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Understanding EV charging behavior

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Abstract

Understanding the charging behavior of electric vehicle drivers is imperative to helping utilities forecast electric vehicle electricity loads. Using data loggers with minute resolution, Salt River Project (SRP), is tracking approximately 100 electric vehicles over a year long time period to better understand when, where and how much electric vehicle drivers charge. This data will help SRP better serve electric vehicle drivers in their service territory and guide planning for the required generation resources. Preliminary analysis shows that almost half of all charges are at power levels below 2 kilowatts. Weekday charging peaks occur when drivers arrive at work, when they return from lunch and when they arrive home.

Keywords: passenger car, EV, utility, consumers, charging, load management

1 Introduction

In the United States, as of June 2017, more than 620,000 electric vehicles (EV) have been sold. With models now available in almost every vehicle class, the options for the EV buyer continues to increase. In addition, with the release of the Chevy Bolt and planned release of the Tesla Model 3 in July 2017, EVs are getting longer electric ranges and are being sold at more affordable prices.

With a shift in fuel from gasoline/diesel to electricity, utilities need to forecast how much electricity these vehicles will be using both in the form of total kilowatt hours and peak kilowatts as utilities need to be able to provide power at all times. Understanding the characteristics of how EV drivers charge their vehicles is essential to understanding EV electricity loads;

- Where are the majority of EV drivers charging and at what level (L1, L2 or DC Fast)?
- How often are they relying on public infrastructure vs. workplace charging vs home charging?
- What is a characteristic load for a Nissan Leaf, Chevy Volt, or a Tesla Model S?

Through tracking approximately 100 electric vehicles over a year long period, Salt River Project (SRP), aims to shed light on these questions as well as many others.

2 Background

Having a general understanding of how people drive electric vehicles is fundamental to help plan the electric infrastructure that will support their charging. There have been many surveys (National Household

Transportation Survey is one) that drills into how people drive and what their daily mileages are but without actual GPS information which makes planning the ideal future charging infrastructure difficult. There have been a couple studies that have tracked GPS location of vehicles over time that have helped shed light on where vehicles are parked as well as how far they go to help identify charging lengths and locations. 2 of the most comprehensive are outlined below.

The Puget Sound Regional Council Traffic Choices study was carried out to understand the effect of time-of-day vehicle road tolling. In this study, the Puget Sound Regional Council placed GPS loggers into the vehicles of about 275 households in the Seattle area. They collected data for approximately 18 months (November 2004 to April 2006) and included 400 vehicles. While the study logged miles from conventional vehicles, through the study of GPS information, it shed light on where people were parking, for how long and what their daily driving distances were. Ultimately, if EVs can easily satisfy the needs of a conventional vehicle driver, then there shouldn't be a large barrier to adoption. Papers have used this data (which is publicly available) to assess how EVs would satisfy normal driving routines [1]. However, while similar to conventional vehicles, electric vehicle drivers may behave slightly differently from conventional vehicle drivers given charging infrastructure.

The EV Project [2] was and still is the largest EV monitoring project that had more than 8,300 vehicles enrolled. The vehicles consisted mainly of Chevrolet Volts and Nissan Leafs. Through a partnership with between Idaho National Labs (INL), Electric Transportation Engineering Corporation (ETEC), Nissan, General Motors and more than 10,000 other regional governments 12,000 AC level 2 chargers and 100 Dual Port DC Fast chargers in were deployed in 20 metro areas. The data was collected from January 1, 2011 through December 31, 2013 and logged both driving and charging information.

Figure 1: Location of cities that participated in the EV project. (source)

The study showed that:

- On average, EV drivers drove less miles than the national average.
- Approximately 14% of the Chevy Volts charge events occurred away from home while 20% of Nissan Leafs.
- Public level 2 charging mainly occured between the hours of 8 AM and 2 PM with an average charge time of 3 hours and 9.1 kWh used.
- When looking at home charging the average EV charged lasted approximately 2 hours and 15 minutes and consumed 8.4 kWh of energy.
- 21% of EV project survey respondents relied completely on home charging and 74% of respondents said that they plug in their vehicle every time that they park at home.
- Most of the PEVS in the project charged at 3.5 kW while some of the 2013 models charged at 6.6 kW.
- On an average day, approximately 88% of EV owners charged their EVs.

While ground breaking, the participants in this study were early adopters with minimal public charging equipment. It could be argued that drivers today have much more infrastructure available (public and workplace in addition to home), many more EV models that may suit their needs better (including vehicles with longer range). Furthermore, each city may charge and drive their EVs differently depending on commute time, HOV lane access, presence of multiple unit dwellings that don't have home charging and climate. While this study is a great starting place, further regional analysis over time as EVs become main stream is needed.

3 SRP Study setup

3.1 Study Participants

This study is currently tracking 100 vehicles. The makeup of these vehicles are mainly Nissan Leafs (40) Chevy Volts (30) and Ford Focus (6). Fig. 2 shows the vehicle models currently enrolled in the study. While SRP aimed to have the study mimic the percentages of vehicle types in their utility territory, this wasn't possible therefore future EV load projections vehicle types will have to be weighted.

