Capturing Evolving Resource Adequacy Challenges in Market & Planning Simulations

AN APPROACH FOR INCORPORATING LONGER-TERM UNCERTAINTIES INTO PLANNING STUDIES

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Brattle

Bulk System Planning Faces a Range of New Challenges

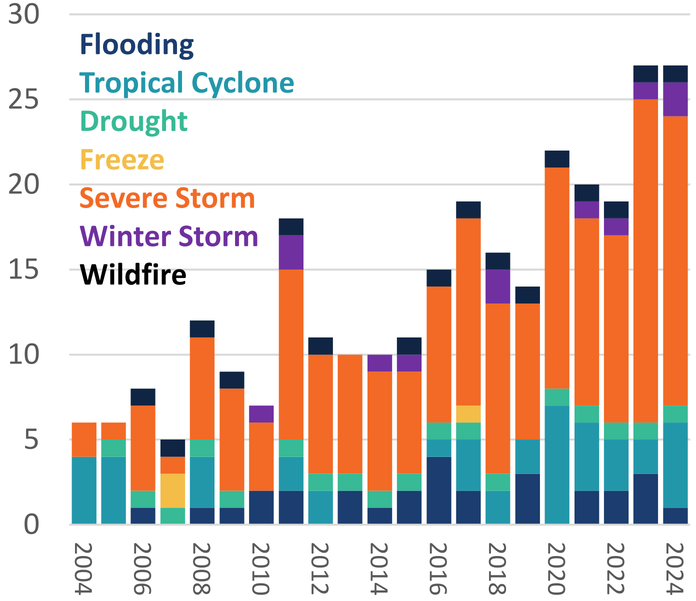
System planning aims to meet anticipated future needs at the lowest cost (and ideally with lowest regret)

- The electric sector is in a period of rapid evolution and facing new and amplified risks to maintaining reliability
- Approaches to planning must be periodically re-evaluated to ensure they adapt to shifting needs drivers

Examples of Key Risk Drivers

Increasing Extreme Weather Event Frequency

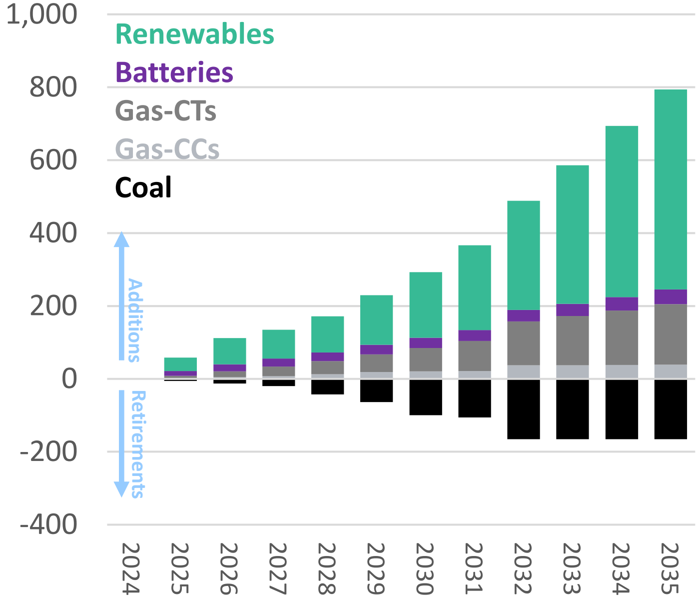
Count of billion-dollar weather events



Source: NOAA billion-dollar disaster event dataset

The Evolving Electric Supply Mix

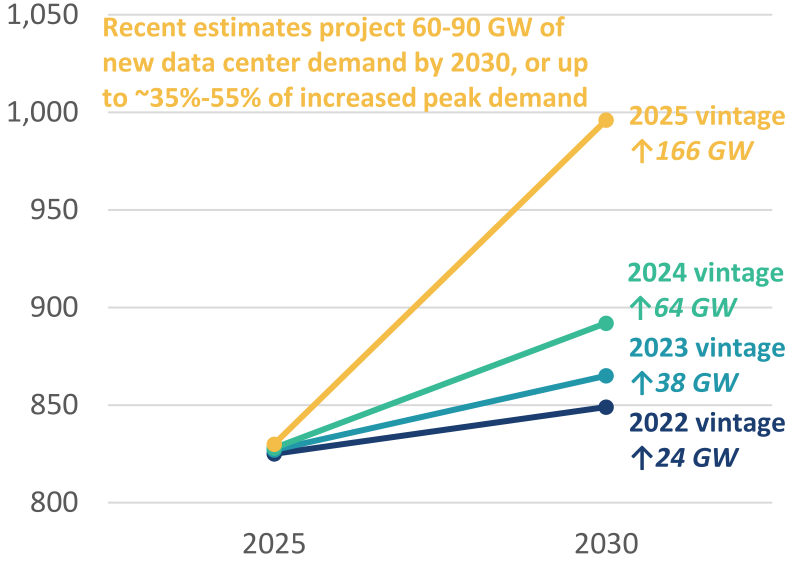
AEO-projected additions/retirements



Source: AEO 2025 Reference Case

Resurgent Electricity Demand, including from Data Centers

Increasing Projections US Peak Demand



Source: Adapted from GridStrategies Power Demand Forecasts Report, November 2025

The Constellation of Bulk Power System Planning Models

Bulk power system planning relies on a range of models and analyses to estimate future system needs and identify and evaluate the effectiveness and cost of solutions that meet those needs

Resource Adequacy
How much capacity is needed to meet anticipated future load given supply & demand uncertainties?

