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Southern Company Passenger Electric Vehicle Data Collection and Analysis

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Executive Summary

Electric vehicle (EV) adoption in the United States has increased steadily over the last decade. For electric utilities, these EVs provide both opportunities and challenges. Replacing internal combustion engine vehicles with electric vehicles provides a role for electric utilities to contribute to reducing air pollution and greenhouse gas emissions associated with the transportation system. Understanding EV charging behavior is critical for electric utilities to effectively plan and prepare for the introduction of a new, large load onto their grid systems. This study aims to understand EV charging behavior and ensuing load shapes by collecting and analyzing EV charging and driving behavior collected from over 100 participants in Alabama over a year long period. This work is part of a larger, ongoing project in which similar data were collected from nearly 300 participants in Alabama, Mississippi, and Georgia. It provides insight into real-world operational characteristics of EVs, of which much data is not yet readily available.

Keywords: case-study, data acquisition, passenger car, telematics, utility

1 Introduction

Electric vehicles (EVs) are becoming increasingly popular throughout the United States, including in Southern Company’s service territory. Electric vehicles first hit the market during the 1990s, and by 2018, electric vehicles made up 4.2% of the 16.9 million lighty duty vehicles sold in the United States during that year[1]. Understanding the charging behavior and corresponding load shapes of these vehicles is critical for utilities to prepare for increased EV adoption. EV charging will likely significantly impact system peak load, generation needs, and capacity in the future and must be planned for accordingly [2]. Gaining a greater understanding of electric vehicle driving and charging behavior helps utilities better understand generation and distribution level impacts and plan for them. This project examines the energy consumption and behavior of over 100 EV drivers in Alabama to understand the impact of these vehicles on the electric grid, and is one of the first projects to provide insight into real-world operational characteristics of EVs, of which much data is not readily available.

1.1 Project Motivation

The Electric Power Research Institute (EPRI), in partnership with Southern Company (Southern), conducted this study to help inform load forecasting in Southern Company's service territory, including the answers to questions such as:

- What kind of efficiency can we expect from different EV model types? How does this efficiency vary with temperature? How will vehicle efficiency and temperature impact charging needs?
- What percentage of charging is conducted at home? How does home charging change the average load shape of a home?

This information is critical for utilities to have so they can prepare their distribution grids accordingly for the impacts of growing EV fleets in their service territories. More insight into EV owner behavior also allows utilities to better tailor their rates offerings.

2 Data Overview

Telematics vehicle data was collected over a 13-month period from participating drivers using a physical device plugged into their vehicles. This data was collected from drivers who resided in the service territory of Alabama Power, one of Southern Company's three operating companies.

2.1 Data Collection

FleetCarma, a division of Geotab, was responsible for collecting and sharing the data from these logging devices. See Table X for a list of data capabilities. For each driver, charging and trip information was collected. Trip data consisted of information collected at the beginning and end of a trip whereas charging data were provided in 15-minute segments throughout the duration of a charge. Both trip and charging data included unique IDs for the drivers and vehicles as well as details about the vehicle's make and model.

Table 1: Information captured through FleetCarma devices

Data collected from vehicle trips	Data collected from vehicle charge events—every 15 minutes
Start and end timestamps	Start and end timestamps
Start and end vehicle state of charge (SOC)	Start and end vehicle state of charge (SOC)
Total distance traveled	Latitude and longitude
Fuel consumed (for PHEVs)	Geofence name (*Alabama Power, No GPS, Inaccurate GPS, Out of territory*)
Energy consumed (for BEVs and PHEVs)	Maximum charge power (kW)
	Charge energy (kWh)
	Charge energy loss (kWh)

3 Participant Information

Vehicle data was collected from September 2020 to September 2021. Over this 13-month period, data was gathered from 135 unique vehicles (123 unique drivers) with between 94 and 127 vehicles reporting data in any given month.