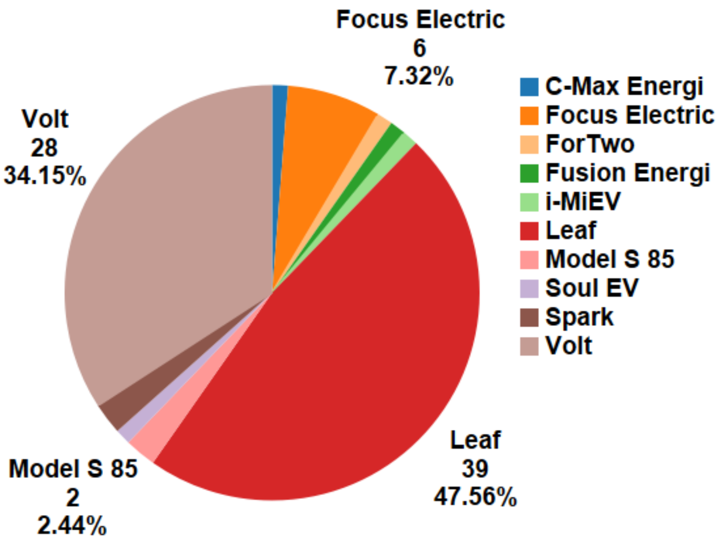


Figure 2: Vehicle types participating in the study by number of vehicles and % of total.

Arizona has seen growth of public charging infrastructure in recent years. Fig. 3 shows the growth of Public DC Fast charging infrastructure over time in Arizona. There are currently 110 Public DC Fast charging stations and just under 900 public level 2 (J1772) charging stations in Arizona therefore proximity to public charging is not a problem. It is also interesting to note that the locations where DC Fast charging infrastructure is located is quite varied (restaurant, hotel, shopping etc.), which gives EV owners options in how they would like to charge. For a DC Fast charge, do EV drivers choose a location where they would like to linger over a longer period of time, or do they simply pick the location that is closet and most convenient.

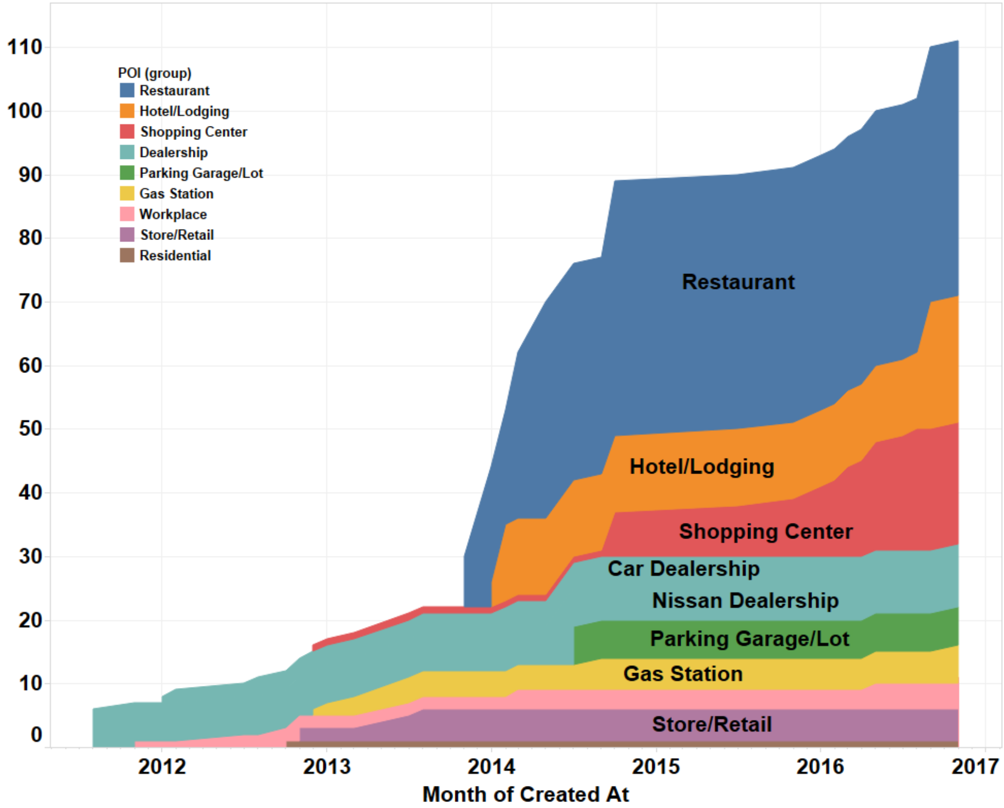


Figure 3: DC Fast Public charging station infrastructure (as of June 22nd) over time in AZ. Colors represent "Point of interest' (POI).