Planning assessments conducted at utility, state, and regional level, with varying degrees of coordination

Capacity Expansion
What mix of resources should be built/retained to meet RA and other system needs (e.g., for flexibility) and the costs associated with that mix?

System Needs & Solutions

Production Cost
Can the system be reliably operated and at what cost under anticipated load, resources, and transmission developments?

Power Flow and Stability
Is the system secure under anticipated the load, resources, and transmission (within voltage, stability, thermal limits under plausible operating scenarios)?

Note: for clarity we do not show the numerous subsidiary models, e.g., for load forecasting, needed to develop assumptions for BPS analyses, though these are also important

Evolving Needs Require Reassessing Conventional Frameworks

Emergent needs drivers, such as more frequent extreme weather events, an evolving supply mix, and the characteristics of new demand sources, may require enhancements to the conventional RA

Resource Adequacy
How much capacity is needed to meet anticipated future load given supply & demand uncertainties?

Planning assessments conducted at utility, state, and regional level, with varying degrees of coordination

Capacity Expansion
What mix of resources should be built/retained to meet RA and other system needs (e.g., for flexibility) and the costs associated with that mix?

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Resource Adequacy Needs Drivers: Past, Present, Future

The list of needs drivers that must be captured to conduct a meaningful RA analysis continues to grow

Expanding RA scope

Historically

- Forecasted peak demand & peak demand uncertainty
- Unanticipated resource outages (largely thermal)
- Expected hydro availability

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Current

- Net load and chronological needs (e.g., flexibility)
- Weather-driven uncertainty (e.g., renewables output)
- Extreme weather events
- Correlated risks (e.g., outages and cold snaps)
- Water availability scenarios
- Energy storage impacts
- Demand-side measures
- Deliverability limits
- Role of non-firm transfers

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Emergent

- Non-traditional sources of demand (e.g., data centers, electrification)
- Interregional transfers and coordination (e.g., through broader markets or expanded/new regional RA programs)
- New technologies (e.g., long-duration storage)
- Large-scale demand-side flexibility, e.g., from EVs
- Dynamic resource accreditation (interdependency of ELCC and capacity mix)

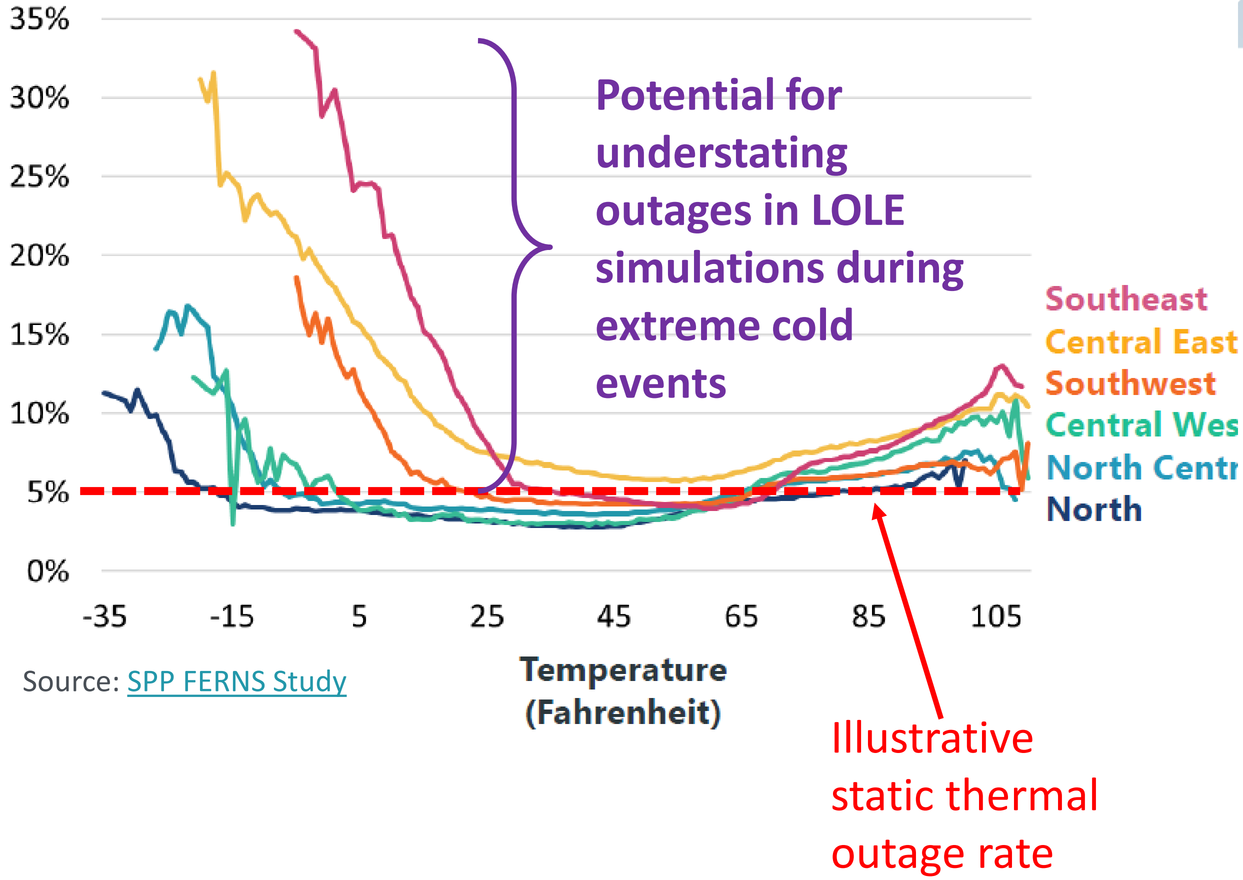
Example: Extreme Weather Impacts on Outage Risks

