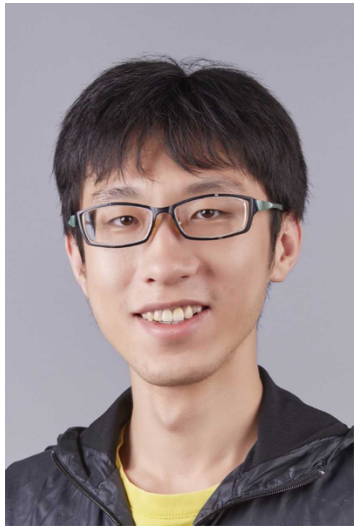
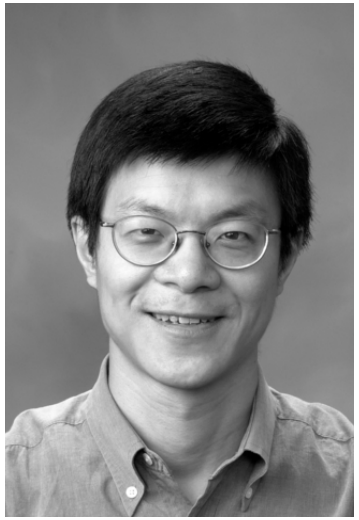
ACN-Data

Analysis and Applications of an Open EV Charging Dataset

Zachary J. Lee, Tongxin Li, Steven H. Low





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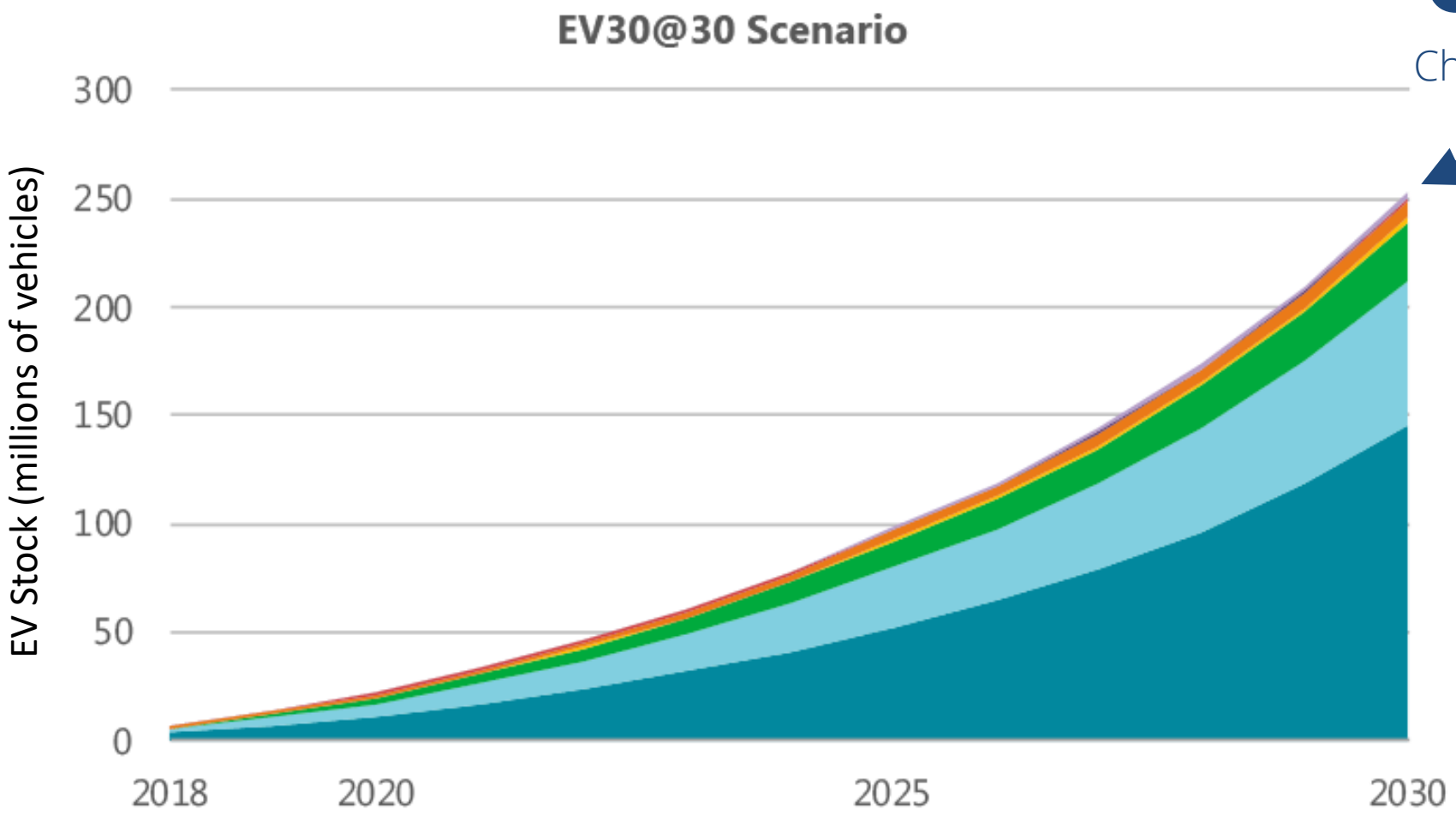
Why care about EV charging?

640 TWh

Charging demand in 2030



Source: IEA analysis developed with the IEA Mobility Model.

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Why care about EV charging?

10 kWh daily
7 kW

29 kWh daily
1.2 kW*

* Average power consumption over day

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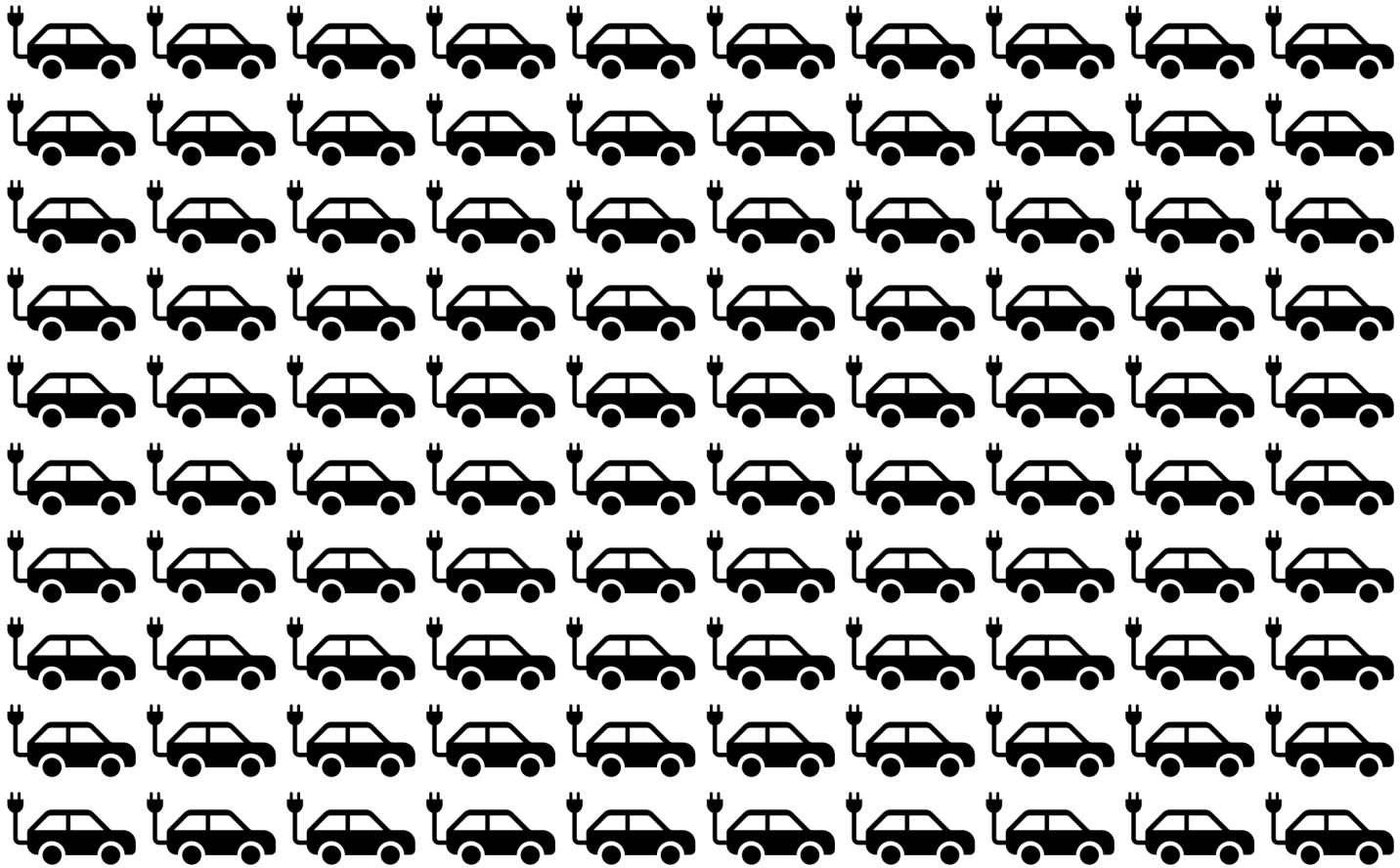
Why care about large-scale EV charging?

Parking lot: 100 EVs

1 MWh daily

700 kW



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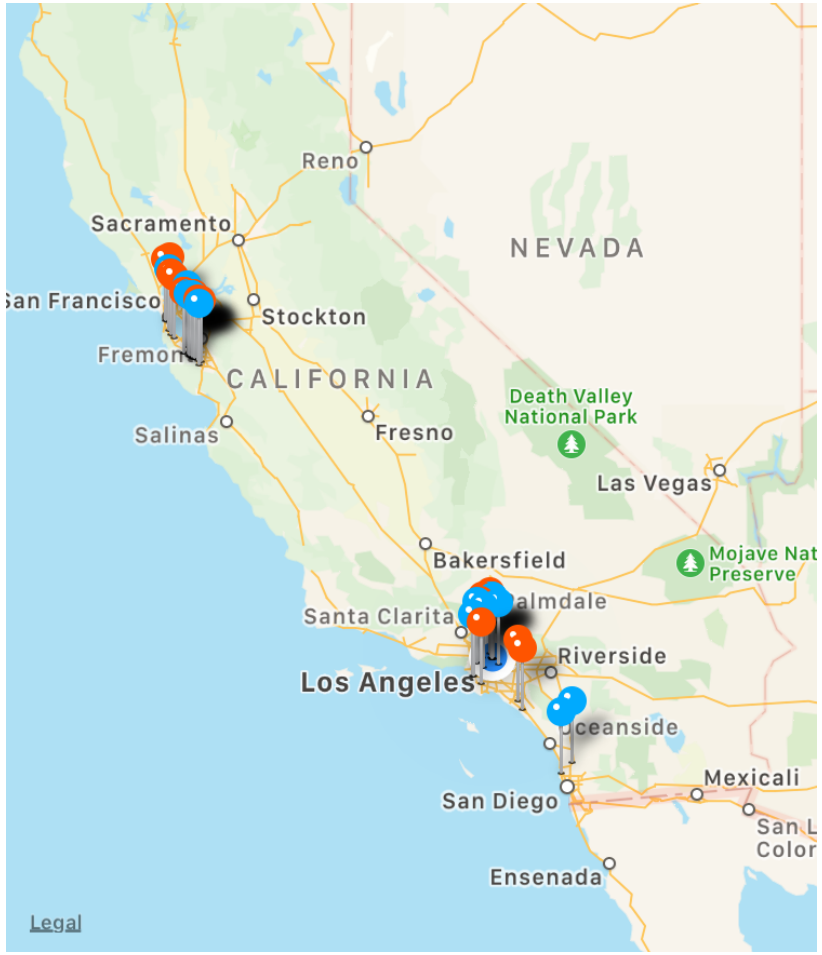
Adaptive Charging Network

Framework for large-scale smart charging networks

Real-time monitoring and control of EV charging

User interaction through app

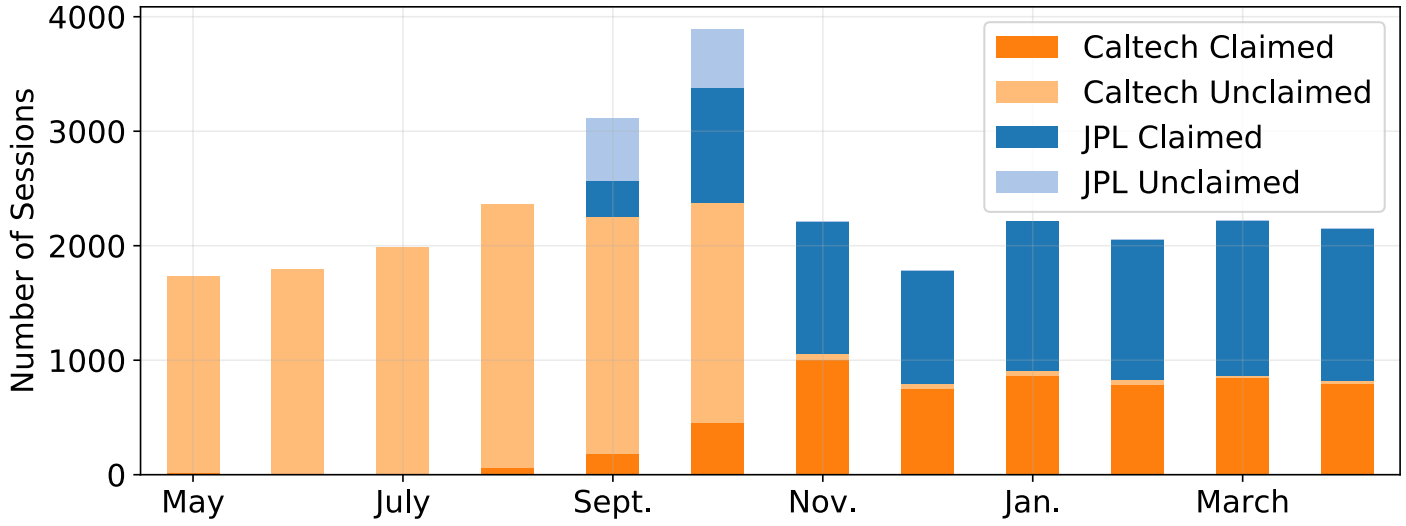
ACNs around the country



What is ACN-Data?

