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RESOLVE Model: Additional Technical Topics

IRP Modeling Advisory Group #3

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Agenda

- RESOLVE modeling framework review
- System and local reliability in RESOLVE
- Operational model detail

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RESOLVE OVERVIEW

RESOLVE Co-optimizes Investment and Operational Decisions

- RESOLVE is a linear program allows portfolio optimization across a long time horizon (10-20 years)
- Fixed costs capture capital, financing, and fixed O&M associated with new physical infrastructure
- Operational detail focuses on primary drivers of renewable integration challenges
- RESOLVE may select portfolio from a variety of potential "solutions," including:
  - Renewable overbuild
  - Energy storage
  - Advanced demand response
  - Conventional gas generation
  - Gas retrofits

RESOLVE Objective Function

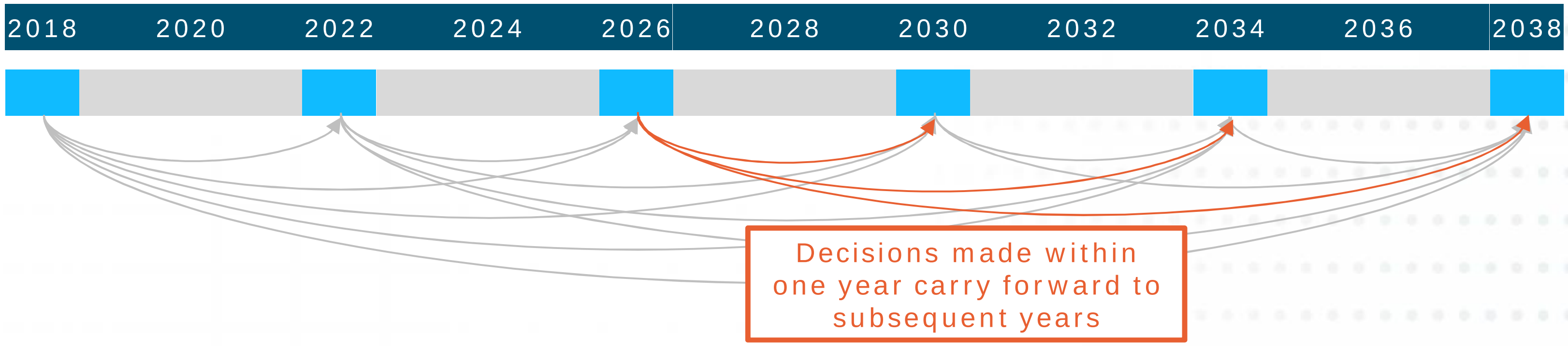
+ **Fixed Costs of New Resources**
  - Renewables
  - Energy storage
  - Demand response
  - Thermal

+ **Fixed Costs of New Transmission**

+ **System Operating Costs**
  - Variable O&M
  - Start costs
  - Fuel costs
  - Carbon

Model Time Horizon

+ RESOLVE minimizes the NPV of total costs across a 20+ year time horizon
  - Additional weight applied to last year of analysis to account for end effects
  - Because of computational complexity, RESOLVE is typically not used to model all years in analysis horizon



In each modeled year, the portfolio is explicitly modeled, and total cost is calculated as the sum of fixed costs of investment and operating costs

In intermediate years, the total cost of the portfolio is calculated by linear interpolation between the two adjacent modeled years

Example Objective Function with Interpolation

- Objective function includes for each year's total cost (TC_{yy}), either explicitly or calculated via interpolation
- Example illustrates five-year analysis horizon with only first and last years modeled
  - 5% discount rate assumed

Year	Method	Total Cost	Discount Factor	Discounted Total Cost
2018	**Modeled**	$\boldsymbol{TC_{18}}$	**1.00**	$\boldsymbol{TC_{18}}$
2019	Interpolated	$0.75TC_{18} + 0.25TC_{22}$	0.95	$0.71TC_{18} + 0.24TC_{22}$
2020	Interpolated	$0.50TC_{18} + 0.50TC_{22}$	0.91	$0.45TC_{18} + 0.45TC_{22}$
2021	Interpolated	$0.25TC_{18} + 0.75TC_{22}$	0.86	$0.22TC_{18} + 0.65TC_{22}$
2022	**Modeled**	$\boldsymbol{TC_{22}}$	**0.82**	$\boldsymbol{TC_{22}}$
Total		$\boldsymbol{2.50TC_{18} + 2.50TC_{22}}$		$\boldsymbol{2.38TC_{18} + 2.34TC_{22}}$

