

PJM and Better Place – EV to Grid Integration

An economic impact assessment on the PJM market

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Agenda

1. Introduction to Better Place
2. Overview and Executive Summary
3. Model
4. Results
5. Conclusions
6. Appendix on Grid Services

Introduction to Better Place



Better Place is a global EV network operator and service provider





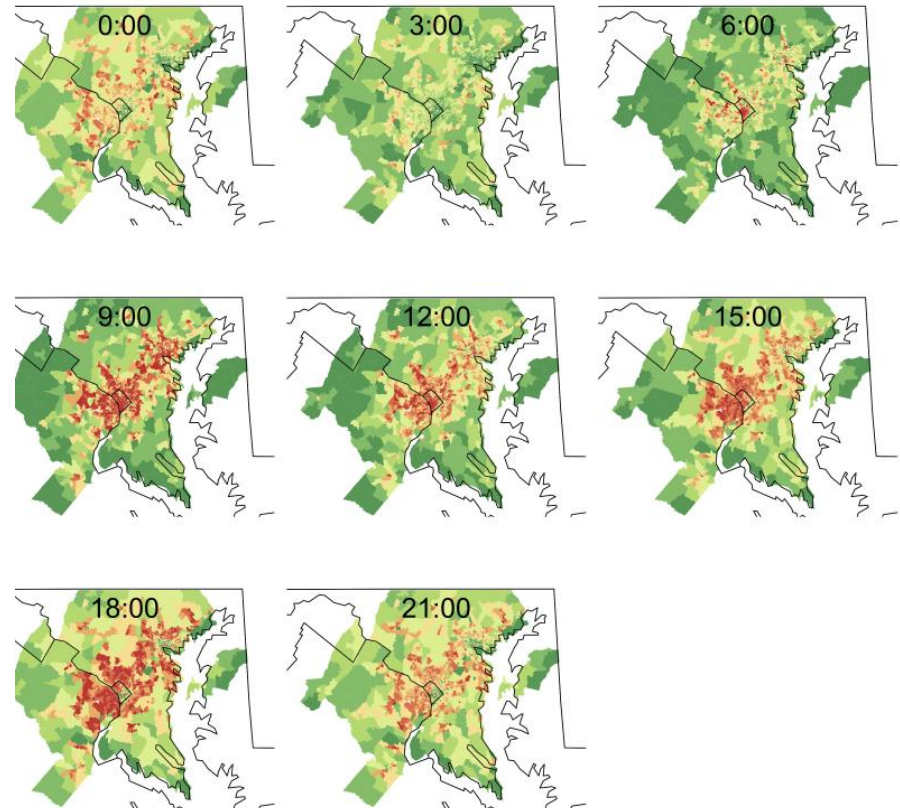
- Real-time communication to every vehicle
- Variable control over the rate of charge to every socket
- Real-time status and communication with every battery in the car (via embedded proprietary software)
- Real-time status of every battery in the battery switch stations
- A control center that delivers energy to all customers in an optimal fashion, recognizing economic and physical constraints

* Footnote

Project Overview



- Modeled the market and pricing impact of 1M EVs.
- The greater Washington – Baltimore area was selected for modeling because it already experiences transmission congestion issues
- Demonstrate the value of EV Network Operator (Aggregator) that manages EV charging
 - Wholesale energy market
 - Production costs
 - Ancillary services
- Enable PJM, Better Place, and other stakeholders to learn from the results



EV Load Intensity Snapshots

* Footnote



- Three grid impact charging scenarios are referenced relative to the base load without EVs
 - Unmanaged Charging
 - Consumer-price-incentivized charging (via time-of-use pricing)
 - Managed charging via a Central Network Operator (CNO)
- A CNO is distinguished by communication with charge spots and software to manage charging demand on a real-time basis
- Wholesale energy costs and production cost were chosen as the metrics for assessing impacts and benefits

* Footnote



- Charging schemes with a Central Network Operator (CNO) have the ability and economic incentives to substantially reduce EV grid impacts with benefits to all stakeholders
- Relative to the Unmanaged Charging Scenario:
 - The annual increase in wholesale energy costs were 4% higher in the time-of-use (TOU) charging scenario. Increases in production costs were reduced by 3%.
 - The annual increase in wholesale energy costs were 45% lower in the CNO managed charging scenario. Increases in production costs were reduced by 23%.