32,000+ EV charging sessions
Publicly available

Growing daily – 90 sessions a day




```
spaceID: "CA-489"
siteID: "0002"
clusterID: "0039"
connectionTime: 2018-05-14 06:50:26.000
```

```
userInputs: Array
  0: Object
      userID: 66
      milesRequested: 20
      WhPerMile: 400
      minutesAvailable: 60
      modifiedAt: 2018-05-14 06:51:52.000
      paymentRequired: true
      requestedDeparture: 2018-05-14 07:50:26.000
      kWhRequested: 8
```

```
disconnectTime: 2018-05-14 16:09:45.000
kWhDelivered: 11.795
pilotSignal: Object
  timestamps: Array
  pilot: Array
chargingCurrent: Object
  timestamps: Array
  current: Array
doneChargingTime: 2018-05-14 13:43:40.000
```

What can I do with this dataset?

Machine Learning and Statistical Modeling

- Understand, model, and predict user behavior
- Apply reinforcement learning to smart charging

Algorithm Design and Evaluation

- Accurately evaluate online scheduling algorithms

System Design and Grid Impacts

- Inform charging system design and planning
- Demonstrate grid impacts and opportunities
- Evaluate the potential of charging + renewable energy sources

Data-Driven Research

What can we learn from **data** about user behavior?

How can we use **data** to model user behavior?

How can we use models to design better charging systems?

How can we use models to understand grid impacts?

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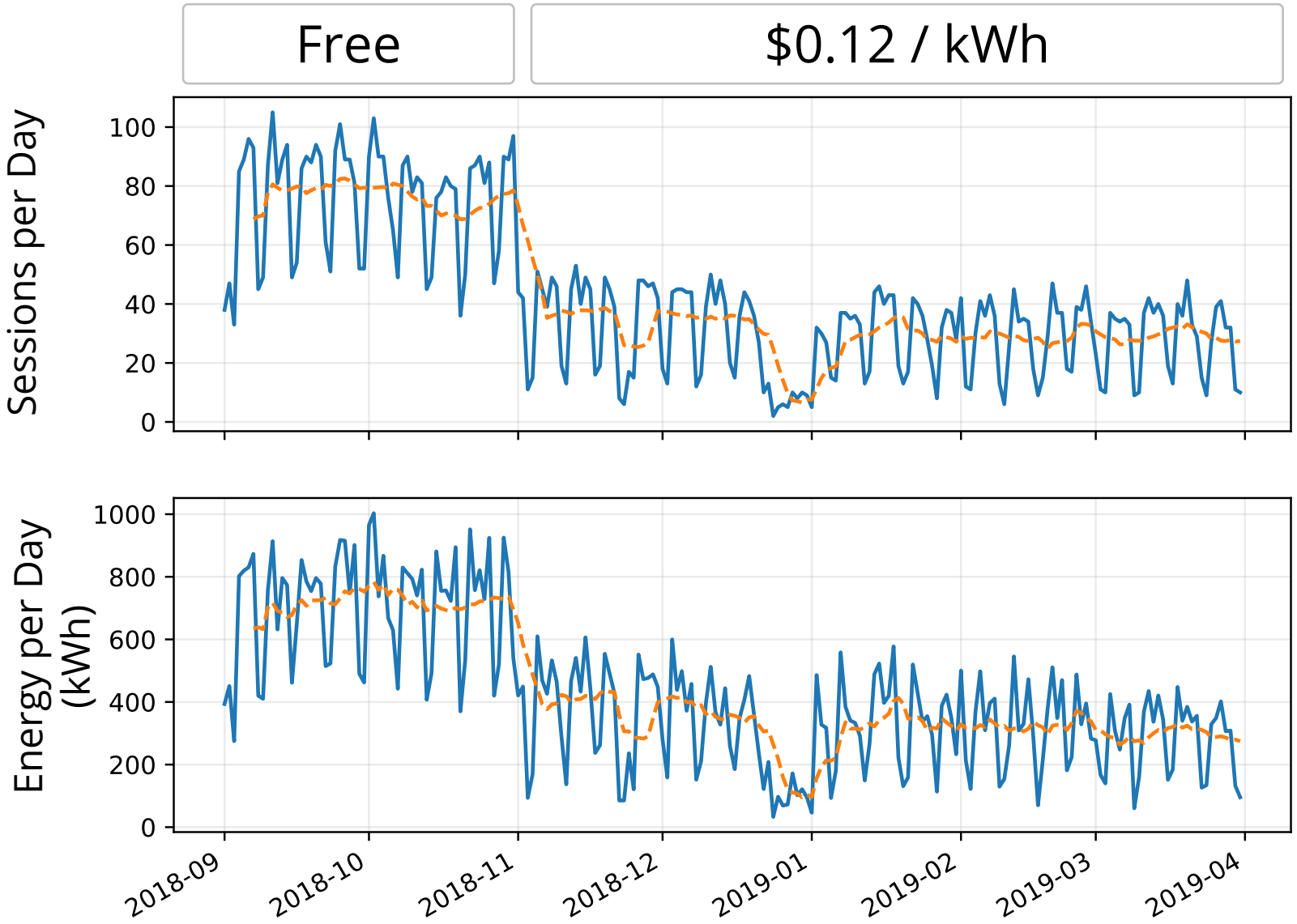
What can we learn from data about user behavior?

How is the system used?



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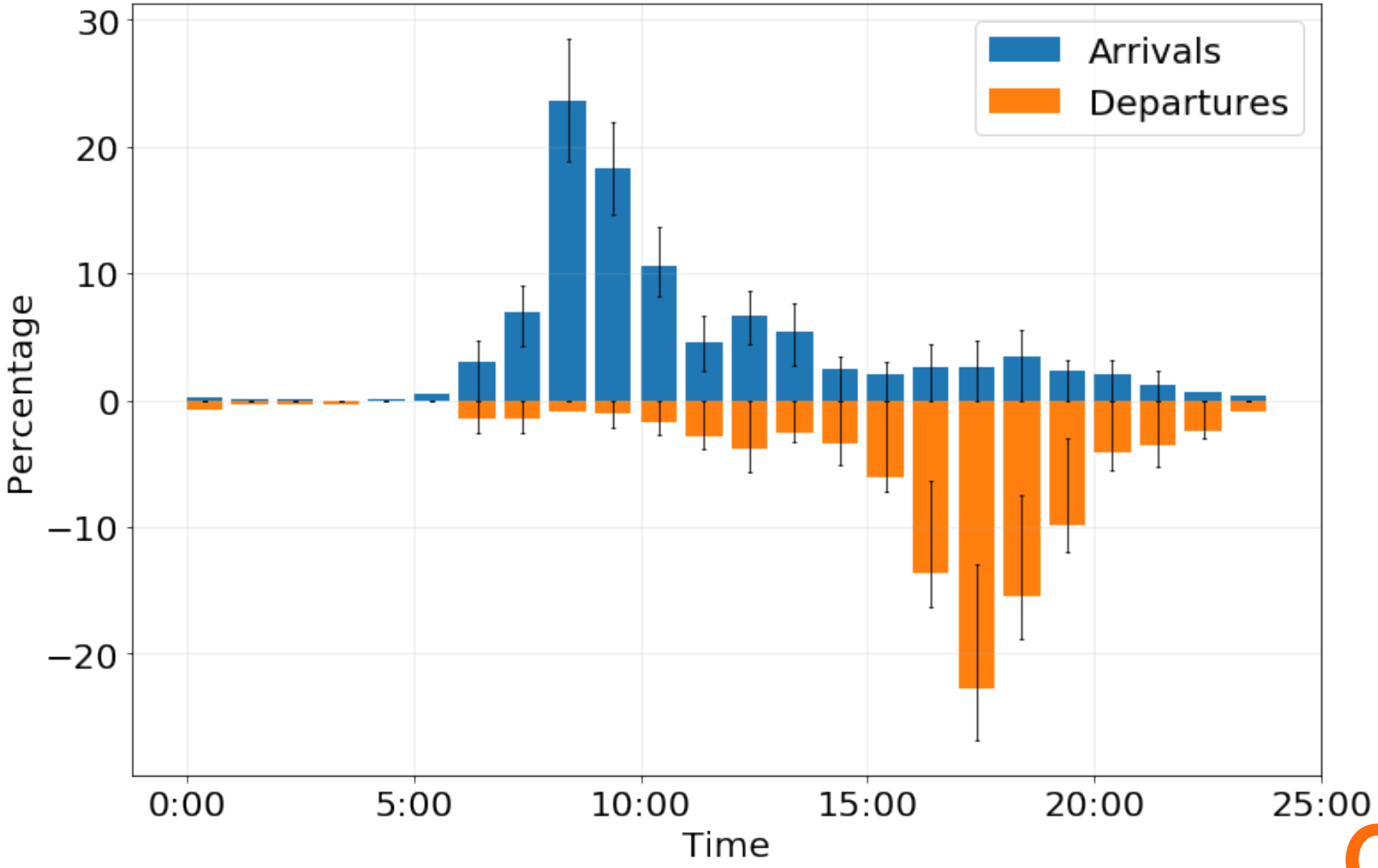
When is the system used?



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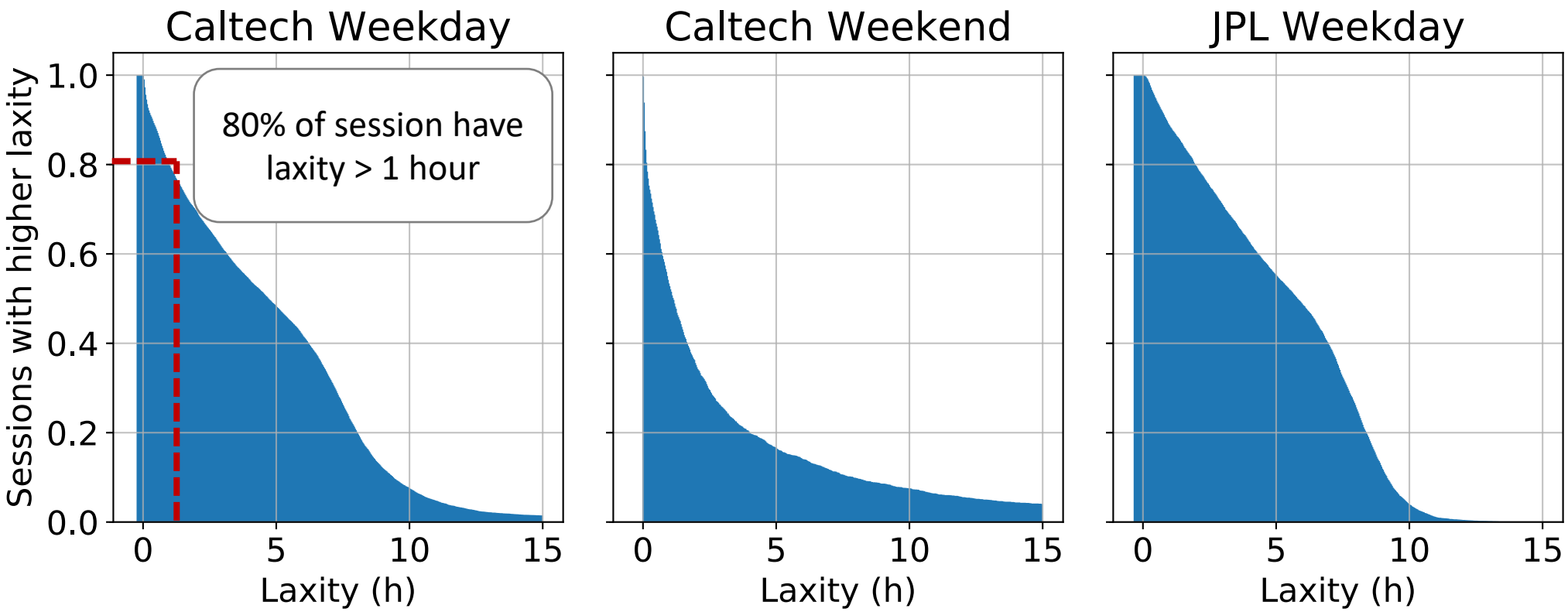
How much flexibility to users have?

