Wholesale Electricity Markets and Resource Adequacy with High Clean Energy Generation Targets

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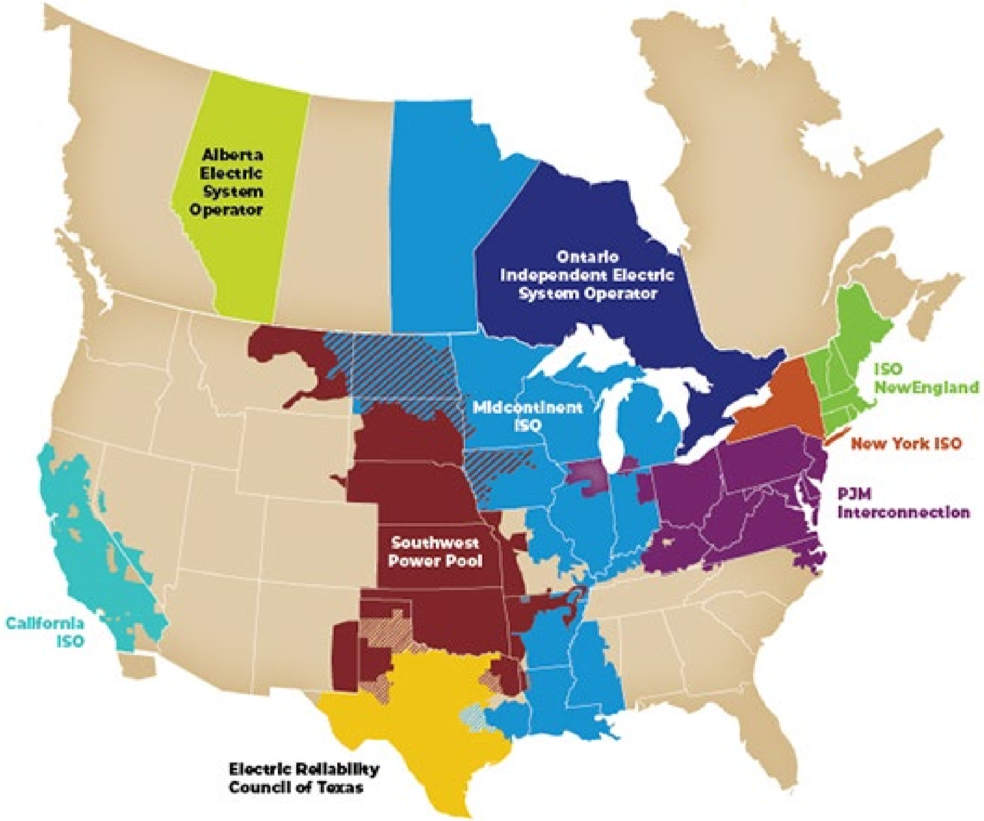
Motivation: explore interface of electricity market design and resource adequacy (RA)

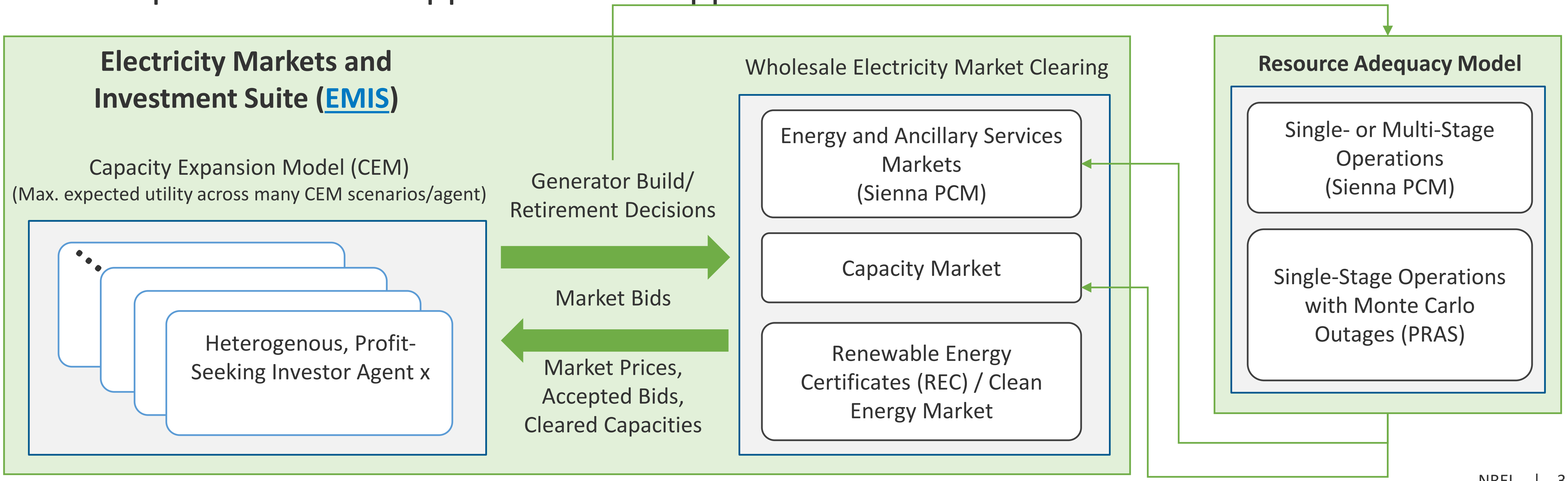
- Market design impacts incentives for investment decisions, which in turn influences **resource adequacy (RA)**, and this interaction is especially challenging under future economic, policy, and system condition **uncertainty**



Source: https://isorto.org/#media-section

EMIS: a fundamentally different modeling approach

- Capture interaction between **market design, investment, and RA**
- Represent multiple perspectives with nuances of investment landscape: imperfect information, varying risk attitudes, technology preferences, and financing parameters
- Integrate with NREL's Probabilistic Resource Adequacy Suite (PRAS) and Sienna tools
- Open source to support broader application

