Energy+Environmental Economics

Renewable Energy Flexibility (REFLEX) Model

CPUC Webinar

May 22, 2013

Introduction

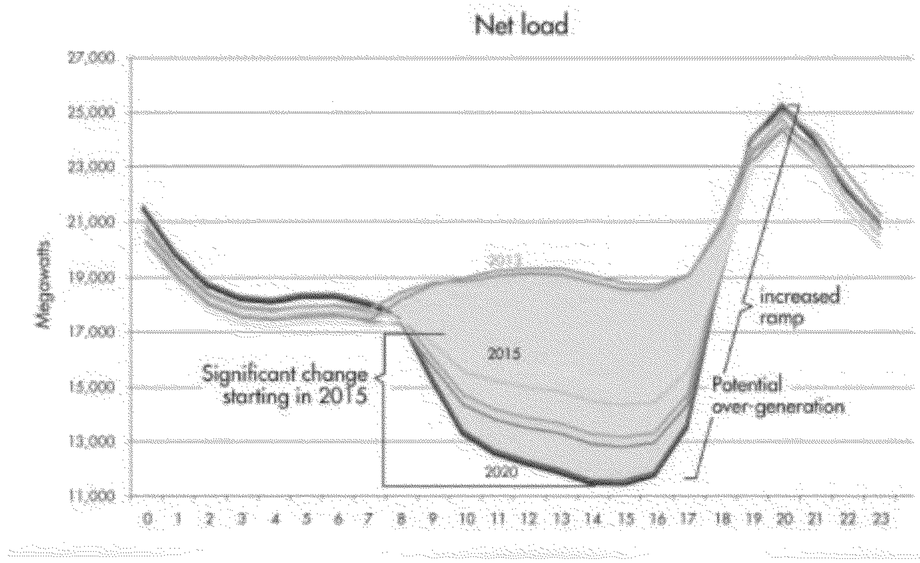
- **Wind and solar are both variable and uncertain, creating a need for power system flexibility**
- **E3 has developed the Renewable Energy Flexibility Model (REFLEX), a tool to calculate the need for power system flexibility under high renewable penetration**
- **The tool can evaluate alternative strategies for meeting power system flexibility needs:**
  - New flexible resources: CTs, ICEs, energy storage
  - Operating strategies: scheduled renewable curtailment, optimal reserve scheduling
  - Structural improvements: within-hour scheduling, Energy Imbalance Market, forecasting improvements
- **E3 is now under contract to CAISO to test REFLEX for PLEXOS in current LTPP cycle**

Existing Tools are Unable to Address Flexibility Needs

+ **Previous studies have focused exclusively on characterizing the operating issues**
  - Deterministic production simulation model runs at various timesteps (5 minutes, 10 minutes, hourly)
  - Stochastic representation of day-ahead forecast errors and sub-timestep flexibility needs
  - Typically select a conservative operating policy, e.g., meet 95% of sub-timestep ramping needs
+ **Previous models do not adequately address the important planning questions:**
  - How much flexible capacity is needed to accommodate a given quantity of wind and solar?
  - How much wind and solar can be added to a given system before more flexible resources are required?

Defining the Problem

+ **Introduction of variable renewables has shifted the capacity planning paradigm**

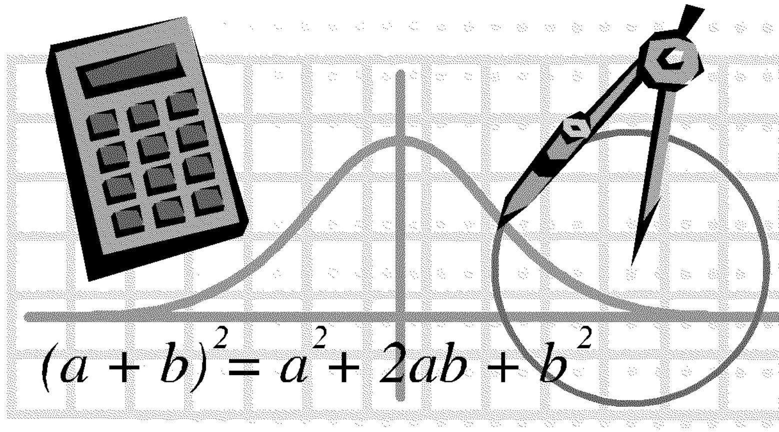


+ **The new planning problem consists of two related questions:**

  1. How many MW of <u>dispatchable</u> resources are needed to (a) meet load, and (b) meet flexibility requirements on various time scales?

  2. What is the optimal mix of new resources, given the characteristics of the existing fleet of conventional and renewable resources?