Objective function

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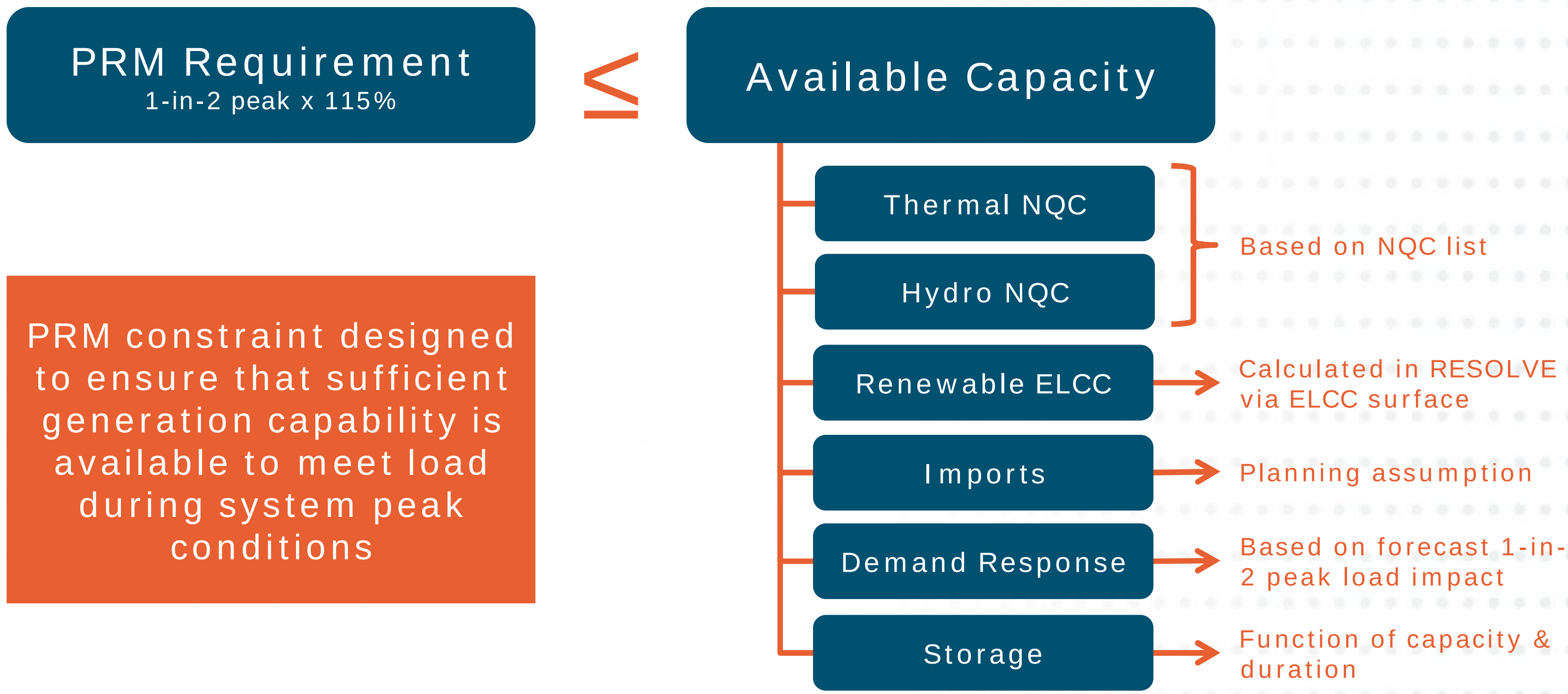
RELIABILITY STANDARDS IN RESOLVE

Reliability Standards in RESOLVE

- Traditionally, these needs are administered to utilities through three requirements:
  1. System RA requirement
  2. Local RA requirement
  3. Flexible RA requirement
- In its optimization, RESOLVE includes multiple constraints that are intended to ensure that the portfolio developed meets system and local reliability needs

