PNM Preliminary Reliability Analysis

Astrape Consulting

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4/18/2017

Topics

- **Resource Adequacy Overview**
- **SERVM Model Overview**
- **Traditional Reserve Margin Target**
- **Flexibility Metrics**
- **RPS Scenarios and Rules of Thumb**

Resource Adequacy Overview

Resource Adequacy

- **Resource Adequacy Definition: The ability of supply-side and demand-side resources to meet the aggregate electrical demand (NERC Definition)**
- **Resource Adequacy Studies**
  - **Reserve Margin Study**
    - Goal: Calculate generating capacity deficiencies and determine the amount of capacity needed to maintain resource adequacy during peak conditions
    - Purpose: Input or validation of expansion planning processes
  - **Flexibility Study**
    - Goal: Determine reliability deficiencies including both firm load shed events and renewable resource curtailment due to system ramping/startup constraints (not capacity deficiencies)
    - Purpose: Provides assistance in setting appropriate parameters for resource additions and to determine system operating reserve requirements

Resource Adequacy Metrics

- **Loss of Load Expectation ($LOLE_{CAP}$):** Expected number of firm load shed events in a given year due to capacity shortfalls
- **Loss of Load Expectation ($LOLE_{FLEX}$):** Expected number of firm load shed events in a given year due to not having enough ramping capability

- **Loss of Load Hours ($LOLH_{CAP}$):** Expected number of hours of firm load shed in a given year due to capacity shortfalls
- **Loss of Load Hours ($LOLH_{FLEX}$):** Expected number of hours of firm load shed in a given year due to not having enough ramping capability

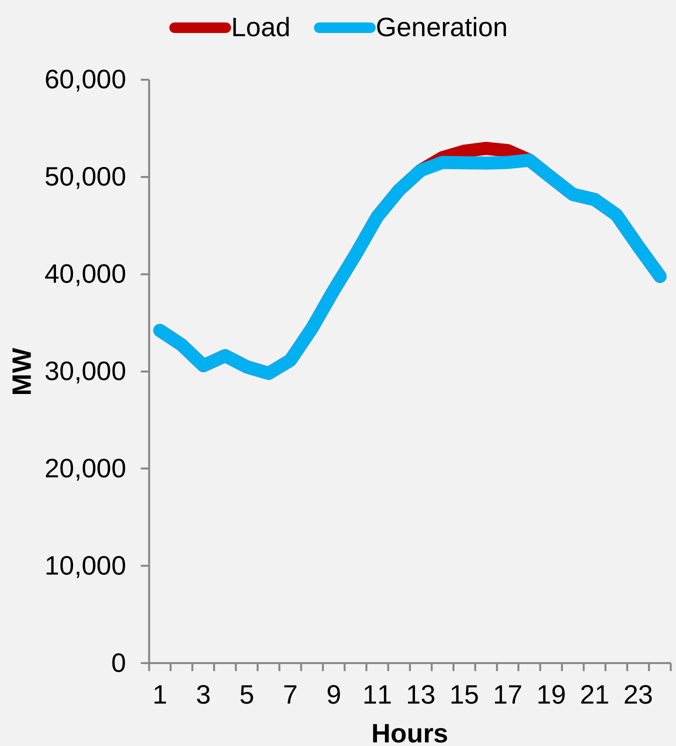
- **Expected Unserved Energy (EUE_{CAP}):** Expected amount of firm load shed in MWh for a given year due to capacity shortfalls
- **Expected Unserved Energy (EUE_{FLEX}):** Expected amount of firm load shed in MWh for a given year due to not having enough ramping capability

Definitions of Existing and New Reliability Metrics

Traditional "Generic Capacity" Metrics

LOLE$_{Cap}$

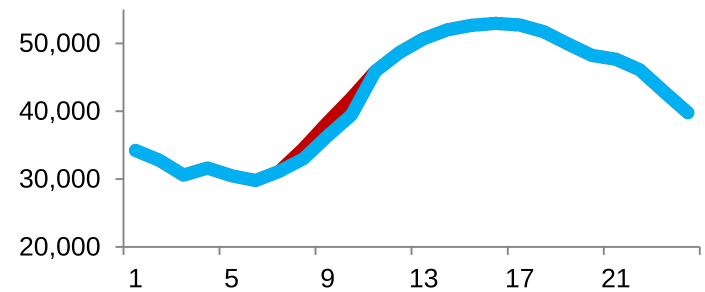
Traditional metric to capture events that occur due to capacity shortfalls in peak conditions



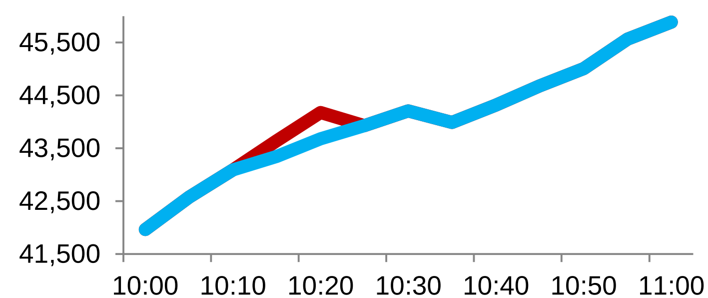
New "Flexible Capacity" Metrics

LOLE$_{FLEX}$

New metric to capture events due to system ramping deficiencies of longer than one hour in duration



New metric to capture events due to system ramping deficiencies inside a single hour



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SERVM Model Overview

Strategic Energy Risk Valuation Model (SERVM)

- **SERVM has over 30 years of use and development**
- **Probabilistic hourly and intra-hour chronological production cost model designed specifically for resource adequacy and system flexibility studies**
- **SERVM calculates both resource adequacy metrics and costs**
- **SERVM used in a variety of applications for the following entities:**

  - Southern Company
  - TVA
  - Louisville Gas & Electric
  - Kentucky Utilities
  - Duke Energy
  - Progress Energy
  - FERC
  - NARUC
  - PNM
  - TNB (Malaysia)
  - EPRI
  - Santee Cooper
  - CLECO
  - California Public Utilities Commission
  - Pacific Gas & Electric
  - ERCOT
  - MISO
  - PJM
  - Terna (Italian Transmission Operator)
  - NCEMC
  - Oglethorpe Power

SERVM Uses

- **Resource Adequacy**
  - Loss of Load Expectation Studies
  - Optimal Reserve Margin
  - Operational Intermittent Integration Studies
    - Penetration Studies
    - System Flexibility Studies
  - Effective Load Carrying Capability of Energy Limited Resources
    - Wind/Solar
    - Demand Response
    - Storage
  - Fuel Reliability Studies
    - Gas/Electric Interdependency Questions
    - Fuel Backup/Fixed Gas Transportation Questions
  - Transmission Interface Studies
- **Resource Planning Studies**
  - Market Price Forecasts
  - Energy Margins for Any Resource
  - System Production Cost Studies
  - Evaluate Environmental/Retirement Decisions
  - Evaluate Expansion Plans

