Unlocking flexible electricity demand

Evidence from 3 field experiments

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The electricity system of the past involved forecasting demand and dispatching supply; the grid of the future will increasingly involve forecasting supply and dispatching demand.

- Jeff Nagle, PacNW Nat'l Lab

Growing role for flexible demand

1. **Need**
   - Higher shares of variable renewables, increased electrification & demand-side uncertainty, growth in coincidental peaks (e.g., EV "Rush Hour")

2. **Potential**
   - Growth of EVs (and other electrification) increases the potential magnitude of flexible load

     ... and also increases the need for DR!

3. **Ability**
   - Technology makes it easier to cost-effectively implement DR via automation

How best to implement DR?

- Time-varing rates (e.g, TOU) and critical peak pricing have been shown to reduce demand (Faruqui et al., 2014)
- Real-time pricing may not be the best policy for tariff design with behavioural biases, inattention, and transaction costs (Fabra et al. 2021; Schneider and Sunstein, 2017)
- Growing evidence that households have a difficult time understanding marginal prices and complexity (Ito, 2014; Shaffer, 2020)
- Technology alone may not be sufficient to drive demand reductions (Brandon et al., 2022)
- Evidence automation can assist in DR when combined with pricing (Bollinger and Hartman, 2020; Blonz et al., 2021)

Evidence from Three Field Experiments

Today I want to review (preliminary) results from 3 new field experiments:

1. Centralized versus Decentralized Demand Response
2. Incentives versus Nudges: Shifting EV Charging Behaviour
3. Coordination benefits: Managed EV charging vs time-of-use rates

Experiment 1: Centralized vs decentralized demand response

Centralized Versus Decentralized Demand Response

- **Key questions**
  - Can we rely entirely on price signals to facilitate DR?
  - What is the potential value in leveraging technology + automation?
  - What are the burdens of effort and attention in enabling demand response?

Centralized Versus Decentralized Demand Response

1. **Centralized**
    - Install technology that can adjust demand remotely
    - Utility initiates load reduction in response to DR event
    - Households given ability to *opt-out*

2. **Decentralized**
    - Households can reduce load in response to DR event
    - Some given ability to respond with load control *technology*
    - Others require more *manual* response
    - Household must actively *opt-in* to event

Trade-offs: ease of response (lower effort/attention) vs benefit of heterogeneity and possibly better acceptability

Research Goal

Compare centralized vs decentralized DR in terms of:

- Take-up rates (**acceptability**)
- Consumption changes during DR events (**responsiveness**)
- Consistency of response (**reliability**)
- Opt-out and attrition (**satisfaction**)

What we do

- We partnered with a large Canadian utility
- We randomize 1800 households into various treatment groups
- We install load control devices in the homes of certain HHs (water heaters, EV chargers, thermostats)
- We run random "peak events" with unique schedules
- Consumption reductions are rewarded financially
  - *From $1 for a 10% reduction*
  - *to up to $6 in the "high incentive" event for a 50% reduction*
- Started Feb 2022, ongoing for 18 months

Treatment assignment

We group eligible HHs on important observables (kmeans clustering) and then randomize offers to one of 5 groups:

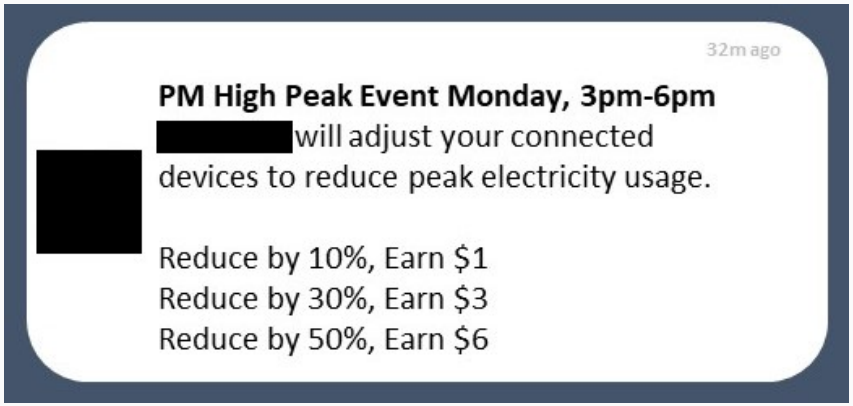
	DR control	Load control tech	Price incentive	Usage info
Central	Utility*	✓	✓	✓
Tech	HH	✓	✓	✓
Manual	HH		✓	✓
Info	HH			✓
Control	HH			

*HH has ability to opt-out

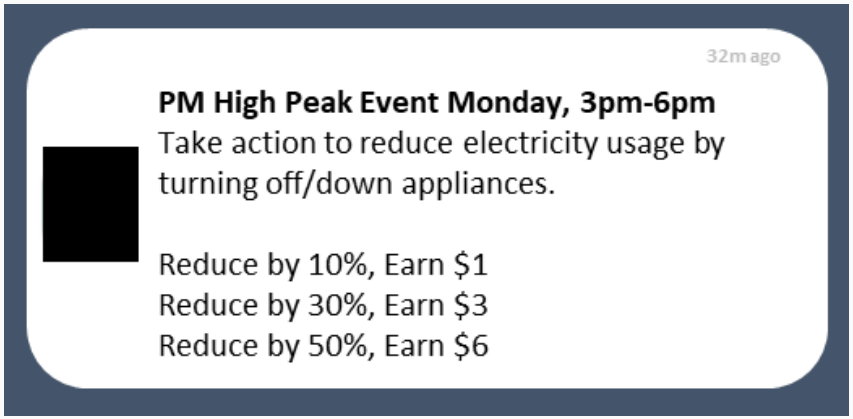
- Central vs Tech: effect of automation/control (passive vs active response)
- Tech vs Manual: effect of technology

Example of Peak Event messaging

Central group 21hr notification with incentives



Tech/Manual group 21hr notification with incentives



Program Acceptance

Acceptance Rates by Group

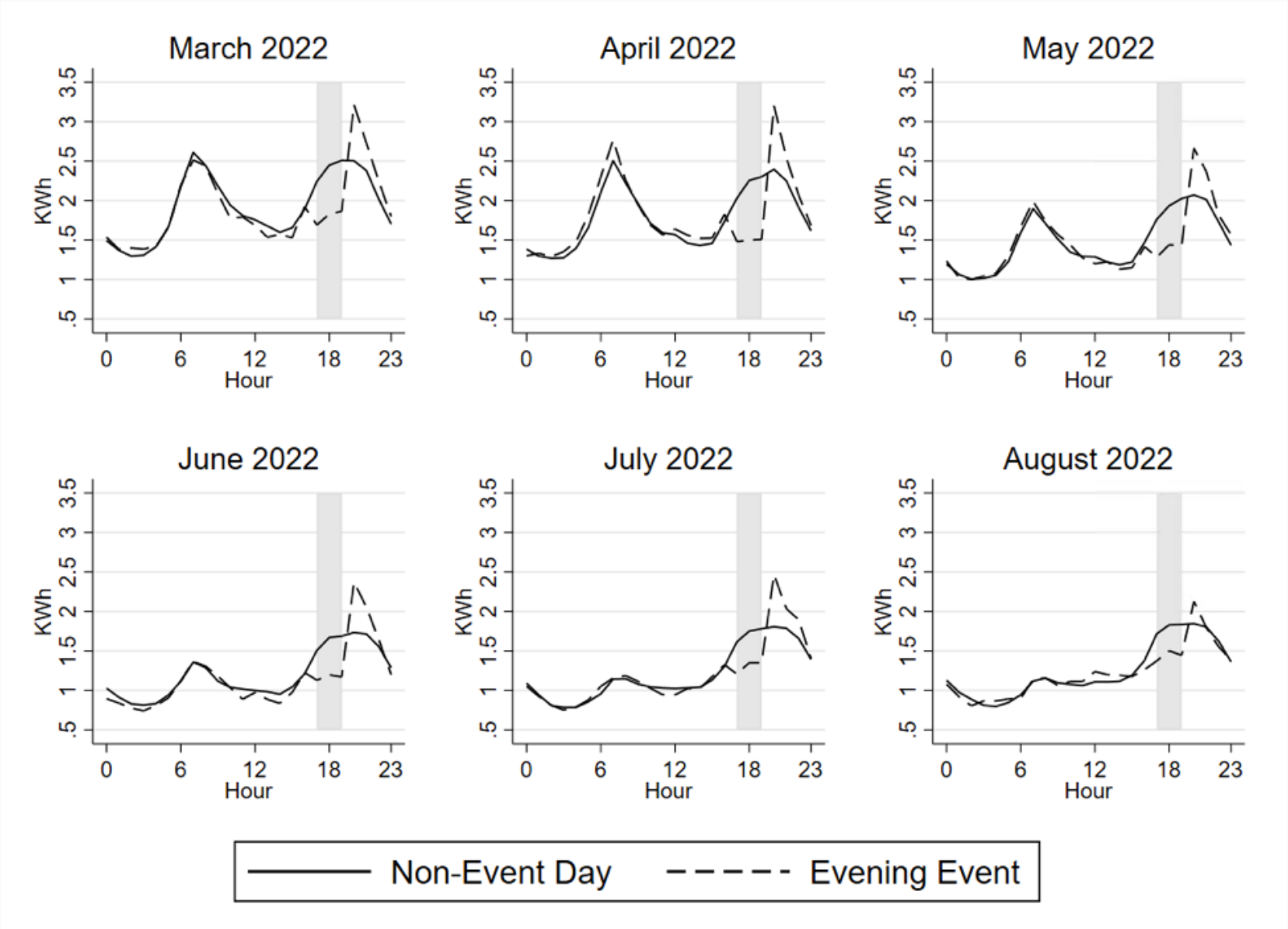
	Central	Tech	Manual	Info	Control
Invited	423	382	409	259	188
Accepted	177	184	242	177	188
	(42%)	(48%)	(59%)	(68%)	(100%)

Acceptance Detailed

What we find...

