Resource Adequacy Analysis – Basics

Jose Lara, Sebastian Machado, and Rafael Monge (NREL) and Allison Campbell and Eran Schweitzer (PNNL)

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The authors are solely responsible for any omissions or errors contained herein.

Webinar Series Overview

1) Overview of Webinar Series and Connections to State Planning Efforts
    - October 14, 2:30-3:30 p.m. Eastern
    - Juliet Homer & Eran Schweitzer (PNNL)
2) Developing Forecasts - General Overview
    - October 23, 4-5 p.m. Eastern
    - Brittany Tarufelli & Allison Campbell (PNNL) and J.P. Carvallo (LBNL)
3) Developing Forecasts – Load Expansion
    - October 29, 4-5 p.m. Eastern
    - Sean Murphy & J.P. Carvallo (LBNL) and Christine Holland (PNNL)
4) Developing Forecasts – Distributed Energy Resources
    - November 6, 2-3 p.m. Eastern
    - Sean Murphy & Margaret Pigman (LBNL) and Shibani Ghosh (NREL)

Webinar Series Overview

5) Resource Adequacy Analysis – Basics

- November 10, 3-4 p.m. Eastern
- Jose Lara, Sebastian Machado, & Rafael Monge (NREL) and Allison Campbell & Eran Schweitzer (PNNL)

6) Transmission and Distribution System Planning – Basics

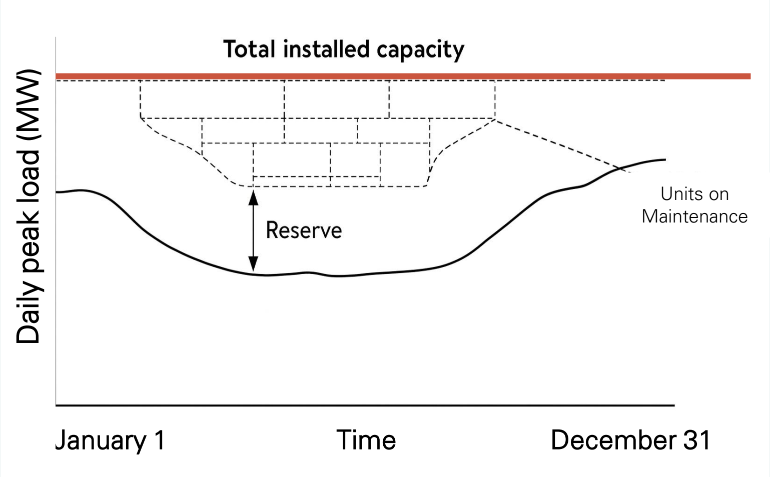
- November 13, 3-4 p.m. Eastern
- Jose Lara & Vincent Westfallen (NREL)

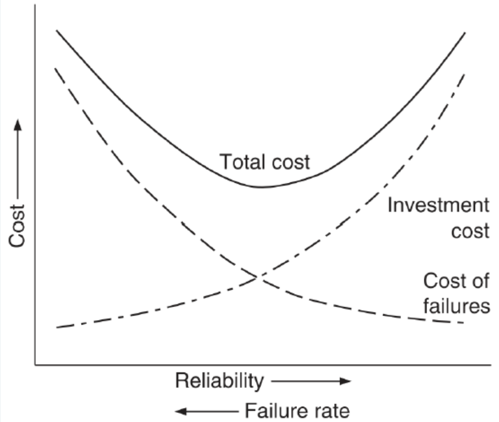
7) The Evolution of Resource Accreditation

- December 2, 3-4 p.m. Eastern
- Travis Douville (PNNL)

What does Resource Adequacy mean?

- Resource adequacy assessment as a discipline traces directly to Roy Billinton and Ronald Allan's work establishing probabilistic reliability theory for power systems although these type of analysis has existed for a long time.
- The primary usage of this discipline has been to **determine reserve margins** in planning application that included reliability considerations.
    - **Low margins** leads to excessive **interruptions**.
    - **High margins** results in excessive **costs.**
- With the transition to de-regulated markets, state agencies took on a higher responsibility in ensuring that enough capacity exists in the system





Source: Billinton, R. et al. Reliability Evaluation of Power Systems. 1983.

A measure of the ability of a power system to meet the electric power and energy requirements of its customers within acceptable technical limits, considering scheduled and unscheduled outages of system components.

Core Drivers for changes in Modern Adequacy Assessment

Uncertainty

Resources are subject to unplanned outages and spatiotemporal correlations might exist

Variability

Time-varying availability decouples peak risk from peak demand

Spatial Coupling

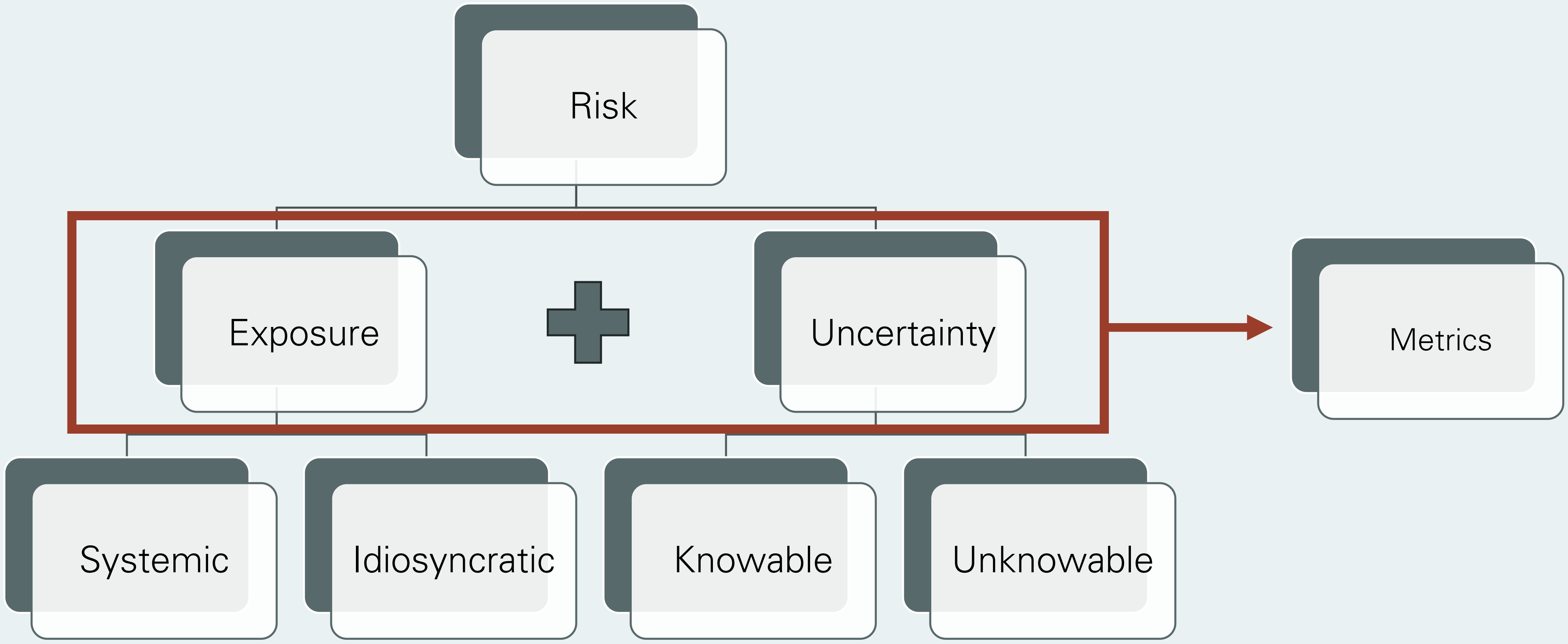
Leveraging wide-area resource diversity requires understanding interregional transmission

Temporal Coupling

Storage and demand response allow shifting electrical energy between time periods

A Risk Assessment Framework for RA

<u>At its core, Resource Adequacy (RA) is a risk assessment and management exercise</u>