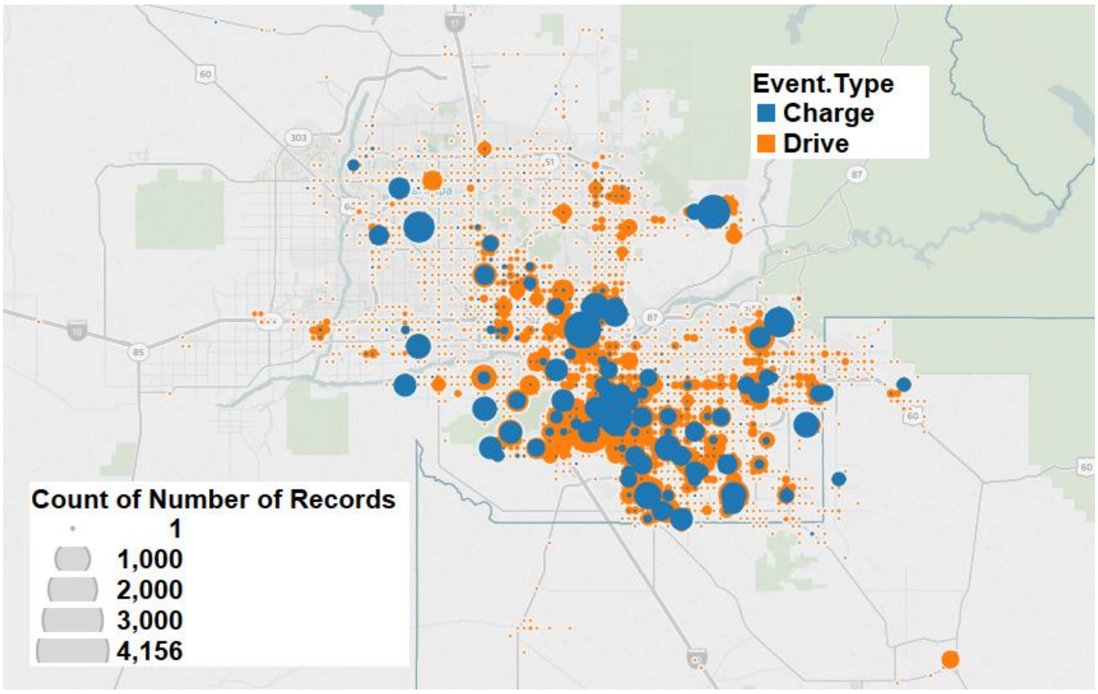


Figure 4: Location of Charges and the start of drives over the length of the study (as of June 22nd). The size of the symbol represents the number of events that have occurred at that location.

The location of charging and driving events covered a wide region in the Phoenix area. And, while not shown here, there were road trips to southern California, Nevada and Idaho.

3.2 Logging devices

Using data logging devices from FleetCarma, SRP began collecting minute resolution data June 1st, 2016. While the specific data logged differs between the different EV models, in general they collect; battery current, battery voltage, vehicle speed, battery state of charge, ambient temperature and GPS coordinates. As of June 22nd 2017, the loggers had captured approximately 31,000 charges and 85,000 drives.

4 Data results

In this study, the data has been broken down in two ways. '*Event summaries'* record statistics from each drive and charge event such as start time, end time, kWh used etc. It allows easy comparison across all the events. '*15 minute kW data'* was also calculated over the whole study. This allows analysis of the total kW required by the entire fleet of vehicles every 15 minutes and can identify times when the vehicles are charging all at once and are therefore demanding a lot of power from the electric grid.

4.1 Event Summary Data

4.1.1 Charges

Table 1: Charging statistics for 3 model types over the study

Model	Charge Level	Avg. kWh per charge event	Average time (hours) per charge event	Number of Charge Events logged	Percentage of total Number of Charge events
Volt	L1	3.0	3.4	7,355	56.0%
	L2	5.6	2.0	5,775	44.0%
Leaf	DC Fast	7.9	0.3	116	0.9%
	L1	2.3	2.7	4,464	35.0%
	L2	7.2	2.0	8,178	64.1%
Focus Electric	L1	3.0	3.4	1,261	59.4%
	L2	6.1	1.3	862	40.6%

