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Market Solutions for ZMC Systems: PCM-based approaches

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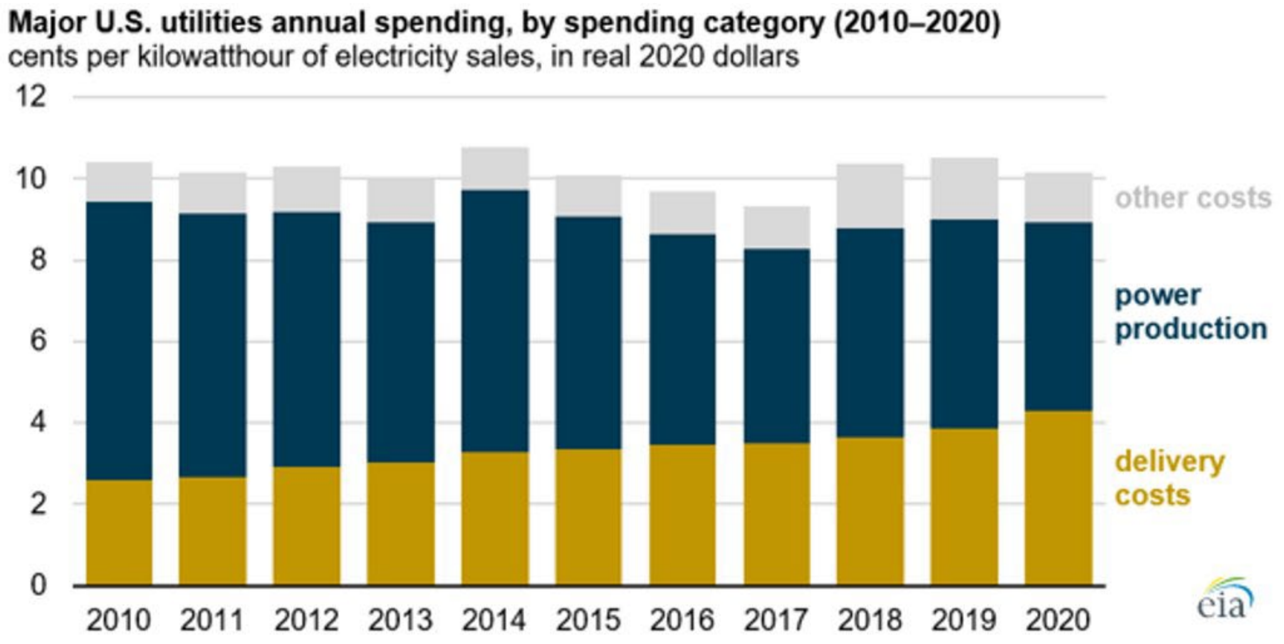
Problem Statement: We need new operations and market models for a decarbonized grid

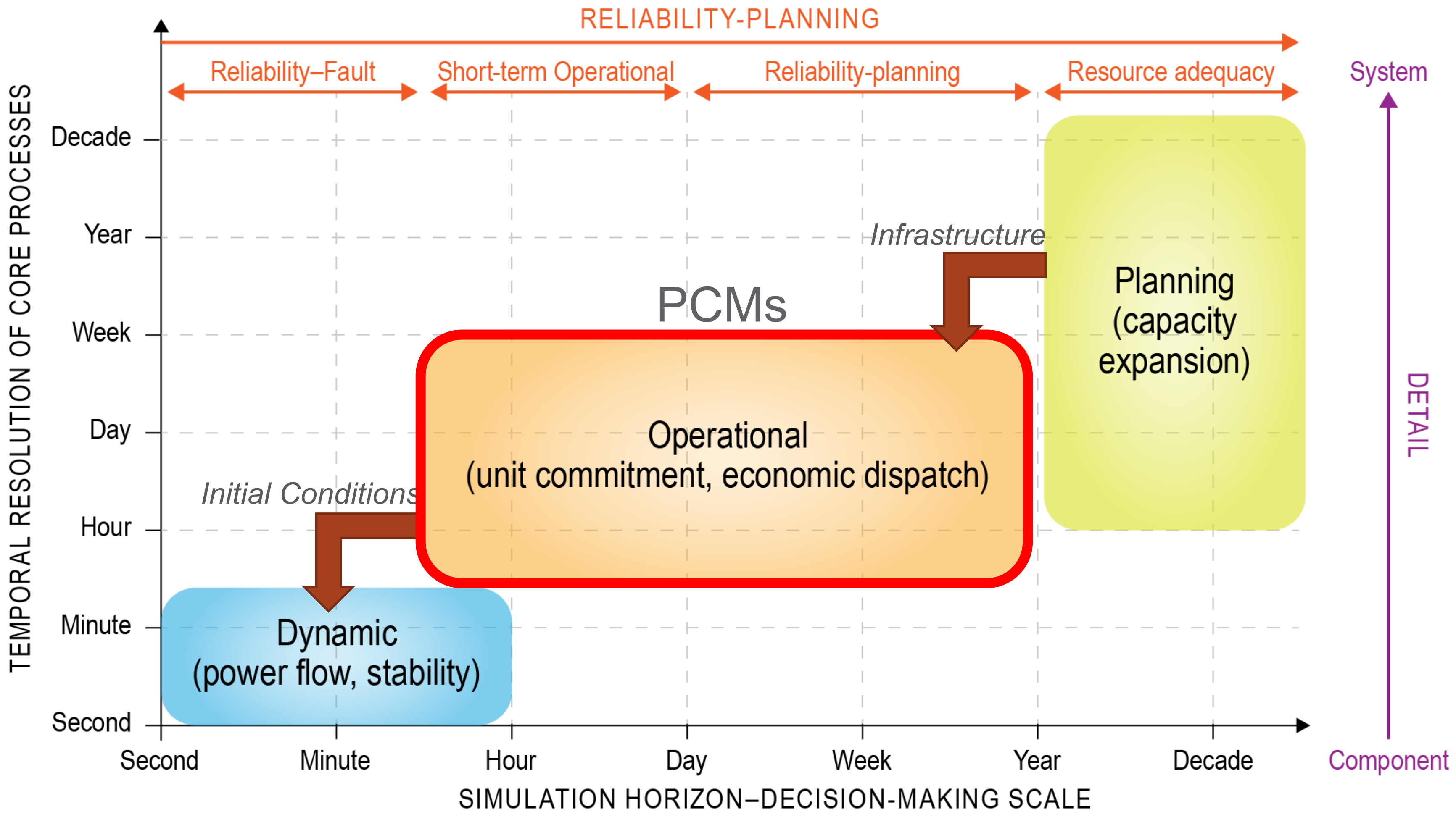
A large body of research has explored pathways to a 60%, 80%, …, 100% renewable (or carbon-free) grid.

- **Motivation:** Once we arrive there, the grid and resources will look very different.
- **Problem Statement:** Current operations and market models may be inadequate for managing a fully decarbonized system with a large proportion of zero-marginal cost resources.



- How do production cost models (PCMs) dispatch and remunerate resources in ZMC systems?
- What will be the ZMC objective function?
- Will revenue uncertainty compromise generation adequacy in the face of new capacity needs?
- How to modify PCMs to incorporate potential policy and market solutions?