LAX(i) := session duration - minimum charging time



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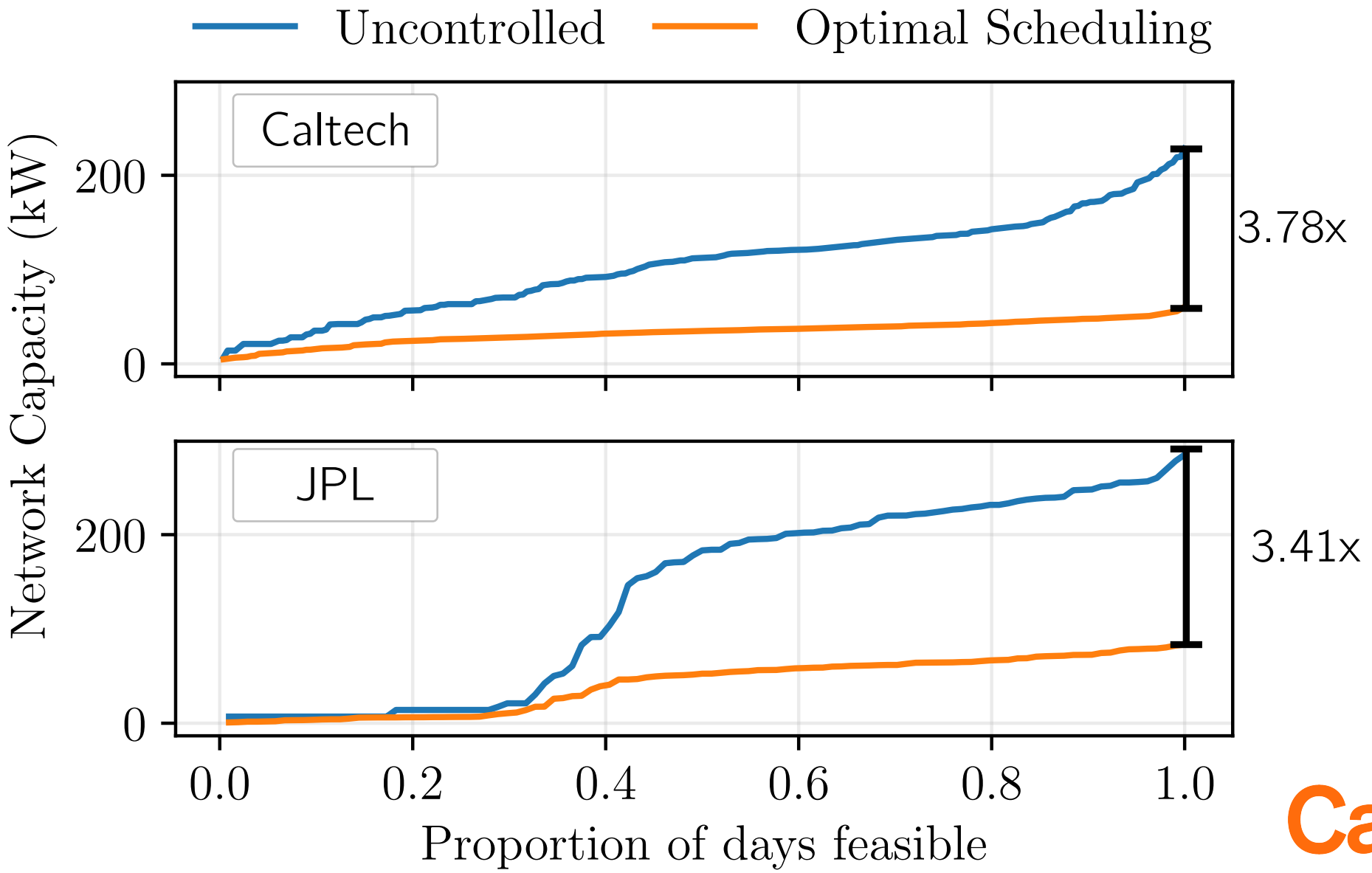
How much flexibility does the system have?



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How can we use data to model charging behavior?

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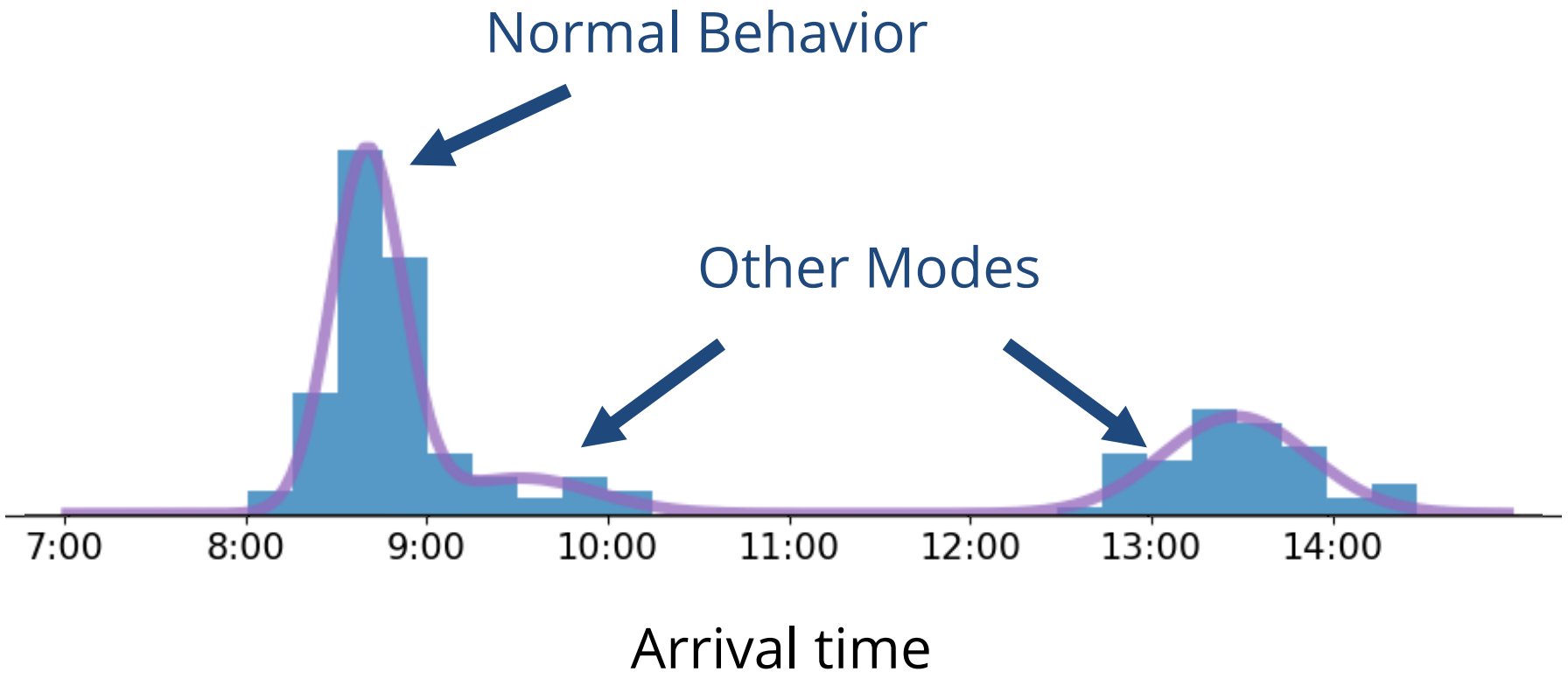
Individual model

Gaussian Mixture Model!

User 334



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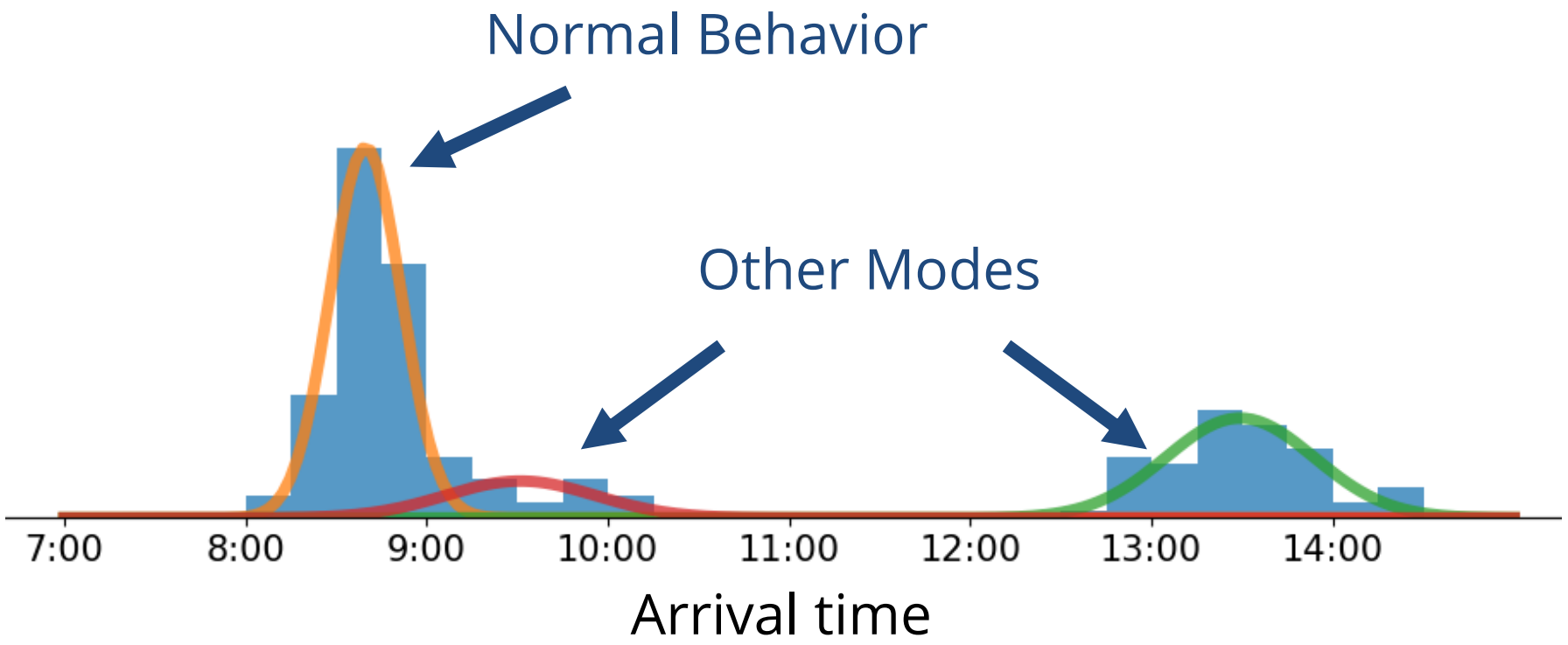
Individual model

Gaussian Mixture Model!

