EVS27
Barcelona, Spain, November 17-20, 2013

Studying the PEV Market in California: Comparing the PEV, PHEV and Hybrid Markets

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Abstract

Who is buying electric vehicles? Who is buying new cars in general? Is the first group a subset of the second? What are the similarities and differences of the two groups? Can we use hybrid buyers to predict the future plug-in electric vehicle (PEV) market? This study explores the characteristics of new car buyer households who purchased a new vehicle in California during 2011-2012 comparing three main populations: internal combustion engine (ICE) buyers, hybrid buyers and PEV buyers. We show that PEV households have different socio-demographic characteristics than ICE buyers with, for example, higher income, higher education, and more new cars while hybrid owners are a middle group with characteristics that fall between those of ICE and PEV owners. We also found differences among PEV buyers. Pure battery electric vehicle (BEV) and plug-in hybrid electric (PHEV) households have similar socio-demographic characteristics but they are differentiated by driving characteristics and home location. The PEV market today is based on small number of buyers and small number of potential new car buyers. Targeting the potential car buyers can more rapidly increase the market, create a used market and will open PEV options to larger segments of the population.

Keywords: PEV ownership, California, New car buyers, market analysis.

1 Introduction

Battery electric vehicles (BEVs) and plug-in hybrid electric vehicles (PHEVs), collectively called electric vehicles (PEVs), are now entering the market in substantial numbers. California, arguably the most active PEV market in the world, is responsible for about 42% of the American market. Plug-in vehicles are expected to play a leading role in reducing greenhouse gases, reduce local emissions and reduce oil usage. In 2012 California adopted a goal of 1.5 million zero-emission vehicles by 2025 and the federal government adopted a goal one million advanced vehicles by 2015[3]. By mid-2013 in California about 45,000 PEVs sold in about two and a half years from more than 20 different models but mostly Nissan Leafs, Chevrolet Volts, Plug-in Priuses and Teslas.

Estimation of the market and deployment of electric vehicles are usually based on cost-benefit analyses using technology development scenarios or on theories of adoption of innovation but are lacking actual data on PEV purchases. This paper focuses on new car buyers in California including PEV buyers in order to improve our knowledge on the characteristics of these households with respect to other new-car buyers and other new vehicle

technology buyers such as hybrid vehicle owners. We study the change in the household vehicle fleet when introducing a limited range BEV and will take a first look at the usage of BEVs and other plug-in vehicles.

1.1 Studies on the PEV Market

Estimating the market of plug-in electric vehicles is an important step in planning for vehicle manufactures, policy makers, planners, and others focusing on the various impacts of alternative fuels. Three years into the new PEV market launch, very few studies are basing market forecasts on actual buyer data. Most studies are focussed on three main methods to estimate the demand. The first method is based on estimating who can use plug-in vehicles and battery electric vehicles based on limiting factors such as the ability to charge the car at home (see for example [1,2]) or the ability to accomplish daily travel with limited travel range (See for example [3,4]). The second method is based on estimating the potential benefit for households who will buy plug-in vehicles. The two basic assumptions within these methods is that the purchasing decision is based on a cost-benefit analysis for the household and that travel patterns with the new vehicle are similar to travel patterns with the new plug-in vehicle. The third method is studying the households purchasing decision process and understanding socio-demographic, norms and beliefs that affect this process (see for example, [5]). All of the above methods are based mostly on assumptions on how the vehicles will be used and then forecasting who will buy them or the other way around; assume who is more likely to buy a PEV and then forecast the usage. A different method of focusing on current buyers to predict future buyers is based on studying the characteristics of the current market and focusing on changes in the adopting households. The first step in following PEV buyers in California is presented in a previous paper by Tal et al [6].

2 Research Methods

To better understand new cars buyers in California, we used data on households who purchased a new car in 2012 based on two different surveys.

The overall target population of this survey is new PEV owners in California who applied for the California Vehicle Rebate Project (CVRP) for plug-in owners between February and August 2012 and have more than 6 months 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 only includes PEV owners that were eligible for the CVRP. 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 period with the vehicles with an average of more than 10 months. 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 PEV 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 PEVs	45	323	45	7	310	336

To compare the survey household characteristics to the general population, we used the CALTRANS 2012 travel survey that included 9,600 households that owned a 2012 model car including 5720 households with ICE vehicles and 612 households with new hybrids. The overall sample of both surveys includes 9,600 households with an oversample of PEVs.

