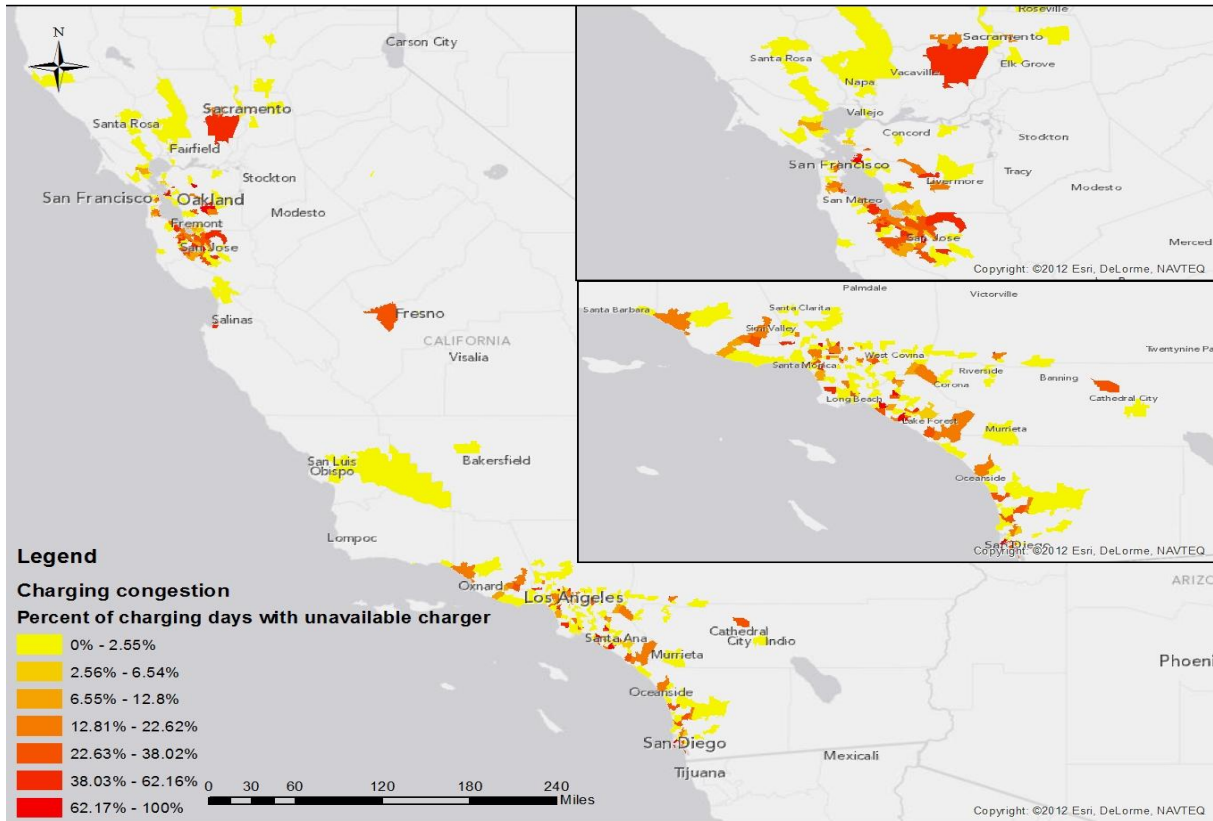


Figure 9: Congestion at workplace chargers by zip code. Minimum 5 respondents per zip code.

Casting the prices in terms of home electricity was done as a matter of convenience rather than to translate the costs into cents per kWh or cents per mile. However, phrasing the question this way is meant to highlight one parameter: will consumers plug in at home or at work? Each of the three pricing scenarios has a unique rationale: free workplace charging represents the economic incentive to arbitrage electricity prices; equal pricing represents how many people could get meaningful benefit for the inconvenience of plugging in; doubling the price represents how many people need the charge to either return home or save money on fuel costs. Since price parity on a cents per mile basis is about 23 cents per kWh for a Prius assuming \$3.66 per gallon gasoline, driving on gasoline may be the rational choice in certain pricing scenarios. However, the 15 cent price can be lower or higher depending on area and pricing plan. PEV owners in many areas are eligible for a special EV rate that is approximately 10 cents.