Recent extreme weather events have highlighted the important linkage between extreme temperatures (mostly cold) and power plant availability

- Conventional resource adequacy assessments typically use static outage rates, which may understate risks in resource adequacy simulations (e.g., due to under-representing outages during heat waves or cold snaps)
- This may in turn result in assessed reserve margins that do not adequately reflect long-term capacity needs

Potential Solution: explicitly model temperature dependent outage rates as part of weather scenarios in resource adequacy assessments

Example: SPP Temperature-Based Thermal Plant Outage Rates



Source: SPP FERNS Study

Example: Interregional Transfer Value

Interregional transfers are often available during weather-driven scarcity events due to the geographic diversity of weather events, load, and renewables availability, allowing neighboring regions to deliver support without jeopardizing their own needs

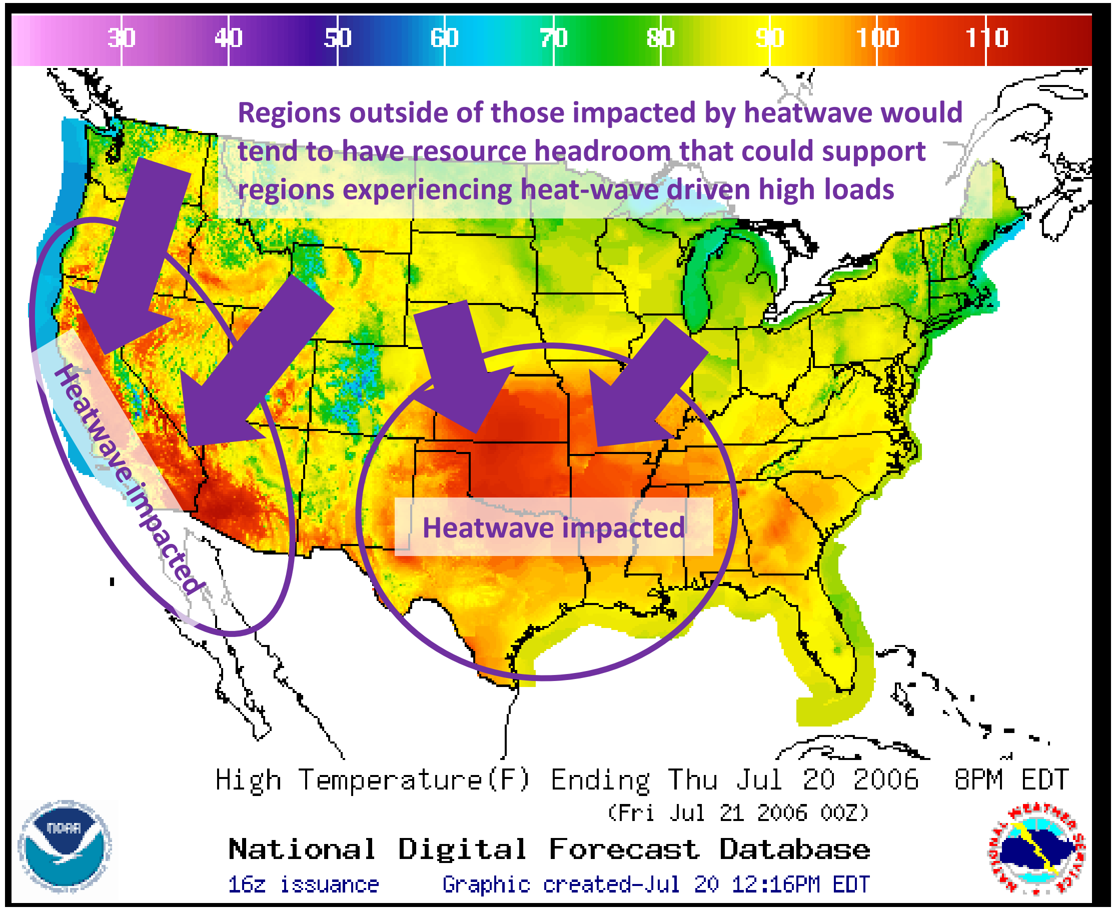
- Such support is typically in the form of non-firm transfers
- Non-firm transfers are often underrepresented in conventional resource adequacy assessments though they have resource adequacy value (just less value than firm transfers), which can overstate resource adequacy risks

