Disruptive Electricity Market Innovation: Motivation & Pathways

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Invited Presentation
What is Next for Our Electricity Markets? Towards a New Market Regulatory Framework
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Presentation Abstract

Today's restructured electricity markets are based on economic principles developed more than two decades ago, allowing competition in the power sector with the objective of improving economic efficiency, shifting risks to investors and, in relevant emerging economies, to reduce the burden on the treasury. Since then, many markets have successfully followed a pragmatic and constant learning-by-doing process, resulting in innovations and changes that allow them to improve power system performance while delivering electricity in a secure and affordable manner. Recently, however, a number of unprecedented developments are threatening to disrupt power systems around the world. These include the need to quickly and affordably decarbonize the economy, the introduction of new supply- and demand-side technologies, and expanded opportunities for consumer engagement. This presentation seeks to provoke a discussion towards disruptive innovation in electricity market design drawing on several recent publications including the ISO New England System Operational Analysis and Renewable Energy Integration Study and the New England Energy-Water Nexus Study. It provides seven key insights: 1.) The reliance on VRE curtailment is unsustainable leading to a 40% erosion of the VRE capacity factor. 2.) The reliance on virtual power plant demand response is also sustainable leading to a cascade of system imbalances and costs relative to a transactive energy model. 3.) Instead, eIoT-enabled transactive energy retail markets are required to activate the grid with a proliferation of decentralized "uber-like" grid services. 4.) Deep decarbonization will impose a "Beyond-Energy-Mindset" that facilitates an expanded portfolio of incentivized ancillary grid services. 5.) Demand-side retail aggregators will provide net social benefits while eroding the incumbent utility business model. 6.) Similarly, demand-side wholesale aggregators will do the same. 7.) Finally, energy storage will emerge as as a capable resource as the LCOE of Storage+VRE systems continues to decline in an energy excess-future.

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- ***Insight 1: Reliance on VRE Curtailment is Unsustainable***
  - *VRE curtailment leads to a 40% erosion in the VRE capacity factor.*
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  - *The presence of demand baseline errors – present only in the VPP implementation – leads to a cascade of system imbalances and costs as compared to a Transactive Energy model.*
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- **Insight 4: Beyond Energy -- the Proliferation of Ancillary Services**
  - *Deep decarbonization imposes tremendous requirements for an expanded portfolio of incentivized ancillary grid services.*
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  - *Self-aggregation of retail customers provides net social benefits while eroding the incumbent utility business model.*
- **Insight 6: The Emergence of the Demand Side Wholesale Aggregator**
  - *The entrance of demand-side aggregators into wholesale electricity markets further provides net social benefits while further eroding the incumbent utility business model.*
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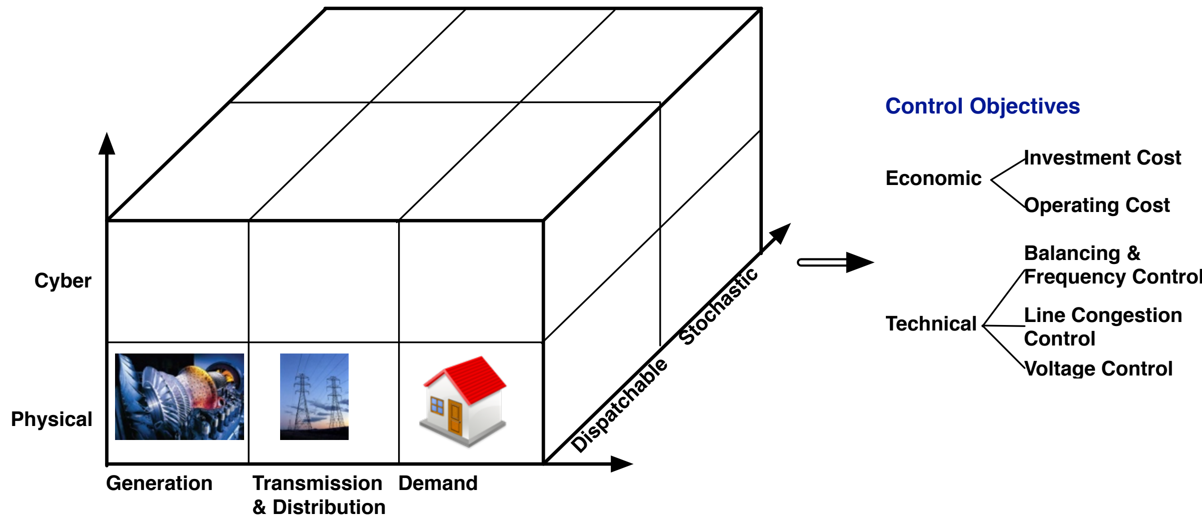
  - *The LCOE of Storage +VRE systems continues to decline in an energy-excess future.*

Drivers for the Evolution of the Electric Power Grid

Traditional power systems were built upon the assumption that generation was controlled by a few centralized generation facilities that were designed to serve fairly passive loads.

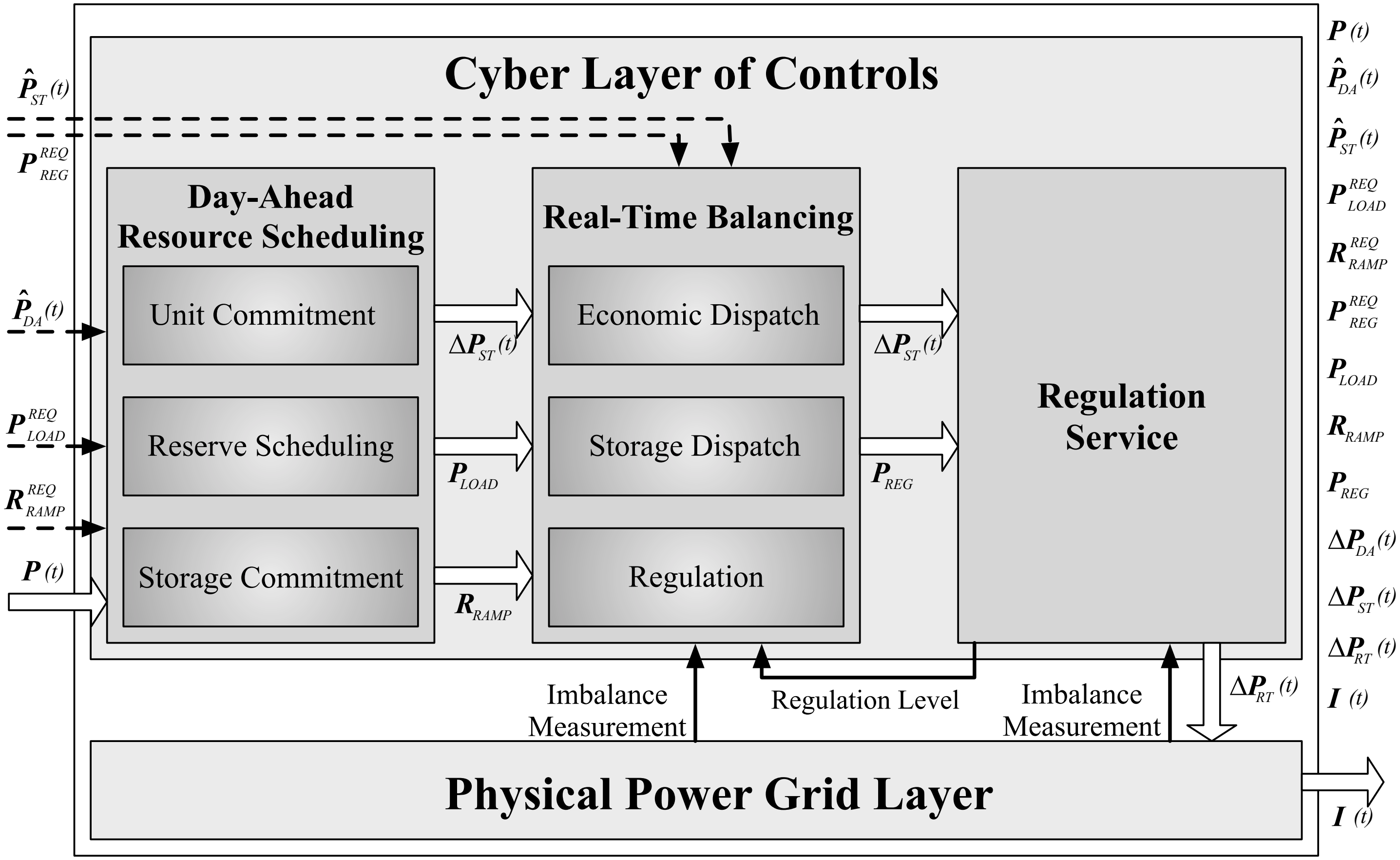
Several drivers have emerged to challenge this assumption:

- Decarbonization
- Growing electricity demand
- Deregulation of electricity markets
- Active end-user participation
- Digital innovations in energy technologies



∴ We need holistic techniques that integrate multiple layers of control and simultaneously manage technical and economic objectives.

Electric Power Enterprise Control System Simulation (EPECS)



- $P(t)$ - Actual net load;
- $\hat{P}_{DA}(t)$ - Net load day-ahead forecast;
- $\hat{P}_{ST}(t)$ - Net load short-term forecast;
- P^{REQ}_{LOAD} - Load following reserve requirement;
- R^{REQ}_{RAMP} - Ramping reserve requirement;
- P^{REQ}_{REG} - Regulation reserve requirement;
- P_{LOAD} - Actually scheduled load following reserves;
- R_{RAMP} - Actually scheduled ramping reserves;
- P_{REG} - Actually scheduled regulation reserves;
- $\Delta P_{DA}(t)$ - Imbalances at the day-ahead scheduling output;
- $\Delta P_{ST}(t)$ - Imbalances at the real-time balancing output;
- $\Delta P_{RT}(t)$ - Imbalances at the regulation service output;
- $I(t)$ - Residual imbalance at the system output;

∴ EPECS Simulation has been used to study techno-economic system performance in the presence of variable renewable energy resources.

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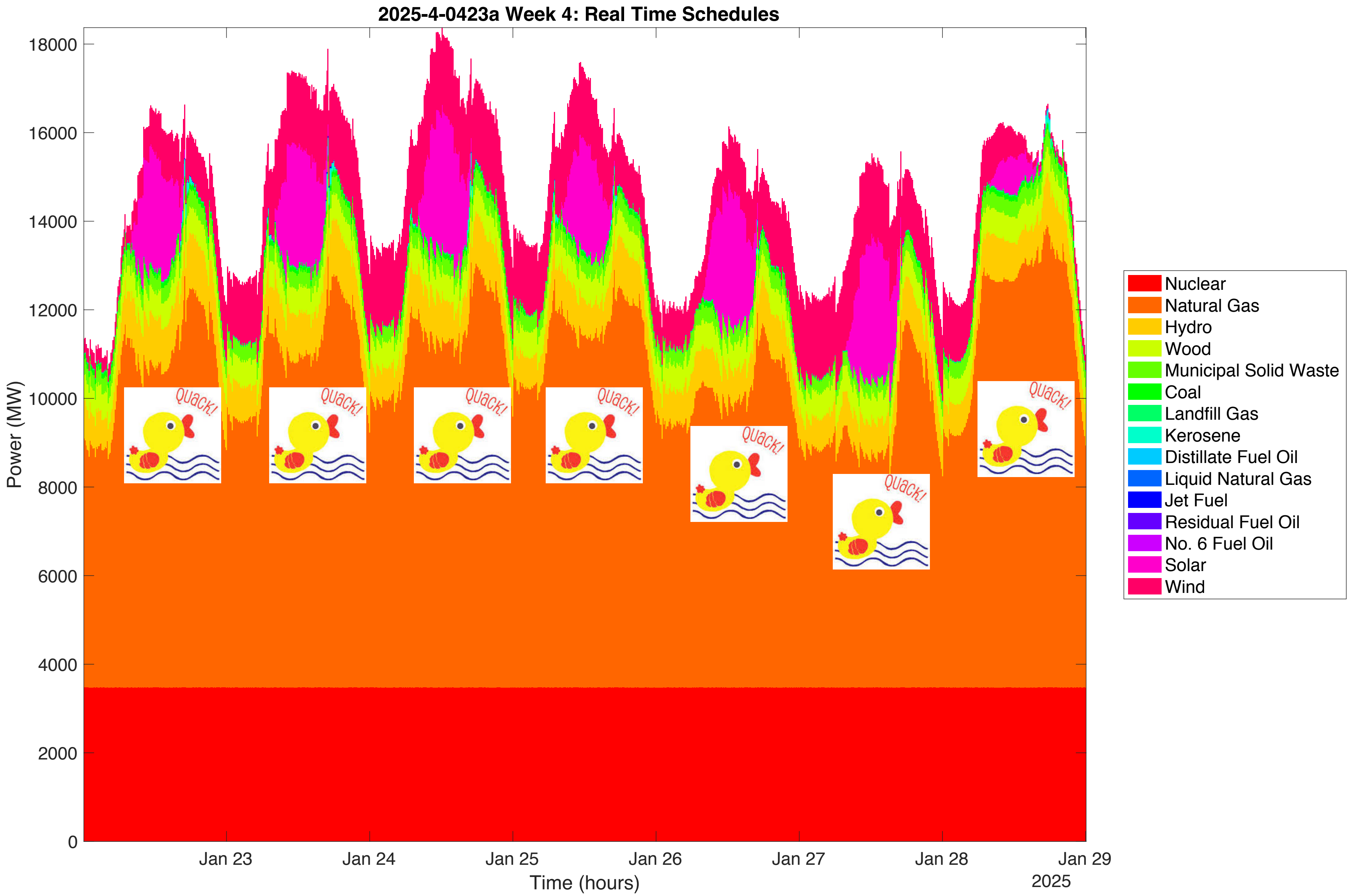
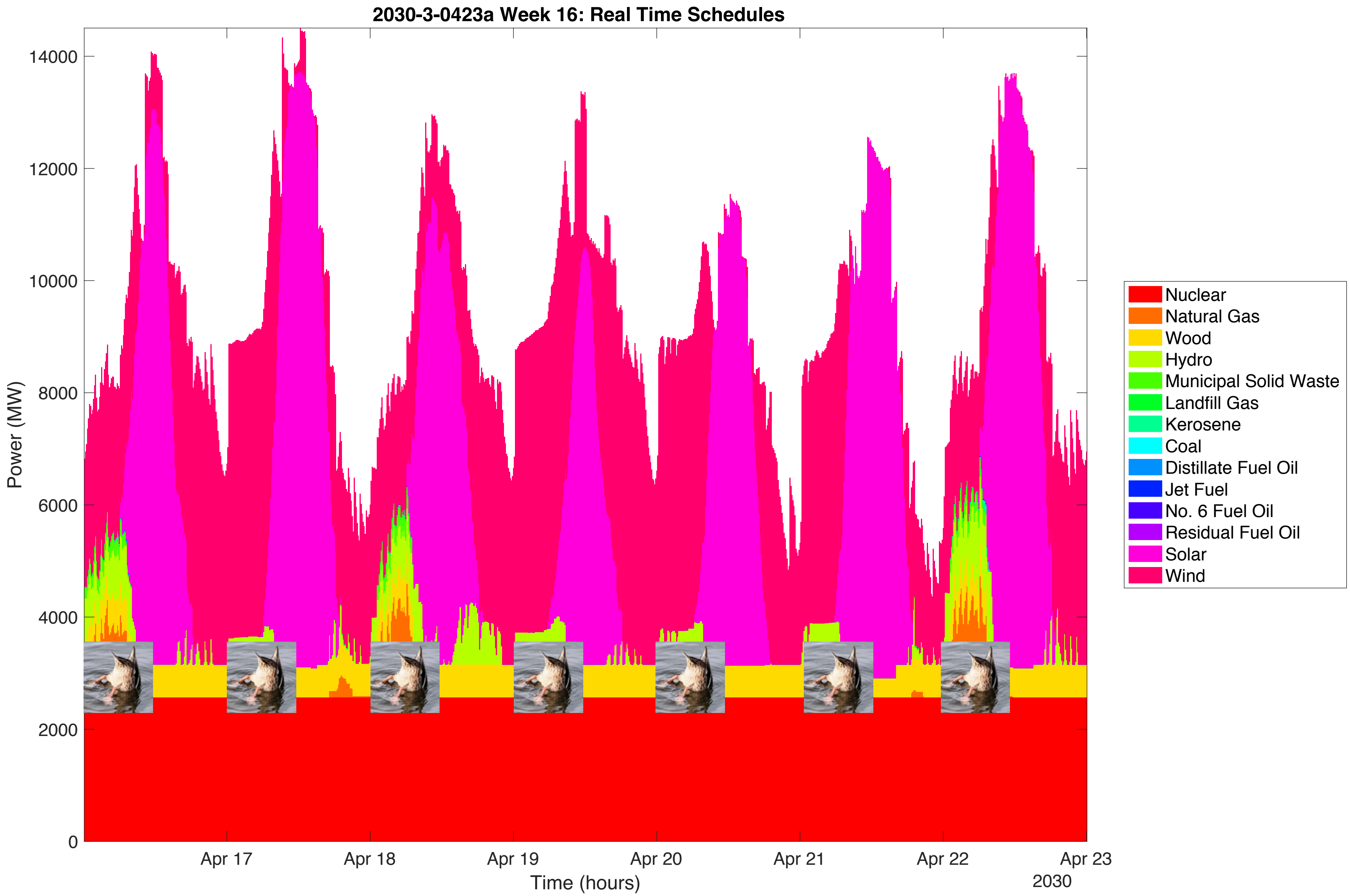
Real-Time Energy Market Dispatch: 2025 Conventional