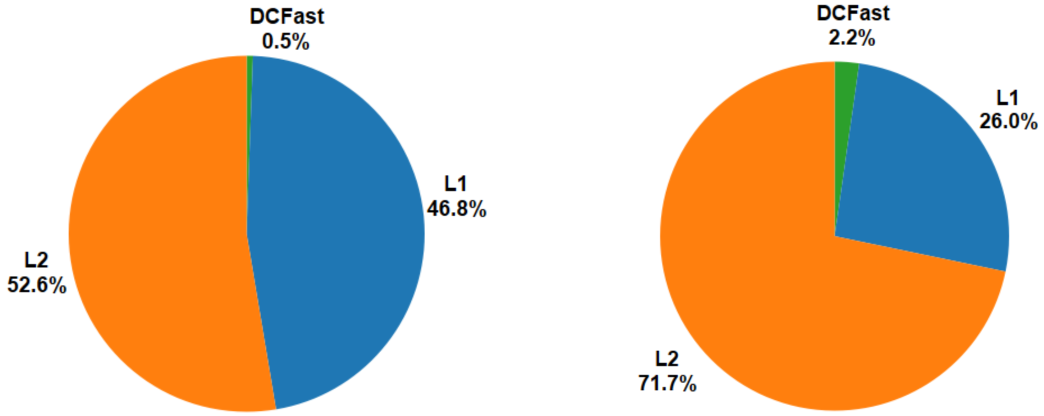
For the purposes of this study Level 1 (L1) was defined as charging with a peak of 2 kW or less. Level 2 (L2) was defined as charging over a range of 2 kW up to 20 kW. DC Fast charging was any charge with a peak above 20 kW. Table 0-1 indicates that while all the vehicles were capable of charging at level 2, and many at DC Fast, for both the Volt and the Focus Electric, the majority of charging took place at L1. This makes sense as a L1 charge over 12 hours can easily charge a vehicle for an average driving day (approximately 24 miles). Leaf owners primarily charged at a L2. Future analysis will separate whether these charges occurred at work, home or public charging.

Out of the over 30,000 charge events, there were 280 unique charging locations. 206 of those charging locations had at least 2 charges logged. 24 of the station locations logged over 50% of all the charges. Of the charging occurring in AZ, 92% were at private charging locations with an average of 5.6 kWh per charge as shown in the table below.

Table 2: Public vs. Private charging statistics

Public	% of Total Charges	Avg. avg. kWh per charge
No	92.1%	5.6
Yes	7.9%	6.2

Figure 5 shows the charge level by number of charging events (left) and by total kWh used. While the breakdown of L1 vs L2 charges by event is relatively equal, the total kWh transferred is much more for L2 charging as more energy is transferred in the same amount of time. The same effect is seen in regards to DCFast charging.



Plot

Figure 5: Charge Type breakdown by charge even (left) and total kWh transferred (right)

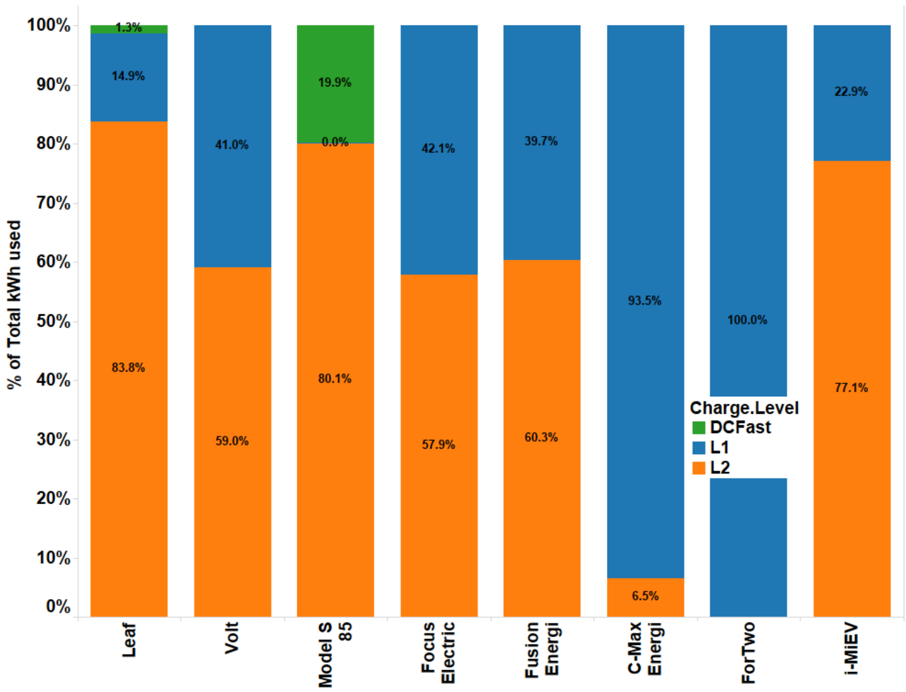


Figure 6: Total kWh used by each vehicle type broken down by Charge level.

As mentioned above, while all vehicles in the study were capable of charging at L2, many chose to charge at L1 as it met their needs. It is likely that the majority of this L1 charging occurred at home. To charge at a L2 at home requires the installation of a electric vehicle charger which is an additional cost. Therefore, vehicle owners who have charging at work or can easily accommodate their charging needs with a L1 charger may choose to not install L2 at home. For example the C-Max and the Smart For Two vehicles almost exclusively charged at L1. The Model S owners used the most DC Fast charging which is a free service included with the purchase of the vehicle. Analysis of where these DCFast events occurred will help define whether the vehicles were on a longer trip or were using the DC Fast charging locally as it is free.