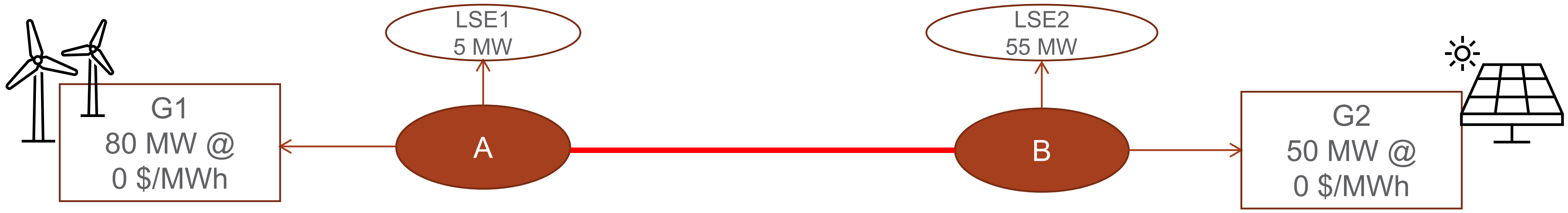
Production Cost Modeling (PCM)



- The dominant model for grid operational dispatch and short-term planning is called ***a production cost model***.
  - Historically rooted in fuel cost for traditional generators
  - Ensured economically efficient outcomes, with additional reliability constraints
  - Proxy for market operations, but with production cost instead of market bids
- With generating resources shifting dominantly to a zero-fuel cost, this conceptualization for prioritizing generator dispatch is likely to be inadequate.

Oikonomou, K., Tarroja, B., Kern, J., & Voisin, N. (2021). Core Process Representation in Power System Operational Models: Gaps, Challenges, and Opportunities for Multisector Dynamics Research. Energy, 122049.

Economic Dispatch with 100% Renewables – Multiple Solutions & Revenue Impacts



Solution 1: No transmission capacity limit

- G1 Dispatch = **5**MW (Bus A) + **40** MW (Export to Bus B)
- G2 Dispatch = **20** MW (Bus B)
- LMP_A= 0 $/MWh, **15** LMP_B = 0 $/MWh
- **$Revenue_A$: $0**
- **$Revenue_B$: $0**

Solution 2: No transmission capacity limit

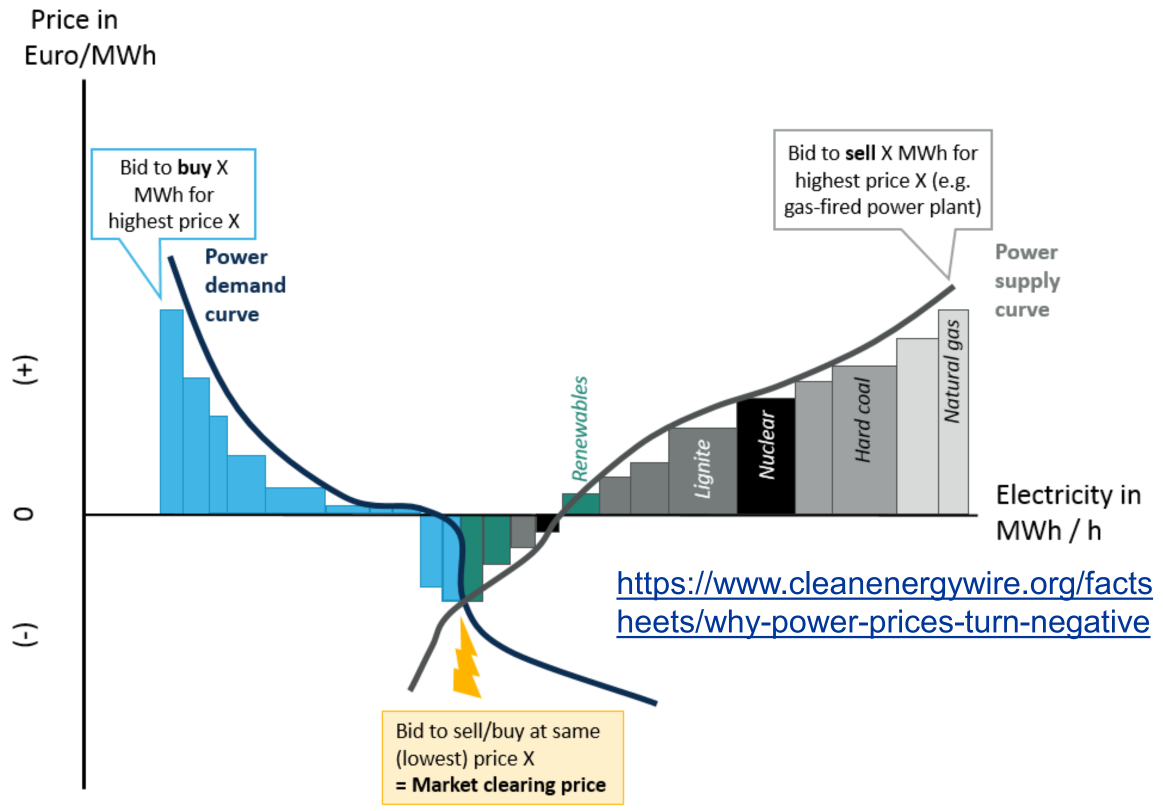
- G1 Dispatch = **5**MW (Bus A) + **39** MW (Export to Bus B)
- G2 Dispatch = **16** MW (Bus B)
- LMP_A= 0 $/MWh, LMP_B = 0 $/MWh
- **$Revenue_A$: $0**
- **$Revenue_B$: $0**

Solution 3: No transmission capacity limit

- G1 Dispatch = **5**MW (Bus A) + **35** MW (Export to Bus B)
- G2 Dispatch = **20** MW (Bus B)
- LMP_A= 0 $/MWh, LMP_B = 0 $/MWh
- **$Revenue_A$: $0**
- **$Revenue_B$: $0**

ZMC Symptoms: Oversupply → Curtailment → Negative Prices

- In ZMC systems negative power prices occur when a high, low-cost, and inflexible power generation appears simultaneously with low electricity demand (oversupply).