Real-Time Energy Market Dispatch: 2030 High VREs Plus



The Emergence of Variable Renewable Energy (VRE)

Past:

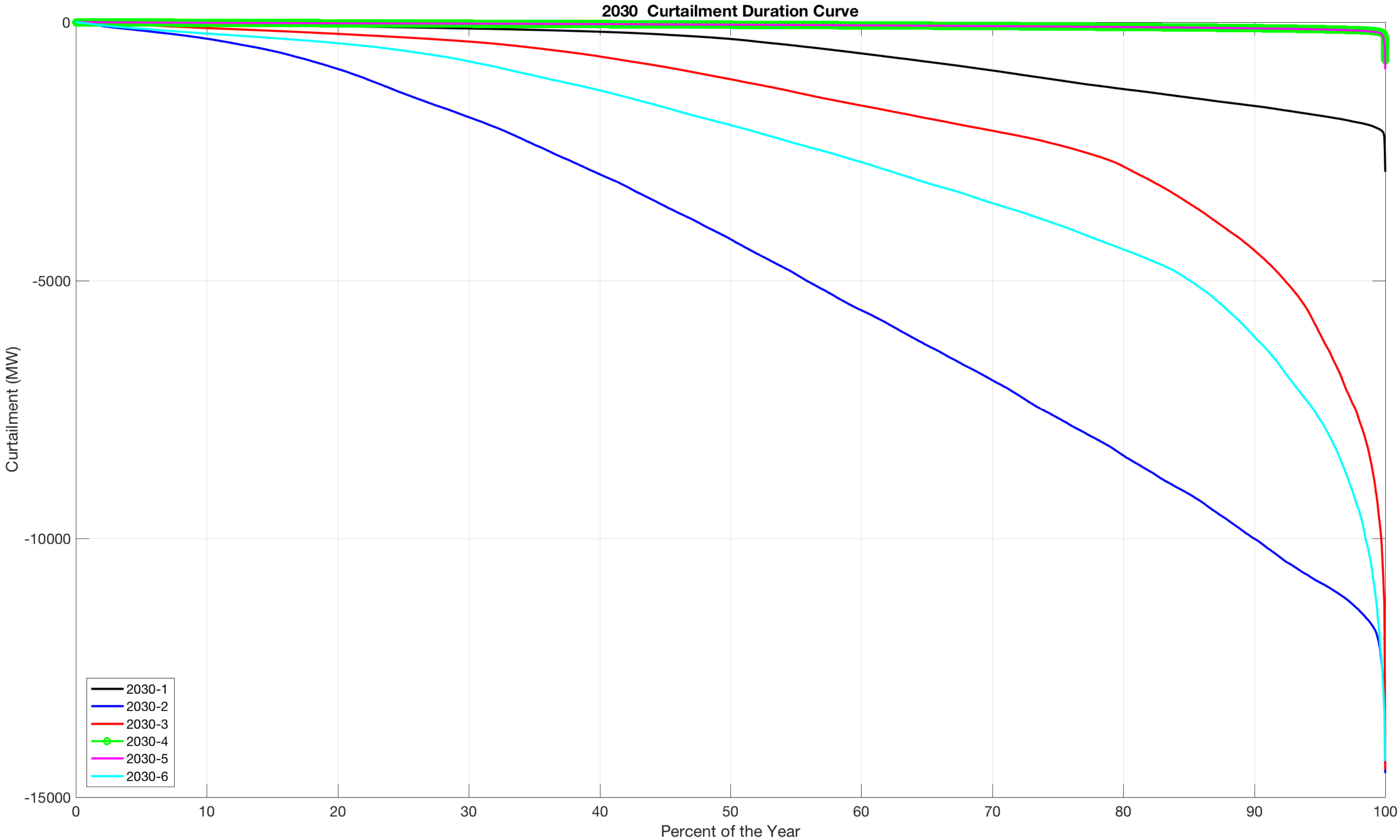
Generation/Supply	Load/Demand
Thermal Units: Few, Well-Controlled, Dispatchable, In Steady-State	Conventional Loads: Slow Moving, Highly Predictable, Always Served

Future:

	Generation/Supply	Load/Demand
Well-Controlled & Dispatchable	Thermal Units: (Potential erosion of capacity factor)	Demand Side Management: (Requires new control & market design)
Stochastic/Forecasted	Solar & Wind Generation: (Can cause unmanaged grid imbalances)	Conventional Loads: (Growing & Needs Curtailment)

