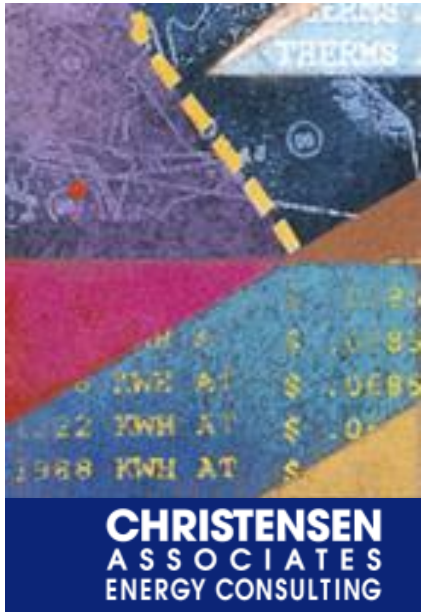

Residential Customer Response to Electric Vehicle Time-of-Use Rates

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Presentation Outline

- Introduction
- SDG&E Time-of-Use (TOU) Rate Overview
- Challenge in estimating EV customer demand response
- Method of identifying EV adopters
- Estimated EV-TOU load impacts

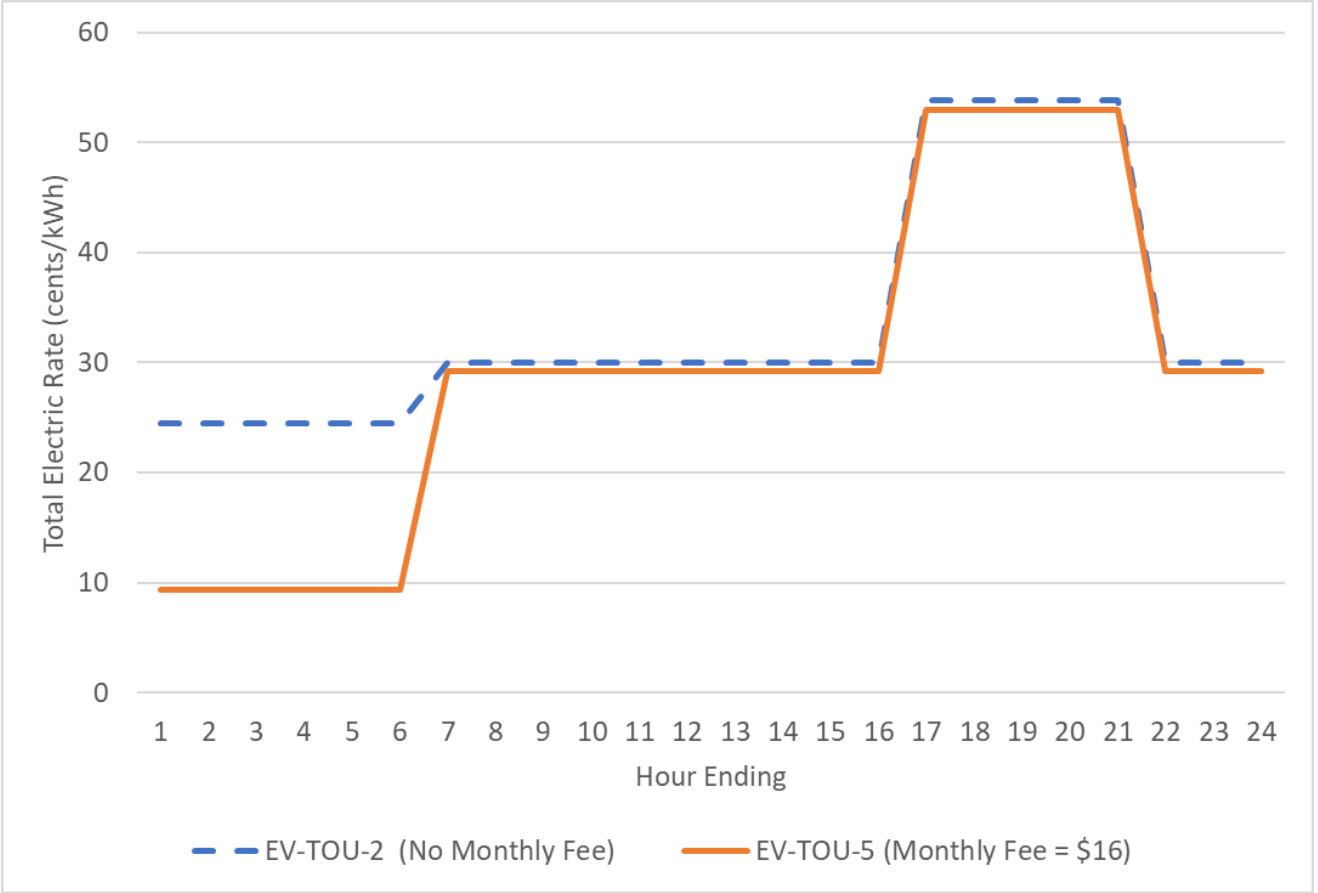
SDG&E's Residential and EV Rates

Rate	Need an EV	TOU	Tiered	Whole House	Super Off-peak	Monthly Fee	CPP
DR			X	X			
TOU-DR-2		X	X	X			
TOU-DR-1		X	X	X	X		
TOU-DR-P		X	X	X	X		X
EV-TOU	X	X			X		
EV-TOU-2	X	X		X	X		
EV-TOU-5	X	X		X	X	X	