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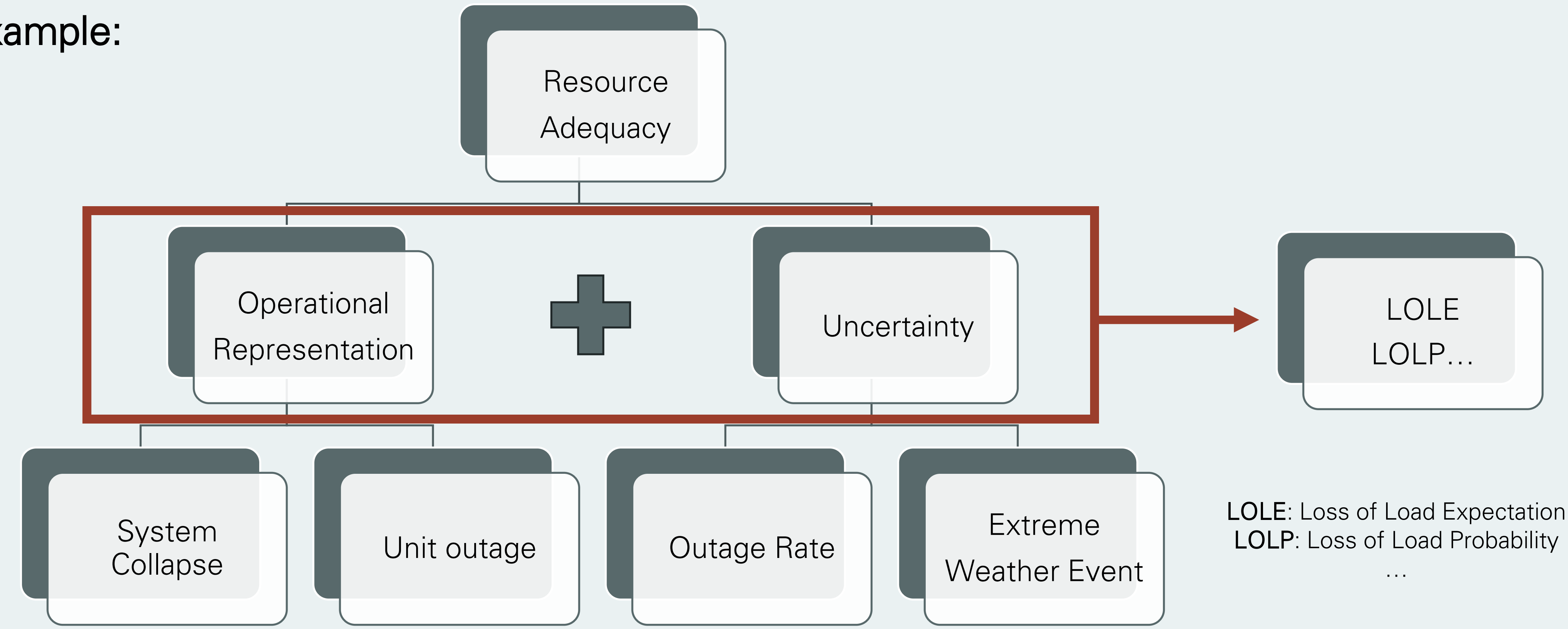
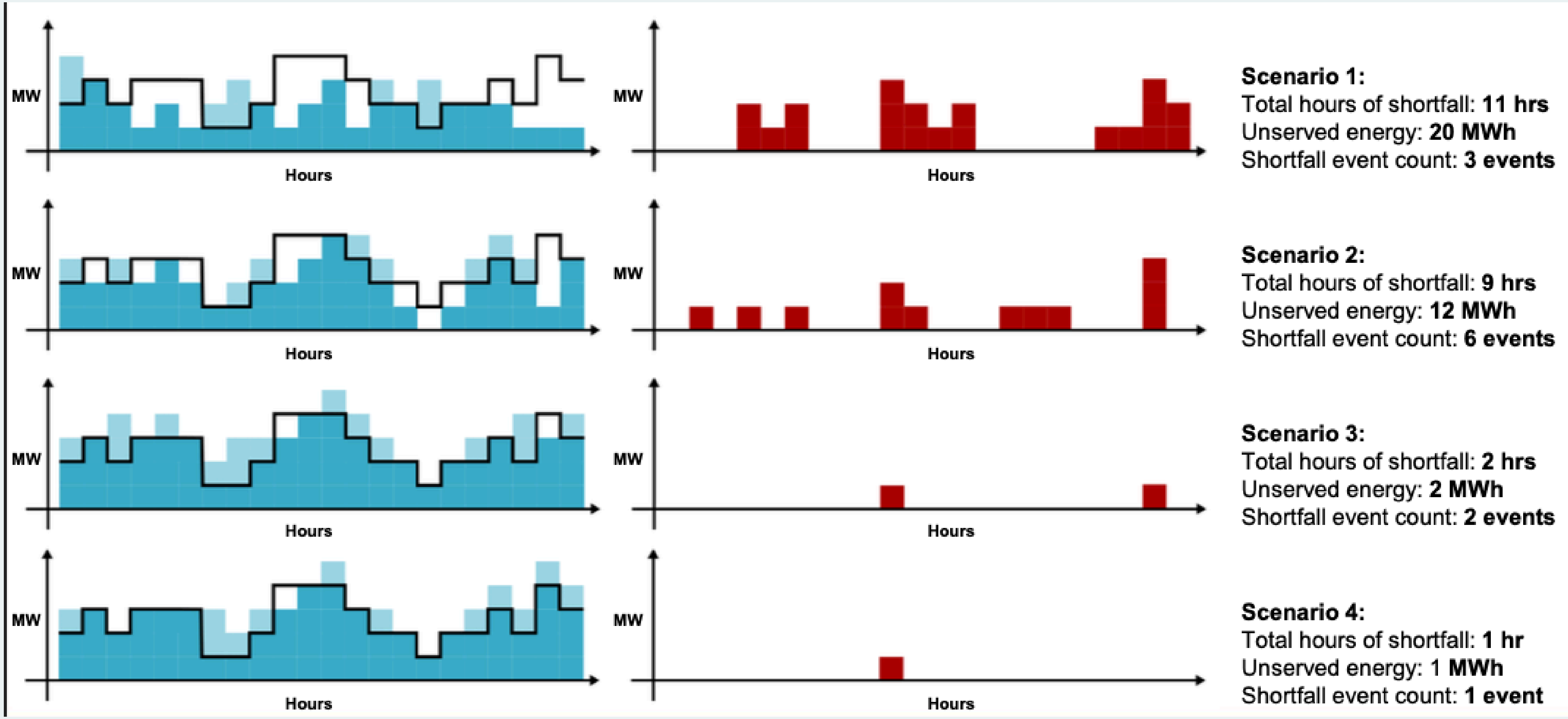
For example:



LOLE: Loss of Load Expectation
LOLP: Loss of Load Probability
…

*Not a comprehensive list of all operational representations and uncertainties

Very Basic Mechanics of performing RA analysis



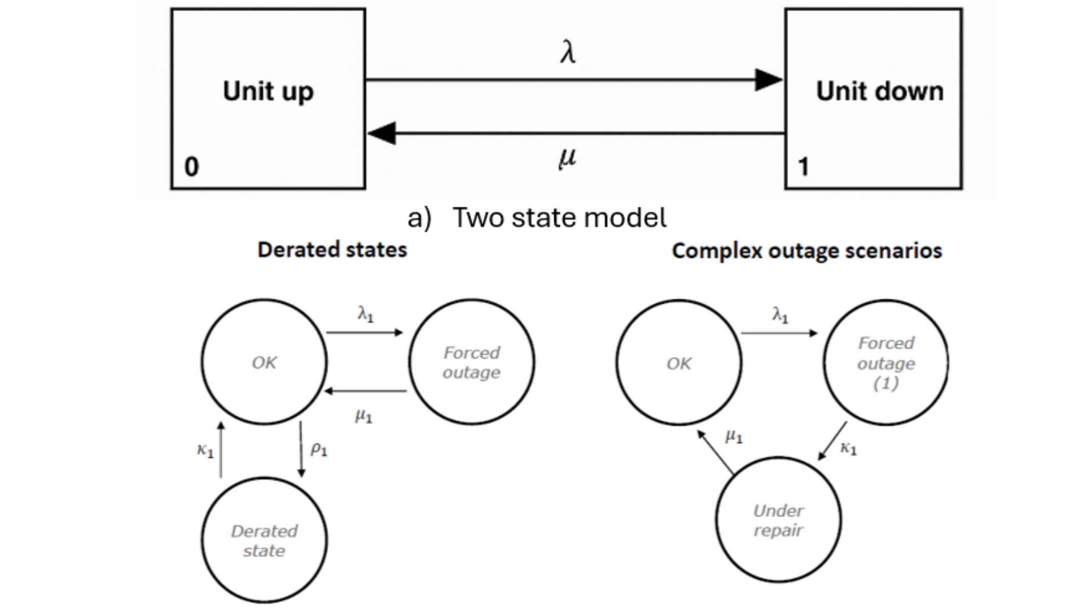
Key metrics for example samples:
LOLH: **5.75 hrs**
EUE: **8.75 MWh**
LOLEv: **3 events**

Source: Stephen, G. et al. *Fundamentals of resource adequacy for modern power systems.* 2024. IEEE https://cmte.ieee.org/pes-rawg/wp-content/uploads/sites/164/2024/08/IEEE_RAtutorial_final.pdf

Uncertainty Representation: Knowable

<u>Outage Rates: Markov Model .</u>

- The classical risk model in RA centers on quantifying the probability of component failures, primarily within the generation fleet.
- Based on Forced Outage Rates (FOR) data, the simplest **Markovian representation** of a dispatchable generator can be formulated in terms of:
  - **Two states**: available (Up) and unavailable (Down)
  - The **transition probabilities** between those states are given by λ and μ
- Notice:
  - **Transition probabilities** are empirical.
  - Frequently are **assumed independent and uncorrelated FOR**. Misrepresentation of reality!
  - However, extreme weather can cause **correlated failures**.



