

Advances in Energy Storage Modeling for Improved Market Efficiency

ESIG 2023 Fall Technical Workshop
Session 7: Market Topics

October 25, 2023



Outline

- Outstanding challenges to better integrating electric storage resources into wholesale electricity markets
- Computational advances to simplify state-of-charge management

Outstanding challenges to better integrating electric storage resources into wholesale electricity markets

Day-ahead market

Computational advances to simplify SoCM

ESR use and SoCM in RUC

Enhanced energy representation for adequate SoC calculation

Real-time market

Approaches to augment incentive compatibility of multi-interval RTSCED problems

Impact of different SoCM options

Ancillary services market

Impact and feasibility of A/S on SoCM

Price formation impacts of sustained duration performance requirements for A/S with storage

Miscellaneous

Representation of degradation

Market power mitigation

Participation models for LDES

Price formation in high VRE systems with storage

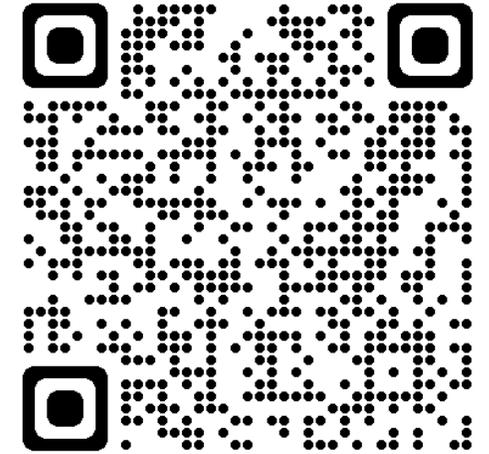


Addressing Computational Efficiency

Scalable ISO SoC Management of Electric Storage Resources in Market Clearing Software

Motivation and summary

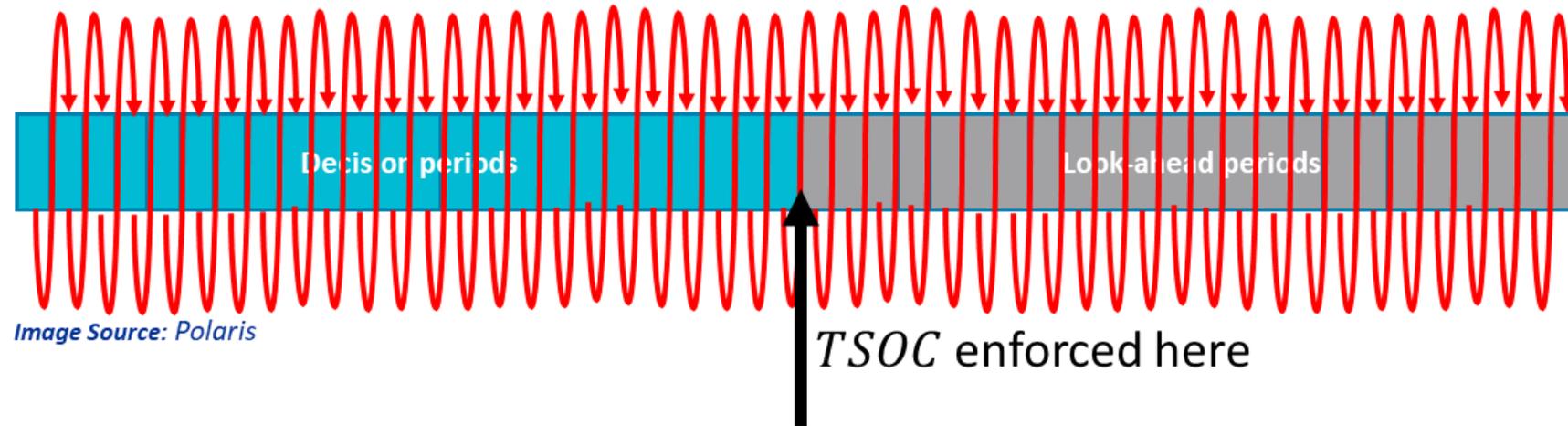
- Use ISO-SOCM at scale
- Present the traditional formulation ('SoC Constraint Formulation')
- Introduce an alternate formulation ('Wrapper Energy Constraint Formulation')
- Compare the two formulations in terms of:
 - Computational efficiency
 - Economic efficiency and reliability
 - SoC and Locational Marginal Price
 - Resource revenues
- Future Directions



