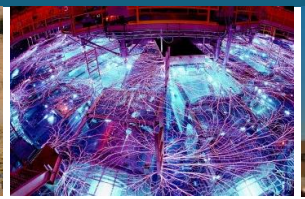
Valuation of Energy Storage in the US Electricity and Frequency Regulation Markets

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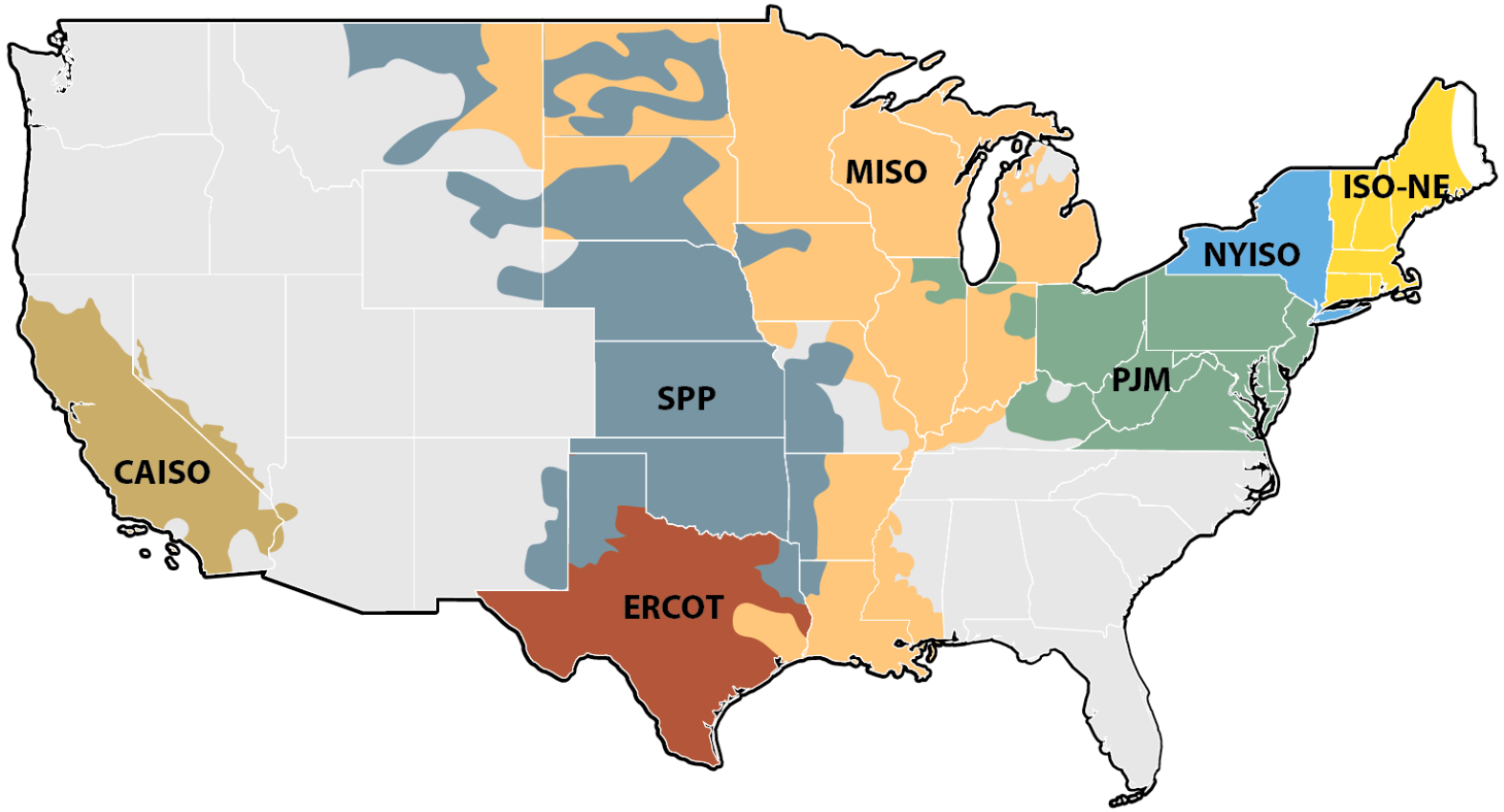
The US Electricity Markets