- EV-TOU: EV-only rate that requires a separate meter
- Focus on EV-TOU-2 and EV-TOU-5 (both whole-house rates)
  - Key difference: EV-TOU-5 has a lower super off-peak rate (~15 cents/kWh lower than EV-TOU-2) in exchange for a $16/month Basic Service Fee
  - On-peak period from 4 to 9 p.m. every day
  - Super off-peak period from midnight to 6 a.m. on non-holiday weekdays; 10 a.m. to 2 p.m. on March and April non-holiday weekdays; midnight to 2 p.m. on weekends and holidays
  - Rates are seasonally differentiated

Focus on EV-TOU-2 and EV-TOU-5

- EV-TOU-5 opened later (in 2018)
- Same pricing periods, both are whole-house rates
- EV-TOU-5 rates are lower, but it includes a $16/month Basic Service Fee
- 9 cents/kWh from midnight to 6 a.m. on EV-TOU-5



EV Customer Response to TOU Pricing

- Two types of demand response may be of interest
- Do EV customers change their usage behavior when they change from EV-TOU-2 to EV-TOU-5?
  - Will EV-TOU-5 customers tend to shift charging into the Super Off-Peak period?
  - Will lower overall rates affect total usage?
- Do EV customers change their usage behavior when they change from the standard tiered rate (Schedule DR) to EV-TOU-2 or EV-TOU-5?
  - Do customers shift usage from high- to low-cost pricing periods?
  - Does the absence of tiered rates affect the overall usage level?

Challenge of Estimating EV Customer Response to TOU Pricing

- Want to estimate how an EV customer changes behavior in response to a rate change
- This can be done via a differences-in-differences analysis, for example:
  - Obtain data before and after EV customers switched from the tiered rate to a TOU rate (the "treatment" customers)
  - Match the treatment customers to "control-group" EV customers, who remain on the tiered rate for the entire analysis period
  - Estimate EV-TOU load impacts as the difference between treatment and control-group customer loads during the treatment period, adjusting for the difference in their loads during the pre-treatment period
- Problem: SDG&E does not know when a customer acquires and begins charging an EV

Need to Know When EV Charging Begins: Get EV and adopt TOU at the same time

Pre-treatment period

Treatment period

On Tiered Rate

On EV-TOU-2 or EV-TOU-5

Get EV and switch to EV-TOU at the same time

Time

In this case, you can't disentangle changes in usage due to beginning charging the EV and switching to the TOU rate because they happen at the same time.

Need to Know When EV Charging Begins: Adopt TOU after owning EV for some time

Pre-treatment period

Treatment period

On Tiered Rate

On EV-TOU-2 or EV-TOU-5

Get EV, take service on tiered rate, then switch to EV-TOU

Time

In this case, you have information about their EV usage under the tiered rate, so you can estimate the effect of switching to the TOU rate.

No Problem for EV-TOU-2 to EV-TOU-5 Switchers

Pre-treatment period

Treatment period

On EV-TOU-2

On EV-TOU-5

Get EV and take service on EV-TOU-2 for a time, then switch to EV-TOU-5

Time

Because you know the customer had an EV while on EV-TOU-2, the effect of changing to EV-TOU-5 can be estimated without confounding effects of EV adoption

But Tiered Rate to EV-TOU Switchers Could Have Had an EV at Any Point

Pre-treatment period

Treatment period

On Tiered Rate

On EV-TOU-2 or EV-TOU-5

Time

Can observe when the rate change occurred, but not when EV charging began

Because you don't know when the customer began charging an EV, you can't distinguish between the effects of EV adoption and TOU rate adoption

EV-TOU Analysis Issues Summary

- Time period definitions
  - Pre-treatment year = October 2017 through September 2018
  - Treatment year = October 2018 through September 2019
- EV-TOU-2 to EV-TOU-5 switchers
  - Treatment group consists of customers who switched from EV-TOU-2 to EV-TOU-5 during the treatment year, who were enrolled in EV-TOU-2 during the entire pre-treatment year
  - Control group consists of customers who were enrolled in EV-TOU-2 for the entire pre-treatment and treatment years
  - Load impacts are estimated using difference-in-differences:

    Load Impact = $(T_1 - C_1) - (T_0 - C_0)$

EV-TOU Analysis Issues Summary (2)

- Tiered rate to EV-TOU-2 or EV-TOU-5
  - Separate analyses for EV-TOU-2 and EV-TOU-5
  - Treatment group consists of customers who switched from the tiered rate to EV-TOU-2 or EV-TOU-5 during the treatment year, who were enrolled in the tiered rate during the entire pre-treatment year
  - There is no control group, as we don't have information about EV ownership for customers on non-EV rates
  - Load impacts are estimated as before vs. after within treatment group, controlling for weather effects

    Load Impact = $(T_1 - T_0)$
  - **Hard part: all treatment customers must have an EV during the entire analysis period**

How to Identify EV Ownership?

