INSTITUTE OF TRANSPORTATION STUDIES

Research Report – UCD-ITS-RR-14-03

How Assumptions About Consumers Influence Estimates of Electric Vehicle Miles Traveled of Plug-in Hybrid Electric Vehicles: A Review of PHEV Use Data and Possible Implications for the SAEJ2841 Utility Factor (UF) Standard

March 2014

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How assumptions about consumers influence estimates of electric vehicle miles traveled of Plug-in hybrid electric vehicles: A review of PHEV use data and possible implications for the SAEJ2841 Utility Factor (UF) standard

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ABSTRACT

To characterize the environmental impact and petroleum displacement potential of Plug-in Hybrid Electric Vehicles (PHEVs) it is necessary to know what fraction of travel occurs in each of the two energy use modes. Currently, the Society of Automotive Engineers (SAE) estimates the fraction of US travel a PHEV with a given Charge Depleting (CD) range will electrify based on travel data from a national, single driving-day diary and the assumption that PHEVs are charged once-per day. This estimate is used by policy makers, transportation researchers and automotive engineers for purposes which range from State Policy (California Zero Emission Vehicle (ZEV) Mandate), battery lifetime estimates, vehicle to grid interactions and other analyses. However, the SAEJ2841 standard is most realistic for instances where its assumptions are valid ; i.e. consumers do not base their PHEV purchase decision on their driving needs, charge once per day *at home, don't have access to or use public charging infrastructure, and drive their PHEV similarly to the vehicle it replaced. This combination of assumptions is only a single use case for PHEVs and represents untested, universal assumptions about how consumers will choose to purchase, drive and recharge PHEVs. We investigate these four assumptions made in the SAE J2841 standard, and compare each one against the best publically available consumer demonstration and academic analyses to begin the process of assessing assumptions and understanding potential implications for analyses or policies which currently use the SAE J2841. Overall, this analysis is meant to bring depth to the discussion of PHEV impacts and policy which seeks to incentivize electric driving.*

INTRODUCTION

Plug-in hybrid electric vehicles (PHEVs) are dual fuel vehicles, which can operate on liquid fuel and grid electricity. As such, the PHEV drivetrain has been discussed as a means to provide consumers with the best of both worlds: an EV driving experience which also allows for the use of the ubiquitous gasoline fueling infrastructure when charging is not possible or practical. However, the dual fuel nature of PHEVs creates an interesting issue for policy makers, energy analysts and consumers who seek to understand the degree to which PHEVs are able to displace gasoline consumption. Due to of their inherent flexibility, PHEVs will provide varying petroleum reductions, and monetary and environmental benefits - the extent of which will depend upon how much gasoline is displaced by grid electricity and the feedstock used to create that electricity**.** Significant effort has been invested in characterizing the per mile impacts of PHEVs on environmental goals depending on how electricity is generated. However, there has been little research done to characterize which PHEVs consumers buy, and how they drive and charge them. As a step towards understanding the relationship between travel, vehicle design and benefits from PHEVs, the Society of Automotive Engineers (SAE) established the SAEJ2841 standard **[1]**. The standard uses a national, single driving-day diary and the assumption that PHEVs are charged once-a day, at home, to estimate what fraction of national driving could be completed in electric mode for a PHEV with a certain all electric CD range. The estimates provided by the SAEJ2841 have been used by analysts to provide guidance on the potential for PHEVs to reduce gasoline consumption, decrease criteria pollutant emissions and impact vehicle greenhouse gas emissions. In the policy realm, the SAEJ2841 has been proposed as a method to calculate the combined EPA fuel economy used in the SAEJ1711 standard **[2]** and is currently used to calculate the portion of California ZEV credits to assign to specific PHEV designs as part of the California Air Resources Board's (ARB) ZEV mandate **[3]**. As such, the SAEJ2841 has implications for shaping consumer expectations, policy, and on the automotive industry that must plan, design and build vehicles which receive meet compliance criteria. However, the SAEJ2841 methodology is most realistic for instances where its **assumptions** are valid. While the conditions of the SAEJ2841 standard are plausible they include untested assumptions about how consumers will choose to recharge and purchase PHEVs, specifically:

1. PHEV owners charge once per day
2. PHEV drivers do not gain additional CD driving from the use of public charging infrastructure
3. Travel behavior does not influence which PHEV a consumer decides to purchase.
4. The travel patterns of PHEVs are similar to those of the Internal Combustion Engine (ICE) vehicles

This analysis draws on the most up to date consumer demonstration data and modeling work to evaluate these four assumptions made in the SAE J2841 utility factor standard, and assesses the implications of changes in those assumptions for the UF. The results of the analysis are meant to build depth and breadth to previous discussions **[4]** and provide perspective to the discussion of PHEV impacts and suggest how they could be influenced in ways independent of increasing battery size (which is costly), and how consumer use and purchase decisions may alter our understanding of the UF and the "right" PHEV battery size.

