

Electric Vehicles and the Energy Transition: Unintended Consequences of a Common Rate Design

Bailey, Brown, Myers, Shaffer & Wolak

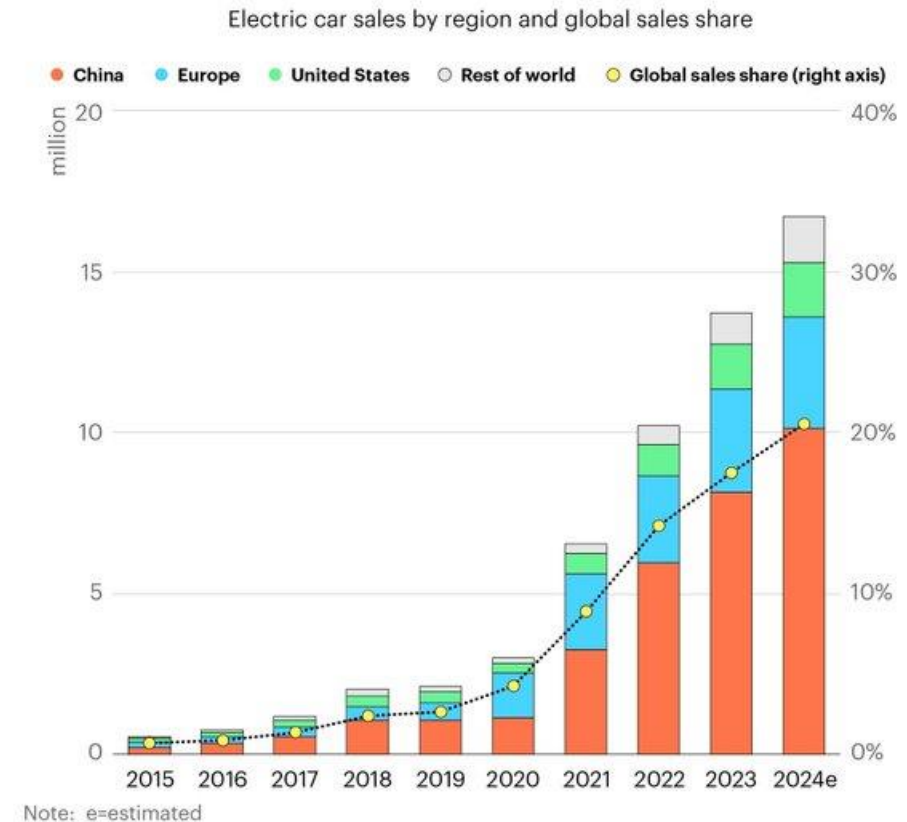
Feb 2025, Melbourne

Some motivating trends...

#1. Electric vehicle sales are rising

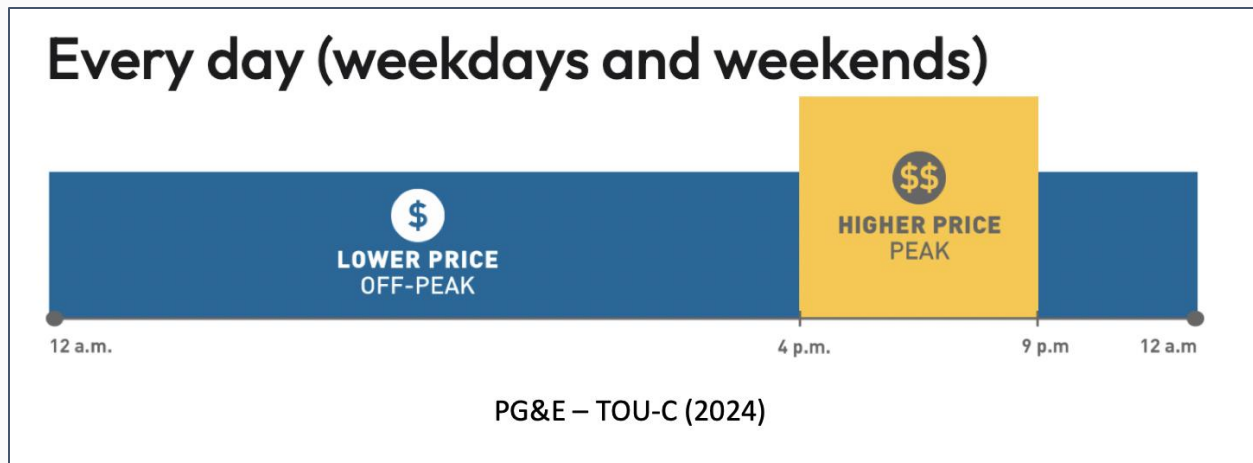
- EV sales continue to grow
- EV charging loads can be large
 - Level 2 (240V): 5-12kW
 - Compare to AC/Oven/Dryer: 1-4kW
- EV charge timing can be very flexible
(Bailey et al, 2024; La Nauze et al, 2024)
- Creates problems and opportunities

Global electric car sales are on track to grow strongly again this year, reaching about 17 million



#2. Increasing use of Time-of-Use (TOU) rates

- TOU is now the default rate in many US states
- Goal: Shift consumption away from peak demand periods