Consistently valuing non-firm transfers in RA assessments can reduce internal needs and associated costs

- Some existing RA frameworks recognize this geographic diversity value in their PRM calculations (e.g., those in ISO-NE and NYISO)

Potential solution: model neighboring systems with sufficient detail to explicitly assess RA value of non-firm imports

Historical Heatwave Temperatures (July 2006)



Source: NOAA

Example: Intra-Regional Transmission Limits

Matching supply and demand in every hour depends on both the availability of resources to meet demand, and the capability of the system to deliver those resources to load

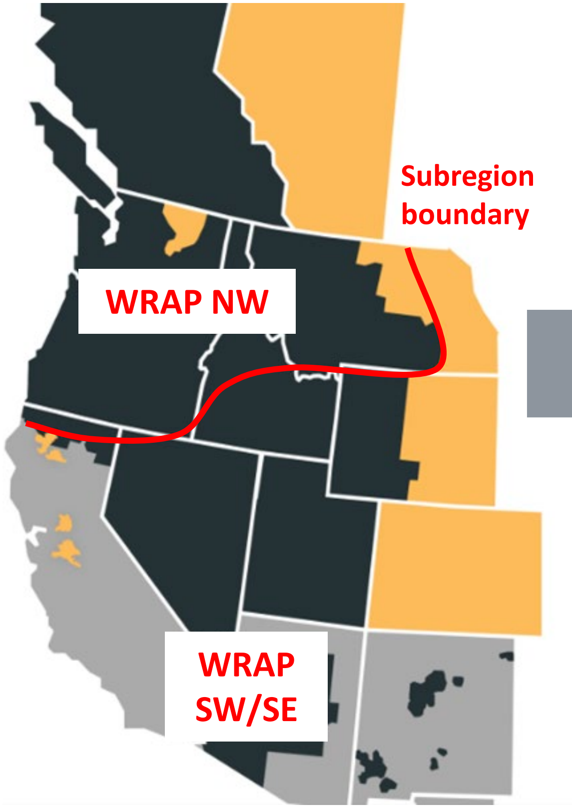
- Conventional resource adequacy assessments often focus on resource availability and simulate regions as a “copper plate”
- Doing so may understate resource adequacy risks, and can also challenge accurate assessment of resource contributions to regional needs (including imports)

Modeling *intra*-regional limits better reflects resource deliverability, and may also identify Tx needs to support resource adequacy

Potential Solution: use a multi-zonal or nodal / pseudo-nodal RA model for assessments

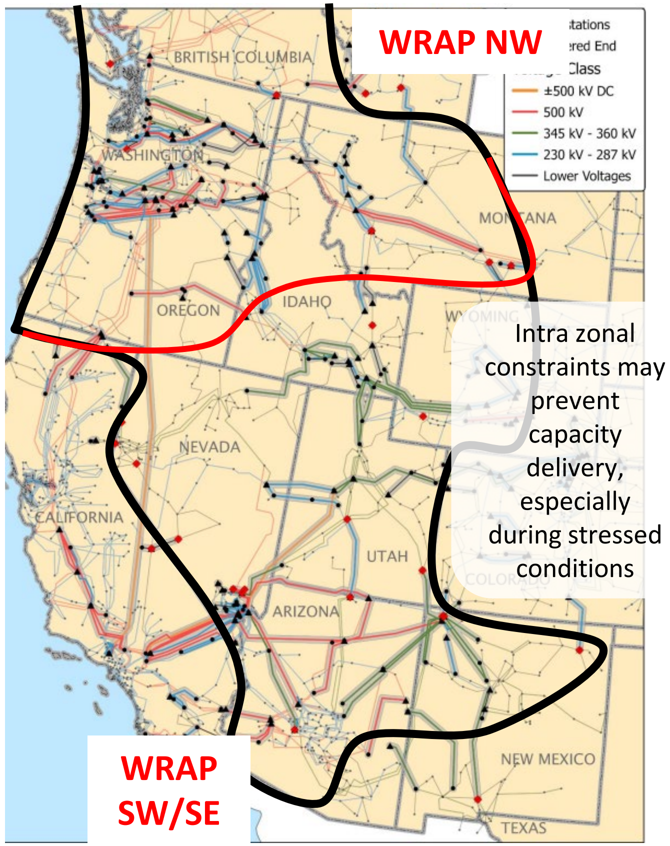
Example Single-Zone Topology

(WRAP Regions each simulated as single zone)



Example Constraints within Zones

(WECC Paths)



Expanding Needs for RA Extend to other Areas of Planning

Broadening the scope of planning simulations that include longer-term weather-related uncertainties can improve outcomes, but how to do it *efficiently*?

