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Research Report – UCD-ITS-RR-14-16

# Exploring the Impact of High Occupancy Vehicle (HOV) Lane Access on Plug-in Vehicle Sales and Usage in California

October 2014

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# Exploring the Impact of High Occupancy Vehicle (HOV) Lane Access on Plug-in Vehicle Sales and Usage in California

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## ABSTRACT

Allowing single-occupant advanced clean vehicles to use carpool or high occupancy vehicle (HOV) lanes is an important non-monetary sales incentive. This incentive needs to be balanced against the potential cost of increased congestion on those lanes and reduced revenue of high occupancy toll (HOT) lanes, especially during peak travel periods. In a 2013 survey, when Plug-In in vehicle buyers were asked about their primary motivation to buy a plug in car, 57% of Plug-in Priuses, 34% of Volts and 38% of LEAFs identified the HOV sticker. Current legislation in California allows a limited number of stickers for plug-in hybrid vehicles and an unlimited number for full battery electric vehicles. This paper offers an analysis on the impact of these stickers on the vehicle purchase decision and the resulting electric miles traveled. We also offer an analysis of the potential cost in terms of miles driven on HOV lanes. The results can help policy makers optimize the benefit for each additional permit while understanding the impact of different vehicle types.

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## INTRODUCTION

High occupancy vehicle (HOV) lane access can be an important non-monetary incentive for increasing advanced clean vehicle sales. Studies on the sales of hybrid cars in relation to the HOV sticker revealed a positive impact that varied mostly by location[1] [2]. This incentive needs to be balanced against the potential cost of increased congestion on HOV lanes and against reducing high occupancy toll (HOT) lane revenue, especially during peak travel periods.

In California, there are two types of single occupancy vehicle HOV access permits: 1) white stickers , available to an unlimited number of qualifying federal inherently-low-emission vehicles, which are mostly 100% battery electric vehicles (BEVs) and compressed natural gas vehicles and 2) green stickers , available to the first 75,000 applicants that purchase or lease cars meeting California's transitional zero emission vehicle (TZEV) requirement, which are mostly plug-in hybrid electric vehicles (PHEVs). The expiration date for both the green and white stickers is 2019.

The green sticker quota was exceeded by mid-2014 and an emergency issuance of 15,000 stickers was made in July 2014. Current discussion focuses on whether to add more green stickers beyond the current limit of 55,000. More stickers will sell more PHEV's but will also increase the number of cars on HOV lanes. In general, every additional vehicle that uses the HOV lane may contribute to performance reduction, especially if added to HOV lanes with usage close to capacity. By developing a better understanding of the costs and benefits of HOV stickers as an incentive, we can better understand how to tailor policy for maximum benefit.

This paper is based on a survey conducted by the UC Davis PH&EV Research Center together with the California Center for Sustainable Energy on behalf of the California Air Resources Board. We surveyed more than 3,500 PEV owners who purchased their car in 2012. All of the respondents had received the State rebate for purchasing or leasing a PEV. Of those customers, about 3,000 had a white or green sticker on their vehicle and 500 did not apply for any sticker. The survey had a limited number of questions on the impact that HOV stickers had on purchasing the car and questions about travel behavior including home and work locations. The results allowed us to model the fastest path from home to work and to estimate HOV usage. This paper focuses on the different impact of the HOV stickers on the purchasing and usage of the most common plug-in vehicles in the market: the Nissan LEAF, the Chevrolet Volt and the Toyota Plug-in Prius.

## LITERATURE REVIEW

Most of the existing literature on the alternative fuel vehicle (AFV) market including the plug-in market is focused on the vehicle cost [3] and attributes like range and refueling time [4]. Other studies add the refueling availability to the analysis. These studies are usually based on analysis of regular car driving and surveys about preferred future AFV's. A few studies reflect actual PEV buyer preference [5-7]. Studies on the impact of HOV access on hybrid vehicle purchases conclude that these incentives have positive impact that are varied by region and HOV lane usage patterns[1, 8, 9]. Most papers used HOV availability by state or county to explain AFV market share but not the actual driving patterns, including HOV lane usage of the AFV owners. To estimate HOV usage, VMT and the energy and related emissions saved, some used estimations rather than data pointing to the need for more travel and charging data. While the existing models used actual travel patterns they required a set of assumptions about charging behavior including frequency and location. Some studies model vehicle idling time as charging events [10], or modeled only home charging once a day [11] [12] [13]. A more refined model used home dwelling time as charging events and specific locations as potential fast charging locations [14, 15]. Our study combined a survey asking the motivation one has to purchase a car with web map questions, and charging frequency questions that allow an analysis of VMT and electric vehicle miles traveled (eVMT) for a specified day.