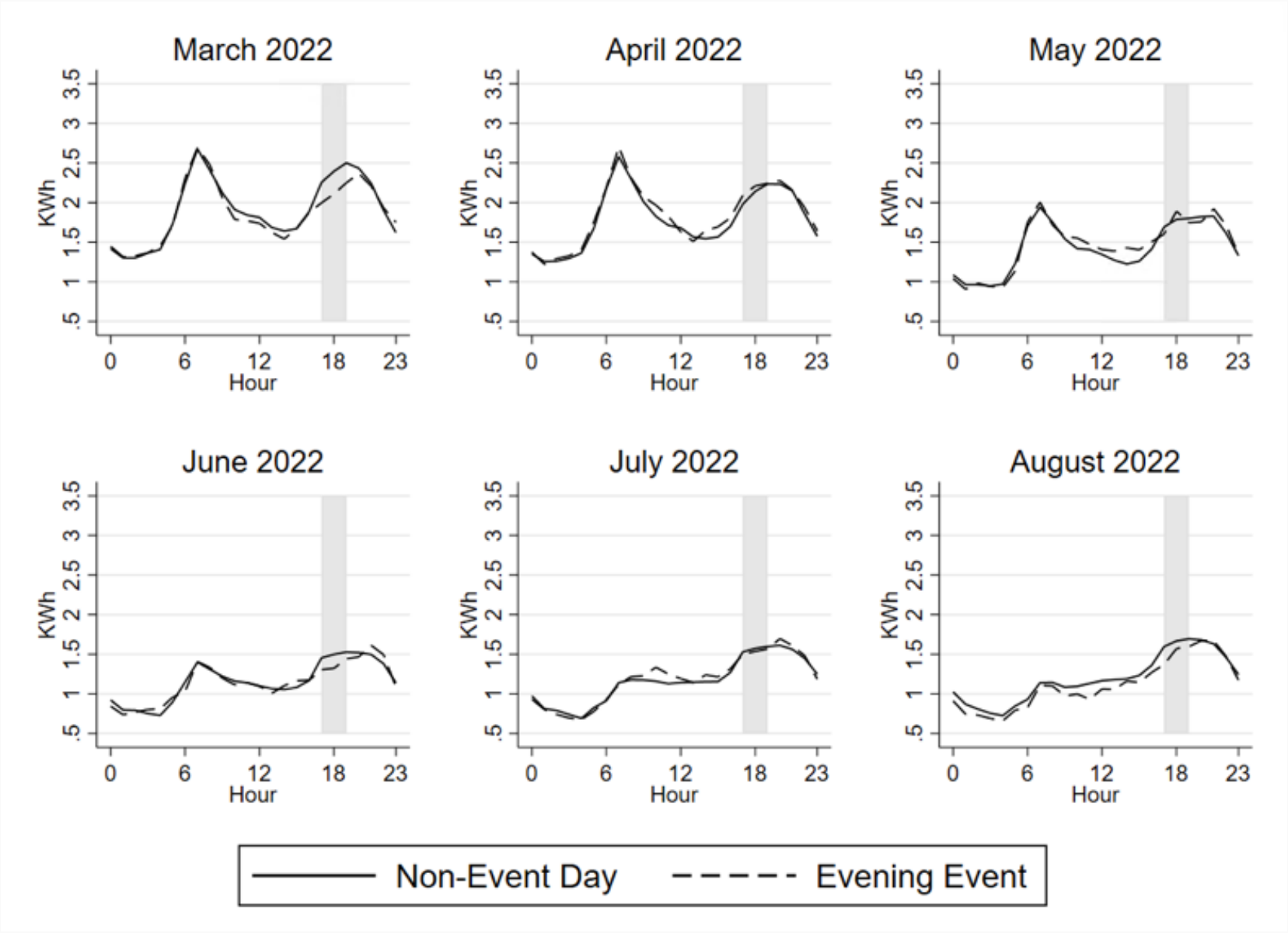
Descriptive analysis of consumption patterns

Central Group: Non-event vs Evening Event days



Descriptive analysis of consumption patterns

Tech Group: Non-event vs Evening Event days



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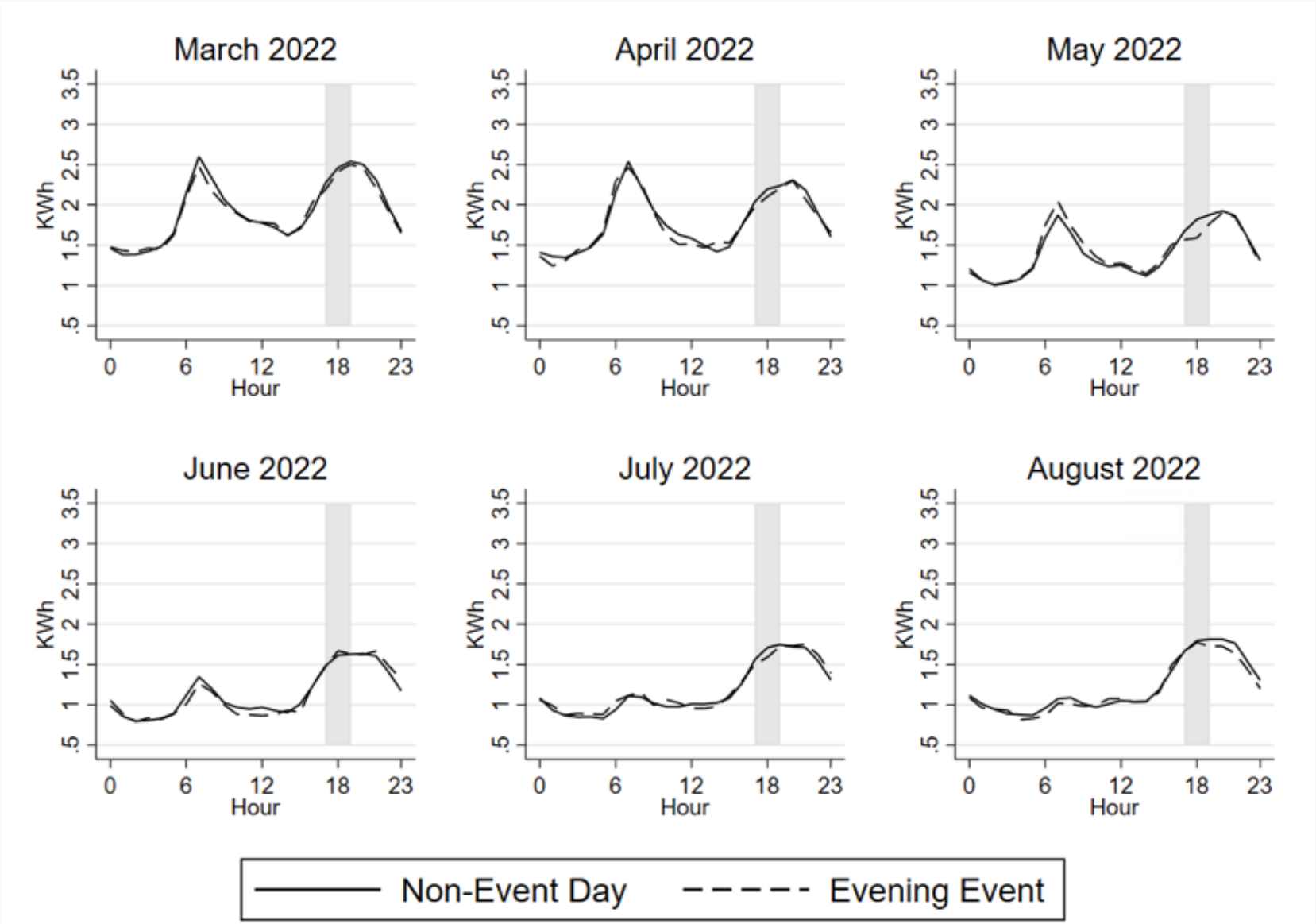
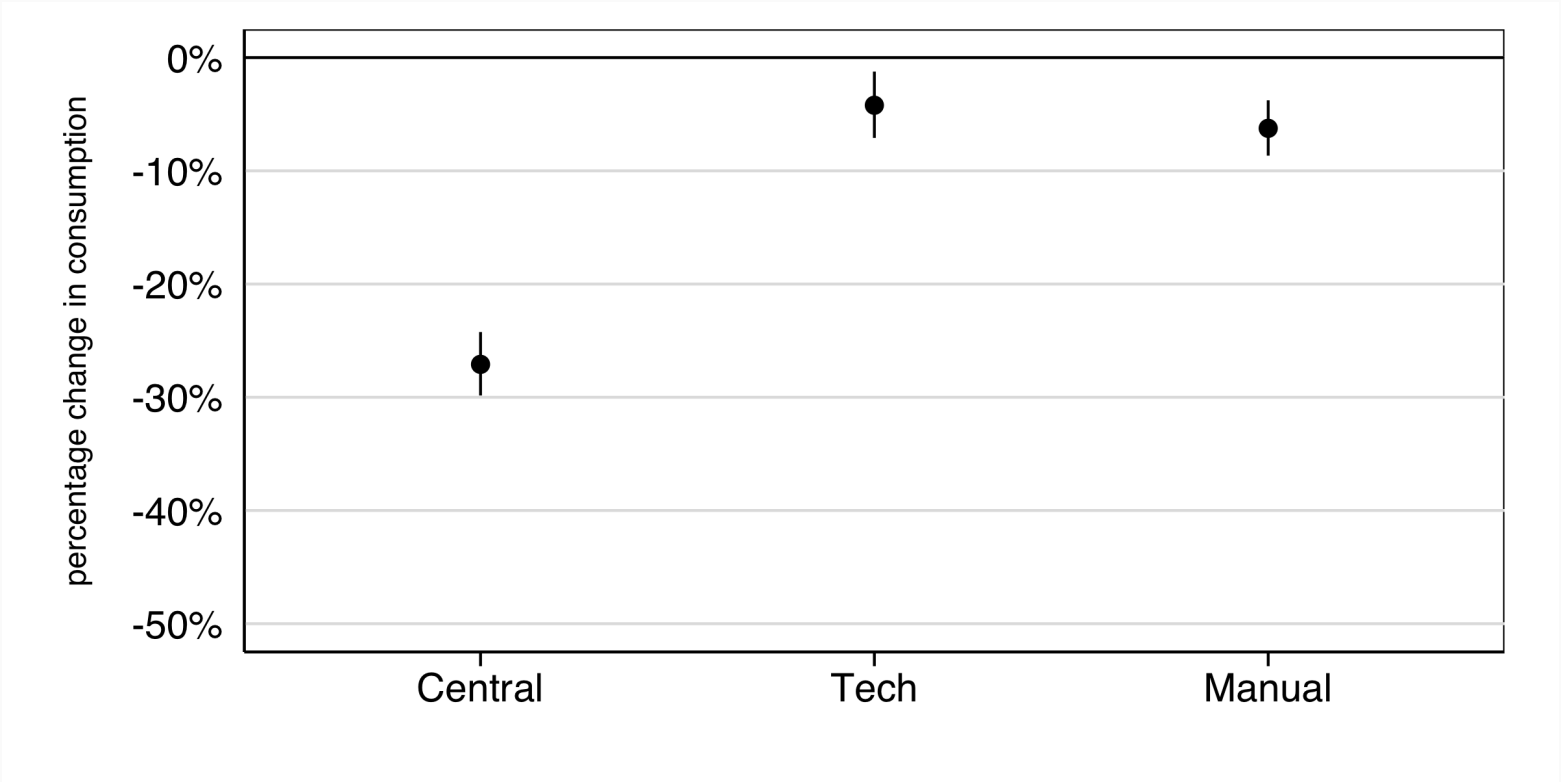
Manual Group: Non-event vs Evening Event days