- Around 60% of the US electric power supply is managed through competitive markets
- There are seven different market regions in the US
- Except for ERCOT, following FERC ORDER 755, the frequency regulation market in other areas is pay for performance



Introduction and Motivation

- From an economic perspective, in a market area an energy storage system (ESS) is only as valuable as the revenue stream its able to generate
- Important to determine how ESS can generate revenue in the different US market areas
- **Main Objective** - determine how ESS systems can generate revenue from:
  - Arbitrage (participation in the electricity market)
  - Providing frequency regulation (a key ancillary services)
- Other Objectives:
  - Identify differences in revenue from the different US markets
  - Identify temporal trends and determine if they are common across the markets
  - Identify differences in *sensitivities* of revenue with respect to the different ES parameters for all the seven markets

Introduction and Motivation

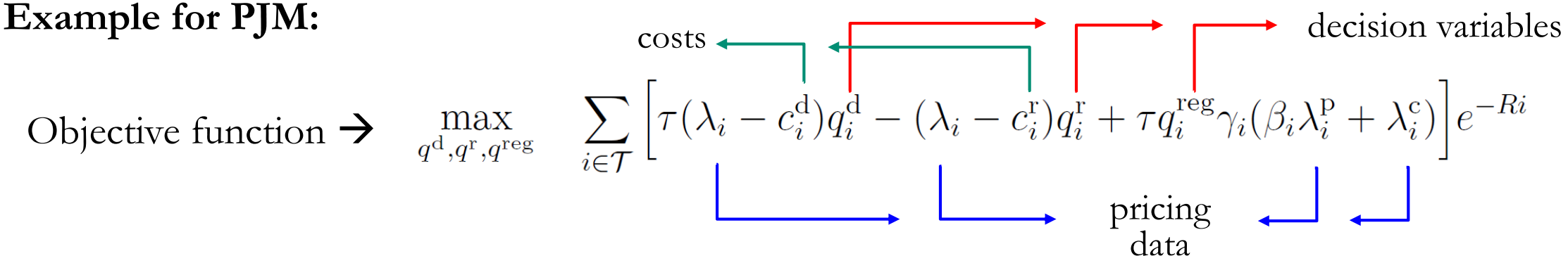
How did this project meet the DOE OE's Energy Storage mission?

- Performing this research lowers barriers to energy storage deployments which helps ensure a resilient, reliable and flexible electricity system. The research in this project identifies opportunities for energy storage and provides open source valuation tools to the energy storage community

Valuation of Energy Storage in the US Markets

- First step: download pricing data and market operation information for all the US markets
- Revenue maximization formulated as an optimization problem

Example for PJM:



Assumptions:

- Prices are known in advance (perfect forecast)
- Day-ahead market

- Results are hence a best scenario calculation but they are important because they provide an upper bound (which can be used to score more realistic trading strategies)

