Estimating electricity demand from uncoordinated BEV charging

ZACH NEEDELL

LAB MEETING, 2/14/2018

Outline

Background: Electric vehicles and the electricity sector

Research Motivation: Risks and opportunities with BEV adoption and the electricity sector

Data and Methods:

- Electricity and weather data sources
- Energy model
- Charge timing model

Research Questions:

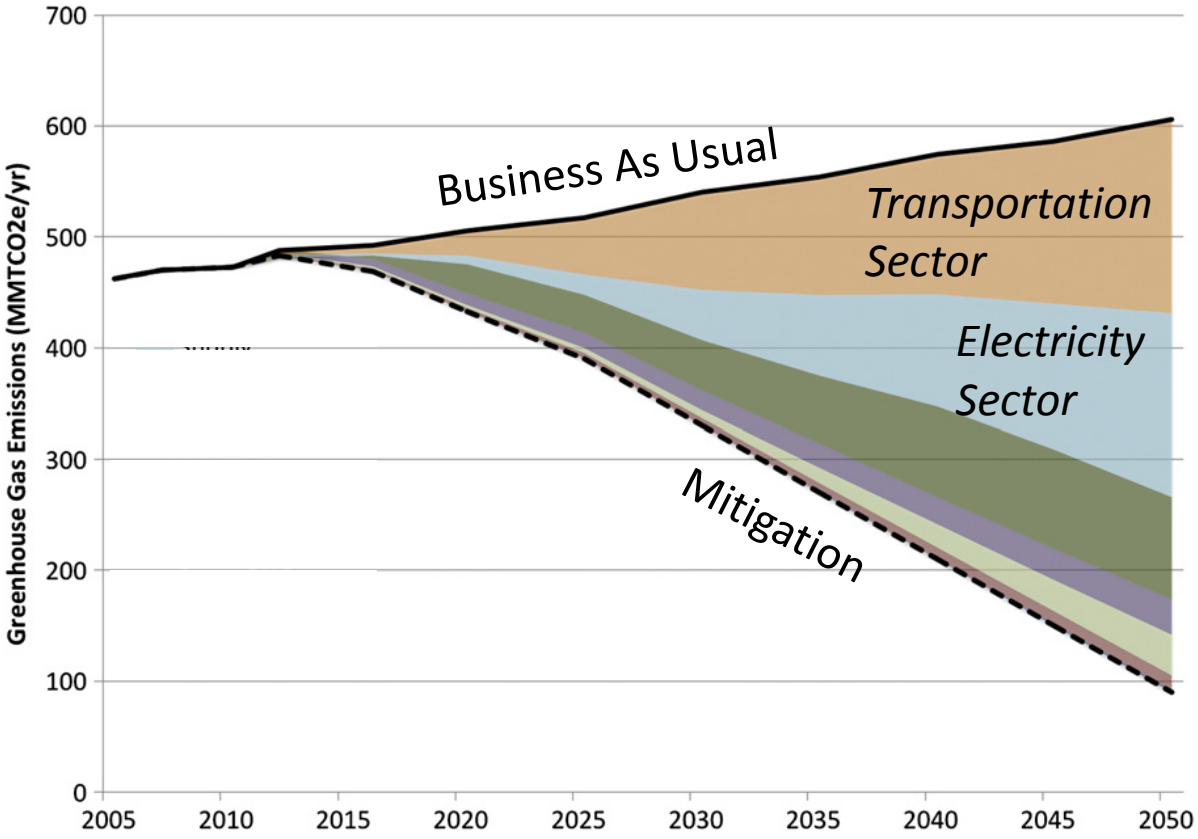
- Comparing charging scenarios
- Integration with solar
- Energy demand vs BEV adoption

Implications:

- Workplace charging
- Policies to promote BEV and solar PV co-benefits

Electric vehicles and the electricity sector

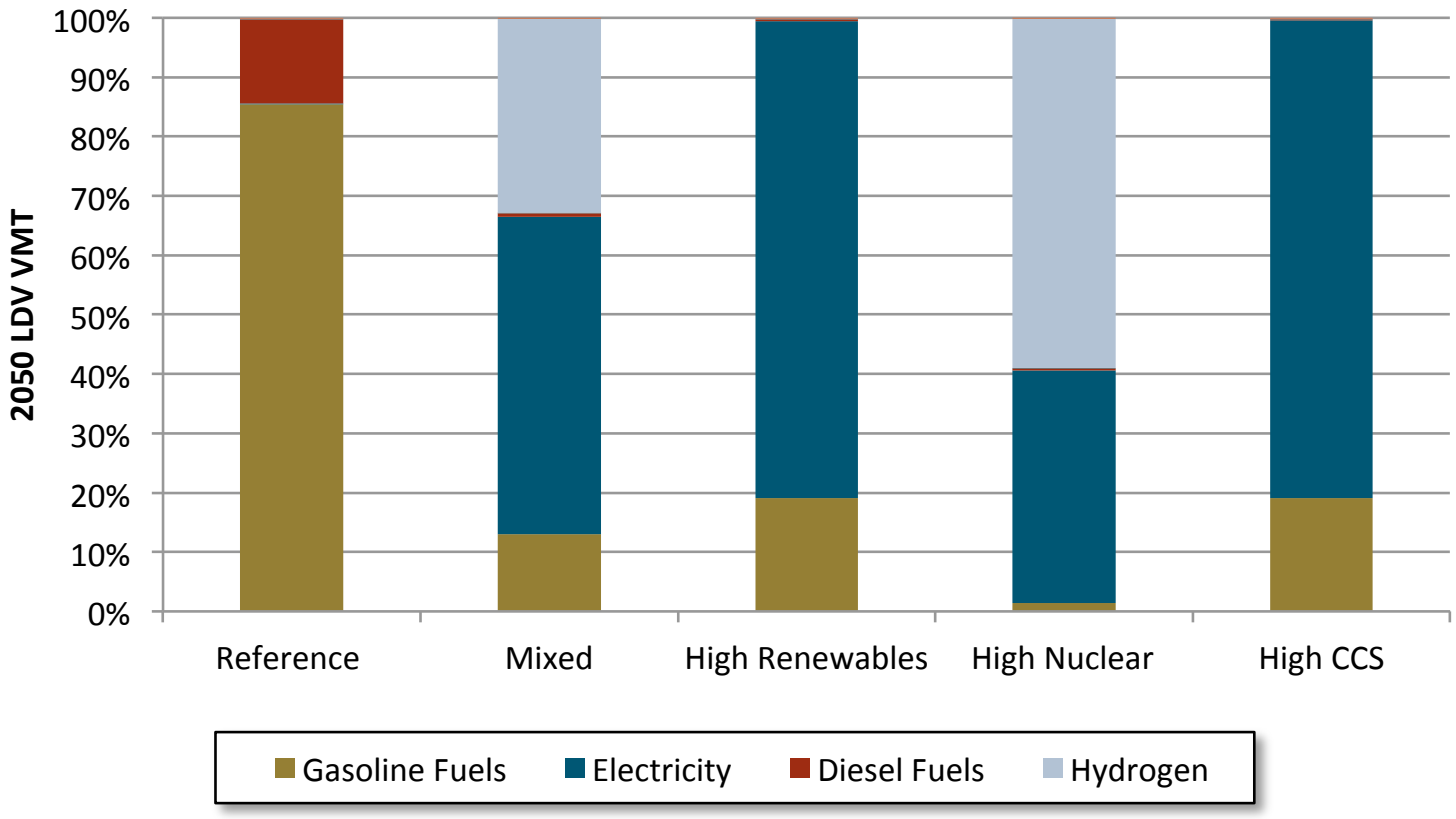
Emissions Reduction Scenarios



- Significant emissions reductions across sectors required to reach targets
- Transportation + Electricity sectors represent majority of reductions

McCollum et al, 2011

Transportation Electrification



- Major transition to electricity a component of all mitigation scenarios
- More efficient, possibility to be powered by low-carbon sources

Source: UN Report: Pathways to deep decarbonization in the United States

Risks and opportunities of BEV integration

Effects on the electricity sector

"as the PEV fleet grows, implementation of an intelligent management system will be necessary in order to avoid **large capital expenditures in network reinforcements and negative effects on electric distribution networks**, such as: voltage deviations, transformers and lines saturations, increase of electrical losses, etc."

(Eric Brown, Fox 13 Salt Lake City)

Richardson, David B. "Electric vehicles and the electric grid: A review of modeling approaches, Impacts, and renewable energy integration." *Renewable and Sustainable Energy Reviews* 19 (2013): 247-254.

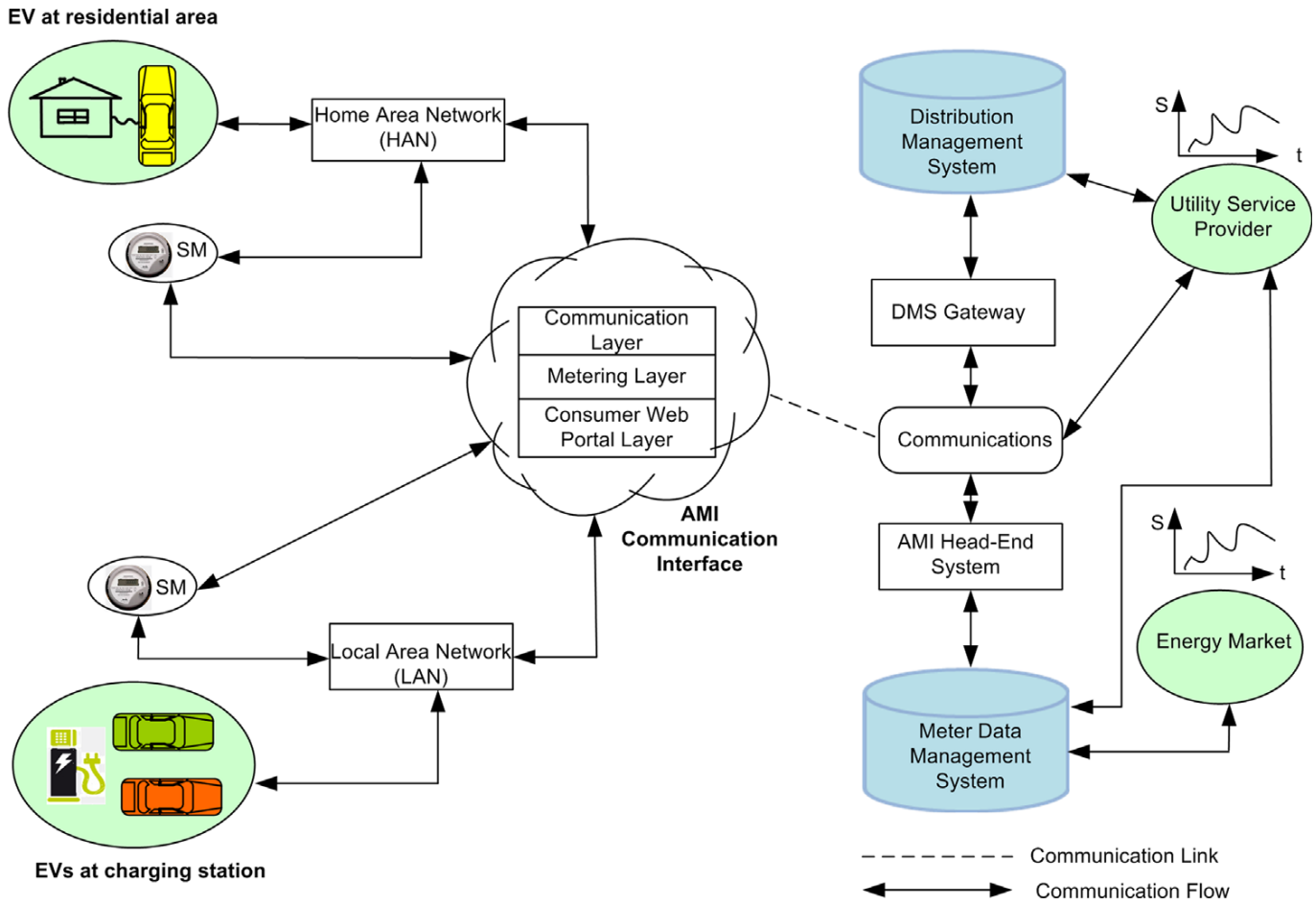
Effects on the electricity sector

"For quite some time any analysis of the distribution grid has been ignored because it has been assumed that **either enough capacity exists or that PHEV adoption will occur slowly enough that utilities will have more than enough time to adjust and reinforce the current networks**. This may or may not be the case…."

— Green, et al. (2011)

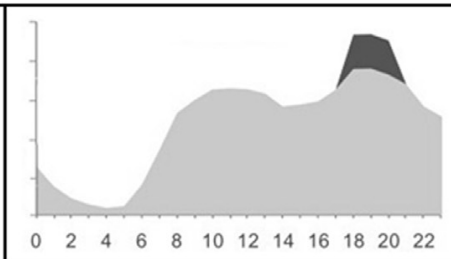
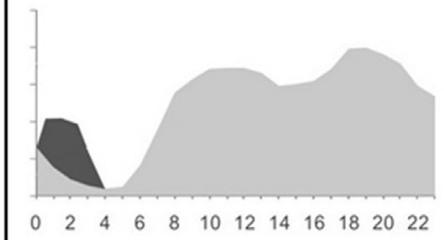
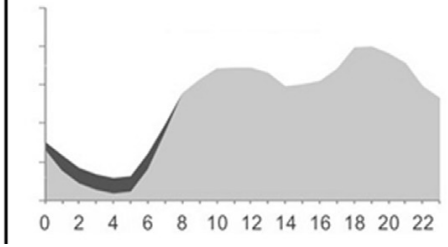
Green II, R.C., Wang, L. and Alam, M., 2011. The impact of plug-in hybrid electric vehicles on distribution networks: A review and outlook. *Renewable and sustainable energy reviews*, *15*(1), pp.544-553

Effects on the electricity sector



Mwasilu, F., Justo, J.J., Kim, E.K., Do, T.D. and Jung, J.W., 2014. Electric vehicles and smart grid interaction: A review on vehicle to grid and renewable energy sources integration. *Renewable and Sustainable Energy Reviews*, *34*, pp.501-516.

Interim solutions

		Advantages	Drawbacks
Uncontrolled Charging		✓ Easy implementation ✓ User friendly	× Overload of transformers and lines × Voltage deviations × Peak power increase × Increase of electricity CO_2 intensity × Electricity cost increase × Needs to reinforce the grid
Off-peak Charging		✓ Easy implementation ✓ Demand profile flattened ✓ Better integration of wind energy at off-peak hours ✓ Delay in grid investments	× Imbalances due to rapid increase of power consumed by PEVs × Possible overload of transformers and lines × Possible voltage deviations × Willingness of the customer required
Smart Charging (Valley filling)		✓ Ancillary services provision ✓ Demand profile flattened ✓ Better integration of wind energy at off-peak hours ✓ Delay in grid investments	× Complex implementation × ICT technologies required × Willingness of the customer required

García-Villalobos, J., et al. "Plug-in electric vehicles in electric distribution networks: A review of smart charging approaches." *Renewable and Sustainable Energy Reviews* 38 (2014): 717-731.

Solar-to-vehicle (S2V) charging

Bhatti, A.R., et al., 2016. Electric vehicles charging using photovoltaic: Status and technological review. *Renewable and Sustainable Energy Reviews*, *54*, pp.34-47

Complexities to consider

- **Travel behavior is complex**
  - Can’t make quantitative statements based on “typical” driving

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  - Grid capacity constraints are likely to be first felt at the metropolitan and (sub) regional scale
- **Electricity use and BEV fuel economy vary with weather**
  - Potential correlations between energy use between sectors

Research questions

- **What do load profiles from BEV charging look like?**
  - Do they vary significantly between cities?
  - How do they change under different charging schema?
- **To what extent will BEVs add to grid capacity constraints?**
  - On what sort of days and times would we expect these issues to arise?
- **How effective are different, easy-to-implement interventions at easing capacity issues?**
- **Can we quantify some of the co-benefits between BEV adoption and workplace solar?**
  - Are there certain situations when this is especially promising?