- As mentioned earlier, SDG&E does not comprehensively track EV ownership of its customers
- However, SDG&E restricts its EV-TOU rates to customers with a plug-in EV
- So we know that a customer served on EV-TOU-2 or EV-TOU-5 had an EV during that time, we just need to confirm they had one while they were on the tiered rate during the pre-treatment period
- We do this via statistical tests for a **structural break** in the customer's usage data

Testing for a Structural Break

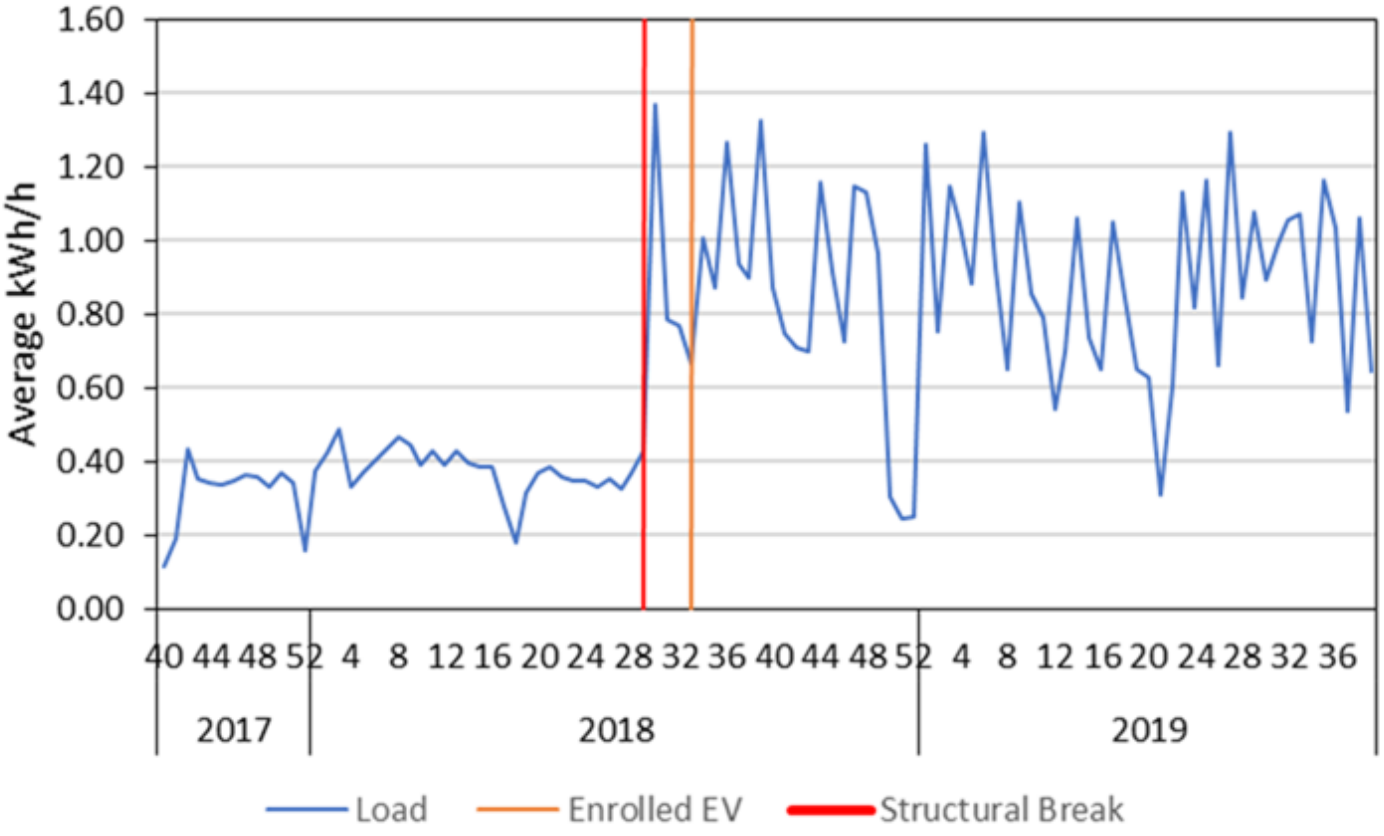
- Develop customer-specific data consisting of weekly total usage
- Estimate customer-specific models of weekly usage as a function of cooling and heating degree days and month indicator variables
- Conduct a Wald test for every possible structural break date (the weeks in the model) using the model's residuals
- That is, the model is trying to find the date where there's the biggest before/after difference in what the model *can't* explain
- Record the date with the most likely structural break (i.e., largest Wald value) and retain the test statistic

Which Customers are Retained for the Analysis?

