Using Sensor Fusion to Put Vacant Buildings to Sleep

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Sponsor: UC Office of the President Carbon Neutrality Initiative Applied Research Working Group // Collaborators: Josh Morejohn

On the UC Davis campus up to 50% of a building's energy consumption occurs while it is completely vacant. For example, the off-hours electricity use for Wickson Hall is nearly equal to its use during operational hours (Fig. 1). Though newer versions of HVAC and lighting systems incorporate occupancy-detecting methods such as motion and CO2 sensing, they do not address the remaining plug load usage.

Goal

This project addresses off-hours energy consumption by providing a building-wide signal of "true vacancy" using existing sensor inputs.

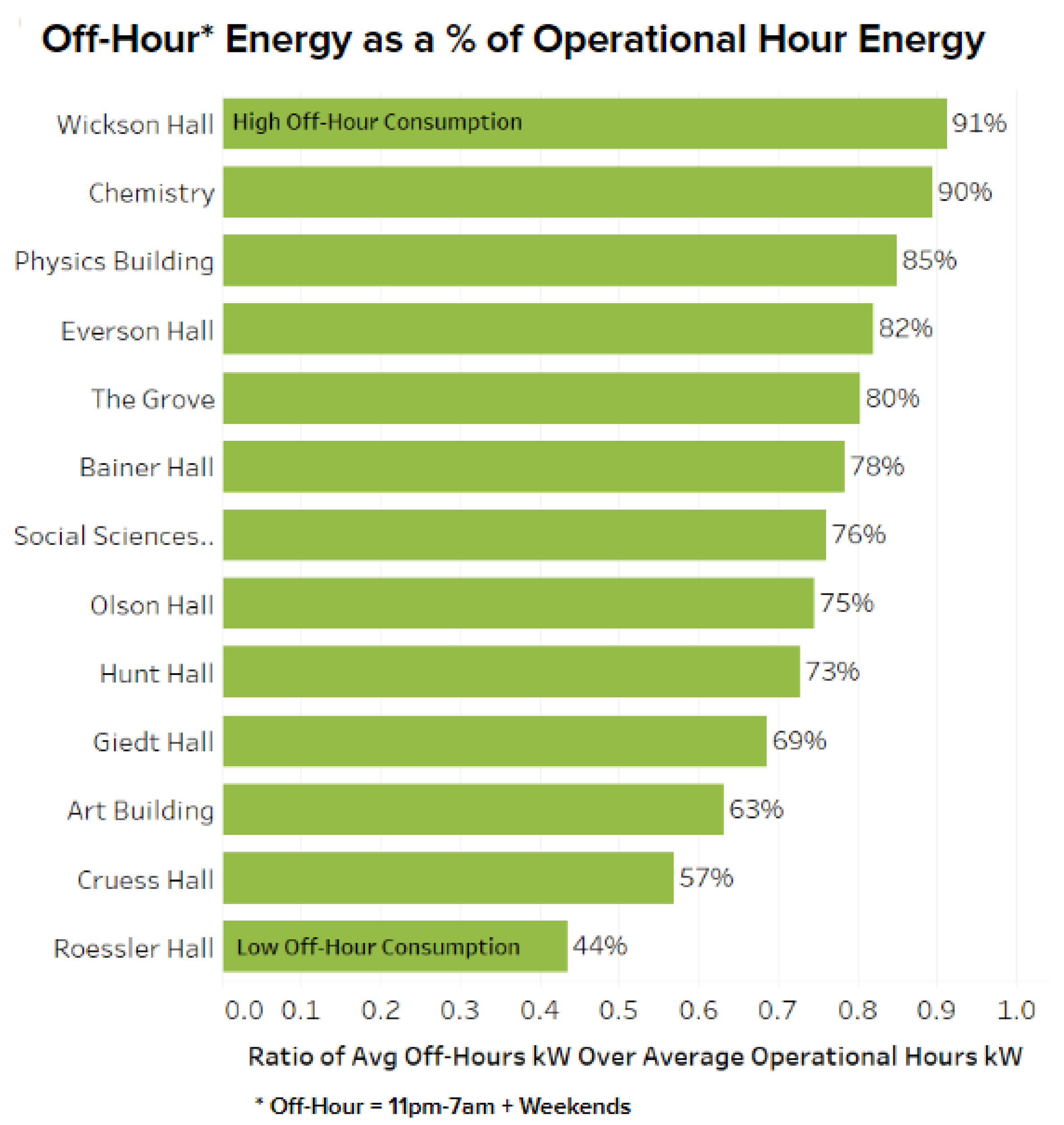


Figure 1. Off-hours usage as a percent of occupied hours usage for some UC Davis buildings. Wickson Hall does very poorly at reducing its consumption when vacant.

Progress/Results

We developed methods to program the Vacancy Inference Engine (VIE). *See system description*

- For each data stream, we constructed the cumulative probability distribution for the vacant case using a **sigmoid curve** to fit the data (Fig. 2). When applied to real-time data the sigmoid did well for single-mode data, but not for dual-mode data as in the case of CO2.
- We attempted to **fuse the resulting probabilities** into a single overall probability of vacancy. The **most promising method is RMS** as it is bounded between 1 and 0 but also provides a high probability compared to the simple average (Fig. 3).

Path Forward

We are currently investigating additional methods of fusion, including multi-sensor Bayesian inference.

