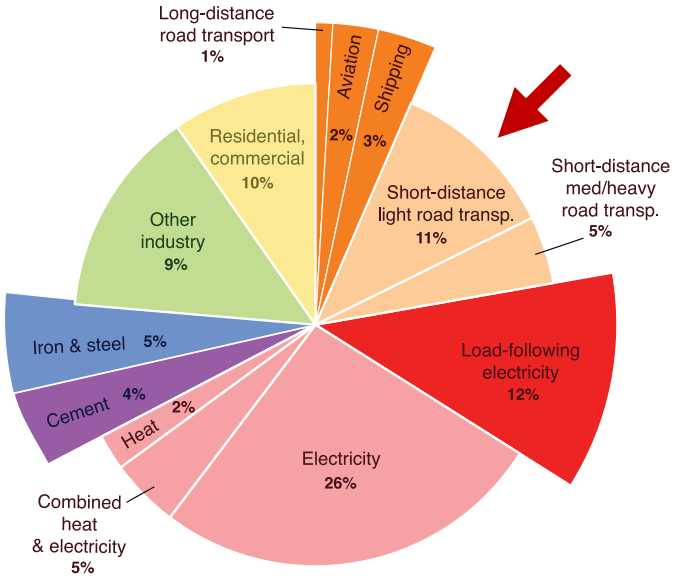
Vehicle to home charging cuts drivers' charging costs and greenhouse gas emissions in most of the US

Chen J, Anderson JE, De Kleine R, Kim HC, Keoleian G, Vaishnav P (2025) Vehicle-to-home charging can cut costs and greenhouse gas emissions across the USA. *Nature Energy*, 10(12):1458–1469. https://doi.org/10.1038/s41560-025-01894-7

Cars, homes: easy to decarbonize through electrification

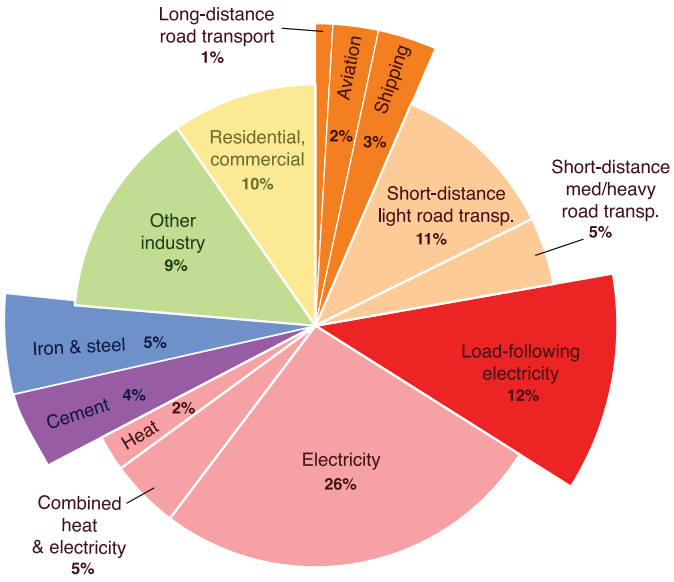
"Energy services such as light-duty transportation, heating, cooling, and lighting may be relatively straightforward to decarbonize by electrifying…"



A **Global fossil fuel & industry emissions, 2014 (33.9 Gt CO_2)**

Davis, S.J., Lewis, N.S., Shaner, M., Aggarwal, S., Arent, D., Azevedo, I.L., Benson, S.M., Bradley, T., Brouwer, J., Chiang, Y.-M., Clack, C.T.M., Cohen, A., Doig, S., Edmonds, J., Fennell, P., Field, C.B., Hannegan, B., Hodge, B.-M., Hoffert, M.I., Ingersoll, E., Jaramillo, P., Lackner, K.S., Mach, K.J., Mastrandrea, M., Ogden, J., Peterson, P.F., Sanchez, D.L., Sperling, D., Stagner, J., Trancik, J.E., Yang, C.-J., Caldeira, K., 2018. Net-zero emissions energy systems. *Science* 360, eaas9793. https://doi.org/10.1126/science.aas9793

Residential electric loads have limited flexibility. **Load-following electricity is hard to decarbonize.**



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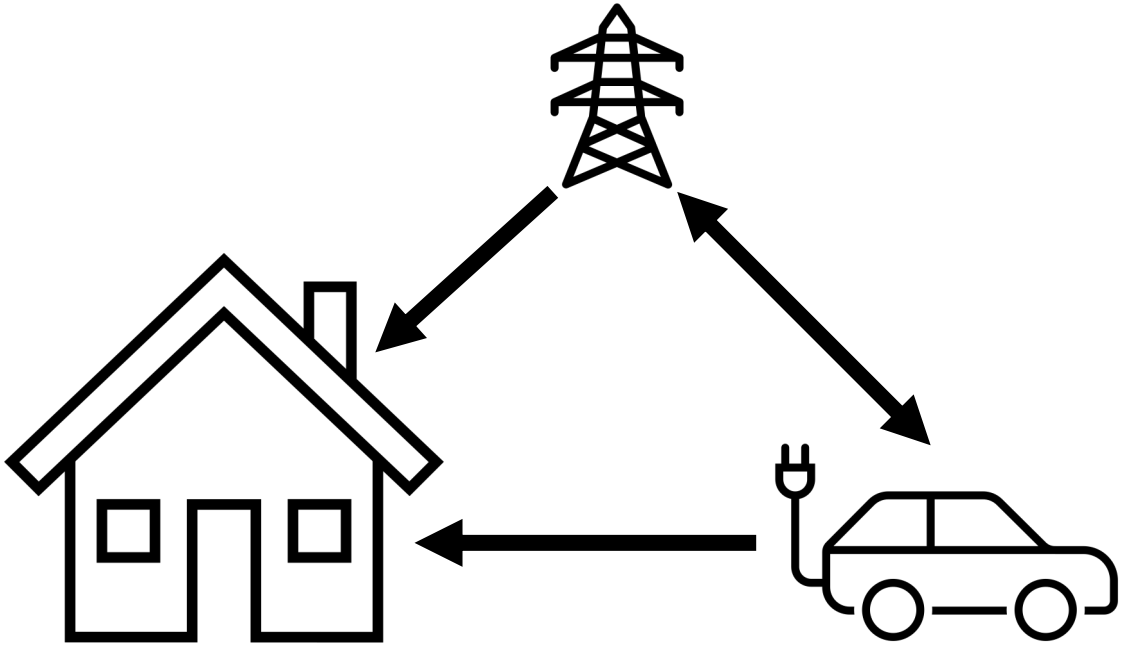
Residential electric loads have limited flexibility.

Load-following electricity is hard to decarbonize.

Can EVs help?

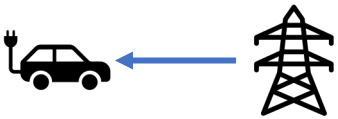


EVs can be a resource instead of burden

Uncontrolled charging

- 1-directional energy flow
- Timing often during evening peak (high costs, high greenhouse gas (GHG) emissions)

Controlled charging

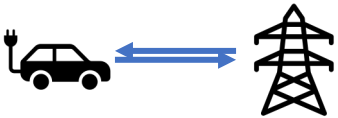


- 1-directional energy flow
- Shift charging to periods of lower cost

Vehicle-to-home (V2H)

