Charging Behavior Impacts on Electric VMT: Evidence from a 2013 California Drivers Survey

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ABSTRACT
The growing plug-in electric vehicle (PEVs) market features new models of battery electric vehicles (BEVs) and Plug-in hybrid vehicles (PHEVs) with varying battery sizes and electric driving range. How are these different models being used in the real world? A common assumption in PEV impact analysis is that PEV owners will maximize their vehicle utility by appropriately sizing their battery to their driving needs and by charging their vehicles as much as possible to recover the cost of the vehicle purchase. Based on these assumptions we expect PHEV owners who drive more to plug-in more and drivers of PHEVs with small battery to plug in more than owners of vehicles with a larger battery and similar driving patterns. This paper examines the assumptions presented using a survey of more than 3,500 PEV owners conducted in California in May and June 2013. The online survey includes extensive data on driving and charging behavior using web-map questions and includes owners of all PEV models in the market including more than 600 Volts and 800 Plug-in Priuses. The results show that small battery PHEV electric vehicle miles traveled (eVMT) are lower than larger range PHEV or BEVs not only because of the battery size but also as a result of the public charging availability and charging behavior. Higher electric range PHEV drivers and BEV drivers charge more often and report more charging opportunities in the same areas that smaller battery PHEVs could not find chargers.

INTRODUCTION
Is a plug-in hybrid more of an electric car in terms of driving and charging or is it more similar to an internal combustion engine (ICE) car? The answer to this question lies less with the technology of the vehicle, and more with the behavior of its user. Driving and charging behavior are the main factors in determining the ratio of gasoline to electric miles driven. In the case of BEVs, the travel and charging behavior will impact the vehicle choice on a specific day and in the case of PHEVs, also the driving mode of the car. Current policies are based on the assumptions that users will charge daily while OEMs argue that users will maximize the electric miles driven (eVMT) with their cars by using home and public infrastructure when available. Public charging infrastructure availability may play a major role in impacting whether or not people are even able to charge. An additionally layer shaping behavior may reflect other monetary and non-monetary costs and benefits of plugging in, even if charging is available. In this paper, we explore the charging and driving behavior of 3,500 PEV owners in California using a self-reported web-map survey conducted in May and June 2013 by the California center for sustainable energy (CCSE) and the PH&EV center at the University of California Davis. The survey allow us to compare the usage of the main PHEVs in the market using a sample size of more than 800 Plug-in Prius and 600 Chevy Volts and the most common BEV, the Nissan Leaf with more than 2,100 households.

LITERATURE REVIEW: CHARGING BEHAVIOR
The on-road performance and environmental impact of plug-in vehicles is the focus of many studies trying to model BEVs and PHEV usage. Only in the last two years the first reports on actual performance started to add to the knowledge base. A wide use type of PHEV and BEV modeling is based on travel data of ICE vehicles simulating plug-in vehicle. This type of modeling uses actual travel patterns but required a set of assumptions about charging behavior including frequency and location. Some studies model vehicle idling time as charging events [1], or modeled only home charging once a day [2] [3] [4]. A more refined modeling work used home dwelling time as charging event and specific locations as potential fast charging locations[5, 6]. Richardson, 2013, did a comprehensive review on the electric vehicles and the electric grid focusing on modeling approaches, Impacts, and renewable energy integration. His review does not include a section about charging behavior and the only assumptions used in modeling the impact on the electric grid are related to smart or simple charging at home[7]. Studies done earlier than 2010 forced to use on modeling or small demonstration project as presented by Davies and Kurani[8]. This work presents the variety of charging frequencies both at home and in public using a small sample of converted plug-in Priuses. Data reported by the EV Project also present a wide variety of charging and driving behavior but does not correlate the two together [9, 10]. Overall, current research illuminates a

gap of knowledge on charging behavior and its impact on eVMT, and understanding the factors that influence this behavior.

SURVEY TOOL AND SAMPLE

The overall target population of this survey is new PEV owners in California who applied for the California rebate for plug-in owners between February and August 2012 and have more than 6 month experience with the car. This population includes most of the PEV buyers in this time frame and includes mostly owners of the Nissan LEAF, Chevrolet Volt and the Plug-in Prius. The sample includes PEV owners that were eligible for the state's Clean Vehicle Rebate Project[18]. This survey was conducted with the California Center for Sustainable Energy (CCSE), in coordination with the California Air Resources Board (ARB). The total number of started surveys was 3,881 with 3,201 usable surveys, reflecting response rates of about 30.6%. The high response rate could be attributed to the willingness of the PEV owners to share their experience and possible feeling of gratitude after receiving state incentives. Only 10% of the sample owned the car for less than 9 months, while 86% owned it less than a year. Leaf owners had the longest time with the vehicles with an average of more than 10 month the survey represents about 13.6% of the CVRP population and about 10% of the PEVs sold in California between January 2010 and June 2013 and have a good representation of the three main vehicle models in use the Nissan LEAF, Chevrolet Volt and Plug in Prius and all five major metropolitan areas. .