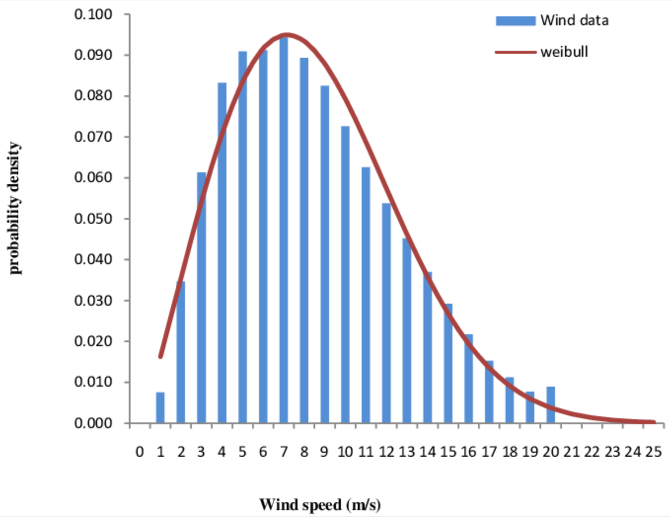
b) Other possible ways to define the Markovian model of a dispatchable generator

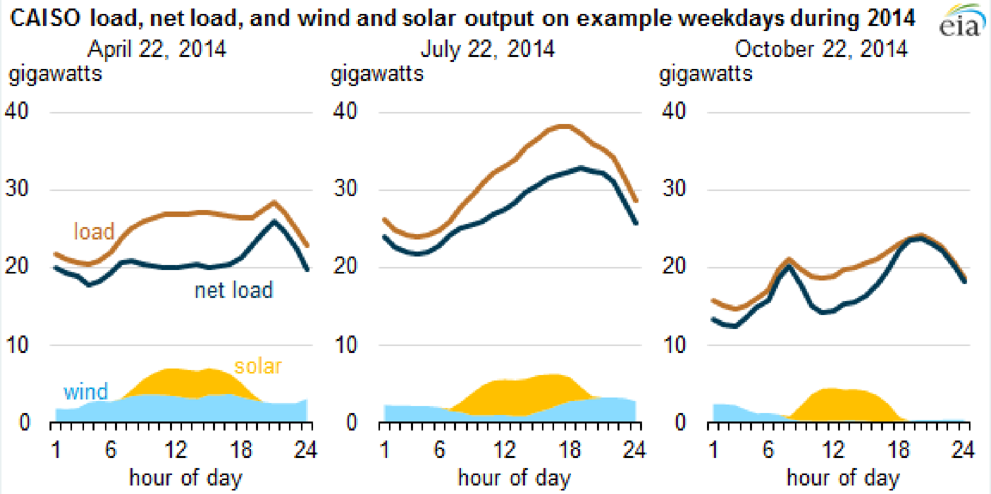
Source: Billinton, R. et al. Reliability Evaluation of Power Systems. 1983.
Source: Stephen, G. et al. *Fundamentals of resource adequacy for modern power systems.* 2024. IEEE https://cmte.ieee.org/pes-rawg/wp-content/uploads/sites/164/2024/08/IEEE_RATutorial_final.pdf

Uncertainty Representation: Knowable

<u>Renewable Energy Availability: Weather Models</u>

- Renewables introduce a **new, continuous, and correlated source of uncertainty** related to the availability of their primary source.
  - **Traditional RA Markovian** models were **not designed to handle continuous variability.**
  - The model needs to account for both **availability of the power plant and availability of the primary source**.
    - Attempts to adapt traditional Markovian models to represent both uncertainties sources introduces **inconsistencies**.
    - Using historical time-series is a common practice (Ignoring stochastic nature).
- Focus **shifts from Gross Peak Load to Net load.**
- Output uncertainty of non-dispatchable source also introduces the necessity of
  - More **temporal resolution**
  - Sequential simulations able to capture the **chronology of the operations**.

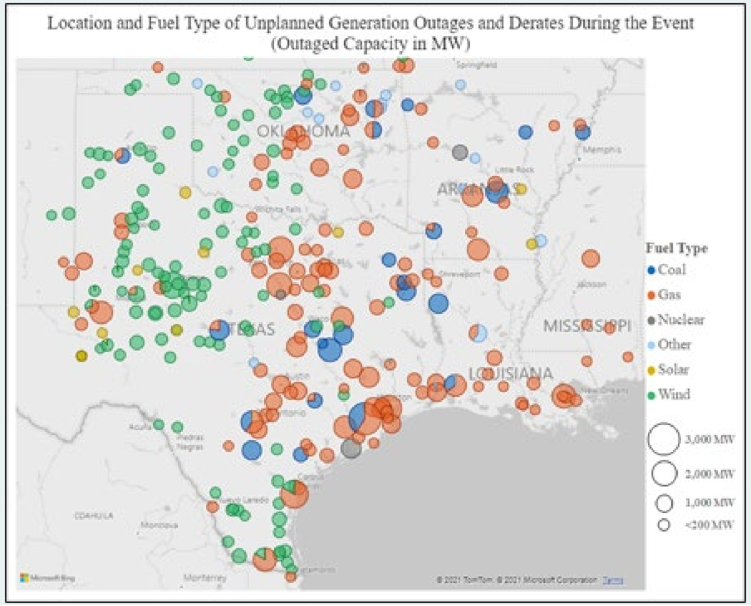


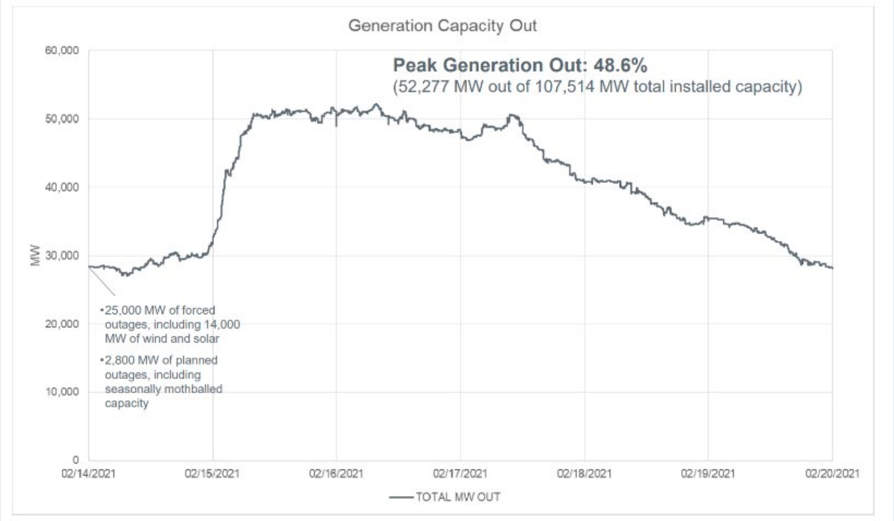


Source: EIA. Increased solar and wind electricity generation in California are changing net load shapes - U.S. Energy Information Administration (EIA).2014

Uncertainty Representation: Unknowable

- Extreme Events driven by **weather conditions** that **correlate the outage** between units across a **geographic region** or even infrastructure assets.
- By the fact of being rare and uncommon for the system those scenarios tend to be located at the **tails of the probability function**.
- The combination of **rarity and high correlation** makes these events extremely **difficult to characterize** from a planning perspective.
    - E.g., Can we expect a 5-day freeze with temperatures below 0 F while the main units for the largest CC power plant is under maintenance?
    - E.g., Can we expect a two-year drought through out the region that decreases effective hydro capacity by 40%?

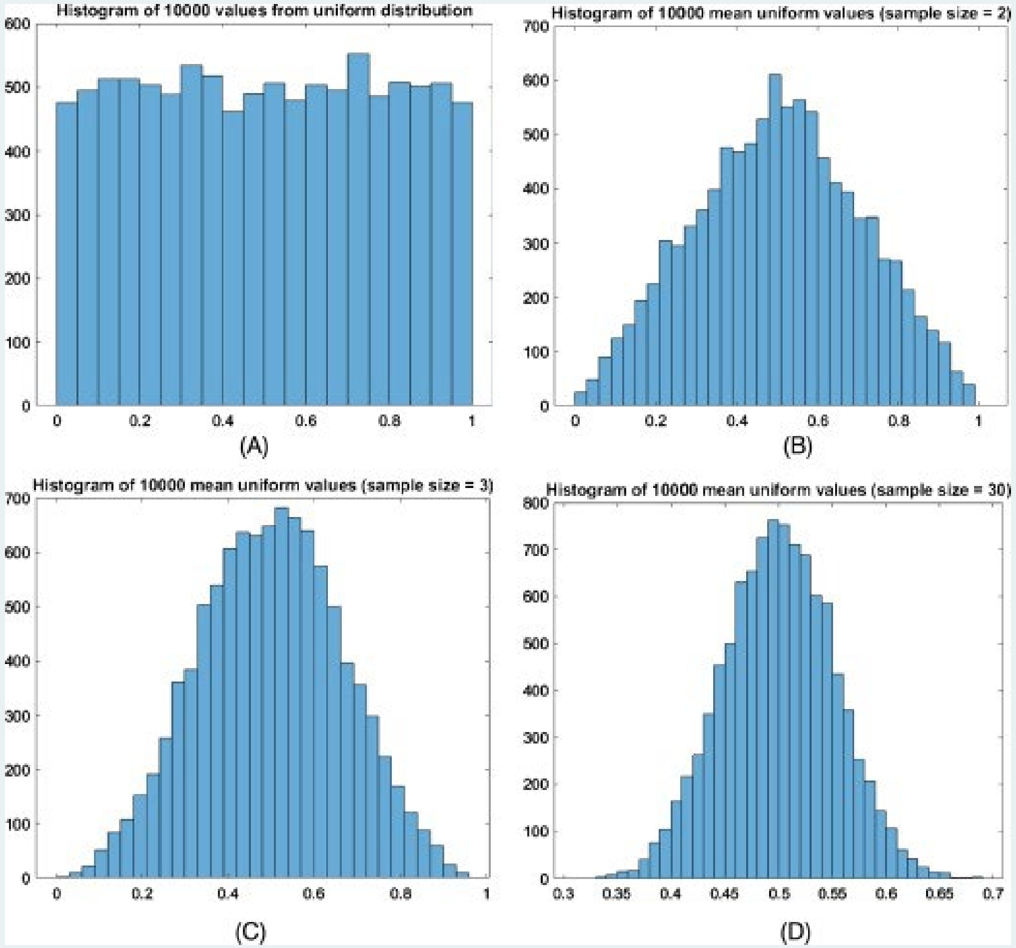




FERC-NER. The February 2021 Cold Weather Outages in Texas and the South Central United States. 2021