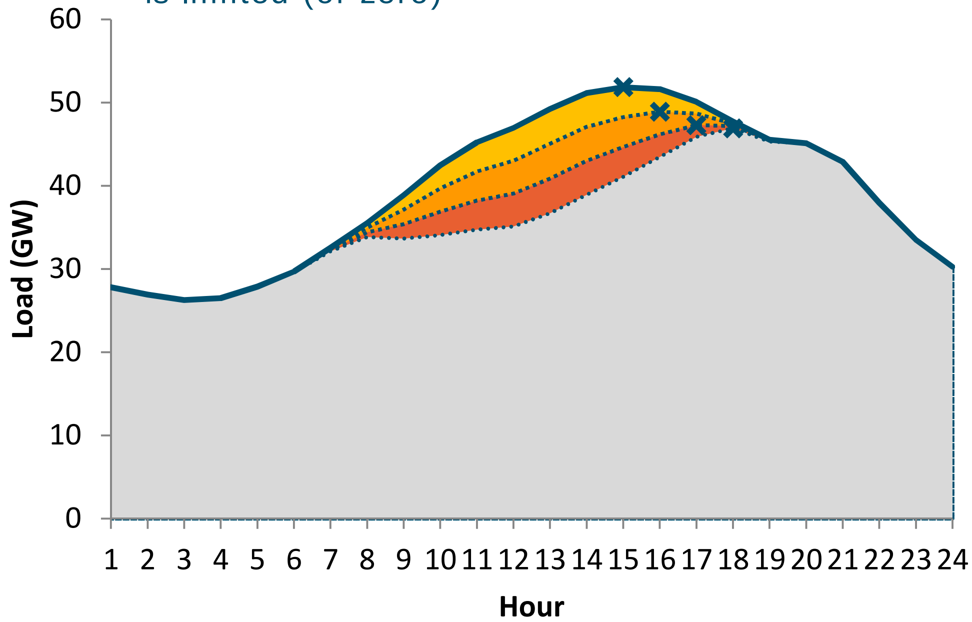
Planning Reserve Margin Constraint

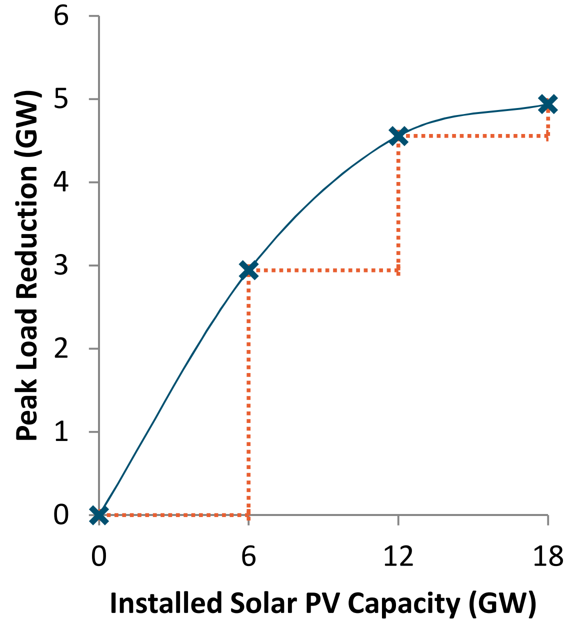
- In each year modeled, RESOLVE imposes a planning reserve margin constraint on the total CAISO generation fleet
- Contribution of each resource to PRM requirement depends on its attributes



Effective Carrying Load Capability for Renewables

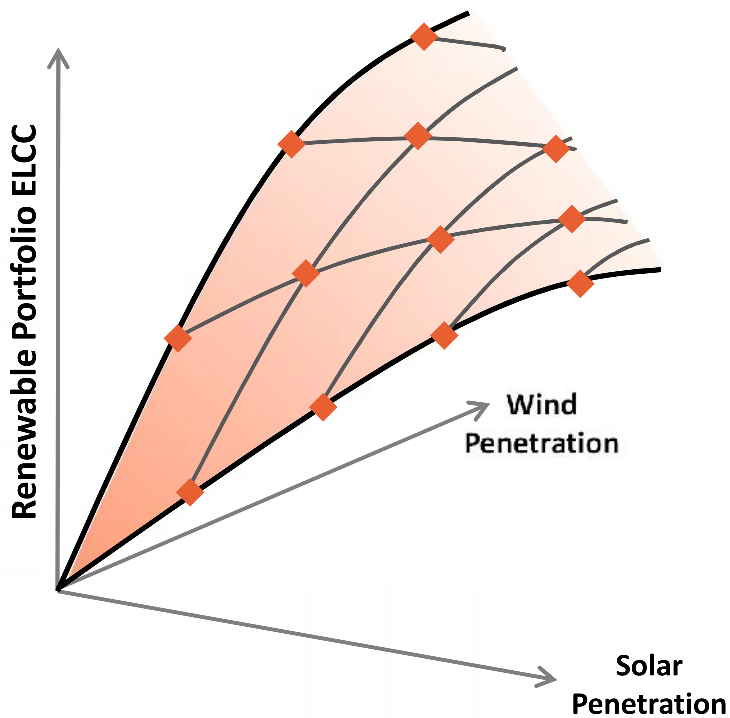
- Effective load carrying capability (ELCC) is a measure of a resource's contribution to system reliability requirements
- For variable resources, marginal ELCC generally declines as a function of penetration
  - For the first increment of solar PV installed, production is largely coincident with peak demand
  - As penetration of solar PV increases, "net load peak" shifts toward evening, when solar PV is limited (or zero)