Table 1: Days Vehicle Owned by Vehicle Model

Vehicle Model	Days own the car					
	N	Mean	Std Dev	Std Err Mean	Lower 95%	Upper 95%
Nissan Leaf	2205	616	135	3	610	622
Toyota Plug-In Prius	851	362	52	2	359	366
Chevrolet Volt	661	329	54	2	325	333
Tesla Roadster	48	778	203	29	719	837
Ford Focus Electric	36	300	24	4	292	308
Mitsubishi i-MiEV	35	428	62	10	407	450
Other	45	323	45	7	310	336

To compare the survey household characteristics to the general population we used the Californian sample of the 2009 National household travel survey (NHTS), which includes 21,225 households that own 44,526 vehicles. The NHTS survey was conducted about 3 years before plug-in vehicles were available in California and includes income and location weights [19].

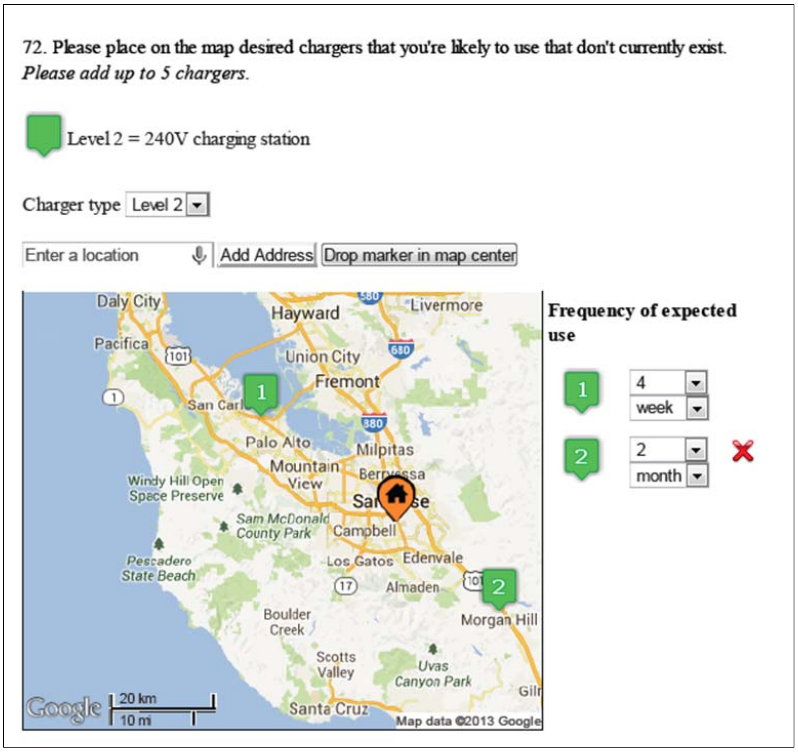

FIGURE 1 Web map question

The survey is based on self-reported travel patterns using web map questions (Figure 1). The web-map questions allow us to collect data on a large sample of habitual travel pattern such as commute trips and charging patterns without using costly travel diaries or GPS loggers. The survey also allows us to inquire about the charging availability, pricing, wiliness to pay and subjective need. The next sections will present PEV owner travel and charging patterns from the survey. To reduce survey burden and improve response and completion rates we allow users to skip on questions that were not relevant or difficult to answer. The actual response rate for each question may vary and reported in every table.

Driving Behavior

Charging patterns revealed in the survey are sub-optimally utilizing the electric driving potential of the vehicle. We use two main data sources for the vehicles. The first is based on odometer reading as reported by the driver and presented as average daily mileage based on ownership time. The second is based on commute trip distance calculated based on the fastest travel route between home and the work location reported by the users. Table 2 shows the average miles per vehicle for the main models in the sample. As expected the PHEVs are driven more than the BEVs and the limited functionality Tesla roadster is driven less than the other cars even though this car has longer range than the other BEVs. For the rest of the paper we will focus on the three most common PEVs: LEAF, Plug-in Prius and Volt.