Data and Methods

Data: Requirements

- Need hourly historical weather and electricity demand data for a 1+ year period
- Localized to the Metropolitan/Regional scale
- Large sample size of travel patterns and energy requirements
- Trips and electricity demand isolated from a coherent geographic region

Data: Sources

DALLAS, TX

Electricity:

- ERCOT North Central zone

Travel:

- NHTS Dallas CBSA

Weather:

- National Solar Radiation Database for grid cell in downtown Dallas

NEW YORK CITY, NY

Electricity:

- NYISO zones for NYC, Long Island, and Rockland/Westchester Counties

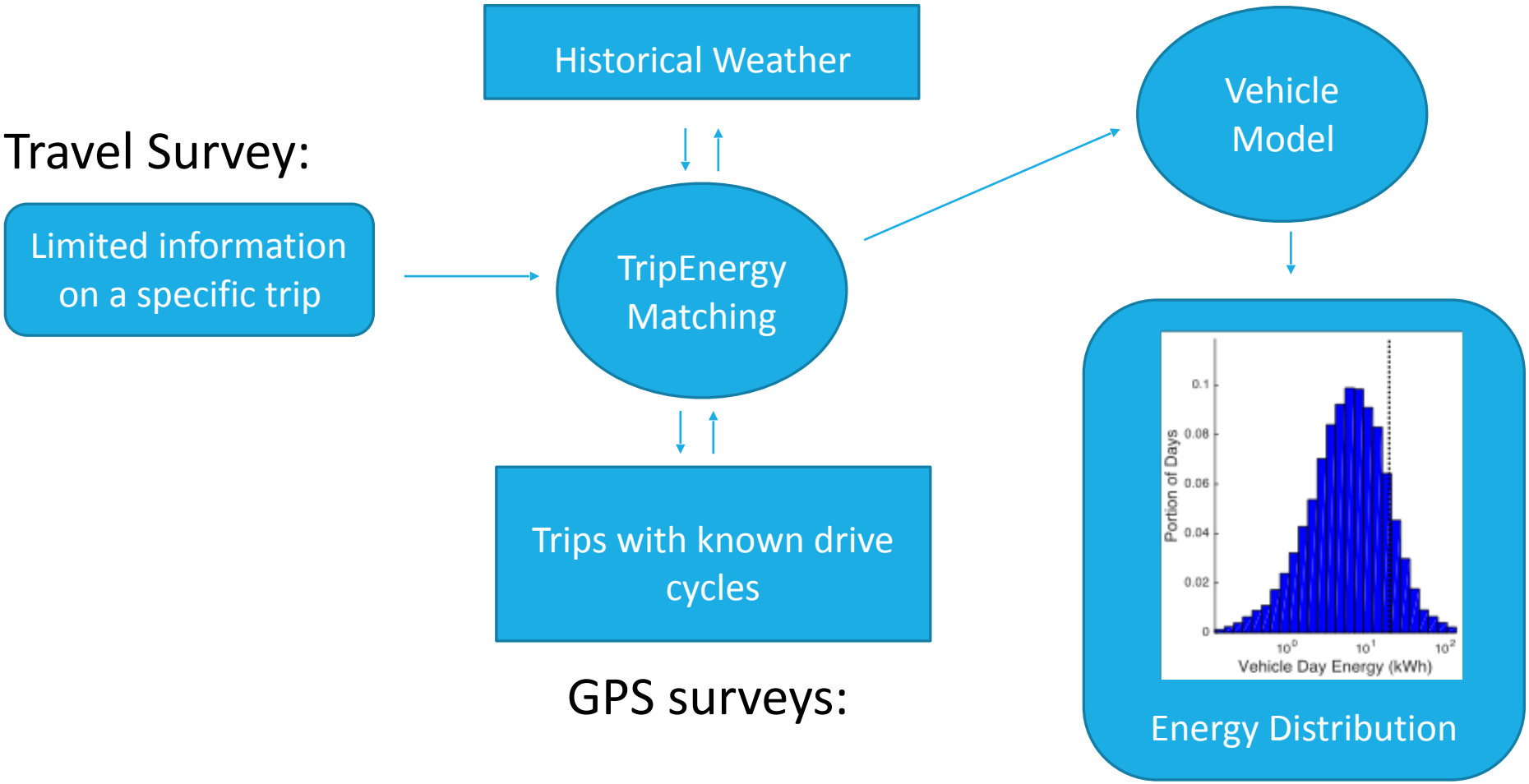
Travel:

- NHTS New York CBSA + New York State

Weather:

- National Solar Radiation Database for grid cell in downtown NYC

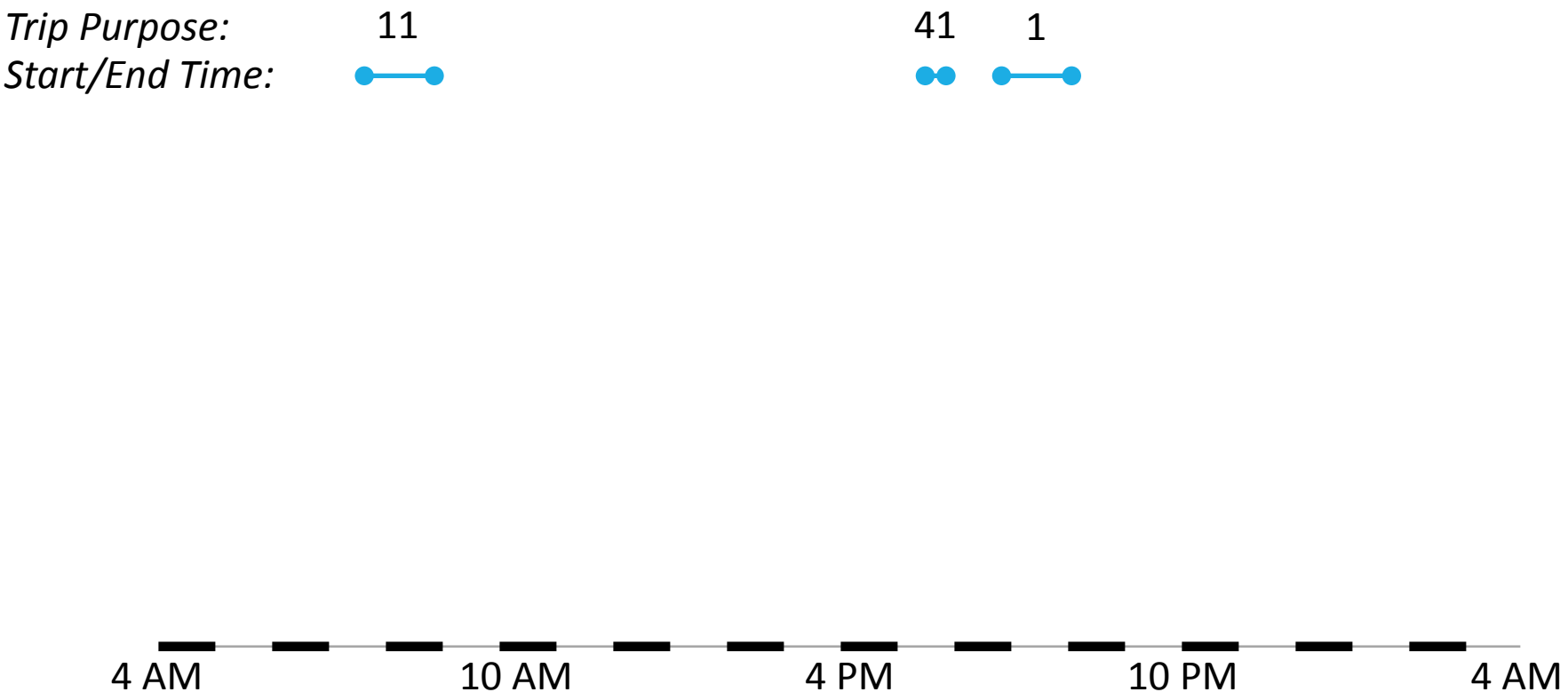
TripEnergy Model



McNerney, J., Needell, Z.A., Chang, M.T., Miotti, M. and Trancik, J.E., 2017. TripEnergy: Estimating Personal Vehicle Energy Consumption Given Limited Travel Survey Data. *Transportation Research Record: Journal of the Transportation Research Board*, (2628), pp.58-66.

Modeling BEV charging

Vehicle-day schematic



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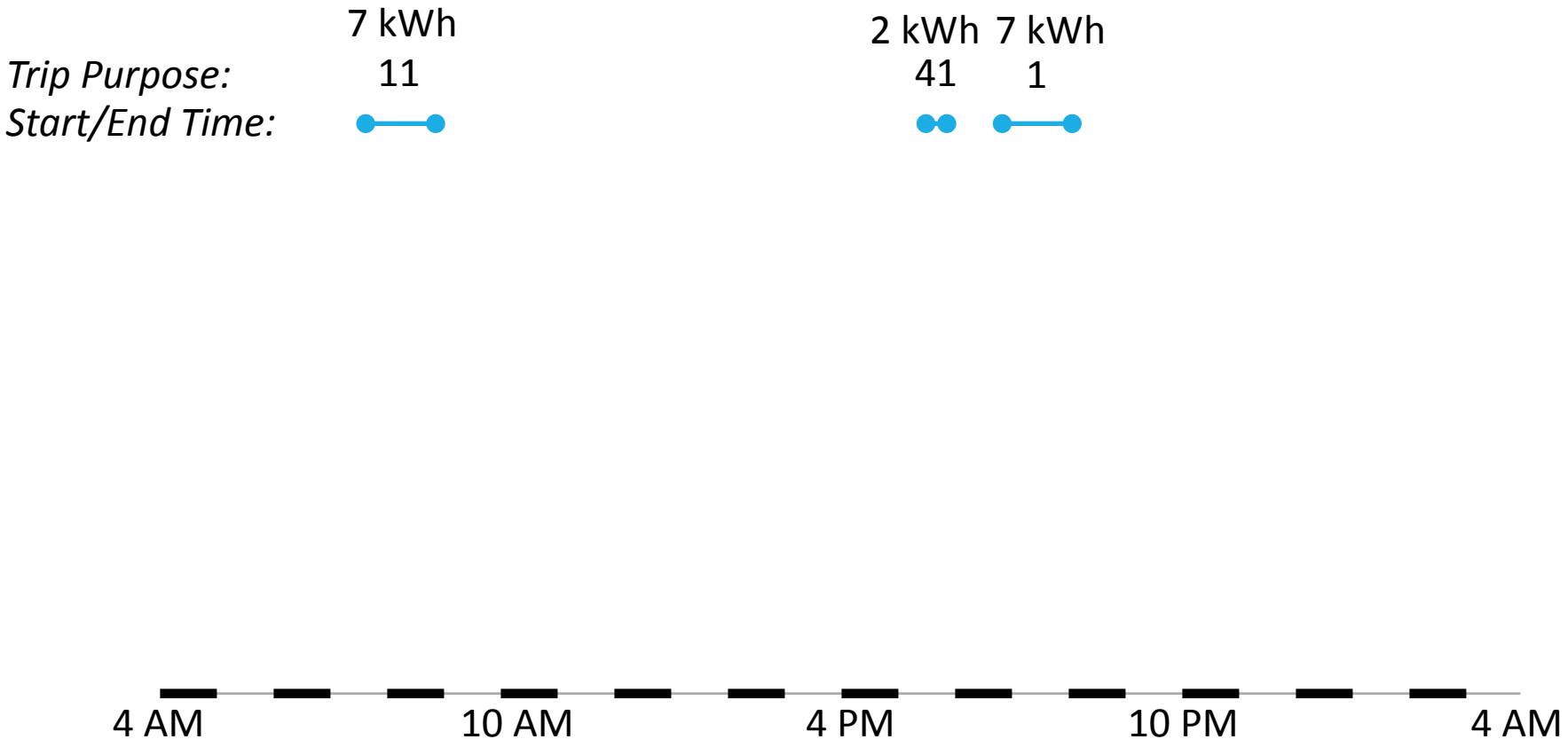

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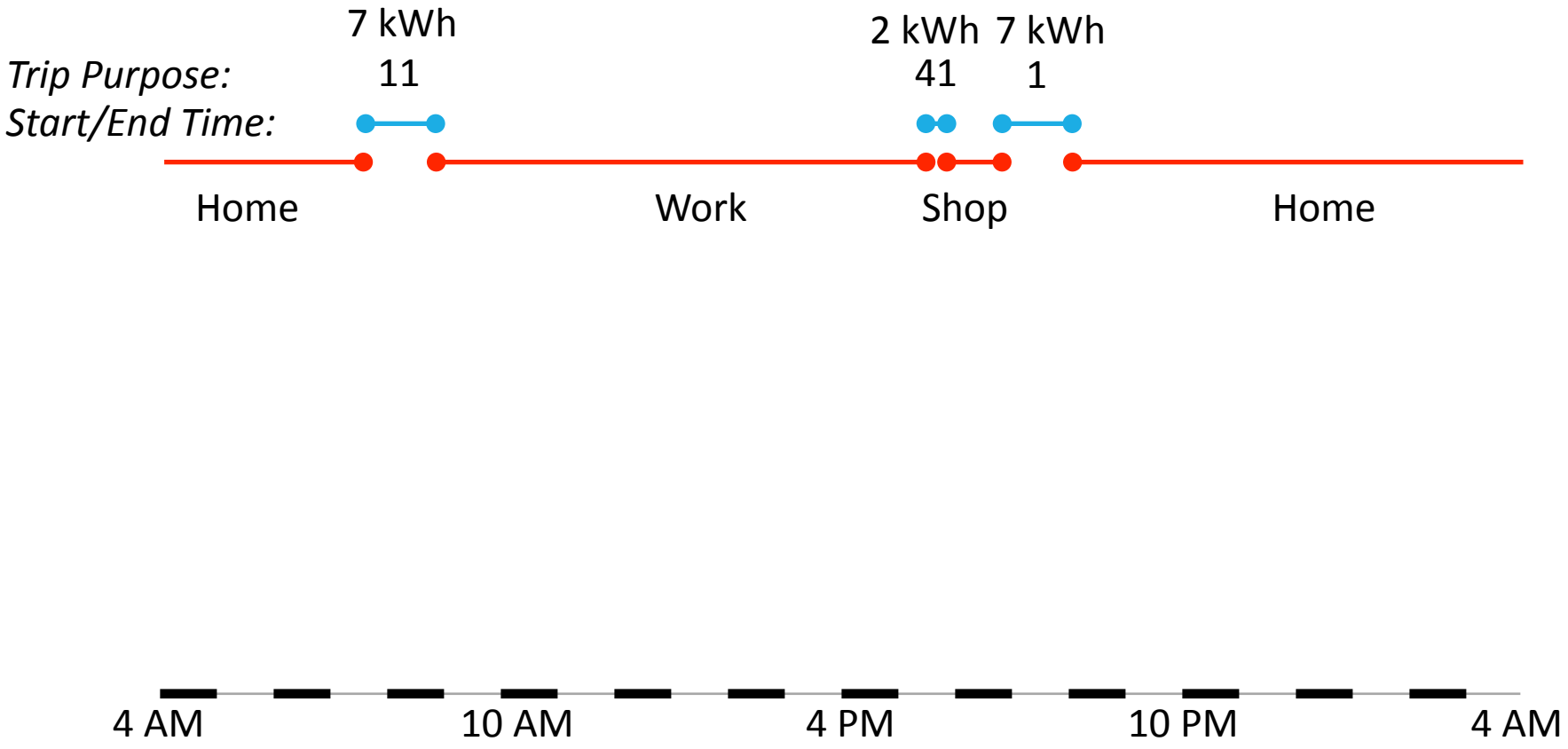

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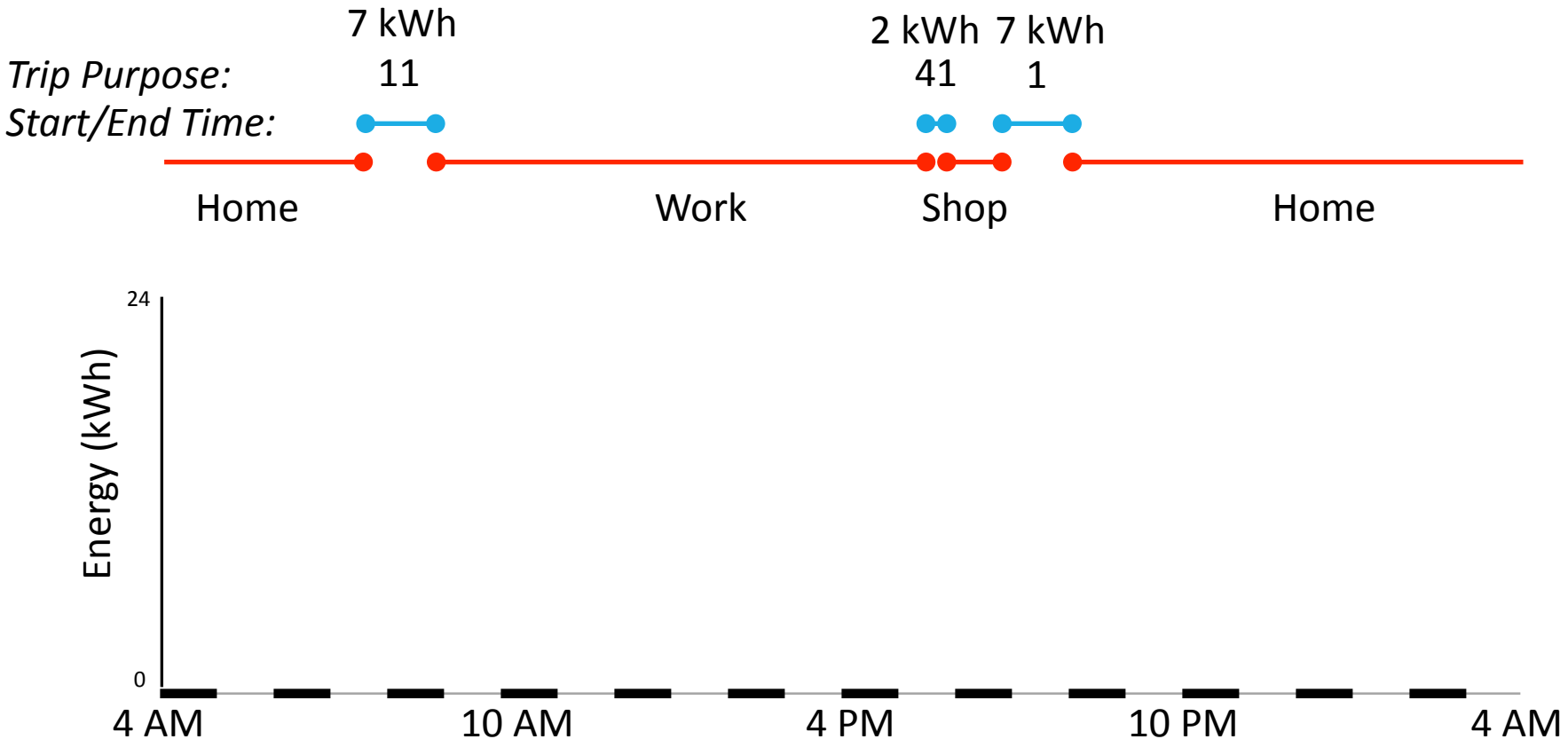