Uncertainty Representation: The Montecarlo Approach

- **Monte Carlo Estimators (MCE)** are currently the default simulation approach for sampling the possible scenarios outcomes of the Markovian representation of the system in RA studies.
    - MCEs is based on the **Central Limit Theorem (CLT)**, and Law of Large Numbers (LLN).
    - The **probability function** that the MCE is sampling **is unknown a priori**.
    - **While the CLT and LLN are valid** it is expected that the **MCE will converge** to the "true value".



Uncertainty Representation: The Montecarlo Approach

- There are some important situations where MCE can potentially fail:
  - When the **events of interest lie far in the tails or the distribution has "Fat Tails"**, Crude Monte Carlo is mathematically proven to be inefficient or fail entirely in such scenarios.
    - **Extreme events** are examples of these cases.
    - In some cases, it isn't possible to determine if the choice of distribution correctly characterizes the tails.
  - When the unknown probability function contains **sharp discontinuities** or highly oscillatory behavior.

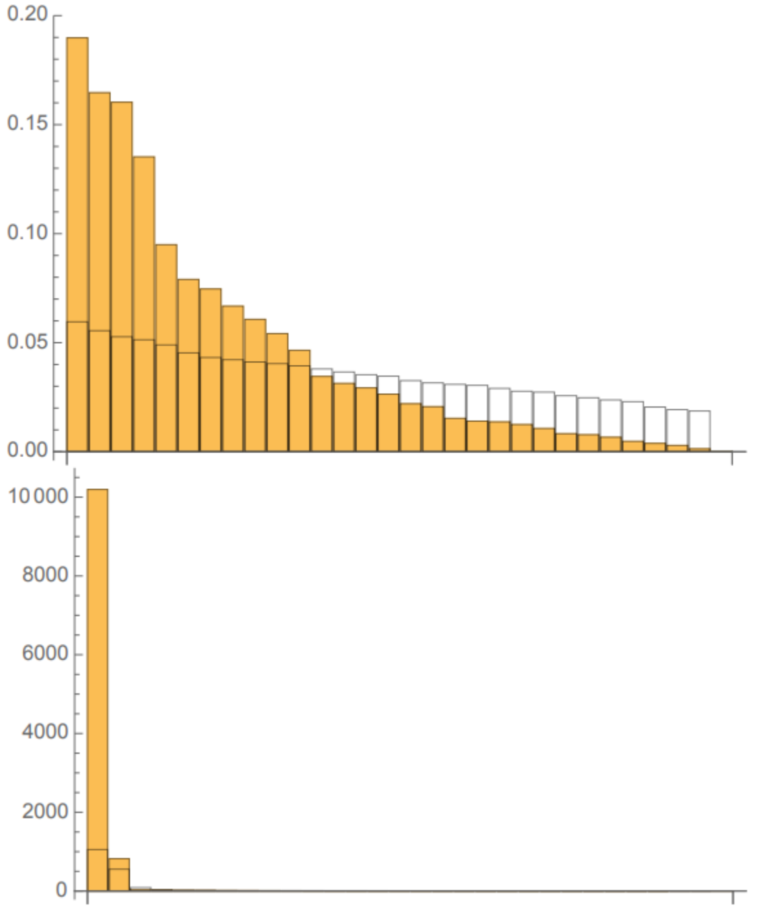
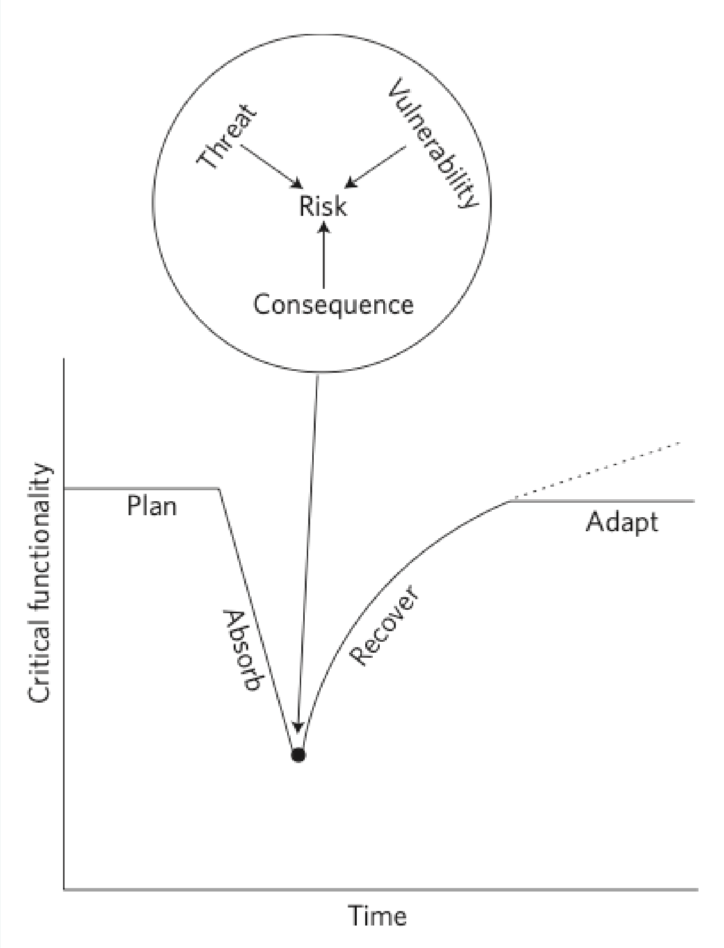


Fig. 7. A Monte Carlo experiment that shows how spurious correlations and covariances are more acute under fat tails. Principal Components ranked by variance for 30 Gaussian uncorrelated variables, n=100 (above) and 1000 data points, and principal Components ranked by variance for 30 Stable Distributed (with tail $\alpha = \frac{3}{2}$, symmetry $\beta = 1$, centrality $\mu = 0$, scale $\sigma = 1$) (below). Both are "uncorrelated" identically distributed variables, n=100 and 1000 data points.

Taleb NN. Probability, Risk, and Extremes. In: Needham D, Weitzdörfer J, eds. *Extremes*. Darwin College Lectures. Cambridge University Press; 2019:46-66. DarwinCollege.pdf

Exposure Representation: System Modeling

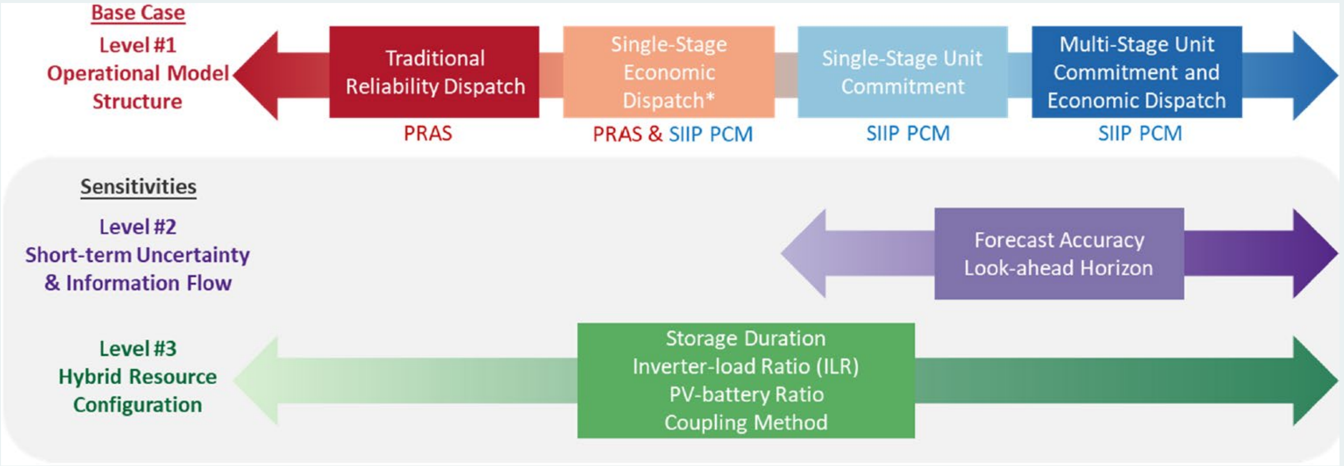
- The **choice of system modeling** is critical to the outcomes of the analysis.
- Risk analysis depends on **characterization of the threats, vulnerabilities and consequences** of adverse events to determine the expected loss of critical functionality.
- The choices about system representation are critical to determine the capacity of the system to absorb and recover from the events.
- Further, in many cases with technologies like **energy storage the adequacy value** heavily depends on the operational regime. I.e., will the asset participate in reserves?

