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Transforming ENERGY

Incorporating Residential Smart Electric Vehicle Charging in Home Energy Management Systems

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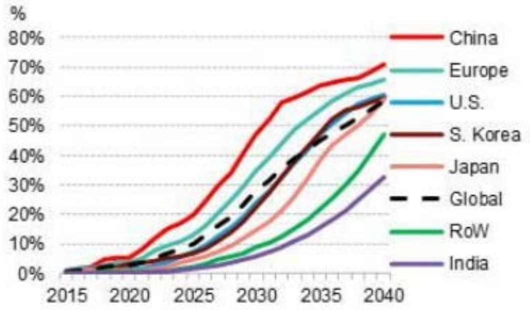
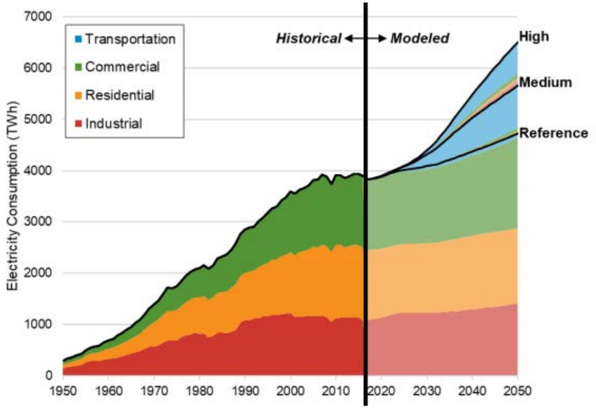
EVs are growing and will impact electricity demand

Figure 2: Global long-term EV share of new passenger vehicle sales by region





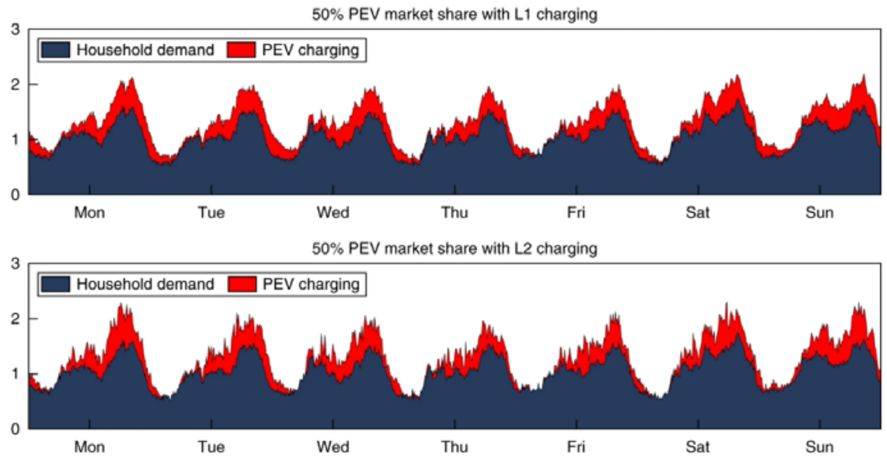
"Because residential charging is convenient and inexpensive, most plug-in electric vehicle drivers do **more than 80% of their charging at home**."

Sources: https://about.bnef.com/electric-vehicle-outlook/; https://www.energy.gov/eere/electricvehicles/charging-home; https://www.nrel.gov/docs/fy18osti/71500.pdf

Uncoordinated EV charging increases peak demand

- Residential peak often occurs in late afternoon
- EV peak is coincident with residential peak

- Best to encourage EV charging at night
- TOU rates can cause large spike in demand!



Source: https://www.nature.com/articles/s41560-017-0074-z

EV Modeling and Control Approach

Approach: Home Energy Management System

- **foresee**™ optimizes home energy usage across multiple DERs
  - Model predictive control with quadratic programming
  - Weights used to adjust relative objective costs

$$
\begin{aligned}
J(t) = & b_m \lambda(t) P_{house}(t) \\
& + b_{air}\left((T_{air}(t) - T_{air}^{max})^2 + (T_{air}^{min} - T_{air}(t))^2 \right) \\
& + b_{wh}\left((T_{wh}(t) - T_{wh}^{max})^2 + (T_{wh}^{min} - T_{wh}(t))^2 \right) \\
& + b_{batt}\left(P_{ch}(t) + P_{dis}(t) \right)
\end{aligned}
$$