Once complete, we will evaluate the accuracy of VIE inferences through construction of a confusion matrix. To do this, ground truth data is being obtained from security camera footage for a test building on campus.

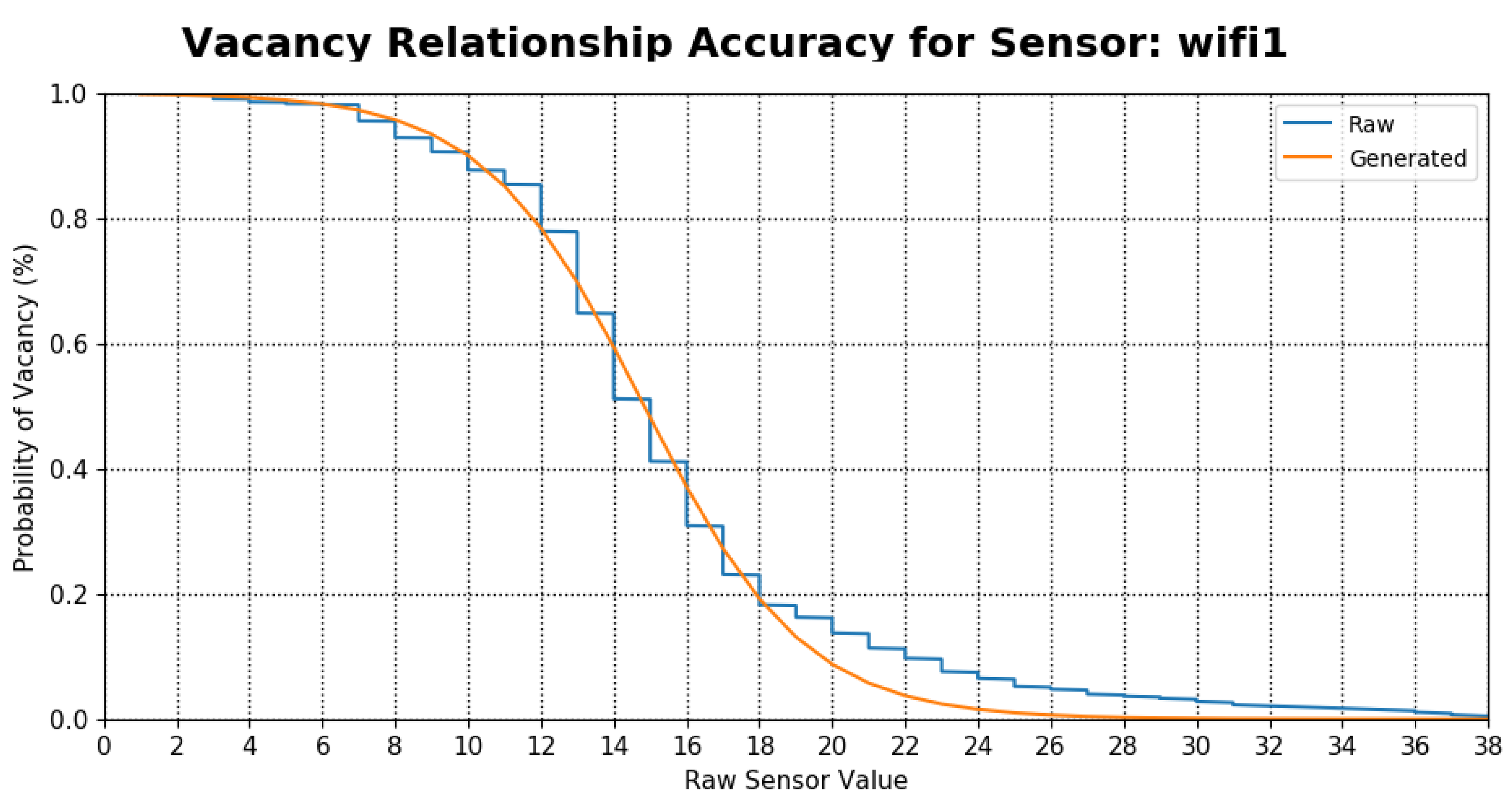
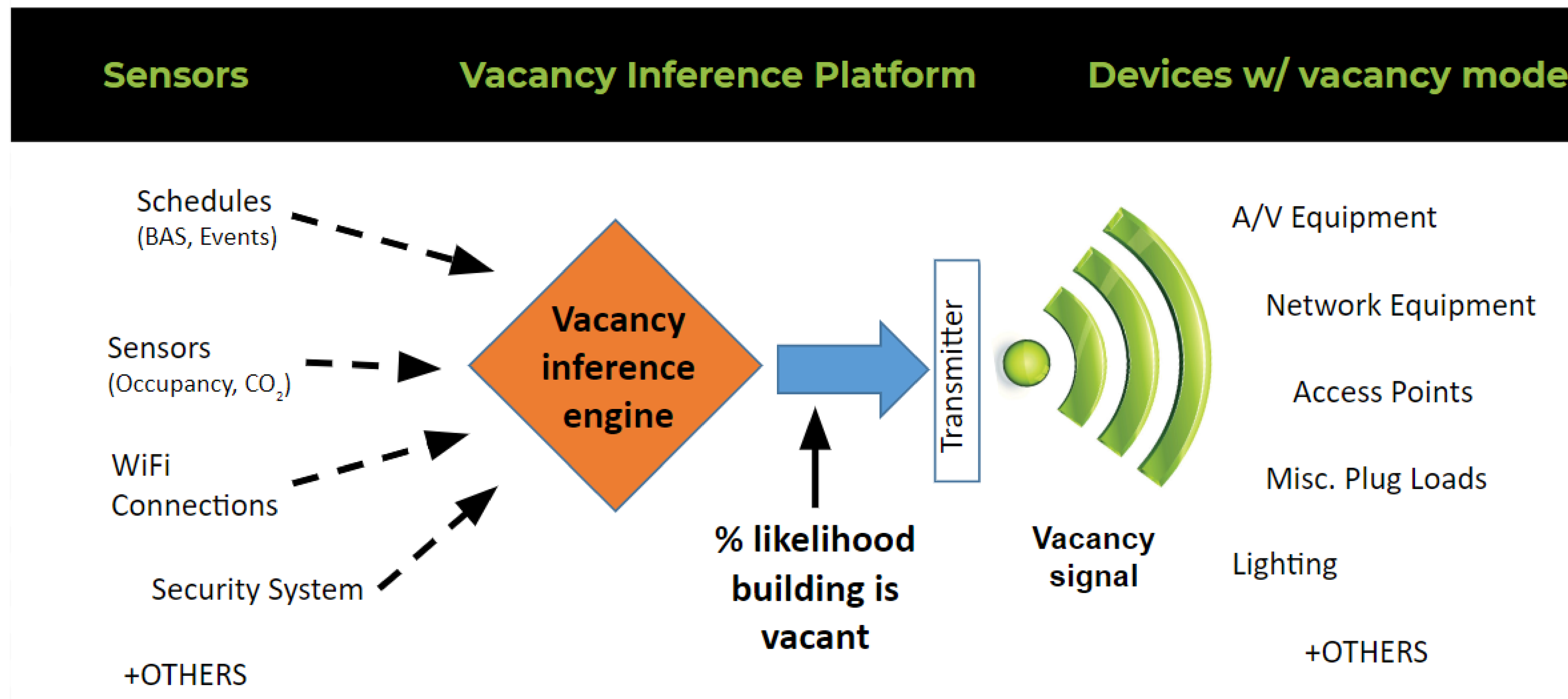