The SAEJ2841 Standard

Figure 1 shows the Fleet Utility Factor defined in the SAEJ2841 standard. The black line represents the percent of EV driving (utility factor fraction) which would be expected if everyone in the US drove a PHEV of a certain charge depleting (CD) range. For instance, a PHEV with 40 miles of charge depleting range would electrify 61.7% of all US travel.

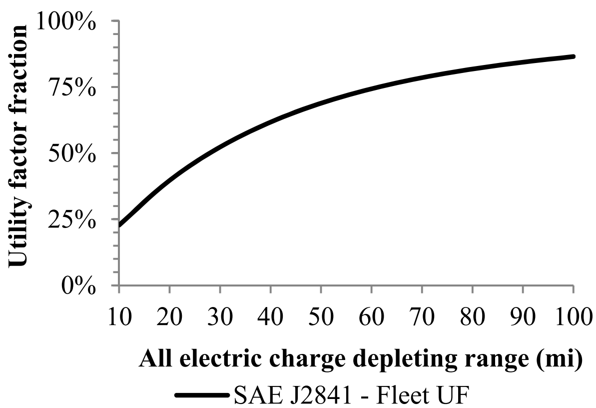

Figure 1. SAEJ2841 Fleet Utility Factor Curve [1]

The line in Figure 1 is the result of a simulation. Single-day driving data from the 2001 National Household Transportation Survey (NHTS) are combined with the assumption that all vehicles in the survey start the day with a fully charged battery. The amount of EV driving for each NHTS respondent is simulated based on how far each car is reported to be driven and the CD range being modeled. Adding together the total simulated EV driving from all participants and dividing by the total driving distance on the survey day produces the Fleet Utility Factor (FUF).

<u>Assumptions About PHEV Use and Consumer Purchase Behavior In The SAEJ2841 Utility Factor Standard</u>

The SAEJ2841 UF standard includes four stated and implied assumptions about how consumers will choose to use and purchase a PHEV.

PEV owners charge once per day at home

The SAEJ2841 standard uses a one per day charging assumption to estimate the amount of electric vehicle miles a PHEV will complete in a driving day. Charging is assumed regardless of where the user starts the day, daily driving distance, timing of driving events, commute status and whether or not a household returns home during the day.

PHEV drivers do not gain additional electric driving from the use of public charging infrastructure

Because of the one per day charging assumption the SAEJ2841 implies that away from home (workplace, public, and DC fast) charging, even if used, does not provide additional electric driving.

Travel behavior does not influence which PHEV a consumer decides to purchase

Implied in the SAE J2841 standard is the assumption that PHEV buyers' purchase decisions will never be influenced by their expected driving behavior, or ability to plug-in. The question of how consumers select which vehicle to purchase is complex. Emotion, lifestyle, manufacturer preference, vehicle options, driving feel, resale value and desired CD range are all factors which may mediate, direct or shape a PHEV purchase decision. There may be a host of motivations for consumers to "optimize" their EV driving and/or minimize fuel cost or consumption by purchasing a vehicle with the right combination of CD range, charge sustaining fuel consumption and incentives.

PHEV travel patterns are similar to the ICE or electric vehicle they replaced

The use of past travel diary data from Internal Combustion Engine (ICE) vehicles assumes that travel behavior and vehicle assignment within a PHEV owning household –which may also own other Battery Electric Vehicles (BEVs), another PHEV, Hybrid Electric Vehicles (HEVs) or ICE vehicles - will remain un-changed. However, the purchase, driving and charging of a PHEV may well be optimized within the household or purchased to complete specific types of travel, such as commuting.

Integrated summary and analysis of multiple PEV consumer and market studies

This analysis integrates six research papers representing the most up to date PEV consumer data and modeling work to evaluate the four assumptions made in the SAE J2841 utility factor standard. Here we provide a brief summary of the six publications which inform this paper.

Longitudinal California New Car Buyer Charging Behavior With A PHEV-Conversion [5]

A PHEV demonstration and market research project at the University of California at Davis placed PHEV-conversions instrumented with data loggers in a total of 80 Northern California households from August 2008 to September 2010. The PHEVs were conversions of Toyota's Prius Hybrid and were equipped with the L2 Hymotion conversion kit, containing a 5kWh lithium-ion phosphate battery pack, which could be recharged within four to five hours from a standard household outlet. Most households achieved a CD range between 30 and 33 miles and an average fuel economy of 75 mpg. Each household was instructed to use the PHEV to replace one of its existing household vehicles for a month and was required to pay all gasoline and electricity costs. Among other valuable research products, the experiment allowed researchers to collect high resolution data regarding consumers' travel and charging behavior with a PHEV. A subset of 25 new car buying households who commuted to a workplace and expressed interest in purchasing a PHEV was selected from the larger sample. This subset contains 600 days of use and over 24,000 miles of travel. This subsample's travel and charging behavior (driving and charging profile) is used as the basis of simulation work detailed later in Davies (2013).