Valuation of Energy Storage in the US Markets

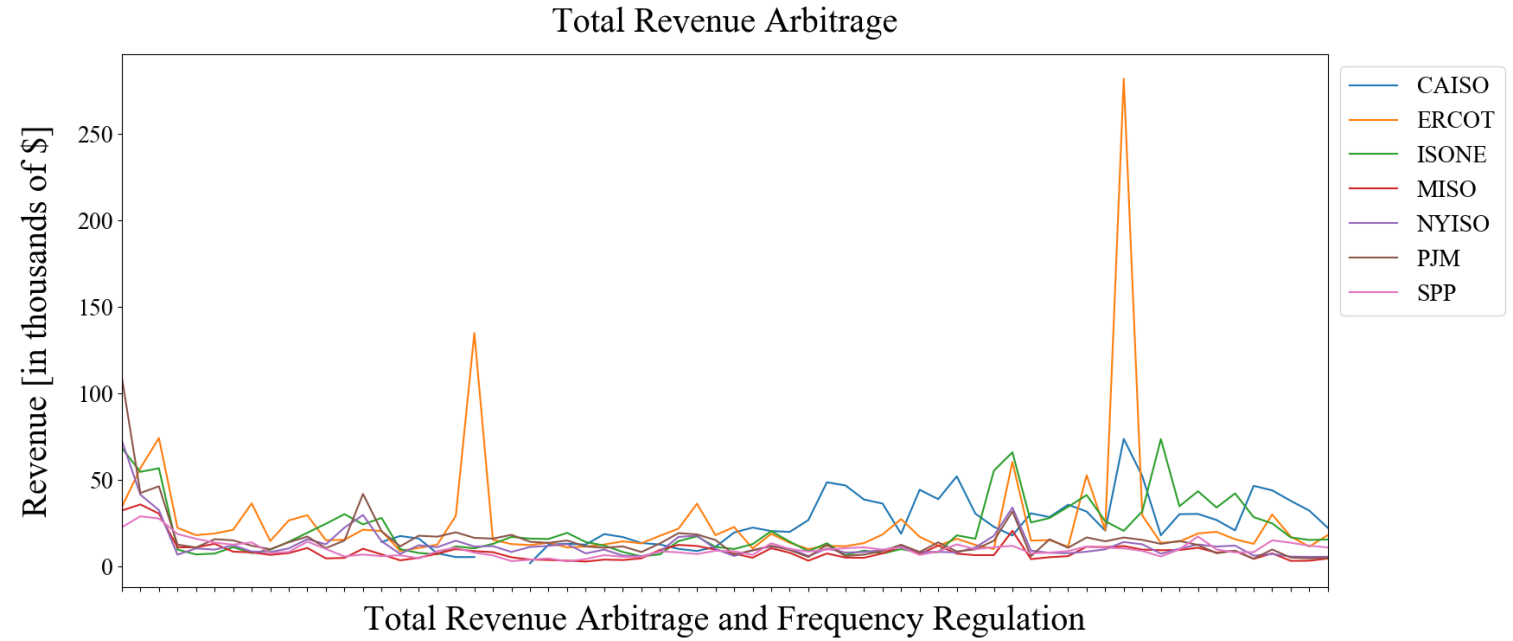
Perform an analysis of revenue maximization for all US markets

- Time interval of analysis: January 2014 to June 2019 (5 and a half years). Analysis was done on a monthly basis (hourly resolution of data –day ahead market-)
- Used an "average" (or representative node) for the electricity prices for each market.