W. Aslam, N. Singhal, E. Ela, and R. Philbrick, At-Scale ISO State-of-Charge Management of Storage Resources Using Simplifying Wrapper Energy Constraints. EPRI, Palo Alto, CA: 2023. 3002026964. [Online]. Available: <https://www.epri.com/research/products/000000003002026964>

Traditional formulation (SoC Constraint Formulation)

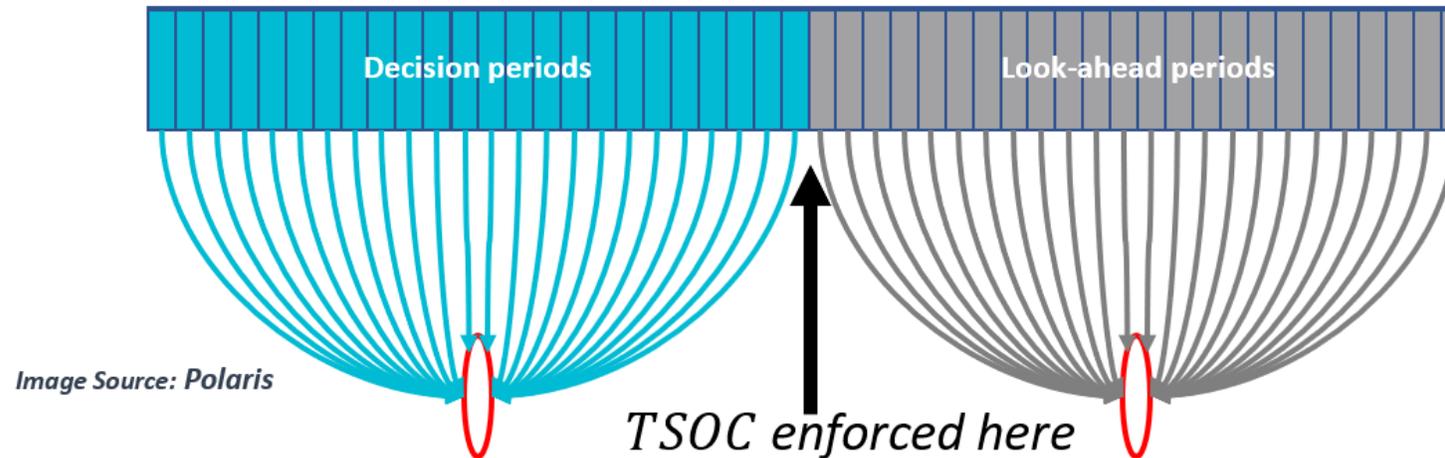
- Chronological hour-to-hour modeling of SoC trajectory
- Target SoC enforced at the end of the optimization horizon
- Time-coupled and hard constraints



- $\text{SoC (interval)} = \text{SoC (previous interval)} - \text{Scheduled Discharge} \times \text{D-Efficiency} + \text{Scheduled Charge} \times \text{C-Efficiency}$
- $\text{SoC (last interval)} = \text{Target SoC}$
- $\text{Minimum SoC} \leq \text{SoC (interval)} \leq \text{Maximum SoC}$

Alternate Formulation (Wrapper Energy Constraint Formulation)

- Energy exchanged over a time window
- SoC trajectory and Target SoC enforced implicitly



- $\text{Sum}_{\text{time_window}} (\text{Scheduled Discharge/D-Efficiency} - \text{Scheduled Charge} \times \text{C-Efficiency}) = \text{SoC} (\text{beginning time_window}) - \text{Target SOC} (\text{end time_window})$
- $\text{Sum}_{\text{time_window}} (\text{Scheduled Discharge/D-Efficiency}) \leq \text{SoC} (\text{beginning time_window}) - \text{Minimum SOC}$
- $\text{Sum}_{\text{time_window}} (\text{Scheduled Charge} \times \text{C-Efficiency}) \leq \text{Maximum SOC} - \text{SoC} (\text{beginning time_window})$

