Charging behavior

ECI 189G: Lecture 10

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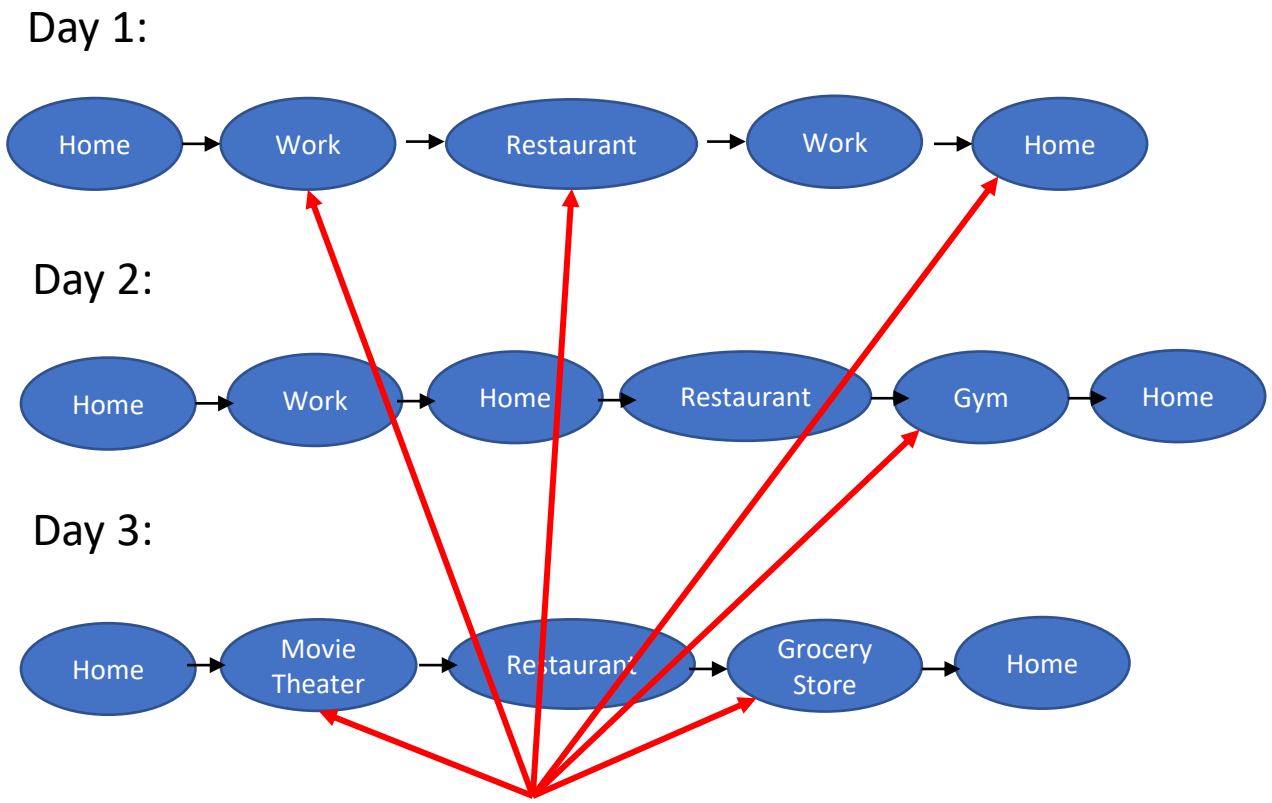
Refueling gasoline vs charging an EV

Gas Car

Drive until the tank is empty and then refill at the gas station

Electric Vehicle

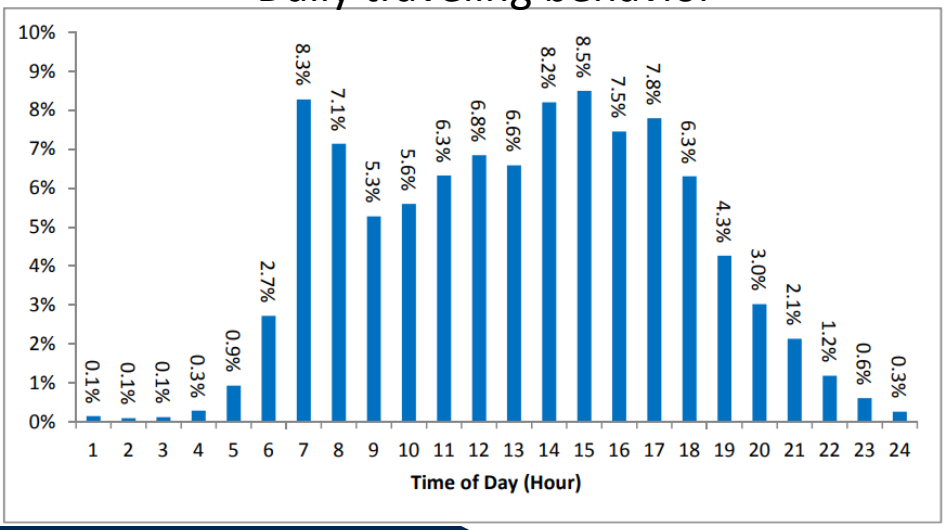


Where and when should I charge? How often should I charge?

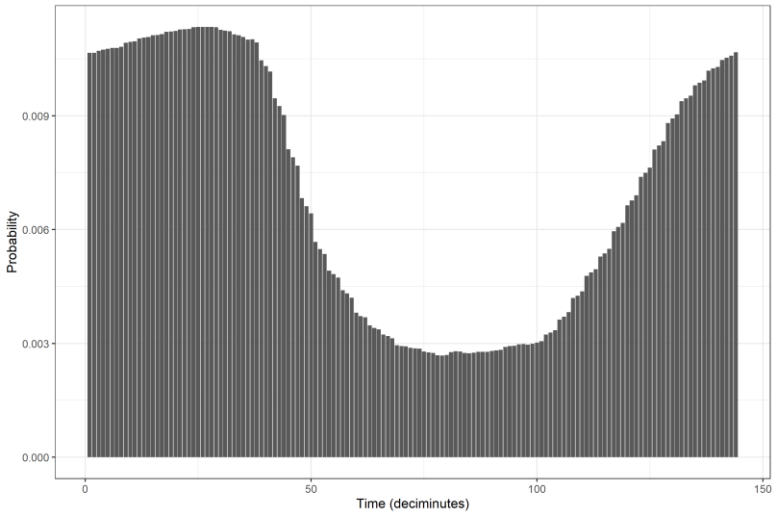
Travel behavior vs charging behavior

- The times and when people drive and when they charge are inversely correlated
- Drivers can't charge when their cars are moving! The more cars are moving, the less cars that are charging