- Regulation prices tend to be area-wide so no "average" node was needed
- The same parameters for the energy storage device were used

Parameter	value
Energy Capacity	20MWh
Power Rating	20MW
Self-discharge Efficiency	0.98
Round Trip Efficiency	0.95

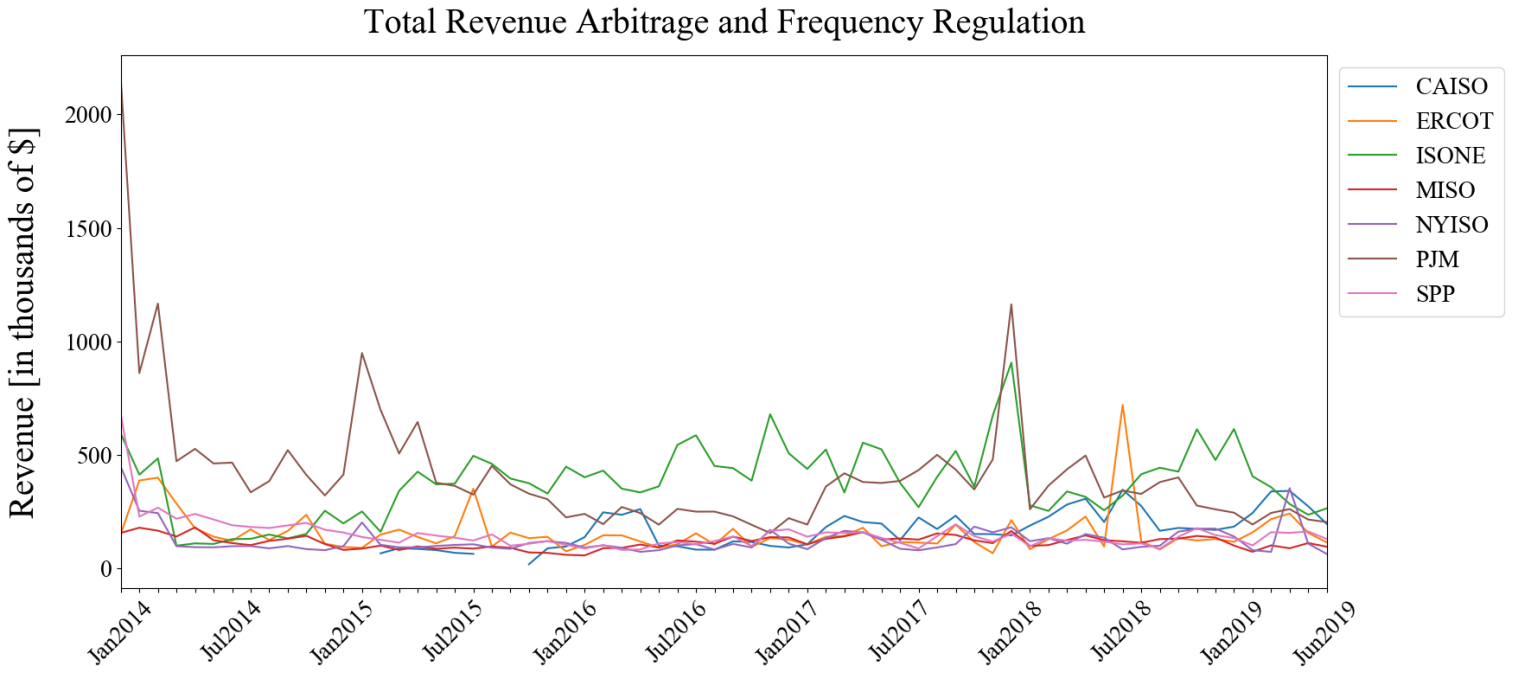
- In addition, the performance score is set to 0.95