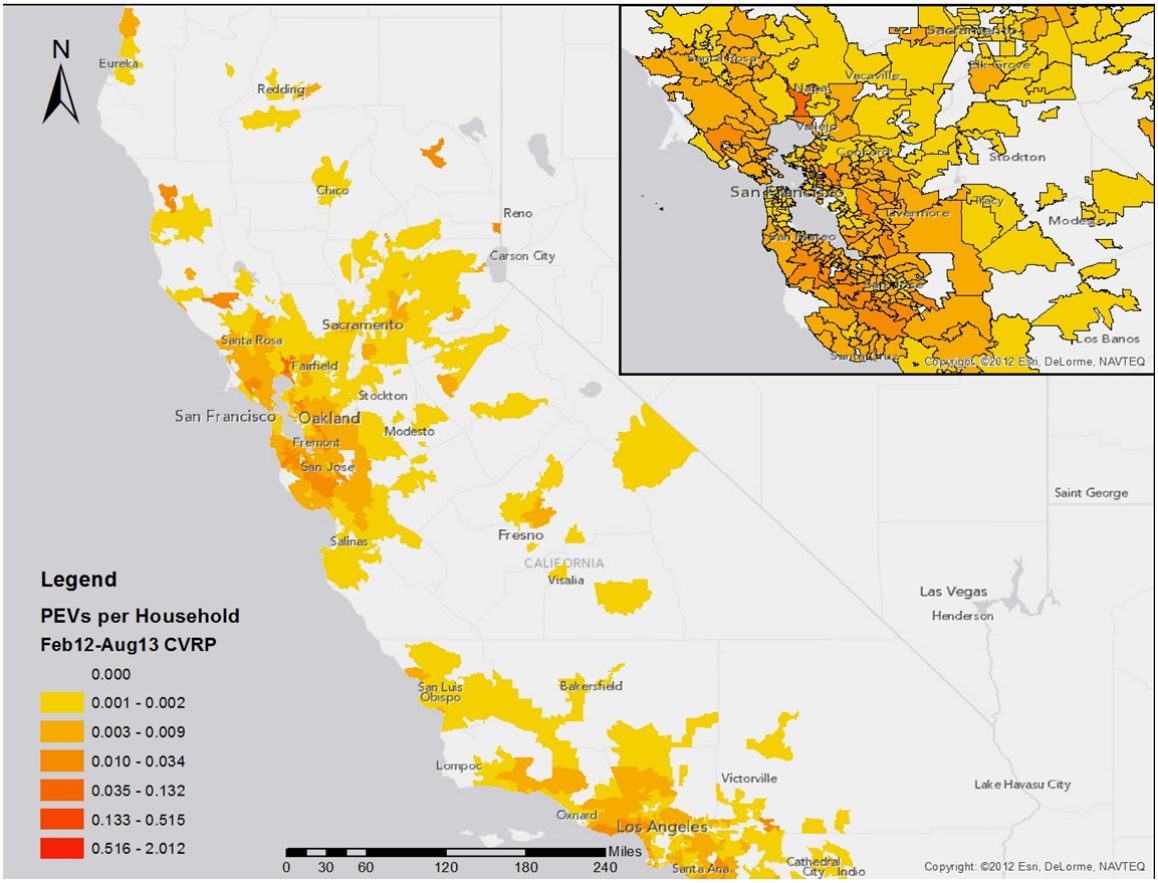


Figure1: PEV per household ratio

3 Household Socio-Demographics

It is clear that PEV owners have higher income than the general population that allows them to buy new cars that on average are more expensive than similar sized ICE cars, but how similar are PEV owners to other new car buyers including hybrid buyers and how different are owners of different PEV models from each other? According to the 2012 Caltrans survey and the 2009 NHTS survey, two thirds of the households surveyed did not purchase a new car in the last 5 years. Some in this group did not purchase any new car and others did it in longer intervals than 5 years. Based on the household current fleet we know that 7% of households purchased 2+ new cars in the last 5 years which make this group responsible to up to one-third of the new vehicles sold. Figure 2, presents the income distribution of those three household groups. As expected, the number of new cars is highly correlated with income but we can also notice a large portion of households with income higher than $100,000 per year who did not purchase any new car in the last 5 years. We can also see households with low income who purchased one or more new cars.