PEV Buyer Charging Behavior From The US Department of Energy EV Project [6]

The EV project, funded by the US Department of Energy and implemented by ECOtality, Inc., subsidized the installation of home and public charging infrastructure in fourteen regions of the US in exchange for access to user charger and vehicle data. The results provide an important lens to help interpret and validate the in-depth results from the UC Davis PHEV-conversion demonstration and market research study.

Energy and Charging Infrastructure Simulations Of PHEV Utility Factors With Away From Home Charging Networks [7]

Using the data from Kurani et al (2010), simulations for PHEV utility factors are estimated, in varying charging infrastructure scenarios. A sub-set of 25 participants' PHEV use profiles is extracted from the data captured from the in-vehicle loggers. Each household profile contained a 1 second time series log of a month of PHEV-conversion driving and charging data, consisting of GPS coordinates, speed, air conditioning use, State of Charge (SOC) and record of when the vehicle was plugged into the grid. A spatial energy use and charging infrastructure model, with customizable inputs for charging power level, CD range, and away from home locations with charging access are combined with these households' use profile and assumptions are derived to simulate how PHEV drivers would decide to charge. The Utility Factor is simulated under a range of battery sizes (10 to 100 miles CD range) and charging network scenarios, which include:

Home charging for commuters

The home charging scenario represents the baseline usage case and no changes are made in the actual timing and location of charging events observed with the PHEV-conversion. The travel and charging data are used to estimate the utility factor and the individual household's performance for a PHEVs with 10 to 100 miles of CD range with a charging rate of 6.6 kW (240volts and 32 amps).

Workplace charging for commuters

The sub-sample of commuting households used in this analysis did not have access to workplace charging, although a large proportion expressed interest in the idea of being able to plug-in at work. The few households who mentioned that they could have plugged-in at work were unsure of the etiquette of taking electricity from their employer, and did not address the issue with their employer because the demonstration was temporary. To model the potential impacts of workplace charging, vehicles were assumed to plug-in every time the household vehicle was parked at work. Comparison between the home charging and workplace charging scenarios provides the maximum potential of workplace charging to change the FUF. Given that this is a sample of commuters, the actual impact of workplace charging for the entire US auto fleet would be different, since it is expected that not all PHEV buyers will be commuters.

Public charging for commuters

The PHEV demonstration project placed PHEV-conversions in households between August 2008 and September 2010, before the SAEJ1772 plug-in standard was developed and public charging infrastructure was deployed. Using a database of existing public charging stations as of July 2012, charging was simulated based on the actual parking locations of households, and the proximity of a charging station to those locations with a distance buffer of approximately 3 blocks. While this provides a rough estimate of public charging impacts, the analysis does not account for households which actively seek out additional public charging infrastructure and plan their trips based on access to a charging station. Furthermore, since this is a sample of commuters it would be expected that public charging infrastructure use would be more likely to occur on weekends.

DC quick charging

A California statewide DC fast charging network consisting of 200 locations optimized for EV travel, and developed in **[8]**, was used to simulate the impacts of DC fast charging. Since the actual travel paths of the PHEV-conversion are known, the model assumed perfect foresight and that the vehicles were charged at the ideal locations to maximize EV driving. Mid-trip and destination fast charging were controlled by a fuzzy logic algorithm, which was designed to take into account the trade-off between gasoline costs, expected pricing of $5 per fast charging session, and the time required to charge. Overall, vehicles were allowed to fast charge up to twice per day, did not fast charge within 50 miles of returning home, and - due to the tradeoff between gasoline savings and the cost of fast charging , only PHEVs with 70 or more miles of range were allowed fast charging capability. It is important to recognize that other pricing and subscription models for fast charging will exist and could change the utilization and impacts on UF as a result of quick charging infrastructure.

A 3 Day Travel and Charging Diary and PEV Design Preference Questionnaire [9]

Approximately 500 new car buyers living in the San Diego area completed an in-depth, multi-part online questionnaire. As part of the questionnaire respondents were asked to complete a three day travel and charging diary and were asked to select a vehicle which they were most interested in purchasing. Respondents were given the option to upgrade the vehicle powertrain by selecting preferences for fuel type (ICE, hybrid, PHEV or EV), vehicle range (for PHEVs and EVs), recharge time, and enhancements to fuel economy. Each "upgrade" increased the cost of the "design" vehicle and participants were asked to choose between the "base" vehicle available for sale today or the vehicle they designed. All upgrade costs were derived according to a battery cost model and converted to consumer prices. The collection of multi-day diary data and vehicle design preferences allows for simulations to explore the relationship between driving and charging behavior and vehicle purchase decisions.

A Survey of California Plug-in Electric Vehicle Buyers [10]

PEV buyers who received a California Clean Vehicle Rebate between June and November 2012 were surveyed about aspects of their PEV use patterns. While the sample does not include a comprehensive set California PEV buyers (up to ¼ of buyers do not claim a rebate and response rate of the survey was 33%) it provides the single best sample of California PEV buyers. As part of the survey, respondents self-reported the PEV they purchased, vehicle purchase date, odometer reading and commute distance to their primary workplace.