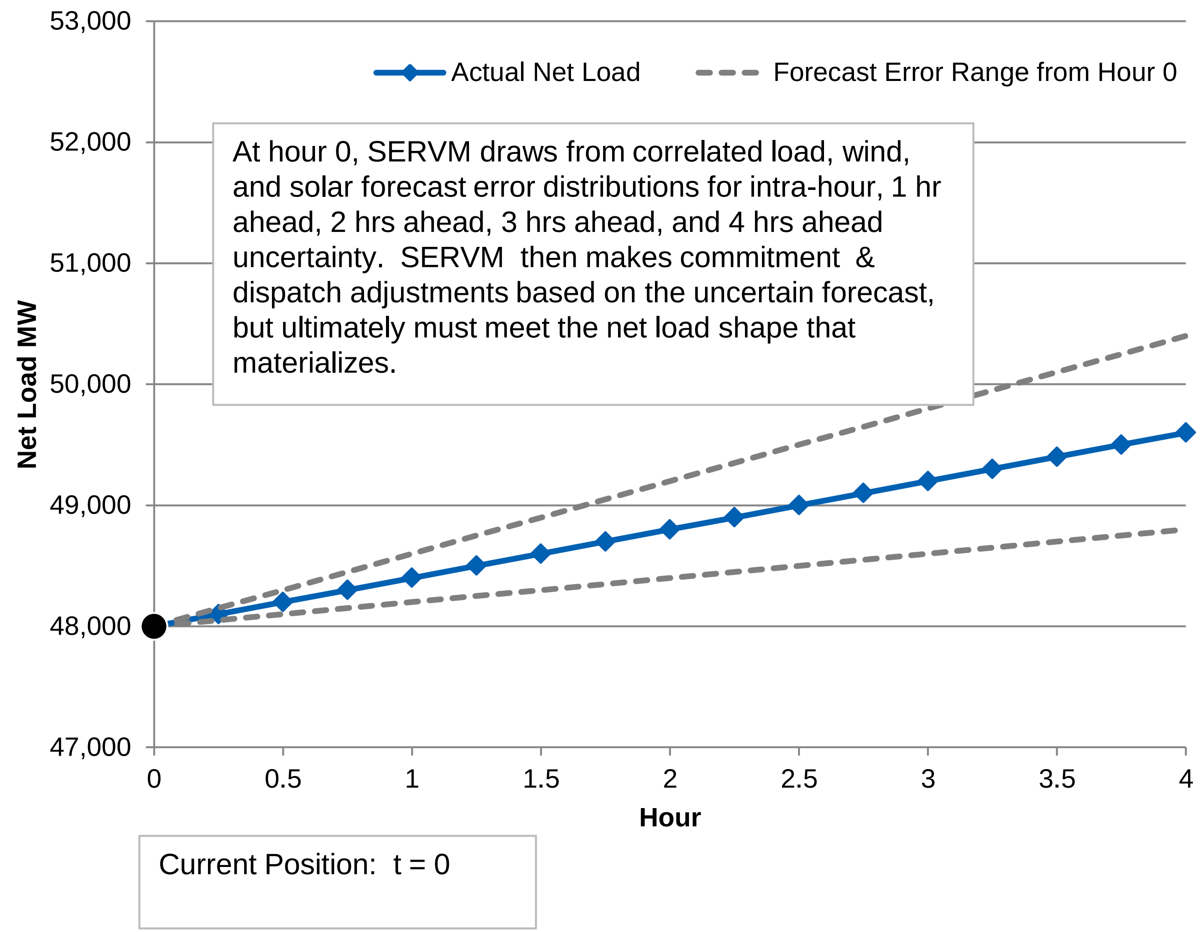
Resource Commitment and Dispatch

- **8760 Hourly Chronological Commitment and Dispatch Model**
- **Simulates 1 year in approximately 1 minute allowing for thousands of scenarios to be simulated which vary weather, load, unit performance, and fuel price**
- **Capability to dispatch to 1 minute interval**
- **Respects all unit constraints**
  - Capacity maximums and minimums
  - Heat rates
  - Startup times and costs
  - Variable O&M
  - Emissions
  - Minimum up times, minimum down times
  - Must run designations
  - Ramp rates
- **Simulations are split across multiple processors linked up to the SQL Server**

Resource Commitment and Dispatch

- **Commitment Decisions on the Following Time Intervals allowing for recourse**
  - Week Ahead
  - Day Ahead
  - 4 Hour Ahead, 3 Hour Ahead, 2 Hour Ahead, 1 Hour Ahead, and Intra-Hour
- **Load, Wind, and Solar Uncertainties at each time interval (decreasing as the prompt hour approaches)**
- **Benchmarked against other production models**

1 - 4 Hour Ahead Forecast Error



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Ancillary Service Modeling

- **Ancillary Services Captured**
  - Regulation Up Reserves
  - Regulation Down Reserves
  - Spinning Reserves
  - Non Spinning Reserves
  - Load Following Reserves
- **Co-Optimization of Energy and Ancillary Services**
  - Each committed resource is designated as serving energy or energy plus one of the ancillary services for each period

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SERVM Framework

- **Base Case Study Years (2021 and 2024)**
  - Weather (36 years of weather history)
    - Impact on Load
    - Impact on Intermittent Resources
  - Economic Load Forecast Error (distribution of 5 points)
  - Unit Outage Modeling (thousands of iterations)
    - Multi-State Monte Carlo
    - Frequency and Duration

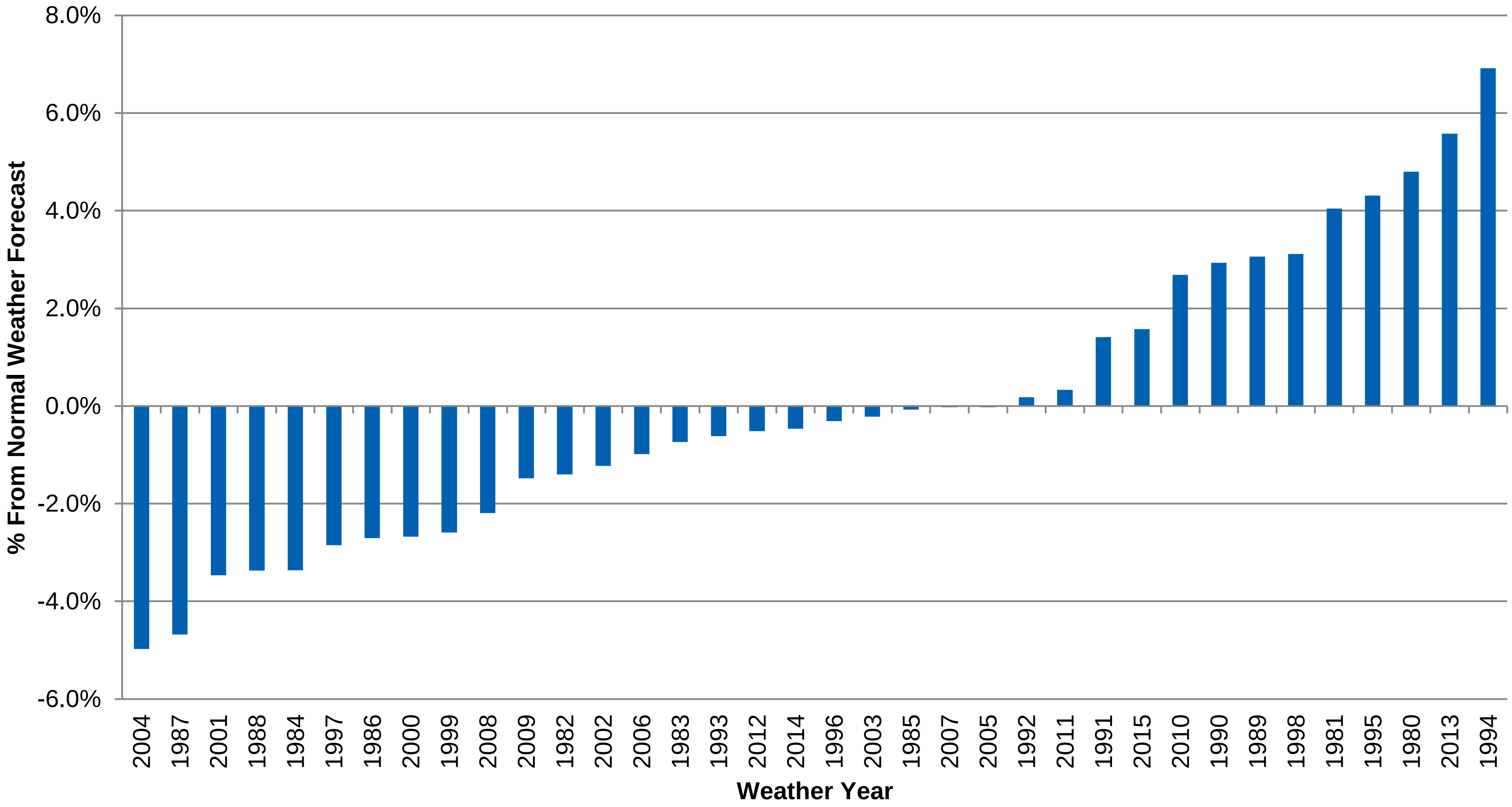
- Base Case Total Scenario Breakdown: 36 weather years x 7 LFE points = 252 scenarios
- Base Case Total Iteration Breakdown: 252 scenarios * 10 unit outage iterations = 2,520 iterations

