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Survey and Data Observation on Consumer Motivations to DC Fast Charge

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Survey and Data Observations on Consumer Motivations to DC Fast Charge

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Summary

Fast charging was analysed through a large fast charge session database from network provider EVgo and through a survey of 162 fast charging respondents. Both short and long-range battery electric vehicle (BEV) usage was close to home where half of all paid charging was 6-8 miles from home as the crow flies but heavy users dominated this metric, and light users charged farther away. Users with no home charging, who had lower income than the median, used fast charging as a replacement for and in conjunction with the Level 2 network. 54% of respondents would not have taken their EV without the fast charging network. About 43% of all respondents shopped at a retail establishment because of charging, spending an average of $30.

Keywords: DC Fast Charging, business model, Level 2

1 Introduction

There have been several modelling attempts to describe the potential uses for fast charging [1-5] these modelling exercises usually depend on an assumed charging behaviour coupled with and external travel dataset. All of the models assume a user has access to charging at home and that the user charges to 100% on those days when range is required. This implies that the fast charger is the charger of last resort and Level 1 120V charging (L1) or Level 2 200+V charging (L2) charging will be used if available.

However, there are situations in which this paradigm is not applicable such as those with no home charger or limited Level 1 home charging. Additionally, familiarity with one's nearby fast charger versus one that may be more "optimal" from a trip perspective but farther away, may influence the choice of fast charger given two supposedly equal alternatives.

Finally, range may have an influence as to the usage of a fast charger both in terms of the number of events per vehicle and the distance away the charger is used. With the recent introduction of more affordable 200+ mile vehicles, we can see a glimpse into what the future may hold for fast charging.

These factors among others are important for planning locations and estimating usage needs, but also hint at what role fast charging is playing and can play in influencing vehicle purchase. We examine this by comparing and combining two datasets: Charging event data and survey data taken at the time of fast charging.

2 Background

Modelling fast charging has been done looking at the travel behaviour of gasoline vehicles in a variety of ways from a small number of GPS tracked vehicles [1] to larger travel diary datasets from a large state-wide survey in California [2-7]. These models focus on locating fast chargers at the point where a battery electric vehicle (BEV) would run out of charge and detailing how many would be needed to serve all travel. This has been called "corridor demand" by some modellers[5]. Ji et al [5] incorporates driver fatigue such that the likelihood of using a BEV declines if travel requires more than one fast charge to complete travel using survey results from Nicholas et al.[2]. Some studies [8, 9] use home and work as likely locations coincident with demand to model fast charging demand. Other studies use the density of highways to scale the number of fast chargers without specifying who will use them and for what reason[10]. However, how well do these models reflect current fast charger usage? Are home and work likely locations coincident with fast charging or does usage correlate with when the battery runs out? One study suggests that drivers of BEVs are unlikely to drive past the one-way range of their vehicle such than an 80 mile BEV will seldom if ever be found 80 miles from home over its lifetime[11]. Another study by Nicholas et. al [12] using in-use charger data consisting of mostly 80-mile range battery electric vehicles (BEV80) suggests that free charging also called free-prepaid charging (prepaid by the auto maker) may replace home charging and results in 50% of charging less than 4.9 miles from home as the crow flies. If the charging session is paid directly by the driver then the median distance from home is and 10.3 miles. Nicholas et al. compare this to stated preference and modelled data to show that the actual charging is closer to home. However, they examine primarily 80-mile vehicle usage for an approximately 3-year period, possibly not reflecting current usage patterns. We examine only recent data within a 70-day period for short and long-range BEVs and compare and combine it with data taken from a fast charging survey from 40 fast charging sites in California over approximately the same time period. This allows deeper investigation into the usage patterns of fast charger and extends the conclusion of that work.

3 Data Description

We examine a California subset of fast charging activity covering 238 sites (multiple chargers were aggregated to one site) consisting of 149,101 sessions approximately covering the survey period. This database was further reduced for analysis of particular vehicles and payment. The distance from home is provided for these sessions when available. To further explain who is using fast chargers and for what purpose, we placed survey requests at 40 fast charger sites throughout the state of California. Users could enter a survey link in their mobile device or scan a QR code to take a survey while fast charging. The questions established home and travel locations as well as information about activities at those locations. They also established activities while fast charging and amount of money spent while fast charging.

