Impacts of Managed Charging and Other Innovative Rates for Electric Vehicle Charging on EV Customer Load and Utility System Grid

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Project Overview

Project Scope:
- The effects of innovative rates on EV charging behavior & utility grid dynamics

Phase 1: Literature Review (COMPLETE)
- Reviewed industry and academic studies of EV innovative rates.
- Investigated managed charging's impact on customer & utility load, especially at the local distribution level.

Phase 2: Development of Analytical Model and Proof-of-Concept (COMPLETE)
- Customer effects: Difference in Differences (DiD) method
- Grid impacts: Time Series Power Flow and Monte Carlo Analysis with stochastic inputs for North Carolina

Phase 3: Case Study (Anticipated Completion Dec. 30, 2024)
- Utilize Duke Energy NC data on EV customers subject to flat, TOU and CPP rates
- Impact of rates on customer load & utility system
  - Current and forecasted

Innovative Rate Study

EV Charging as a Flexible Load

Which pricing structure– Time-of-Use (TOU) or Critical Peak Pricing (CPP)– better encourages efficient EV charging and helps manage peak load demands?

- Discount Period
- Off-peak Period
- On-peak Period

EV Charging for May-September 2021-2023

Logit Regression for Changes in Peak Charging Time

$$\log\left(\frac{P(\text{EV\_charging}=1)}{P(\text{EV\_charging}=0)}\right) = \beta_0 + \beta_1 \times \text{CPP} + \beta_2 \times \text{TOU} + \beta_3 \times \text{peak} + \beta_4 \times \text{discount} + \beta_5 \times \text{off\_peak} +$$

$$\beta_6 \times \text{CPP\_peak} + \beta_7 \times \text{peak\_TOU} + \beta_8 \times \text{off\_peak\_TOU} + \beta_9 \times \text{CPP\_discount}$$

where CPP is the CPP rate effect, TOU is the TOU rate effect, peak, off peak and discount represent their respective effects and are specified by rate type.

Logit Regression for Critical Peak Event Charging Time:

$$\log\left(\frac{P(\text{EV\_charging}=1)}{P(\text{EV\_charging}=0)}\right) = \beta_0 + \beta_1 \times \text{CPP\_day\_ind} + \beta_2 \times \text{CPP} + \beta_3 \times \text{cppinteract}$$

where CPP_day_ind is the CPP event day effect, CPP is the CPP rate effect, and cppinteract is the interaction of CPP rate and event day.