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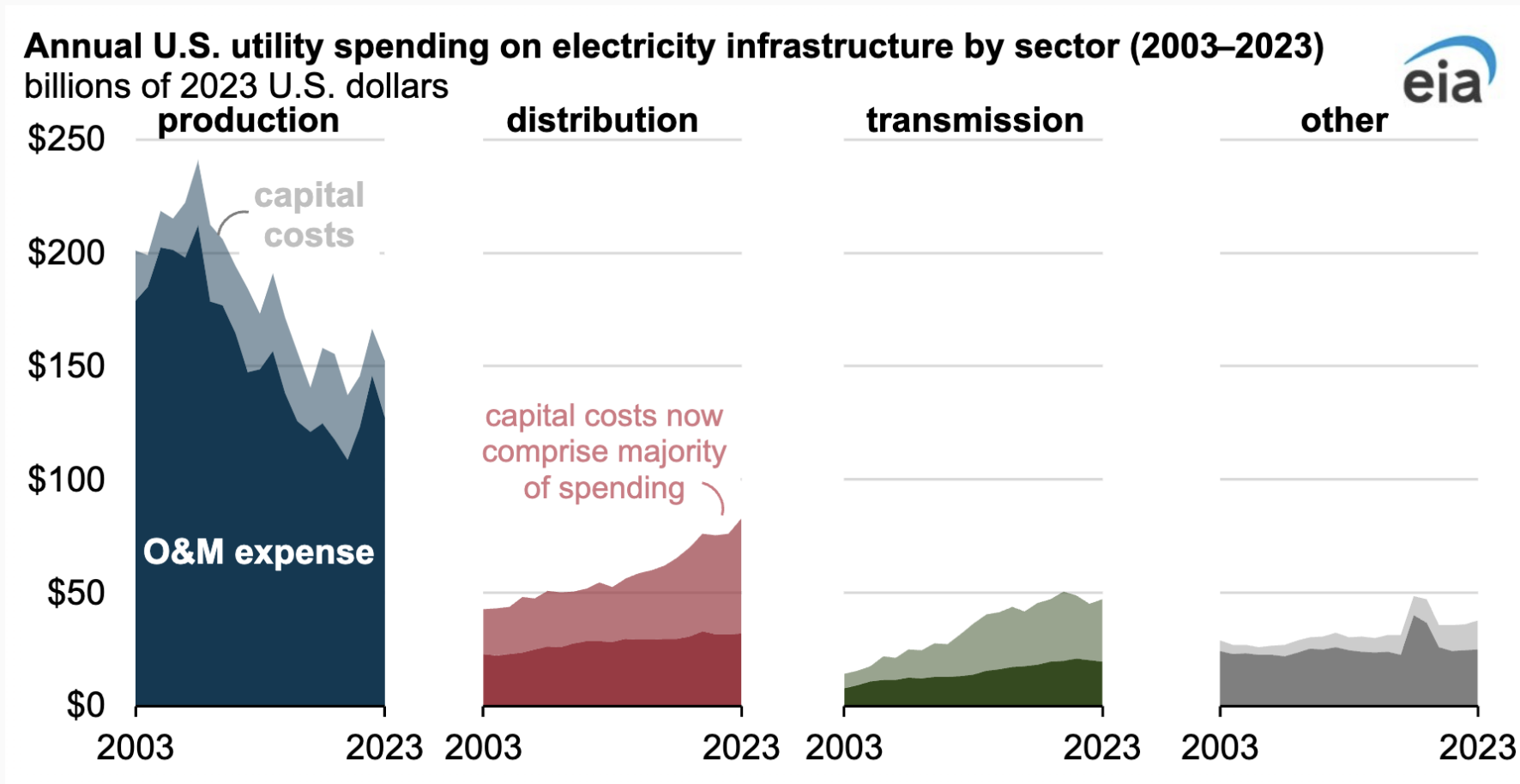
B.C. Hydro launches new optional time-of-day pricing

Customers who choose to use electricity during off-peak hours can save money by opting into the new rate system

Joseph Ruttle

Published Jun 06, 2024 • 2 minute read

#3. Distribution costs are rising



Capital spend on **distribution** now largest of all sectors

How will EVs affect the electricity system?

In terms of...

1. **Energy** (level of demand)
2. **Capacity** (timing of demand)

How will EVs affect the electricity system?

In terms of...

1. Energy (level of demand)
 2. Capacity (timing of demand)
- a. the bulk energy system
- b. local distribution systems

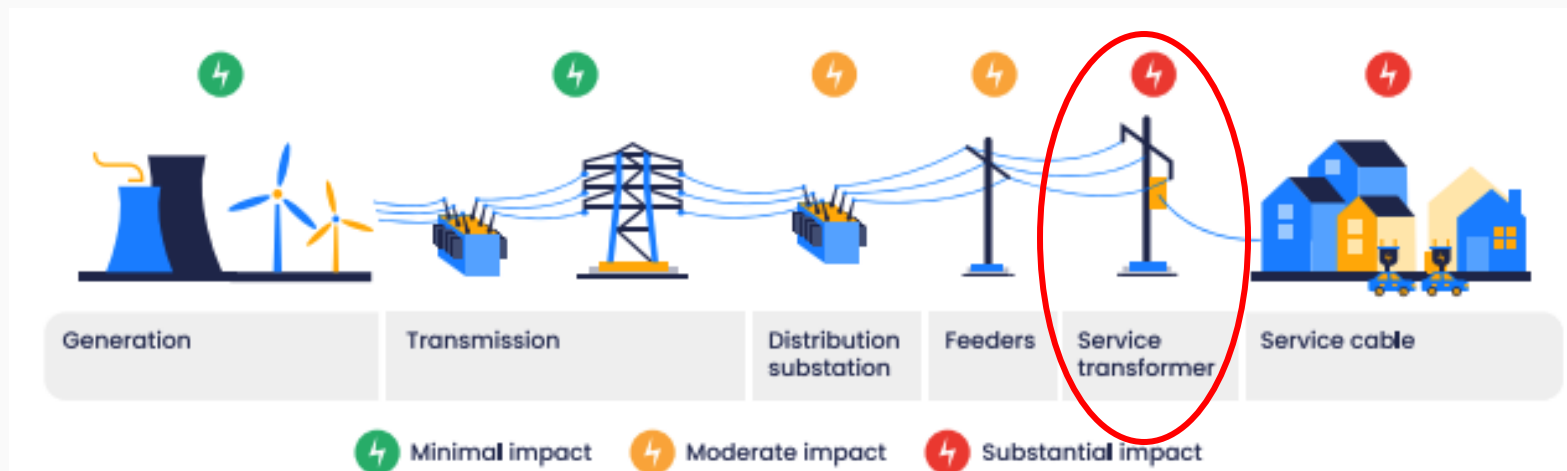
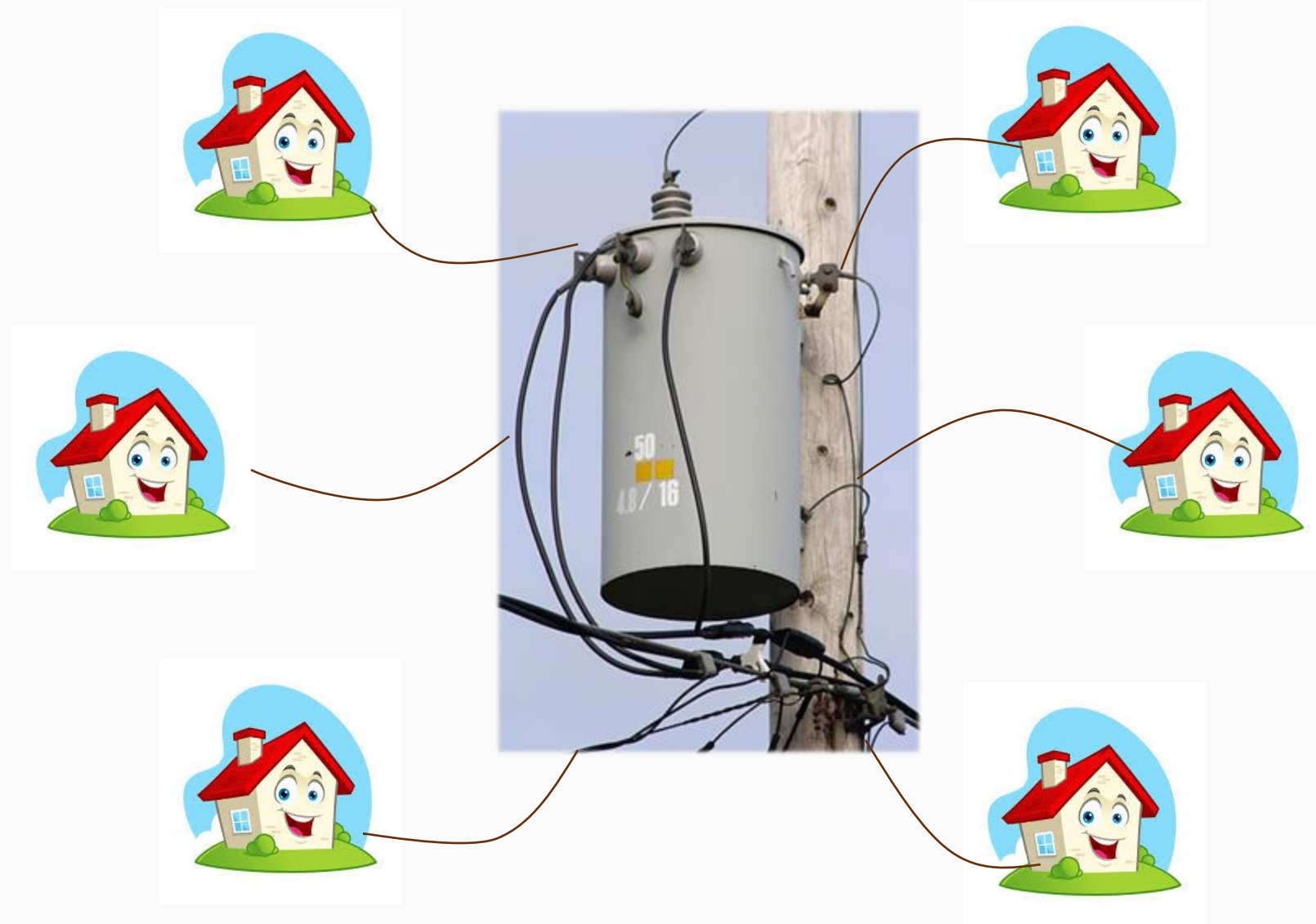