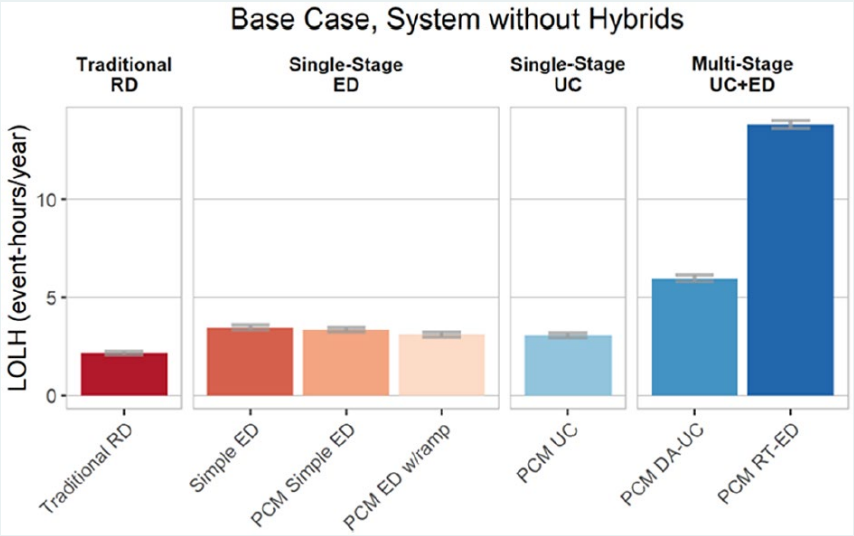


Linkov, I., Bridges, T., Creutzig, F. et al. Changing the resilience paradigm. Nature Clim Change 4, 407–409 (2014). https://doi.org/10.1038/nclimate2227

Exposure Representation: System Modeling

- **Each system exhibits unique characteristics** that may **influence** the underlying design philosophy of **system modeling** for RA studies.
- **Characterization and identification** of the most **relevant exposure factors** is critical for choosing a system representation:
  - Dispatch approach (RA, PCM ED, PCM UC)
  - Single stage / Multistage
  - Network representation (Copper plate, Zonal, Nodal).
  - Generation (Ramping, primary source availability, aggregations)…





Yinong Sun, *et. al.*, Insights into methodologies and operational details of resource adequacy assessment: A case study with application to a broader flexibility framework, Applied Energy,

Exposure Representation: Transmission Adequacy

- As transmission capacity has become more limited, there is a need to raise question of whether the implied existing energy can be transported in the event of an outage.
- Elevates the relevance of having more regional models and larger geographies when developing the system models.
- However, there are cases when reducing risk is not riskless. As a result, the evaluation of RA that includes utilizing more transmission makes the system modeling more difficult and require more detail

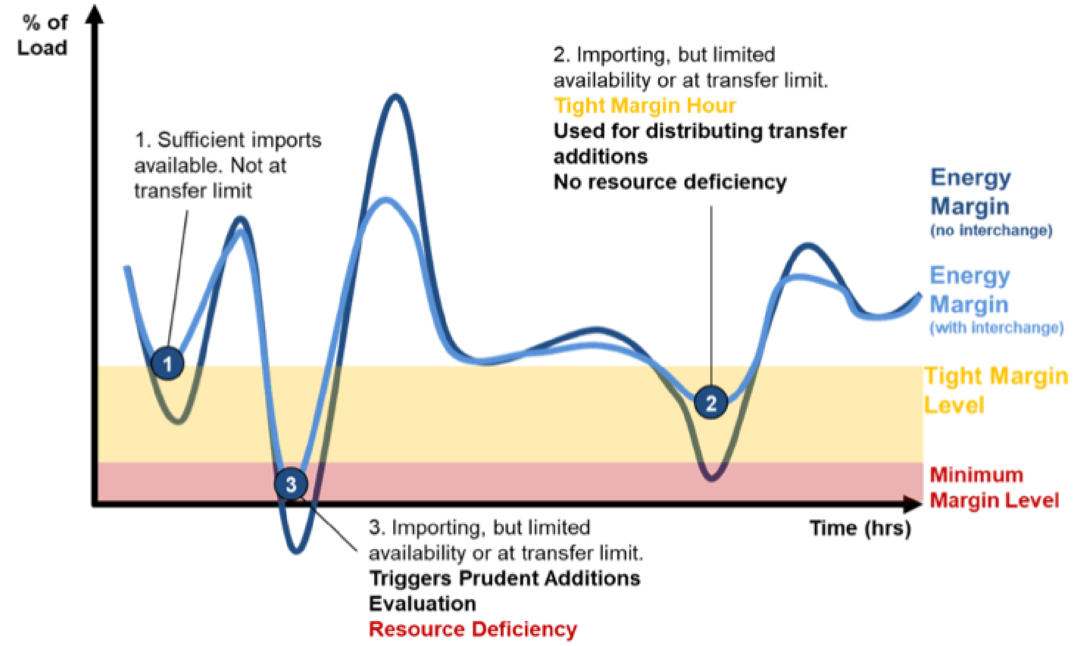
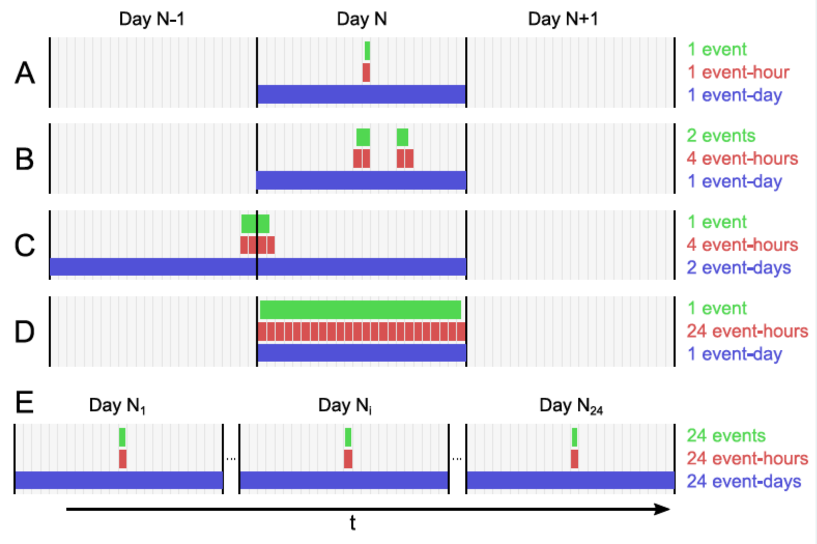


Figure 2.5: Illustrative Example Showing Impacts of Imported Energy

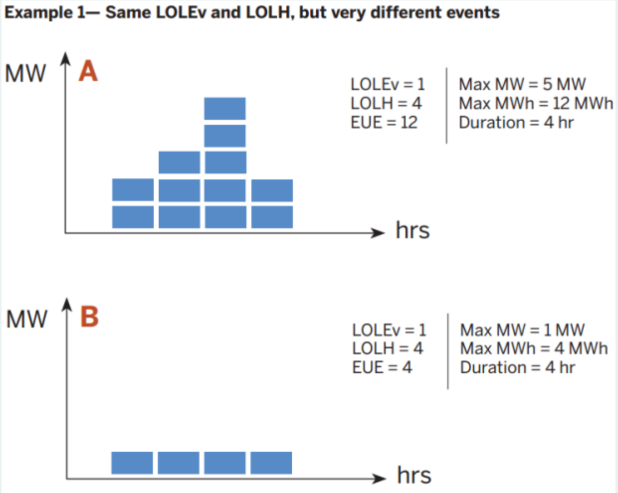
NERC. Interregional Transfer Capability Study (ITCS) Strengthening Reliability Through the Energy Transformation. https://www.nerc.com/pa/RAPA/Documents/ITCS_Part2_Part3.pdf. 2024.

RA Metrics

- RA criteria for Loss Of Load Expectation (LOLE) of 1 day-event in 10 years was the standard value before RA studies hourly optimization models to simulate.
- When hourly RA simulations started, intuition makes to engineers to translate this metric into "24 hour-events each 10 years", which corresponds to "2.4 event-hours in 1 year".
  - However, "2.4 event-hours in 1 year" corresponds to a less reliable system compared to one that meets 1 day-event in 10 years criterion (See Top Figure).
- **LOLE definition**: The expected count of event-periods per horizon, where an event-period is defined as a period of time where system resources were not sufficient
  - LOLE is **not a measure of expected total shortfall duration**. Shortfalls may be shorter than the event-periods in which they occur.
- Distinct RA events can correspond to identical values of a single RA metric.
  - **A single metric could not be enough to understand system adequacy.**



Stephen. G, et al. 2022. Clarifying the Interpretation and Use of the LOLE Resource Adequacy Metric.