- Intra Hour Simulations at 5-minute Intervals

Reserve Margin Study

Load Modeling: Summer Peak Weather Uncertainty

Includes Entire Balancing Area



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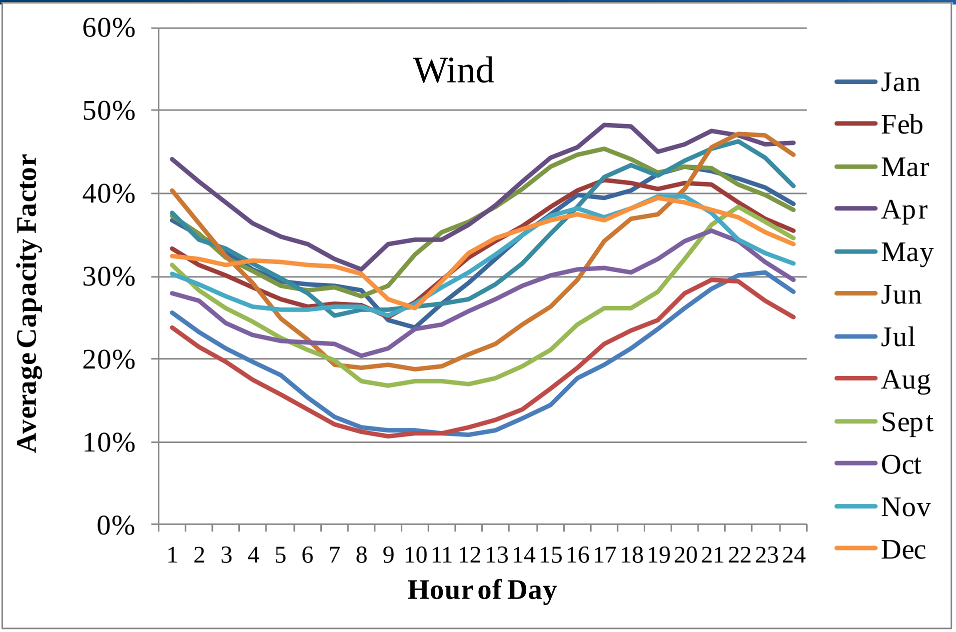
Economic Load Forecast Error

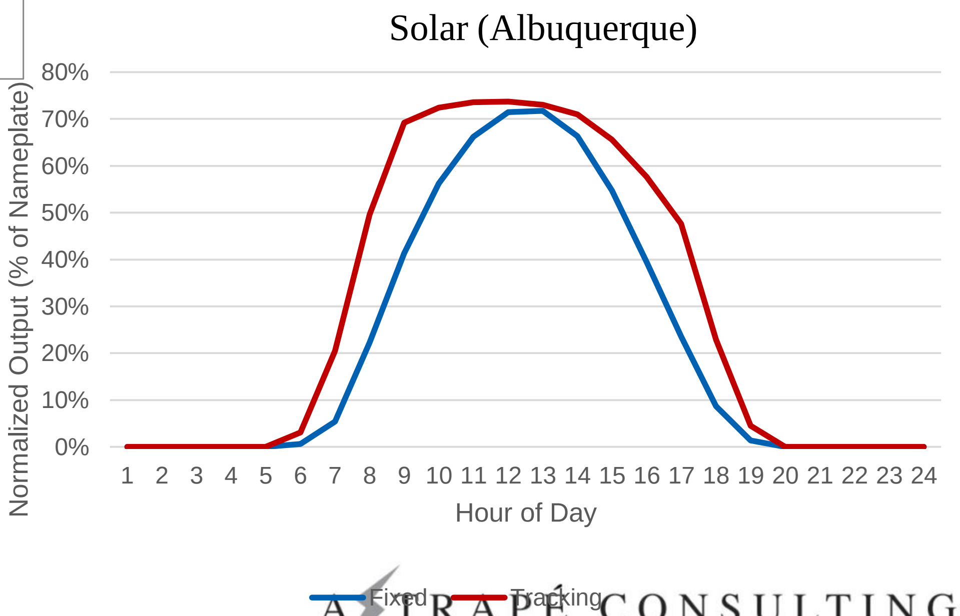
Using CBO GDP approach and assuming 30% multiplier for electric load growth compared to GDP growth

Load Forecast Error Multipliers	Probability %
0.95	2.7%
0.97	14%
0.99	23.8%
1.00	19.1%
1.01	23.8%
1.03	14%
1.05	2.7%

Renewable Shapes: 36 Years



- Wind Shapes Based on Historical Data
- New Wind given 40+% Capacity Factor



- Solar Shapes Based on NREL Data
- Represented by 6 Locations Across the State
- Both Fixed and Tracking

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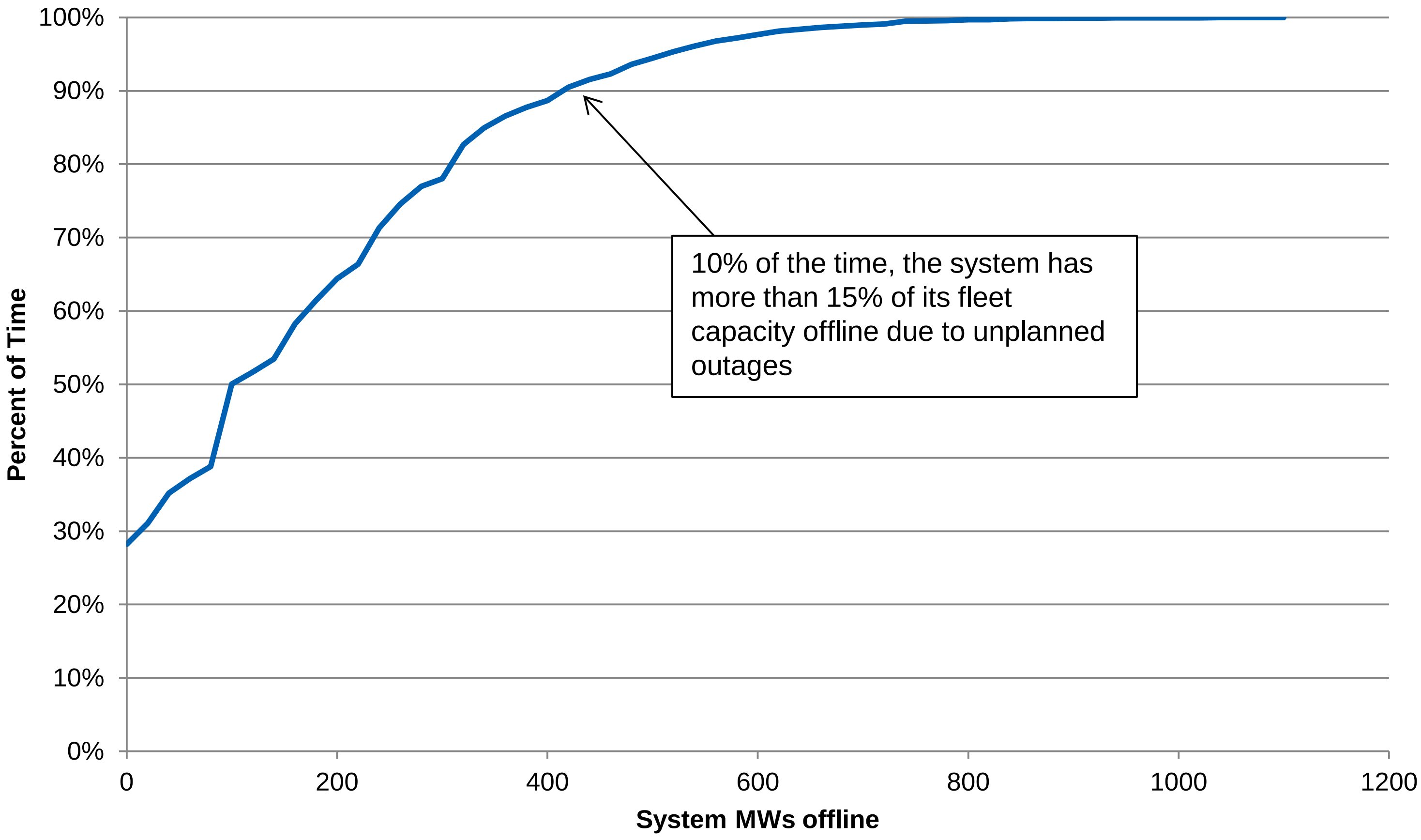
Preliminary Draft Results