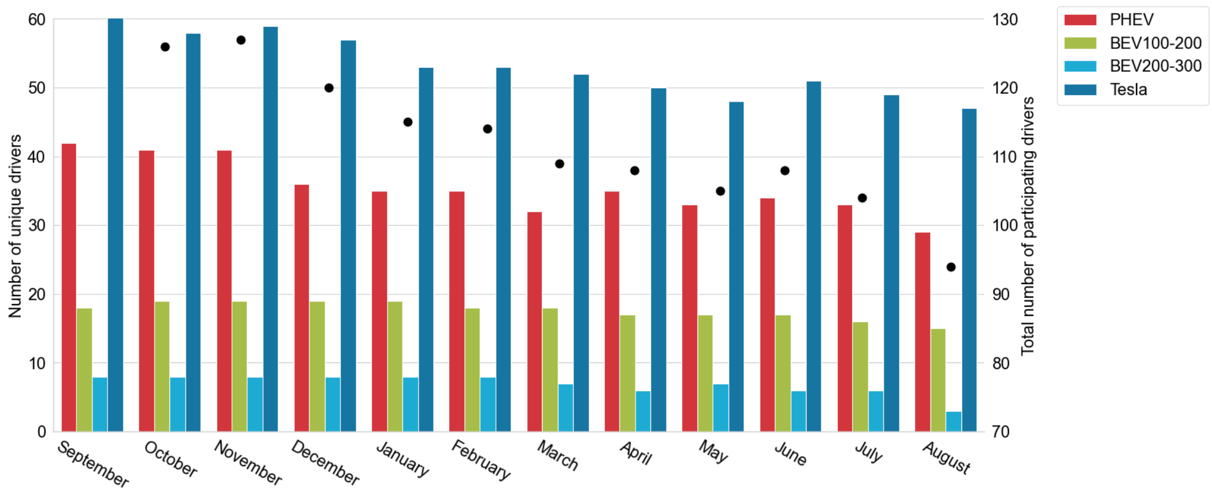

Figure 1: Participant information by month

3.1 Vehicle Groups

These vehicle models are further grouped into four categories: 1) PHEVs, 2) BEVs with an all electric range [AER] between 100 miles and 200 miles, 3) BEVs with an AER between 200 miles and 300 miles, and 4) Teslas. Teslas are grouped into its own category because they often exhibit differing behavior from other EVs.

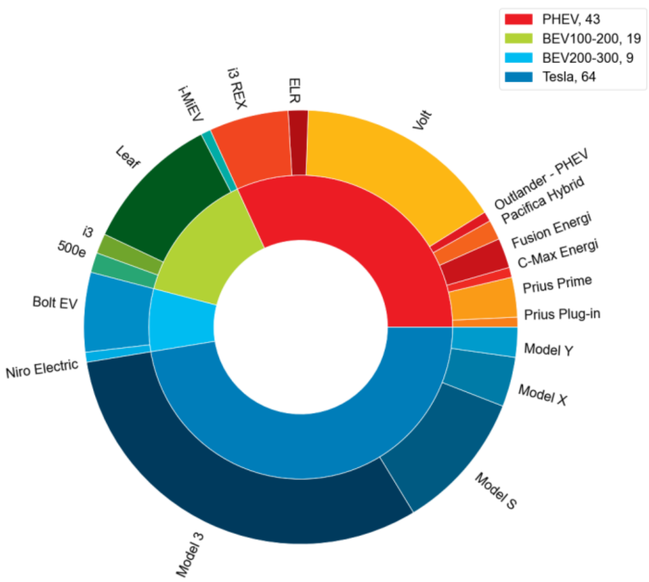

Figure 2: Distribution of vehicle models by vehicle groups for participating drivers

4 Participant Vehicle Driving Behavior

Overall, drivers in the PHEVs and Teslas have similar daily mileage distributions with average daily mileage near 25 miles and numerous outliers corresponding to long trips. The distribution of long trips for Tesla and PHEV drivers is similar perhaps because both vehicle types have access to extended range capabilities—Teslas through their long-range and widespread public charging network and PHEVs through their internal combustion engines. All Tesla miles are electric whereas PHEV miles are approximately 60% electric and 40% gasoline powered. Drivers in the BEV200-300 group (composed of 9 drivers) travel an average of 33 miles per day. Of these 9 BEV200-300 drivers, 6 drivers drive an average of 60 or fewer miles per day, while the other 3 drive an average of 70, 86, and 96 miles per day. The fewest number of average daily miles is traveled by the BEV100-200 group (composed of 19 drivers) who travel an average of 12 miles per day.