Table 2: Average Daily Miles by Model

Vehicle	N	Mean	Std Dev	25%	Median	75%	Max
Ford Focus Electric	36	28.8	10.4	19	31	38	45
Leaf	2192	27.9	12.1	20	27	34	87
Mitsubishi i-MiEV	34	22.3	12.0	12	21	31	48
Other	44	28.8	11.9	21	28	37	54
Plug-In Prius	845	45.6	20.7	30	43	57	128
Tesla Roadster	48	19.6	12.8	10	18	25	73
Volt	658	38.1	16.4	27	36	46	114

Figure 2 focuses on the three primary vehicle models and present not only the average daily miles but also the one way commute distance calculated based on the fastest route between the reported home and workplace (N=1663 calculated for respondents who reported on decodable home and work locations). The density curves show that the driving patters of the three cars are different not only by average and mean, seen by the varying density peaks, but also with the extra-long tail of Prius owners reflecting high VMT and long commute distances.

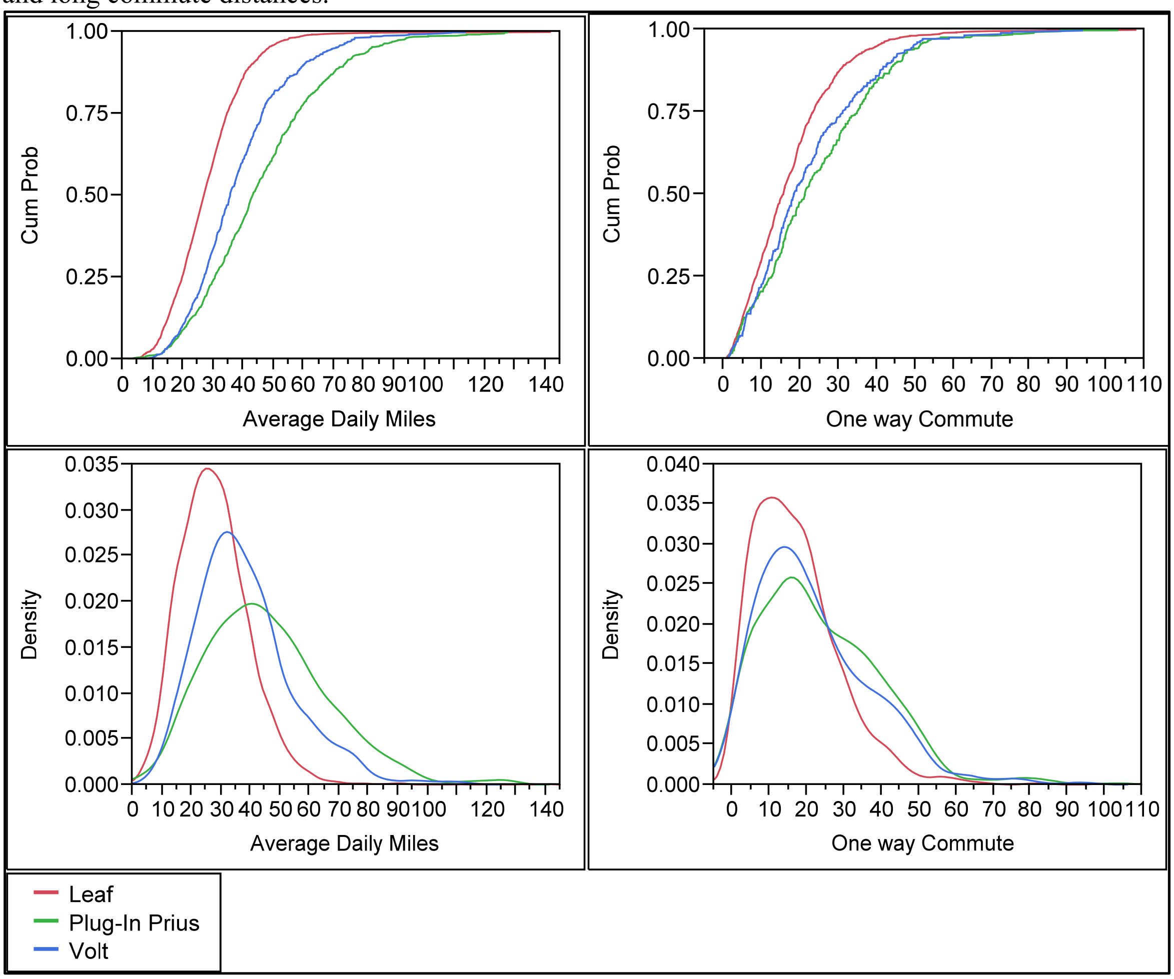

FIGURE 2: CDF and density distributions of average daily driving and one way commute