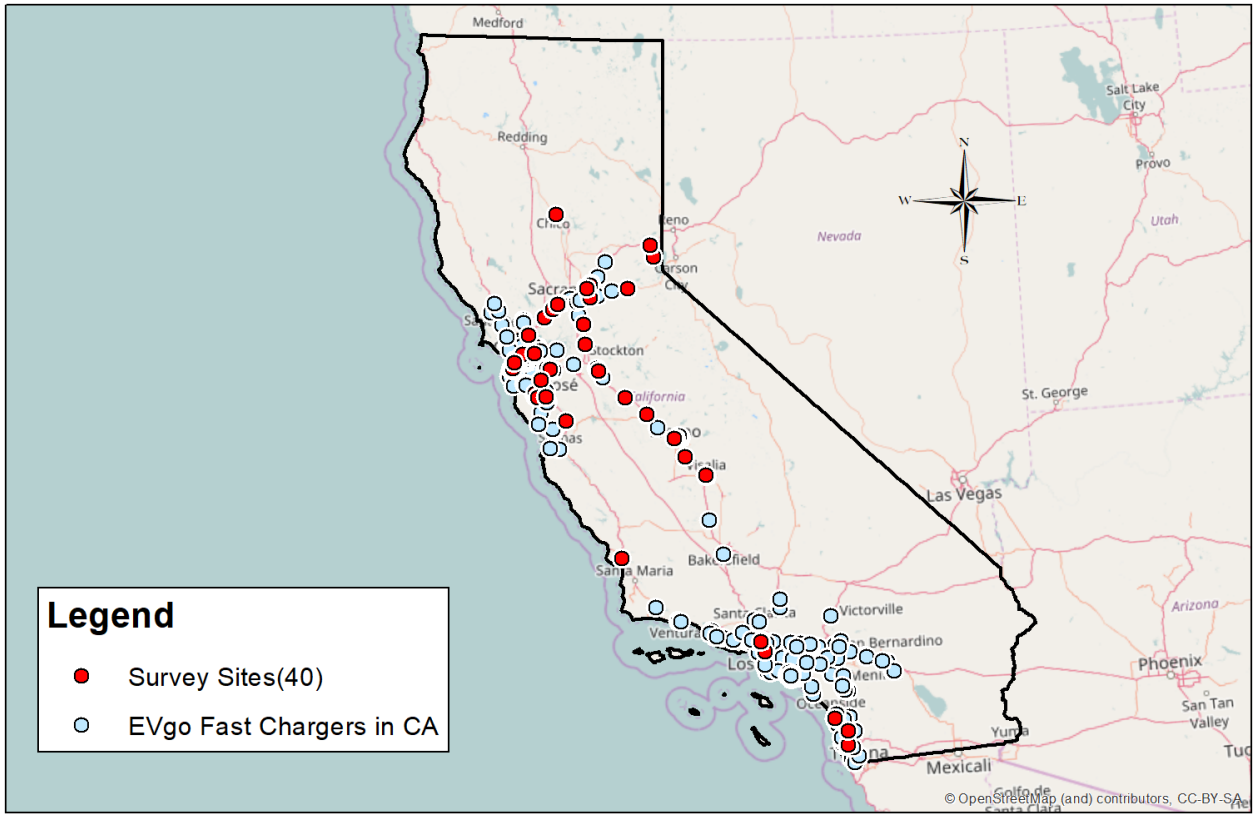

Figure 1: Location of survey sites within the context of all EVgo chargers

We chose 40 charging sites and placed a survey on all fast chargers at those sites. The sites were chosen not to represent all chargers in the EVgo system, but were chosen based on three research criteria: Heavy usage, long distance travel, and usage by those without a key FOB ID (these sessions could be less routine and represent a critical need). This resulted in a mix of high and low use sites, but differed from the overall charger mix.

4 Data Exploration

Nicholas et al. provide a starting point to examine how modelling and stated preference differs from in-use data in terms of how far away from home users fast charge [12] (Figure 2).

Their data are taken from 3 sources shown in Figure 2 from left to right for a BEV80: actual paid session data from EVgo, modelled fast charging locations based on the point a battery would run out[5], and stated location preference for fast charging[3].

