DC Fast Charging Infrastructure for Electrified Road Trips

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Rationale & Objective

- From the charging infrastructure standpoint, to electrify road trips in CA:

  1) **How many** charging stations (or plugs/connectors) do we need?
  2) **Where** do we need those charging stations?
  3) What is the impact of charging load on **the electric grid**?

- To answer those questions, a new charging infrastructure simulation tool (EVI-Pro RoadTrip) has been developed:

EVI-Pro RoadTrip
– Focused on long-distance (100+ miles/day) travels.
– Based on waypoint charging (stop to charge).

EVI-Pro
– Focused on short-distance travels.
– Based on destination charging (charge when stop).

- Scope:
  - CA-bound/originated road trips
  - DC fast charging (DCFC)
  - Domestic (inter-state) & international
  - Personal light-duty BEVs (battery electric vehicles)

EVI-Pro RoadTrip: Overall Structure & Spatio-Temporal Resolution

Road Trip Volume and Pattern + BEV Energy Use and Charging Simulation + Station Design (Siting and Sizing) + Capacity Analysis

Transportation | Refueling Infrastructure | Electric Grid

Spatial resolution (default: longitude & latitude)

- Coords. (origin, destination, trip simulation, etc.)
- 30m x 30m (land use type, etc.)
- TAZ (traffic analysis zone, capacity analysis, etc.)
- County (county-level aggregation)
- State (state-wide total number of stations, etc.)

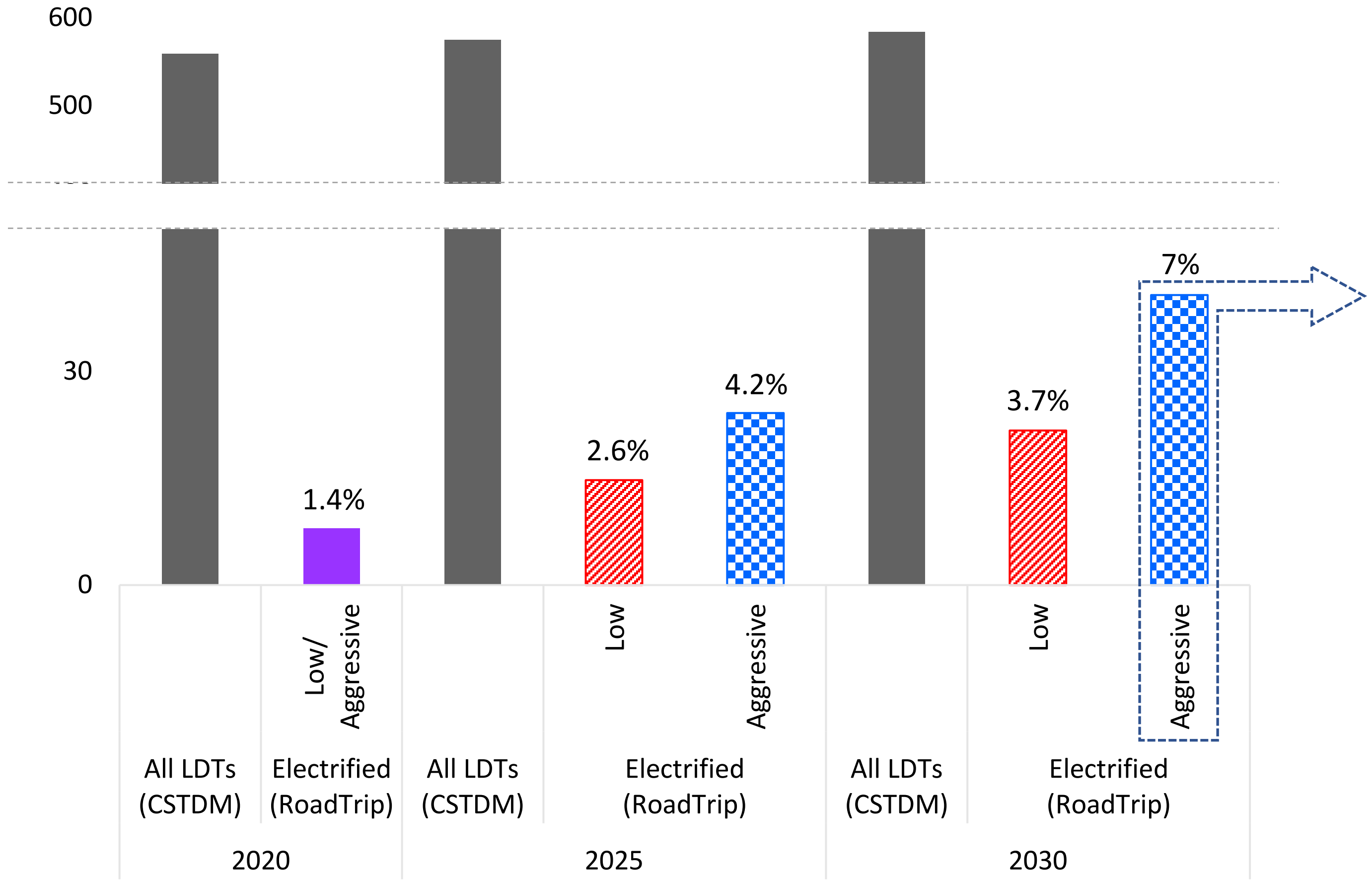
Temporal resolution (default: 1 minute)

- Seconds (trip simulation, vehicular energy use, etc.)
- Minutes (charging time, detour to charging stations, etc.)
- Hours (intra-state road trip duration, etc.)
- Days (cross-country road trip duration, etc.)
- Years (infrastructure build-out, BEV adoption, etc.)

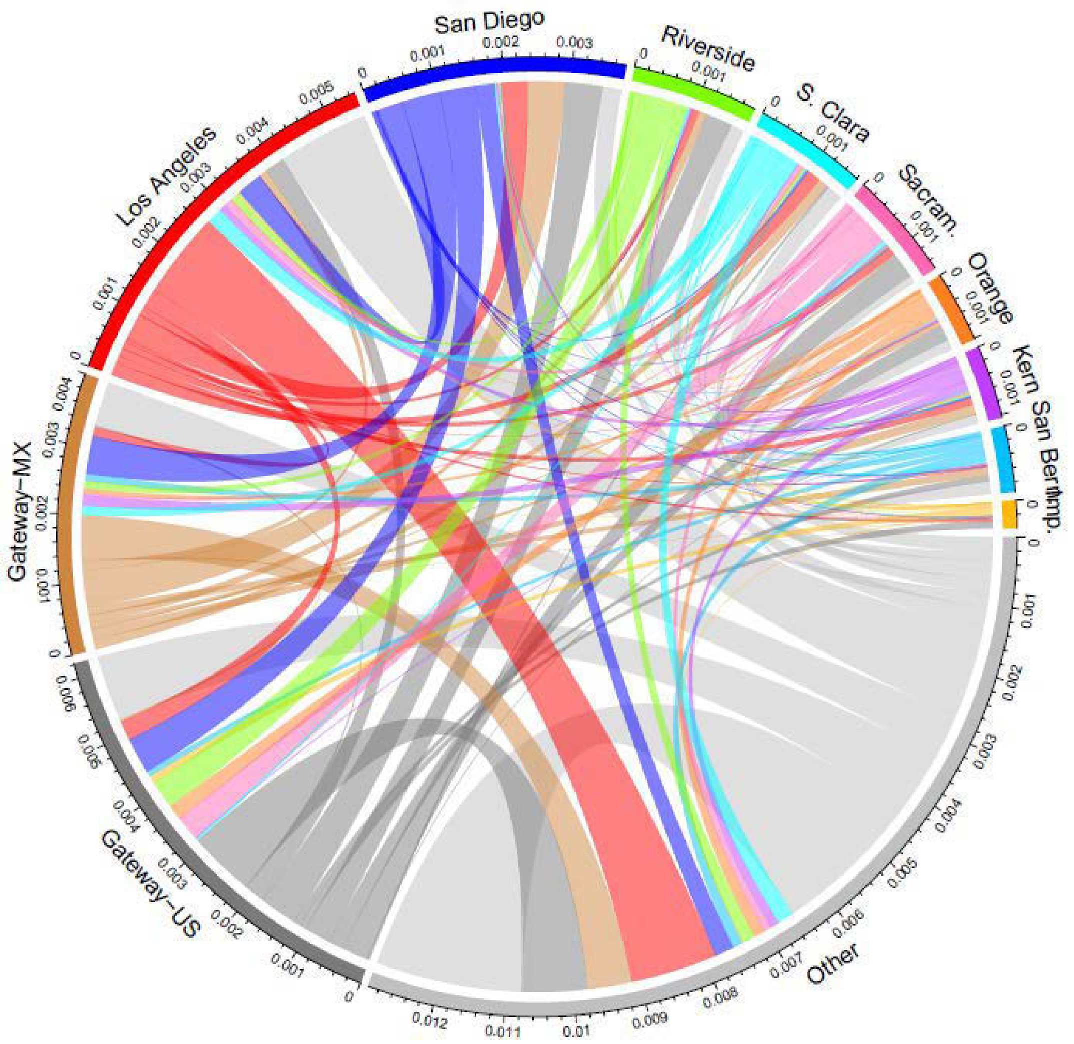
Volume & Pattern of Electrified Road Trips

- TAZ-by-TAZ* road trip activity: Caltrans (CA DOT) CSTDM* (V3)
- CA electrification projections: CEC Energy Assessments Division's forecasts by 2030 (Low: 1.5M BEVs; Aggressive: 3.1M BEVs)
- Non-CA electrification projections: EIA and IEA forecasts

Long-Distance Travel (LDT) Volume (1,000s) in 2020, 2025, and 2030



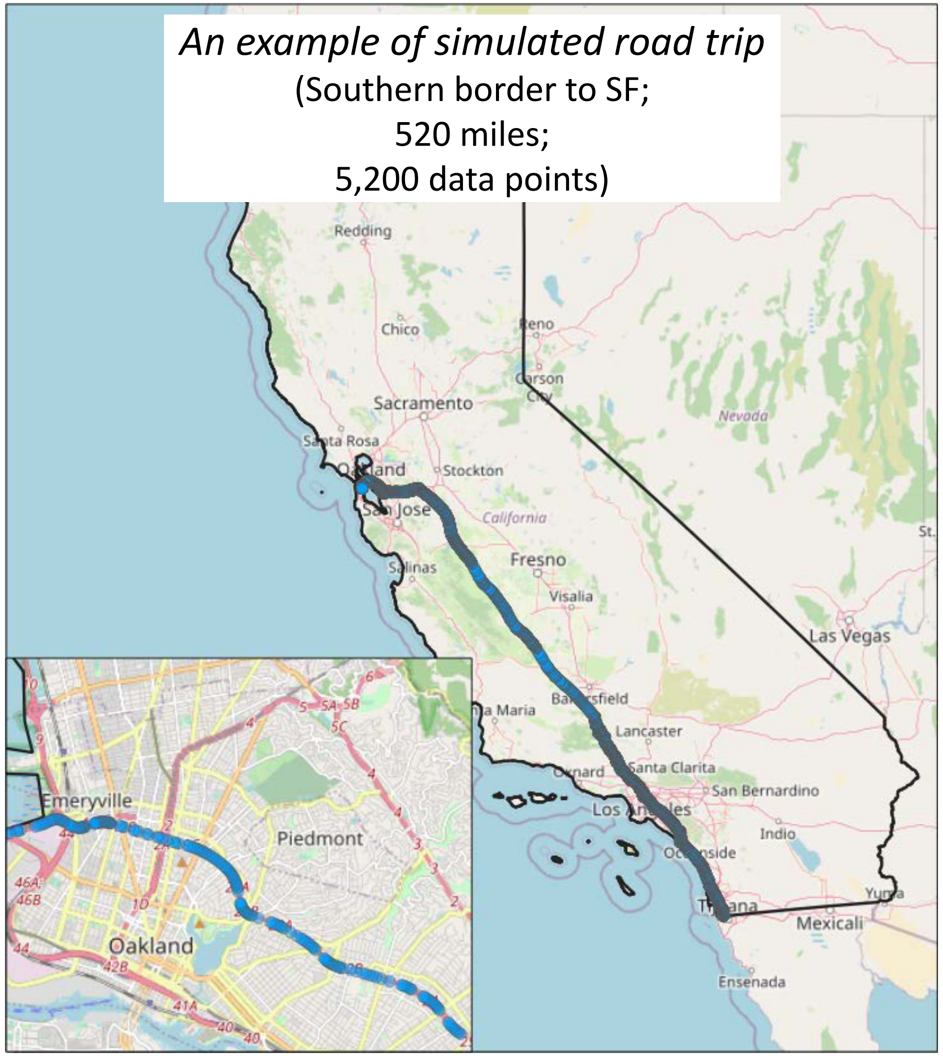
County-level characterization of electrified road trips (in millions) per day in 2030



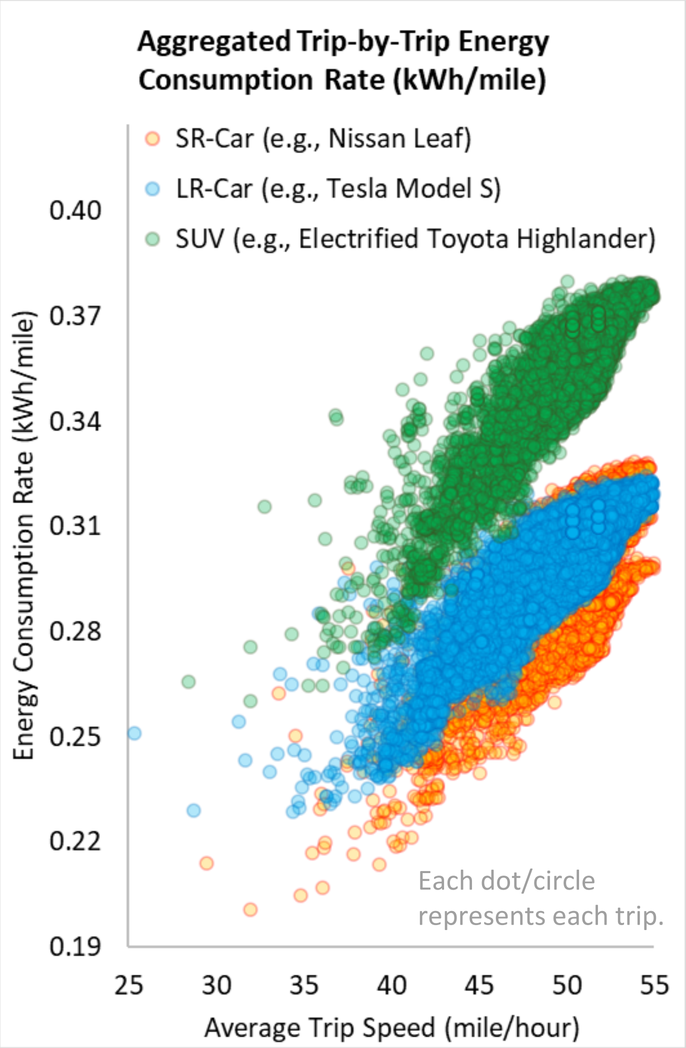
* TAZ: Traffic analysis zone (commonly used in transportation planning) – adopted as a basic geographical entity for travel demand estimation in CSTDM.
* CSTDM: California Statewide Travel Demand Model

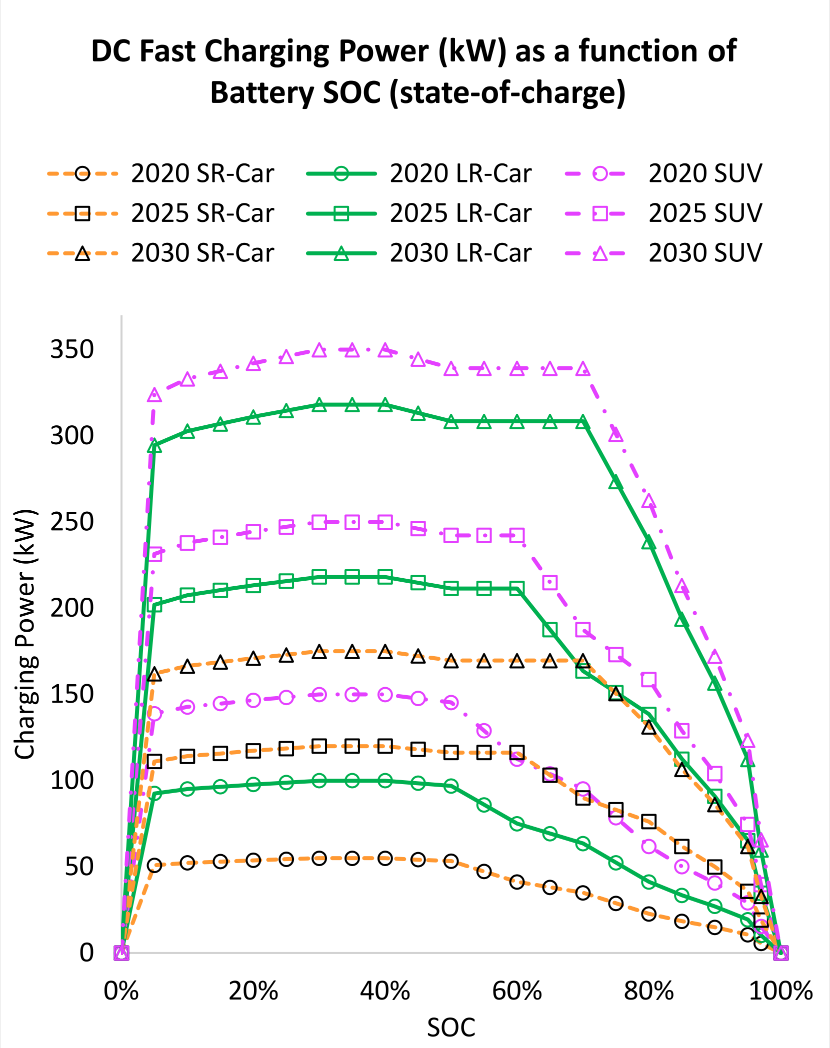
Trip, Vehicle Energy Use, and Charging Simulation

- Three BEV types: SR (short range) Car, LR (long range) Car, and SUV.
- Leveraged NREL's FASTSim (vehicle dynamic simulation tool).
- Detailed energy use and charging simulation for each road trip sample.



An example of simulated road trip
(Southern border to SF;
520 miles;
5,200 data points)

