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Managing imbalance risk in DA electricity markets

Simulations with Flexibility Options vs. Imbalance Reserves

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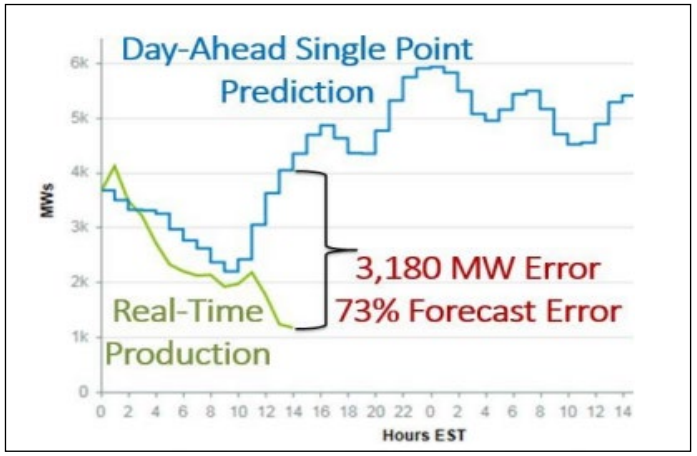
- Team:
  - National Renewable Energy Laboratory: M. Blonsky, M. Cai
  - Johns Hopkins University: B.F. Hobbs, Q. Zhang, S. Tyagi
  - Electric Power Research Institute: I. Krad, R. B. Hytowitz, L. Li

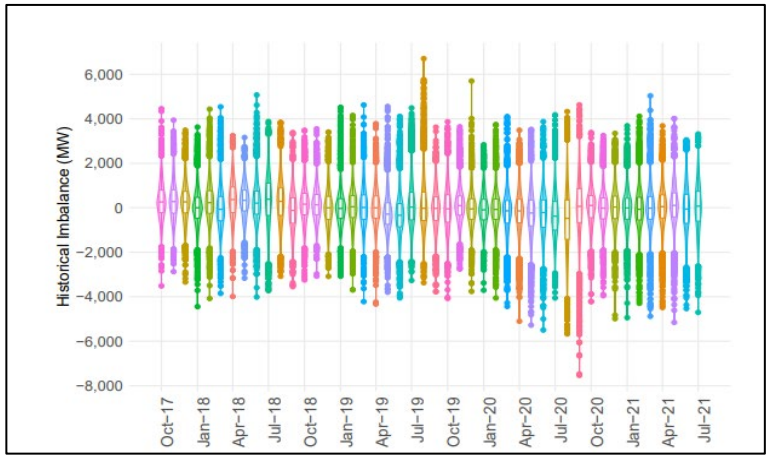
System operators *and flexible resources* must manage challenging imbalances

Net Load = Load – Variable Renewable Generation

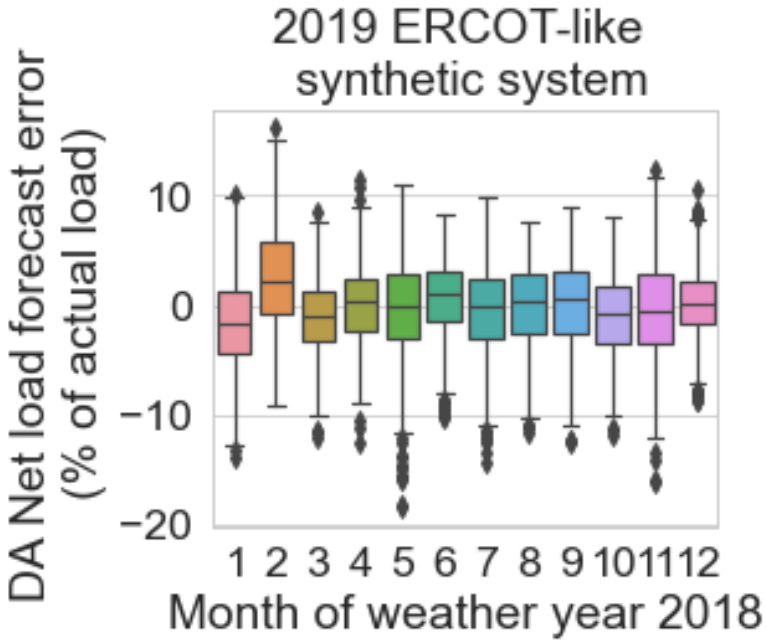
Net Load Imbalance = **Actual** Net Load – Day-ahead Net Load **Schedule**



MISO day-ahead renewable forecast versus real-time production, 6/26/19



CAISO historical net load imbalances mostly within 4 GW range



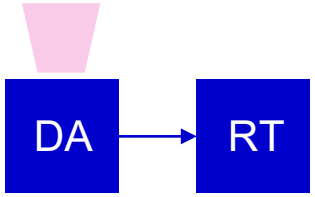
ERCOT-like test system day-ahead net load forecast errors

Source: ARPA-E Performance-based Energy Resource Feedback, Optimization, And Risk Management (PERFORM) FOA; CAISO Day-Ahead Market Enhancements Third Revised Straw Proposal (Apr. 2022); CAISO Energy Markets Price Performance Report (Sep. 2019); ARPA-E PERFORM Forecast Dataset (https://registry.opendata.aws/arpa-e-perform), ORFEUS-PERFORM Data Plan (https://electricgrids.engr.tamu.edu/orfeus-perform-data-plan/)

Rich spectrum of solutions to manage imbalance risk

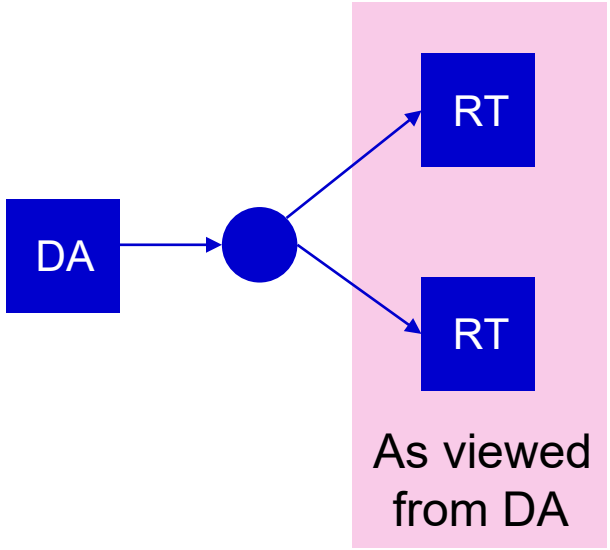
Modifying market inputs [1,2]