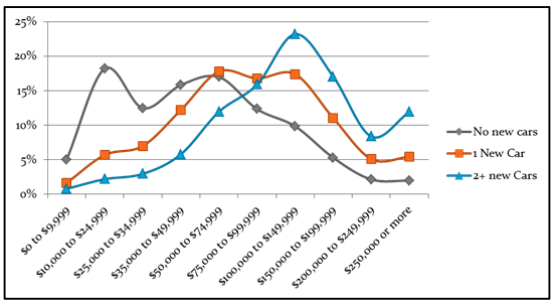
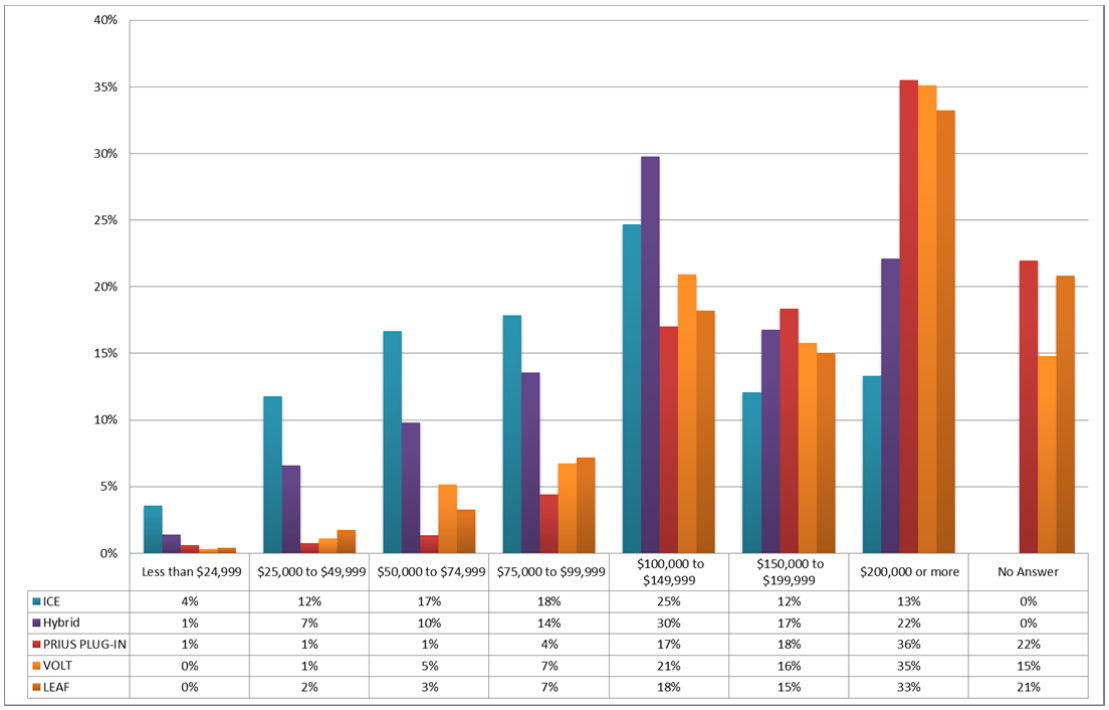


Figure2: Household income by new cars in the last 5 years for the general population

In our 2012 survey that samples the very early adopters of PEVs (mostly LEAFs) in California[6] we found that about half of the PEV households belong to the group who did not purchase a new car in the last five years despite a relatively high income for most of these households. In the new survey we found that only 36% of the new PEV buyers belong to this category most likely as a result of lower number of people who buy the new cars mainly because of the new technology available and a shift to plug-in car buyers who purchased those cars mainly because of the need to



	Less than $24,999	$25,000 to $49,999	$50,000 to $74,999	$75,000 to $99,999	$100,000 to $149,999	$150,000 to $199,999	$200,000 or more	No Answer
ICE	4%	12%	17%	18%	25%	12%	13%	0%
Hybrid	1%	7%	10%	14%	30%	17%	22%	0%
PRIUS PLUG-IN	1%	1%	1%	4%	17%	18%	36%	22%
VOLT	0%	1%	5%	7%	21%	16%	35%	15%
LEAF	0%	2%	3%	7%	18%	15%	33%	21%

Figure 3: Household income by vehicle type

buy a new car not simply to try a new technology. When focusing on the household income of new car buyers for only model year 2012 (Figure 3) we see a major difference between ICE hybrid and PEV buyers. 51% of new ICE car buyers (or leasers) reported an income lower than $100,000 per year.

Only 32% of hybrid owners and 11% of PEV owners reported similar income. On the other end of the spectrum, only 13% of ICE buyers reported an income higher than $200,000 per year versus 34% of the PEV owners who also have 20% who decline to state meaning likely more than 34% of PEV owners earn more than $200,000 per year.

