Flexibility Metrics and Standards Project
– a California Energy Systems for the 21st Century (CES-21) Project

CPUC Workshop

August 15, 2017

Project Team: Astrape Consulting, EPRI, LLNL, PG&E and SDG&E

Advisory Group: CAISO, CEC, CPUC, ORA, SCE, and TURN

Agenda

1. Project Objective
2. Framework and Study Cases
3. Results and Recommendations
4. Closing Thoughts

Project Objective – Key Questions

- Did the range of projected CAISO system scenarios have sufficient capacity and operating flexibility to meet the 1 day in 10 years **reliability standard** in 2026?
- How did operating flexibility, or the lack of it, **impact costs and emissions** (i.e., system operations)? And what are the main drivers?
- Do we need to create new **planning standards** to maintain operational flexibility, if so, what would those standards be? (one example of planning metric/standard is Planning Reserve Margin as a % of peak load)

In Scope	**Out of Scope**
Examine whether planning standards need to be updated to explicitly include operating flexibility by studying the CAISO system under some pre-defined future scenarios	Develop optimal solution to meet reliability, operating flexibility (and cost) goals for a generic electric system

Data: CAISO, WECC, and Uncertainties

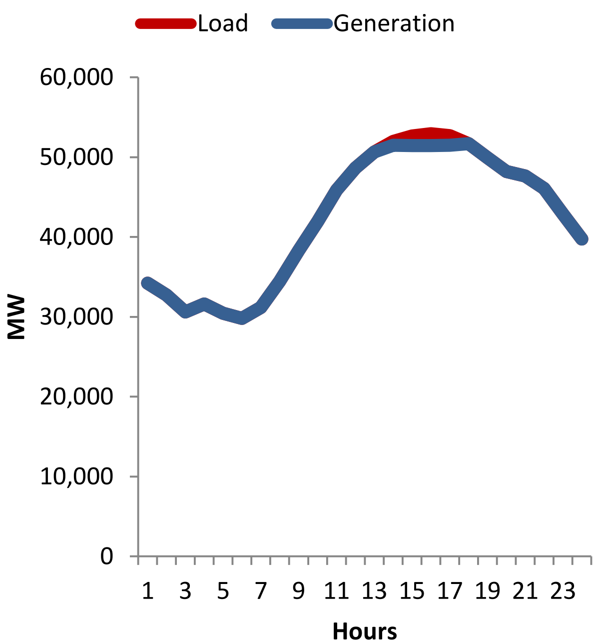
- Updated **CAISO** modeling using 2016 LTPP assumptions
- Completed detailed modeling of **WECC** using TEPPC 2026 Common Case assumptions
- Modeled **Uncertainties**:
  - 33 **weather years** (correlated profiles for load / wind / solar)
  - 5 **economic load growth uncertainty** levels
  - 25 (or more) resource **outage draws**
  - **Forecast errors** for load / wind / solar (intra-day and intra-hour)

CES-21 project created a comprehensive, detailed representation of the projected 2026 planning year

Reliability Metrics: Existing and Additional

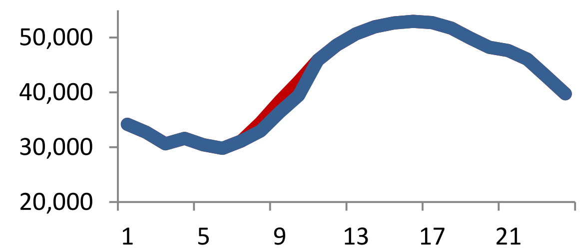
LOLE GENERIC-CAPACITY

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



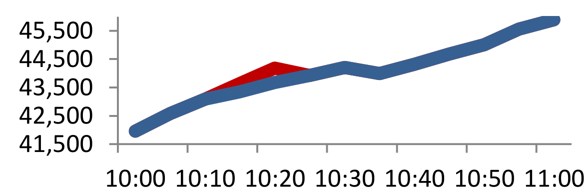
LOLE MULTI-HOUR

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



LOLE INTRA-HOUR

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



CES-21 project created additional reliability metrics to explicitly detect a system's deficiencies in flexibility

CES-21 Scenarios: List of Study Cases

Case #	Type of Case	RPS % by 2026	Load Following	System Pmin	Interchange 3-Hr Ramp	Net Exports Limit
BC_01	PRM Base Cases[1]	33%	5% of Load	Base Case	Unlimited	2,000 MW
BC_02		43%	7% of Load			
BC_03		50%	9% of Load			
SC_01	**CES-21 Reference Study Case[2]**	**50%**	**9% of Load**	**Base Case**	**Unlimited**	**2,000 MW**
SC_02	Load Following (% of Load)		5%			
SC_03			7%			
SC_04			11%			
SC_05	Load Following (WSL Observed)[3]		95th Percentile			
SC_06			99th Percentile			
SC_07			100th Percentile			
SC_08	System Pmin(+/- MW)[4]			High Flex (-4,000)		
SC_09				(-2,000)		
SC_10				(+2,000)		
SC_11				Low Flex (+4,000)		
SC_12	Interchange 3-Hour Ramp Limit[5]				3,000 MW	
SC_13					6,000 MW	
SC_14					9,000 MW	
SC_15	Net Exports					3,500 MW
SC_16						5,000 MW
SC_17						8,000 MW

1. PRM Base Cases are designed at various RPS %, then adding or subtracting conventional resources to achieve LOLE of 1 event in 10 years
2. The CES-21 Study Case is designed to have 50% RPS and 1xAAEE, then adding 600 MW of AAEE to achieve LOLE of 1 event ini 10 years;
3. This load Following requirement is set based on observed net load – load minus wind & solar – volatility in the previous 60 days ("WSL Observed")
4. Maximum amount of interchange ramping (in either direction) within 3 hours
5. Adjust the aggregate Pmin level for conventional resources (e.g., ~16,000 MW of installed capacity and ~7,000 MW of aggregated Pmin for case SC_01)

Analytical Framework & Modeling Tool: Holistic Design

Inputs

Load and Resource Assumptions

(e.g., CAISO system with 50% RPS in 2026; TEPPC case for WECC)

Uncertainties considered:

- 33 **weather years** (correlated profiles for load / wind / solar)
- 5 **economic load growth uncertainty** levels
- 25 (or more) resource **outage draws**
- **Forecast errors** for load / wind / solar (intra-day and intra-hour)

Model

Strategic Energy Risk Valuation Model (SERVM)

(A hybrid resource adequacy and production cost model)

Modeling parameters:

- **# of simulations**: 33 * 5 * 25 * 20 = 82,500 full years (8,760 hours each at 5 minute intervals) of system operation
- **20 cases** (operating policies/scenarios)
- **Loss of Load (LOL)** defined as operating reserves (including regulations) drop below 4.5% of load
- **Load Following Reserves** set to address intra-hour ramping needs

Results

System Performance

Reliability (capacity / flexibility)
Cost
Environmental Impact

Results included:

- LOLE due to lack of capacity
- LOLE due to lack of flexibility
  Unserved Energy
- Production costs
- CO2 emissions
- RPS curtailment
- InFLEXion analysis (based on SERVM commitment/dispatch)

LLNL's High Performance Computing Platform

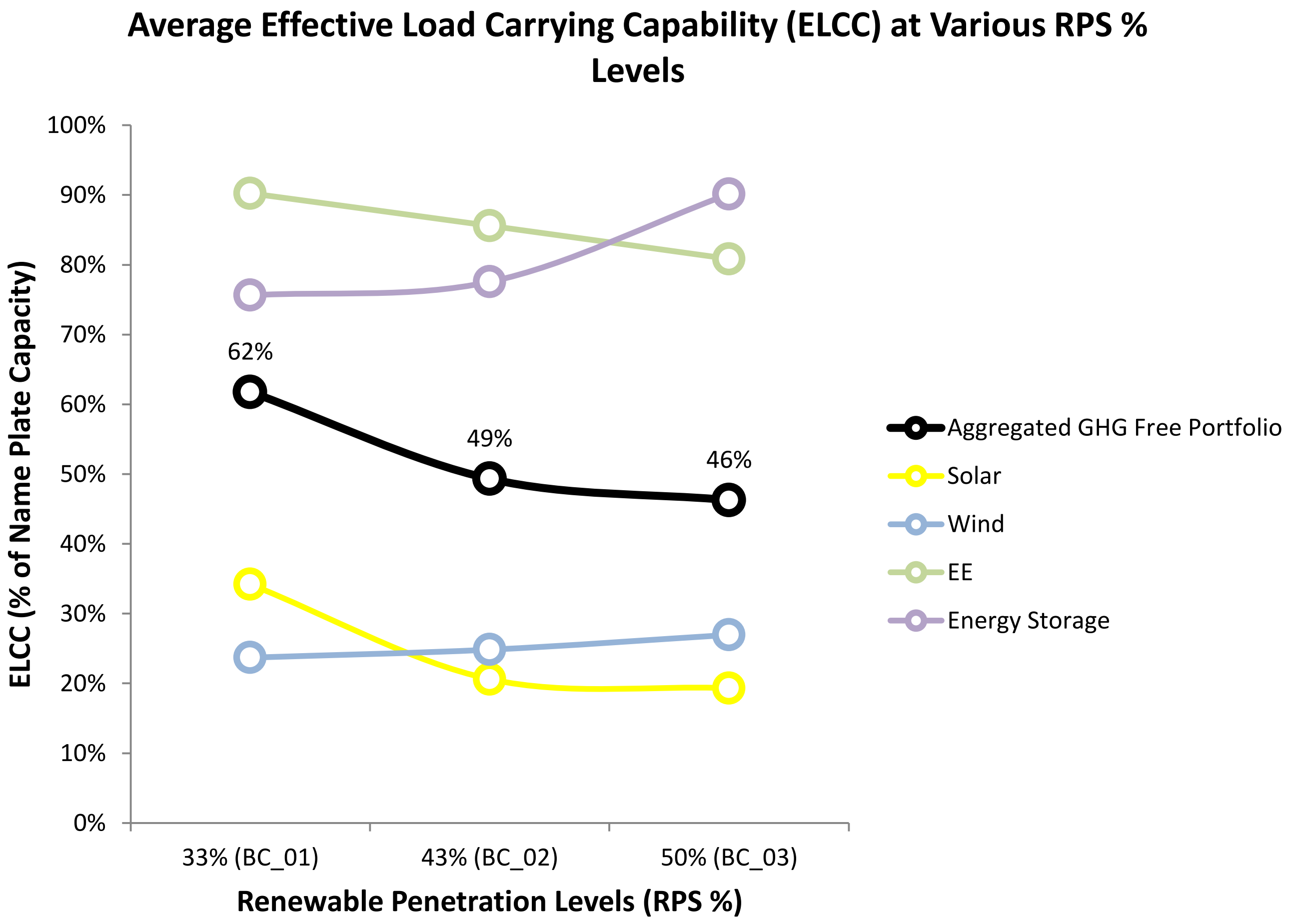
CES-21 project created a unique framework to assess holistic system impacts across a wide range of uncertainties & scenarios