Comparison of SOC and Wrapper Formulations

■ Test System

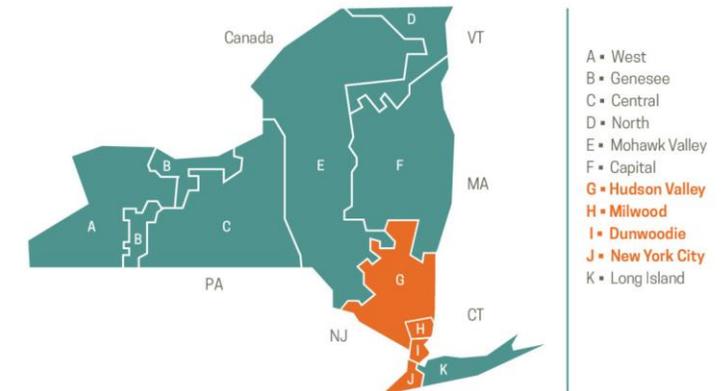
- Newton Energy Group: NYISO Fundamentals Model
- System: 11 areas, 568 generators (including CC, ST, Nuclear, Wind), ~46 GW capacity, key inter-zonal constraints
- Electric Storage Resources
 - 1000 added (across 6 different areas – A, C, D, E, I, K)
 - MW capacity between 3-40 MW (total around 8 GW)
 - MWh capacity between 18-200 MWh
 - Duration between 2 to 10 hours

■ Production Cost Model in PSO

- Day-ahead energy and ancillary services market
- No ancillary services from ESRs
- 12-hour Time Window for wrapper constraints



Power System
Optimizer



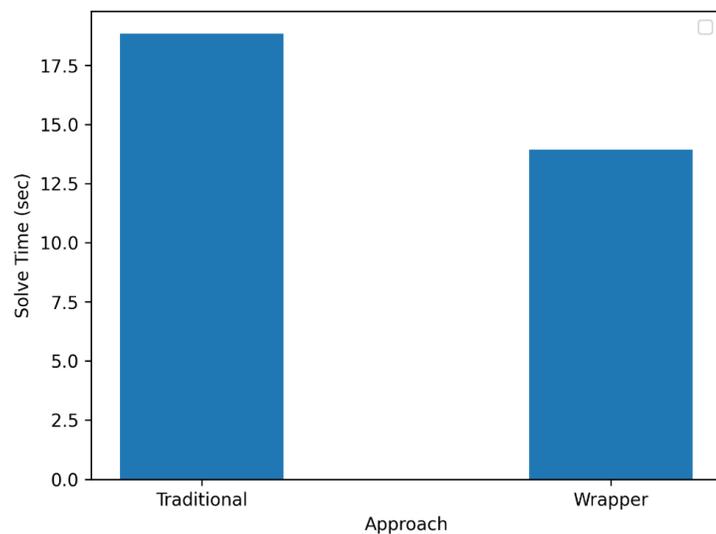
Problem Size

PROBLEM CHARACTERISTIC	SOC CONSTRAINT	WRAPPER ENERGY CONSTRAINT
Avg. num. of constraints	255k	206k
Avg. num. of variables	362k	312k
Avg. num. of integer variables	2.6k	2.6k