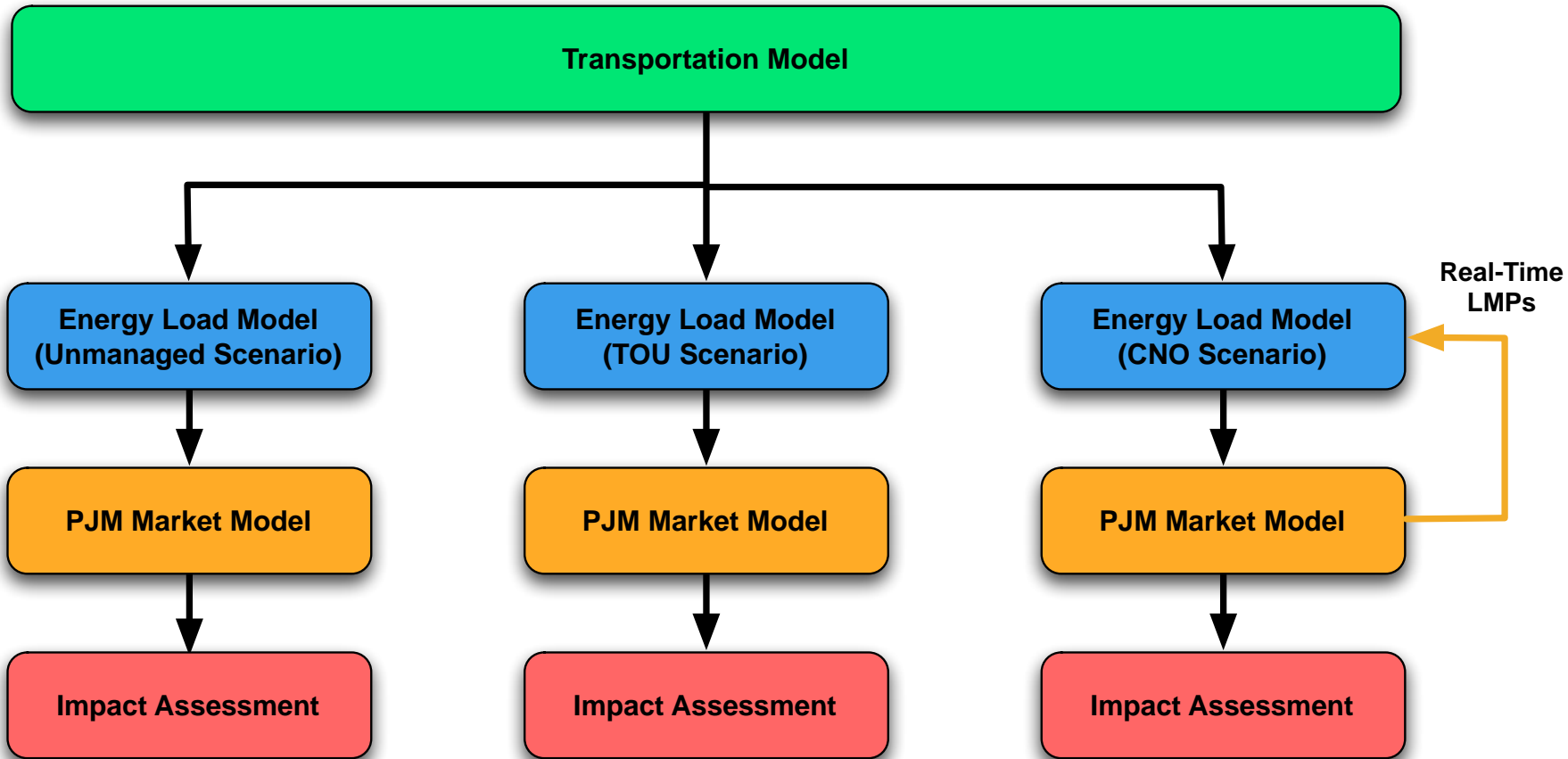
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- Reducing grid-side impacts requires *measurement* and real-time variable *control* of EV charge demand
- A CNO enables network measurements and a centralized control system
 - Aggregate real-time and forecasted demand
 - Ability to process and respond to LMPs across network
 - Potential to provide services to support real-time operations
- Example: synchronous response to price signals
 - “Local intelligence” could attempt to avoid uniform responses through random charging delays, frequency sensing, etc.
 - But, only a CNO could *measure* and *control* how many other agents are acting on the same price signal

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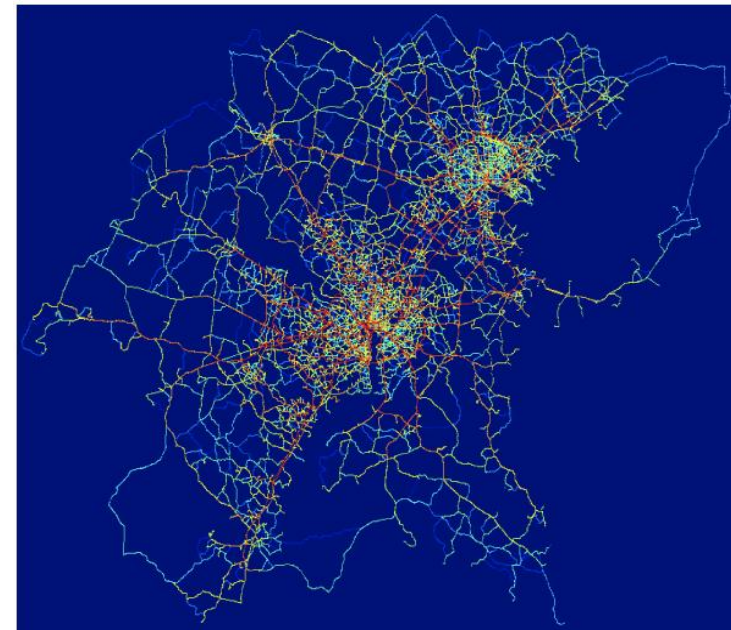
The Model





Transportation Model

- Bottom-up time-based model that reflects driving patterns
- Census tract resolution in Washington-Baltimore Metro Area (used as proxy for charge spot distribution and grid mapping)
- Trip generation and route assignments based on publicly available data:
 - Projected vehicle ownership
 - Employment records
 - Public transit data
 - Traffic routes



EV Route Densities from Census and Transportation Data

* Footnote



Transportation Model – Instant Range Extension

- EV Range extension modeled in two distinct ways:
 - Battery Switch Stations (BSS)
 - Battery Quick Chargers (BQCs)
- Transportation model kept constant in all scenarios
 - All range extension / flexibility technologies were treated equally: instant range extension
- Energy impacts vary between scenarios
 - Fast-charging technology not an option (3 min charge, 400kW)

Unmanaged and TOU Scenarios

Battery Quick Chargers (BQC)

Energy impact: 80% charge in ~30 min (~40kW)

CNO Scenario

Battery Switch Stations (BSS)

Energy Impact: 24kW charge until full

* Footnote



Energy Models – Unmanaged Charging Scenario

- Cars begin charging immediately on plug-in
- Once plugged in, batteries are charged until full
- No physical or economic constraints placed on charging
- Flat-rate pricing (i.e., no incentive tariff)
- There is no CNO / Aggregator