PRM Cases – RPS Portfolios

Resource Type (Name Plate MW)	33% RPS	43% RPS	50% RPS
Aggregated GHG Free Portfolio	**38,888**	**50,000**	**54,289**
Solar (IFM + BTMPV)[1]	**13,075**	**23,897**	**27,495**
Wind	**6,027**	**6,317**	**7,008**
Other Renewables	4,522	4,522	4,522
Energy Efficiency (EE)[2]	4,491	4,491	4,491
Energy Storage	1,350	1,350	1,350
Demand Response	1,559	1,559	1,559
Hydro and PSH[3]	7,863	7,863	7,863
Conventional			
Fossil Resources (CAISO)	26,740	26,740	26,740
Imports	11,665	11,665	11,665

1. In front of the meter and behind the meter PV;
2. EE values are based on IEPR Mid Base - Mid AAEE forecast (e.g., 1xAAEE)
3. Pumped Storage Hydro

PRM Cases – ELCC Captures Changes in Reliability Contribution



For certain resources, ELCC changed noticeably across different system portfolios

PRM Cases – PRM metric still useful if resources are counted by their reliability contribution

Line	PRM Calculation	33% RPS	43.3% RPS	50% RPS
	Demand			
1	Peak Gross Consumption (MW)	54,727	54,727	54,727
	Supply			
2	Aggregated GHG Free Portfolio[1] (MW)	**24,025**	**24,662**	**25,123**
3	Fossil Resources (MW)	26,740	26,740	26,740
4	Imports (MW)	11,665	11,665	11,665
	Deficiency / (Surplus) to reach LOLE standard			
5	Generic Resource Additions (MW)	**1,348**	**730**	**393**
6	Total Supply to reach LOLE standard	63,778	63,797	63,921
	PRM to satisfy LOLE standard (%)	**116.5%**	**116.6%**	**116.8%**

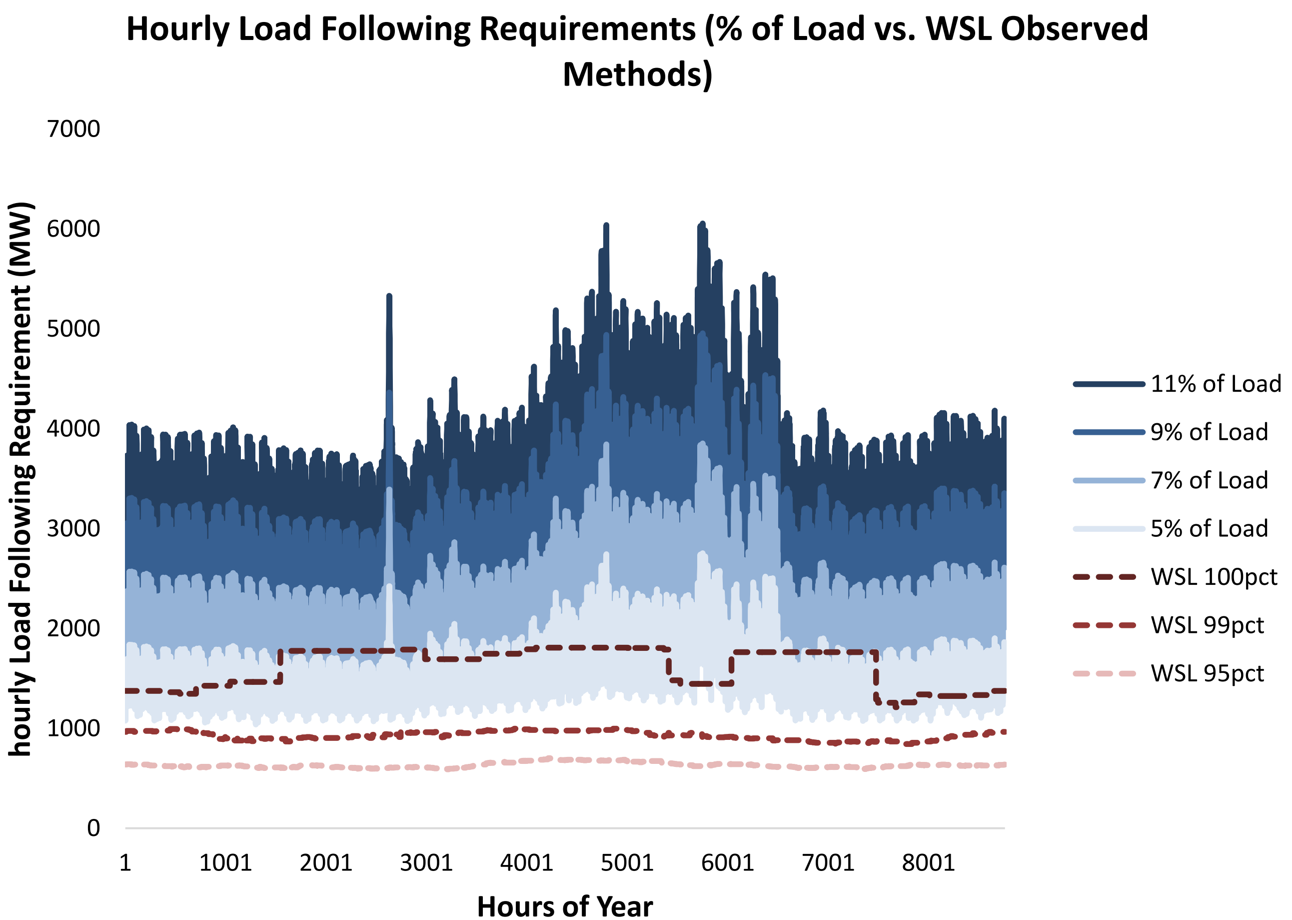
1. Measured in ELCC, including all supply and demand side (e.g., EE, BTMPV) resources

Notes and Caveats:

- The calculation of PRM is tied to a specific reliability standard, in this case LOLE = 1 in 10 years
- PRM values are derived based upon specific counting methods, in this case all resources (including demand side resources) are counted by their ELCC values
- One cannot use these PRM values and compare against PRMs derived using different counting methods (e.g., treating demand side resources as load modifiers may result in a higher PRM)

Recommendation: Measure and count resources by their reliability contributions when using the PRM planning metric

Load Following Cases



We tested a wide range of required load following reserves

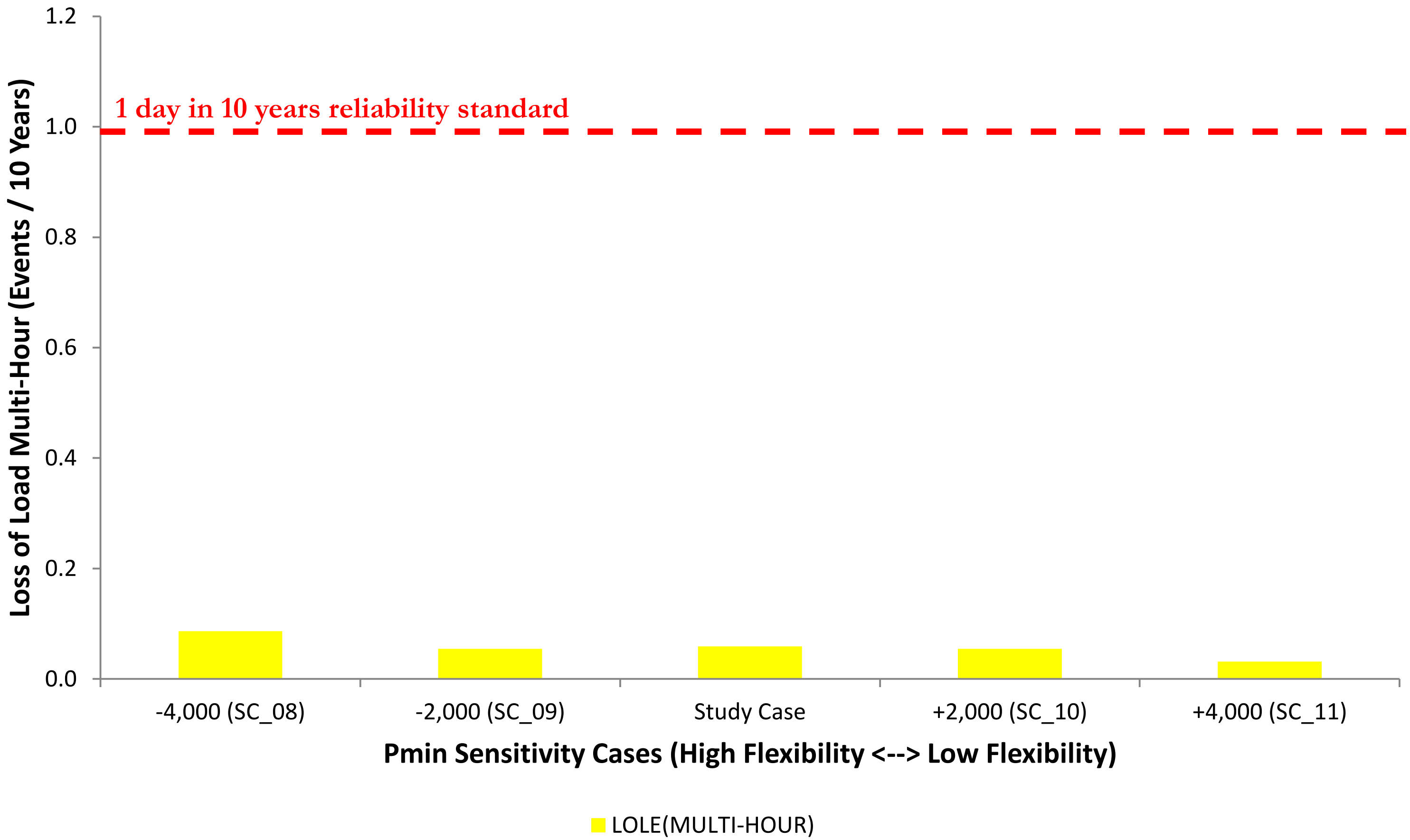
Direct relationship between the amount of LF reserved vs. LOLE Intra-Hour events