4.1.2 Drive information

Table 3: Summary statistics from drive events. *This does not include trips that used gasoline.

Vehicle Model	Number of vehicles	Total Driving Time [Hr]	Avg. drive length [Min]	Total Drive Distance [Mi]	Avg.Trip distance [Mi]	Avg. Electricity Consumed [kWh]	Avg. Mi/kWh
Focus EV	6	1,090	17.1	41,414	10.8	2.7	4.0
Leaf	40	8,035	16.4	301,383	10.3	2.4	4.3
Volt	30	7,093	20.4	166,617	10.4	2.7	3.9*

Table 3 shows that the Volts and the Leafs had very similar average trip distance when powered solely on electricity. Leafs remain the most efficient vehicles in terms of Miles/kWh. While trip distance does define the distance to another potential charging location, quantifying how far people went in a day is more helpful as that would identify the kWhs needed to satisfy the daily needs which could potentially be satisfied solely by an overnight charge at home.

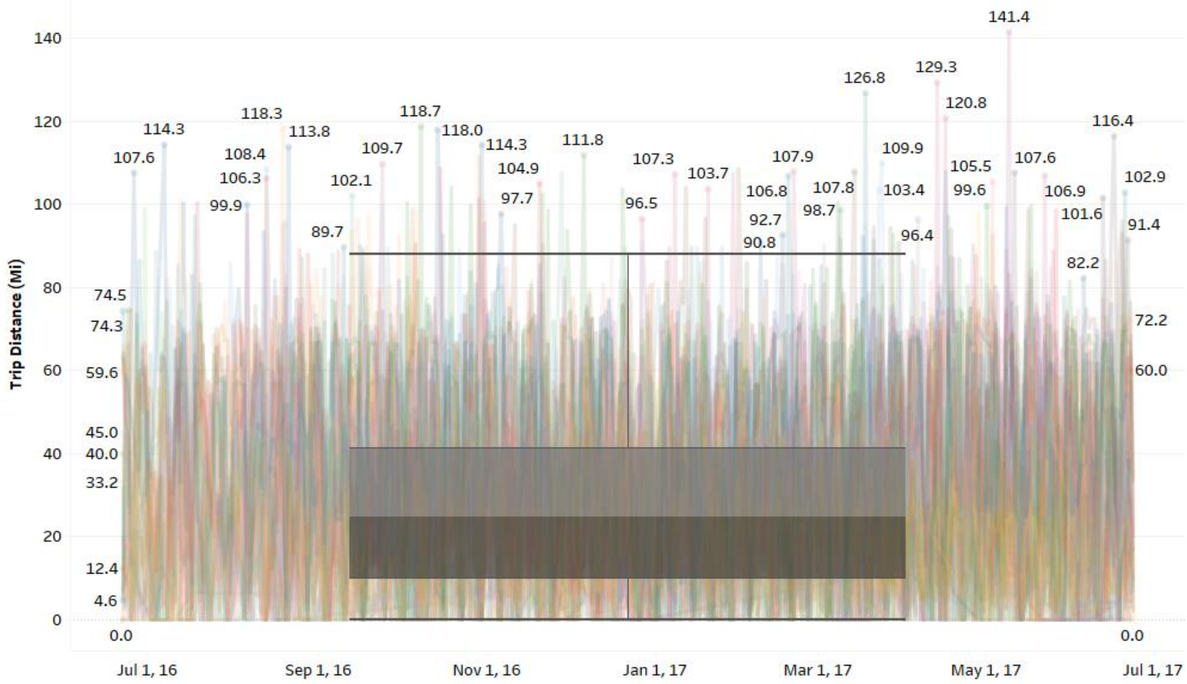


Figure 7: Miles driven per day by all vehicles over the study with a box plot. Box plot median: *24.8, 3rd quartile: 41.1, upper whisker: 88.1, first quartile: 9.7, and lower wisker:0.*

Fig. 7 shows the miles driven daily for each vehicle over the length of the study. The median over all vehicles is 24.8 miles. It is interesting to note that 75% of the total daily miles were below 41 miles. Therefore for 75% of the days, without day time charging, the need could be met with a very low range vehicle.