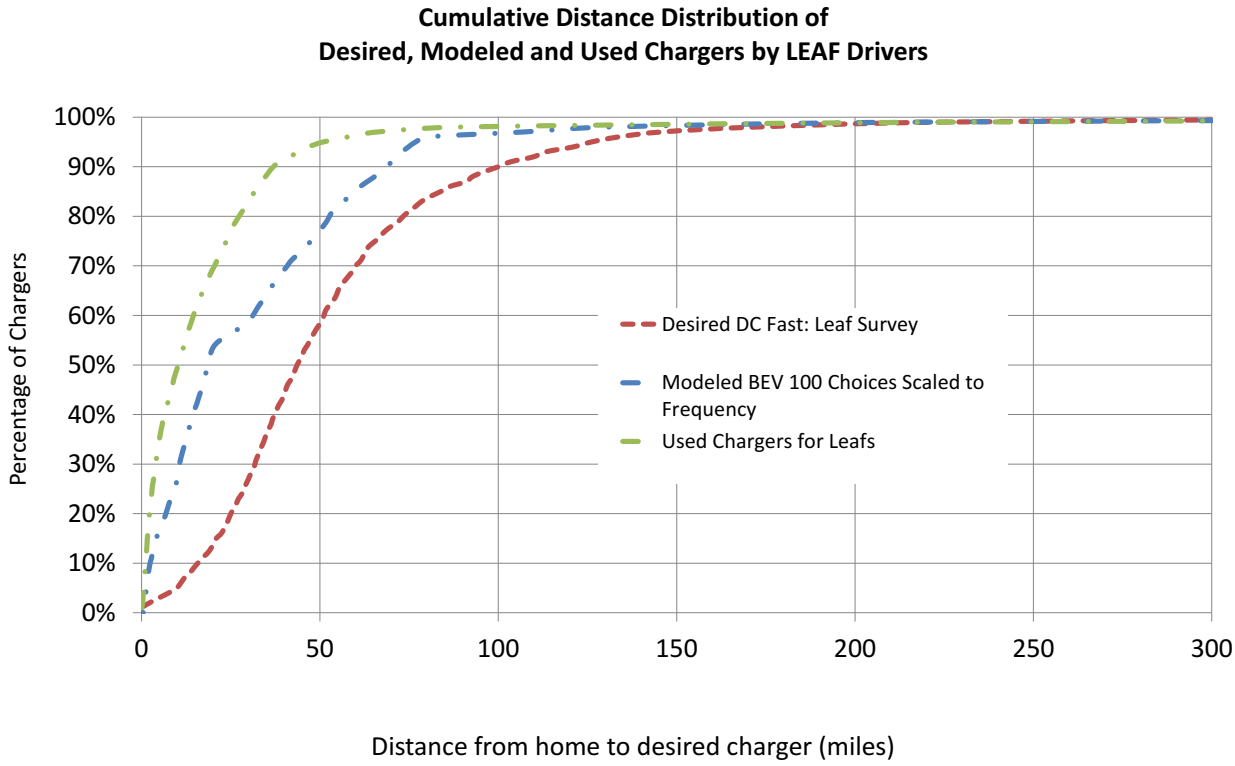

Figure 2: Comparison of the distance from home of used, modelled and desired fast chargers (reproduced with permission from Nicholas et al. [12])

The median distances as the crow flies from left to right in Figure 2 are 10.2 miles, 18.5 miles and 44 miles. Clearly the answers are different based on how the data are analysed. The actual session data and the modelled data are weighted based on frequency, so they should be similar. The aspirational stated preference responses are not surprisingly farther away. We focus on the lower than expected values for the distance from home in this analysis.

5 Results

5.1 Session Data

The studies by Nicholas et al. showed the distance from home to a charger for a BEV80 to be a median of 4.9 miles when free-prepaid and 10.3 when paid. The analysis was done for all fast charging occurring since January 2014 nationwide. The current analysis focusses only on a recent 70-day period in California and shows different results shown in Figure 3.

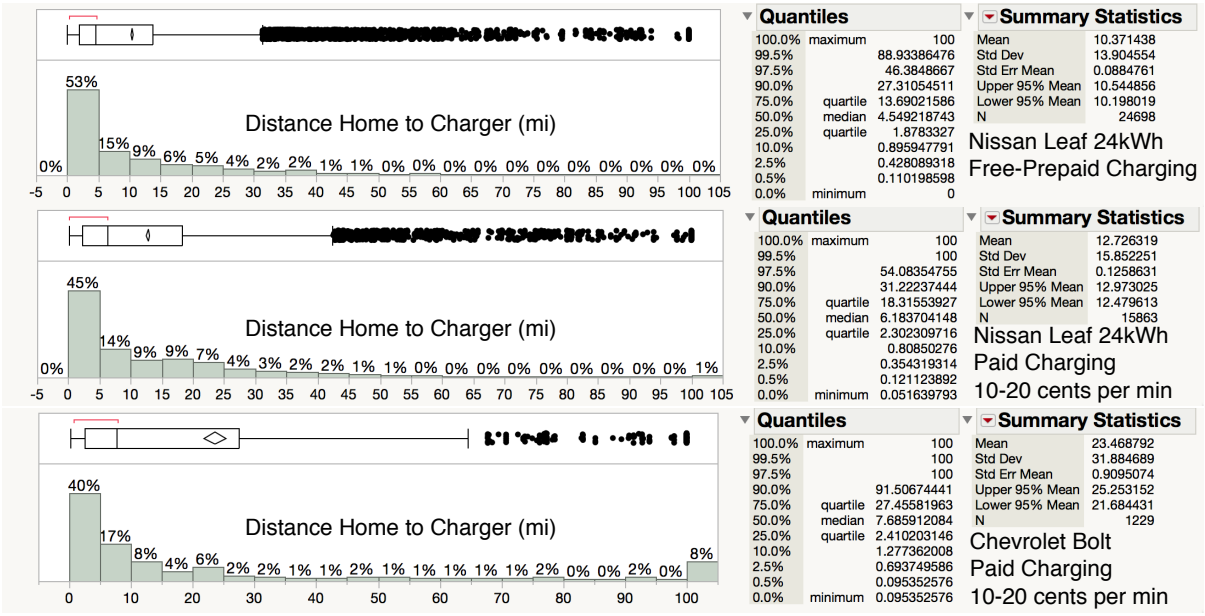

Figure 3: Comparison of free-prepaid and paid charging for the BEV80 Nissan Leaf and the BEV200+ Chevrolet Bolt

The distance from home to the fast charger has decreased slightly from the previous study for free-prepaid sessions in the BEV80 Nissan Leaf and decreased markedly for paid Nissan Leaf charging from 10.3 to 6.2 miles between the two studies. To test the effect of range on the market for fast charging, we examine the distance from home to charger for the 200+ mile Chevrolet Bolt. The median distance from home is similar to that of the Leaf, but the 50th-100th percentile is likely to be farther away and 8% of Bolt charging is over 100 miles away from customers' homes. All distances over 100 miles are grouped into the last mileage bin, skewing the mean.

The results show that the majority of fast charging is local even when vehicle range increases. The 90th percentile is also suggestive in that 10% of charging is beyond the round-trip range (and 1% of sessions are beyond the one-way range) of a Leaf or a Bolt when accounting for actual road distance. The constant percentage regardless of range could indicate a consumer preference for a safety buffer. Weather and range buffers may bring this lower than 10%.