Our sample also includes 50 households with a Tesla Model S who purchased it in addition to another PEV or as a replacement for recently purchased PEV. 50% of Tesla owners reported income higher than $200,000 and 22% decline to state their income. Overall we see no difference between the LEAF, Volt and Plug-in Prius households but we see a statistically significant

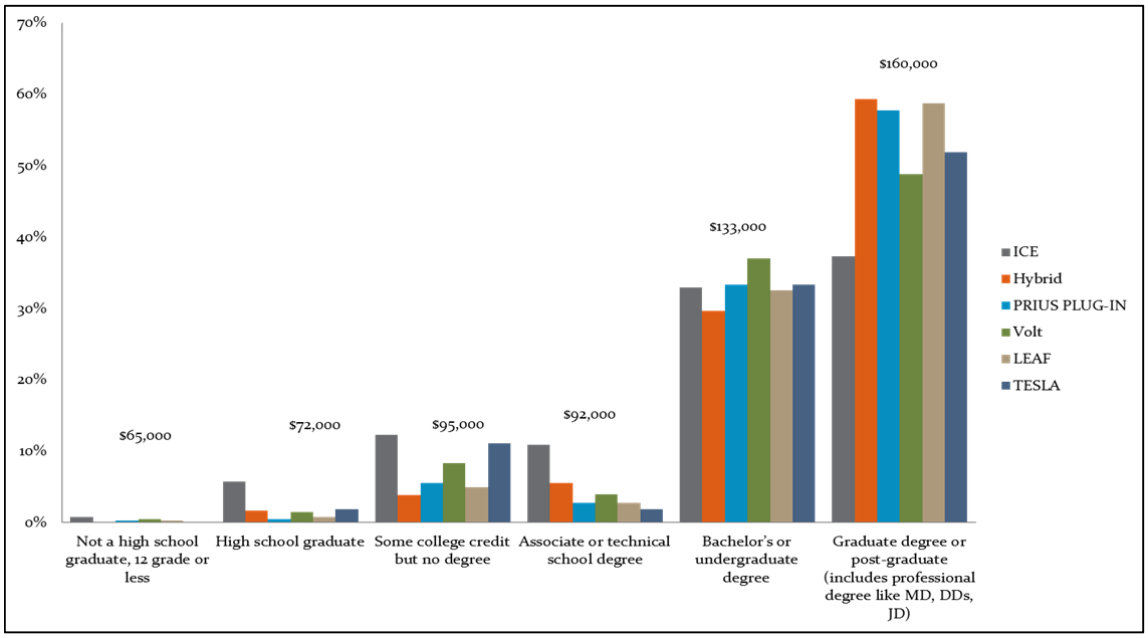


Figure 4: Education of those who purchased a new car in the last 5 years

difference between PEV, hybrid and ICE households' income.

Education level is highly correlated with income and therefore it is not surprising to find high correlation between the highest level of income in the house and the vehicle type (Figure 4). In this case, we see that hybrid owners' education level is similar to PEV owners' and are both higher than ICE owners' education.

Most of the population in California lives in one of the major metropolitan regions and PEV owners are no different. Multi-unit dwellings, called MUDs (24% of households, must be over 4 units to qualify), and rentals are not common among new car buyers in general.
87% of new ICE vehicle buyers live in a detached house, similar to hybrid and PHEV owners. LEAFs are less common for MUD residents by 3%. Plug-in owners typically don't live in MUDs (particularly apartments/condominiums) or in rental properties but still 6% of PHEV owners live in apartments/condos as well as 3% of the LEAFs.

Table 2: Housing type by Vehicle Model

Model	N	Detached house	Attached house (townhome, duplex, triplex, etc)	Apartment/Condo	Other
ICE	5108	86.63%	5.29%	7.97%	0.04%
Hybrid	612	87.42%	5.23%	7.35%	0.00%
PRIUS PIP	814	86.36%	7.49%	6.02%	0.12%
Volt	623	84.43%	8.83%	6.10%	0.64%
LEAF	2130	90.14%	6.10%	3.05%	0.70%
TESLA	47	91.49%	4.26%	4.26%	0.00%

New car buyers also have a similar level of motorization regardless of the region or vehicle type. We compared only vehicles that are in regular use limiting the comparison to less than 20 year old vehicles and up to 5 cars per household. We found that among new car buyers, income and region were not correlated with number of vehicles in use by the household.
Plug-in owners have a slightly higher number of vehicles per person.
We see higher numbers per household for the Tesla Roadster and the Mitsubishi-iMiev but not for the LEAF which may indicate that the number of cars has some correlation with the vehicle functionality based on size but maybe less based on vehicle range.