Innovative Rate Study

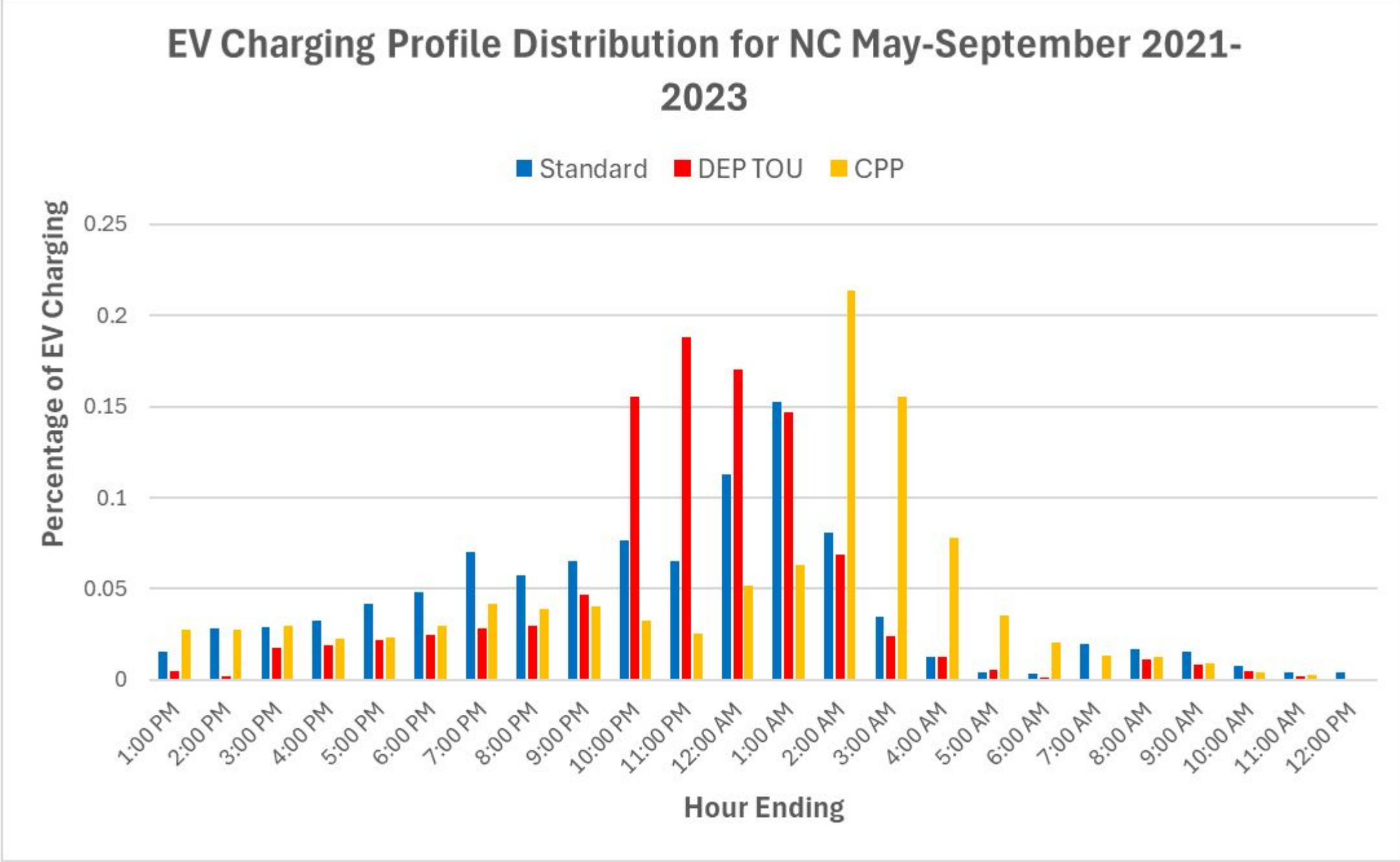**Log-Odds