Revenue of Energy Storage in the US Markets



For Arbitrage

- ERCOT is prone to spikes (due to spikes in prices)
- CAISO and ISO-NE generate more revenue than other markets since 2017



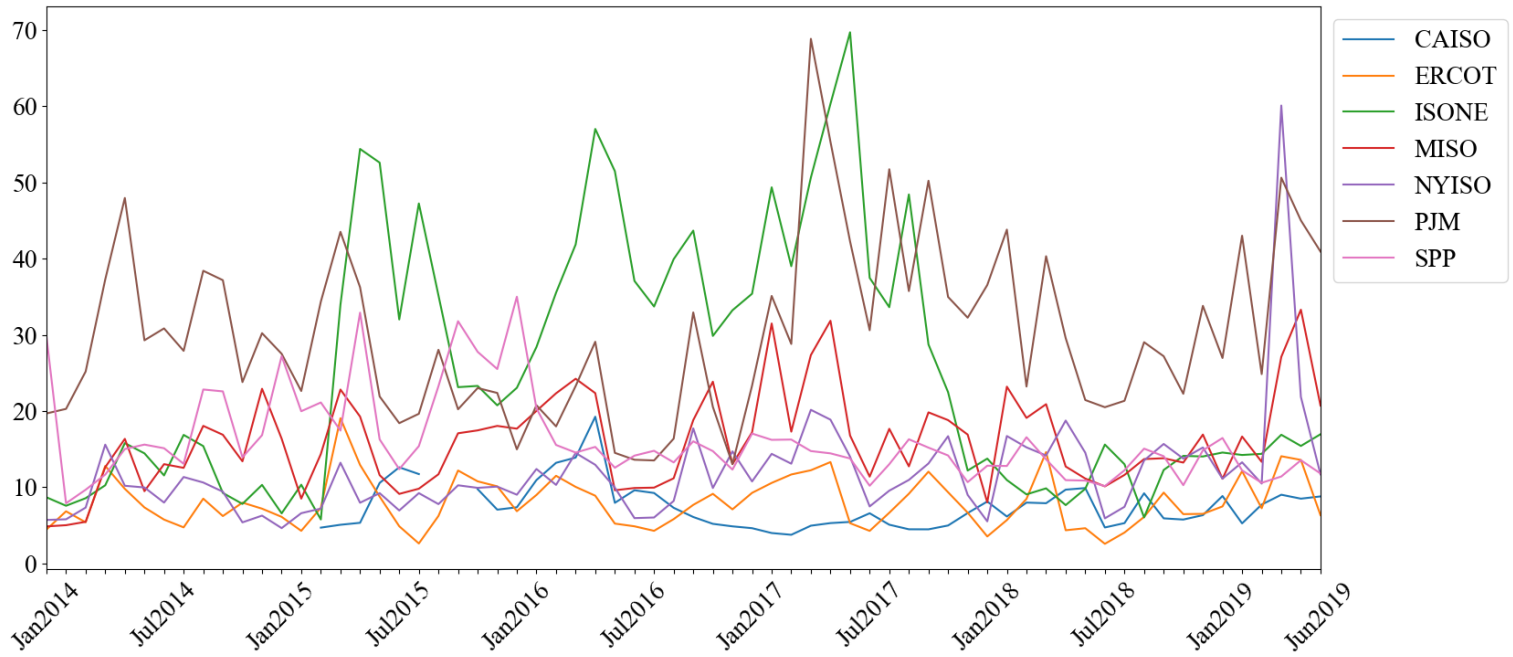
For Arbitrage and Freq. Regulation

- PJM and ISO NE are the markets that generate more revenue

Revenue of Energy Storage in the US Markets

- Revenue ratio: the ratio of revenue generated from arbitrage and arbitrage plus frequency regulation.
- Consistently, for all the markets and for all the time period considered, arbitrage + freq. regulation generates more revenue than arbitrage only. ISO-NE and PJM are the markets that present higher ratios while CAISO present the lowest ratios

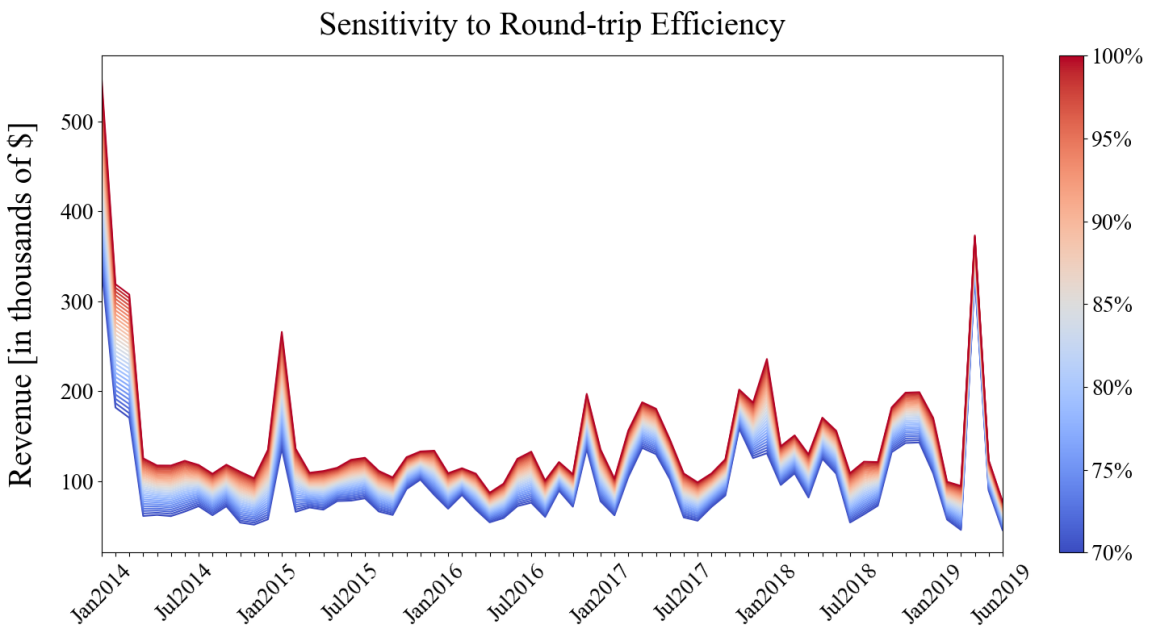
Ratio of arbitrage+freq. reg to arbitrage only