Unit Outage Modeling

- **Full Outages**
  - Time to Repair
  - Time to Failure
- **Partial Outages**
  - Time to Repair
  - Time to Failure
  - Derate Percentage
- **Startup Failures**
- **Maintenance Outages**
- **Planned Outages**
- **Based on Historical Operation**

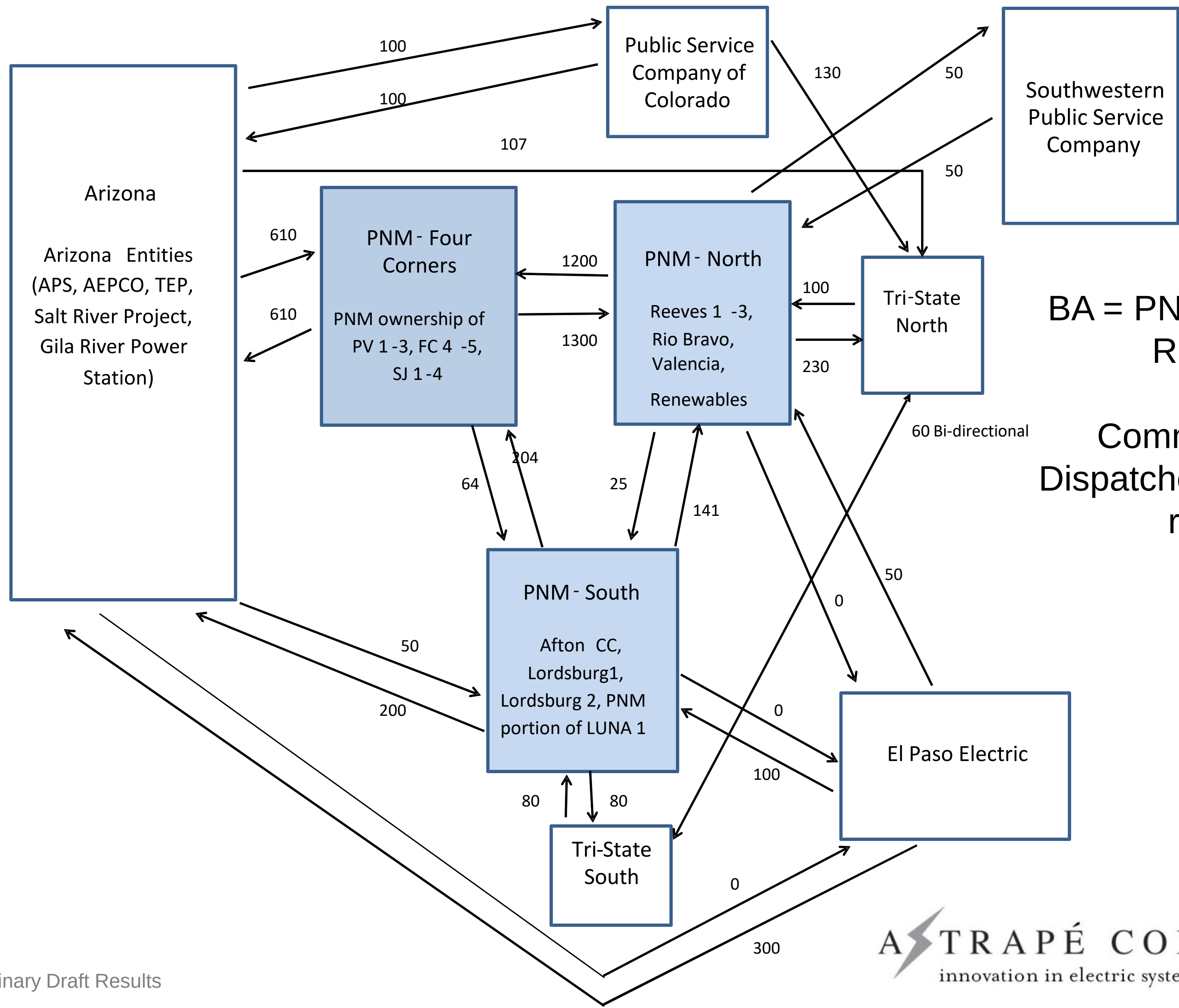
Unit Name	Capacity (MW)	EFOR
P. VERDE_1	134	2.15
P. VERDE_2	134	0.73
P. VERDE_3	134	3.11
FOURCORN_4	100	20.75
FOURCORN_5	100	17.61
SAN JUAN_1	170	18.29
SAN JUAN_4	327	16.06
LUNA_1	185	5.42
AFTONCC_1	230	5.77
DELTA_1	138	9.32
La_Luz	40	6.64
REEVES_1	44	5.05
REEVES_2	44	0.71
REEVES_3	66	7.17
VLNCPPA_1	145	1.43
LORDSBRG_1	40	7.08
LORDSBRG_2	40	6.45

System Unplanned Outages



Study Topology and Market Assistance

2013 Reserve Margin Study



BA = PNM + Tri-State Regions

Committed and Dispatched as a single region

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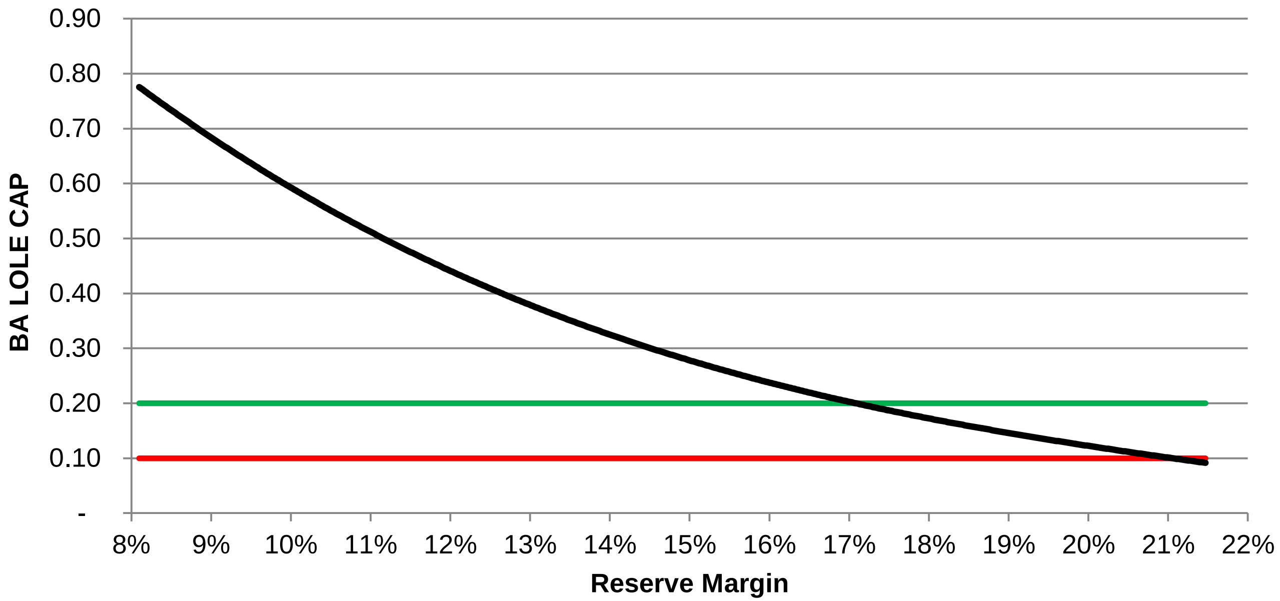
Emergency Operating Procedures