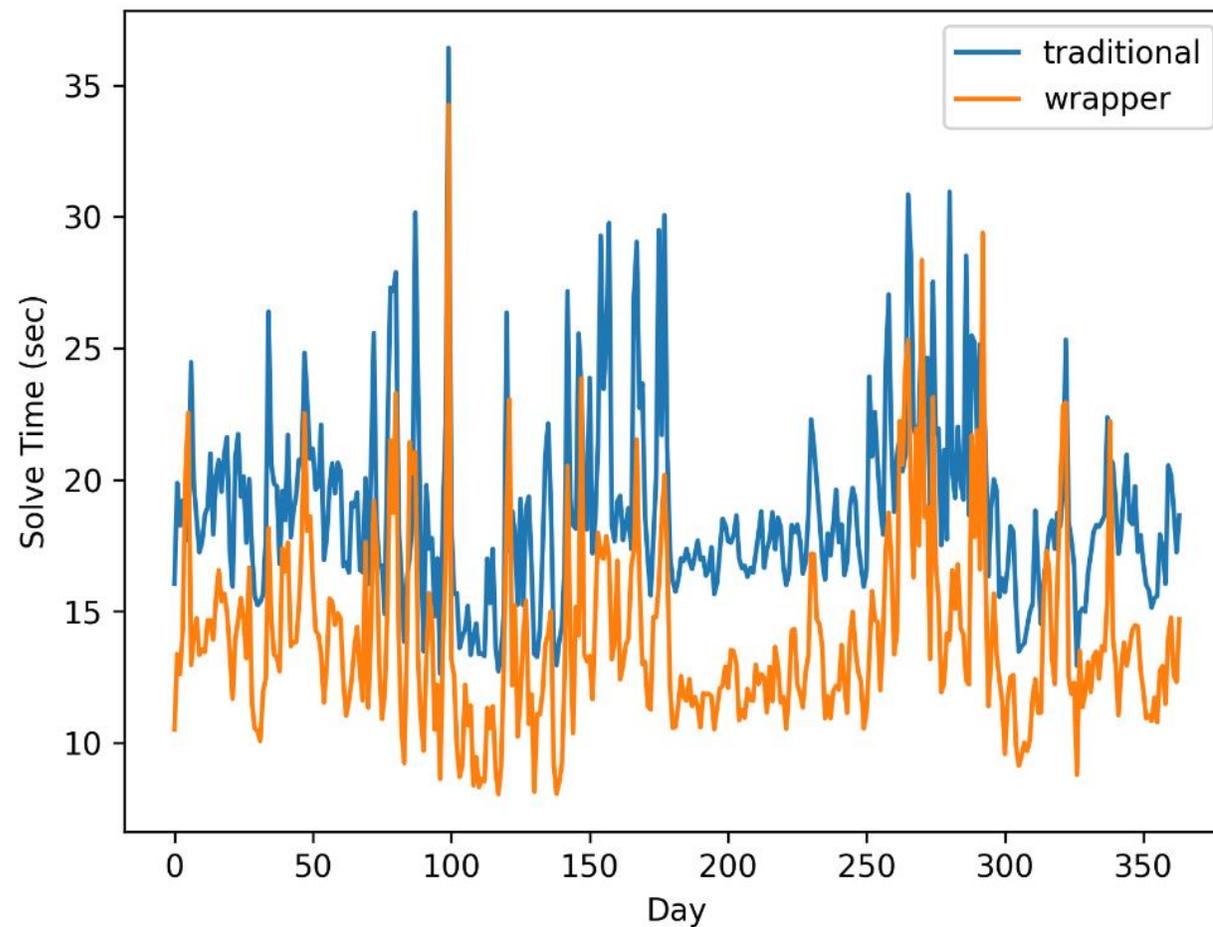
SoC Constraint Formulation has **larger** number of constraints and variables