User 334



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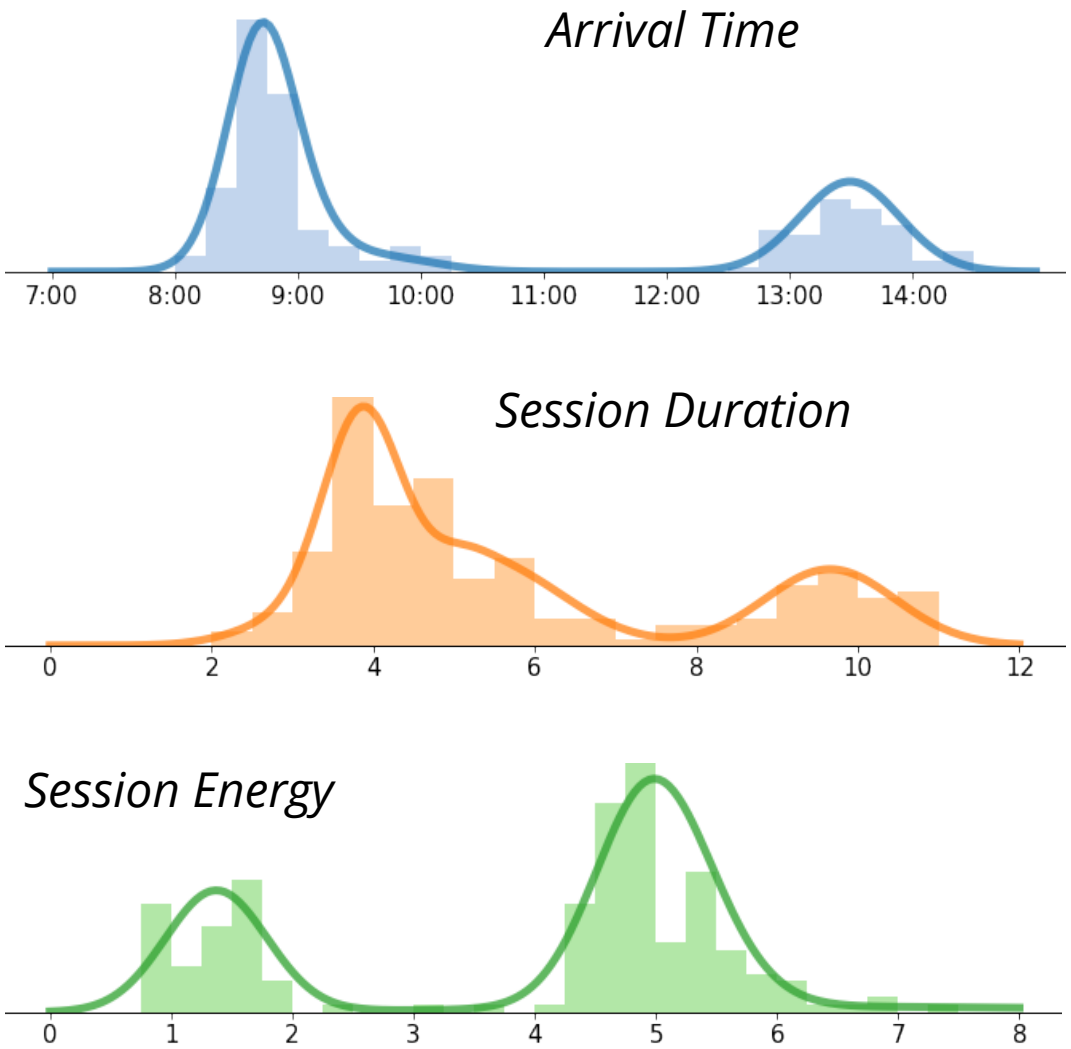
Individual Gaussian Mixture Model

User 334



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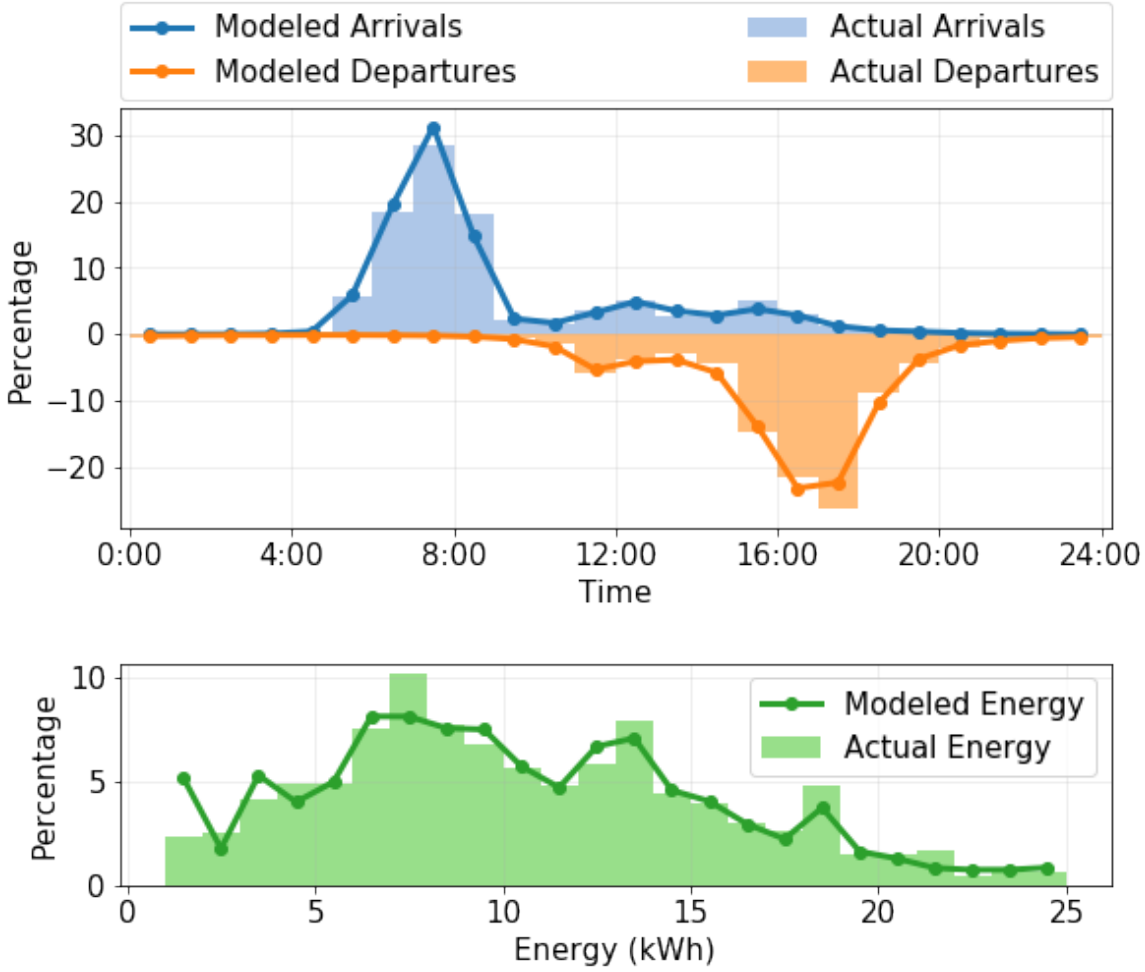
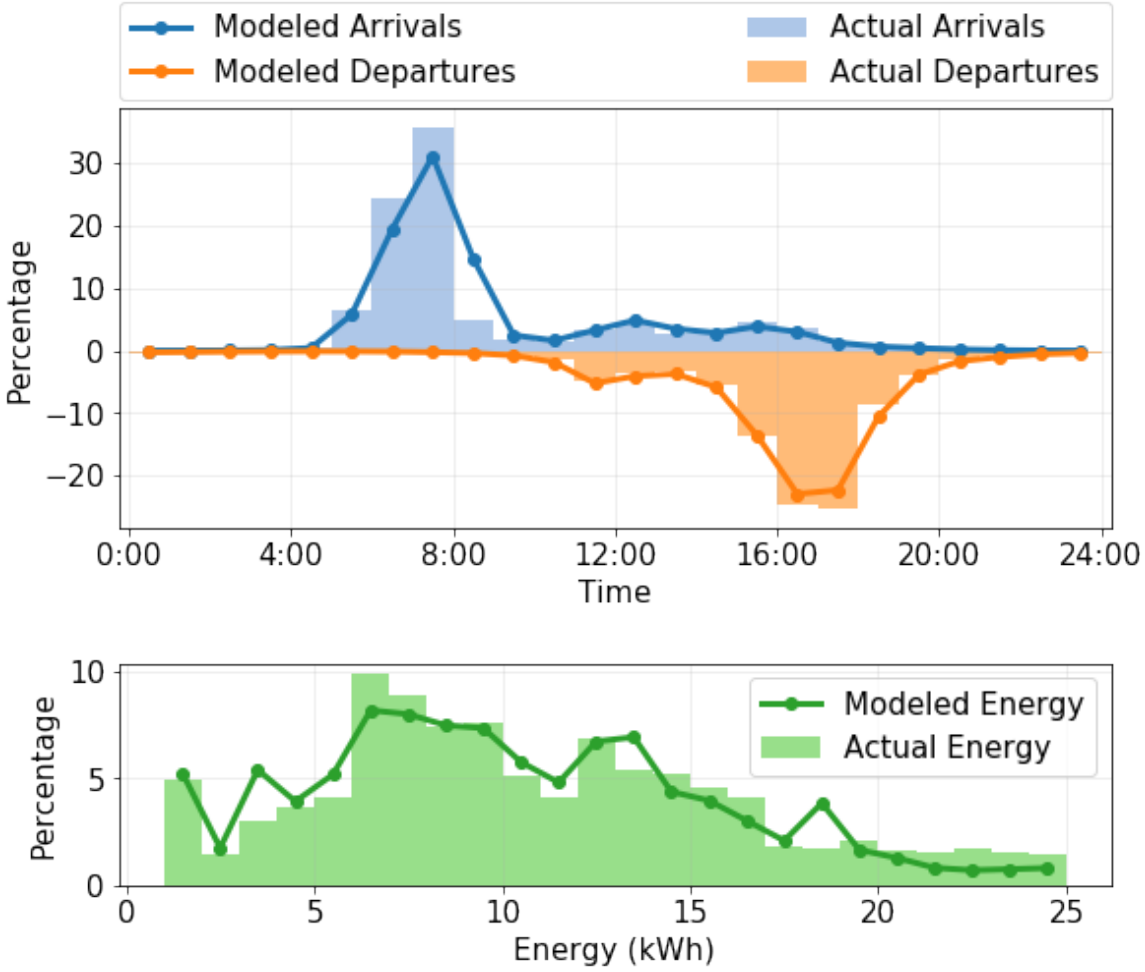
Population Gaussian Mixture Model

Testing Accuracy **(9/1/18 – 11/1/18)**



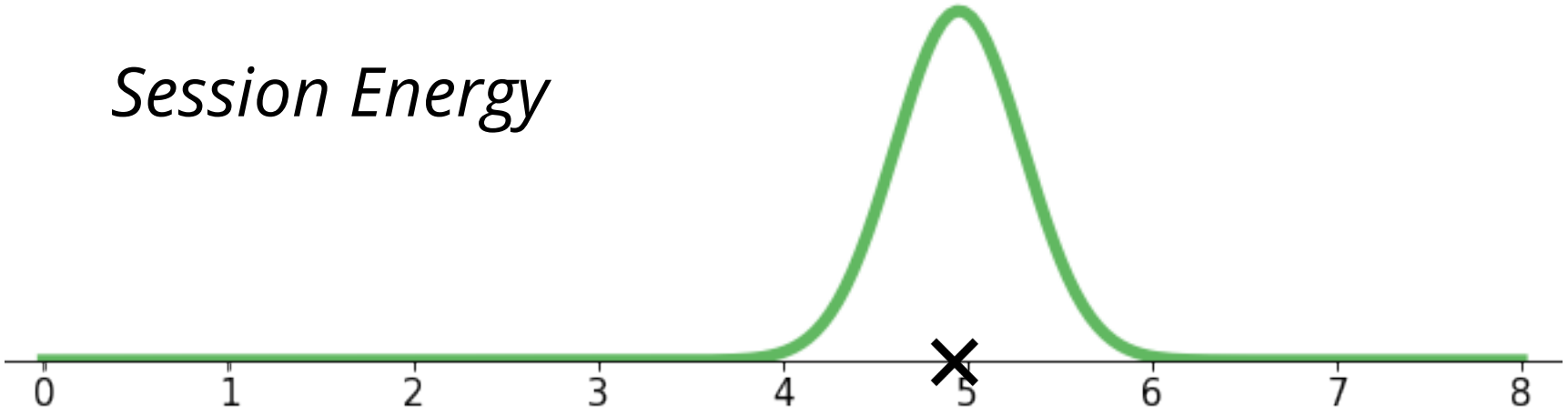
Evaluation Set Accuracy **(12/1/18 – 5/1/19)**