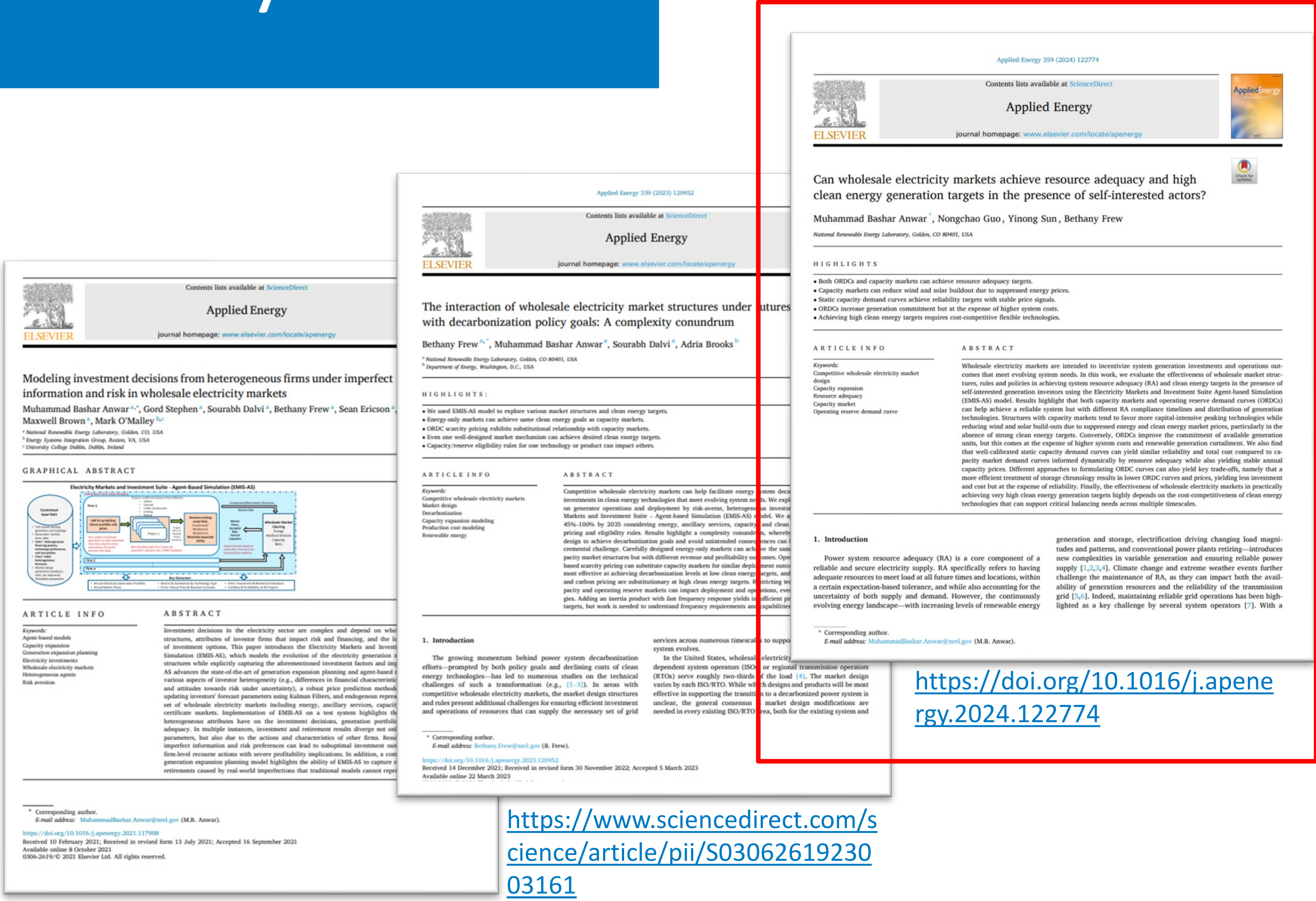


Modified from https://doi.org/10.1016/j.apenergy.2021.117908

PCM = Production Cost Model (minimize unit commitment and economic dispatch)

Published EMIS Analyses

- Impacts of investor heterogeneity, uncertainty, risk aversion, etc.
- Different wholesale market structures and products:
  - Energy-only
  - Capacity market
  - Clean Energy Certificates
  - Operating Reserve Demand Curves (ORDCs)
  - Inertia/FFR
  - Eligibility rules like Minimum Offer Pricing Rule (MOPR)
  - RA-informed ORDCs and capacity market demand curves



https://www.sciencedirect.com/science/article/pii/S0306261921012198

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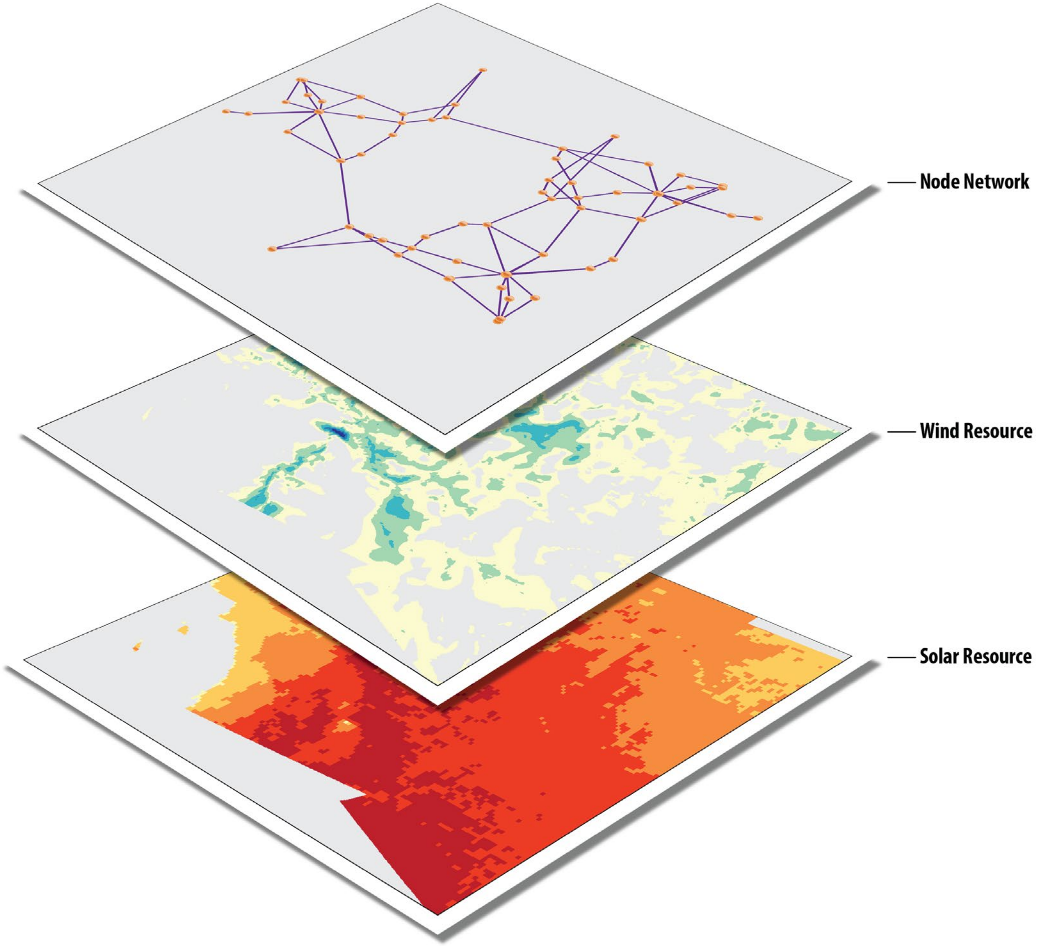
https://doi.org/10.1016/j.apenergy.2024.122774