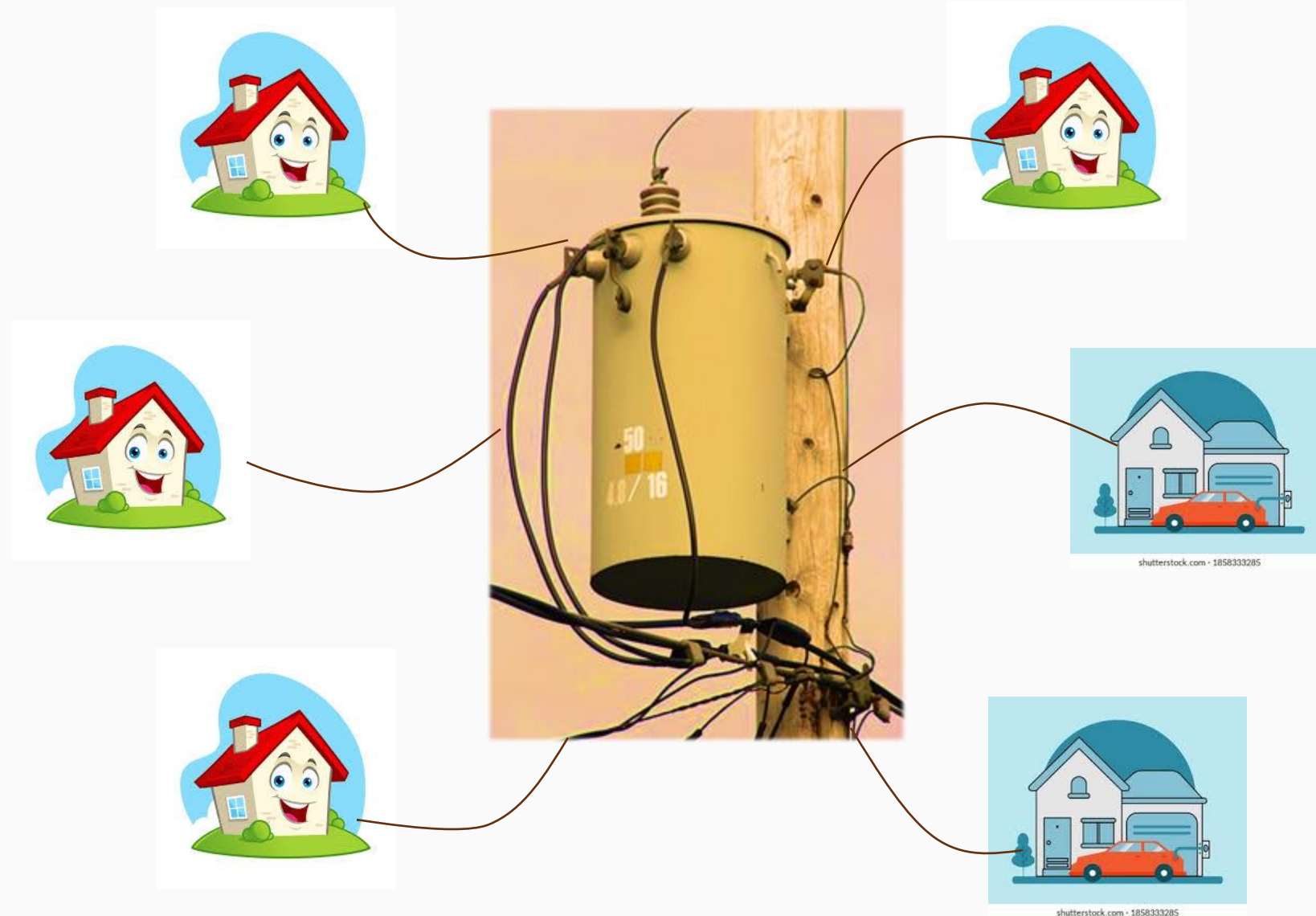
Image from EnergyHub (2023)

The mighty transformer....



- Residential transformer serves approx. 10 homes
- Steps down voltage to customers
- Last link in the distribution network before the customer
- Must be sized to meet aggregate downstream peak demand

The mighty transformer....