Resource Adequacy
How much capacity is needed to meet anticipated future load given supply & demand uncertainties?

Capacity Expansion
What mix of resources should be built/retained to meet RA and other system needs (e.g., for flexibility) and the costs associated with that mix?

Potential benefits include:

- Better alignment between build/retire results and resource adequacy needs
- Improved assessment of benefits, e.g., for transmission (by capturing outsized benefits during extreme conditions)
- Improved assessment of resource contributions to capacity & operating needs during non-normalized conditions
- Eliminate need for exogenous ELCC assumptions in capacity expansion (which can heavily influence builds)

Production Cost
Can the system be reliably operated and at what cost under anticipated load, resources, and transmission developments?

Power Flow and Stability
Is the system secure under anticipated the load, resources, and transmission (within voltage, stability, thermal limits under plausible operating scenarios)?

Note: for clarity we do not show the numerous subsidiary models, e.g., for load forecasting, needed to develop assumptions for BPS analyses, though these are also important

Weather and Resource Adequacy Sampling (WRAS)

Brattle's WRAS tool creates a weather-reflective proxy year with appropriately probability weighted multi-day periods reflecting the range of load, renewable, and generation outage conditions that are expected to occur over the course of 20+ weather years. **WRAS greatly enhances the representation of resource adequacy issues (and how to address them) in deeply decarbonized capacity expansion and production cost simulations.**

INPUTS

20+ weather years of system-wide and zonal data:

- Load forecasts for weather years
- Wind, solar, and hydro profiles (including multi-day renewable droughts and variable hydro conditions) for weather years
- Planned and forced generation outages (including high hot/ cold weather outages)

OUTPUTS

- Proxy year composed of multi-day proxy periods (or proxy weeks)…
- … that reflects the renewable, load, and generation outage conditions that are expected to occur over many weather years
- Load and renewable/hydro generation profiles for each of the multi-day proxy periods
- Weights for each proxy period that reflect the expected frequency over entire weather sample

Why use our Weather and Resource Adequacy Sampling Tool?

Weather

Q1

Why do we need to account for weather uncertainty in production cost (PC) and capacity expansion (CE) models?

Resource Adequacy

Q2

How can it help incorporate RA considerations in PC and CE models & ELCC accounting?

Sampling

Q3

Why sample and not just simulate *all* weather conditions?

Why use our **Weather** and Resource Adequacy Sampling Tool?

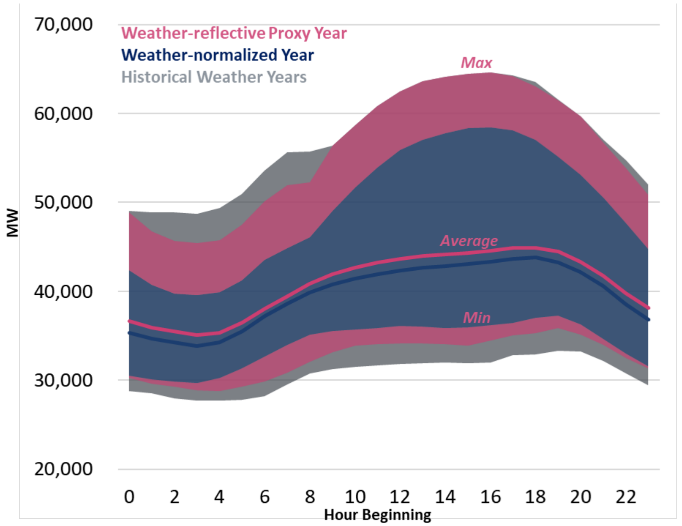
Weather

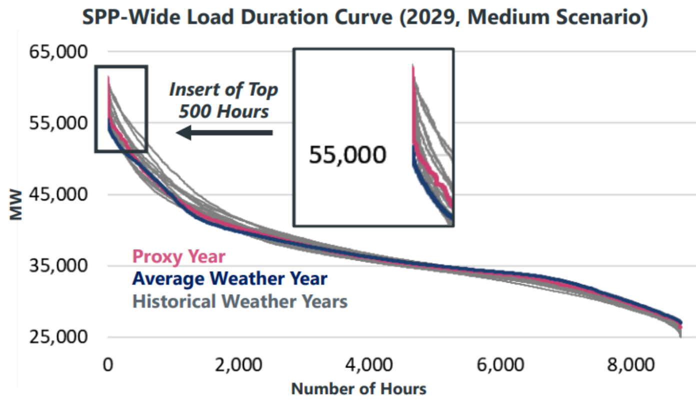
Q1. Why do we need to account for weather uncertainty?