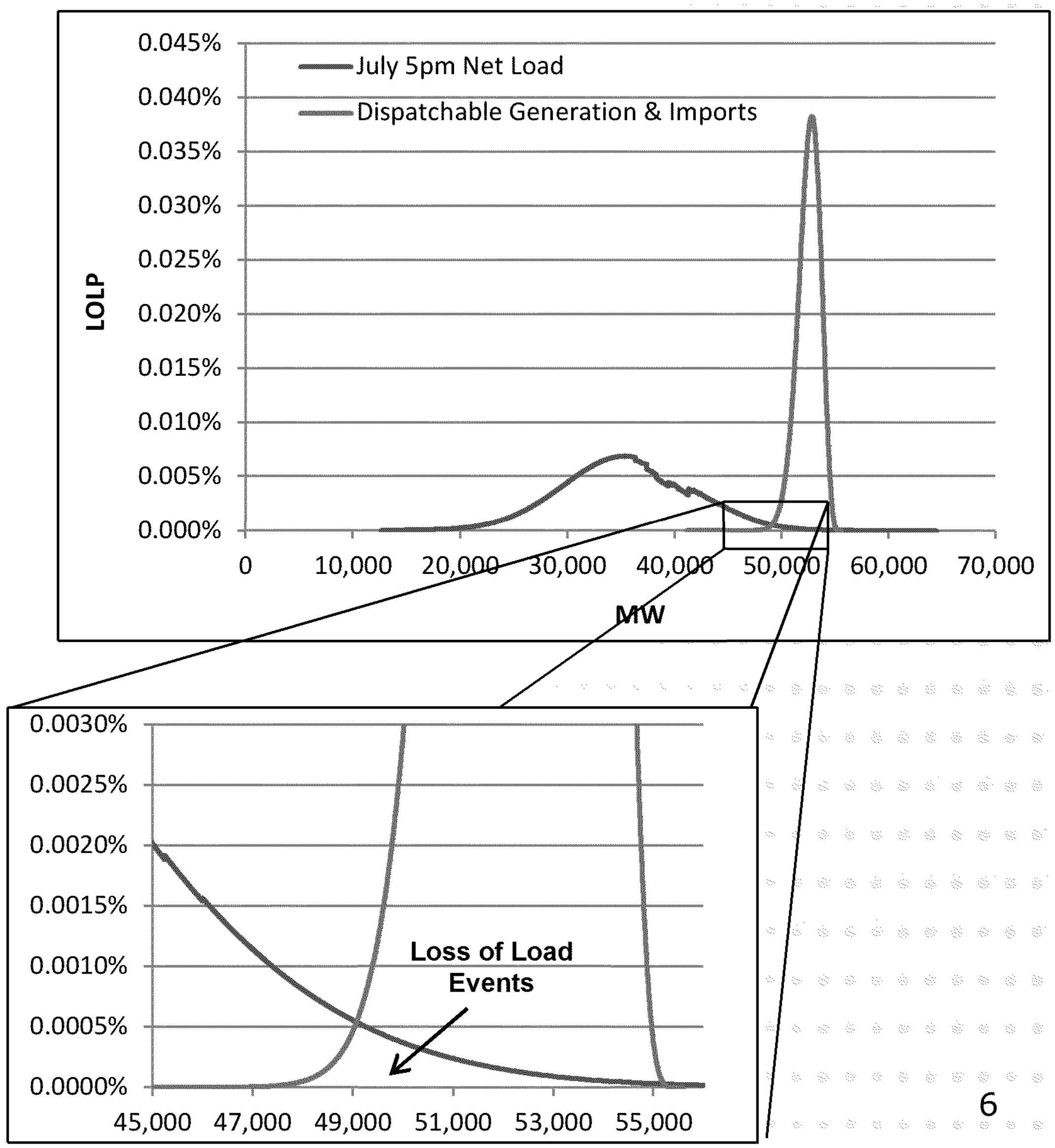
Problem is Stochastic in Nature



- **Load is variable and uncertain**
  - Often characterized as "1-in-5" or "1-in-10"
  - Subject to forecast error
- **Renewable output is also variable and uncertain**
- **Supplies can also be stochastic**
  - Hydro endowment varies from year to year
  - Generator forced outages are random
- **Need to know size, probability and duration of any shortfalls**

Stochastic Modeling Must be Robust

- **Need occurs during "tail" events for both demand and supply**
  - Need enough draws to accurately characterize the frequency, size and duration of any resource insufficiencies
- **Flexibility need shortages will be related to capacity shortages**
  - Large ramping events are more likely to cause problems under "stress" load conditions
  - Inflexible generation may be able to "free up" flexible capacity to be available for ramping events