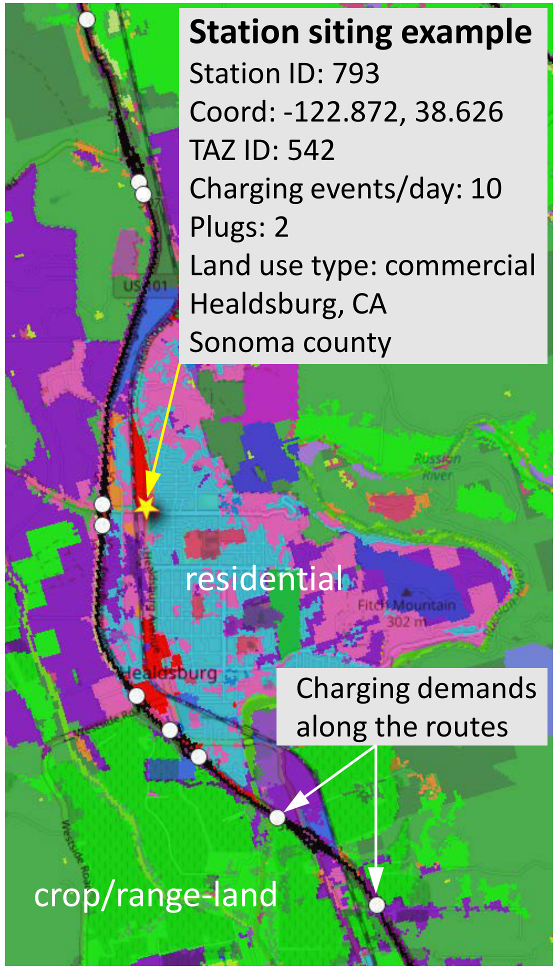


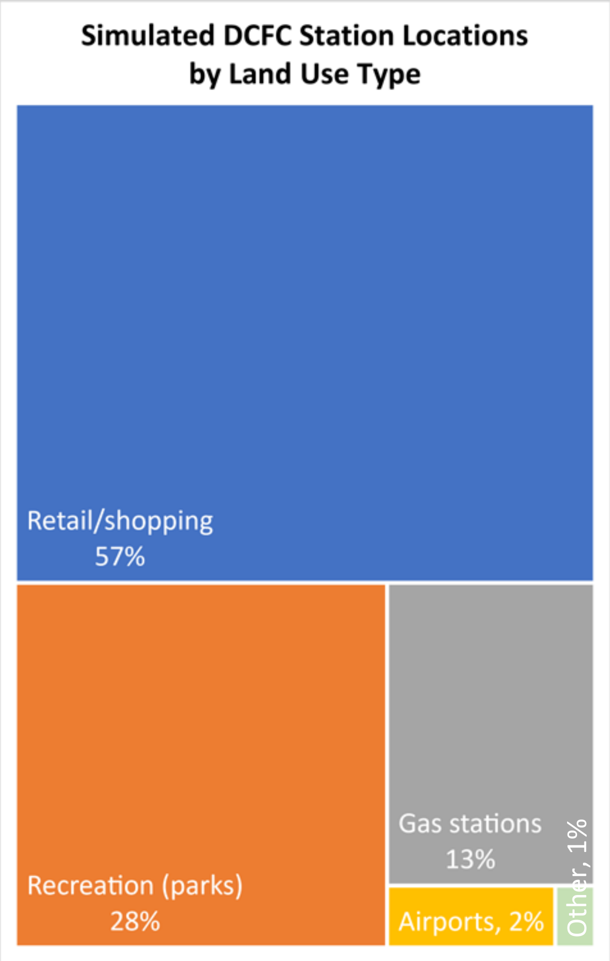


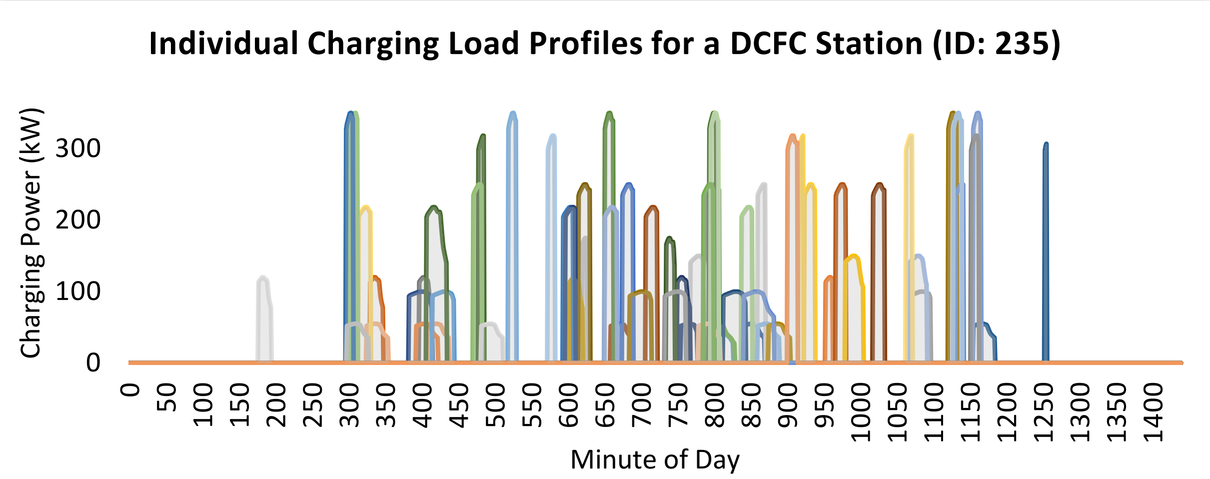
DCFC Station Siting & Sizing

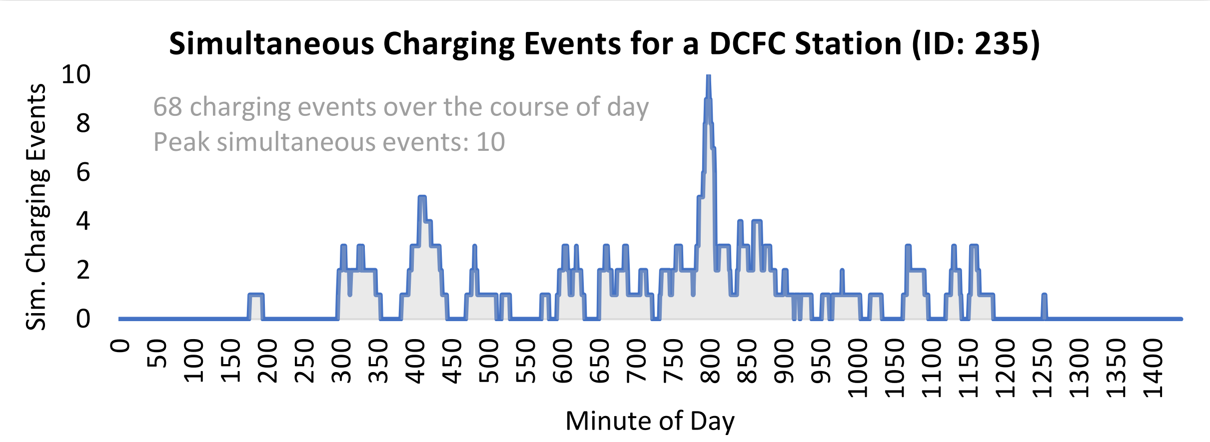
- Locate stations in commercial areas & other preferred sites.
- CEC collected station developers' input to prioritize candidate sites.
- Leveraged national land use data (NLUD, in 30m x 30m), as well as coordinate data of 6,000 gas stations in CA.

- Station sizing is based on station-by-station load profiles.
- The number of plugs: max simultaneous charging events.
- The number of plugs per station is capped at 10.

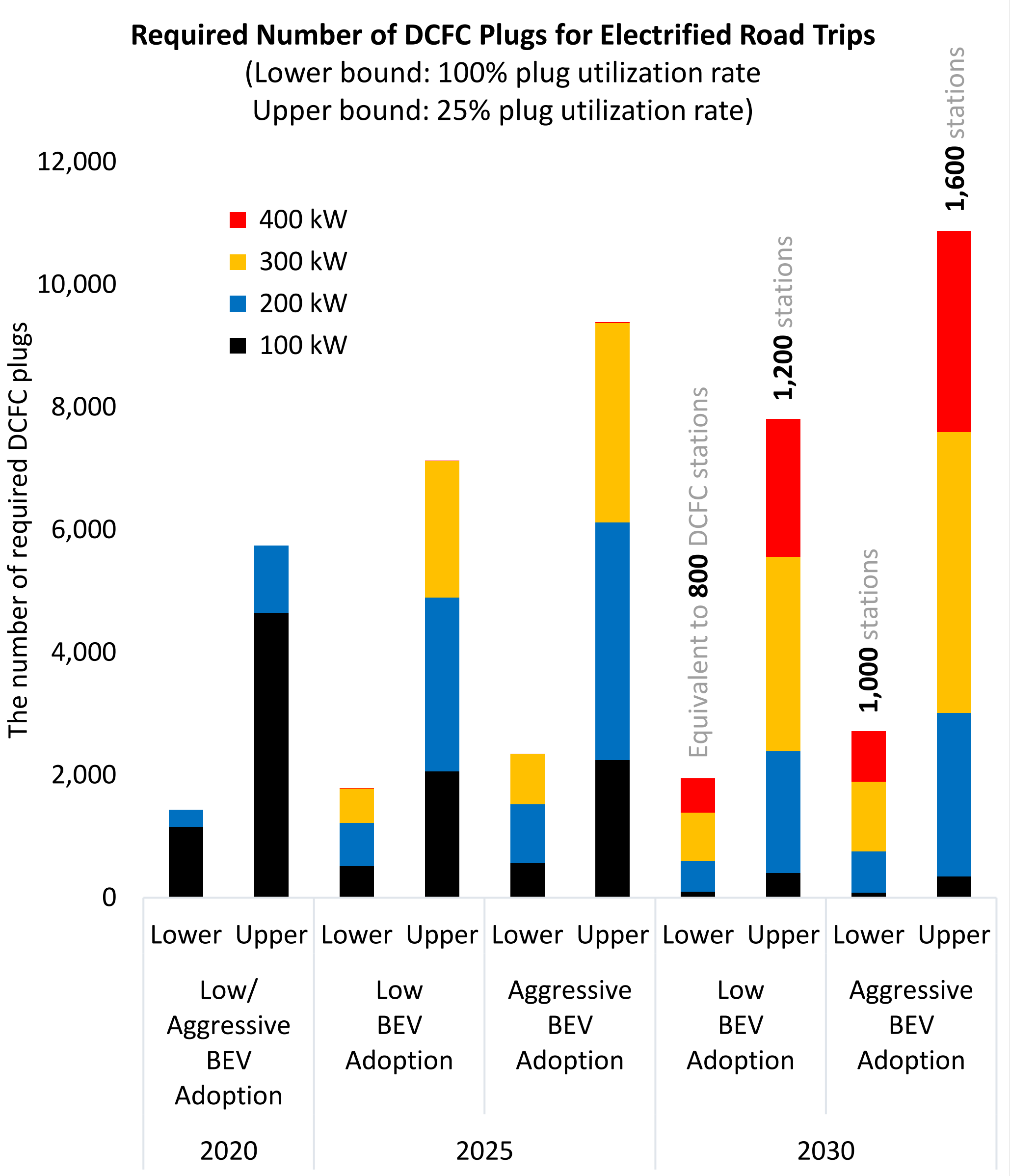






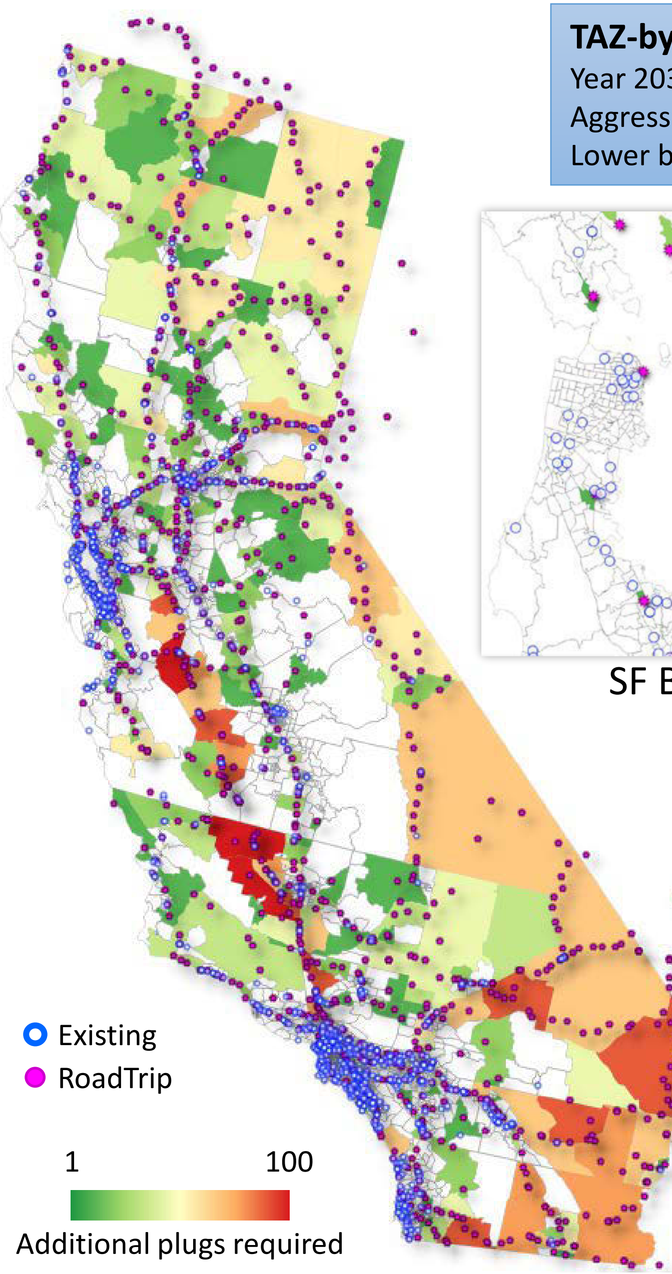


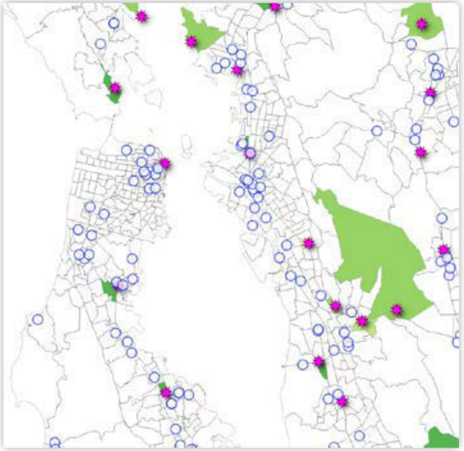
Results: Stations and Plugs/Connectors

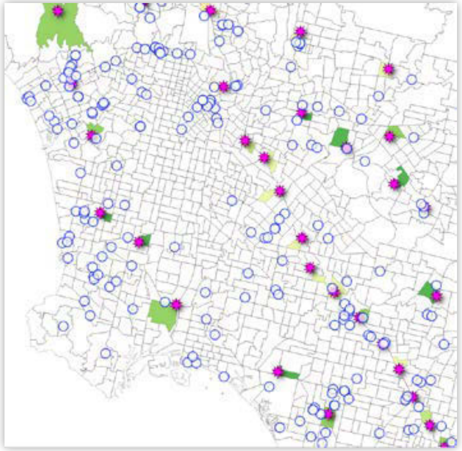


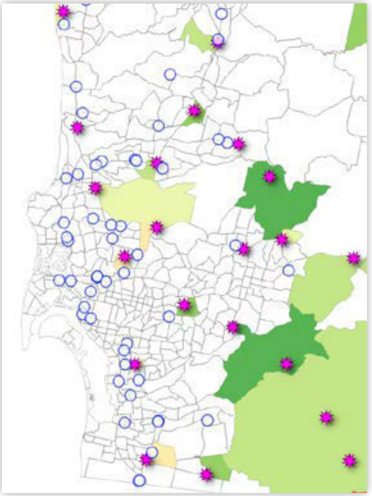
Snapshot for each simulation year (2020, 2025, and 2030) without the consideration of existing conditions from previous years.

TAZ-by-TAZ net deficit of DCFC plugs required
Year 2030
Aggressive BEV adoption
Lower bound (100% peak plug utilization rate)




SF Bay Area

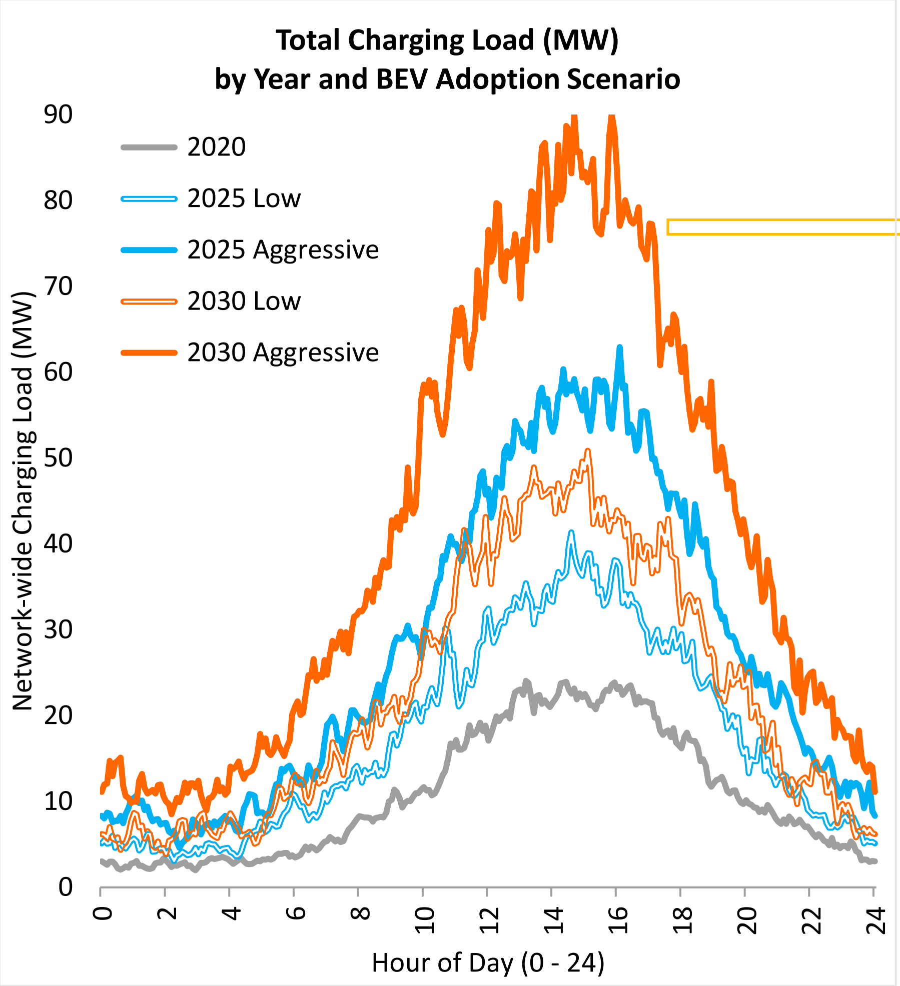

Los Angeles

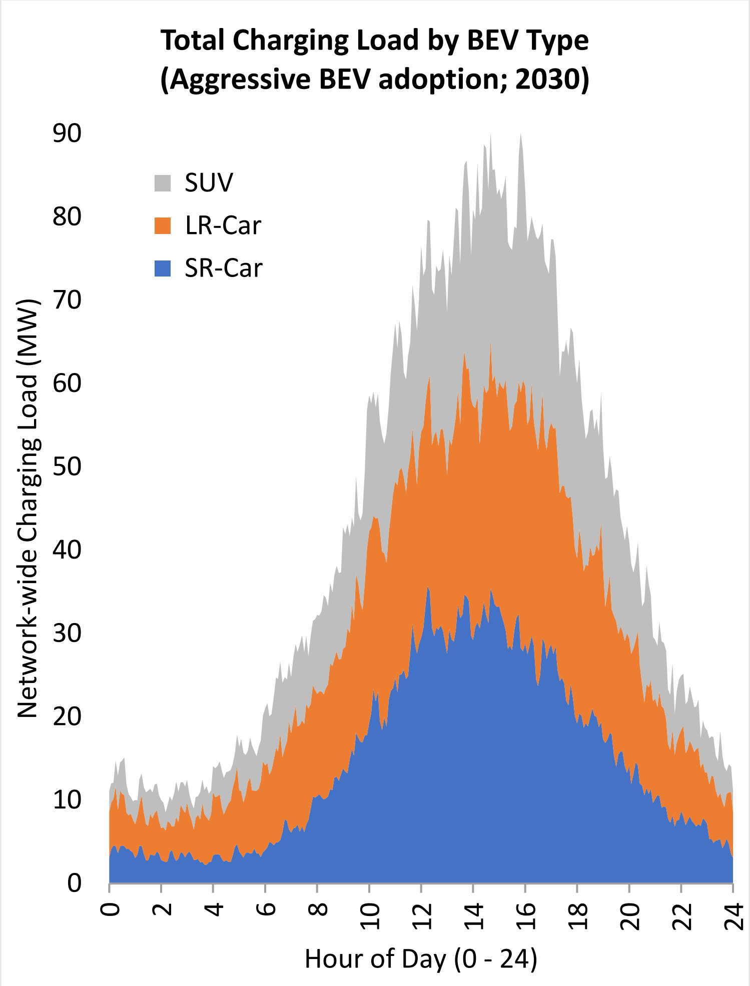

San Diego

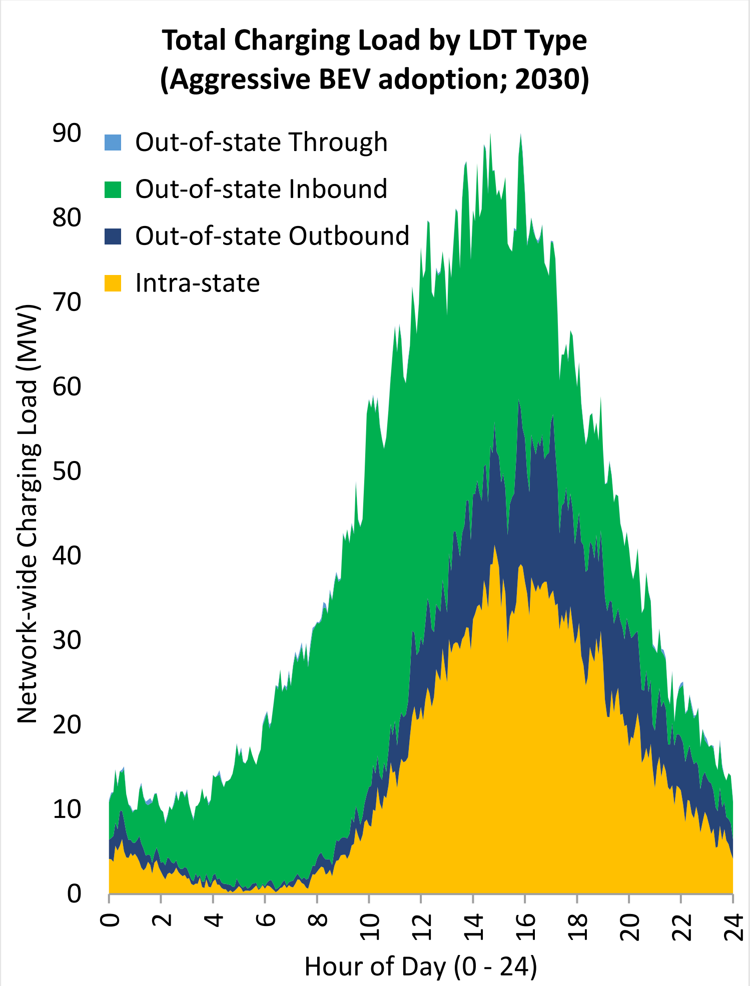
Currently, existing stations are not considered in the process of station siting or network design in EVI-Pro RoadTrip.

Results: Load Profiles

- Network-wide total charging load reaches around 90 MW in peak hours in 2030 for Aggressive BEV adoption scenario (50 MW for Low scenario).
- Notable difference of load shapes between out-of-state inbound LDTs and the other types of LDTs (e.g., intra-state).