4 Vehicle Usage and the Motivation for Buying PEVs?

The factors we discuss in the previous sections point to the ability to buy a plug-in vehicle and to general socio-demographic characteristics of those owners. The next section will focus on potential motivations for buying a plug-in car.

4.1 PEV Driving Patterns

We use two main data sources to estimate usage of PEVs based on the self-reported survey data. 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 users.
Table 3 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. The means presented in this table are based on long term averages but still capture the regional difference that mostly stem from different commute paters.

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)

More than 80% of the PEVs are being used for commuting though only 58% commute with this car daily (Figure 6). Leaf drivers and "other" car drivers which are mostly BEVs have a lower commute frequency than PHEV drivers. Regions have minor impacts on commute frequency except from San-Diego with a few more non-commuters. This lower commute frequency is also correlated with higher rates of BEVs and the "other" regions which are mostly non metropolitan areas with

higher rates of retirees and telecommuters. 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 shorter than the Prius by 1.9 miles, but the Leaf commute is significantly shorter at 17.3 miles. In all cases Los Angeles and rural areas have the longest commute.

The commute represents the most common miles driven, but the correlation between commute distance and average daily miles is relatively low (R2=0.28) meaning that the distance of the non-commute trips is diverse and not correlated with commute distance.

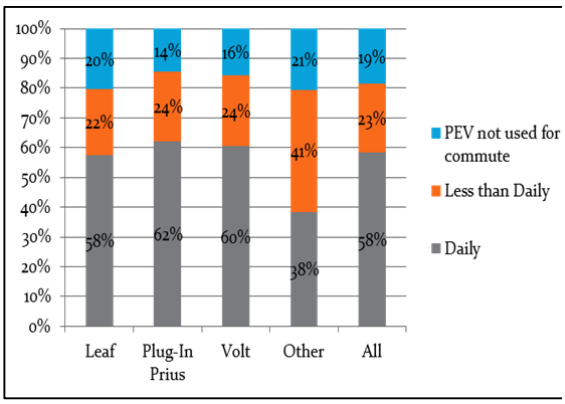


Figure 6: Commuting frequency by type

In all cases, Prius users drive on average more than other drivers. It is not clear if this difference is correlated with trip type and with location, socio demographic and other factors.

We use 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 households. Driving distance distribution of BEVs in our sample is different than PHEVs given the limited daily travel range. PHEVs and especially the very efficient Prius are being used for very long commutes as showed on Figure 7.

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 is only limited by short refuelling stop.

4.2 High Occupancy Vehicle Lane Permit

3164 out of 3757 in our sample have an HOV sticker that allows them to drive in the high-