An Electric Vehicle Consumer Demonstration Study [11]

Working with The BMW Group, The PH&EV Research Center at UC Davis led the US portion of an international consumer research study of drivers in Los Angeles, New York and New Jersey who leased MINI E electric vehicles for a year. Throughout the project MINI E customers provided feedback on the vehicles and their use through surveys, focus groups and interviews. The result of those exercises provided insights into how the travel and charging behaviors of new PEV owners may change with experience.

RESEARCH RESULTS AND ANALYSIS

PHEV Owners Charge Once Per Driving Day

The SAE J2841 standard assumes that PHEV drivers plug-in their vehicles once per day, regardless of how far they drive or how many times they return home during the same driving day. We compare this assumed frequency of 1 charging event per day from the J2841 standard to the real world measurement of 1.2 charging events per day observed in the PHEV demonstration. One might reasonably ask whether an average of 1.2 charging events per day is sufficient to allow the once-per-day assumption to stand. However, central to this discussion are the potential differences between a mean daily charging frequency and the assumption that all PEVs are charged once on every driving day. The methodology applied to calculate the SAE J2841implies that there should be no distribution associated with daily charging frequency and no correlation between driving distance and charging frequency. We begin to explore these assumptions about PHEV user charging frequency in Figure 2 where the daily charging frequency of the PHEV-conversion users is plotted by the percent of driving days. The results illustrate that while the PHEV-conversions were plugged-in once on 57% of driving days, there was a significant number of days on which the PHEV-conversions were not plugged in at all, or were plugged-in twice or more times. The figure illustrates that there is a distribution associated with daily charging frequency.

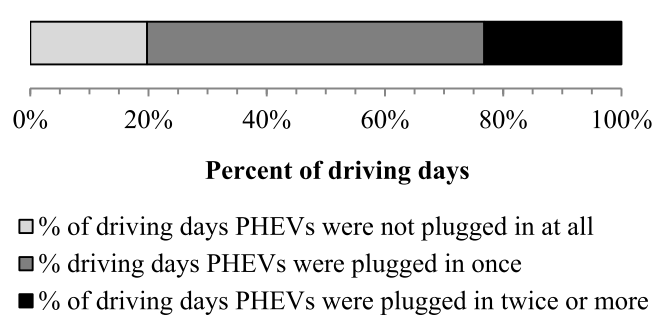

FIGURE 2. Daily charging distribution from Kurani et al 2010 [5]

Statistics reported from the EV project documented in Smart et al 2013 provide a reference point by which to compare the PHEV-conversion demonstration participants' charging frequency with that of a subset of Chevrolet Volt buyers who have been participating in the EV project. Smart et al 2013reports an average charging frequency of 1.46 charging events per driving day. Analysis of the data corroborates the PHEV-conversion demonstration project findings – namely that some PHEV users exhibit charging behaviors which are more complicated than the once per day routine. The distribution of daily charging frequency is shown in Figure 4, and was mostly between 0 to 4 charging events per day. Although charging once per driving day was the most common daily charging outcome, Volt drivers plugged-in more than once per day on 40% of driving days.

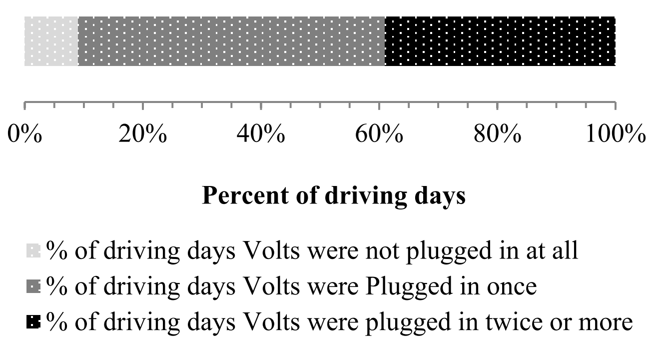

Figure 3. Distribution of Daily Charging Frequency for Volt Drivers modified from Smart et al 2013 [6]

Figures 2 and 3 clearly show that, from the limited real world data available, there is a distribution of charging behaviors. While the mode daily charging frequency is one single event in both cases, there are clearly times when vehicles are plugged-in more than once per driving day. The significance of a distribution of charging frequencies has clear consequences for the time of day energy use in relation to PHEVs. However, the extent to which multiple charging events per day affect the UF implies that additional PHEV charging results in electric miles which would not have been driven otherwise.

The ability of PHEV-conversion users to adapt charging behavior to enhance CD driving distance can be observed in Figure 4 through the relationship between the number of times a vehicle was plugged-in at home and the average daily driving distance. Together, Figures 2, 3 and 4 illustrate several real world measures of charging behavior. Actual user charging behavior is composed of a distribution of home charging frequencies, in one dataset, has a relationship with daily VMT.