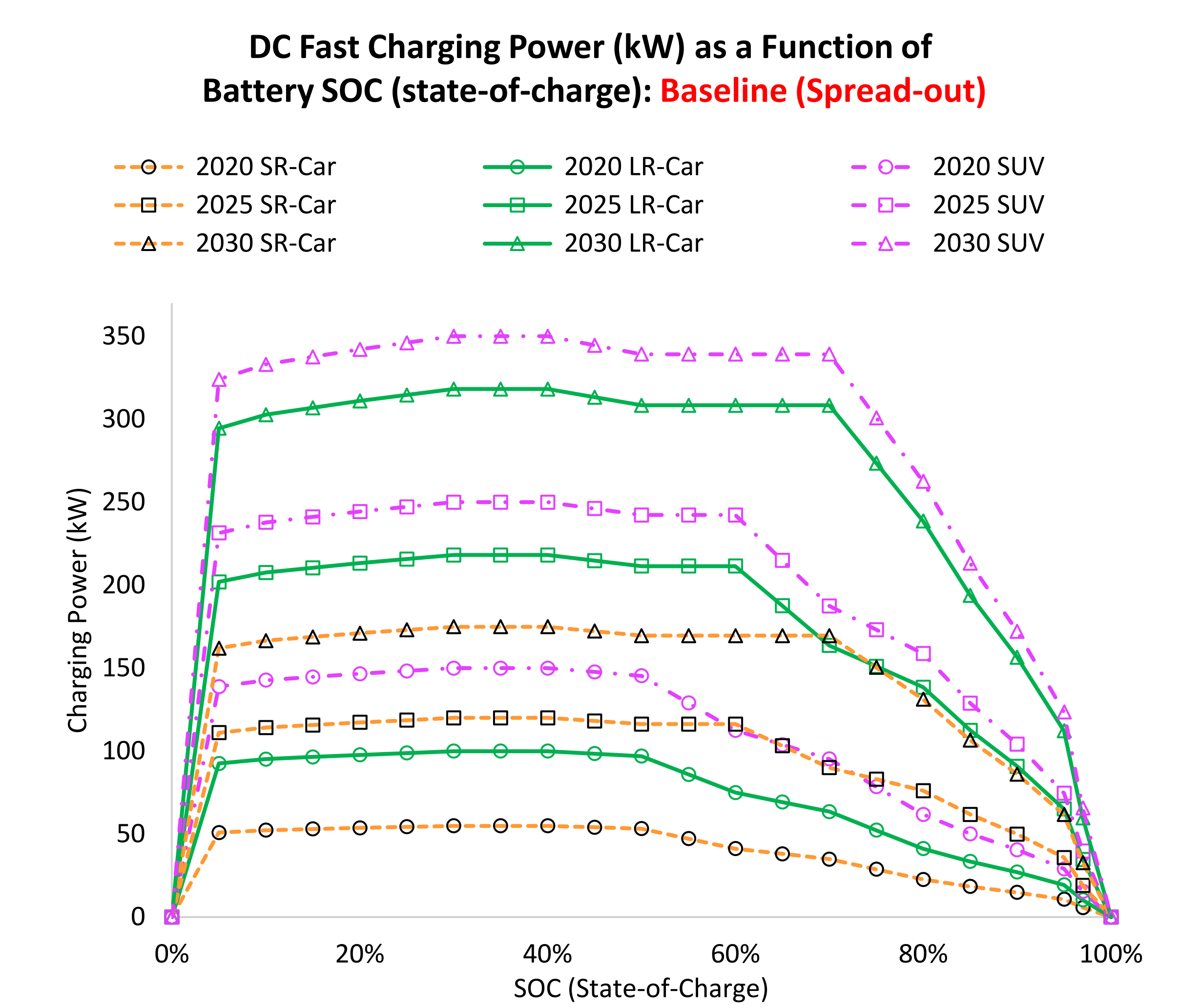




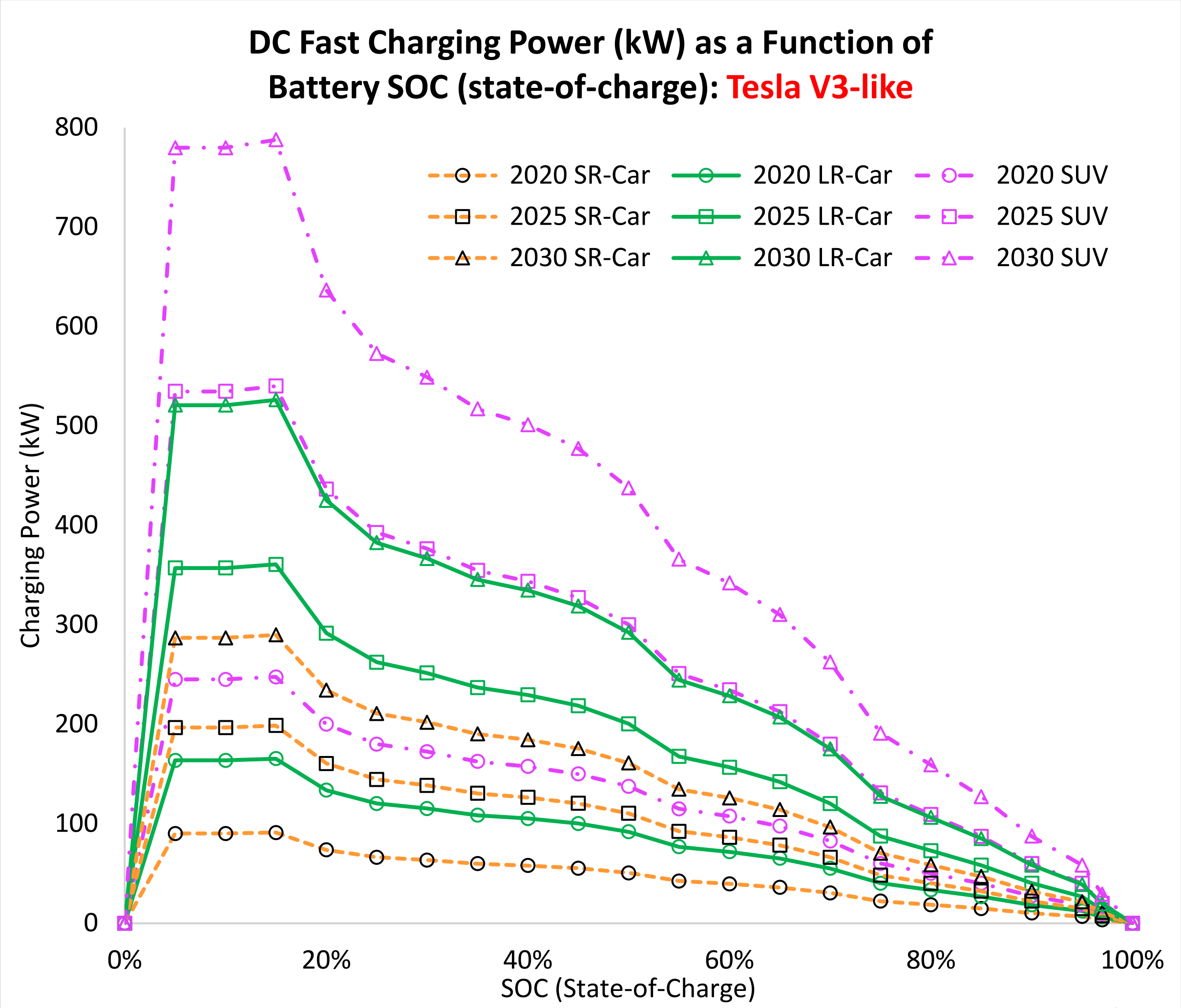


Sensitivity Analysis: Charging Behavior & Technology

- **Charging behavior** related to plug-out SOC:
  - TPM: Time penalty minimization (plug out at around 85% of SOC)
  - ATO: Always top off (plug out at 99% of SOC)

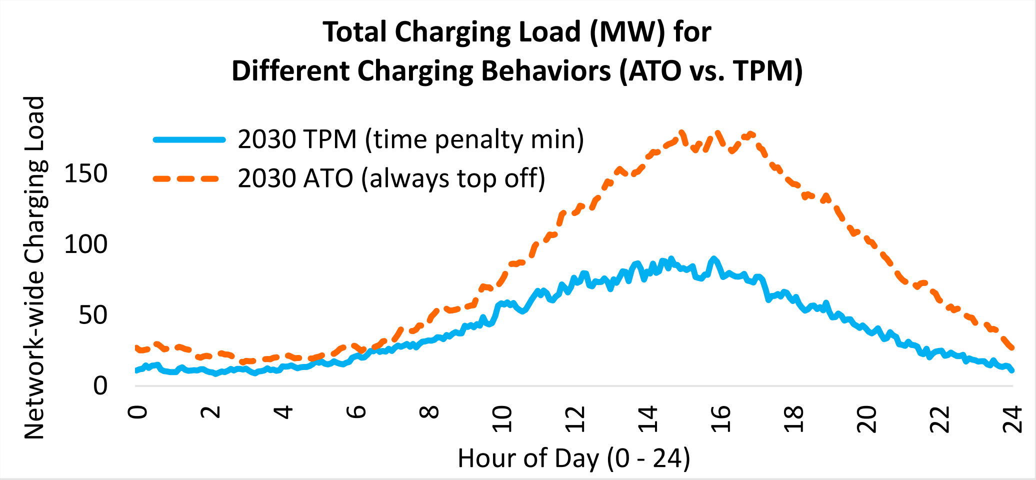


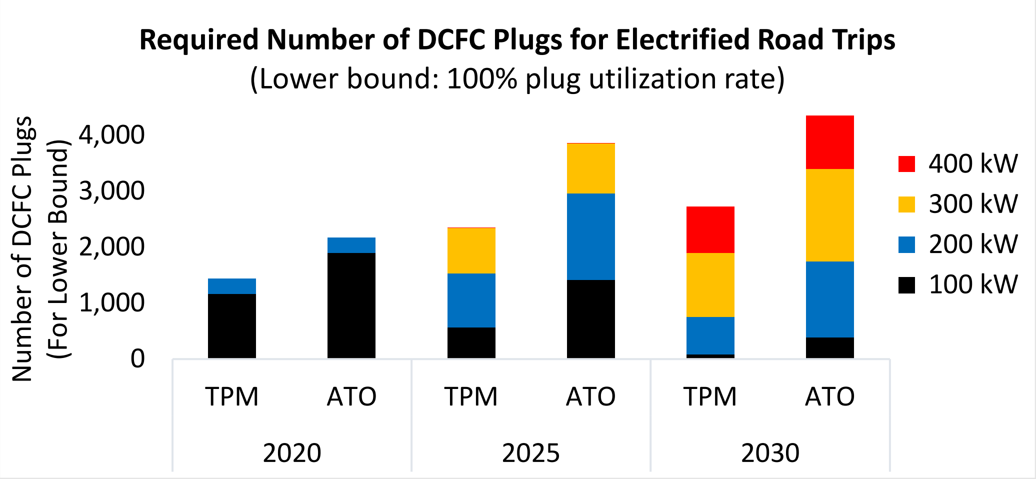
- **Charging technology** (speed, power, etc.) is still evolving.
- What if Tesla V3-like kW-SOC curves are used?



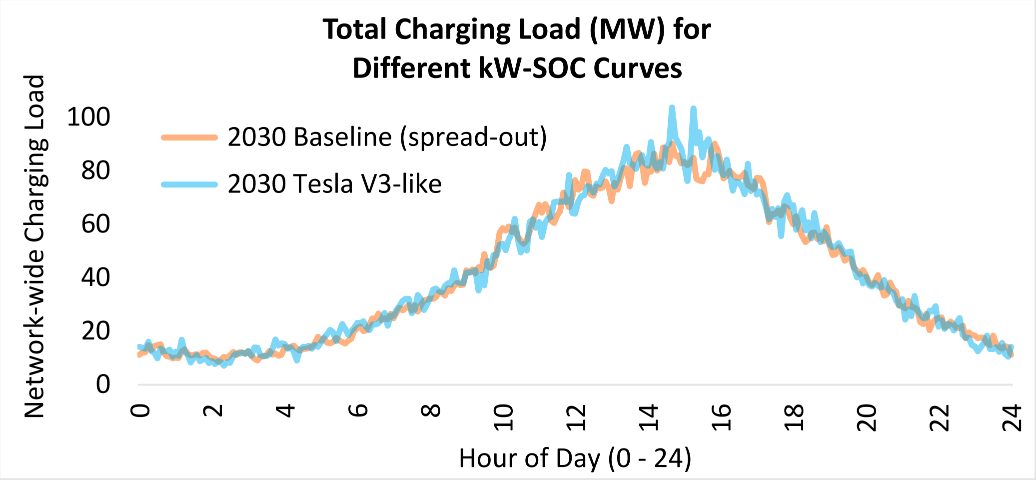
Impact of Charging Behavior & Technology

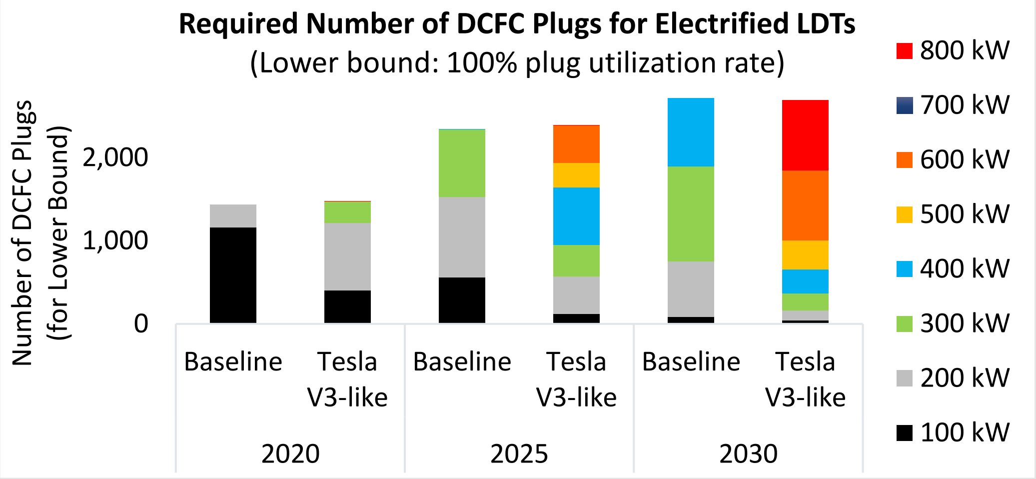
- **Charging behavior** (TPM vs. ATO):
  - Significant impact on load profiles and plug counts.
  - Plug composition (power rating) is mostly the same.





- **Charging technology** (kW-SOC curves):
  - Less-than-significant impact on load profiles or plug counts.
  - Drastic difference in terms of plug composition (power rating).





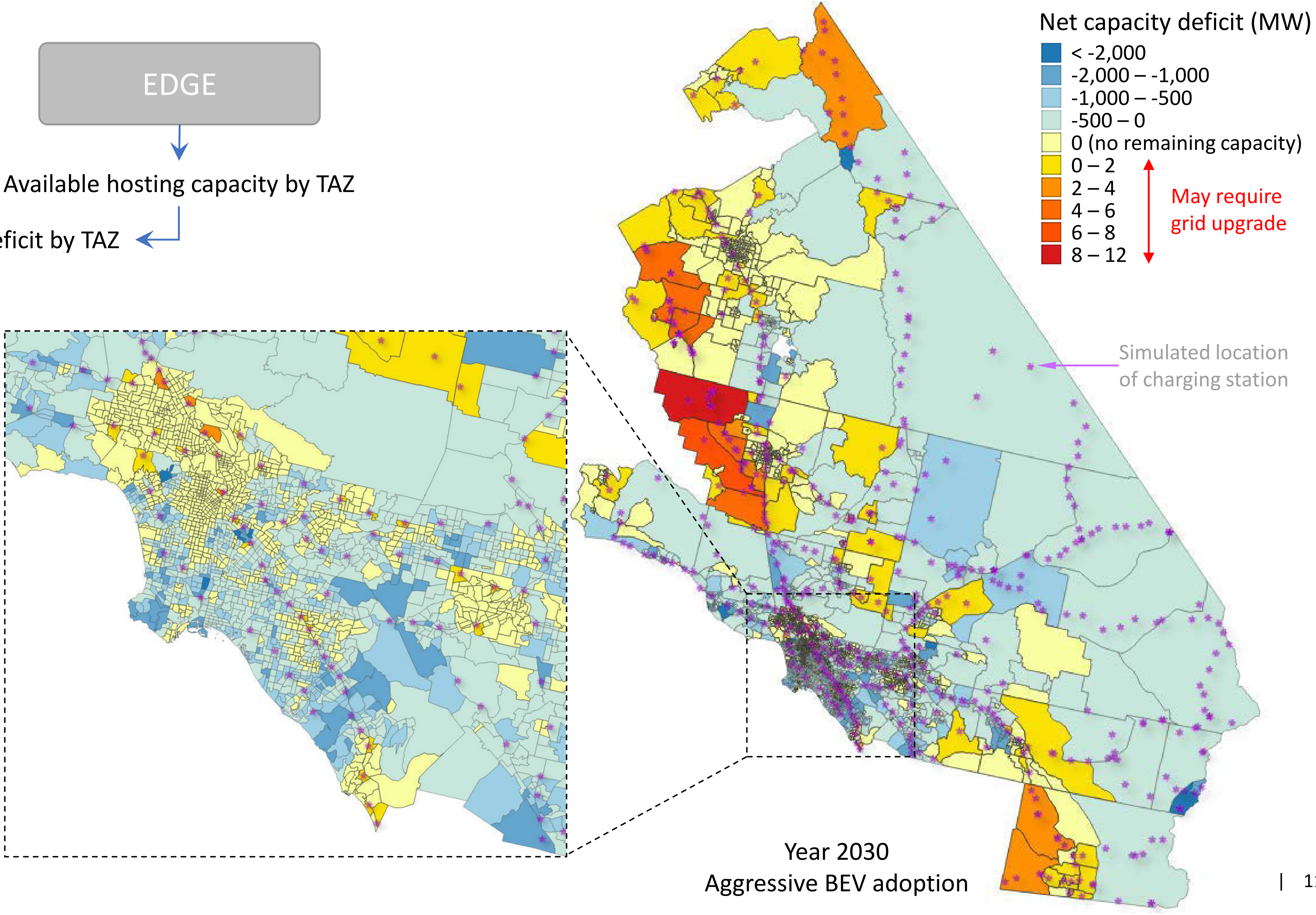
Results: Capacity Analysis – SCE (Southern California Edison) Case Study

EVI-Pro RoadTrip → Required capacity by TAZ

EDGE → Available hosting capacity by TAZ

→ Net capacity deficit by TAZ ←

- TAZ-by-TAZ capacity deficit ranges from 0 to 20 MW.
- Data quality of hosting capacity is to be improved.



Year 2030
Aggressive BEV adoption

Policy Implications (informed by CEC Staff)

1. **Need real world high-resolution data.**
   ● Model usefulness depends on high quality input data that capture *real-world travel/driving behavior and charging session characteristics.*

2. **Enhance grid integration at all levels.**
   ● DCFC loading (for electrified road trips) at the system-level *may align with solar power generation*.
   ● Initial capacity analyses suggest that electrified road trips *alone* might be accommodated. However, when accounting for integrated electrical load (road trips, short distance travels, buildings, etc.), California should encourage efforts to *manage network over-build* (“turnover” pricing) and *proactively mitigate grid impacts*.

3. **Plan for RoadTrip stations as part of a holistic expansion of the network.**
   ● Technology improvements *moderate the growth in the number of stations* and plugs needed to serve more BEVs in 2030, compared to 2025, highlighting the importance of *future proofing equipment and maximizing BEV-plug interoperability today*.
   ● Integrating the RoadTrip analysis with EVI-Pro 2 can *optimize the network of stations*.

Limitations & Future Work

- **"V1" of EVI-Pro RoadTrip (a model is a model).**
- **Need more realistic and rigorous methods and data for better characterization of driving & charging.**
- **Long-distance travels (or road trips): Traditionally under-researched area in transportation field.**

- **Future work** (not exhaustive):
  - Consider infrastructure co-utilization by entire LDV fleet (short-distance travels, TNC, etc.).
  - Internalize existing charging infrastructure in the overall station network design.
  - More integrated and advanced analysis (decision-making) of driving (drivers) and charging (infrastructure).
  - Account for dynamic aspects of the refueling network (e.g., coordinated charging, station congestion).
  - More realistic method for DCFC station siting and sizing (e.g., by reaching out to relevant stakeholders).
  - Stochastic approach for key parameters (e.g., heterogeneity of charging behavior).
  - State-wide capacity analysis (beyond the SCE area).

Thank You

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Appendix

Road Trip Electrification Projections

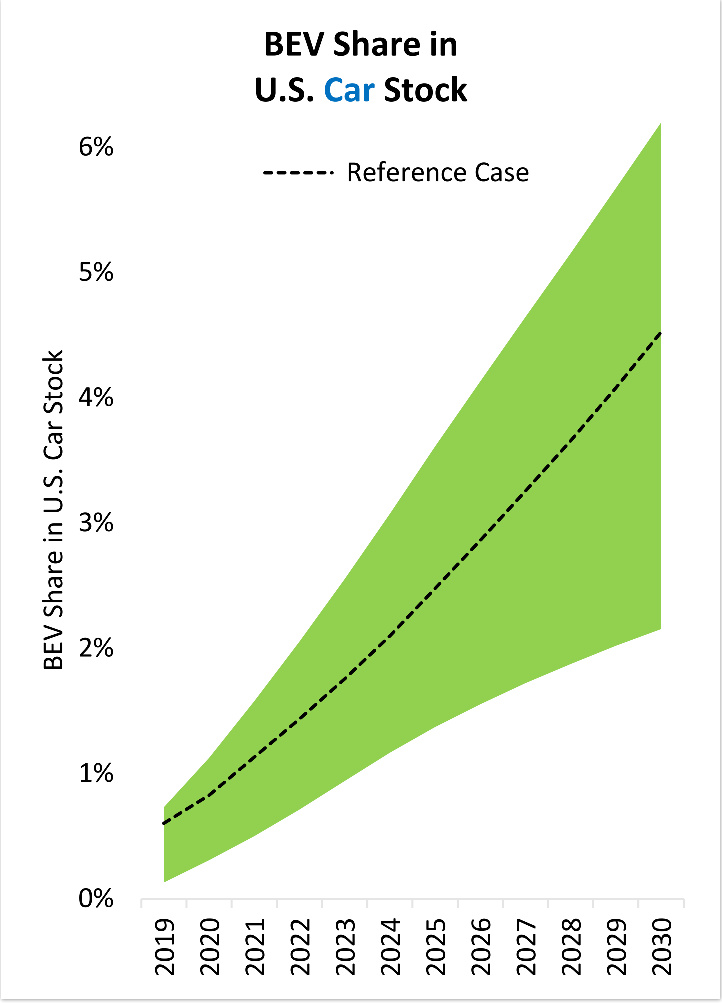
- Road trip electrification is based on general light-duty vehicle electrification projections (BEV adoption).
  - California: 10% by 2030 (based on the forecasts made by CEC's Energy Assessments Division)
  - Non-CA states: 2.5% by 2030 (based on EIA AEO – see next slide)
  - Mexico: 0.05% by 2030 (based on IEA projections)