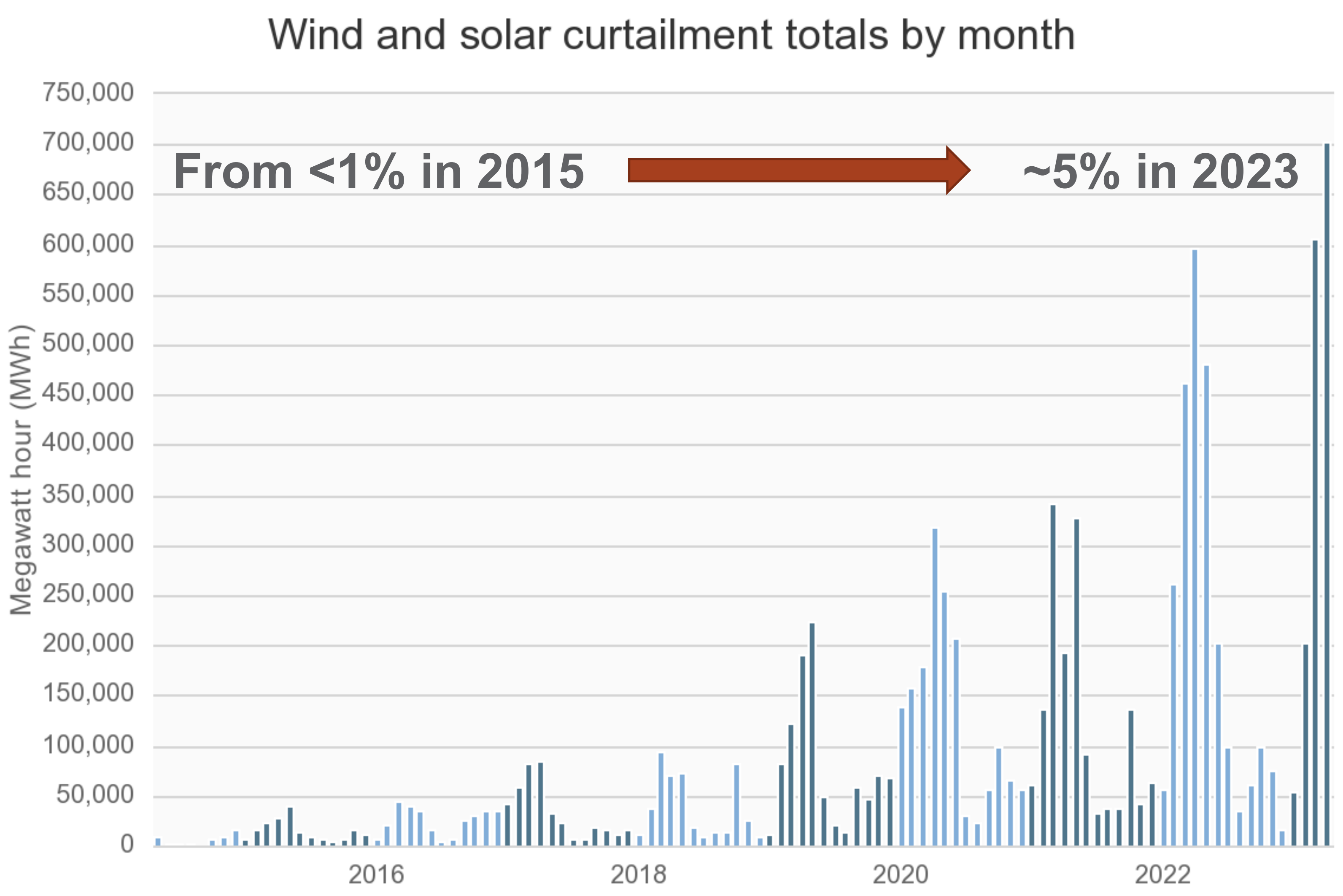
https://www.cleanenergywire.org/factsheets/why-power-prices-turn-negative

Drivers of Negative/Low Prices

- Low-marginal cost renewables
- Decline of fuel prices
- Transmission Limitations
- Policy
- Heat Rate Efficiency Gains
- Physical Constraints/ Inflexibility

- **Certain amount of oversupply is tolerable**:
  - System operators curtail generation before a reliability problem occurs
    - ✓ **Economic curtailment**
  - Reliability becomes an issue only when downward flexibility has been exhausted and there is limited transfer capability
    - ✓ **Technical curtailment**

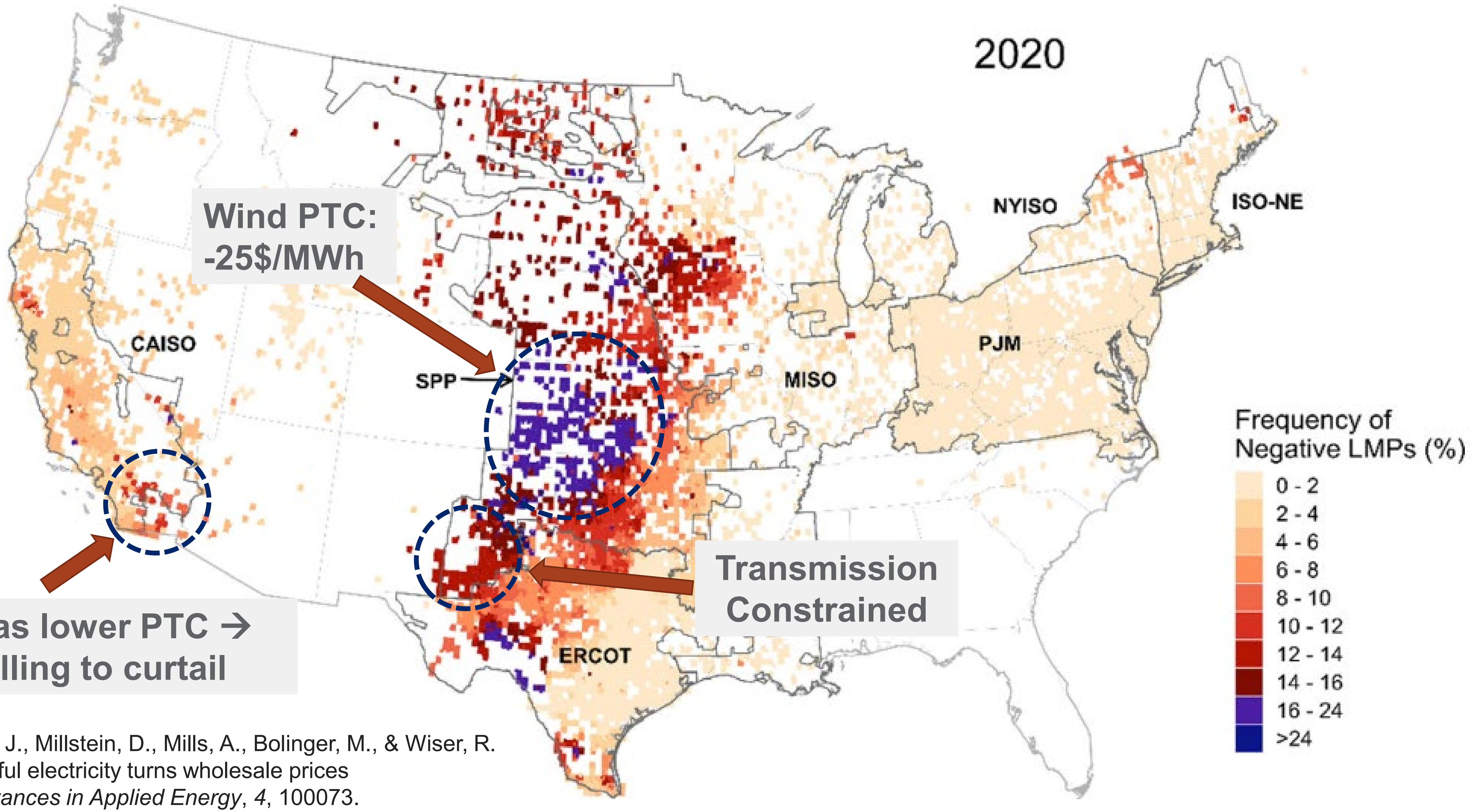
Curtailments on the Rise – California Independent System Operator (CAISO)



(Source-CAISO) http://www.caiso.com/informed/Pages/ManagingOversupply.aspx

- From <1% in 2016 to 5% in 2023
  - **Curtailment at low levels is acceptable and not a problem**
- As states invest more and more in renewable resources curtailment levels are expected to increase
- Types of curtailments
  - **Market Based (system or local)**:
    - Economic
    - Self scheduled
  - **Manual (system or local)**:
    - Technical (Operator exceptional dispatch)

Frequency of Negative Marginal Prices at Nodes in the 7 Organized Wholesale Markets in 2020



Source: Seel, J., Millstein, D., Mills, A., Bolinger, M., & Wiser, R. (2021). Plentiful electricity turns wholesale prices negative. *Advances in Applied Energy*, *4*, 100073.