Stephen. G, et al. 2022. Evolving Metrics for Resource Adequacy Assessment.

Capacity Accreditation within RA

Capacity accreditation impacts the quantity of resources which are allowed to be added to the system.

The accreditation de-rates the capacity for each resource, which is fed into the Capacity Expansion Model. Within the RA model, the full capacity and full time series is used to determine adequacy.

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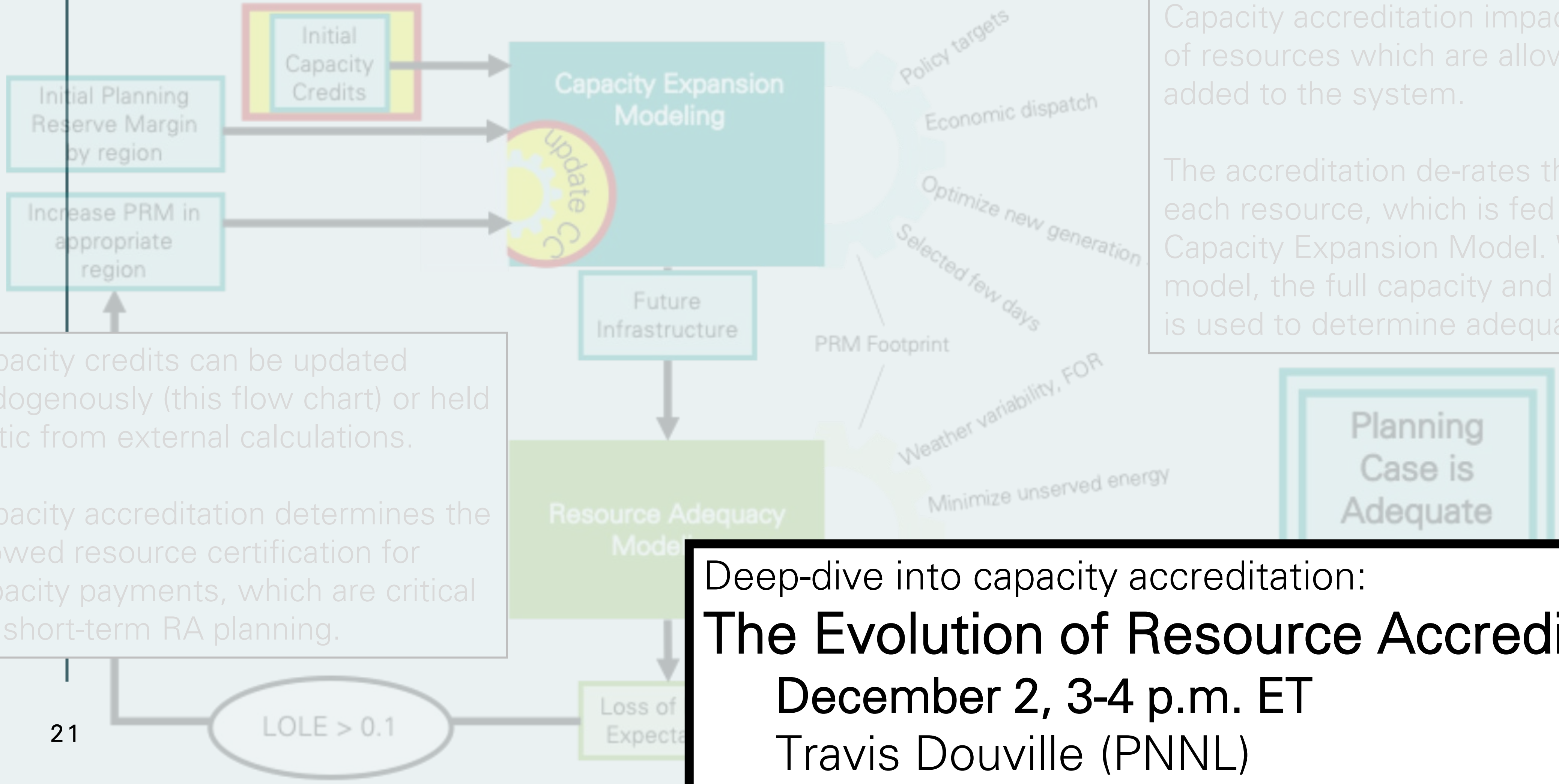
Capacity credits can be updated endogenously (this flow chart) or held static from external calculations.

Capacity accreditation determines the allowed resource certification for capacity payments, which are critical for short-term RA planning.

Capacity Accreditation within RA



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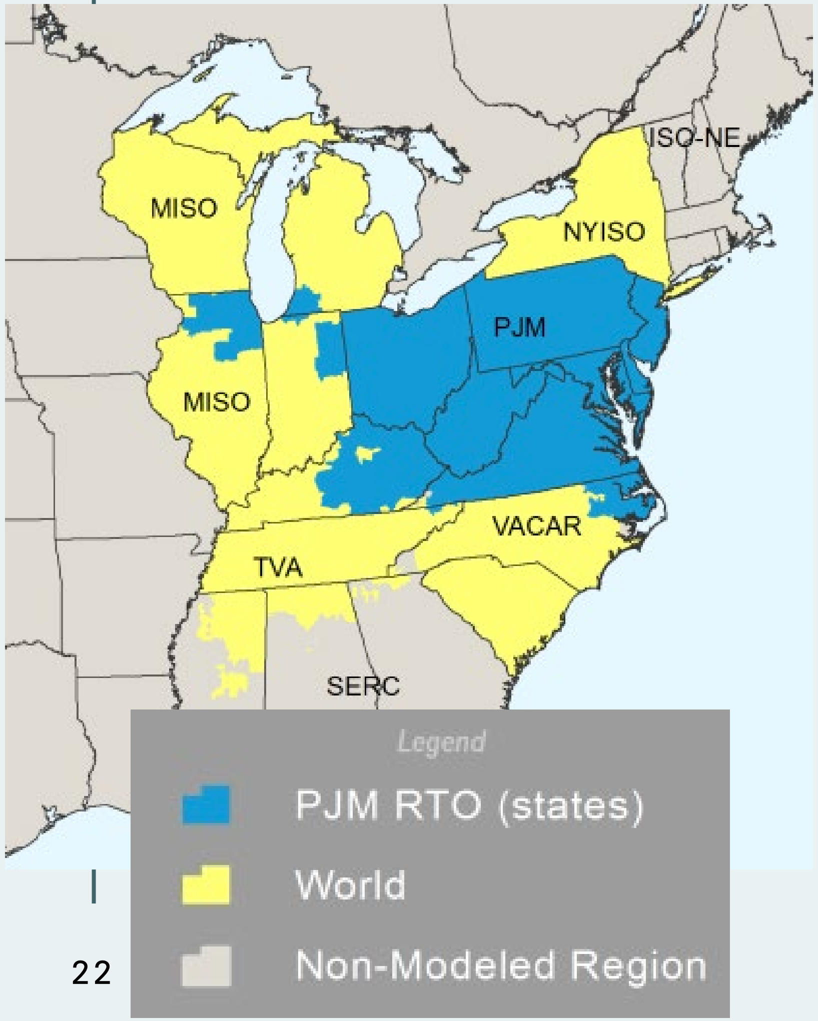
Deep-dive into capacity accreditation:

The Evolution of Resource Accreditation

December 2, 3-4 p.m. ET

Travis Douville (PNNL)

Popular Modeling Tools – Industry



	SERVM	PlanOS Resource Adequacy *(GE MARS)*	PRISM	PLEXOS
Developer	PowerGEM *(Astrapé Consulting)*	GE Vernova	PJM (in-house)	Energy Exemplar
Planning Entity	CPUC MISO SPP ERCOT	NYISO ISONE Illinois Power Agency PJM (for outside markets)	PJM (PJM system only)	DOE NERC CAISO MISO
Planning Regions	Multi-area	Multi-area	2-area	Multi-area

See Resource Adequacy Assessment Tool Guide: EPRI Resource Adequacy Assessment Framework for additional tools
https://www.epri.com/research/products/3002027832

https://www.pjm.com/-/media/DotCom/documents/manuals/archive/m20/m20v11-resource-adequacy-analysis-08-01-2021.pdf

Popular Modeling Tools – Open Source

	GridPath	PRAS	ProGRESS	Antares
Developer	Sylvan Energy Analytics	NREL	Sandia National Lab	RTE (French Electric Transmission System Operator)
Source	https://gridlab.org/gridpathratoolkit/	https://www.nrel.gov/analysis/pras	https://github.com/sandialabs/snl-progress	https://antares-simulator.org/