## 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 months of experience with the car. This population includes most of the PEV buyers in this time frame including owners of the Nissan LEAF, the Chevrolet Volt and the Plug-in Prius. The sample includes PEV owners that were eligible for the state's Clean Vehicle Rebate Project (CVRP) [18]. This survey was conducted with the California Center for Sustainable Energy (CCSE), on behalf of the California Air Resources Board (CARB). The total number of started surveys was 3,659 with 2,346 commuters, reflecting response rates of about 30%. 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 which is a good representation of the three main vehicle models in use, including the Nissan LEAF, Chevrolet Volt and Plug-in Prius in all five major metropolitan areas (Table 1). The survey is based on self-reported travel patterns using web map questions. The web-map questions allow us to collect data on a large sample of habitual travel 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, willingess to pay and subjective need. Using the survey web-map questions and GIS analysis we estimated commute trip distance, HOV lane usage on the commute and average eVMT. For more details on the survey and the travel activity estimation see Tal et al. 2014 [16].

Table 1: Total Sample and Commuter Share per Region and Main Vehicle Type

| Sample<br>% Daily commuters | San Francisco Bay Area | Los Angeles Area | Sacramento | San Diego | Other | Total |
|---|---|---|---|---|---|---|
| LEAF | 890<br>69% | 647<br>67% | 64<br>73% | 378<br>61% | 188<br>51% | 2167<br>66% |
| Plug-in Prius | 271<br>65% | 456<br>60% | 19<br>68% | 47<br>62% | 51<br>61% | 844<br>62% |
| Volt | 235<br>67% | 292<br>55% | 23<br>52% | 50<br>64% | 48<br>75% | 648<br>61% |
| Total | 1396<br>68% | 1395<br>62% | 106<br>68% | 475<br>62% | 287<br>57% | 3659<br>64% |

## HOV sticker and PEV purchasing

The survey includes three types of questions related to the importance of the HOV stickers to the purchase decision. The first question asks if the sticker is present on the car, the second asks for the primary purchase motivation and the third asks for the importance of different incentives and vehicle performance factors in the purchase decision. The percentage of those that applied for the HOV access sticker include 95% of Plug-in Priuses, 89% of Volts and 79% of LEAFs. When asked about their primary motivation to buy the car 57% of Plug-in Priuses, 34% of Volts and 38% of LEAFs identified it as the HOV sticker (a more recent 4Q 2013 analysis shows somewhat lower percentages - 34%, 20%, and 15% respectively [17]). Figure 1 presents the regional distribution of HOV access as the main motivation for purchasing by vehicle type and location. As expected, the motivation in the Los Angeles region and the Bay Area, areas with many HOV lanes, is higher than other regions. We also notice that in the Los Angeles region, an area with longer average trips, the impact on the Plug-in Prius is higher than on other vehicle types. More than 80% of the PEVs are being used for commuting, which is highly correlated with applying for stickers though only 58% commute with such a car daily. LEAF drivers and "other" car drivers, mostly BEVs, have a lower commute frequency than PHEV drivers. Regions have minor impacts on commute frequency, except those from San Diego that have a few more non-commuters. Commute trips have an important impact on total miles, with more than 70% of households using their PEV for this purpose.