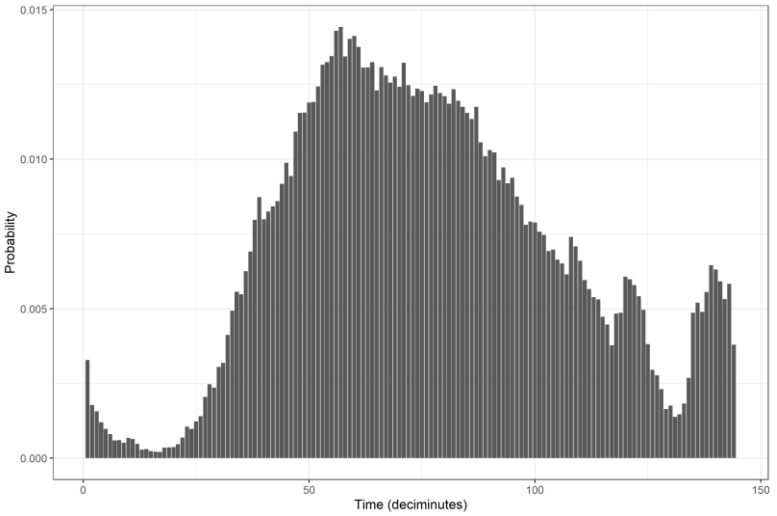
Daily traveling behavior



Daily home charging behavior

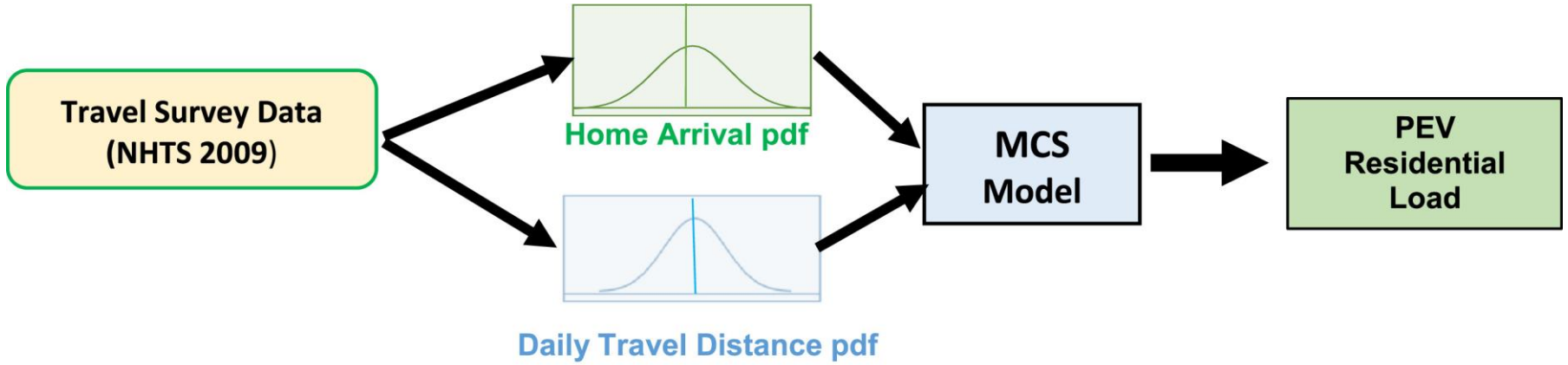


Daily public charging behavior



Existing studies and charging assumptions

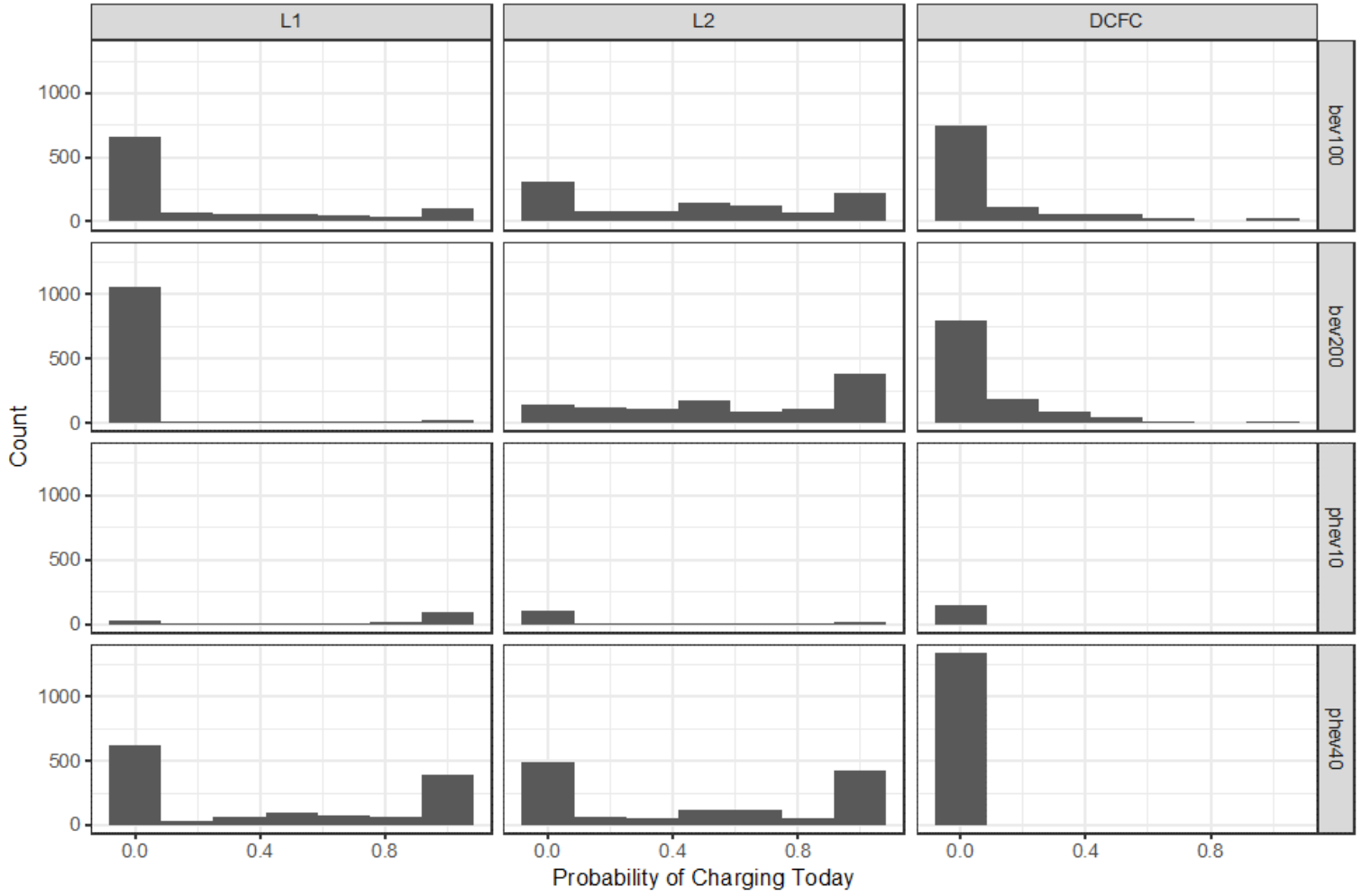
- A very large number of studies of assume (with empirical data from NHTS):
  1. Vehicles drive some number of miles every day
  2. They arrive at home at a certain time
  3. Vehicles can then charge based on their daily usage after arriving at home
- Is this a reasonable set of assumptions for modeling charging behavior?



Empirical Charging Behavior from Data

How often do drivers charge?

- Even if NHTS is accurate for EVs, there is an additional set of assumptions extending to the residential charging patterns
- In our empirical data, almost *no one* charges every single day!



Some drivers don't charge at all!

- In the early days of electric vehicles, many Toyota Prius PHEVs were clearly not charging their vehicles

Essentially the same daily commute

TABLE 7 Average Daily Estimated eVMT, by Model

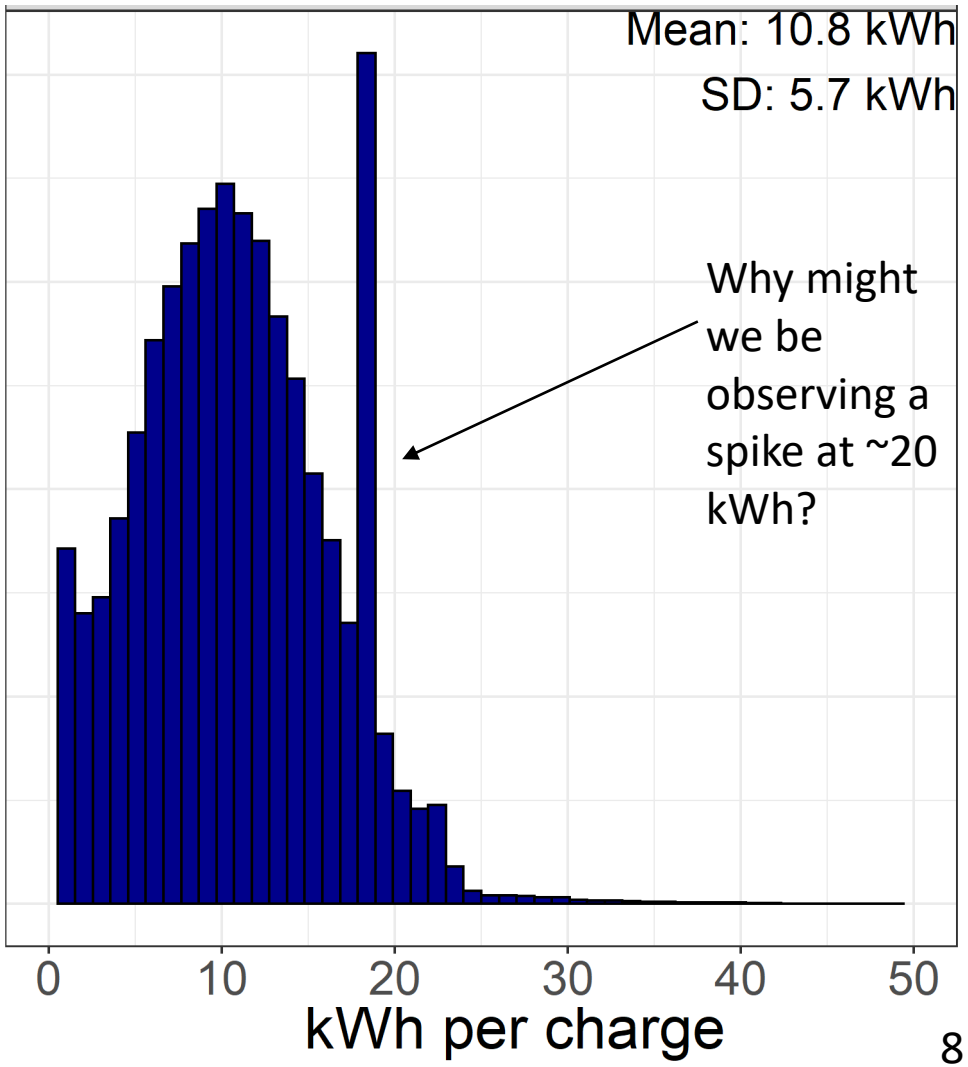
	Chevrolet Volt (48.6 commuter daily miles)			Toyota Prius Plug-In (52.8 commuter daily miles)		
Commuters Travel	*N*	eVMT	eVMT Share	*N*	eVMT	eVMT Share
Potential eVMT						
Home-charging eVMT	284	30.3	62.3%	381	10.5	19.9%
eVMT with work charging	284	43.3	89.1%	381	19.7	37.3%
Estimated eVMT						
Home-charging eVMT	284	26.6	54.7%	381	8.4	16.1%
eVMT with work charging	283	32.8	67.5%	381	10.6	20.1%

Huge discrepancy in eVMT

How much do drivers charge in a given session?

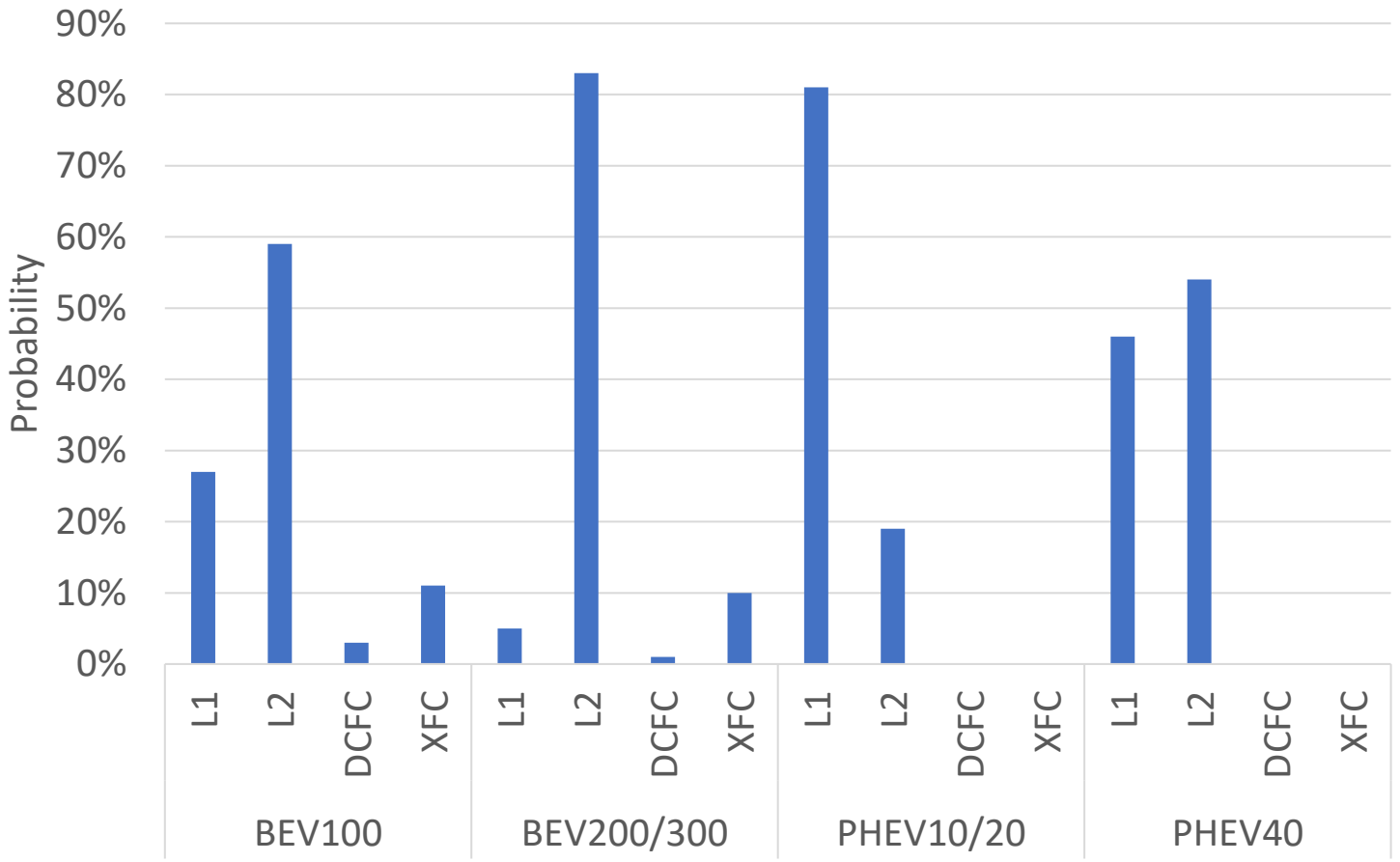
- Many early studies also assume that EVs always charge their batteries to full
- This is less common at public charging events—often faced with time constraints
- More common with home charging—but often dependent on the battery size of the EV (less common to fill up to 100% on longer range vehicles)