- Demand Response

	Power Saver Program	Peak Saver Program
Capacity (MW)	33.75	20
Season	June-Sept	June-Sept
Hours Per Year	100	100
Hours Per Day	4	6

- Firm load shed to maintain reserves equal to 4% of load

LOLE$_{CAP}$ Results
2021 Study Year



Month	LOLE$_{Cap}$
1	0%
2	0%
3	0%
4	0%
5	0%
6	22%
7	45%
8	32%
9	1%
10	0%
11	0%
12	0%

- Recommend minimum reserve margin at no higher than 0.2 LOLE$_{CAP}$: 17% reserve margin
- Traditional 1 day in 10 year standard: 0.1 LOLE$_{CAP}$ = 21% reserve margin

- Assuming no external regions, a 16.5% reserve margin results in over 8 LOLE$_{CAP}$ events per year. Neighbor assistance during peak hours can range from 0 MW to 300 MW depending on neighbor conditions.

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Flexibility Metrics

Definitions of Existing and New Reliability Metrics

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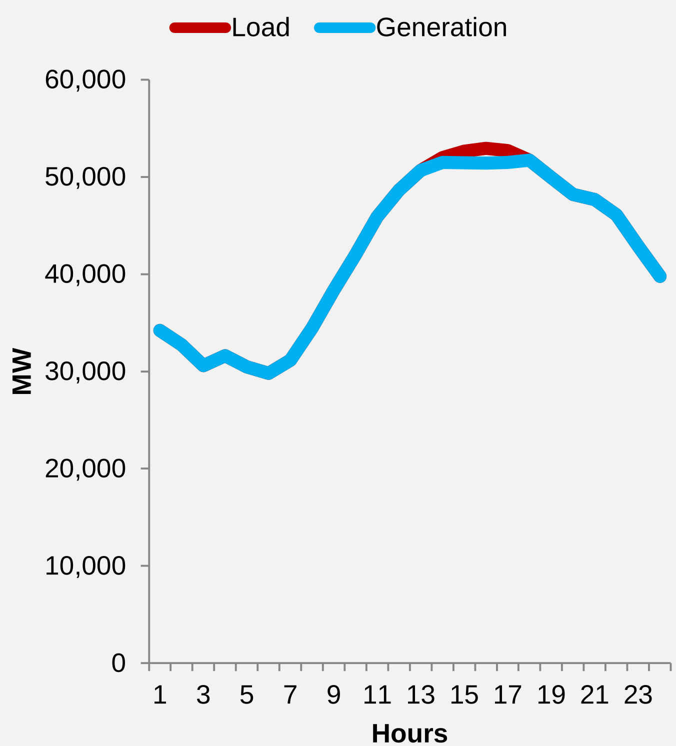
$LOLE_{Cap}$

Traditional metric to capture events that occur due to capacity shortfalls in peak conditions



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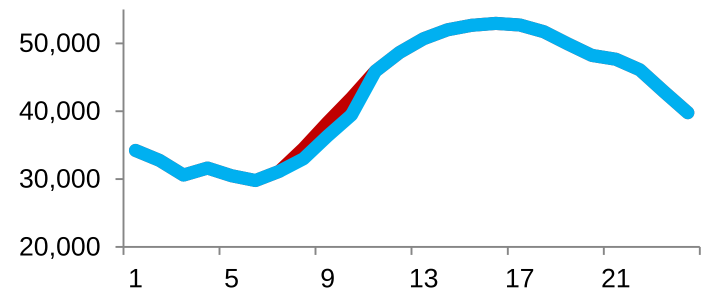

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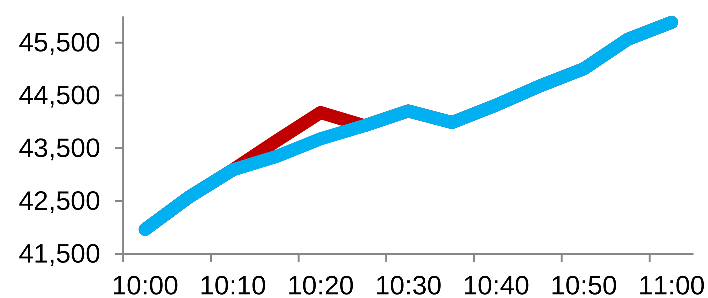

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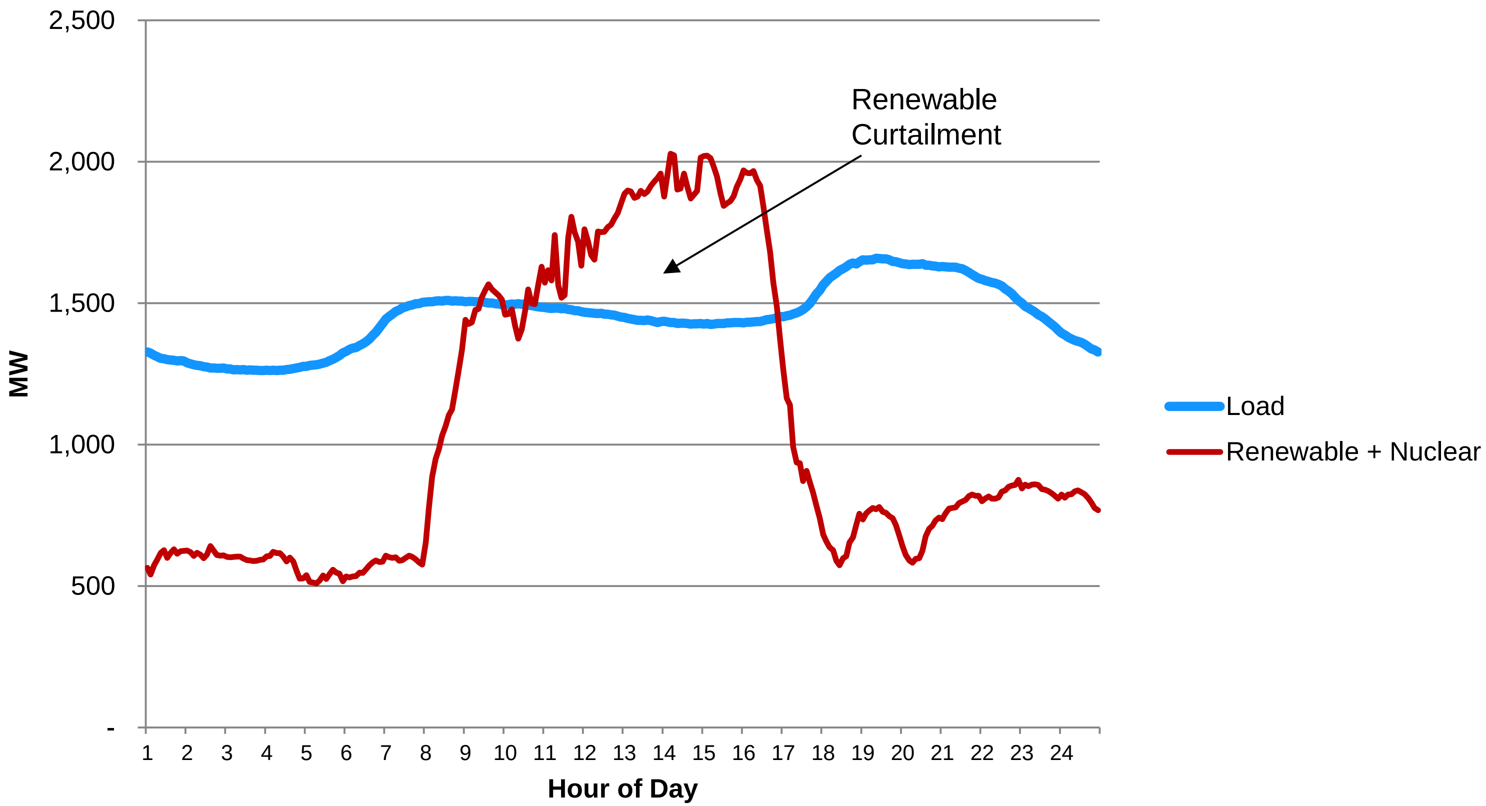
Renewable Curtailment Example