∴ **The emergence of VRE necessitates active demand side resources.**

VRE Curtailment: 2030 Scenarios



∴ **Relative to the conventional scenarios, high VREs require significant curtailment.**

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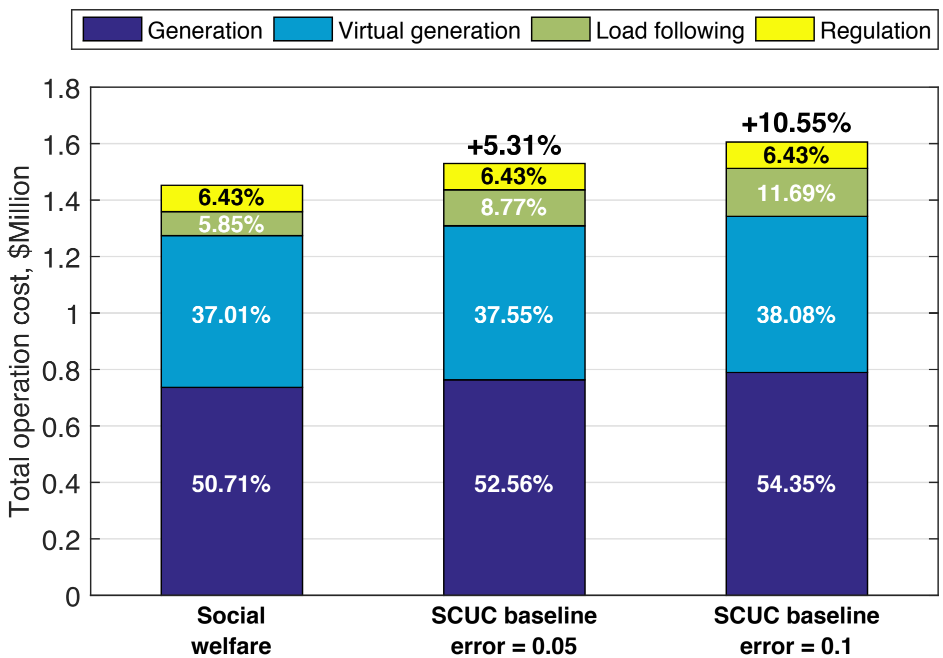
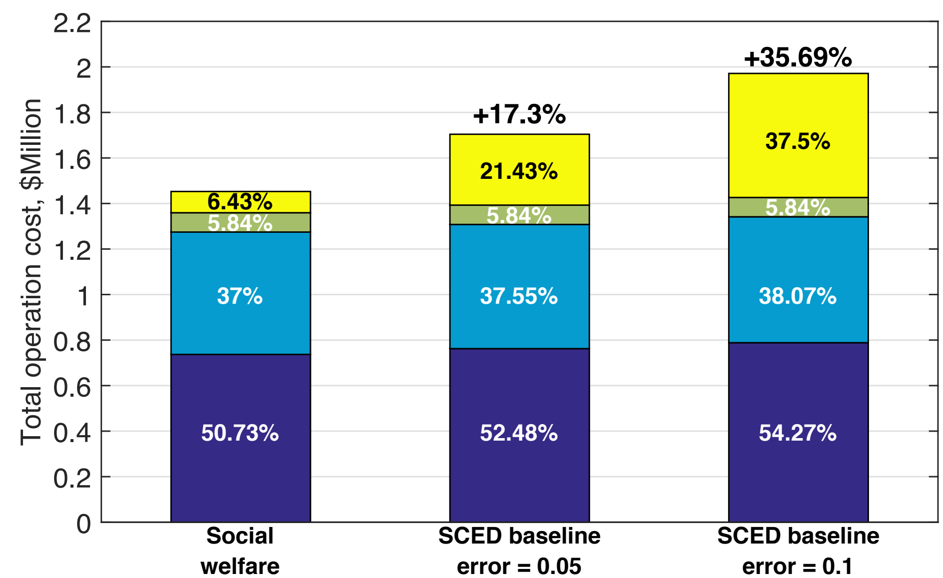
Reliance on Virtual Power Plant DR is Unsustainable