RTS-GMLC test system

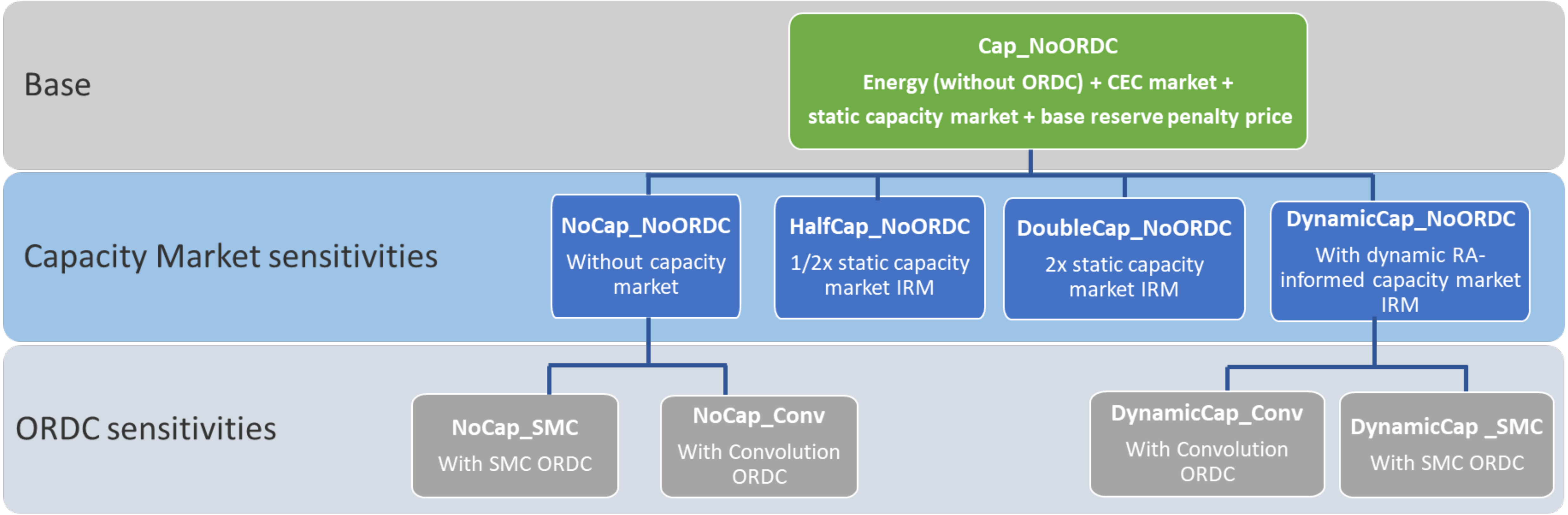
- 3 zones based loosely on portions of the SW U.S. (CA, NV, AZ)
  - Initial System Reliability Requirement: ~8900 MW
  - Initial System Derated (Unforced) Capacity: ~8400 MW
- Uncertainty Parameter: Load Growth
- Horizon: 15 years (10 year rolling horizon 2020-2035)
- Representative Days: 20
- Markets: energy, operating reserves (reg up, reg down, flex up, flex down, primary, synchronous), forward capacity, clean energy credit
- Clean Energy Targets (CETs) by 2035: 45% (low), 75% (mid), 100% (high)



https://github.com/GridMod/RTS-GMLC

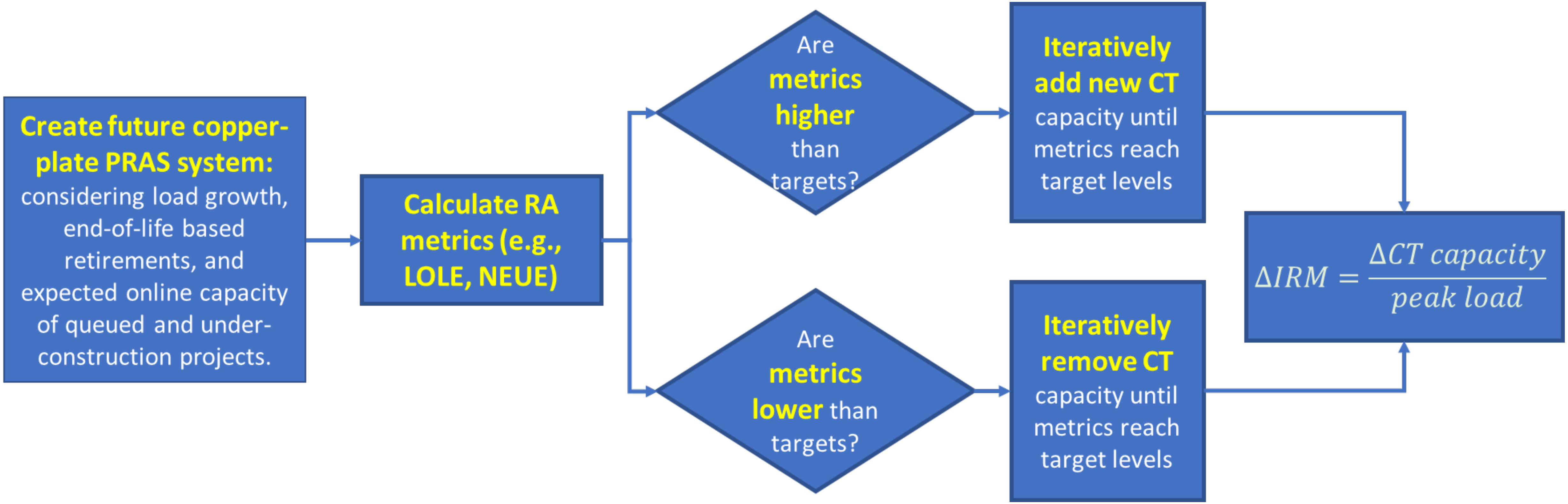
Highlights of recent electricity markets analysis using EMIS modeling suite

Scenarios



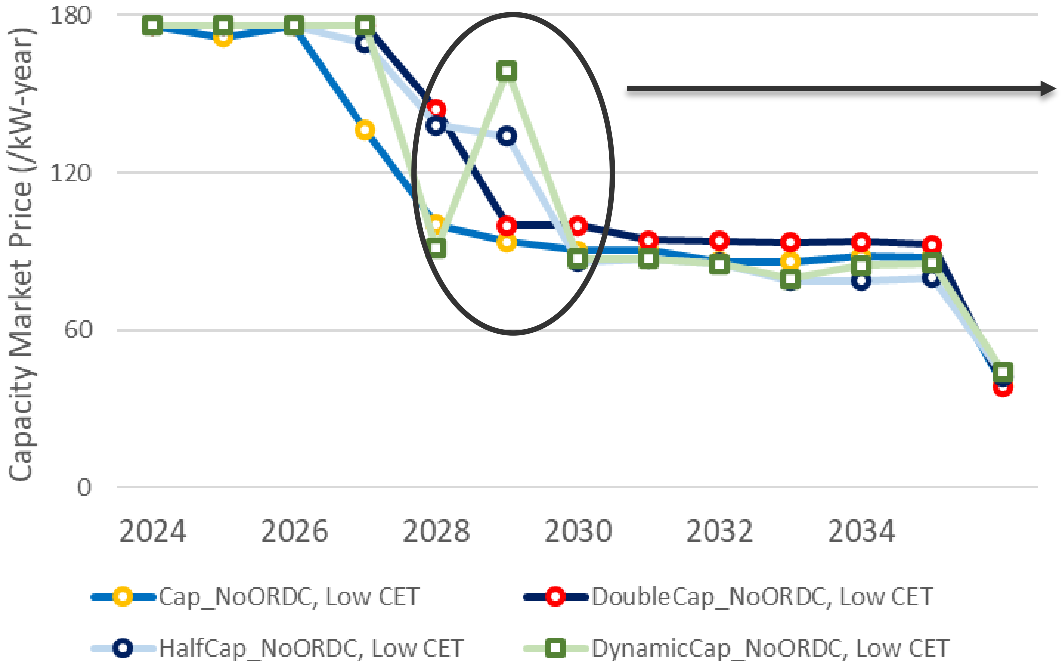
IRM = Installed Reserve Margin; ORDC = Operating Reserve Demand Curve; SMC = Sequential Monte Carlo; CEC = Clean Energy Credit