Represents a day in the 2021 50% RPS scenario

Flexibility Study Approach

- **Identify $LOLE_{FLEX}$ events and renewable curtailment (overgen) events**
- **Solve the deficiencies using the following approaches and calculate costs:**
  - Change operating procedures (i.e. raise load following requirement)
  - Add flexible capacity and/or replace existing capacity
- **Production Costs = Fuel Costs + Variable O&M + Emission Costs + Cost of EUE**
  - PPA prices assumed for wind and solar

Base Case Physical Reliability Results
Varying Operating Reserve Levels

- **Study Years: 2021**
- **Reg Requirement: 4% of Load**
- **Spin + Load Following Requirement = Simulated at 5% and 7%**
- **Quick Start Target: 4% of Load**

System reliability is reasonable with 7% LF target

	Renewable Penetration	LF Target	Renewable Curtailment	Renewable Curtailment	LOLE CAP	LOLE FLEX	Production Costs
	% of Load	% of Load	% of Renewable	MWh	Events Per Year	Events Per Year	M$
2021 Base Case	17.0%	5.0%	1.8%	43,131	0.18	0.18	369.9
2021 Base Case	17.0%	7.0%	1.9%	45,019	0.18	0.08	373.3

Cost Increase due to LF increase

Curtailment Comparison 1x20 MW solar plant = annual output of 44,000 MWh

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Base Case Physical Reliability Results Varying Operating Reserve Levels

- **Study Year: 2024**
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System reliability is reasonable with 7% LF target

	Renewable Penetration	LF Target	Renewable Curtailment	Renewable Curtailment	LOLE CAP	LOLE FLEX	Production Costs
	% of Load	% of Load	% of Renewable	MWh	Events Per Year	Events Per Year	M$
2024 Base Case	21.1%	5.0%	1.1%	34,213	0.19	0.44	514.2
2024 Base Case	21.1%	7.0%	1.1%	34,747	0.19	0.11	519.6

Cost Increase due to LF increase

Curtailment Comparison 1x20 MW solar plant = annual output of 44,000 MWh

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2024 Base Case (Monthly Basis)

2024 Month	LOLE Cap Events Per Year	LOLE Flex Events Per Year	Curtailment MWh
1	-	0.007	2,667
2	-	0.008	3,455
3	-	0.026	3,718
4	-	0.016	3,413
5	-	0.007	4,747
6	0.036	0.002	1,918
7	0.090	0.009	931
8	0.064	0.007	1,001
9	0.003	0.000	1,920
10	-	0.016	2,440
11	-	0.011	4,494
12	-	0.005	3,044
Total	0.193	0.114	33,747

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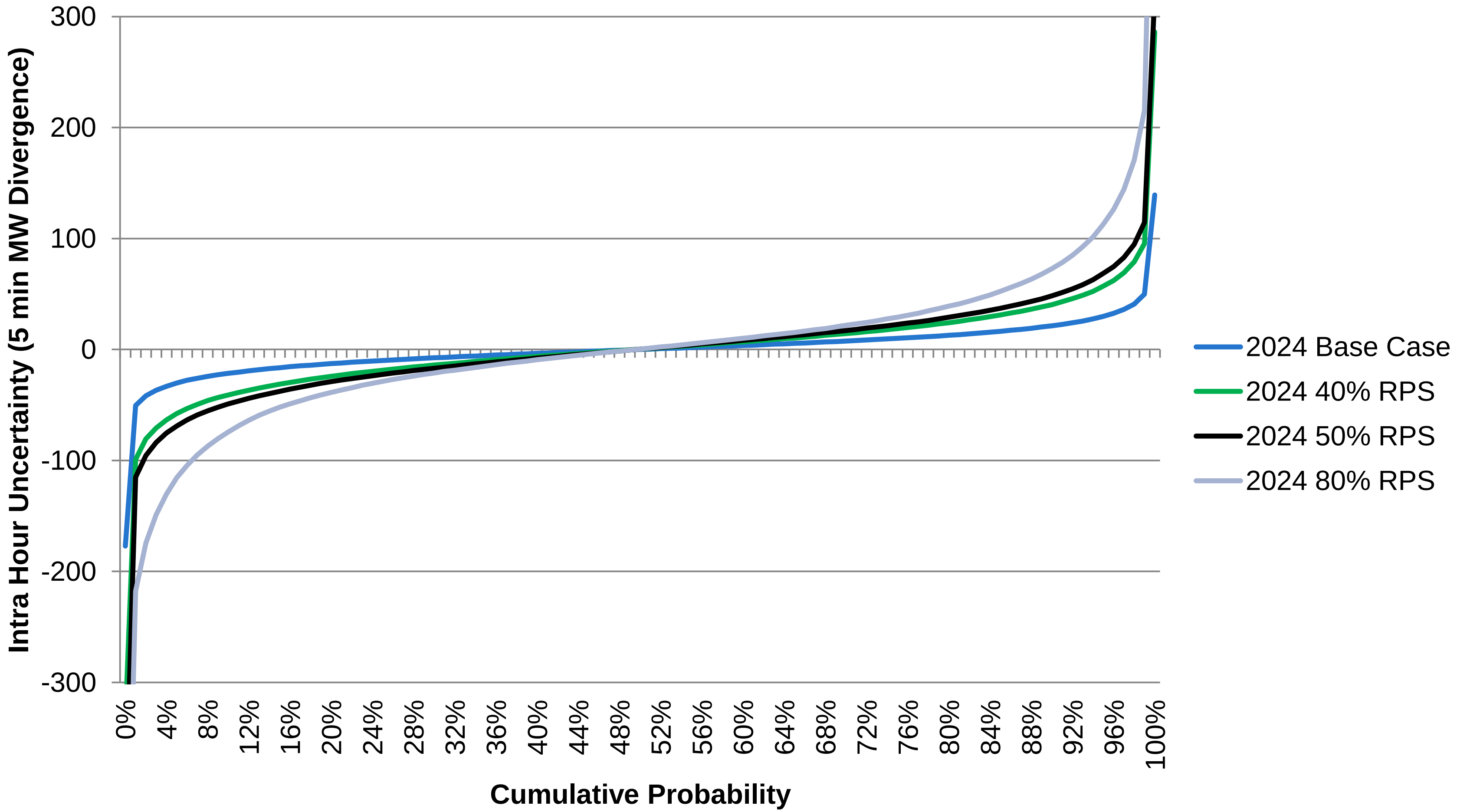
RPS Scenarios and Rules of Thumb