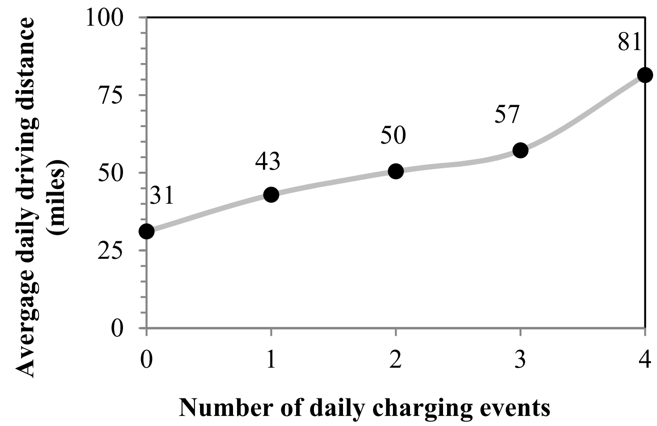

Figure 4. Relationship between average daily driving distance and the number of plug-in even from Kurani et al 2010 [5]

Away From Home Charging Does Not Change the Utility Factor of PHEVs

The SAEJ2841 assumes all charging for PHEVs occurs at home. However, Electric Vehicle Supply Equipment Manufacturers (EVSE), electric utility companies, vehicle manufacturers and the US Department of Energy (DOE) are actively engaged in the process of installing, and advocating for the installation of, away from home charging infrastructure such as: at the workplace, in public locations and along regional travel corridors. There are complications in estimating the potential of charging infrastructure to alter EV driving. A number of factors may shape when and where PHEV users decide to plug-in. These factors include travel patterns, vehicle specifications -CD range and Charge Sustaining (CS) fuel economy- vehicle charging rate, the price of energy (gas and electricity) and the location of charging stations. Thus, away from home charging may serve to increase the utility factor of PHEVs but the exact amount of this increase will be difficult to establish through survey work alone. In an attempt to characterize the maximum impact of away from home charging for PHEVs, we employ each of the 25 new car buying commuters' use profile and assumptions for away home charging (as discussed in the previous section) to simulate the maximum, incremental impact of away from home charging infrastructure on the Utility Factor, as shown in Figure 5.

Comparing the SAEJ2841 fleet utility factor with the UC Davis fleet utility factor, we see general agreement. The two curves diverge slowly as CD range increases. This divergence, on the order of 3%, is caused by the difference in recharging frequency between the two analyses. SAEJ2841 assumes a single charging event every day, while the households participating in the PHEV demonstration were able to adapt charging behavior to travel patterns, with some choosing to plug-in more than once per day. Hence, as CD range increases, multiple charging events per day make a larger difference in the fleet utility factor.

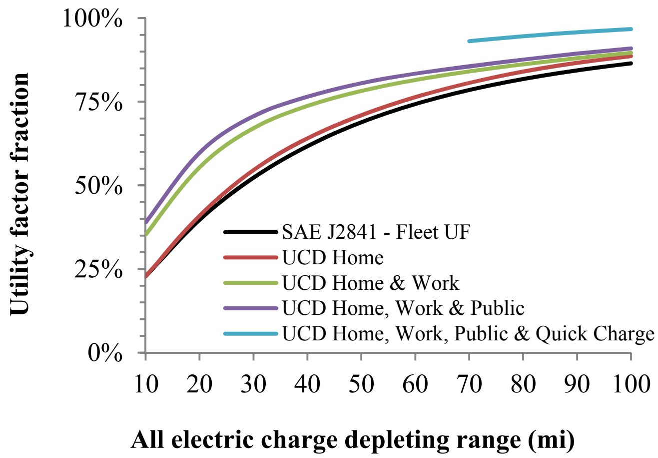

Figure 5. Utility Factor with Expanded Charging Infrastructure – results from simulations [7]

The provision of ubiquitous workplace charging could have an appreciable impact on the fleet utility factor. In the simulation results shown here, the impact of workplace charging varies depending on the vehicle CD range. The impact of the current public charging infrastructure appears to be substantially less than that of workplace charging, which might be expected, given that the sample comprised commuters who would primarily travel to locations where public charging was available during the weekends. Furthermore, given that a public charging network now exists, we expected that PHEV consumers' trips might be influenced by the availability of public charging, with the location of charging stations becoming a consideration when planning travel routes. In which case, we may expect public charging to have a larger impact on the fleet utility factor than shown here. For high CD ranges the fast charging scenarios have the largest impact of any charging infrastructure on the utility factor. The relatively large impact is attributed to the ability of fast charging to complement the long distance travel patterns which, while not a large proportion of total trips, still account for a large percentage of miles traveled. Overall, 80 to 90% of fast charging events would have happened on weekends, but up to 10% of the households in the simulation would have needed to use fast charging at least once over the course of the month for the purpose of their commute.