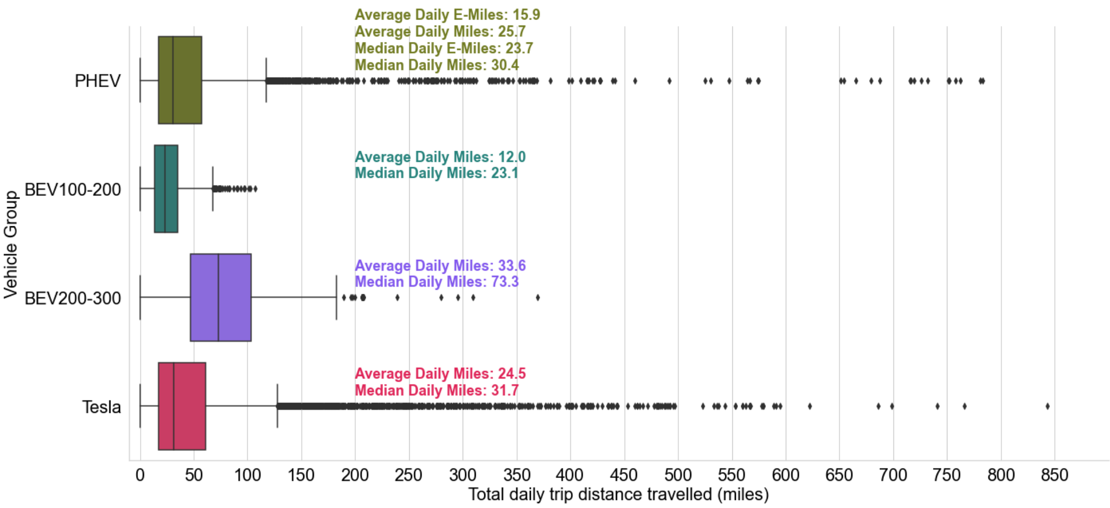

Figure 3 : Total daily driving distance distribution by vehicle group

Figure 3 is also represented in tabular format by vehicle group and daily miles travelled in Table 1. Although not surprising, Table 1 underlines the fact that most days (just under 90% of days), vehicles were going under 100 miles. Even with a reliable charging network, Teslas showed that only 1.55% of the total days did the vehicles go farther than 250 miles. Most vehicles are not using their full battery capacity daily, and only a small percentage of travel days in the data are above 250 miles. Less than 2% of days per vehicle group were above 250 miles of travel.

Table 1: Average and median daily charge energy and mileage for participating drivers by vehicle group

Daily Miles Traveled	PHEV	BEV100-200	BEV200-300	Tesla
0–100 miles	7,880 [92.4%]	4,052 [99.9%]	1,273 [78.7%]	11,092 [89.5%]
100–250 miles	1,091 [6.1%]	2 [0.1%]	341 [21.1%]	1,091 [8.8%]
250–500 miles	182 [1.1%]	-	3 [.19%]	182 [1.5%]
500+ miles	24 [.37%]	-	-	24 [0.2%]

Table 2: Average efficiency, mileage for participating drivers by vehicle group by month, with ambient temperature

Month	Vehicle Group	PHEV		BEV100-200		BEV200-300		Tesla	
	Avg Ambient Temp (F)	Efficiency (kWh/mi)	Daily E-Miles (Avg)	Efficiency (kWh/mi)	Daily E-Miles (Avg)	Efficiency (kWh/mi)	Daily E-Miles (Avg)	Efficiency (kWh/mi)	Daily E-Miles (Avg)
September	77.6°	3.14	29.5	2.55	26.8	3.02	87.2	2.15	51.6
October	72.0°	3.07	30.0	2.57	25.4	2.89	76.2	2.17	54.7
November	63.2°	2.90	28.2	2.48	25.0	3.02	71.4	2.17	52.2
December	52.0°	2.53	25.7	2.33	25.0	2.90	73.9	2.09	52.9
January	51.2°	2.57	24.1	2.31	24.1	2.83	69.8	2.04	49.2
February	53.7°	2.54	24.5	2.47	24.1	2.78	69.5	1.99	48.5
March	64.4°	2.95	27.9	2.59	24.1	2.97	75.7	2.34	55.2
April	68.5°	3.04	28.8	2.67	25.4	2.96	73.8	2.35	56.8
May	76.0°	3.14	30.8	2.67	23.4	2.70	60.0	2.30	61.8
June	82.0°	3.11	30.1	2.39	23.7	3.20	78.6	2.31	58.3
July	83.2°	2.96	30.1	2.64	26.3	3.13	72.4	2.34	60.3
August	83.7°	2.95	27.1	2.64	26.6	2.71	63.1	2.25	54.3
September	78.9°	2.88	26.2	2.89	27.7	3.07	72.1	2.39	55.2

Table 2 shows the likely impact of temperature on efficiency – during colder months, the efficiency of vehicles dropped slightly – in colder and hotter months, up to 25 percent more energy is needed per mile compared to the most efficient months, based on the observed charging and driving data. This is probably due to the increased cooling/heating needs of the vehicle cabin. In Teslas, particularly, extra energy may be expended per mile due to the battery pre-conditioning cycles that are standard for Teslas – they see slightly higher energy needs per mile in comparison to the other vehicle groups.

5 Participant Vehicle Charging Behavior

Over the 13 months during which data are collected from Alabama drivers, a total of 352 MWh of energy was used to charge vehicles. Table 1 presents a summary of participants' charging and driving behavior. In general, drivers use an average of 8 kWh each day. BEV100-200s and PHEVs consume the least daily average energy —about 5kWh—while BEV200-300s and Teslas consume nearly twice as much. Overall, drivers in the PHEVs and Tesla grouping have similar daily mileage distributions, averaging 25 miles.