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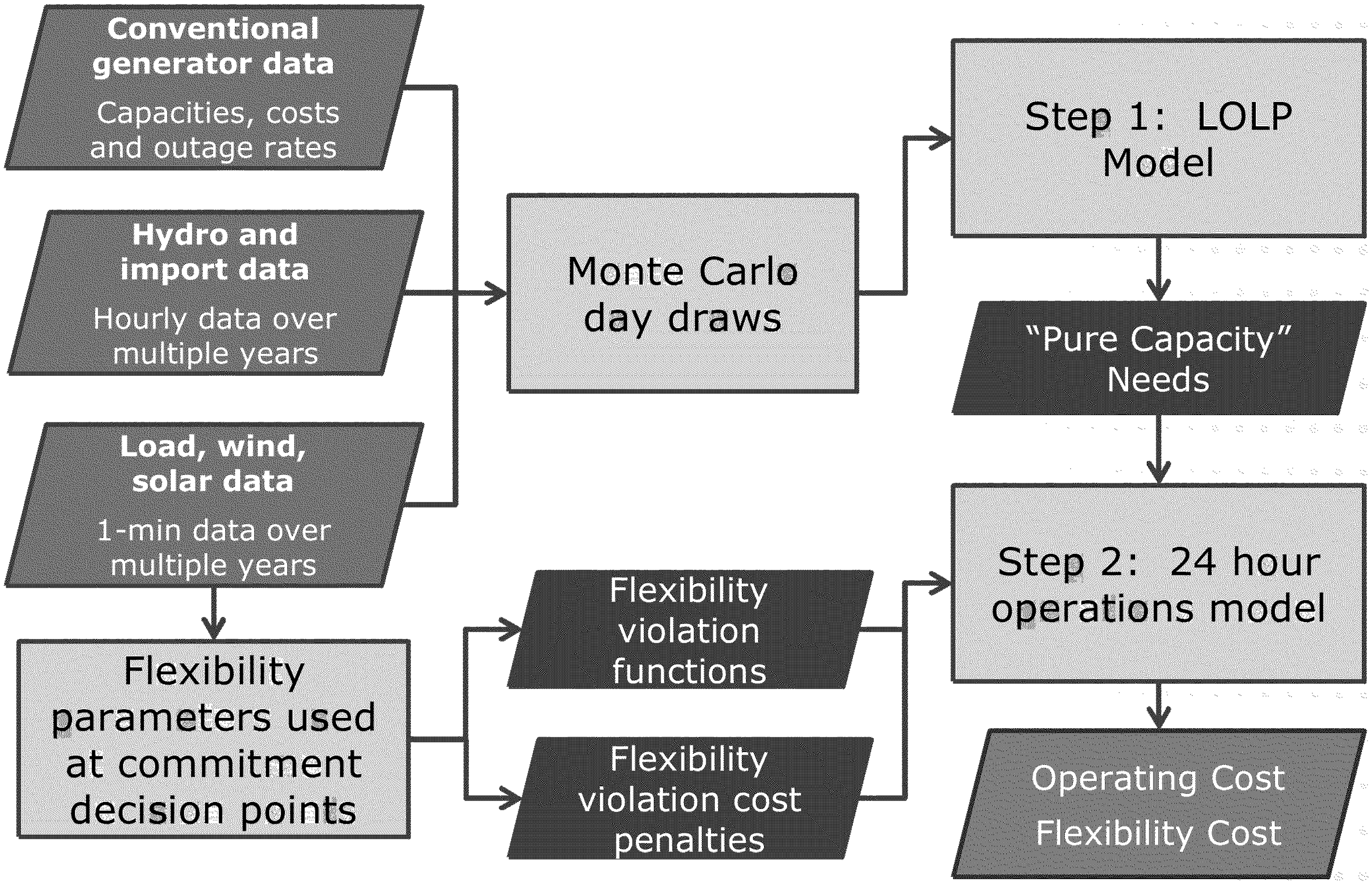
The REFLEX Model

REFLEX is an Extension of Conventional Capacity Planning

+ **REFLEX utilizes a framework similar to conventional reliability planning based on Loss of Load Probability (LOLP) or Expected Unserved Energy (EUE)**
  - Similar metrics are calculated for Expected Unserved Ramp (EUR), in both the upward and downward direction, and Expected Overgeneration (EOG)
  - Flexibility costs are calculated as the product of the expected flexibility violations and a penalty value

	Quantity of Generation	Speed of Generation
Upward Direction	EUE	EUR_U
Downward Direction	EOG	EUR_D