- The model keeps customers for whom we **cannot** identify a statistically significant structural break in their usage data
- That is, we'd expect an EV adopter to see a significant increase in total usage due to charging
- If that occurs during our sample timeframe, our method should be able to identify a statistically significant structural break in the usage data
- When we can't identify such a break and we know the customer had an EV at some point (because they were on an EV-TOU rate), we infer they had an EV during the entire analysis period

Example Customer, Screened Out Due to EV Adoption

This customer was rejected from the EV-TOU load impact study because the model identifies a statistically significant structural break in their usage data

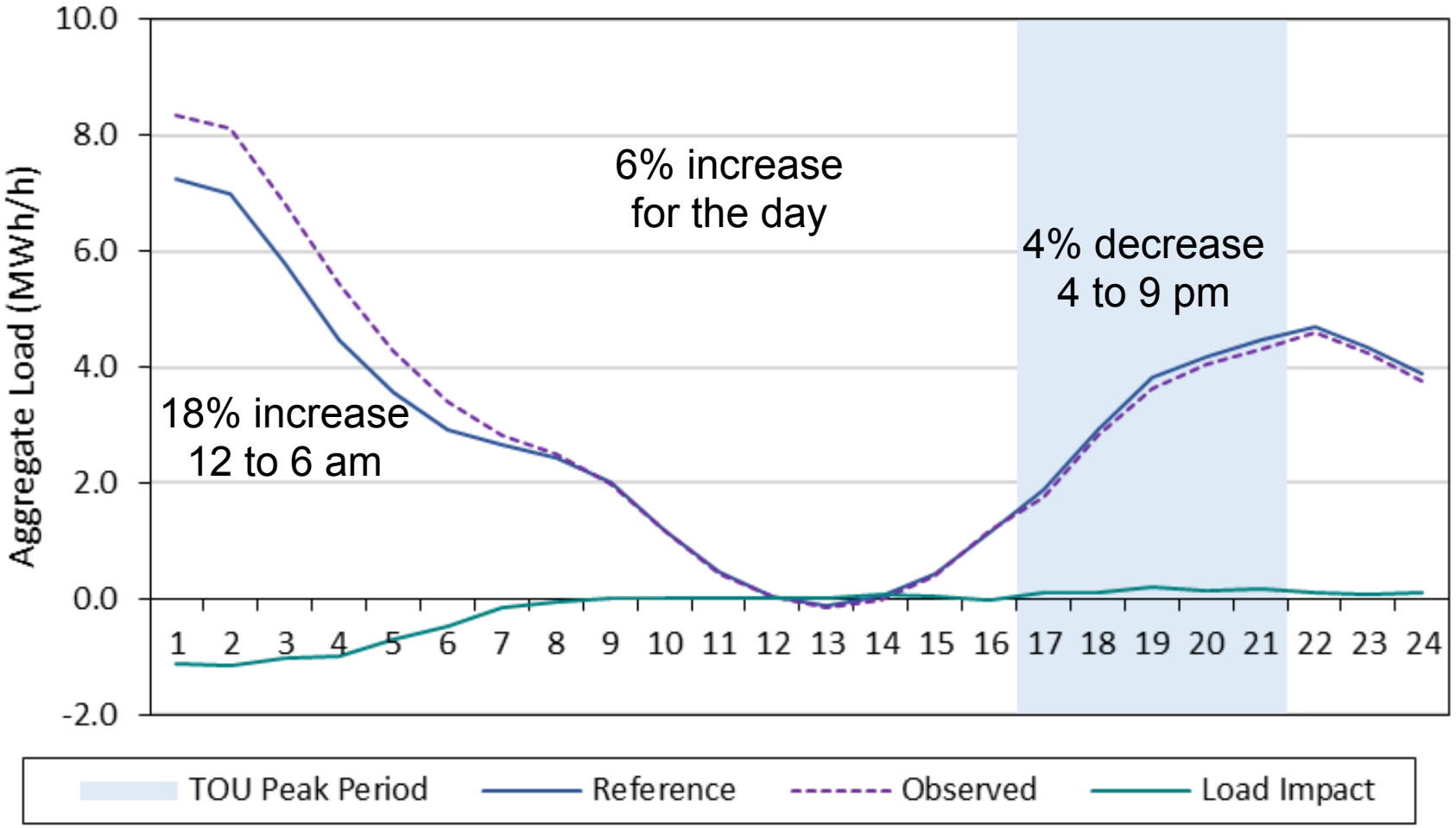


Estimated Load Impacts

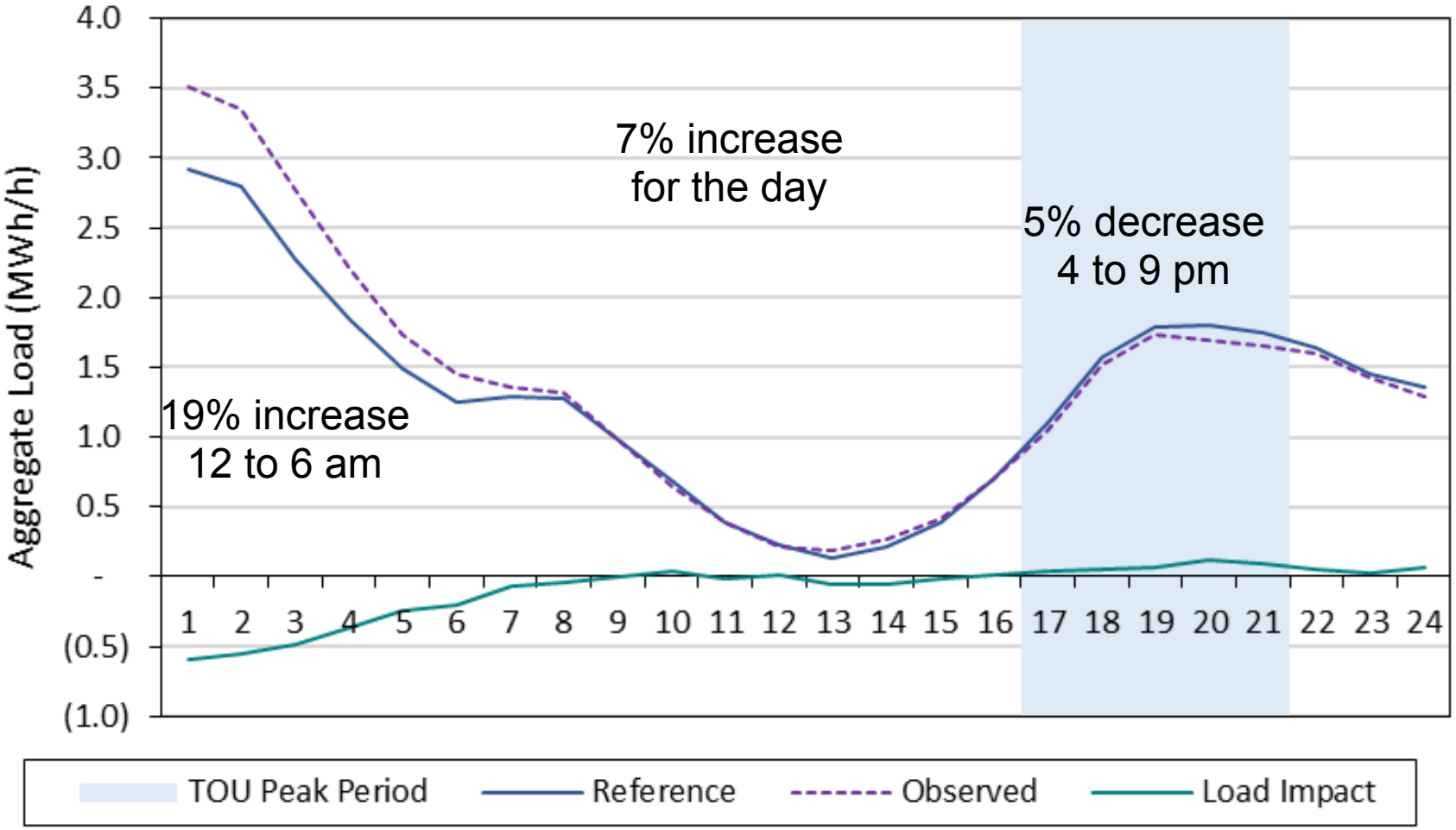
EV-TOU-2 to EV-TOU-5 Switchers

- Recall that EV-TOU-5 has somewhat lower energy rates overall and a much lower rate during the Super Off-Peak period (midnight to 6 a.m.)
- Estimates show that after switching to EV-TOU-5, customers
  - Use much more in the Super Off-Peak period
  - Use somewhat less during the On-Peak period
  - Increase total daily usage

EV-TOU-2 to EV-TOU-5 Switchers: August 2019 Average Weekday



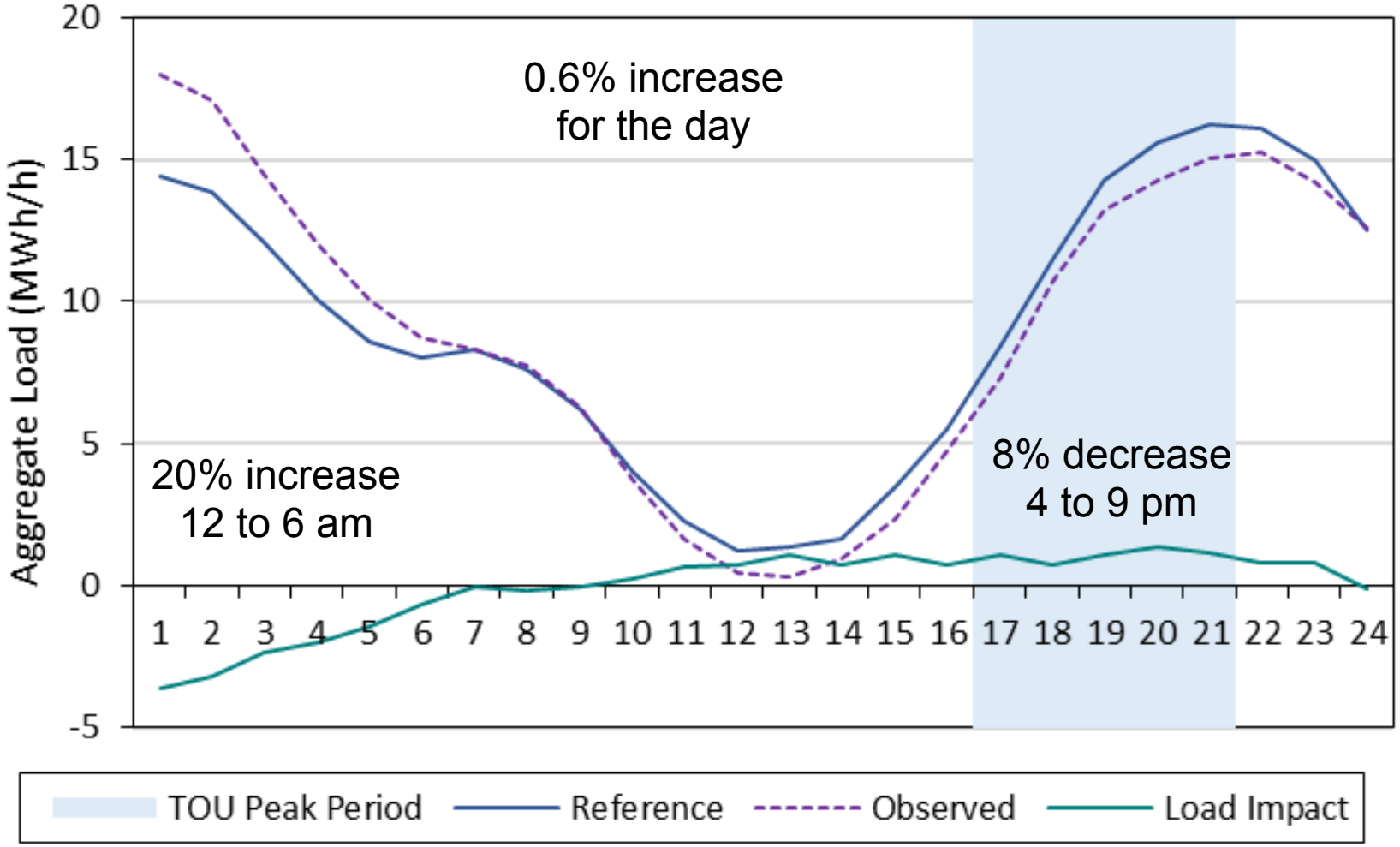
EV-TOU-2 to EV-TOU-5 Switchers: January 2019 Average Weekday