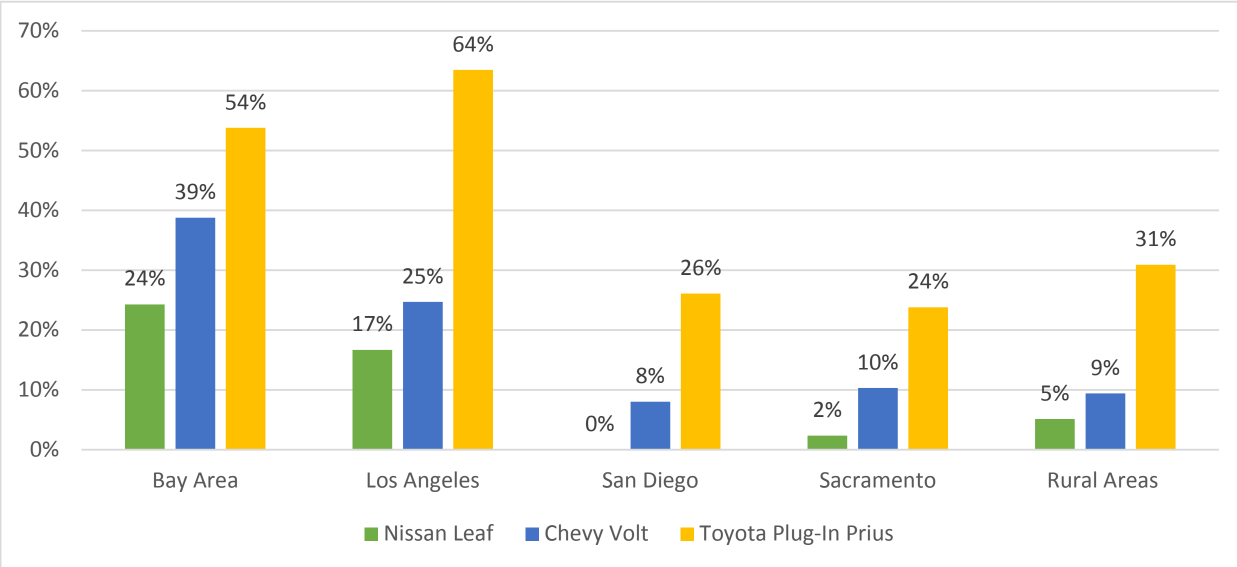

Figure 1: HOV access as a primary purchasing motivation

97% of the buyers who selected HOV access as the most important motivation for purchasing the PEV also selected HOV access as extremely important to this purchase on a scale of 1 to 5. On the other hand, only 58% of the buyers who select HOV as extremely important also selected it as the most important motivation. This sub group who selected HOV as extremely important but not as the most important motivation tend to select many extremely important motivations and incentives (more than 60% overlap) including federal tax credit, state rebate, reduced environmental impacts, and saving money on fuel. As expected, HOV usage is also highly correlated with the motivation for purchasing. 80% of the buyers who selected HOV as most important used those lanes for their daily commute. HOV access importance may not be directly correlated only with HOV usage or commute trips. The ability or potential to save time, even on low frequency trips, including non-commute trips, may have a strong impact on the importance of this incentive. We tested the correlation between the household distance from the nearest HOV lane (regardless of actual usage) and the HOV importance (Figure 2). Among those who live close to an HOV lane, there are fewer LEAF drivers who see the HOV sticker as important compared to Volt drivers or Prius drivers. Additionally, LEAF drivers who live 29 miles from an HOV lane see it as not at all important vs. 66 miles for the few Prius drivers.