Another possible effect of range is the number of charging events per vehicle per month. However, both the 24kWh Nissan Leafs and the Bolts in these 70 days charged a median of 1.3 times per month when paid while those Leafs with free-prepaid charging charged a median of 2.8 times per month. The implication is that many users have the same need or value of time threshold regardless of range. We also investigate the frequency of usage on a customer level as proxy for behaviour and an indication of what home charging access is in Figure 4. I.e. those who charge 30 times per month may have different behaviour and home charging than those who charge once per month. This disaggregation also helps explain the medians in Figure 3.

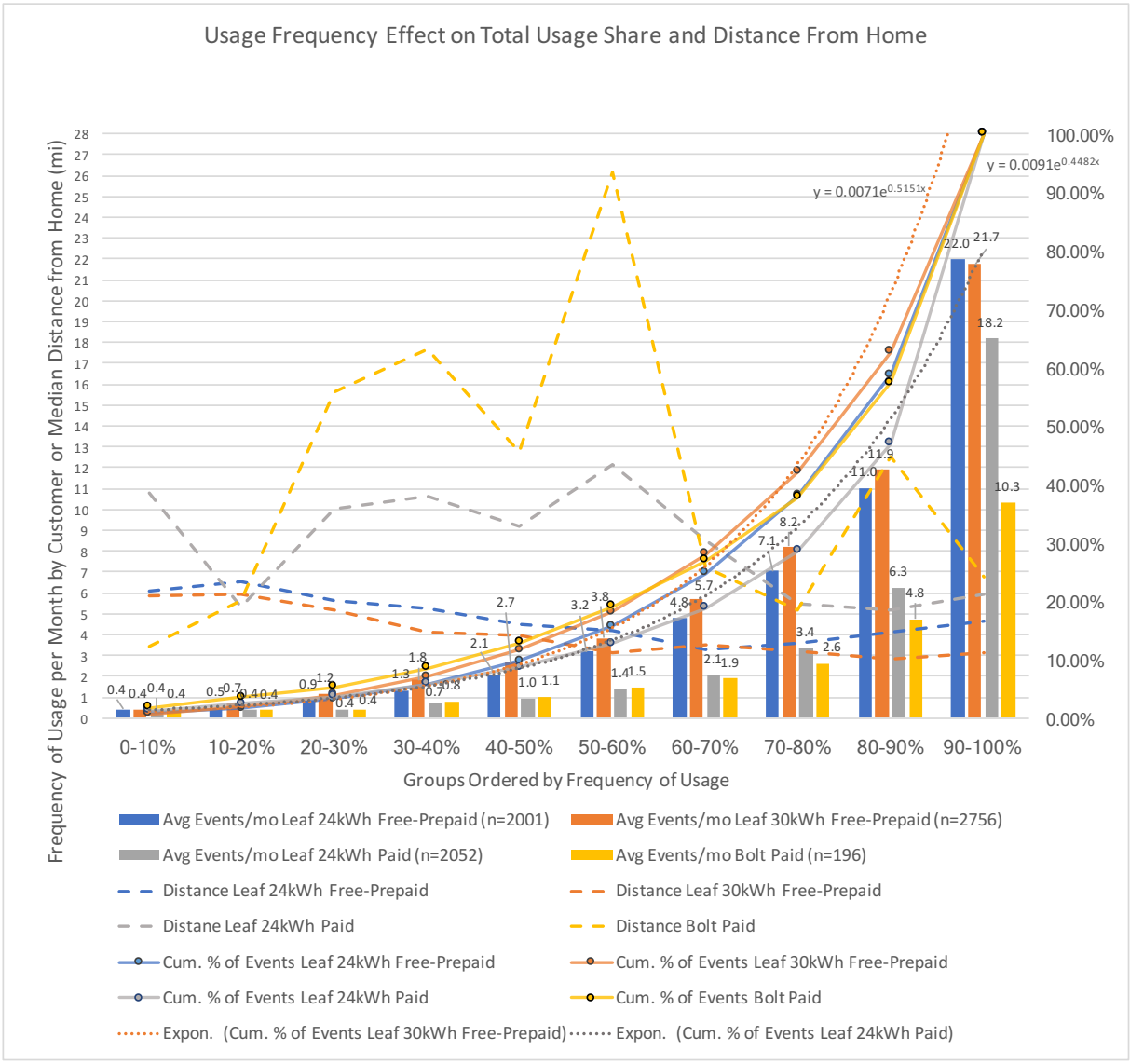

Figure 4: Customers ordered by frequency of usage per month and its effect on distance from home

Figure 4 shows the binning of customers by their average number of events per month. For example, there are 2001 Unique user IDs for Leaf Free-prepaid, and the 200 with the lowest usage are in the 0-10% group and their average monthly usage is 0.4 events per month as shown in the graph. The cumulative effect is shown on the right axis such that the 10% lightest users account for 0.8%-1.7% of the total. The 10% heaviest users account for 40%-50% of sessions by contrast. Those users with zero events in the last 70 days were excluded from this analysis. In each case, occasional customers (0^{th}-50th percentile) who paid were approximately twice as far from home when they charged than the 50% heaviest users. More detail is shown by usage frequency group in Figure 4. Although the median distance from home by user ID (median of medians by user ID) was 4.5, 3.8, 8.3 and 9.7 miles for Leaf 24kWh-Free, Leaf 30kWh-Free, Leaf 24kWh-Paid, and Bolt-Paid respectively, closer inspection of the groups of customers ordered by usage shows additional insights. Among the paying customers, occasional users (20%-60% groups) were more likely to be farther from home. The heaviest 40% of users were likely to be closer to home. And the 10%-20% groups for the Leaf Paid show a less discernible pattern.