Case #	LF Method	Description	Annual LF Amount (TWh)	$LOLE_{INTRA-HOUR}$ (Events / 10 Years)
SC_05	WSL Observed	95 Pct	**6**	**99.5**
SC_06		99 Pct	**8**	**25.3**
SC_07		100 Pct	**14**	**2.4**
SC_02	% of Gross Load	5%	**14**	**0.6**
SC_03		7%	**19**	**0.1**
SC_01		9%	**25**	**0.1**
SC_04		11%	**31**	**0.1**

Note: The interpretation of $LOLE_{INTRA\text{-}HOUR}$ is an area of open discussion (e.g., should we treat a 5 minute event occurring in spring low load hours the same as loss of load when the system can readily lean on its neighbors for balancing?)

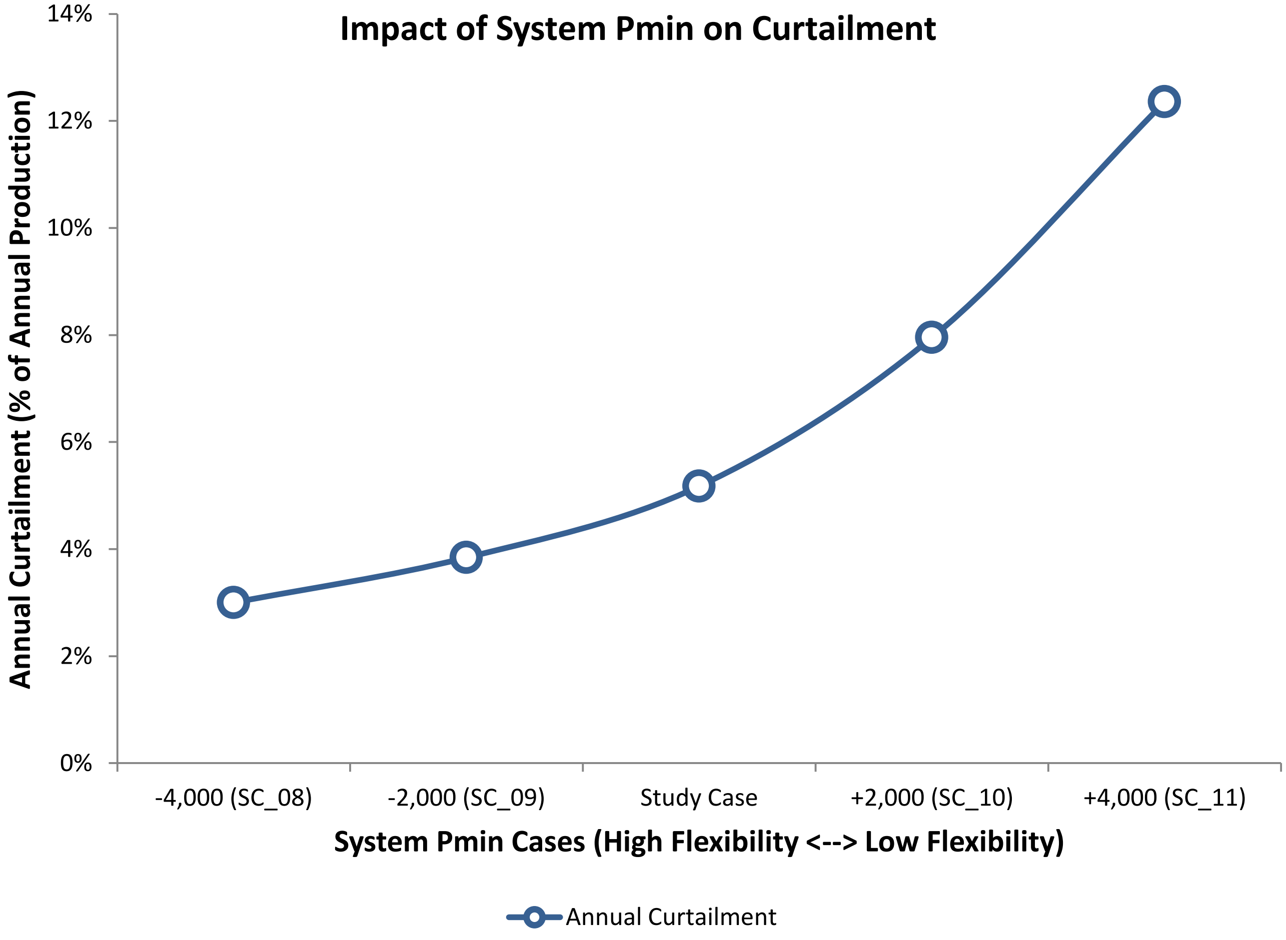
Recommendation: Maintain sufficient load following capability to secure a desired level of reliability

System Pmin Cases – Reliability Results



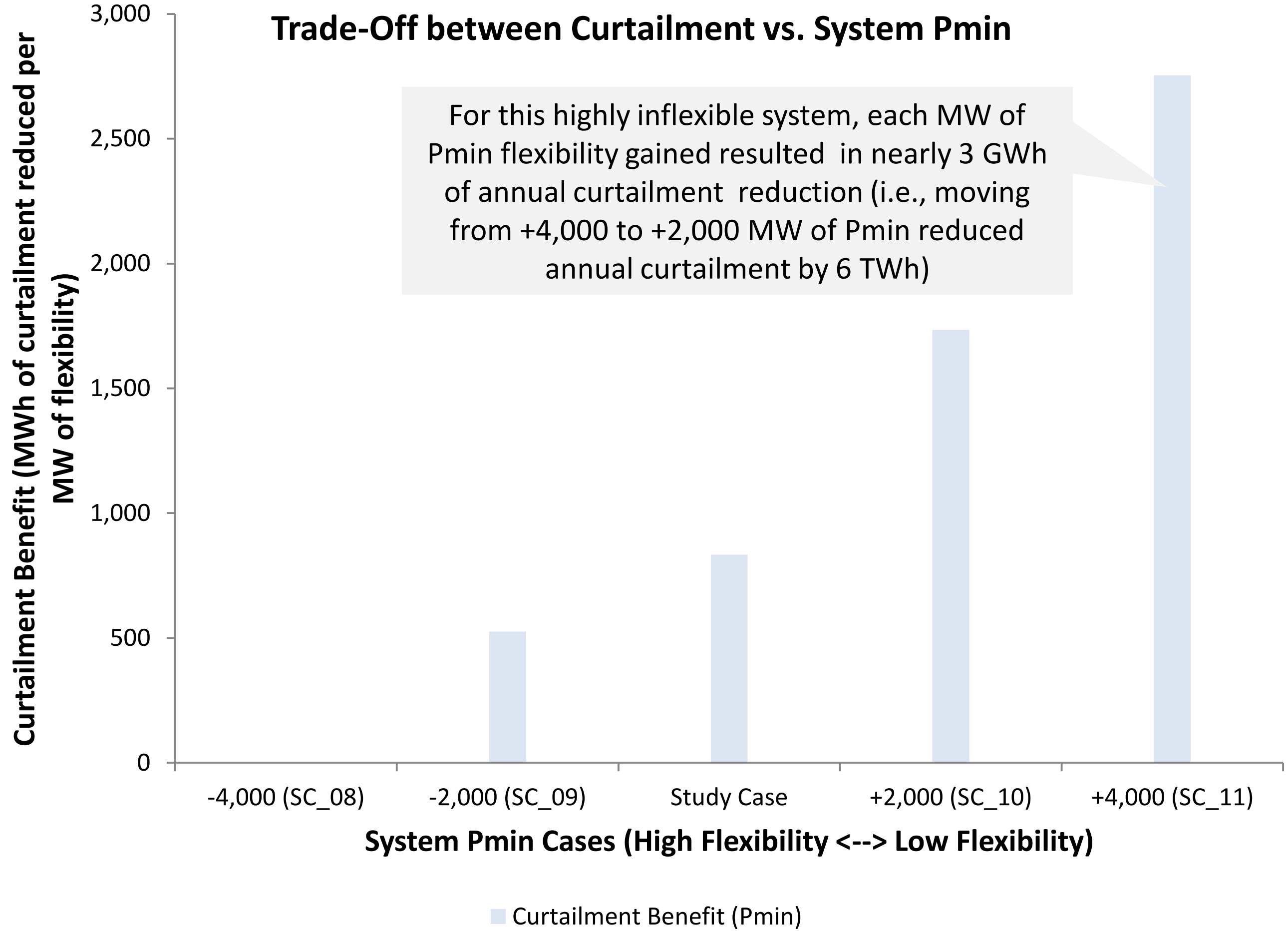
Compared to the 1 day in 10 years LOLE standard, the reliability issues explicitly detected by flexibility metrics were small