2024 RPS Scenarios

Technology	LF Target
Base Case	5%, 7%
Base Case 40% RPS (66.7% Solar)	7%, 13%, 15%
Base Case 40% RPS (66.7% Wind)	7%, 13%, 15%
Base Case 50% RPS (66.7% Solar)	7%, 13%, 15%
Base Case 50% RPS (66.7% Wind)	7%, 13%, 15%
Base Case 80% RPS (66.7% Solar)	7%, 13%, 15%
Base Case 80% RPS (66.7% Wind)	7%, 13%, 15%

To build RPS portfolios, additional solar and wind was added to the system: Either 66% of the incremental additions were designated as wind or solar

Net Load Intra Hour Uncertainty



Preliminary Draft Results

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2024 RPS Scenarios @ 7% LF

	Renewable Penetration	LF Target	Curtailment	Curtailment	$LOLE_{FLEX}$	Production Costs
	% of Load	**% of Load**	% of Renewable	MWh	Events Per Year	M$
Base Case	21.1%	**7.0%**	1.1%	33,747	0.11	519.6
Base Case 40% RPS (66.7% Solar)	40.9%	**7.0%**	10.5%	613,496	6.83	527.5
Base Case 40% RPS (66.7% Wind)	40.6%	**7.0%**	7.8%	454,097	5.04	523.5
Base Case 50% RPS (66.7% Solar)	51.4%	**7.0%**	18.2%	1,333,517	16.05	553.8
Base Case 50% RPS (66.7% Wind)	50.8%	**7.0%**	13.1%	948,907	16.39	541.4
Base Case 80% RPS (66.7% Solar)	82.8%	**7.0%**	37.7%	4,457,962	55.62	686.2
Base Case 80% RPS (66.7% Wind)	81.7%	**7.0%**	29.4%	3,423,730	68.60	650.3

Curtailment Comparison 1x20 MW solar plant = annual output of 44,000 MWh
1x500 MW solar plant = annual output of 1,100,000 MWh

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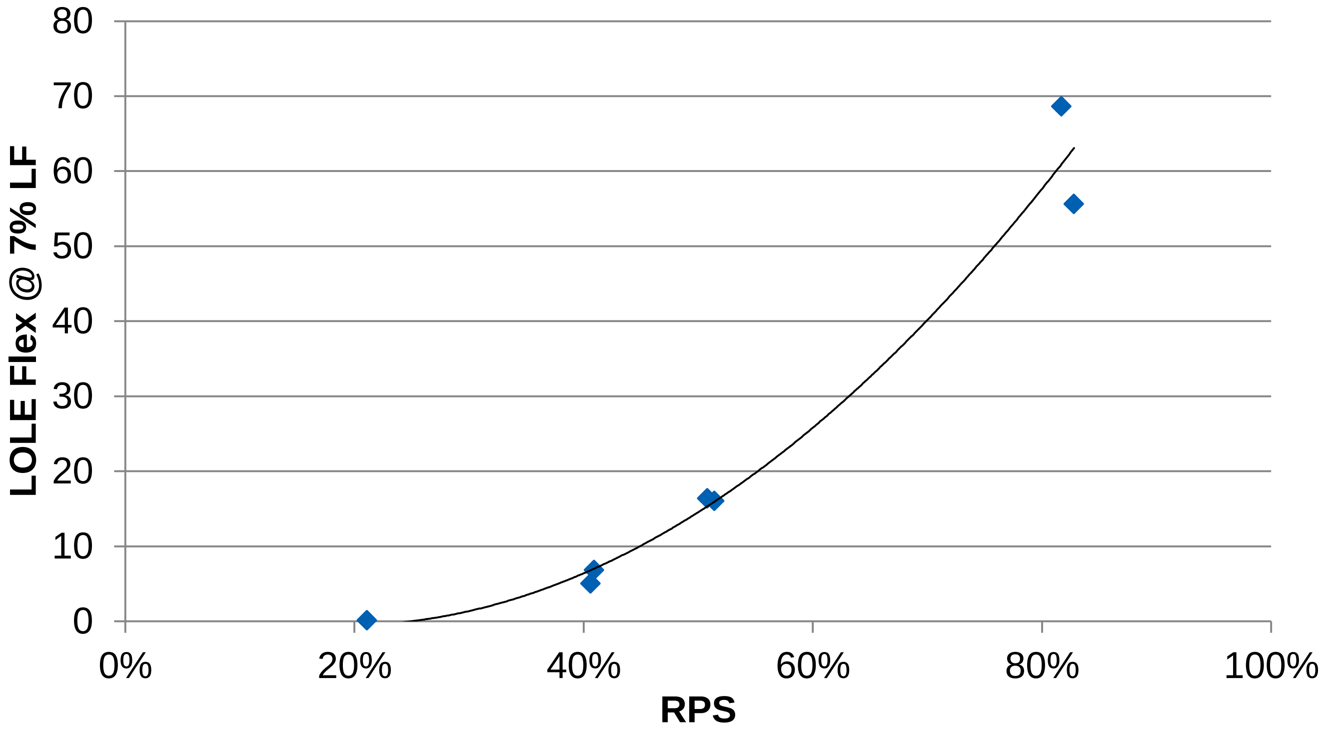
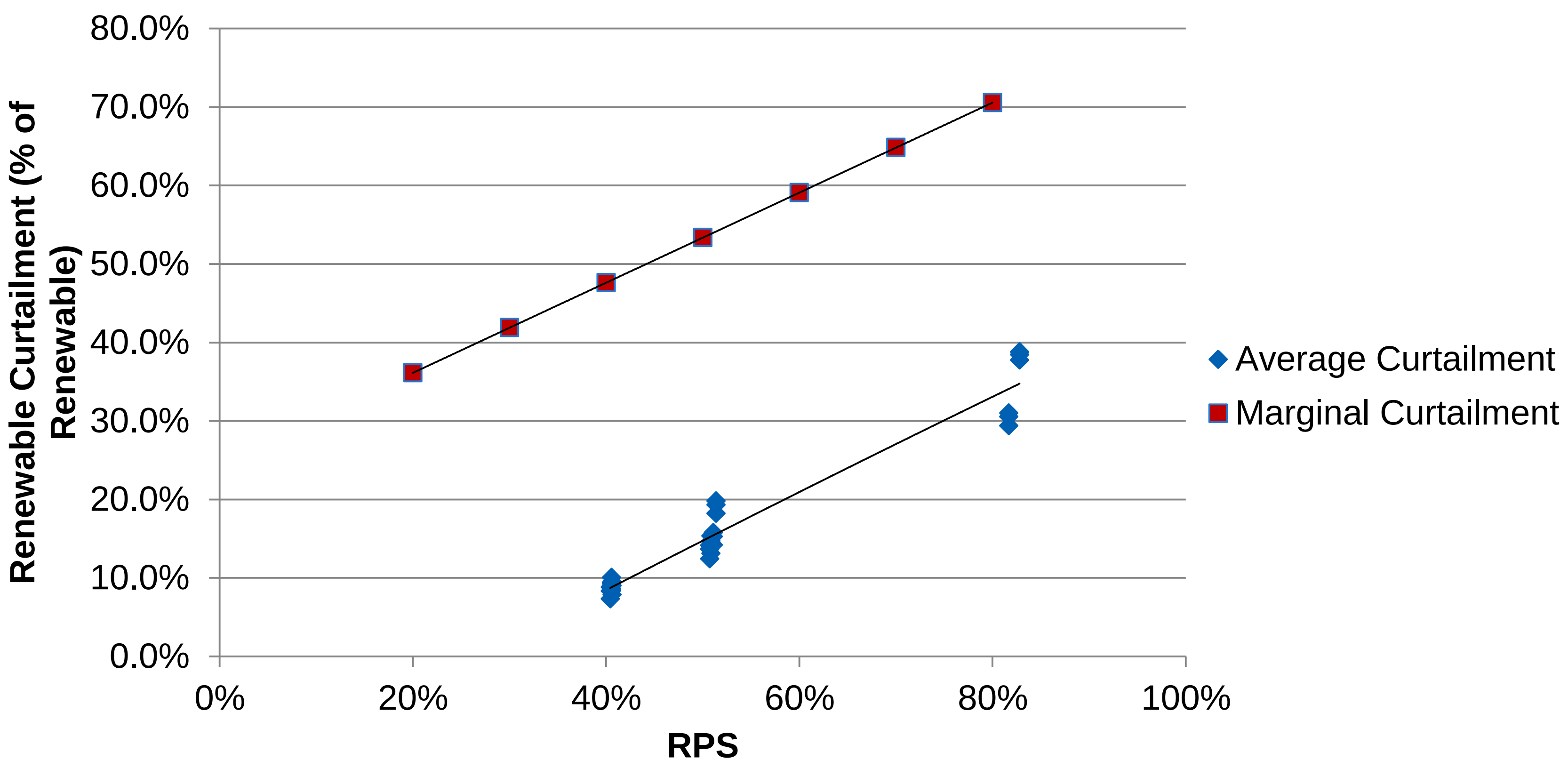
2024 RPS Scenarios @ 7% LF