Public DC Fast Charging Amounts

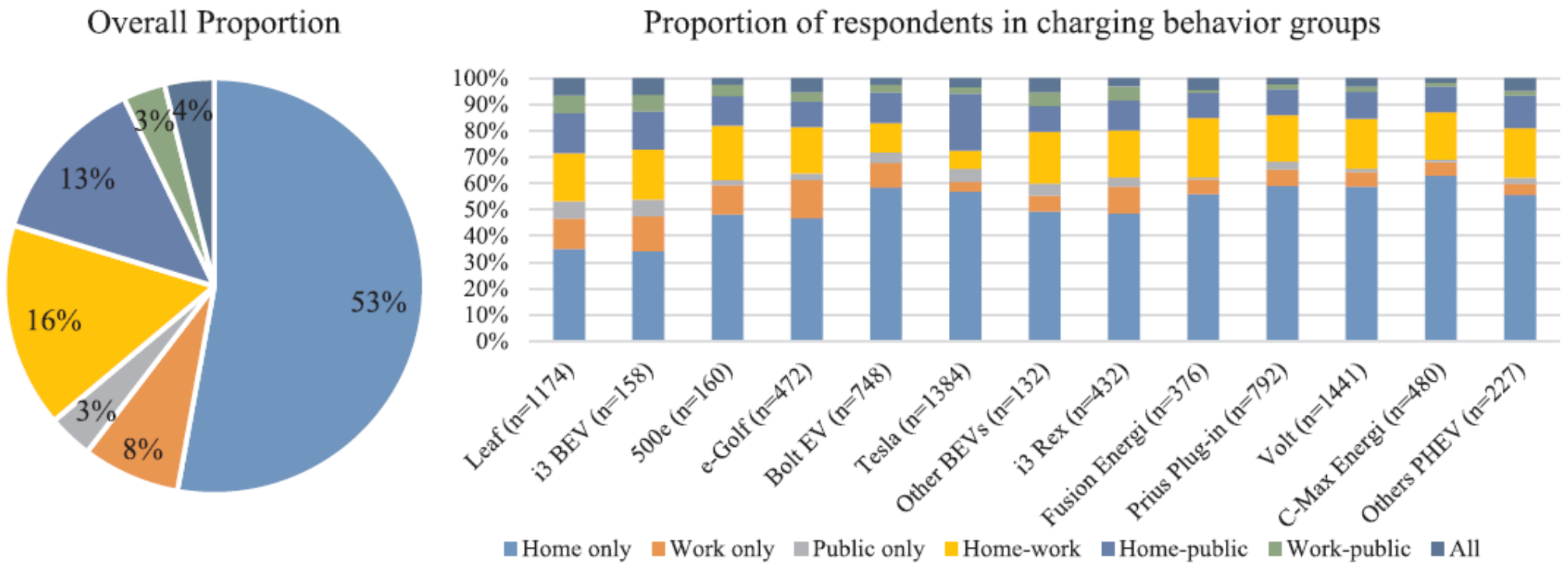


Does the type of vehicle affect charging behavior?

- Research has consistently shown that the charging behavior (speed and frequency) depends on:
  - Battery size/range
  - Technology type (PHEV vs BEV)
- Larger range tends to use faster charging but oftentimes less frequent charging

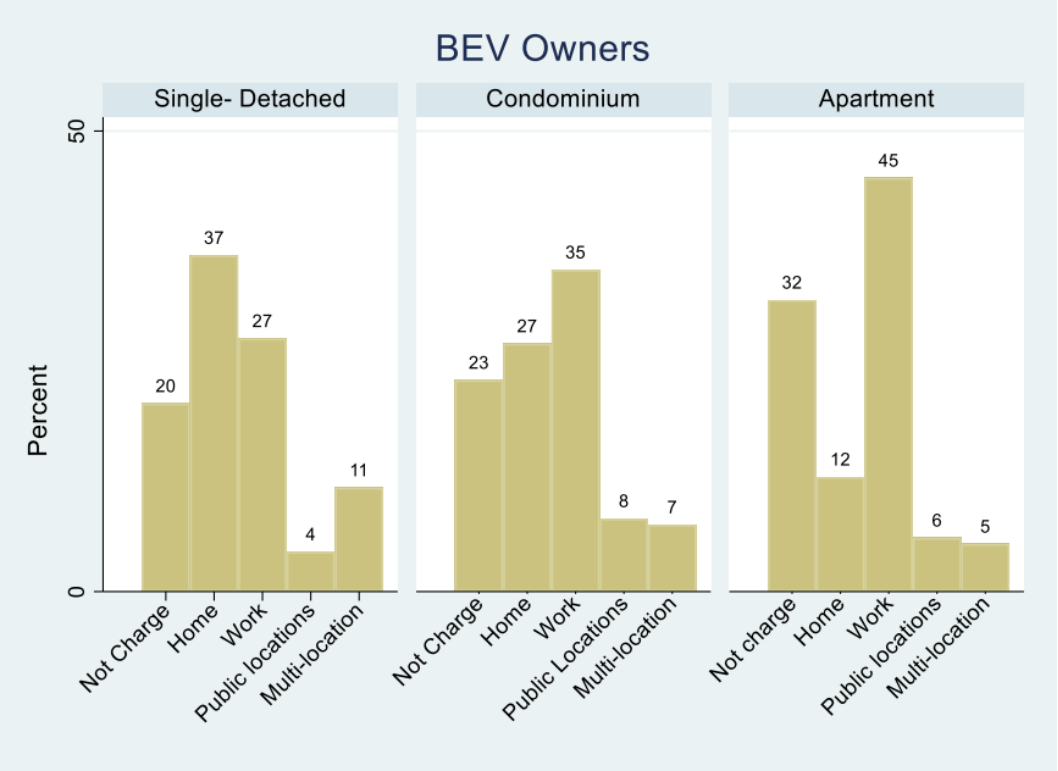


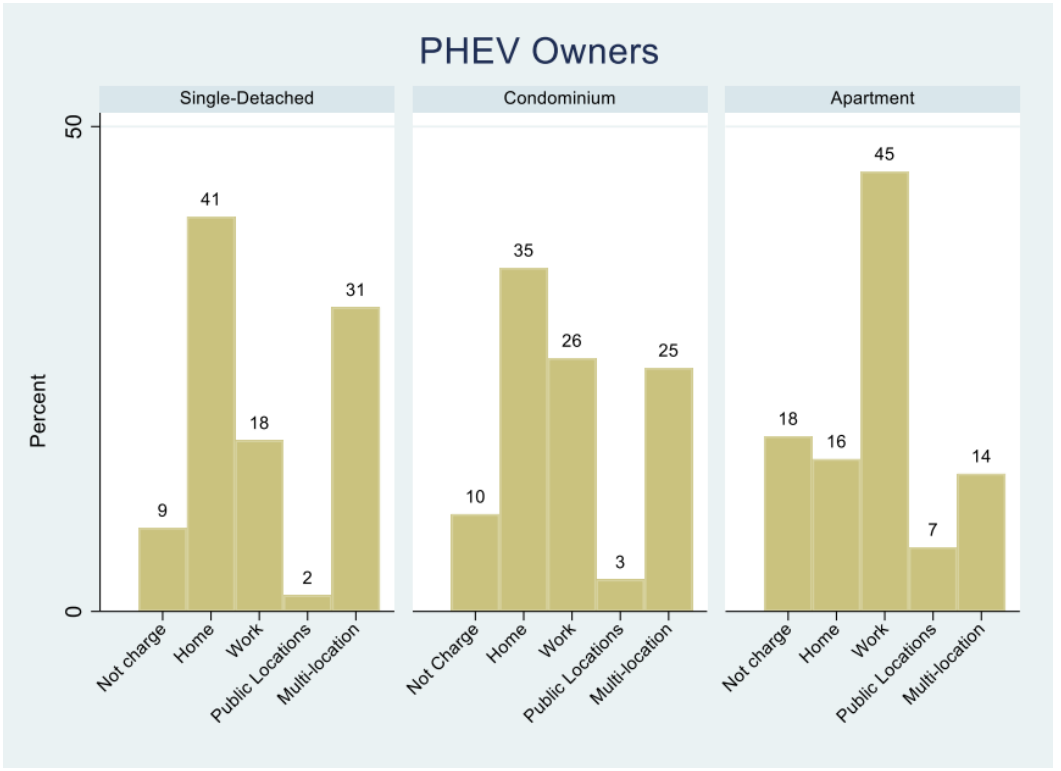
Where do drivers charge their cars?



- Home charging accounts for the vast majority of charging events (>80% across all combinations)
- Some differences among vehicle models, but generally consistent