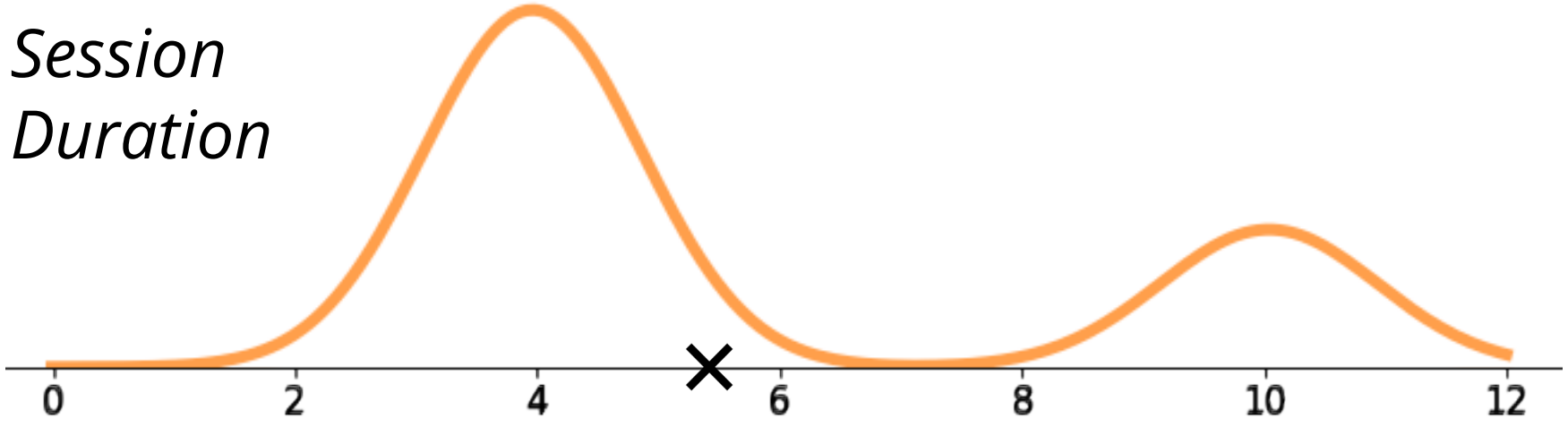


Predicting User Behavior

User 334

8:30 AM





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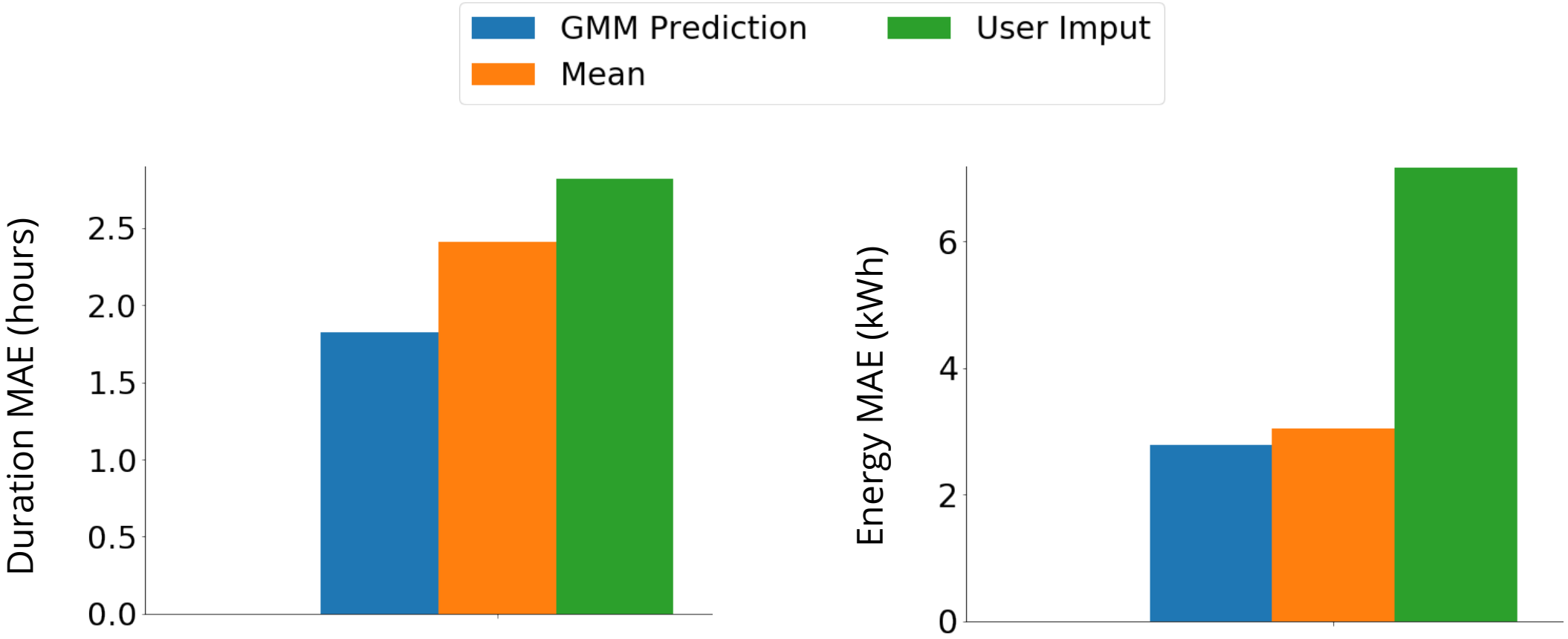
Predicting User Behavior



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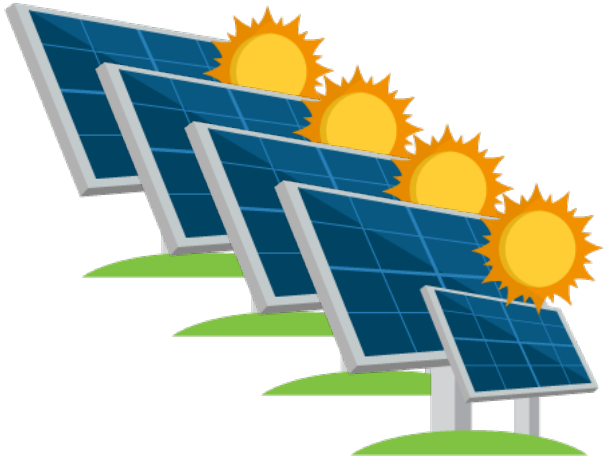
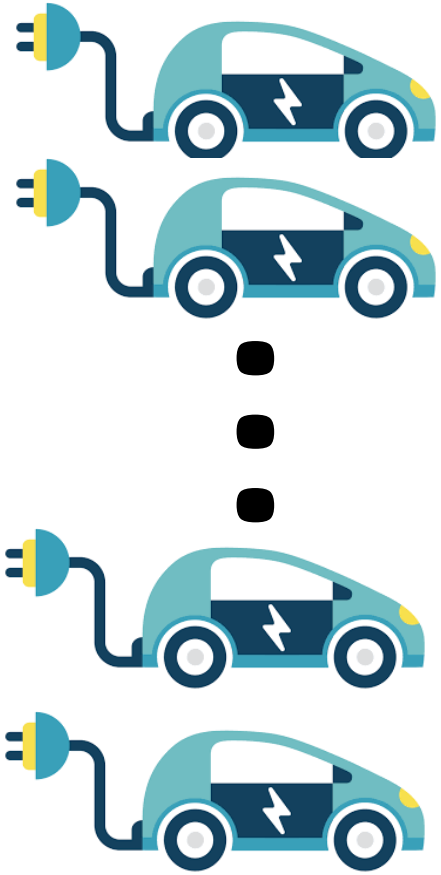
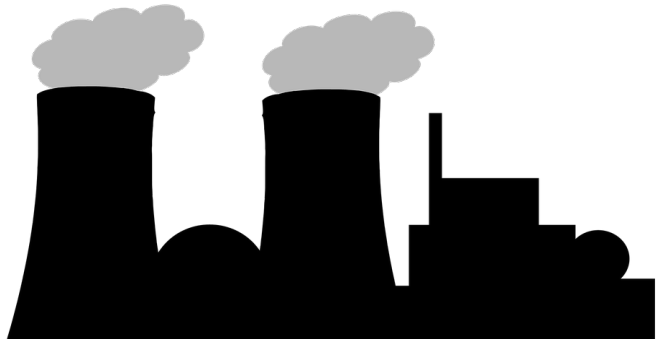
How can these models help us design better charging systems?

Right-sizing on-site solar







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Problem Formulation

Optimal Cost Schedule

$$c^*(\alpha, \mathcal{V}) := \min_{\mathbf{r} \in \hat{\mathcal{R}}} C_{sol}(\alpha, \mathcal{V})$$

Set of EVs

Infrastructure Constraints

$$C_{sol} := \underbrace{c_s \alpha \sum_t s(t)}_{\text{Cost of Solar}} + \underbrace{\sum_t c_e(t) \left[\sum_i r_i(t) - s(t) \right]^+}_{\text{Energy Cost (grid)}} + \underbrace{\Delta \max_t \sum_i r_i(t)}_{\text{Demand Charge}}$$

$s(t) :=$

Solar Curve (TMY)

$$\alpha^* := \arg\min_{\alpha} \mathbb{E}_{\mathcal{V}}[c^*(\alpha, \mathcal{V})] \approx \boldsymbol{\arg\min_{\alpha} \frac{1}{S} \sum_{j=1}^{S} C_{sol}(\alpha, \mathcal{V}_j)}$$

Scenarios from learned distribution

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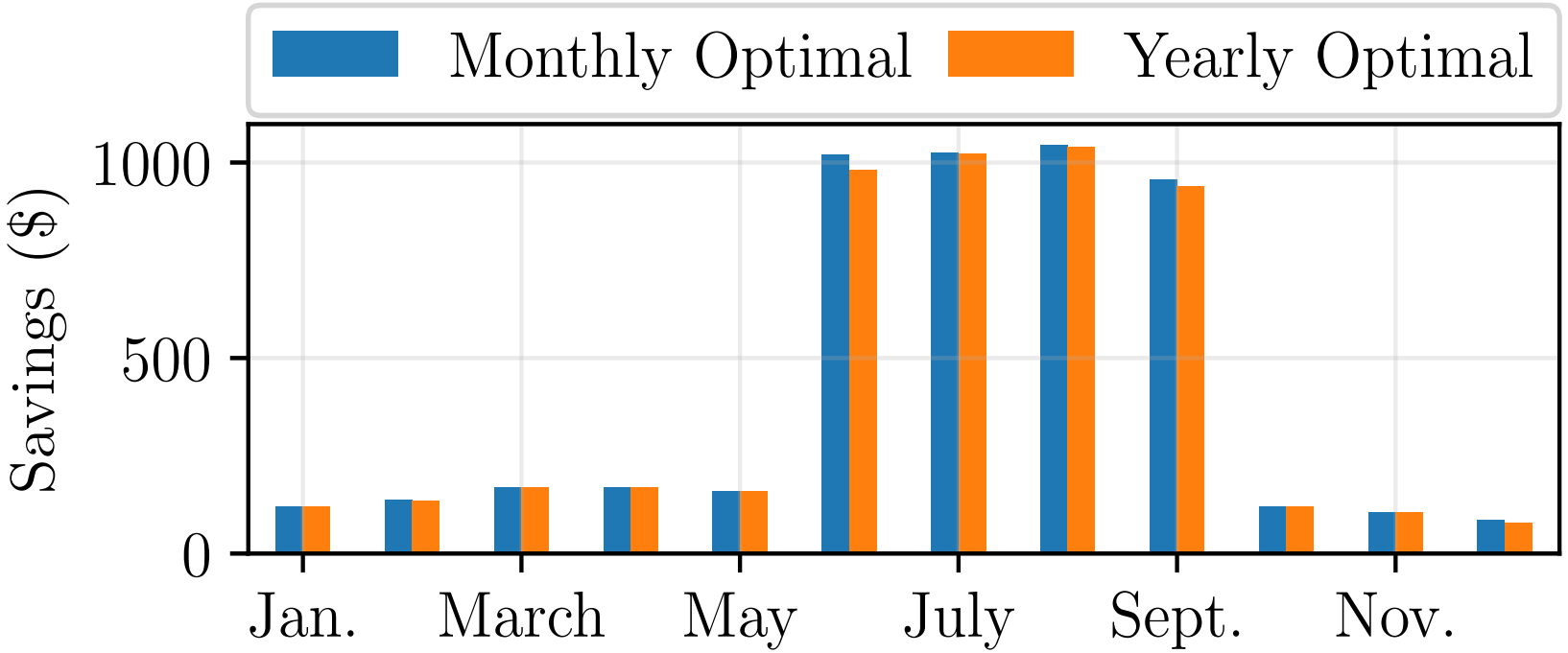
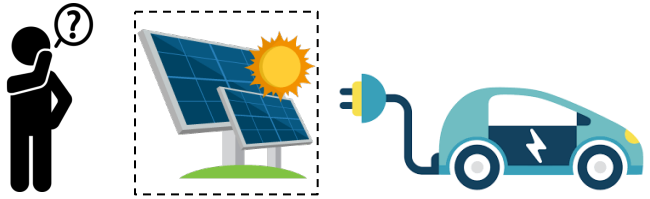
Monthly Savings with Optimal Solar



	Summer	Winter
On-Peak	$0.25 / kWh	$0.08 / kWh
Mid-Peak	$0.09 / kWh	$0.08 / kWh
Off-Peak	$0.06 / kWh	$0.07 / kWh
Demand Charge	$15.48 / kW/month	