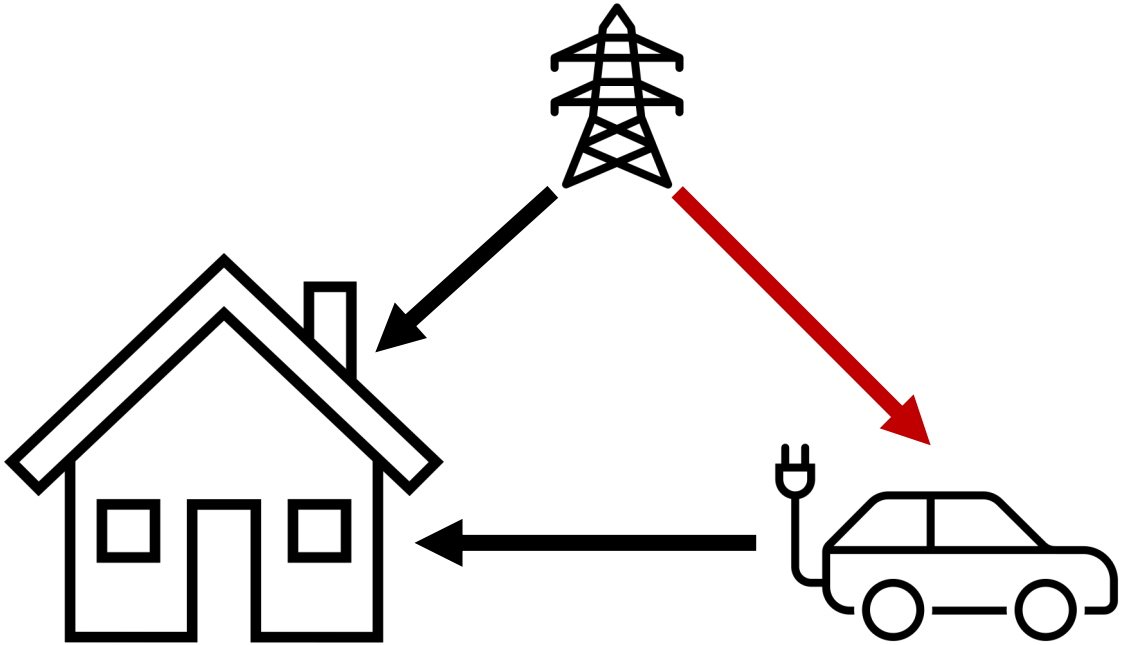
- 2-directional energy flow
- Energy not sold back to the grid
- Storage

Vehicle-to-grid (V2G)



- 2-directional energy flow
- Storage

Are there synergies between home and vehicle electrification?



If SOC <= 40%, charge to 80% at the first opportunity

minimize sum(vehicle charging electricity costs ~~+ monetized GHG externalities~~);
2 weeks foresight;
driving needs always met

minimize sum(all household electricity costs ~~+ monetized GHG externalities~~);
2 weeks foresight;
driving needs always met;
home electricity needs always met

	Charging strategy		
	Uncontrolled	Controlled	V2H
Baseline heating	x	x	
Heat pump heating	x	x	

Steps	Method & data	Key assumptions	Outcome of the step
Driving profile simulation	Synthesis with **NHTS** • Daily-->Annual driving profiles	EVs meet the same driving demand as ICEVs	Hourly vehicle activity profile for 1 yr; trip origin /destination categories and times

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EV energy consumption	• Fuel economy: **EPA rated fuel economy**	Adjust efficiency based on temperature using method developed by Wu *et al.* 2019	Driving energy consumption 432 regions x 15 vehicles