Modified input
(e.g., bias forecast)



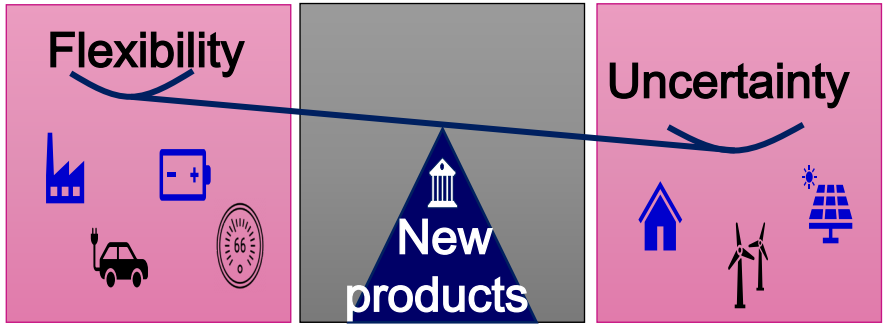
(+) easy to implement
(-) lacks flexibility price signal
(-) no physical flexibility
explicitly scheduled

Stochastic unit commitment [3,4]



(+) theoretically optimal
(-) curse of dimensionality
(-) challenging price formation

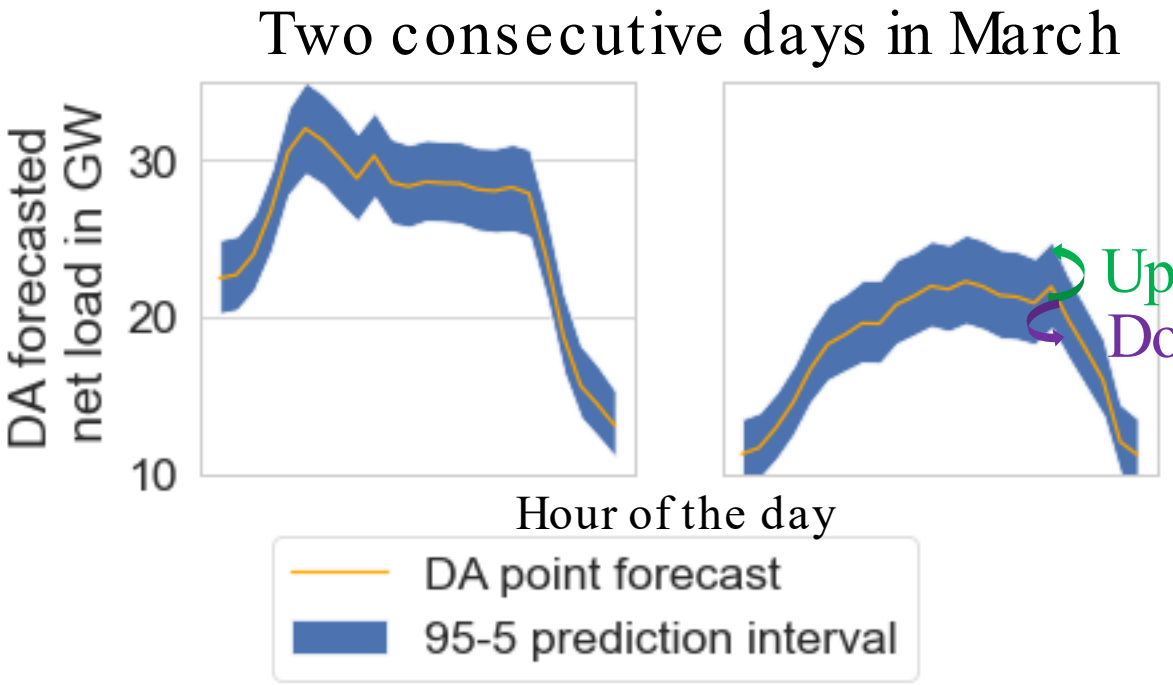
Hedging instruments & Dynamic reserve products [5-7]