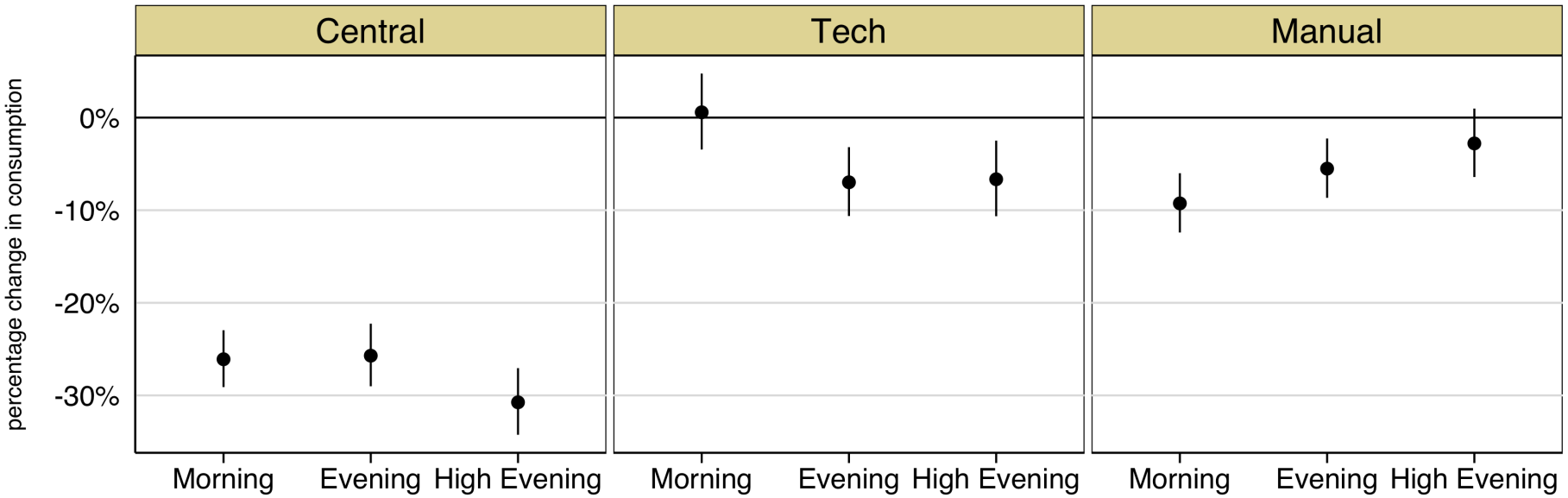
Regression results: Hourly consumption changes by group



Central group is crushing Tech group...

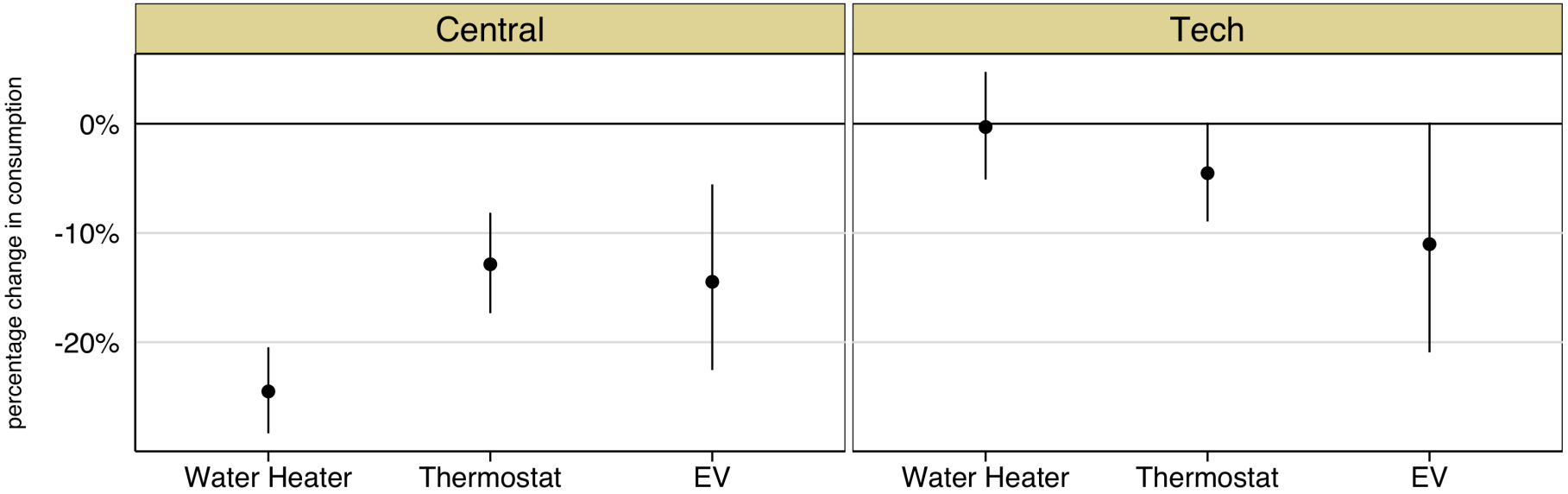
...and Tech group not doing better than Manual group.

Hourly consumption results by event type



- Central responding to greater incentives
  - *Initial analyses: May be due to action on top of central utility control.*
- Tech/Manual not responding to greater incentives
- Tech group not taking action in mornings.