- Larger loads strain transformer capacity
- Made more challenging with geographically concentrated loads
- **NREL (2023) projects ~200% increase in transformer capacity required by 2050 due to electrification**

Our study

Research Questions

1. What is the impact of TOU pricing on EV charge timing?
2. What implication does this have on distribution infrastructure?
3. Are there ways to alleviate this pressure?

Preview of Results

1. What is the impact of TOU pricing on EV charge timing?
 - Large shift away from peak (-55%) to off-peak (+54%) charging
 - Charging concentrated at start of off-peak period
2. What implication does this have on distribution infrastructure?
 - TOU induces new and larger “shadow peaks”
 - +139% increase in transformer capacity violations in off-peak
3. Are there ways to alleviate this pressure?
 - Managed charging: systematically reduces constraint violations by spreading charging over spare network capacity

The Field Experiment

What we do

- Partnered with **FortisAlberta**, a local distribution company in suburban Alberta, Canada
- Worked with **Optiwatt**, a software “app” company
- Recruited approx. **200 EVs**
- Monitor all vehicles’ charging behaviour pre-intervention and then **randomize** to treatment arms

The Treatment Groups

1. Control

- no additional messaging

2. TOU

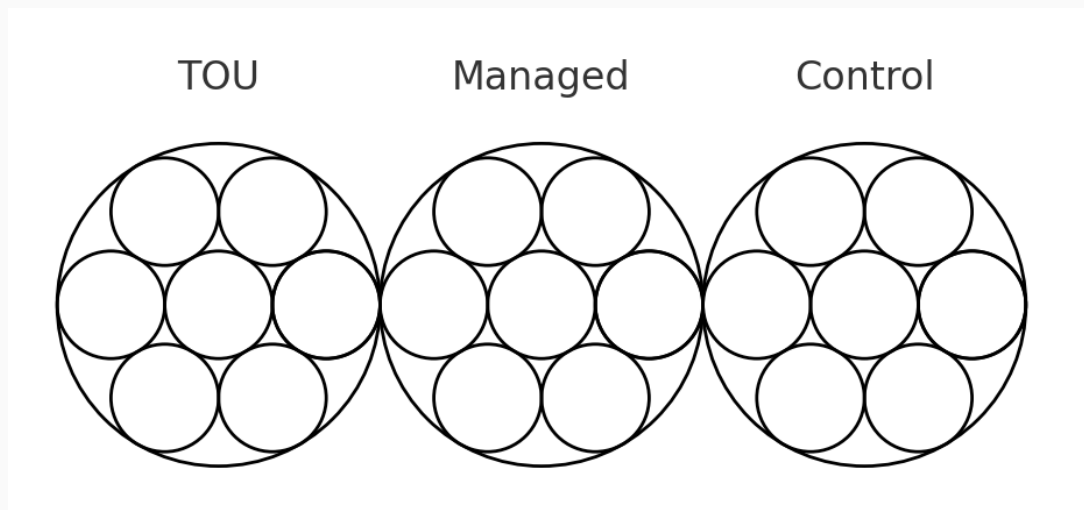
- receive 3.5c/kWh reward for all off-peak charging (Off-peak: 10 AM - 2 PM; 10 PM - 6 AM)

≈ 20% rate reduction

3. Managed Charging

- receive a 3.5 ¢/kWh reward for all *managed charging* at home
- EV drivers set desired departure time and state-of-charge
- Optiwatt *sequences* charging to:
 - satisfy charging preferences
 - remain within available transformer capacity
- EV owner can override by pushing “Charge Now” button on app

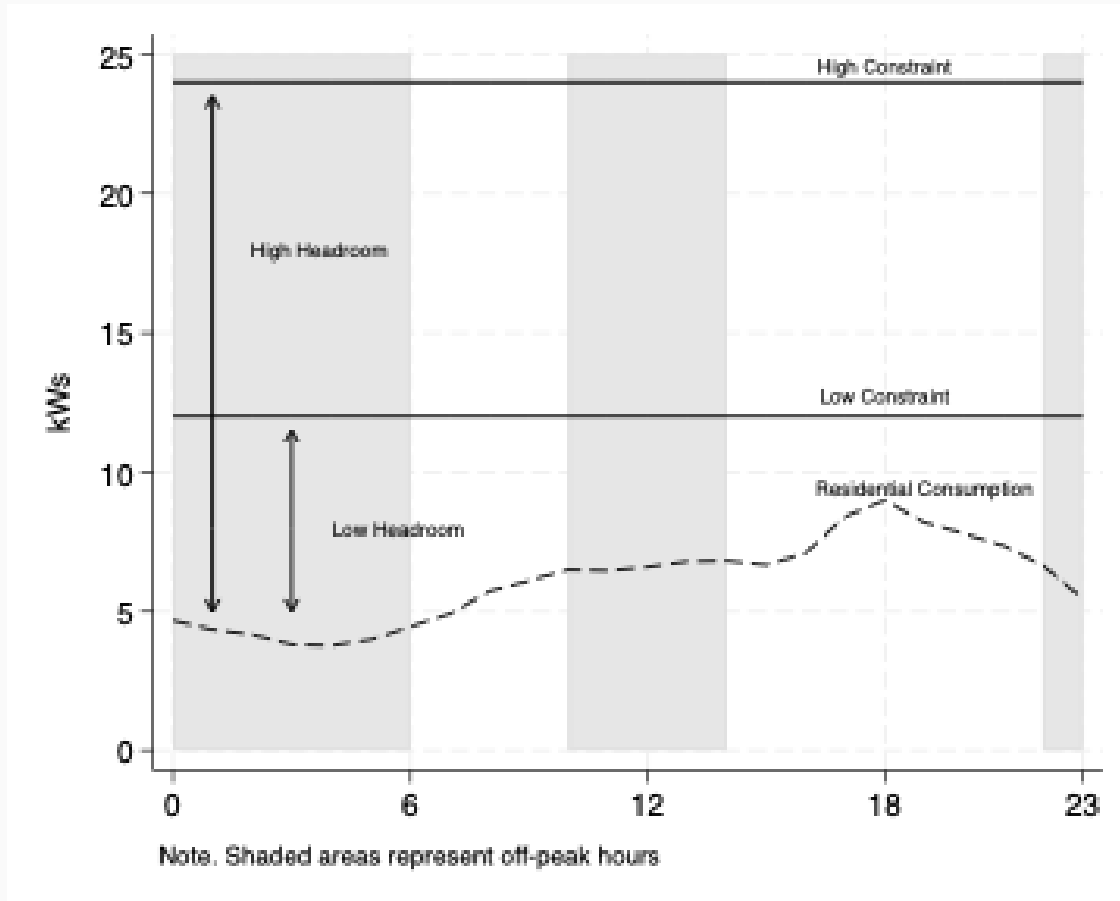
“Virtual transformers”: Going beyond individual behaviour