Key model enhancement #1: Dynamic, RA-informed capacity market demand curve



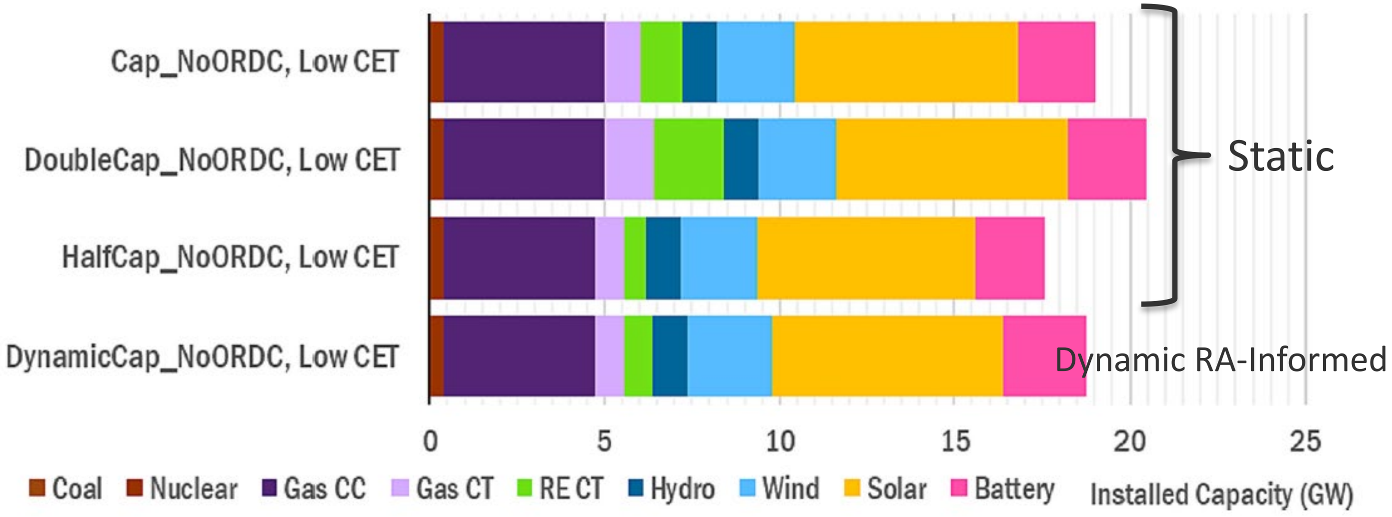
IRM = Installed Reserve Margin (% total installed capacity relative to peak load)

Impact of capacity market demand curves



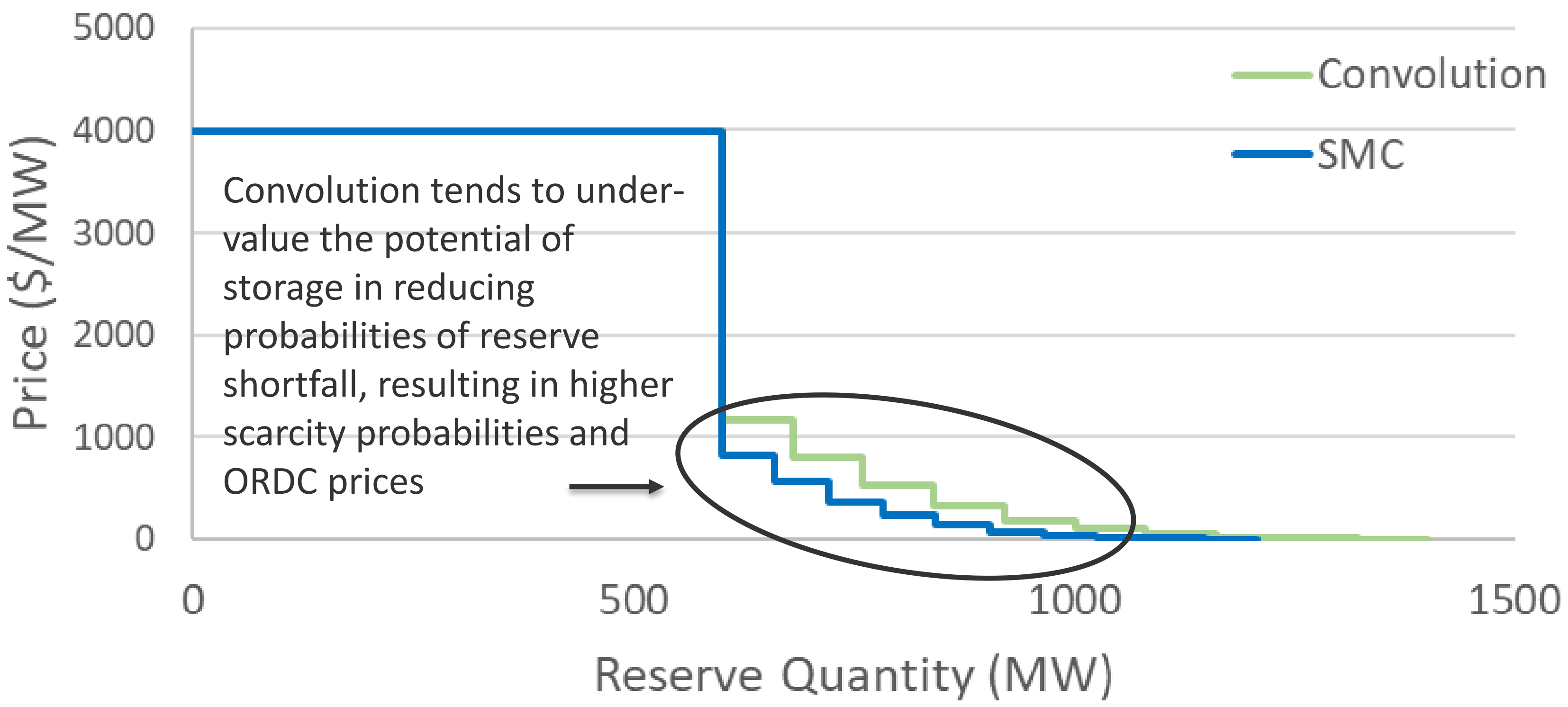
Dynamic RA-informed capacity market demand curve may lead to oscillations in capacity market prices

Well-calibrated static curves reach similar RA (not shown) and system buildout outcomes as dynamic RA-informed curves



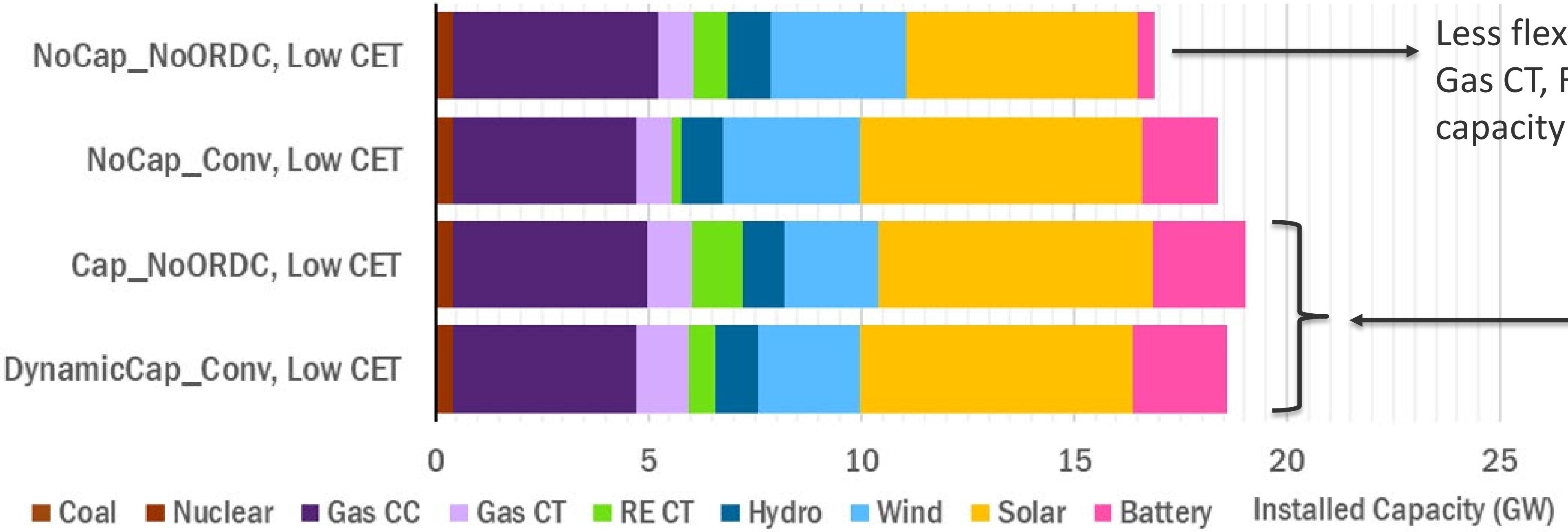
Key model enhancement #1: Sequential ORDCs

Calculate generator and storage resource unavailability profiles based on **sequential Monte Carlo (SMC) simulations**, which takes into account the **chronological** factors affecting the resource unavailability profiles. This improves upon the previous Convolution-based method that does not account for chronology.