Figure 2. Raw vs. fitted cumulative probability distribution for # of active WiFi connections during vacancy periods in a UC Davis building. 1 = vacant, 0 = occupied. This is used to generate the vacancy of probability for this input.

System Description



"UC Davis buildings use up to half of their electricity while they are vacant."

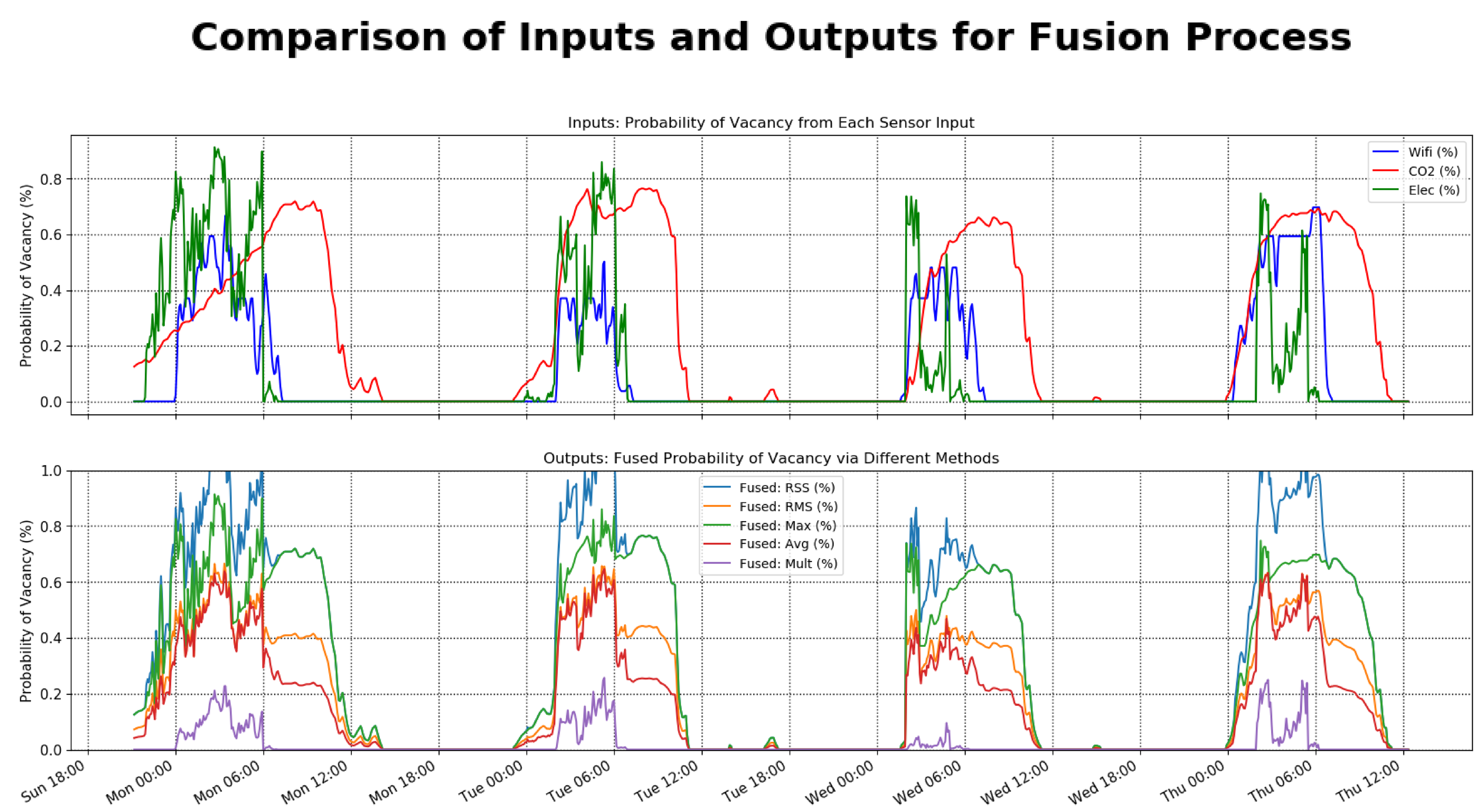


Figure 3. Performance of various data fusion techniques. RSS=root sum square, RMS=root mean square, Max=maximum, Avg=average, Mult=multiplication. All fall short of required criterion, though RMS is the best method identified so far.

UCDAVIS
Energy and Efficiency Institute

UC Davis Office of Naval Research Collaboration

UC Davis was selected as one of six universities to receive multi-million dollar funding from the **U.S. Office of Naval Research** to conduct energy research and train military personnel as part of the Navy Enterprise Partnership Teaming with Universities for National Excellence **(NEPTUNE)** program.

Purpose

NEPTUNE aims to help the Navy and Marine Corps discover ways to improve energy conservation, generate renewable energy, and implement energy-efficient technologies, while giving active duty military, military students, and veterans the chance to immerse themselves in university-level research.

Sponsors

U.S. Office of Naval Research

Projects