Table 3: Average and median count of charges, charge energy, and mileage across drivers by vehicle group

Vehicle Group	# of Drivers	Charges Per Day		Daily Charge Energy (kwh)		Daily E-Miles	
		Average	Median	Average	Median	Average	Median
PHEV	43	1.00	1	5.5	8.3	15.9	23.7
BEV100-200	19	0.65	1	4.7	9.0	12.0	23.1
BEV200-300	9	0.79	1	11.5	24.3	33.6	73.2
Tesla	64	1.39	1	11.1	19.4	24.5	31.7
Total	**135**	**1.1**	**1**	**8.3**	**11.5**	**20.4**	**27.6**

5.1 Charging Locations

Electric vehicles can charge at multiple locations, and the typical locations of interest are drivers' homes and workplaces, as well as public charging, due to the different requirements for infrastructure needed at the different location types. Within the study, participants charge primarily at home, as expected, with approximately 10% of the energy being charged at DCFC public charging locations, 5% at work locations, and the remainder at home, when accounting for unknown locations. Unknown locations were locations that were not the participant's provided home or work locations, or a public charger identified within the Plugshare database.

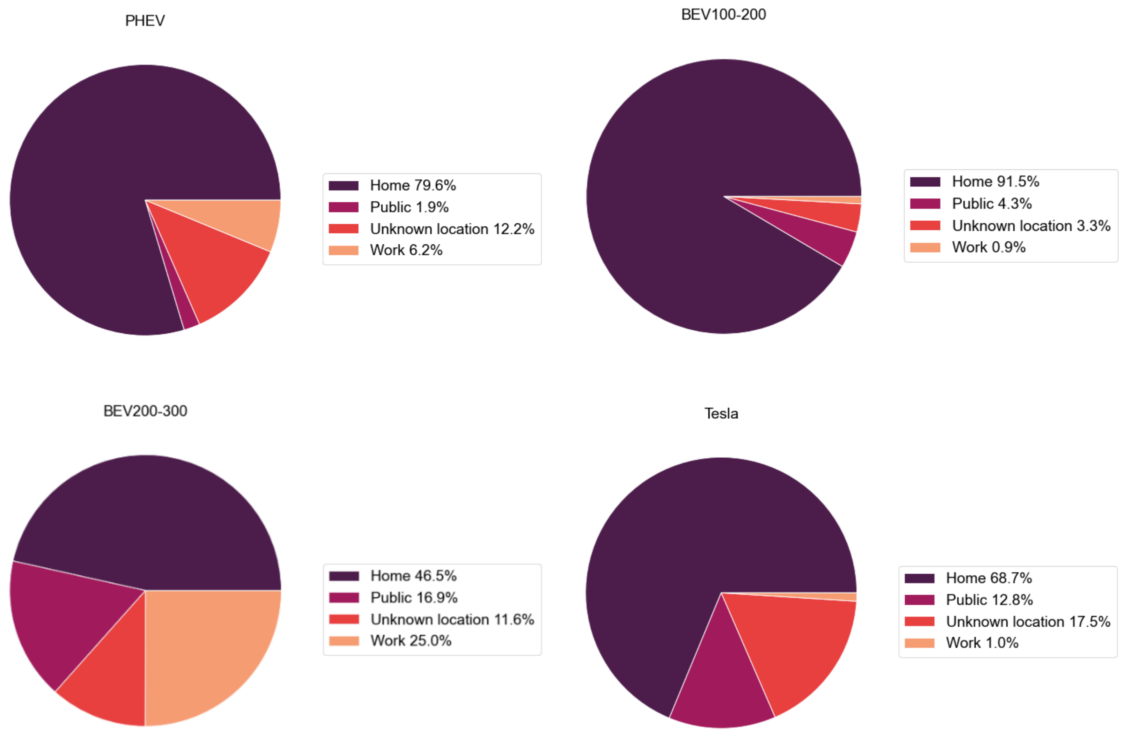

Figure 4: Distribution of charging energy by identified location across vehicle groups

5.2 Charging Power Distribution

Figure 5 shows fraction of total charge energy (kWh) that occurred at different power levels for each vehicle group by proportion of energy used. The power level breakdown is defined as follows:

- L1 < 2 kW
- Low L2 > 2kW and less than 8 kW
- High L2 > 8 kW and less than 20 kW
- DCFC as greater than 20 kW

PHEVs, BEV100-200s, and BEV200-300s all had similar breakdowns of charge energy by power level, with the majority of charging taking place at Low L2 followed by L1 charging. Tesla vehicles showed significantly different results, with most Tesla charging taking place at High L2 followed by Low L2, then DCFC, and lastly L1.