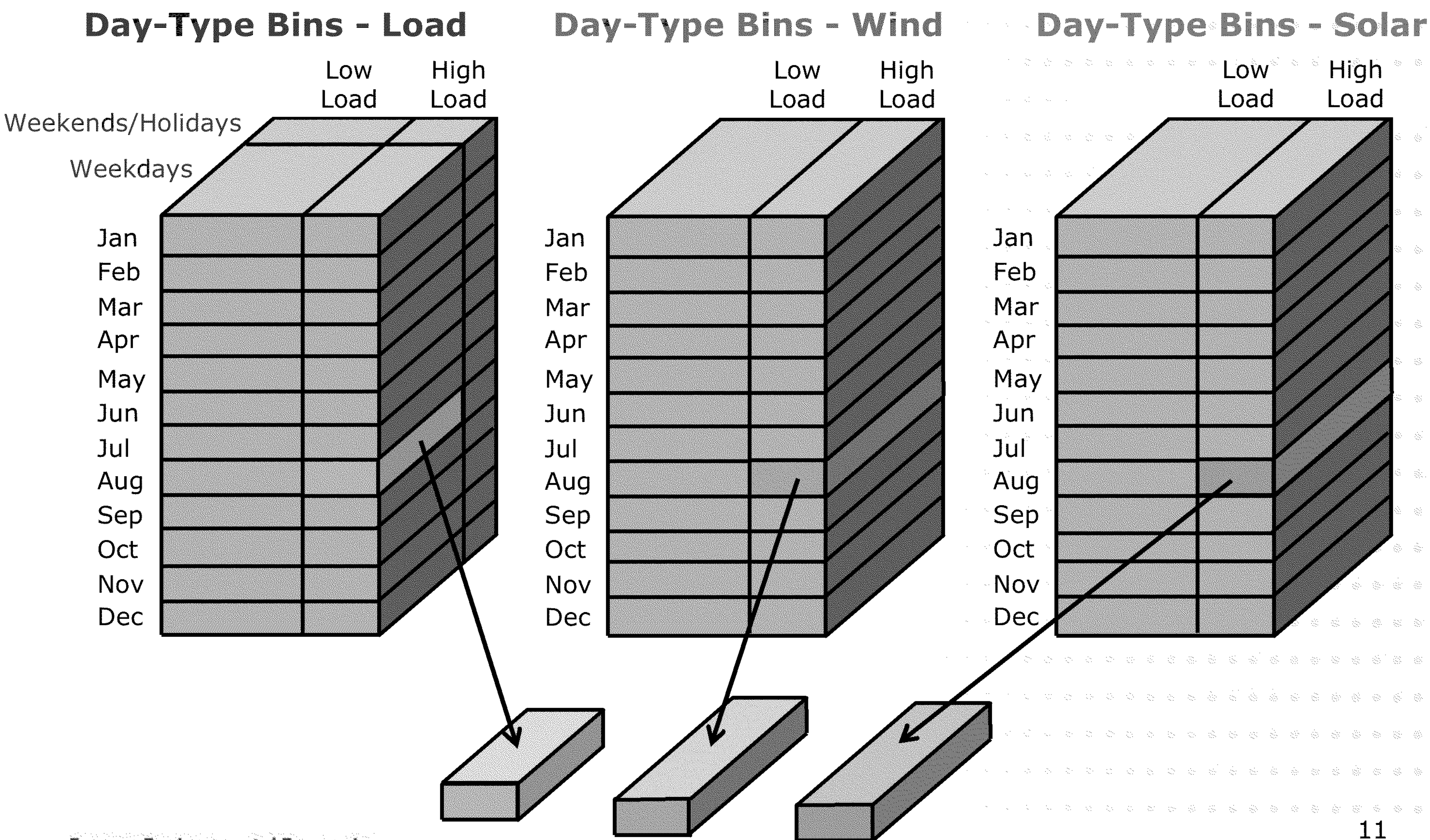
High-level Model Organization



REFLEX Modeling Approach

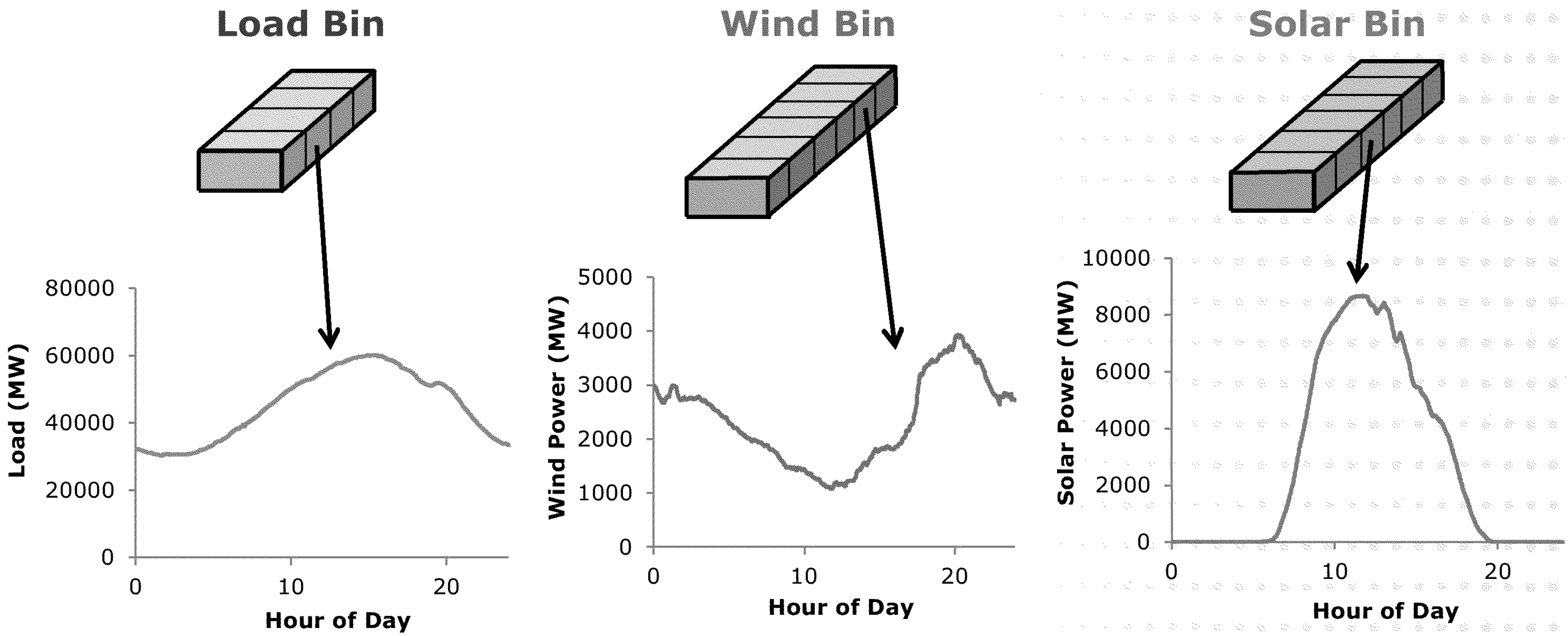
- **Robust, stochastic production simulation modeling**
  - 24 hours of time-sequential operations to capture unit commitment, forecast errors and ramping requirements
    - Day-ahead, hour-ahead and five-minute timesteps
  - Optimal unit commitment and dispatch over 24-hour period
    - Response surfaces consider variability and forecast error
  - Simplification of operating problem is required to obtain acceptable run times
- **Correlated draws of load, wind, solar and hydro shapes to capture full distribution of operating conditions the system is likely to encounter**
  - Sample from largest possible range of conditions to ensure robustness of solution – might need 5000 draws
  - Calculates the likelihood, magnitude, duration and cost of flexibility violations to inform potential solutions