As part of the NEPTUNE program, UC Davis is undertaking **8 energy-related research projects.** Each project will help the Navy reach its energy goals and will employ and train undergraduate and graduate level military-affiliated students; including veterans, active duty, reservists, ROTC, and military dependents.

- **Studies of Electron Transfer in Mixed-Valent Systems to Improve Design of Non-Aqueous Redox Flow Batteries**
  (PI: Louise Berben)
- **Smart Energy Management for Unmanned Aerial System Operation in Complex Military Missions**
  (PIs: Xinfan Lin and Zhaodan Kong)
- **Scaling a Building Energy Audit Tool**
  (PI: Josh Morejohn)
- **Adaptive Sensor-Based Lighting for Security Applications**
  (PI: Michael Siminovitch)
- **Microchannel Heat Exchanger Designs for Power Generation and Cooling**
  (PI: Vinod Narayanan)
- **Modular Solar-Battery Microgrid Utilizing 2nd Life Electric Vehicle Batteries with Advanced Energy Management Control**
  (PI: JaeWan Park)
- **Non-tactical Transportation Energy in the Marine Corps**
  (PI: Gil Tal)
- **Fuel Integrated Energy Recuperative Aero-Derivative Gas Turbines**
  (PI: Paul Erickson)

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Life Cycle Environmental Impacts of Light Duty Electric Vehicles

UC DAVIS SUSTAINABLE TRANSPORTATION ENERGY PATHWAYS
An Institute of Transportation Studies Program

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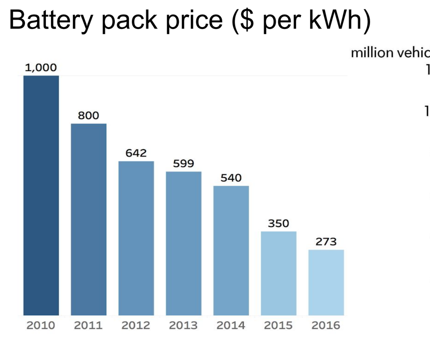
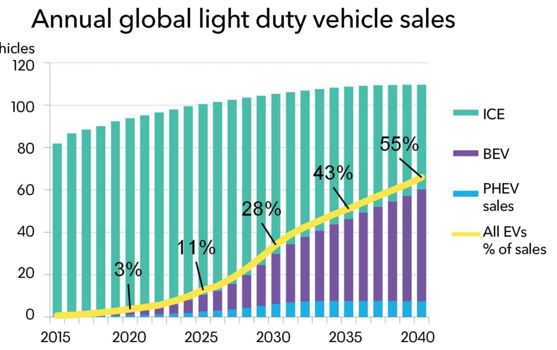
UC DAVIS UNIVERSITY OF CALIFORNIA