- Further randomize into **sets of 10 EVs** within treatment arms
- Monitor aggregate loads on each “**virtual transformer**”
- Assign capacity limits for virtual transformers
- Key metric: ***Violations of virtual transformer constraints***

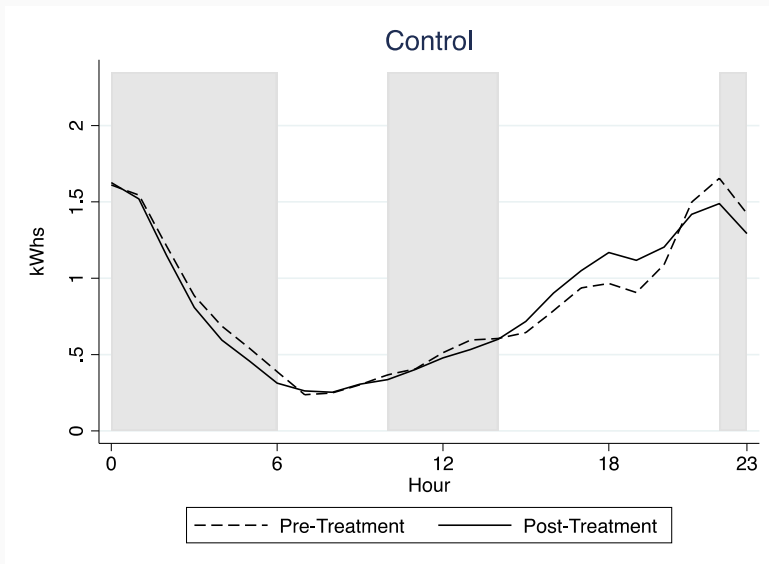
Transformer constraints and charging headroom

- Randomize a *range* of capacity constraints
- Use representative non-EV load shape
- Headroom = transformer capacity – non-EV load
- Sized to allow for a range of potential headroom for EV charging



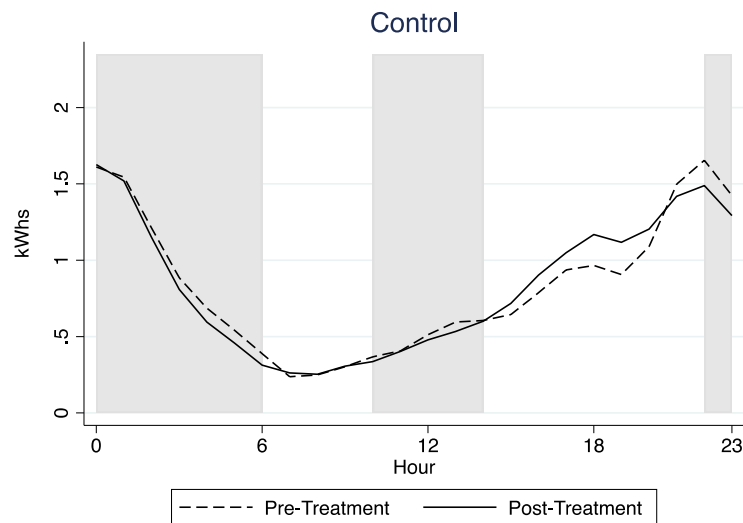
What we find

Average Hourly Load Shape

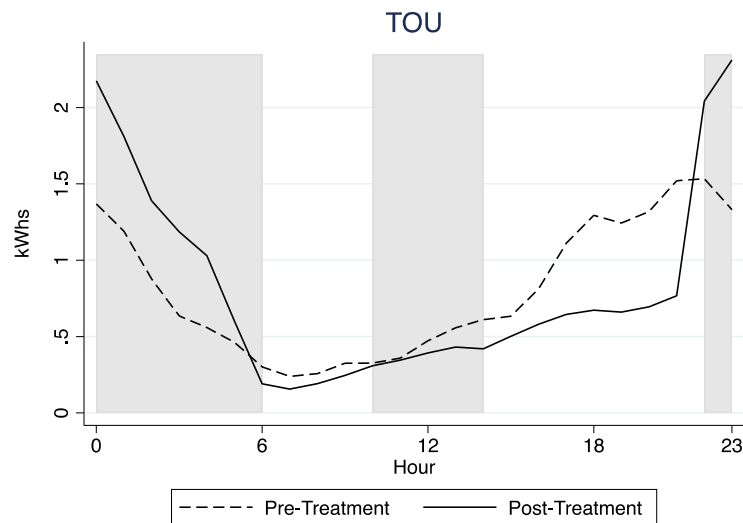


- No change to **Control**

Average Hourly Load Shape

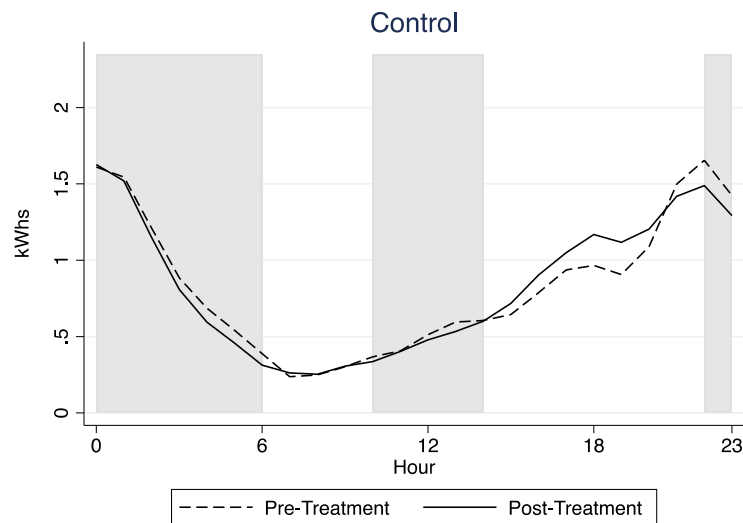


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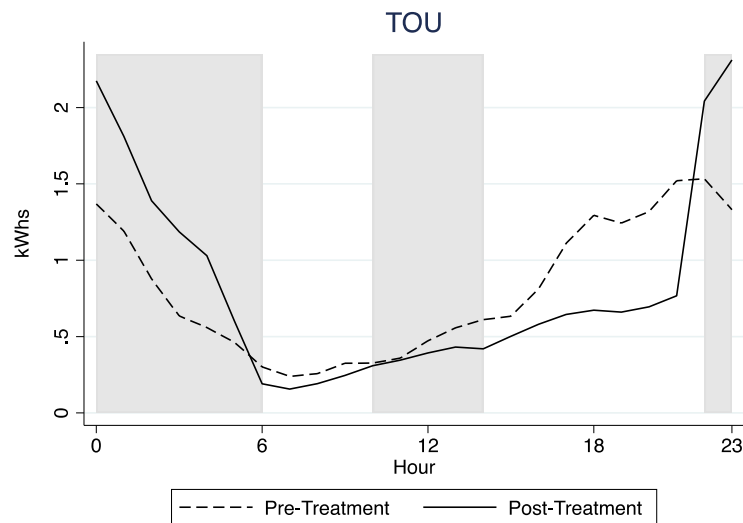