Interpretation:**
Variable: cppinteract
Coefficient = -2.04**
Exponentiate:
e^-2.04 ≈ 0.129
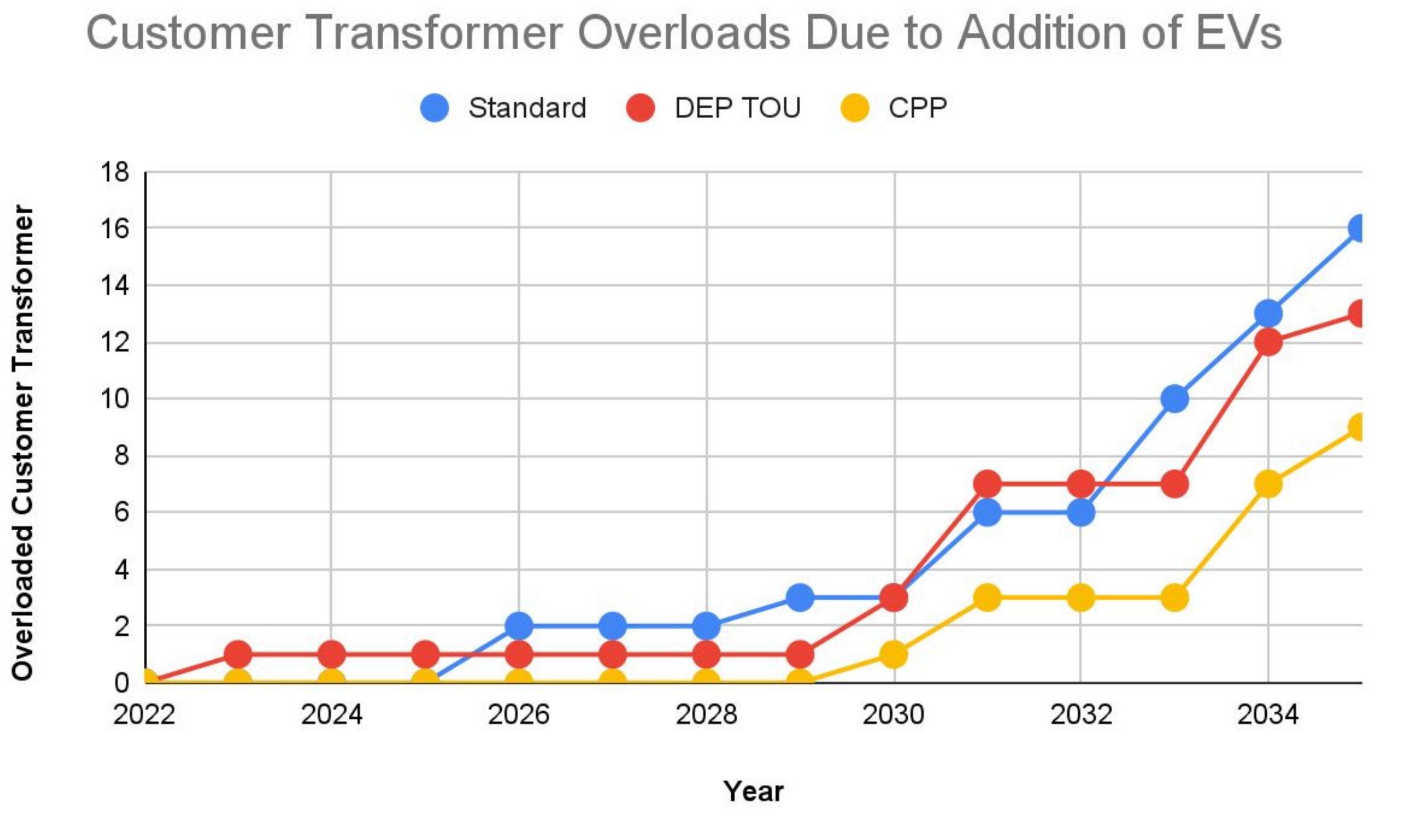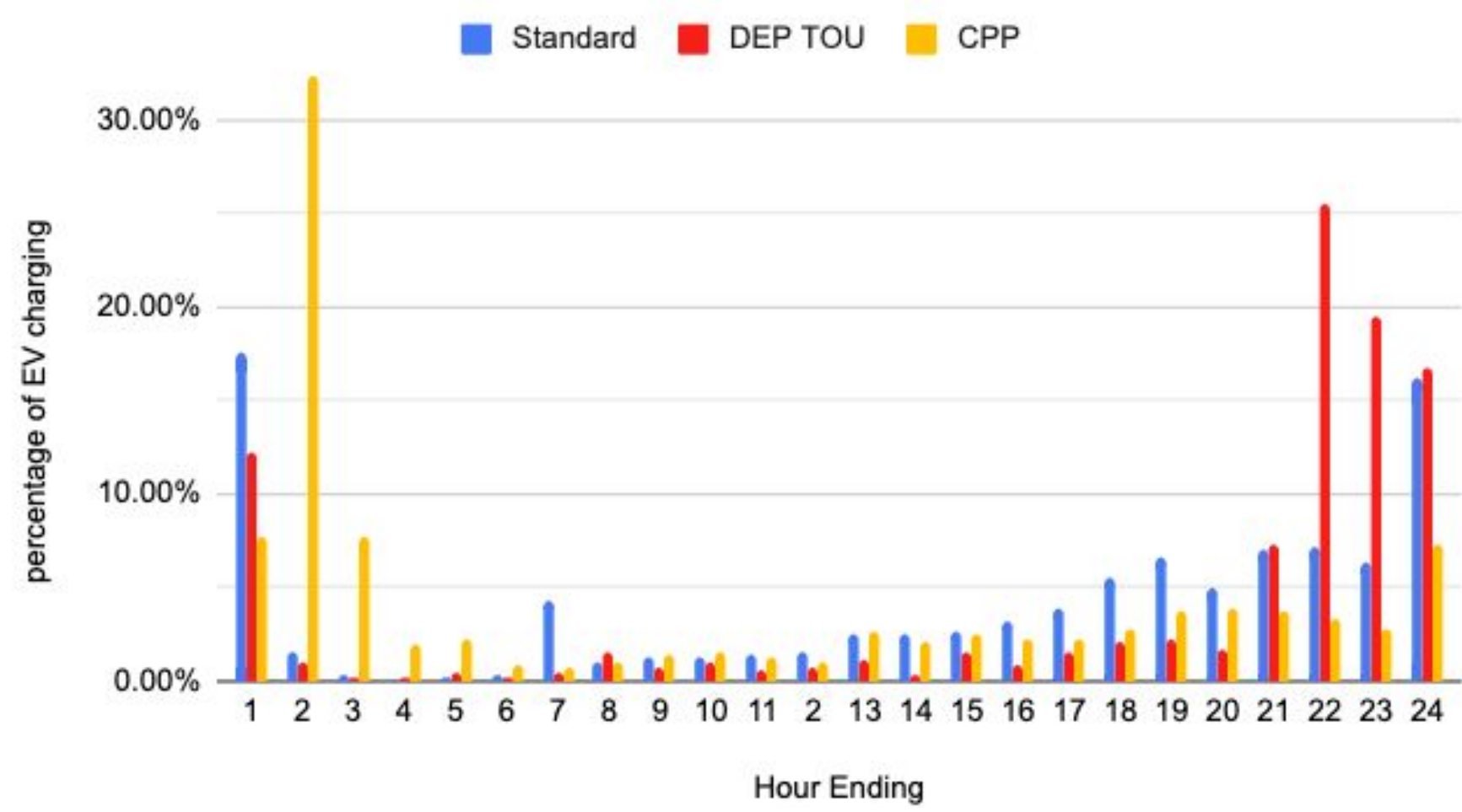