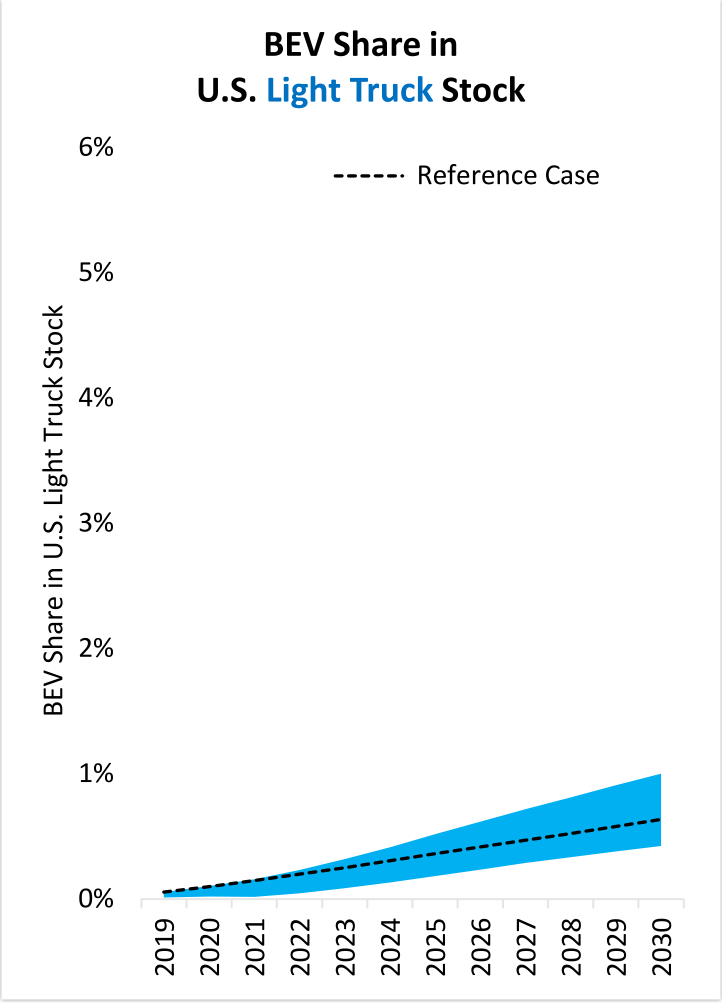
- BEV adoption scenarios:
  - Baseline/aggressive (3.1M BEVs by 2030): Business as usual
  - Low (1.5M BEVs by 2030): Potential aftermath (e.g., slower electrification) of the ongoing pandemic (COVID-19)

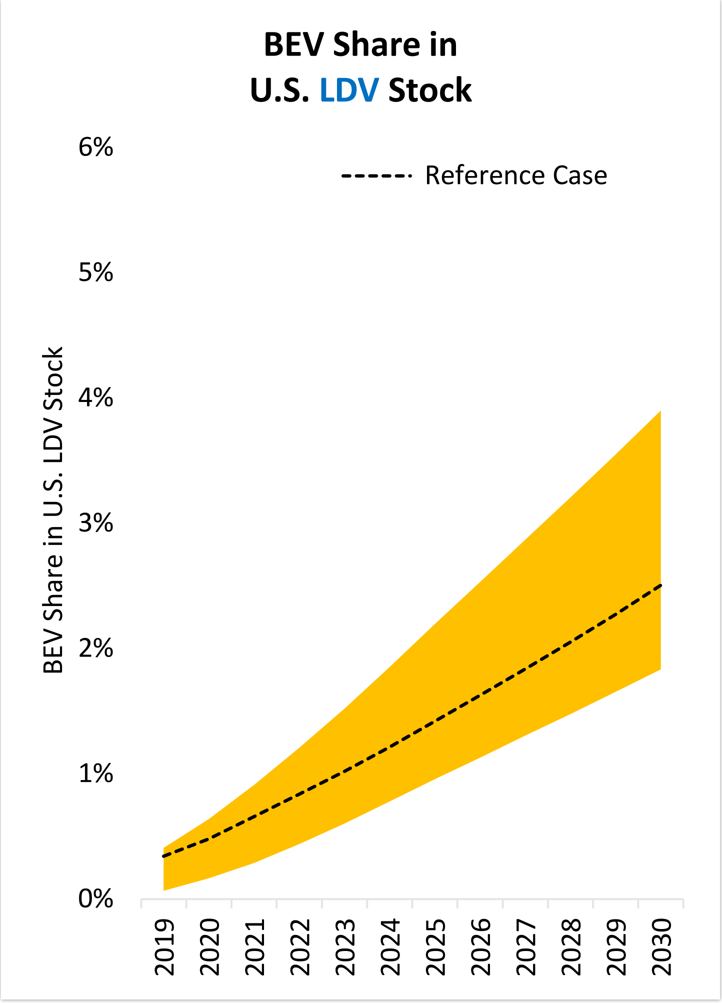
Daily travel volume of road trips in California		Baseline (Aggressive) BEV Adoption			Low BEV Adoption		
		Intra-state	External	Total	Intra-state	External	Total
2020	CSTDM (All)	215,151	344,058	559,209	215,151	344,058	559,209
	RoadTrip (Electrified)	4,226	3,762	7,988	4,226	3,762	7,988
2025	CSTDM (All)	211,684	363,005	574,689	211,684	363,005	574,689
	RoadTrip (Electrified)	12,332	11,810	24,142	7,205	7,514	14,719
2030	CSTDM (All)	210,844	372,856	583,700	210,844	372,856	583,700
	RoadTrip (Electrified)	20,425	20,323	40,748	10,212	11,503	21,715

BEV Adoption in Non-CA States

- EIA AEO 2020 projection: 2–4% of total LDV (light-duty vehicle) stock in the U.S. will be BEVs by 2030.
- The range reflects 23 different scenarios EIA evaluated.





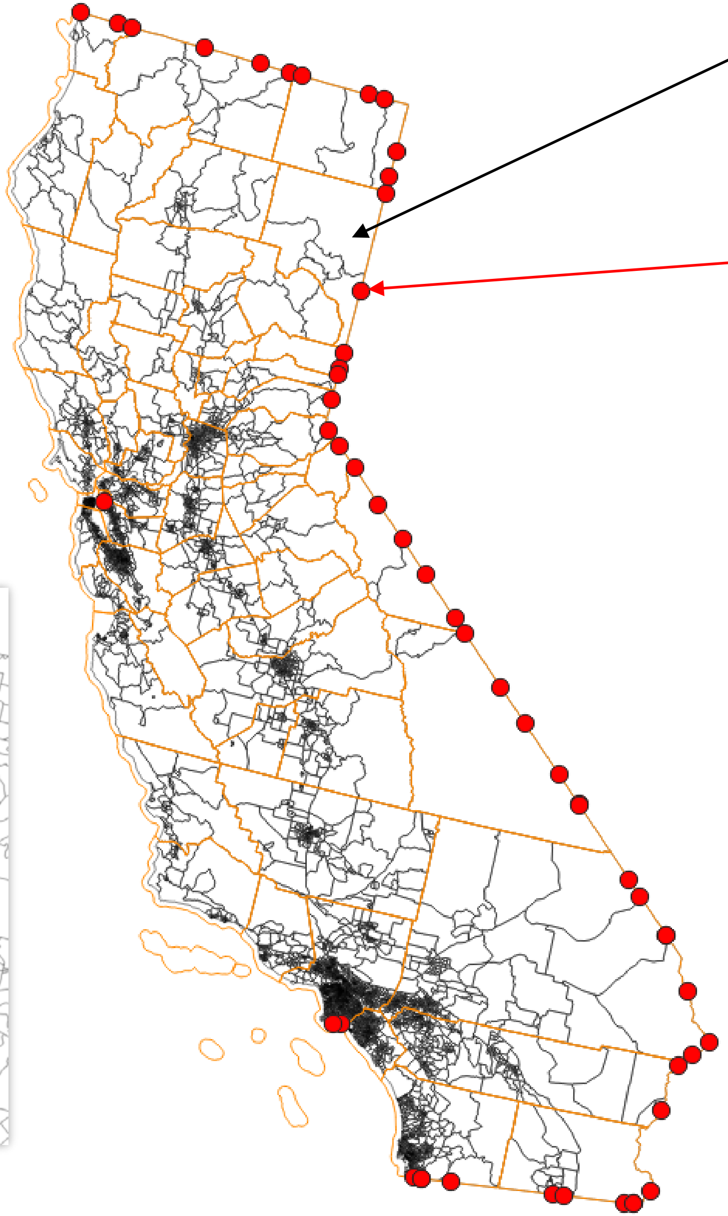


Data source: EIA AEO 2020

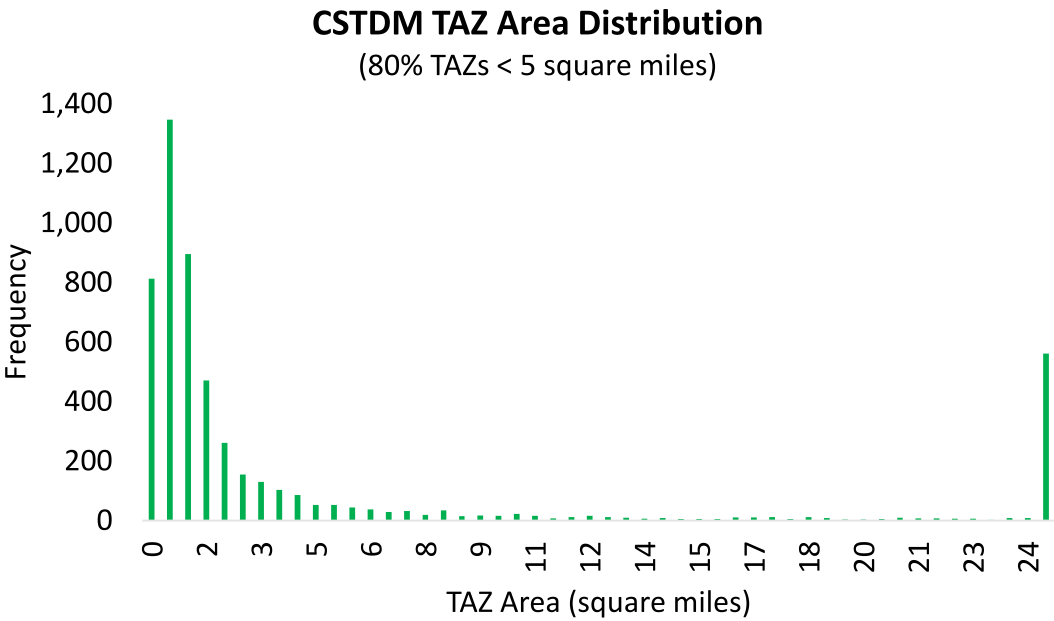
TAZs (Traffic Analysis Zones) & Gateways in CSTDM


San Francisco


Los Angeles

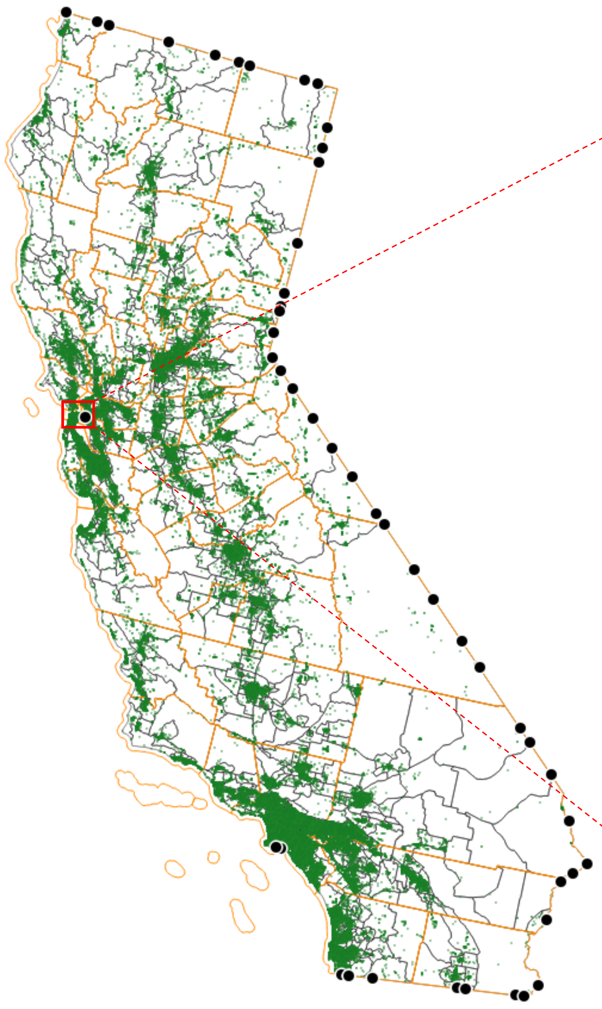


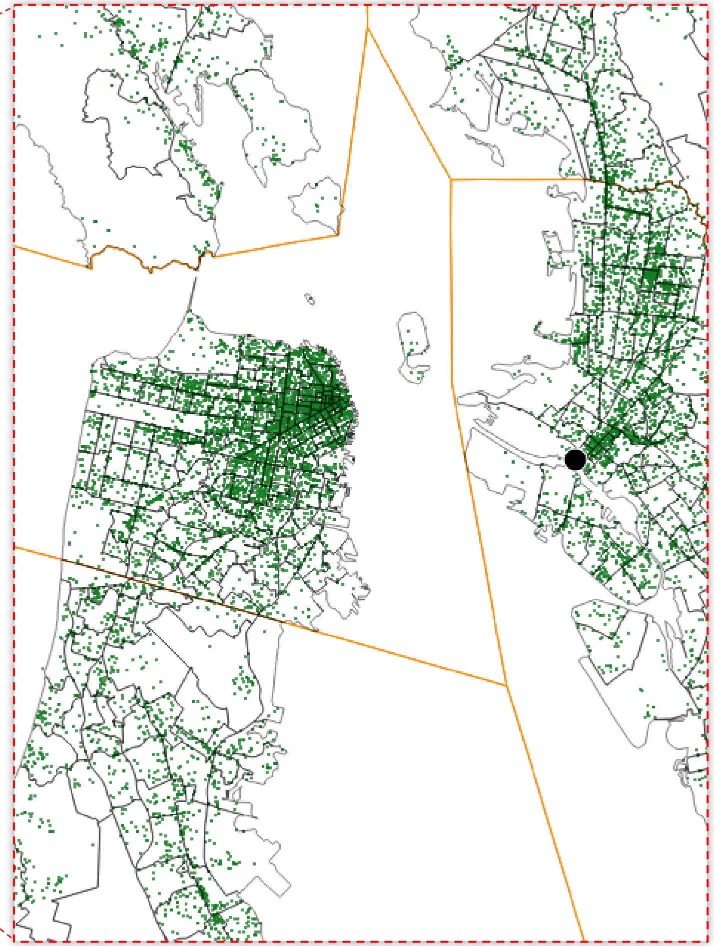
- **5,454 internal TAZs**
  - Used for short-distance (SHT) and long-distance (LNG) travel volume
- **53 external TAZs (gateways)**
  - 3 ports (Port of Oakland, POLA, & POLB)
  - 50 roadways crossing CA boundary
  - Used for external (EXT) travel volume



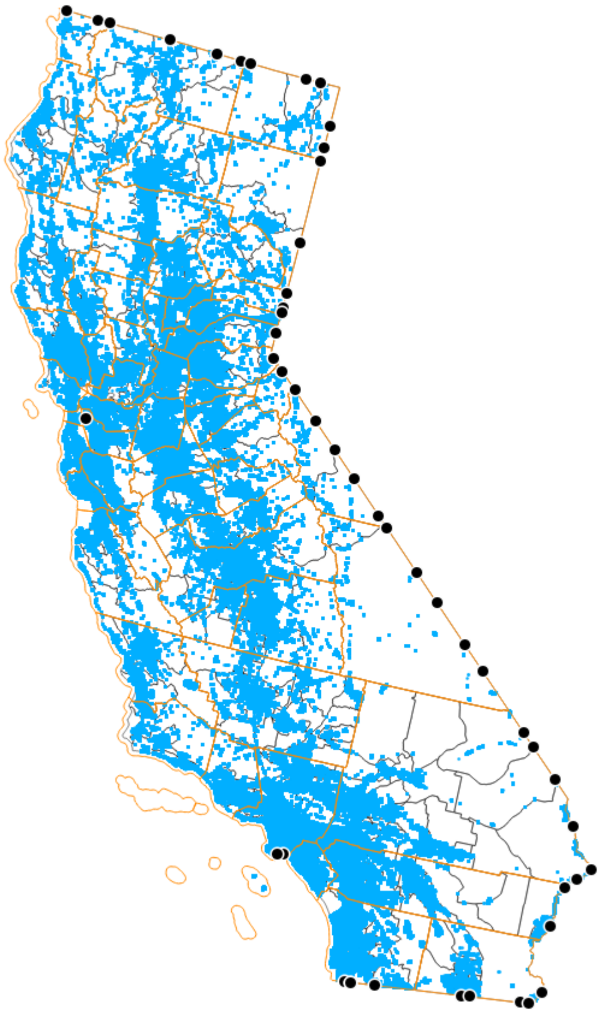
Seed Coordinates for Origins and Destinations: CHTS + NLUD

CHTS (California Household Travel Survey):
About 0.2 million unique coordinates as reference points for origins/destinations; the spatial density is correlated with population centers.



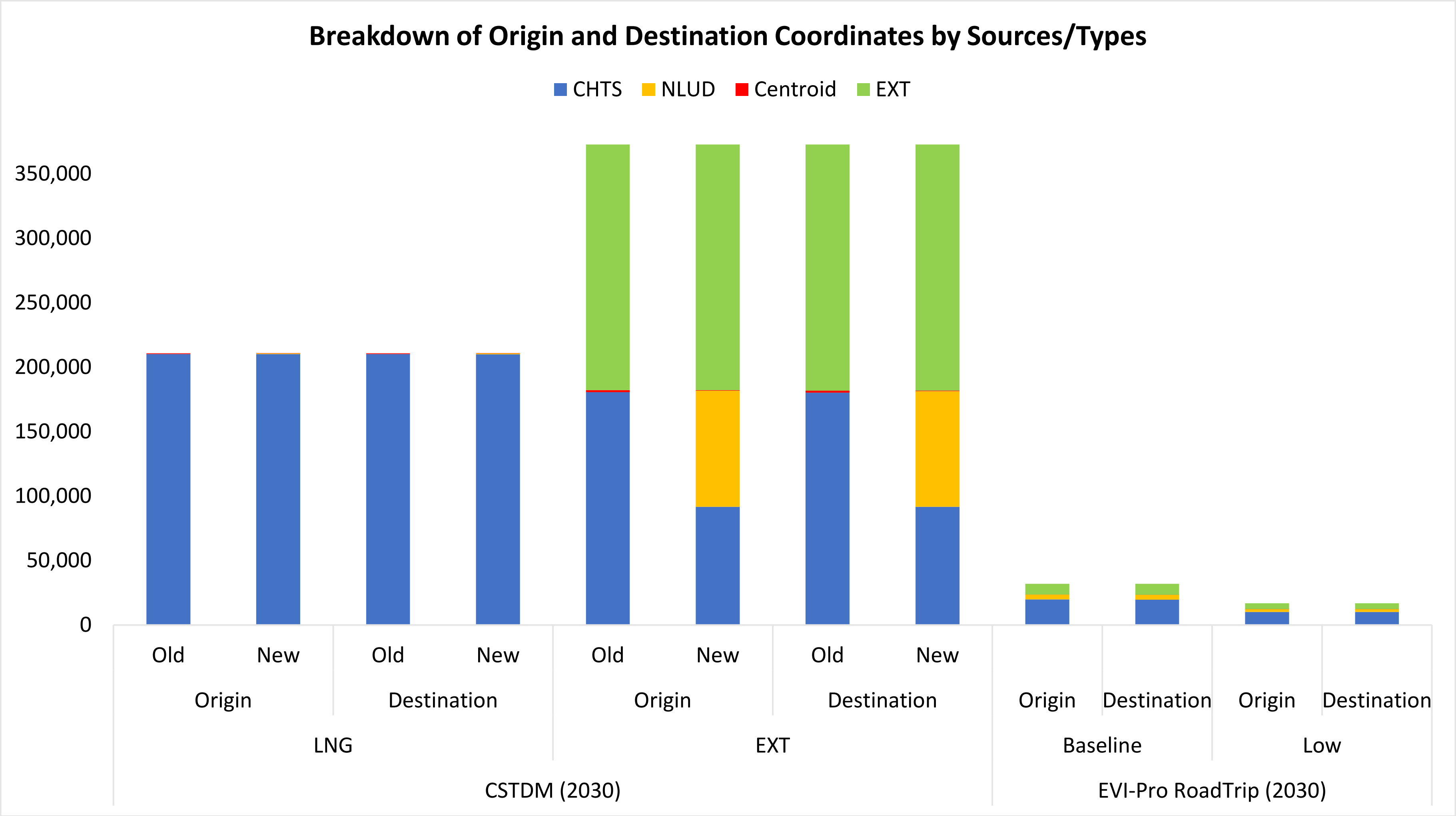


NLUD (National Land Use Data):
Down-sampled for residential and commercial spots (30m x 30m)



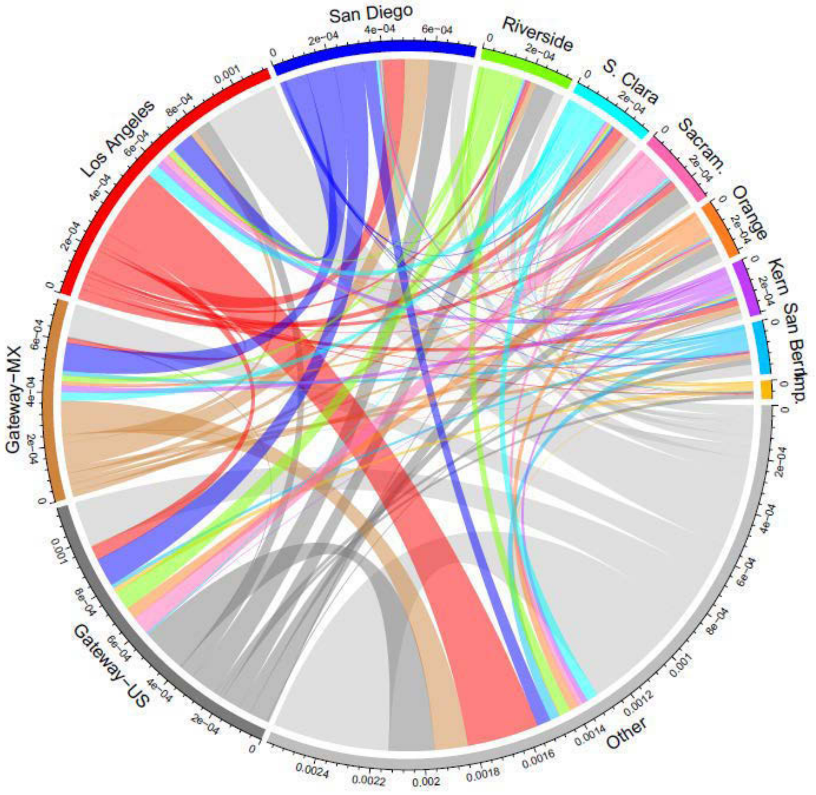
Breakdown of Origin and Destination Coordinates by Sources/Types

- Replaced centroids (used when no CHTS coordinates are available) with NLUD coordinates.
- Reduced duplicate CHTS samples.
- In the final input data (trips) for simulation, NLUD coordinates account for about 11%.