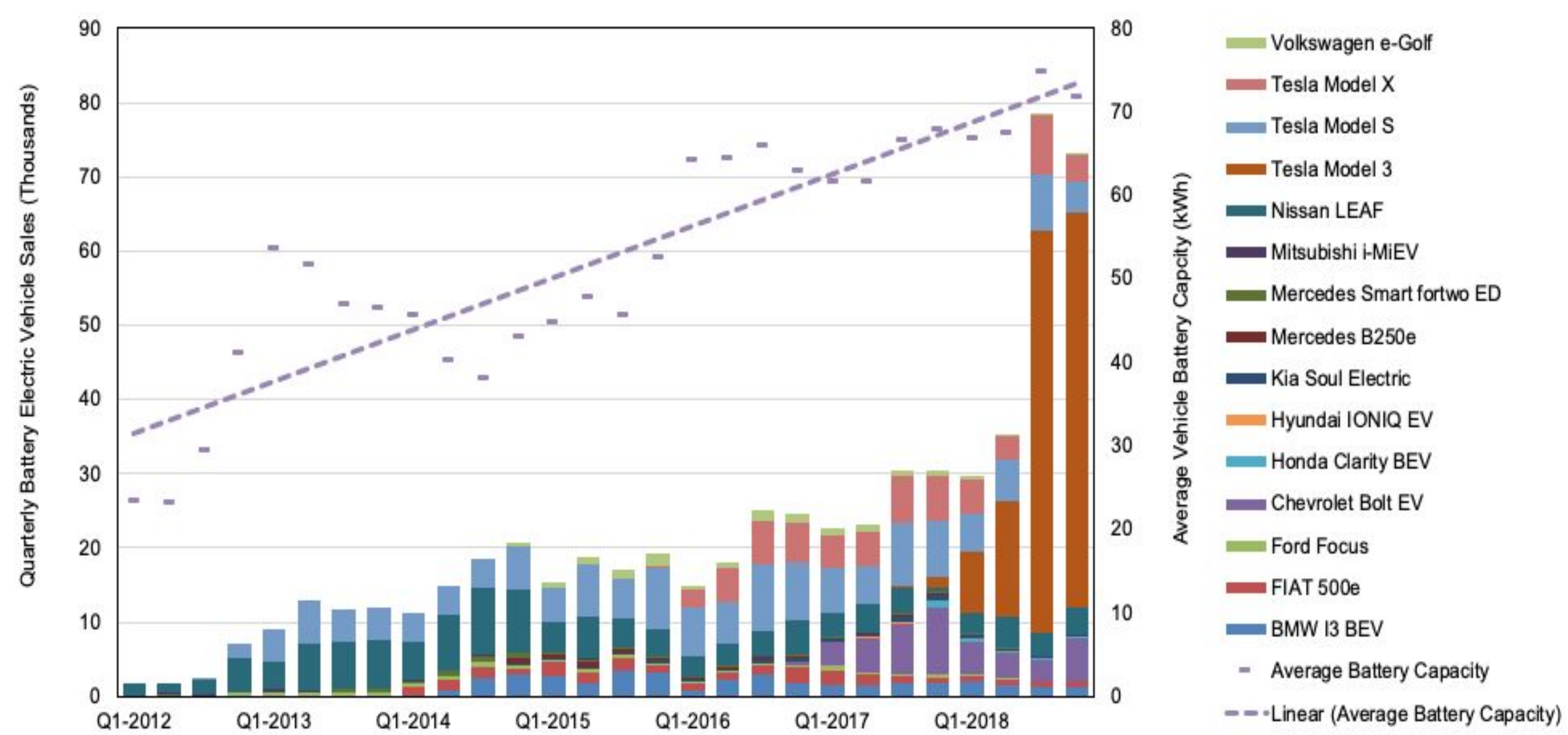
Research Motivation

(1) How do current trends in BEV vehicle design, including increased battery capacity and high performance and luxury vehicles, affect life cycle GHG intensity of vehicle?
(2) What is the combined effect of vehicle design trends and technology and electricity grid evolution on the life cycle GHG emissions intensity of BEVs?
(3) How will these trends affect future emissions rates of BEVs, particularly in high-mileage applications like shared ride fleets?





Source: BNEF EV Outlook 2018 (Global)



Methodology and Data

Goal: Evaluate three vehicle models for their environmental impact

Scope: Production phase and Use phase (electricity consumption)

Life Cycle Inventory: Vehicle teardown data, GREET model, Data on Vehicles, Battery model