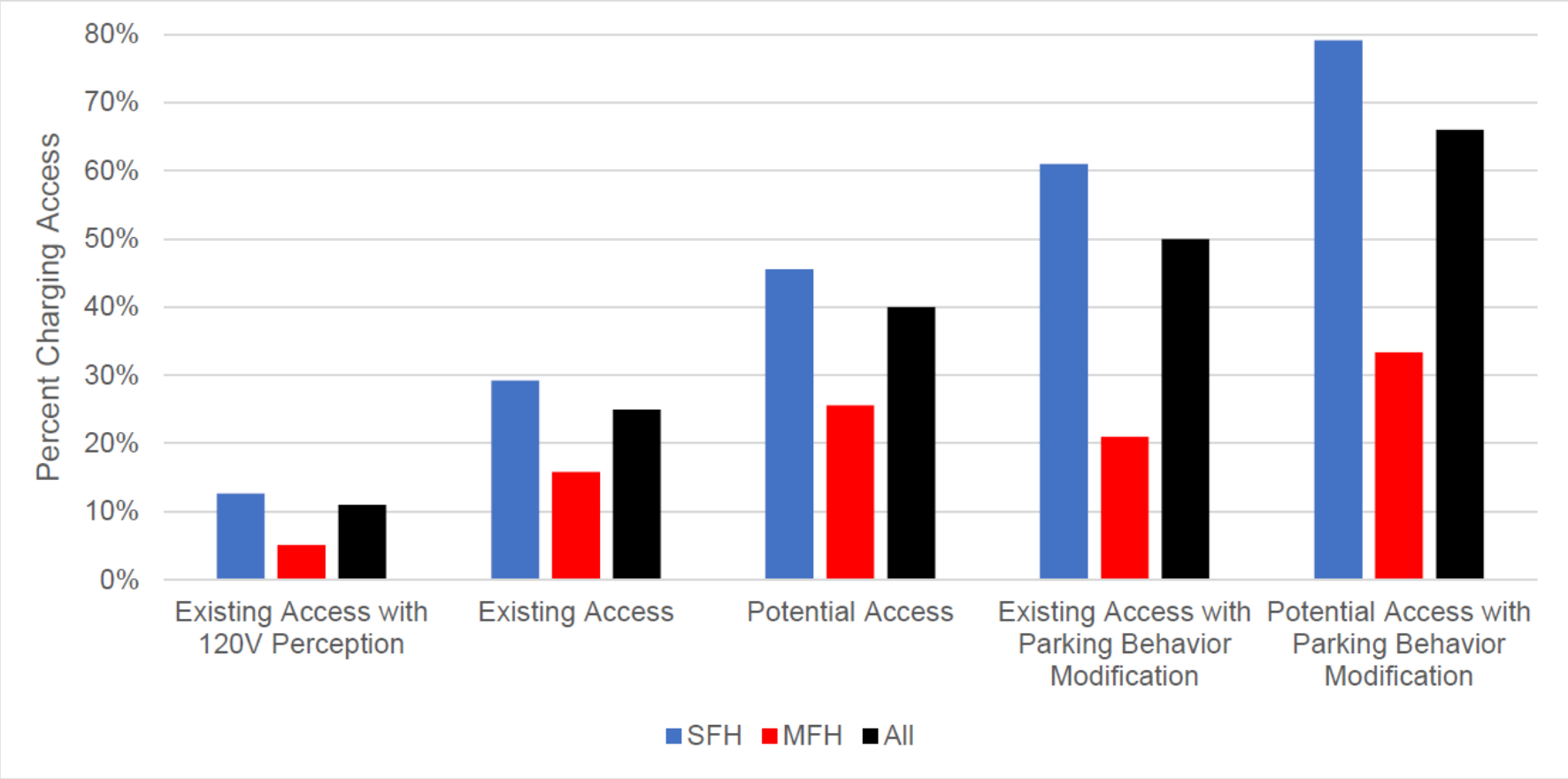
Where you live and how you charge



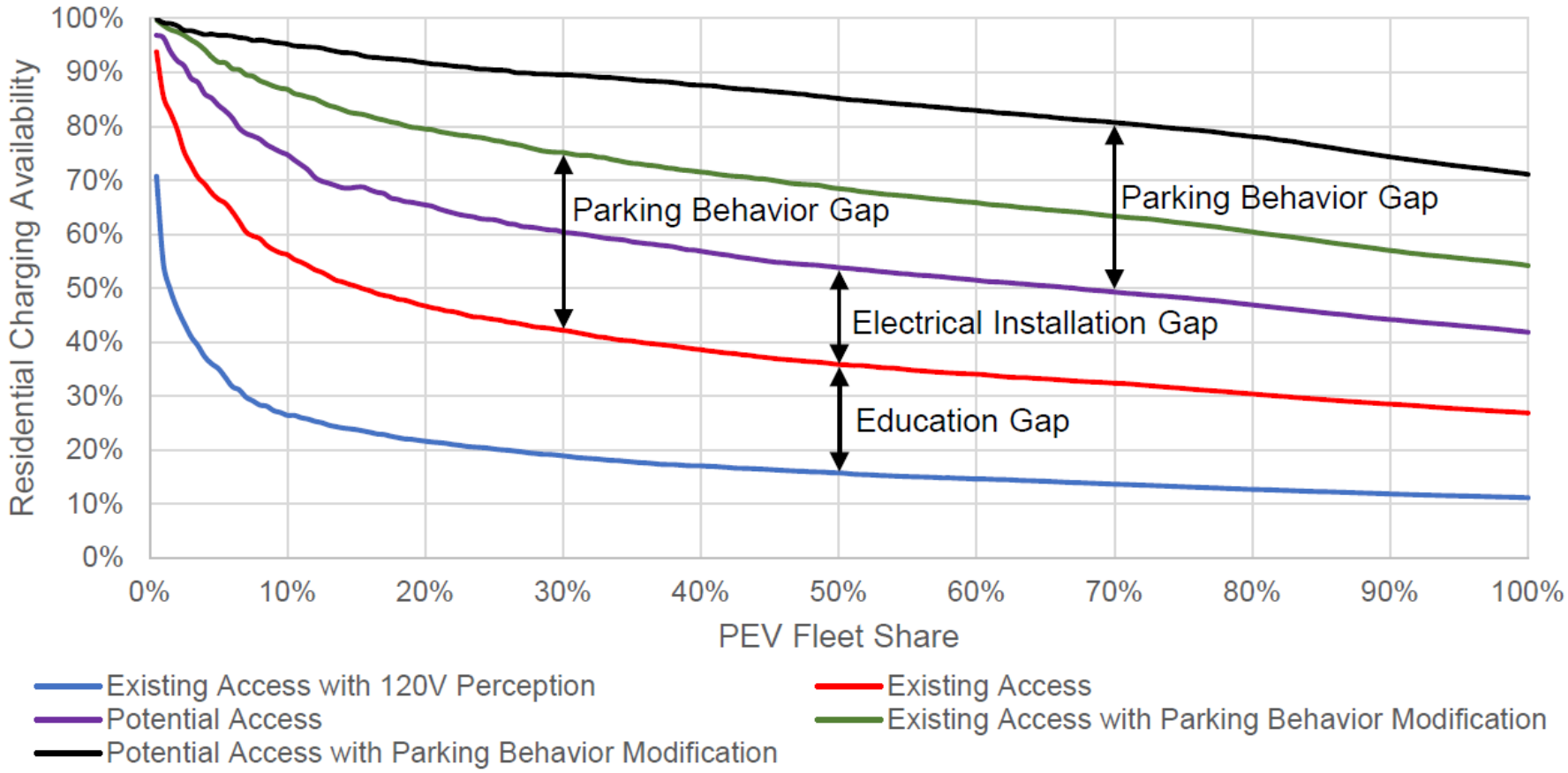


- If you live in a single-detached house, you are 3x more likely to charge at home compared to if you live in an apartment. Why is this?

How many homes can support charging?

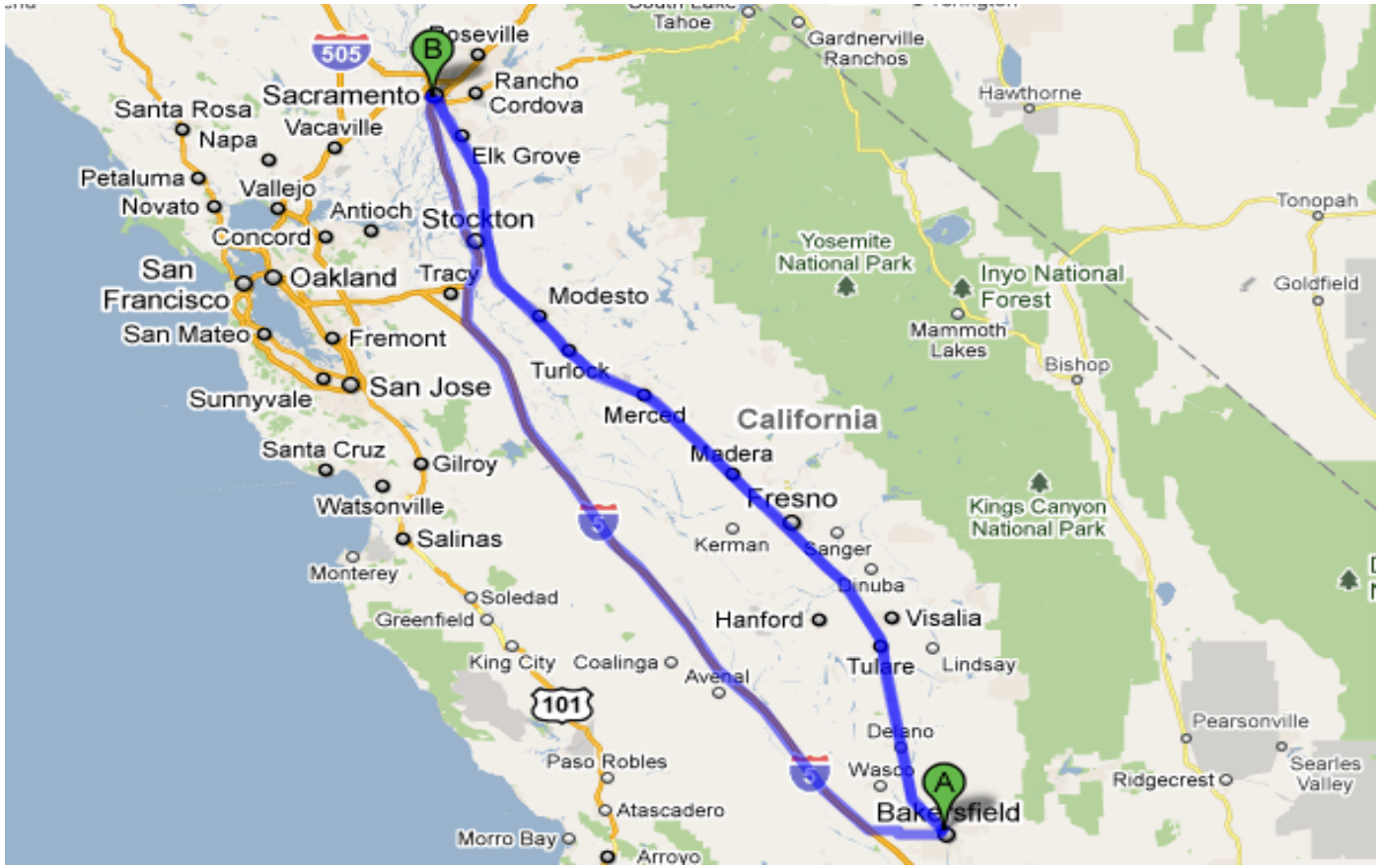


How might access change over time?

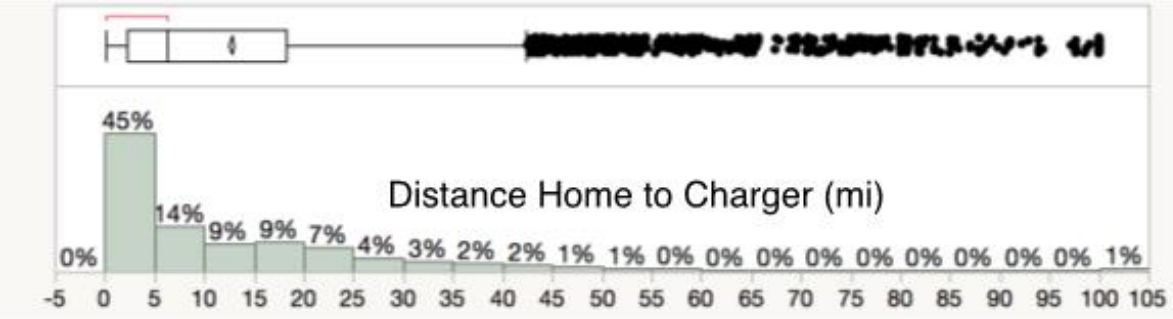


Corridor charging vs local charging

- In the early days of DC fast charger deployment: how much support for
  - Long-distance corridor charging
  - Local area charging
- Which chargers do you think will be more utilized?



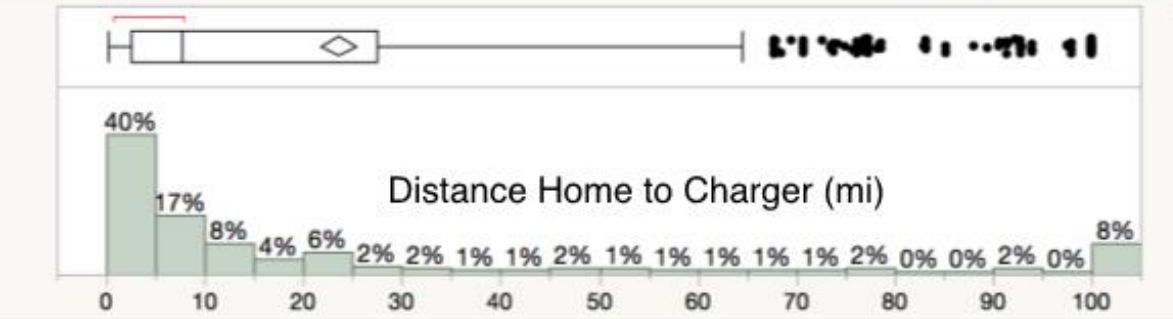
How far from home do they charge?