Assuming no net metering or alternative uses of solar

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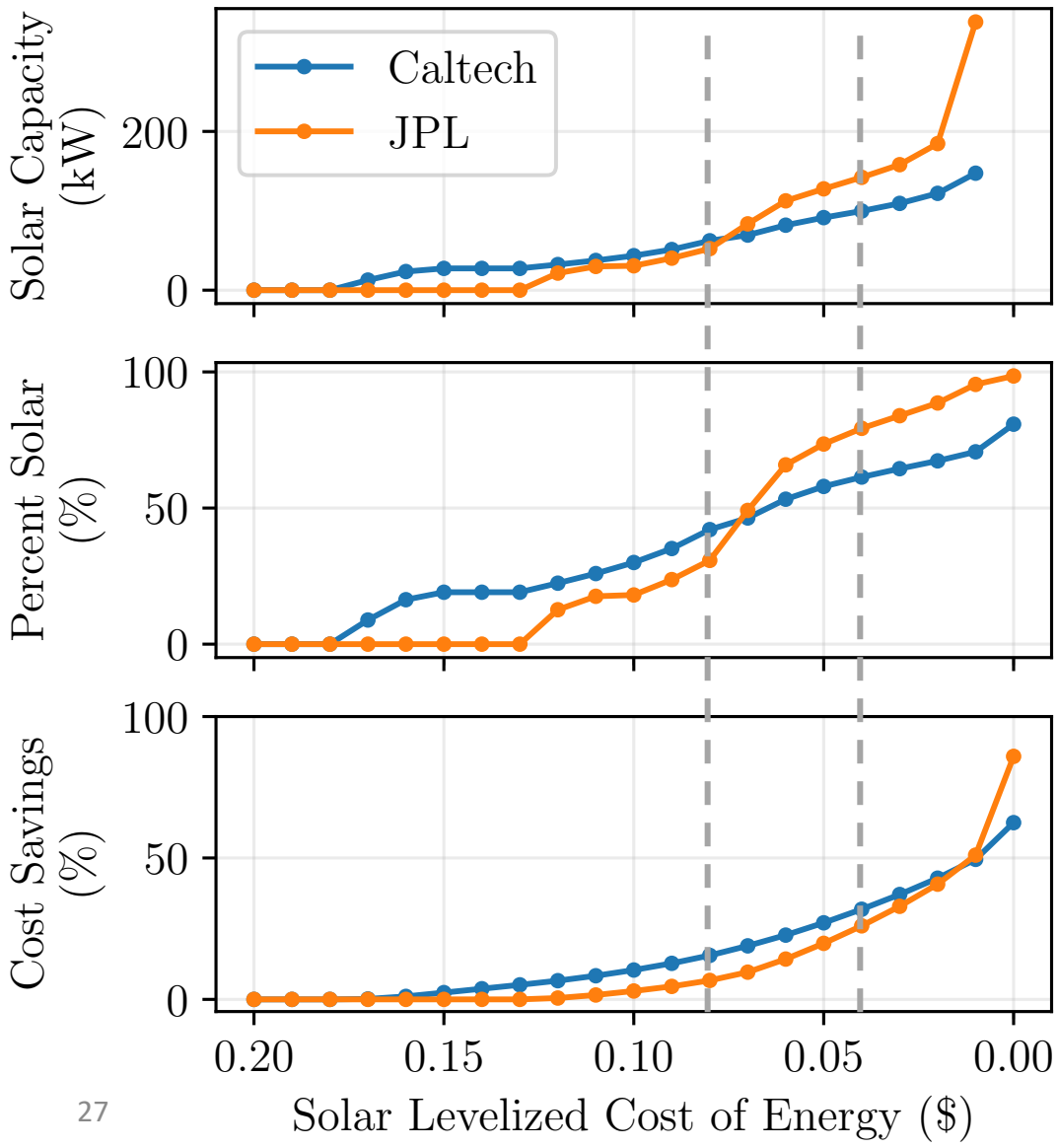
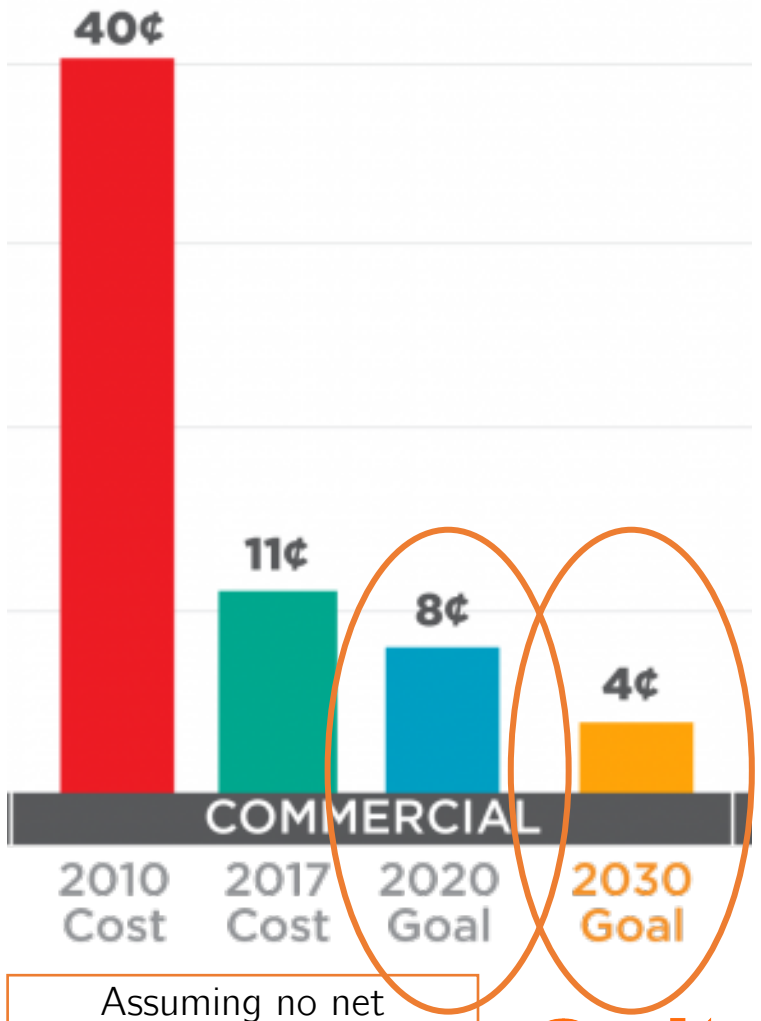
Sensitivity to LCOE of Solar





Assuming no net metering or alternative uses of solar

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How can data help us understand the impact of EV charging on the grid?

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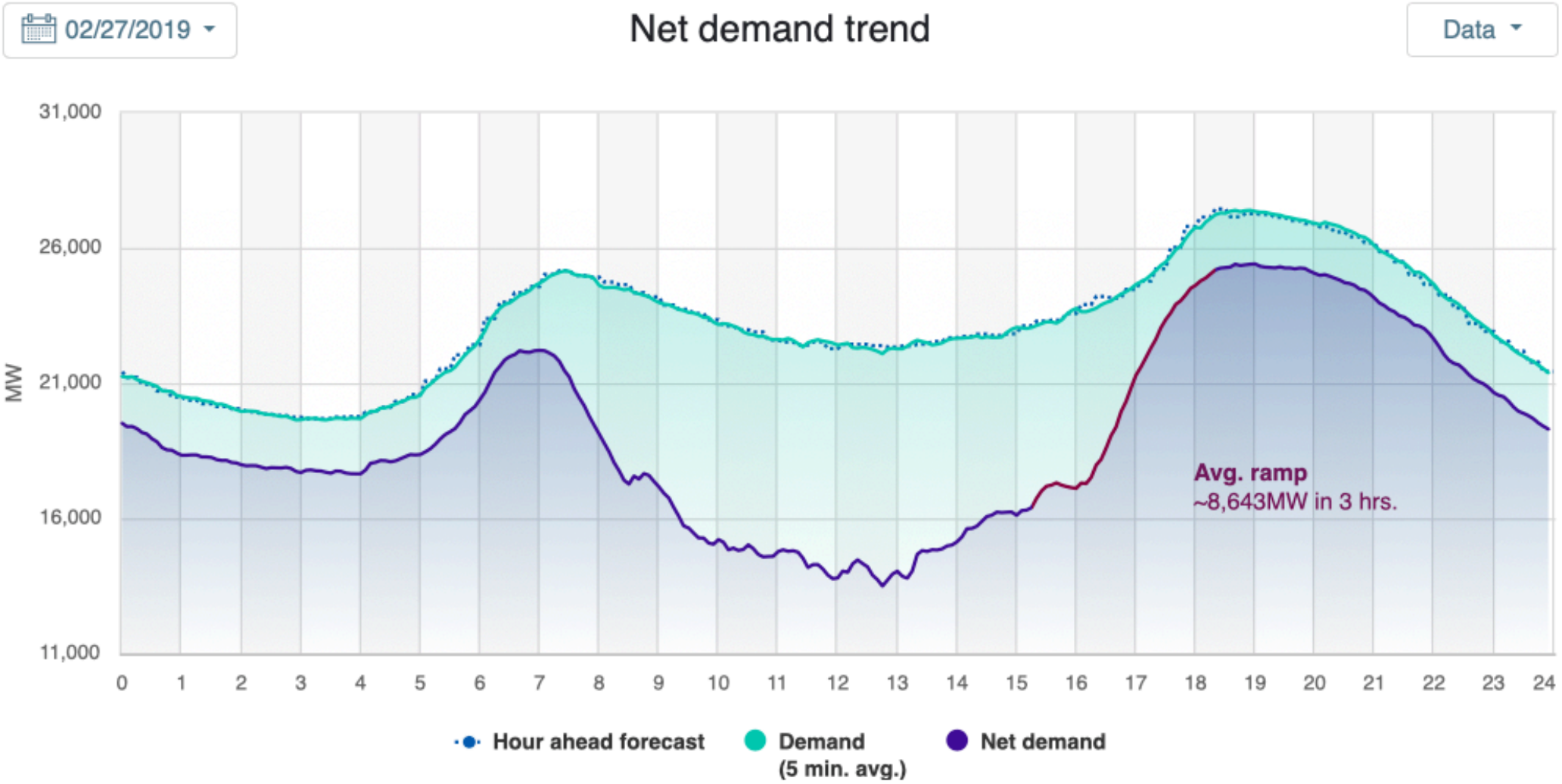
Problem Formulation



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Problem Formulation

Minimum Ramp Schedule

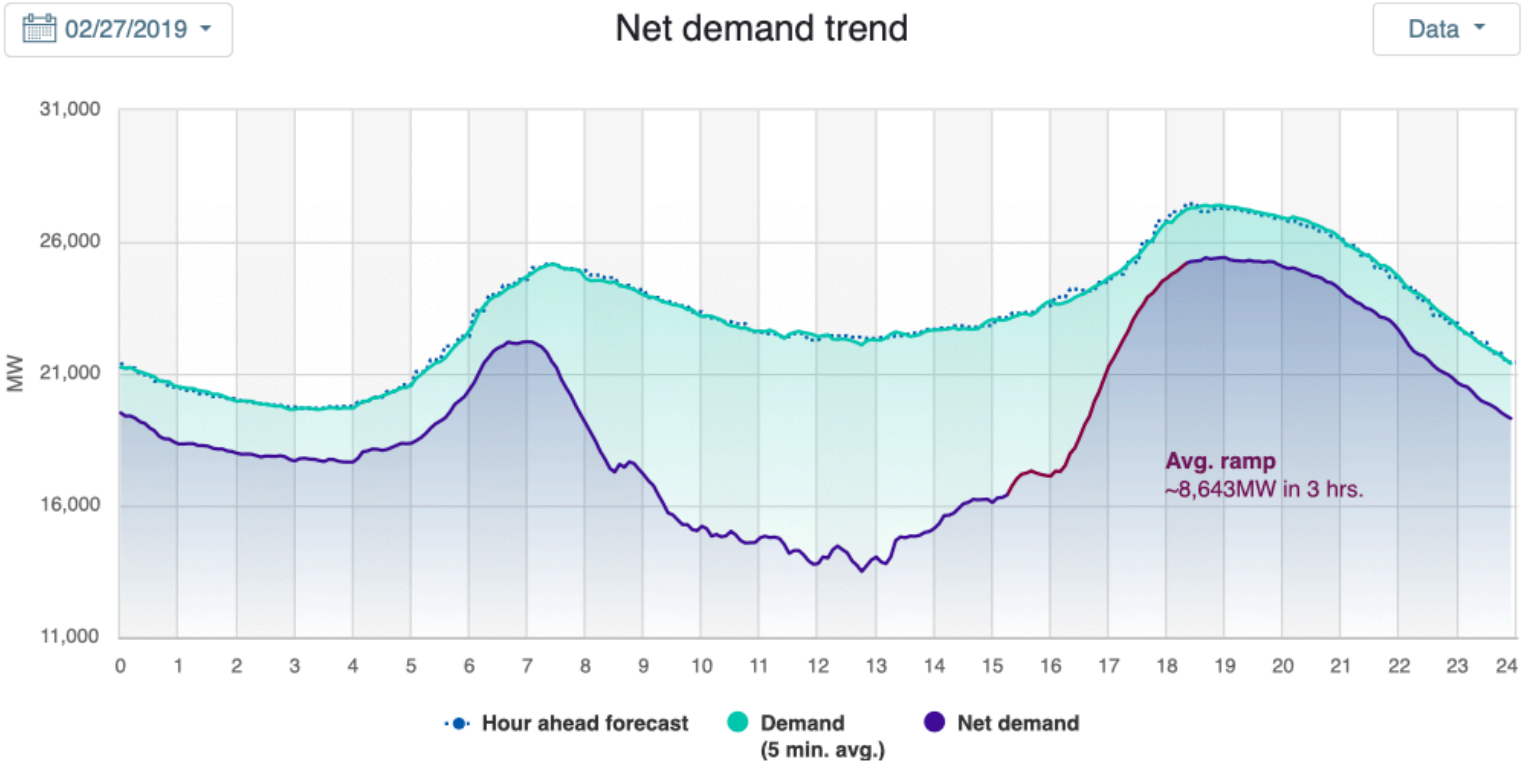
$$\min_{r \in \hat{\mathcal{R}}} \; U_{ramp}(\mathcal{V})$$