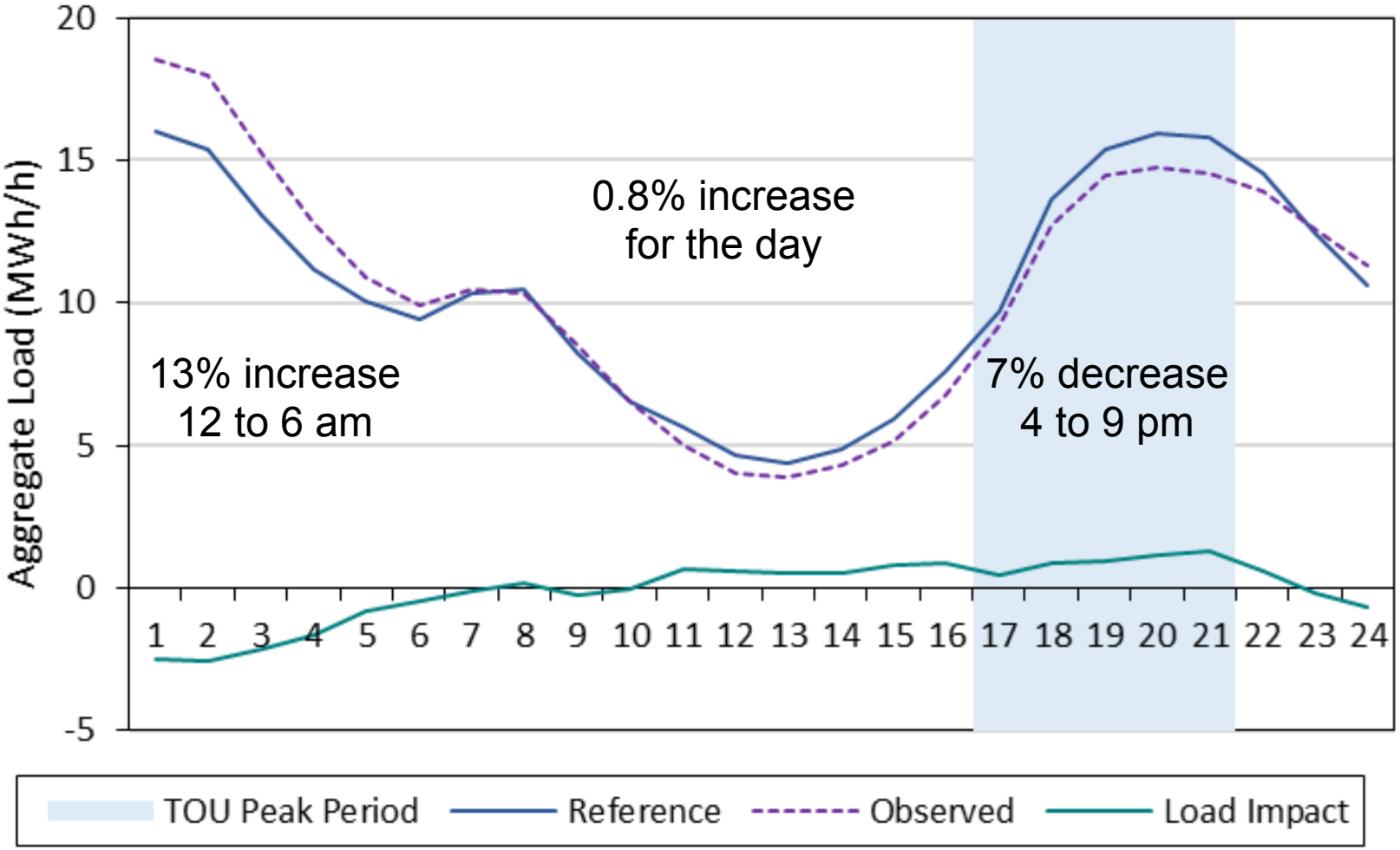
Tiered Rate to EV-TOU-2

- Relative to the standard tiered rate, EV-TOU-2:
  - Has no tiered component (rate does not vary with total billing-month sales)
  - Has prices that vary by time of day (versus the same all day)
- Estimates show that after switching to EV-TOU-2, customers