Quantiles		
100.0%	maximum	100
99.5%		100
97.5%		54.08354755
90.0%		31.22237444
75.0%	quartile	18.31553927
50.0%	median	6.183704148
25.0%	quartile	2.302309716
10.0%		0.80850276
2.5%		0.354319314
0.5%		0.121123892
0.0%	minimum	0.051639793

Summary Statistics	
Mean	12.726319
Std Dev	15.852251
Std Err Mean	0.1258631
Upper 95% Mean	12.973025
Lower 95% Mean	12.479613
N	15863

Nissan Leaf 24kWh
Paid Charging
10-20 cents per min



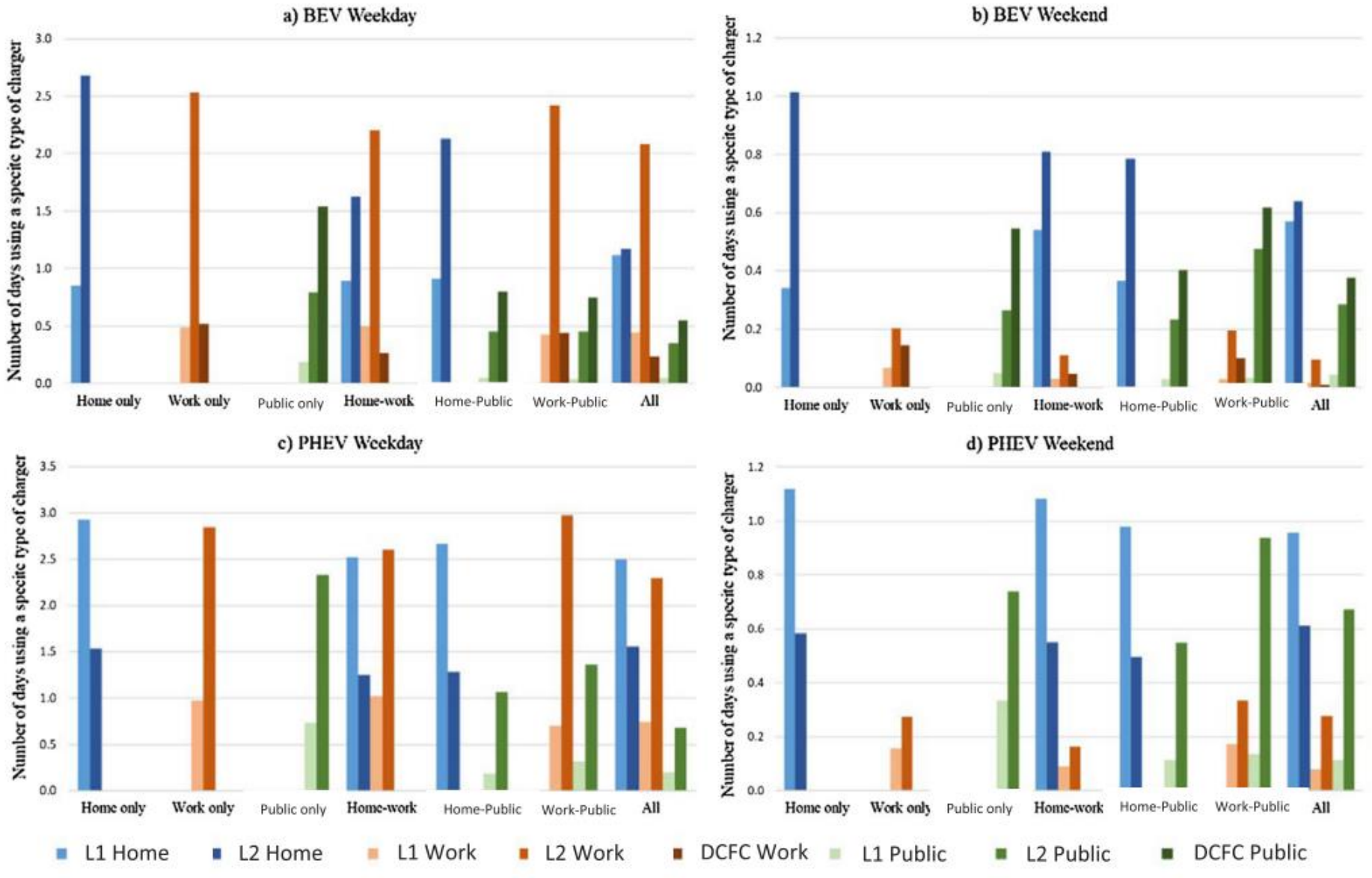
Quantiles		
100.0%	maximum	100
99.5%		100
97.5%		100
90.0%		91.50674441
75.0%	quartile	27.45581963
50.0%	median	7.685912084
25.0%	quartile	2.410203146
10.0%		1.277362008
2.5%		0.693749586
0.5%		0.095352576
0.0%	minimum	0.095352576

Summary Statistics	
Mean	23.468792
Std Dev	31.884689
Std Err Mean	0.9095074
Upper 95% Mean	25.253152
Lower 95% Mean	21.684431
N	1229

Chevrolet Bolt
Paid Charging
10-20 cents per min

- In our data, we found the majority of public charging events happen within 5-10 miles of home
- This doesn't mean to ignore corridor charging! But gives some perspective on how to prioritize public charging deployment

How fast do drivers charge?

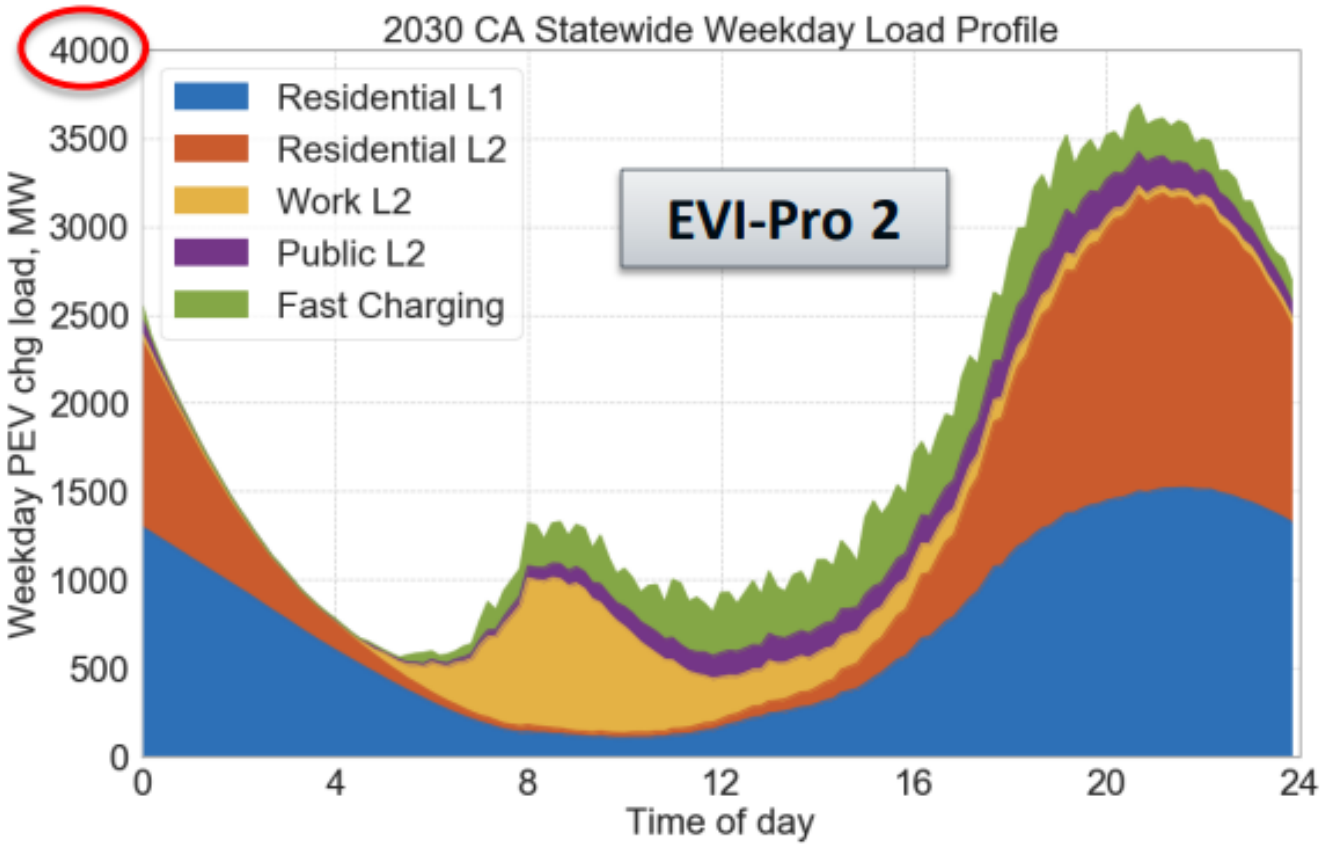


EVI-Pro

- The National Renewable Energy Laboratory (NREL) developed a tool called “Electric Vehicle Infrastructure – Projection Tool” aka “EVI-Pro”. The most recent version was conducted in collaboration with the California Energy Commission and UC Davis
- Used to:
  - Analyze the typical daily travel patterns of light-duty vehicles, estimate related charging demand, and design infrastructure capable of meeting the demand
  - Account for variations and uncertainty in vehicle and charger technologies, user demographics, market adoption conditions, the shared use of chargers, and EV travel and charging preferences.
- Online “Lite” version: https://afdc.energy.gov/evi-pro-lite

Aggregate EV charging profile

- Example of simulated charging patterns from EVI-Pro
- Lots of variability in charging patterns of an individual driver but in aggregate the pattern becomes much more regular
- Majority home charging with public/work charging during the day



Charger congestion

- As electric vehicles become increasingly popular, so too will crowds at charging stations

Charger etiquette

- Guides on proper charging etiquette are becoming popular:
  1. Charging spaces are for charging (not just if you are driving an EV)
  2. Monitor your charge while away from vehicle
  3. Switch to L2 @ 80% SOC
  4. Put the connector back when you're done
  5. Leave a note
  6. Move your vehicle when finished!

Utilization vs reliability

Customers want this: high reliability stations, in other words if I go to charge here, I can count on spots being empty so I have no problem charging

Businesses want this: high utilization stations, in other words chargers that are constantly used so that I'm maximizing my rate of return

Altering Charging Behavior

Free charging shifts charging behavior

- When charging at work is free…more people charge at work! (…surprise)
- But we have data to quantify this effect (blue to purple/stripped red to stripped purple)
- Exclusive home charging halves while exclusive work charging doubles