Convolution vs SMC ORDCs. This example curve is for the Primary operating reserve product, but ORDCs were also applied to the Synchronous operating reserve product.

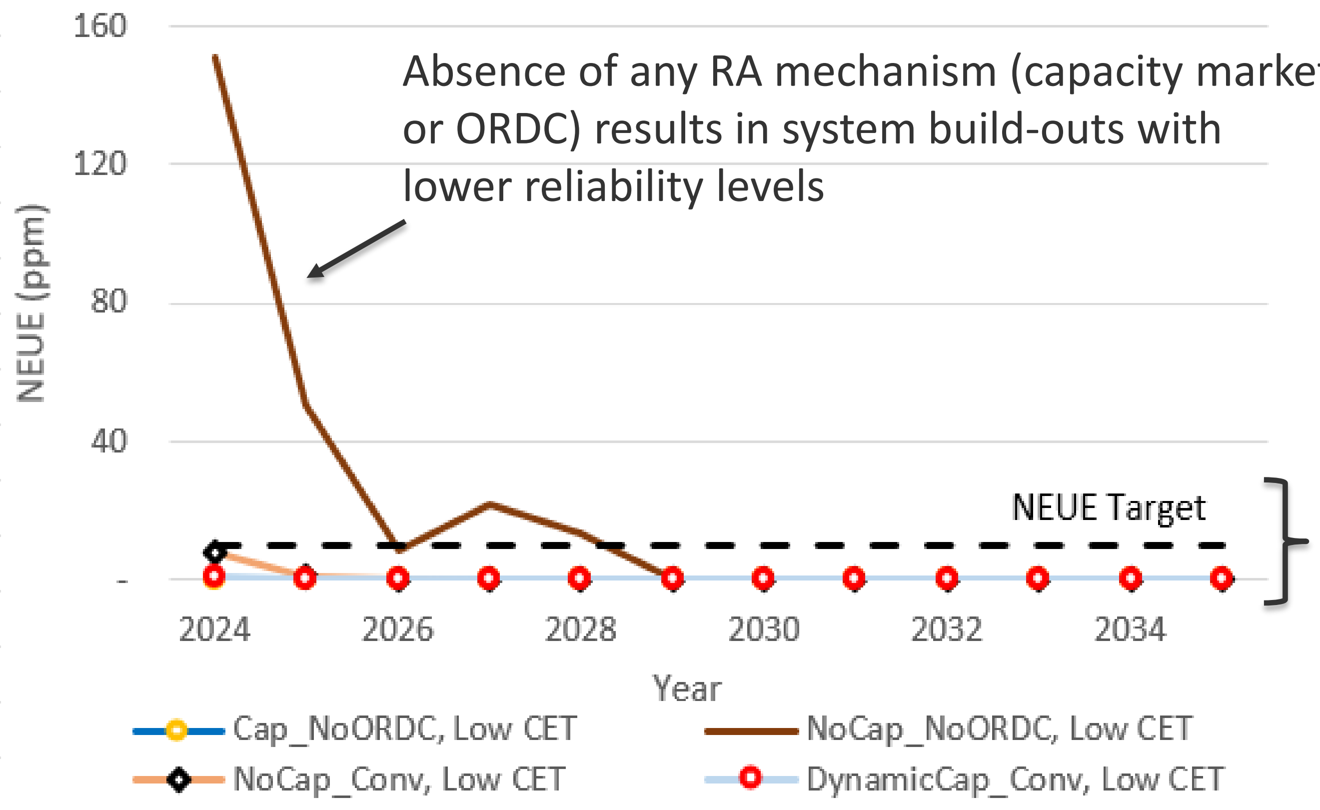
Comparing resource adequacy mechanisms



Less flexible and peaking units (i.e., Gas CT, RE-CT, batteries) if neither capacity market or ORDC

Structures with capacity markets tend to favor more capital-intensive peaking technologies while reducing wind and solar build-outs due to suppressed energy and clean energy market prices, particularly in the absence of strong clean energy targets (i.e., low CET cases).