  - Use much more in the Super Off-Peak period
  - Use somewhat less during the On-Peak period
  - Display minimal change in total daily usage

Tiered Rate to EV-TOU-2: August 2019 Average Weekday



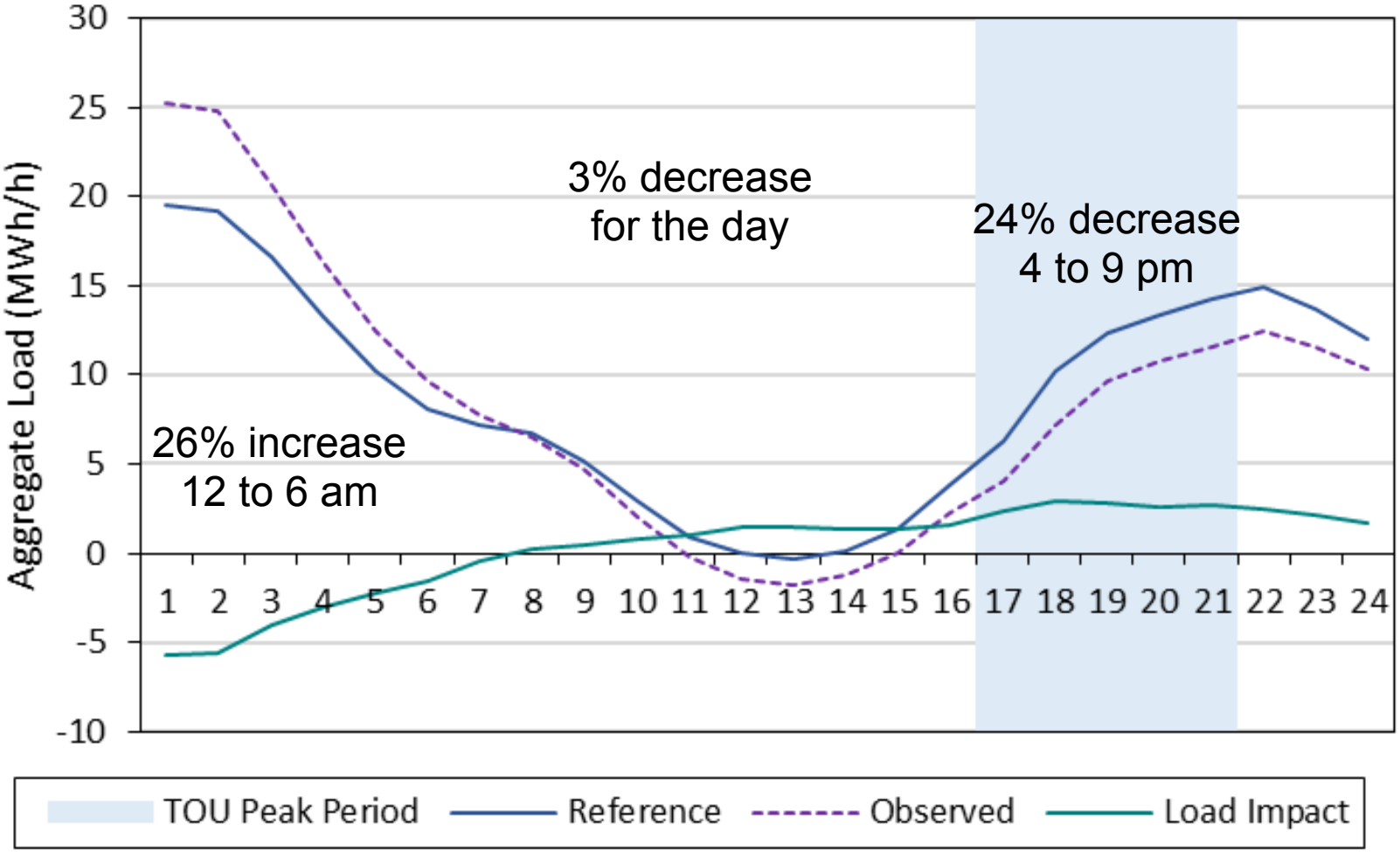
Tiered Rate to EV-TOU-2: January 2019 Average Weekday