Implications of Negative/Low Energy Prices

- Perspectives differ on whether the presence of negative or low prices imply an actual problem:
  - **Pros**:
    - ✓ Renewable electricity is delivering carbon free energy every MWh → **Societal Benefits**
    - ✓ Needed to provide sufficient downward flexibility → **Avoid technical curtailment**
  - **Cons**:
    - ✓ Policies that encourage negative bidding, including the PTC and RPS mandates, **distort the market** and **increase the size of payments to inflexible generators**
    - ✓ Could lead to exercising market power with extreme low bids in RT

- **Investment signals**: Low (and negative) electricity prices could result in price signals that do not lead to long run price expectations that adequately incent efficient investment decisions.
  - Unless policy incentives continue to exist or switch to PPAs

- **Loss of value in fossil fuel assets (stranded assets) that could lead to early retirements**
  - Increase of O&M costs incurred by thermal cycling
  - Additional investments in zero carbon flexible resources come with a high cost

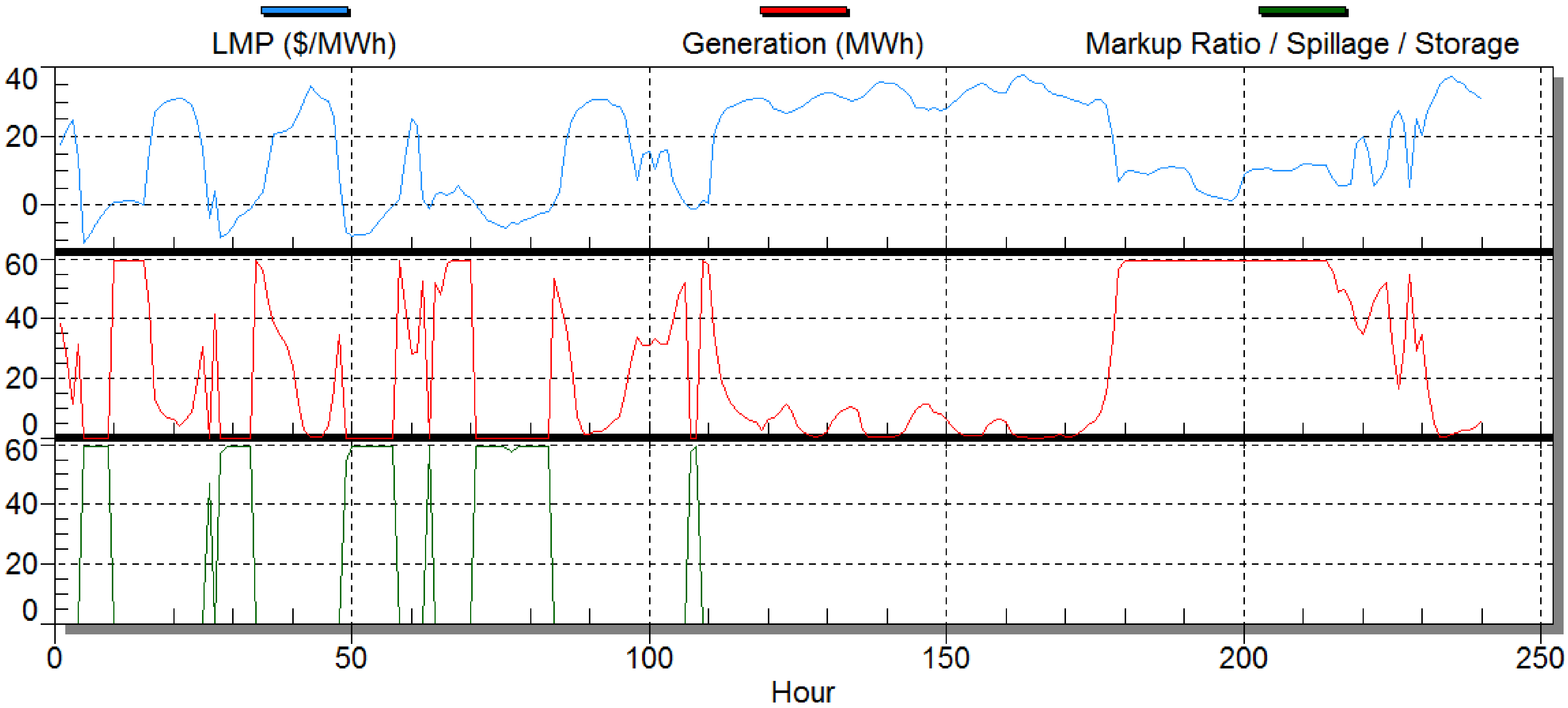
Market Design Allows Curtailment (and negative prices) via the decremental bidding process

- In 2013, FERC approved RTOs proposal to create a **bidding floor** to more efficiently address a growing “over generation” problem due increasing renewable resources
- RTOs must pay generators **not to produce**, so they solicit “**decremental bids**” from generators to express the price at *which they would be willing not to be dispatched* (***Market Based Curtailment***).
  - If there are too few bids to decrease output, RTOs must address the over-generation condition by issuing dispatch instructions (**Exceptional Dispatch**) → can result in the inefficient dispatch of resources
  - To encourage variable resources to make decremental bids, FERC approved CAISO’s proposal to lower the bid floor to **-$150/MWh** (from -$30/MWh before 2013) to ingest production tax, renewable energy credits, other incentives/revenues or contract penalties.
  - Renewable resources can submit economic decremental bids and still **cover their opportunity costs for not producing – loss of production**.

Decremental Bids in Production Cost Models – Sources of Negative Prices during Overgeneration

- Decremental bids are placed by technology type and load area

Generator	M1	M2	M3	M4	M5	M6	M7	M8	M9	M10	M11	M12
ArlingtonWind	-15	-15	-15	-15	-15	-15	-15	-15	-15	-15	-15	-15
Arrow Canyon Solar	-25	-25	-25	-25	-25	-25	-25	-25	-25	-25	-25	-25

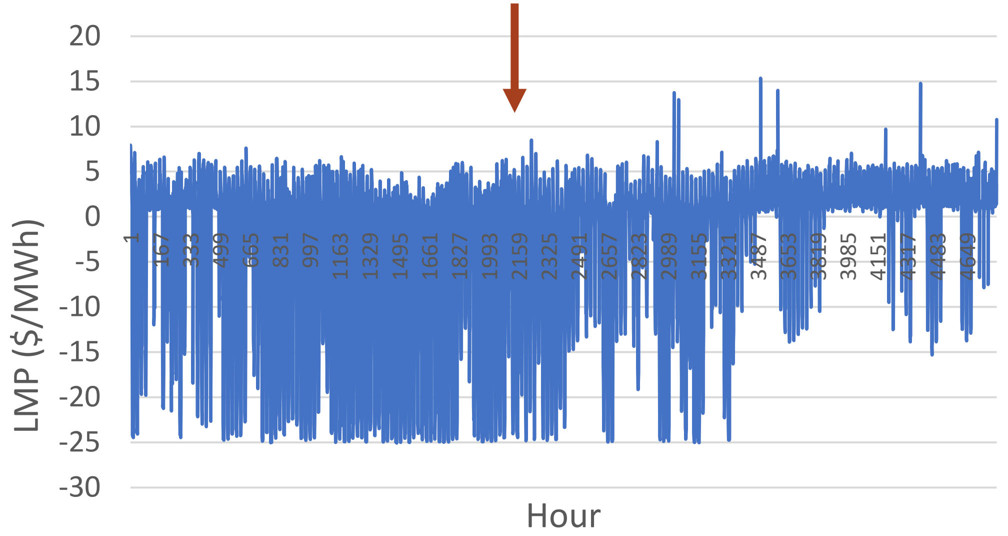


Modeling Framework

Large Scale PCMs (WECC) - GridView

1. Decarbonization scenarios

2. Identify operational issues that result from existing modeling gaps



Simplified - Open Source PCMs

3. Test Market & Policy solutions to address PCM modeling gaps in ZMC environments:

- Extended Operating Reserve Demand Curves (ORDC) and Weather Driven Reserves
- Water Values in hydro-dominated systems
- Price-responsive demand