We found no correlation of average daily VMT with time of ownership, probably as the sample contains users who owned the car for more than 6 months. Home locations have an effect on the average travel distance for the Prius but not for the Leaf. Volt owners in urban areas drive similar average daily miles but the small group of rural Volts drivers travel farther (Table 3).

Table 3: Average Daily Miles by Region and Model

	Volt		Plug-in Prius		Leaf	
Area	N	Mean	N	Mean	N	Mean
all	*659*	*[a] 38.2*	*845*	*[b] 45.7*	*2191*	*[c] 27.9*
Bay Area	233	[a,A] 37.2	271	[b,B] 39.9	882	[c,A] 28.3
Los Angeles	291	[a, A] 38.3	451	[b, A] 48.8	644	[c, A] 28.6
Sacramento	23	[a, A] 34.4	19	[b, A,B] 48.3	64	[c, A] 26.7
San Diego	49	[a, A] 36.5	46	[a, B] 41.4	378	[b, A] 26.8
Rural areas	48	[a] 44.2	51	[b, A] 53.5	187	[c, A] 26.6

Within an area compare the lower case letters to determine if the vehicles behave similarly e.g. San Diego Volts (a) are similar to Plug-in Priuses (a)Uppercase letters should be read vertically and are region comparisons e.g. Volts are similar in Los Angeles and Sacramento (Comparisons for each pair using Student's t)

In all cases, Prius users drive on average more than other drivers. t is not clear if this different stem from different travel needs that are correlated with location, socio demographic and other factors. Table 4 includes two linear models exploring the potential correlation with average VMT. The first model includes all available variables and the second a more parsimonious model that includes only the statistically significant terms. In both cases the Plug-in Prius is positively correlated with VMT even when controlling for location and socio-economics. As expected, commuters and HOV users drive more as well as younger drivers or drivers from bigger household.

Table 4: Regression Analysis of Average Daily Miles

	Model 1		***Model 2***	
Term	Coeff.	*p*-value	Coeff.	*p*-value
Intercept	37.5991	<.0001	36.5016	<.0001
Region[Bay Area]	-3.6196	<.0001	-2.6251	<.0001
Region[Los Angeles]	1.2363	0.0694	0.6039	0.2691
Region[Other]	5.3777	<.0001	4.0911	<.0001
Region[Sacramento]	-0.0815	0.9597	-1.0101	0.4241
Model[Leaf]	-8.7958	<.0001	-7.7638	<.0001
Model[Plug-In Prius]	8.4081	<.0001	7.2492	<.0001
HOV sticker[No]	-2.2041	<.0001	-1.9961	<.0001
Income	0.0000	0.0804		
People in HH	1.4079	<.0001	1.5602	<.0001
Children_under_12	-0.4461	0.357		
Number of vehicles in the household	1.2898	0.0002		
Commute[No]	-3.9008	<.0001	-3.8791	<.0001
Region[Bay Area]*model[Leaf]	2.7020	0.001		
Region[Bay Area]*model[Plug-In Prius]	-3.3831	0.0019		
Region[Los Angeles]*model[Leaf]	-0.4809	0.555		
Region[Los Angeles]*model[Plug-In Prius]	1.1020	0.2765		
Region[Other]*model[Leaf]	-4.2316	0.0007		

Region[Other]*model[Plug-In Prius]	5.1992	0.0012		
Region[Sacramento]*model[Leaf]	-0.5104	0.7881		
Region[Sacramento]*model[Plug-In Prius]	1.1532	0.6374		
Driver age	-0.1838	<.0001	-0.1571	<.0001
Driver sex	-0.3694	0.9006		
Type of residence[Detached house]	0.0215	0.985		
Type of residence[Attached house]	2.2384	0.103		
Type of residence[Apartment/Condominium]	-1.6861	0.2582		
Adjusted R2	**0.31**		**0.27**	

Commute trips have an important impact on total miles, with more than 70% of households using their PEV for this purpose. Prius commute trips are the longest with an average of 24 miles one way calculated based on the shortest path. The Volt commute is close the Prius, only 1.9 miles less, but the Leaf commute is significantly shorter at 17.3 miles. In all cases Los Angeles and rural areas have the longest commute.