∴FERC Order 745 vs Transactive Energy: A Techno-Economic Policy Case

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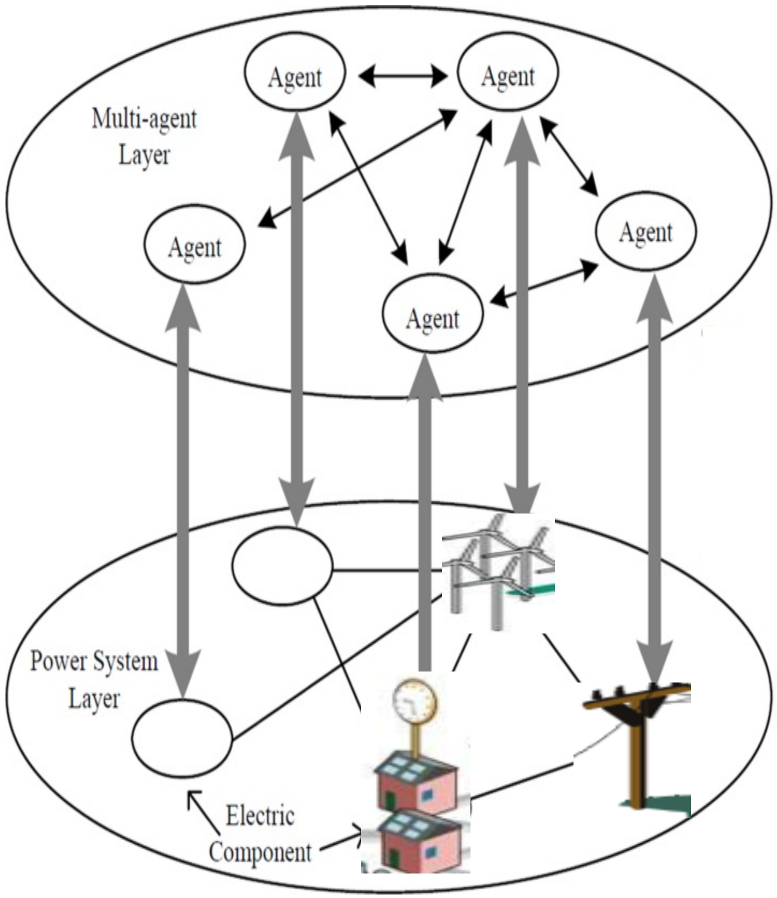
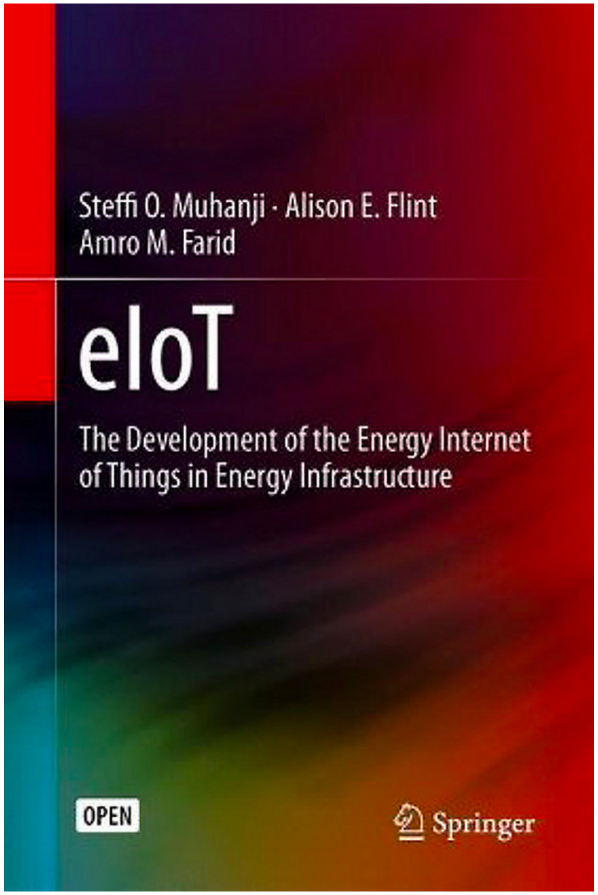
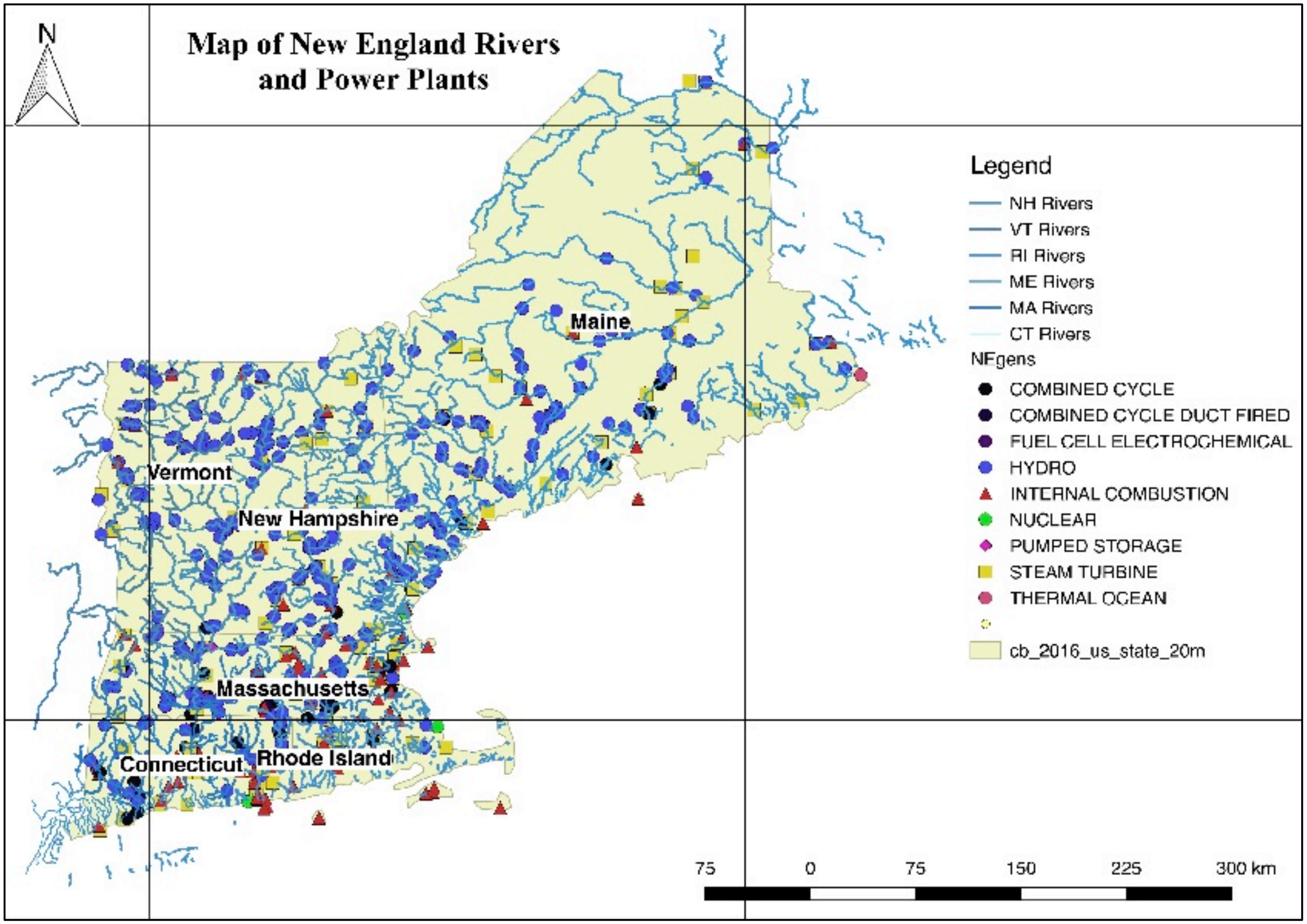
Enabling DSRs with the energy Internet of Things





∴ The emergence of demand side resources necessitates the distributed transactive control through the energy Internet of Things.

New England Power Plants and Rivers



Most power plants are located near a water source. This indicates the strong coupling between the water supply and energy supply systems.

New England Energy Water Nexus Study: Key Findings

In 6 New England Scenarios, flexible energy-water resources are shown to enhance:

- Average levels (~150MW) and minimum levels (~150MW) of upward load following reserves
- Average levels (~900MW) and minimum levels (~1.2GW) of downward load following reserves
- Water withdrawals (~26,000 m^3/min)
- Day Ahead Energy Market Production Costs (~3600$/hr)
- Real Time Energy Market Production Costs (~500/hr)