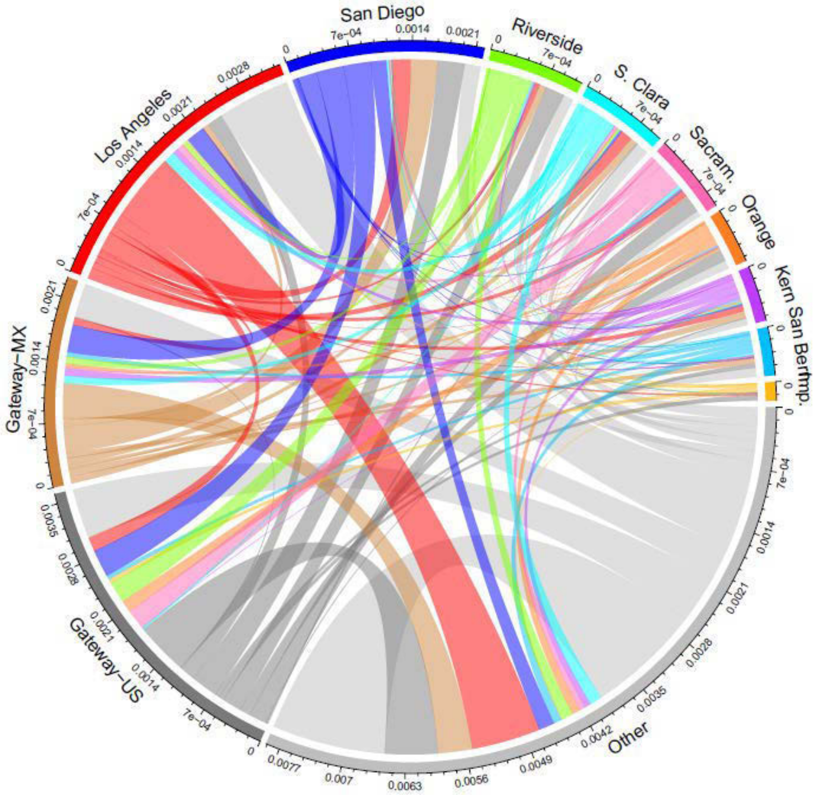


Road Trip Pattern by Year (Baseline BEV Adoption)

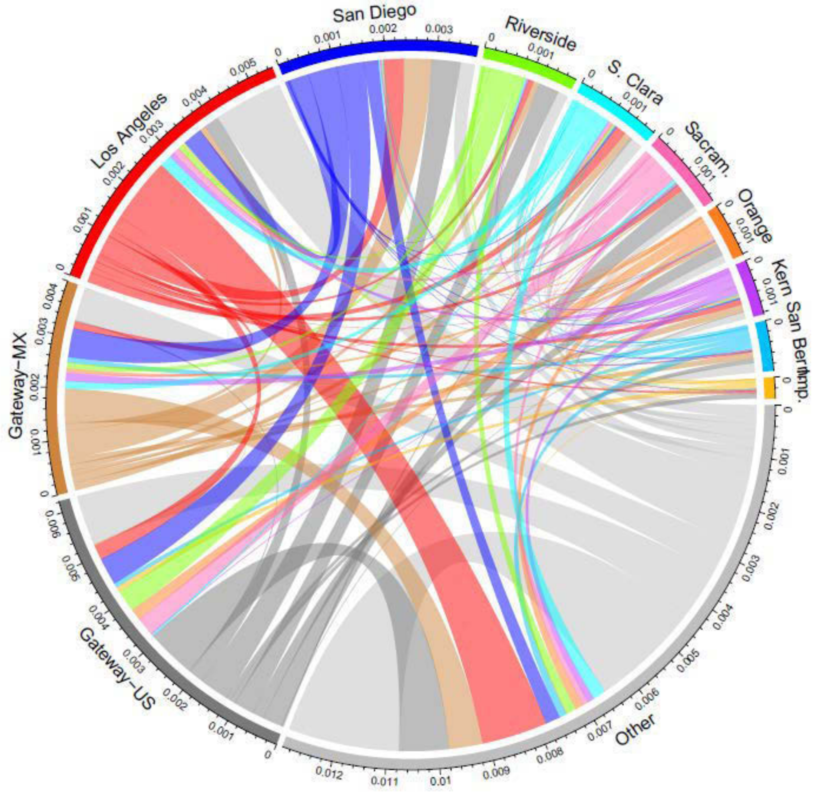
2020



2025

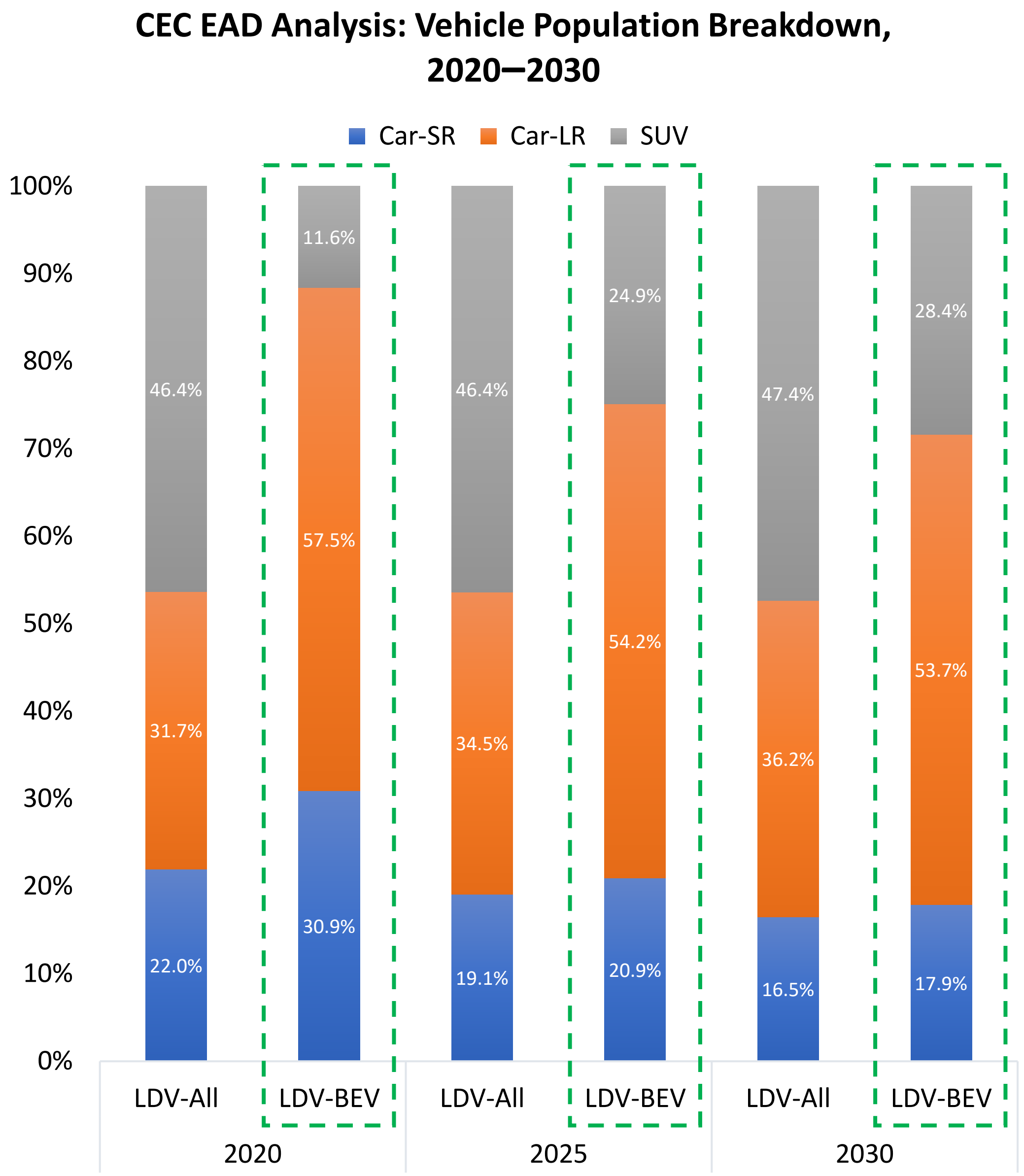


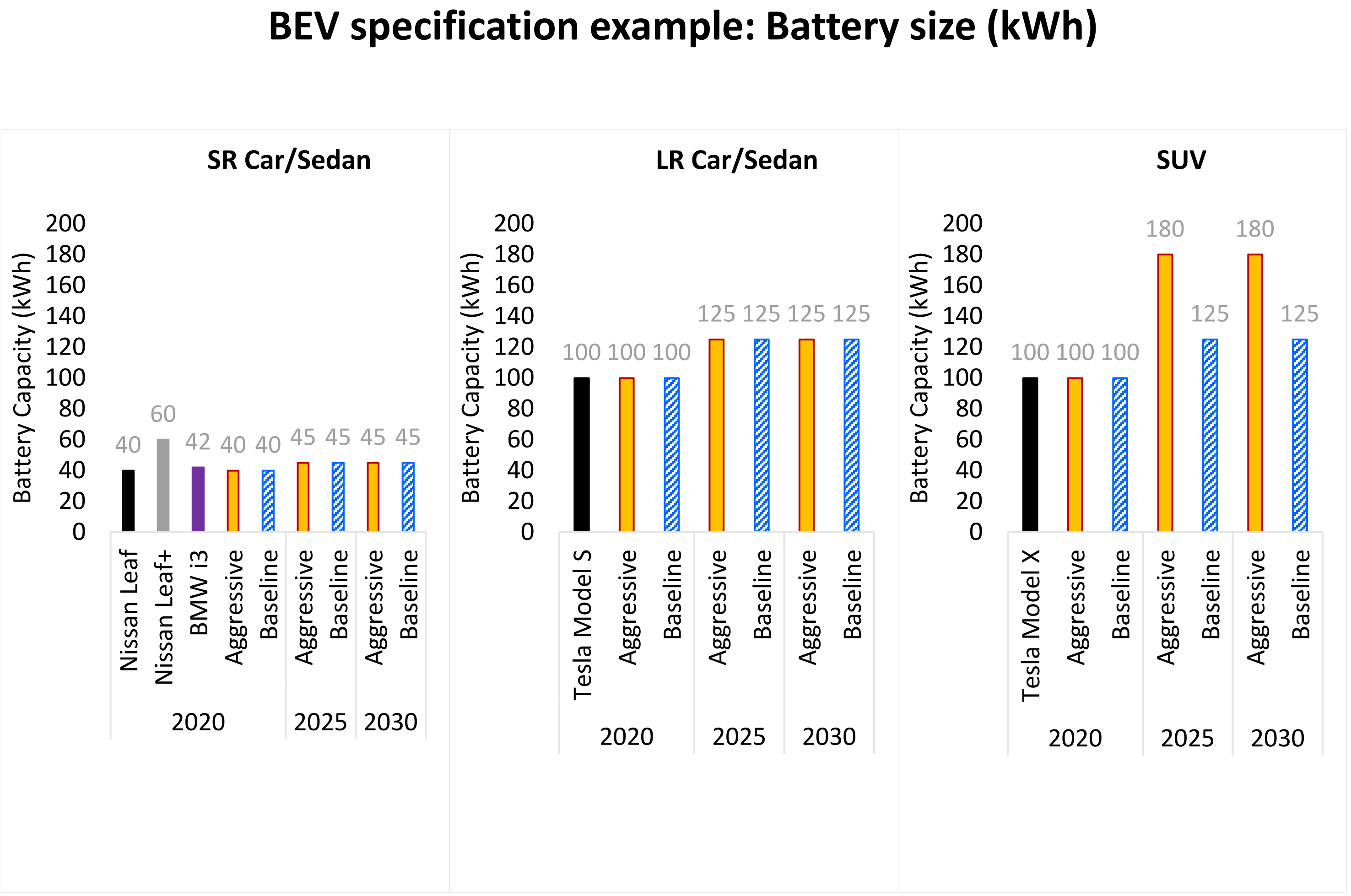
2030



Travel volume increases over time, but the overall spatial pattern of road trips remains similar.

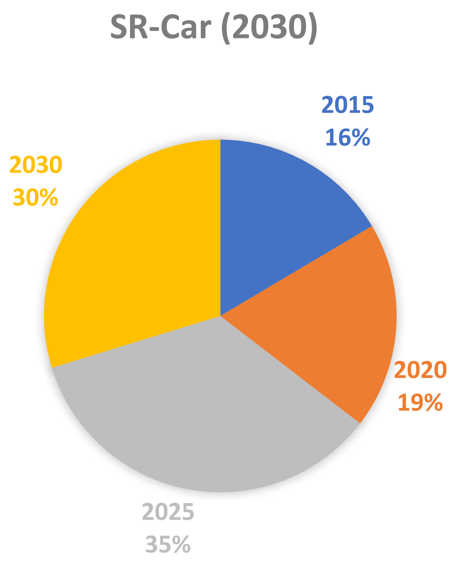
BEV Type, Population, and Specifications

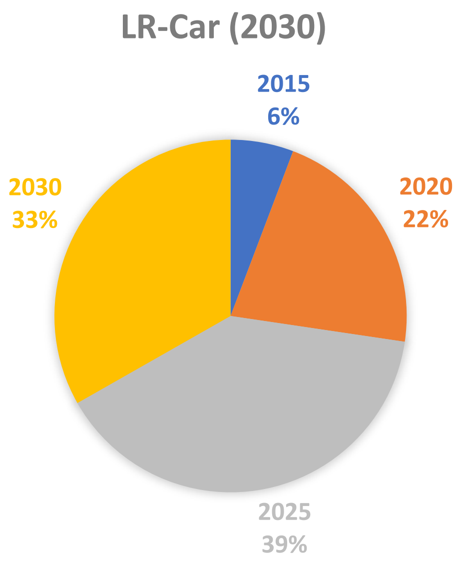


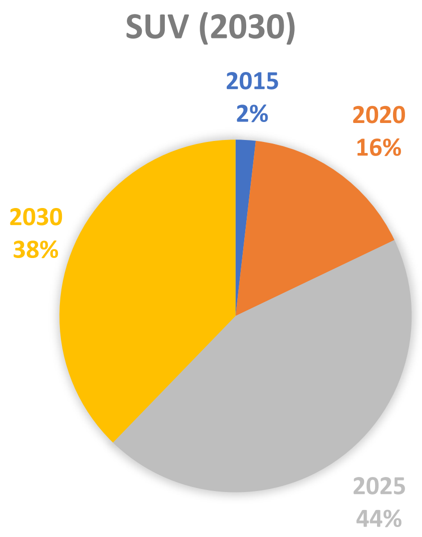


Model Year (MY) Distribution (adapted from CEC EAD data)