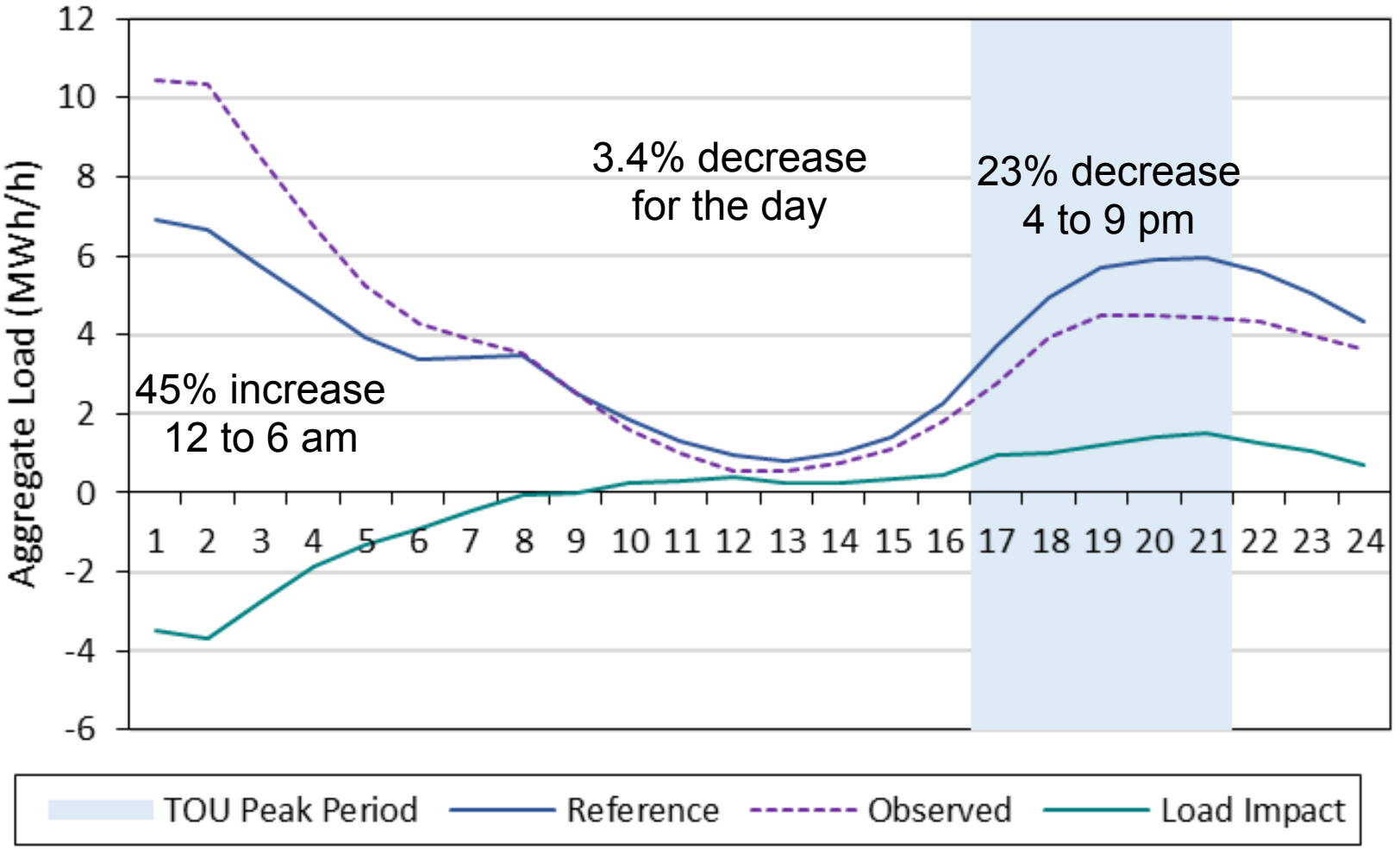
Tiered Rate to EV-TOU-5

- Relative to the standard tiered rate, EV-TOU-5:
  - Has no tiered component (rate does not vary with total billing-month sales)
  - Has prices that vary by time of day (versus the same all day)
  - Introduces a monthly Basic Service Fee of $16
  - Reduces energy prices relative to EV-TOU-2 in exchange for Basic Service Fee
- Estimates show that after switching to EV-TOU-5, customers
  - Use much more in the Super Off-Peak period
  - Use less during the On-Peak period
  - Display mixed results regarding the change in total daily usage

Tiered Rate to EV-TOU-5: August 2019 Average Weekday



Tiered Rate to EV-TOU-5: January 2019 Average Weekday



Comparison Across Rates

- The table below summarizes per-customer reference loads and load impacts by rate and pricing period for August 2019
  - Positive load impact = load reduction
  - Negative load impact = load increase

Group	On-Peak Period			Super Off-Peak Period		
	Reference Load (kWh/ hr)	Load Impact (kWh/hr)	% Impact	Reference Load (kWh/hr)	Load Impact (kWh/hr)	% Impact
EV-TOU-2 to EV-TOU-5	1.53	0.06	4.2%	2.29	-0.40	-17.5%
Tiered to EV-TOU-2	1.62	0.13	8.2%	1.38	-0.27	-19.9%
Tiered to EV-TOU5	1.56	0.37	23.6%	2.00	-0.51	-25.7%

Summary

- The results appear to reflect success in identifying EV adopters vs. those who had an EV during the entire analysis timeframe
- Time-of-use pricing appears to be very effective at moving EV charging into overnight hours (midnight to 6 a.m.)
- The magnitude of customer response increased with the TOU price differential

Questions?

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