When looking at heavy usage over 15 times per unique user ID (as opposed to the average of the 90^{th}-100^{th} percentile), we see 10%, 5%, and 2% for Leaf free-prepaid, Leaf paid and Bolt paid customers respectively. At this level, we can postulate that fast charging is their primary charging solution. Since the Bolt has

double the range of a Leaf, we may assume a percentage of customers higher than 2% of Bolts are using fast charging as a primary solution. The distance and frequency metrics when paid suggest two possible groups: less frequent users who have home charging and behave more similarly to previous models and more frequent users who have marginal charging options at home or work and depend on fast charging as an integral part of their charging.

5.2 Survey Results

The data show that many drivers are charging close to home. To investigate this we ask drivers through an in-use survey at the charger. Our survey sites are not completely representative of the chargers in California we have more rural sites in our dataset. To classify survey sites and compare to all chargers, we examine the number of people within 5 miles of a site (approximately 78 square miles). 19% of EVgo sites have less than 100,000 people within 5 miles and the survey subset has 35% of sites with less than 100,000 people. The sites with fewer people around them are predominantly highway sites in smaller communities.

At the 40 sites, there were 4861 unique customers from the session data and we received 165 useable surveys from unique users, a response rate of 3.4% of customers (not of sessions).

Table 1: Sample Size

Frequencies

Level	Count	Prob
BMW i3 20kWh	4	0.02469
BMW i3 REx 20kWh	17	0.10494
BMW i3 REx 30kWh	7	0.04321
Chevrolet Bolt	17	0.10494
Chevrolet Spark EV	13	0.08025
Kia Soul EV	6	0.03704
Nissan Leaf 24kWh	64	0.39506
Nissan Leaf 30kWh	22	0.13580
Tesla Model S	3	0.01852
Toyota RAV4 EV	2	0.01235
VW eGolf	7	0.04321
Total	162	1.00000

Customers were allowed to take the survey more than once, but most did not. Three were dropped from the results as they were drivers for Uber or Lyft to bring the useable surveys to 162. Not all questions were mandatory so different answers have different sample sizes.

Although fast charging events are relatively close to home, little is known about what activities drivers are engaged in before and after they charge. Figure 5 gives an idea of these activities.

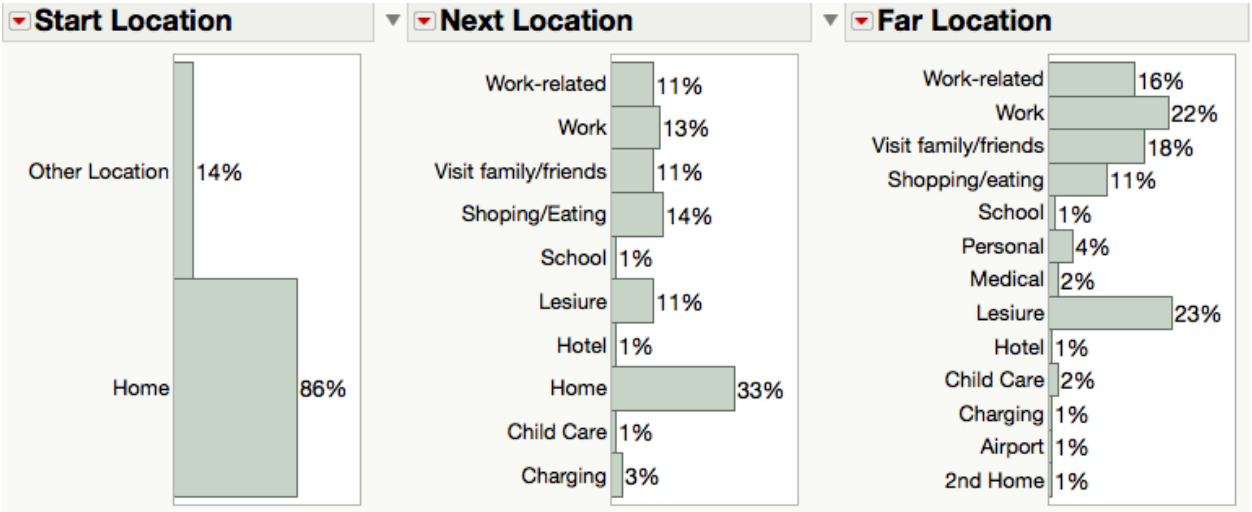

Figure 5: Activites related to fast charging events

Most people start at home but a large number are starting at a place other than home. The most likely place to go after fast charging is home possibly explaining why many sessions are near home, but a work related

location is a likely next stop as well. The farthest locations from home in a day are work, lesiure, and visiting others. These results suggest that work and home are likely indidcators of demand.

The large session database establishes that people charge close to home but are they coming from or going to home? Figure 6 breaks down when in the vehicle tour the charging happens.