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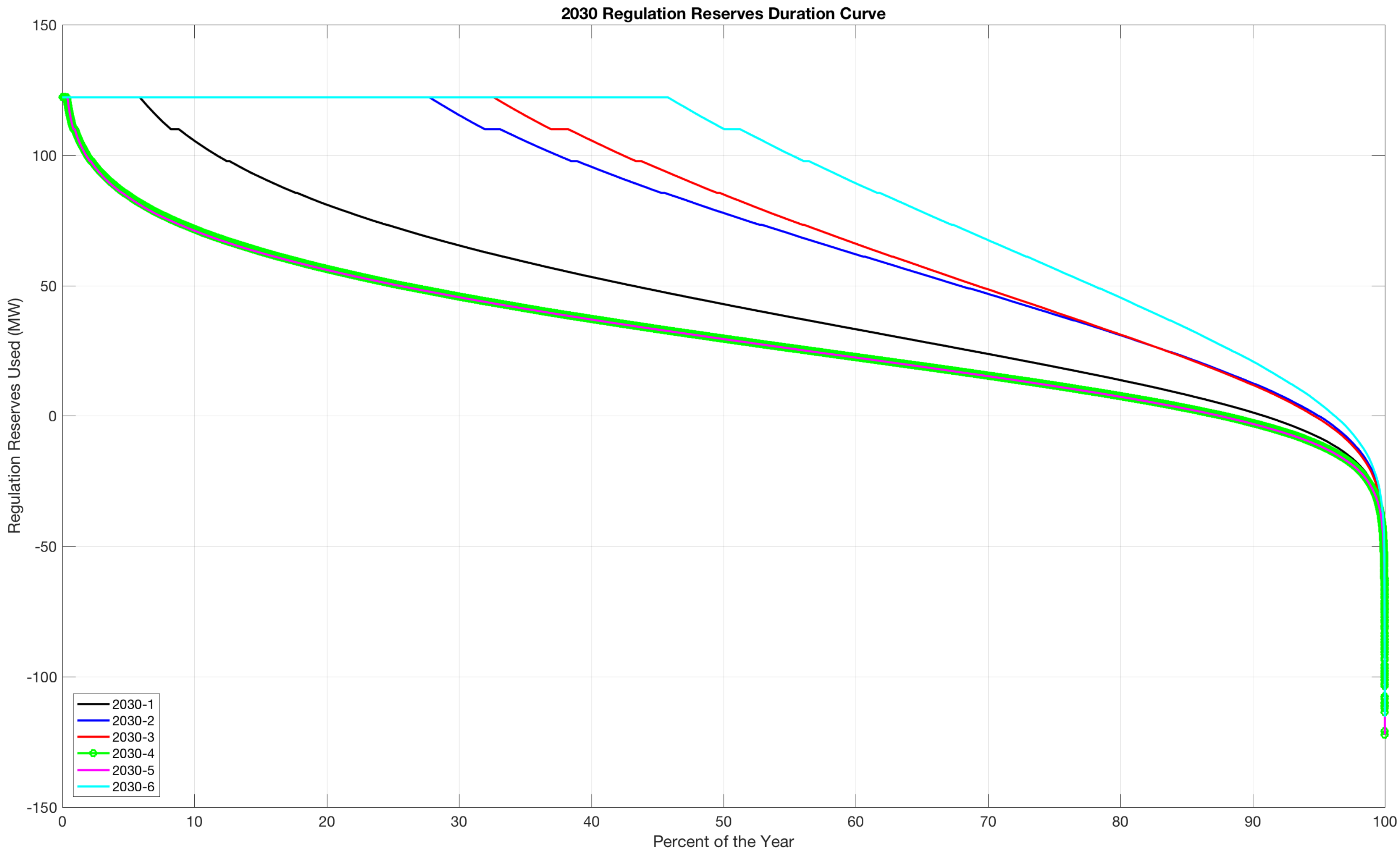
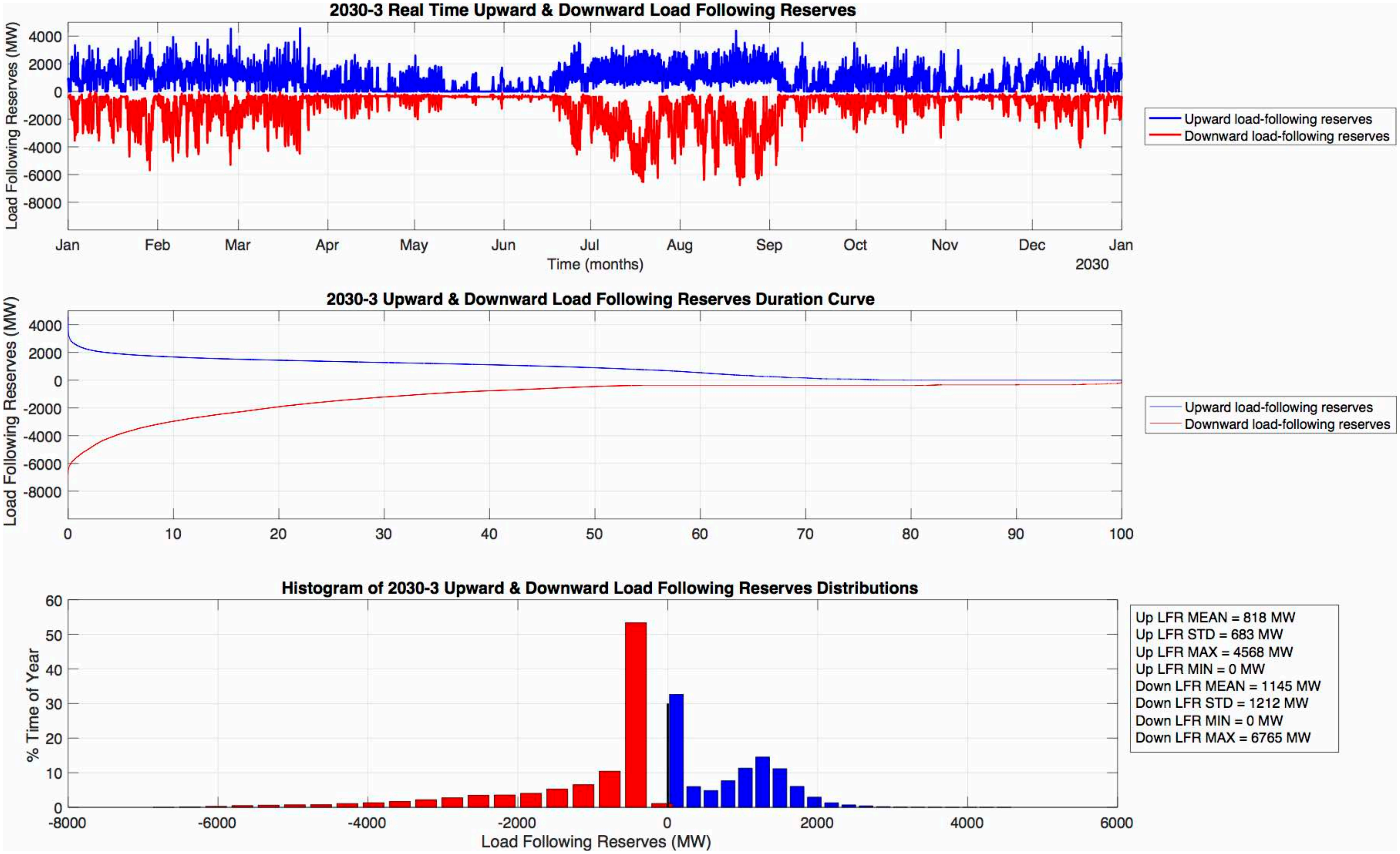
Regulation Reserves: 2030 Scenarios