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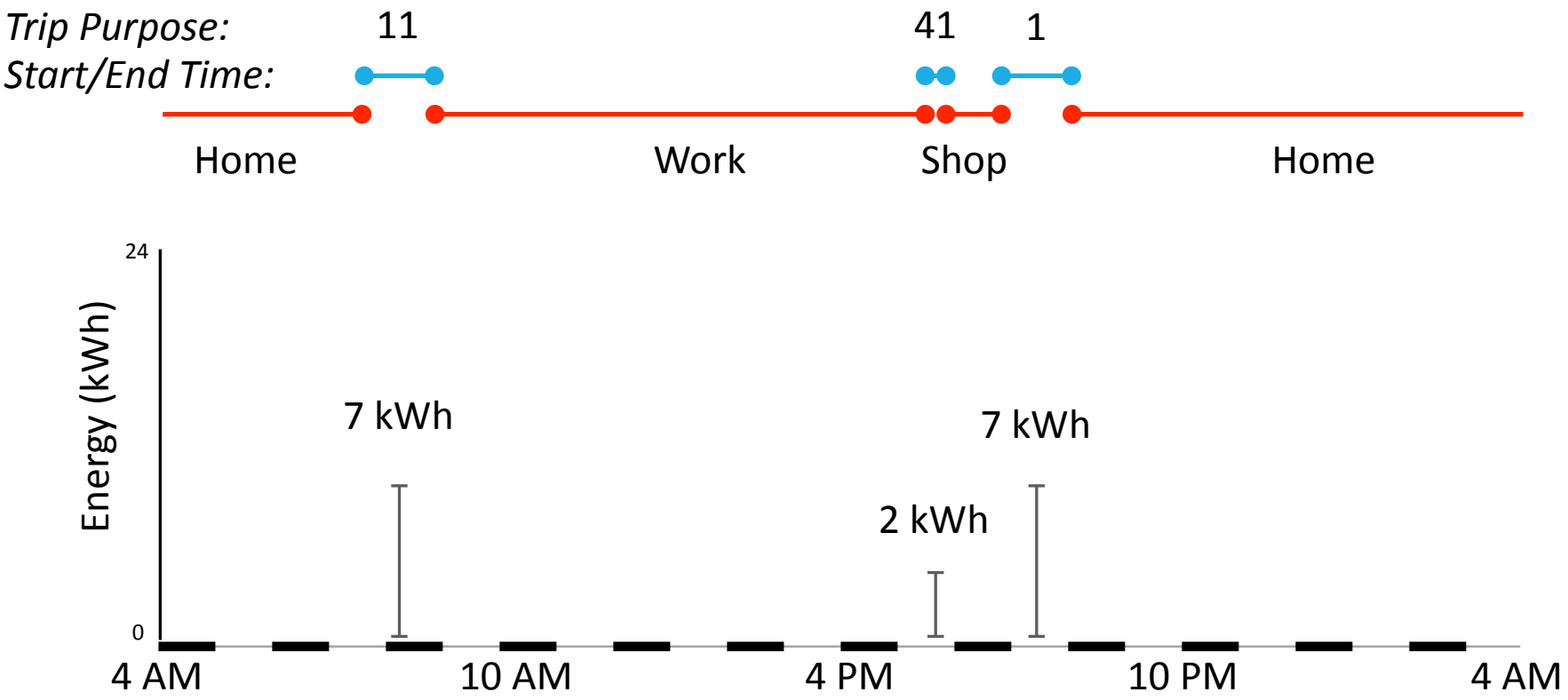

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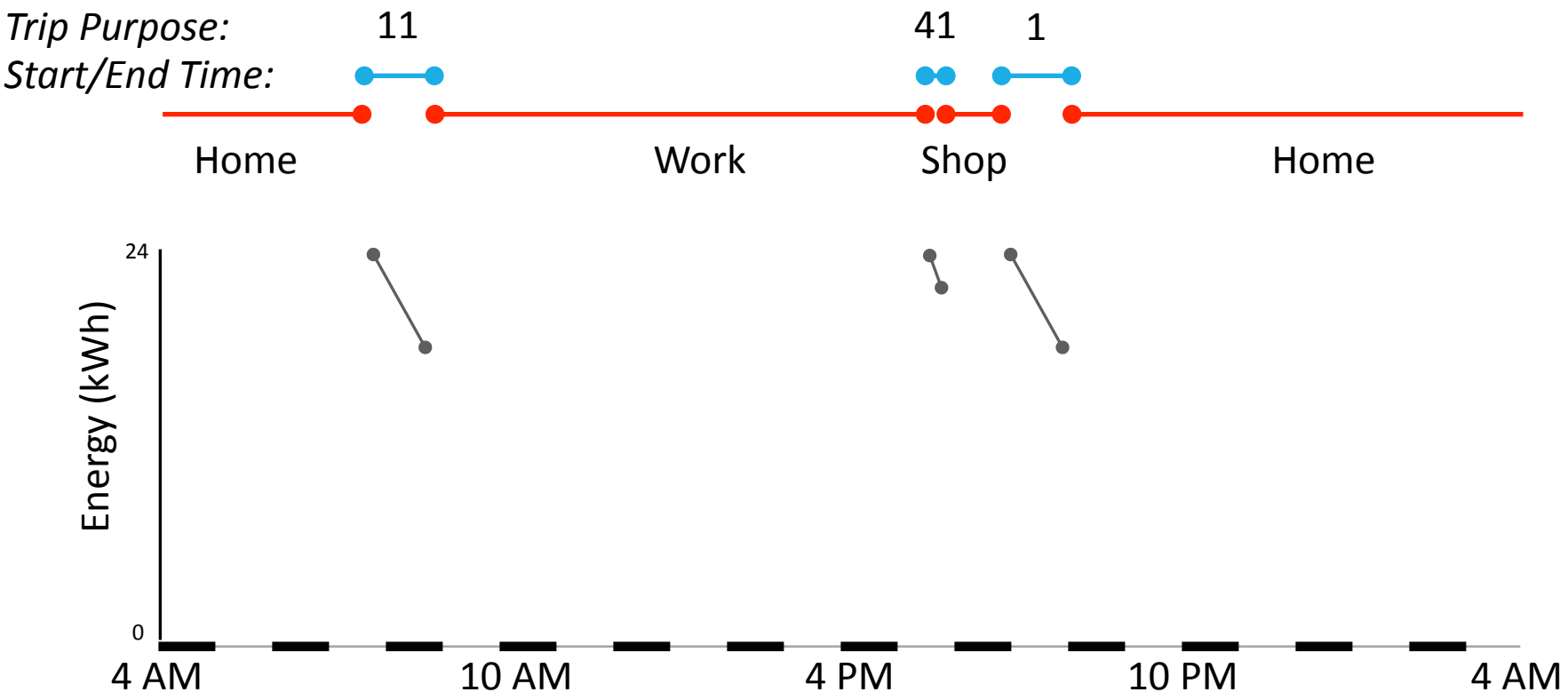

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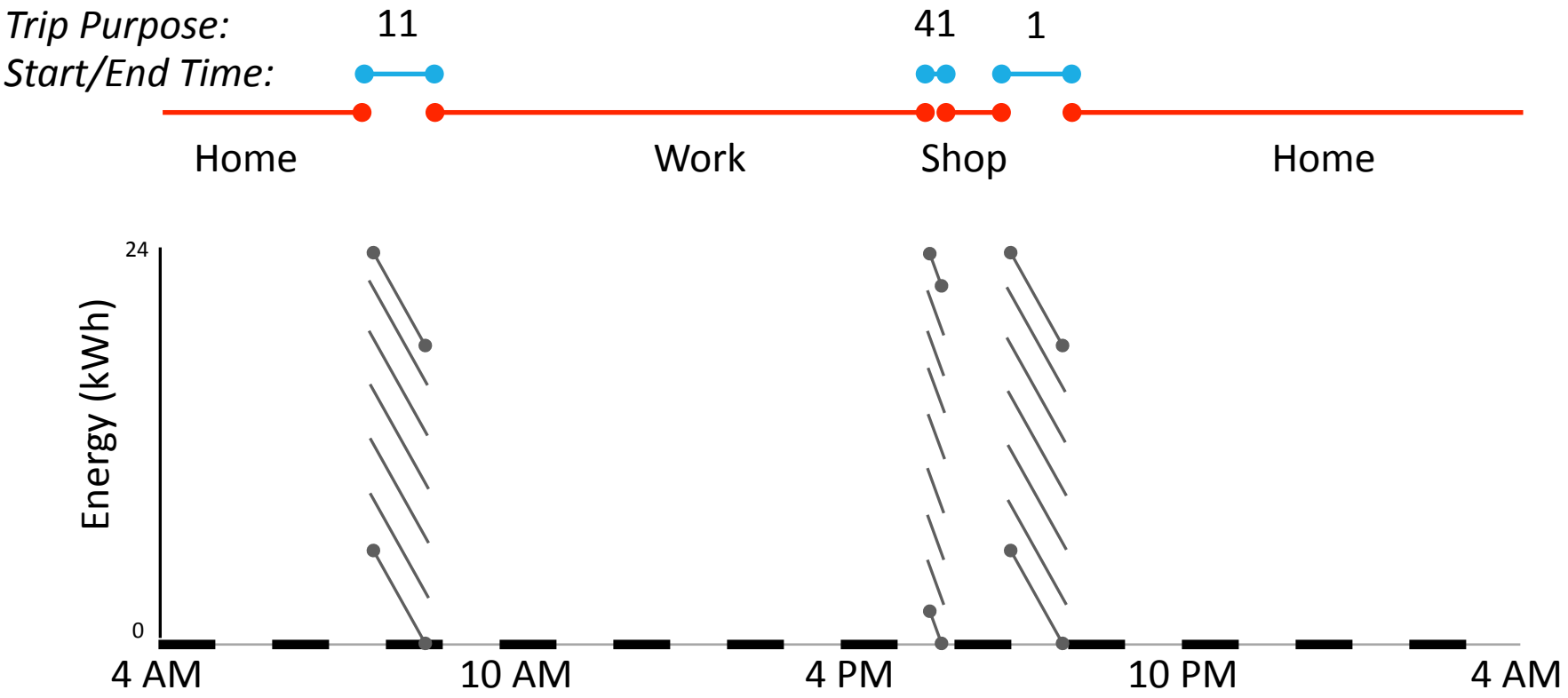

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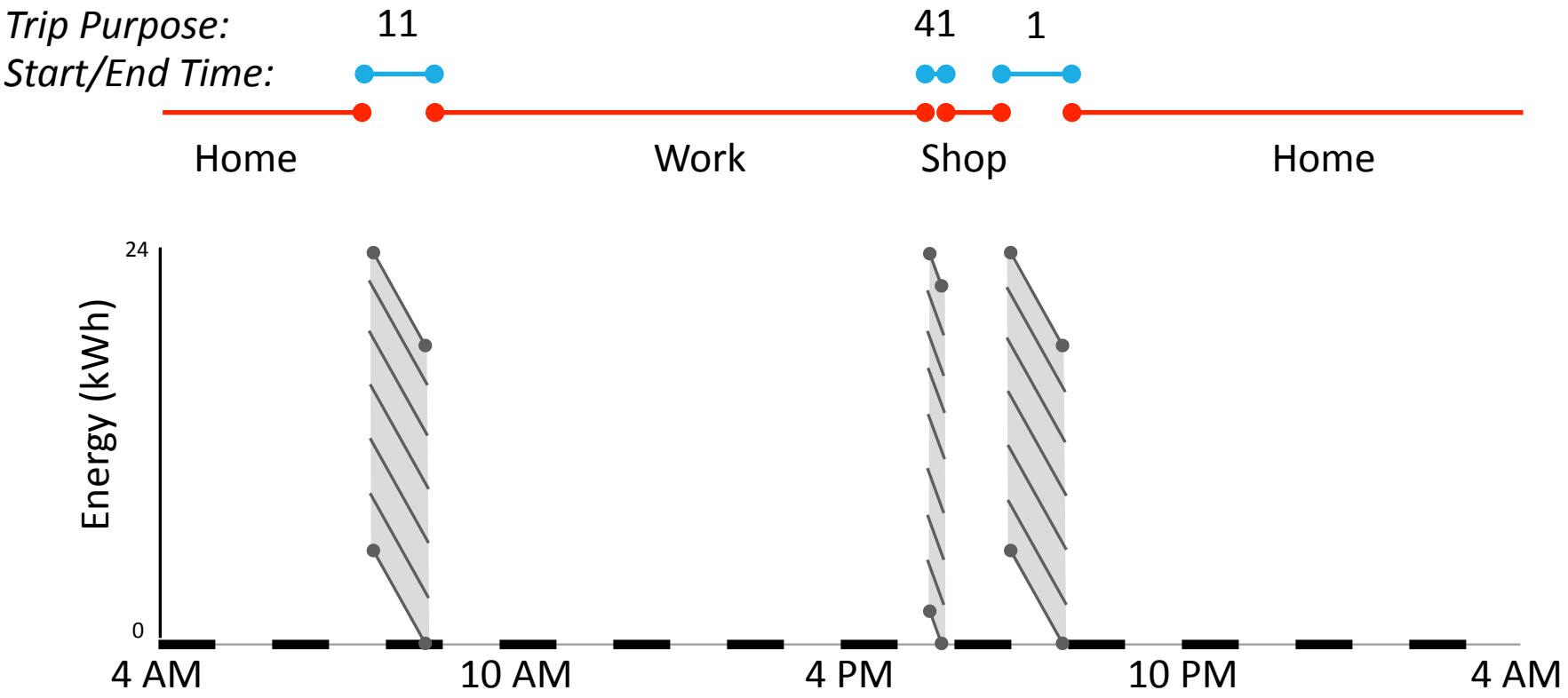

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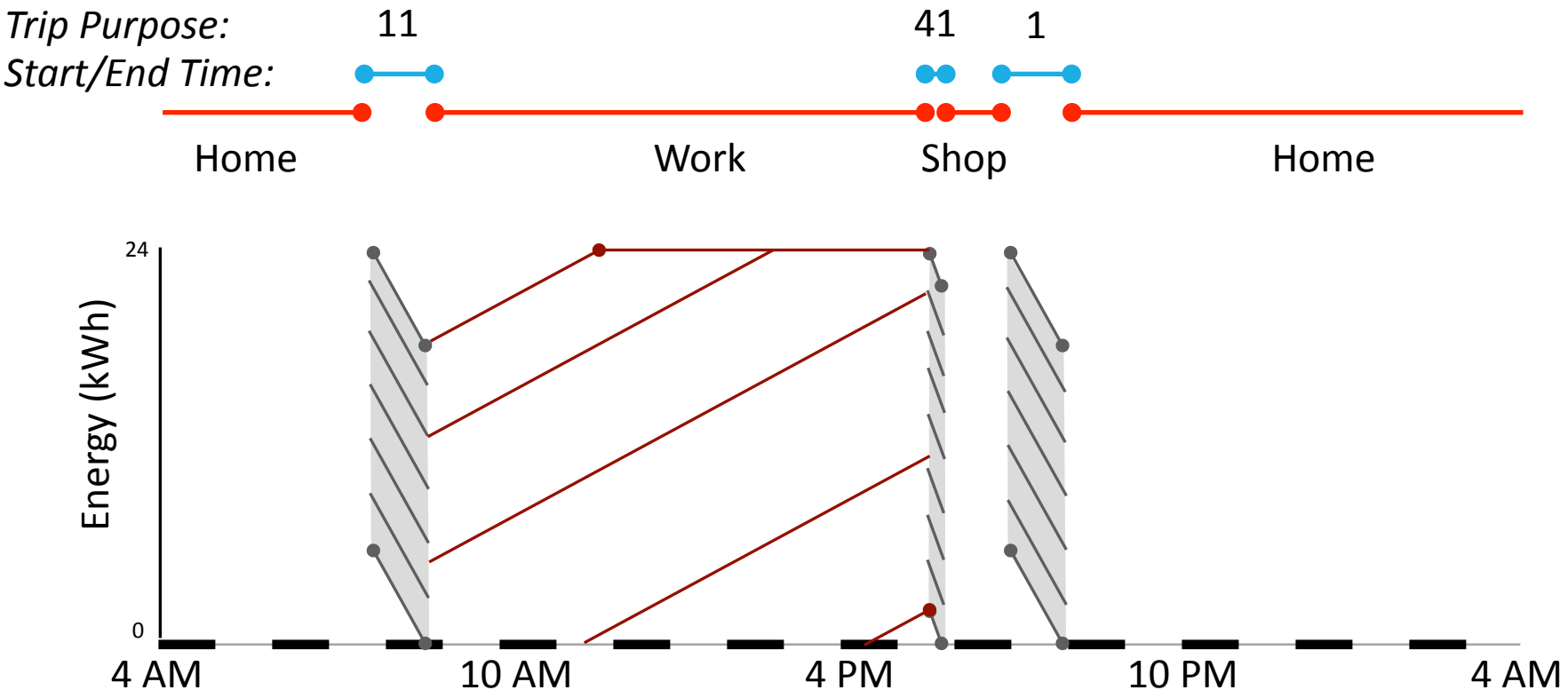