Implementation of ELCC Surface

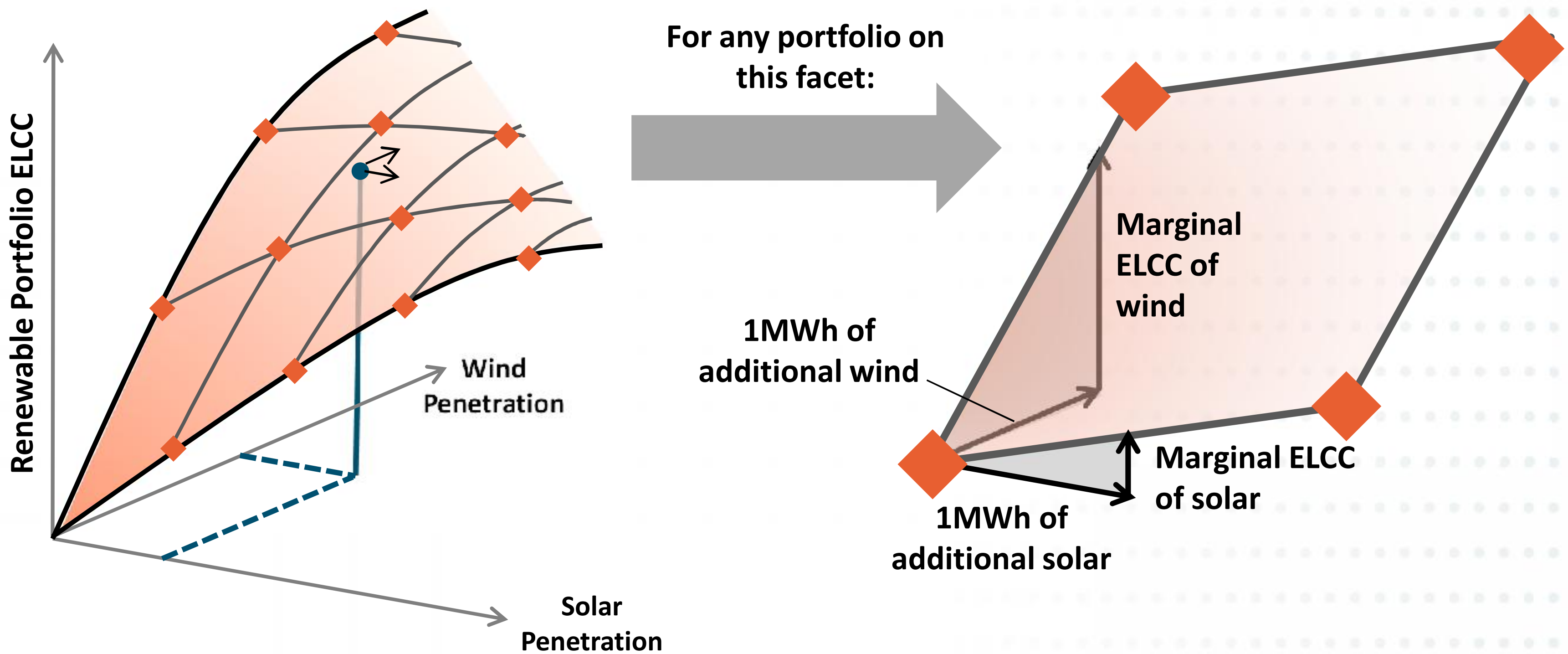
- A reasonable model of renewable ELCC must capture multiple dynamics:
  1. Declining marginal ELCC with increasing penetration
  2. Interactions between multiple variable renewable technologies



- To accomplish this, E3 uses RECAP—an LOLP model—to create a multi-dimensional ELCC "surface"
  - ELCC surface developed outside of RESOLVE to parametrize relationship of installed capacity to ELCC
  - Each point on the surface reflects the total ELCC of a renewable portfolio as a function of the penetration of each of its resource types (e.g. wind, solar)
  - The "slope" of the surface in any direction represents the marginal ELCC for that resource type

Implementation of ELCC Surface

- Within RESOLVE, the ELCC surface is expressed as a piecewise linear function of multiple variables (e.g. wind and solar penetration)
  - Current formulation includes two dimensions (wind & solar); surface may be expanded to include additional dimensions if necessary



Local RA Constraints

- Results of CAISO's Transmission Plan will be integrated to characterize need for local capacity resources
  - "Deficiency" will be adjusted to reflect any key differences in assumptions between prior TPP and current IRP (e.g. changes in assumed retirements, load forecast)

Table D2: Summary of Long-Term LCR Needs (2025) for Local Reliability Areas in Southern California

	Qualifying Capacity (MW)			2025 LCR Need Based on Single-Element Contingency (MW)			2025 LCR Need Based on Multiple-Element Contingency (MW)		
Local Area Name	Existing Resources	CPUC-approved procurement contracts	Total	Available Capacity Needed	Deficiency	Total	Available Capacity Needed	Deficiency	Total
Western LA Basin	2,728	1,813	4,541	4,541	(695)	5,236	4,541	(973)[8]	5,514
Eastern LA Basin	3,531	N/A	3,531	2,132	0	2,132	2,805	0	2,805
Big Creek/Ventura	3,667	Pending review and decision from the CPUC for the Moorpark sub-area procurement selection	3,667	2,111	0	2,111	2,455	234	2,689
San Diego/ Imperial Valley	4,618	800	4,618[9]	3,151	0	3,151	4,618	(250)[10]	4,868

Additional constraints on resource build-out

Implementing Local RA Constraints

- In each local area with a deficiency, new resources will be required to meet the identified need in each modeled year

Local Deficiency [MW] $\leq$ **New Resources** [MW] $\times$ **Assumed NQC** [%]

New Resources:
- Gas CCGT / CT
- Storage
- Distributed PV
- Demand Response

Local RA constraint designed to ensure that sufficient generation capability is available to meet load in local areas during peak periods

- The addition of local RA constraints offer additional location-specific value for candidate resources

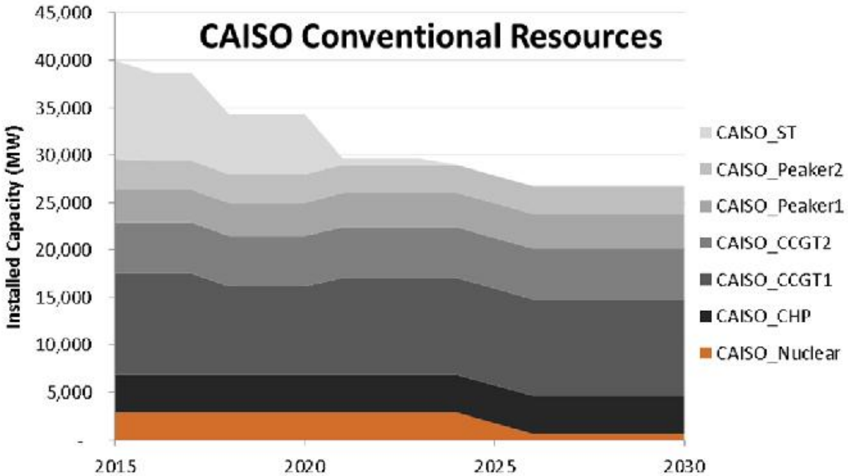
Flexible RA Constraints

- Flexible RA requirements are <u>not</u> represented explicitly in RESOLVE
  - Production simulation modeling indicates this constraint will not be binding upon portfolio decisions
- Instead, “need” for flexibility is determined by system economics
  - Renewable curtailment provides a backstop to system flexibility, but comes at significant cost
  - Integration solutions are justified if the economic value of their flexibility offsets the required investment