* Footnote



Energy Models – CNO Charging Scenario

- CNOs are distinguished by:
 - Real-time communication with charge spots and NOC; variable control rate of charge at CS
 - NOC software to optimally dispatch charging demand on real-time basis
 - Real-time demand measurements, forecasting, and aggregation
 - Ability to process and respond to real-time LMPs
- CNO motivated to reduce the electricity costs
 - This includes avoiding load spikes
- Charging algorithm charges probabilistically based on:
 - Energy needed for next planned or predicted trip
 - Current battery state-of-charge (SOC)
 - Time of day
 - Forecasted LMPs
 - Real-time LMPs

* Footnote



Energy Models – TOU Charging Scenario

- TOU Scenario reflects a distributed intelligence platform with a fixed pricing schedule
 - All charge spots / EVs have the ability to accept a price signal
 - Minimizes energy cost to EV driver while avoiding coincident demand
- Two-tier pricing schedule
 - Forecasted and real-time prices are fixed
 - Adapted from Southern California Edison’s “Schedule TOU-EV-1” *
- Model Assumption: 70% of customers are adhere to this pricing schedule

* <http://www.sce.com/NR/sc3/tm2/pdf/ce114-12.pdf>

* Footnote



- PJM uses the optimization tool – PROBE to simulate the energy market changes after EV load added to the grid, assuming all the market information, other types of load, and transmission situation are known, which is the similar to Perfect Dispatch Program
- This tool applies a security-constrained economic dispatch to balance supply and demand for energy
 - PJM dispatches supply (generation) in least-production cost merit order to meet demand (consumption)
 - PJM coordinates the reliability of the bulk electric system by monitoring real and potential overloads (contingencies)
 - PJM directs some units “off-cost” to relieve transmission constraints
- This tool also provides the simulating results of Locational Marginal Prices (LMPs) prices for energy nodally (at PNODEs)

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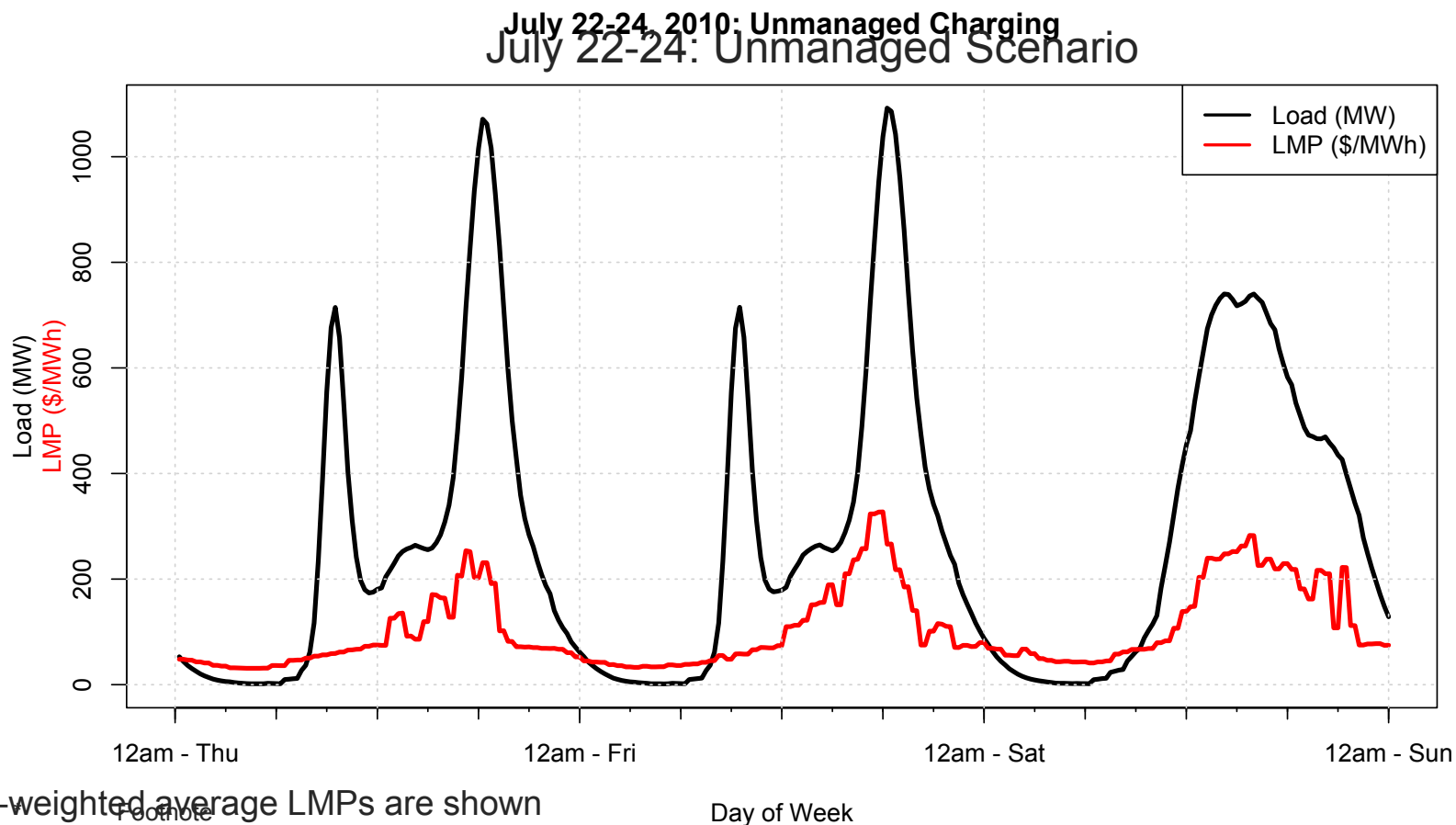
- Electricity Production Cost
 - Minimizing the production cost is the objective function of simulation tool -PROBE, and also it is a measurement of market efficiency.
 - Added EV load causes the production costs of committed units to increase, and the production cost results includes all committed units behavior
- Wholesale Energy Cost
 - The Locational Marginal Prices (LMPs) prices are used to calculate wholesale energy cost
 - The LMPs are mainly impacted by the cost of marginal units, not the whole set of committed units, and congestion (transmission constraints) cost
 - Comparing the production cost, wholesale energy cost is more vacillate and unpredictable, but it is widely used in energy market