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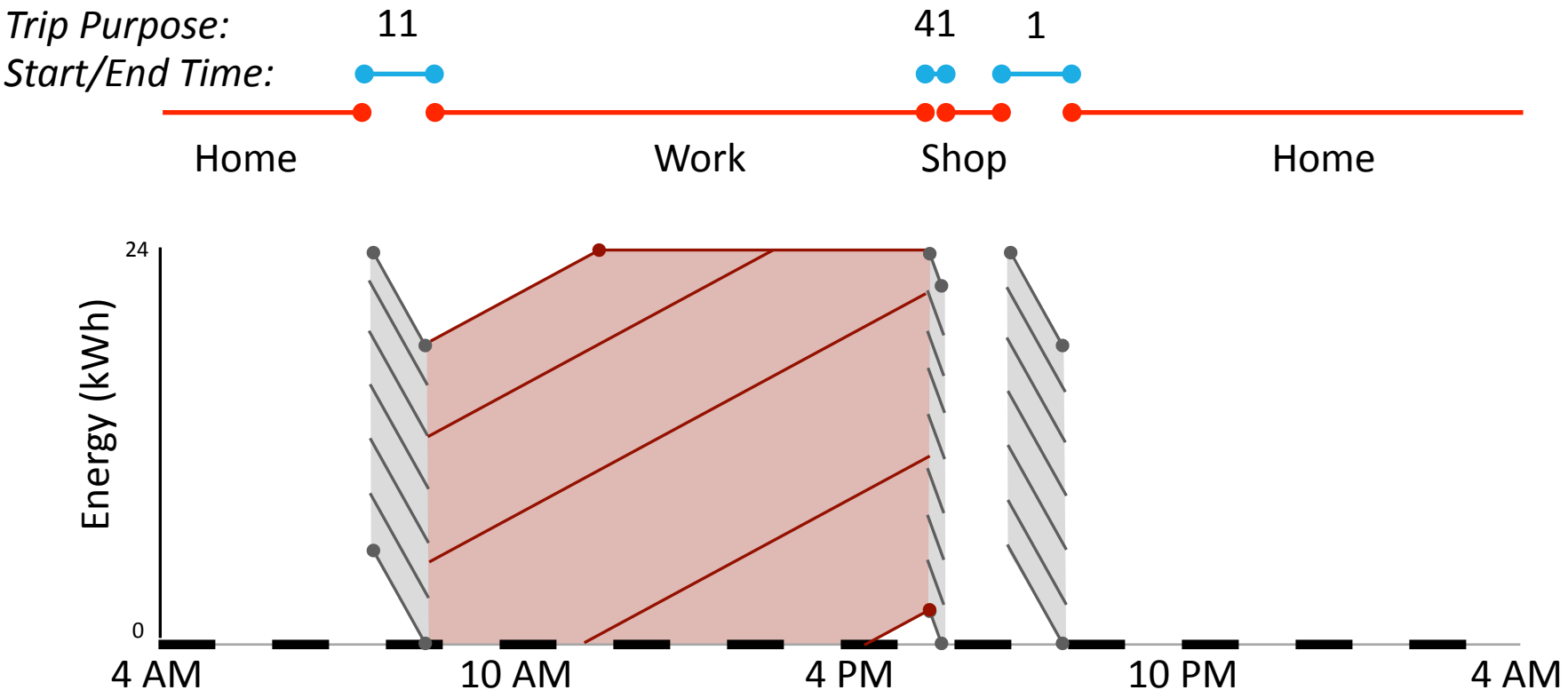

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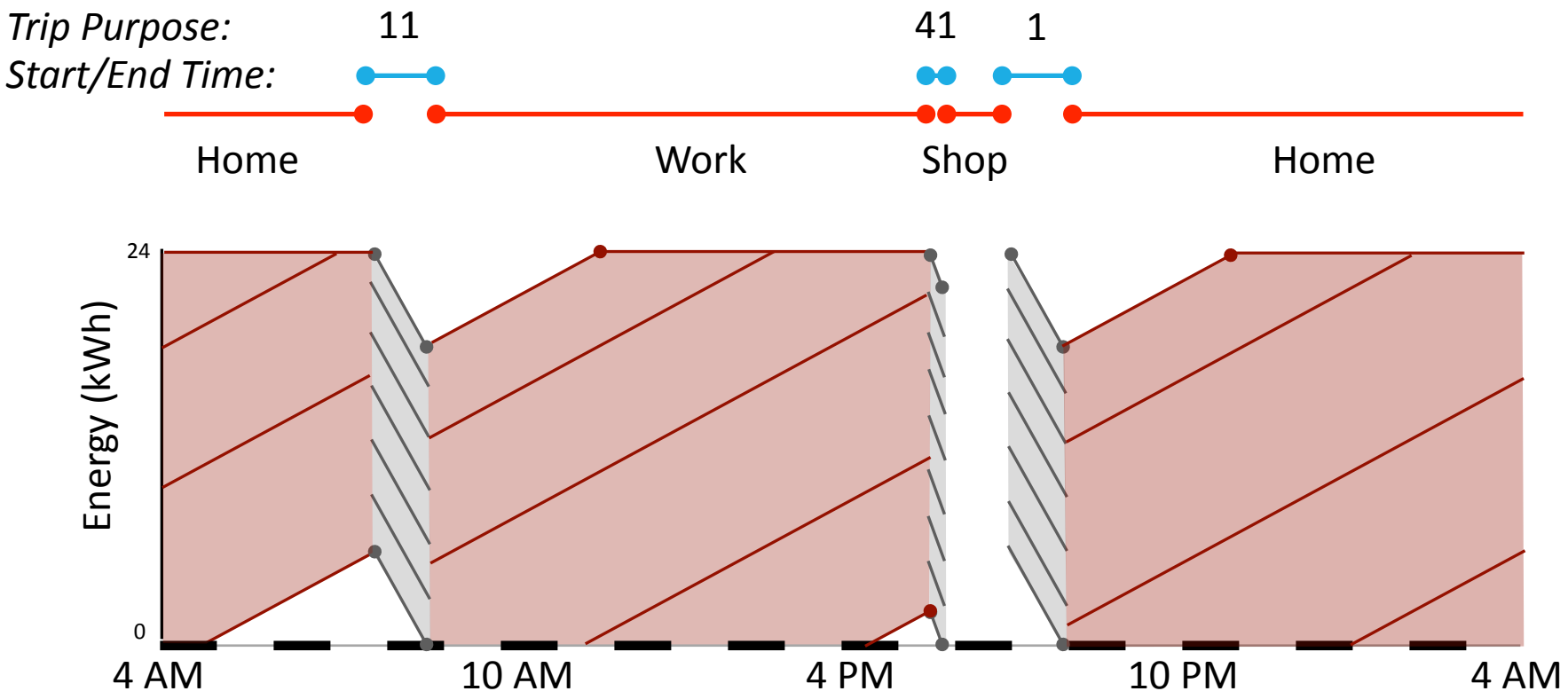

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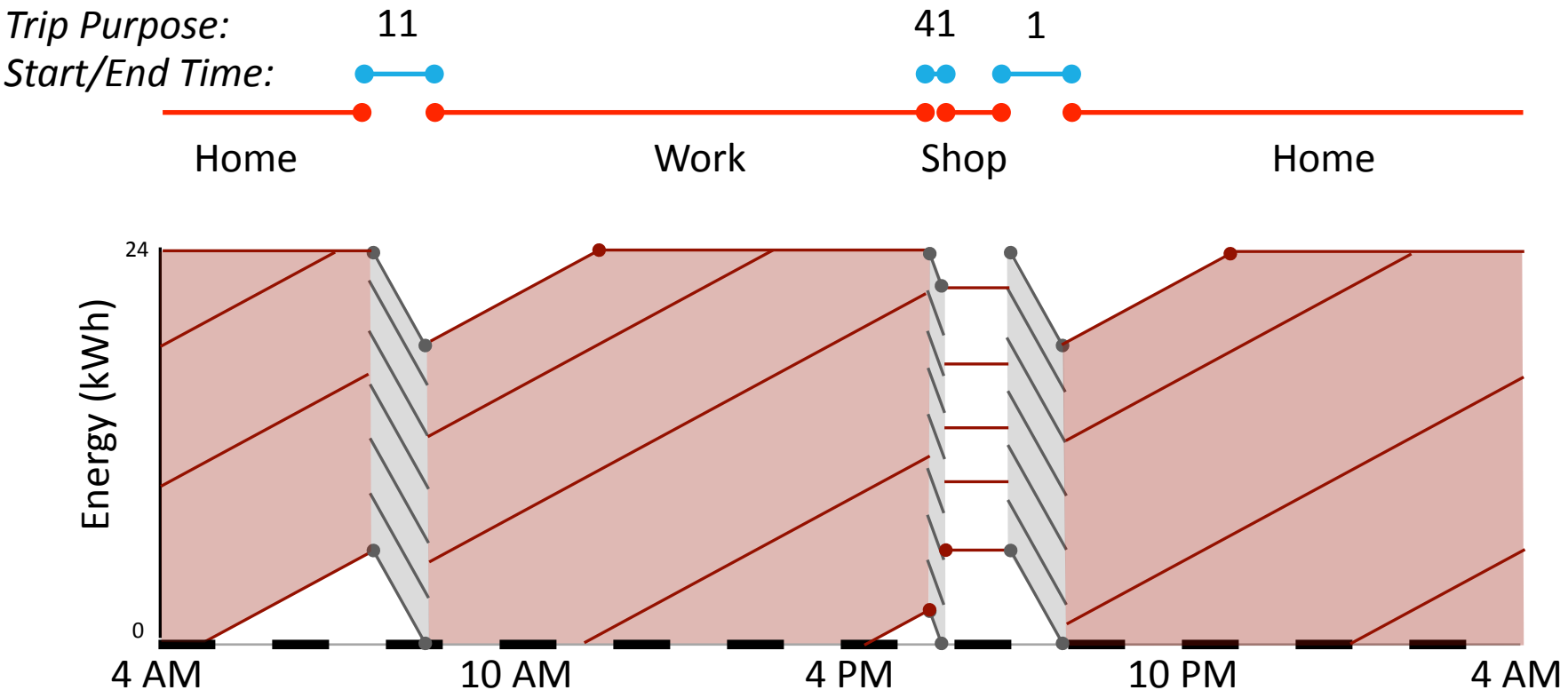

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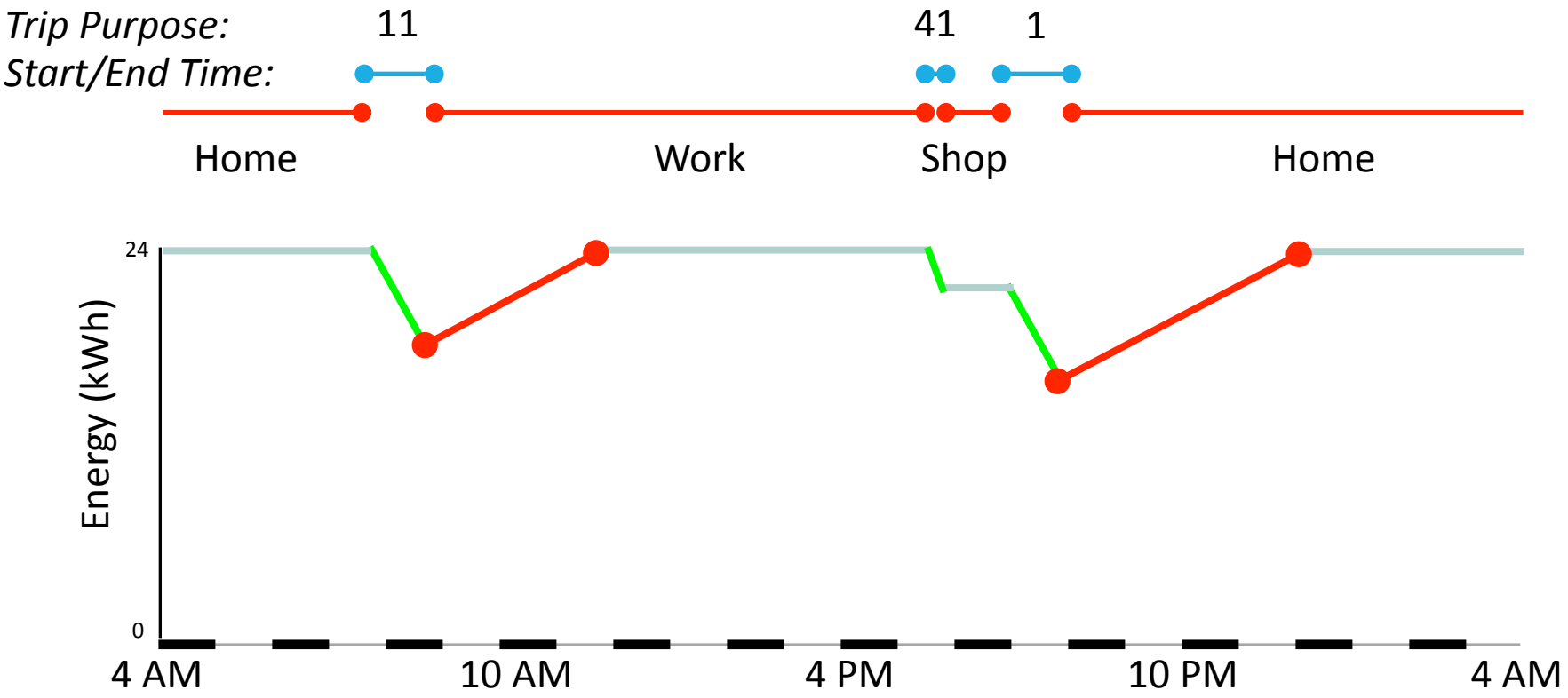

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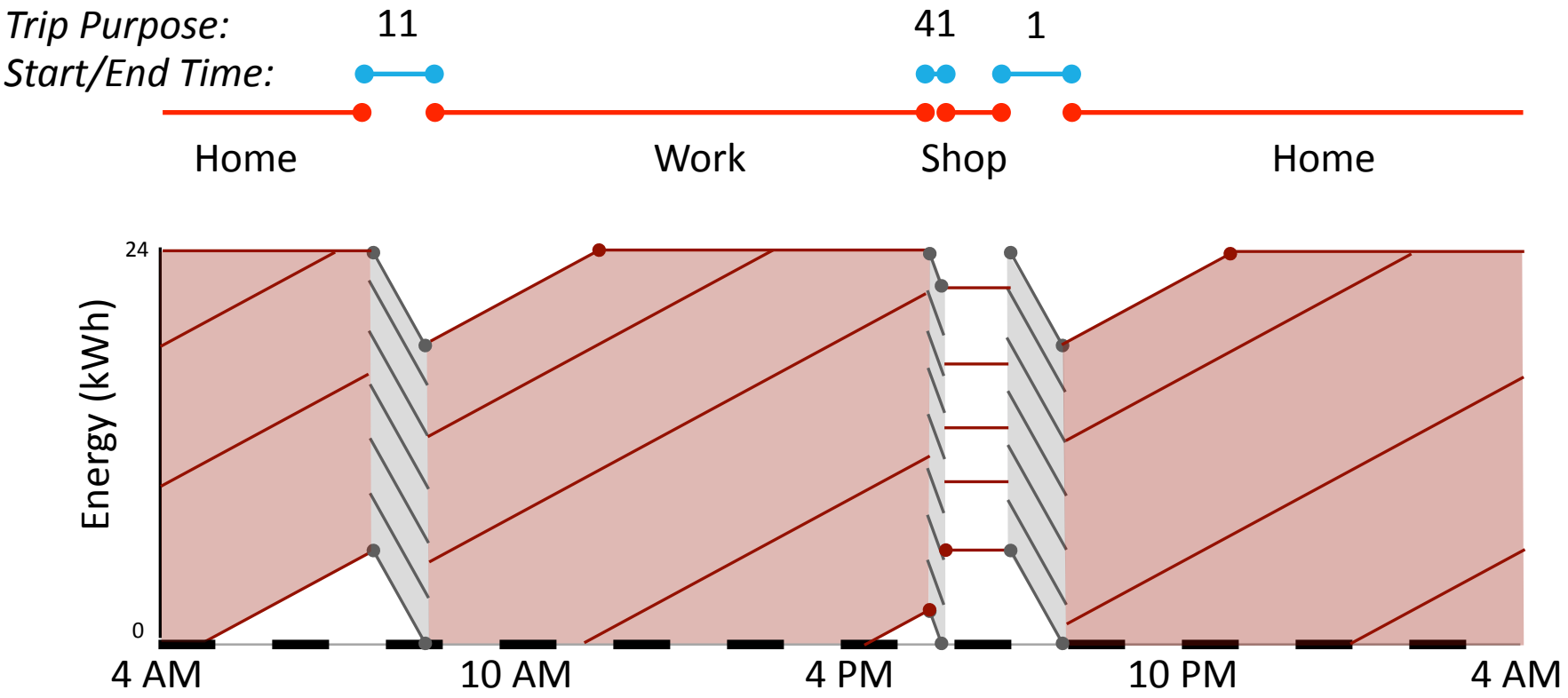