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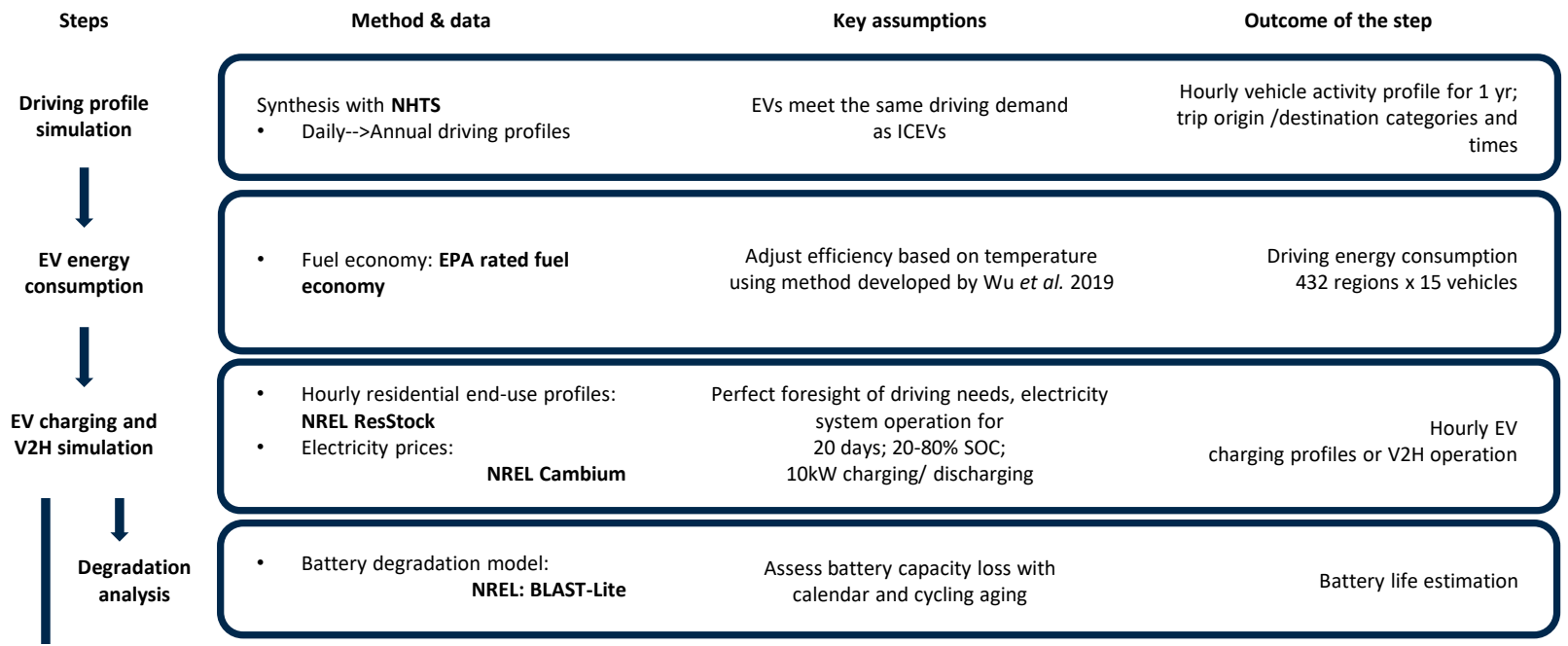
EV charging and V2H simulation	• Hourly residential end-use profiles: **NREL ResStock** • Electricity prices: **NREL Cambium**	Perfect foresight of driving needs, electricity system operation for 20 days; 20-80% SOC; 10kW charging/ discharging	Hourly EV charging profiles or V2H operation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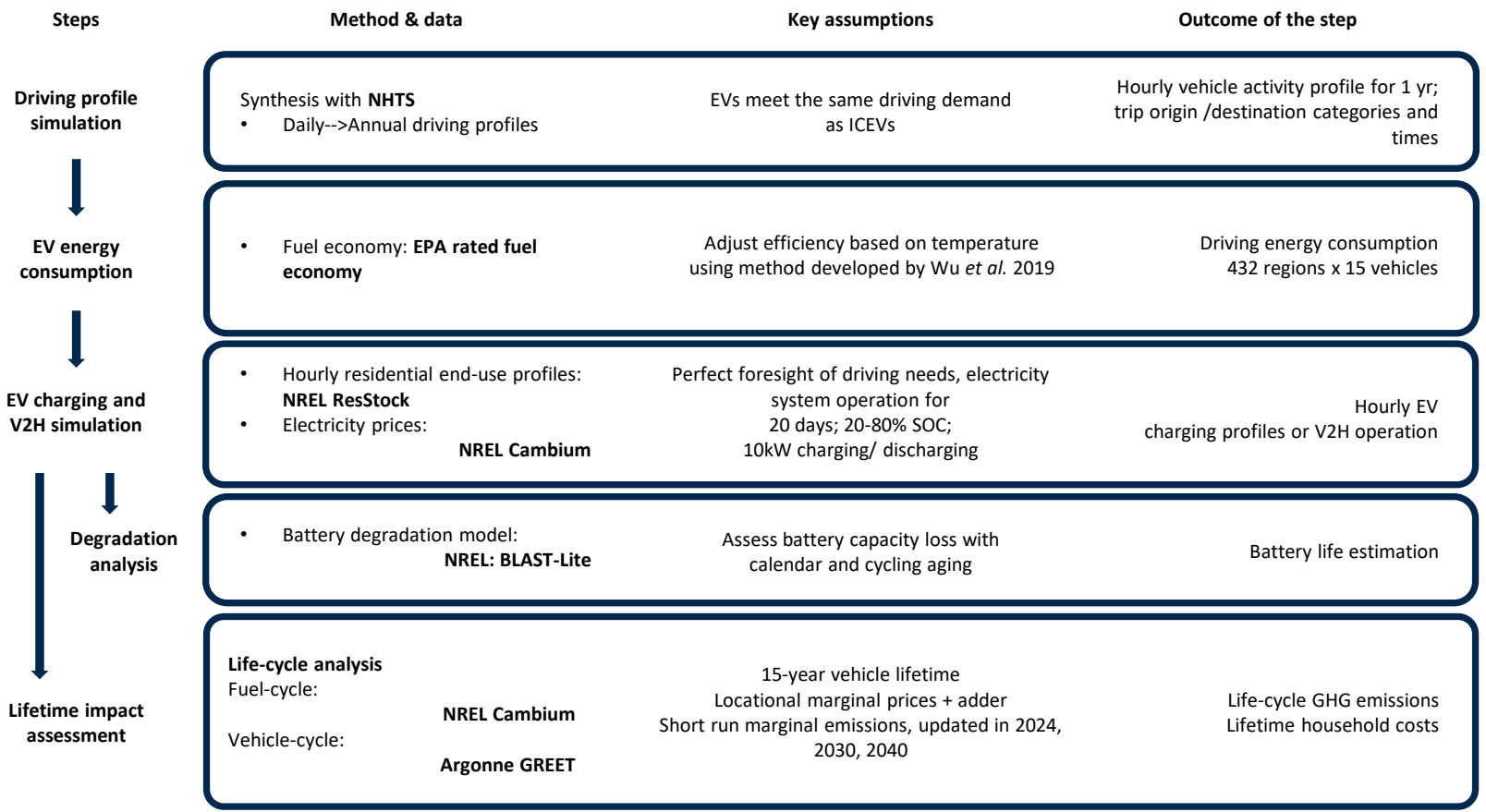
Degradation analysis
• Battery degradation model: NREL: BLAST-Lite
Assess battery capacity loss with calendar and cycling aging
Battery life estimation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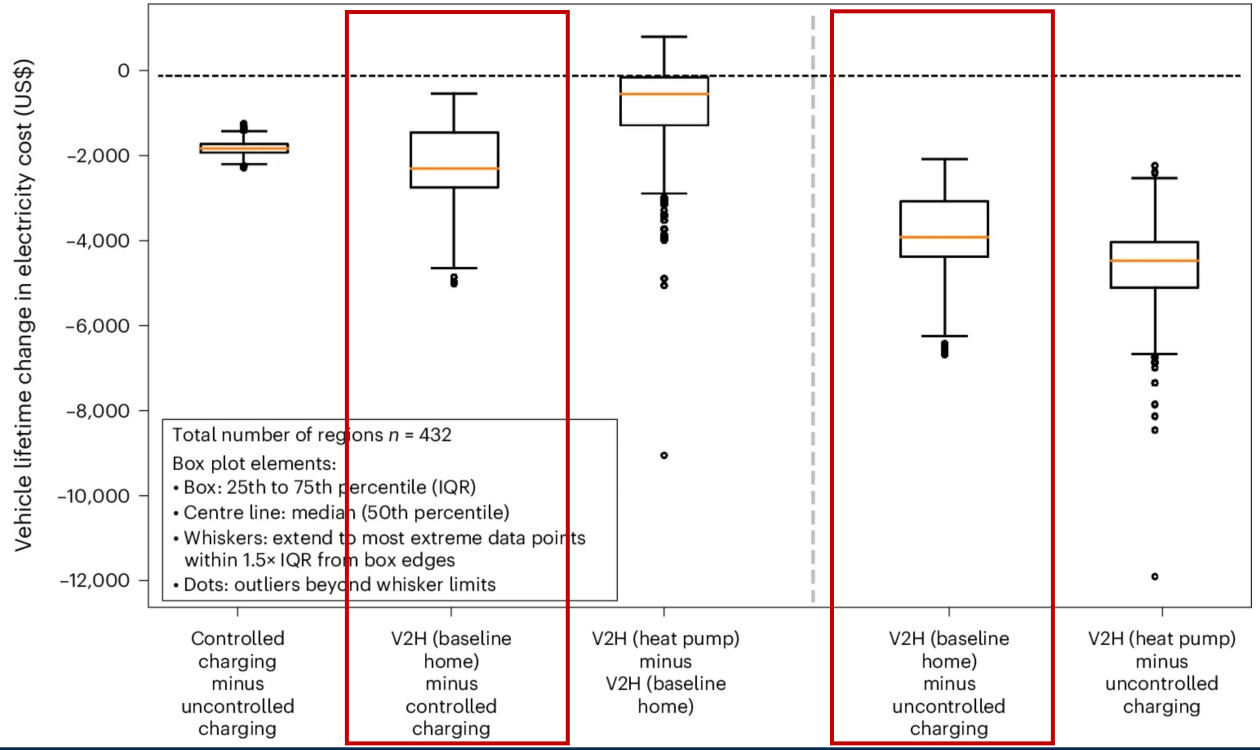
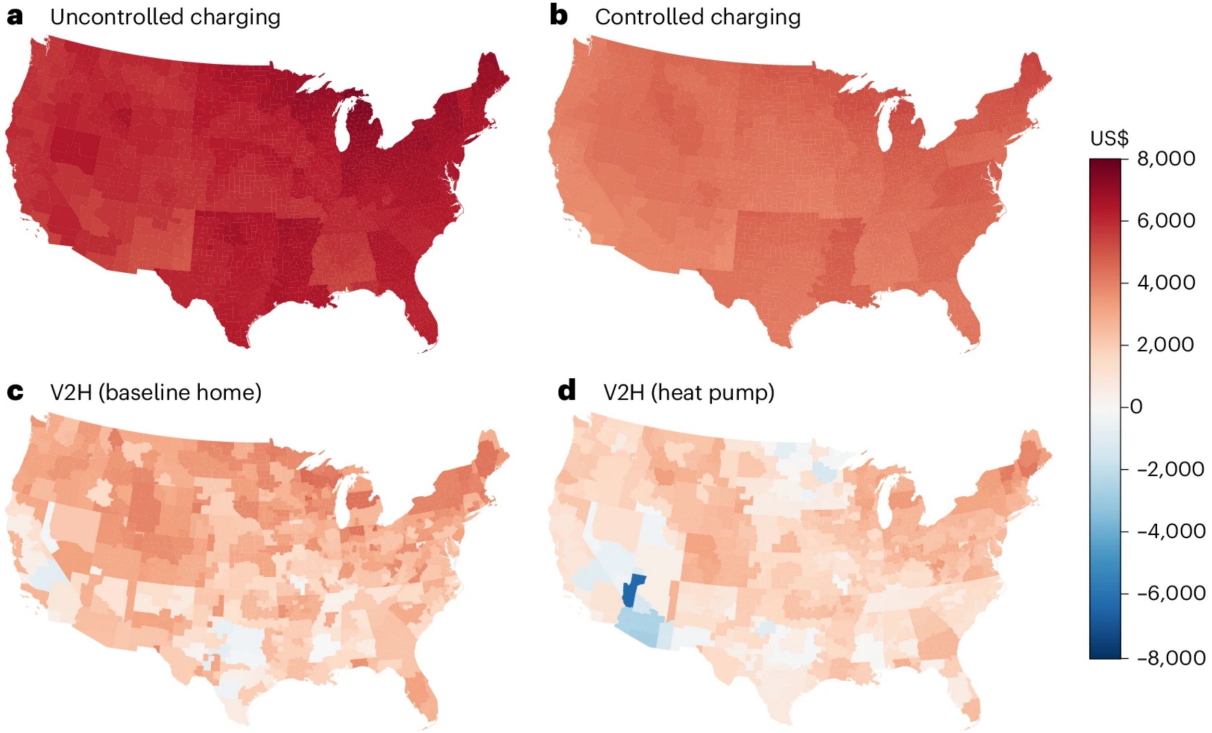
Lifetime impact assessment
Life-cycle analysis
Fuel-cycle: NREL Cambium
Vehicle-cycle: Argonne GREET
15-year vehicle lifetime
Locational marginal prices + adder
Short run marginal emissions, updated in 2024, 2030, 2040
Life-cycle GHG emissions
Lifetime household costs