- Weather-normal load projections/shapes do not capture full range of weather conditions particularly when reliability events may occur, such as extreme heatwaves and cold snaps
- For example, CE models use PRM to account for this uncertainty – but that construct is unable to dynamically account for varying reliability contributions of renewables, storage and interactions with outage events

SPP-Wide 24-Hour Load Shape (2029, Medium Scenario)

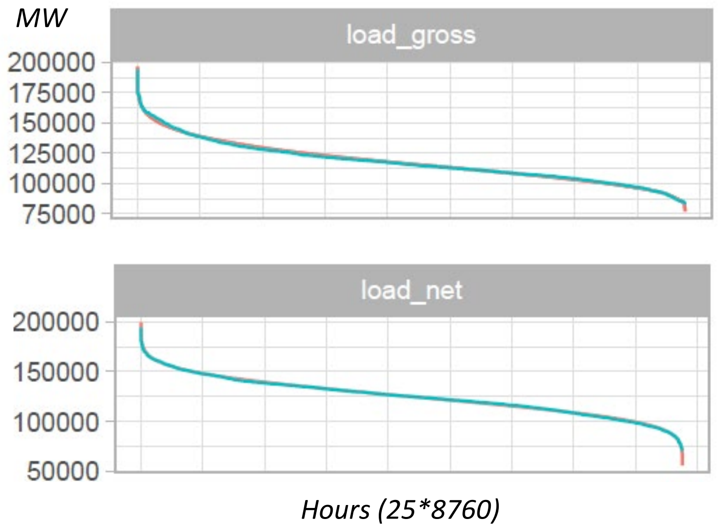
Significantly wider range of conditions captured when using WRAS based sampling





As shown by figure on the right, method closely approximates 25 weather years using a single proxy year selected using WRAS

PJM-Wide WRAS Sampling Results



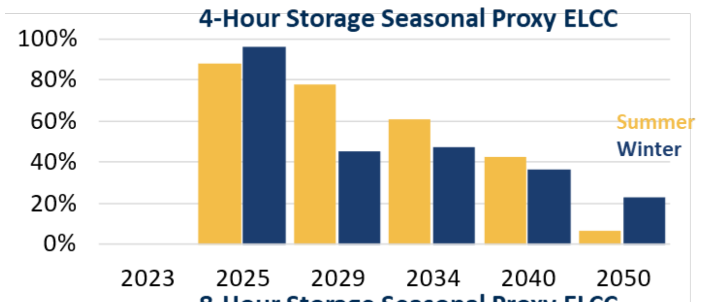
Why use our Weather and **Resource Adequacy** Sampling Tool?

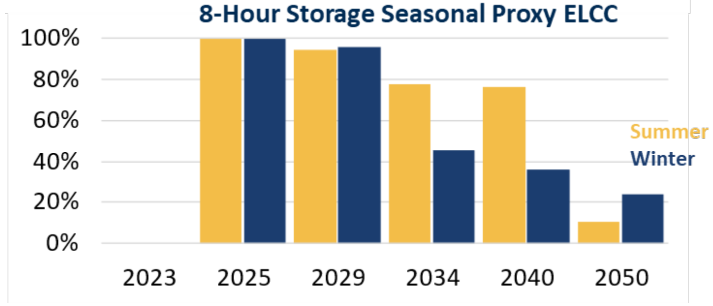
Resource Adequacy

Q2. How can it help incorporate RA considerations in PC and CE models & ELCC accounting?

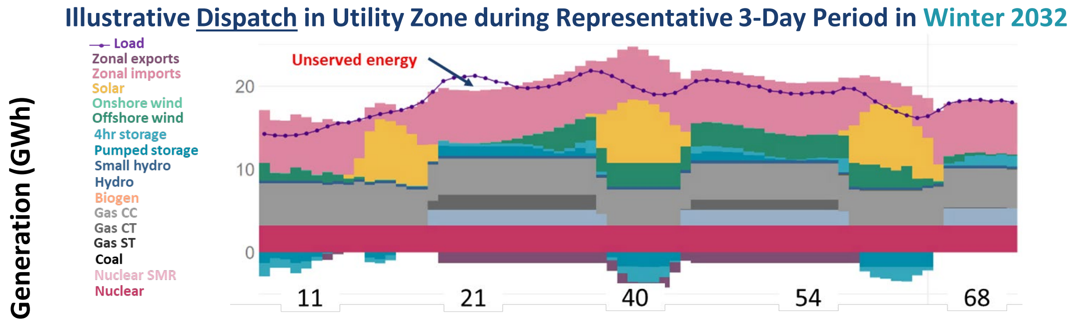
- **Because WRAS-generated conditions already account for weather uncertainty and include extreme weather peaks,** instead of weather normalized peaks + PRM, we can now directly simulate an hourly RA req., enforcing a constraint on demand + operating reserves in all hours
- Endogenously attributes capacity value to renewables, storage, and thermal assets based on their hourly availability during tight system conditions - captures the dynamics and interactions of between all resource types in an evolving market