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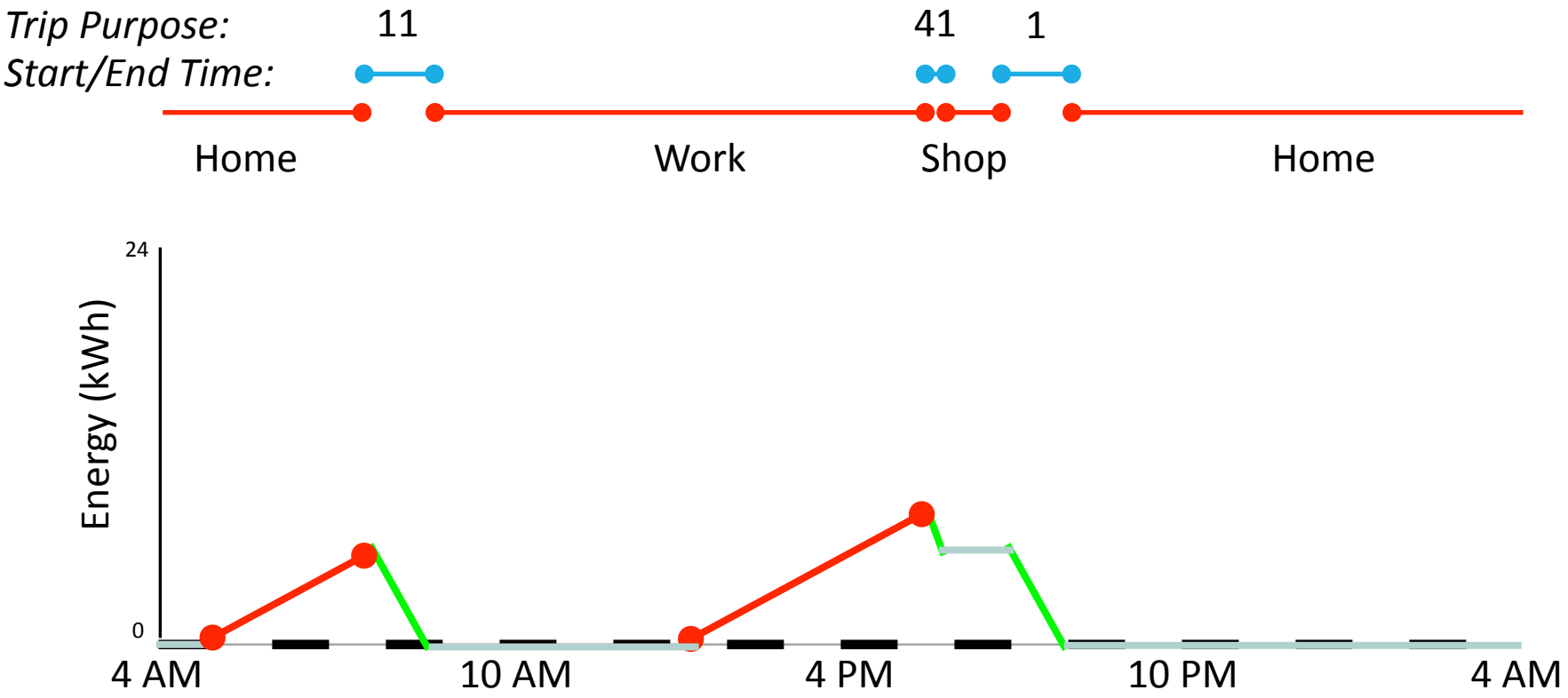

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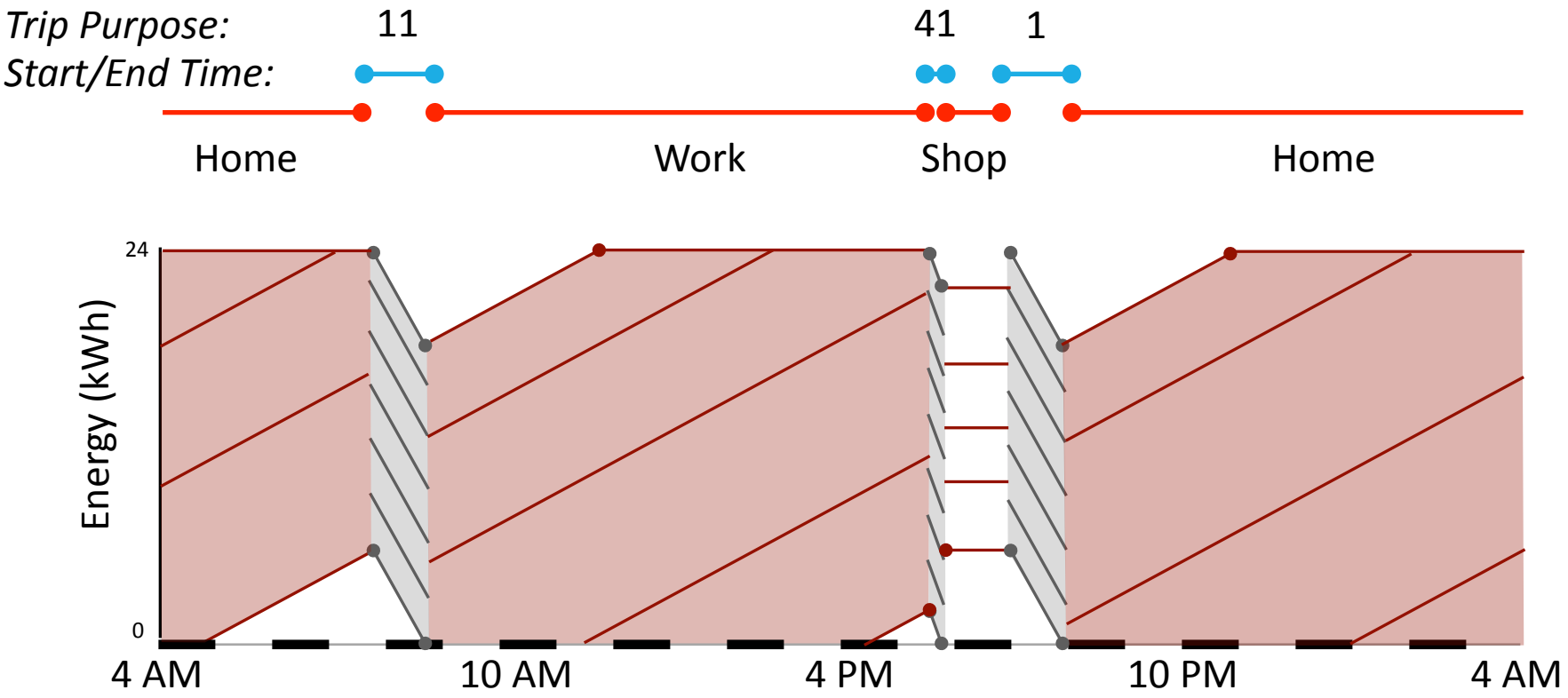
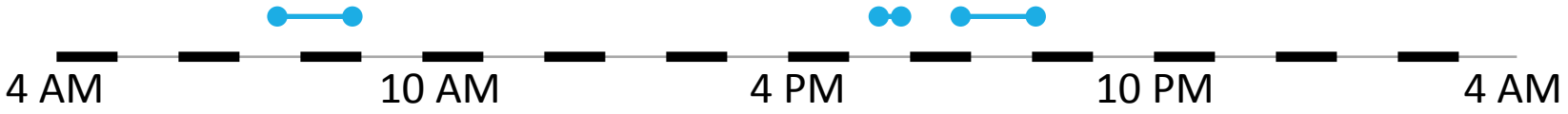


Breaking the day into time periods



- Break day into hourly intervals
- Split hour intervals at trip start/end times
- End up with 24 + 2k time intervals, given k trips

Variables

c: State of charge of the battery at the beginning of each interval
p: Energy drawn from the grid during each interval
d: Energy demand from the battery due to driving

Charge timing optimization function

minimize

subject to

minimize

subject to $c_i - c_{i-1} = \eta_{charge}\, p_i - d_i$

$c_N - c_1 = \eta_{charge}\, p_N - d_N$

Conservation of Energy

minimize

subject to $c_i - c_{i-1} = \eta_{charge}\, p_i - d_i$

$c_N - c_1 = \eta_{charge}\, p_N - d_N$

$0 < p_i < p_i^{max}$ Charging rate constraint

minimize

subject to $c_i - c_{i-1} = \eta_{charge}\, p_i - d_i$

$c_N - c_1 = \eta_{charge}\, p_N - d_N$

$0 < p_i < p_i^{max}$

$$p_i^{max} = \begin{cases} p_j^{max} & \text{if parked at location } j \\ 0 & \text{if driving} \end{cases}$$

Location-specific charging rate

minimize

subject to $c_i - c_{i-1} = \eta_{charge}\, p_i - d_i$

$c_N - c_1 = \eta_{charge}\, p_N - d_N$

$0 < p_i < p_i^{max}$

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$0 < c_i < c_i^{max}$ Battery capacity constraint

$$\text{minimize} \quad \sum_{i=1}^{N} \beta c_i + \alpha_i p_i$$

Flexible objective function

$$\text{subject to} \quad c_i - c_{i-1} = \eta_{charge}\, p_i - d_i$$

$$c_N - c_1 = \eta_{charge}\, p_N - d_N$$

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$$0 < c_i < c_i^{max}$$

Objective function

$$\sum_{i=1}^{N} \beta c_i + \alpha_i p_i$$

Battery state of charge during time period *i*

Average charging power during time period *i*

Objective function

$$\sum_{i=1}^{N} \beta c_i + \alpha_i p_i$$

Opportunity cost of having battery not fully charged

Effective cost of electricity

Objective function

$$\sum_{i=1}^{N} \beta c_i + \alpha_i p_i$$

Two regimes:

- $\alpha = 0$ —> Last minute ($\beta > 0$) or instant ($\beta < 0$) charging
- $\beta \ll \alpha$ —> Minimize cost first, then schedule timing

- NOT an econometric analysis!

Estimating aggregate demand

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    1.1. Using NHTS weights
    1.2. Only consider “feasible” days

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4. **Multiply average profile by number of BEV vehicle-days**

Reality check

Do the demand profiles make sense?

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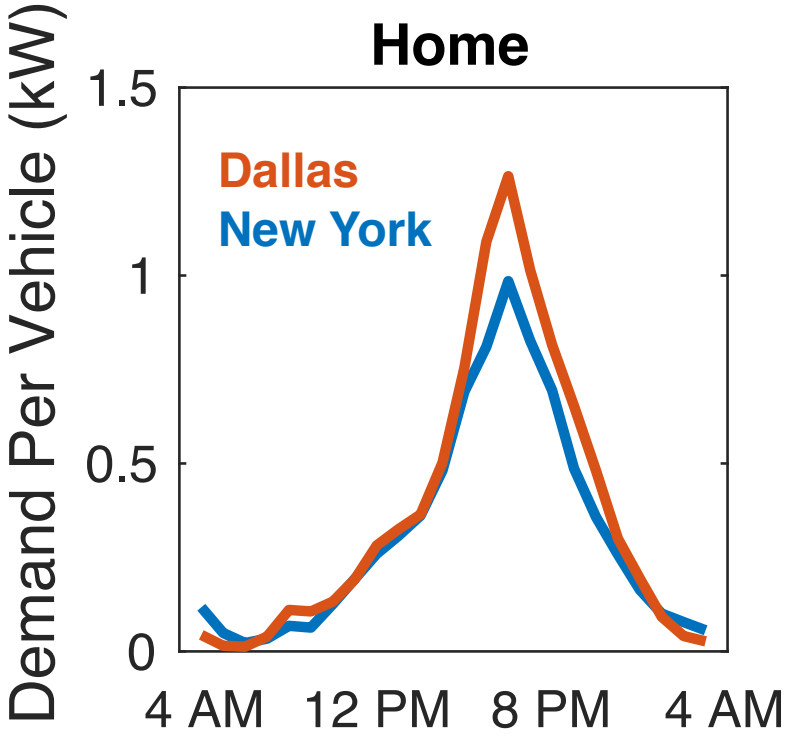
- 2016 Nissan Leaf
- Assuming instant charging, 6kW at home
- Peak in the afternoon
- At most, ~1/6th of vehicles are charging at once
- DAP of 90.2% (Dallas) and 90.5% (NYC)



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Are capacity constraints a likely problem?

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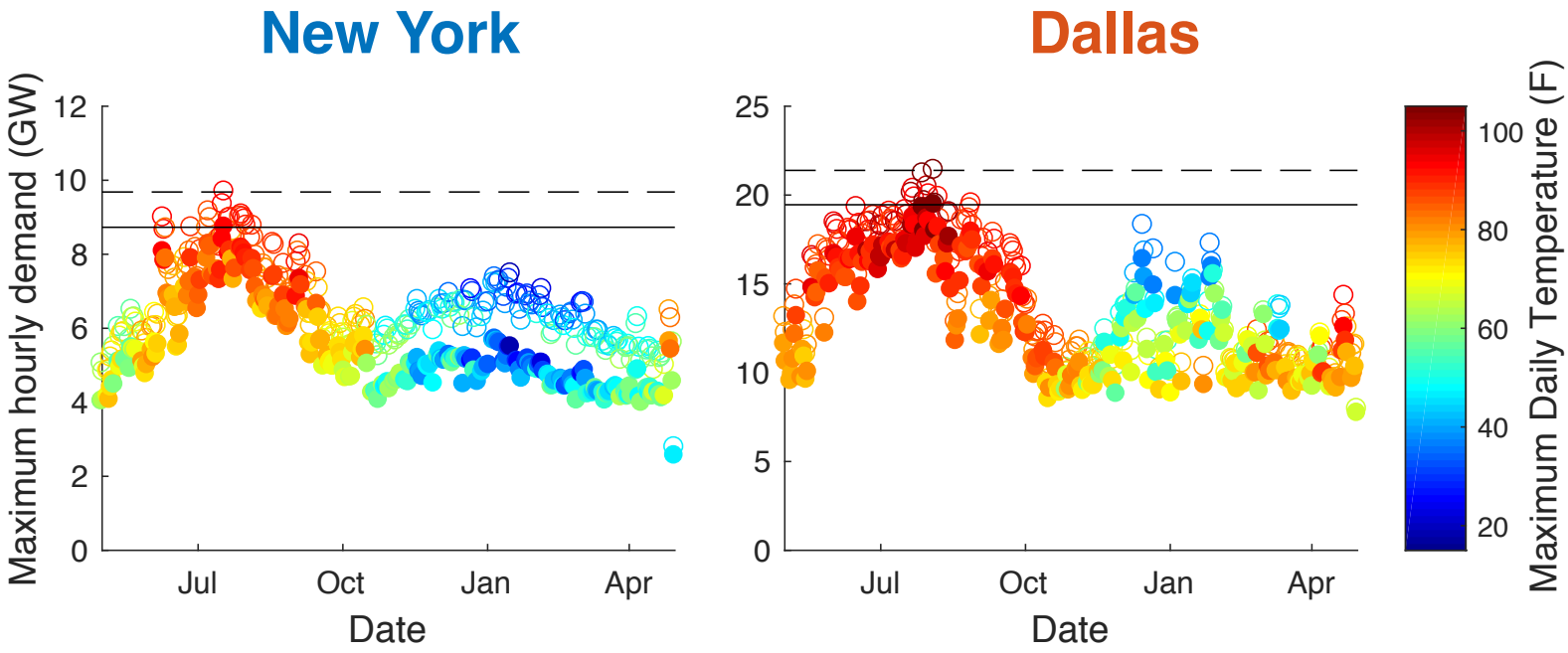
Daily peak demand assuming 50% adoption:



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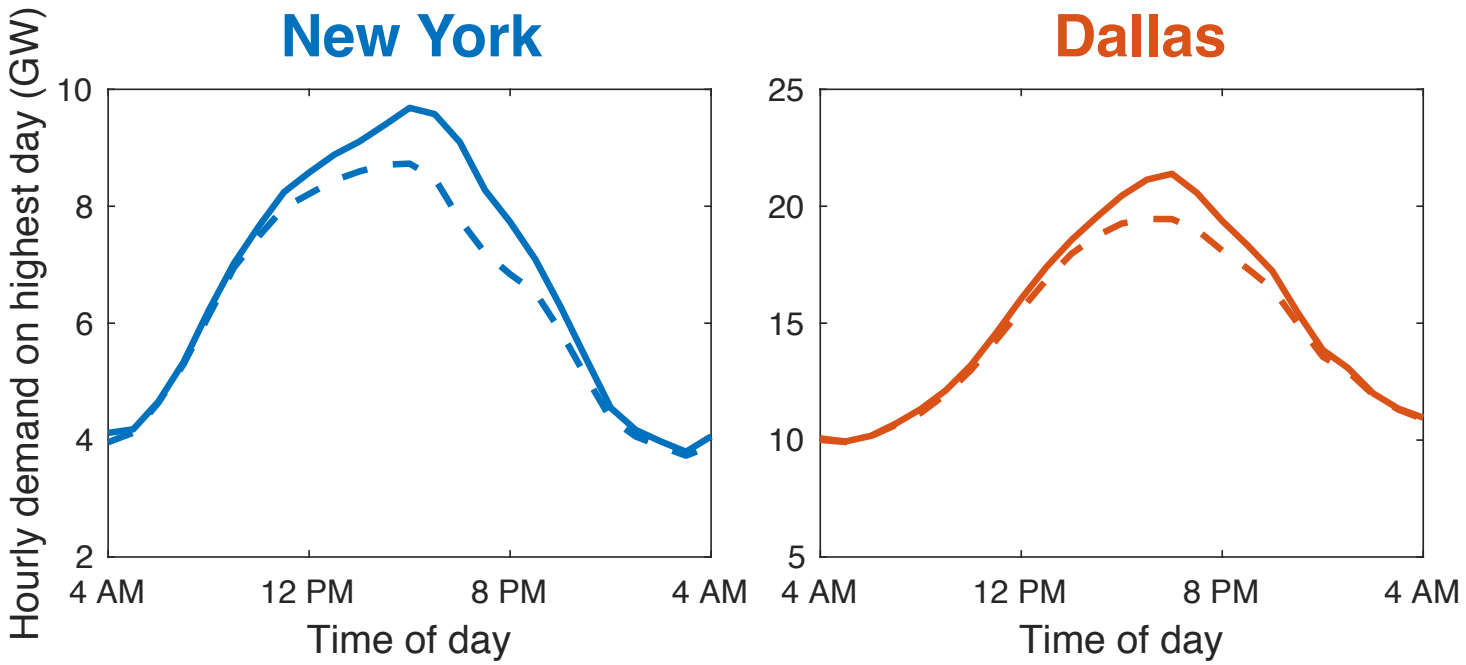


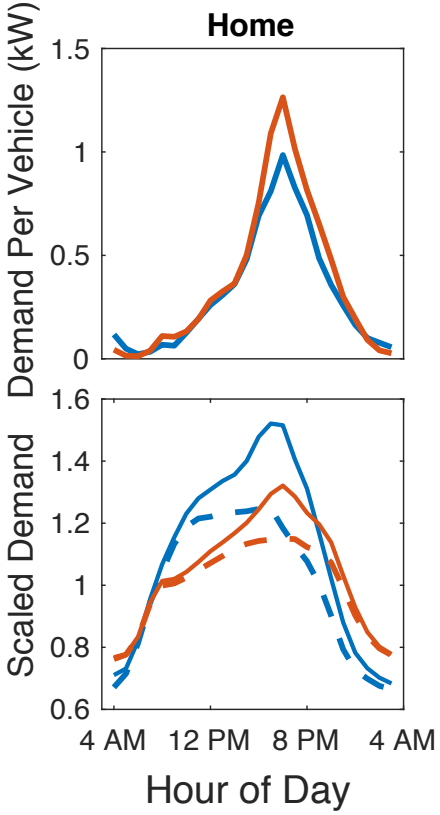
Results

Charging strategies

1. **Home**
   - Level 2 charger (6 kW) at home, begin charging immediately
2. **Home + Work**
   - Level 2 charger at home, either Level 1 (1.8 kW) or Level 2 charger at work, begin charging immediately
3. **Home + Incentivized Work**
   - Level 2 charger at home, Level 1 charger at work, begin charging immediately
   - Maximize charging done at work before charging at home
4. **Delayed Home**
   - Level 2 charger at home, charge as late as possible

Average Profiles

Dallas
New York



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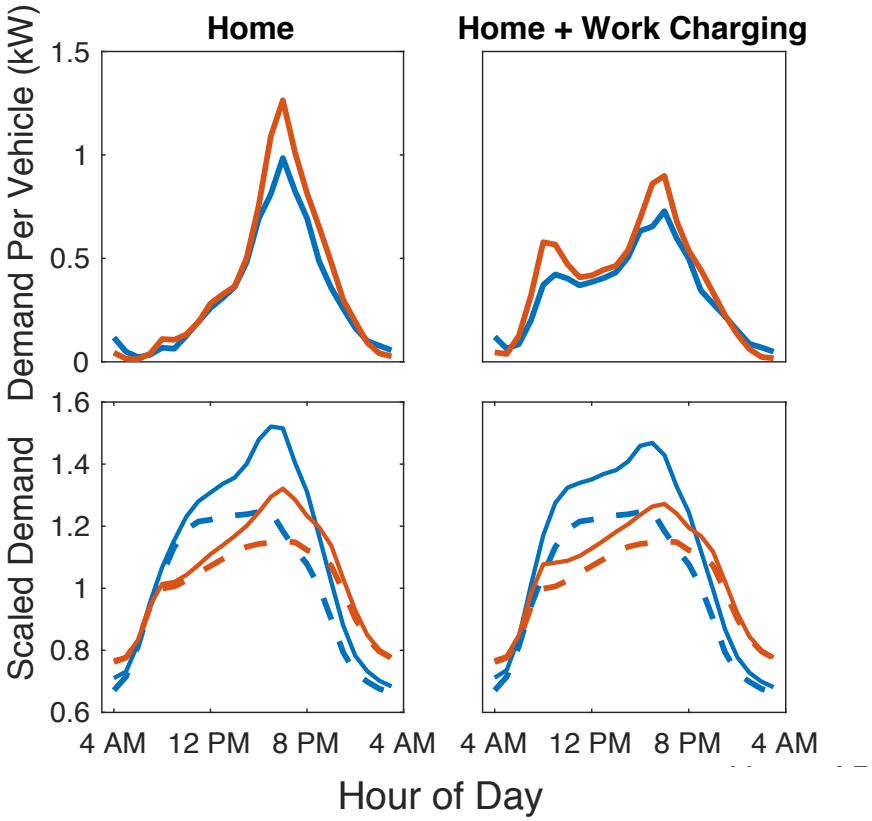

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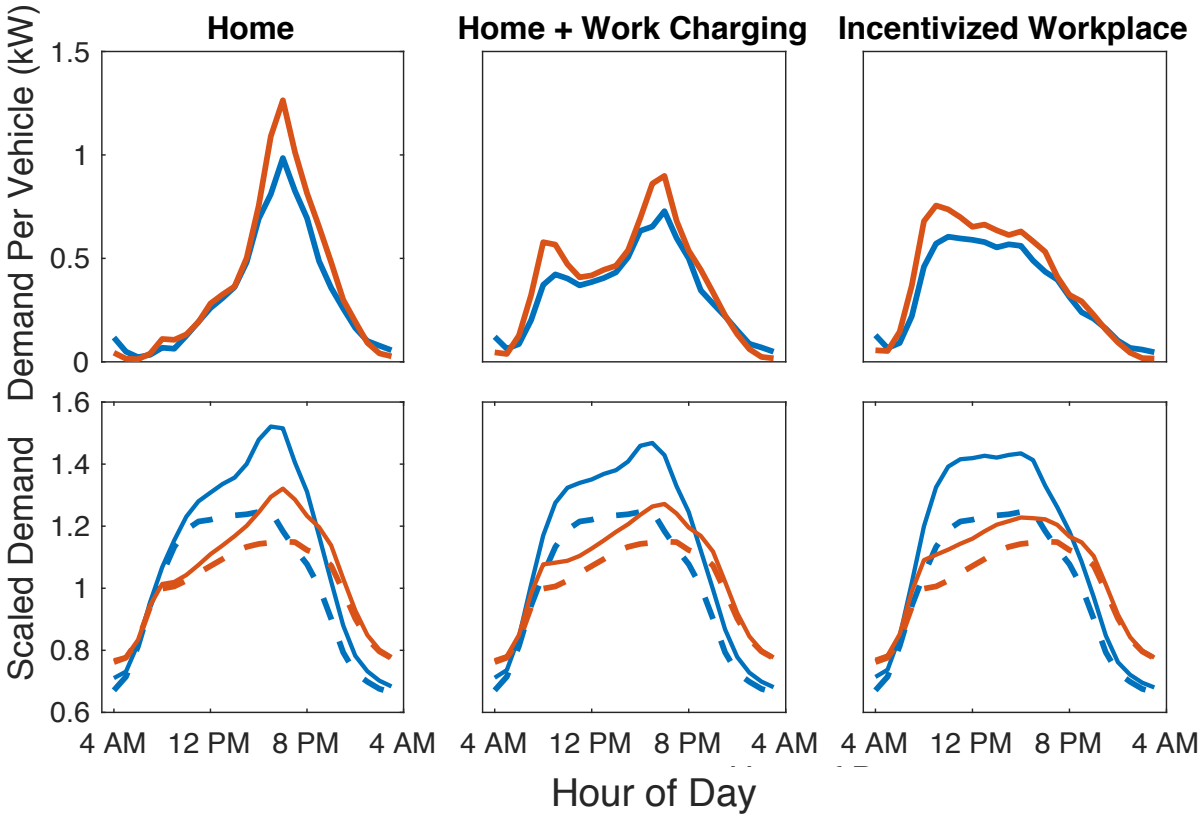

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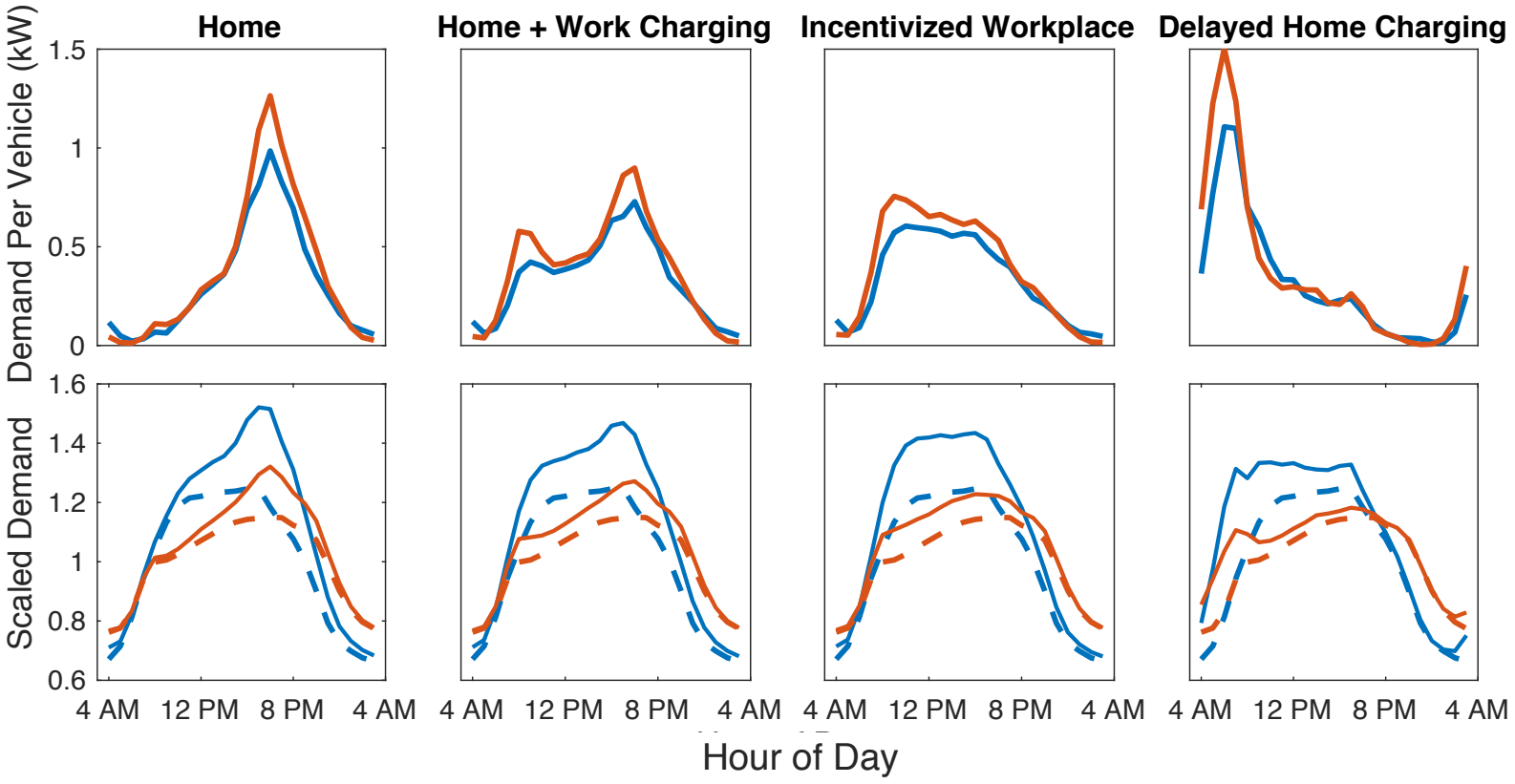
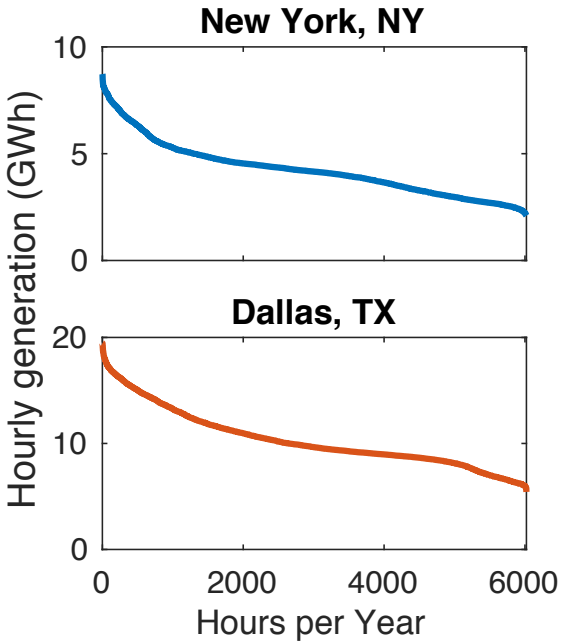


Impact on hourly demand

Load duration curve gives a measure of the variability in electricity demand



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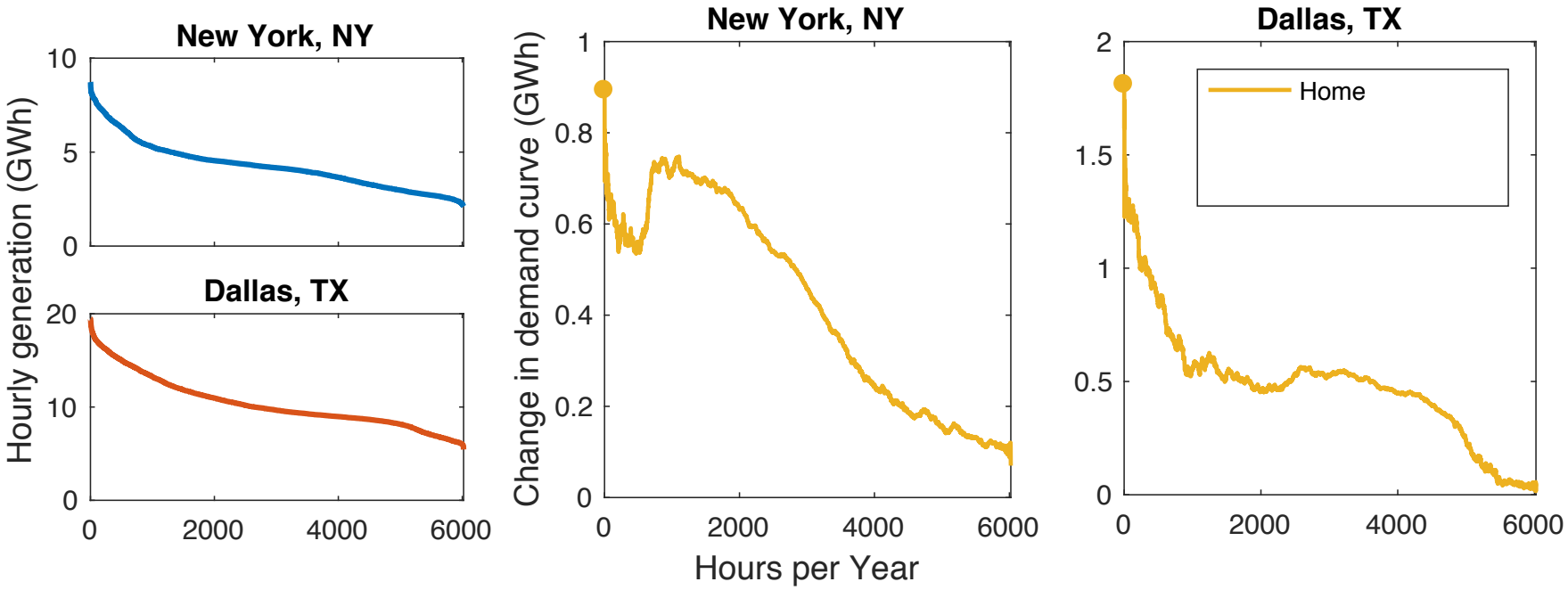