V2H cuts lifetime charging costs relative to uncontrolled and controlled charging



Chen, J. *et al.* Vehicle-to-home charging can cut costs and greenhouse gas emissions across the USA. *Nat Energy* **10**, 1458–1469 (2025).

In parts of Texas and California, V2H savings could exceed charging costs



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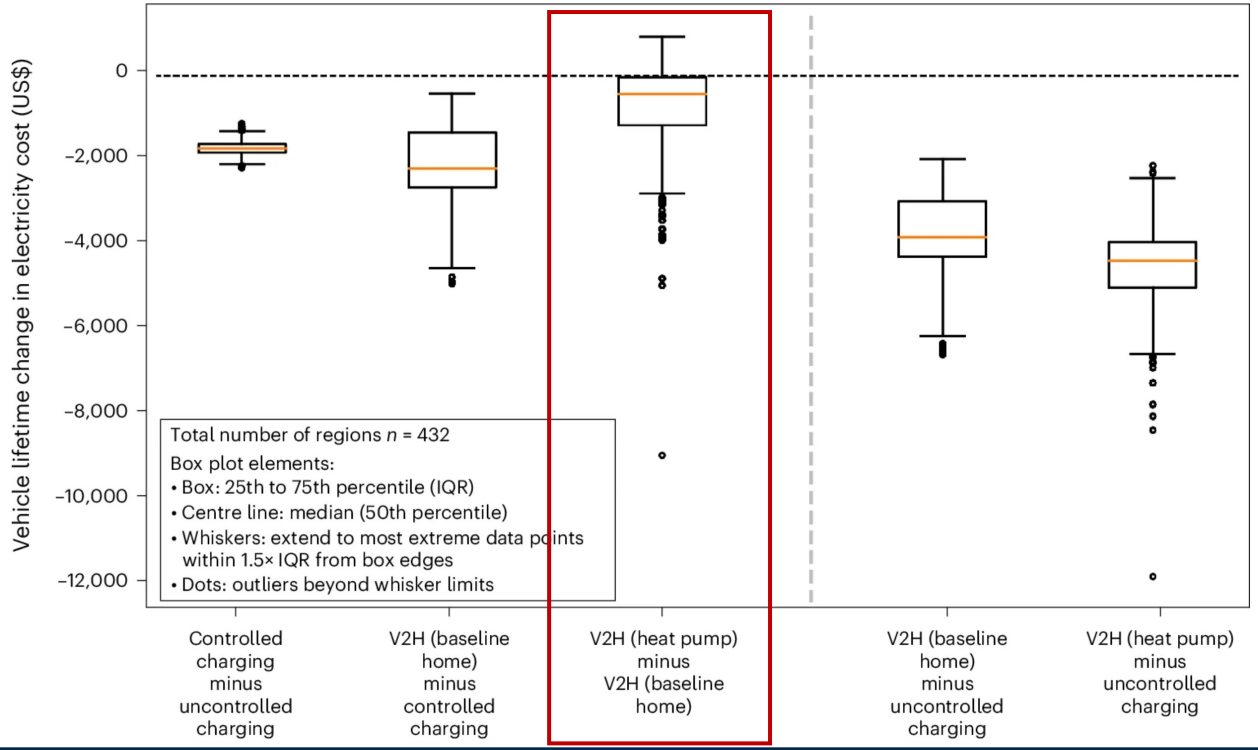
There is a (small) synergy between heat pump adoption and V2H