Consumers Expected Use Profiles Do Not Inform Their PHEV Purchase Decisions

To test the assumption in the SAEJ2841 that travel behavior and preference for CD range are independent of each other, we dissect the results of a multi-mode survey of residents of San Diego, California. The survey asked each participant to record three days of travel data for the household vehicle that they were interested in next replacing. After completing the travel diary, respondents participated in a hypothetical PEV design game in which they were given the option to design their next new vehicle with a gasoline, hybrid, PHEV or BEV powertrain. All the PHEV options allowed respondents to pick charge depleting ranges of either 10, 20 or 40 miles. A battery cost model modified the consumer price of the hypothetical design PEV to be commensurate with battery size. In Figure 6 we plot the cumulative distribution of daily driving distances among three groups of respondents who designed PHEV10s, PHEV20s and PHEV40s, respectively, as their next new vehicle. The assumption used in SAEJ2841 implies there should not be a difference in the cumulative daily driving distributions between PHEV10, PHEV20 and PHEV40 buyers.

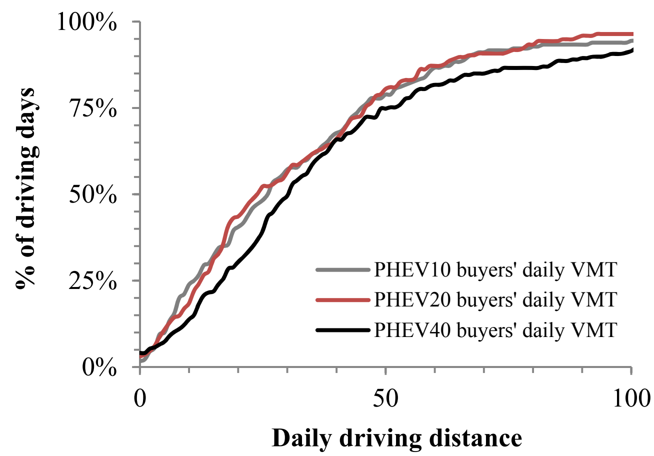

Figure 6. Cumulative daily driving distribution for survey respondents by design PHEV CD range [9]

We observe differences between the cumulative daily driving distribution of all respondents who designed PHEV40s and that of those respondents who designed PHEV10s and PHEV20s. The daily driving distribution of respondents who designed a PHEV40 had a daily driving distribution that shifted to the right of the graph, towards 30 to 50 miles. They drove 10 miles more per day on average, and they had a higher percentage of travel days with VMT over 40 miles.

These survey results explore the potential relationship between respondent daily driving distance and their vehicle selection, as based on responses to an online questionnaire. In the current PEV market there are other factors which might influence consumer vehicle selection that are not captured in this survey, including High Occupancy Vehicle (HOV) lane eligibility stickers (not available on Chevrolet Volt before 2012), seating capacity, drivability, dealer inventory or education efforts, vehicle features and attributes, CS fuel economy and vehicle efficiency (or fuel costs), maintenance costs, expected reliability, anticipated resale value, cheap lease pricing, vehicle rebates or tax incentives (State, Local and

Federal), brand loyalty, access to charging infrastructure, price of charging infrastructure, price or complexity of home charging station installation, insurance costs (liability only as offered by the Honda Fit EV), free or reduced parking costs, or even enough space to carry the family pet, to name just a few. In Figure 7 we explore results from **[10]** which summarizes the distribution of round trip commute distances of a sample California Plug-in Prius and Chevrolet Volt owners.

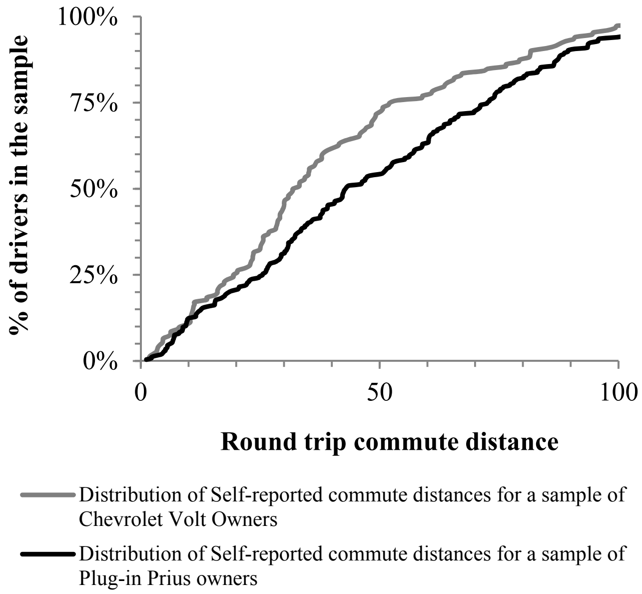

Figure 7. Distribution of self-reported commute distances for a sample of Chevrolet Volt and Plug-in Prius owners [10]

These two sets of results provide book ends for the discussion of the possible link between travel behavior and PHEV purchase behavior. In **[9]** and **[10]** the distributions of travel behavior differ by vehicle type/ model. However in Tal et al (2013) Plug-in Prius owners (who have less CD range than Volt owners) had longer commutes than Chevrolet Volt owners. In this case we hypothesize that the lower CS fuel consumption, lower price (at launch), and HOV sticker (at launch) made the Plug-in Prius relatively more attractive to long distance commuters than the Chevrolet Volt (It should be noted that two of these three variables have since changed for the 2013 model year). These countervailing results, and possible hypotheses to explain them, suggest that in the "near term" the extent to which real consumers self-select into PHEV models may be influenced by vehicle and market attributes, including: vehicle specifications (CD range, CS fuel economy, vehicle size, driving feel), consumer travel and/or charging patterns, vehicle price, and available incentives. As suggested by the results from [9], in a "healthy" and established PHEV market (with no relative incentives towards battery size, non-monetary incentives such as HOV stickers, with all vehicles available as a PHEV variant, and equal CS fuel consumption among models) consumer purchase behavior and self-selection will be different.