Table 5: One-way Commute (in miles) by Region and Model

	Volt		**Plug-in Prius**		**Leaf**	
Area	N	Mean	N	Mean	N	Mean
All	*284*	*[a]22.1*	*381*	*[a]24.0*	*998*	*[b]17.3*
Bay Area	111	[a, A]22.2	132	[a, C] 20.7	424	[b,A,B] 17.5
Los Angeles	119	[a, A] 22.9	195	[a, B] 26.1	297	[b, A] 18.8
Sacramento	7	[a] 15.3	8	[a, B,C] 18.0	26	[a,B,C] 13.0
San Diego	19	[a] 15.6	25	[a, C] 13.0	163	[a, C] 14.6
Rural areas	24	[a, A] 23.7	18	[b, A] 36.6	72	[a, A] 19.6

Within an area compare the lower case letters to determine if the vehicles behave similarly e.g. San Diego Volts (a) are similar to Plug-in Priuses (a.)Uppercase letters should be read vertically and are region comparisons e.g. Volts are similar in Los Angeles and rural areas (Comparisons for each pair using Student's t)

The commute represents the most common miles driven, but the correlation between commute distance and average daily miles is relatively low (R^2=0.28) meaning that distance of the non-commute trips is diverse and not correlated with commute distance. Overall we see a self-selection of vehicle type and total miles and commute distance as Leaf owners drive well within the range of home charging, Volt users take longer commute trips and overall miles, utilizing their full electric range, while Prius drivers take advantage of their good MPG and their range only limited by short refuel stop and drive longer than others. The eVMT of PHEVs is also a function of the users charging behavior explored in the next section.

Charging Behavior

In this survey we used three sets of questions to collect data on charging behavior. First, we asked about charging at home using average plugged-in frequency over 2 hour increments. Even though this question has the potential to calculate charging time, we used it to calculate the number of charging events (i.e. plug-in events) assuming that each event results in a full battery. Second, we asked about the level of charging power and their electricity rates. For work charging we asked about commute days, charging availability, charging events, cost and number of days unable to charge due to congestion. A third set of web-map questions was used to collect data on other public charging locations and frequencies. We used the three sets to calculate average number of charging events and potential of eVMT per day based on the EPA electric range. Table 5 represents the number of home and total daily average charging events by model and region. Prius owners plug in fewer times both at home and in total including public even though they reported on the highest VMT and have the shortest EV range. In most cases Volt and Leaf drivers have the same charging patterns accept for Volts in rural areas and in Sacramento who plug in more. Bay Area drivers plug in the most while Los Angeles the least with the Prius plugging in much less than the Volt or Leaf drivers.

Table 6: average reported charging events

	Volt				Plug-in Prius				Leaf			
	Home		Total		Home		Total		Home		Total	
Area	N	Mean	N	Mean	N	Mean	N	Mean	N	Mean	N	Mean
All	*662*	*^{a}5.4*	*662*	*^{a}6.5*	*848*	*^{b}5.0*	*848*	*^{b}5.8*	*2165*	*^{a}5.4*	*2202*	*^{a}6.4*
Bay Area	235	$^{a\,A}$5.6	235	^{a,A}7.1	270	^{a,A}5.5	270	^{b,A}6.4	889	^{a,B}5.4	889	^{b,A}6.5
Los Angeles	292	$^{a\,A}$5.2	292	^{a,B}6.2	454	^{b,B}4.7	436	^{b,B}5.3	647	^{a,B,C}5.3	642	^{a,A}6.4
Sacramento	23	$^{a\,A}$5.8	21	^{a,A,B}6.5	19	^{a,A,B}5.3	19	^{a,A,B}6.5	64	^{a,B,C}5.1	64	^{a,A,B}6.1
San Diego	50	$^{b\,A}$5.2	48	^{b,B}5.8	47	^{a,b,A}5.6	47	^{a,b,A,B}5.9	378	^{a,A}6.1	370	^{a,A}6.7
Rural areas	48	$^{a\,A}$5.5	48	^{a,A,B}6.4	51	^{a,A,B}5.3	47	^{a,A,B}5.9	187	^{a,C}4.9	178	^{a,B}5.6

Within an area compare the lower case letters to determine if the vehicles behave similarly e.g. San Diego Volts (a) are similar to Plug-in Priuses (a)Uppercase letters should be read vertically and are region comparisons e.g. Volts are similar in Los Angeles and Sacramento (Comparisons for each pair using Student's t)