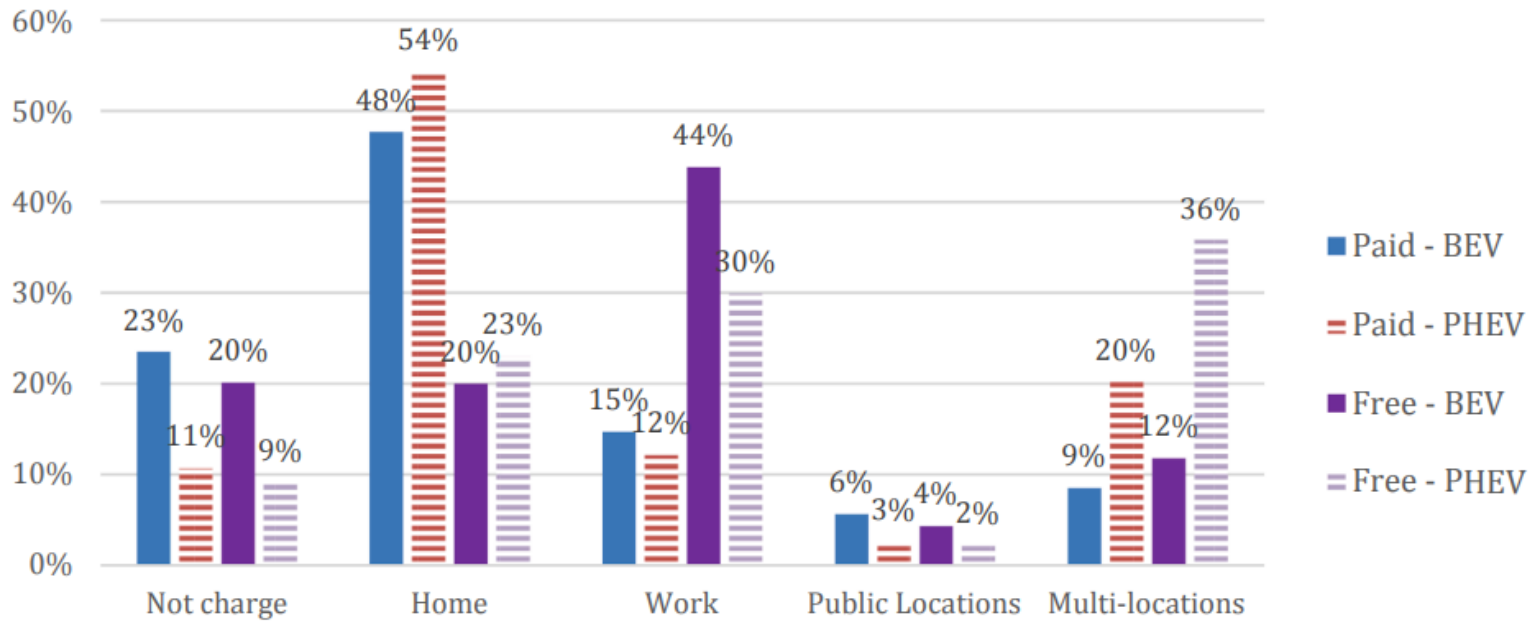
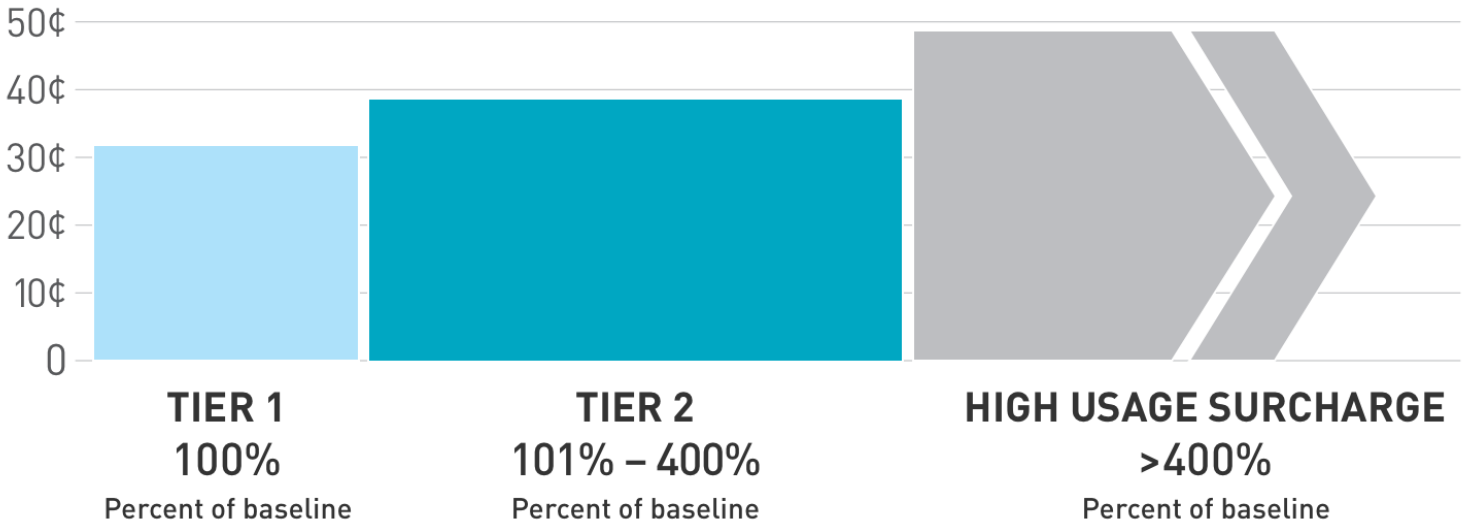


Fig. 5. Distribution of charging locations by cost of charging at work.

“Flat Rate” (Tiered) PG&E rates



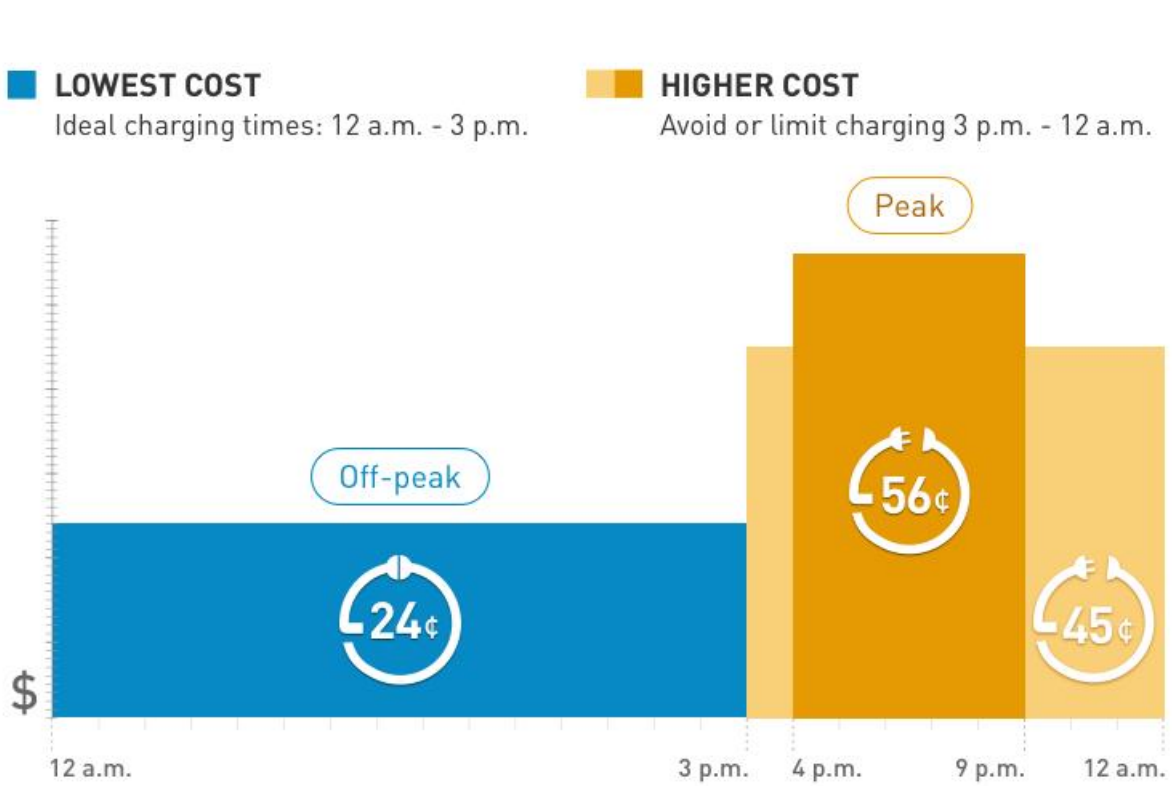
A.M. Sun Solar, Inc.	2007	2014	2017	Increase since 2007
Tier 1	11.0¢	15.0¢	18.0¢	67%
Tier 2	13.0¢	18.0¢	24.0¢	87%
Tier 3	23.0¢	26.0¢	40.0¢	75%

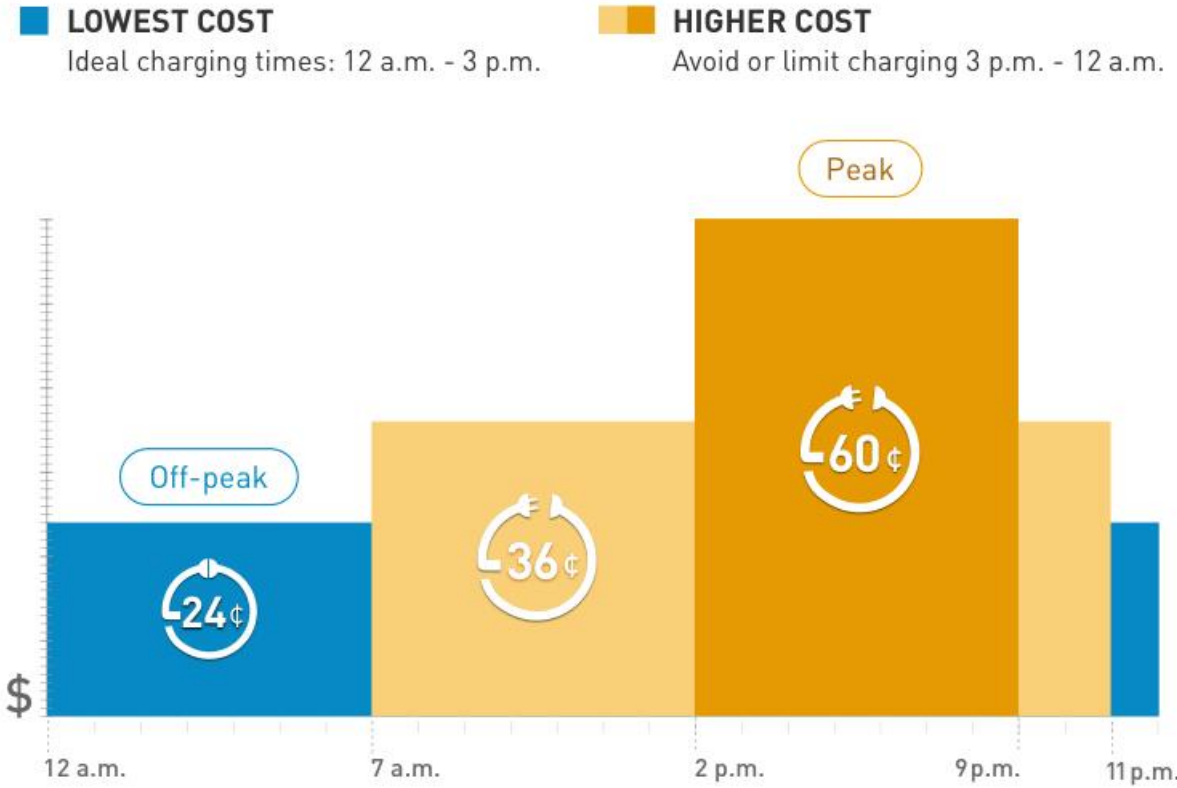
- PG&E tiered rates are now defunct
- Up to a certain baseline you pay a certain amount, all electricity you consume past that increases in price
- All PG&E customers have since been shifted to time-of-use rates

Time-of-Use PG&E rates

- Time-of-use rates charge prices based on the season and the time of the day that you use electricity
- Times are bundled into two (sometimes three) categories: on-peak and off-peak
- Prices are structured to correspond to the cost of producing electricity

Special EV PG&E rates





- Instead of traditional time-of-use rates, EV owners can opt into special electricity rates.
- Peak prices are more expensive, but off-peak prices are cheaper