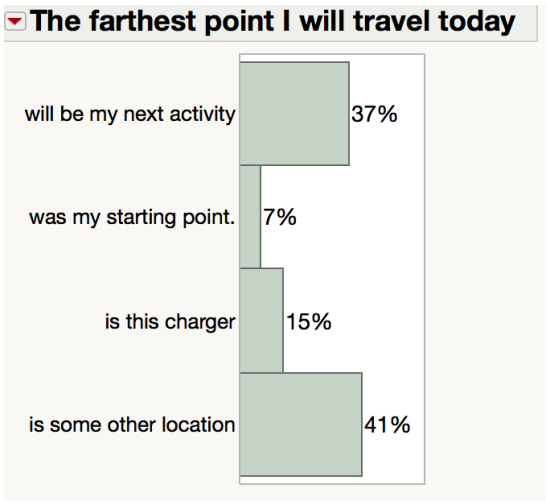

Figure 6: Activity at the farthest point from home

For 37% of respondents, they are on their way to their farthest destination. For up to 63% of people, they are on their way back from their farthest destination. It is not clear how much of the 41% could have stopped at an intermediate point on their way to a farther destination however meaning that the number of people past the apex of their distance from home is likely somewhat less than 63%. The farthest destination is a median distance of 5.2 miles from the charger. Althoug the charger is at time farther away, locating the activity (home or work) may be a good proxy for location of demand.

The farthest distance a respondent is willing to go is also explored by asking the range of their vehicle and drawing a circle around their home at that distance and displaying on a map as shown in Figure 7 and asking about the willingness to go beyond the one-way range of a BEV or range extended electric vehicle.

Figure 7: Representative question about willingness to travel beyond one-way range

Displaying the map this way gives the respondent the chance to visualize the destinations he or she might travel to and better consider the question. The results are shown in Table 2 for the willingness to go beyond the one-way range of one's vehicle.

Table 2: Willingness to go past the one way range of the vehicle

Survey Model	Would consider going past the one way range of the vehicle	
Row %	No	Yes
BMW i3 20kWh	50.00	50.00
BMW i3 REx 20kWh	26.67	73.33
BMW i3 REx 30kWh	20.00	80.00
Chevrolet Bolt	28.57	71.43
Chevrolet Spark EV	40.00	60.00
Kia Soul EV	50.00	50.00
Nissan Leaf 24kWh	55.00	45.00
Nissan Leaf 30kWh	59.09	40.91
Tesla Model S	33.33	66.67
Toyota RAV4 EV	50.00	50.00
VW eGolf	71.43	28.57

Longer range vehicles are more likely to be driven beyond the one way range of a vehicle corresponding with other studies[11], and the overall stated willingness to go past the one way range of one's vehicle is 52%. However, from actual session data since January 2014 for which aproximately 34,000 users have distances available, comprising about 1.3 million fast charging sessions, only 2.6% of users went beyond their one way range accounting for 1% of total sessions. The stated preference of 52% clearly does not match the behavior of 2.6% further explainging the discrepancies in Figure 1. This may indicate that the desire to go far is important for many people, regardless of whether they would do it.

Considering the distance to charger from home metric again, the charging situation at home as shown in Figure 8 may also help explain this short distance.

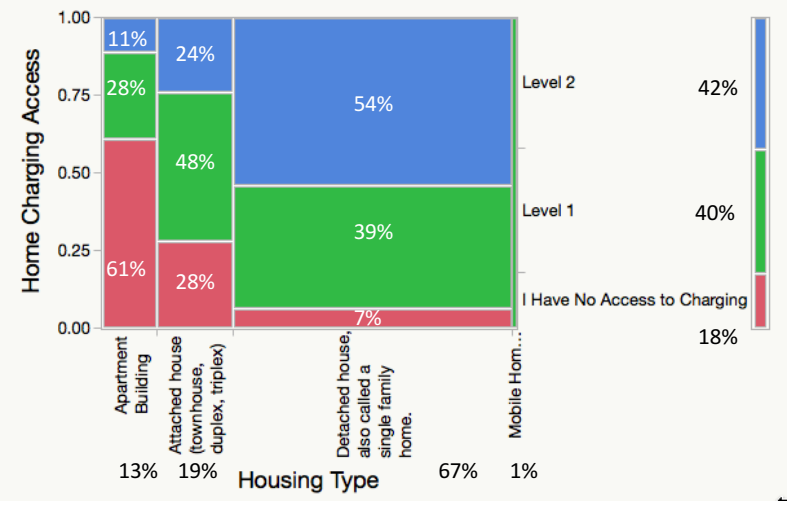

Figure 8: Housing type associated with home charging access

Interestingly 18% of those taking the survey did not have a home charger - mostly Leafs and eGolfs. In other studies those without charging access at home numbered less than 5%, so fast charging appears to be an option for them. Housing type also affects access to charging with 61% of apartment dwellers having no place to charge at home.

The frequency of usage appears to be a function of home charging access as shown in Table 3.