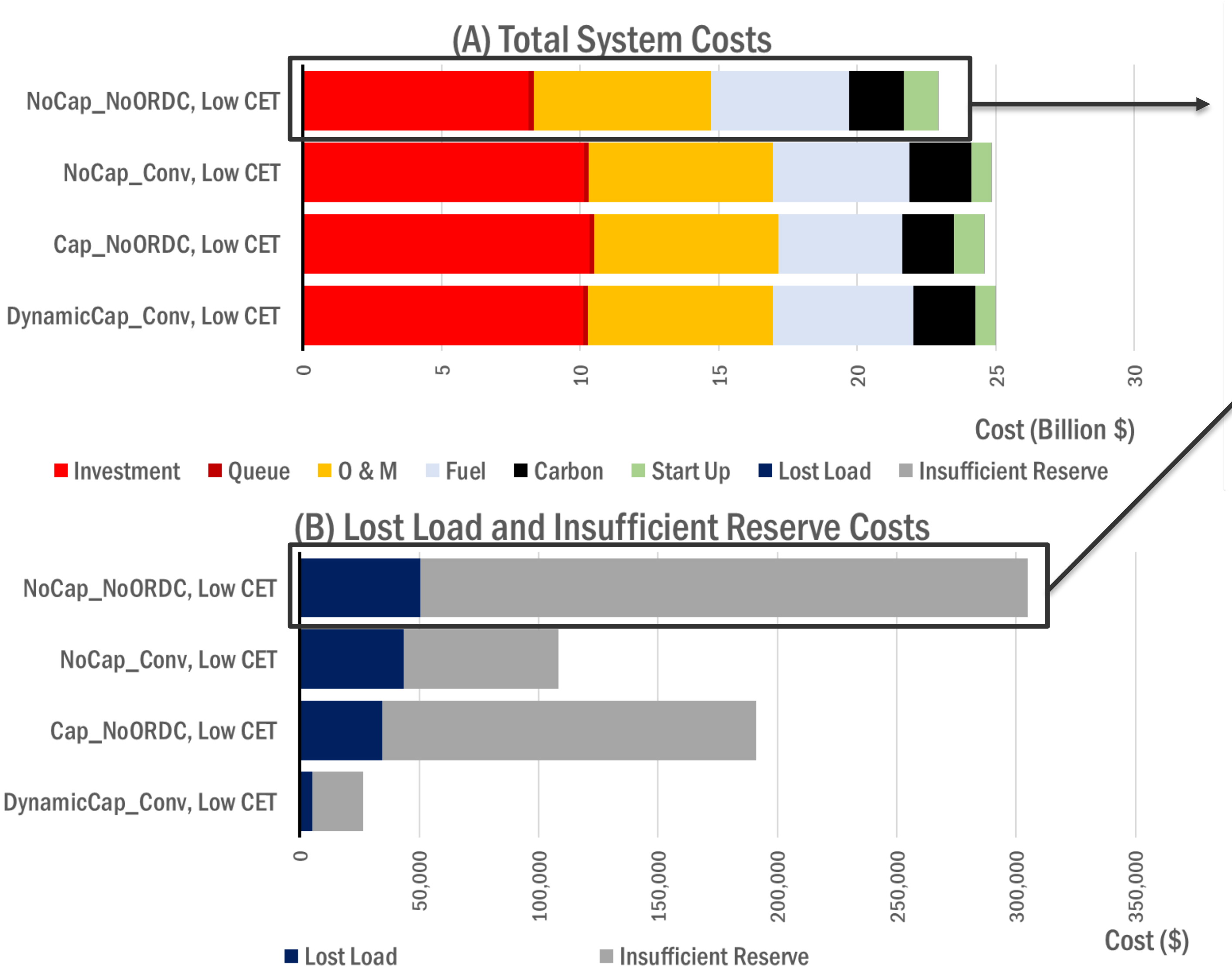
Comparing resource adequacy mechanisms



Absence of any RA mechanism (capacity market or ORDC) results in system build-outs with lower reliability levels

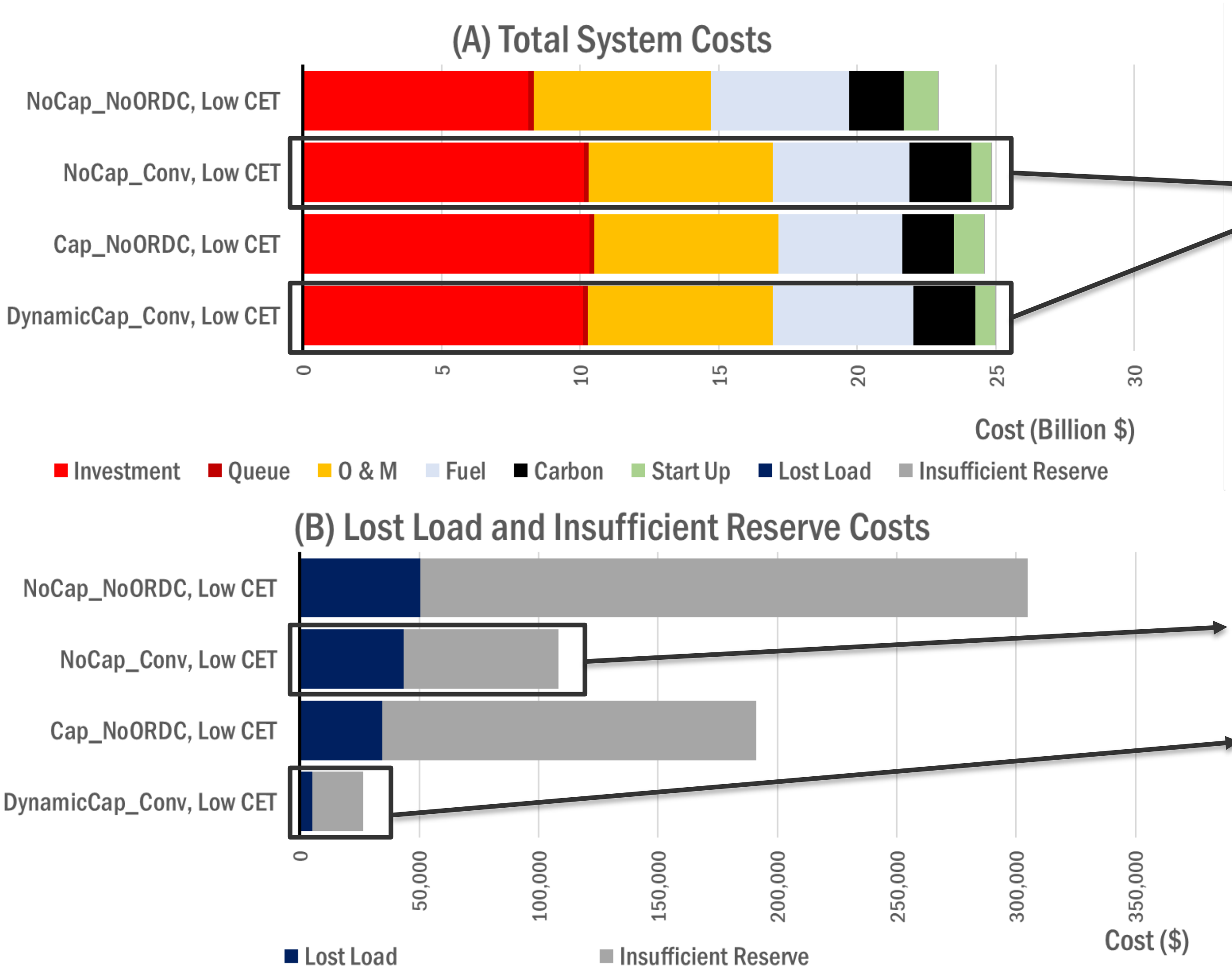
Capacity markets and ORDC can both achieve RA target

Costs under different RA mechanisms



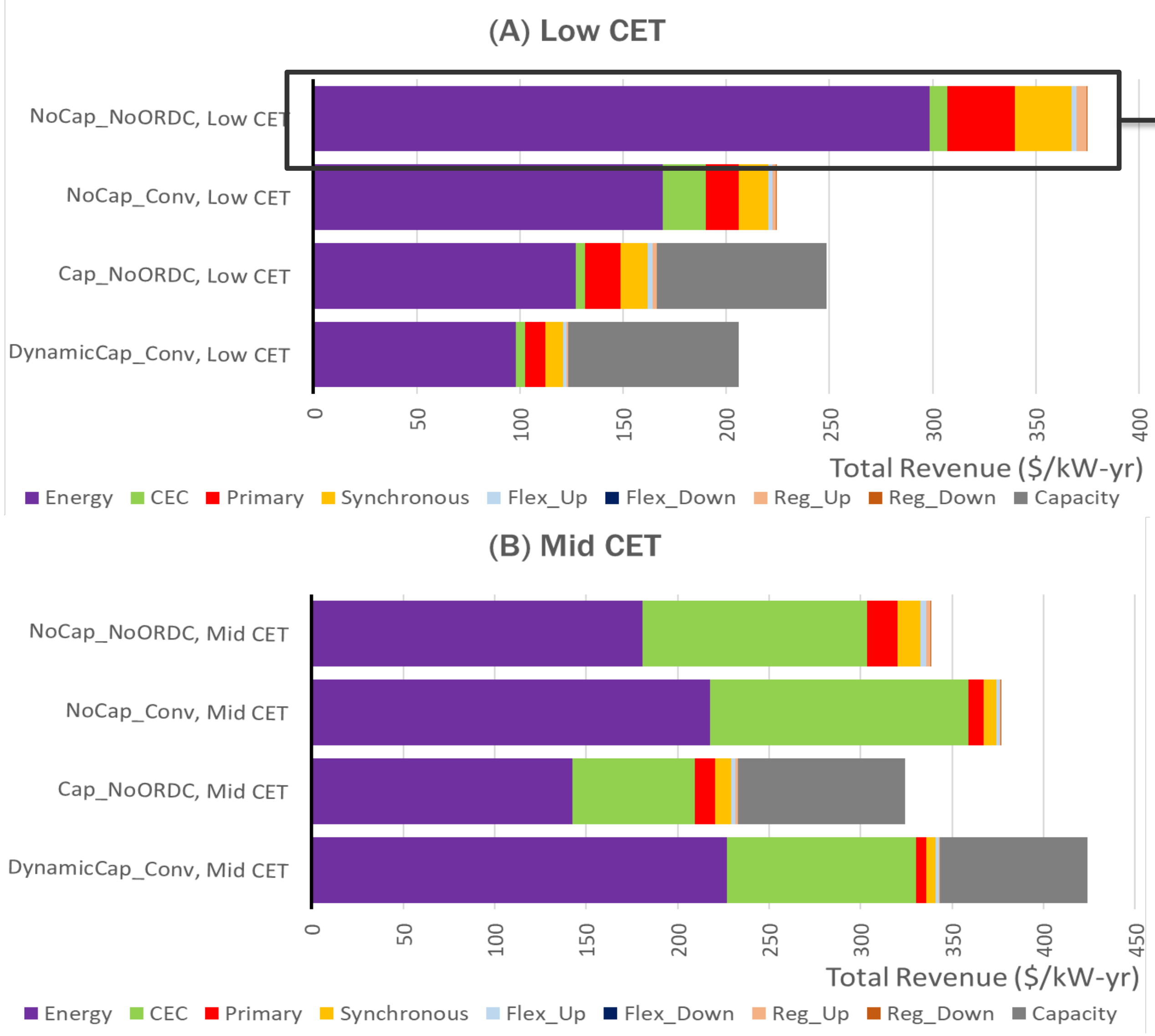
- Absence of both a capacity market and ORDCs has the lowest investment and fixed costs, but the highest lost load and insufficient reserve costs