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Results: Unmanaged Charging Scenario



- Load shape determined primarily by driving behavior
- Peak load increases by >1000 MW
- Peak load and LMPs are correlated

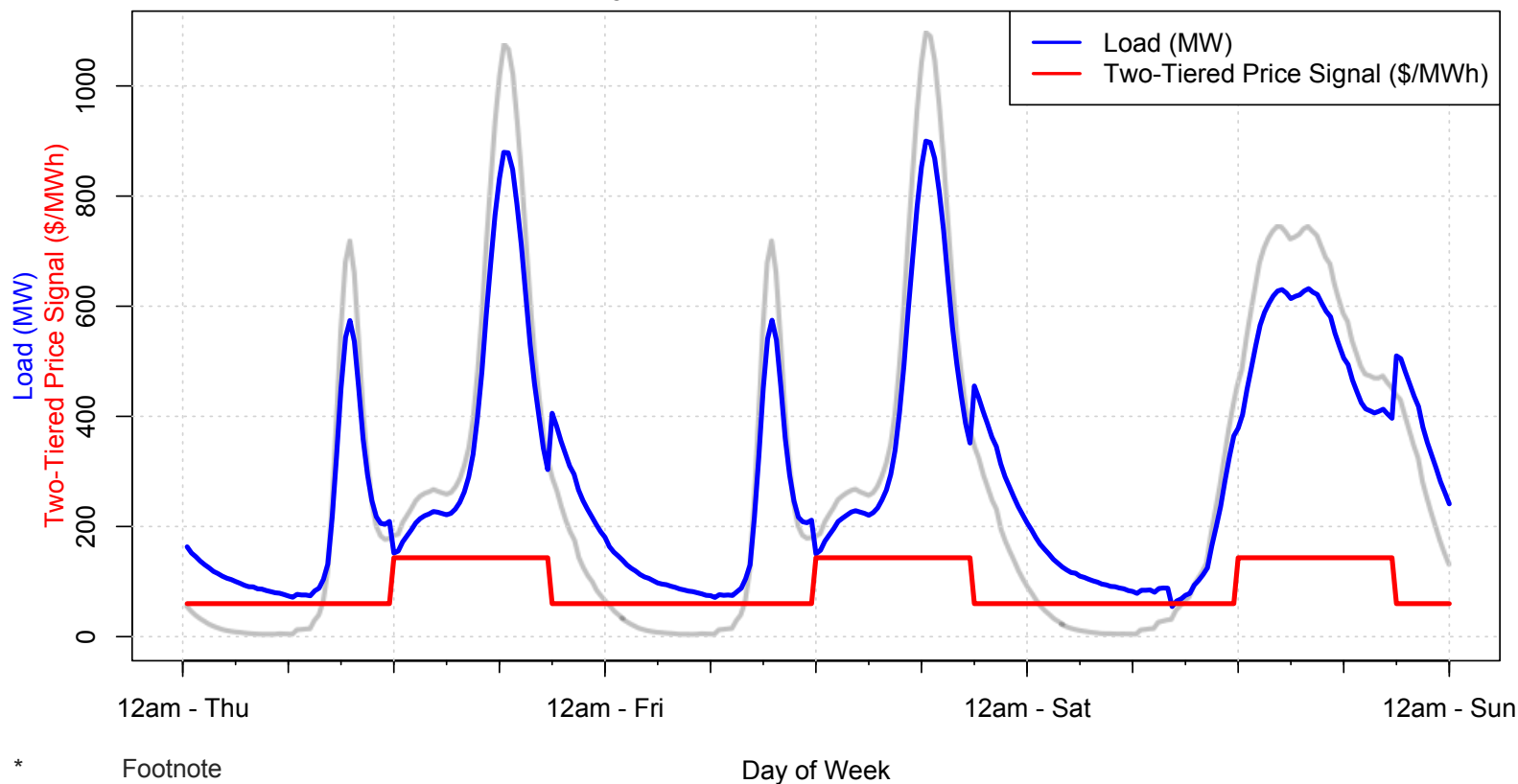


Results: TOU Charging Scenario



- Load shape still determined primarily by driving behavior
- 20% reduction in peak load increase
- Predetermined time-of-use pricing schedule