Computational Time

- SoC constraints: 18.84s per day
- Wrapper constraints: 13.9s per day



Average time per horizon

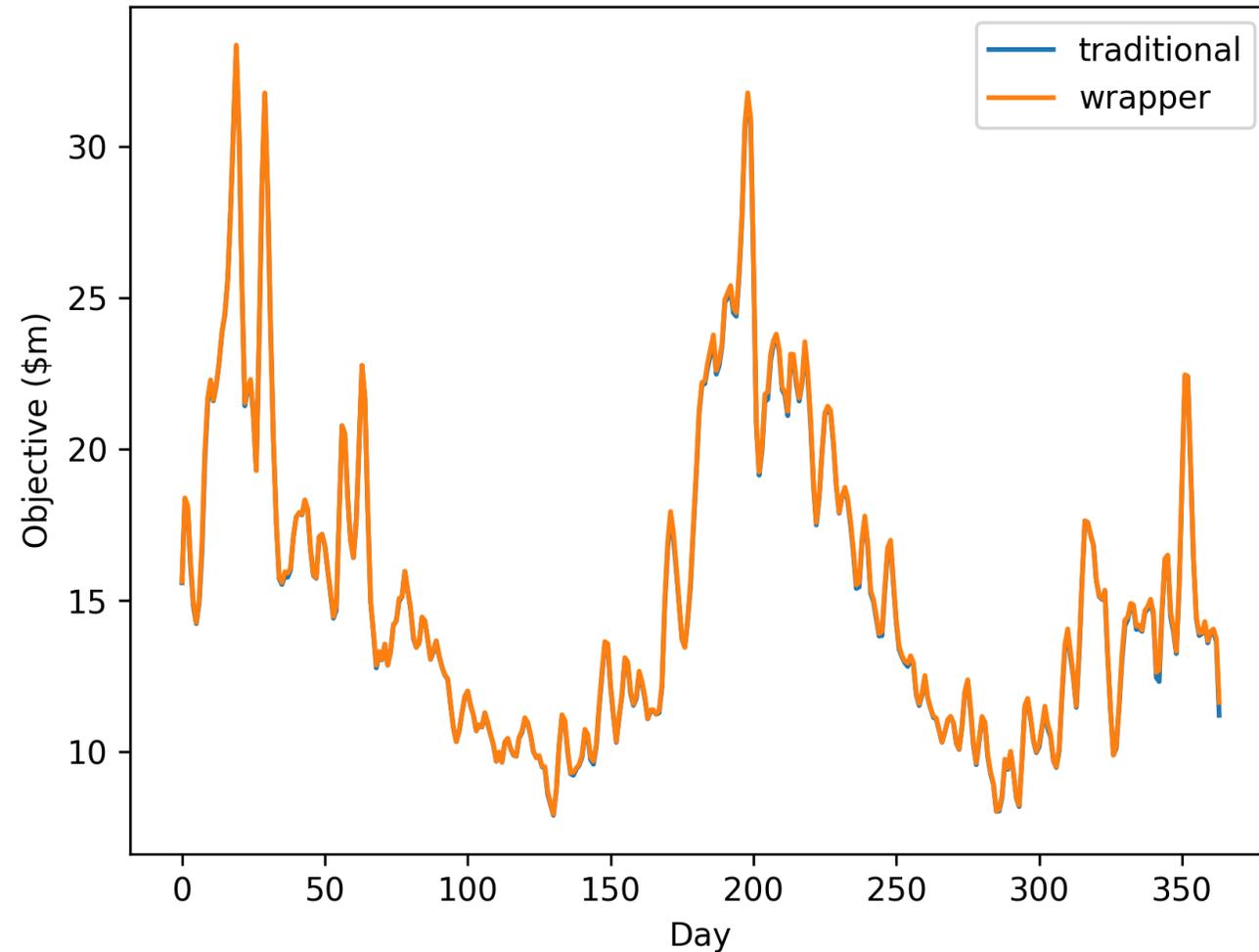


Time for each horizon

Wrapper Energy Constraint Formulation has **lower** computational time

Production Cost

- Average Daily Cost
 - SoC Constraints: 15.333M
 - Wrapper Constraints: 15.399M
 - 0.43% increase in cost
- Maximum Daily Delta: \$378k
- Annual Cost
 - SoC Constraints: 5,581M
 - Wrapper Constraints: 5,605M
 - Difference of ~24M