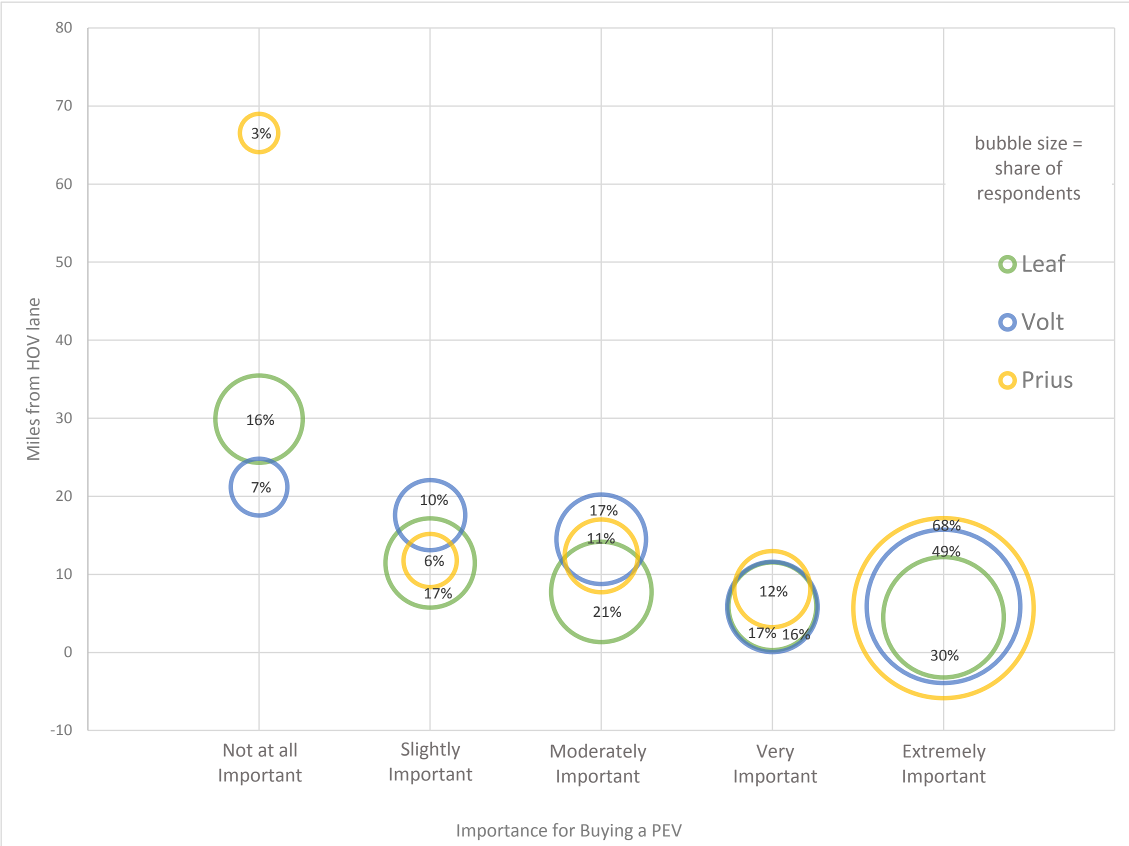


Figure 2: Household distance from HOV lane by vehicle type

Table 2 presents two logit model results. We regress "HOV as the most important motivation" on the household characteristics, vehicle model, and region. When the Volt is compared to other vehicles in the logit model we see the comparative coefficients. Similar to the result presented above, we see that "HOV as the most important motivation" is positively correlated with Prius and negatively correlated with the LEAF. This means that Leaf owners are less likely to select the sticker as the most important even when controlling for other variables in the model and the Prius is more likely. "HOV as most important motivation" also positively correlated with regions that have more lane miles (vs San Diego) and with higher need for travel.

Table 2: HOV Access as a Primary Purchasing Motivation

| **Term** | **Model 1** | | **Model 2** | |
|---|---|---|---|---|
| | Coeff. | *p*-value | Coeff. | *p*-value |
| Intercept | -1113.74 | 0.0016 | -1087.23 | 0.002 |
| Model [LEAF] | -0.28318 | 0.0253 | -0.28175 | 0.0258 |
| Model [Plug-In Prius] | 0.819967 | <.0001 | 0.802992 | <.0001 |
| Income | 1.23E-05 | <.0001 | 1.23E-05 | <.0001 |
| People in HH | -0.05699 | 0.286 | - | - |
| Region[Bay Area] | 0.966739 | <.0001 | 0.966939 | <.0001 |
| Region[Los Angeles] | 0.803991 | <.0001 | 0.804114 | <.0001 |
| Region[Sacramento] | -0.77611 | 0.0597 | -0.79838 | 0.0522 |
| Region[Other] | 0.196264 | 0.3677 | 0.226175 | 0.2974 |
| Age | -0.01591 | 0.0121 | -0.0123 | 0.0375 |

| | | | | |
|---|---|---|---|---|
| Number of Vehicles in the HH | 0.104586 | 0.1225 | - | - |
| Average Daily Miles (Odometer based) | 0.027656 | <.0001 | 0.027976 | <.0001 |
| Commute [Y] | 0.76344 | <.0001 | -0.76892 | <.0001 |
| Adjusted R2 | 0.25 | | 0.256 | |

Overall HOV access is positively collated with the potential to use the lanes. Socio-demographic factors are found to be not significant.

## Correlating Purchasing and Driving Behavior

We used GIS network analysis to estimate commute distance and HOV usage per commute day and odometer readings to estimate average daily miles. Figure 3 shows the HOV usage commute distance and average daily miles by HOV importance and vehicle type. It is clear that people who buy PEVs, where the HOV sticker is the most important incentive, drive more than their counterparts who pick other main motivations. As expected, HOV importance is highly correlated with HOV usage as LEAF drivers travel 11.7 miles to work on HOV lanes while the PHEV drivers travel 13.8 for the Volt and 15 for the Prius. The commute range and average miles are also lower for the LEAF drivers compared to the PHEV drivers, but in this case commute distance for drivers who did not select HOV as most important is similar for all models.