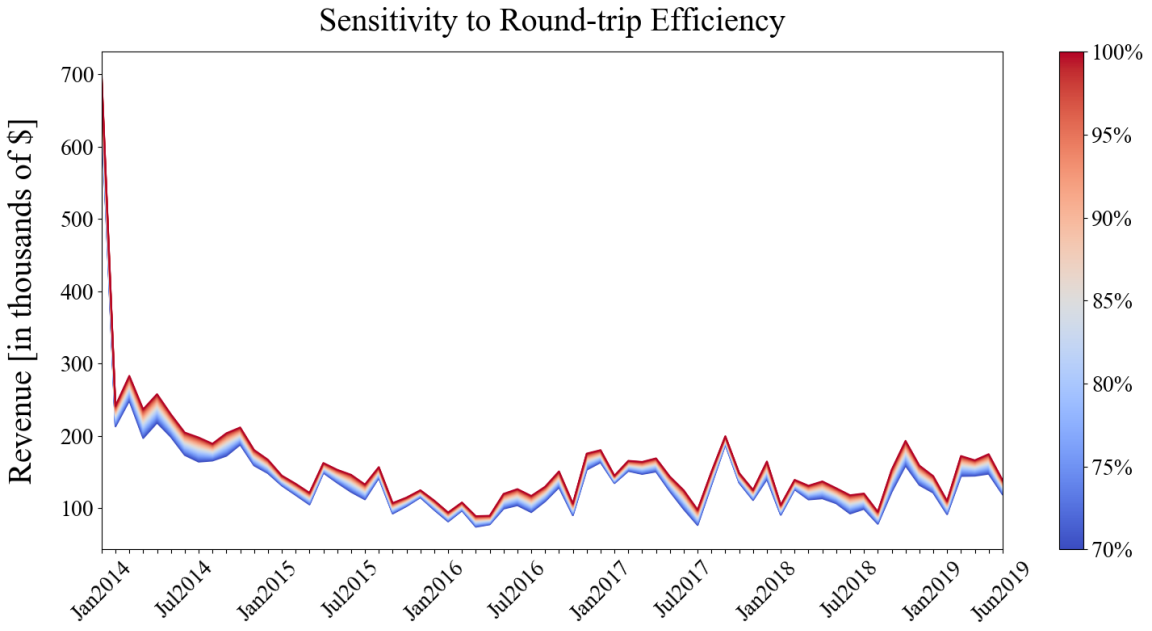
How Sensitive are the Results?

- For every market the sensitivity of the results to the parameters of the energy storage device was computed
- For example, the NYISO and SPP sensitivities to the round-trip efficiency parameters are shown below:

NYISO



SPP

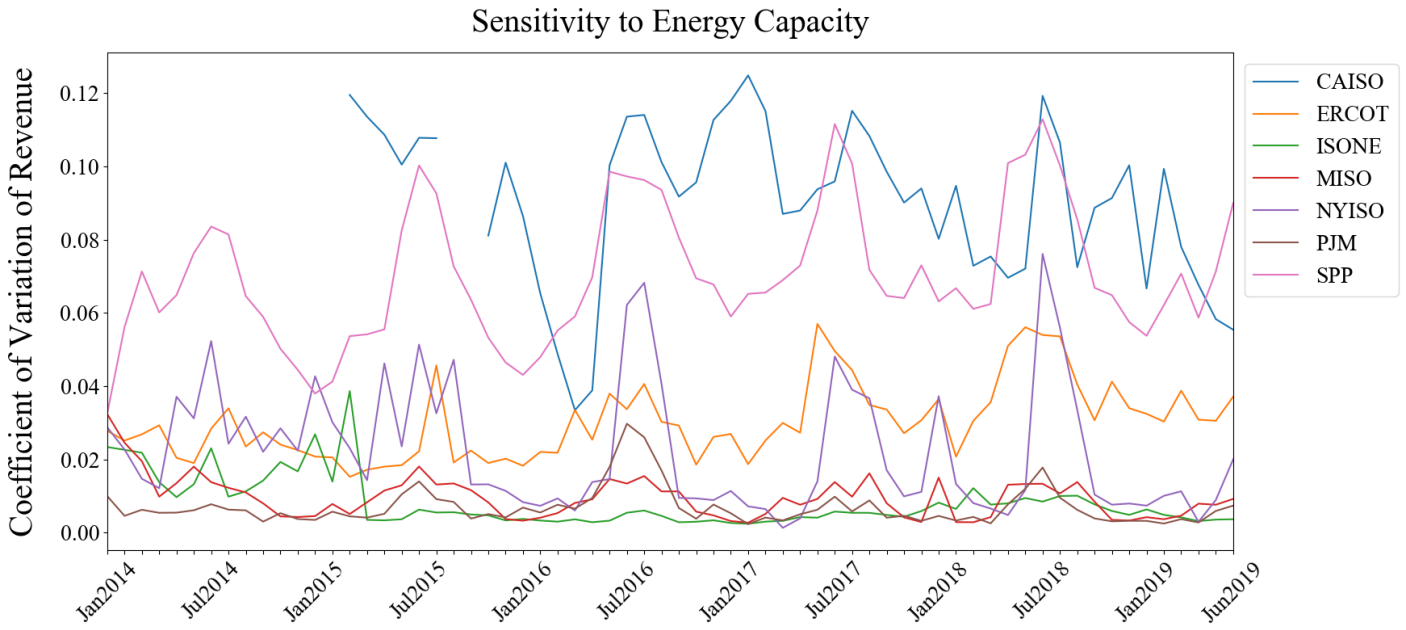


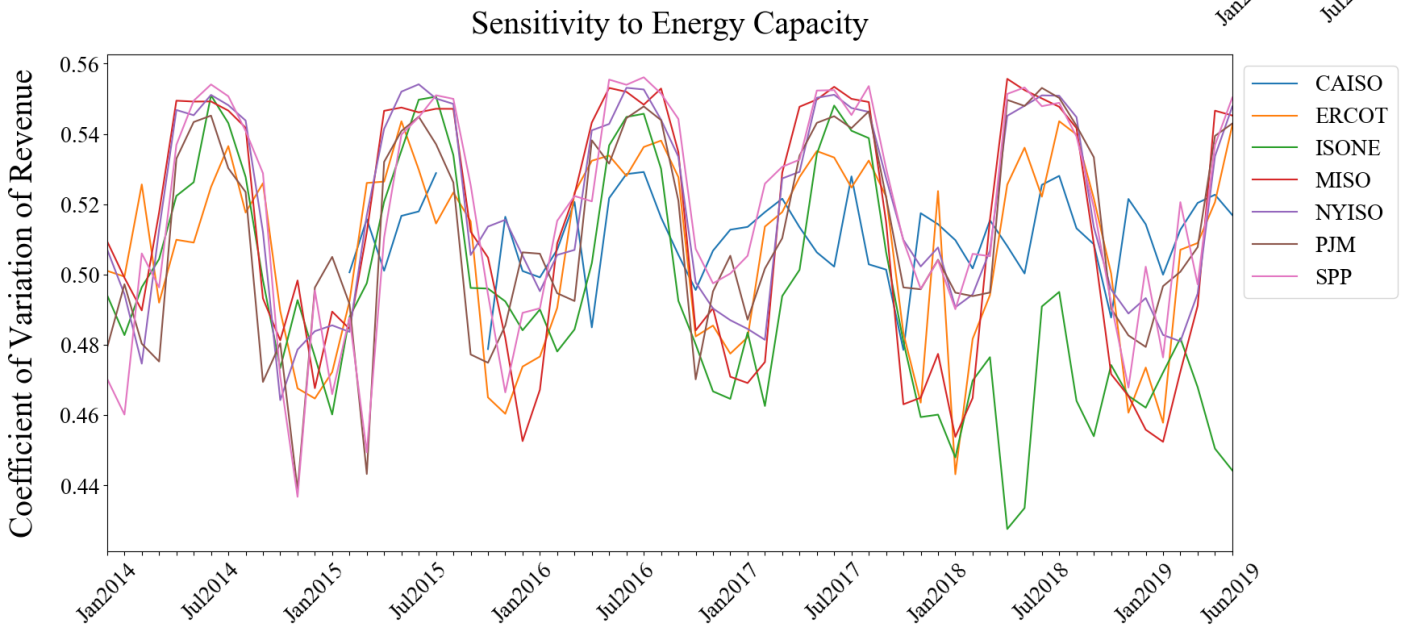
Coefficient of Variation → $\text{coef. variation} = \frac{\text{std}}{\text{mean}}$

Example for Energy Capacity

For arbitrage and frequency regulation: →

- CAISO and SPP are <u>more</u> sensitive to energy capacity





← For arbitrage only

- Arbitrage is <u>more</u> sensitive to energy capacity than arbitrage + freq. regulation
- It also has **seasonality** with summer months showing more variation

Accomplishments

- The overall project has published over10 papers with the formulation on revenue maximization for every market
- About to submit a journal publication consolidating all the results
- The formulations advances in this work form the basis of the valuation application of the QuESt Tool

Conclusions and Future Work

- The revenue maximization formulation for all the US electricity markets is available as part of the QuESt suite (is open source)
- Consistently frequency regulation generates more revenue than arbitrage for all the markets and during all the period of time analyzed
- Analyzed how sensitive is the revenue generated with respect to different parameters of energy storage systems

- Future work:
  - Include more detailed models for the energy storage system to take into account degradation
  - Include formulation for real-time market
  - Include other revenue streams such as the other ancillary services products (e.g., spinning reserves and voltage support)

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Thank You!

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Questions?