Electric Miles: eVMT

Assuming a full vehicle charge (to 100%) for each charging event we can calculate the portion of average eVMT per vehicle type and location. The LEAF eVMT has to be 100% of the VMT and is used to validate the quality of the reported data. The average charging behavior report fits all the VMT reported by 94% of the Leaf owners while the other 6% under report an average of 30% of their charging events. Overall, after correcting for the underreported charging, the average eVMT calculated for the Volt population was 80% of the total VMT and the average eVMT calculated for the Prius population was 26% of the total VMT. Prius drivers use electricity for only about a quarter of the trip or about 10.6 miles per day, significantly lower than the Volt with an average of 28.9 electric miles per day, or the 28 miles of the leaf. To calculate the potential eVMT on an average driving day, we used two-way commute travel calculated based on the fastest network path plus 10% VMT per day to compensate for other destinations during the day that is correlated with the half the average ratio between commute trips and daily VMT in California based on the 2001 Caltrans travel survey. Drivers who report charging at home more days than their commute days were modeled as leaving home with full battery, while drivers who charge at home with lower frequency start with an electric range that reflects charging to commute ratio. Charging at work allows a full electric range on the travel from work to home, again scaled based on times charging at work over times commuting. Table 7 represents the potential eVMT of PHEV owners in a commute day when charging at home or at home and work. The battery size of the Volt allows up to an average of 43.3 electric miles per day which is almost 90% of the daily miles if plugging in twice a day. A Prius can get up to almost 20 miles which is 37.3% of the daily miles. Actual behavior reflects lower charging rates at home and even less at work but still commuters who plug in at work get up to 67.5% of their VMT on electricity for the Volt and up to 20% for the Prius. The last two rows compare the potential vs. actual eVMT based on the difference between reported charging behavior and charging daily at home and work.

Table 7: Average Daily Estimated eVMT Miles by Region and Model

Commuters travel	Volt (commuters daily miles 48.6)			Prius (commuters daily miles 52.8)		
Potential eVMT	N	eVMT	eVMT share	N	eVMT	eVMT share
Home charging eVMT	284	30.3	62.3%	381	10.5	19.9%
eVMT with work charging	284	43.3	89.1%	381	19.7	37.3%
Estimated eVMT						
Home charging eVMT	284	26.6	54.7%	381	8.4	16.1%
eVMT with work charging	283	32.8	67.5%	381	10.6	20.1%
to Potential						
	N	eVMT difference	eVMT ratio	N	eVMT difference	eVMT ratio
Home charging eVMT	284	3.7	87.8%	381	2.1	80.0%
eVMT with work charging	283	10.5	75.7%	381	9.1	53.8%

The Estimated eVMT of the Volt is significantly higher mostly as the electric range is higher but also because of the difference in charging behavior between the Prius and the Volt owners. Prius owners use their battery less because of a lower charging rate at home and at work/public. In the next section we will explore potential reasons for the charging behavioral differences focusing on the barriers of PHEV owners in maximizing eVMT.

Charging Barriers

What are the barriers for Plug-in owners from charging when needed? Our survey suggests that PHEV owners are less likely to plug in at home than BEV owners, and that Prius owners plug in less than Volt owners. 12% of Leaf owners do not have level 2 (208-240V) chargers at home. 53% of the Volt owners and 89% of the Prius owners also do not have a level 2 charger but do they need one? A Prius is not utilizing the charging speed allowed by a level 2 charger but even though it can charge an empty battery in less than two hours. A Volt will need about 5 hours, but in both cases level 1 (120V) is sufficient for one charging event, likely overnight, per day. Level 1 charging at home reduces charging frequency at home by 12% on average, though the difference is mostly attributed to the vehicle type. One main reason for using less home charging may be because of the need to use the convenience cord, which needs to be carried out of the car and plugged to the wall socket and the car. If a driver should choose to leave the convenience cord at home it may reduce public charging by preventing the use of level 1 away from home. The lack of Level 2 at home may also reflect the low priority for optimizing the usage of home electricity by applying for EV or time of use rates. In other cases, PHEV users of level 1 at home are more likely to leave the cord at home and not to plug in in public places.