- Added EV control to maximize EV SOC near departure time
  - Approximates the "inconvenience cost" of low SOC / range anxiety

$$
J_{ev}(t) = \begin{cases} b_{ev}(1 - SOC(t)) \frac{t-k}{k_{end}-k} & k_0 \leq t < k_{end} \\ 0 & \text{otherwise} \end{cases}
$$

Approach: Controllable EV + Building Model

- Using the Object-oriented Controllable High-resolution Residential Energy (OCHRE) model
  - Designed for building-to-grid co-simulation

- Linear EV model to track SOC
- EV model generates stochastic parking "events" for each simulation day, variables include:
  - Arrival and departure times
  - Arrival SOC
  - Number of events per day

$$SOC(k+1) = SOC(k) + \frac{t_s \eta_{ev}}{\kappa_{ev}} P_{ev}(k)$$

$$SOC(k_0) = SOC_0$$

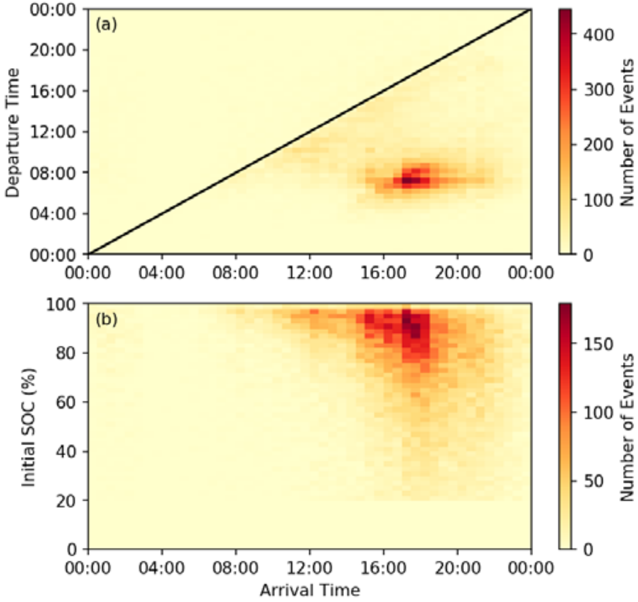
$$P_{ev}(k) = \begin{cases} \min(\frac{\kappa_{ev}}{t_s \eta_{ev}}(1 - SOC(k)), P_{max}) & k_0 \leq k < k_{end} \\ 0 & \text{otherwise} \end{cases}$$

Approach: EV Data from EVI-Pro

- Data from Electric Vehicle Infrastructure Projection Tool (EVI-Pro)
  - Models EV driving and charging
  - We only use residential charging data

- EVI-Pro input parameters:
  - EV type (BEV vs. PHEV)
  - EV range
  - Charging level
  - Ambient temperature (for driving efficiency)
  - Weekday vs. weekend