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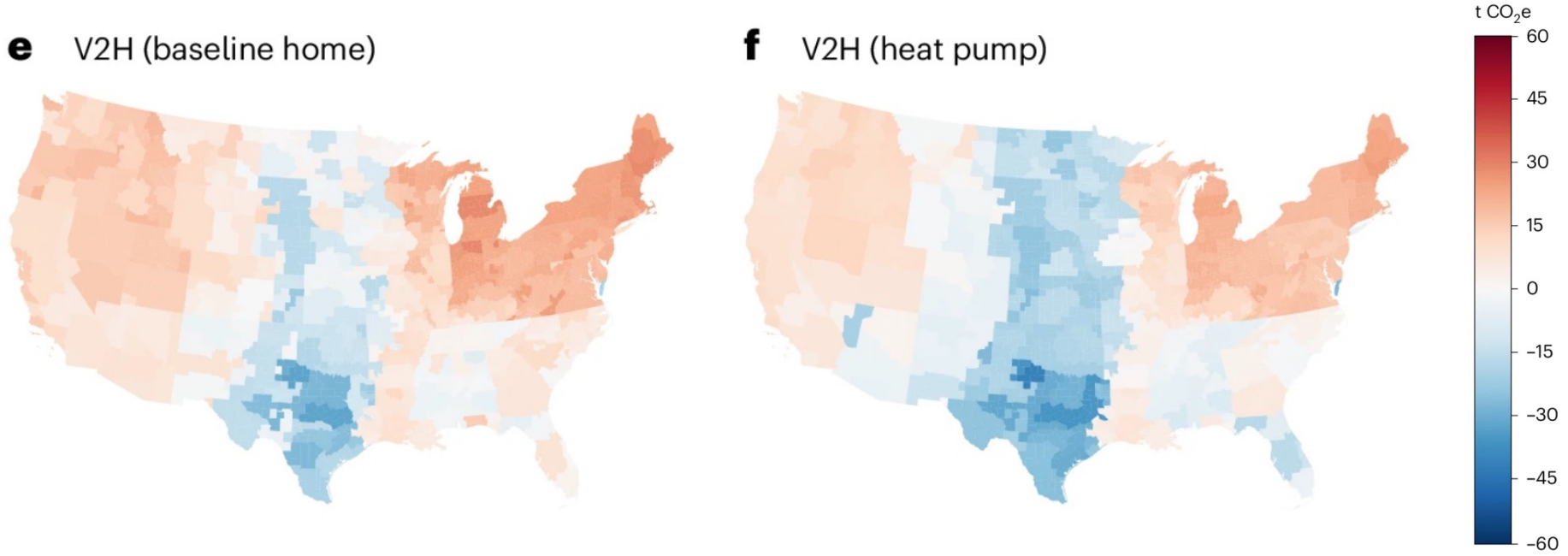
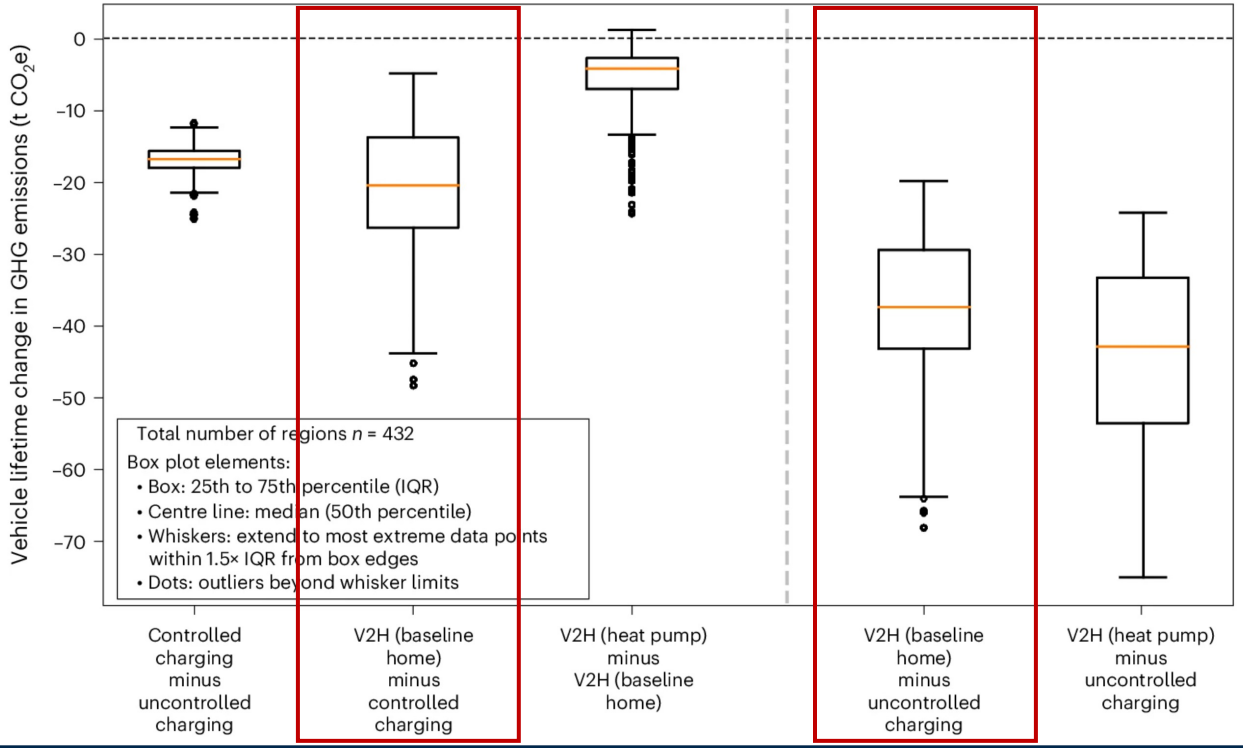
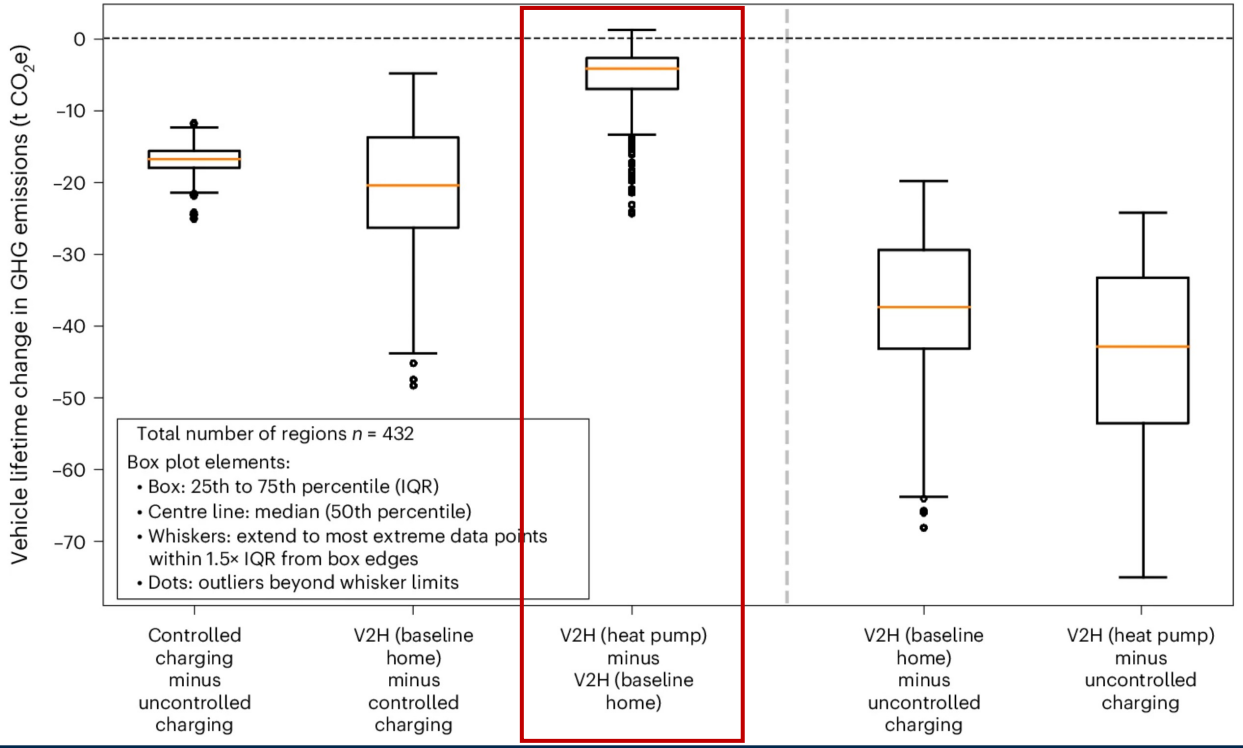
V2H can cut lifecycle GHG emissions from electricity use relative to a no-EV counterfactual



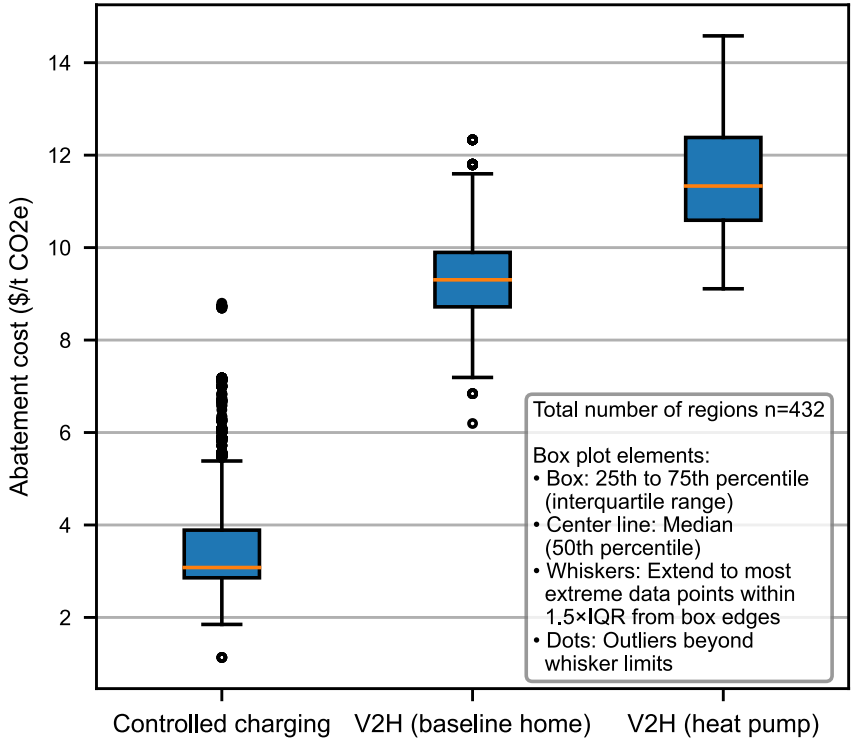
V2H eliminates charging emissions in counties containing 62% of the population



There is a small emissions synergy between V2H and heat pumps



Including GHG externalities in charging decisions is a low-cost abatement strategy



V2H could be low-hanging fruit to cut EV charging emissions and costs

- This depends on the installation costs of V2H equipment
  - Back-up power is a compelling application, which we do not account for
- V2H can cut EV charging cost if owners are exposed to locational marginal prices (e.g., through an aggregator)
- For 70% of U.S. counties, representing 60% of the population, V2H eliminates charging GHG emissions
- V2H creates synergies between vehicle, heating electrification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Thank you!