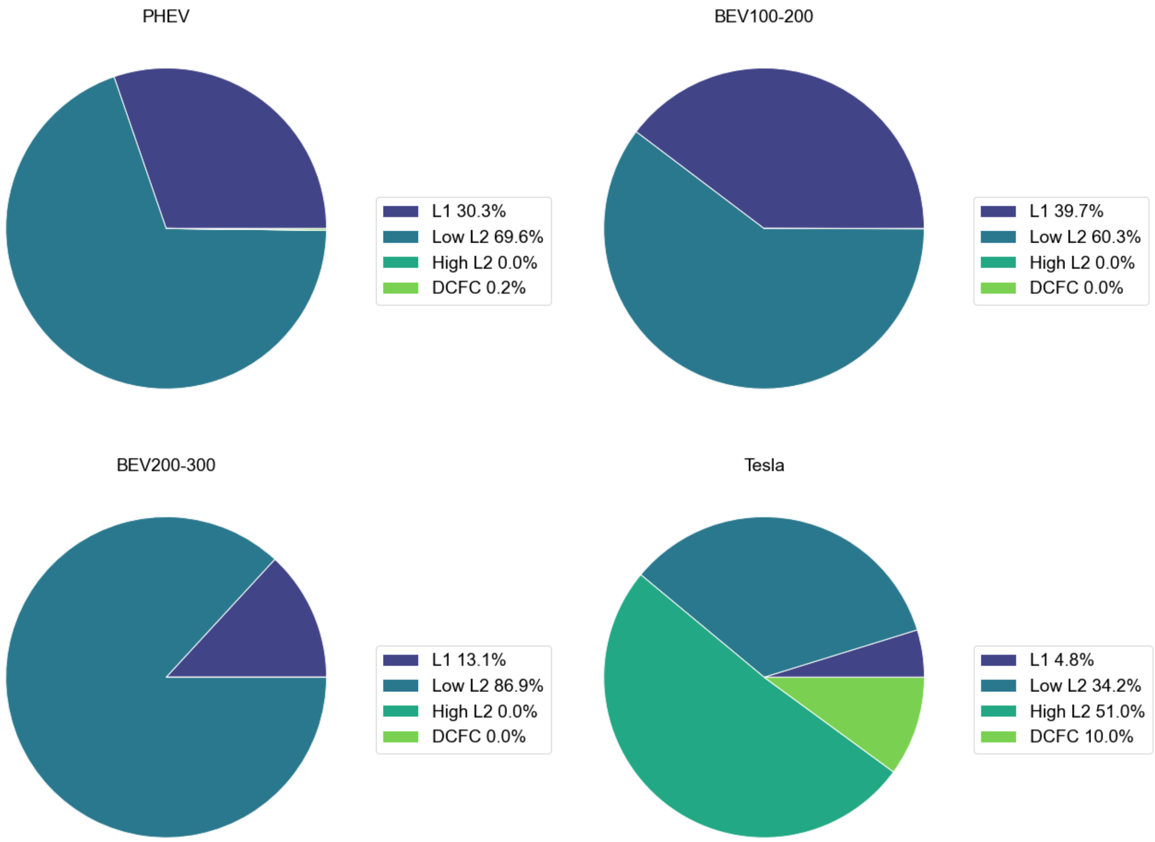

Figure 5: Distribution of charging energy by charge power across vehicle groups

Charge session duration by power level for each vehicle group is shown in Table 3. All vehicle groups except Teslas charge almost exclusively at Level 1 and Low Level 2. PHEVs and BEV100-200s have shorter charge sessions in general, corresponding to their smaller battery size, while BEV200-300s charge longer (still at low power levels) to fill their larger batteries. Tesla charge durations also tend to be shorter than those of BEV200-300s because the Teslas are often charging at higher power levels (High L2).

Table 3: Average and median charge session length and kWh by charging level by vehicle type

	L1			Low L2		
	Average kWh	Average duration	# of Sessions	Average kWh	Average duration	# of Sessions
PHEV	4.2 kWh	3.8 hrs	5,493	6.9 kWh	2.1	7,463
BEV100-200	6.3 kWh	5.3 hrs	2,056	8.1 kWh	3.6	2,390
BEV200-300	5.4 kWh	4.8 hrs	731	18.4 kWh	3.0	1,425
Tesla	4.0 kWh	5.7 hrs	1,508	14.3 kWh	2.2	5,696
Total	5.3 kWh	4.5 hrs	9,788	10.5 kWh	2.4	16,974

	High L2			DCFC		
	Average kWh	Average duration	# of Sessions	Average kWh	Average duration	# of Sessions
PHEV	-	-	-	11.21 kWh	0.4 hrs	11
BEV100-200	-	-	-	3.4 kWh	0.2 hrs	2
BEV200-300	-	-	-		-	-
Tesla	19.37 kWh	1.93 hrs	6,329	30.2 kWh	0.5 hrs	754
Total	19.37 kWh	1.93 hrs	6,329	29.9 kWh	0.5 hrs	767

6 Participant Load Shapes and Home Energy Usage

Vehicle charging data in this study were provided in approximately 15-minute time intervals. To create 24-hour load profiles, vehicle charge energy is assigned to the start hour during which it occurred. To generate the average load shapes, the charge energy at each hour of the day for each vehicle is summed and then divided by the total number of days during which the same vehicle was active in the study; this includes averaging over days and times during which the vehicle was not charging. This load shape can be used to understand average energy use over time.