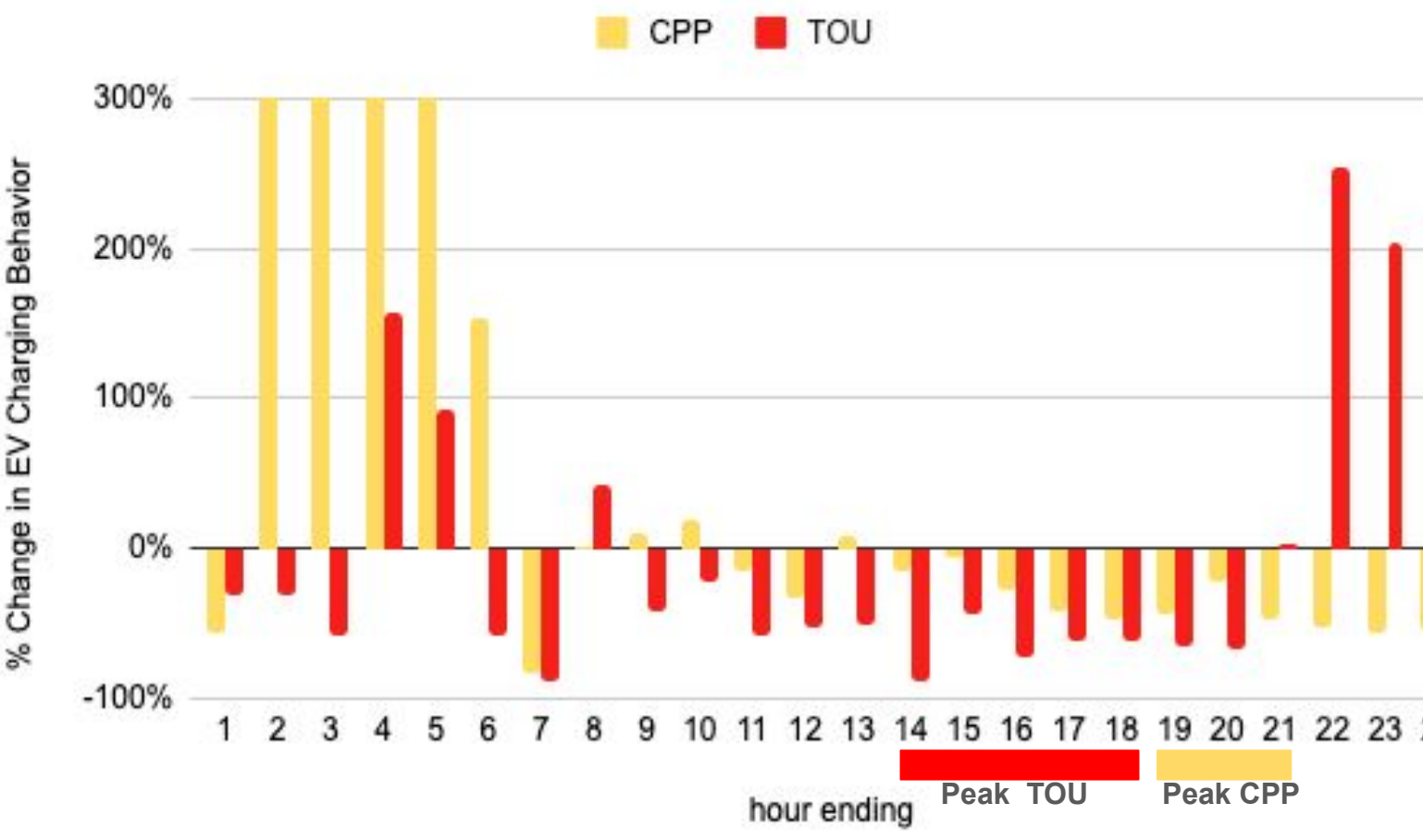1-0.129
= 87.1%