System Pmin – Curtailment as a flexibility solution



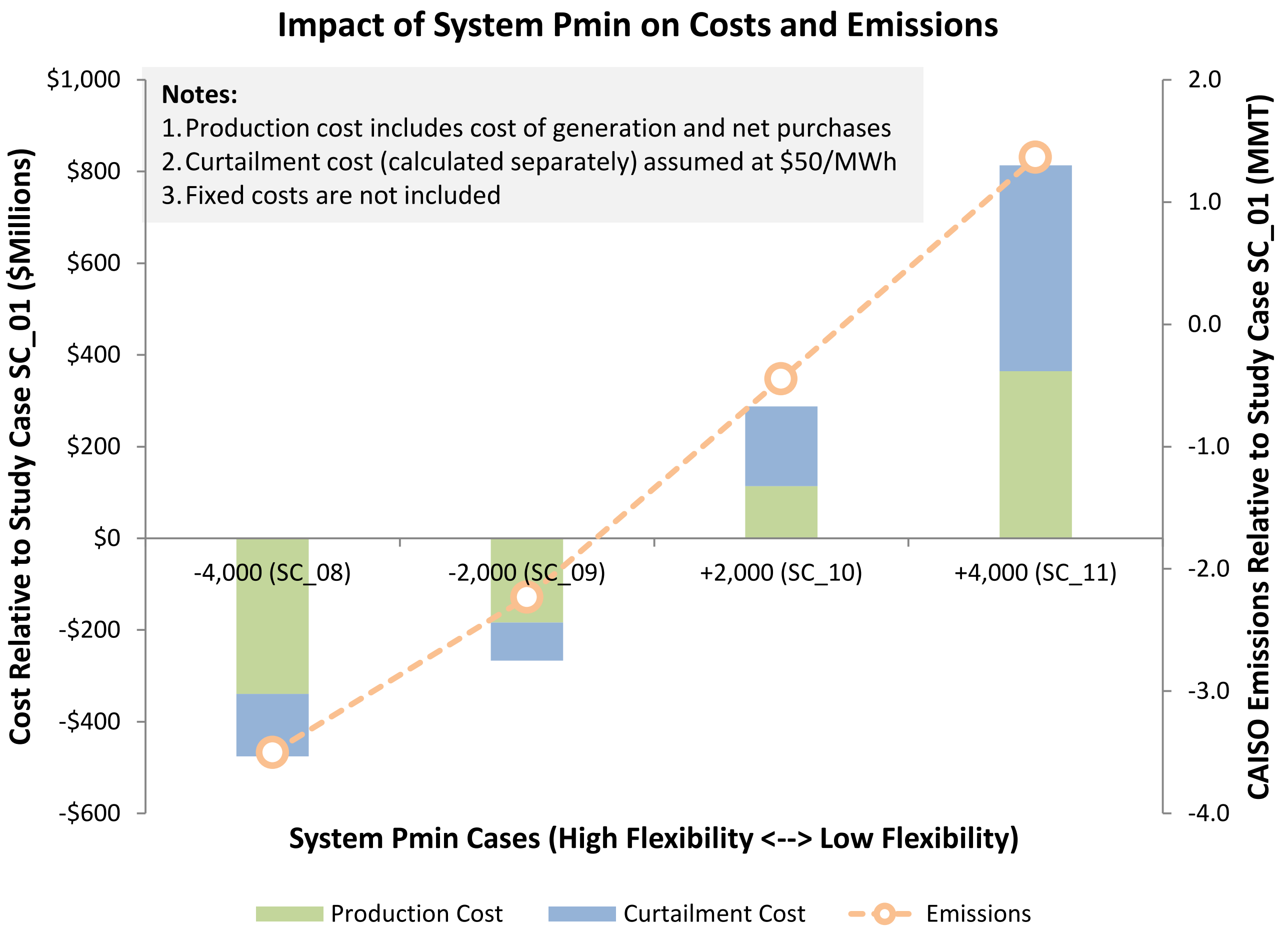
An inflexible system leans on curtailment to maintain reliability

System Pmin – Trade-off between flexibility solutions



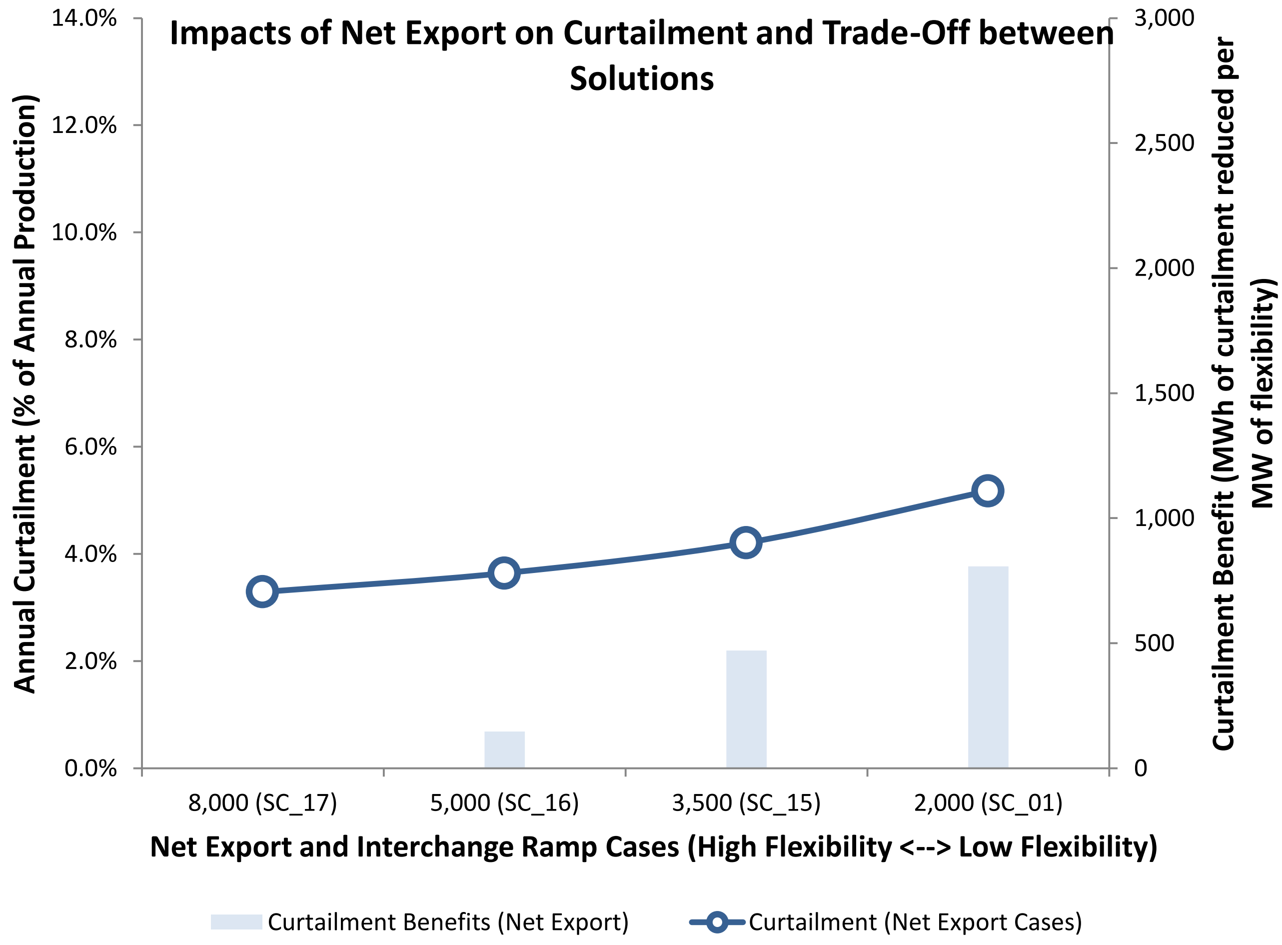
As a flexibility solution, results show the marginal curtailment benefit of one MW of Pmin is greatest to a highly inflexible system