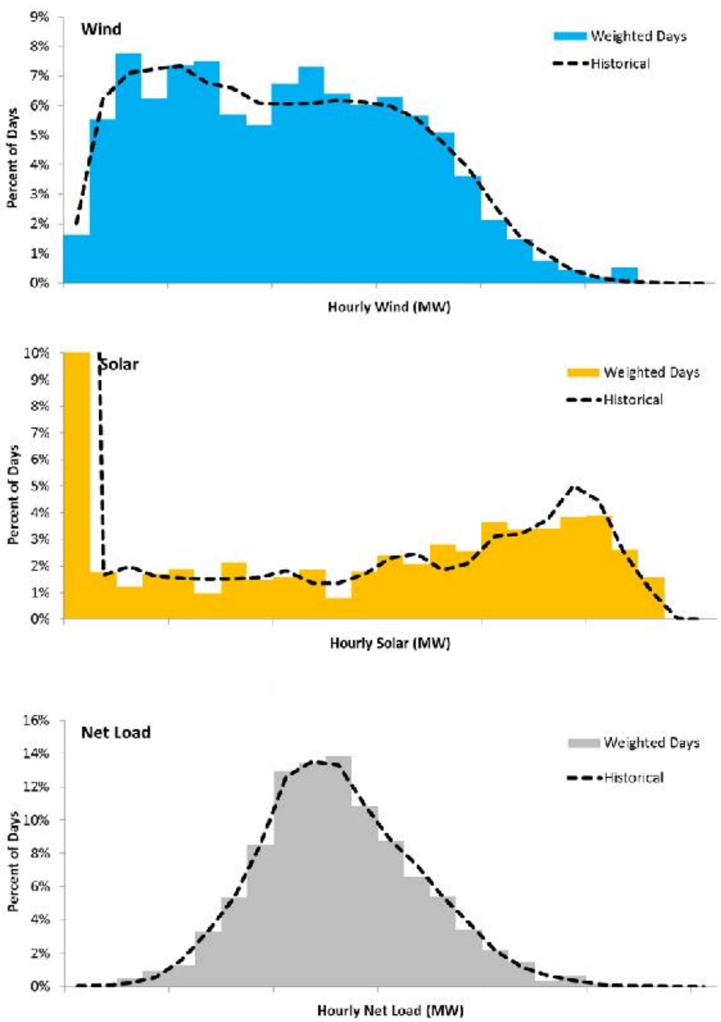
CONSTRAINTS ON OPERATIONAL MODEL

Overview of Operational Model

+ RESOLVE uses an hourly operational model to simulate the economics of system operations, accounting for:
  - Hourly profiles for load, wind, and solar resources
  - Daily hydro energy budgets
  - Operating constraints on thermal generators and storage resources
  - Regulation, flexibility reserve & frequency response requirements
    - Spinning & non-spinning reserves not currently modeled
+ Rather than modeling each generator individually, RESOLVE groups similar plants together to model different classes of thermal generation
  - CAISO existing thermal fleet represented by seven categories of generation