Costs under different RA mechanisms



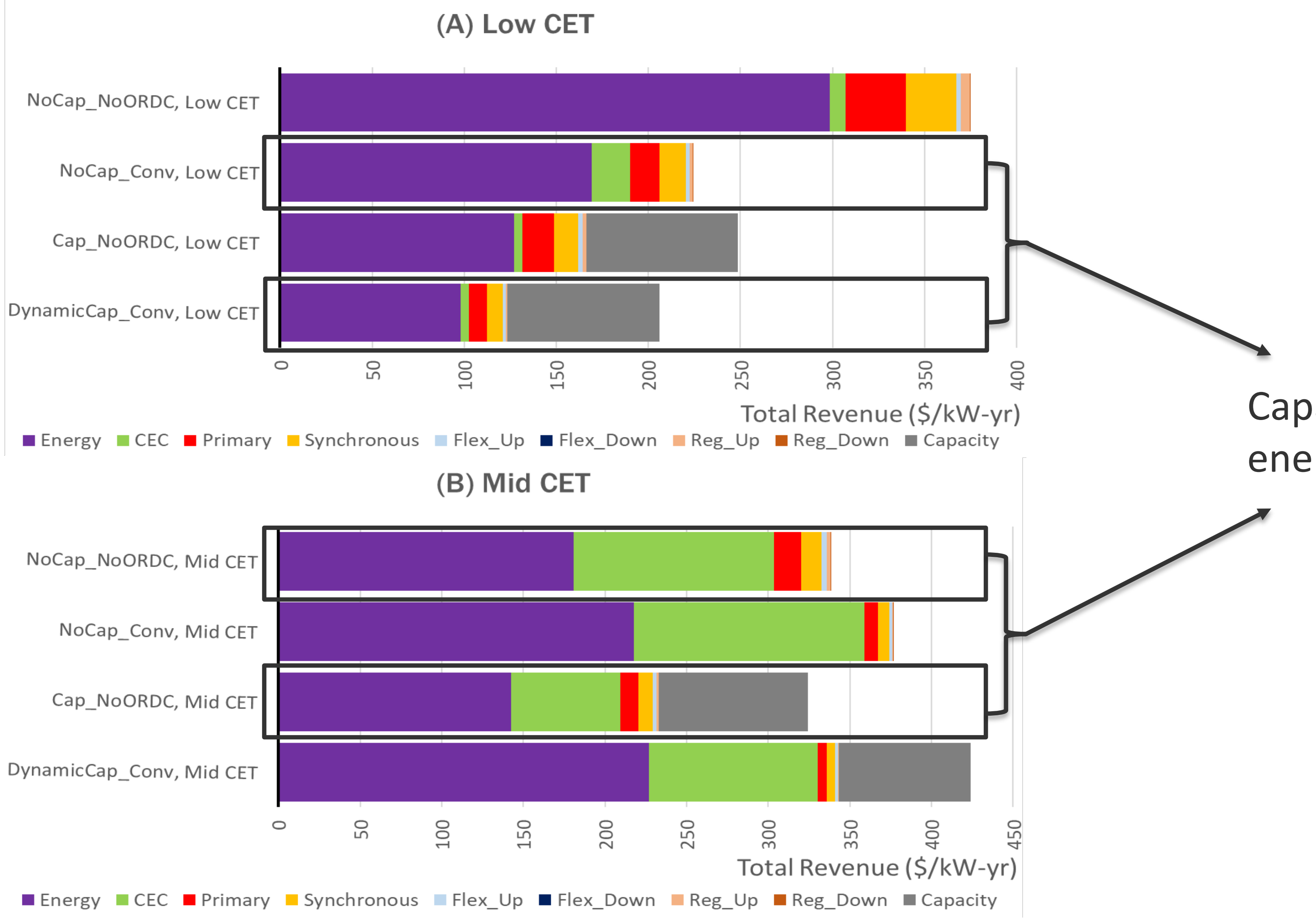
- The presence of ORDCs increases total system costs, including higher carbon costs.
- However, these cases have significantly lower levels of lost load and insufficient reserves, despite having less installed capacity than the corresponding cases with capacity markets. This indicates that ORDCs may increase the commitment of available generation units.

Annual market revenues under different RA mechanisms



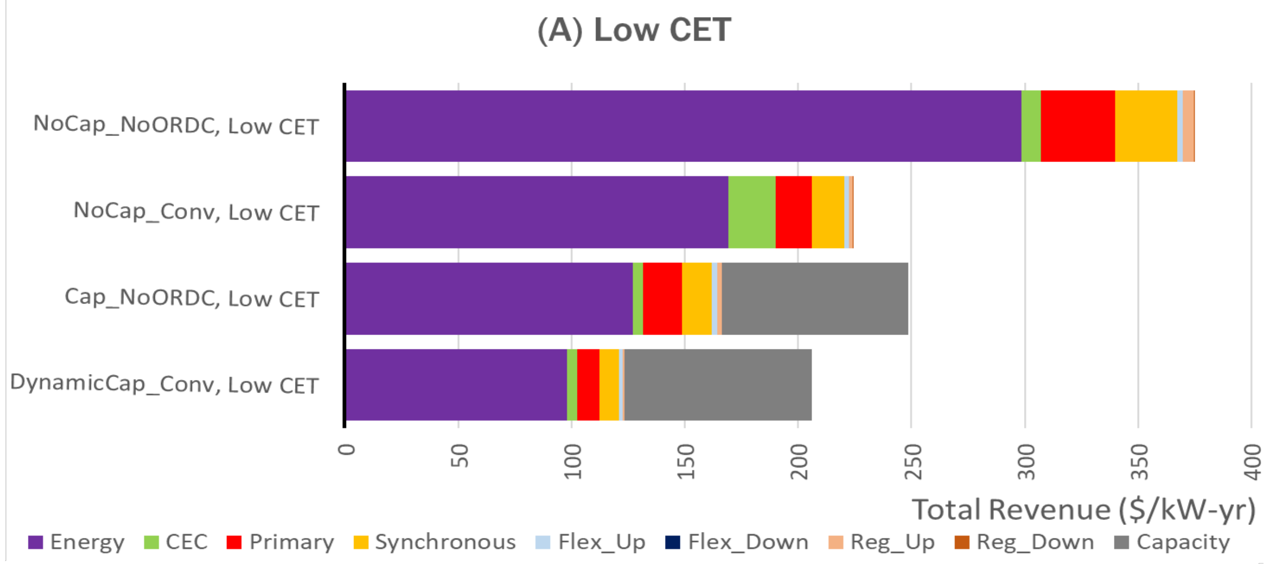
Unusually high energy and ancillary service revenues are due to significantly high number of loss of load and resource insufficiency events in the early simulation years