- Large shift to **TOU** shape

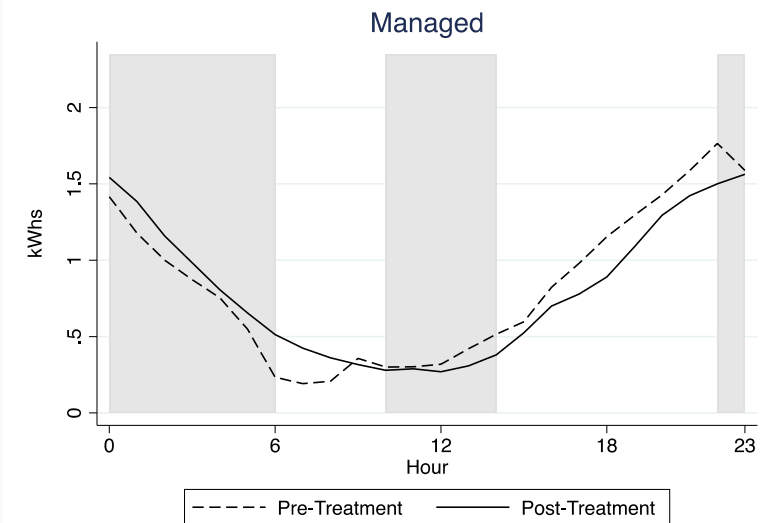
Average Hourly Load Shape



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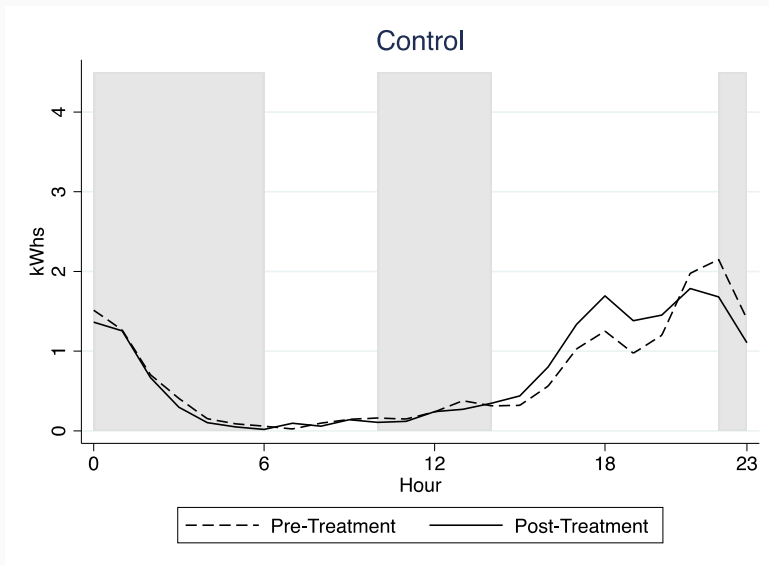