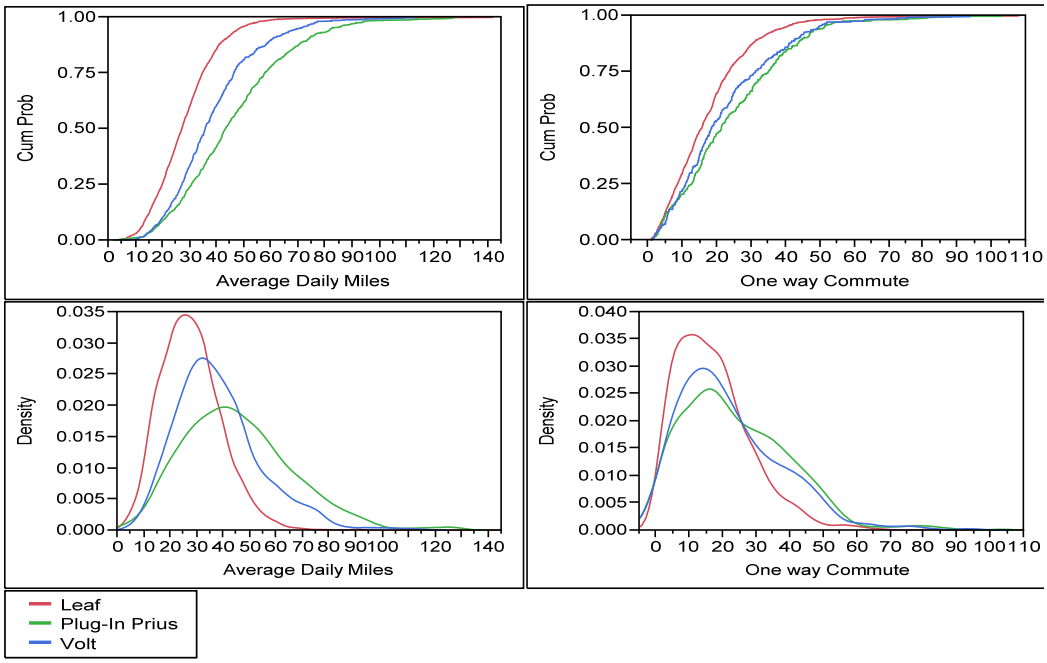


Figure 7: Average daily miles and one way commute distance

occupancy toll lane with only one driver. PHEVs tend to have more stickers with Prius at 95% and Volt at 89%. The highest BEV, the LEAF, has only 79%. When testing the impact of the region we see that the Bay area and the Los Angeles area have a higher share of stickers for all vehicles and also a higher share of PHEVs but even when controlling for this we still have a significant impact of the vehicle type. HOV stickers are correlated with the higher driving distance and commuting distance of PHEVs.

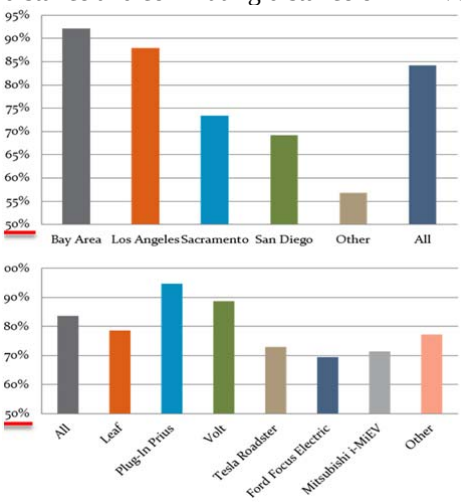


Figure 8: PEVs with HOV stickers (bars start at 50%)

4.3 The Impact of Location on the BEV or PHEV Purchasing Decision

The household location is correlated with socio-demographic characteristics and with travel behavior patterns. Location is one of the main factors in understanding whether to buy a BEV or a PHEV. We use the data from the California rebate program (26,571 privately owned BEVs and PHEVs purchased between Feb 2012 and Aug 2013) to study the BEV-to-PHEV ratio by zip code in California (Figure 9.) the map revealed two distinguishing phenomena. First, when focusing on the Bay Area, it is clear that the inner ring of the metropolitan area has a higher ratio of BEVs while the PHEVs have a higher ratio on the outer ring. This pattern can be correlated with commute distance, usage of HOV stickers and also higher income levels in some inner areas that may be correlated with Tesla ownership. The second pattern we observed is the high number of PHEVs in Los Angeles region comparing to lower levels in San Diego area. Here, again, we correlate the differences with usage patterns as Los Angeles drivers have longer commutes and longer driving distances on average. Los Angeles drivers may also have higher energy demand that may be challenging to the midrange BEVs with not only longer trips but also with a longer portion of freeway speed trips (partially resulting from the HOV sticker) and warmer weather requiring A/C.