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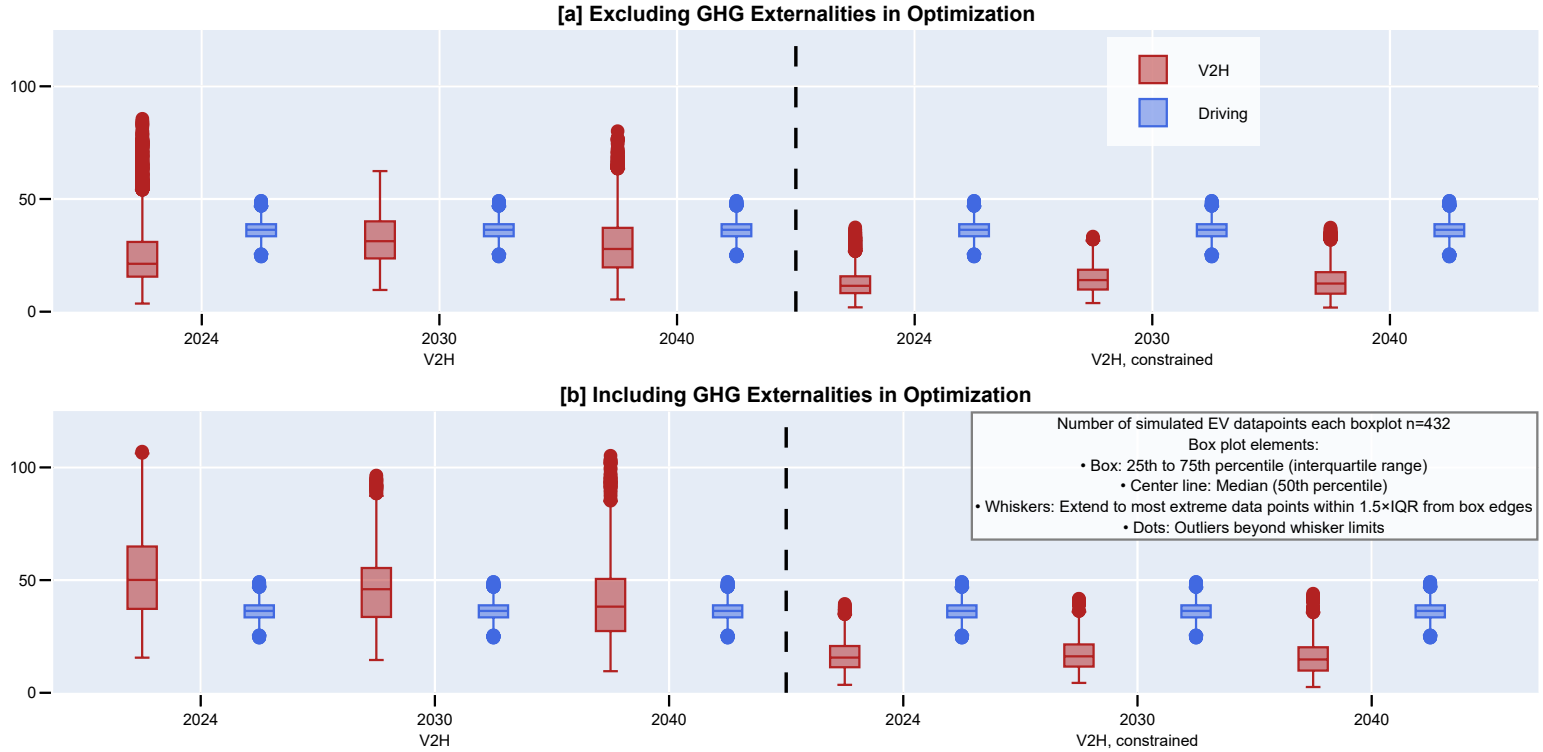
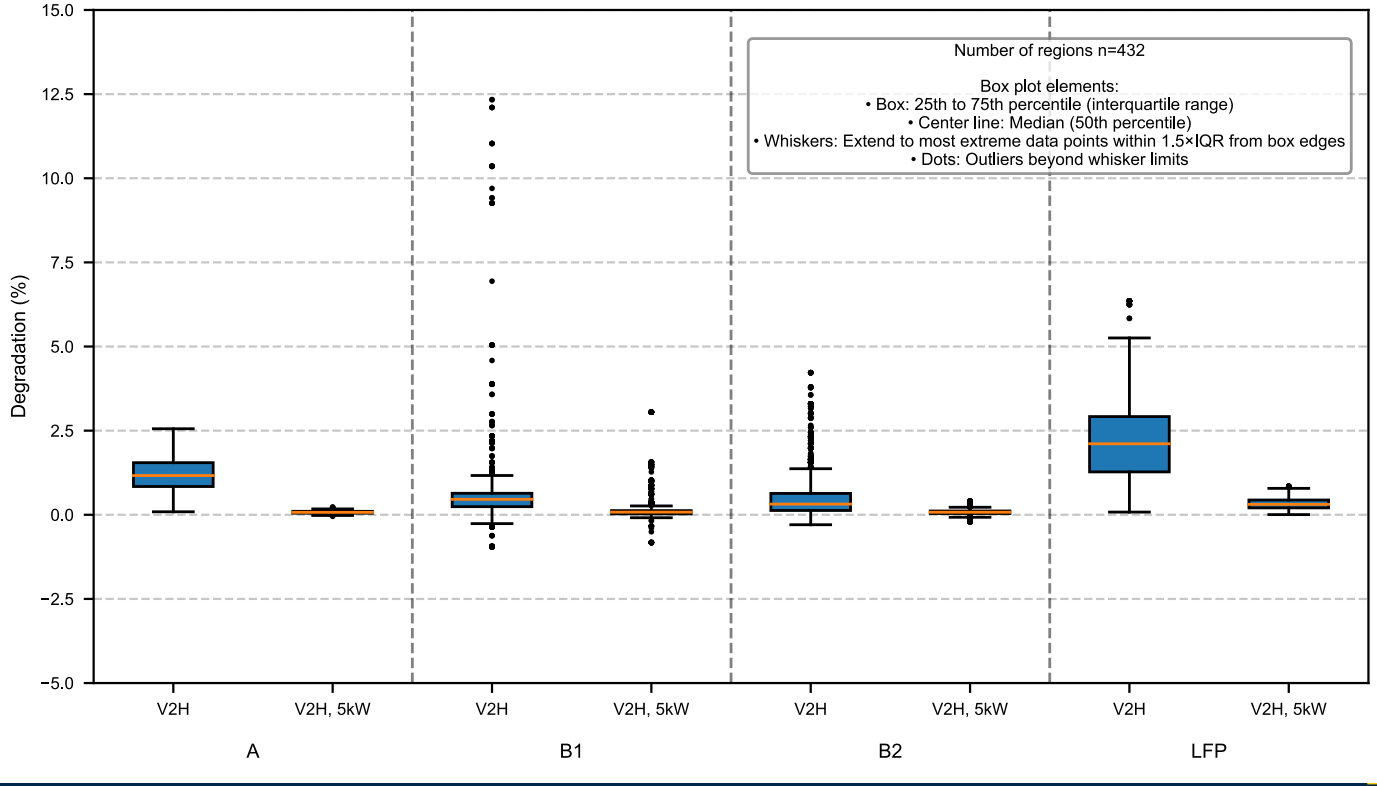
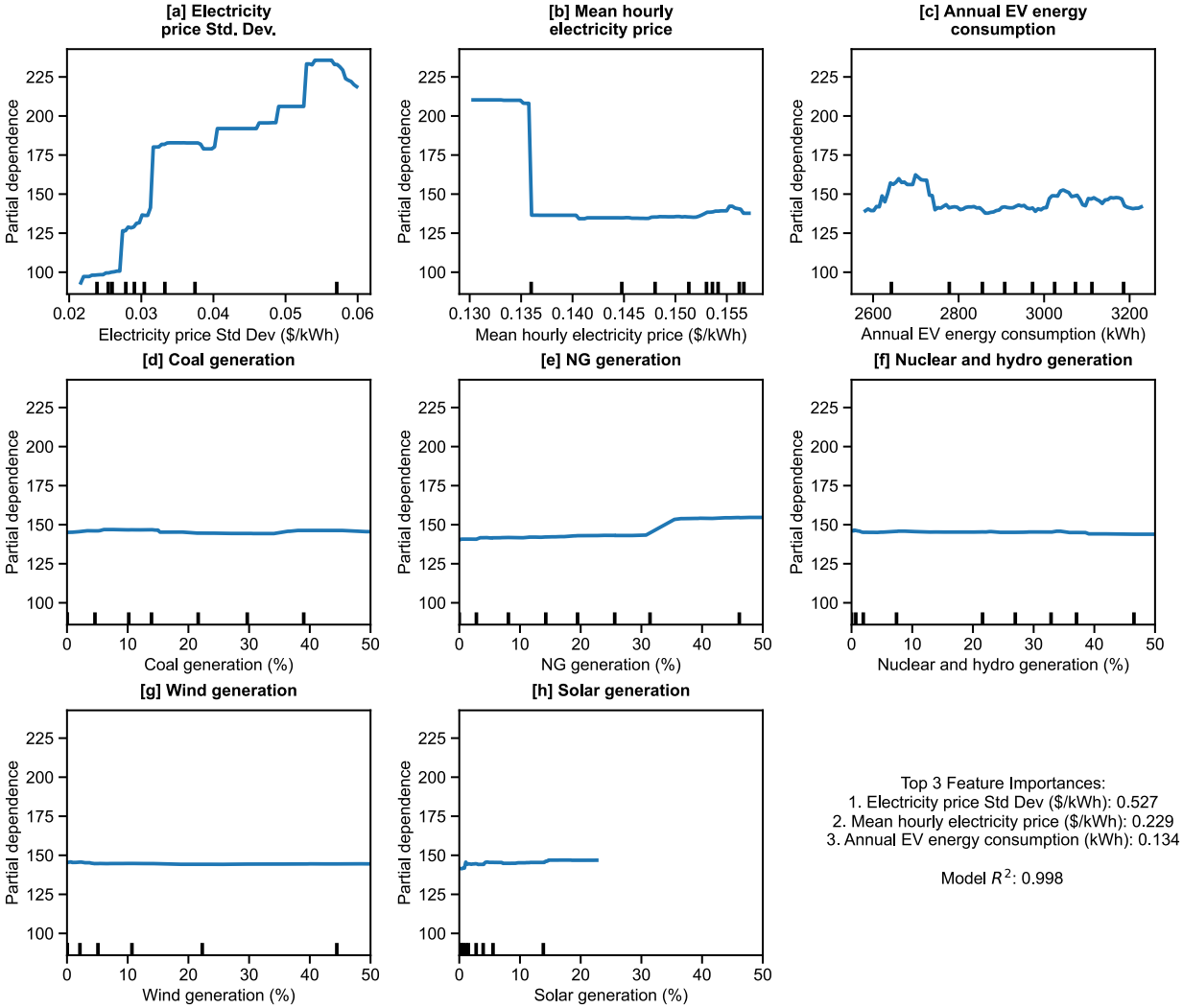
V2H sharply increases battery cycles