Table 3: Reported monthly usage frequency by fast charger payment and home charger access

Payment and Home Charger	Sample Size	Minimum	10%	25%	Median	75%	90%	Maximum
Free Prepaid - I Have No Access to Charging	9	3	3	8	12	27.5	30	30
Free Prepaid - Level 1	31	0	1	4	10	20	40	80
Free Prepaid - Level 2	29	1	1	3.5	5	10	20	36
Paid - I Have No Access to Charging	24	3	4.5	7.25	15	20	45	80
Paid - Level 1	26	0	0.7	2	5.5	8.5	14.4	30
Paid - Level 2	28	0	0.9	2	4	9.25	20	40
Unknown - Level 1	7	0	0	0	4	8	12	12
Unknown - Level 2	7	0	0	0	4	25	45	45

Looking at the those with no charger access at home, about 50% charge at a fast charger more than every other day. Those with home charger access and have to pay per event are less likely to use the fast charging network heavily. This table shows a possible explanation for who are the heavy users of fast charging based on the session data in Figure 4, however it is not directly comparable as the survey is more likely to be taken by more frequent fast chargers. Those with Level 1 at home are the most sensitive to price.

Distance from home to charger also appears to correlate with the access to a charger suggesting that a fast charger is a substitute for home charging in some situations (Table 4). The difference in median distances from home to charger is significant between those with no home charger and those with Level 2 at home.

Table 4: Distance from home to fast charger by home charger access

Quantiles - Distance From Home to Charger

Level	Minimum	10%	25%	Median	75%	90%	Maximum
I Have No Access to Charging	0.409141	0.840803	1.592119	4.347499	16.9726	39.61005	70.76352
Level 1	0.368871	1.621753	3.445774	12.98716	28.64488	72.37676	434.3432
Level 2	0.442603	1.879793	3.821927	24.58775	50.49014	107.203	416.8471

Table 5: Income by charger access

Quantiles - Access to Charging by Income

Level	Minimum	10%	25%	Median	75%	90%	Maximum
I Have No Access to Charging	35000	35000	45000	125000	175000	175000	275000
Level 1	35000	35000	75000	125000	225000	245000	500000
Level 2	35000	75000	75000	125000	225000	275000	500000

Additionally, Table 5 shows that lower income customers are less likely to not have access to charging and that fast charging provides a charging option outside the home.

DC Fast chargers are also enabling more travel. 54% of respondents would have taken another vehicle (presumably a gasoline vehicle) if there were no fast charging network. Figure 9 shows the influence of fast charging on the decision to use an EV by charging access.

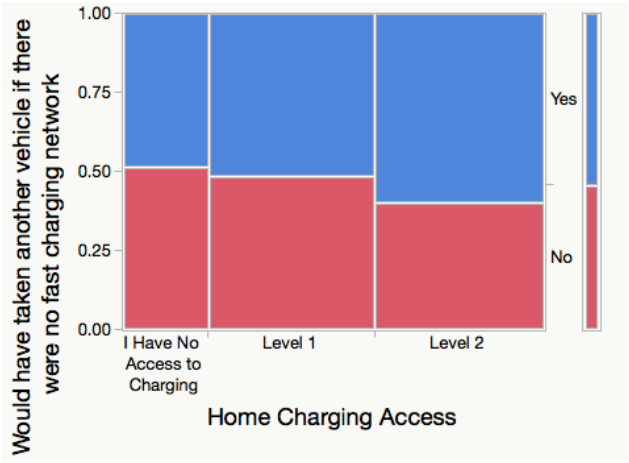

Figure 9: Access to fast charging and vehicle driving choice

Paradoxically, those with no access to home charging would be more likely to use their electric vehicle regardless of fast charging access. This counterintuitive result could be a function of income where those with no access to home charging are also less likely to have another alternative.

When a home charger is available (82% of respondents), there are many reasons to fast charge. The reasons for fast charging are listed in Figure 10.

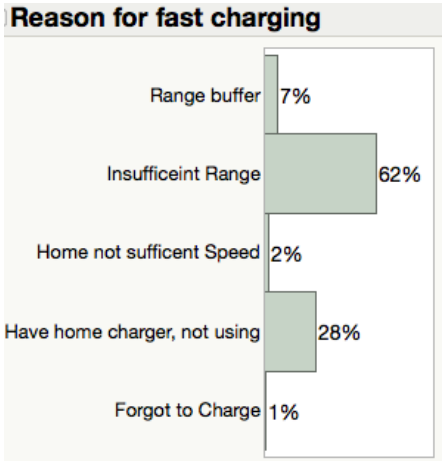

Figure 10: Reason to fast charge when home charging is available

About 69% of respondents with home charging used it for lack of range while 28% of them used it instead of home charging.

Additionally, fast charging is used in combination with Level 1 and Level 2 charging. In some cases, the Level 2 would be sufficient, but they don't exist or are occupied. Those 68% who cited insufficient range as were asked why Level 2 was not an option, shown in Figure 11.