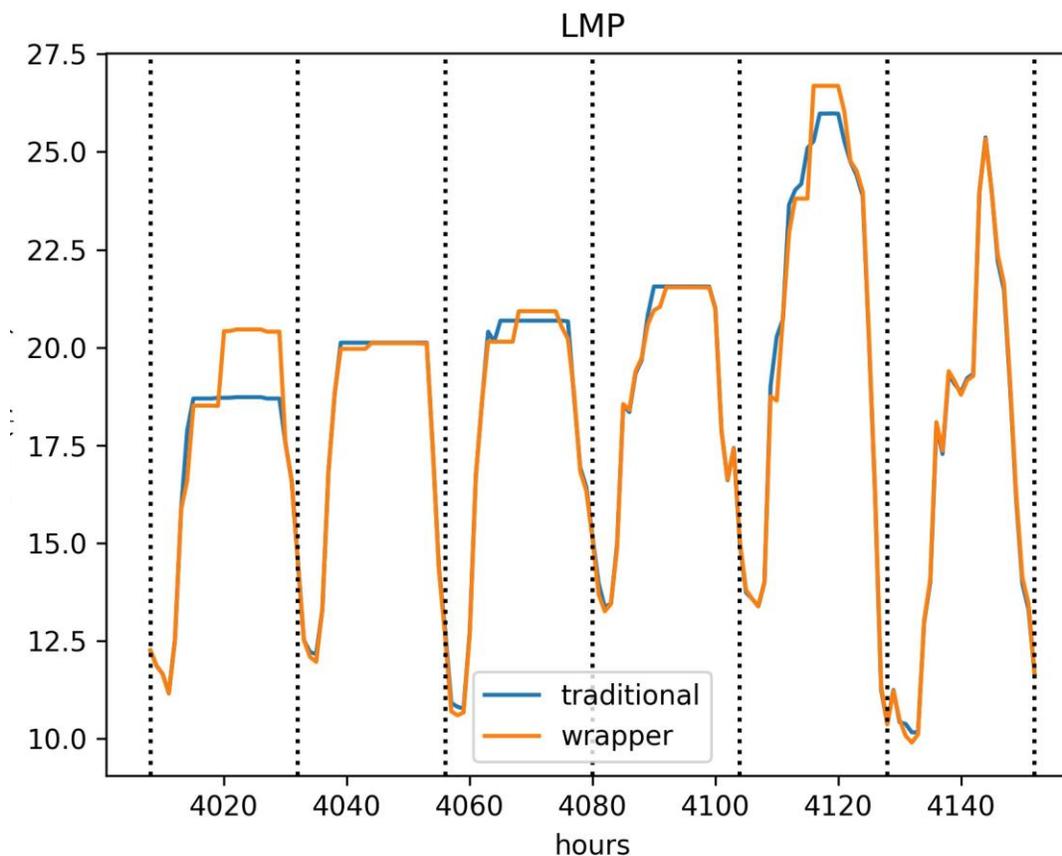
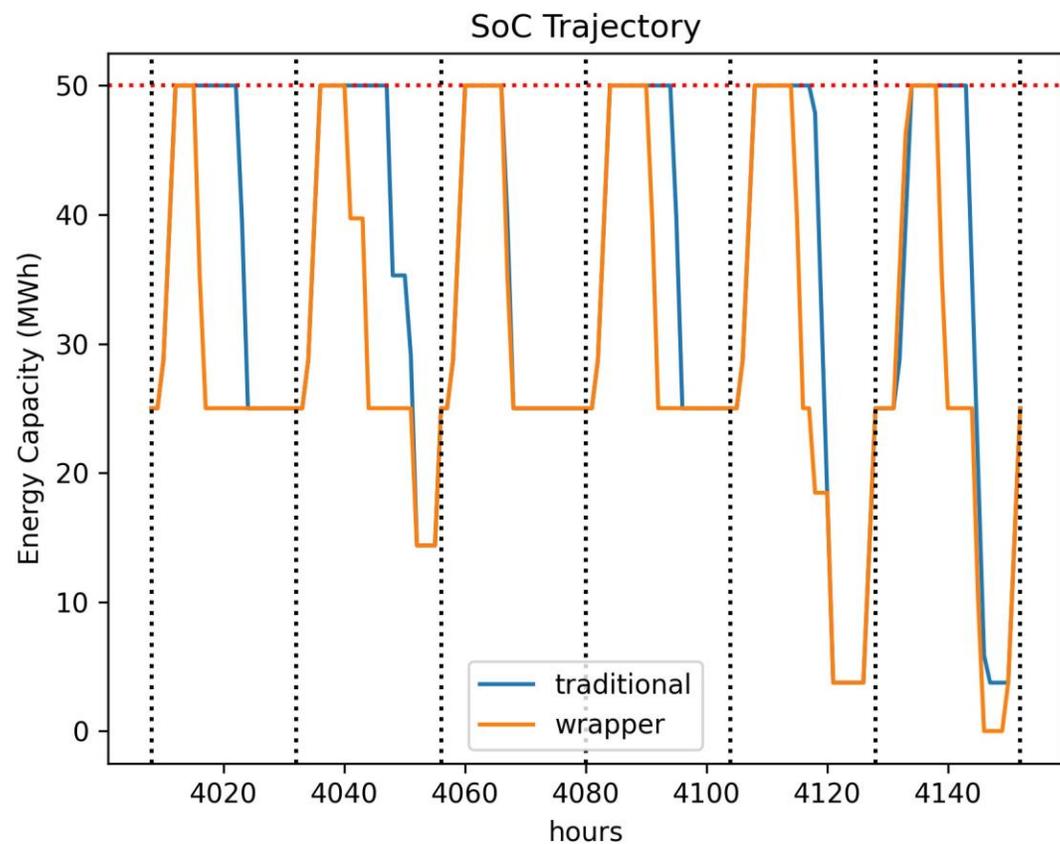