Linktest Robustness Check:

The **_hat** variable being significant suggests that the predicted values are strongly related to the outcome.

The **_hatsq** variable being insignificant suggests that there is no evidence of misspecification.

Hourly % Change in EV Charging May-September 2021-2023
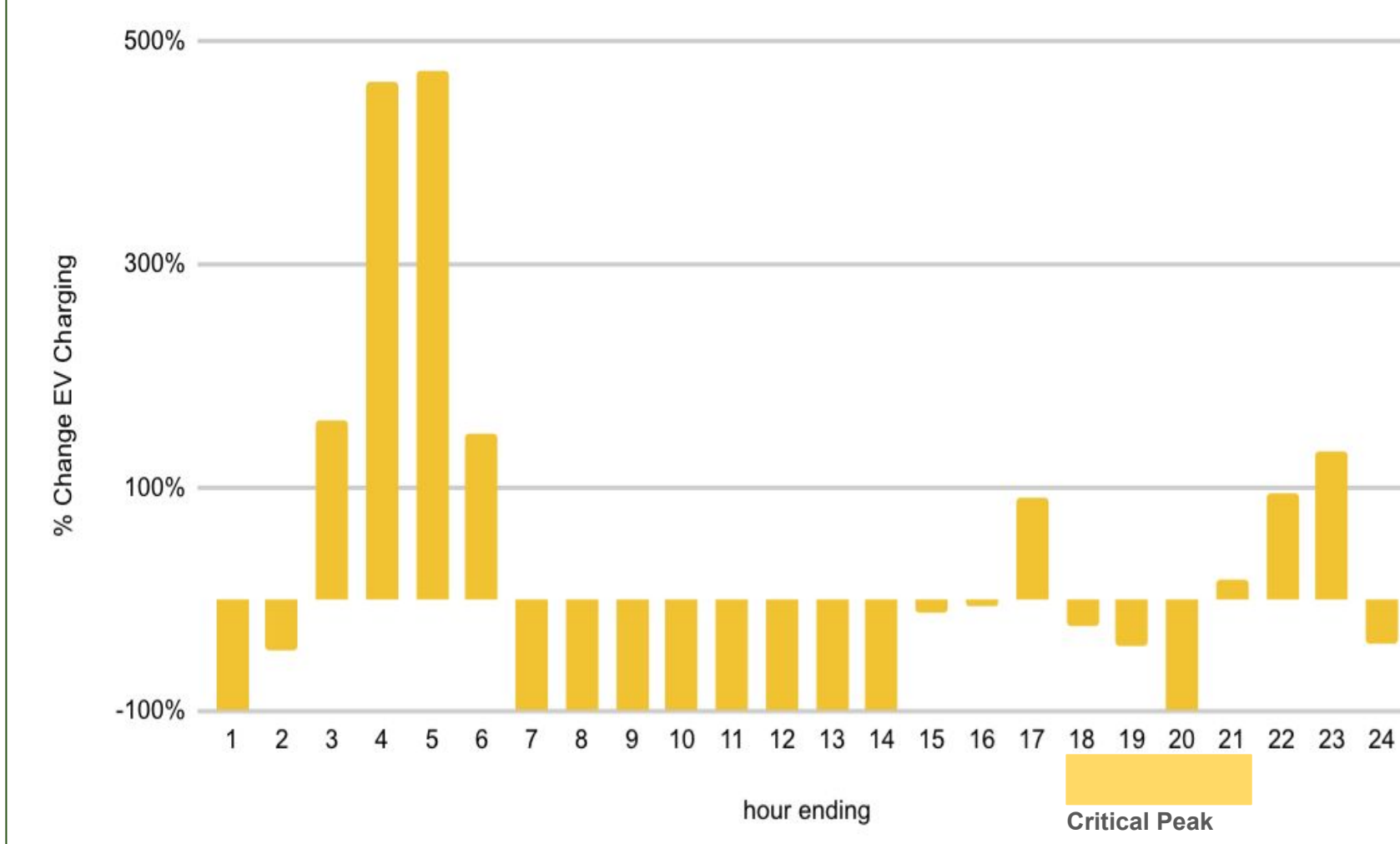
TOU: Reduces the likelihood of peak EV charging by **55%** compared to non-TOU rates.