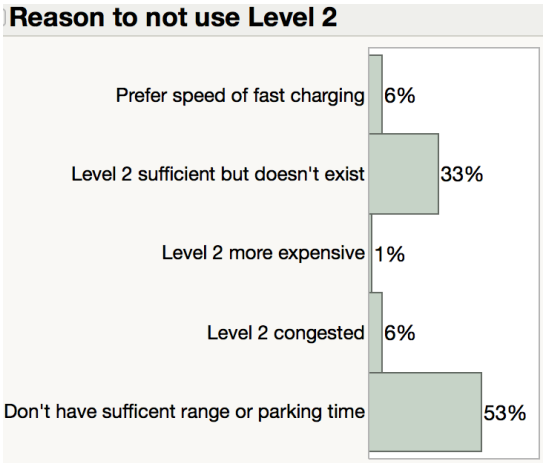

Figure 11: Reason to not use Level 2

Figure 11 suggests that if a home charging solution exists, 47% of public charging could be completed with a Level 2 charger. This shows the crucial role that fast charging is playing in the charging ecosystem and how it may supplement, or in some cases replace, the role of Level 2 could play. It is difficult to make equivalencies for the number of Level 2 chargers a fast charger is replacing because the representativeness of the sample is not established. When plentiful and available, Level 2 may be preferred over fast charging since it may be combined with a parking event but it appears to be reasonable that consumers are willing to travel to a centrally located fast charger in lieu of charging at a distributed Level 2 network. This suggests that fast charging is playing a vital role when the Level 2 network is insufficient.

Indeed, we see in Figure 12 that only 30% exclusively use fast charging on the day of the survey.

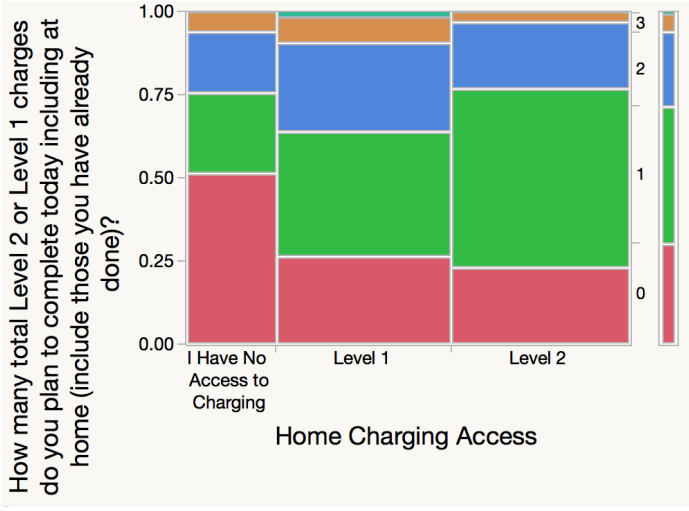

Figure 12: Number of Level 1 and Level 2 charges completed on the day of the fast charging survey as a function of the type of home charger

Those with no home charging access are less likely use other charging, but even those with access to home charging may only use fast charging throughout the day.

5.3 Activities and Shopping While Charging

Since charging takes long enough to engage in a side activity, we ask customers what they do, to give insight into the motivation for charging. Activities while charging are shown in Figure 13.

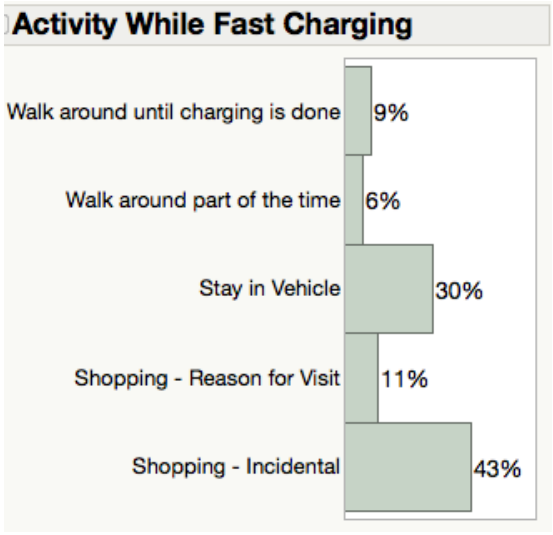

Figure 13: Activity while fast charging

More than half of the fast charger customers shop. Some of those stop specifically to shop, and some shop because they are charging. The average dollars spent is $29.33 if the shopping is incidental and $45.94 if shopping is the reason for the trip.

6 Conclusions

This look at a large dataset of in-use fast charging data and follow-on survey data show that modeled behavior differs somewhat from these sources. The large in-use data show charging close to home suggesting a different use case than long trips or travel days. Most of the usage is driven by heavy users where 10% are responsible for 40%-50% of the charging events and are close to home. The follow-on

survey results suggest several things. First, that some fast charge customers are using a fast charger because they have no home charger and those customers use the closest fast charger to home. Those customers are more likely to be lower income and live in an apartment than those with better home charging access. Secondly, many customers *would consider* but are *not* using their BEV or range extended BEV for purposes far from home. Thirdly, fast charging is used in conjunction with and in some cases as a substitute for Level 2 about half the time either because it is not available at home or in public or it is prefered over Level 2. Fourth, the farthest destination that is attained on the day of a fast charging event is fairly close to the fast charger itself where 50% of those far points are within 5 miles of the fast charger. Fifth, 54% of people would not have used their EV without fast charging. Finally, the results show that the chargers are bringing in 43% of customers who would not otherwise come to a store or establisment and they spend aproximately $30 on average. These results are early and the sample size is not sufficient to establish significance on many metrics. However, the general agreement with the larger dataset shows promise to help establish how and why people fast charge and how fast charging is able to be a flexible solution to fill multiple roles, including a interim replacement for Level 2, as the market for EVs expands. These results may help consumers, automakers, site owners, charging providers and government agencies effectively plan and use fast charging to advance electric vehicles.

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