The possibility of self-selection bias among PHEV consumers raises interesting potential implications for the SAEJ2841 utility factor analysis. To begin to assess the possible influence of this bias, we examine additional simulation and analysis of the household PHEV-demonstration dataset from **[7]**. The results in Figure 5 and the SAEJ2841 standard are reported as an average. The average strips away all the variation among households which results from differences in travel behavior and charging frequency. This variation is key to understanding why different consumers might not value increases in CD range in the same way. In Figure 8 we disaggregate the average UF result from Figure 5 to show each of the 25 households' individual simulated UF using at home charging only. The black dashed lines represent the relationship between CD range and UF for each of the 25 PHEV demonstration households and the blue line is the average UF from Figure 5. The resulting cloud of data in Figure 8 shows the distribution of individual consumer UFs among all respondents given CD range and only home charging. Given the distributions of UF outcomes one might ask if all households are equally likely to purchase a PHEV20? What about a PHEV10 or a PHEV80?

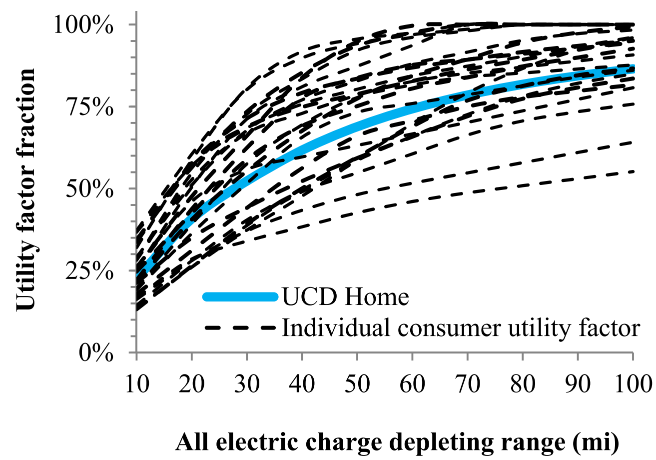

Figure 8. Simulated individual consumer utility factor using home only charging data from PHEV-demonstration [7]

The use of away from home charging infrastructure changes the distribution of simulated UFs as can be seen by comparing Figures 8 and 9. The addition of this hypothetical, "best case" workplace, public and quick-charging infrastructure increases the variation in the UF among users, and highlights that not every household benefits equally from increases in CD range. This variation makes for an interesting case when considering consumer purchase decisions. Could there be consumers whose knowledge of their daily driving and access to charging infrastructure leads them to pick a vehicle with an "optimal" range given their lifestyle? Or perhaps their lack of access to charging infrastructure and long driving distances dissuade them from purchasing a PHEV? In both cases the UF line (which assumes that no –one has a preference for CD range) could be biased downwards.

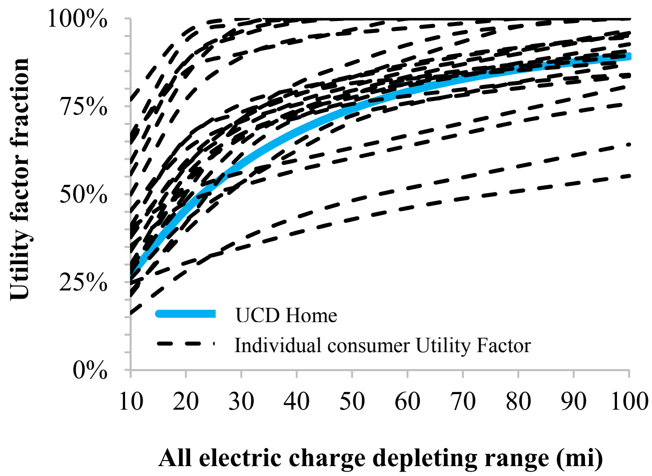

Figure 9. Hypothetical individual consumer utility factor using home charging data from PHEV-demonstration and simulations for workplace and public charging [7]

PHEV Travel Patterns Are Similar To Those of Existing Internal Combustion Engine Vehicles