Hourly consumption results by home device



- Central group HHs reduce more than Tech group, by device
  - Electric vehicles are the one exception
- Central group: Untapped potential for flexibility in water heaters
  - Tech group not touching water heaters

Device Level Results

Summing up

Expectation:

1. Larger take-up rate with Tech than Central

Result:

1. Minimal differences in take-up rates across Central and Tech

Summing up

Expectation:

1. Larger take-up rate with Tech than Central
2. Uncertain whether Tech or Central will have a stronger response

Result:

1. Minimal differences in take-up rates across Central and Tech
2. Central has a considerably larger response to events than Tech

Summing up

Expectation:

1. Larger take-up rate with Tech than Central
2. Uncertain whether Tech or Central will have a stronger response
3. Tech group would respond more to events than Manual

Result:

1. Minimal differences in take-up rates across Central and Tech
2. Central has a considerably larger response to events than Tech
3. Tech and manual responses are very similar

Summing up

Expectation:

1. Larger take-up rate with Tech than Central
2. Uncertain whether Tech or Central will have a stronger response
3. Tech group would respond more to events than Manual
4. Electric vehicle households will generate the largest reduction during events

Result:

1. Minimal differences in take-up rates across Central and Tech
2. Central has a considerably larger response to events than Tech
3. Tech and manual responses are very similar
4. Hot water heater households yield the largest demand reduction during events

Summing up

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2. Central has a considerably larger response to events than Tech
3. Tech and manual responses are very similar
4. Hot water heater households yield the largest demand reduction during events

- **Giving households technology does not result in larger demand response than manual control**
- **Reducing effort costs and overcoming inattention is key! (Although EVs may be different...)**

Experiment 2: Shifting EV charging times

Objectives

- To better understand EV charging patterns
- To assess willingness to shift EV charging to off-peak hours
- To compare effectiveness of financial incentives vs education

What we do

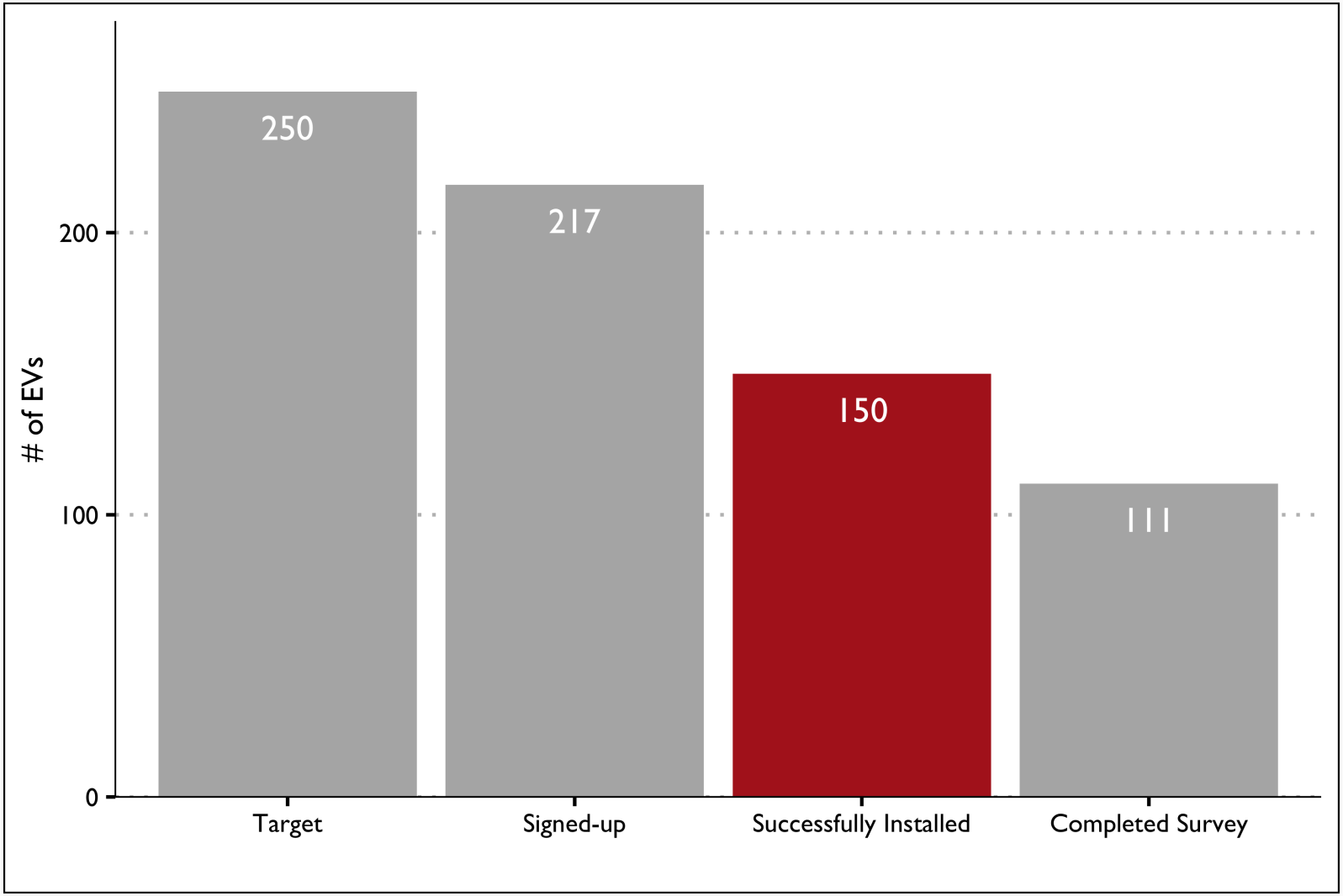
- Working with ENMAX, we recruit up to 250 EVs in Calgary to a randomized control trial
- Assign EV owners to one of 3 groups:
  - Rewards
  - Education
  - Control
- Monitor charging behaviour before and after assignment to groups
- Compare changes in charging patterns across groups

Phase 1: Recruitment and initial monitoring

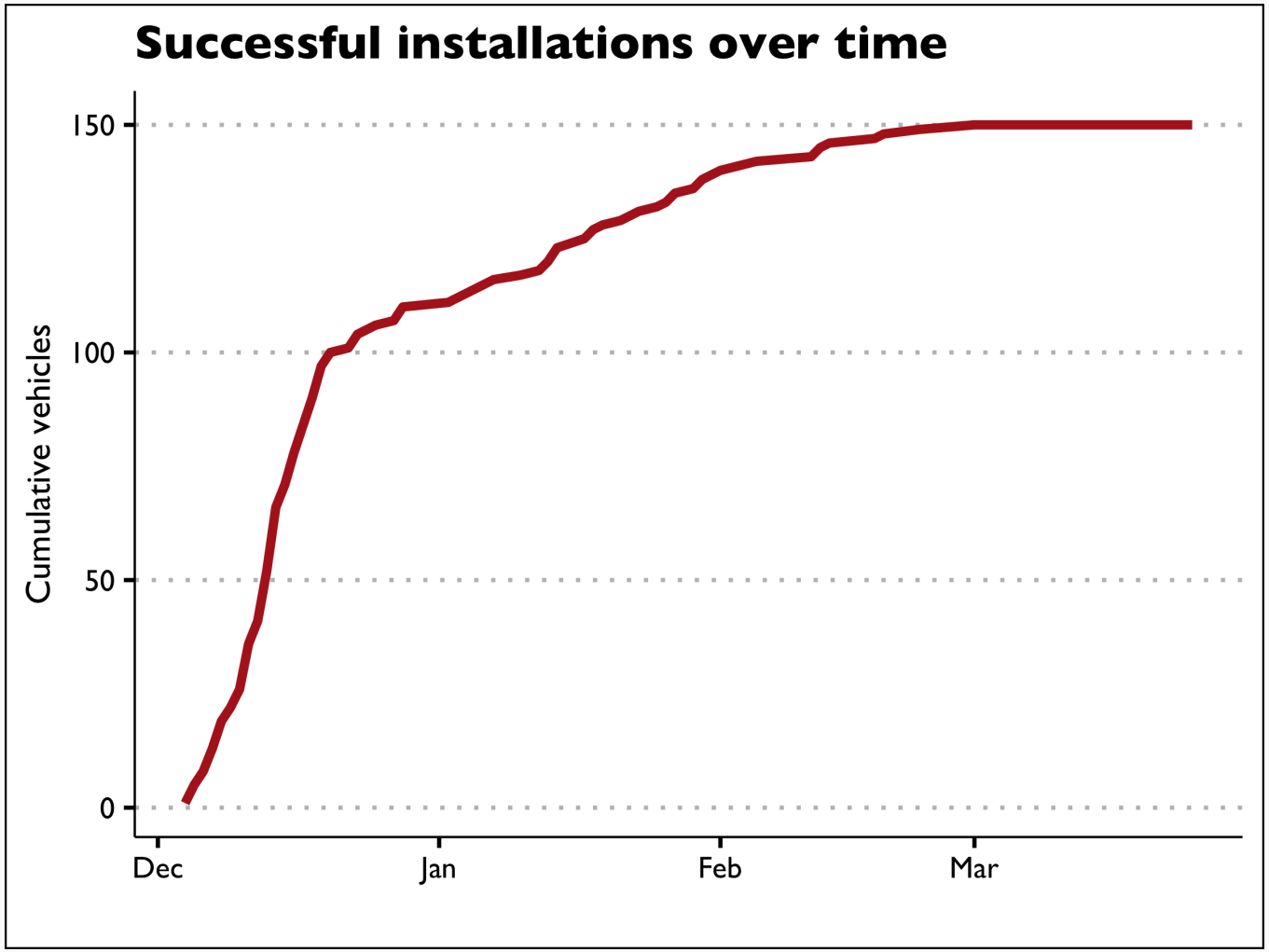
Recruitment

- Media and marketing campaign to raise awareness of pilot
- Voluntary sign-up to the program
- Sign-on and end-of-pilot payments as incentives