EVI-Pro residential data for a 250-mile BEV, Level 2 charger

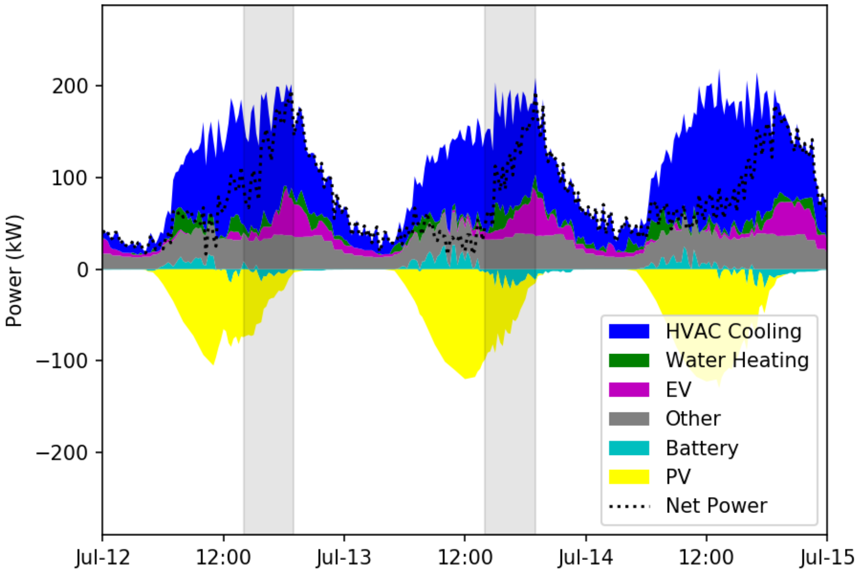


Results

Results: Baseline Scenario

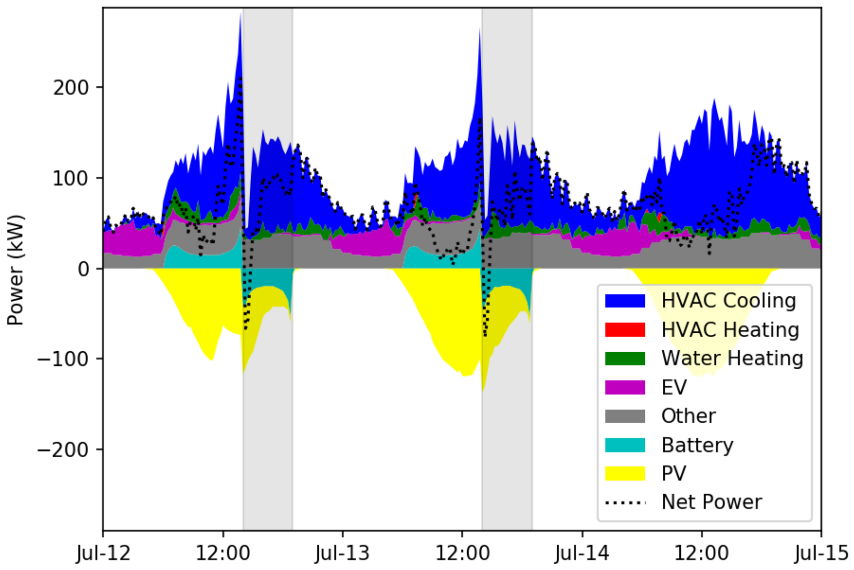
- Scenario parameters:
  - 50 home community near Washington D.C.
  - Typical building stock using ResStock^{TM}
  - 50% EV penetration with mix of BEV/PEV and Level 1/Level 2 chargers
- Goal: assess impacts of EV controls on a typical distribution system
  - Simple delay control
  - Control with **foresee**
  - Control with **foresee** + demand charge

Baseline Community Power

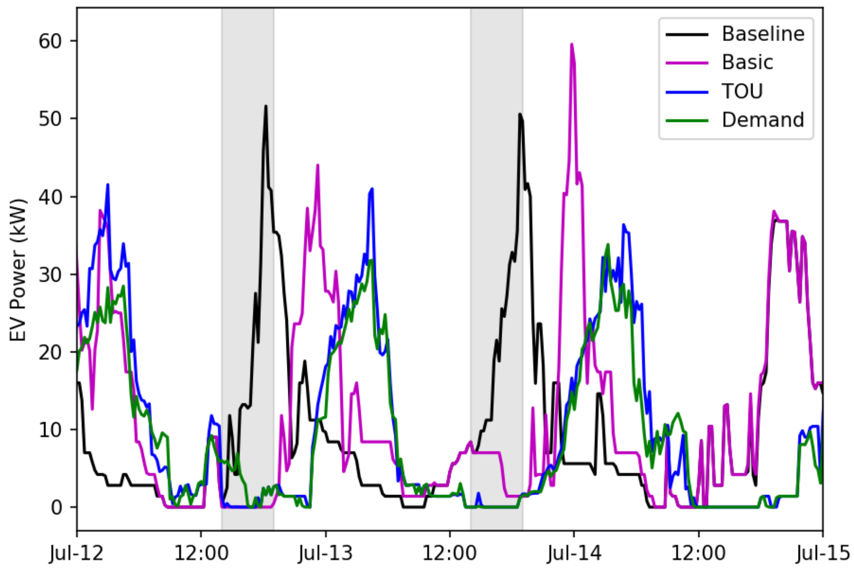


Results: Control Scenarios

Control with **foresee**



Total EV Power



Conclusions

- Developed framework for modeling and controlling residential EVs
  - Integrated EV model with OCHRE
  - Integrated EV controls with **foresee** HEMS
- Simulations show reductions in on-peak demand for a community with high EV penetration
  - And smooth nighttime charging profiles
- Future Work:
  - Using stochastic control techniques to account for uncertainty in occupant behavior

Thank You

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