CPP: Reduces the likelihood of peak EV charging by **38%** compared to non-TOU rates.

Timer Peaks: EV charging is **3 times more likely** during the lowest-priced periods of the day.

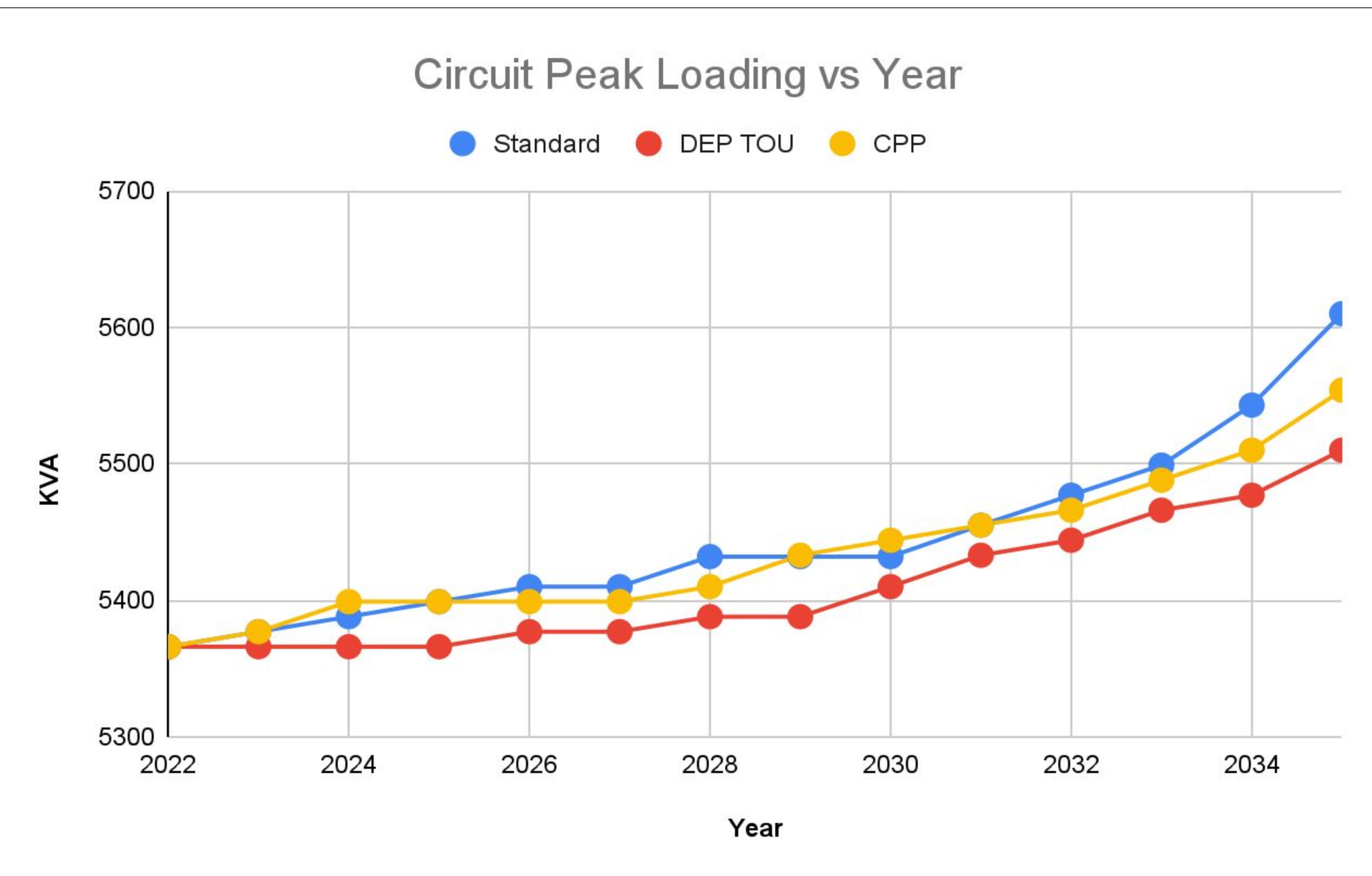CPP Event vs Non-Event EV Charging Behavior Summer 2023