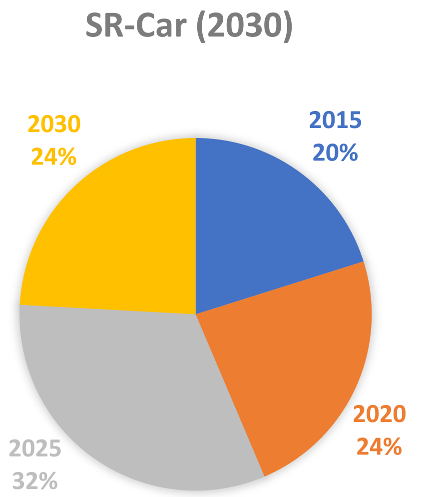
Baseline (Aggressive) BEV Adoption

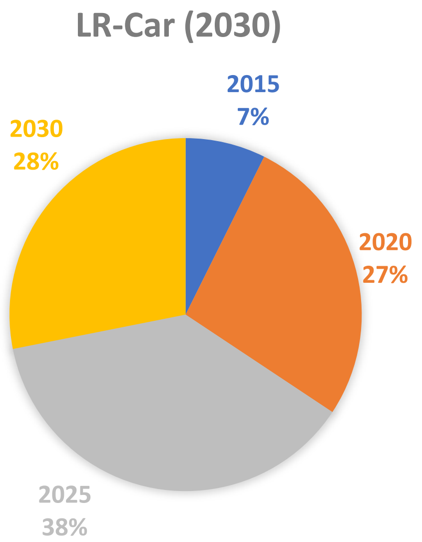


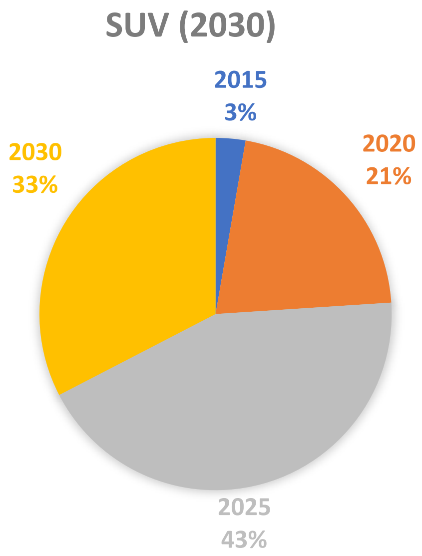




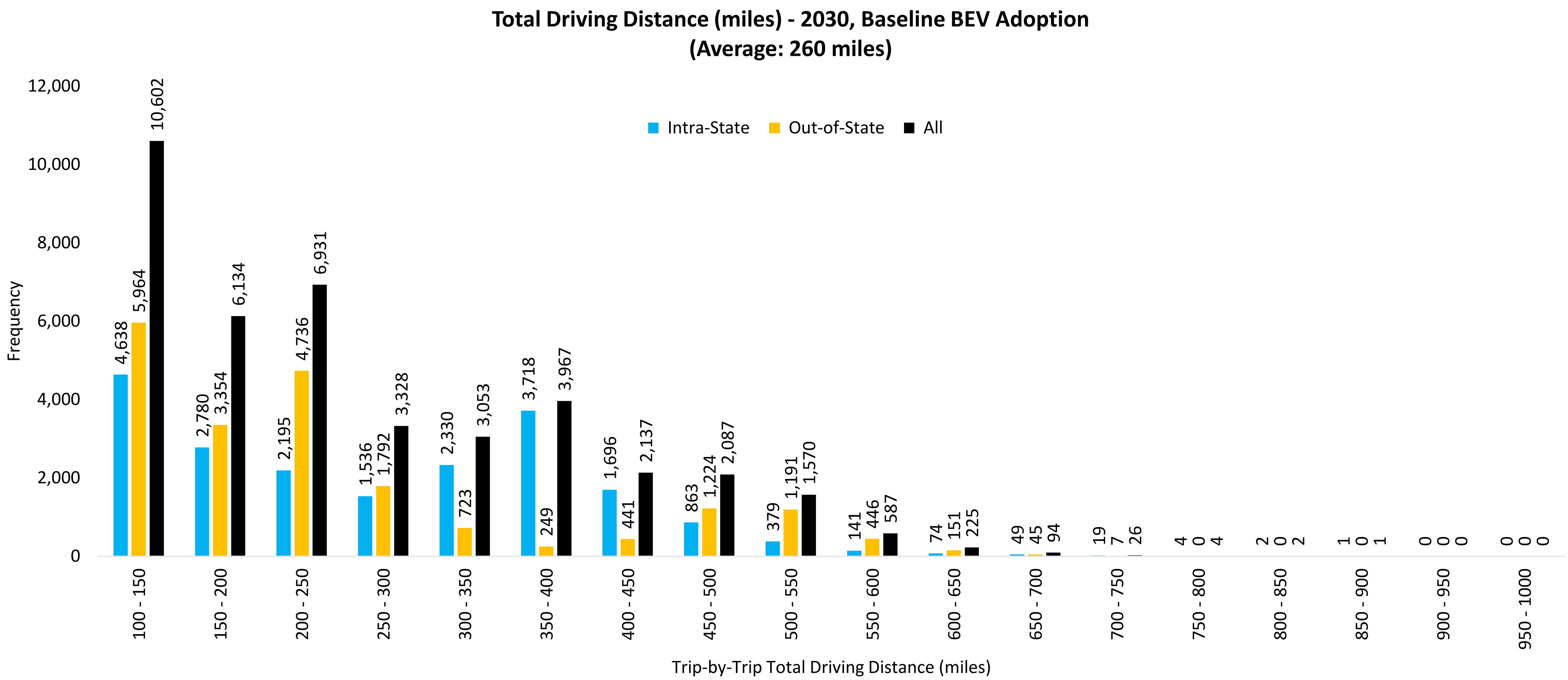
Low BEV Adoption





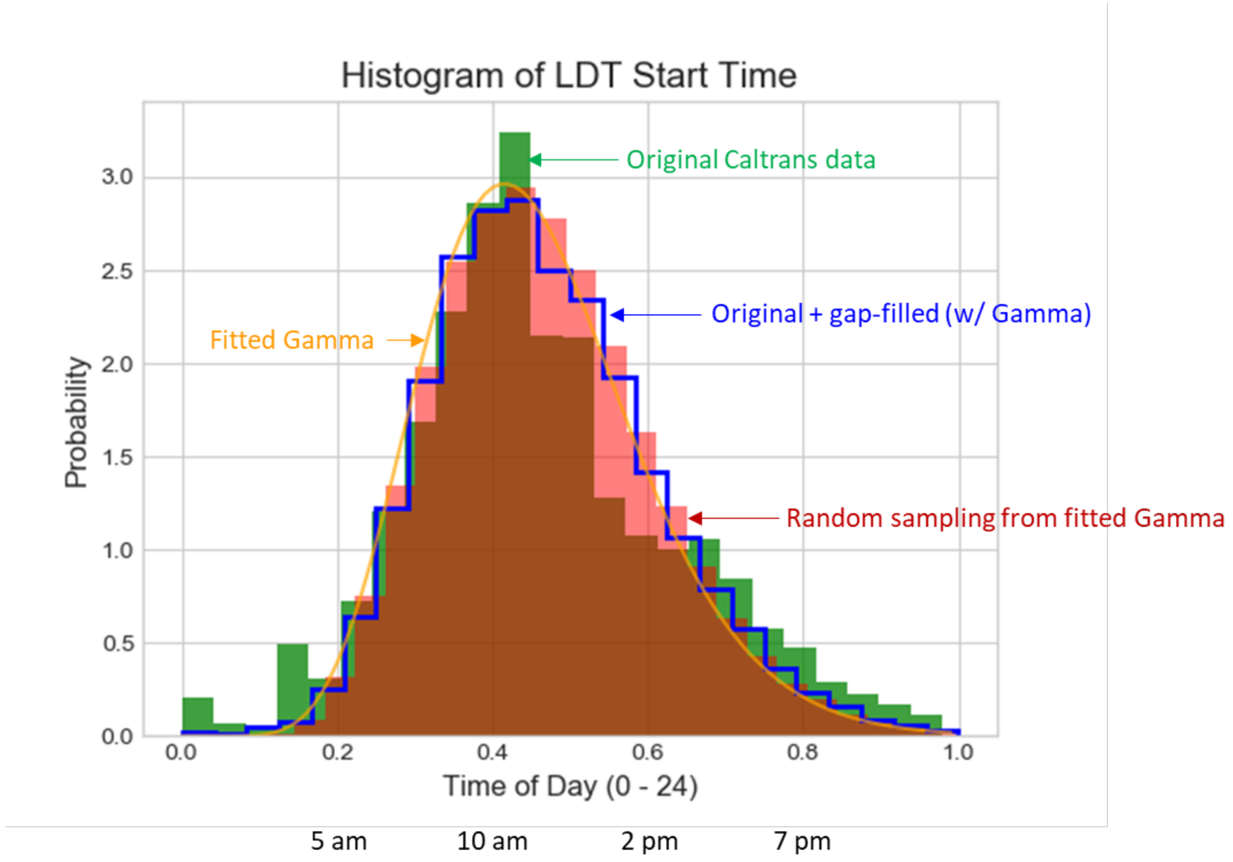


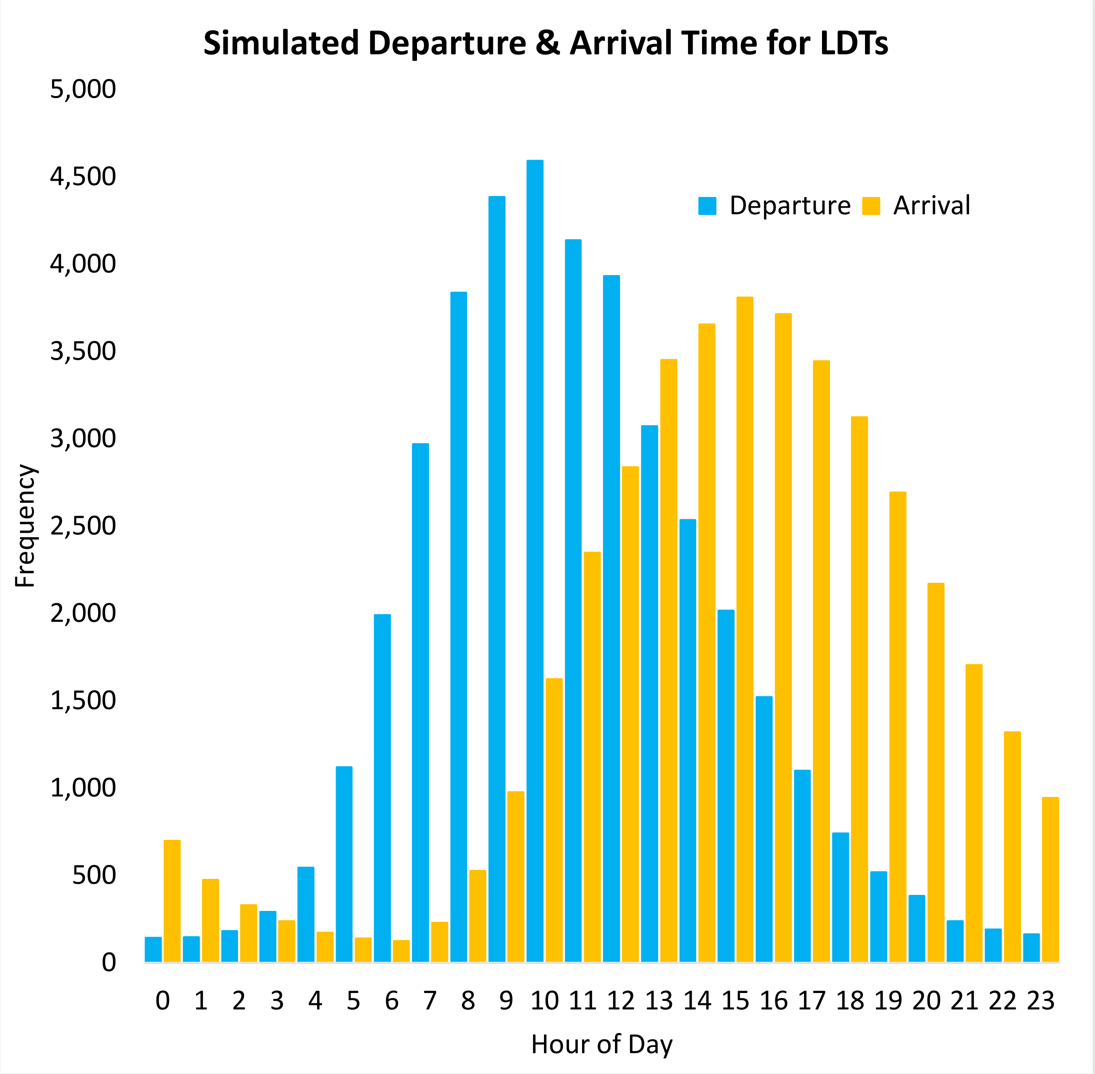
Road Trip Distance Statistics



Trip Initialization

- CHTS-LDT (long-distance travel) indicates that trip start/departure time centers around 10–11 am.
- CHTS-LDT start time distribution (below) is used as reference for departure time.

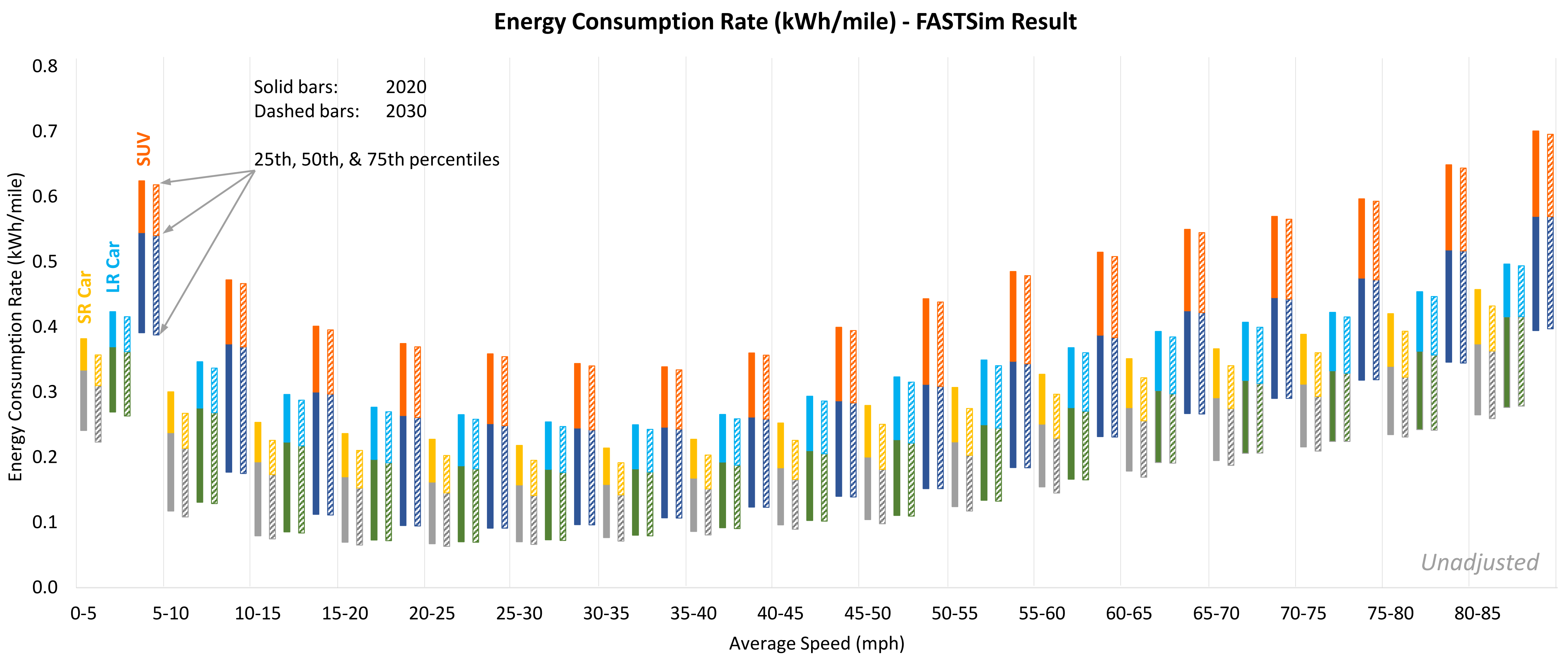




(Based on California Household Travel Survey)

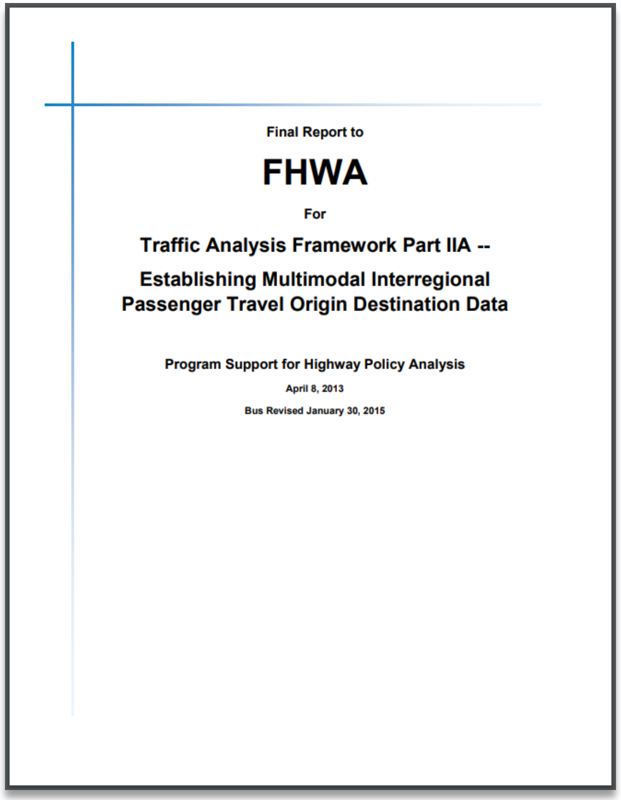
Energy Consumption Rate (kWh/mile)

- Generic energy consumption rate (kWh/mile) was developed from NREL's FASTSim simulation with CEC/CARB/NREL vehicle specifications and millions of real-world drive cycles.



Departure and Entry SOC (State-of-Charge)

- Departure SOC for intra-state road trips: FleetCarma NE data.
- Entry SOC for out-of-state inbound road trips: SOC at the point of entering the state (CA) boundary.
- Run EVI-Pro RoadTrip with FHWA TAF (Traffic Analysis Framework) O-D matrix (for 2040).


Final Report to

FHWA

For

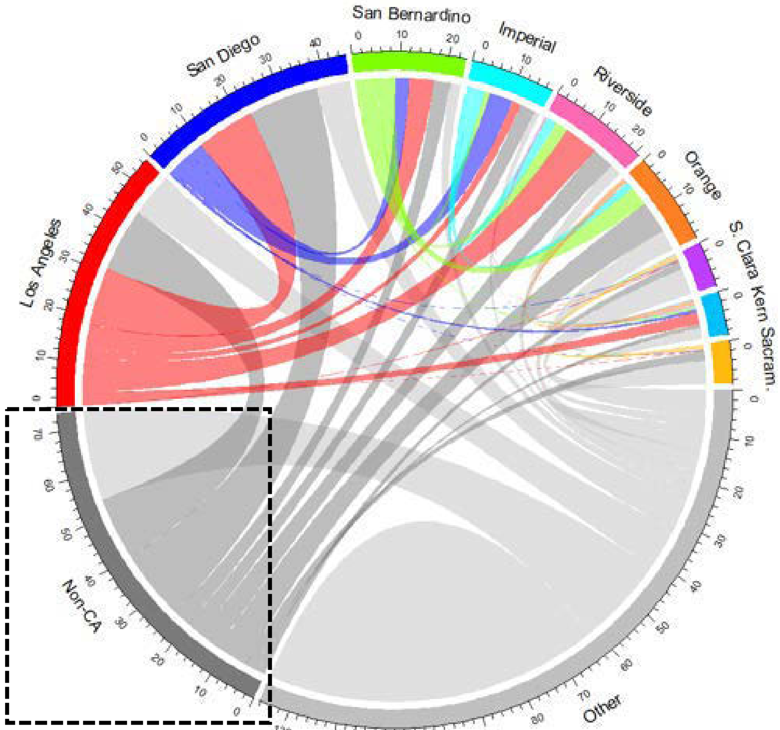
Traffic Analysis Framework Part IIA --
Establishing Multimodal Interregional Passenger Travel Origin Destination Data

Program Support for Highway Policy Analysis

April 8, 2013

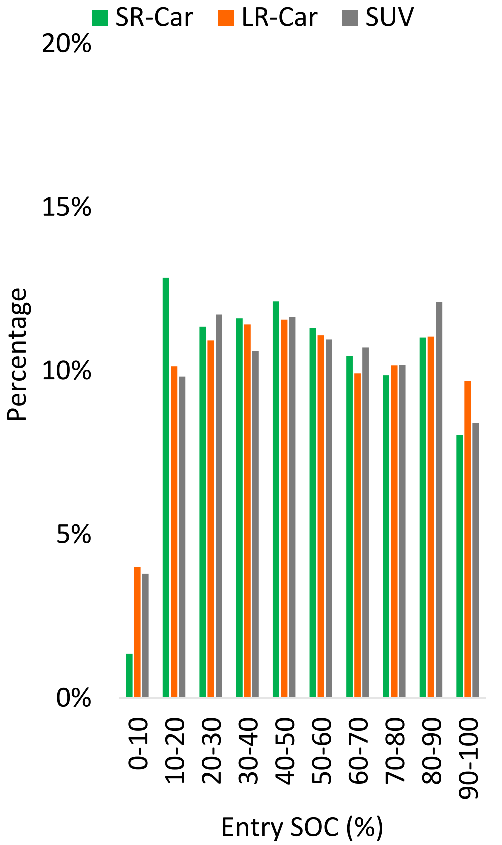
Bus Revised January 30, 2015

https://www.fhwa.dot.gov/policyinformation/analysisframework/docs/taf_final_report.pdf

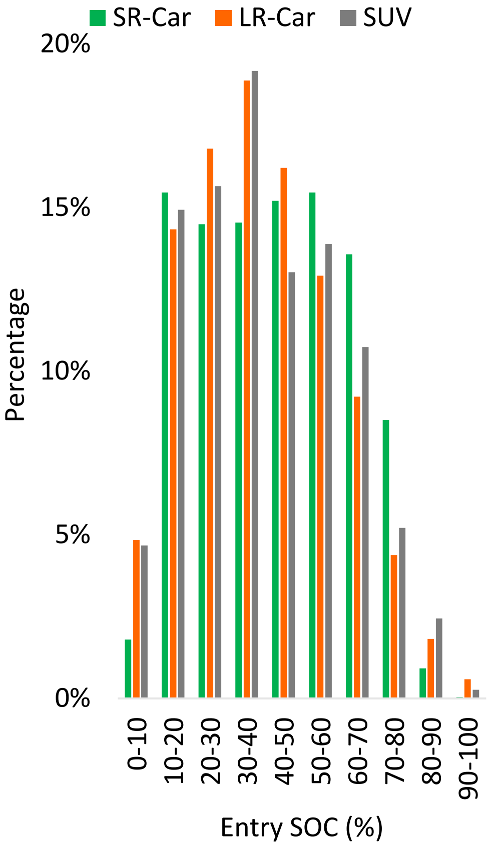


External inbound (domestic only)

Entry SOC Distribution (ATO, 2030)

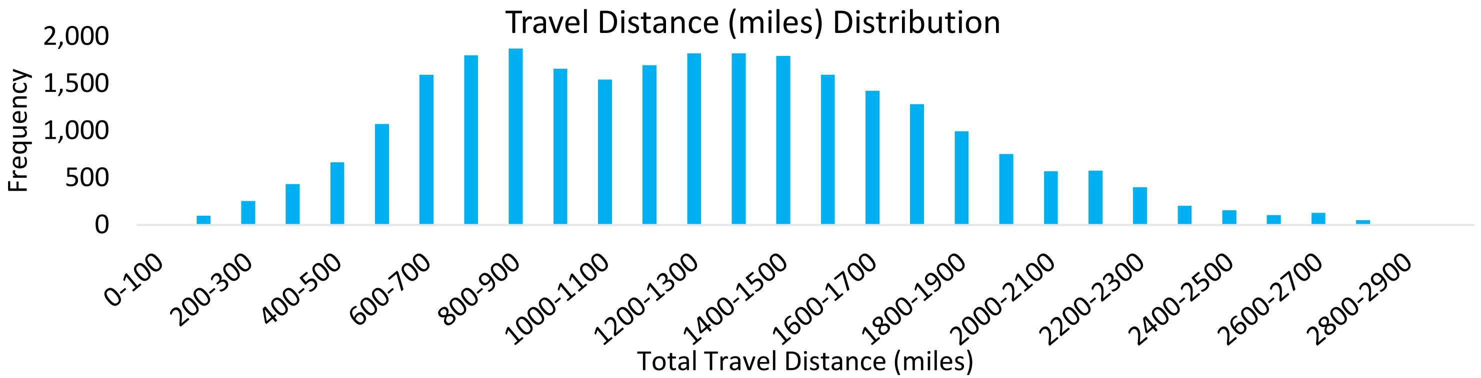


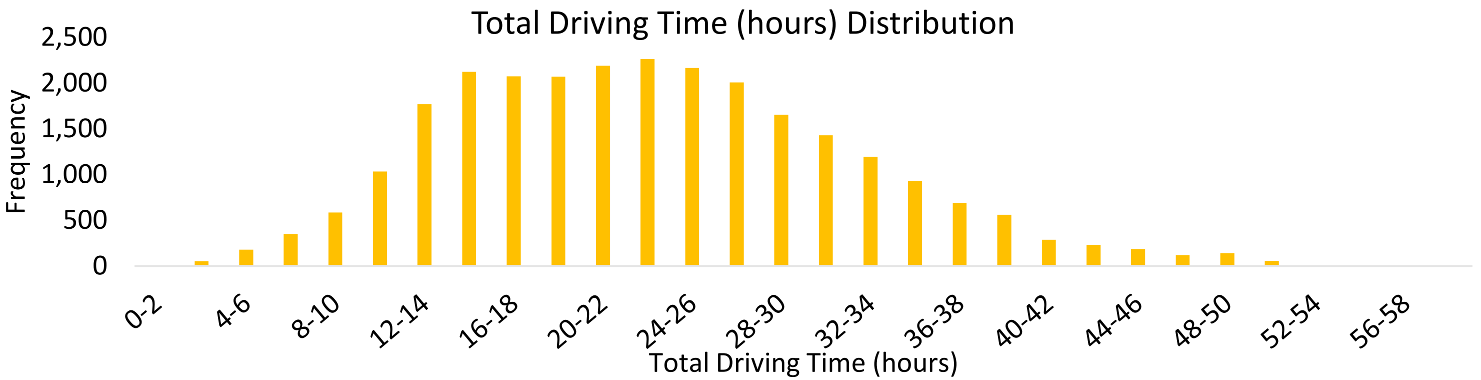
Entry SOC Distribution (TPM, 2030)