We could not model a scenario where V2H contributed to a lot of additional degradation

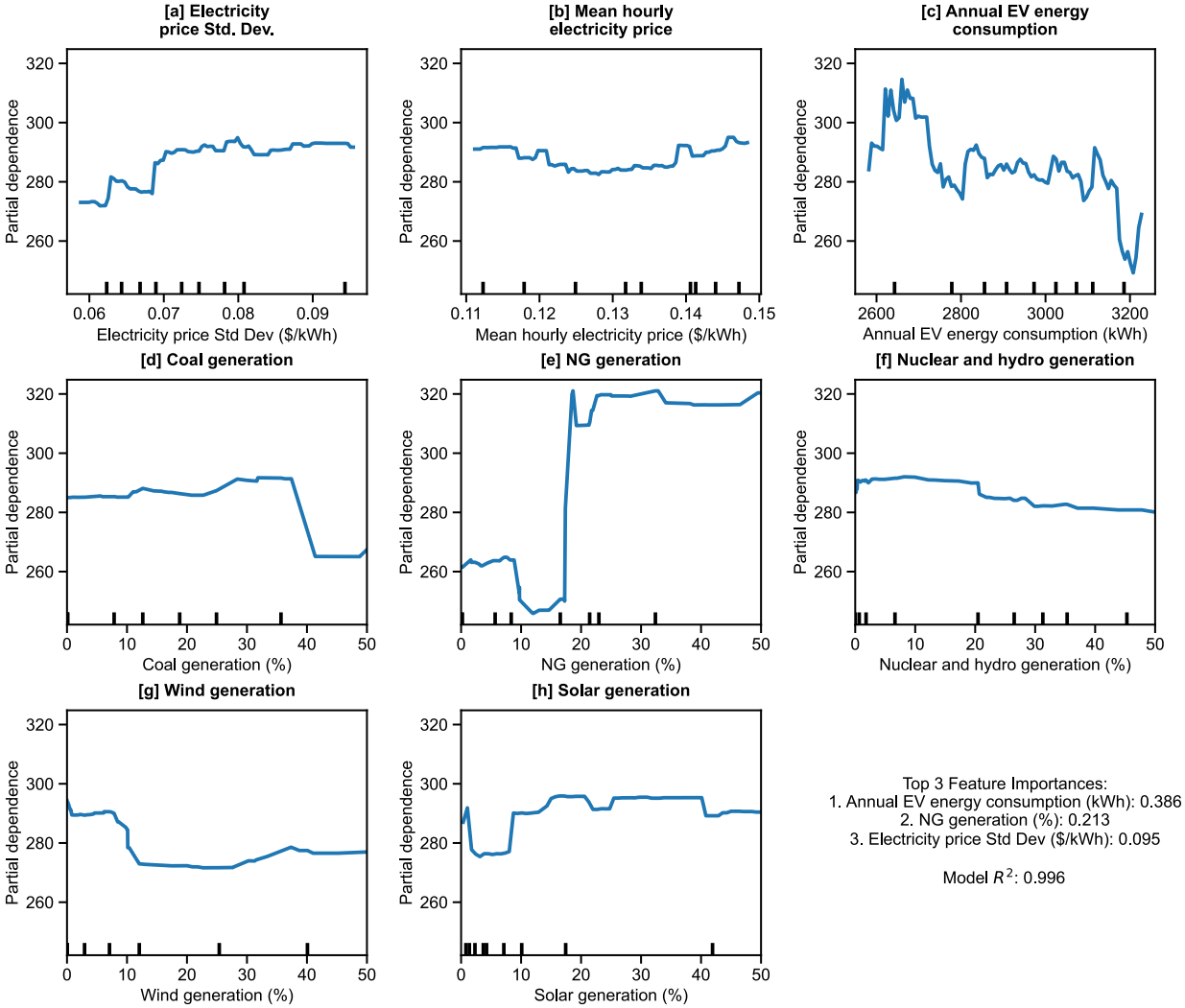




Differences in variability in electricity price and EV energy use explained variability in V2H benefits

Top 3 Feature Importances:
1. Electricity price Std Dev ($/kWh): 0.527
2. Mean hourly electricity price ($/kWh): 0.229
3. Annual EV energy consumption (kWh): 0.134