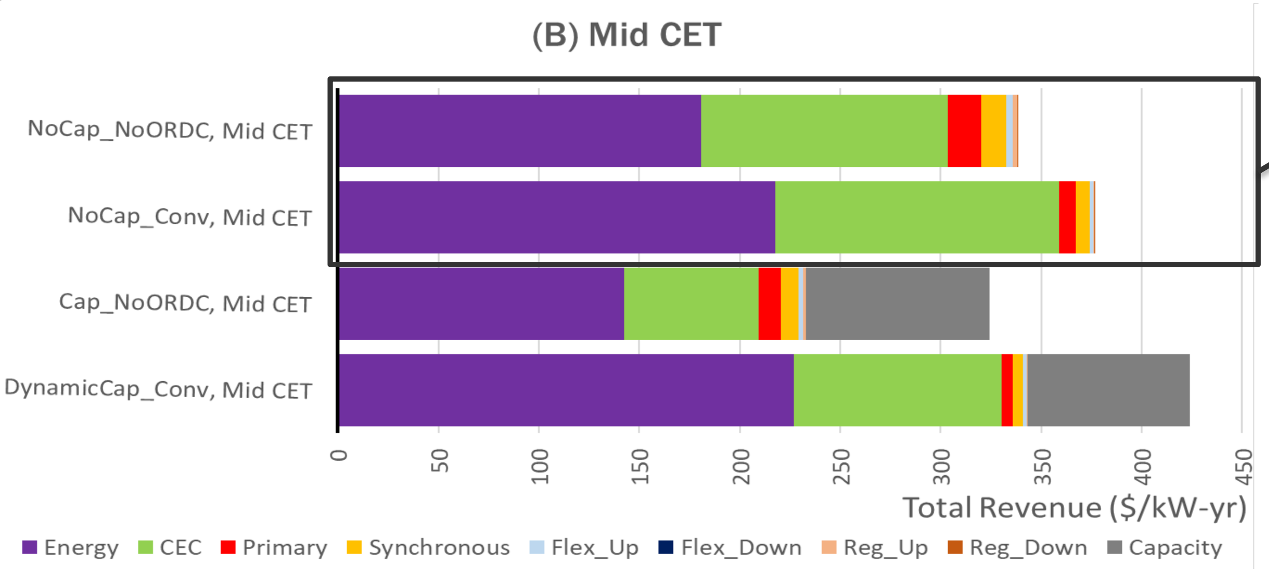
Annual market revenues under different RA mechanisms



Capacity markets suppress energy and REC prices

Annual market revenues under different RA mechanisms

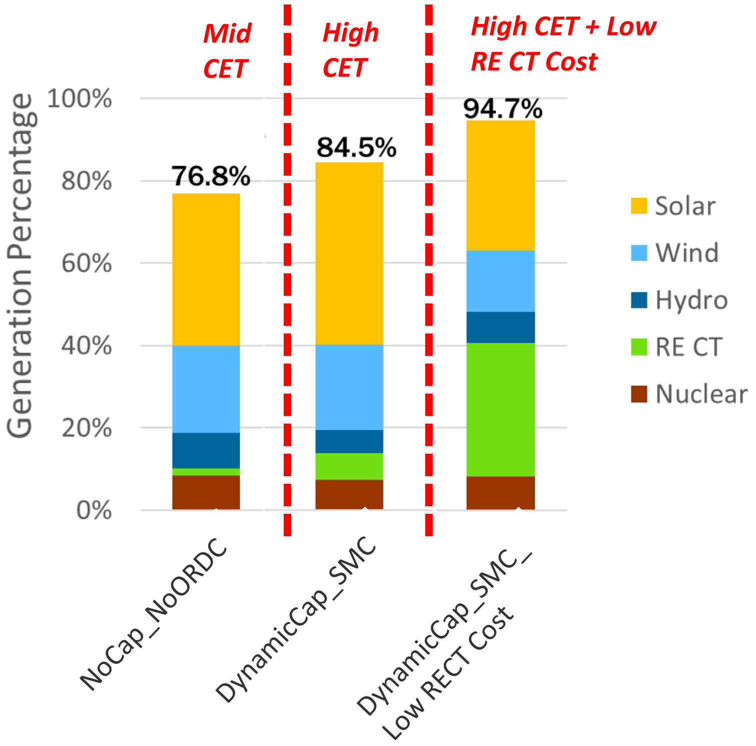




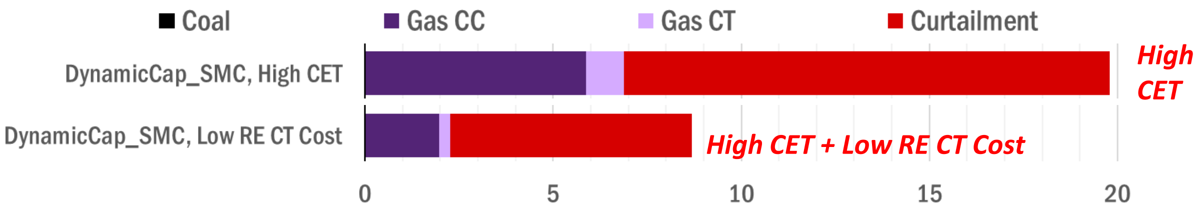
Inclusion of ORDC increases energy market prices and revenues

Reaching "High" Clean Energy Targets (CETs)

Total Annual Generation Percentage by Technology



Total Annual Generation and Curtailment (TWh)



- Achieving very high clean energy generation targets depends on the cost-competitiveness of clean energy technologies that can support balancing needs across multiple timescales

- Total annual wind and solar curtailment substantially exceeds the annual generation output of carbon-emitting resources in the 100% CET case
  - Curtailment is significantly reduced with low-cost RE CTs
  - Points to the potential value which long-duration storage technologies and multiday (or even multi-week) operating products can add to systems as they approach very high CETs

Summary and next steps

- **Summary**
  - The effectiveness of different wholesale market structures are evaluated in an agent-based model -- taking into account the profit-seeking behavior of heterogenous generation investors
  - Our model is able to capture the interactions among different market products, as well as the feedback effects between price/revenue and buildouts
  - Both ORDCs and capacity markets can achieve resource adequacy targets, but with noticeable differences in the types of resources built (e.g., capacity markets favor more capital-intensive peaking technologies)
  - There is a disconnect between annual clean energy targets and operational unit commitment / dispatch
  - The effectiveness of wholesale markets in achieving very high CETs highly depends on the cost-competitiveness of dispatchable clean energy technologies (e.g., RE-CTs)
- **Current and future work**
  - Incorporate multiple years of climate change adjusted data
  - Implement additional operational and settlement structures to better value Long Duration Energy Storage (LDES) and energy availability more generally
  - Explore adoption/discontinuation of certain market products

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Thank you!

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