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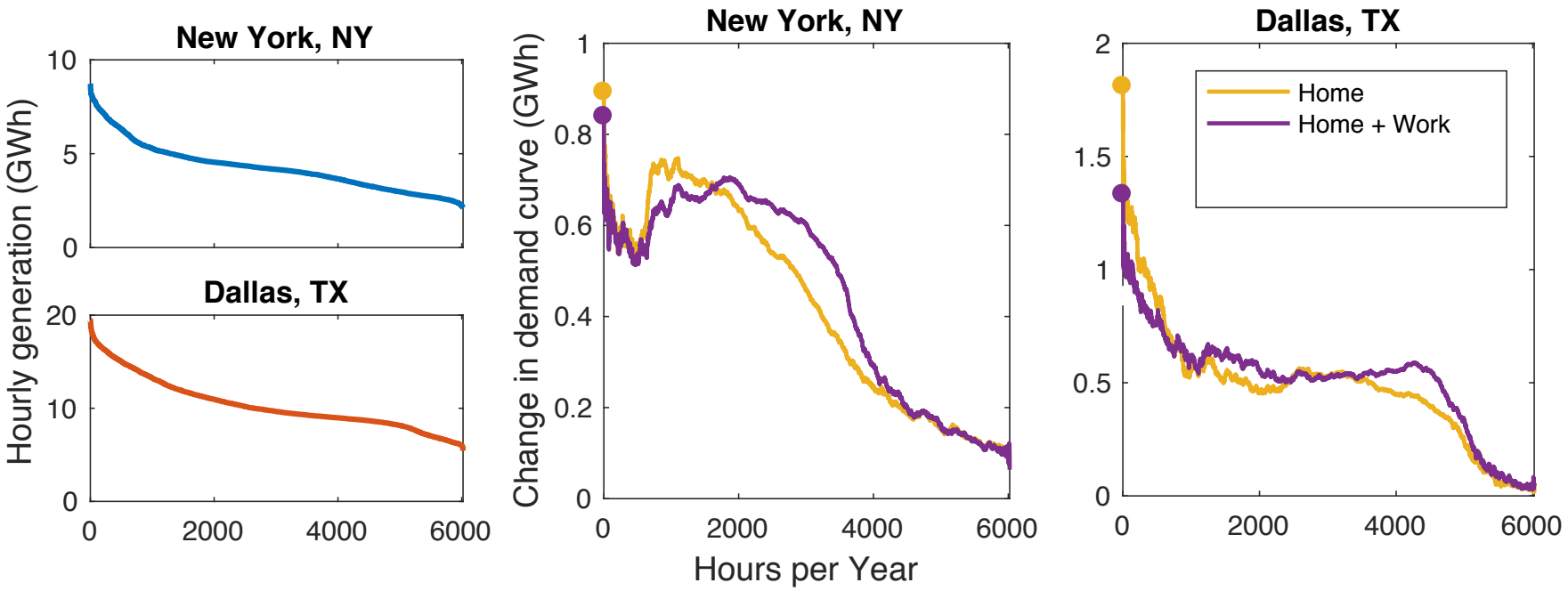

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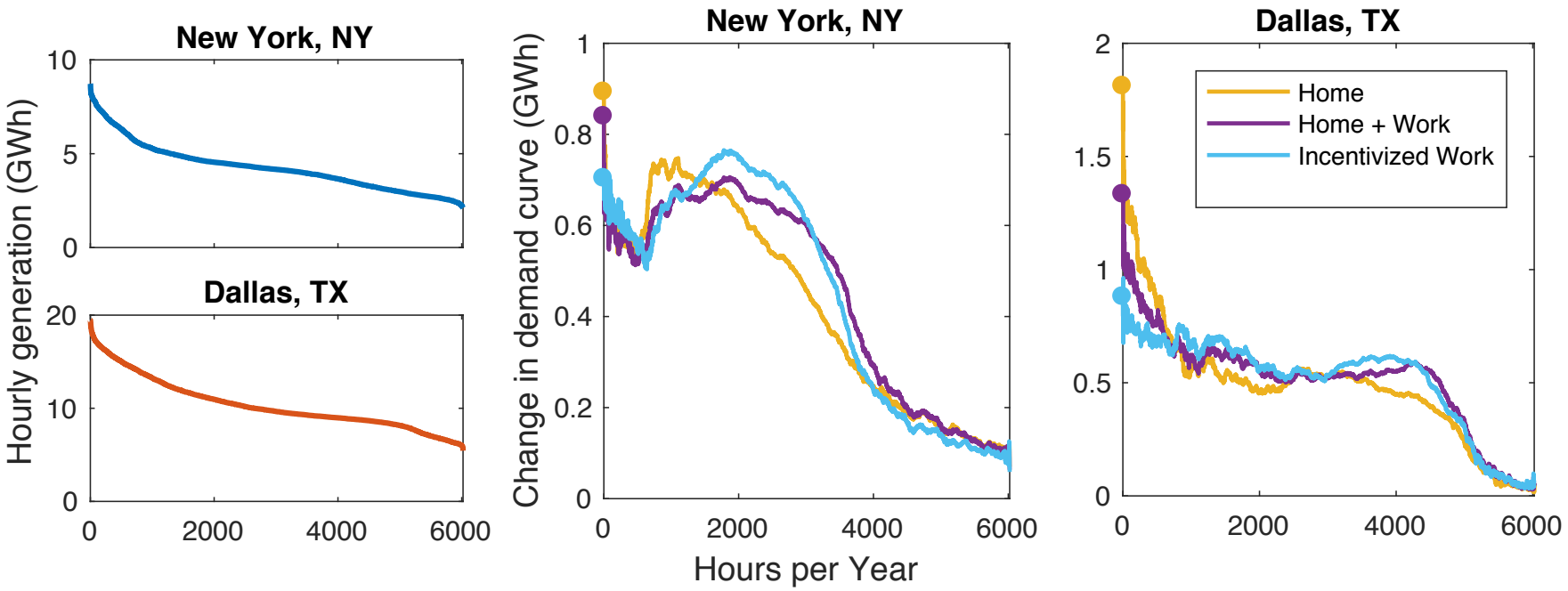

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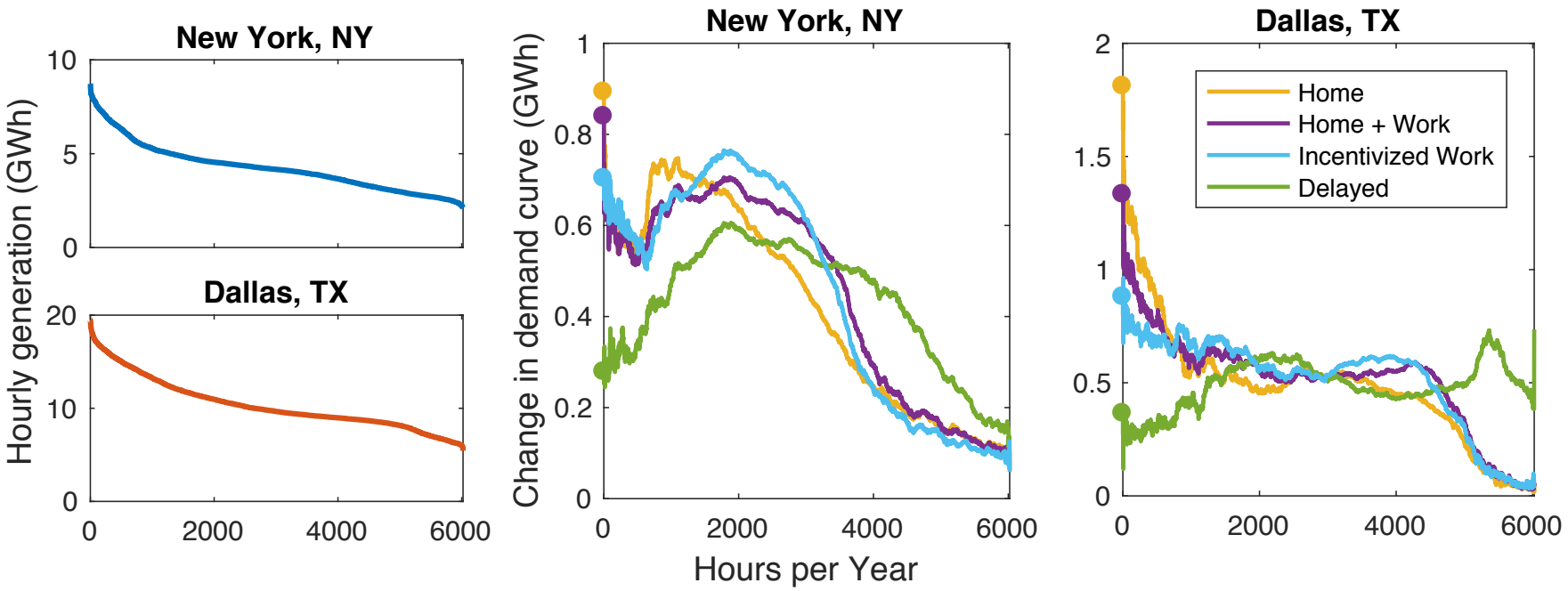

Meeting BEV demand with solar?

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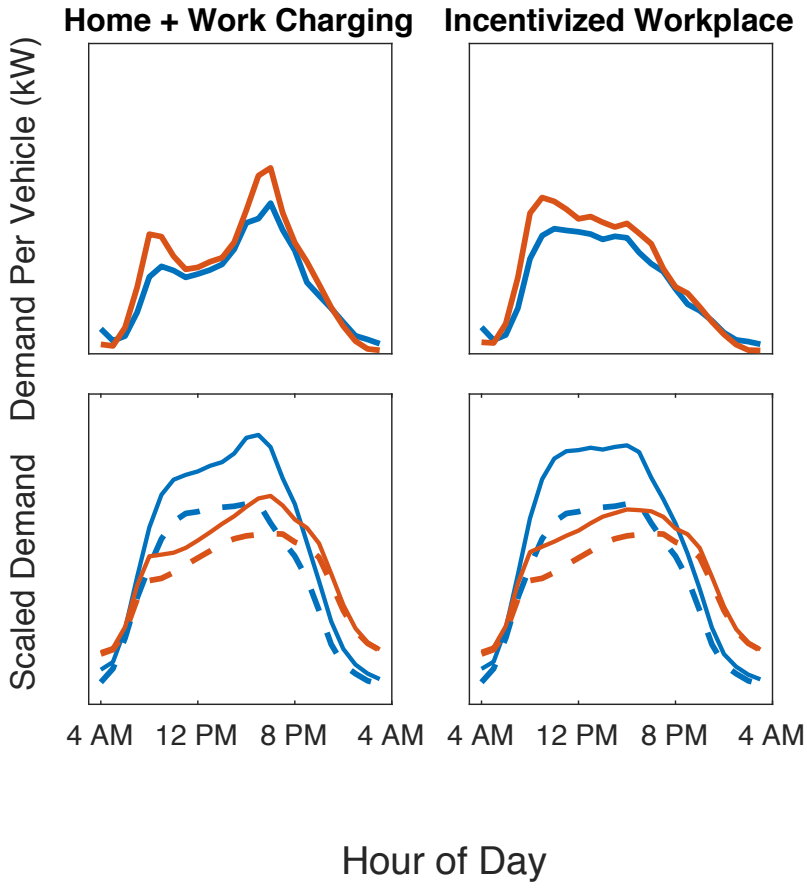
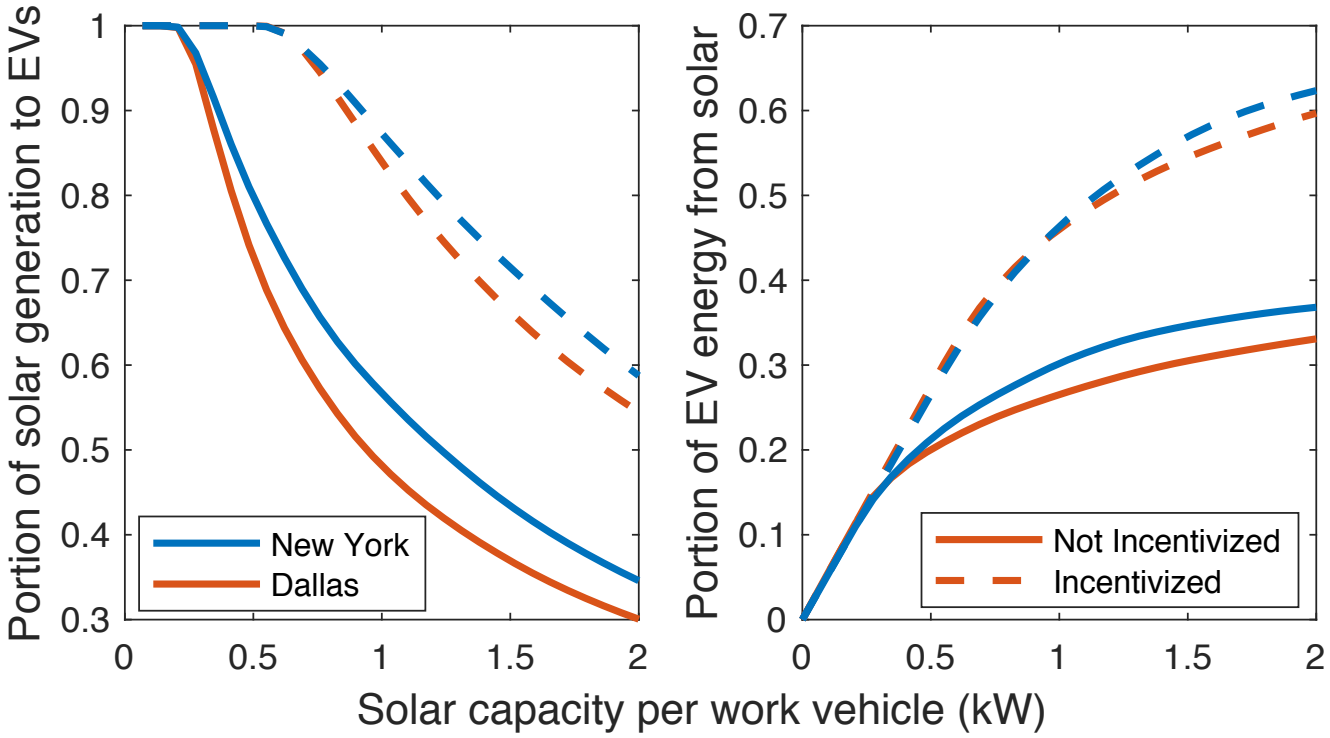
- **Workplace charging reduces afternoon peak**
  - Due to spread-out plugin times at home
  - Especially true when preferred over home charging
- **Solar resource availability aligns with workday**
  - This is the case despite variability in travel patterns
  - How much solar infrastructure is required?



Meeting BEV demand with solar?