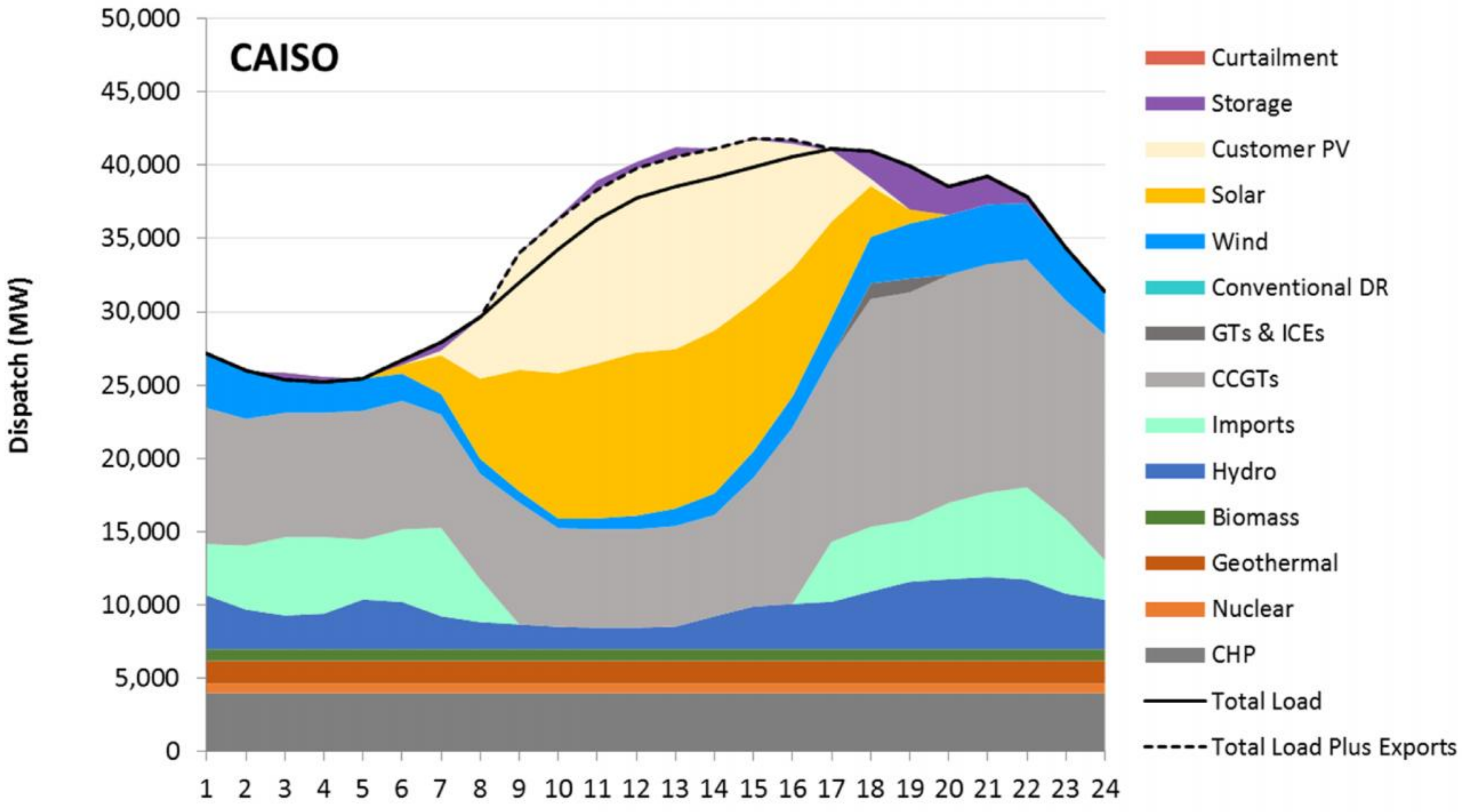
Sampling of Days Captures Long-Run Expectation of Net Load Distribution



- For each modeled year in the analysis horizon, RESOLVE simulates operations for 37 independent days
- Results of 37 days weighted to approximate long-run distributions of:
  - Hourly load
  - Hourly solar
  - Hourly wind
  - Hourly net load
  - Daily hydro energy
  - Monthly hydro energy
  - Monthly renewable capacity factors by site