1 Decarbonization scenarios

Scenario Development

The problem space needs to be comprehensively analyzed:

- Evaluate the extent of this issue, based on **different decarbonization scenarios**

Scenarios	Description
1	Industry Planning Case (WECC 2030 ADS)
2	Scenario 1 + 30% Retire Coal and Repower with Wind and Solar
3	Scenario 1 + 100% Retire Coal and Repower with Wind and Solar
4	Scenario 3 + **Storage**
5	Scenario 3 + **Transmission**
6	Scenario 3 + **Storage + Transmission**
7	Scenario 6 + **50% NG retirements**

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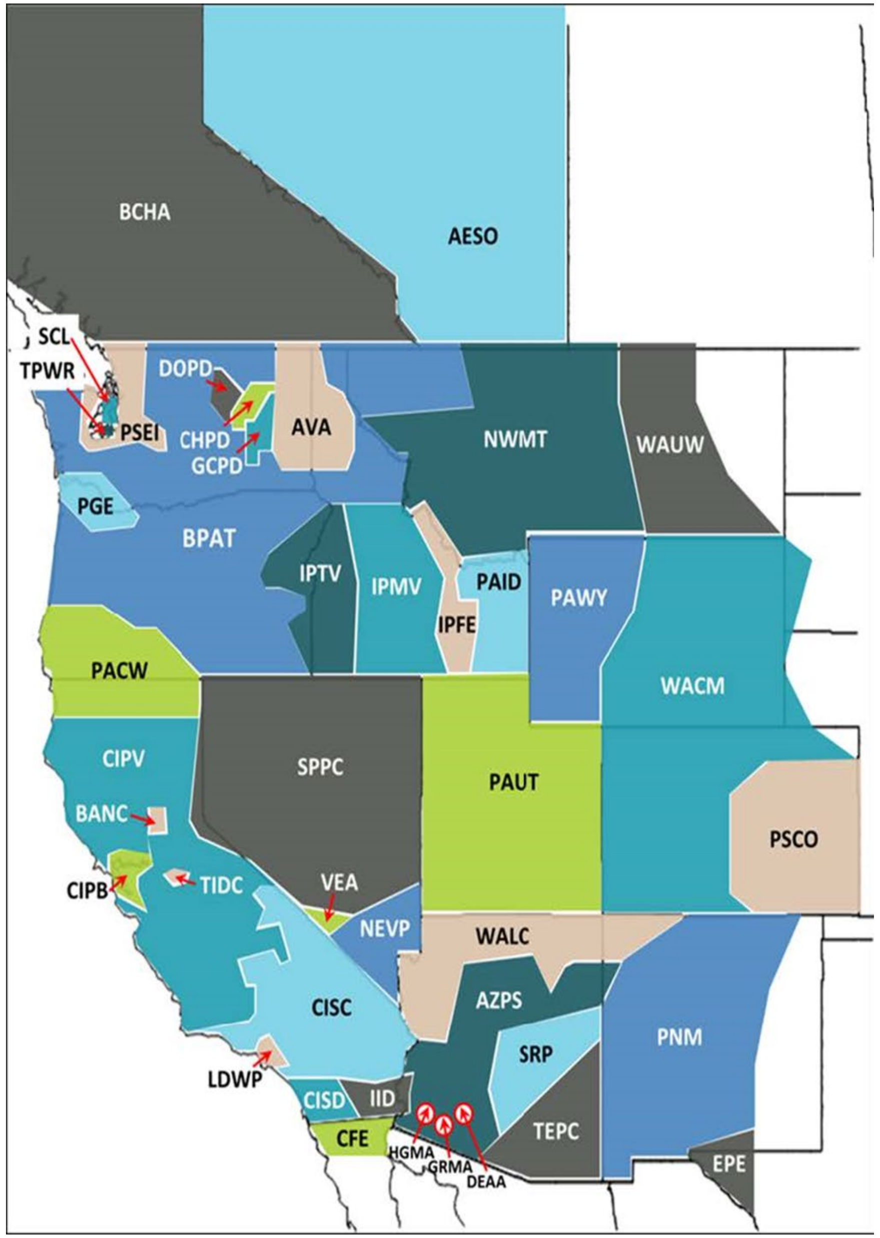
Industry Planning Case (WECC 2030 ADS)

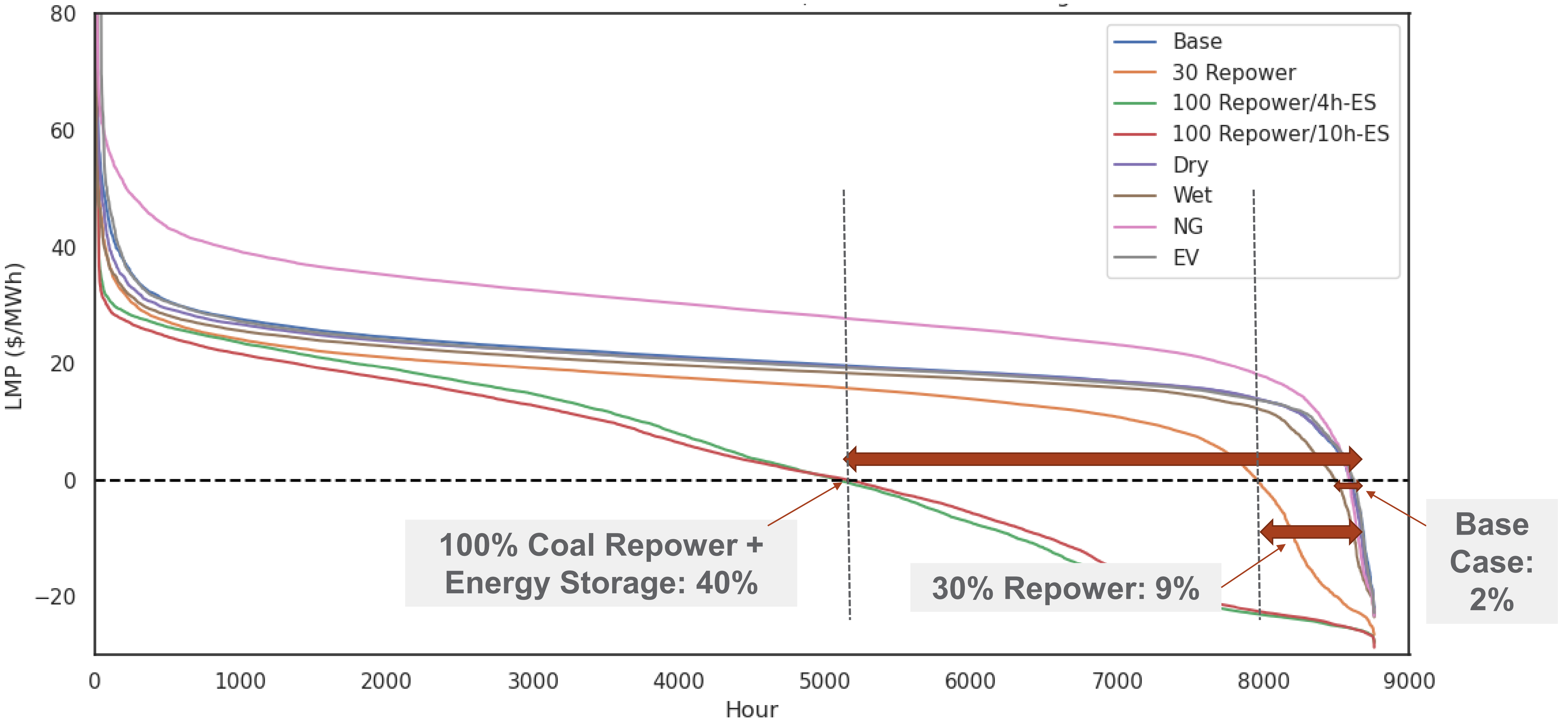
- The WECC 2030 Anchor Data Set (ADS) Production Cost Model (PCM) **represents the best available projection of new generation, generation retirements, transmission assets**, and load growth **10 years in the future from a given reference year**.
- There are **38 functional Balancing Authorities** (BA) in the Western Interconnection.
- The WECC 2030 ADS provides a detailed representation of the WI power grid topology: **~22k nodes and ~26k transmission lines**
- Modeling Assumptions:
  - The transmission network topology for the WECC 2030 ADS PCM was carried over from the 2030HS1 (Heavy Summer) Power Flow.
  - The wind hourly shapes use 2009 NREL wind speed and weather data, while the solar hourly shapes are using 2009 NREL irradiance and weather data.
  - Hydro resources are modeled using monthly average generation values from the EIA 906/920 for the year 2009, which is considered an average hydrologic year
  - The hourly load profiles are projected for each WI load area using with a 2009 historical load shape



