Residential Electric Vehicle Charging Patterns and Management

Tinghan Ye, Cornell
Eleftheria Kontou PhD, UIUC

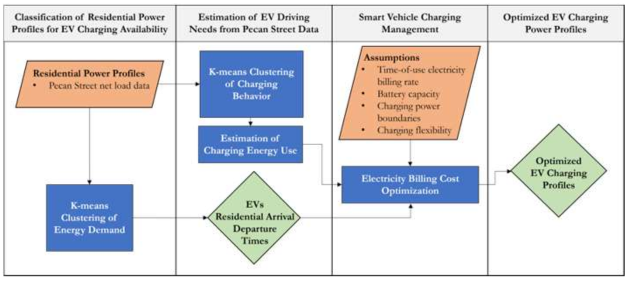
- Since the introduction of electric vehicles (EVs) in the U.S. automobile market, more than 1.9 million electric automobiles have been sold.
- The transition to EVs is expected to increase electricity use in residences, where most users tend to recharge.

Objective

A mathematical programming framework for managing EV residential charging to minimize the electricity costs that a household incurs due to charging their vehicle, while meeting the needs for daily travel and drivers' preferences.

METHODOLOGY

Figure 1. A graphic representation of the computational workflow



Optimization Model Formulation

$$\min \sum_{n}^{N}\sum_{t}^{T}(Cost_{EV}(t)\cdot x_{n,t} + Cost_{RE}(t)\cdot P_{n,t})\cdot \tau \quad (1)$$

$$0 \le \sum_{t\in Q^{(t)}} \tau \cdot (x_{n,t}) \le 90\%B, \quad \forall n \in N, \forall t \in T_n \quad (2)$$

$$0 \le x_{n,t} \le p_n \times \eta, \quad \forall n \in N, \forall t \in T_n \quad (3)$$

$$\sum_{t\in T_n} \tau \cdot x_{n,t} = D_n, \quad \forall n \in N, \forall t \in T_n \quad (4)$$

(1) minimizes the total electricity costs of all households. (2) enforces the battery capacity constraint. (3) restricts power charged to the EV to be within the power limit. (4) ensures that travel demands of households are satisfied. In addition, 4 different charging scenarios are developed to account for households' and the community's preferences.

- Scenario 1: Charge as fast as possible

$$x_{n,t} = \arg\min_{x} \sum_{n}^{N}\sum_{t}^{T} t\cdot x_{n,t}, \quad \forall n \in N, \forall t \in T_n \quad (5)$$

- Scenario 2: Charge as late as possible

$$x_{n,t} = \arg\max_{x} \sum_{n}^{N}\sum_{t}^{T} t\cdot x_{n,t}, \quad \forall n \in N, \forall t \in T_n \quad (6)$$

- Scenario 3: Charge flexibly (coordinated with valley filling and peak shaving)

$$x_{n,t} = \arg\min_{x} \sum_{n}^{N}\sum_{t}^{T} (x_{n,t} + P_{n,t} - C_n)^2, \quad \forall n \in N, \forall t \in T_n \quad (7)$$

$$C_n = \frac{[max(P_n) + min(P_n)]}{2} \quad (8)$$

- Scenario 4: Shared DC fast charging station

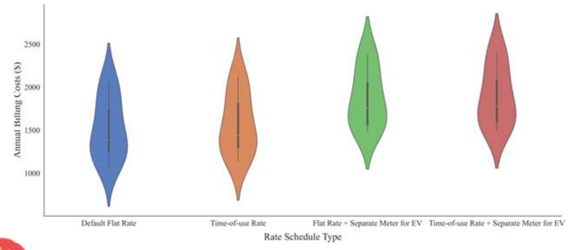
$$\min \sum_{n}^{N}\sum_{t}^{T}(Cost_{EV}(t)\cdot x_{n,t}\cdot a_{n,t} + Cost_{RE}(t)\cdot P_{n,t})\cdot \tau \quad (9)$$

$$\sum_{n\in N}(a_{n,t}) \le s^*, \quad \forall t \in T_n \quad (10)$$

$$\sum_{t\in T_n} \tau \cdot x_{n,t}\cdot a_{n,t} = D_n, \quad \forall n \in N, \forall t \in T_n \quad (11)$$

RESULTS

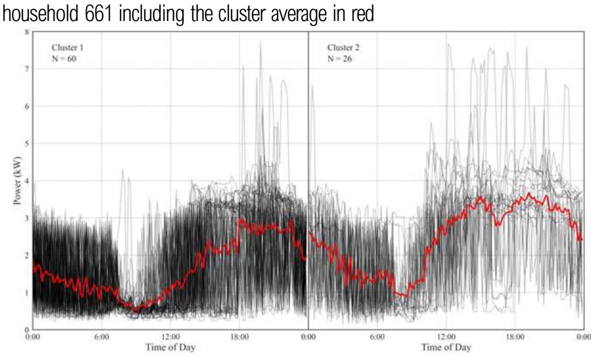
Figure 2. Comparison of electricity bills under different pricing scheme in 2018



OBSERVATION #1

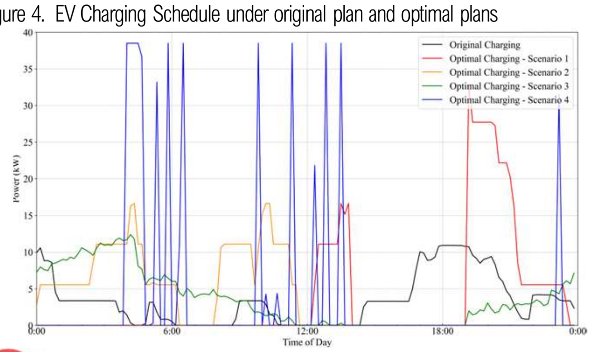
- ✓ Installing a separate meter for EV is more expensive than including EV as part of the residential energy consumption since households only reacted to the residential flat rate schedule in 2018
- ✓ It's possible that households will react differently to adjust for the time-of-use EV charging rate.

Figure 3. Plot showing the breakout of summer weekdays electricity demand clusters of household 661 including the cluster average in red



- ✓ The cluster average of Cluster 1 on Figure 2 left is chosen to be the most representative daily electricity demand profile on summer weekdays of household #661.

Figure 4. EV Charging Schedule under original plan and optimal plans



OBSERVATION #2

- ✓ All 4 scenarios perfectly avoid the on-peak hour (2pm – 7pm) of the EV charging rate schedule, thus effectively minimizing the total electricity billing costs.
- ✓ Scenario 1,2,4 allow drivers to have more flexible time despite of high peak loads; Scenario 3 not only minimize the cost but also flattens the load curve.

CONCLUSIONS

- Sensitivity analysis is conducted on cost functions, travel patterns, and energy demand, which proves the applicability of the model under different settings.
- Future works can extend the model by incorporating additional user-imposed constraints, such as pro-environmental preferences.