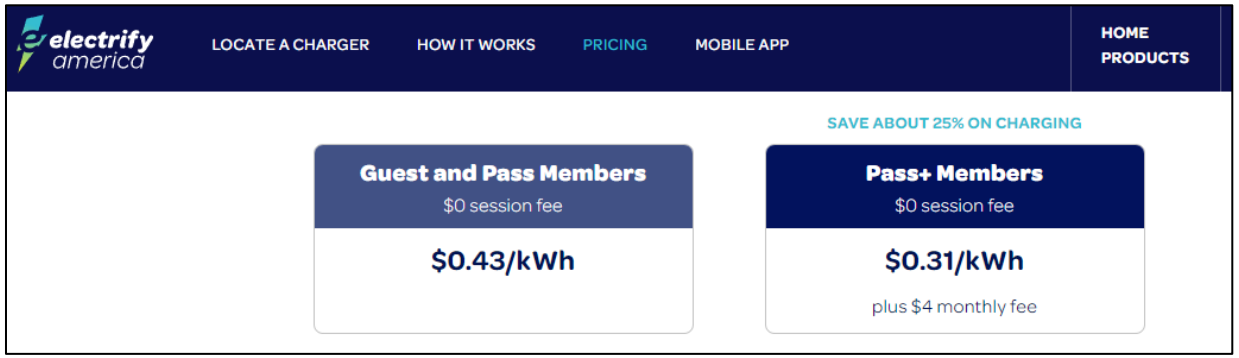
Public charging rates

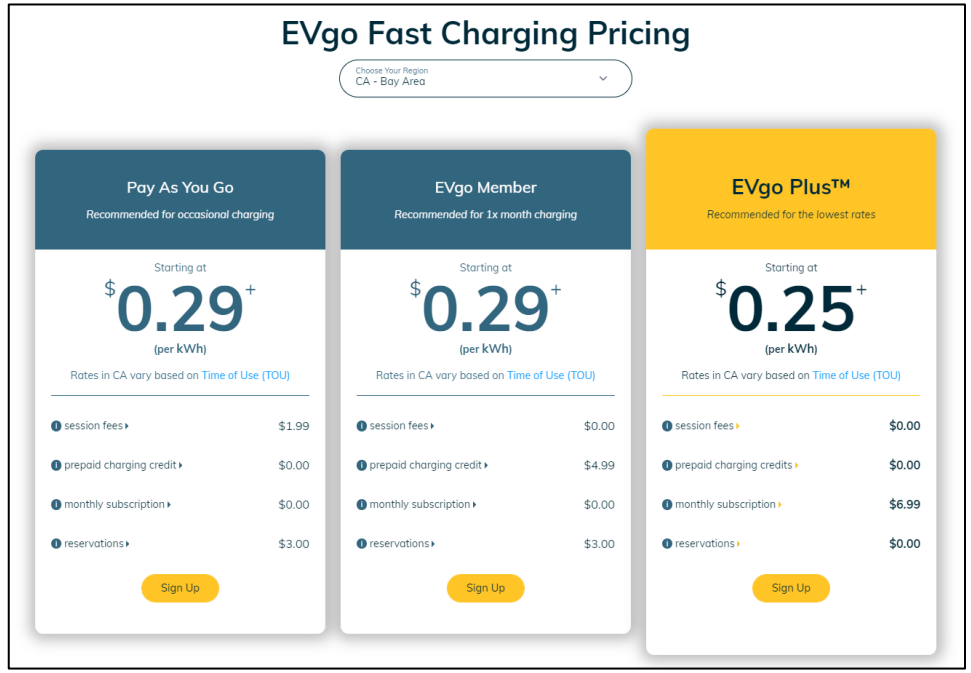
TESLA

Tier 1	Tier 2	Tier 3	Tier 4
Charging at or below 60 kW	Charging above 60 kW, at or below 100 kW	Charging above 100 kW, at or below 180 kW	Charging above 180 kW
Lowest price per minute	Second-lowest price per minute	Second-highest price per minute	Highest price per minute

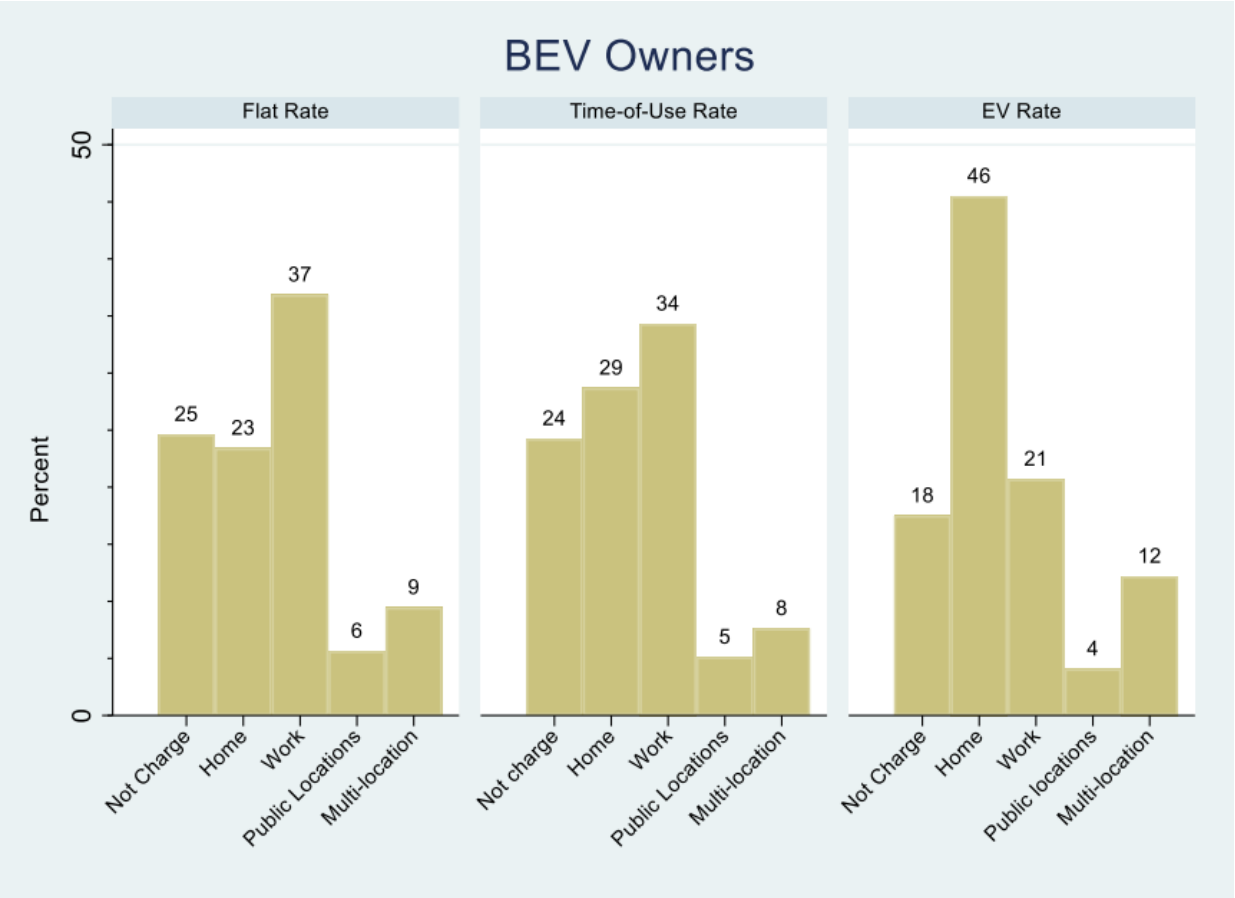
$0.17/min @60kW: $0.17/kWh	$0.45/min @100kW: $0.27/kWh	$0.84/min @180kW: $0.28/kWh	$1.35/min @250kW: $0.324/kWh

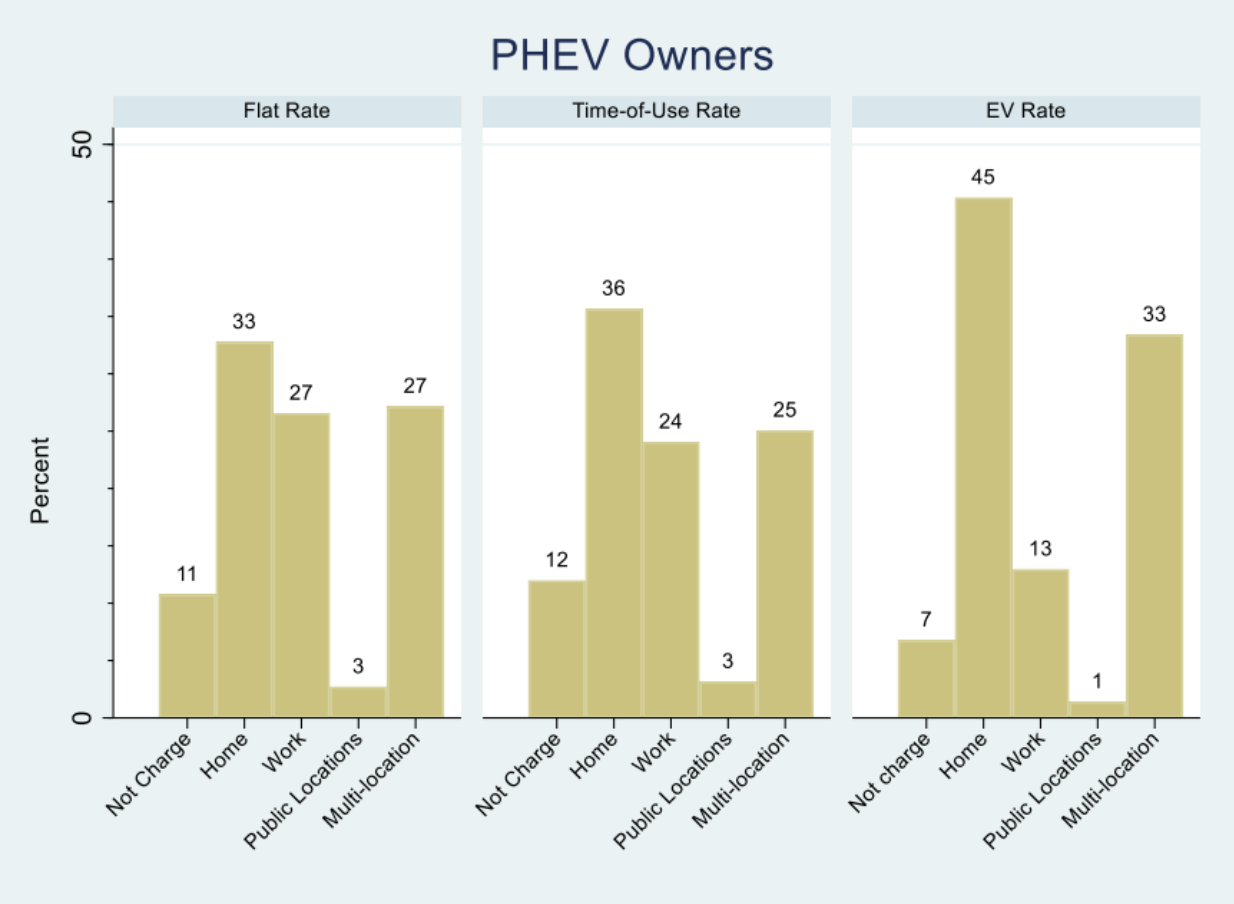
Country	Currency	Idle fee (per minute)	Idle fee (per minute) when the station is 100% occupied
United States	USD	$0.50	$1.00
Canada	CAD	$0.50	$1.00





Electricity rates make a difference!