Recruitment



Successful installs over time

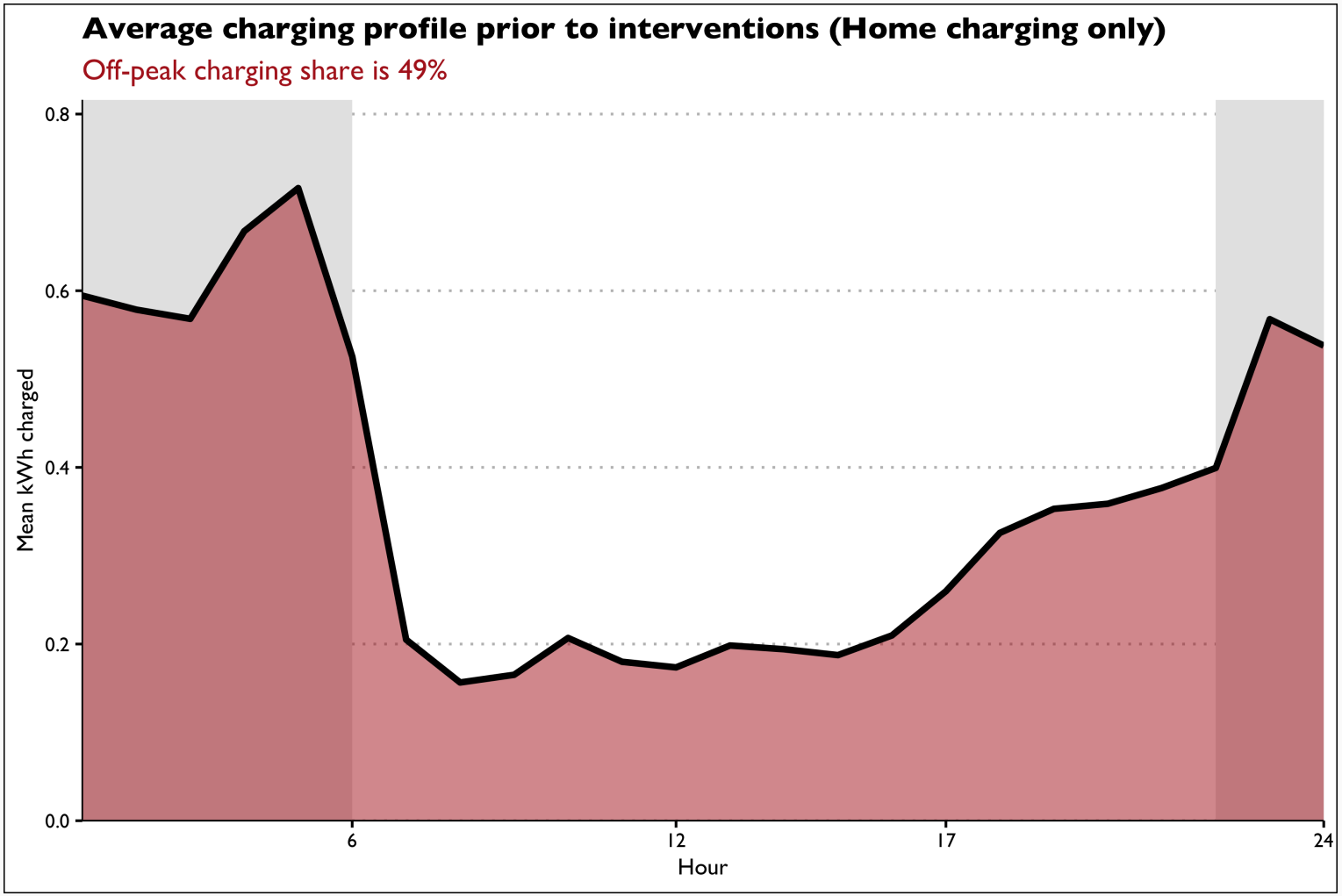


Breakdown by group

Number of vehicles by group, among successful installs:

Rewards	Education	Control
68	45	37

Pre-intervention charging profile



Phase 2: Intervention and treatment effects

The intervention

On March 31, the **Education group** received an email with the following text:

"Did you know that EV drivers often plug their vehicles in at 5:00PM? This timing coincides with existing system load peaks and can lead utilities to upgrade wires and equipment ahead of schedule to meet this growing peak demand.

To help reduce costs for all Calgarians and reduce strain on electric infrastructure, EV drivers can use their EV scheduled charging feature to charge between 10:00PM and 6:00AM when grid demand is low, or wait until 10:00PM to plug in. This simple change can make a big impact and will benefit the entire system as EV adoption continues."

The intervention

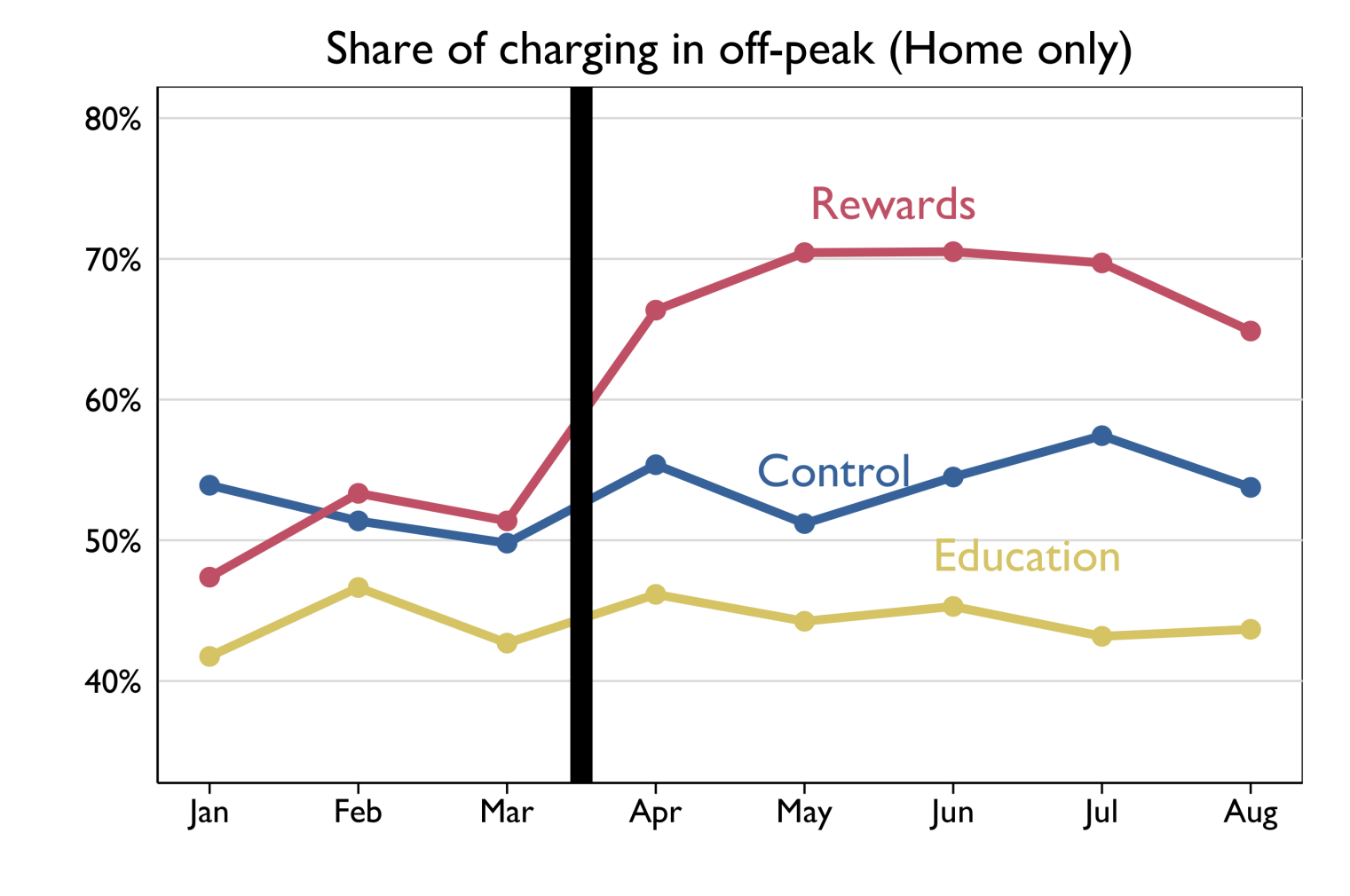
The **Rewards group** received an email with the same text plus an added paragraph:

"Did you know that EV drivers often plug their vehicles in at 5:00PM? This timing coincides with existing system load peaks and can lead utilities to upgrade wires and equipment ahead of schedule to meet this growing peak demand.

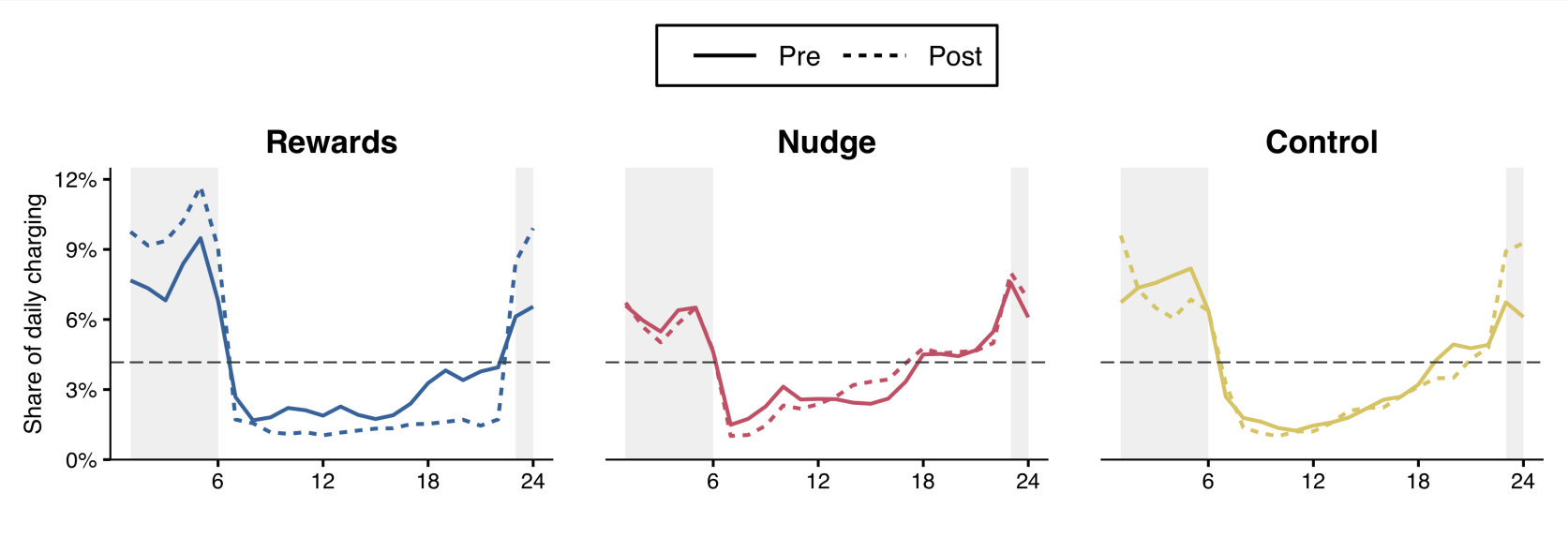
To help reduce costs for all Calgarians and reduce strain on electric infrastructure, EV drivers can use their EV scheduled charging feature to charge between 10:00PM and 6:00AM when grid demand is low, or wait until 10:00PM to plug in. This simple change can make a big impact and will benefit the entire system as EV adoption continues.