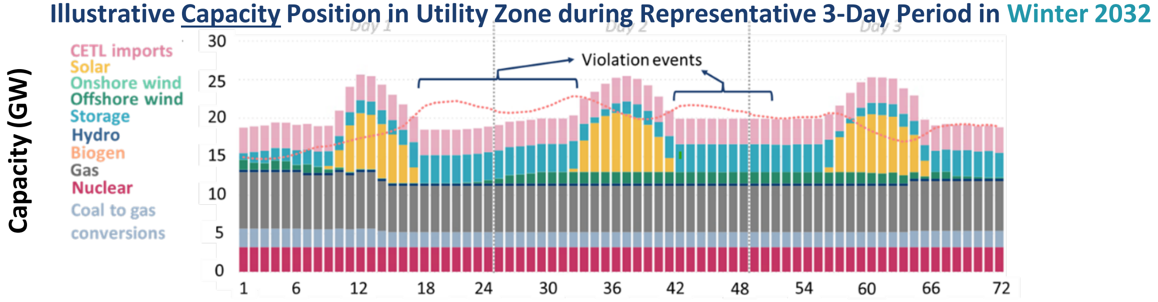
Proxy ELCC values calculated based on the simple average of resource performance during the top 100 RA risk hours





Simultaneously evaluates energy and capacity position in every hour; can assess duration of reliability events; insights into resource interaction and effect on capacity contribution





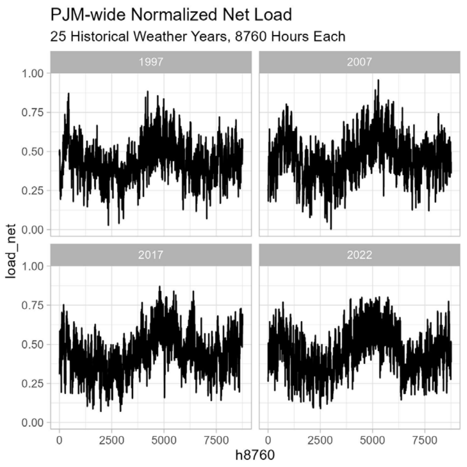
Why use our Weather and Resource Adequacy **Sampling** Tool?

Sampling

Q3. Why sample and not just simulate *all* weather conditions?

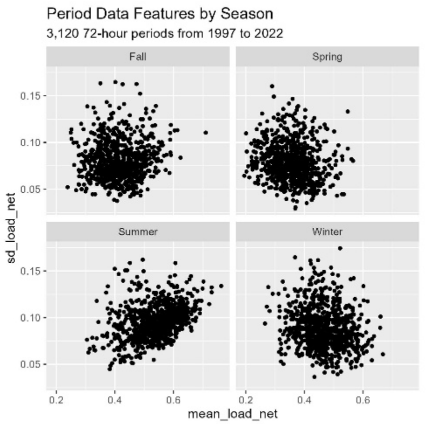
- Because it would be highly computationally expensive, particularly when modeling large systems
- It is also often redundant – many hours are identical over weather years. WRAS exploits this and reduces the sample space modeled searching for "similar" and "distinct" periods, with chronological linkage for a set number of days in every period (typically 3, so storage can be reasonably modeled.)

Estimate Adjusted Net Load (Gross Load – Renewable Gen based on future capacity estimate + Thermal Outage) for a fixed future year

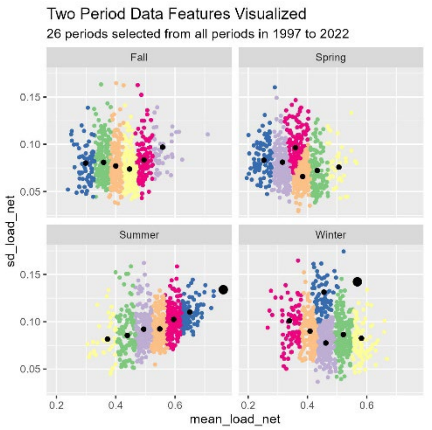


Transform to lesser dimensional space using selected "Data Features": Mean of Net Load and Std Deviation of net load of 72 hours (within 1 period)

Divide periods into season; decide how many period per season will be ultimately modeled in SIM



Run algorithm for clustering –centroid period for each cluster is weather data modeled in all future years; # of periods in each cluster is the weight



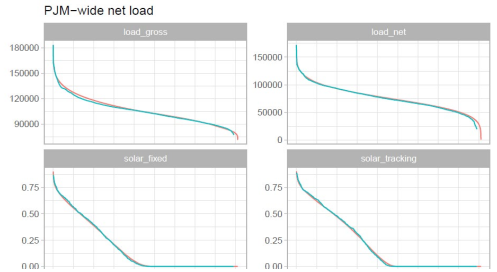
Pull out data inputs associated for each weather data in all future model years; Benchmark data to actuals