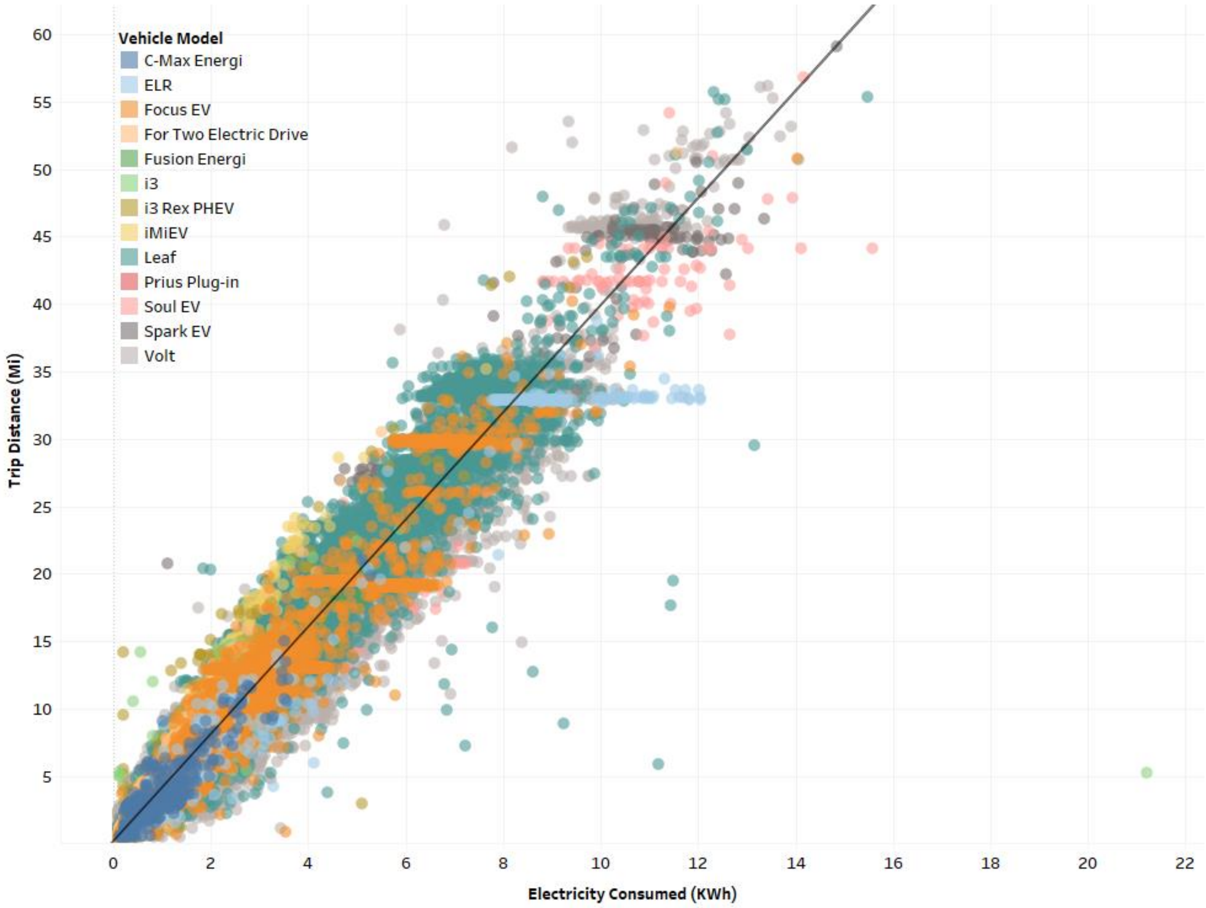


Figure 8: kWh consumed and trip distance for all trips in the study colored by vehicle type. Only purely electric trips were used. Line slope is 3.97 with an R squared value of 0.95.

A value between 3 and 4 miles per kWh is often used in electric vehicle energy estimates. This study confirms these values with the average value at almost 4 miles per kWh across all vehicles. Note that Leafs are the majority of the vehicles in this study and therefore probably help determine the higher efficiency. Summer months, when vehicle owners are likely to be using the air conditioning, may prove to be less efficient. Variability between the vehicles can be attributed to many factors including vehicle efficiency, heating/air conditioning in the car, time spent idling and driving speed.

4.2 15 Minute kW data

Quantifying the electricity load peaks and variability over time is imperative from a utility perspective as utilities need to be to make sure that they can deliver enough power to charge all the vehicles in their territory.