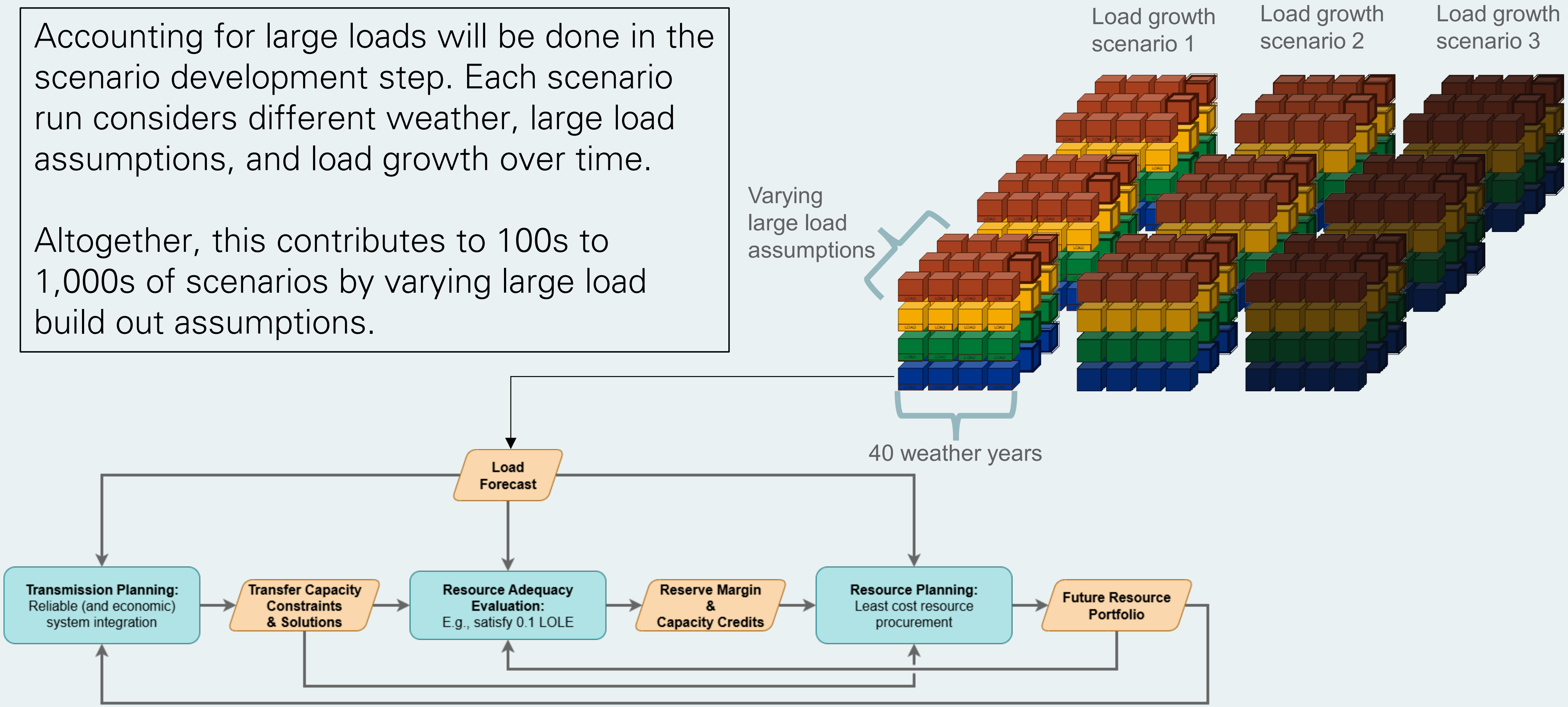
Common publicly-available datasets leveraged with these tools include:

- NERC – resources outages:
  - GADS – Generation forced outage rates
  - TADS – Transmission Availability Data System
- EIA -- capacities:
  - 860 (projections of retirements)
- NREL – variable resource time series:
  - WIND Toolkit
  - National Solar Radiation Database

Approaches to RA: Large Loads

Accounting for large loads will be done in the scenario development step. Each scenario run considers different weather, large load assumptions, and load growth over time.

Altogether, this contributes to 100s to 1,000s of scenarios by varying large load build out assumptions.

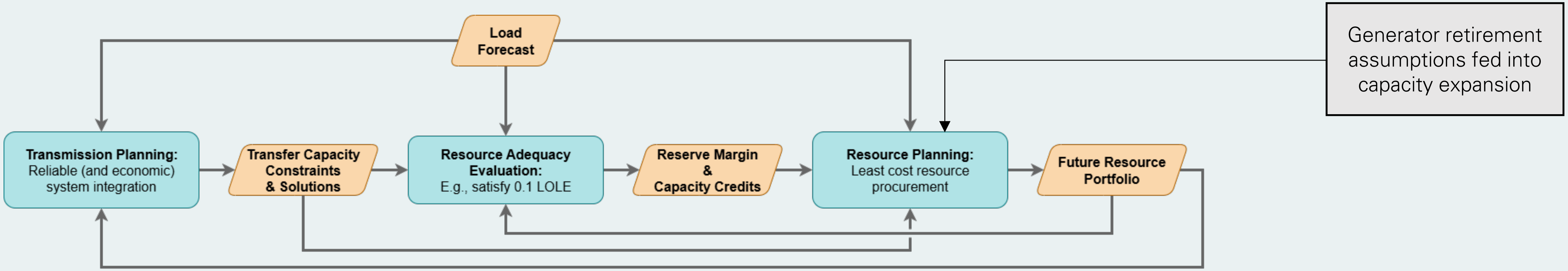


Approaches to RA: Generation Retirement

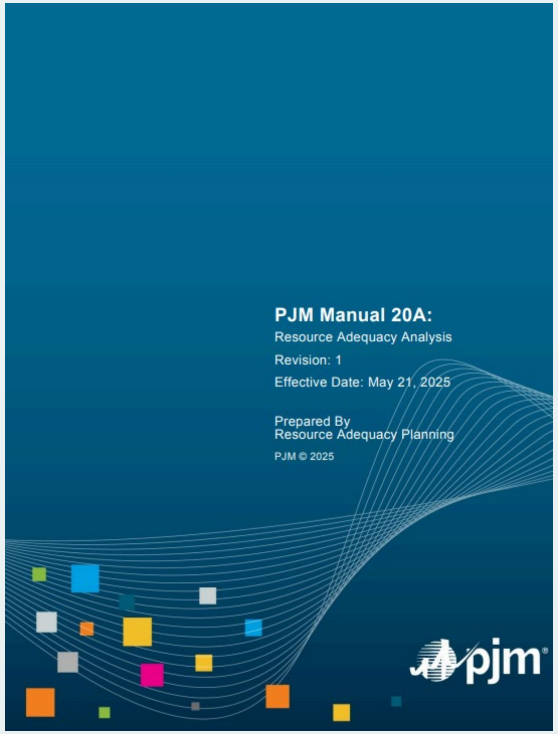
Generation retirement is an input into capacity expansion (Resource Planning). Retirements and rates of retirement are often policy-informed – this will be an assumption or scenario in capacity expansion.

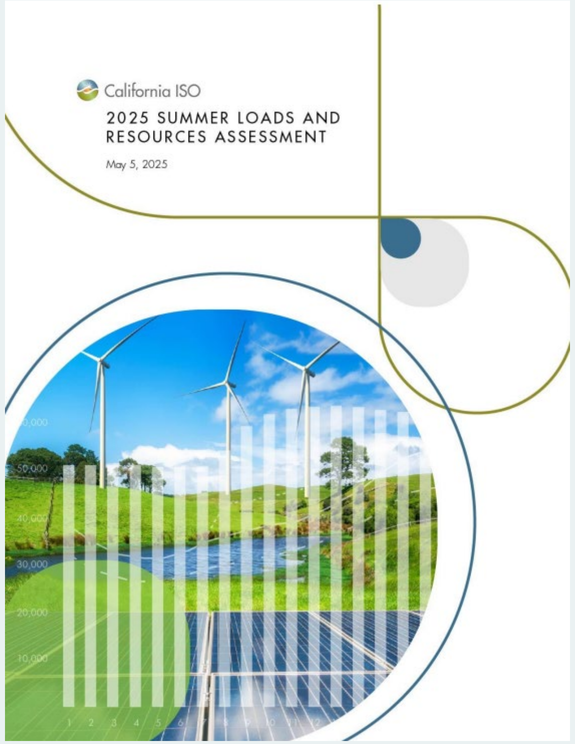
Two types of retirement:

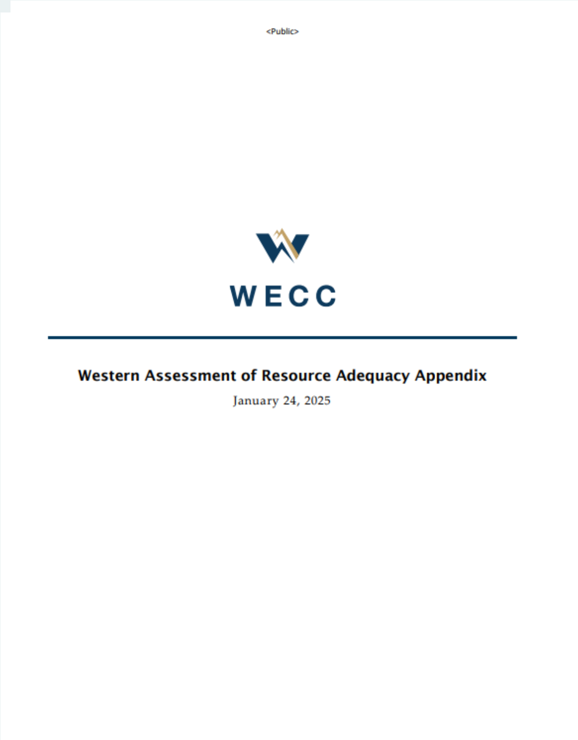
1. Exogenous – known/announced, anticipated, assumed end-of-life
2. Endogenous – determined within the capacity expansion model based on economic retirement of units.