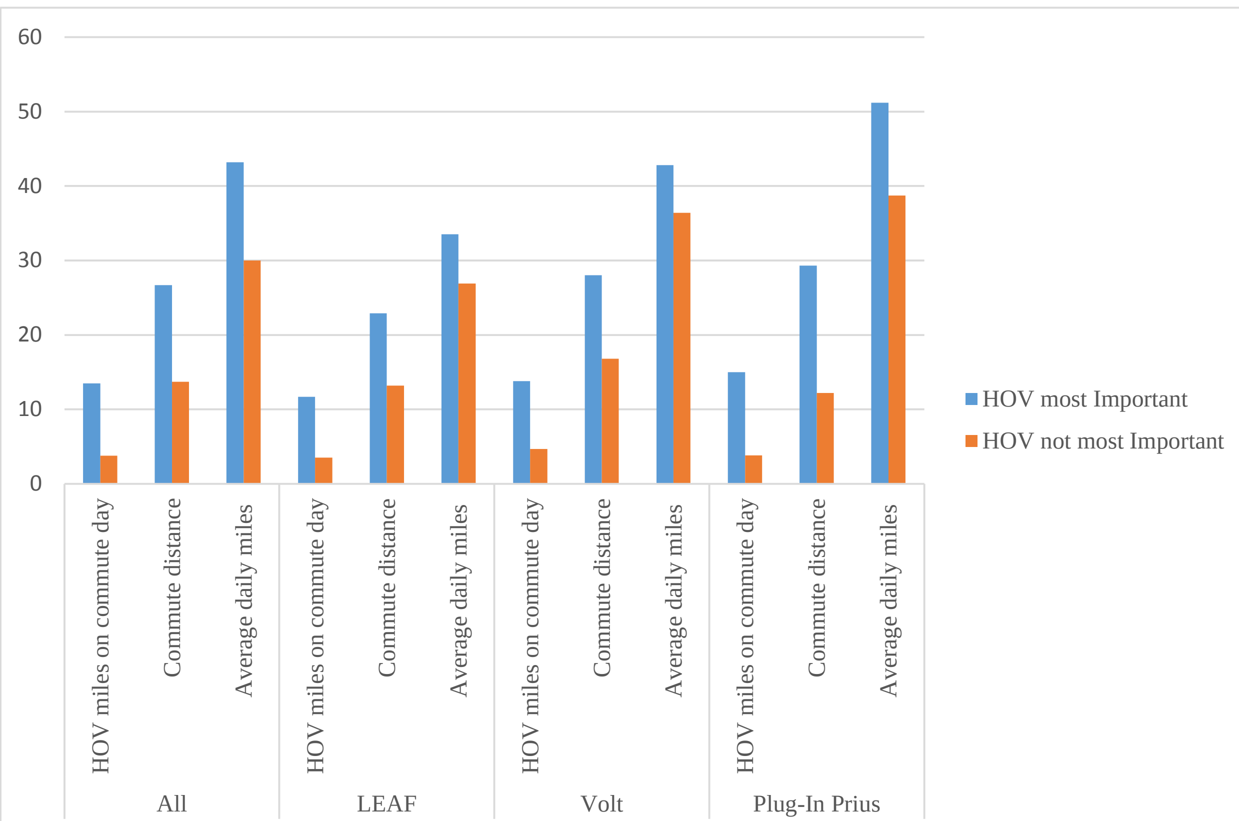


Figure 3:  Travel distance by importance of HOV Sticker

## HOV Stickers and EVMT

The benefit of a PEVs purchase and usage can be measured based on the amount of zero emission usage of both BEVs and PHEVs. A basic measure for the emission reduction can be measured as eVMT, while the incentive performance of the HOV stickers can be measured in terms of eVMT per mile of HOV usage. The vehicle usage is measured both by odometer readings and modeled home-to-work fastest routes. We estimated what share of the daily commute was electric and what part was gasoline powered based on reported home/work charging[16]. The survey data limited the eVMT estimation to commuters and commute trips only. The total daily eVMT is equal to the travel distance for the case of the full electric LEAF and limited to the battery range in case of traveling with a fully charged PHEV, such as the Volt or the Prius. The average daily eVMT calculation is based on home and work charging frequency, battery size and travel distance. For the LEAF we calculated an average commute day mileage of 31 miles (all electric for a BEV) per day for drivers who didn't choose HOV lanes as the main motivation vs. 48 miles per day for drivers who chose HOV lanes as the main motivation. The Volt drivers that did not select HOV lanes as the main motivation were traveling 29 eVMT per day vs. 40 for drivers who chose HOV lanes. For Prius users with much lower electric range the HOV lane groups drove 11 miles per day on electric vs. 10 miles for