To encourage you to charge during off-peak hours, effective immediately ENMAX will issue you a 3.5¢/kWh reward for charging that takes place between 10:00PM and 6:00AM. This reward will be paid monthly through the SmartCharge Rewards platform. You are still free to charge your car whenever you like, and there will be no changes to your electric service. "(emph added)

Descriptive Results



Descriptive Results: Hourly profiles



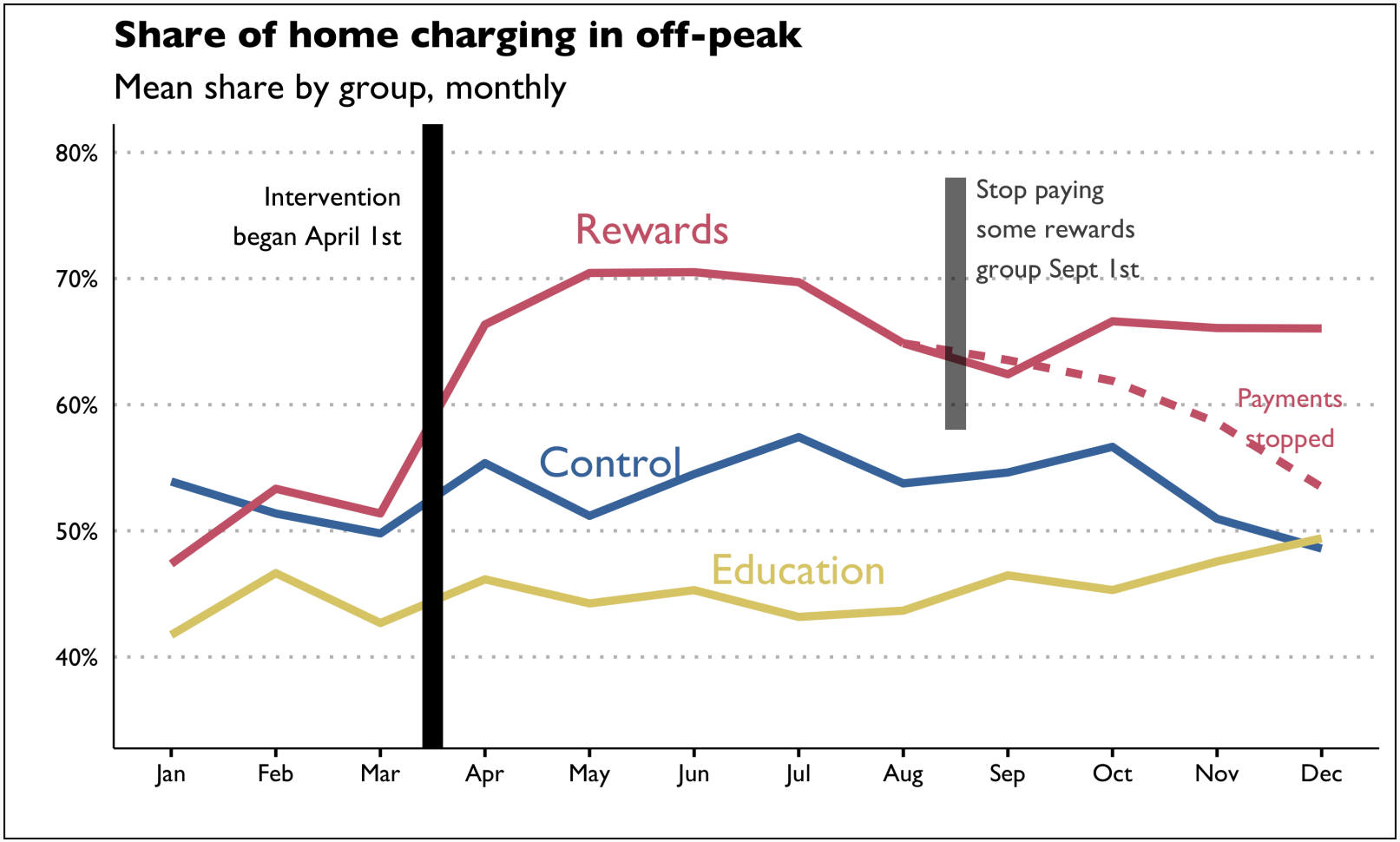
Phase 3: Test for habit formation

What we do

As of September 1:

- We stop payments for **half the Rewards group** to assess whether their off-peak charging behaviour persists

Descriptive Results



Key Takeaways from Experiment 2

1. Using physical devices to monitor charging behaviour inhibited take-up rates
2. **Strong evidence financial rewards significantly shift charging behaviour**
3. No evidence education shifts charging behaviour
4. No evidence of habit formation from incentives as behaviour reverted to pre-intervention behavior once payments ended

Experiment 3: Managed charging vs time-of-use rates

Motivation

- Experiment 2 demonstrates financial incentives are effective in shifting EV charging to off-peak
- BUT... this can create a *shadow peak* if people set their charger schedules to start right at midnight, for example
- (see also the "snapback" issue from Experiment 1)
- There are benefits to the *distribution system* of avoiding synchronous local peaks, even during off-peak hours

Enter: Experiment 3 and **managed charging**

What we (are about to) do

- Working with Fortis Alberta, an electric distribution company in Alberta we are currently recruiting 600 EVs (recruitment started Jan 2023)
- Users install an app (Optiwatt) to monitor and control their charging
- Randomize to 3 groups:
  - Managed charging
  - Off-peak discount
  - Control group

Phase 1 analysis

- Place groups of 8-10 EVs on a "virtual transformer" (due to sparsity of current EV ownership)
- Compare change in charging profiles across groups
- Compare peak loads on "virtual" transformers across groups
- **Key metric**: frequency of the group load violating a virtual transformer limit

Preliminary Results

- Time-of-use rates actually *increase* the frequency of distribution system violations, as compared to the status quo
- Managed charging, as expected, significantly reduces the frequency of distribution system violations

Phase 2 analysis

- All participants will be opted-out of the program and given the chance to enroll (or re-enroll) in managed charging at various pricing levels
- Allows us determine:
  - the role of experience
  - the role of defaults
  - the role of pricing

Key Takeaways

Key Takeaways

1. Making it *easy* (set it and forget it) is key to residential demand response
2. There is *tremendous* flexibility to shift home EV charging times; financial incentives are key
3. TOU rates may unintentionally exacerbate distribution system constraints; managed (or coordinated) charging is key

Thank you!

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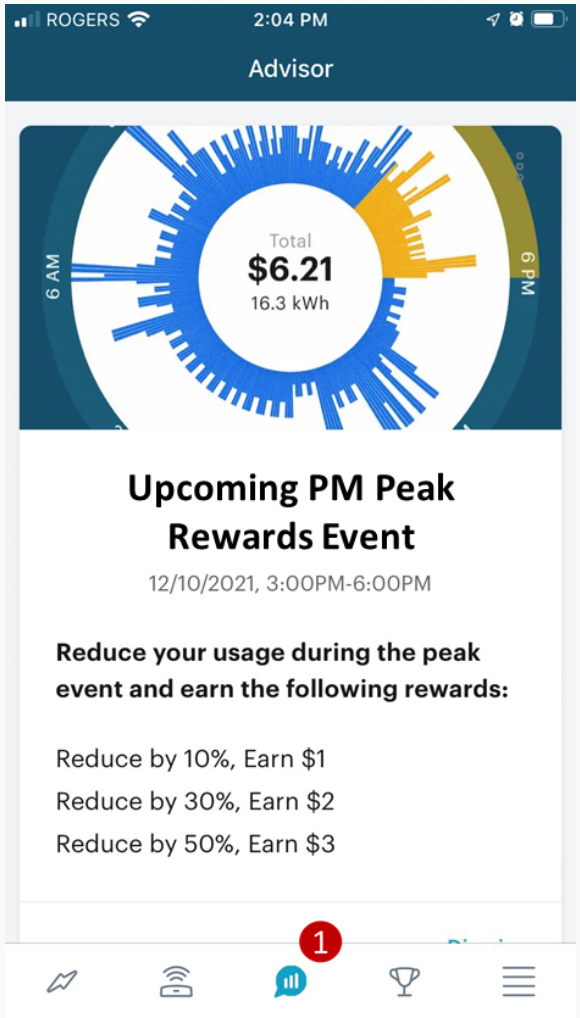
web: blakeshaffer.ca