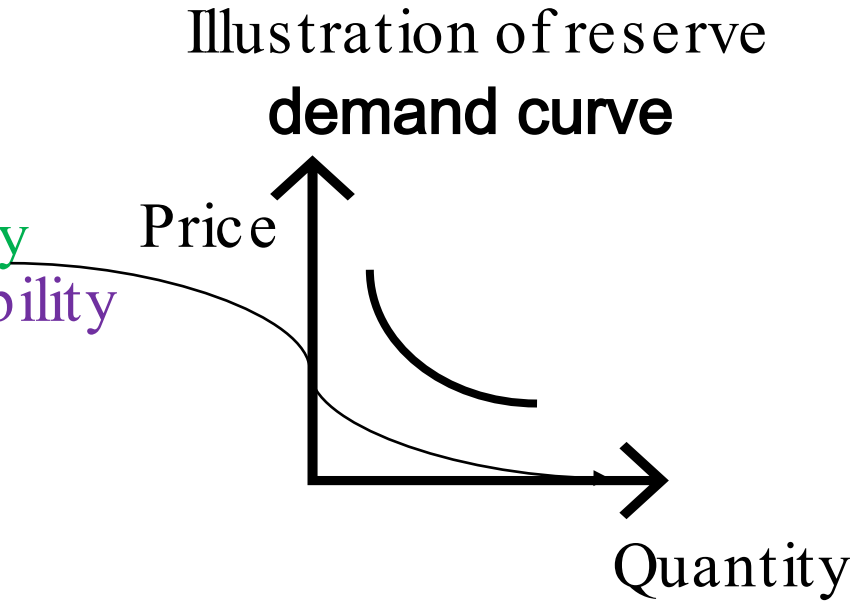


(+) flexibility price signal
(-) challenging estimation of demand curve

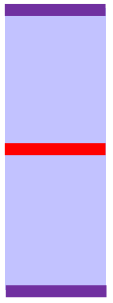
[1] J. M. Morales, M. Zugno, et al., "Electricity market clearing with improved scheduling of stochastic production," Eur. J. Oper. Res., vol. 235, no. 3, pp. 765–774, 2014. [2] J. Bushnell, S. M. Harvey, and B. F. Hobbs., "Opinion on Energy Imbalance Market (EIM) resource sufficiency evaluation enhancements, Phase 2," Market Surveillance Committee of the California ISO, Revised Draft, October 23, 2022. [3] A. Papavasiliou and S. Oren, "Multiarea stochastic unit commitment for high wind penetration in a transmission constrained network," Oper. Res., vol. 61, no. 3, pp. 578–592, 2013. [4] J. Kazempour, P. Pinson, and B. F. Hobbs, "A stochastic market design with revenue adequacy and cost recovery by scenario: Benefits and costs," IEEE Trans. Power Syst., vol. 33, no. 4, pp. 3531–3545, 2018. [5] FERC Staff Paper, "Energy and ancillary services market reforms to address changing system needs," Federal Energy Regulatory Commission (FERC), Docket NO. AD21-10- 000, 2021. [6] California Independent System Operator, "Day-ahead Market Enhancements," Revised Final Proposal, May 2023. [7] C. Johnathon, A. P. Agalgaonkar, C. Planiden, and J. Kennedy, "A proposed hedge-based energy market model to manage renewable intermittency," Renewable Energy, vol. 207, pp. 376–384, 2023.

Dynamic reserve products





Suppliers of dynamic reserves



DA energy + upward reserve

DA energy

DA energy - downward reserve

Questions:

(1) How do alternative designs encourage cost-effective procurement of flexibility?

(2) Who will pay for the reserve procurement costs?

Data for ERCOT-like 2019 synthetic system from ORFEUS-PERFORM Data Plan (https://electricgrids.engr.tamu.edu/orfeus-perform-data-plan/)

Dynamic reserve for imbalances

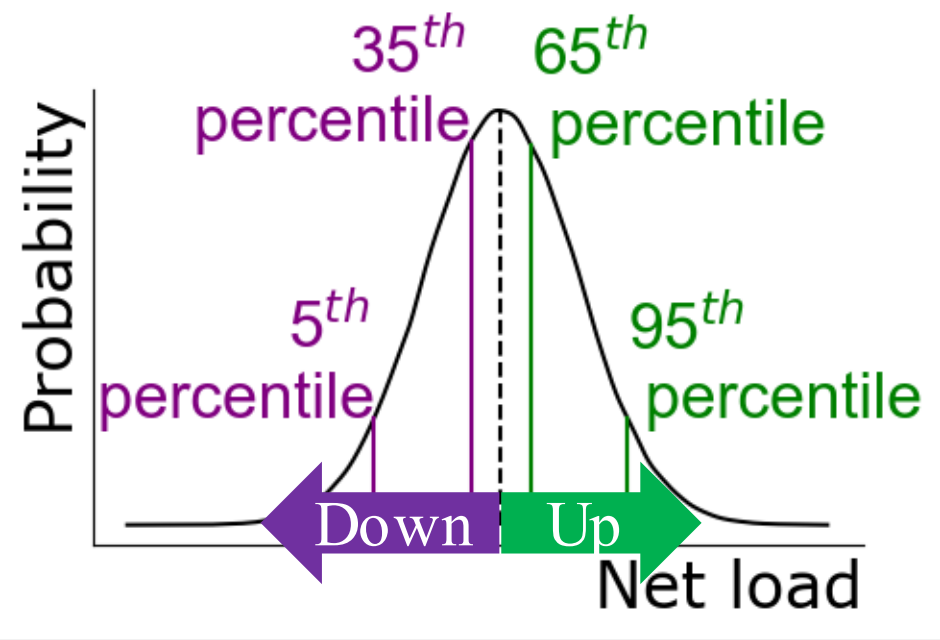
Our implementation of novel ISO products in simulations

IMBALANCE RESERVES (IR): reserve product under implementation at CAISO

PROACTIVE: co-optimized DA

Day-ahead

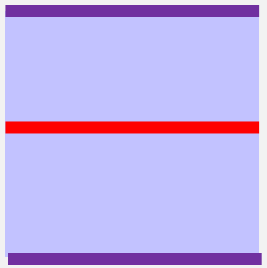
ISO determines the **DEMAND**



Scarcity prices* ($/MW)	8	55	1.2k	250

Real-time

IR Seller



DA energy schedule +IR up

DA energy schedule

DA energy schedule -IR down

RT availability ensured via

- day-ahead reserve price
- real-time must-offer bid range

Participants with RT-DA imbalances **pay** for reserve procurement cost

*Values have been updated in latest CAISO proposal

Flexibility Options: Summary of our proposed product design

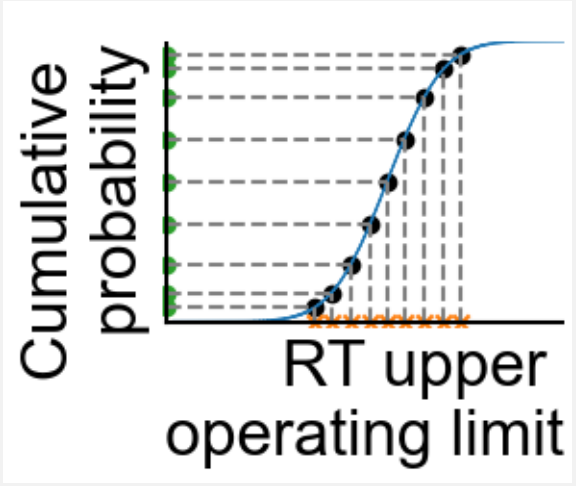
FLEXIBILITY OPTIONS: proposed dual-trigger option for DA market

PROACTIVE: co-optimized DA & objective incl. probability-weighted deployment cost