The driving of PHEVs within the context a household's entire vehicle fleet has not been investigated well. In general, after the purchase of a new vehicle, households may re-assign travel from their older to newer vehicles **[11]**. The process happens organically within households who genuinely enjoy driving their new vehicle and who may have purchased it specifically in anticipation of more driving. The assumption in the SAEJ2841 is that PHEVs will be driven in a manner similar to the ICE vehicle it replaced. However, one might expect that the use of a new, high fuel economy or electric vehicle within a household would also be influenced to some extent by its operational cost advantages when compared to the rest of the vehicles at the household's disposal, or by other factors such as sense of ownership within households, technical/ physical barriers to vehicle use (such as the placement of a child car seat), personal aspirations for expanding the share of EV driving, and overall driving experience. To complicate matters, these factors may be dynamic and may well change over time in relation to variations in fuel cost, access to charging infrastructure and lifestyle, as well as with experience with the vehicle or specific vehicle design. Anecdotes of changes in vehicle trip assignments and use patterns have been on the part of some PHEV and BEV owners which indicate that at least some PHEVs or EVs may be used in a different manner than the ICE vehicle they replaced. For instance, the BMW Mini E demonstration observed two particular effects that access to an electric vehicle had on household travel patterns.

Firstly, households **adapted** their lifestyle and driving patterns to match their new mobility option – this included shifting travel in certain conditions to other ICE vehicles, forgoing trips, or changing driving behavior and adjusting climate control use or driving behavior to maintain range.

Secondly, households actively looked for opportunities to **expand** their EV driving. This included taking trips in the Mini E which were normally taken in another household vehicle, trip chaining, and even changing destinations to match their EV range. Interestingly, Mini E owner's EV driving expanded as a result of experience with their vehicle and understanding of driving territory. However, overall, definitive measurement of these **adaptation and expansion behaviors** was difficult because the Mini E was a two door vehicle, which in itself may have caused adaptation behaviors on the part of the households.

DISCUSSION – WHAT DO NOT KNOW AND WHY IT MATTERS

The analysis presented here points to the need to take a dynamic and fluid approach to the issues under investigation. As vehicle technology, price, infrastructure, fuel prices, and consumer ambitions change and develop, so will consumer PHEV use and purchasing behavior.. That being said, this analysis is a snapshot of our current understanding of PHEV purchase, user behaviors and simulated outcomes. One conclusion from this process is clear and simple – namely that the type, quantity and quality of the data needed to actually assess, validate or reject the assumptions in the SAEJ2841 do not exist. However, based on our limited sample of data we do observe some differences between actual vehicle use and the assumptions made in the SAEJ2841, and evidence suggests that these are sufficient to merit further exploration, particularly with regard to the concepts of once per day charging, the use of public charging infrastructure and self-selection bias among PHEV consumers.

While the SAEJ2841 was developed as a standard to support proposed fuel economy labeling, it has been applied outside of this initial purview by analysts who draw upon it to estimate PHEV impacts, and by the California Air Resources Board to estimate credits for Partial Zero Emission Vehicles (PZEVs) in the Zero Emission Vehicle (ZEV) mandate. To that extent the validity of the assumptions in the SAEJ2841 affects the PHEV market and plays a role in California policy. Further, the presentation of the Utility Factor as an average across the entire fleet also hides the variation in consumer travel and charging behaviors. This leads to over-simplistic assessments that more range benefits all consumers equally and that battery range is the only factor which affects charge depleting driving. In reality, however, the distribution of consumer travel and charging behavior leads to a diversity of outcomes such as those shown in Figures 7 and 8. From this perspective, an increase in PHEV battery capacity has different implications for each household. Furthermore, since we are in a new and evolving PHEV market period and environment, dynamic factors such as relative fuel prices, individual vehicle needs, consumer budgets, developments in charging infrastructure access, travel behavior patterns and purchase incentives may also shape what vehicle consumers purchase and how they use it. Lastly analysis is framed by the personal vehicle ownership model which is predominant in the United States. The use of PHEVs in different applications (such as car share) will likely affect the performance of PHEVs in different ways then examined here.

The need to evaluate PHEVs in the context of other vehicles is essential both policy and for the benefit and information of consumers. However, such evaluations should accurately (rather than assume to) reflect the conditions in which vehicles are used and purchased. In this early phase of a PEV market launch where real world data is not available sufficient scale, or capable of being shared, we must rely on the analytical community to challenge routine assumptions and to make a more consistent effort to understand how –and to what extent - the impacts of PHEVS are, and will be, shaped by the role of consumers and the market in which they live. Premature simplification can have long-term and potentially detrimental consequences for the setting of standards, vehicle design and performance based incentive programs.

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DEFINITIONS/ABBREVIATIONS

BEV	Battery Electric Vehicle
CARB	California Air Resources Board
CD	Charge Depleting
CS	Charge Sustaining
DOE	Department of Energy
EVSE	Electric Vehicle Supply Equipment
FUF	Fleet Utility Factor
HEV	Hybrid Electric Vehicle
HOV	High Occupancy Vehicle
ICE	Internal Combustion Engine
NHTS	National Household Transportation Survey
PHEV	Plug-in Hybrid Electric Vehicle
SAE	Society of Automotive Engineers
SOC	State of Charge
UF	Utility Factor
ZEV	Zero Emission Vehicle