6.1 Vehicle Load Shapes

The average home charging load shapes across all vehicle groups is shown inFigure 6. Note that these don't include charging that occurred at work or at public locations. In this figure, the mean (dark line) and the 95% confidence interval around the mean (lighter colored shading around the mean line) are shown. Most charging happened during the nighttime hours, as evidenced by the peak between hours 22 and 5. Average charging power levels were between 0.1–0.2 kW average power between 6 am and 8 pm with a pronounced jump to 1.3 kW at 10 pm.

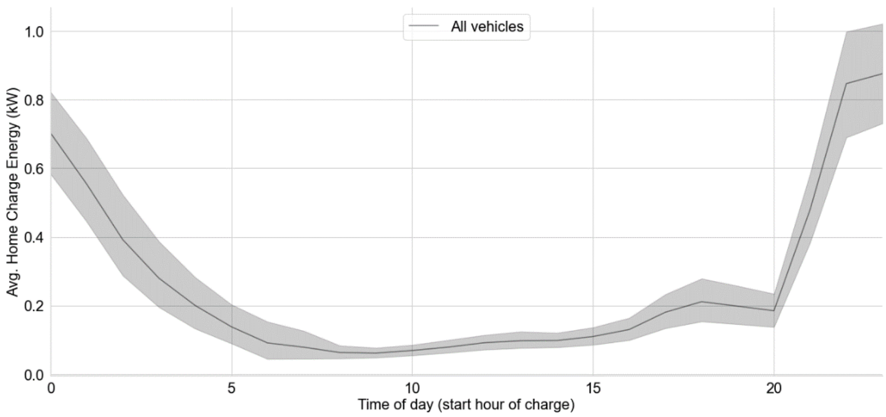

Figure 6: Average 24 hour load shape across all vehicles participating in the study

Table 4: TOU and Non-TOU Rate Rider Participant Statistics

Vehicle Group	# of Drivers in TOU	% of Energy Charged on Peak [for drivers enrolled]	# of Drivers Not in TOU	% of Energy Charged on Peak [for drivers not enrolled on TOU]	# of Drivers with No AMI Information
PHEV	30 (69.7%)	17.4% (11,765 kWh)	6 (13.9%)	19.4% (1,912 kWh)	7 (16.4%)
BEV100-200	14 (73.7%)	12.8% (3,254 kWh)	3 (15.8%)	9.25% (397 kWh)	2 (10.5%)
BEV200-300	8 (88.8%)	14.2% (3,691 kWh)	0	-	1 (11.2%)
Tesla	43 (67.2%)	10.9% (21,640 kWh)	10 (15.6%)	19.2% (8,590 kWh)	11 (17.2%)

6.2 Advanced Metering Infrastructure (AMI) Load Shapes

Alabama Power has a time of use (TOU) rate rider for electric vehicles that encourages home charging between 9 pm and 5 am, and discounts all energy usage by the house, even for use cases outside of vehicle charging, between those hours. The impact of this TOU rate can be clearly seen on the average 24-hour load profile in Figure 6 and Figure 7 - most evening charging starts after 9 pm. In addition, they have advanced metering infrastructure (AMI) meters that allow them to track home energy usage, and 104 participants opted in to providing both their vehicle charging and AMI home energy usage information.

Of the 104 drivers for which both vehicle charging and AMI information is available, 88 (85%) are on Alabama Power's EV TOU rate plan. Survey data indicate that most drivers who are enrolled in the TOU plan program their EVs or their home chargers to start charging after 9 pm. However, some drivers opt to program their EVs to be fully charged by the morning (5 am), and some drivers manually plug their cars in after 9 pm. **Error! Reference source not found.** summarizes statistics about the number of drivers that were enrolled in the TOU rate as well as the total charge energy supplied to drivers during the peak period, which was defined as 5–9 pm. For both the PHEV and the Tesla grouping, less energy was charged during peak times for those on the TOU rate than those who were not. For the Tesla group, the energy charged during peak was halved for the group on the TOU rate. This wasn't the case for the BEV100-200 where more energy was charged on peak for drivers on the TOU rate (12.8%) vs. those who weren't on TOU (9.25%); however, the sample size of the drivers not on the TOU rate numbers only 3—therefore, the behavior of one driver could be skewing the results.

Error! Reference source not found. shows that, across all the vehicles for which we have AMI data, home vehicle charging on average adds power needs at the average customer home peak (6 pm) and a large amount at 11 pm. Not all the drivers were on the TOU rate, so there is potential here to shift the peak more into the 9 pm–5 am window. Furthermore, is it unknown whether the drivers in the study chose to charge their vehicle at the highest available charge immediately at 9 pm or if they programmed their vehicle to finish charging at 5 pm (thus shifting the load more to the morning hours). Further investigation is warranted to see if a managed charging system that flattens all EV power between the hours of 9 pm and 5 am is helpful.