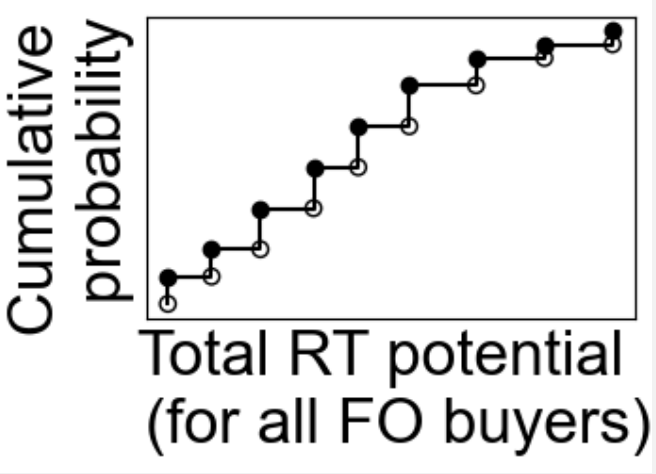
Day-ahead

FO suppliers submit strike prices for ramp up/down (receive FO premium)

Each FO buyer submits trigger quantities (pays FO premium)



Endogenous **demand**



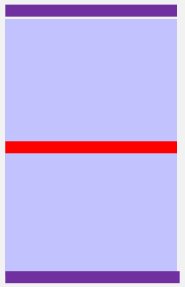
× Trigger quantities

● Probability of exercise (up)

Real-time

FO Buyer: receives FO payoff if two trigger conditions met e.g., for up options (1) $RT\ price > strike^{\uparrow}$ (2) buyer availability < trigger quantity

FO Seller pays



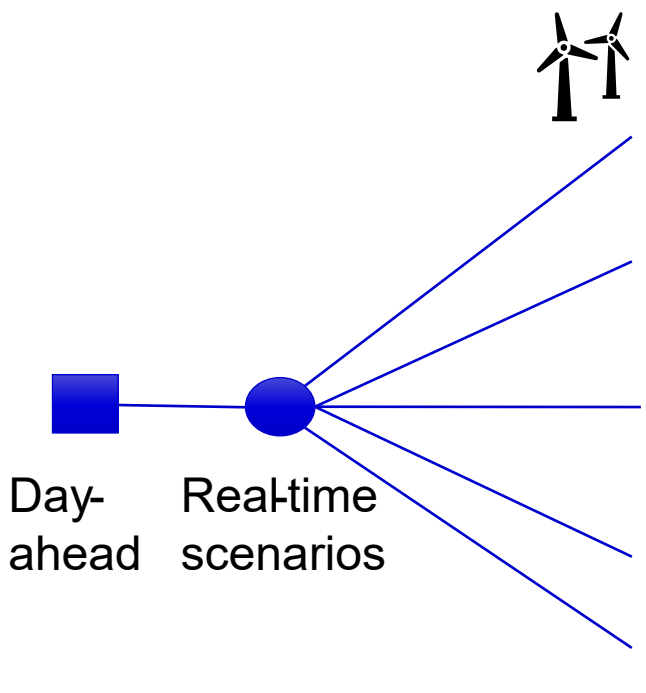
$\max(0, RT\ price - strike^{\uparrow})$

$\max(0, strike^{\downarrow} - RT\ price)$

AVAILABILITY ensured via DA option premium & RT price exposure

Simple 1-hour example

	ST1	CT2	CT3	CT4
Capacity (MW)	50	10	10	10
Cost ($/MWh)	20	35	50	60
Ramping (MW/h)				
Strike up/down prices ($/MWh)	Varying assumptions			



Electricity demand: 200 MWh
Simple because it
- Excludes "surprises": Uncertainty perfectly quantified and revealed by the FO buyer (wind)
- Single-hour: ramping from day-ahead schedule

✓Including FOs in the DA market is **equally or more effective** as inclusion of IRs because FO includes probability-weighted deployment cost in the DA objective.

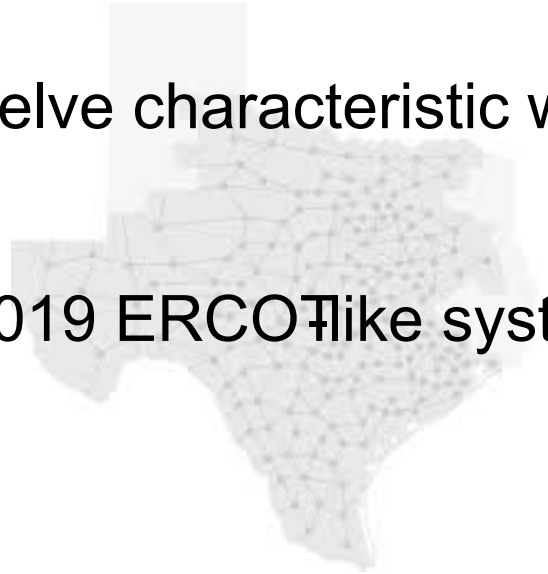
✓ With FOs, DART energy **prices converge** without adding a virtual bidder because wind acts as virtual bidder.

✓ With FOs, **revenue neutral** system operator

✓ With FOs, **less volatile** flexibility-related
- ✓ revenue for flexible participants
- ✓ payment for participants with imbalances