drivers who chose HOV as their main motivation. The differences in eVMT reflect longer trips for the LEAF and longer trips plus higher charging rates for the Volt. For the Prius drivers, longer trips of the HOV group is not reflected in the eVMT because of the short EV range. Furthermore, Prius buyers who see HOV as the main motivation plug-in their car less than those who purchased the car for other reasons, therefore having a lower average eVMT.  Figure 4 presents a CDF plot of the share of eVMT in an average commute day. In both cases, HOV as the primary motivation is correlated with lower eVMT share, which may result from lower charging frequency and trips longer than the vehicle range. These results suggest that drivers who purchased the car with HOV lane access as the main motivation are not choosing a vehicle battery size to maximize eVMT during their commute days, comparing to drivers who purchased the car with other main motivations.

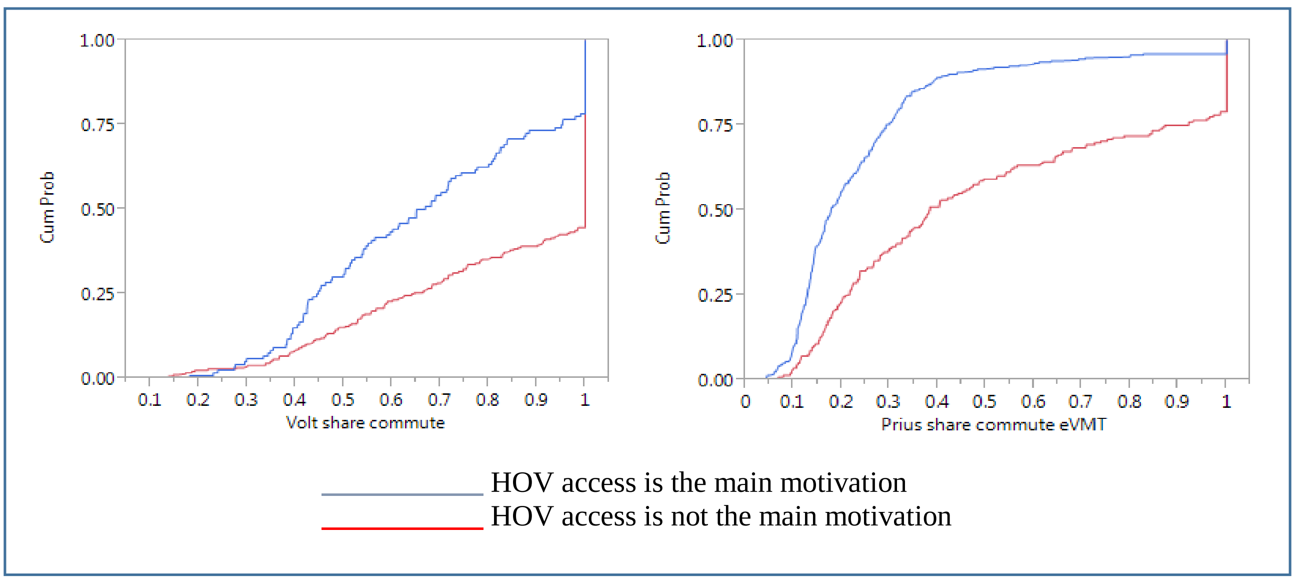


Figure 4:  Share of commute day eVMT for Volt and Prius PHEVs

The social cost of adding single occupancy vehicles to the HOV lane is mostly reducing the lanes' level of service and slowing other drivers especially in areas with traffic close to capacity. While more quantitative analysis is needed to determine the amount of increased congestion due to PEVs, comparing areas with a high presence of plug-in vehicles to CALTRANS HOV lanes designated as close to capacity, we see many overlapping areas both in the Bay Area and in the Los Angeles Area[18].