The second barrier for charging at home is cost of electricity compared to the cost of gasoline. Figure 3 present the cost per mile based on average electricity price and gasoline price in California. For the Plug-in Prius, the range of prices above home electricity (>15₵) and below the break-even gasoline price (23₵) is smaller than for other vehicles. A driver paying higher electricity rates commented in our survey stating, *“the Toyota Prius only gets 10 miles per charge which could take several hours charging. It makes no sense to charge this vehicle. Your survey has no provisions for customers that choose not to charge the vehicle.*” Others calculated the cost of electricity to explain why they are not charging at home, *“My Plug-in Prius increased my electricity usage by 10% but my bill by 30%. This would be tough sell going electric paying 38 cents a kW/h if I had to charge at home.”* And: *“One clarification: It costs more per mile to run my Prius plug-in hybrid on electricity (at the electricity price at my home, ~$.25 per kWh) than gasoline (it gets about 50 mpg on gasoline).”* No Volt driver indicated not plugging in the car and both Volt and Leaf drivers did not comment on home electricity price, most likely because they moved to better rates and their gasoline substitute is less attractive. The small battery of the Prius and the marginal savings were also named as a reason for not plugging in at home. It is not known if drivers planned this charging behavior before they purchased the vehicle.

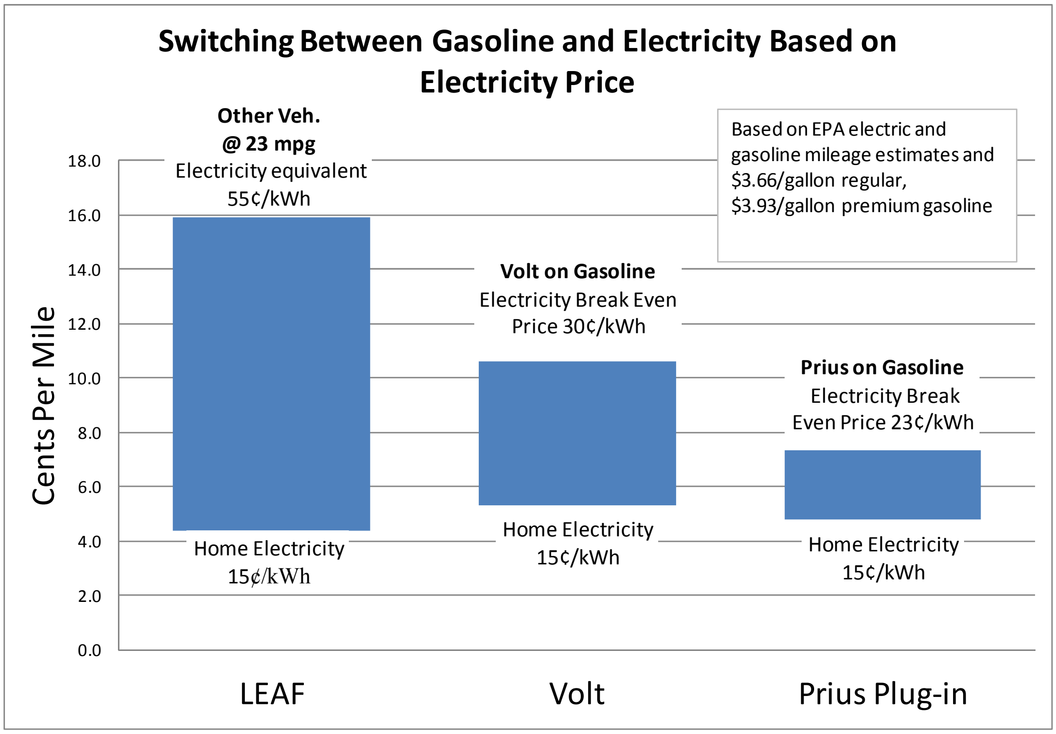

FIGURE 2: Electricity breakeven price points when arbitraging electricity against gasoline.

Workplace charging is the second most important charging location and as presented in the previous section is most important to limited electric range PHEVs. Table 8, explores the differences in workplace charging among the three main vehicle models. Almost half of the Leaf and Volt drivers have workplace chargers versus only 38% of the Prius. However, only 4.6% of the Leafs commuters need workplace chargers, compared to one-third of the Volts, and about 70% of the Priuses. There are two possible explanations to the gap between the need and the availability of chargers. First, PHEV owners are self-selecting to buy the car even if they don't have workplace charging. In this case, Prius drivers have a higher tendency than Volts to buy a PHEV even though they will not be able to maximize their commute eVMT most likely because of the lower EV range and the resulting savings. The second explanation may be a response bias as driver who saves less on charging their car are less likely to look for charging options and may report lower availability. Even among drivers who need and have free charging we find that only 81.6% (62 out of 76) of the Volt drivers and only 47.2% (60 out of 127) of the Prius are plugging in to maximize eVMT.