- Large shift to **TOU** shape



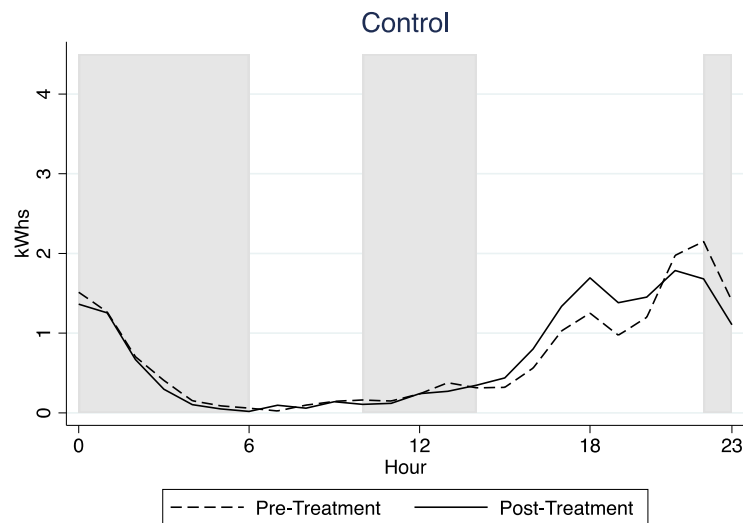
- No change to **Managed** shape

Average Hourly Transformer Violations

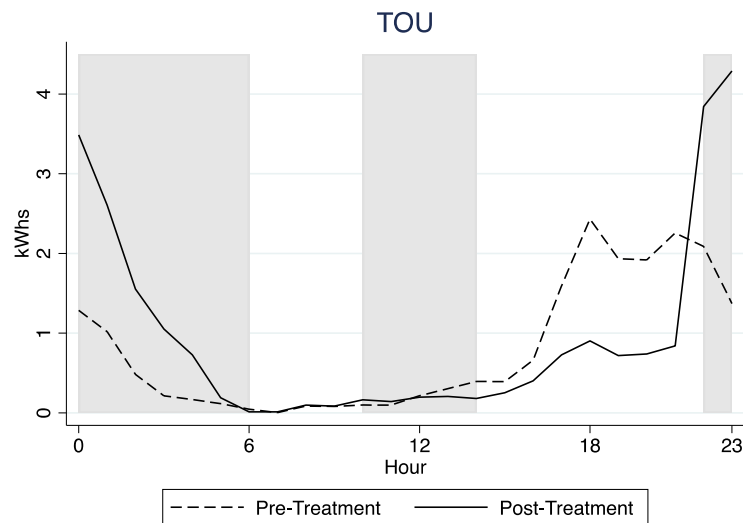


- No change to **Control**

Average Hourly Transformer Violations

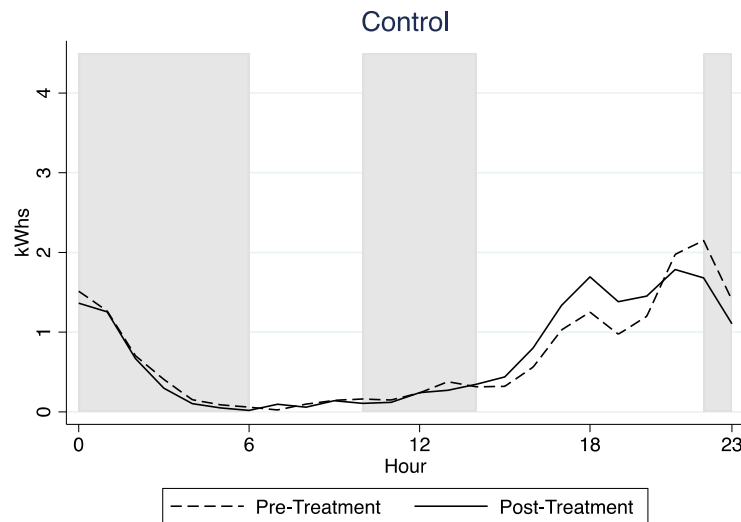


- No change to **Control**

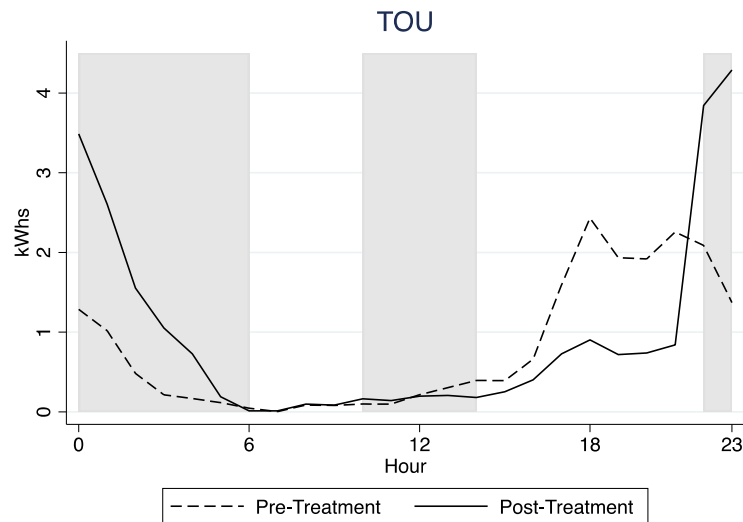


- Larger violations for **TOU**
- New “shadow peak” is greater than prior peak

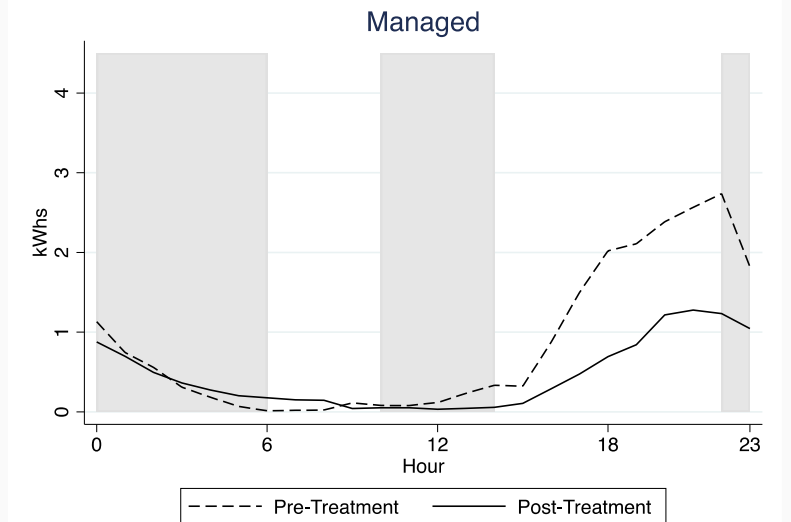
Average Hourly Transformer Violations



- No change to **Control**



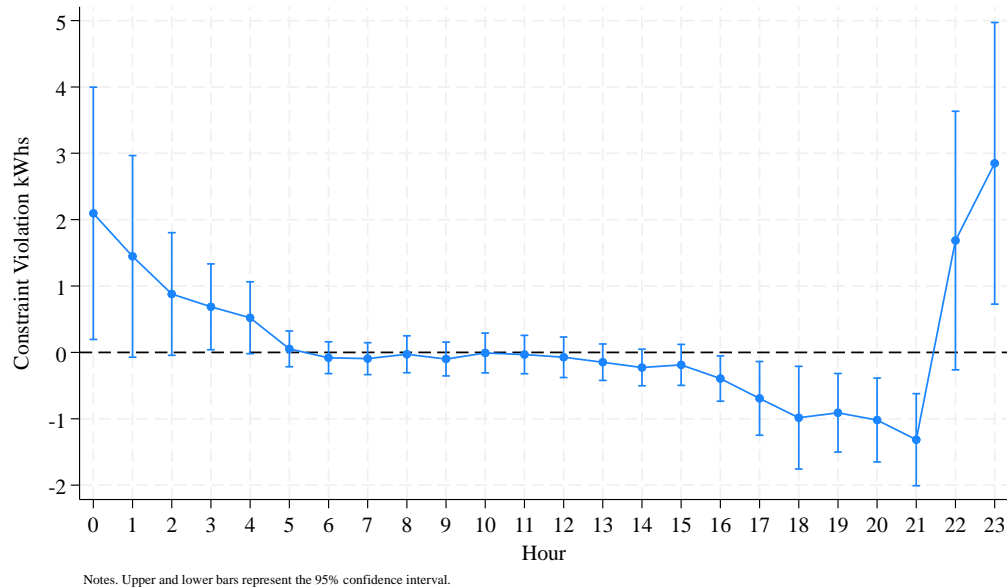
- Larger violations for **TOU**
- New “shadow peak” is greater than prior peak