Example Draw:
High Load Weekday in August



Example Draw: High Load Weekday in August

- Within each bin, choose each (load, wind, and solar) daily profile randomly, and independent of other daily profiles.

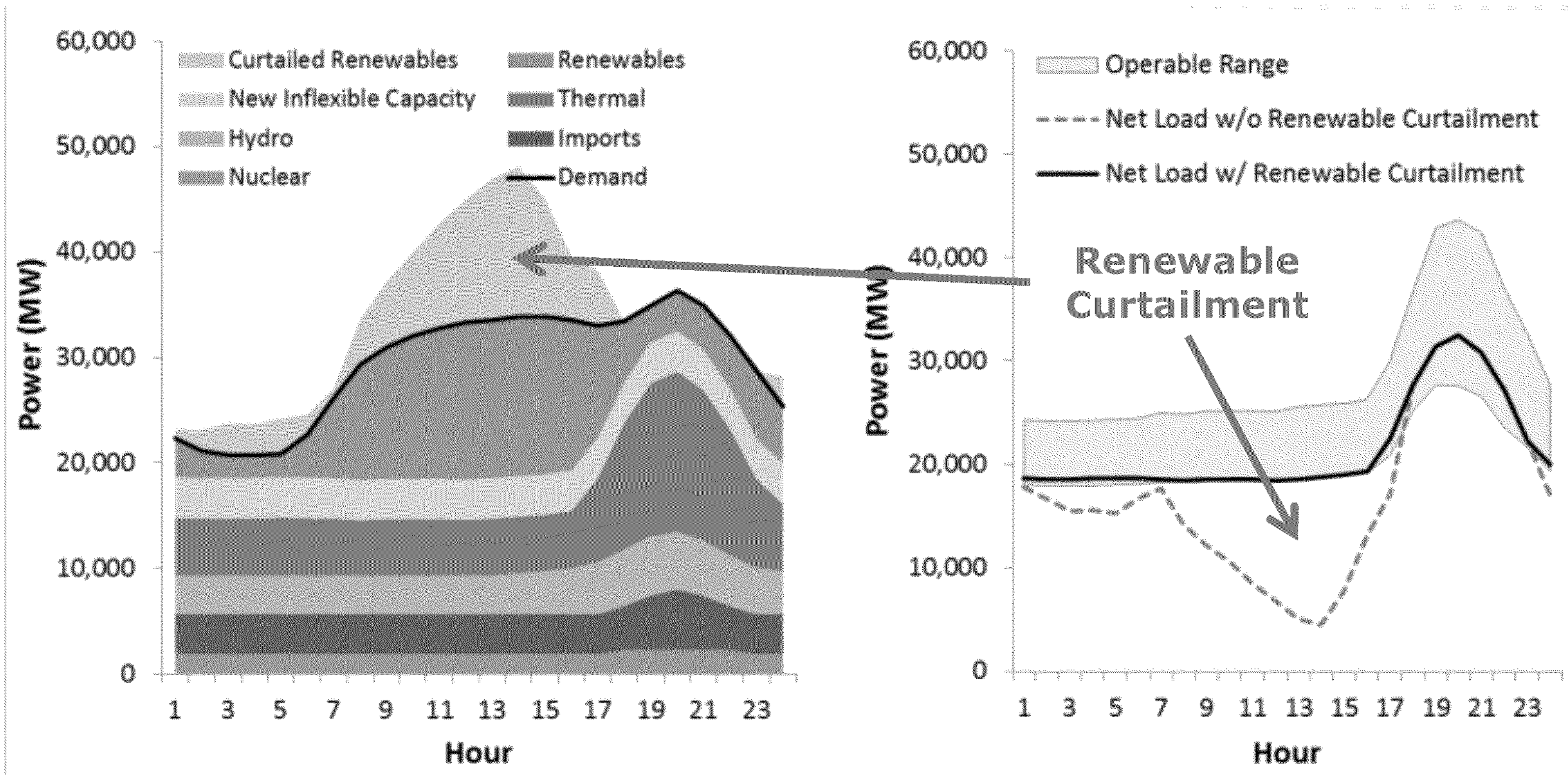


Flexibility Cost Penalties

- Relative cost penalties impose flexibility mitigation strategy "loading order"
- Costs will depend on specific system and applicable policies
- Assuming that all renewables must be delivered is equivalent to placing an infinite penalty on curtailment and overgeneration