Testing the design in a realistic but not real system

Twelve characteristic weeks



2019 ERCOT-like system

FESTIV simulations

Day-ahead Unit Commitment

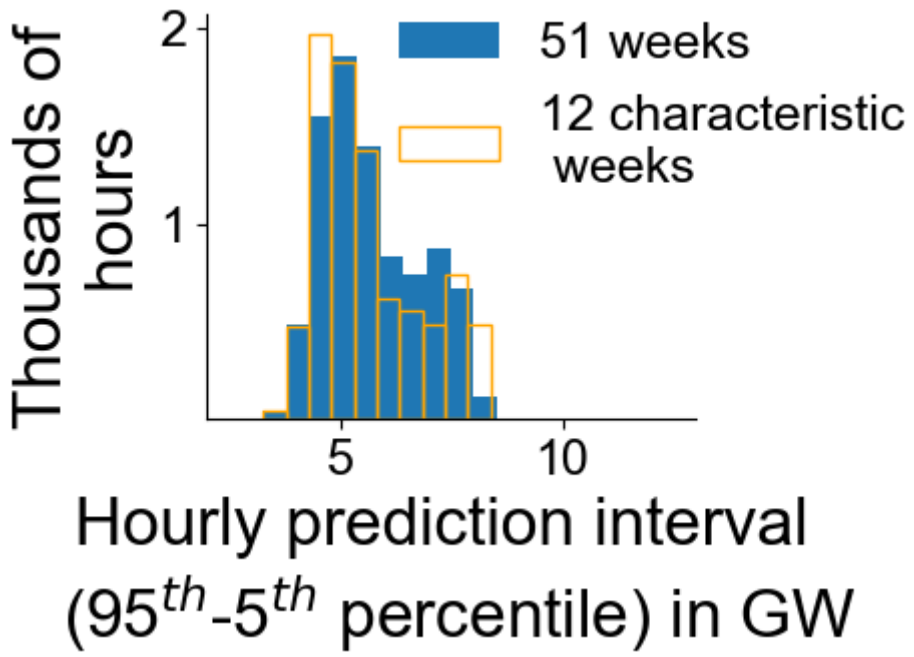
Hour-ahead Unit Commitment

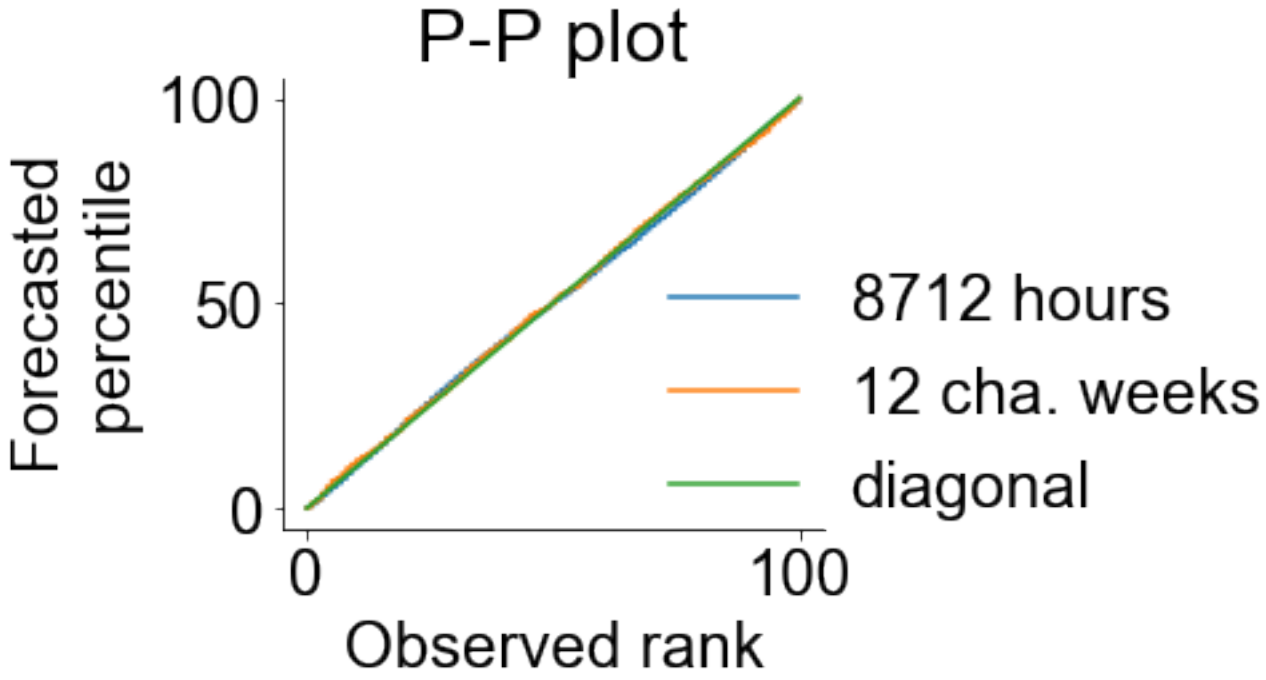
Minutes-ahead Economic Dispatch

FESTIV model: https://www.nrel.gov/grid/festiv-model.html
System data from https://electricgrids.engr.tamu.edu/electric-grid-test-cases/datasets-for-arpa-e-perform-program/;

Testing the design in a realistic but not real system: The forecasts

The probabilistic forecasts from ORFEUS PERFORM Data team appear well calibrated and relatively sharp.