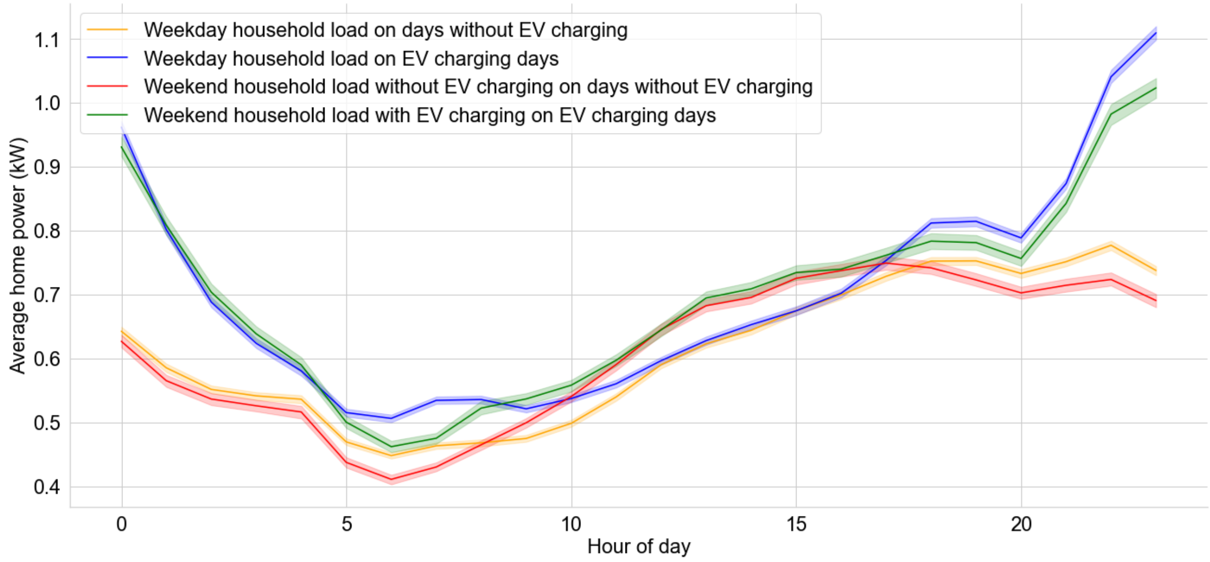

Figure 7: Average home energy use on days with home vehicle charging and days without home vehicle charging for all vehicle groups.

6.3 Multi-EV Households

Average home energy usage was also plotted for users with multiple EVs at home (see Figure 8). On average, on days with home charging, users with multiple vehicles tend to have higher energy usage, as is expected. For the households with two vehicles, there is more of a pronounced power jump at 8 pm and similar power decrease at 4 am. One explanation for this could be that those households with two EVs may be a bit more aware of their power impact and may be more likely to adopt some kind of managed charging schedule to adhere to a TOU rate. Note that this plot averages over days when home charging did occur so the load shape would be lower in magnitude if days that the vehicles weren't charging were also averaged in.

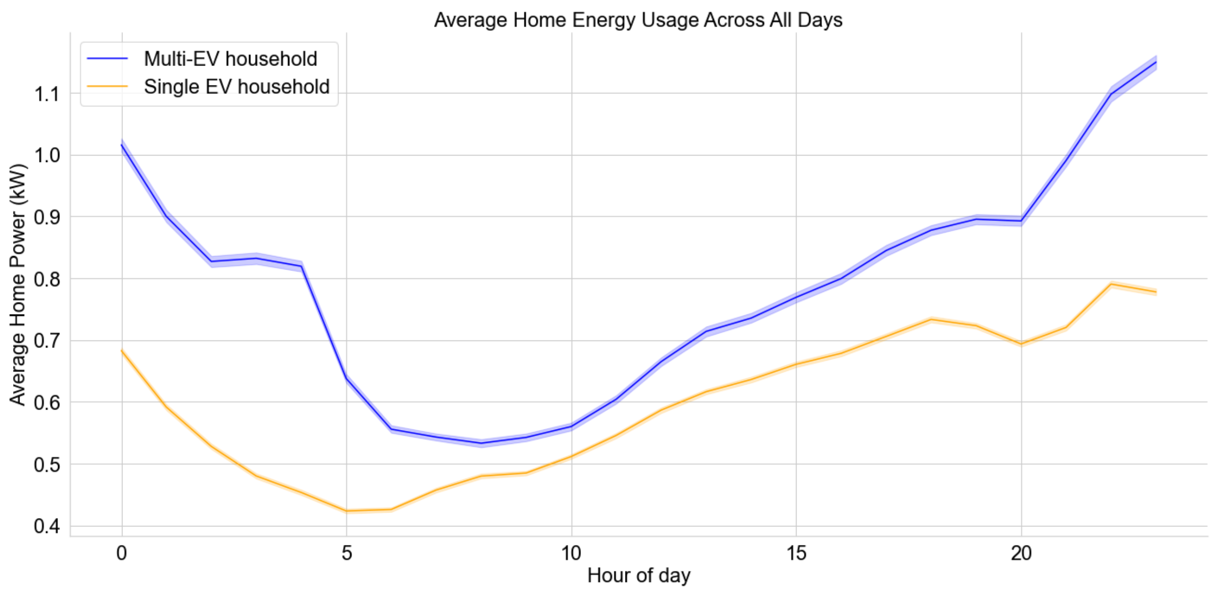

Figure 8: Average home energy use on days with home vehicle charging and days without home vehicle charging for all vehicle groups.