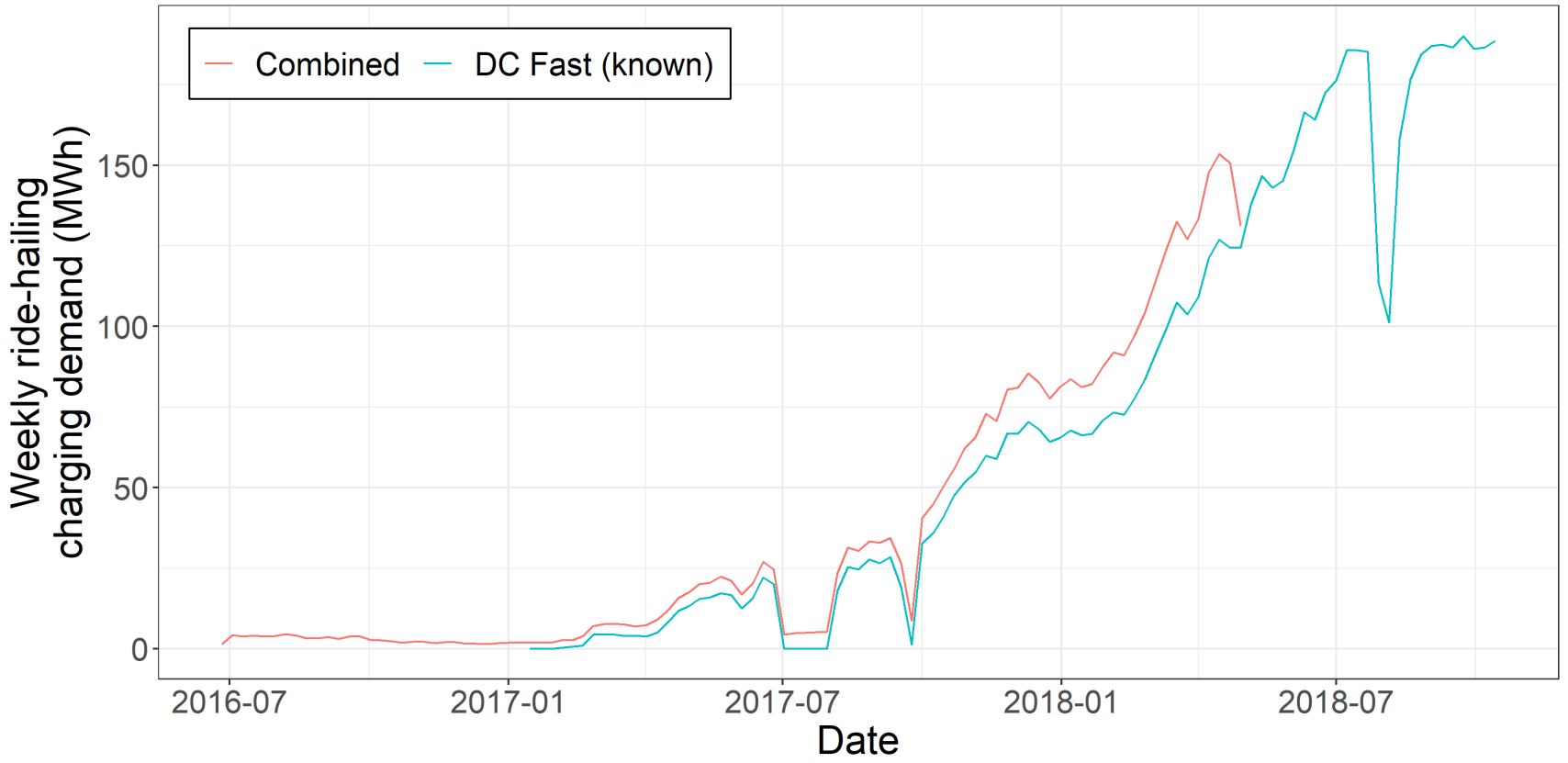




Much more likely to charge at home if enrolled in an EV rate

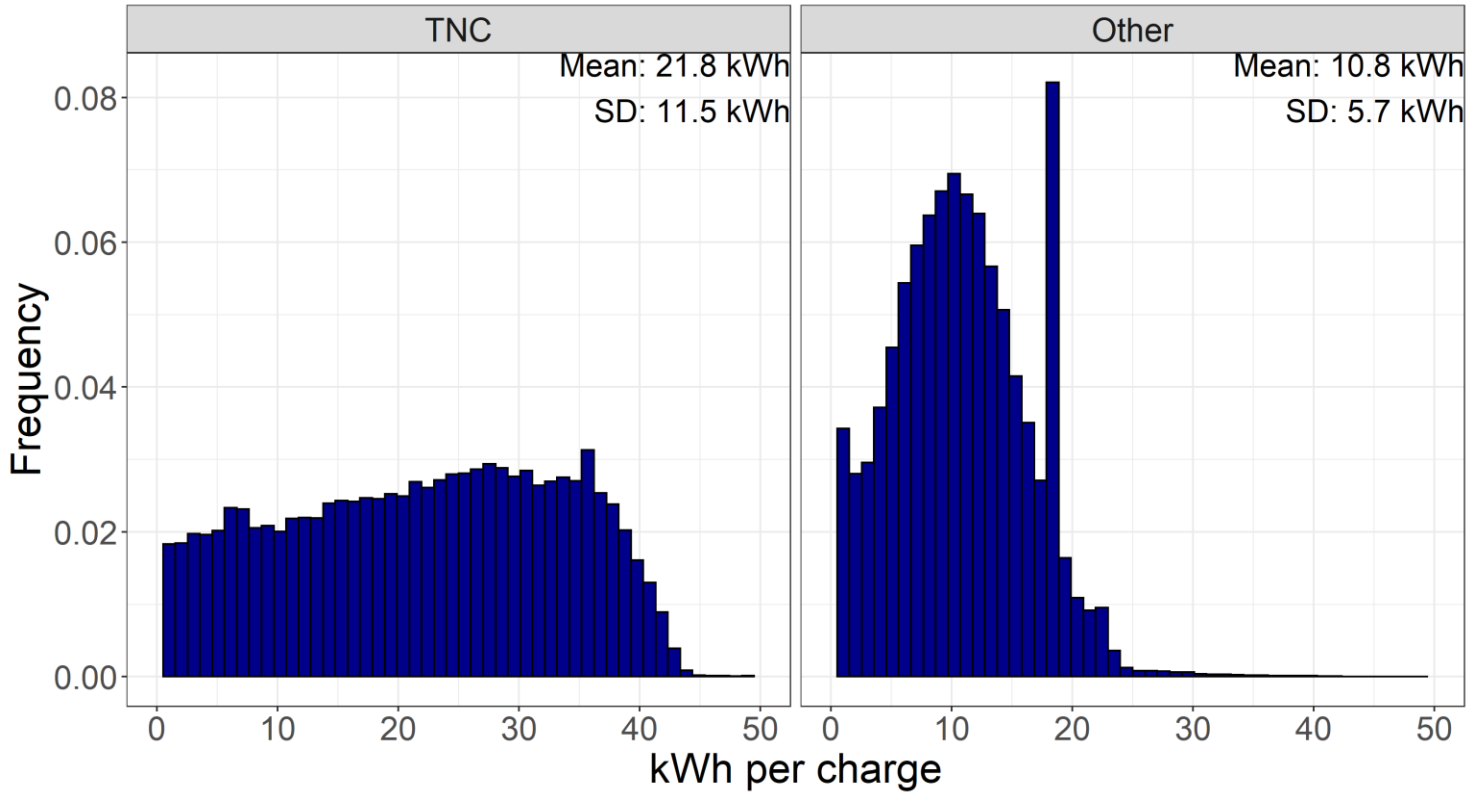
“Special” cases of charging behavior

The growth of electric vehicles in Uber and Lyft



- By 2018, EVs driving for Uber/Lyft constituted only 0.5% of EVs on the road but were responsible for over 35% of all non-Tesla DC fast charging in California!

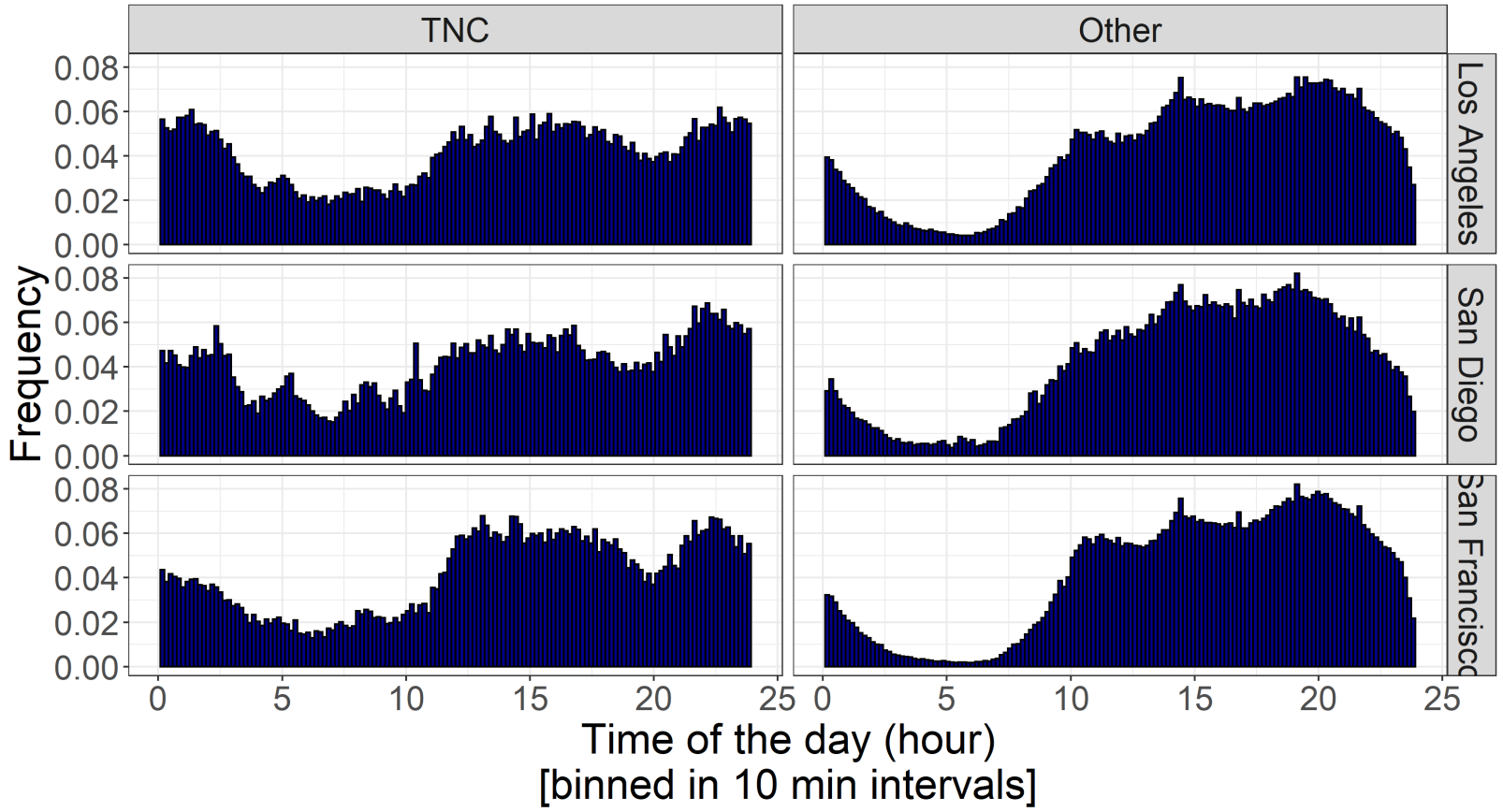
Ride-hailing vehicles charge a lot!



- We find the average non-Tesla BEV uses a DC fast charger once every 2-3 weeks
- Full-time drivers for Uber and Lyft were using DC fast chargers 2-3 times a day!
- Each visit also led to twice as much energy being dispensed

TNC EV charging patterns differ

- Uber and Lyft drivers tend to charge less during peak commute hours (to provide their services)
- Much higher proportion of charging in late evening/early morning hours



Smart charging

- Smart charging is a form of charging that integrates information from the electricity grid
- What are the technical challenges associated with smart charging?
- What are the social behavioral challenges associated with smart charging?