System Pmin – System Cost & Emissions



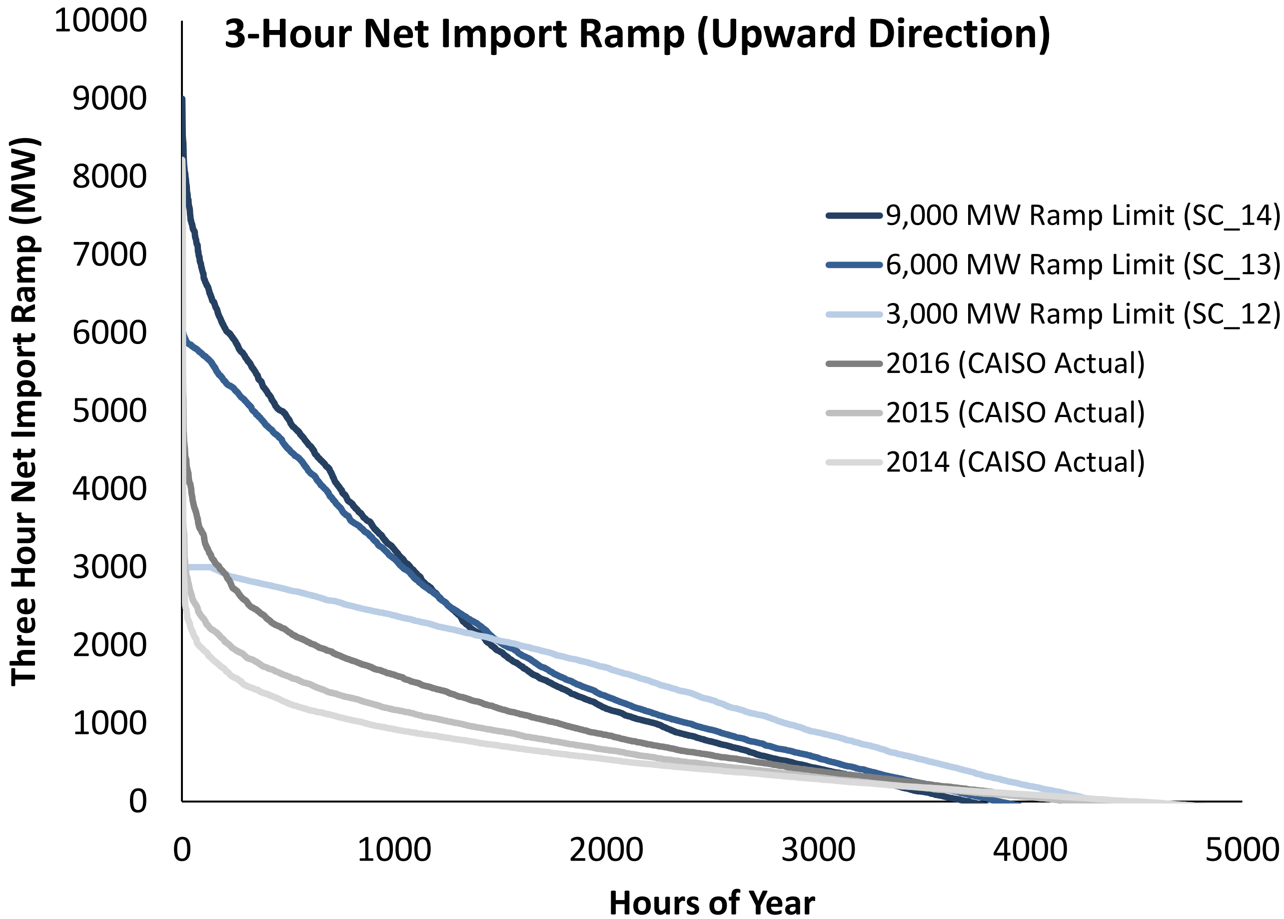
In general, we found a less flexible system yields higher costs and emissions

Net Export Cases



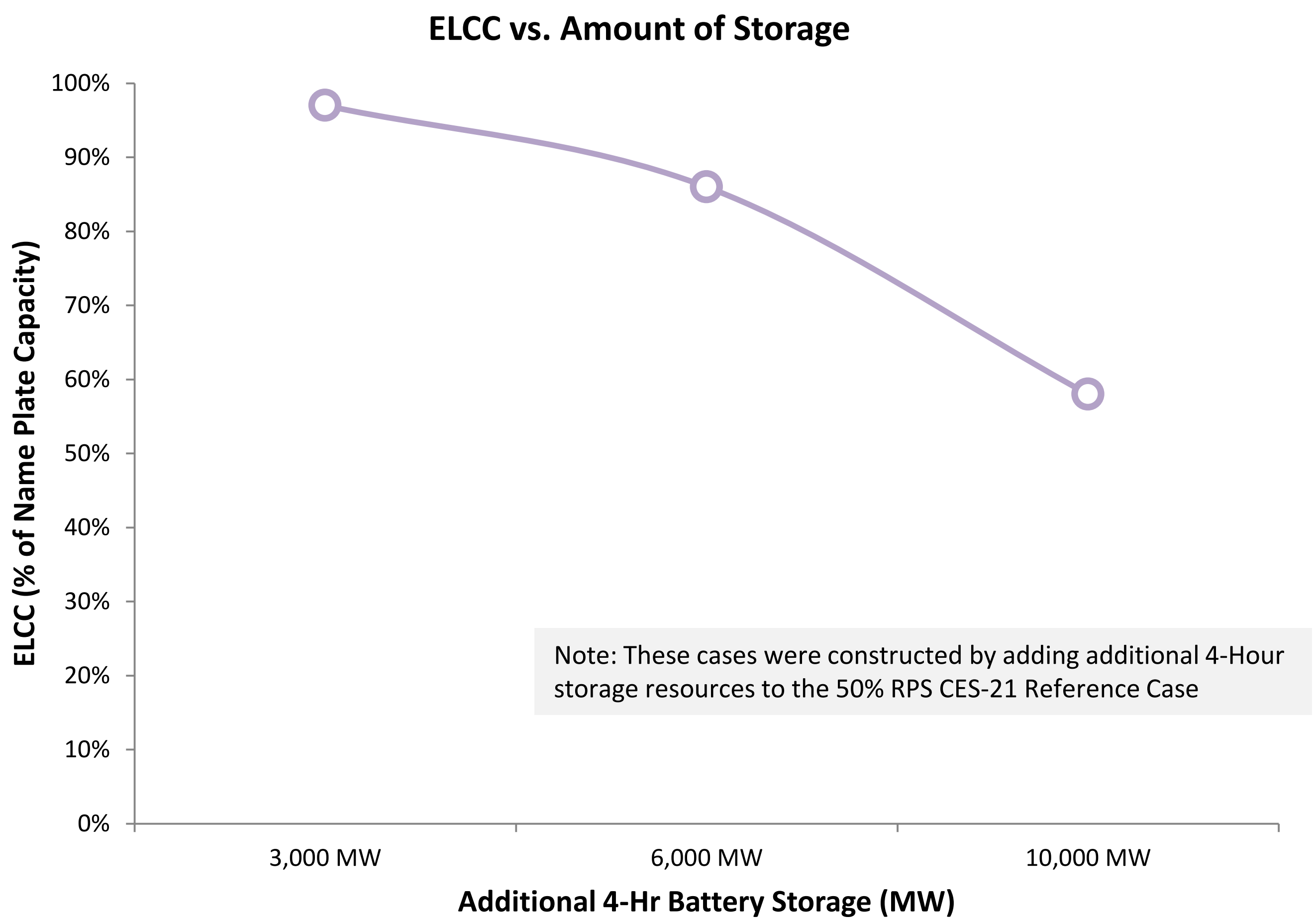
Similar to the System Pmin results, there is a trade off between curtailment and (in this case) expanding the net export limit

Interchange 3-Hour Ramp Cases



Interchange provides a valuable source of flexibility, especially as we add more renewables to our system

Storage Sensitivities – Capacity Credit



The ELCC values of storage is reduced as more storage is added to the system (i.e., due to flattening of the peak net load)

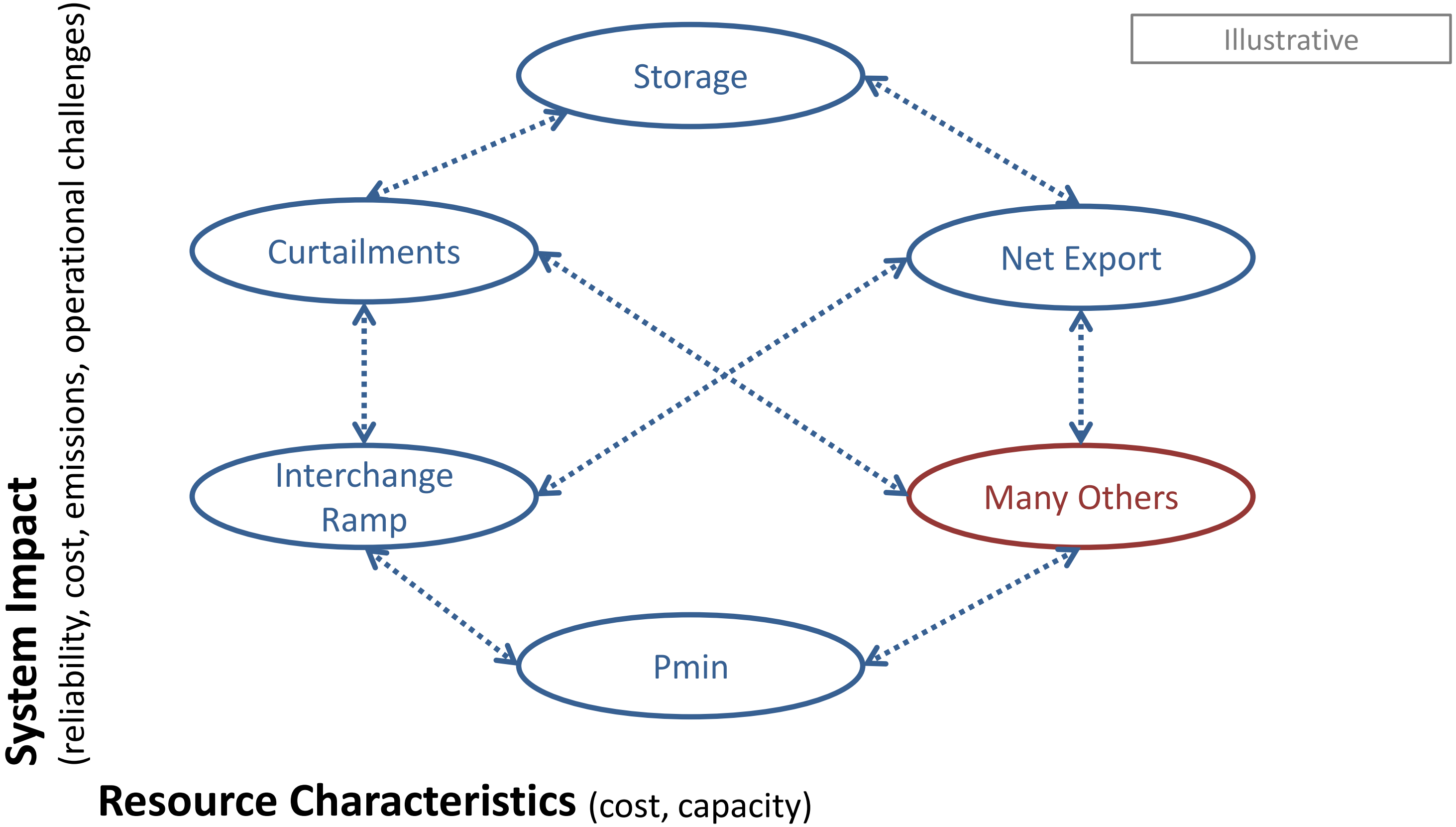
Storage Sensitivities – Economic and Curtailment Benefits