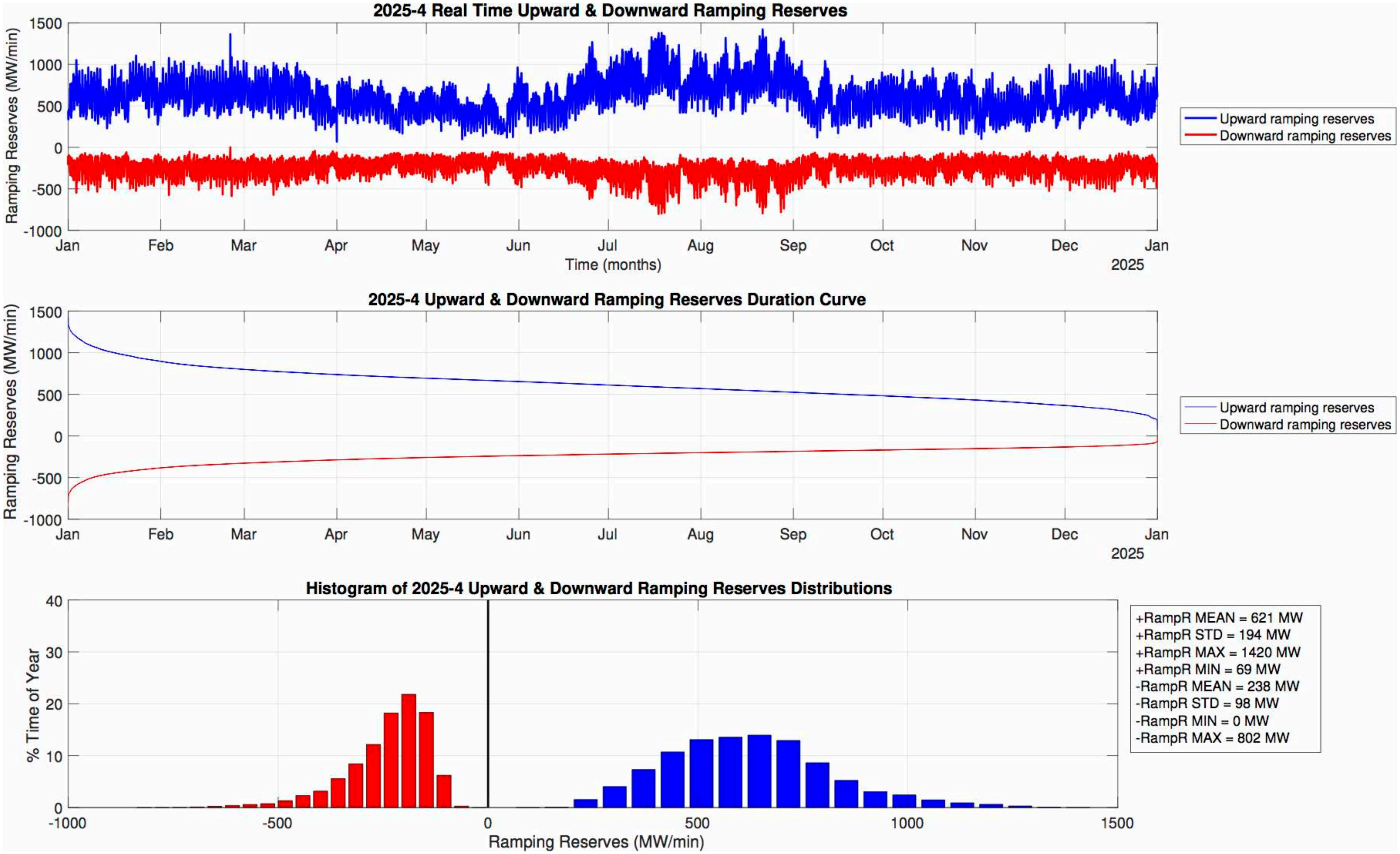
∴ **Relative to the conventional scenarios, high VREs saturate regulation reserves.**

Load Following Reserves: 2030 High VREs Plus Scenario



∴ **In Spring & Autumn, the ability to track low net load conditions is constrained.**

Ramping Reserves: 2025 Conventional Scenario



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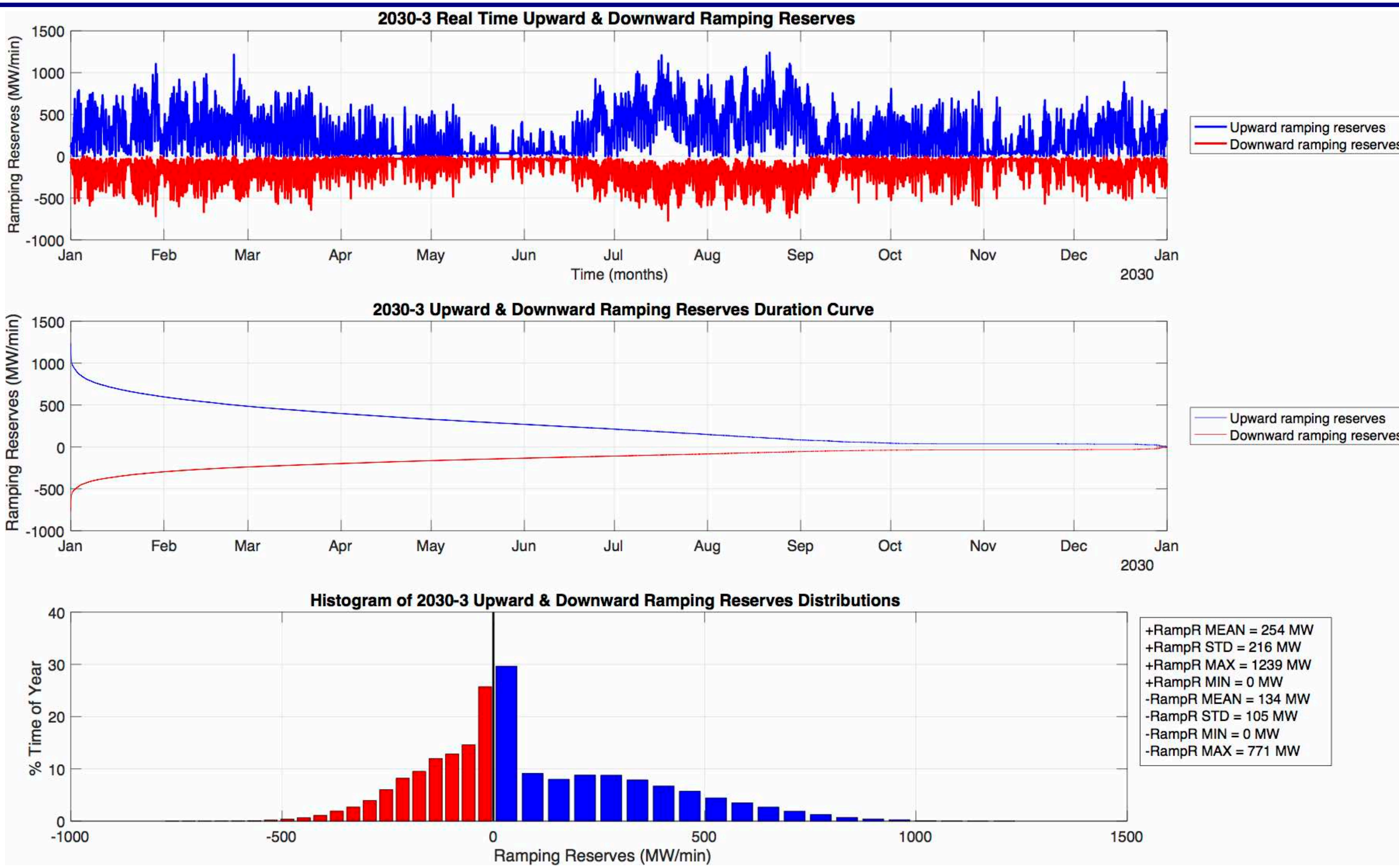
Ramping Reserves: 2030 High VREs Plus Scenario



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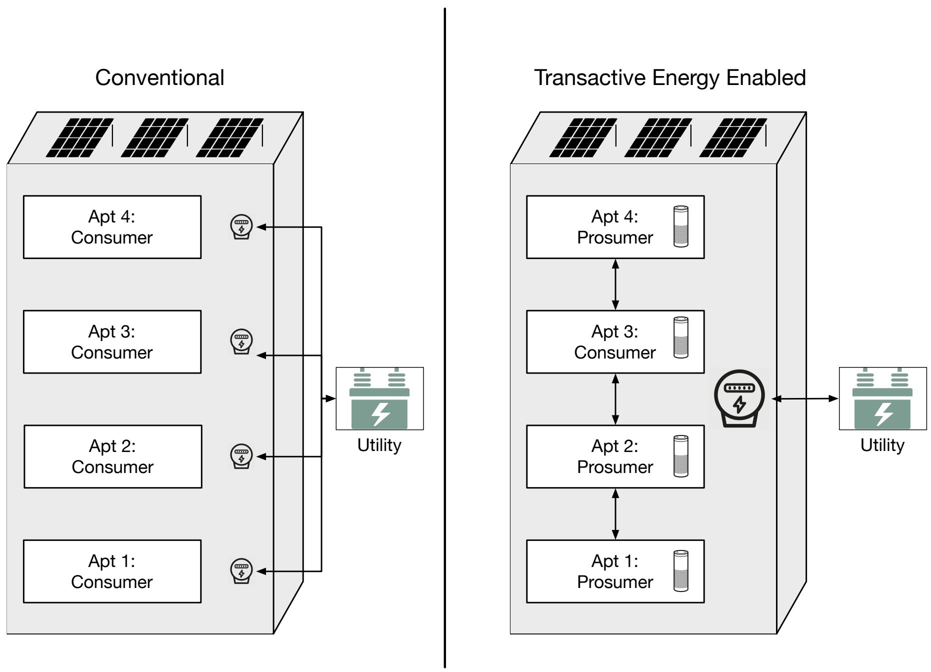
The Emergence of the Demand Side Retail Aggregator