RA Assessments across the US







RA across US regions – who does what and how

Region	How RA is set	What to pull for review
PJM	Annual RA study (Manual 20A) sets IRM and Forecast Pool Requirement using probabilistic simulations tied to 1-in-10 LOLE. Accreditation uses ELCC. Obligations flow through RPM.	IRM and FPR values; ELCC method and credits; load forecast and weather years; link from IRM/FPR to RPM obligations.
MISO	Annual LOLE Study sets seasonal Planning Reserve Margins and Local Reliability Requirements with probabilistic analysis.	Seasonal PRMs; LOLE inputs and high-risk hours; transfer limits and zonal import capability.
NYISO / NYSRC	NYSRC runs the IRM study with NYISO support to satisfy 1-in-10 LOLE. IRM becomes the statewide installed capacity requirement.	IRM level; LSE obligation math; key assumptions (EFORd, load, transmission constraints).
CAISO	Summer Loads and Resources Assessment uses full-year chronological simulations to test 1-in-10; CPUC sets RA requirements using these inputs.	Simulation scope; demand forecast source; RA portfolio (storage, DR); extreme-weather sensitivities.
ISO-NE	Installed Capacity Requirement developed to meet NPCC Directory 1 criteria using probabilistic methods and tie benefits.	ICR calculation; tie-benefit assumptions; local capacity zones and transfer limits.
SPP	Long-term RA uses LOLE and is adding EUE due to high VRE and storage portfolios.	Whether both LOLE and EUE are reported; storage duration assumptions; correlation of VRE output.
ERCOT	Energy-only market. No mandated PRM. Publishes MORA monthly outlook. Probabilistic risk metrics used as guidance.	MORA risk results; outage and fuel constraints; scarcity-pricing implications for new entry.
Non-market West / WECC / WRAP	Utilities or WRAP conduct RA aligned to WECC assessments. WECC applies a 1-in-10 threshold and is advancing energy-based methods.	Adopted threshold; hydro and climate assumptions; imports and transmission availability.

Reading an RA Assessment

- Confirm scope: footprint, study horizon, target standard
- Map the chain: load forecast → IRM or PRM → accreditation → obligation → procurement
- Separate adequacy risk vs operational risk
- Keep a state lens: policy targets, local reliability drivers, affordability

Metrics and methods to focus

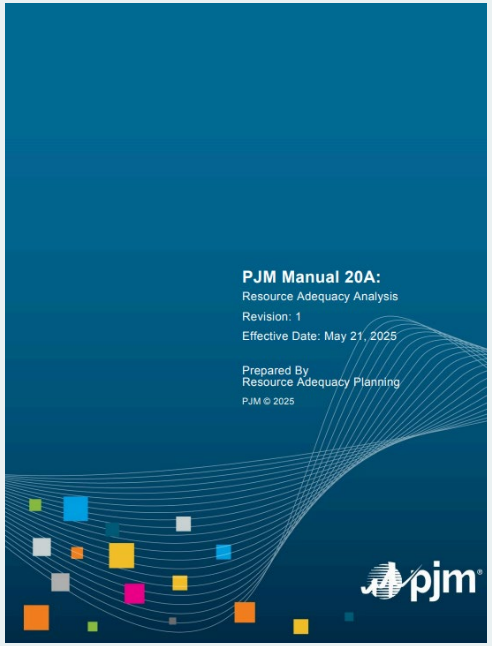
- Metrics: LOLE or events per year, LOLH, EUE or EENS, plus when and where events occur
- Methods: probabilistic and chronological modeling preferred over single-hour margin checks
- Accreditation: ELCC for wind, solar, storage, hybrids - watch portfolio effects and seasons

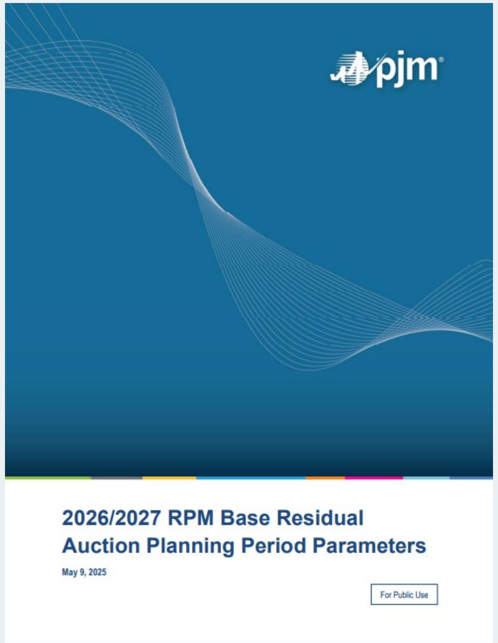
Inputs that move results and common red flags

- Load: electrification, data centers, many weather years, extremes
- Outages: forced rates, correlations, maintenance logic, winter performance
- VRE and storage: profile sources, geographic correlation, duration and charge limits
- Transmission and imports: tie benefits, transfer limits, outage modeling
- Red flags: old load forecasts, static ELCC, thin winter sensitivities, untested imports, unrealistic entry or retirement

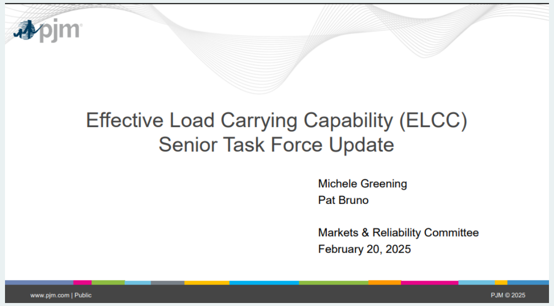
PJM at a glance

- Read: Manual 20A + the latest Reserve Requirement Study + ELCC docs + Load Forecast.
- Flow: IRM → FPR → VRR curve → RPM auction obligations
- Metrics: historic focus on LOLE; EUE also reported to capture magnitude
- Focus areas: winter risk and correlated outages, accreditation shifts as fleets grow


PJM Manual 20A:
Resource Adequacy Analysis
Revision: 1
Effective Date: May 21, 2025
Prepared By
Resource Adequacy Planning
PJM © 2025



2026/2027 RPM Base Residual Auction Planning Period Parameters
May 9, 2025
For Public Use

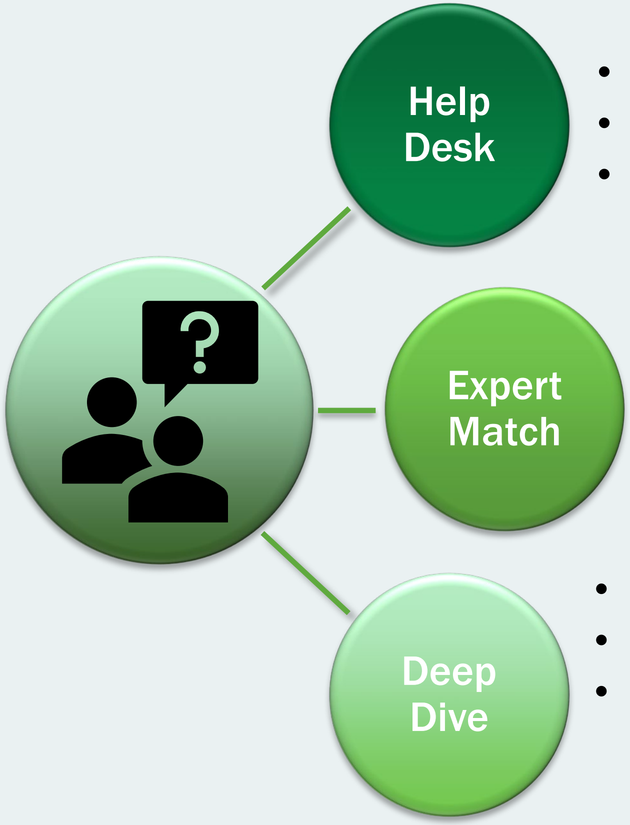


Effective Load Carrying Capability (ELCC) Senior Task Force Update
Michele Greening
Pat Bruno
Markets & Reliability Committee
February 20, 2025
www.pjm.com | Public
PJM © 2025

2025
PJM Long-Term Load Forecast Report
Posted Date: January 24, 2025
Prepared by PJM Resource Adequacy Planning Department
For Public Use

DOE-funded Resources and Assistance for State Energy Offices and Regulators Program

https://StateTAProgram.lbl.gov



Help Desk

- Online intake form w/ rolling review
- SME provides up to **4 person-hours of support**
- Intake form and support available now

Expert Match

- Online intake form w/ rolling review
- SME provides up to **100 person-hours of support**
- Intake form and support available now

Deep Dive

- Detailed application form in planned ~6-month cycle
- Team of SMEs provide **100+ person-hours of support**
- Detailed online application available soon

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