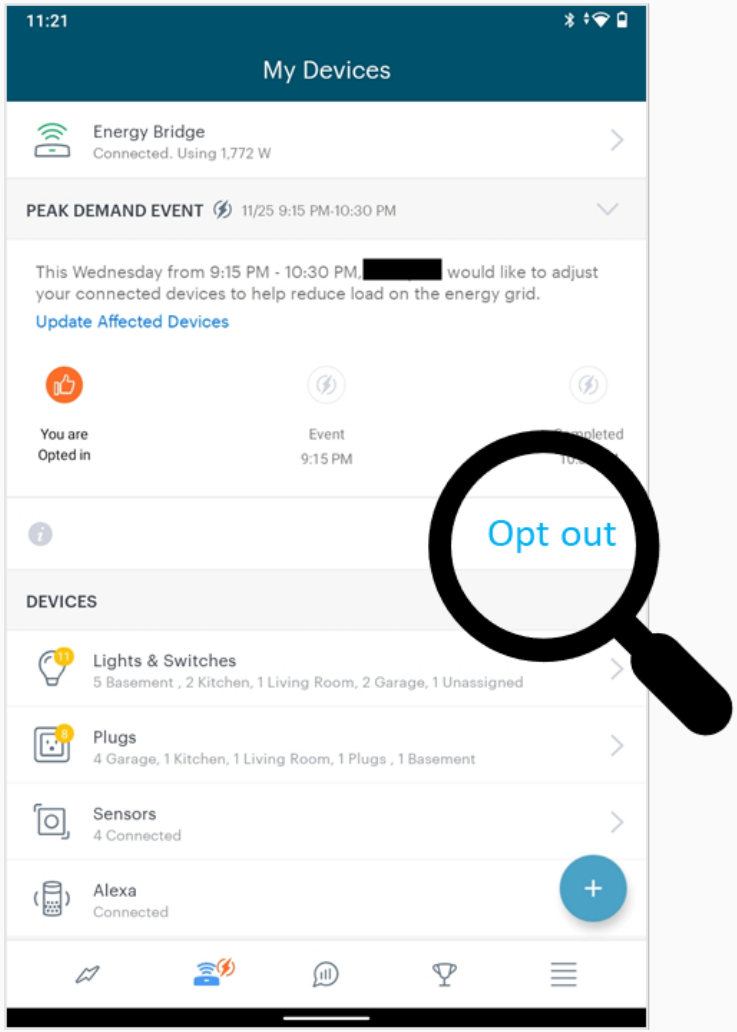
Appendix

Example of Peak Event messaging

In-app notification



Central - Opt out of DLC



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Program Acceptance

Acceptance Rates by Group

	Central	Tech	Manual	Info	Control
Invited	423	382	409	259	188
Accept (Initial)	245 (58%)	261 (68%)	273 (67%)	198 (77%)	188 (100%)
Accept (Final)	177 (42%)	184 (48%)	242 (59%)	177 (68%)	188 (100%)
Withdrawn	68 [28%]	77 [30%]	31 [11%]	21 [11%]	0 [0%]

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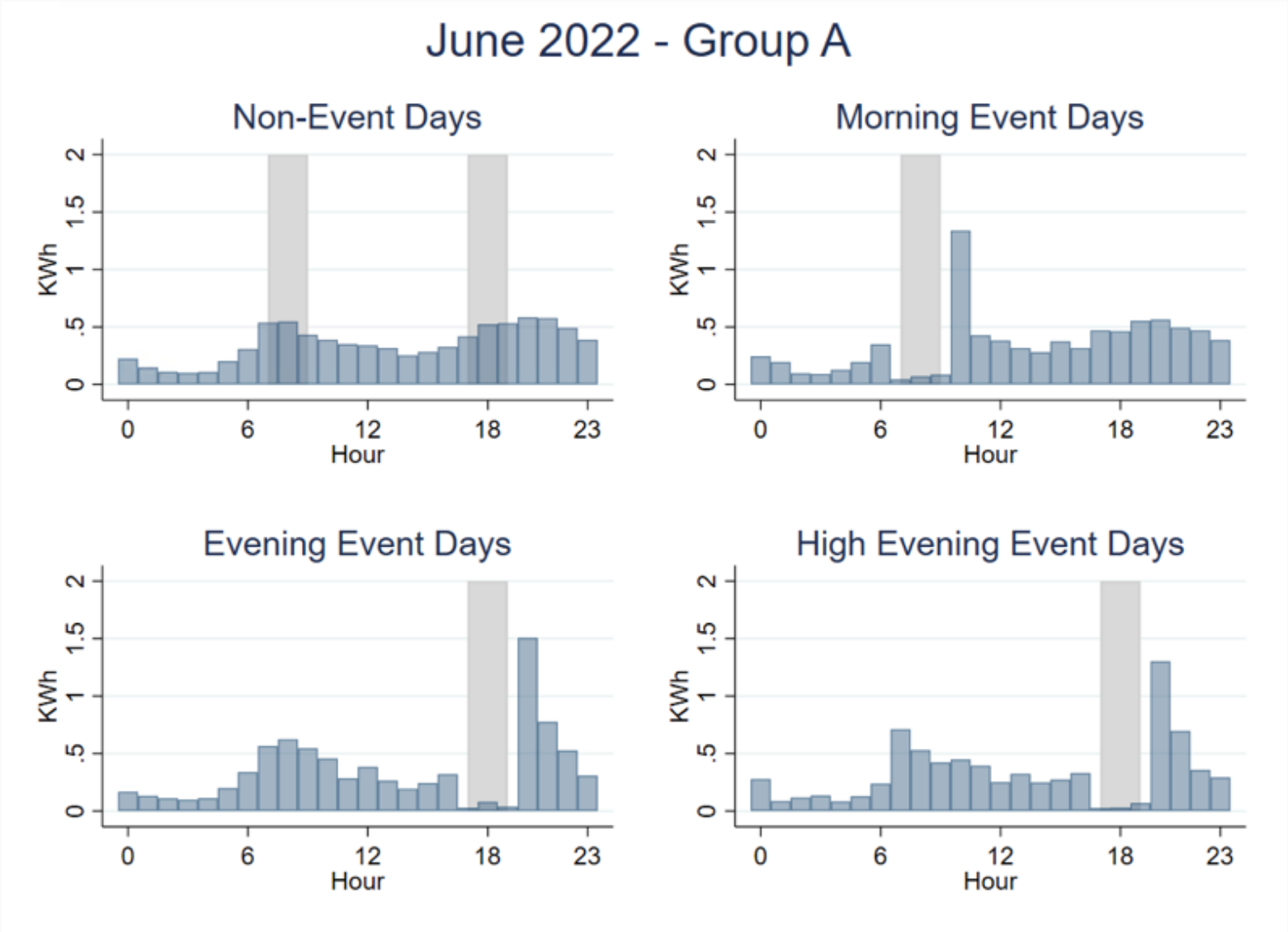
Descriptive analysis of device-level consumption

Central Group: Hot Water Heaters



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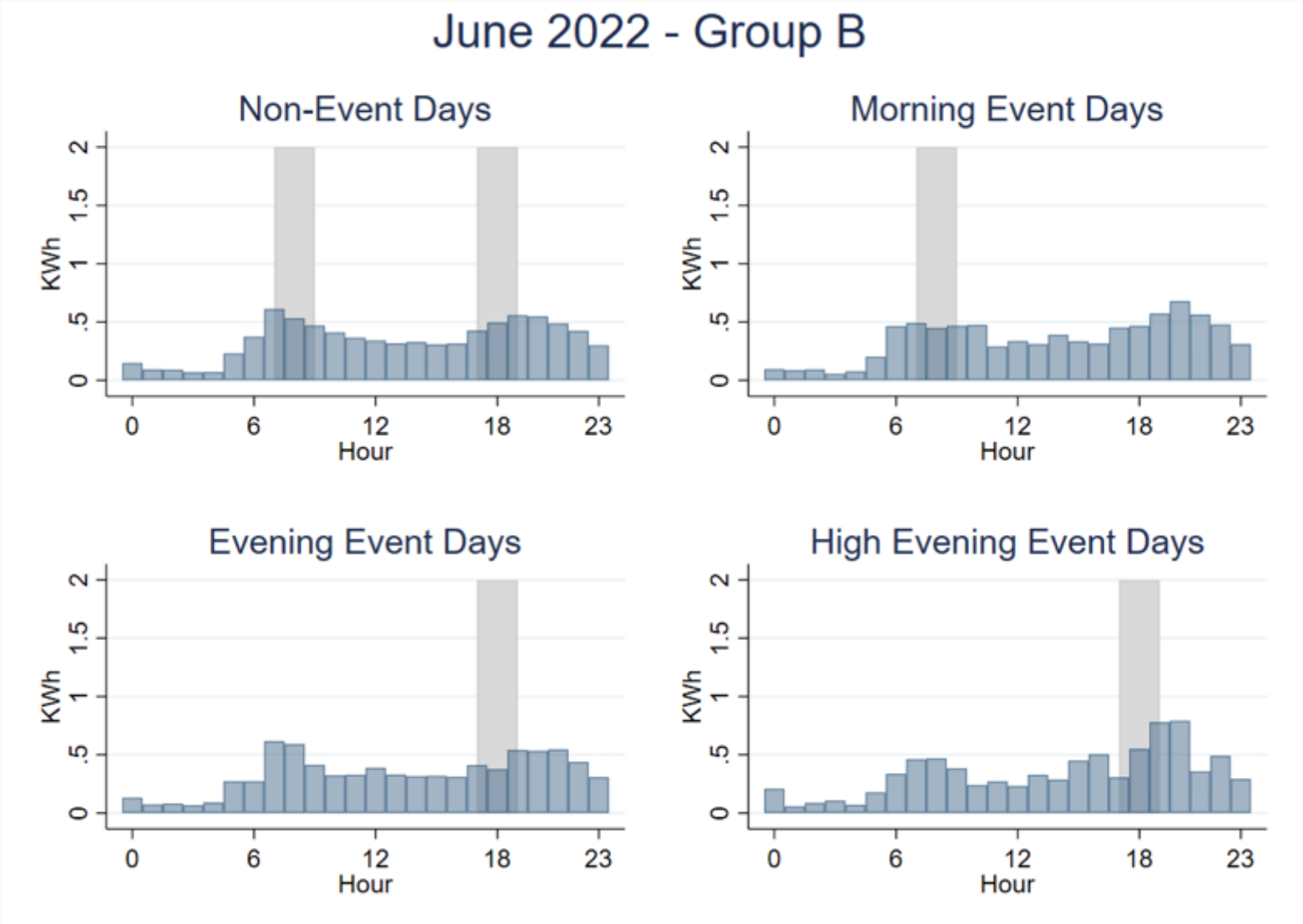
Descriptive analysis of device-level consumption