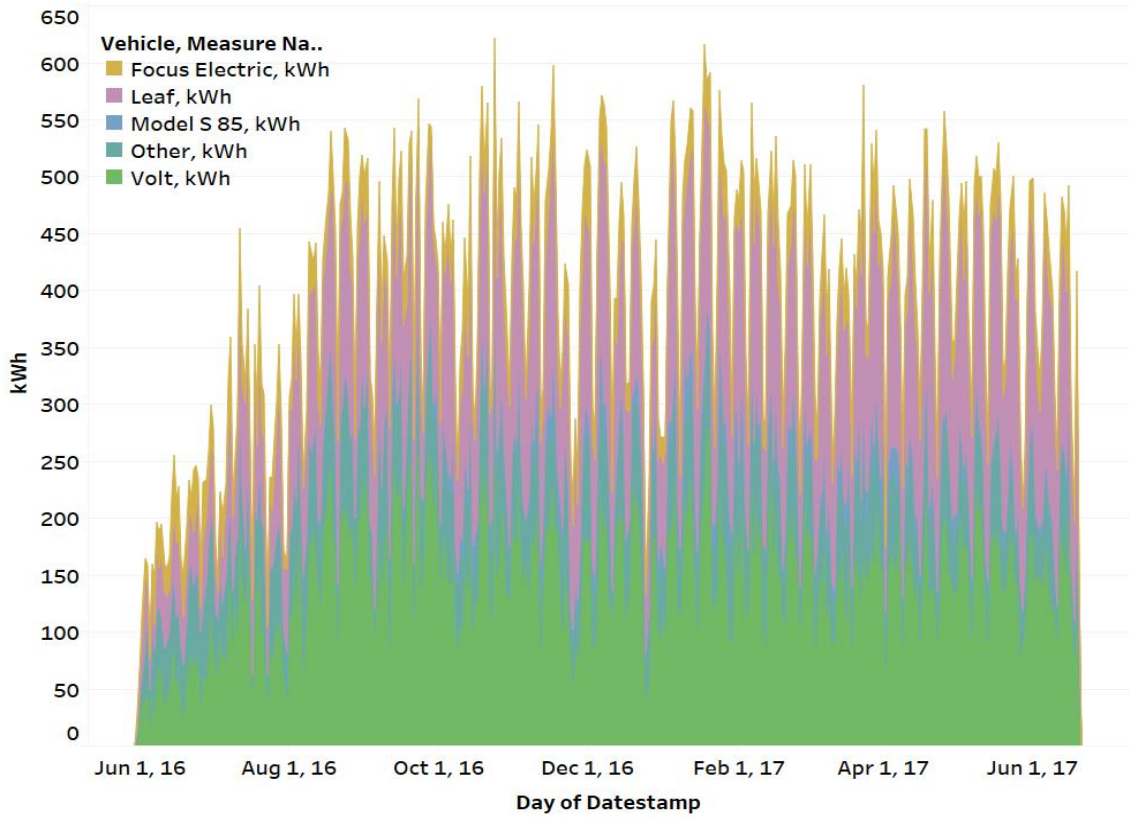


Figure 9: Total kWh used each day over the study colored by vehicle type.

Fig. 9 shows the total kWh used each day over the study. Daily variation ranged from 150 kWh to more than 600. 150 to 600 is quite a pronounced spread and understanding which hours of the day most of the charging occurs is helpful to help utilities plan. Similarly. Fig. 10 shows kW over time and indicates variability from 0 to 110 kW.

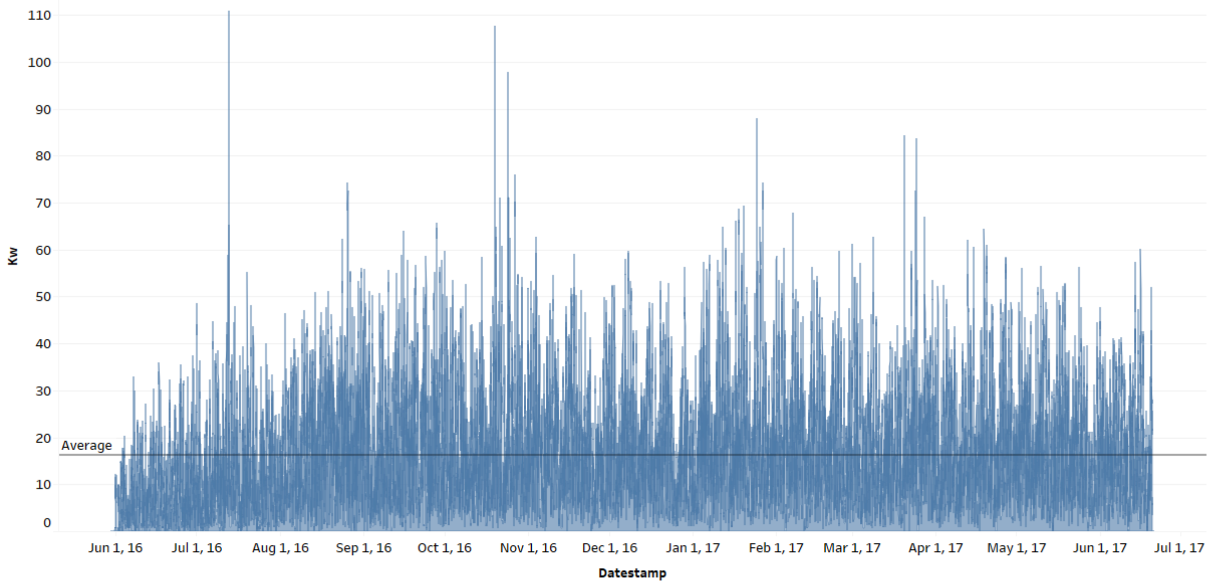


Figure 10: Total kW over time over all vehicles in the study. Average line has been placed for reference (16.4 kW)