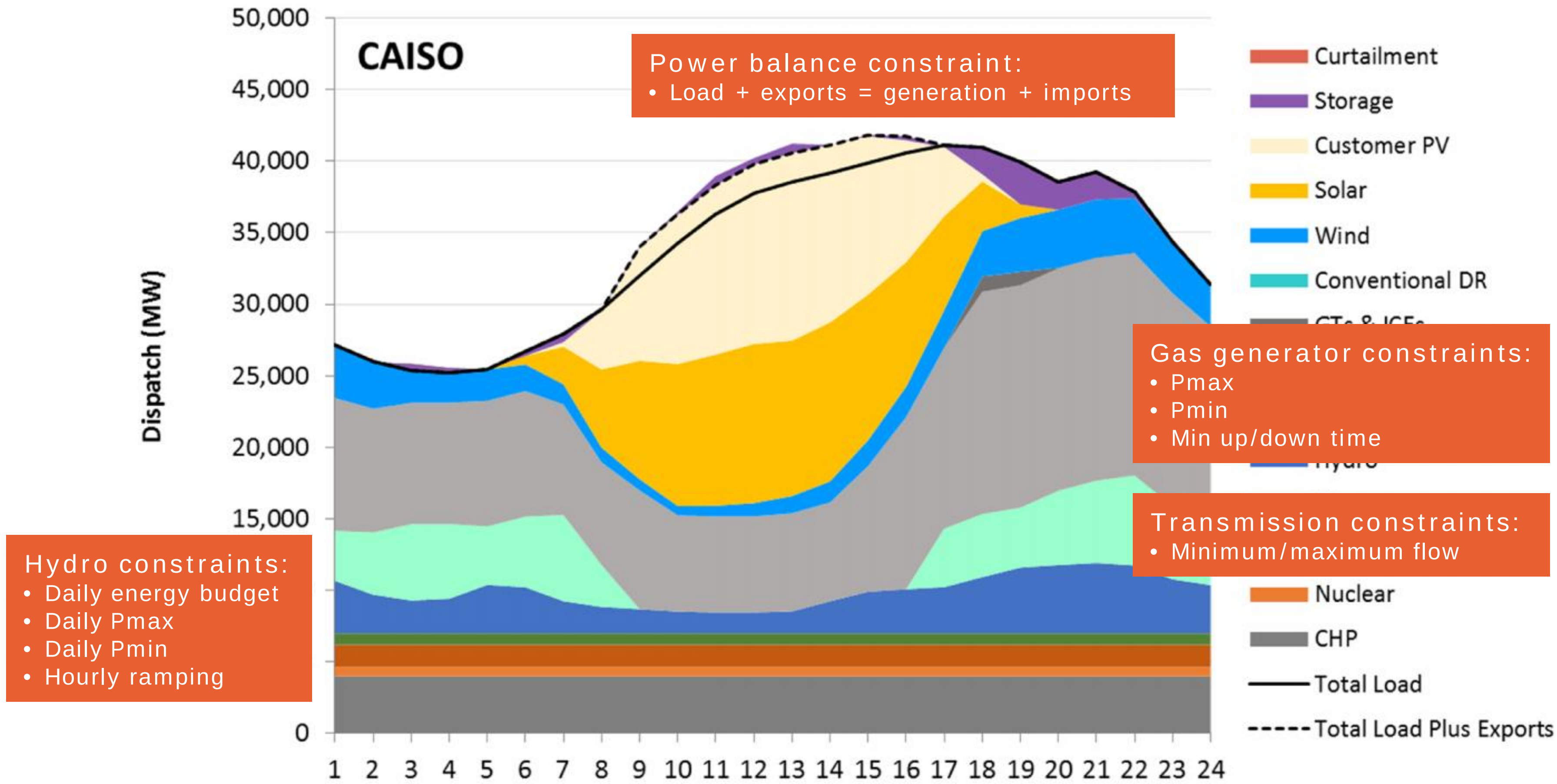
Daily Operational Simulations

+ Operations for each of the 37 days is simulated independently



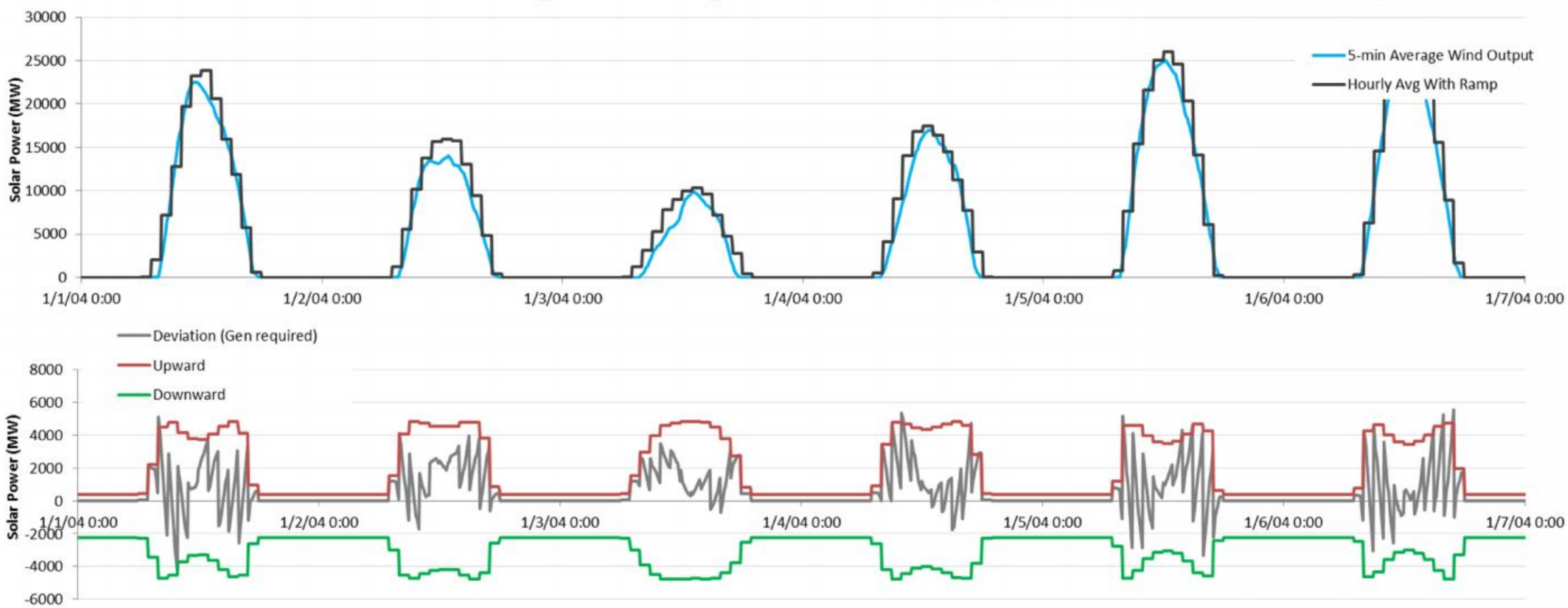
Daily Operational Constraints

+ Hourly operations is constrained by many factors:



Flexibility Reserve Requirements

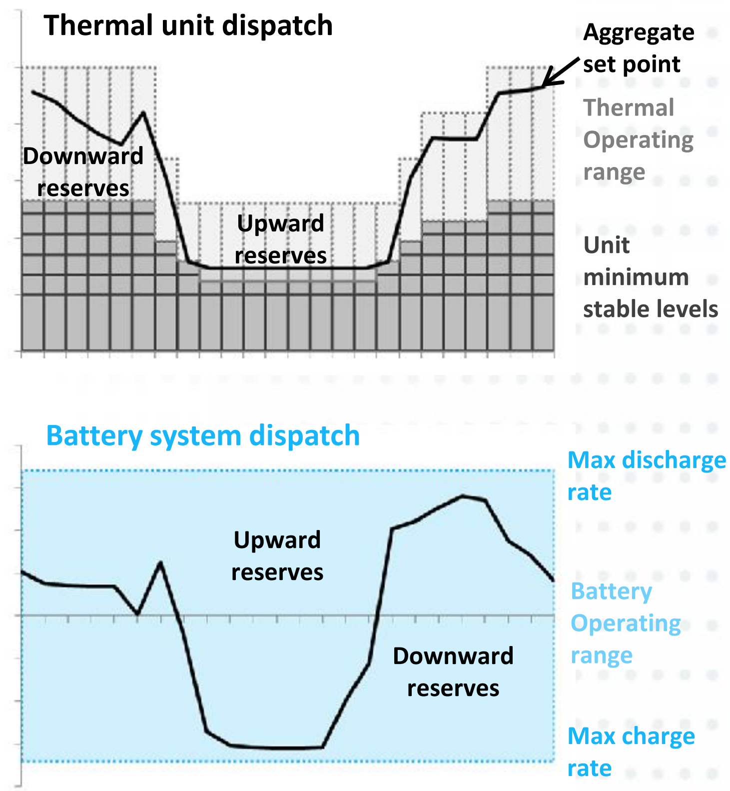
- Flexibility ("load following") reserve requirements are imposed to ensure that sufficient flexible capacity is reserved to meet subhourly load and renewable variability
- Flexibility reserve requirements are developed exogenously through analysis of five-minute variability and hour-ahead forecast error; example analysis for solar PV shown below:



Meeting Flexibility Reserve Needs

+ At high penetrations of renewable generation, flexibility reserve requirements are large and have a significant impact on how a system operates
+ RESOLVE assumes that flexibility reserve requirements can be met by a variety of resources:
  - Thermal & hydro resources, based on available headroom & footroom
  - Storage resources, based on available headroom & footroom
    - State of charge assumed to adjust based on assumed utilization of reserves within hour of 20% of reserve contribution
    - e.g. holding 10 MW of upward flex reserves with storage will decrease state of charge by 2 MWh
  - Renewable resources (downward reserves only)

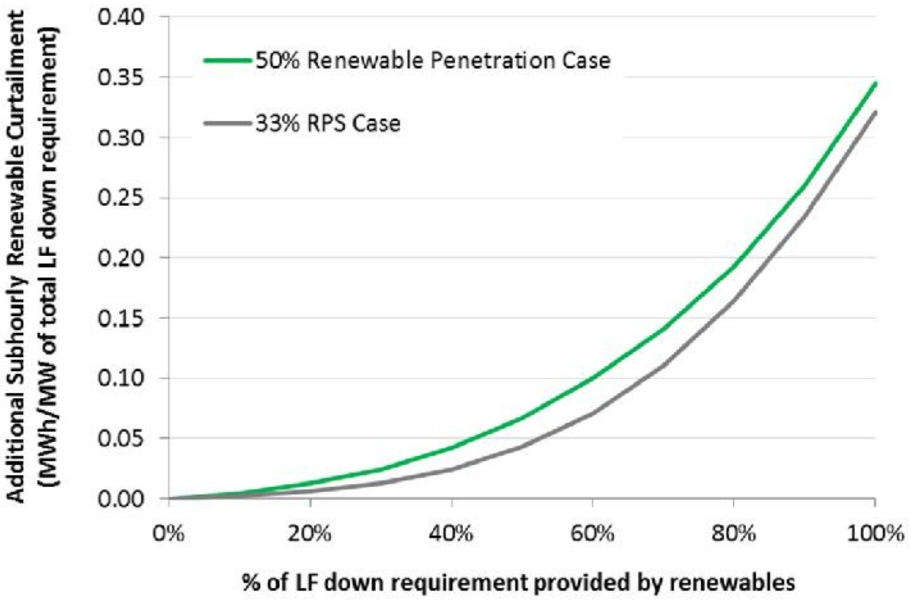
Simulates economic dispatch on each day subject to technical operating constraints



Contributions of Renewables to Downward Reserves

+ Renewable resources are assumed to contribute to meet downward flexibility reserve needs—with two important qualifications:

    1. Maximum contribution of renewables to meeting downward reserves is 50% of requirement (based on guidance from CAISO)



    2. Using renewables to meet downward reserves is assumed to result in subhourly curtailment, which is incorporated into the RPS constraint
        - In other words, with all else equal, meeting downward flex reserves with renewables will require additional renewable build to offset subhourly curtailment
        - Relationship between contribution of renewables to downward reserves and expected subhourly curtailment based on 5-minute simulations

Frequency Response Constraint

- Post contingency, fast response is needed
  - <1 minute response assured by frequency response
  - Note: different from and in addition to frequency regulation
- In Resolve, frequency response is an upward reserve of 770 MW held in each hour in CAISO
  - Hydro and pumped hydro contribute half of requirement
    - 385 MW response assumed but not modeled
  - Batteries can respond quickly
    - Each MW reserved counts 100% towards requirement
  - Dispatchable thermal generators respond more slowly
    - 8% of committed capacity counts toward requirement
  - Other technologies do not currently contribute

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Thank You!

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