July 22-24, 2010: Two-Tiered Charging Plan
July 22-24: TOU Scenario



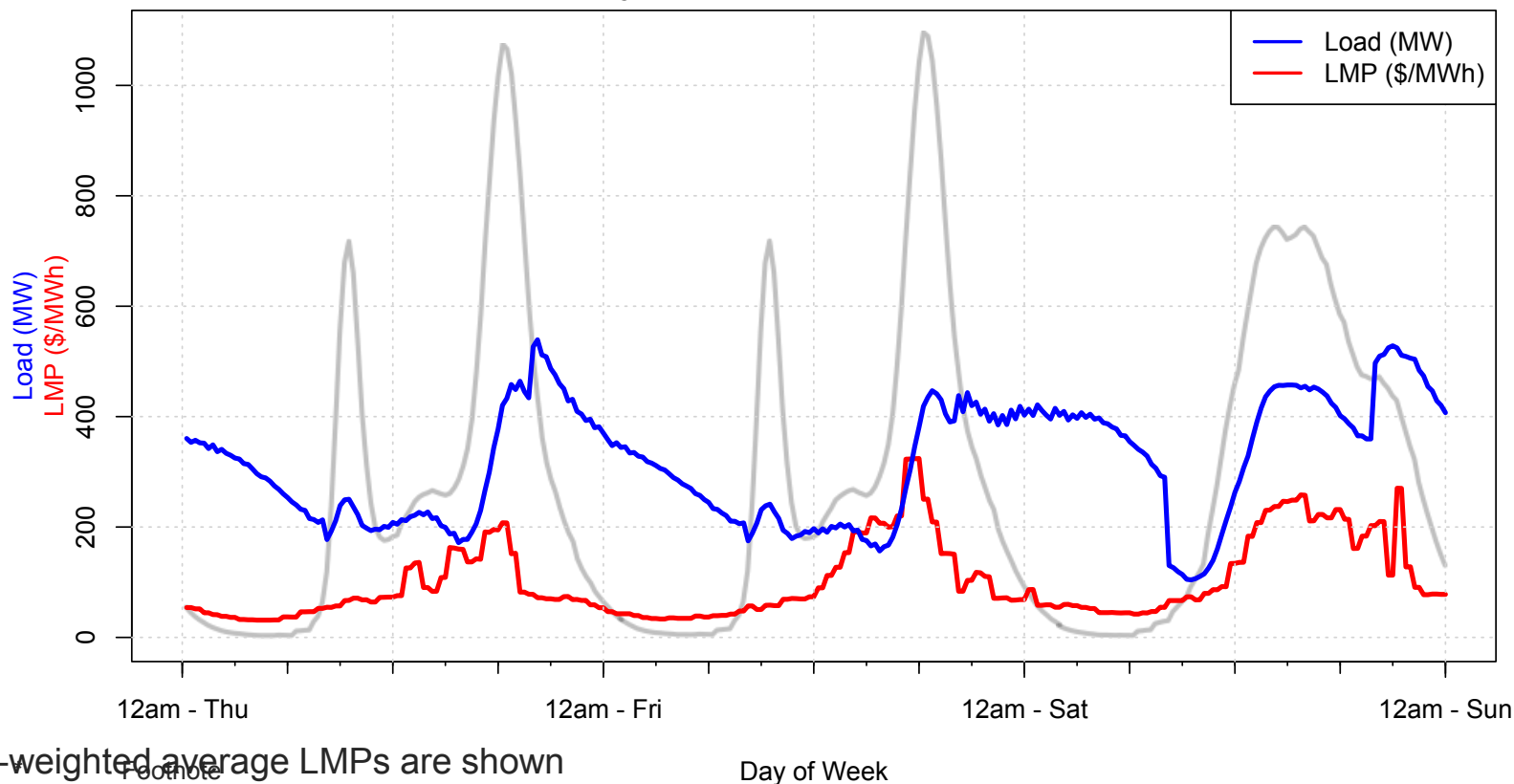
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Results: CNO Charging Scenario



- Centrally managed charging responds to real-time LMPs
- Significantly altered load shape from the Unmanaged Scenario
- Peak load and peak LMPs are not correlated

July 22-24, 2010: Better Place Managed Charging Plan
July 22-24: CNO Scenario



* Load-weighted average LMPs are shown

Managed charging by a CNO reduces energy costs for EV owners

- Energy costs are not directly comparable between the TOU and LMP Pricing columns (retail vs. wholesale), but we can compare the % savings.
- Under the TOU pricing scheme, the collective cost of energy to EV owners is reduced by 3.7% when 70% of customers are sensitive to the pricing schedule

Table I: Summary of Rate-Payer Cost Increases as a Result of Added Electric Vehicle Load. Total costs to ratepayers is calculated for all three scenarios with percent savings scaled relative to the Unmanaged Scenario. These weeks are presumed to be representative of the entire year with equal weightings.

Collective Cost of Energy to EV Owners

Week	TOU Pricing			LMP Pricing		
	Unmanaged Scenario \$ Millions	TOU Scenario \$ Millions	Savings (%)	Unmanaged Scenario \$ Millions	CNO Scenario \$ Millions	Savings (%)
February	5.62	5.38	4.3%	2.58	2.26	12%
April	5.60	5.42	3.3%	2.21	1.75	21%
June	5.78	5.53	4.4%	3.76	2.92	22%
July	5.75	5.60	2.7%	5.40	3.82	29%
October	5.68	5.47	3.8%	1.99	1.66	16%
Annually	295.8	284.9	3.7%	165.8	129.1	22%

* * savings shown relative to Unmanaged Scenario

Table II: Summary of Rate-Payer Cost Increases as a Result of Added Electric Vehicle Load. Total costs to ratepayers is calculated for all three scenarios with percent savings scaled relative to the Unmanaged Scenario. These weeks are presumed to be representative of the entire year with equal weightings.

Charging Impact on Wholesale Energy Cost



- The TOU Scenario yields an inconsistent savings. Relative to the Unmanaged Scenario, wholesale costs increase by 4% annually.
- By responding to LMPs with a CNO, increases in wholesale energy costs are reduced by 45%

Wholesale Energy Cost Increase from EV Charging

Week	Unmanaged Scenario	TOU Scenario		CNO Scenario	
	\$ Millions	\$ Millions	Savings (%)	\$ Millions	Savings (%)
February	6.41	10.15	-58%	5.21	19%
April	11.21	5.03	55%	1.36	88%
June	20.48	21.33	-4%	11.38	44%
July	30.83	28.97	6%	21.84	29%
October	6.68	13.24	-98%	2.13	68%
Annually	786.3	818.7	-4%	436.0	45%

* savings shown relative to Unmanaged Scenario

Figure 1: Summary of Rate-Payer Cost Increases as a Result of Added Electric Vehicle Load. Total costs to ratepayers is calculated for all three scenarios with percent savings scaled relative to the Unmanaged

Charging Impact on Production Cost



- PJM’s software optimizes the balance of energy supply and demand to satisfy all transmission flow limits with a least production cost algorithm.
- Both the TOU and CNO scenarios show reductions in production cost relative to the Unmanaged Scenario

Source: Summary of Rate-Payer Cost Increases as a Result of Added Electric Vehicle Load. Total cost increases is calculated for all three scenarios with percent savings scaled relative to the Unmanaged Scenario. These weeks are presumed to be representative of the entire year with equal weightings.