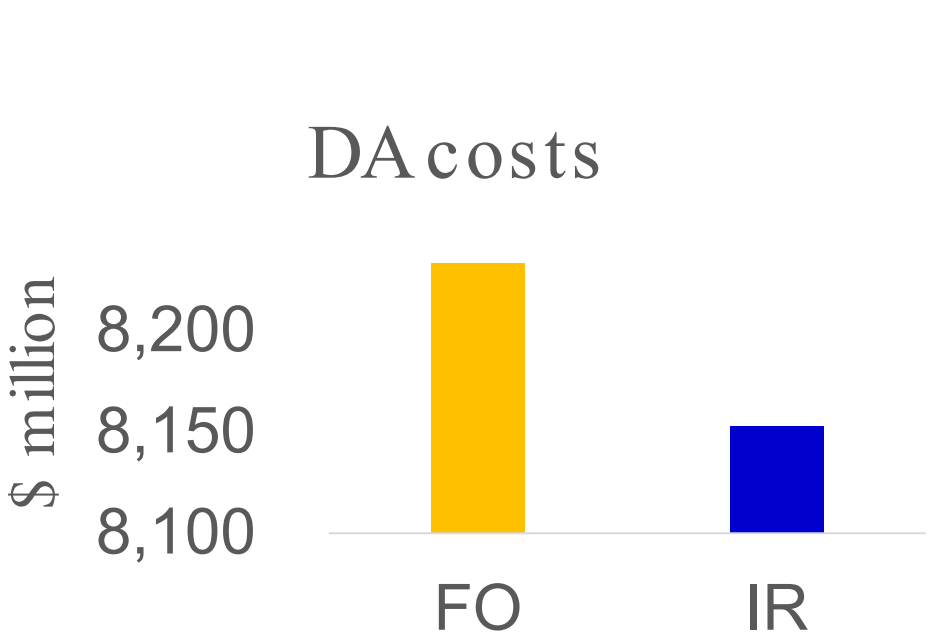


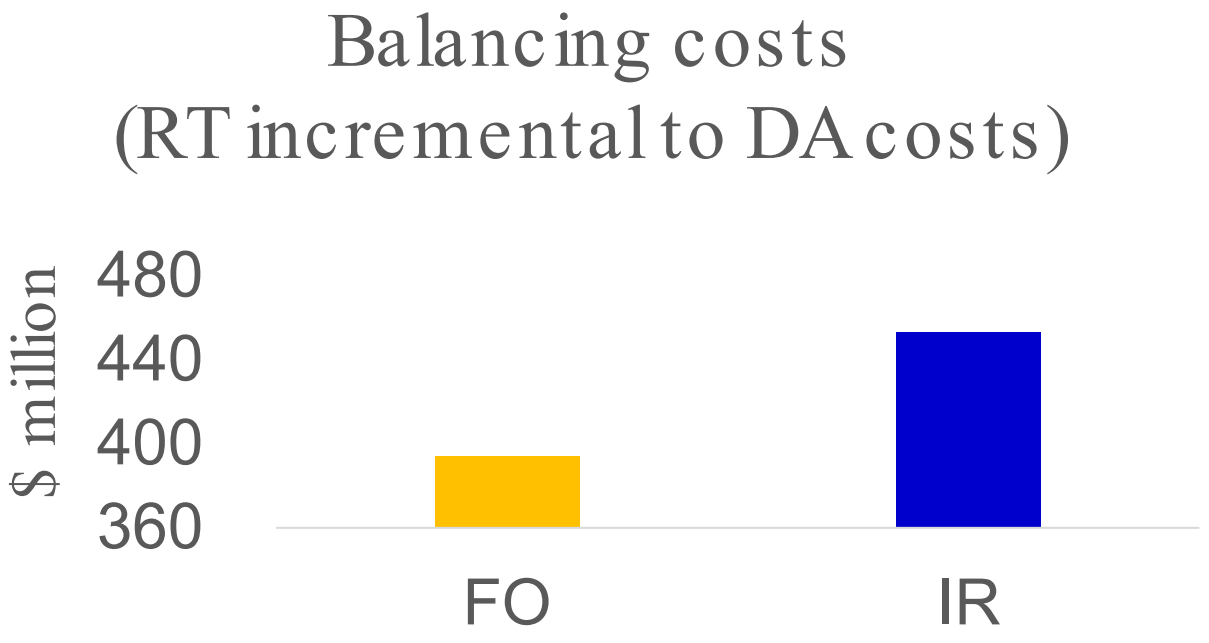


Probabilistic forecasts from https://electricgrids.engr.tamu.edu/orfeus-perform-data-plan/
Actual data from https://registry.opendata.aws/arpa-e-perform/; FESTIV model: https://www.nrel.gov/grid/festiv-model.html
System data from https://electricgrids.engr.tamu.edu/electric-grid-test-cases/datasets-for-arpa-e-perform-program/;

Both IR and FO effectively manage imbalances
Results over 12 characteristic weeks for 2019 ERCOT-like system

- FO and IR **equally effective** in managing imbalances, with system costs ~3% higher than system costs with perfect forecasts
- Different DA/RT cost composition: FO lower balancing costs, but higher DA costs vs IR





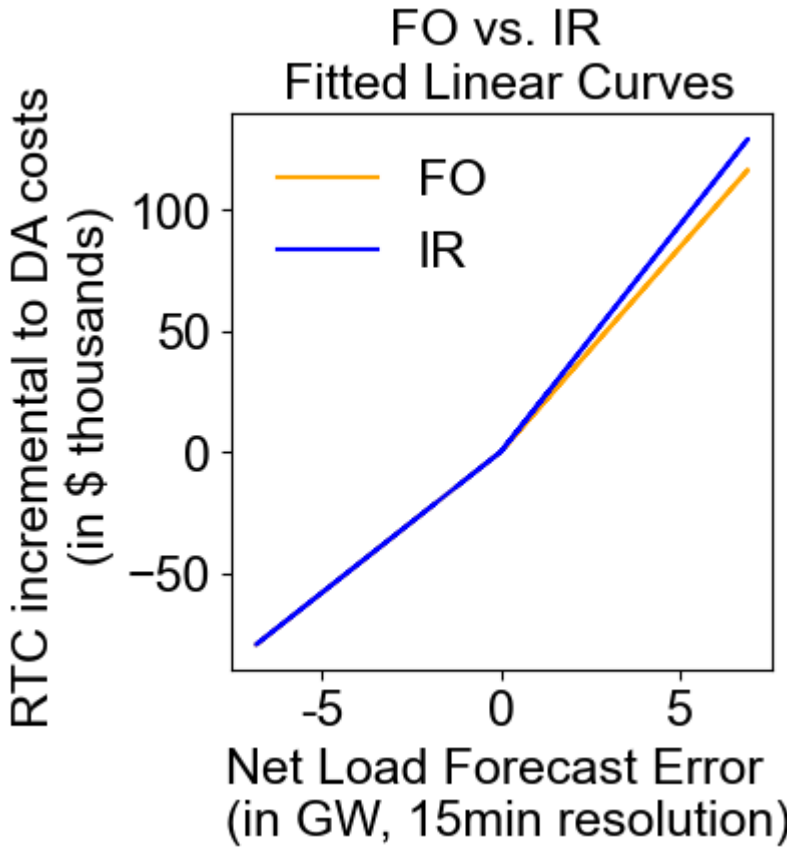
RT supply curves less steep in simulations with FOs vs IRs