https://www.wecc.org/Pages/home.aspx

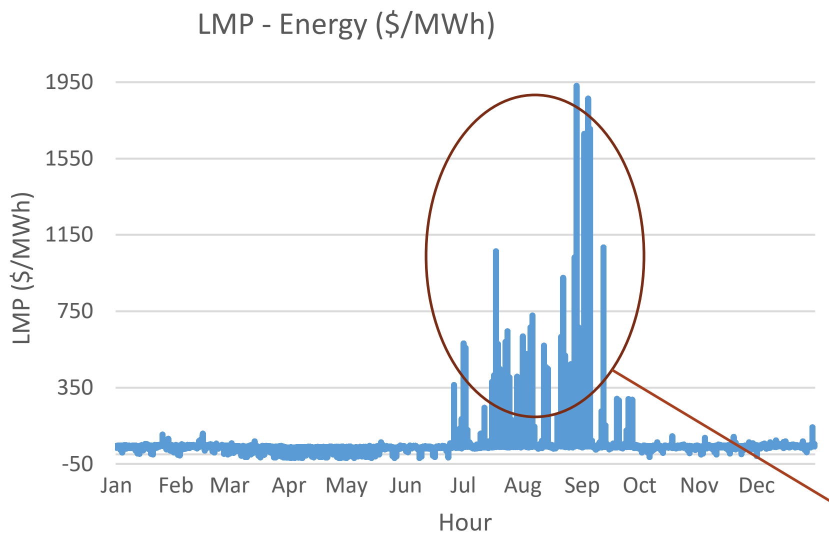
Price Duration Curves (WECC Wide)

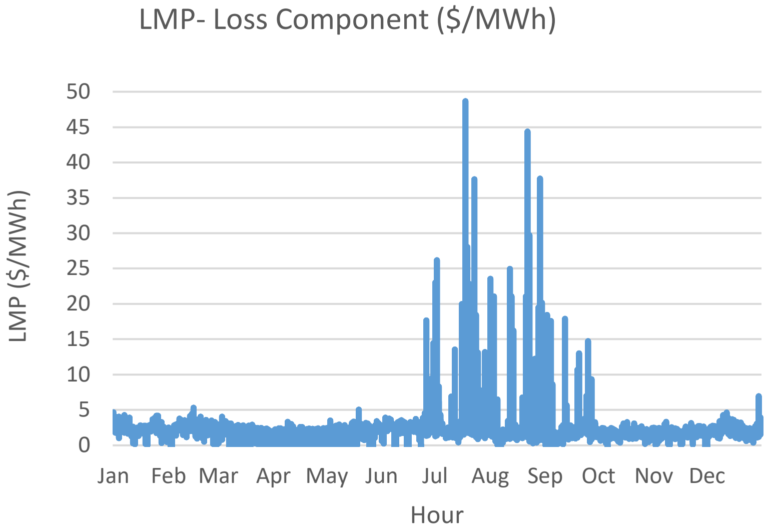
2
Identify operational issues that result from existing modeling gaps

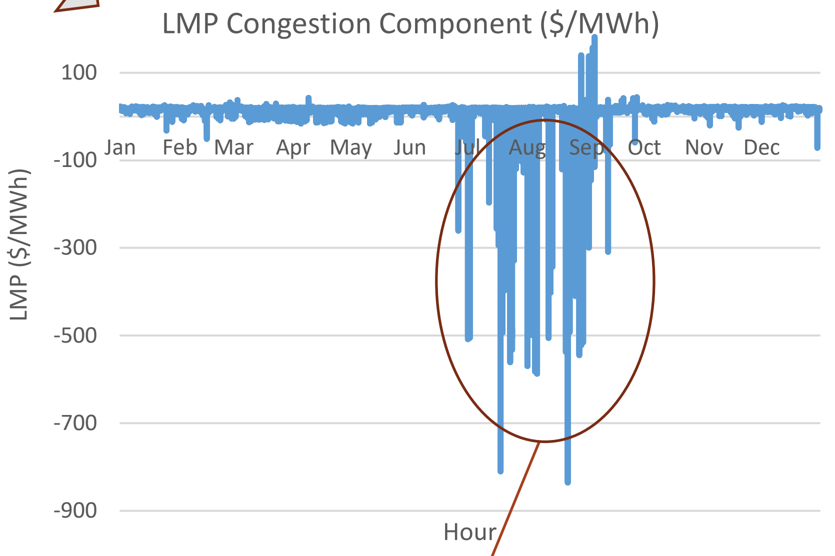


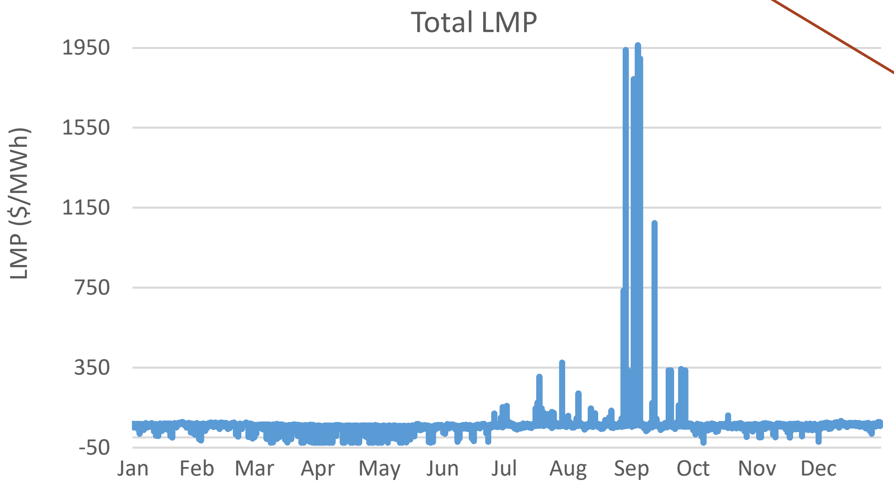
100% Coal Scenario: Price Decomposition for CAISO

$$LMP = LMP_{energy} + LMP_{losses} + LMP_{congestion}$$









Energy component is identical for all BAs (centralized optimization); load shedding penalty is responsible for high values