Production Cost Increases and Savings

Week	Unmanaged Scenario	TOU Scenario		CNO Scenario	
	\$ Millions	\$ Millions	Savings (%)	\$ Millions	Savings (%)
February	1.42	1.42	0.0%	1.23	13%
April	1.21	1.16	4.1%	0.93	23%
June	1.97	1.88	4.6%	1.48	25%
July	2.83	2.71	4.2%	1.97	30%
October	0.99	1.00	-1.0%	0.85	14%
Annually	87.6	85.0	3.0%	67.18	23%

* savings shown relative to Unmanaged Scenario

Source: Summary of Production cost Increases as a Result of Added Electric Vehicle Load. Total production cost is calculated for all three scenarios with percent savings scaled relative to the Unmanaged Scenario. These weeks are presumed to be representative of the entire year with equal weightings.



1. Added EV load can have significant impacts on the grid and it is necessary to mitigate the magnitude of the impacts
 - Unmanaged charging is the most detrimental

2. Relative to the Unmanaged Scenario, the TOU Scenario was not effective in minimizing its own electricity costs or grid-side impacts

3. Relative to the Unmanaged Scenario, rational behavior by the CNO:
 - Reduces its own electricity costs transportation costs (22% reduction)
 - Reduces increases in wholesale energy costs (45% reduction)
 - Reduces increases in electricity production cost (23% reduction)

* Footnote



1. Charging schemes with a CNO have the *ability* and *economic incentives* to substantially reduce EV grid impacts

2. Measurement and control are critical
 - Real-Time LMPs are a useful measurement for grid-side impacts
 - But, a CNO is the enabling entity that is capable of price predictions and responses to those real-time prices

* Footnote

Next Steps and suggested topics for future studies



Next steps:

PJM and Better Place would like to discuss the results of this study publically and use the knowledge gained in performing the assessment to better equip their systems for mass EV deployment.

PJM will share the results of the studies internally with the PJM Markets, Operations and Planning organizations to help determine and prepare for the potential impact of electric vehicles.

Suggested topics for future study:

Distribution network impacts

Beyond grid-impacts and ancillary services, dispatchable load can be leveraged for:

- Long-term planning
- Optimizing generator dispatch
- Deferral of capital expenses on infrastructure upgrades
- Increase capacity factors of renewables

* Footnote

Thanks to all involved in this project



PJM

Scott Benner

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Xu Xu

Better Place

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Hugh McDermott

Stephen Schneider

And all the additional support from local teams at PJM and Better Place

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better place 



Appendix on Grid Services

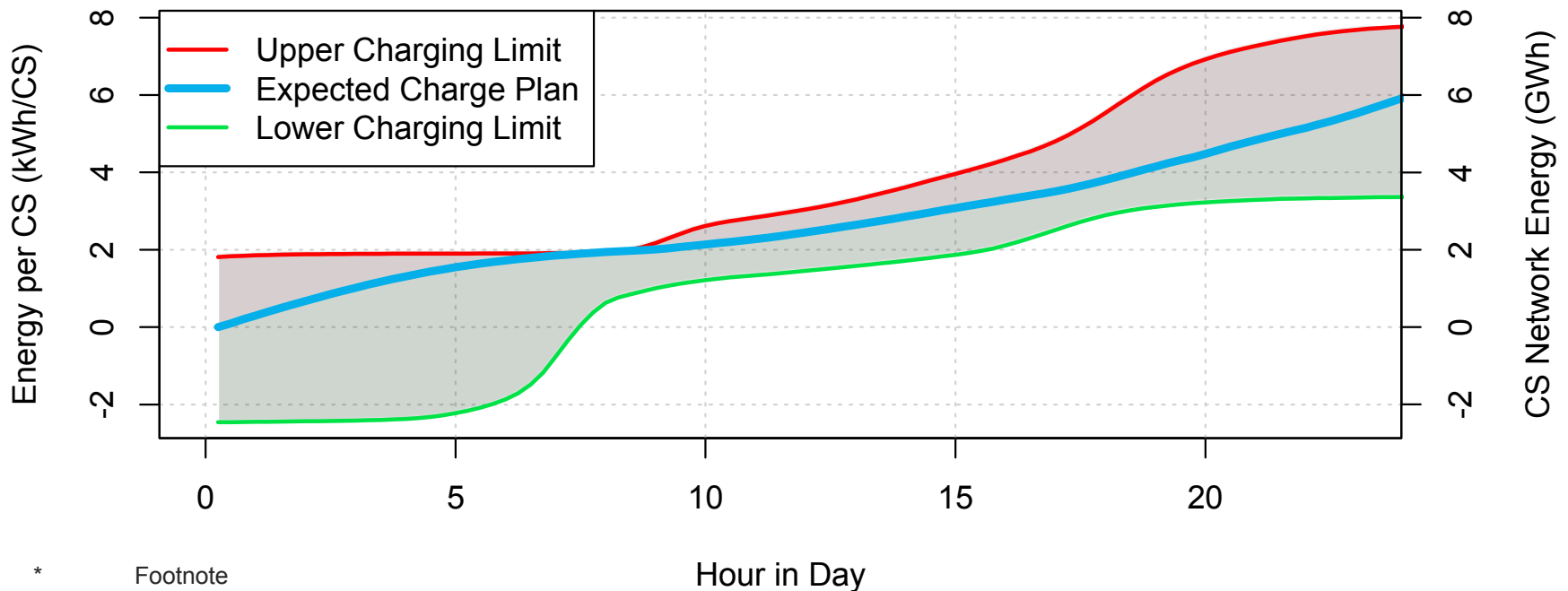
- A. Load Forecasting
- B. Primary Reserves from BSS
- C. Secondary Reserves from Charge Spots
- D. Tertiary Reserves from Charge Spots