Economic Sensitivity Studies[1]	Marginal Economic Benefit ($/kw-yr per incremental MWh of storage capacity)[2,3]	Marginal Curtailment Benefit (MWh curtailment reduction per incremental MWh storage capability)
0→2 HR Storage	**24**	**133**
2→4 HR Storage	**16**	**103**
4→6 HR Storage	**8**	**58**
6→8 HR Storage	**2**	**6**

1. Studies constructed by adding 1,000 MW of each duration type to the 50% RPS CES-21 Reference Case
2. Does not include any resource cost
3. Includes CAISO production cost benefits, net purchase cost benefits, and the economic scarcity rent.

For the projected 50% RPS system, the marginal economic and curtailment benefits of additional energy decline past a few hours of storage

Finding the "right" flexibility solutions



<u>Recommendation</u>: Comprehensively evaluate and select the most efficient flexibility solutions

Open Questions / Future Work

- Operational feasibility and costs of more frequent and larger magnitude in curtailment and import / export ramps?
- Assumptions regarding availability of capacity in neighboring systems need to be verified
- Economic parameters of energy limited resources such as DR need to be examined because they impact reliability contribution
- What can we assume for intra-hour diversity benefit amongst renewable resources at higher penetrations?

Recommendation: Repeat this analysis as system conditions change sufficiently

Next Steps – Project Close out

- Submit final report
- Allow parties to provide comments
- Offer training course to Commission staff
- Make input data available to parties

1. Project objectives and Requirements
2. Definitions by LOLE Type
3. Model Comparison (From the 2014 Collaborative Review of Planning Models)
4. 20 Sensitivity Cases – Summary of Results
5. InFLEXion Results
6. PRM Calculation – Treating EE as supply resource vs. load modifier
7. Additional results from study cases

APPENDIX

Project Objective and Requirements

PROJECT OBJECTIVE

Study and recommend, if appropriate, planning metrics and standards that explicitly consider operational flexibility

RESOLUTION E-4677 REQUIREMENTS

Leverage results from collaborative review of planning model work

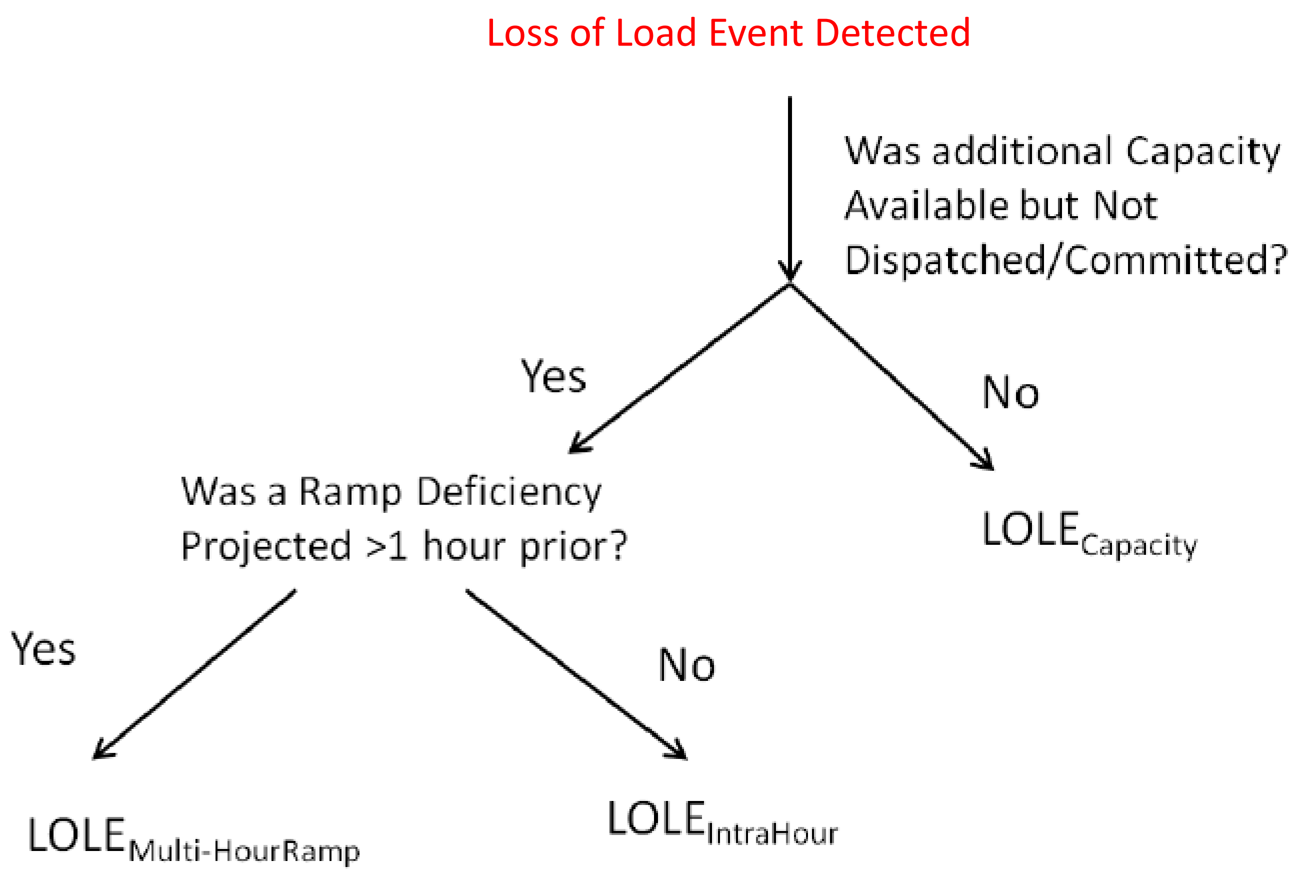
Form a collaborative advisory group

- Meet every six months
- Connect project progress with LTPP/RA flexibility modeling efforts

Produce results for use in the 2016 LTPP

- Present preliminary results / recommendations in a public workshop using 2014 LTPP assumptions
- Demonstrate recommended metrics / standards in the 2016 LTPP using updated assumptions

Definitions by LOLE Type



Model Comparison
(From the 2014 Collaborative Review of Planning Models)

Models/Approaches	Scenario(s) Considered	Simulating Operating Decisions
Deterministic (CAISO Deterministic)	A single "base case" or "stress" scenario at a time	Assumes perfect foresight, considers operating cost
Stochastic, statistical (SCE)	Many scenarios, enables calculation of probability metrics (e.g. LOLE)	Assumes perfect foresight, caps resource outage to 1,000 MW
Stochastic + uncertainty + recourse (REFLEX, SERVM)		Considers uncertainty, operating costs, and ability to adjust decisions (recourse)
Physics-based weather uncertainty + stochastic unit commitment (LLNL)		Considers physics-based weather uncertainty, operating costs, stochastic unit commitment

Modeling approaches vary:

- One vs. multiple scenarios at a time
- A range vs. a cap of resource outages
- Various degrees of forecast error and variability
- Recourse

Summary of Results

Case #	Type of Case	Description	LOLE CAPACITY	LOLE INTRA-HOUR (Events / 10 Years)	LOLE MULTI-HOUR	LOLE[1] TOTAL	Curtailment (GWh)[2]	Curtailment (%)[3]	Emissions (MMT)	Total Cost[4] ($ Billion)
BC_01	PRM Base Cases	33%	1.0	0.1	0.0	1.0	242	0.2%	61	7.2
BC_02		43%	1.0	0.1	0.0	1.0	2,652	2.1%	52	6.4
BC_03		50%	1.0	0.1	0.1	1.0	6,129	4.9%	49	6.5
SC_01	**Study Case**		**1.0**	**0.1**	**0.1**	**1.0**	**6,466**	**5.2%**	**48**	**6.4**
SC_02	Load Following (% of Load)	5%	0.8	0.6	0.0	1.4	5,503	4.4%	47	6.1
SC_03		7%	0.9	0.1	0.0	0.9	5,961	4.8%	47	6.3
SC_04		11%	1.1	0.1	0.0	1.1	7,045	5.6%	49	6.7
SC_05	Load Following (WSL Observed)	95 Pct	0.9	99.5	13.6	113.0	4,797	3.8%	46	5.9
SC_06		99 Pct	0.7	25.3	1.5	27.4	4,987	4.0%	46	6.0
SC_07		100 Pct	0.7	2.4	0.0	3.1	5,624	4.5%	47	6.2
SC_08	Pmin(+/- MW)	(-4,000 MW)	1.0	0.2	0.1	1.2	3,751	3.0%	46	6.0
SC_09		(-2,000 MW)	1.0	0.1	0.1	1.0	4,802	3.8%	47	6.2
SC_10		(+2,000 MW)	0.9	0.1	0.1	0.9	9,940	8.0%	49	6.7
SC_11		(+4,000 MW)	1.0	0.1	0.0	1.0	15,447	12.4%	51	7.3
SC_12	Interchange 3-Hour Ramp Limit	3,000 MW	1.7	0.2	0.1	1.7	8,548	6.8%	49	8.5
SC_13		6,000 MW	0.9	0.1	0.0	0.9	6,835	5.5%	48	7.1
SC_14		9,000 MW	0.9	0.1	0.0	0.9	6,572	5.3%	48	6.7
SC_15	Net Exports	3,500 MW	1.0	0.1	0.0	1.0	5,259	4.2%	48	6.3
SC_16		5,000 MW	1.0	0.1	0.0	1.0	4,553	3.6%	47	6.3
SC_17		8,000 MW	1.1	0.1	0.0	1.1	4,113	3.3%	47	6.3