- Reduced violations for **Managed**

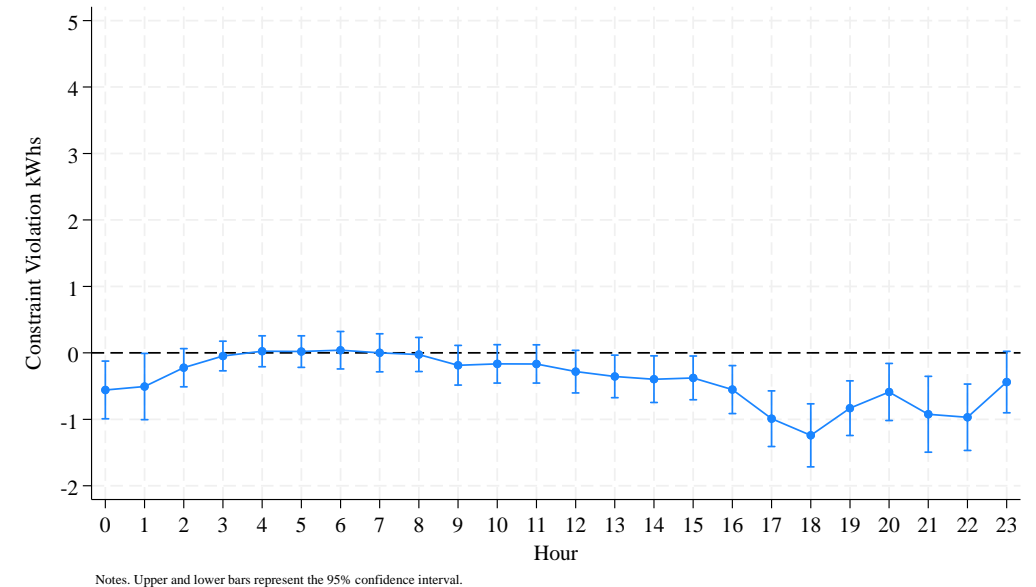
Regression Results: Constraint violations

TOU Group



- Increased violations in off-peak
- Slight reduction in peak

Managed Group







- Reduced violations in most hours

Willingness to accept managed charging



- 1. Intensive margin (charging control)**
 - Out of 5,743 managed charging events, we observe 44 “overrides” (~1%)
- 2. Extensive margin (exiting)**
 - Attrition rates were similar across TOU and managed groups
- 3. Extensive margin (joining)**
 - At end of pilot, offers made to control group to join managed charging program with various incentives (\$0, \$75, \$150)
 - 34/35 respondents opted to join (rejector was part of \$0 group)

Summary of Main Findings

Time-of-Use:

- Effective at shifting charge timing
 - Peak charging  55%
 - Off-peak charging  54%
- But... ***TOU increases transformer violations!***
 - Peak violations  47%
 - Off-peak violations  139%

Managed Charging:

- Reduces transformer violations by spreading charging more evenly
 - Peak violations  49%
 - Off-peak violations  45%
- Limited “boosting”
 - Less than 1% of charge-days over-ridden by EV owners

Key Implications

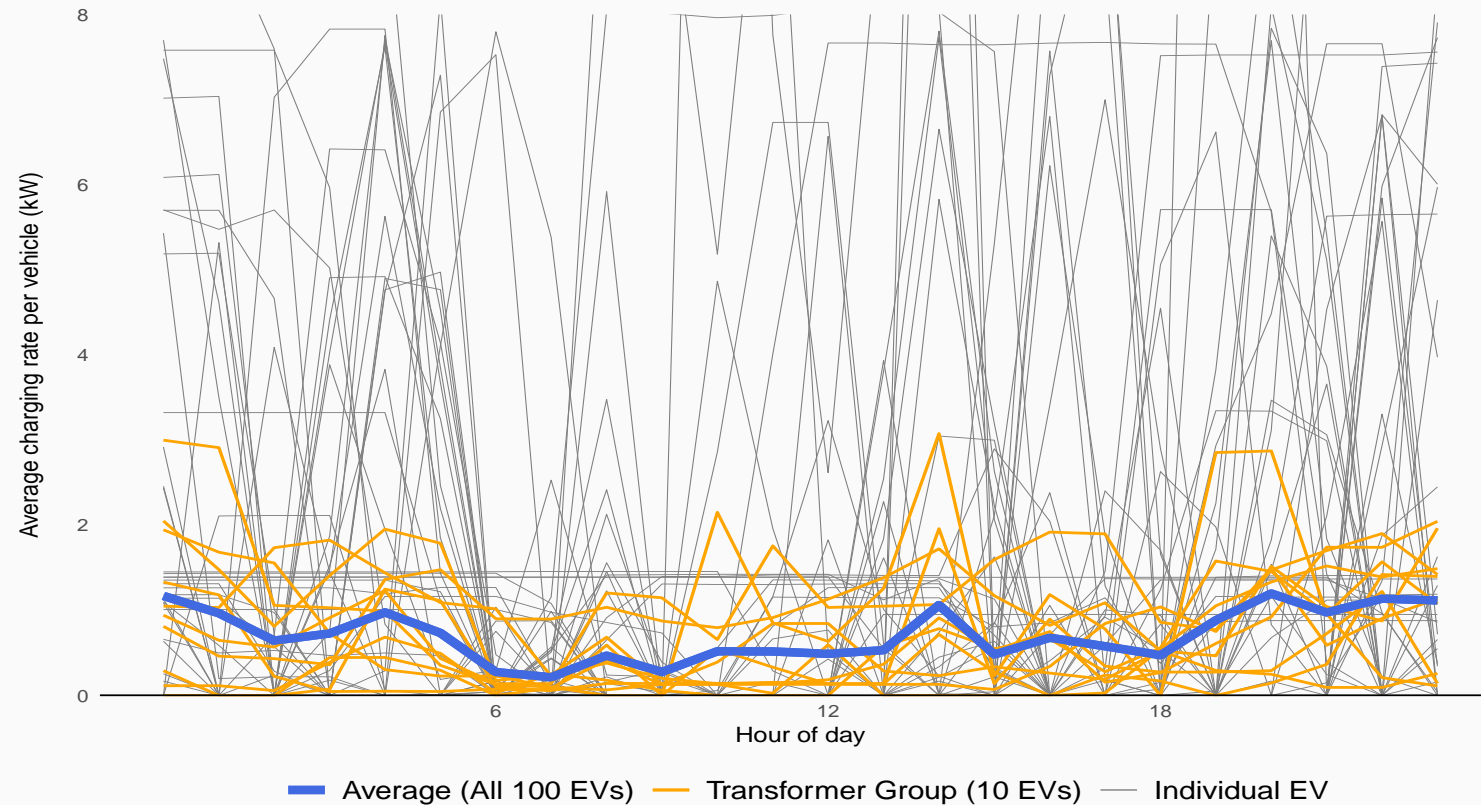
1. Why is this “unintended consequence” more of an issue with EVs?
 - *Big power draw and very flexible (leading to greater correlation)*
2. Need to rethink TOU as a solution to EV charging
 - *Likely to **increase** distribution costs with large EV adoption!*
3. Dynamic (“hourly”) pricing makes it worse
 - *Concentrates charging into narrower time window, further increases correlation*
4. Pricing solution requires more complex prices
 - *Household-time specific and real-time updating*
5. Managed charging can resolve the coordination challenge
 - *... but how to get people comfortable with it?*

Thank you!

Questions?

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Load profiles become more *irregular* at smaller aggregations



- Picture for a single day
- *Diversity factor* decreases at smaller aggregations
- Individual profiles are extremely erratic; average is smoothed