Table 8: Charging at Work

	Volt		Plug-in Prius		Leaf	
	N	% of Com	N	% of Com	N	% of Com
Total	502		644		1835	
Commuters	415	**100%**	545	**100%**	1449	**100%**
Have work charger	195	**47%**	206	**38%**	724	**50%**
Need work charger	136	**33%**	381	**70%**	67	**5%**
Need and Have (free) Charger	76	**18%**	127	**23%**	62	**4%**
Need Have (free) and Use (per commute)*	62	**15%**	60	**11%**	56	**4%**

* calculated based on the ratio between commute days and charging at work days per week

Pricing on level 2 charging was a barrier especially for Prius drivers who resist high connection payment (per plug-in event fee), and don't want to move their car after a short time charging. Additionally, lack of free level 1 charging was presented as barrier by many users. The need to use the vehicle's convenience cord was not only more work than level 2, but also posed a high financial risk (up to $1,000) in case of theft or damage to the cord. Reviewing the open comment section of the survey revealed only Prius owners mentioned the level 1 charging cable.

Discussion

The data presented an unmet eVMT potential of PEV as charging availability and charging behavior fail to match travel behavior. The main reason for low public charging is, as expected, charging availability but within this category we also find differences between the availability Prius drivers face vs. Volts and Leafs. Charger availability is a factor of the geographic location, driver awareness and driver wiliness to use the chargers. A convenience 120V plug at the workplace parking lot may be reported and used by one driver or ignored by other. Level 1 in public locations was not seen as an option for some drivers' as a result of the extra work in plugging in and because of the potential risk for theft or damage. Charging at home is also more frequent when level 2 is installed and the causality in this case works both ways. Cost of charging has an impact both at home and at public charging especially for Prius drivers but also for Volts. The potential benefit, i.e. total cost/saving per trip or charging event, which is lower for small battery car, may have stronger impact than the cost per kWh or mile as reflected in the difference between Prius and Volt charging. The open text comments also suggest that the short electric range of the Prius together with the longer trips Prius owners drive, make the savings by plugging in negligible compared to the total cost of travel or to the cost of any alternative car. The positive feedback of charging a small battery is lower both in monetary saving and in driving experience as reflected in both the charging frequency and the comments of the Prius users Actual charging behavior is a factor of driving need, vehicle type and charging availability and need to be modeled based on actual behavior of vehicle owners. . Some of the comments on the survey complained that we neglected PHEV owners who choose not to plug-in at all and we suspect that our charging behavior data may be under reporting this group. These comments may point on a self-selection of some PHEV owners who purchased the car knowing that they are unable or unwilling to charge it regularly. The main possible reason for paying extra for a plug-in vehicle over regular hybrid may be the HOV privilege in California but more research is needed to understand charging behavior self-selection.

Conclusion

The utility factor of PHEVs measured as eVMT were calculated based on users self-reported driving and charging behavior. The results show that small battery PHEVs have a low correlation between needed charging and actual charging behavior mainly because of public charging availability as reported by the drivers. There might be a self-selection bias when drivers who do not intend to charge often are buying small battery PHEVs to utilize the HOV sticker. Higher range PHEV drivers and BEV drivers charge more often and report more charging opportunity in the same areas that smaller battery PHEVs could not find chargers. Charging behavior is correlated with eVMT and we believe that the study results suggest that the short EV range of small battery PHEVs may not create a high enough incentive to encourage users to charge their car as often as needed to maximize eVMT. We also see that small battery PHEV owners are less likely to install EVSEs at home or to plug in their car on level 1 when possible. The diverse results raise the question of a more accurate way to measure the impact of plug-in vehicles in reducing ICE driving substituting it for eVMT. Charging and driving behavior are important in measuring the true impact of PEVs. A better understanding of the impact of charging behavior on vehicle usage and the factors that influence charging behavior will allow us to shift to performance based policies that will incentivize vehicles based on their actual on road performance. Current policies may incentivze the purchase of plug-in cars by users who are less likely to maximize the potential of their car and substitute ICE VMT with electric VMT but the data for measuring the technology and policy performance have to be based on a combination of vehicle performance data focusing on driving and charging as well as behavior data focusing on motivations and charging availability.

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