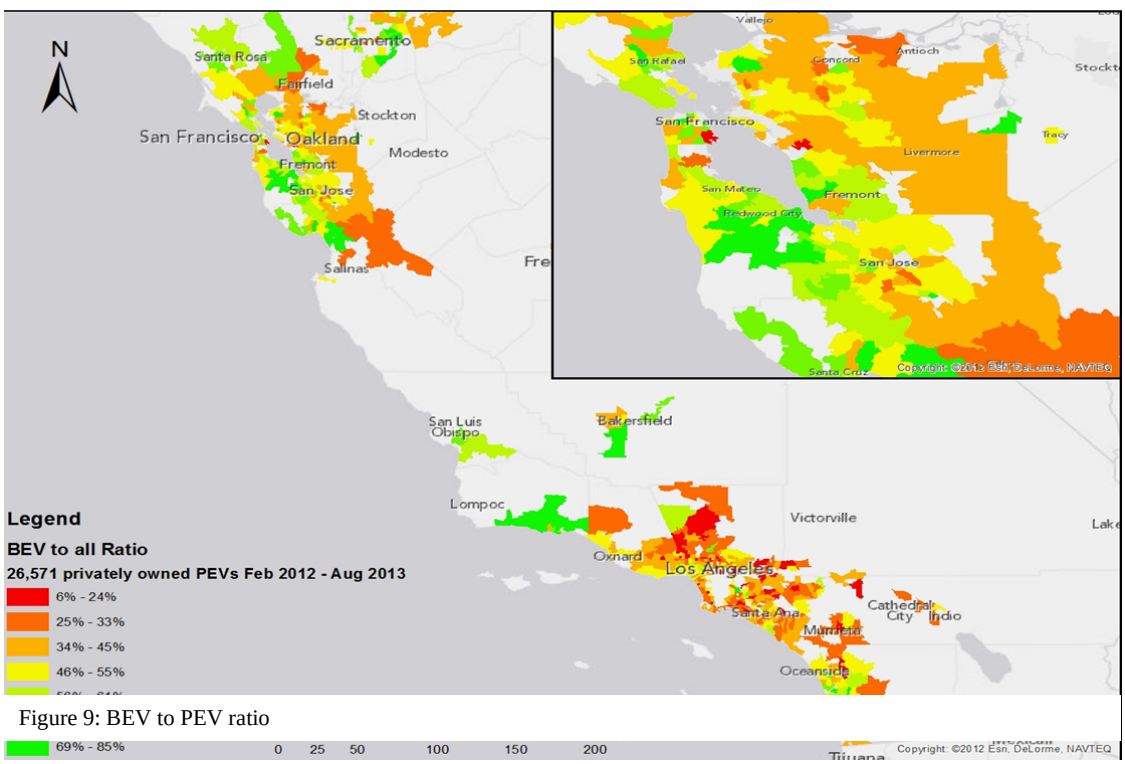


Figure 9: BEV to PEV ratio

5 Household Fleet and Purchasing Behaviour

PEV owners' past and current vehicle fleet can help in understanding the motivations for PEV purchasing and the tendency to adopt new alternative fuel vehicles. Furthermore, focusing on future PEV purchases, we can learn about future decisions of the household based on current investment in EVSE, purchase or lease decision, hybrid or second PEV ownership and more.

5.1 Alternative Fuel Vehicle Ownership

Current or past ownership of alternative fuel vehicles in the household reflect the household disposition to purchase new technologies that aim to reduce gasoline consumption. We have two data points on alternative fuel vehicle experience for the household. The first is based on the household current fleet including after purchasing the PEV. The second data point is based on a question about cars the household has previously owned. Both data sources are presented in Figure 10 and show us that about a third of the PEV households have or had alternative fuel vehicles in the past and that in many BEV households, hybrids are still a second car. We see that in case of the 50 Tesla Model S households in the sample (all have or had a second PEV before the Tesla Model S) hybrid ownership was replaced by PEV ownership while Prius households still own both a plug-in and a hybrid.

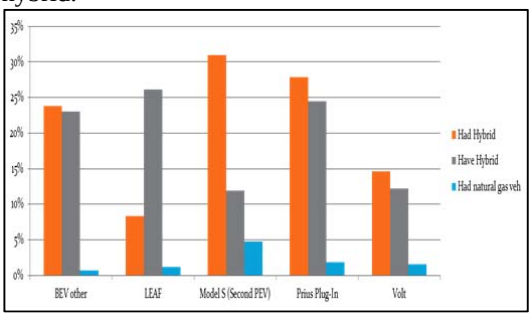


Figure 10: Alternative fuel and electric drive vehicles for PEV households

Overall if we assume no overlap between "have" and "had" a hybrid, at least half of the new PEV owners are new to electric drive or alternative fuel vehicles. The large majority of those who have experienced these vehicles have or had hybrids while LNG, diesel or other fuel used by around 1% of the households.

5.2 Multi PEV Households

For many households, PEVs will be the only type of new car they will purchase. Other households are still experimenting with PEVs trying both BEVs and PHEVs. Our 2013 survey includes 8% of households who owned more than one PEV as presented in Table 4.

Table 4: Other PEVs in Household

Model	N	PHEV	BEV	All
Model S	42	14%	21%	36%
BEV other	143	8%	20%	28%
LEAF	1825	2%	4%	7%
Volt	498	4%	2%	6%
Prius Plug-In	654	3%	3%	6%
All	*3162*	*3%*	*5%*	*8%*

The Tesla Model S have the highest number of second PEVs as all Model S owners in our survey were invited because of a previous PEV and not because of the new Model S they own. The Model S owners in our sample together with the other less common BEV owners represent the more experimenting household who have the means to buy a second PEV the same year. Nevertheless, the large group of Leaf, Volt and Prius owners also includes 6 to 7 percent households with two PEVs. Our initial expectation was to find a second BEV in a PHEV household and vice versa but many households have two BEVs or PHEVs some of the same model. The two-PEV households may be a indication at the way future household fleets will look or just a minor outlier group. In any case this group helps in launching the market and is likely to contribute to the used PEV market.