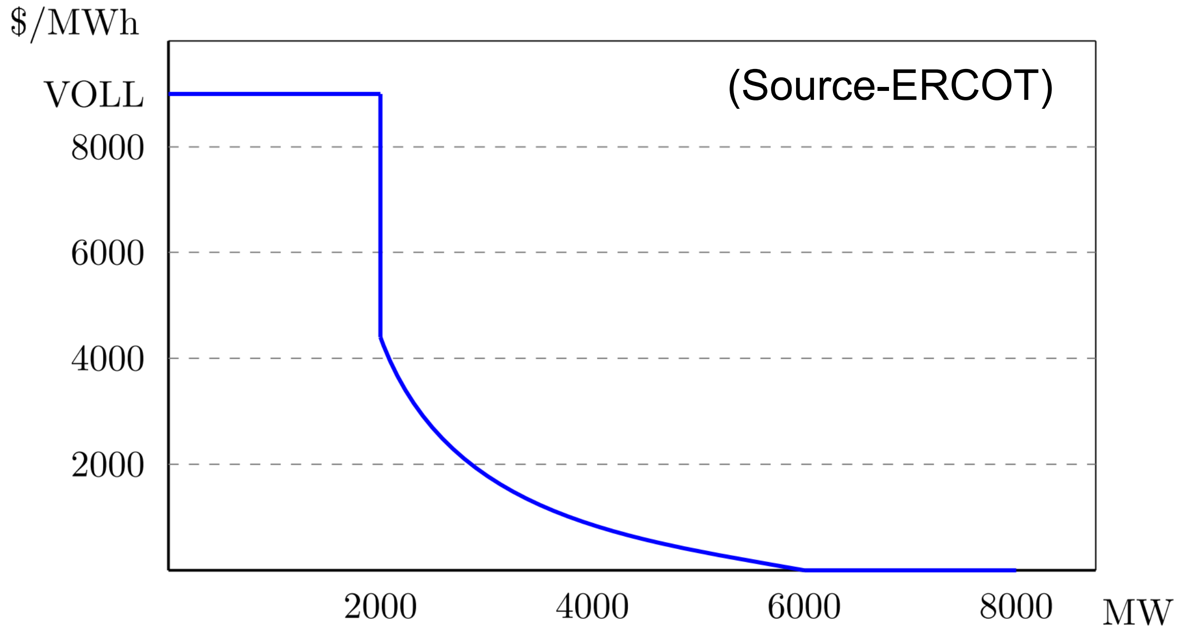
Negative congestion prices indicate that there are transmission limitations preventing lower cost generation in CIPV from **flowing to other locations**

Solution 1: Operating Reserve Demand Curves (ORDC)

3

Test market & Policy solutions to address PCM modeling gaps in hydro-dominated environments:

- The idea of the ORDC is to replace the fixed reserve requirement with the variable value of different levels of operating reserves.
  - This is analogous to replacing a fixed load requirement with the variable value of different levels of operating reserves.
- The ORDC is a market-based construct for valuing operating reserves according to their scarcity.
  - Incentivize generation for being there when it is needed. In its essence, as system reserves begin to fall, these adders begin to kick in.
  - Gradual increases in the reserve violation penalty are calculated based on value of lost load (VOLL) times the loss of load probability (LOLP) due to the procurement of additional reserves.
- Situations that drive prices to the cap depend on **weather**, generation performance and other factors.



Operating Reserves

Weather-dependent reserves based on correlated renewable variability can be another option of procuring reserves

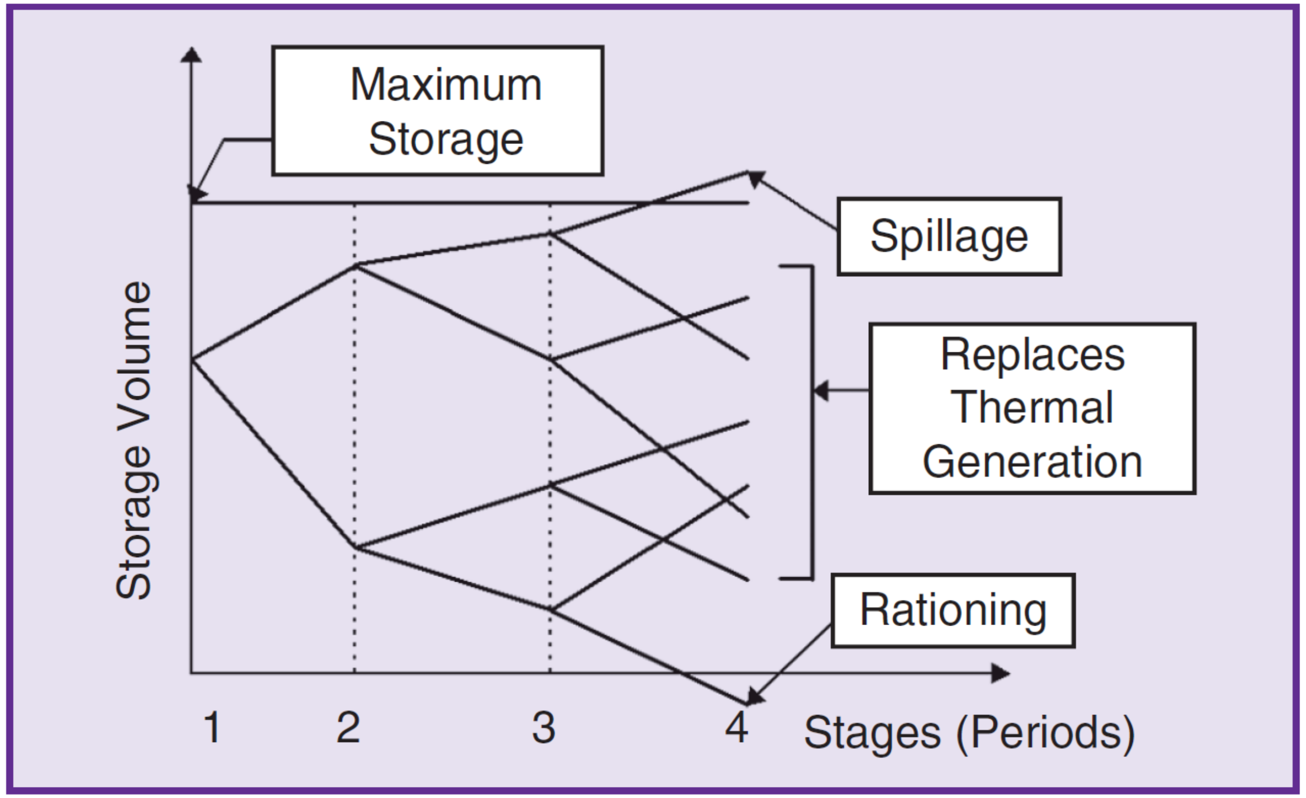
Solution 2. Use of ORDC-logic to Calculate Water Values in hydro-dominated systems

3

Test market & Policy solutions to address PCM modeling gaps in hydro-dominated environments:

- Provided that all available generation resources have zero marginal cost, the water value can be approximated by the product of the VoLL multiplied by a probability of energy shortages, reflecting **the opportunity cost of not having water for generating power** in the near future.