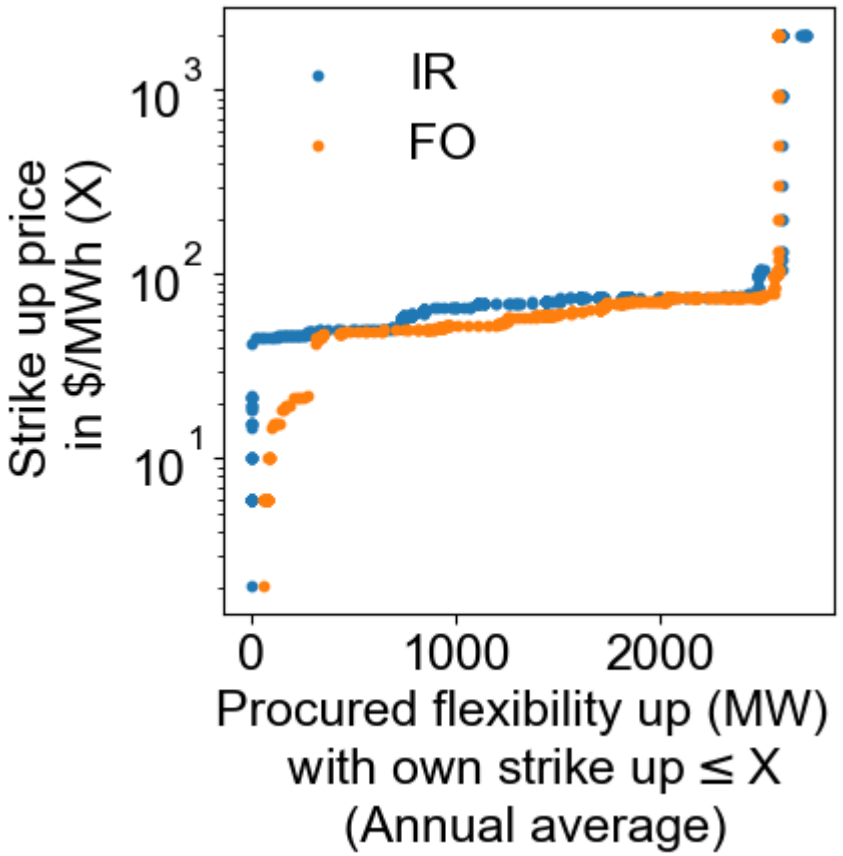
Results over 12 characteristic weeks for 2019 ERCOT-like system

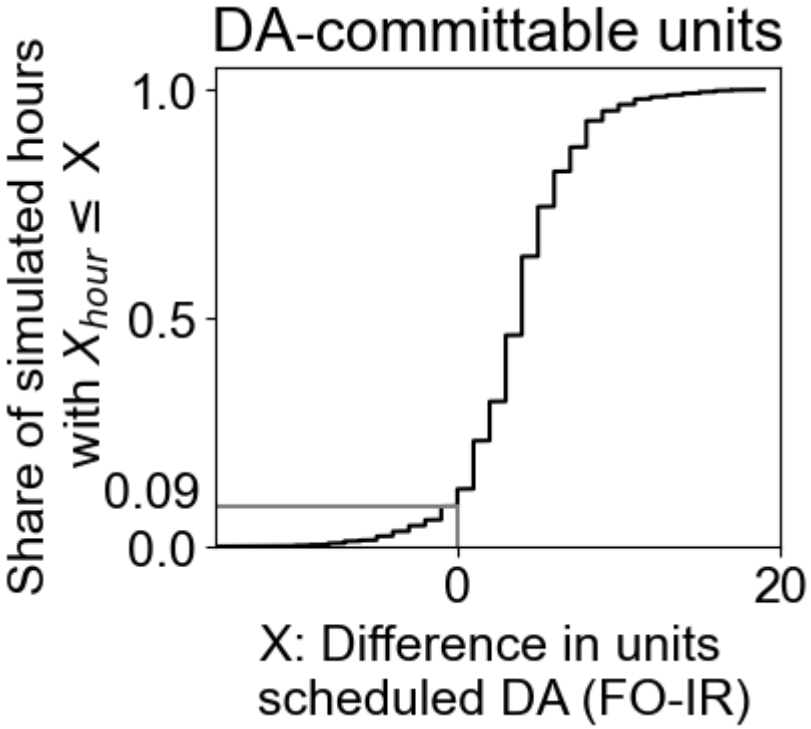
RT supply curve less steep in FO ...