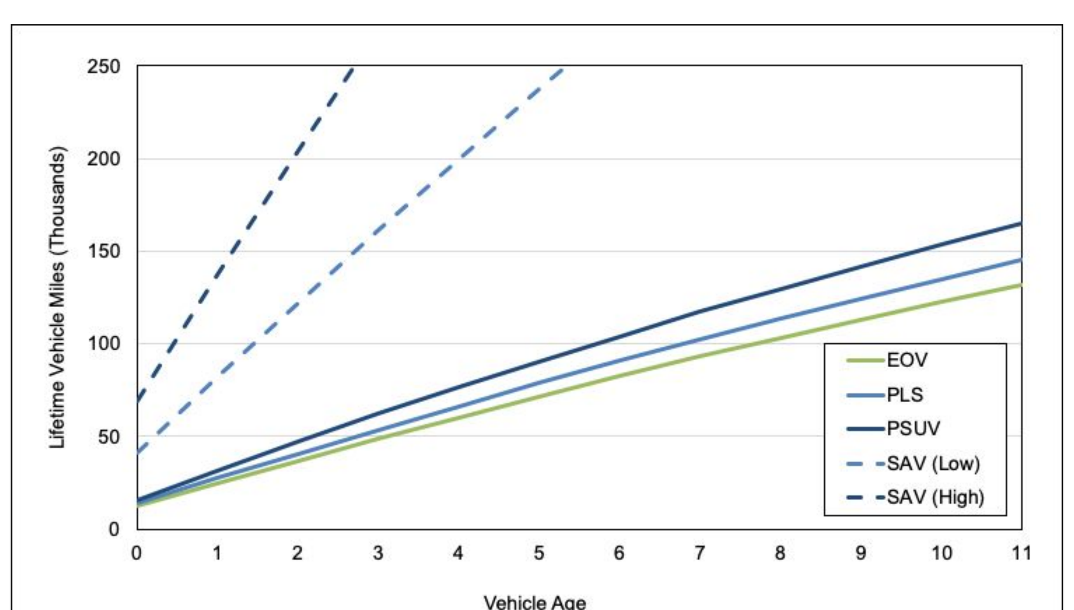
Modeling Approach

1. **Glider (Balance of Vehicle System)**
   – Objective: To estimate BOM and mass of materials
   – Method: Combining aggregated and breakdown (component-level) data
   – Data: Vehicle teardown reports, GaBi datasets, Other models (GREET, UCSB Automotive model)
2. **Battery system**
   – Objective: To estimate BOM and mass of materials for a given battery performance characteristics
   – Method:
   - 4 scenarios: NCA-G, NMC-G, LFP-G, LMO-G
   - % Cell material composition was estimated using BatPac model (ANL) which is scaled with the system
3. **Electricity (use-phase)**
   – Objective: To estimate the Electricity consumption for vehicle operation
   – Method: FASTSim model by NREL is used to find electricity consumption based on given vehicle characteristics and travel behavior
   – Data: eVMT project data from PHEV to incorporate the naturalistic driving patterns in the FASTSim model

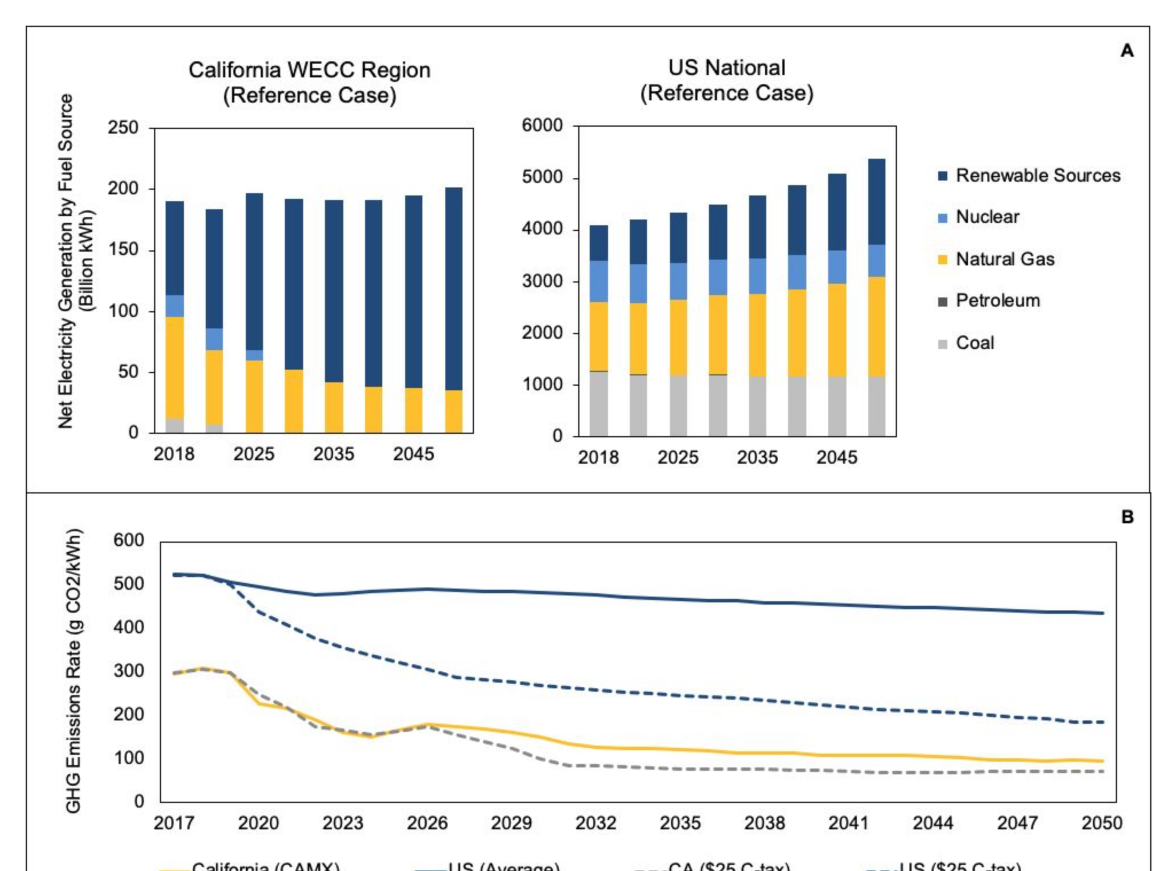
	Efficiency Oriented Vehicle	Performance Luxury Sedan	Performance Sports Utility Vehicle
Battery Size	50-100 kWh	75-150 kWh	75-200 kWh
Motor Size	150 kW	300 kW	600 kW
AE Range	150-300 miles	250-400 miles	200-400 miles
Price point	< $30,000	> $50,000	> $50,000
Curb Weight	1600 kg	2000 kg	2600 kg
Case Study Example	Chevrolet Bolt	Tesla Model S	Tesla Model X

- Based on the market trends, 3 vehicles categories stand out as important trends. Each category is assigned a representative vehicle model as shown in the table.