Tech Group: Hot Water Heaters



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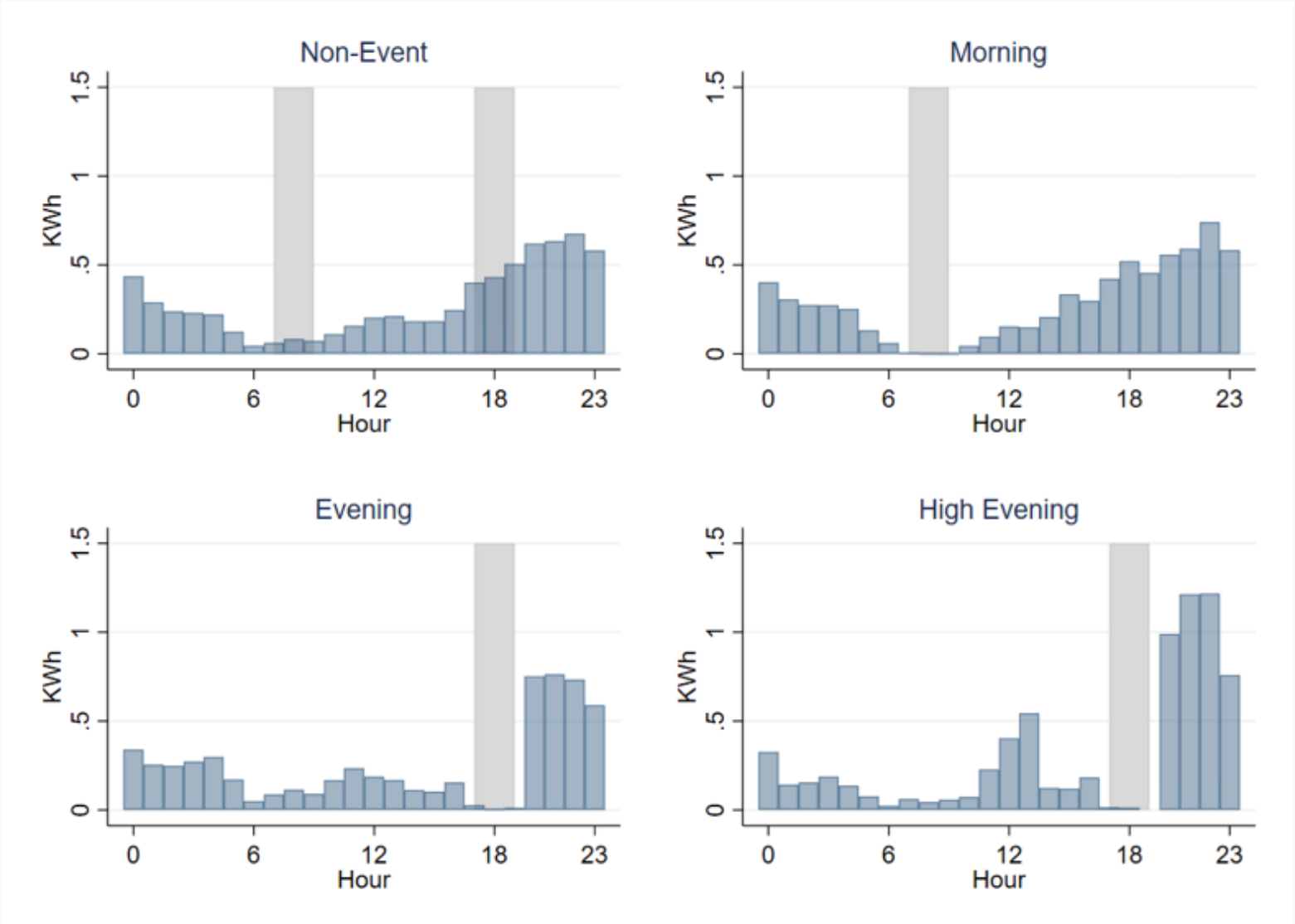
Central Group: EV Chargers



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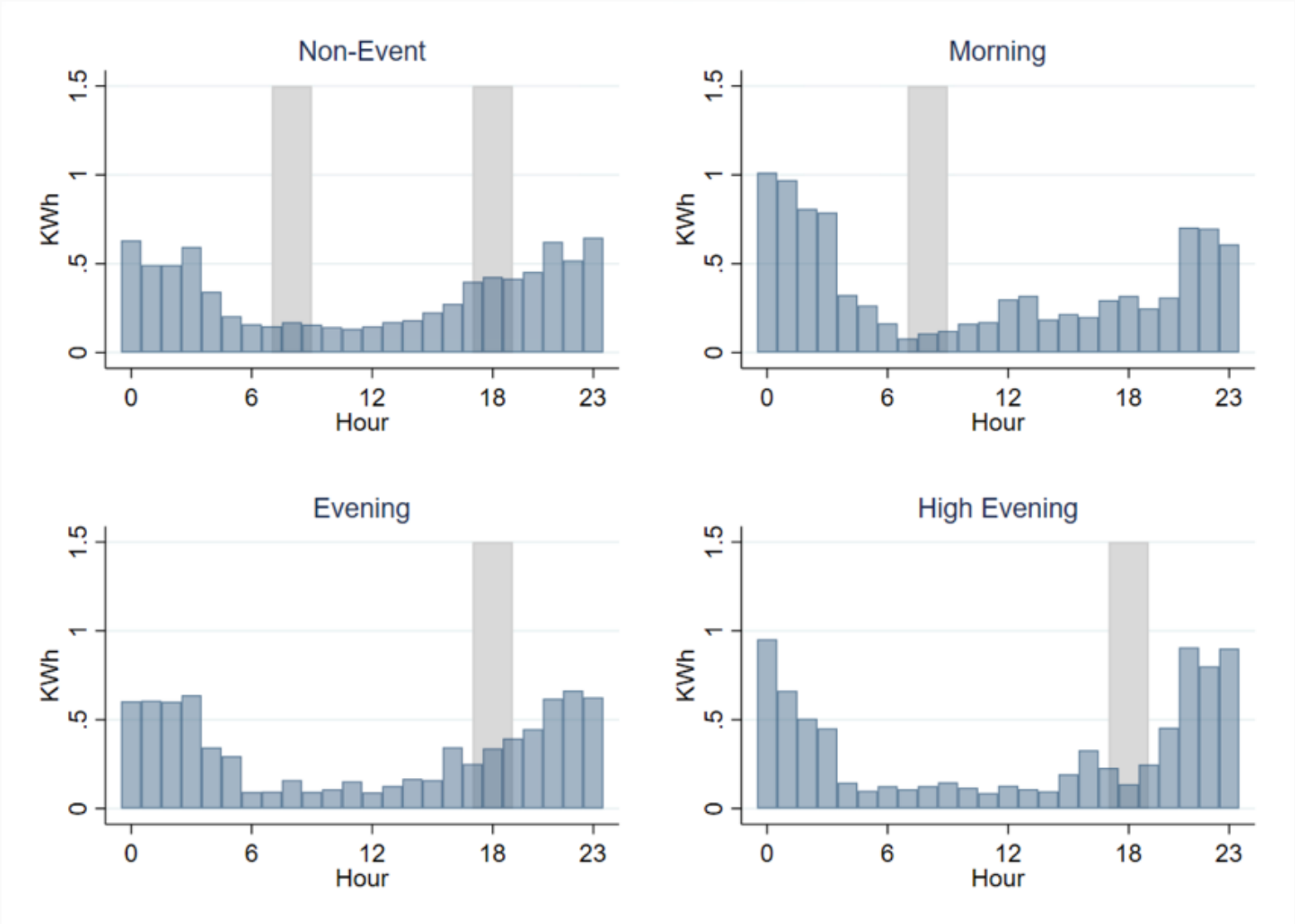
Descriptive analysis of device-level consumption

Tech Group: EV Chargers



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