Load Forecasting and Dynamic Load Control



- EV Loads from charge spots (CS) can be predicted on a Day-Ahead and Real-Time basis
- Dynamic Load Control with flexible needs allows network to provide secondary and tertiary reserves.
- The expected charge plan here fills up all batteries by ~8am

Cumulative CS Daily Energy Consumption



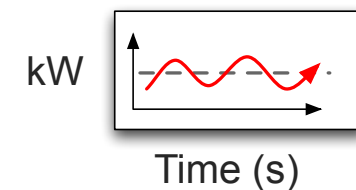
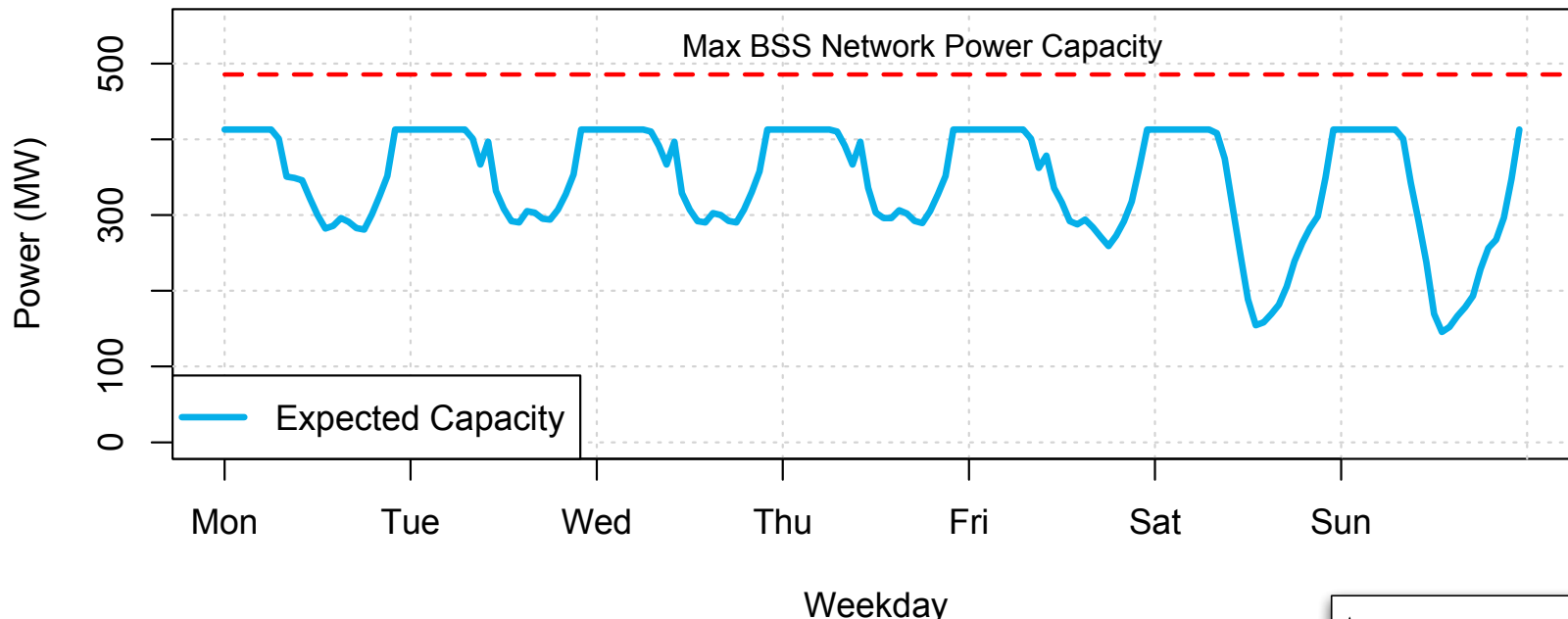
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Primary Reserves (“Frequency Regulation”) from BSS



- Across the BSS Network, a large capacity is available for grid services (CF~65%) despite dual use of transportation and grid services
- Highly predictable capacity estimates are possible since they are based on planned and forecasted energy needs