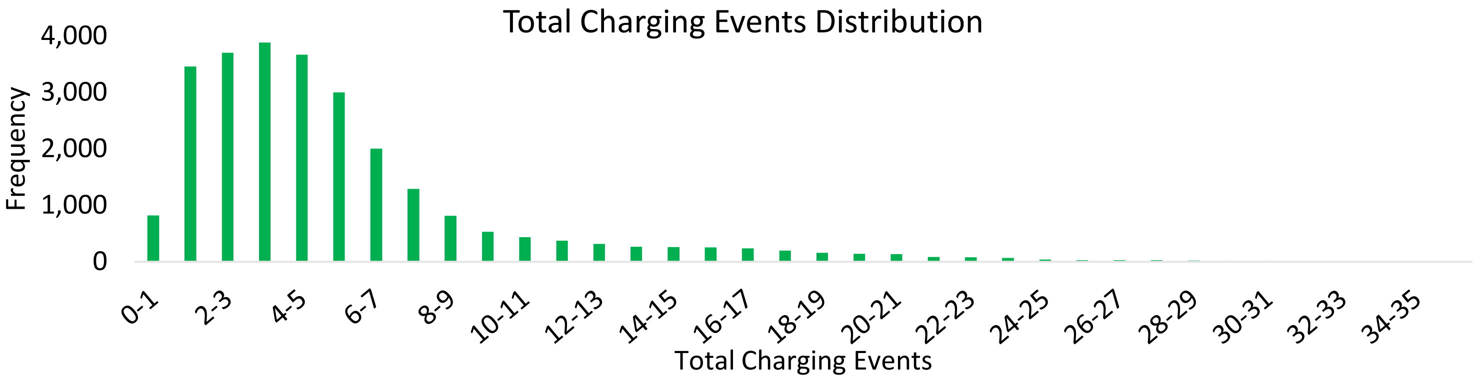


Estimating Entry SOC for “External Inbound” Trips

- FHWA TAF O-D (county-by-county LDT) + EVI-Pro RoadTrip

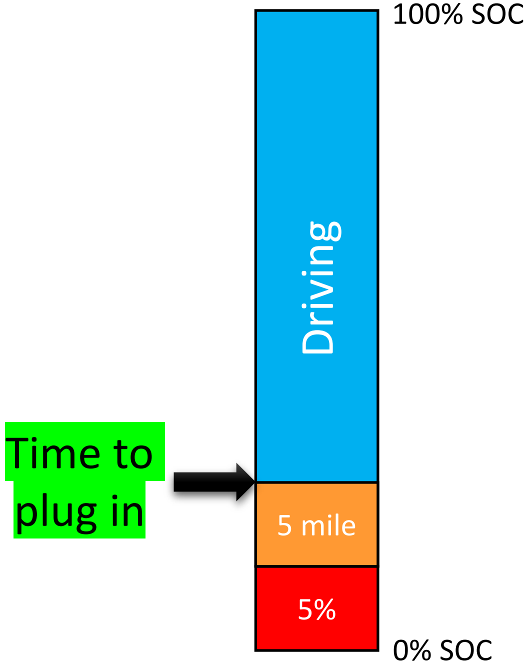


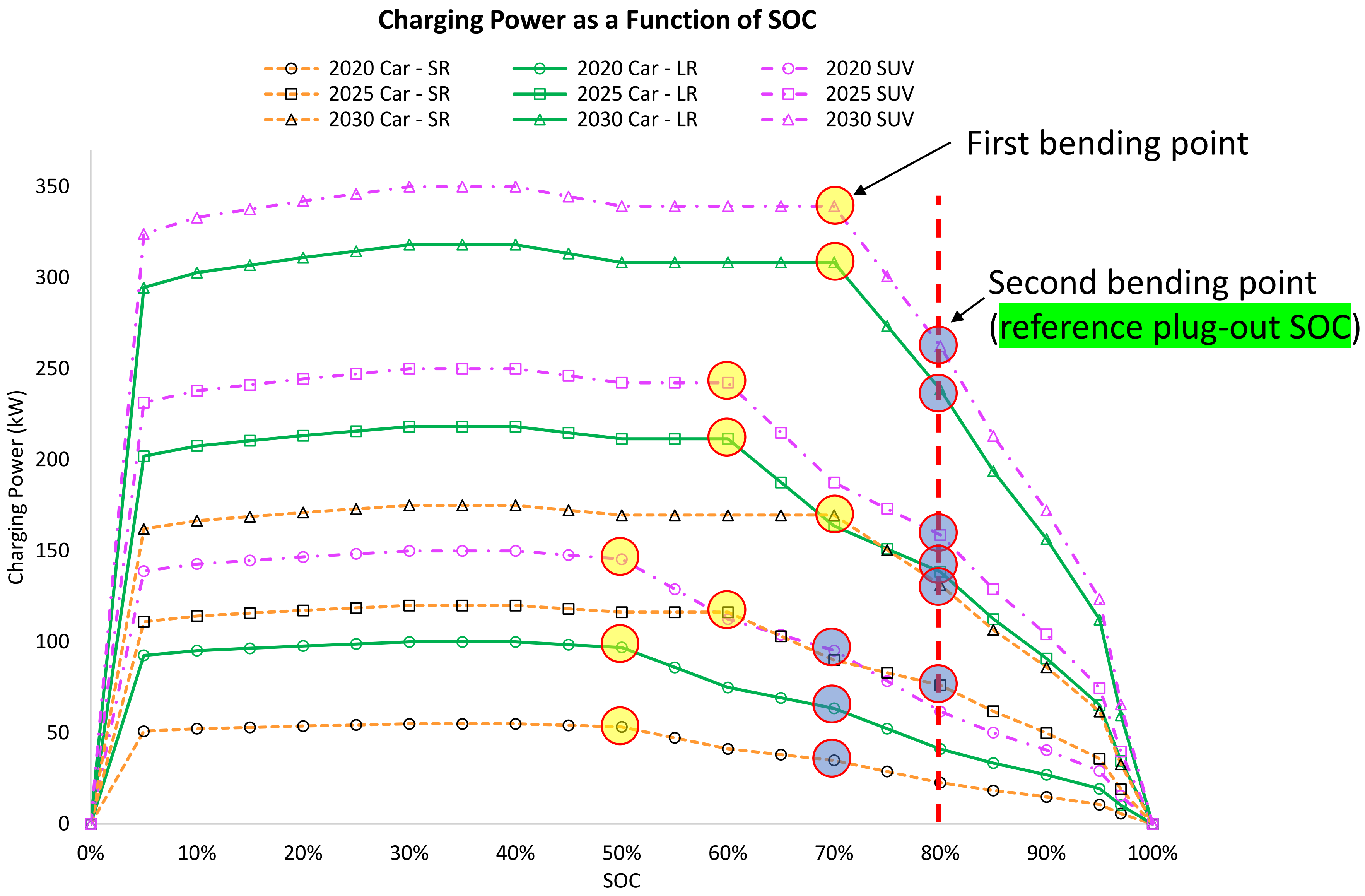




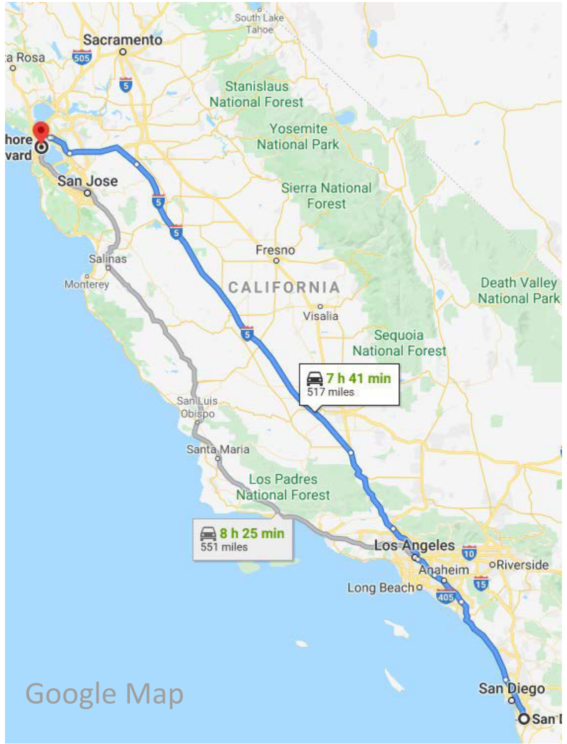
Plug-In and Plug-Out SOC (State-of-Charge)

Plug-in SOC



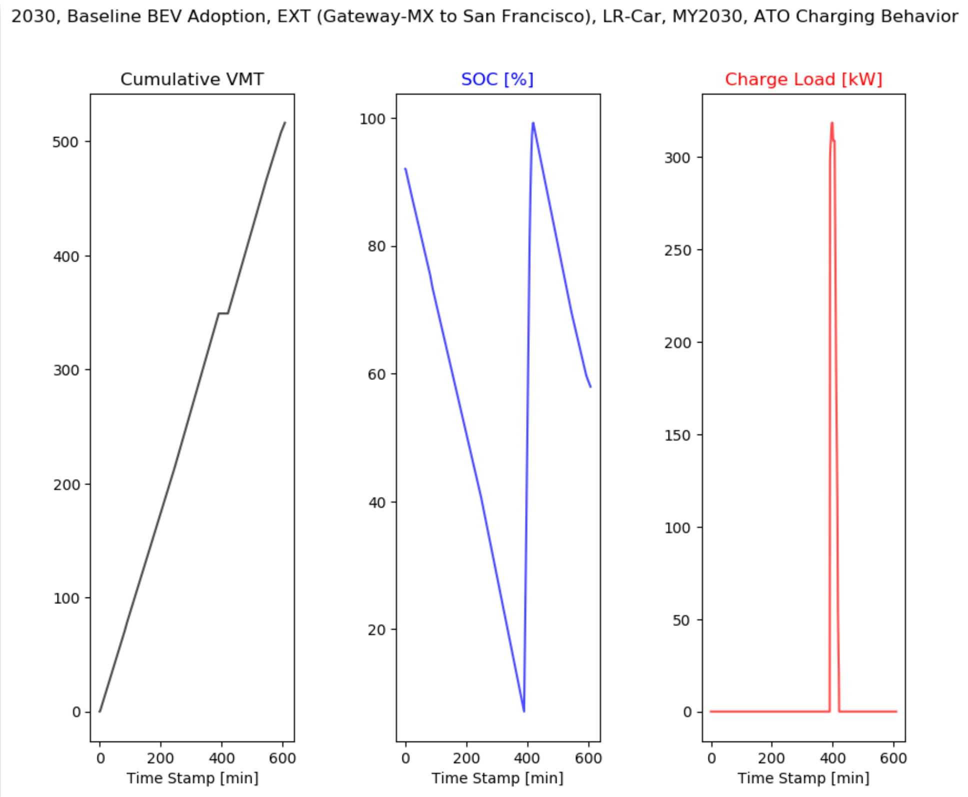


Example Energy and Charging Simulation: External Trip

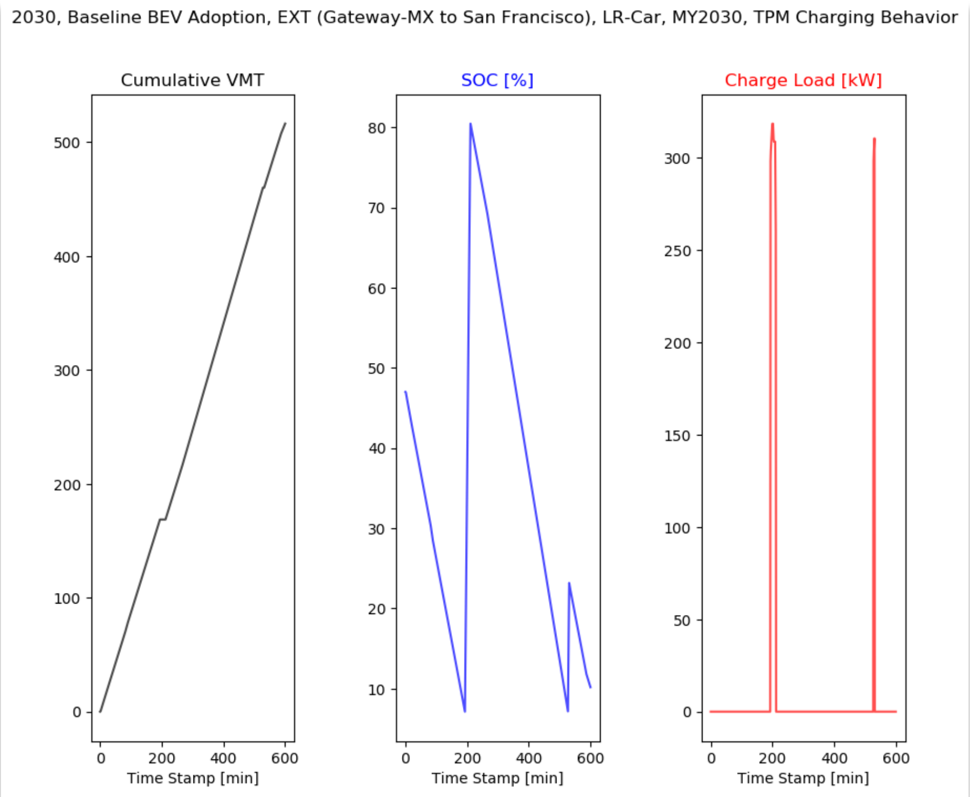


- Trip ID: 38212
- Traveling from the southern border to SF
- Approximately 520 miles
- Average MPH: 52 (excluding charging)
- Simulation year: 2030
- Vehicle: LR-Car
- MY: 2030

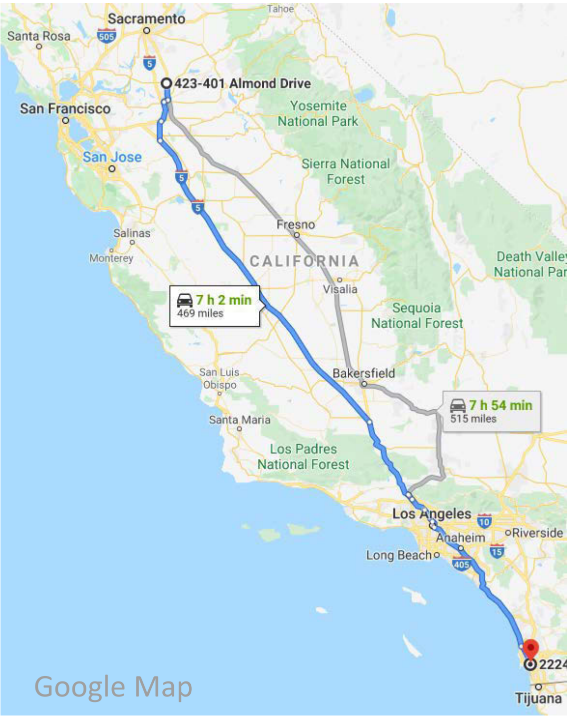
ATO (always top off);
1 rounds of charging for 30 minutes



TPM (time penalty minimization);
2 rounds of charging for 22 minutes

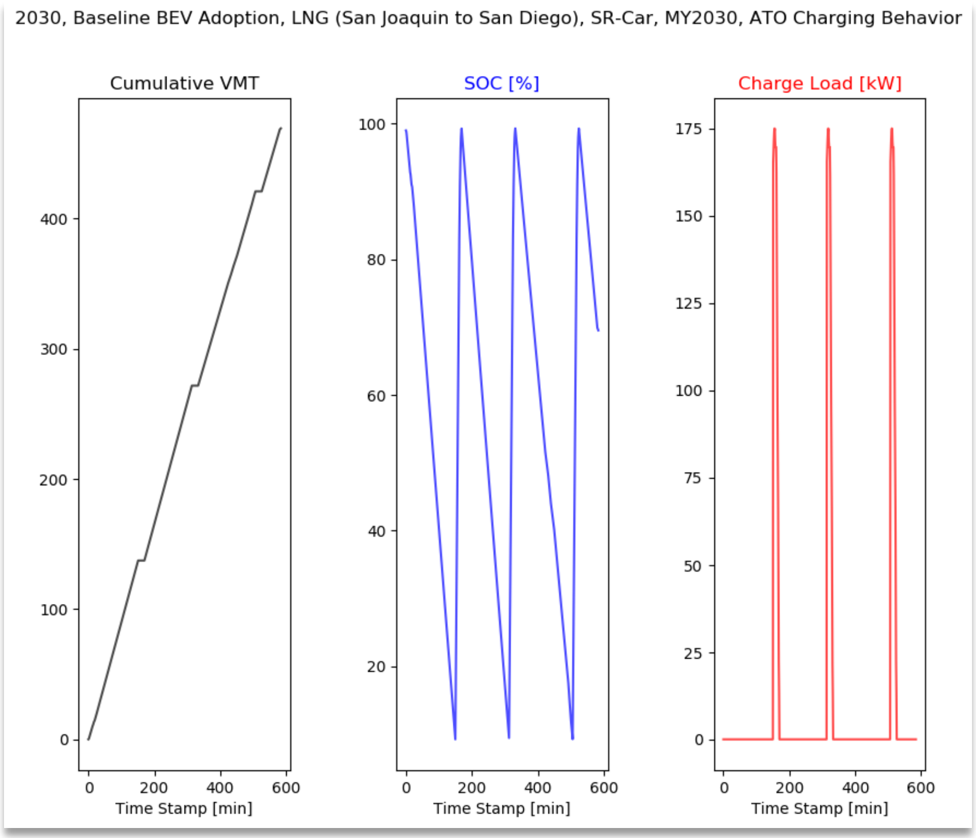


Example Energy and Charging Simulation: Intra-State Trip

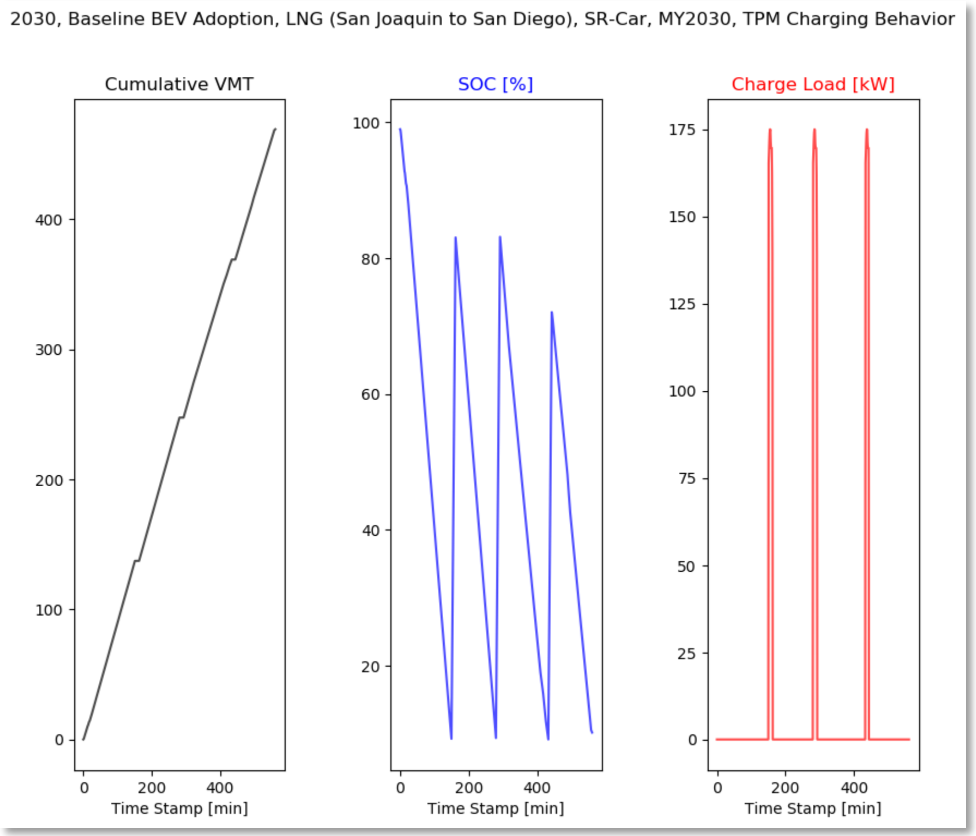


- Trip ID: 7148
- Traveling from Joaquin to San Diego
- Approximately 470 miles
- Average MPH: 52 (excluding charging)
- Simulation year: 2030
- Vehicle: SR-Car
- MY: 2030

ATO (always top off);
3 rounds of charging for 57 minutes



TPM (time penalty minimization);
3 rounds of charging for 34 minutes



Prioritized Preferred Sites for DCFC Stations

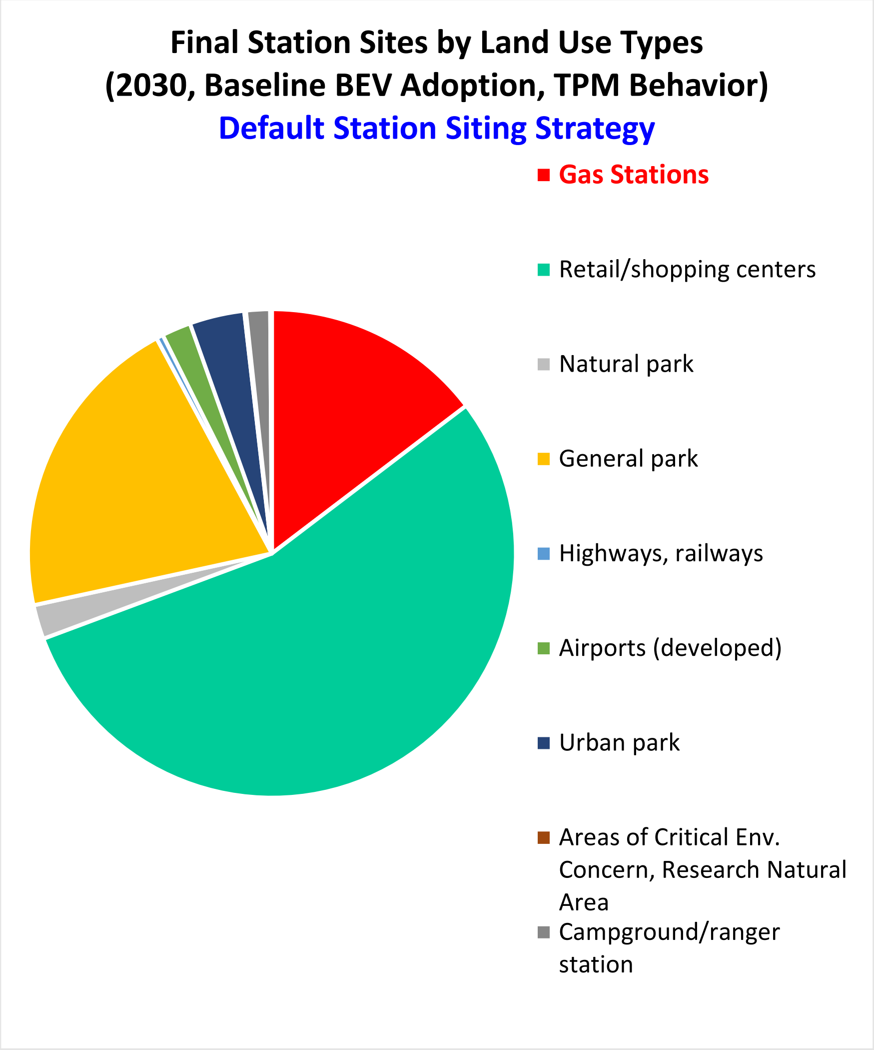
Priority Group	Land Use Type
1	Retail/shopping
	Gas stations
	Lodge
2	Airports
	Port, train station
3	Urban park
	General Park
	Natural park
	Off-highway vehicle staging area/trailhead
	Motorized park
	Entertainment (stadiums)
	Designated recreation area
	Campground/ranger station
	Marina
	Resort/ski area
	Picnic/trailhead

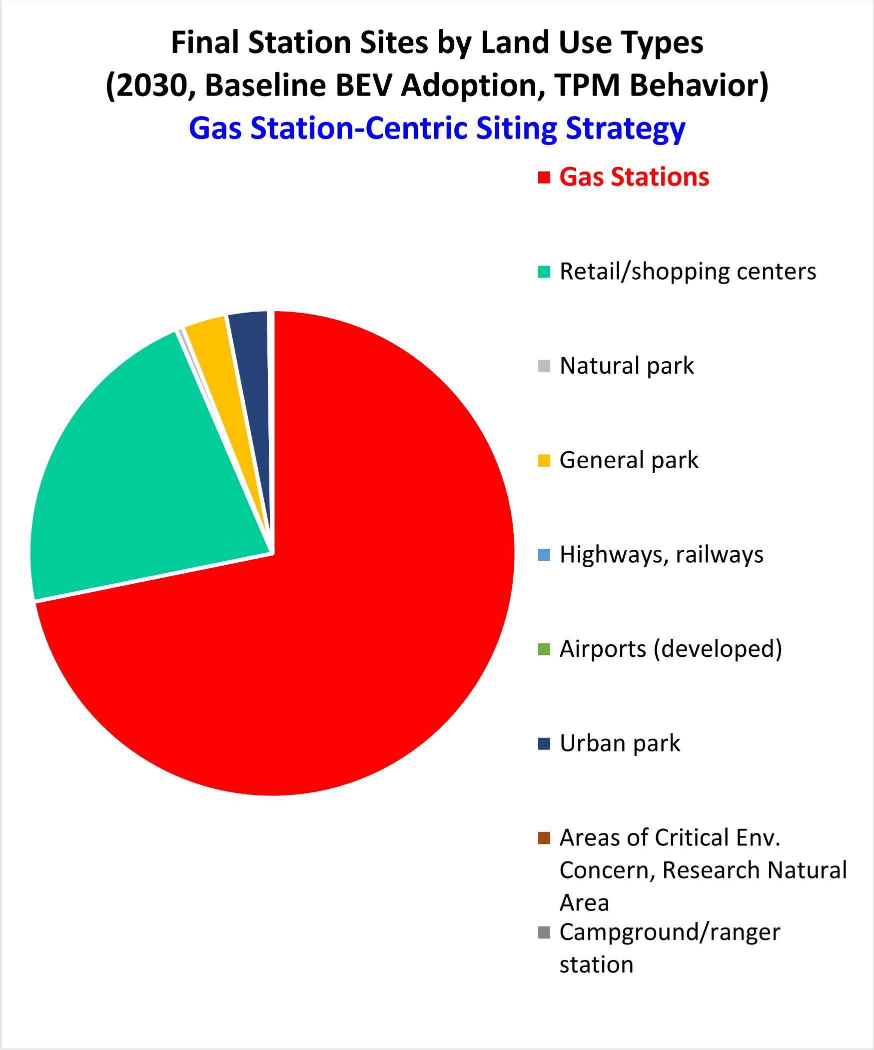
Sensitivity Analysis Cases

- BEV type share (e.g., SUV-dominant).
- Battery size.
- Energy consumption rate (kWh/mile).
- Plug-in SOC (related to the radius of station service area or coverage).
- Plug-out SOC.
- kW-SOC curves.
- Ambient temperature and corresponding accessory load (e.g., heating).
- Potential sites for DCFC stations (e.g., gas station-centric).
- Station sizing – peak-hour plug utilization rate (e.g., 100% vs. 25%).