4. Sensitivity Analysis
– Objective: Estimate the response of per-mile carbon intensity to different scenarios
– Method:
- 4 grid mix scenarios: WECC and US national averages with and without a $25 carbon tax
- Different utilization rates as privately owned vehicles, and low and high shared automated vehicles

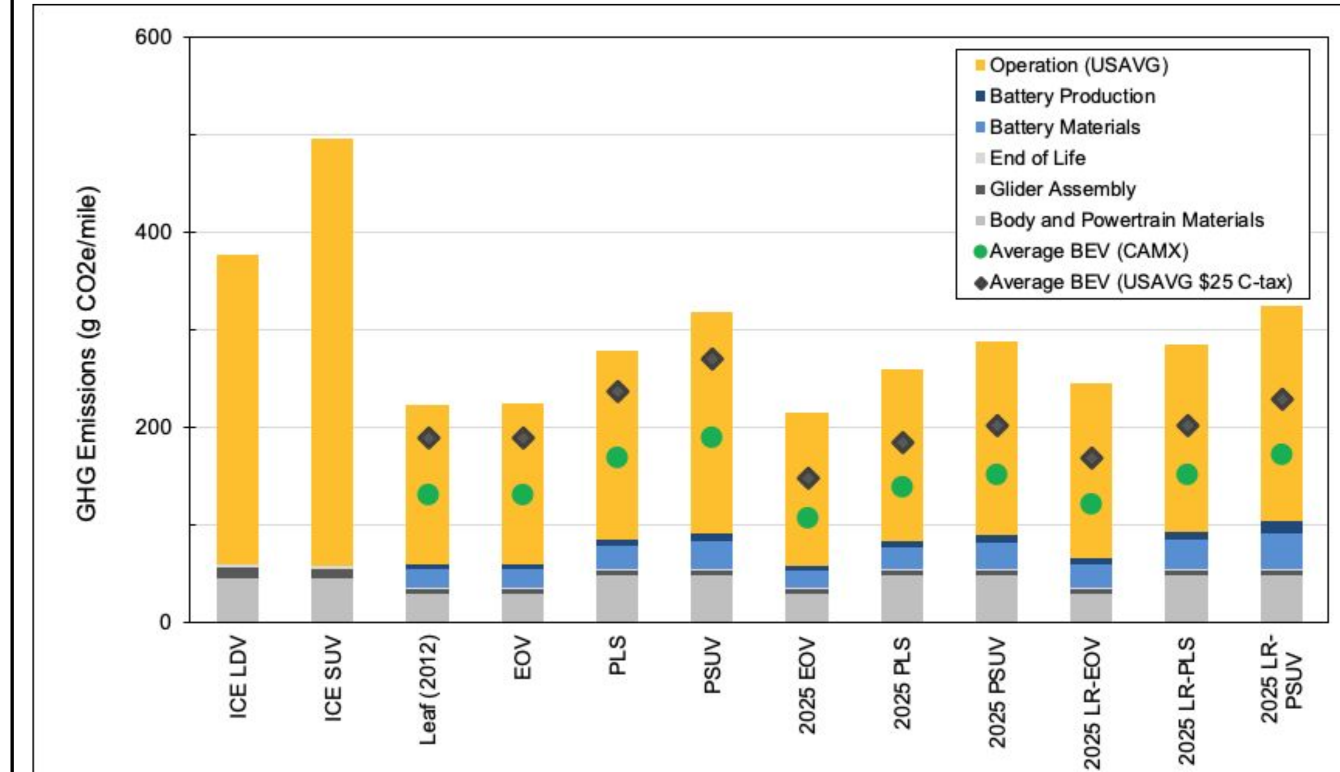


Annual Vehicle Miles Travelled by Scenario

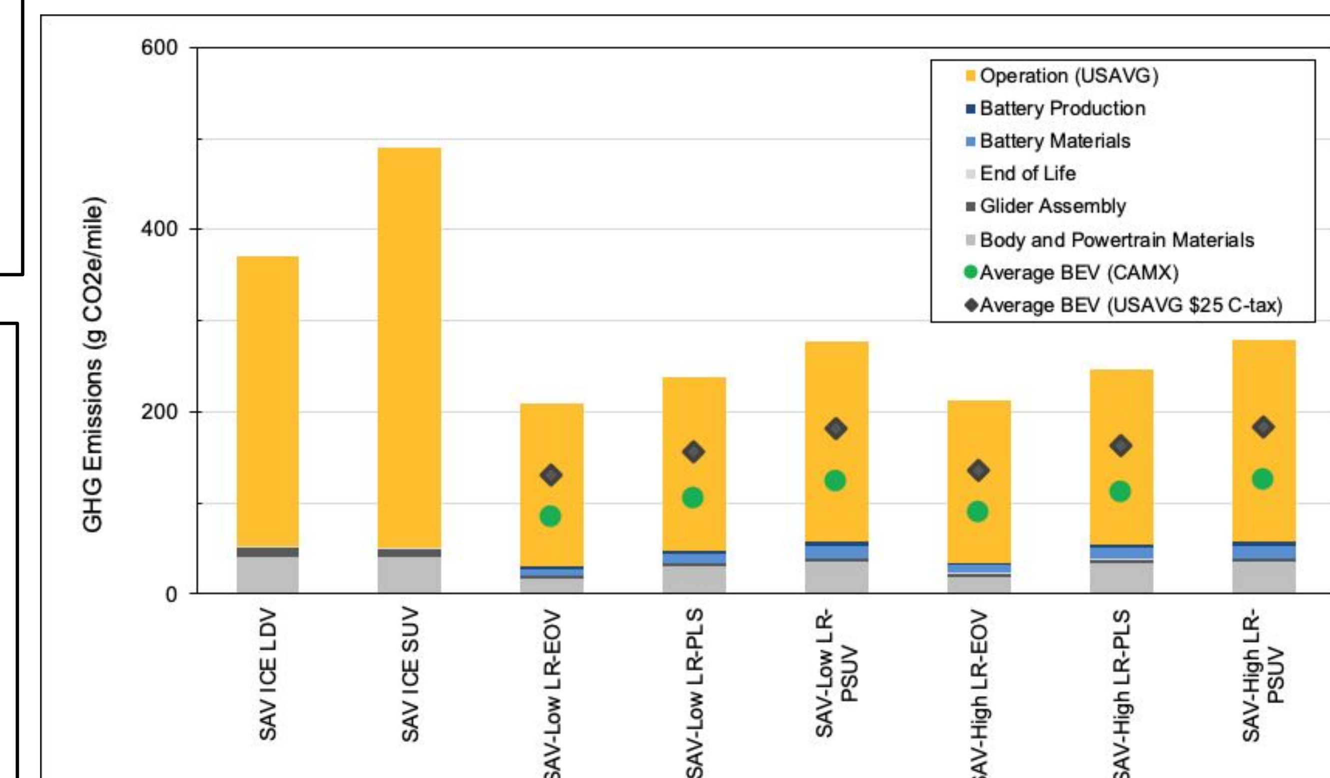


(A) Total Electricity Generation by Fuel Source and (B) Average GHG Emissions per kWh for Residential and Commercial End-Uses w/ and w/o a Carbon Tax, 2017 – 2050