Opportunity Cost of Water



Barroso, Luiz, et al. "Zero-marginal-cost Electricity market designs: Lessons learned from hydro systems in Latin America might be applicable for decarbonization." IEEE Power and Energy Magazine 19.1 (2021): 64-73.

The water value is zero in scenarios where dams are overflowing, which is often the case in extremely **wet seasons**.

In scenarios with **intermediate inflows**, the value of water is usually equal to the cost of the cheapest thermal plant in the system

When the system is unable to meet demand **in a given dry scenario and stage**, the opportunity cost of water is equal to the cost of unserved energy

Solution 3. Price Responsive Demand

3

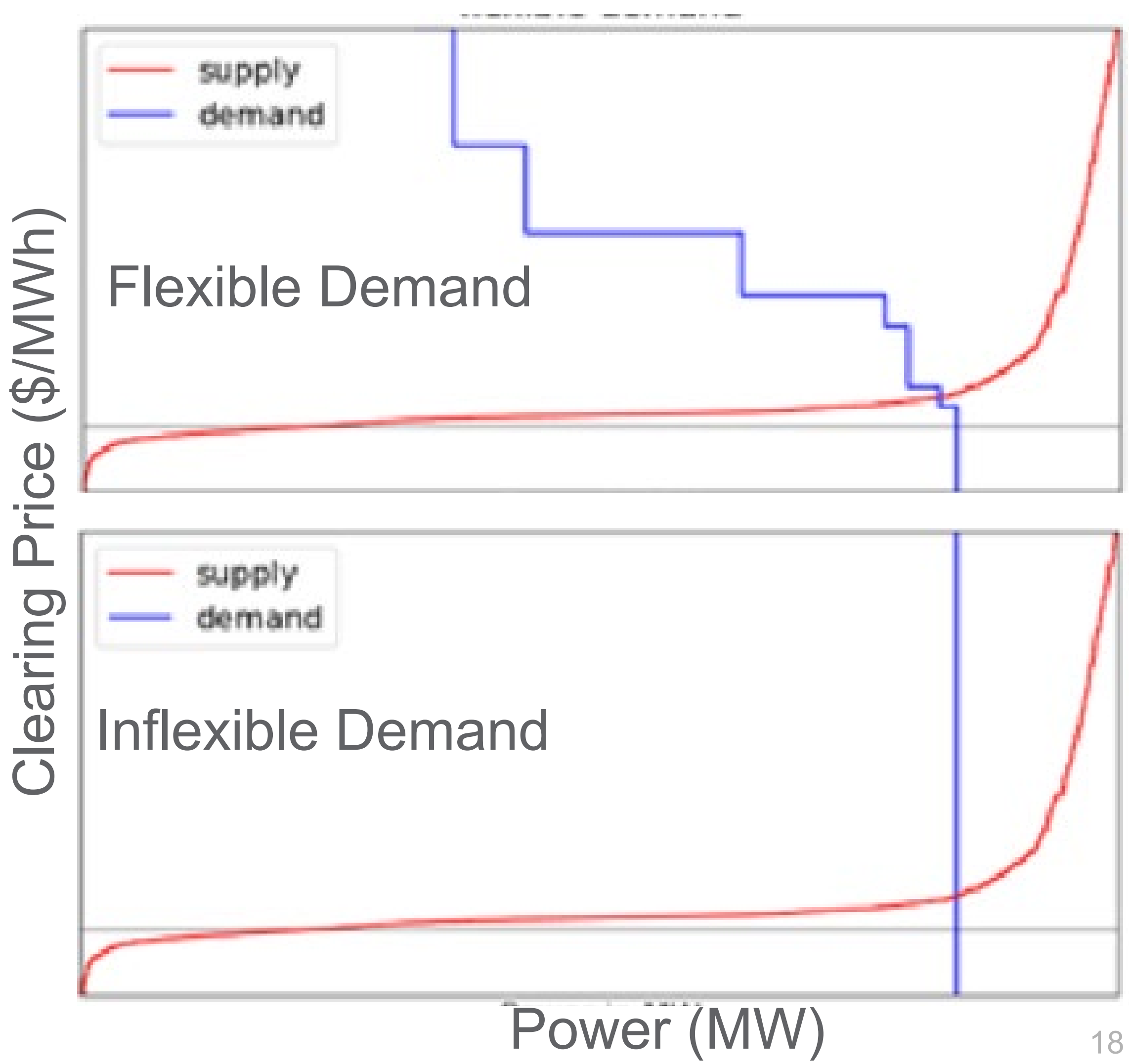
Test market & Policy solutions to address PCM modeling gaps in hydro-dominated environments:

- Enhance flexibility demand initiatives could enable adjustments in consumer demand, both up and down to balance the uncertainty from renewables.
  - Industrial energy-intensive consumers
  - Power-to-X" demand curves (e.g., water sector)

- Flexible demand could participate in the energy and reserves market by submitting a bid value for the energy consumed
  - Energy consumers could be grouped into different energy bid valuations based on reliability preferences.

- Bid values could reflect the potential reduction in reliability (i.e., demand that provides reserves will be curtailed first if there is a supply shortage -VOLL)

- Wholesale prices in the presence of flexible are determined by a combination of consumer demand and opportunity costs.



Other Potential Solutions (not necessary within the scope of the PCM-based approaches)

Technology	Other Market Design Reforms	Out of Market Policies
Transmission Upgrades (conventional upgrades, MTDC, DLR, FACTS, etc)	Intra-day markets	Power purchase agreements
Storage and hybrid energy storage systems	Longer look ahead horizons in both DA and RT	Carbon pricing
	Decentralized Markets	
	Energy Imbalance Market	
	Opportunity costs for non-power commodities (water, hydrogen)	

Key Takeaways

- **Periods with surplus renewable generation may see prices fall to or below zero**
  - VRE bids offer a priority curtailment strategy based on out-of-market opportunity costs
  - This could be a temporarily solution as VRE is not supposed to curtail at high levels
  - Reliability concerns arise with limited transmission

- In ZMC systems, **flexibility needs will be provided by some combination of hydropower resources, energy storage technologies, and flexible demand-side participation**.
  - The ideal role of the demand side in operations models is not very clear
    - ✓ Bid using application-specific participation models or more generic bid formats
    - ✓ Individual end-users or through aggregators
  - Opportunity cost for water/hydro is difficult to predict and incorporate in traditional centralized PCMs
    - ✓ Combining probabilistic values of water with large scale PCM models

- Could be **a shift in what types of optimization tools will be most appropriate for ensuring reliable and economically efficient wholesale power markets**: cost-based vs. bid based vs. PPA based vs. Stochastic/SDDP or a combination.
  - Computational cost might be prohibited for some detailed formulations while others may simplify assumptions
  - Objective function may be adjusted to include more components: opportunity and scarcity costs / benefits from procurement of reserves, penalties for violations, storage charging cost, etc. What else?

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Thank you

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