5.3 Buy or Lease?

71% of the sample of 3,800 PEV owners who acquired their car after February 2012 bought the car and only 29% leased it. Out of the three main models, Volt owners have the highest lease share of 38%, the Leaf lease share is 31% and the Plug-in Prius lease share is 18%. We believe that the higher number of buyers reflect trust in the new technology as well as the regular car shopping behavior of the new car buyers. The differences between the models may reflect differences in market preference as Prius owners plan two hold their car for longer than LEAF or Volt owners but it may also reflect the car dealers and car manufacturers' preferences. We also learn that the lease or buy distribution is not correlated with

income and that 28% of the households who reported income higher than $200,000 a year lease their car. We found some correlation with location as owners in Los Angeles have higher lease rates but this may be explained by the high number of car company employees who lease PEVs and live in this area.

5.4 EVSE (Electric Vehicle Supply Equipment) Installation at Home

The cost of installing level 2 charging at home can be a barrier for many potential buyers and a reason for buying the next PEV for households who already invest in it. As expected, EVSE is installed by BEV households more than that of PHEVs and by cars with larger battery capacity more than cars with a small battery (Figure 11). We expect leasers with EVSE at home to be the first group to trade their PEV for a new PEV around 2015.

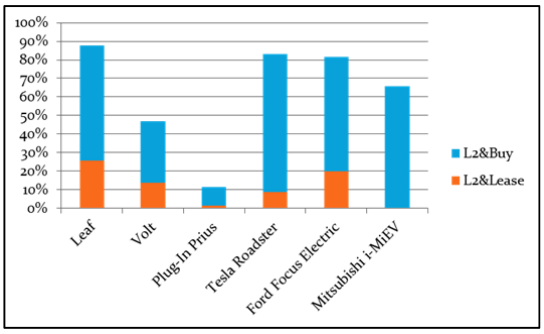


Figure 11: EVSE by buy/lease

The group of potential second PEV buyers included mostly LEAF and Volt owners with only few of the many Prius owners and few of the small volume cars owners.

6 Discussion

New car buyers are a small group in the population with unique socio-demographic characteristics. PEV buyers are an even smaller group with similar characteristics but even higher income, education, alternative fuel cars, live in a single family or townhouse style dwelling and have high home ownership rates. Despite the similarities, PEV buyers are not a subset of the regular routine car buyers and some have not purchased a car for many years before buying the new plug-in. Nevertheless, many of the PEV households are part of multi-new-car households who are responsible for about third of the new vehicle market and can stimulate the used PEV market. In general, new car buyers don't live in MUDs, PEV owners are even less likely to live in MUDs or to be single-vehicle households.

The main differences between ICE and PEV buyers are socio-demographic. Further, PEV owners are different in their higher ownership level of hybrids and other alternative fuel vehicles which may indicate the next group of potential customers. The main difference between BEVs and PHEVs are in driving patterns and home location. It is difficult to predict BEV vs. PHEV ownership but we can see the differences in the impact of incentives such as the HOV sticker.

7 Conclusions

At market launch most of the initial buyers will be those households with relatively high income who are willing to take the risk of buying new technology with oftentimes underdeveloped public charging infrastructure. The buyers are more likely to be found in non-rental detached houses, but some early buyers will be found in multi-unit dwellings. First adopters are more likely to buy many new cars and will both launch the new car market and create the used PEV market. We are not suggesting PEV buyers are all buying vehicles for altruistic reasons but those households can benefit from the federal tax credit, need the HOV stickers and are willing to pay for the car and the EVSE installation when needed. To continue momentum, market policies need to target mutli-new car buyer households, encourage EVSE installation and focus on populations who are willing to pay for the technologies. High demand will lead the used PEV market and will help decrease the price of all PEVs in a way that will benefit wider segments of the population. The policies and incentives need to be adjusted based on continuous studies similar to the one presented in this paper to gauge changes in the market and public preferences and to target the next likely buyers to continue market momentum.

Acknowledgments

The California Center for Sustainable was invaluable partner in collecting the data for the PEV owners' survey. Daniel Scrivano deserves special thanks for programming the survey under tight deadlines.

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