MIP Gap used in the simulations was 0.01%

SoC Constraint Formulation results in **increased** economic efficiency

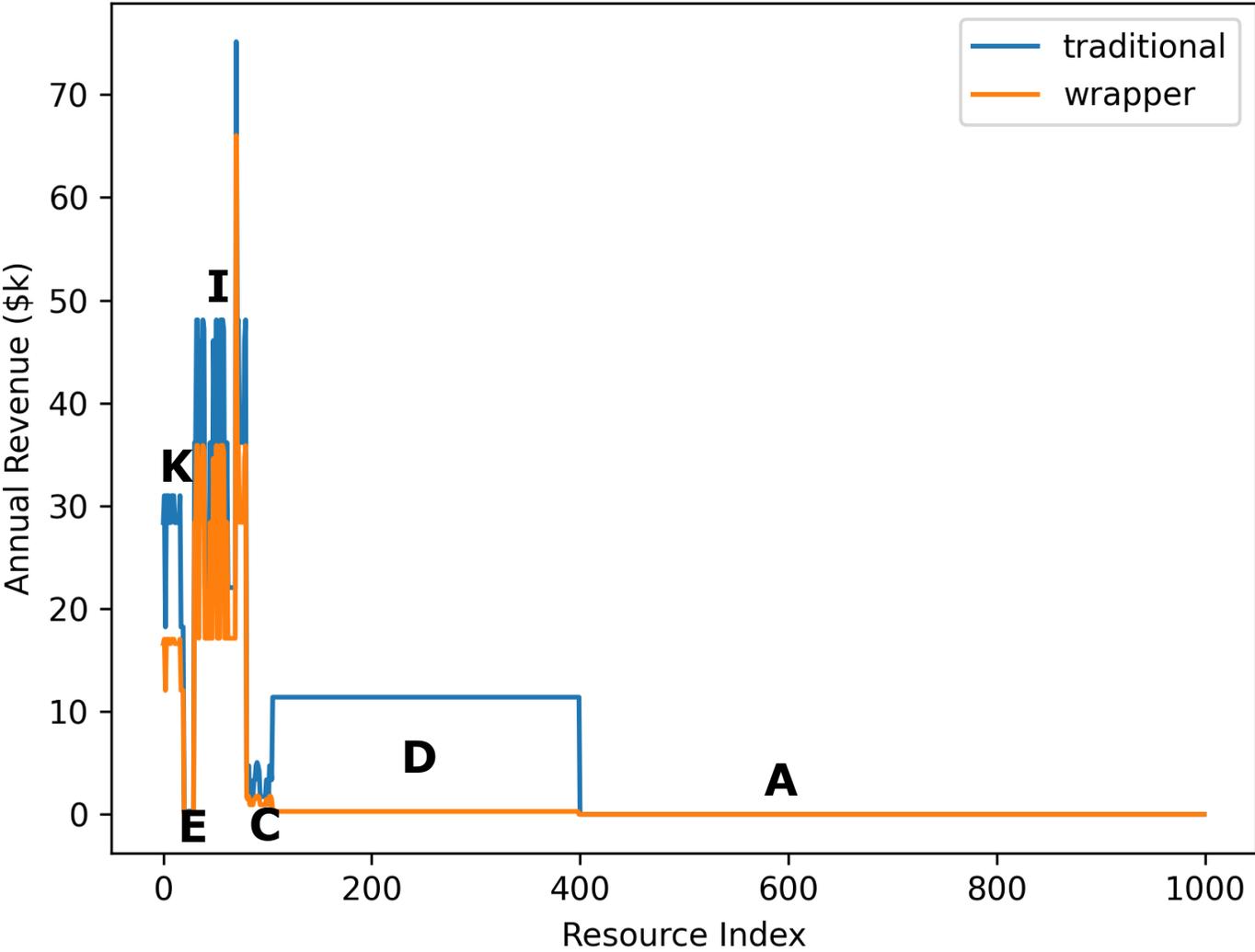
SoC Trajectory and LMP

- ESR specs: 50 MWh, 12.5 MW, 0.85 charging/discharging efficiency



Wrapper Energy Constraint Formulation has **lesser** ESR utilization

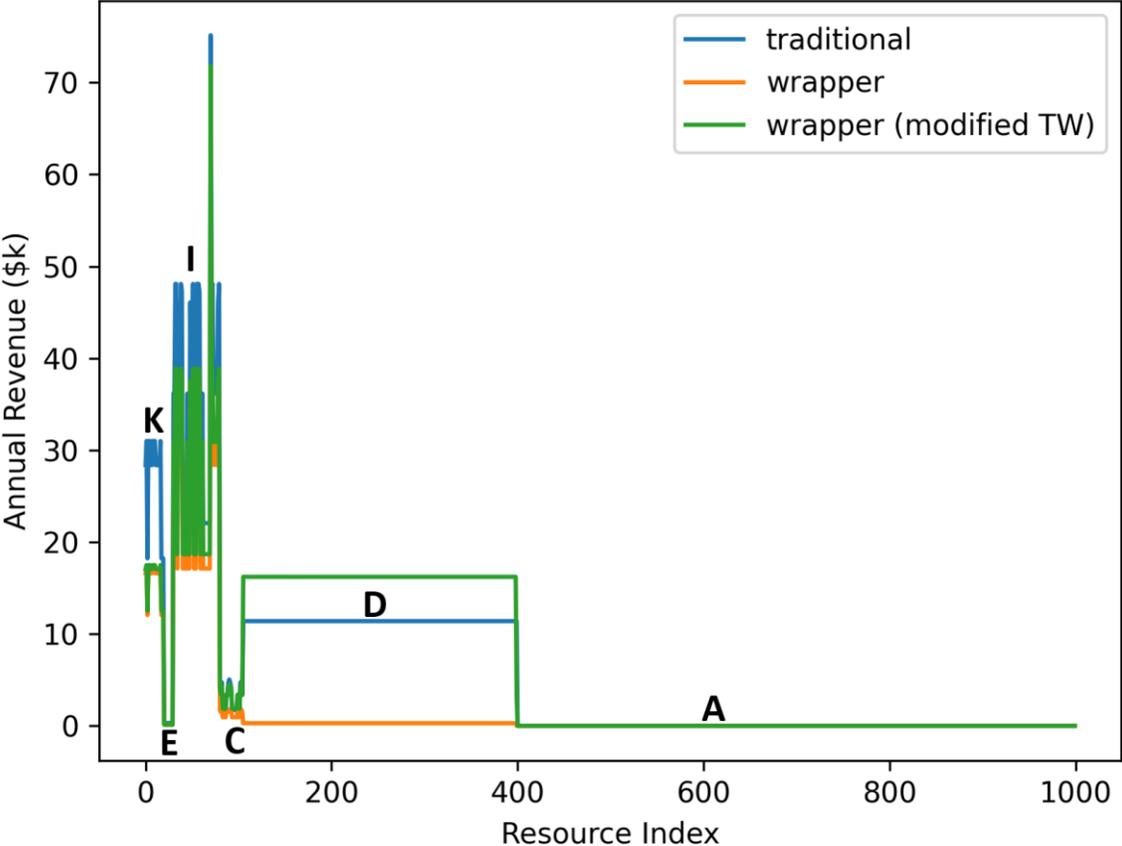
Resource Revenue (year)



Wrapper Energy Constraint Formulation leads to **lower** resource revenue

Different TW for Area D resources

- Modified TW duration for Area-D resources: 24-hour



METRIC (AVG)	SOC	WRAPPER	WRAPPER MODIFIED TW
Objective (\$m)	15.33	15.39	15.36
Comp. Time (sec)	18.84	13.90	13.61

- Annual Cost
 - SoC Constraints: 5,581M
 - Wrapper Constraints: 5,591.98M
 - Difference of ~11M

Wrapper Energy Constraint Formulation can benefit from a better understanding of market conditions, forecasts and risk tolerance.

Other Variants and Future Directions

Planning Problems

- Capacity expansion studies require less accuracy for short-term operation but often multiple scenarios

Assess Influence of Different Parameters within the Alternate Formulation

- Modified time window duration
- Use of dynamic schedules
- Role of resource mix
- Prior system knowledge or forecasts can help drive the heuristics
- Streamlining and automation of parameter selection

Extension of Alternate Formulation

- Ancillary services provision
- Real-time dispatch problem
- Hybrid storage resources

A blue-tinted photograph of four people standing in a row. From left to right: a man with curly hair and glasses wearing a white lab coat; a man with glasses wearing a white lab coat; a woman wearing a white hard hat and a dark polo shirt; and a man with glasses and a beard wearing a light-colored button-down shirt. The text 'Together...Shaping the Future of Energy®' is overlaid in white in the center.

Together...Shaping the Future of Energy®