$$U_{ramp} := \sum_{t} -\left(\hat{d}(t) - \hat{d}(t-1)\right)^2$$

$$\hat{d}(t) := \sum_{i \in \mathcal{V}} r_i(t) - d(t)$$

$$\mathrm{d}(t) :=$$

Net Demand Curve



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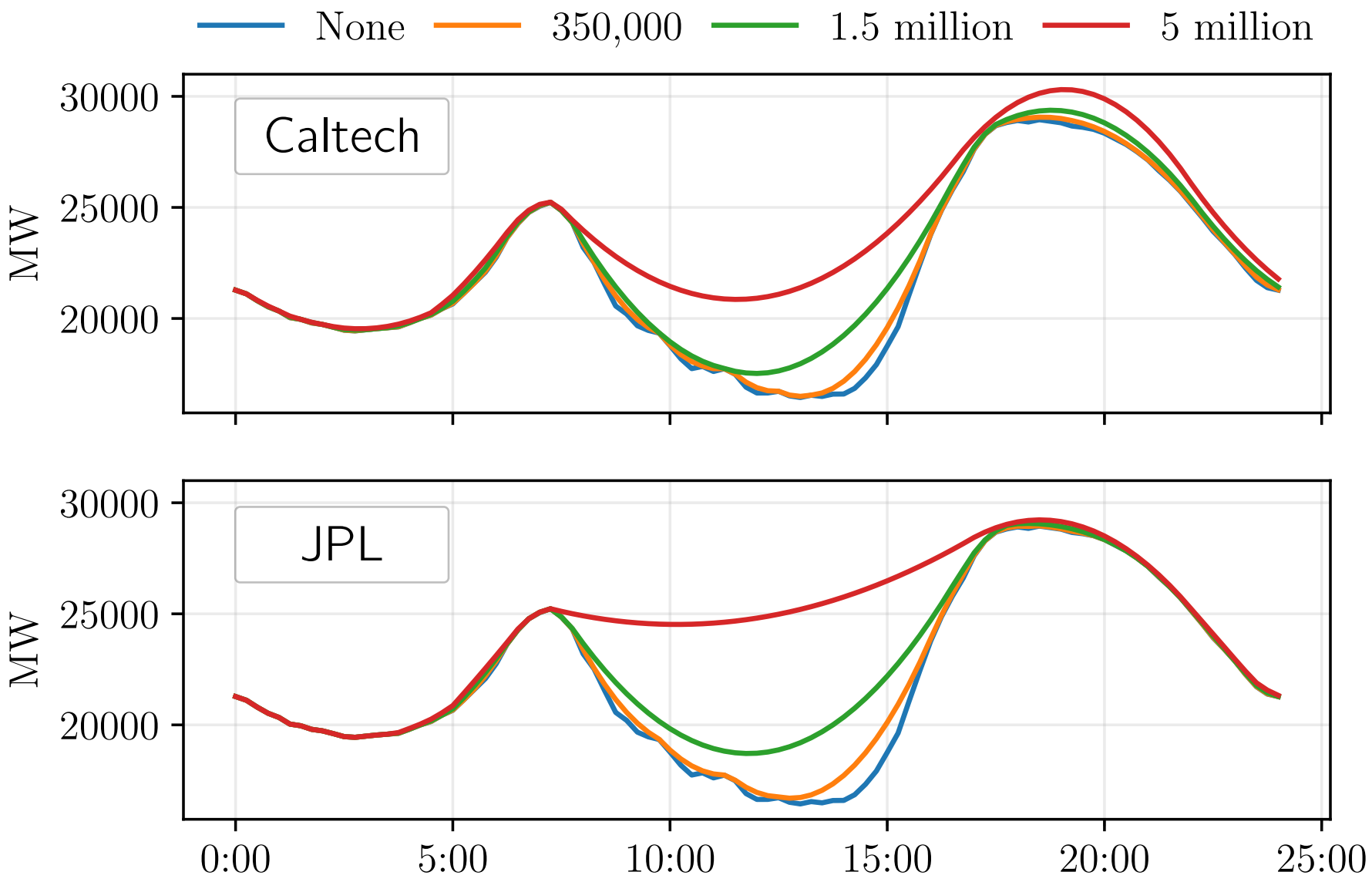
Qualitative Results



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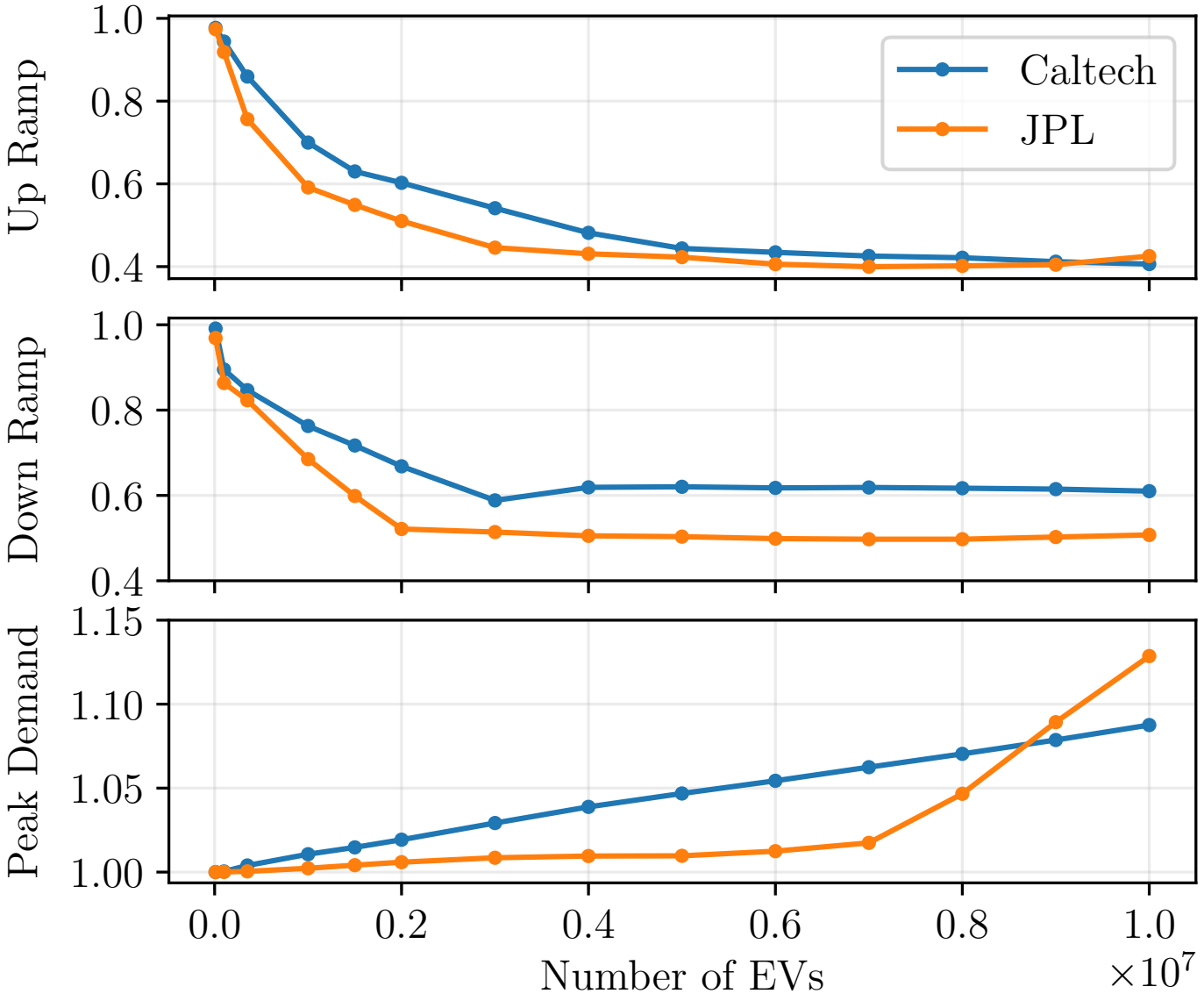
Quantitative Results