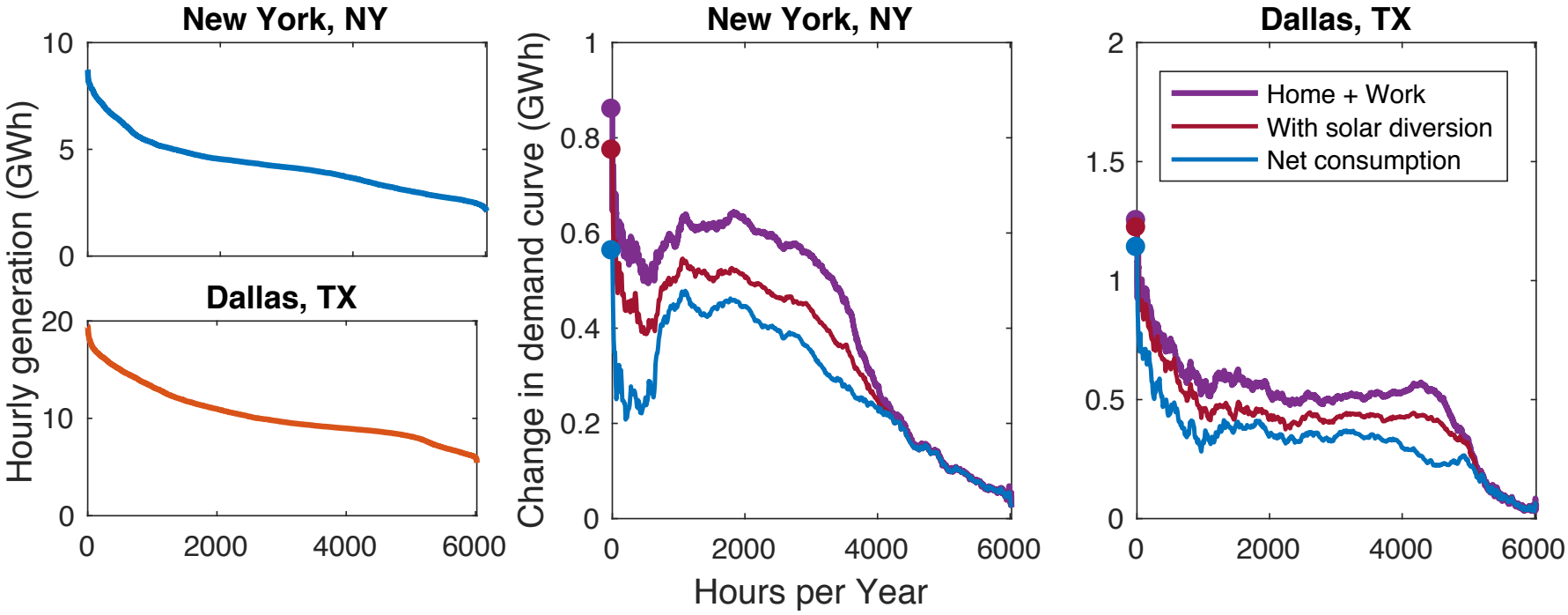
Impact of S2V on hourly demand

Two cases:

- *Solar Diversion*: BEVs draw electricity from workplace solar when available, make up the difference from the grid. Any extra electricity from PV is ignored
- *Net Consumption*: Any extra electricity from PV is assumed to be fed back into the grid and subtracted from required generation/transmission/distribution totals

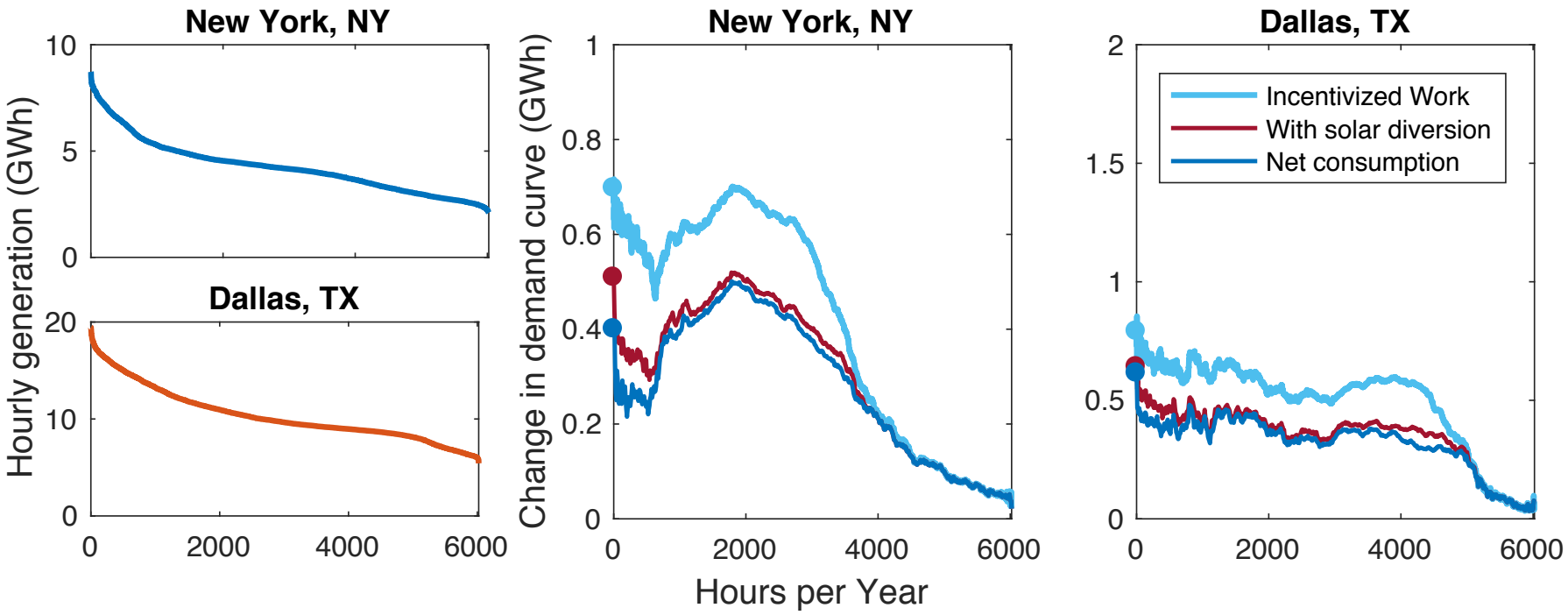
Impact of S2V on hourly demand

Not incentivized:



Impact of S2V on hourly demand

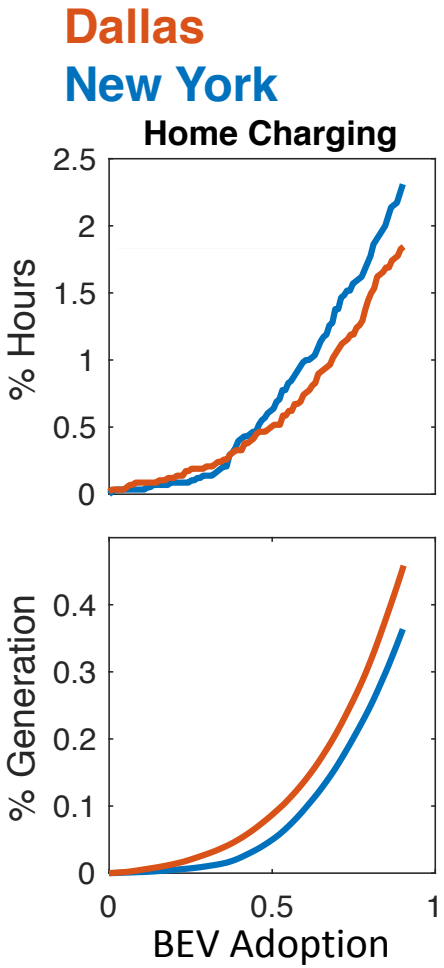
Incentivized:



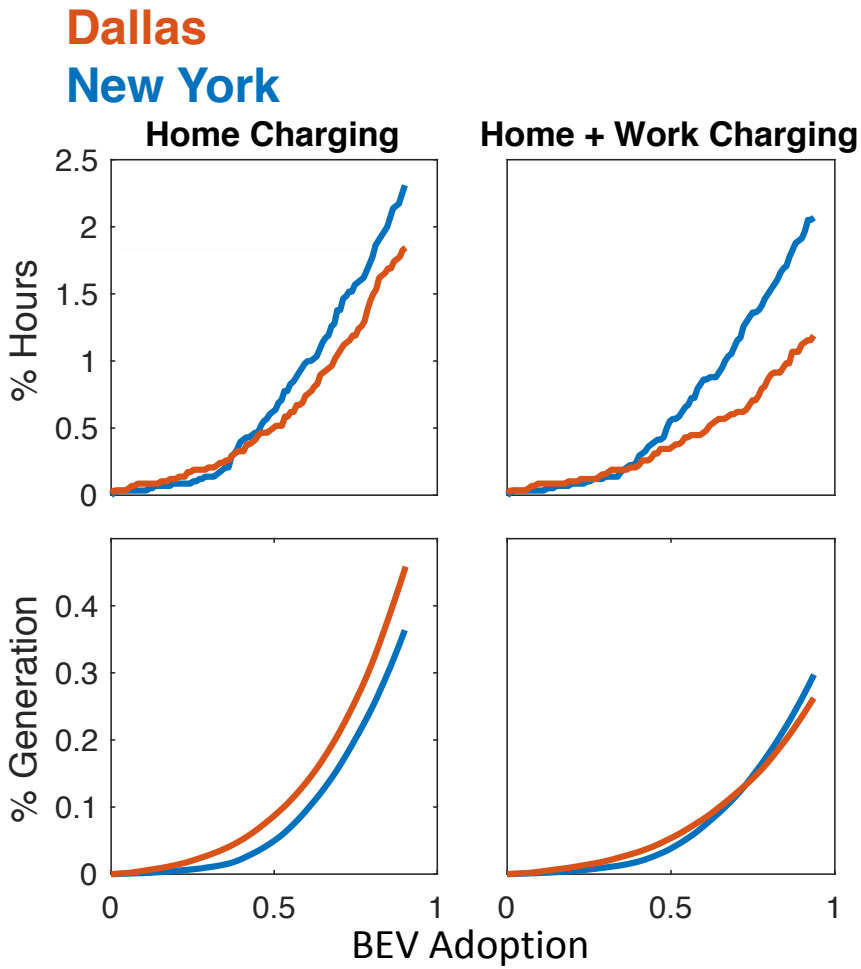
Effect of BEV adoption rate

- **What is the relationship between BEV adoption and the degree current capacity is exceeded?**
- **At what level of BEV adoption do generation/ transmission constraints become important?**
  - Is there a threshold effect or do impacts increase steadily with adoption?
  - What differences and similarities are there between the two cities?
- **How do the proposed interventions perform?**
  - Are any of the low-inconvenience alternatives effective?
  - Is the effectiveness of solar diversion hurt by resource variability?

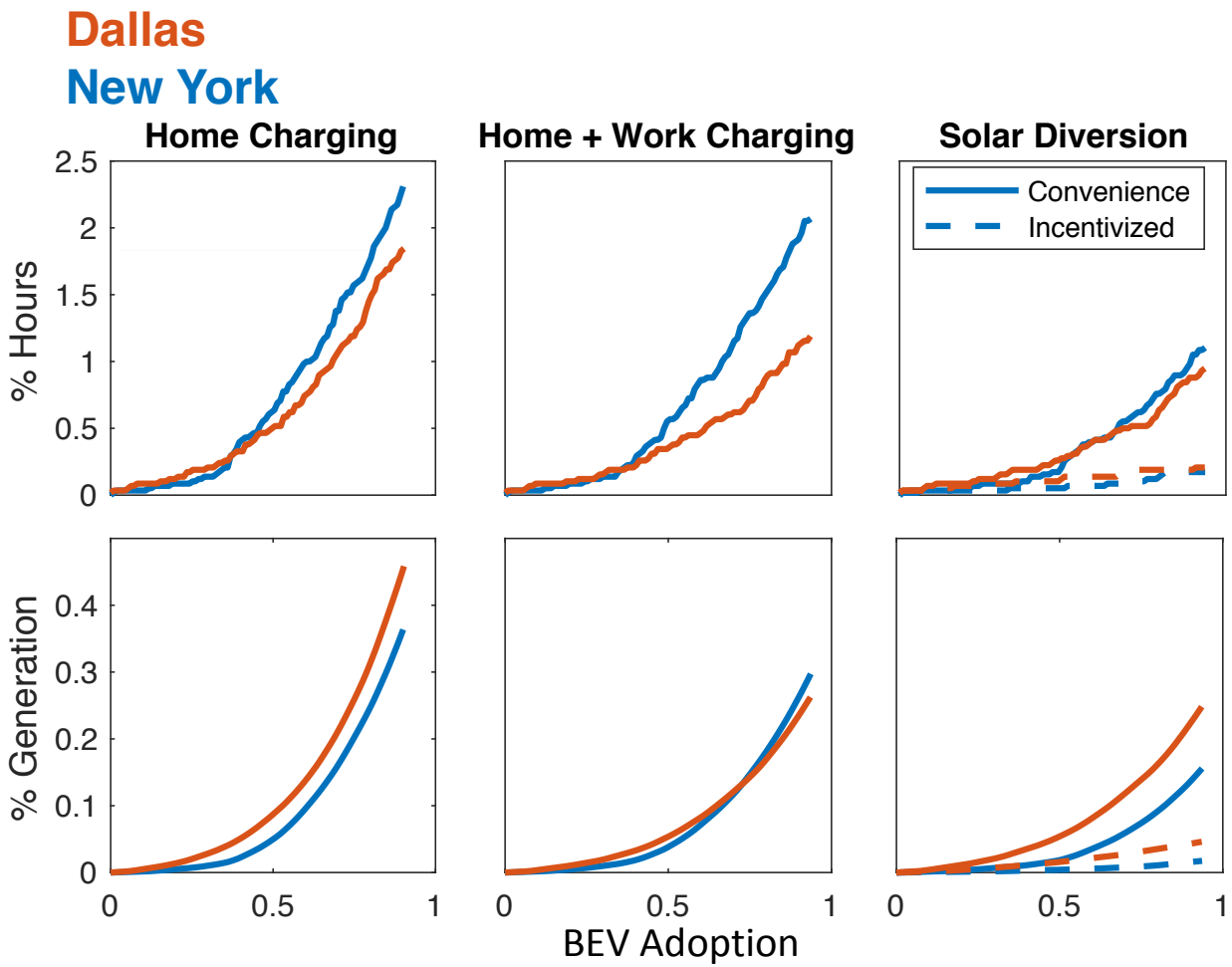
Effect of BEV adoption rate



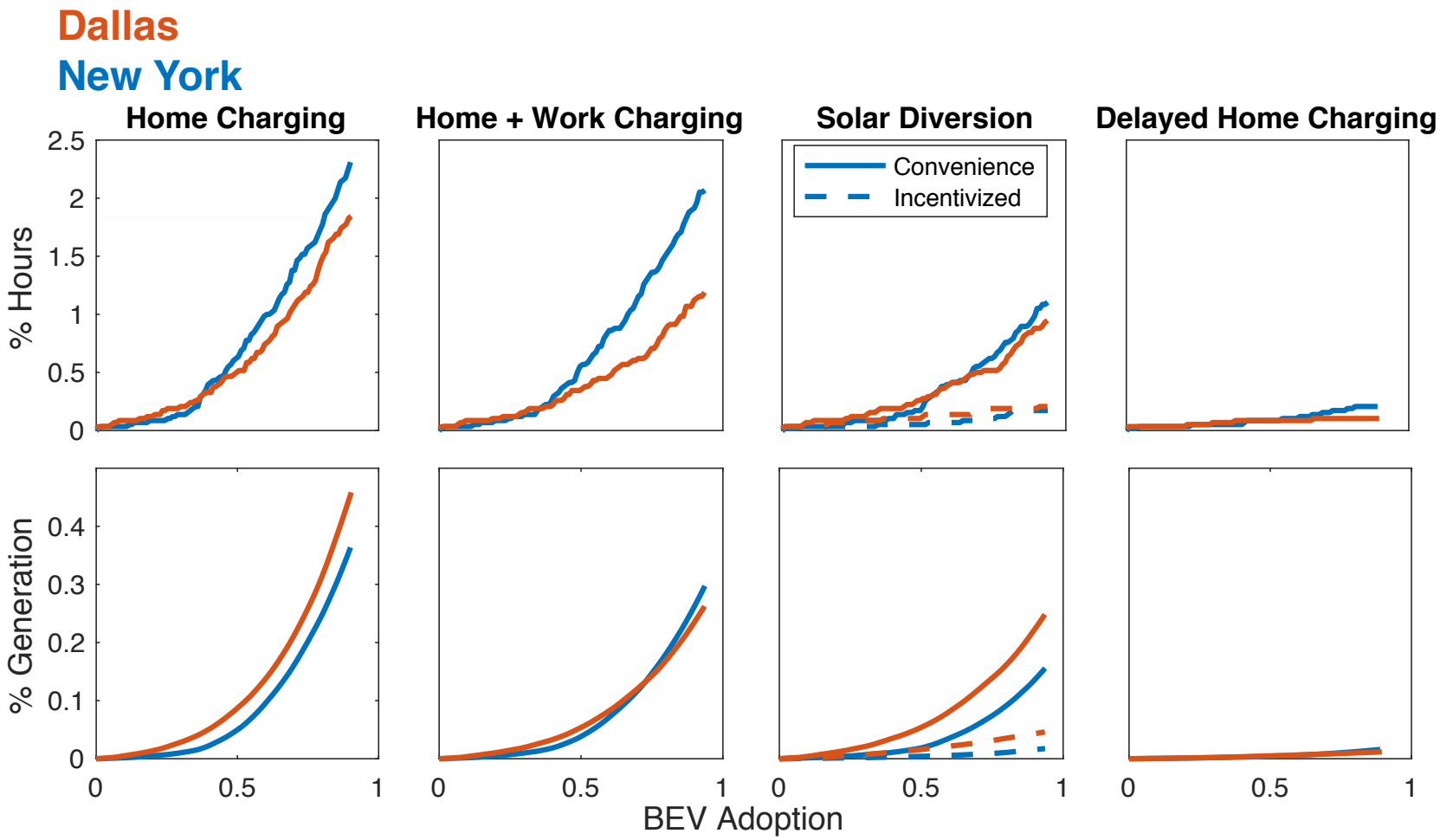
Effect of BEV adoption rate



Effect of BEV adoption rate



Effect of BEV adoption rate



Conclusions and discussion

Findings

- **Location-specific average load profiles**
  - Average BEV would add a total of 1.4 and 1.0 kW to peak loads in Dallas and New York
  - With access to Level 2 charging at work, peak drops to 0.88 kW in Dallas and 0.68 kW in New York
  - Incentivized workplace charging flattens peak, last-minute charging removes it

Findings

- **Comparisons of methods to lessen grid capacity constraints**
  - Workplace charging somewhat effective in Dallas, especially when drivers prefer it to charging at home
  - Workplace charging not effective New York (esp. with NJ commuters?)
  - Last-minute charging very effective in both cities
- **Evaluating workplace S2V**
  - Effective at reducing capacity constraints, especially in New York
  - Potential to not even connect panels to the grid with up to ~1kW per work vehicle

Policy implications

- **Expand workplace charging infrastructure**
  - Especially in cities with higher evening peak in existing demand
  - Level 1 is likely a better investment than Level 2
- **With high workplace PV penetration, it is helpful to incentivize workplace charging**
  - Greatly increases fuel economy of BEV fleet
  - Decreases the impact of PV sources on the grid
  - Important not to incentivize driving over other modes