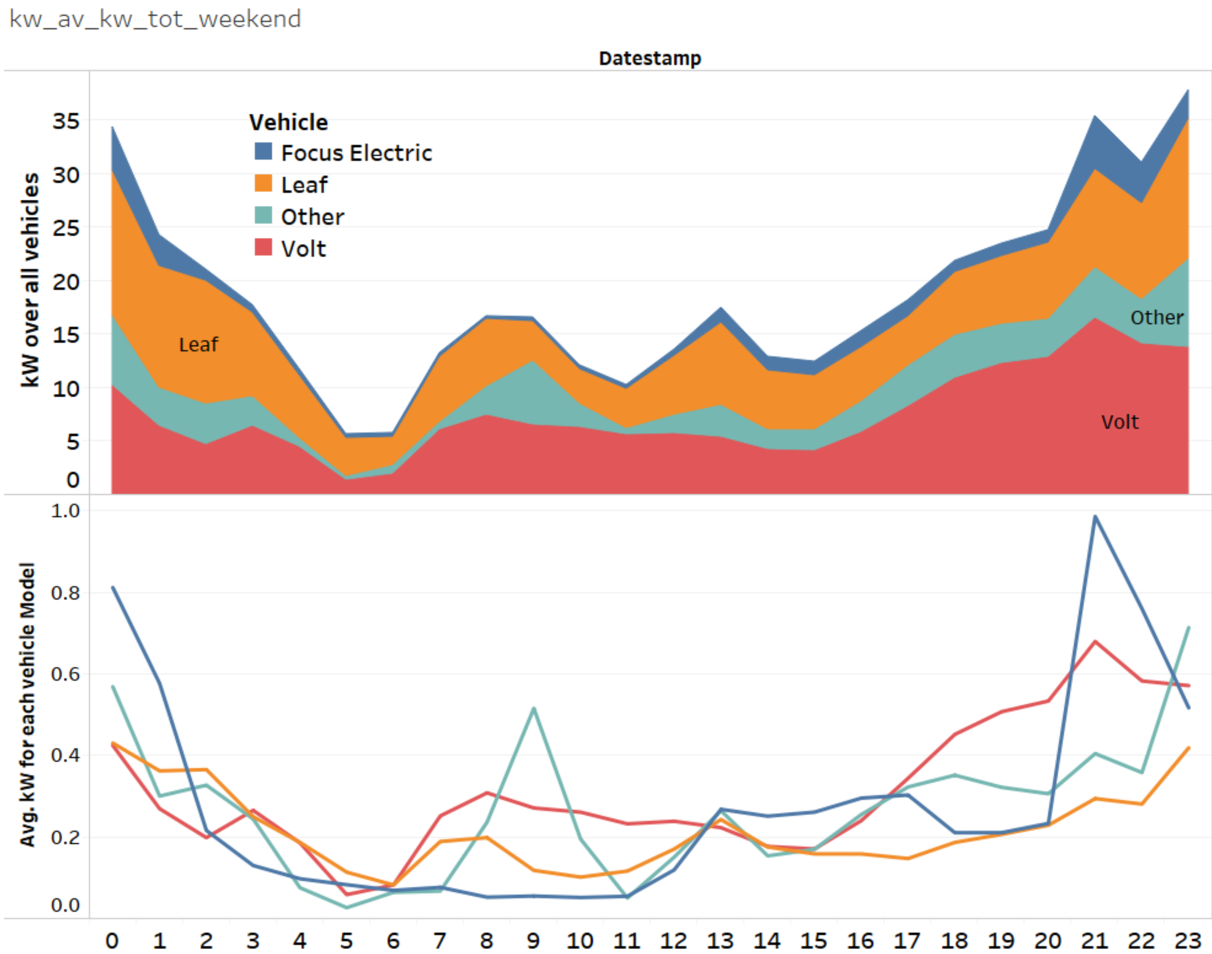


Figure 11: Total kW over the study fleet on a typical weekday (top) and average kW by vehicle type on a typical weekday.

Fig. 11 shows the load shape on a typical weekday colored by vehicle type. Volts and Leafs are the largest percentage of the study and therefore make up most of the load. Three peaks can be seen. These peaks are when people arrive at work, when they plug in after lunch (or switch with another EV driver in the middle of the day) and when they get home at night. The highest peak is during the night time hours. Further analysis will break this down into home, work and public charging locations. Regardless of the vehicle type the average kW added by each vehicle is fairly similar. All of them show increased charging in the night hours at about 0.4-0.6 kW per vehicle. There is a distinct difference in the morning hours of 7-11 between the Focus Electric and Other vehicles. The Focus electric vehicles are SRP fleet vehicles and therefore remain at work and do not commute in the morning this differs from those who commute and plug in at work.

Similar load shapes can be pulled for the weekend. As one might expect, the weekend load curves are much more Gaussian as EV drivers are less attuned to a schedule.

5 Conclusions

While analysis is ongoing, this dataset will help shed light on electric vehicle charging characteristics. Due to the variability of electric vehicle models as well as the length of the study, analysis can shed light on the tendencies of specific vehicle models as well as seasonal vehicle energy use. These charging characteristics when combined with electric vehicle fleet projections will help SRP support and prepare for electric vehicle adopters effectively.

References

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Authors

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