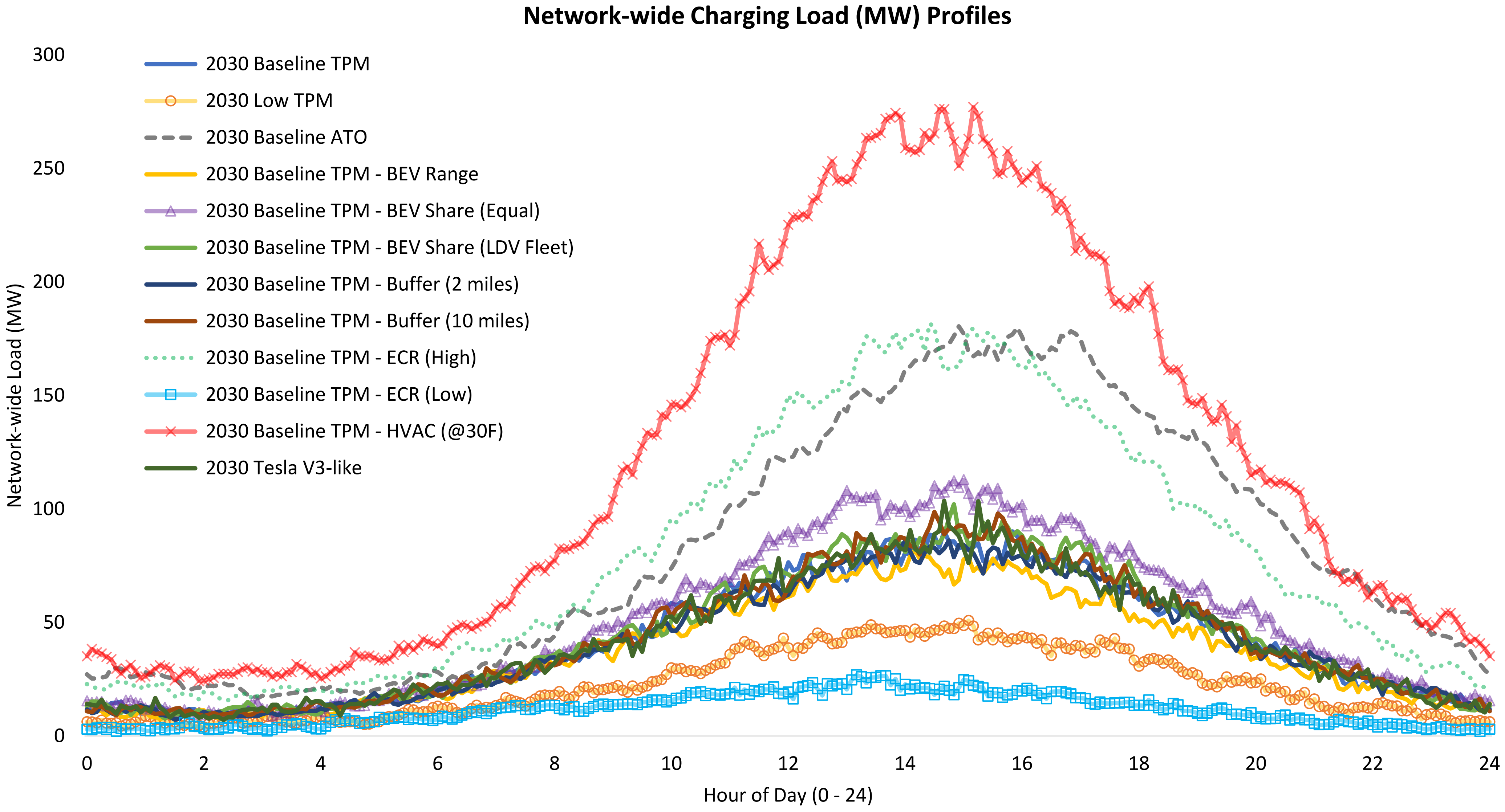
(What-If) Alternative Station Siting Strategy: Gas Station-Centric

- Existing gas stations can absorb/host around 70% of DCFC stations needed.
- Forcing gas stations for potential sites transforms the overall structure as well
  - for example, see how the share of retail/shopping centers changes.



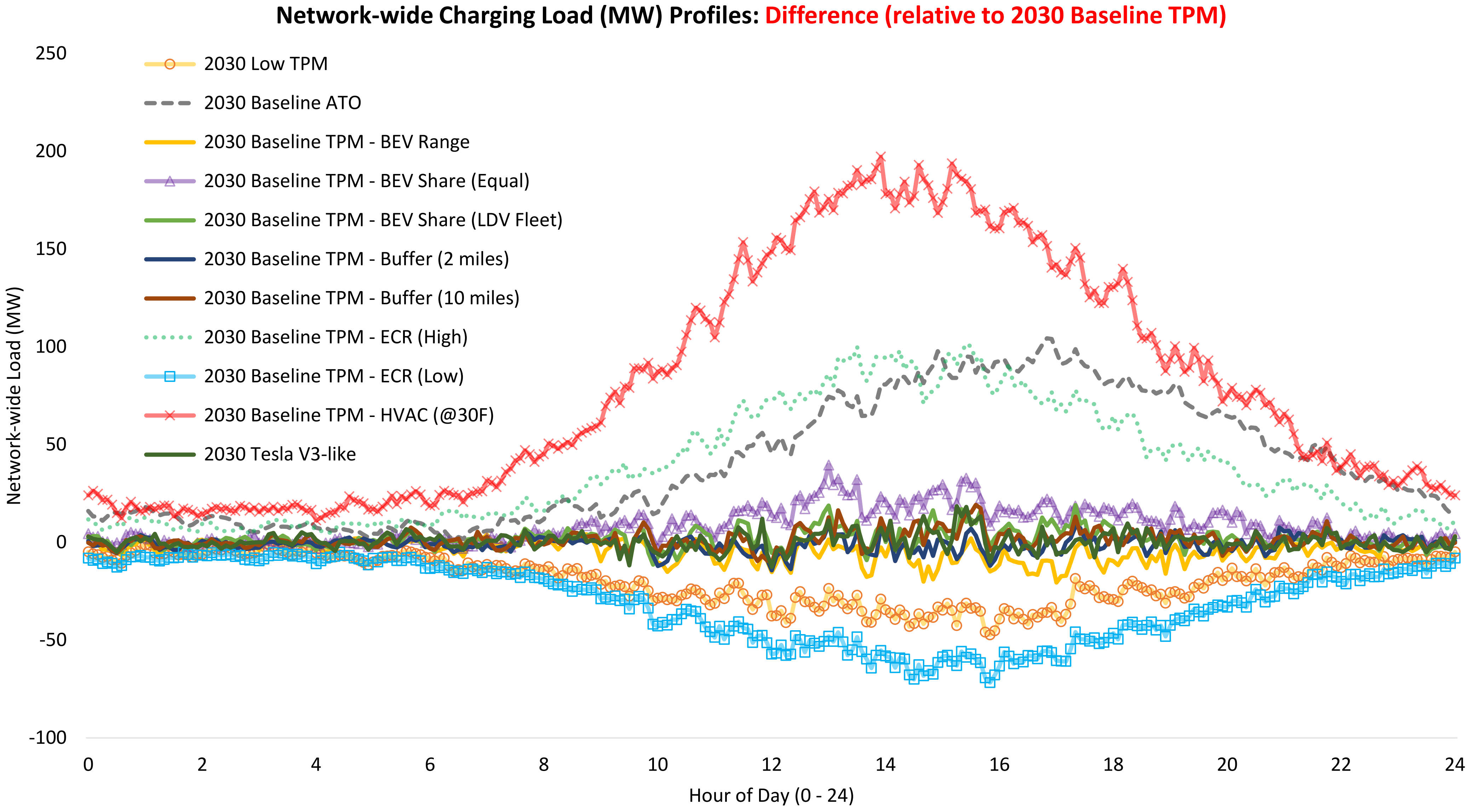


Network-Wide Load Profiles (for Electrified Road Trips)



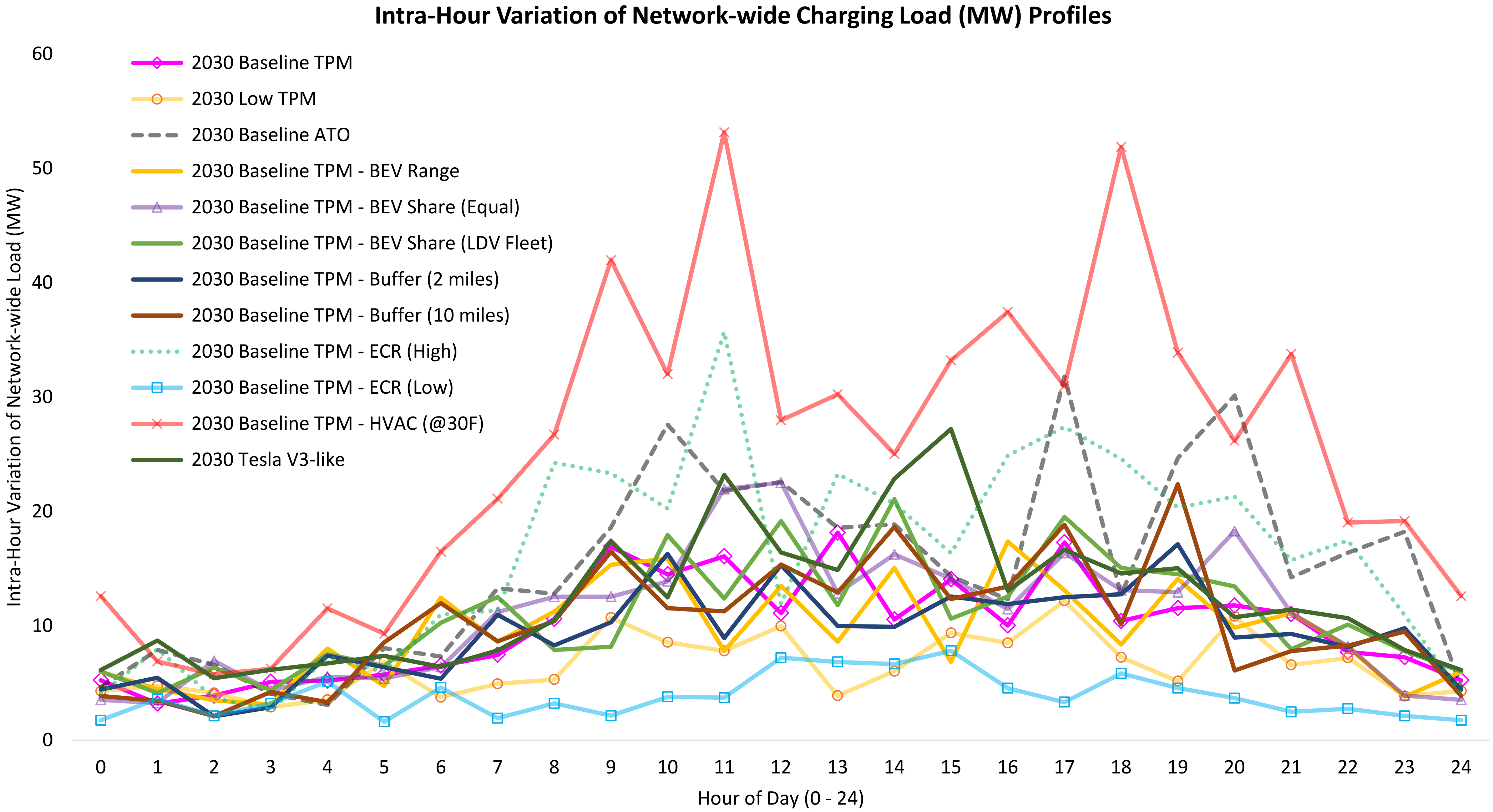
Preliminary results. Subject to review/change.

Load Profiles: Difference relative to 2030 Baseline TPM



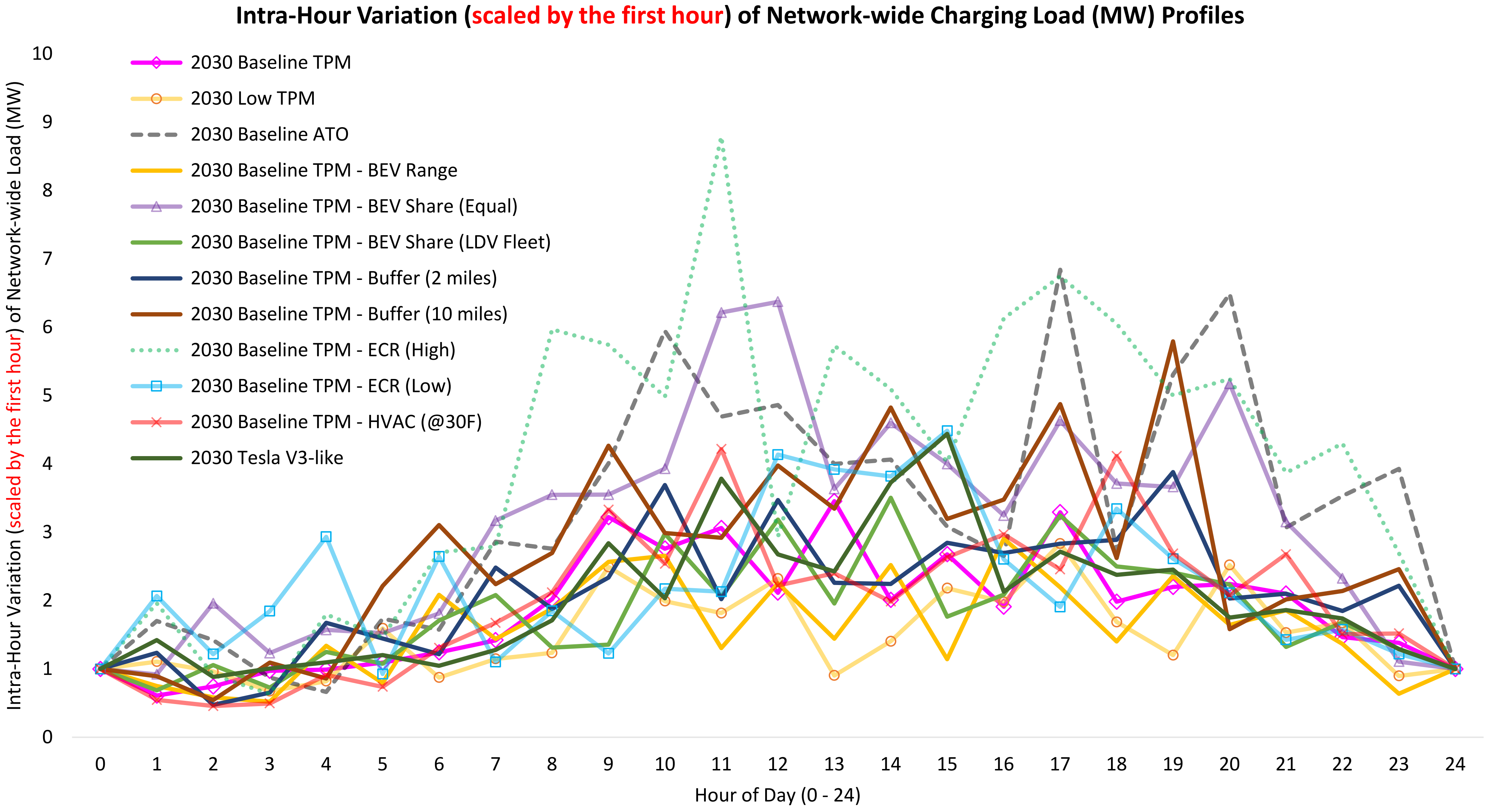
Preliminary results. Subject to review/change.

Load Profiles: Intra-Hour Variation



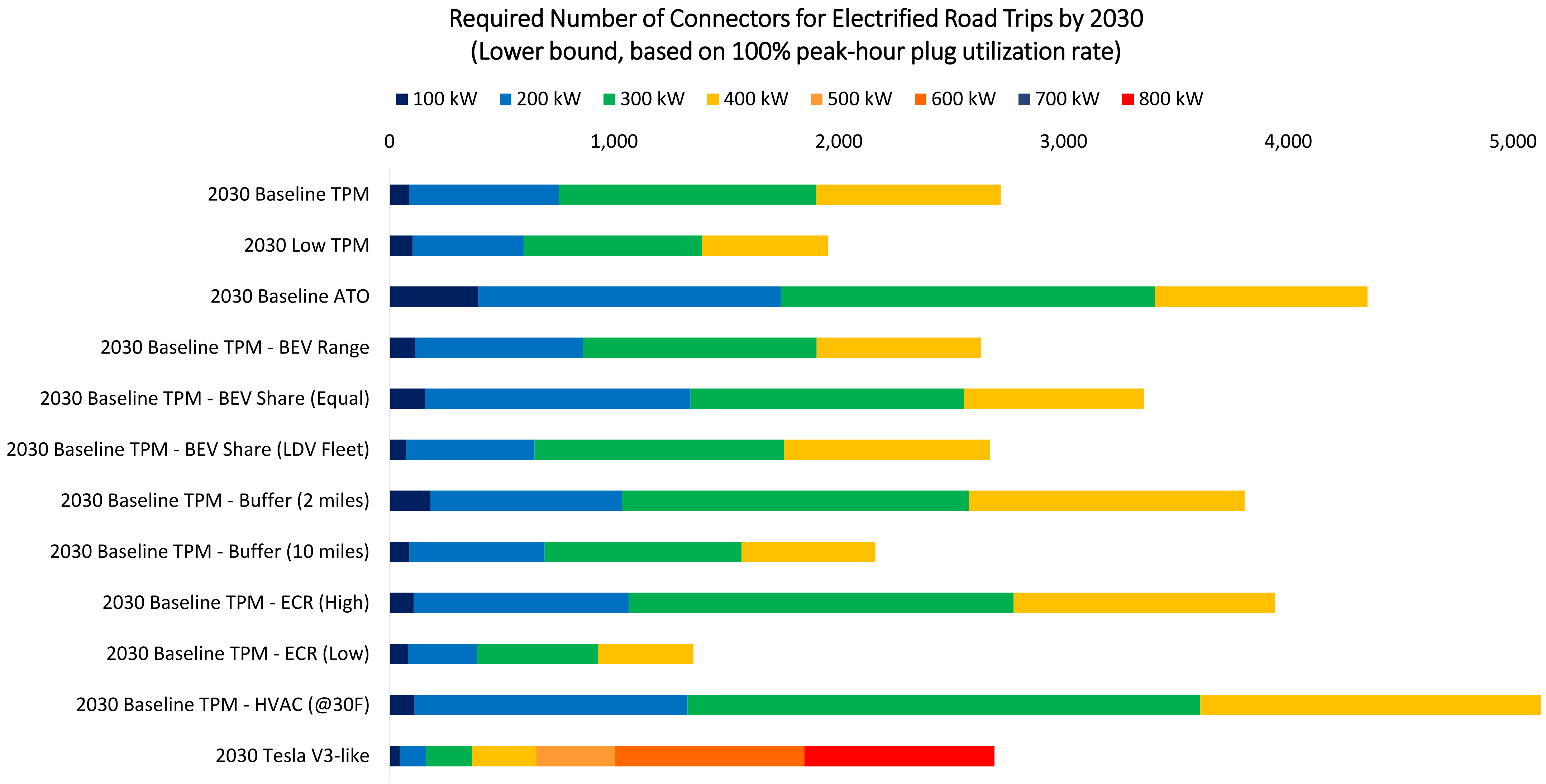
Preliminary results. Subject to review/change.

Load Profiles: Intra-Hour Variation (scaled by the first hour)



Preliminary results. Subject to review/change.

Required Number of Connectors



Preliminary results. Subject to review/change.