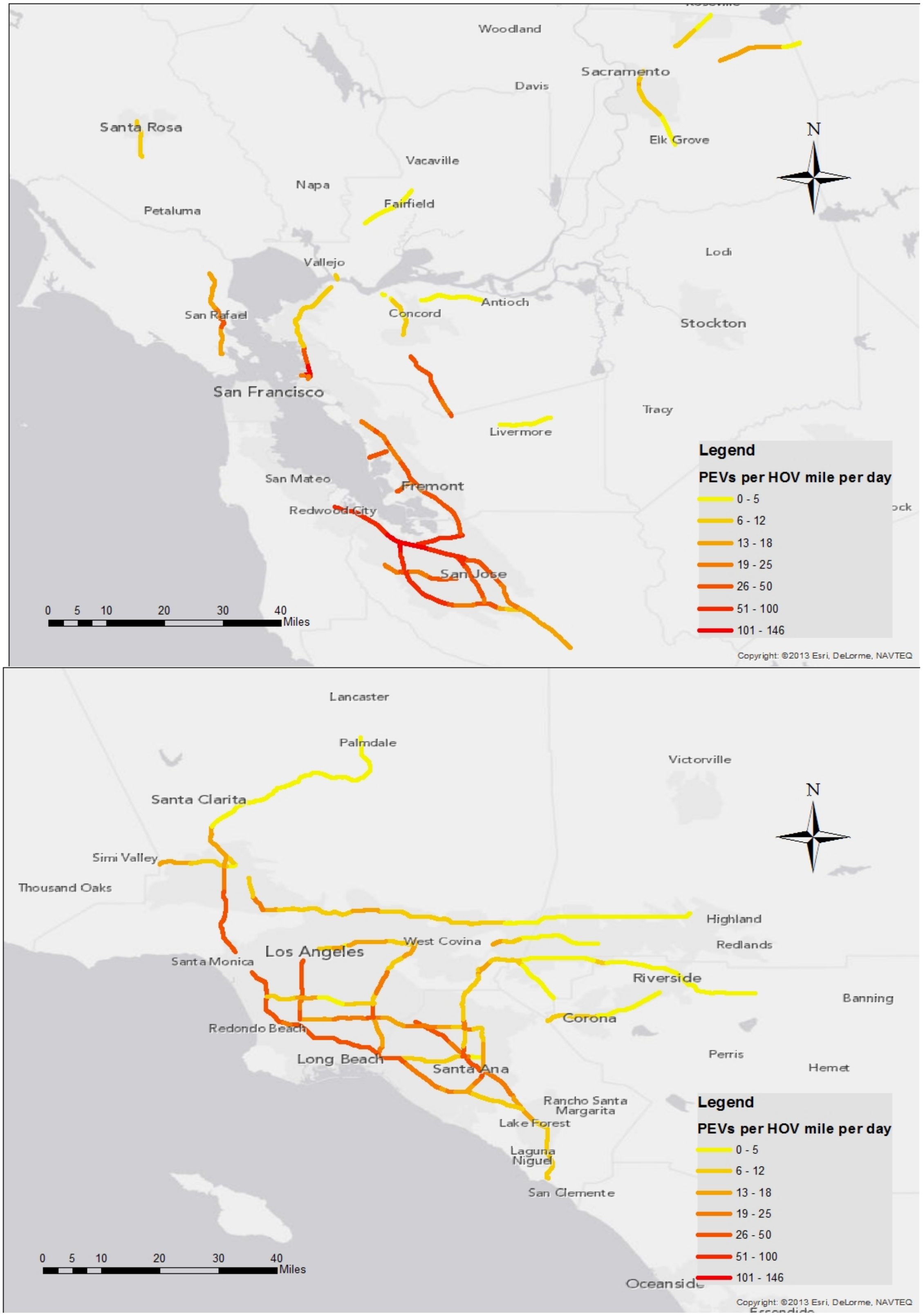


Figure 5: PEV daily miles on HOV lanes

A different way to estimate the cost benefit of the HOV incentive is by computing the ratio between the benefit in terms of eVMT and the cost in terms of HOV lane miles traveled (Figure 6). For every mile a

LEAF is driven on an HOV lane we estimate 4 electric miles are driven (e.g 40 electric miles on a commute with 10 miles on HOV lanes). This compares to less than 1 electric mile for every mile on an HOV lane for the Prius. For all vehicles, HOV lane as the main motivation is correlated with a lower ratio of electric miles to HOV miles.