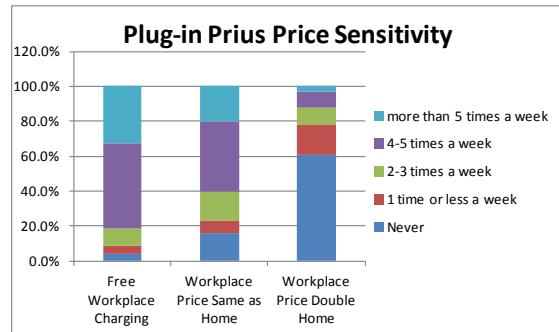


Figure 10: Percentage of Plug-in Prius respondents who would plug in under different pricing scenarios

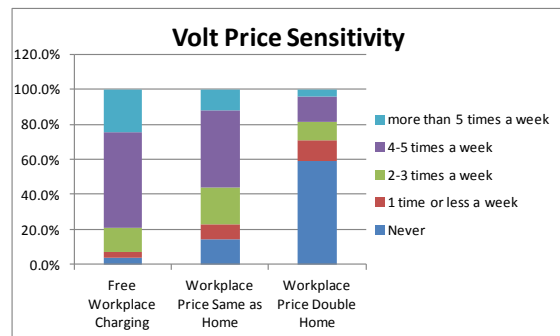


Figure 11: Percentage of Volt respondents who would plug in under different pricing scenarios

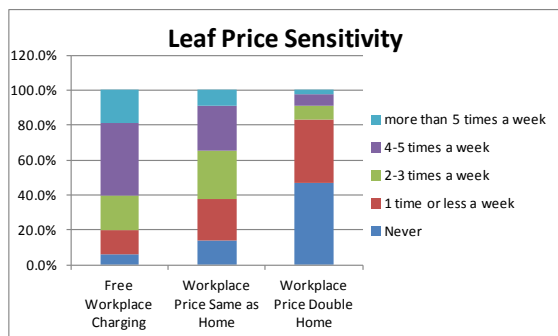


Figure 12: Percentage of Volt respondents who would plug in under different pricing scenarios

Providers of workplace infrastructure should expect to need 2-4 times the number of chargers they would need under a priced scenario. As an example, using the preferences above assuming a fictitious U.S. market of 33% Plug-in Prius, 33% Chevrolet Volt, and 34% Nissan Leaf we can make some representative calculations on the number of chargers and possible investment required in different scenarios. Assuming that a Level 2 charger can serve on average of 2 cars per day and drivers charge with the frequency in the free scenario above, 41 chargers would be needed per 100 vehicles. With a price equal to home, 32 chargers would be needed. With a double-priced scenario 11 chargers would be needed. These estimates will double if only one car per day uses the charger.

4.2 Dependability Preference for BEVs

Dependability is an important factor when deciding to buy or use a BEV. The range of the vehicle limits what driving can be done but charging can address some of these limitations and give confidence to the driver that he or she can complete a journey. When deciding to buy a vehicle, customers may consider dependable charging as a factor in whether a BEV will meet their travel needs, and in turn influence their purchase decision. Dependable charging also affects the use of the vehicle on any particular day. On longer travel days, if there is a doubt as to the ability to complete a trip with a BEV, then a gasoline vehicle may be chosen – if another vehicle is even available.

We see evidence of the importance of dependable charging in Figure 13 by comparing the willingness to pay for charging at double the cost of home electricity.

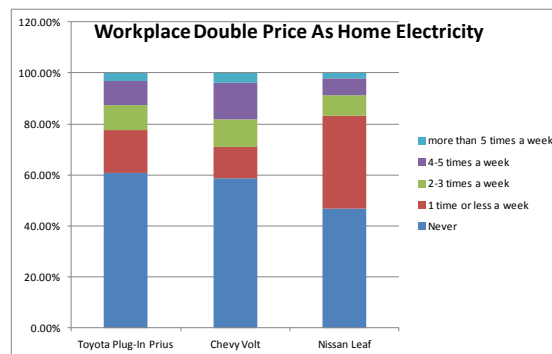


Figure 13 Expected charging frequency assuming workplace charging were double the price of home electricity.