BSS FR Availability



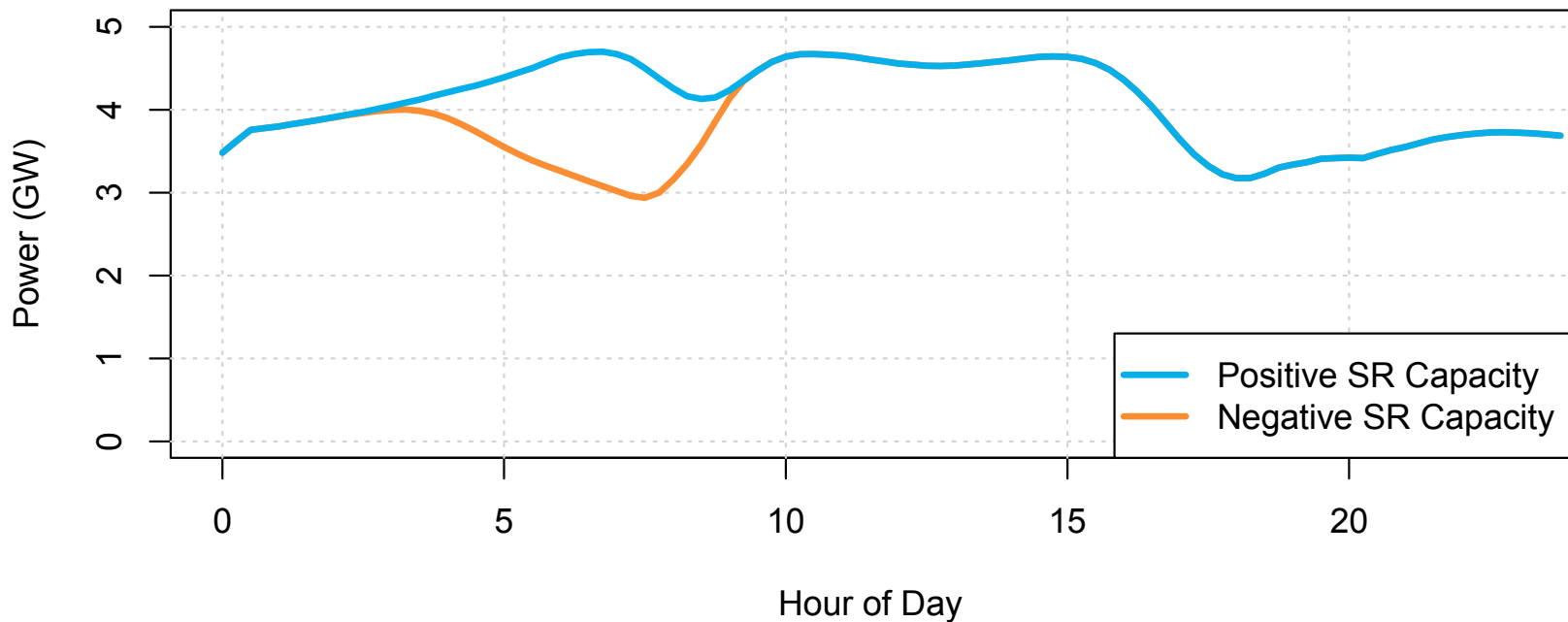
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Secondary Reserves (“Spinning Reserves”) from EVs



- Highly predictable resource that is generally power limited rather than energy limited
- Operation of positive secondary reserves does not deplete battery below 40% SOC.
- Does not affect vehicles taking planned trips; factors in unplanned trips based on probabilities
- Typical operation will have minimal impact to operations and battery management

Pos/Neg Secondary Reserves (30-Minute Activation) from CS Network



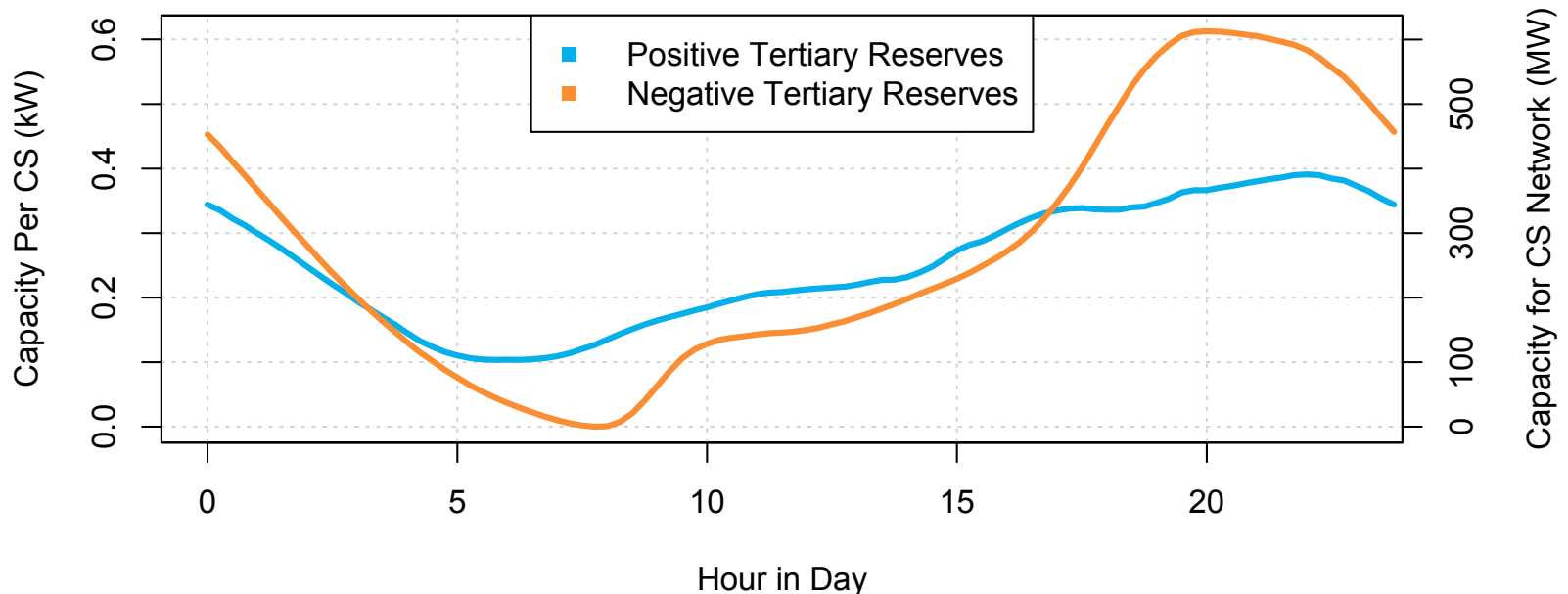
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Tertiary Reserves (or Demand Response) from EVs



- Tertiary reserve capabilities are calculated to maintain the network within precise operating limits
- Positive reserve capacities shown below have little to no impact on drivers and therefore comes at a near zero-cost to Better Place.
- Negative Reserves simply charge batteries ahead of schedule.
- Curtailment tends to be lower during the day since most charging is planned at night to reduce energy costs.

4-Hour Tertiary Reserves from CS



* Footnote