2024 RPS Scenarios @ 15% LF

	Renewable Penetration	LF Target	Renewable Curtailment	Renewable Curtailment	$LOLE_{FLEX}$	Production Costs
	% of Load	% of Load	% of Renewable	MWh	Events Per Year	M$
Base Case	21.1%	7.0%	1.1%	33,747	0.11	519.6
Base Case 40% RPS (66.7% Solar)	40.9%	15.0%	12.9%	751,179	0.44	554.0
Base Case 40% RPS (66.7% Wind)	40.6%	15.0%	10.0%	579,932	0.28	549.7
Base Case 50% RPS (66.7% Solar)	51.4%	15.0%	19.8%	1,450,165	1.22	575.1
Base Case 50% RPS (66.7% Wind)	50.8%	15.0%	15.3%	1,111,892	0.85	564.2
Base Case 80% RPS (66.7% Solar)	82.8%	15.0%	38.8%	4,578,472	7.12	694.7
Base Case 80% RPS (66.7% Wind)	81.7%	15.0%	31.0%	3,610,875	10.15	656.2

Renewable Curtailment



Average = % of total renewable fleet curtailed at each RPS level
Marginal = % of next MWh that will be curtailed at each RPS level

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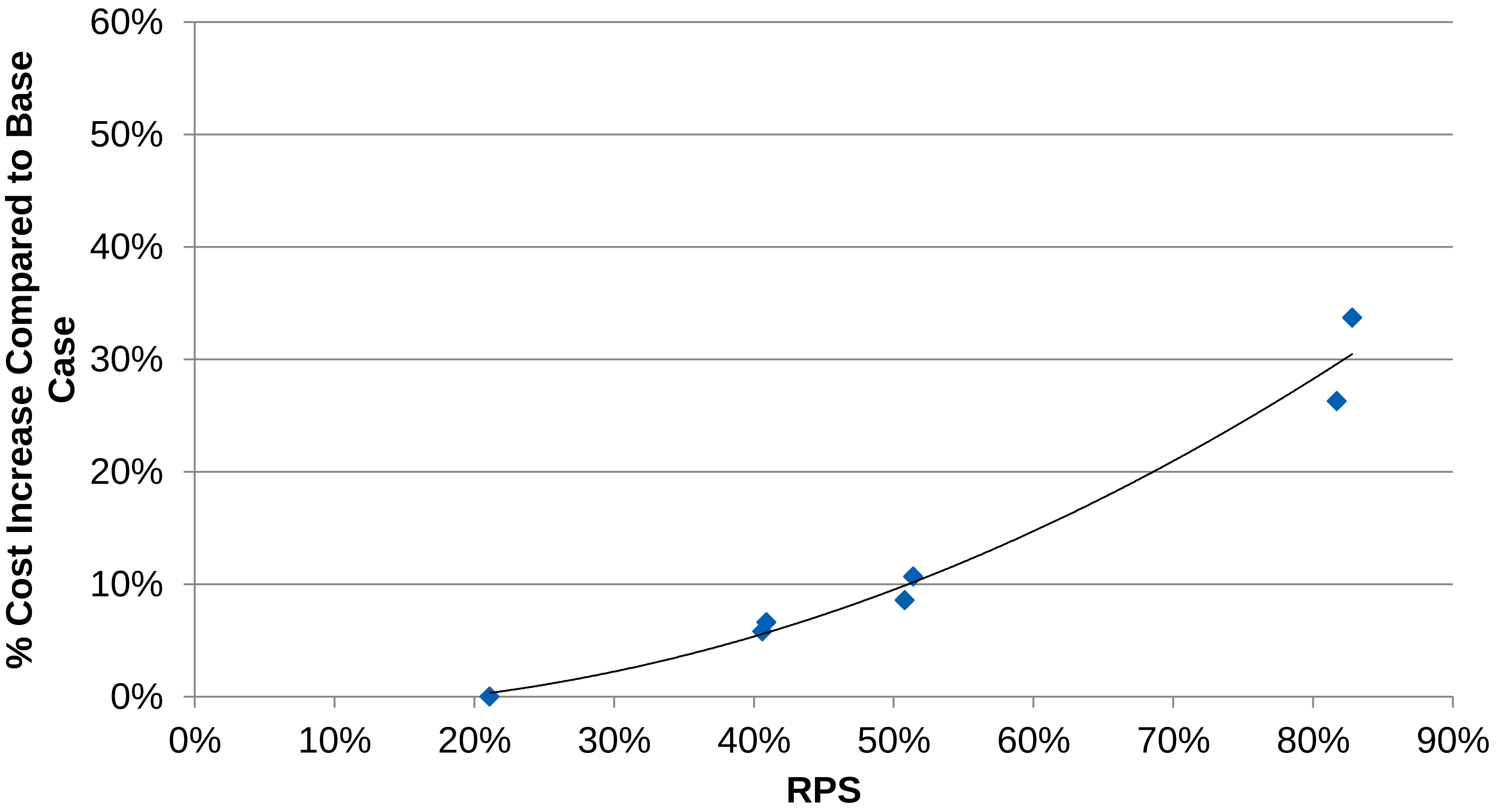
Cost by RPS Level



Assumes $39 PPA pricing for new solar and $40 PPA pricing for new wind.

2024 RPS Scenarios add Flexible Generation or Battery

	Renewable Penetration	LF Target	Curtailment	Curtail-ment	$LOLE_{CAP}$	$LOLE_{FLEX}$	ProductionCosts
	% of Load	% of Load	%	MWh	Events Per Year	Events Per Year	M$
Base Case 40% RPS (66.7% Wind)	40.6%	13%	9.4%	541,689	0.10	0.48	543.0
Base Case 40% RPS (66.7% Wind)	40.6%	15%	10.0%	579,932	0.10	0.28	549.7
Base Case 40% RPS (66.7% Wind) and 2 LM6000 (80 MW)	40.6%	13%	9.2%	534,093	0.04	0.50	539.0
Base Case 40% RPS (66.7% Wind) and 100 MW 2 hour storage	40.6%	13%	8.9%	514,306	0.04	0.31	536.7
Base Case 40% RPS (66.7% Wind) and 100 MW 4 hour storage	40.6%	13%	8.6%	495,383	0.03	0.27	535.7
Base Case 40% RPS (66.7% Wind) and 100 MW 6 hour storage	40.6%	13%	8.4%	483,445	0.02	0.27	535.5

Represents First Pass at Results; Production Costs do not include capital costs

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Load Following Requirements
General Takeaways

RPS	Required Load Following	Renewable Curtailment
20%	7% of Load	<50,000 MWh
30%	13% of Load	100,000 - 200,000 MWh
40%	>15% of Load	400,000 - 800,000 MWh
50%	>15% of Load + Significant Additional Flexible Resources	900,000 - 1,500,000 MWh
80%	>15% of Load + Significant Additional Flexible Resources	3,500,000 - 4,500,000 MWh