Cost of Flexibility Mitigation Strategies	
Scheduled Renewable Curtailment	*$0-50/MWh*
Overgeneration	$50-250/MWh
Subhourly Downward Flexibility Violation	$250-500/MWh
Subhourly Upward Flexibility Violation	$2,000-10,000/MWh
Unserved Energy	$10,000-30,000/MWh

Curtailment of Renewable Output Could Play a Significant Role



+ **Scheduled curtailment of renewables can help position conventional resources to meet ramping requirements**
+ **How does the cost of curtailment compare to the cost of procuring new flexible resources?**

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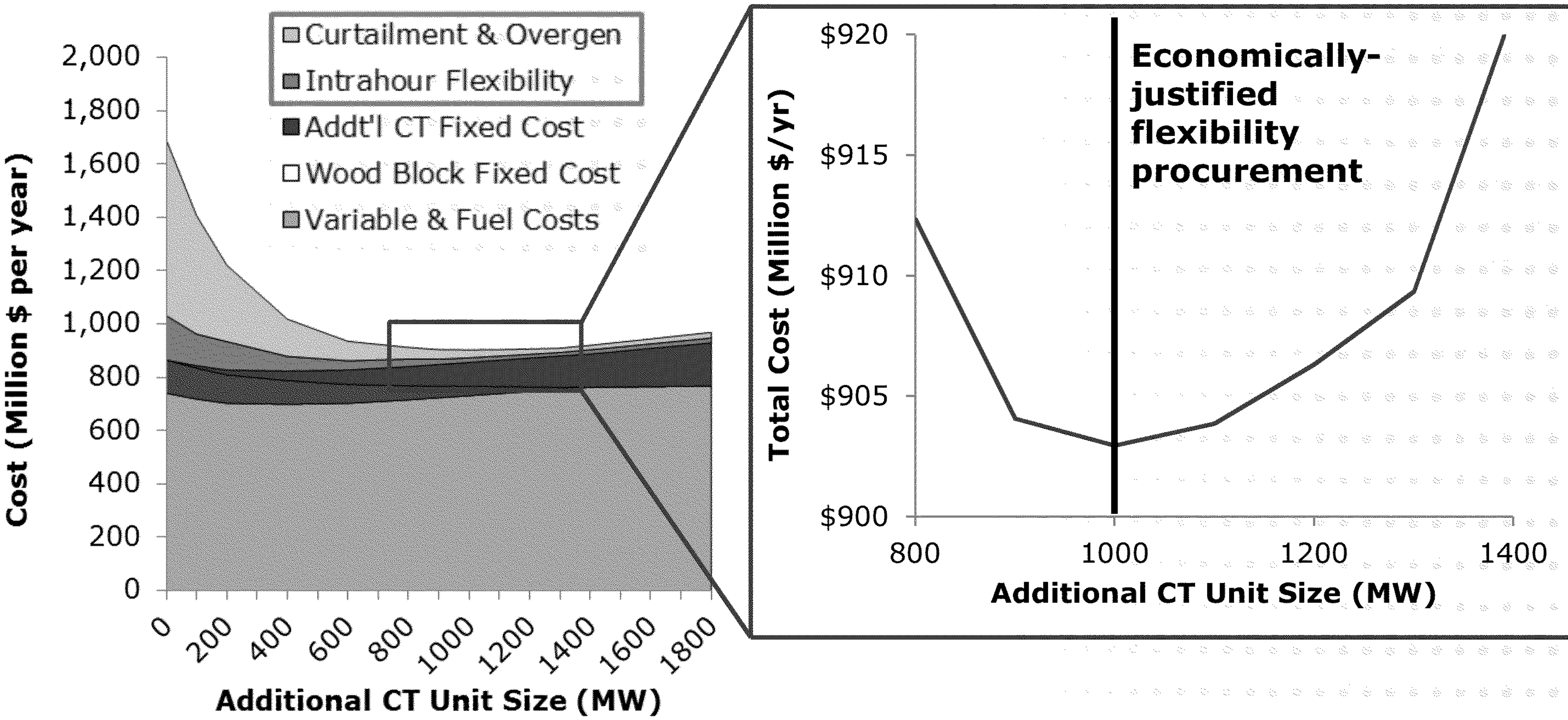
Optimal Flexibility Investment

+ **REFLEX provides an economic framework for determining optimal flexible capacity investments by trading off the cost of new resources against the value of avoided flexibility violations**



Load Following Needs

- **Load Following needs can be parameterized through stochastic analysis of potential flexibility violations given a set of operating choices**
  - Used at each defined commitment interval (e.g., day-ahead, hour-ahead, 15 minutes)
- **Unit Commitment model selects optimal Load Following reserve levels from a set of pre-defined "ramping policies"**
  - Model minimizes total cost, including costs of sub-interval flexibility deficiencies (unserved energy or overgeneration)
  - Carrying more Load Following reserves reduces sub-interval ramp deficiencies, but increases operating costs
- **Can also used fixed load following and regulation parameters**
  - E.g., CAISO "Step 1"