Critical Peak: CPP customers reduce the likelihood of EV charging by an additional **49%** during critical peak hours compared to their usual behavior on non-event days.

Duke Energy Distribution Circuit Test Case Overview

- Circuit Overview
  - Real DEP Circuit in Jacksonville, NC (Onslow County)
  - Mostly Single-Phase Residential Customers
- Simulation Inputs
  - Standard, DEP TOU, CPP EV Charging Profiles
  - Forecasted EV Penetration
  - Address-Specific EV Allocation Using Property Tax Value
- Preliminary Simulation Results for a Single Simulation Iteration
  - Standard, DEP TOU, CPP
  - Circuit Peak Loading
  - Circuit Violations

Duke Energy Distribution Circuit Test Case
Standard, DEP TOU, CPP EV Profiles Charging Distribution

EV Charging Profile Distribution for NC May-September 2021-2023

Duke Energy Distribution Circuit Test Case
Forecasted EV Penetration

Forecasted EV Penetration for Jacksonville, NC (Onslow County) Duke Distribution Circuit
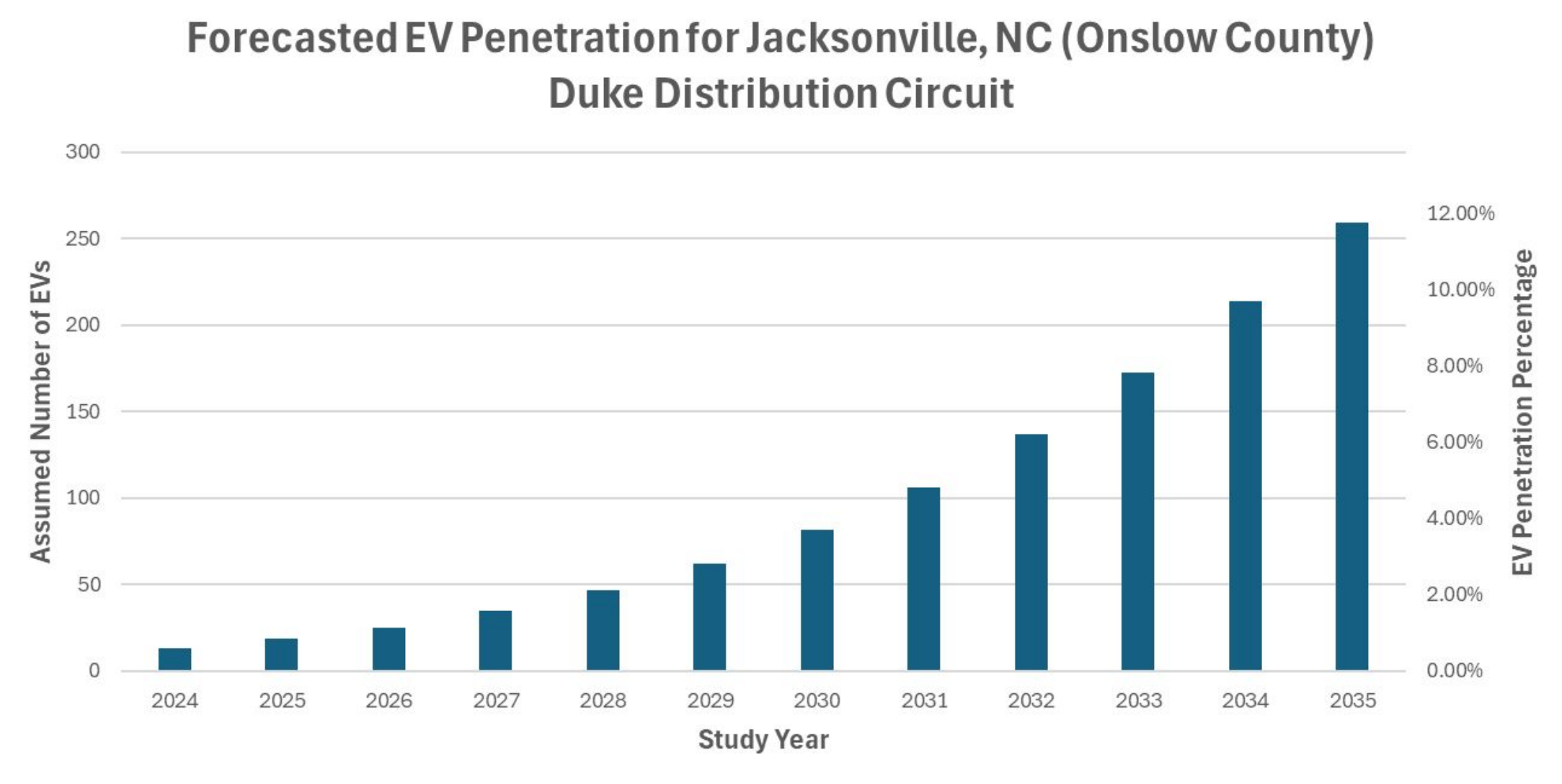
Duke Energy Distribution Circuit Test Case
Preliminary Peak-Loading Results

Circuit Peak Loading vs Year

Duke Energy Distribution Circuit Test Case
Preliminary Transformer Overloading Results

Customer Transformer Overloads Due to Addition of EVs

Duke Energy Distribution Circuit Test Case
Impact Study Phase III

Impacts to be considered:
- Circuit Peak loading
- Voltage violations
  - Max voltage deviation: 0.006 pu
- Transformer overloading
- Conductor overloading
  - Max loading: 45.8% (Base case)
  - Max loading: 48.1% (2035)
- Phase imbalance

Takeaways

- Customers clearly respond to TOU, CPP rates
  - They move out of the peak period
    - The shift results in off-peak timer peaks
    - Effects are strongest on CPP event days
- Load profiles show the highest charging for the hour ending at 1 am, 11 pm, and 2 am respectively under standard rates, TOU and CPP
  - Penetration reaches just over 11.5% by 2035 in Onslow County, NC
- By 2035, circuit peak loading is highest for standard rates, lowest for TOU
  - Customer transformer overloading is highest for standard rates, lowest for CPP;
  - Conductor overloading increases steadily, reaching 48.1% by 2035
- Steps remaining: Refine simulation code to generate results more efficiently. Evaluate Monte Carlo results for this circuit as well as other circuits with varying topologies and penetration levels.