Conventional Case:

Utility Revenue = (2000kWh) ∗ (**0.1$/kWh**)

− (1200kWh) ∗ (**0.08$/kWh**)

= $200 − $96 = $104

Consumer Cost = $200

Solar PV Revenue = $96

Transactive Energy Case:

Utility Revenue = (800 kWh) ∗ (**0.1$/kWh**)

= $80

Consumer Cost = (800kWh) ∗ (**0.1$/kWh**)

+ (1200kWh) ∗ (**0.09$/kWh**)

= $188

Solar PV Revenue = $108

∴ Self-aggregation of retail customers provides net social benefits while eroding the incumbent utility business model.

Emergence of the Demand Side Retail Aggregator

The eIoT transactive energy aggregation use case above shows net social benefits due to several enabling factors:

- The presence of prosumers with local solar generation that is, at times, ***inadequately compensated*** by utilities encourages the emergence of a transactive energy marketplace.
- The solar generator's value proposition leaves local consumers at times ***over-billed*** by utilities.
- The transactive energy marketplace is likely to be strengthened if there is a strong ***sense of community*** within the apartment building.
- There exists nearly ***ubiquitous*** measurement, communication, and decision-making capabilities within the building to support the transactions. It provides price and quantity information for rational decision-making. The user-friendliness of these information technologies encourages greater adoption.
- There exists a ***sparsity*** of measurement, communication, and decision- making capabilities between the building and the utility.

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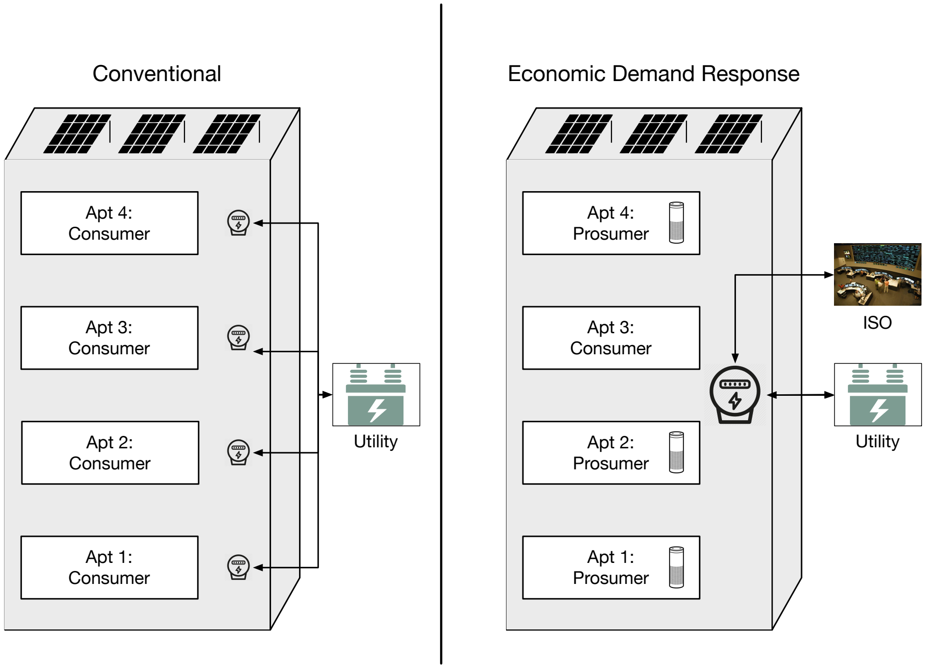
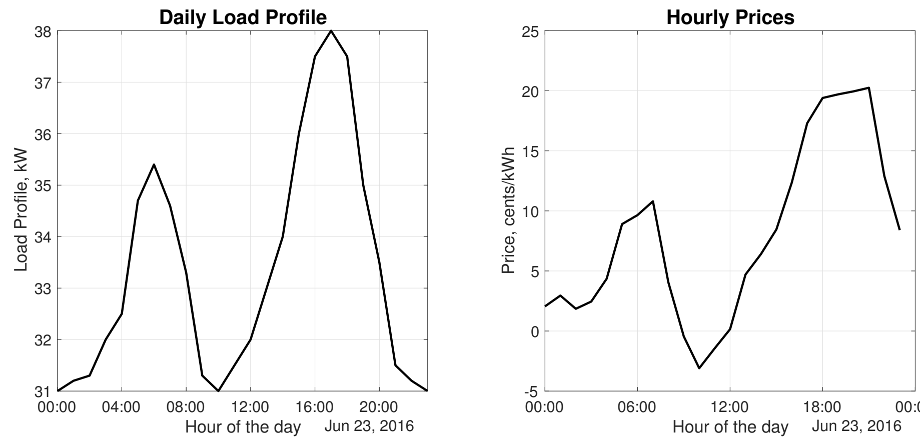


∴ The entrance of demand-side aggregators into wholesale electricity markets further provides net social benefits while further eroding the incumbent utility business model.

Conventional Retail Rate Case:

Consumer Cost = $200



Wholesale Real-Time Pricing Case:

Consumer Cost = $162

Utility Revenue = **$0**

Wholesale Real-Time Pricing w/ Load Shifting Case:

Consumer Cost = $134

Utility Revenue = **$0**

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The Emergence of Energy Storage

- In May 2017, SolarCity (a subsidiary of Tesla) partnered with the Kauai Island Utility Cooperative (KIUC) to install a 15 MW solar array paired with an 11 MW battery storage system. The project was financed using a 20-year PPA at a price of ***$139/MWh***.
- In early 2017, KIUC signed a PPA with AES corporation at ***$110/MWh*** to finance a 28 MW solar array paired with a 20 MW/100 MWh battery system that is slated to come online by the end of 2018.
- In May 2017, NextEra Energy entered into a 20-year PPA with Tucson Electric Power to finance a 100 MW solar array paired with a 30 MW/120 MWh energy storage system—the agreed-upon price was **$45/MWh**.
- In December 2017, Xcel Energy's Colorado utility subsidiary announced the results of a recent solicitation where the median bid price for solar-plus-storage projects was $36/MWh and the median bid price for wind-plus-storage projects was ***$21/MWh***.

Source EIA U.S. Battery Storage Market Trends 2018

- ***FERC Order 841*** is a game-changer for energy-storage assets
- **Prediction**: *Driven by a need to capitalize on solar projects, energy storage adoption will follow a physics-constrained supply curve 1.) fluidic-hydro 2.) thermal-building 3.) chemical-battery 4.) chemical-hydrogen*

∴ The LCOE of Storage + VRE systems continues to decline in an energy-excess future.

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