One of the most striking features is the willingness of Leaf drivers to occasionally (1 time or less per week) pay double for charging relative to the other vehicle types. This makes sense since Leafs have few options on longer travel days other than to charge to complete their trips. In this case, dependability of charging is of higher value for BEVs than for other vehicle types. This suggests that a charging fee may actually help Leaf or other BEV drivers. However, another interesting finding from survey responses is that less than 20% of Leaf owners would charge more than once per week. Overall, these two points combined imply that Leaf owners would need fewer chargers at workplaces than other vehicle types, preferring to charge at home in normal circumstances. These chargers, though, need to be more dependable in terms of their availability.

4.3 Low Power Charging is Sufficient for Most Vehicles

From survey responses about low power charging (Figure 14), we see that about 30% of people disagree or strongly disagree that “Level 1 charging at work is sufficient for my needs.” (Low power level 2 is not well known so this phrasing was not used). However, about half agree that low power charging is sufficient at work. The modeling discussed in Section 3 suggests that 80% of chargers could be low power and the surveys support this by showing that low power charging could meet 50%-80% of consumers charging preference.

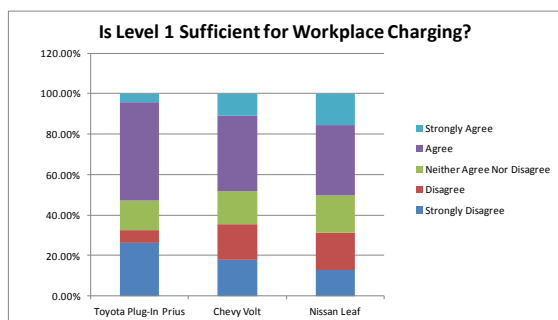


Figure 14: Survey responses to the sufficiency of low power charging at the workplace show that many agree that low power charging is sufficient.

Sufficiency can also be viewed in terms of the power possible to gain in an 8 hour workday with low power charging. Assuming a lower power 1.2kW charging rate for 8 hours, 9.6 kWh of energy can be gained in a day. In a Leaf, this translates to 29.2 miles, enough to return most people home, as the median one way commute for survey respondents is 14.6 miles. 90% commute less than 35 miles.

5 Conclusions

Both the modelling and the survey support some early recommendations for workplace charging. First, low power charging can very easily address 50%-80% of the charging needs at work. Due to the long parking duration, most cars will recover enough energy to return home on electricity. Low power does not have to mean level 1, but can also mean low power level 2 at lower cost and higher efficiency than an equal number of level 1 chargers.

Second, workplace charging can improve electric vehicle miles travelled by up to 10%. Electric vehicle miles travelled has a direct relationship to emissions and may be a significant benefit to the environment. This percentage increase in vehicle miles travelled may be larger for the initial group of buyers however, as many people may optimize their car purchase to maximize workplace charging benefit.

Third, pricing is the largest factor in determining charger use. The survey indicates that 8 out of 10 vehicles will use a charger on any given day if it is free, but this usage drops to 2 out of 10 vehicles if the price is double that of home electricity. A doubling roughly represents a price that is likely cheaper than gasoline on a per mile basis, so we assume that in most cases, only 2 out of 10 vehicles need charging on any particular day. Similar results in terms of usage are supported in the modelling.

There are some aspects that can change the analysis results. One aspect is that some people don't have a location to charge at home, and so a high power workplace charger may be the only way to provide power to a vehicle. This is especially true for PHEVs which are more appropriate for apartment and single vehicle households who are less likely to have a home EVSE.

Overall, a range of charging speeds should be provided at work. All should at least be priced at parity with home electricity. Higher power level 2, which is important for BEVs and some PHEVs, should be priced at a slightly higher price than home electricity, but less than the price of gas to ensure efficient usage of chargers. In order to spur market growth free low power charging may be a desirable short term strategy.

Acknowledgments

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