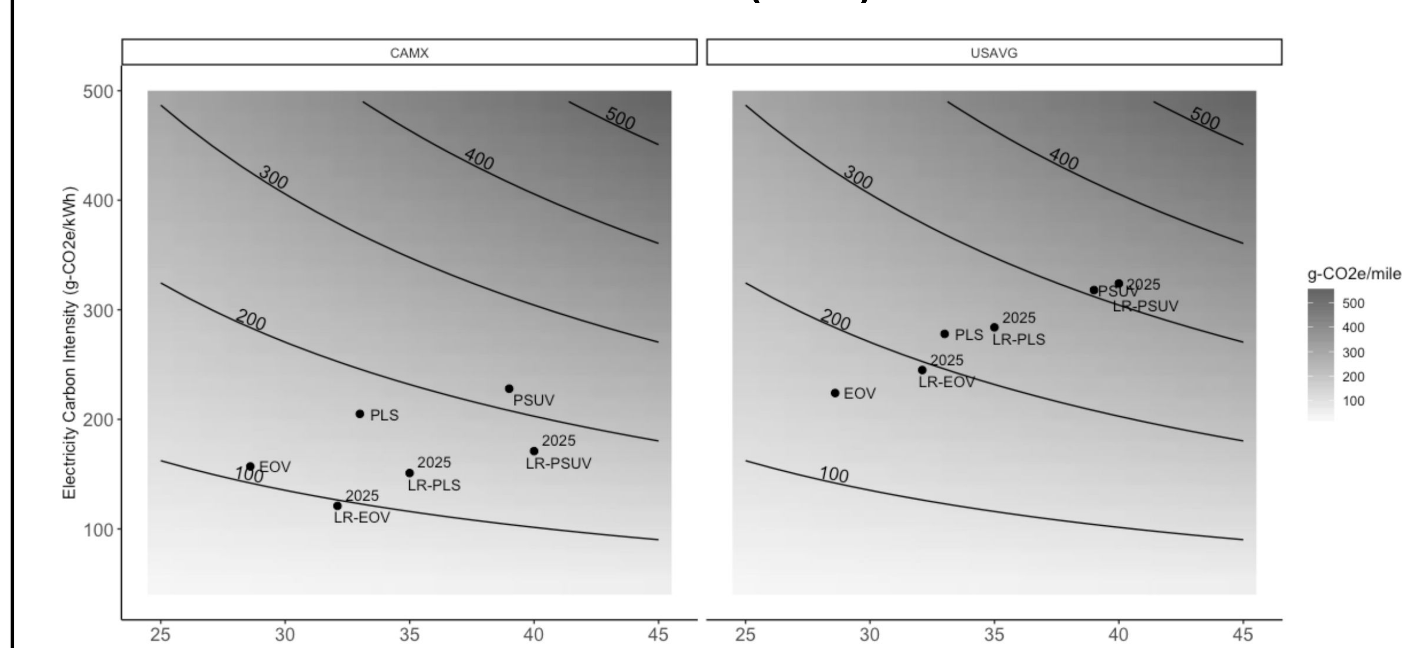
Results



Life Cycle GHG Emissions for ICEVs and BEVs under the Reference Grid Scenario



Life Cycle GHG Emissions for 2025 Private vs. 2025 Shared Automated Vehicle (SAV)



EV Life Cycle GHG Emissions per Mile with Sensitivity to Grid Emissions and Vehicle Efficiency

Next Steps

- Add a hybrid electric vehicle model for a more robust comparison.

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