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Recap

Over 32,000 EV Charging Sessions

Machine Learning and Statistical Modeling

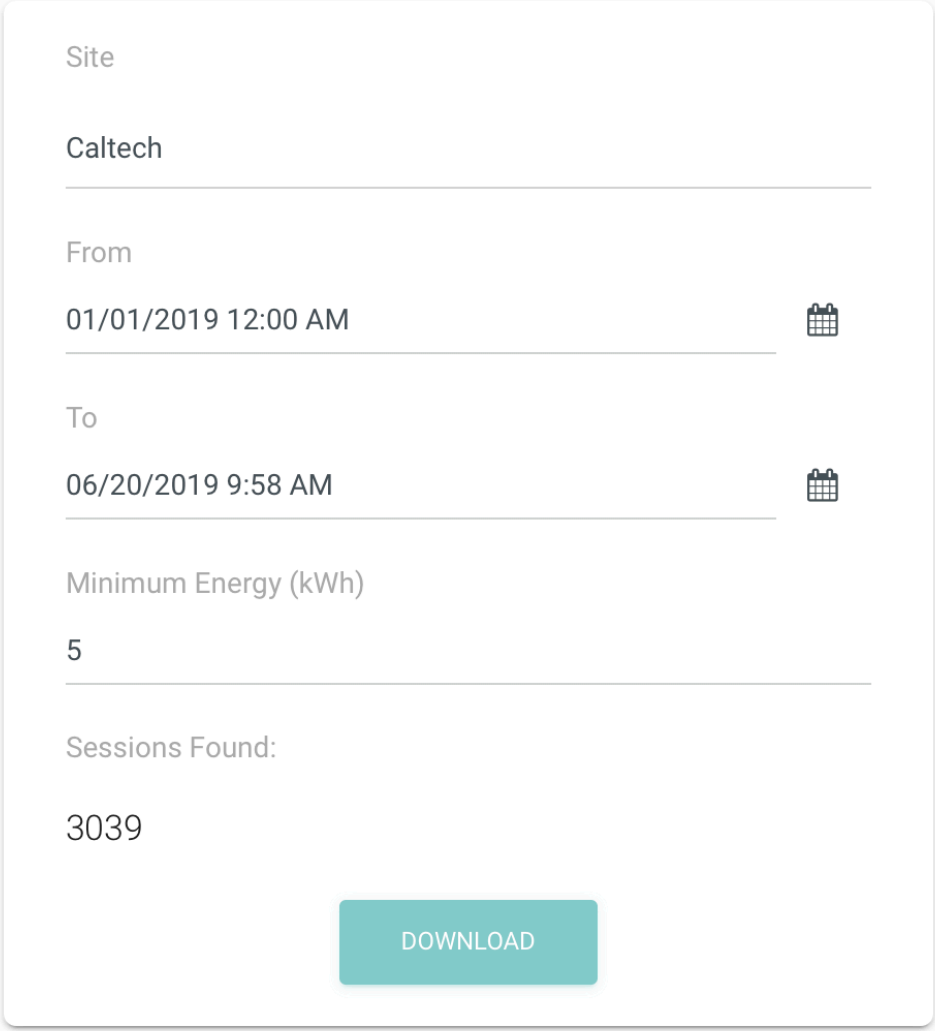
Algorithm Design and Evaluation

System Design and Grid Impacts

Your idea here…

Accessing the dataset

- Web Interface
- API
- Python Client
- ACN-Sim



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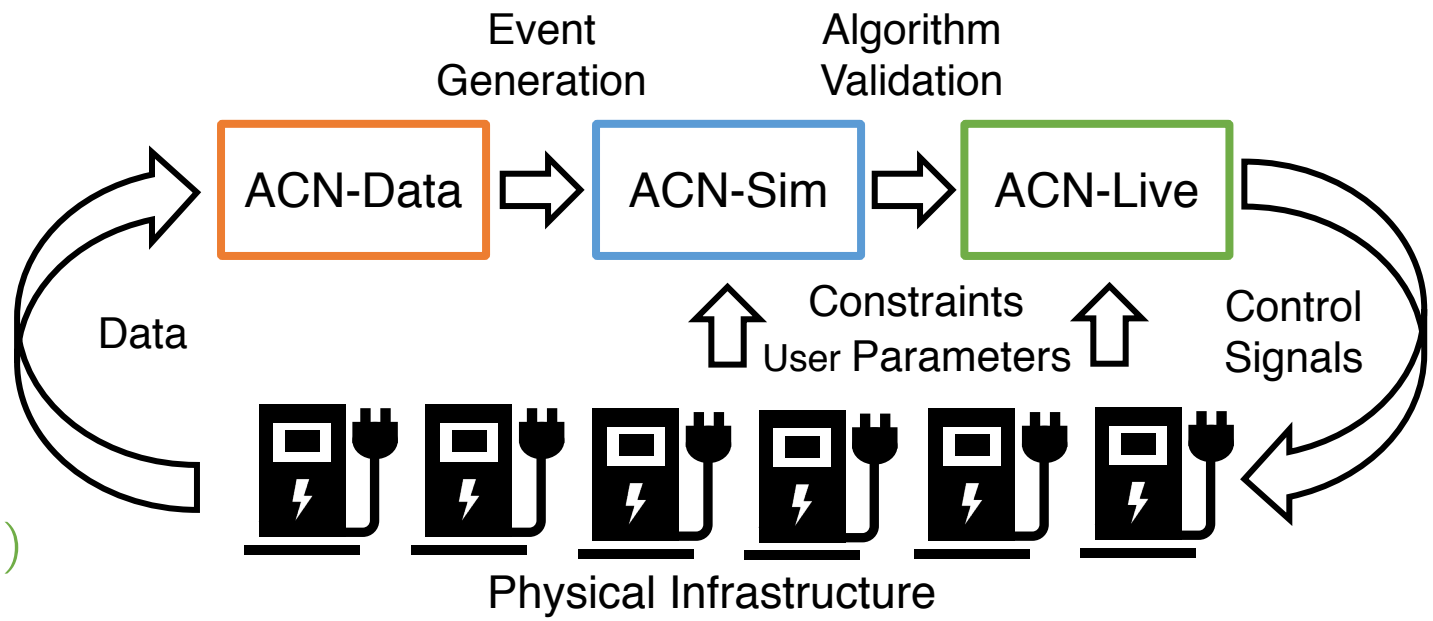
More tools for EV research

ACN Research Portal

- *Phase 0:* ACN Testbed
- *Phase 1:* ACN-Data
- *Phase 2:* ACN-Sim
- *Phase 3:* Integration with OpenAI Gym
- *Phase 4:* ACN-Live (hardware-in-the-loop)
- *Phase 5:* Integration with grid simulator



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ACN-Sim

A common environment to accelerate large-scale EV charging research.

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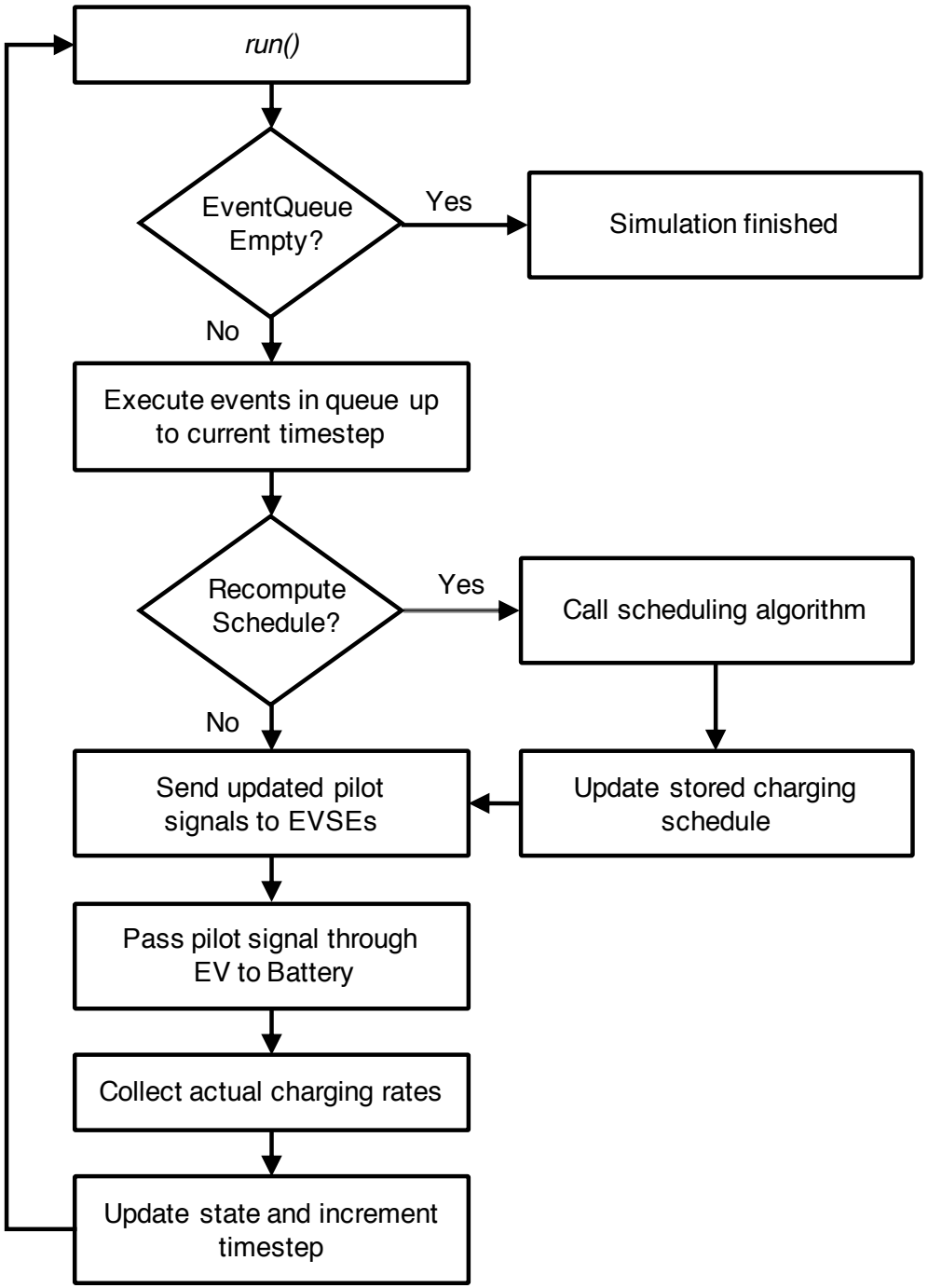
Simulation Loop



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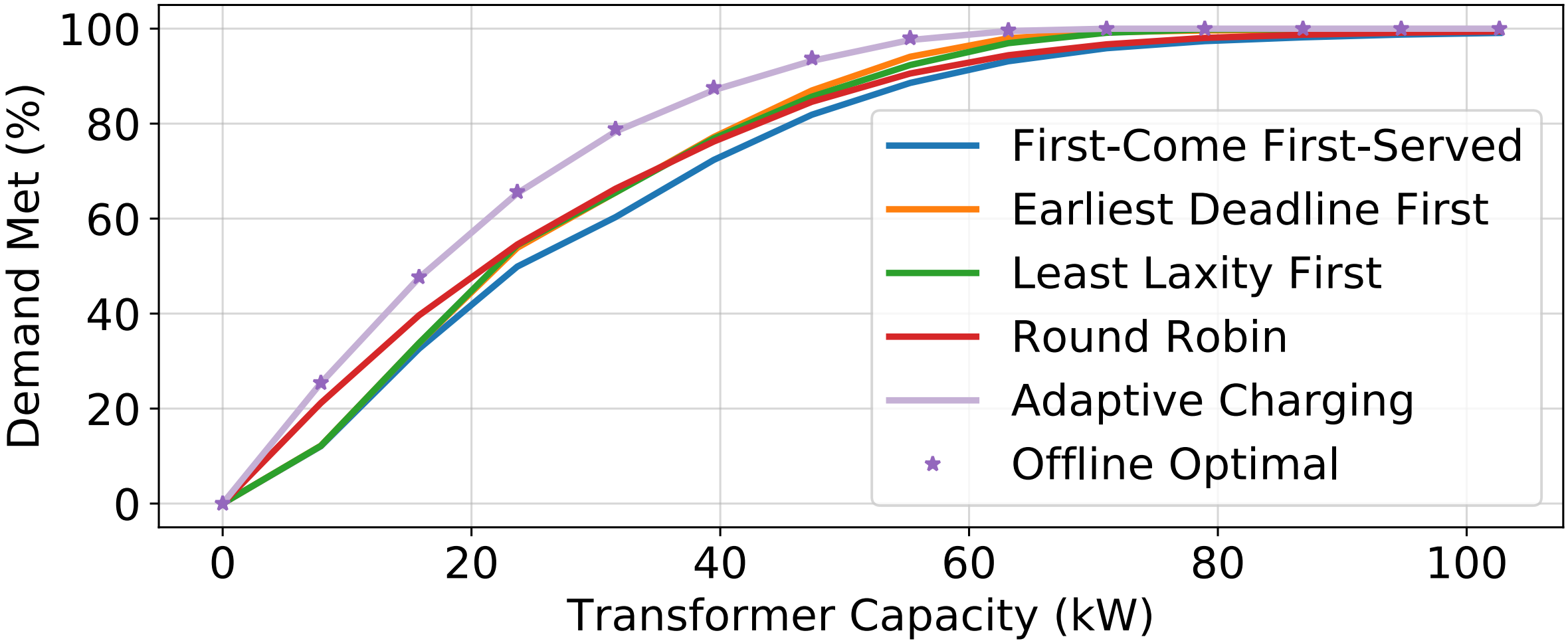
ACN-Sim + ACN-Data



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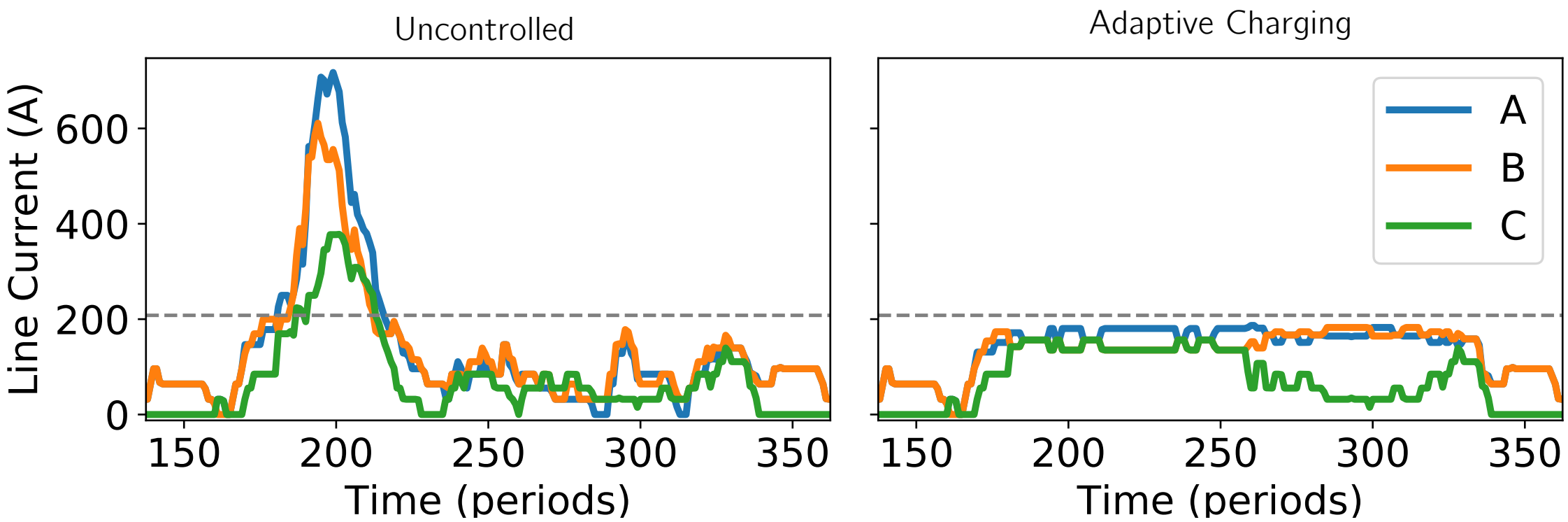
Oversubscribing Unbalanced Three-Phase Infrastructure



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Adaptive Charging Network
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SIMULATOR
ACCOUNT
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Accelerating Electric Vehicle Research @ Caltech and Beyond
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