1. Total LOLE represents the number of days with events of any LOLE type, and does not necessarily equal to the summation of LOLEs by type (e.g., two types of LOLE events can occur on a given day and only counted as 1 occurrence under LOLE total); 2. This study did not model additional resources to replace curtailed energy to meet RPS %
3. Percent of annual RPS output; 4. System production cost (includes cost of net imports) + cost of curtailment (assuming $50 / MWh)

InFLEXion analysis

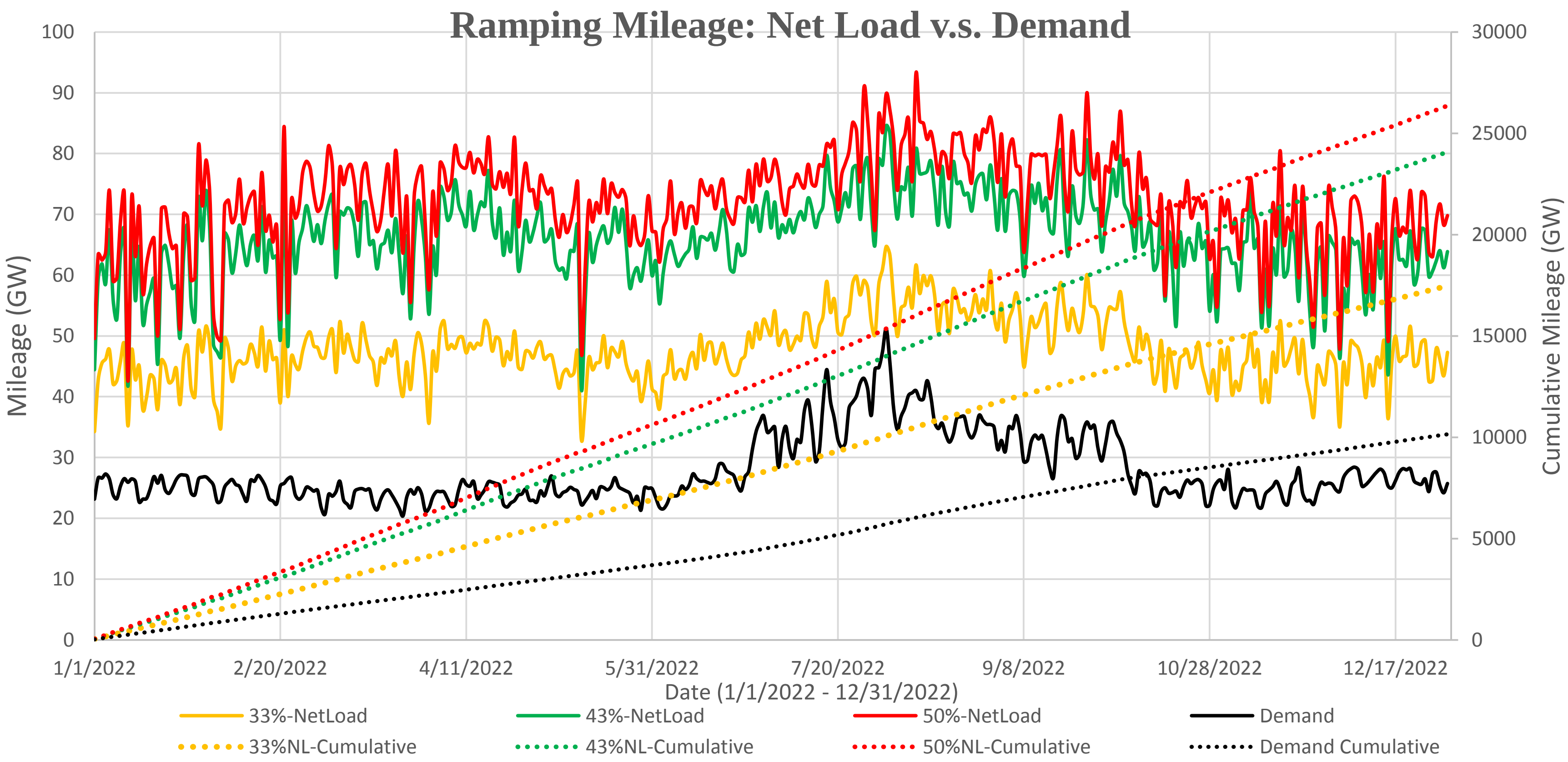
- Further analysis of SERVM results using EPRI-developed flexibility tool and metrics

- Examines ramp available in each time period against requirements in different time horizons

- Provide additional insights for specific one-year runs of SERVM (not entire cases)

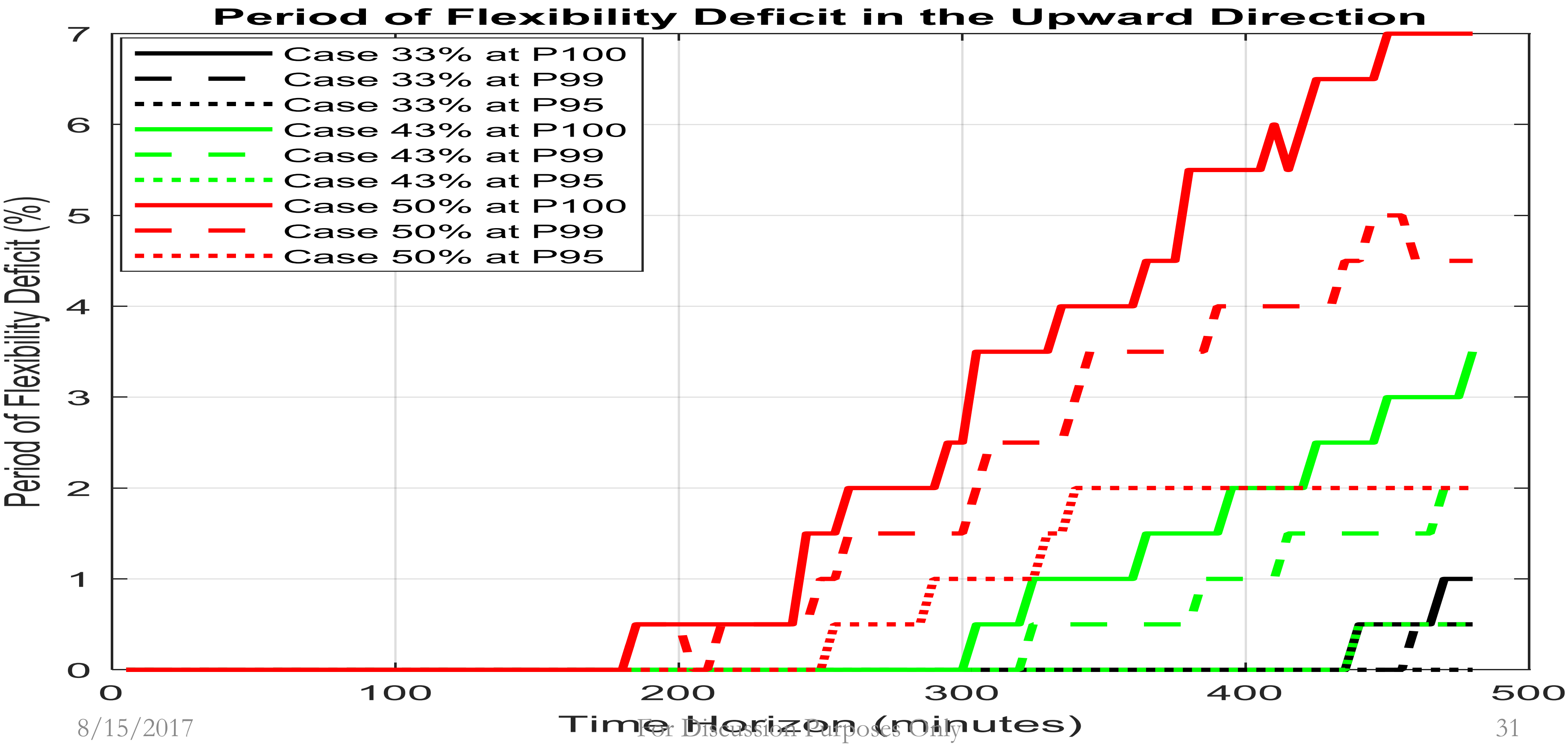
Ramping Mileage: daily time series and accumulation

- Absolute ramping from 5-minute data – daily (solid) and cumulative (dashed)
- Cumulative mileage percentage at last day (12/31): Net Load/Demand Ratio
  - 33% case: 172.2%; 43% case: 237.3%; 50% case: 259.8%
- Significant increase in ramping for 43% and 50% cases vs 33%