Starting Date for 72-hour Rep Periods

Winter	Spring	Summer	Fall
1/1/1997	3/28/2002	8/3/2008	10/13/2001
1/10/2001	3/16/2009	6/25/2010	10/28/2005
12/7/2002	5/21/2010	6/19/2013	11/21/2005
1/1/2005	4/3/2011	6/13/2014	9/1/2011
2/9/2006	4/6/2018	6/7/2015	10/4/2012
1/22/2012	4/9/2018	7/7/2020	9/19/2022
1/19/1997		*7/31/2006*	

Corresponding Weights *(adds up to 365 divided by 3)*

3.11	7.55	7.94	2.91
2.71	7.98	6.65	7.04
3.62	4.64	6.65	8.14
5.78	3.58	4.33	1.69
6.72	5.51	1.57	6.84
7.67	1.42	3.50	4.05
0.04		*0.04*	



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- Traditional models use PRM to account for this uncertainty – but that construct is unable to dynamically account for varying reliability contributions of renewables, storage and interactions with outage events

Resource Adequacy

Q2. How can it help improve RA modeling in traditional models & ELCC accounting?

- **Because WRAS-generated conditions already account for weather uncertainty and include extreme weather peaks,** instead of weather normalized peaks + PRM, we can now directly simulate an hourly RA req., where the system has to maintain demand + operating reserves in all hours with available resources
- Model can now endogenously attributes capacity value to renewables, storage, and thermal assets based on their hourly availability during tight system conditions which captures the dynamics and interactions of between all resource types in an evolving market. (e.g. storage capacity value increases with more solar without any additional system changes)

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WRAS Applications

WRAS is a cutting-edge approach that integrates into expansion planning and production cost simulations to allow for greatly enhanced resource adequacy modeling with reasonable computational effort:

- Feasibly compliments production cost and capacity expansion modeling by relying on multi-day proxy periods with respective weights to represent 8,760+ hours of data
- Allows for sophisticated resource adequacy modeling when integrated in capacity expansion modeling with combined hourly approach to resource adequacy (instead of the traditional planning reserve margin, normalized load, and static ELCCs)
- Eliminates the need for simplistic or computationally expensive representations of ELCC by allowing of endogenous modeling of resource accreditation within a capacity expansion or production cost simulation that captures full weather conditions
- Identifies periods with resource adequacy challenges over a 20+ weather year sample – and how challenges change with evolving resource mixes and load growth over time
- Meaningfully informs the relative severity of energy shortfall across the identified reliability events (severity of reliability events), especially because WRAS includes the tail-events of weather and load.
- Overall, WRAS yields more realistic expansion planning and market simulation results:
  - Realistic, resource-adequate, and more resilient (scenario-based) projections of generation expansion
  - Realistic wholesale power prices (zonal or nodal), reflecting real-world scarcity conditions, resilience challenges, and geographic diversity
  - Realistic congestion prices and congestion-related costs
  - Realistic estimates of future generation investment and operating costs
  - Realistic benefit-cost analyses for transmission planning and market reforms

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Dr. Kai Van Horn leverages electricity system modeling, analysis, and visualization to illuminate and navigate the opportunities and challenges presented by the energy transition.

He has worked with market participants, market operators, utilities, and an array of other stakeholders on a diverse range of matters. He has experience with energy and capacity market design, transmission and generation planning, the modeling and analysis of financial transmission rights, carbon pricing issues, on- and offshore renewables integration, and transmission benefits analysis.

Dr. Van Horn has nearly a decade of experience analyzing wholesale market designs, planning, and operations via the development of large-scale power system models in commercially available software packages, as well as custom-built simulation and analysis platforms. He has led numerous teams in the deployment of such models and worked with clients to develop new modeling approaches that meet the evolving needs of the energy transition

Examples of Brattle Work on Resource Adequacy

- Regional Resource Adequacy Program Footprint PRM Study
- Are Resource Adequacy Markets Adequate?
- SPP Future Energy & Resource Needs Study (FERNS)
- MISO Reliability Attributes "Solution Space:" Initial Assessment of Promising Solutions
- Modeling Storage and Resource Adequacy in Capacity Expansion Models
- Industry Changes in Resource Adequacy Requirements, Metrics, and Design Elements
- Estimation of the Market Equilibrium and Economically Optimal Reserve Margins for the ERCOT Region
- Alternative Resource Adequacy Structures for New Jersey
- Alternative Resource Adequacy Structures for Maryland
- Quantitative Analysis of Resource Adequacy Structures in New York
- Impacts of Renewable Integration on Resource Adequacy in Michigan
- Resource Adequacy in Western Australia: Alternatives to the Reserve Capacity Mechanism
- Resource Adequacy Requirements: Reliability and Economic Implications (for FERC)
- ERCOT Investment Incentives and Resource Adequacy
- The Economics of Reliability and Resource Adequacy Planning
- Resource Adequacy in California: Options for Improving Efficiency and Effectiveness
- Resource Adequacy Requirements, Scarcity Pricing, and Electricity Market Design Implications
- Best Practices in Resource Adequacy