6.4 TOU Impacts on Charging Behavior

Error! Reference source not found. shows average home charge energy for drivers separated by the different utilities (Alabama Power, Georgia Power, and Mississippi Power). The average 24 hour home charge energy for Mississippi is far flatter across the day, indicating that drivers are charging at all hours, with no preference to when their charging starts for the most part. Alabama and Georgia Power peak at different hours – specifically, for Alabama, when the rate rider discount can be applied, and for Georgia Power, when the super-off peak rate begins. This data seems to indicate that customers shift their charging behavior towards what is the most cost efficient, and has implications for how utilities might design their rates, and how customers may respond to the rates.

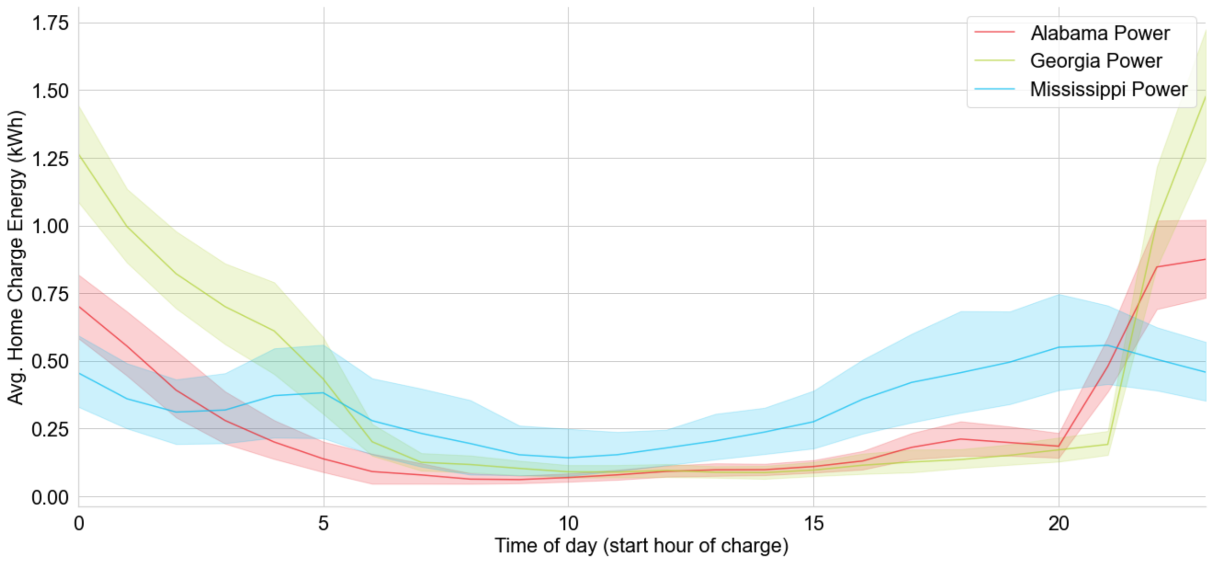

Figure 9: Average home energy by utility program across Southern Company's operating companies

7 Conclusion

This study describes EV behavior over a year-long period from participants in Alabama Power's service territory. Driving information reveal average trip length as well as miles driven in a day, shedding light on what some charging solutions might be in the future. Vehicles on average drive 25–60 miles a day with a significant variation between vehicle type. As previous studies have shown, most charging occurs at home, which this study supports. This study also supports the exploration of further questions – how do these early adopters of electric vehicles differ from the typical driver?

Understanding electric vehicle load shape is instrumental in helping utilities plan for EV adoption. In this study, the charging data are segmented by vehicle type (by electric range and engine type) as well as by whether a vehicle was on a TOU rate. Unlike a similar previous study done by Salt River Project [3, 4], this study incorporates home meter data to see how the load of the EV impacts the peak load in the home. Analysis of the vehicle driving data today with household AMI data shows that EVs account for approximately 10% of the household energy. Understanding how these EV household load shapes will impact the grid with higher adoption is key to planning both for future power needs and for how those needs could be reduced through innovative charge management schemes. (1)

Acknowledgments

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Presenter Biography

Jennifer Kwong is a technical leader on the transportation team at the Electric Power Research Institute (EPRI) in Palo Alto, California. She received her masters' in transportation system engineering and urban planning from the University of California, Irvine and her bachelors' in civil engineering and geography from the University of Maryland, College Park.

Her current work at EPRI focuses on translating passenger, medium, and heavy duty vehicle behavior into load shapes for utility planning purposes to help the electric grid prepare for transportation electrification.