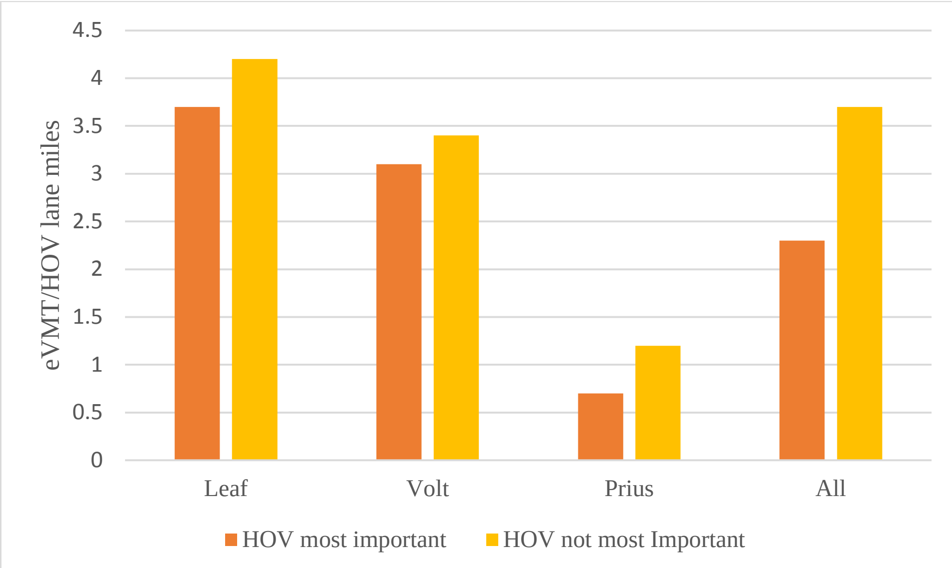


Figure 6: eVMT per HOV mile traveled

## Discussion

The HOV stickers are a strong incentive in regions with many miles of HOV lanes. However, if the HOV lane sticker were not available can we estimate how many fewer sales would result? It is possible that the second or third motivations are strong enough so that the household will purchase the vehicle anyway? On the other hand, the HOV sticker may be second in importance but still the tipping point for making the purchase decision. In both cases, it is clear that the impact of the sticker is higher for shorter range PHEVs with longer commutes and lower eVMT ratio. Commuters who use these lanes are the more likely to buy PEVs, setting the sticker as the main motivation. The stickers also have higher impact on purchasing PHEVs over BEVs most likely as a result of the range limitation that reduce the impact of the sticker. We also see a higher impact on purchasing the small battery Prius over the longer range Volt. In this case, the higher number of Prius buyers who chose HOV as most important may reflect the lower importance of EV range in comparison to other factors such as gasoline efficiency and cargo space.

By using eVMT as a way to evaluate the benefit of HOV stickers, we show the potential to maximize the impact of each additional green sticker in terms of cost, (i.e. miles traveled on the HOV lane) and benefit (i.e. number of eVMT or zero emission miles created per day). Our data do not allow us to analyze the HOT lane revenue loss or the actual level of service reduction per PEV driven on the lanes, but it indicates the average effect on potential policy recommendations. The total eVMT per HOV mile may change in the future if charging availability changes or if cost of charging changes. In case of better charging availability, we expect higher eVMT for PHEVs, limited by the battery size and charging behavior and more importantly a higher number of BEVs who will use the HOV lanes. Pricing of public charging could reduce eVMT but also provide more reliable charging for BEVs thereby increasing eVMT for this group.

## Conclusion

HOV stickers are a very strong non-monetary incentive and as such it is important to maximize their benefits on the alternative fuel market and on the impact of alternative fuel vehicles. First, the results suggest that the HOV sticker may alone be enough to prompt a purchase of a PEV for drivers who use HOV lanes extensively. The impact of the HOV stickers is different for each vehicle type and household based on the location, travel needs, income and other socio-economic variables. Furthermore, we found that the different incentives have differential impacts on the vehicle usage by vehicle type. Smaller battery PHEVs are more likely to be purchased because of the HOV sticker incentive but produce fewer electric miles as a ratio of total miles on HOV lanes. This is different than simply saying that smaller batteries of course get less eVMT, but rather shows that those vehicles are more intensive users of the HOV system in general. Differentiating sticker access between the PHEVs based on their electric range will help maximize eVMT. This can be done by raising the minimum battery size requirement, creating a separate quota for each PHEV type or by creating different sunset dates for each vehicle type. Better data are needed to quantify the impact of the stickers for different vehicles and locations in order to optimize the impact of the HOV and monetary incentives.

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