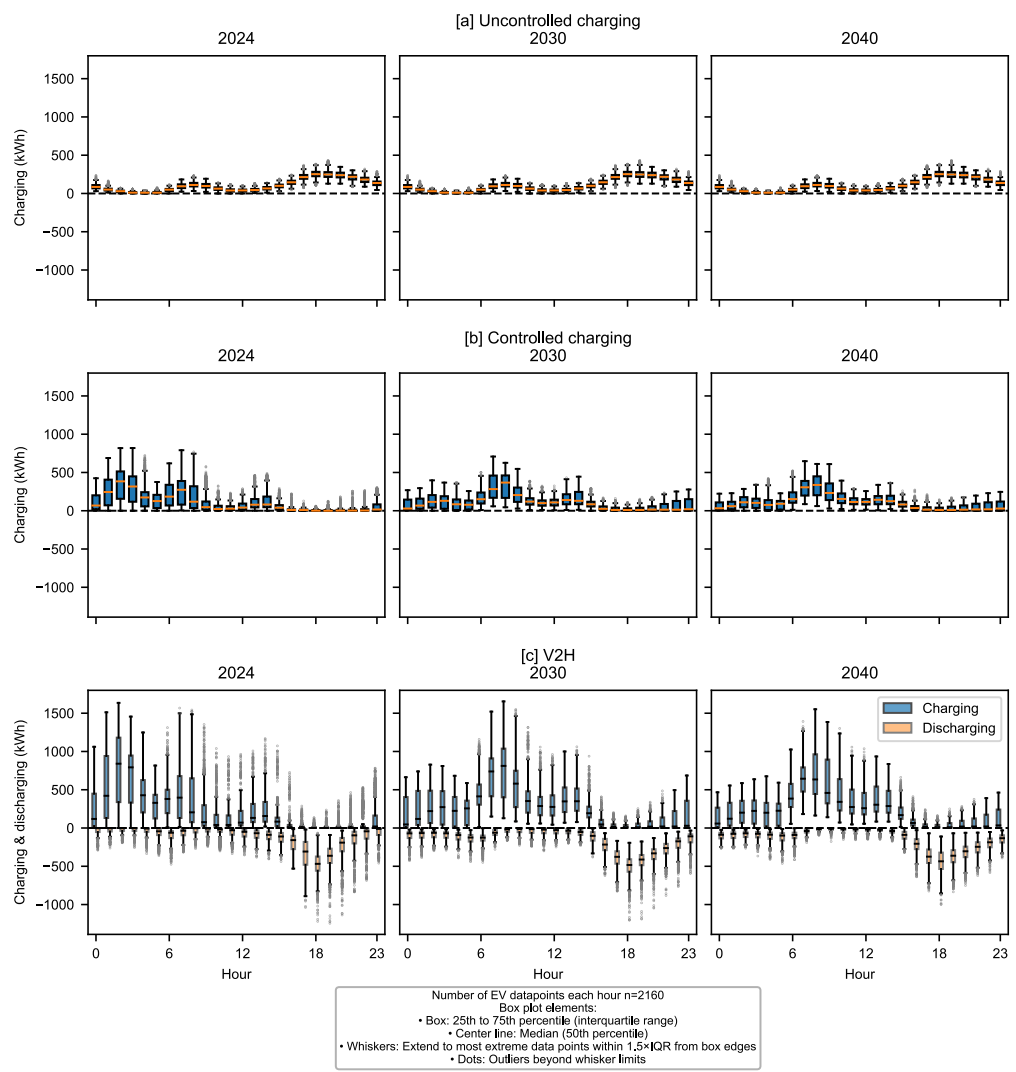
Model R^2: 0.998



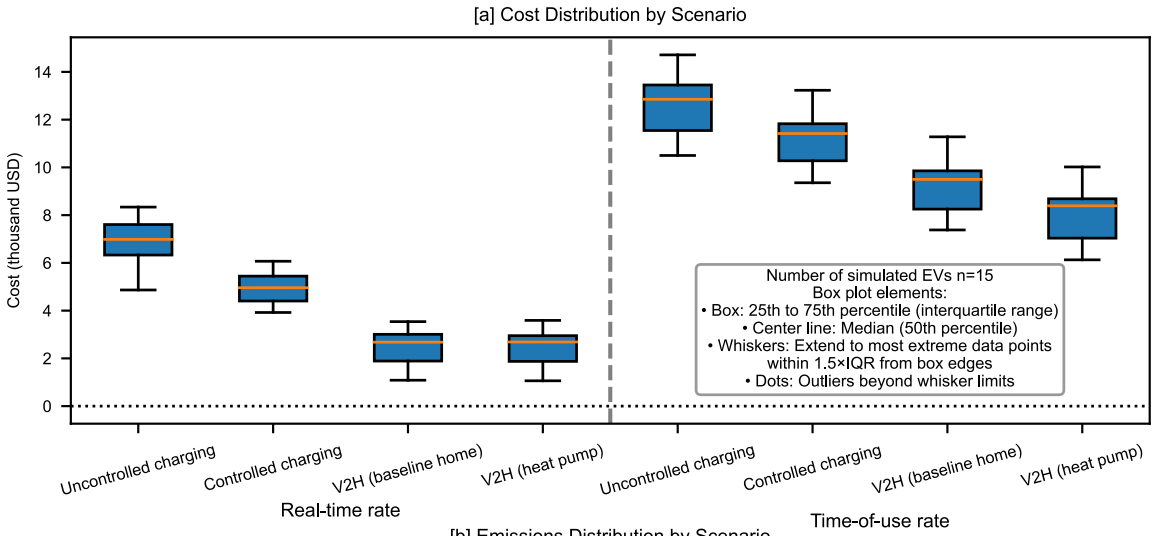
Differences in variability in electricity price and EV energy use explained variability in V2H benefits

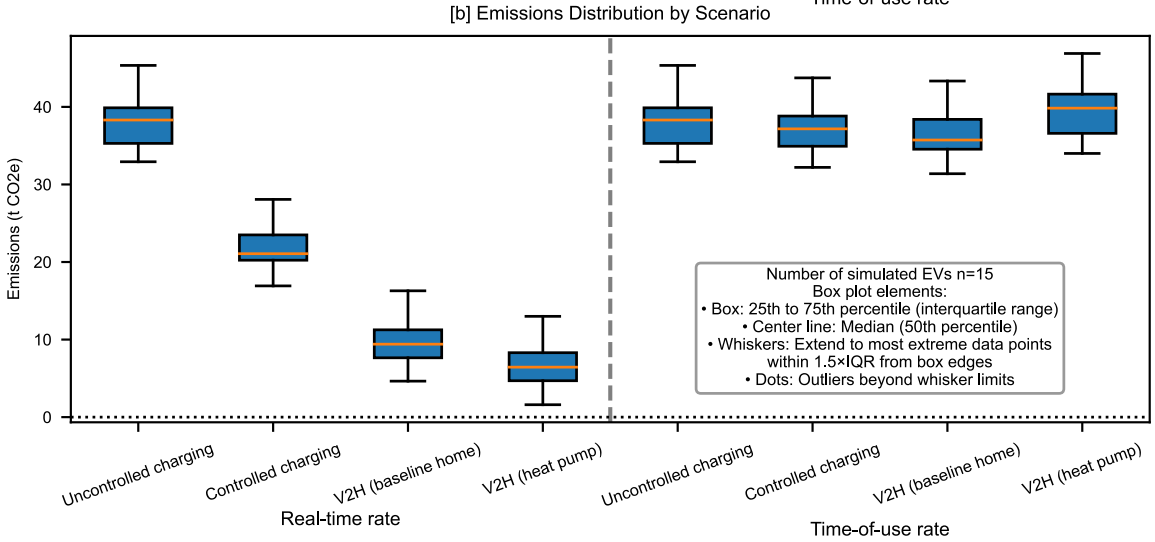
Top 3 Feature Importances:
1. Annual EV energy consumption (kWh): 0.386
2. NG generation (%): 0.213
3. Electricity price Std Dev ($/kWh): 0.095

Model R^2: 0.996



V2H creates large secondary charging peaks





Basing the optimization on current utility rate structures eliminates GHG emissions benefits in grids where fossil fuels continue to be the marginal generators