Incorporating Forecast Error

- **REFLEX makes unit commitment decisions at specified intervals**
  - Day-ahead, hour-ahead
  - Ramping policy functions incorporated into commitment decisions
- **Ramping policy functions account for both forecast error and net load variability**
  - Forecast error incorporated through choice on capacity (MW) axis
  - Sub-interval variability incorporated through choice on ramp rate (MW/min.) axis
- **If forecast error is reduced, ramping policy function will show smaller probability of flexibility violations under a given policy**

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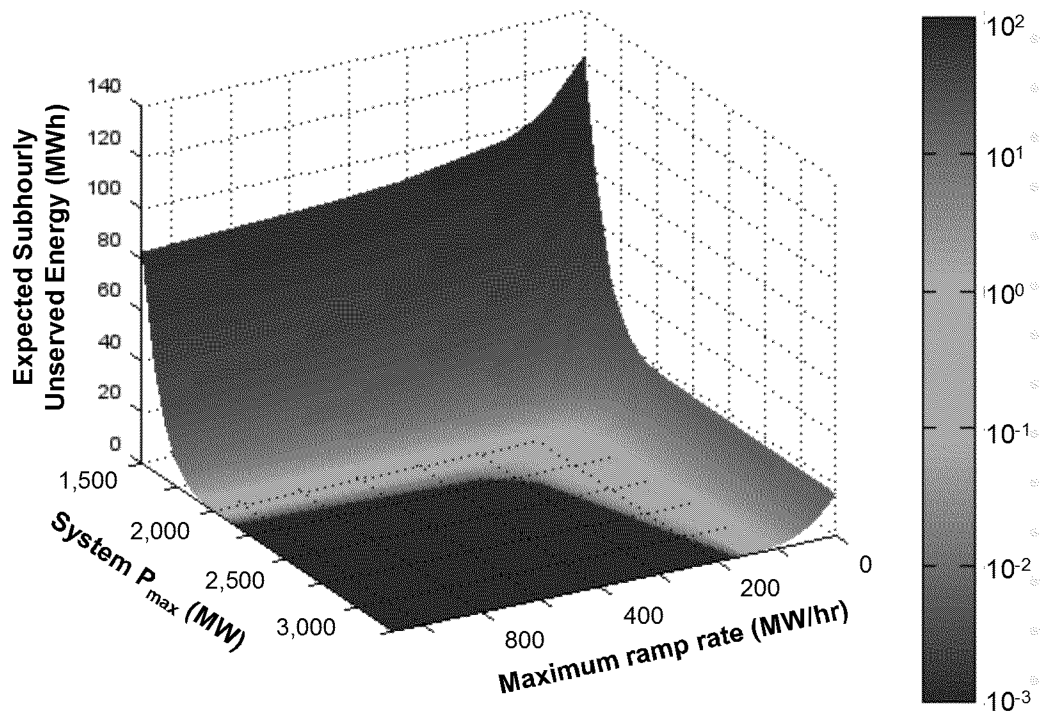
Example Ramping Policy Function

- **Approximate expected sub-interval flexibility violations using 1-min data**
- **Flexibility violations depend on the following variables:**
  - **Demand**
  - **Renewables**
  - **Generic properties of dispatch decision:**
    Committed capacity (MW)
    Max. ramp rate (MW/min.)
- **Simulate these violations over wide range of each of these variables**
- **Ramping policy functions serve as input to dispatch model to trade off operating cost against flexibility violations**

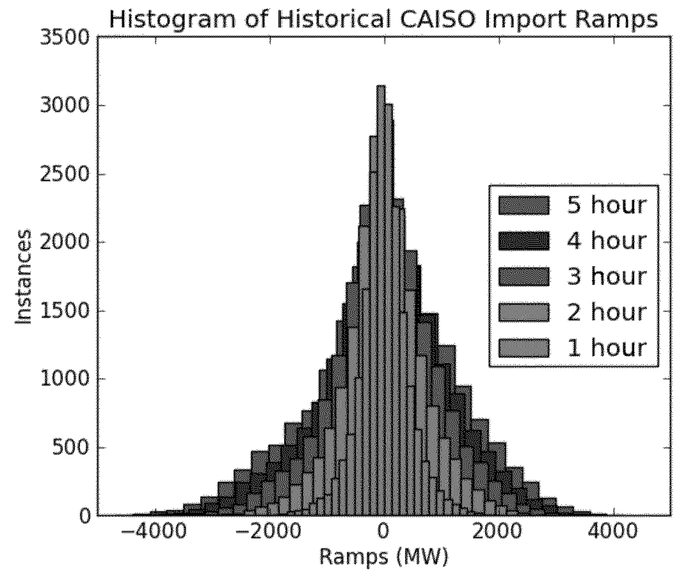
Example subhourly unserved energy function for hour with:

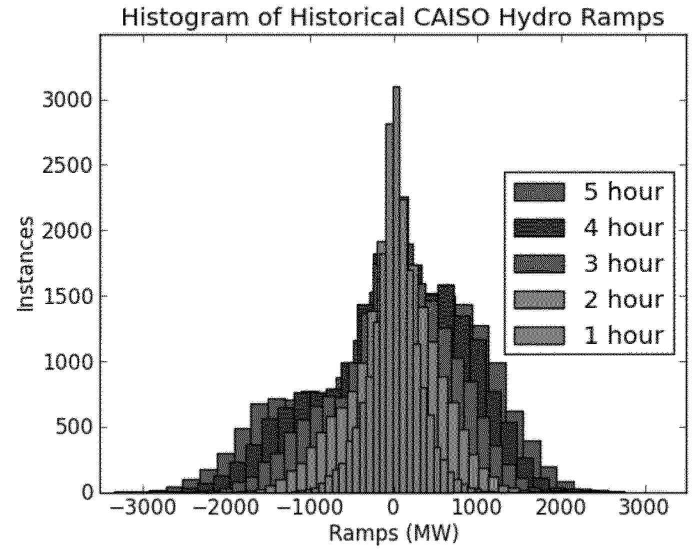
Demand = 2,000 MW
Renewables = 500 MW



Stochastic Treatment of Hydro and Imports

- **Initial import and hydro levels drawn from historical record**
  - Adjusted by unit commitment and dispatch engine
  - Subject to multi-hour ramping constraints developed from historical record (e.g., 95th percentile)
  - Min and max values to further bound the range of values
- **Framework allows for use of alternative methods (e.g., fixed planning values)**



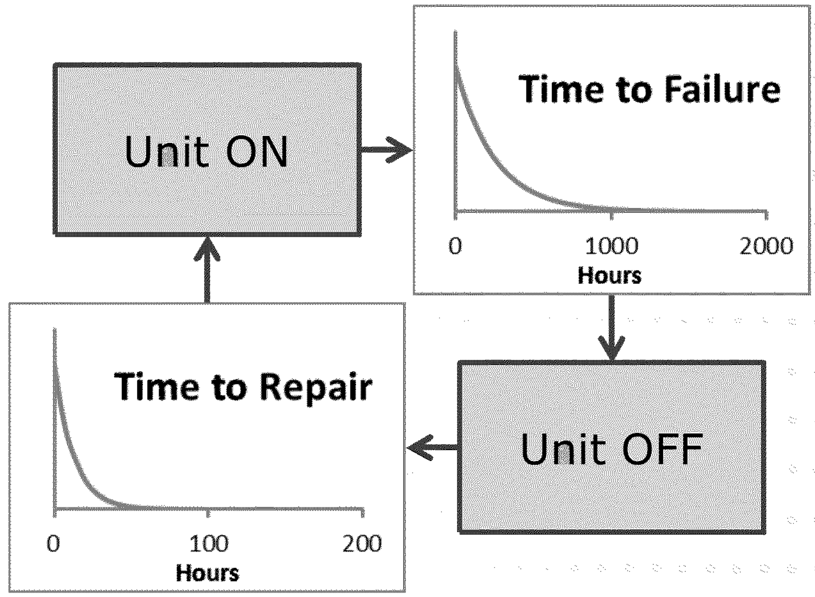


Forced outage and Maintenance

+ **Forced outages are modeled using mean time to failure and mean time to repair and assuming exponential distributions**

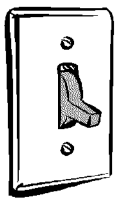
+ **Maintenance is allocated after an initial model runs identify unconstrained months**

Simple Markov Chain Forced Outage Model



REFLEX Applications

+ **Analyzing strategies for renewable integration:**

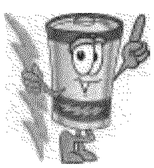


Operational Strategies

+ Renewable curtailment
+ Demand response
+ Forecast improvements
+ Market structure changes

Physical Solutions

+ Flexible generation
+ Energy storage
+ Transmission to improve access to flexible resources



Additional applications

+ Loss of Load Probability/Planning reserve margin analysis
+ Renewables Effective Load-Carrying Capability (ELCC)
+ Calculate renewable integration cost adders
+ Economically efficient procurement of operating reserves
+ RPS or low-carbon policy evaluation

Comparison between LTPP approaches

Item	2012 LTPP Deterministic Modeling	SSNAP	REFLEX
Load Peak and Shape	1 Draw	Draws from 30 years	Draws from 63 years
Intermittent Generation	1 Draw	Draws from 1 year	Draws from 3 years (wind) – 8 years (solar)
Maintenance and Forced Outage	1 Draw	Monte Carlo Draws	Monte Carlo Draws
Dispatch Granularity	Hourly	5 minutes	5 minutes
Dispatch Horizon	8760 Hours	One day per season	One day per month
Economic Dispatch	Yes	No	Yes
Reserve Shortfall	Load following, regulation, spin	Regulation, Spin	Regulation, Spin
Internal transmission constraints enforced	Yes (zonal)	Yes (zonal)	Optional (zonal)
Reliability Measure	Reserve Shortfall	Loss of Load Probability (LOLP)	LOLP, LOLF,EUE, EUR_U, EUR_D, EOG

LTPP REFLEX Cases

- **2012 Historical Case**
  - 2012 Loads and Renewables
  - Test and refine REFLEX model
    - Develop model for imports and test internal transmission constraints
- **TPP/Commercial Interest Case**
  - Develop multi-year datasets with the same build assumptions as the deterministic case
    - Define probabilistic context for CAISO deterministic case
  - Initial model runs with Step 1 reserve requirements, additional model runs solving for load following endogenously
  - Test the need for flexible capacity and determine the value of operational solutions like economic pre-curtailment

Thank You!

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