… because DA flexibility scheduled accounting for deployment costs

… proactively relying in this case on more units that can only be committed DA



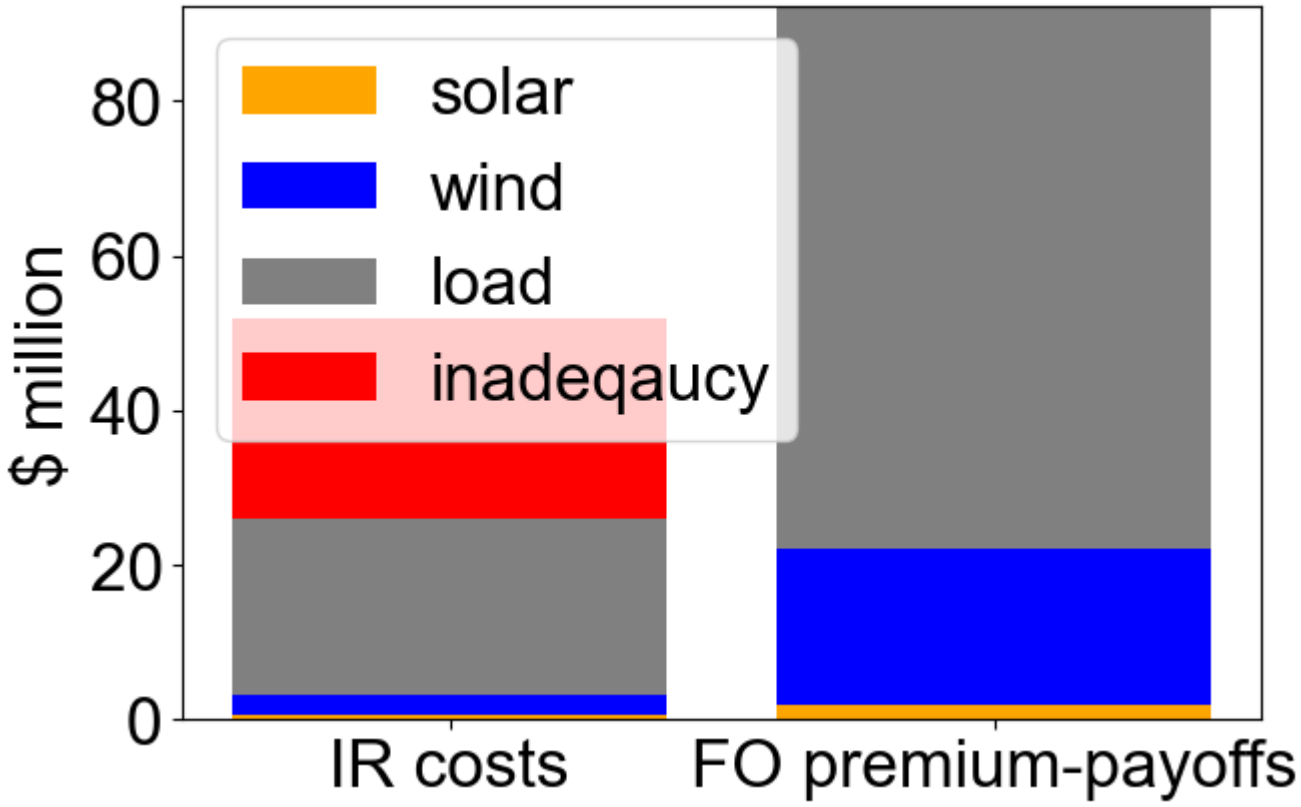




FO settlements follow cost-causation principles and keep ISO revenue neutral

Results over 12 characteristic weeks for 2019 ERCOT-like system

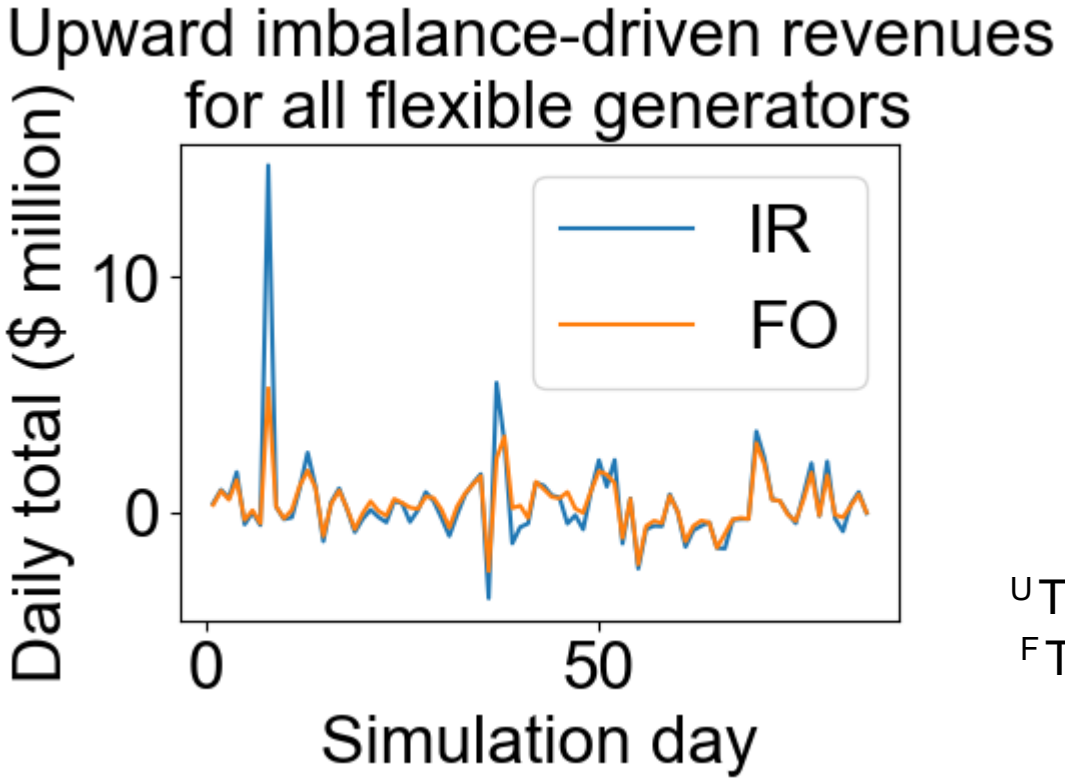
FO/IR-related payments by participants with imbalances under IR and FO simulations



- In this case, approximately 50% of the DA IR costs is socialized across all participants.
- Flexibility product-related costs distributed different among resources based on **anticipated** (FO) vs **realized** (IR) imbalances.

Imbalance-driven revenues to flexible resources less variable under FO vs IR

Results over 12 characteristic weeks for 2019 ERCOT-like system



Mean and standard deviation of daily upward imbalance-driven revenues[1]

Simulations	Mean	Standard deviation
FO	-0.33[U]/0.33[F]	1.09[U]/1.09[F]
IR	-0.28[U]/0.43[F]	1.64[U]/1.62[F]

[U] Total payments by participants that contribute to net load imbalance;

[F] Total revenues received by resources that manage net load imbalanc

[1] Revenues include: (FO) DA FO premium−DA FO payoffs +RT energy;
(IR) DA IR payment (RT-realized for uncertain units/DA for reserve sellers) +RT energy

Conclusions

Introduction of Flexibility Options could

- ✓ Keep ISO revenue neutral and support cost-effective and reliable power system operations
- ✓ Address hedging needs of resources prone to imbalances (less volatile payments for imbalances)
- ✓ Provide revenue to flexible resources that is less volatile

Benefits come with responsibilities

- ✓ The system operator must facilitate FO trading
- ✓ FO sellers must commit to financially binding strike prices
- ✓ FO buyers must project the probability distribution of their RT outputs

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Thank you

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