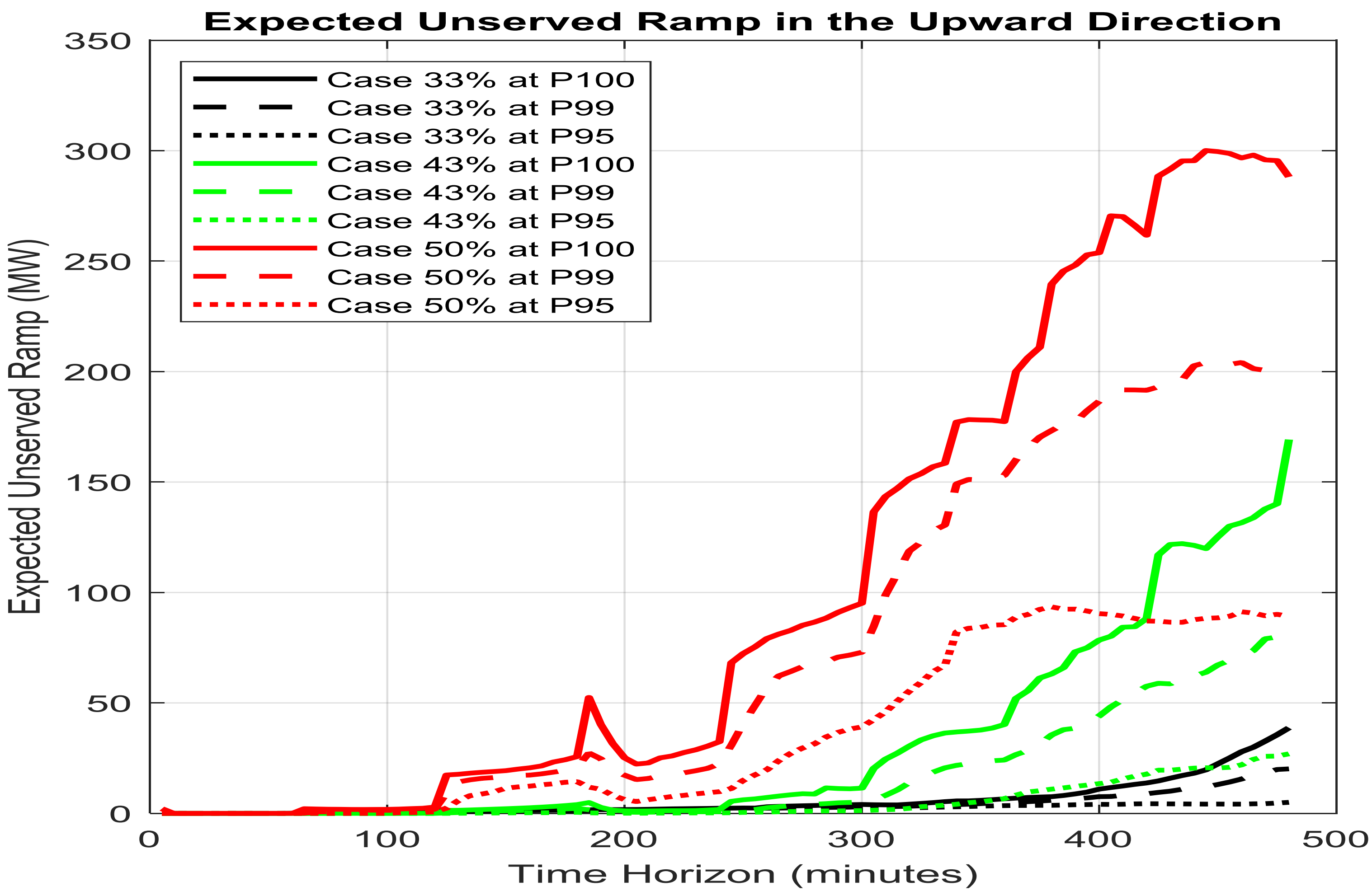
Periods of Flexibility Deficit

- Frequency of available ramp less than observed ramp - different percentiles and horizons
- Shows that <3 hour ramps do not have any ramping issues, but may have a few percent of hours where largest observed 8-hour ramp is greater than available
- Can be fixed with commitment or other operational issues
- Downwards ramping more significant, but main impact is curtailment



Expected Unserved Ramping

- Average expected unserved ramp in the upward is relatively small
  - Recall that the maximum 3-hours upward ramping in the 50% case was ~26000MW



Detailed PRM Calculation – EE as supply resource

Line	PRM Calculation	33% RPS	43% RPS	50% RPS
	Demand			
1	Gross Consumption (MW)	54,727	54,727	54,727
	Supply			
2	RPS Resources[1]	8,297	8,419	9,158
3	Fossil Resources	26,740	26,740	26,740
4	Non Fossil, Non RPS[2]	8,494	8,564	8,696
5	Imports	11,665	11,665	11,665
	Demand Side Resources Modeled as Supply			
6	BTMPV	1,723	2,295	2,151
7	Energy Efficiency[3]	4,053	3,844	3,631
8	Demand Response	1,457	1,539	1,485
	Deficiency / (Surplus) to reach LOLE standard			
9	Generic Resource Additions	1,348	730	393
	PRM to satisfy LOLE standard (%)	**116.5%**	**116.6%**	**116.8%**

1. Includes Utility solar, wind, geothermal, biomass; 2. Hydro and Others; 3. EE calculation is based on a single profile from the CEC; further study will be helpful as individual EE programs do not have the same load impacts; 4. PRM = Sum (Lines 2 through 9) / Line 1

Detailed PRM Calculation – EE as load modifier

Line	PRM Calculation	33% RPS	43% RPS	50% RPS
	Demand			
1	Gross Consumption (MW)	54,727	54,727	54,727
2	Energy Efficiency[3]	4,491	4,491	4,491
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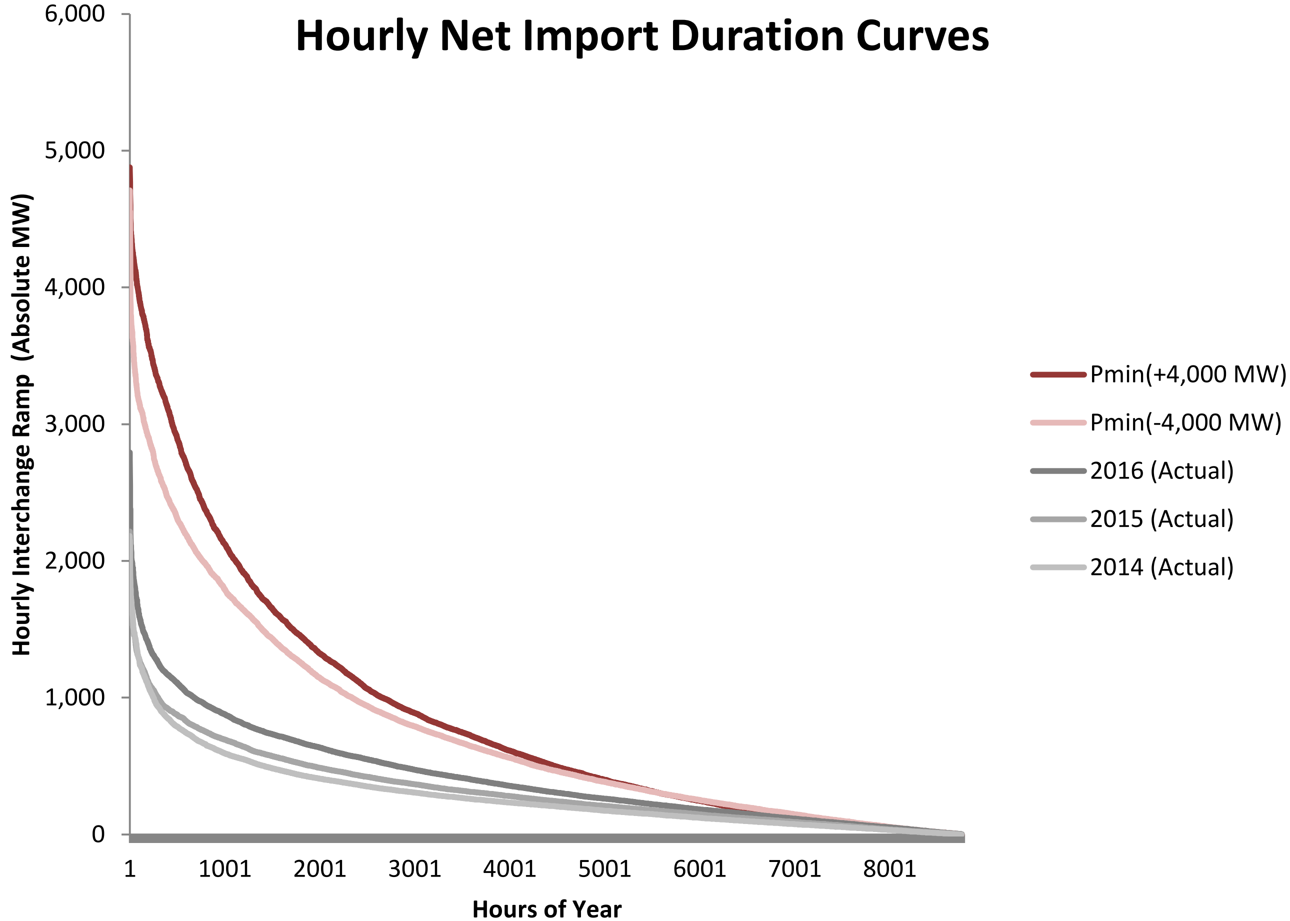
8	Demand Response	1,457	1,539	1,485
	Deficiency / (Surplus) to reach LOLE standard			
9	Generic Resource Additions	1,348	730	393
	PRM to satisfy LOLE standard (%)	**118.9%**	**119.3%**	**120.0%**

1. Includes Utility solar, wind, geothermal, biomass; 2. Hydro and Others; 3. EE calculation is based on a single profile from the CEC; further study will be helpful as individual EE programs do not have the same load impacts; 4. PRM = Sum (Lines 3 through 9) /(Line 1 - Line 2)

Using a different counting method that treats EE as load modifier, a higher PRM is required to achieve the same LOLE

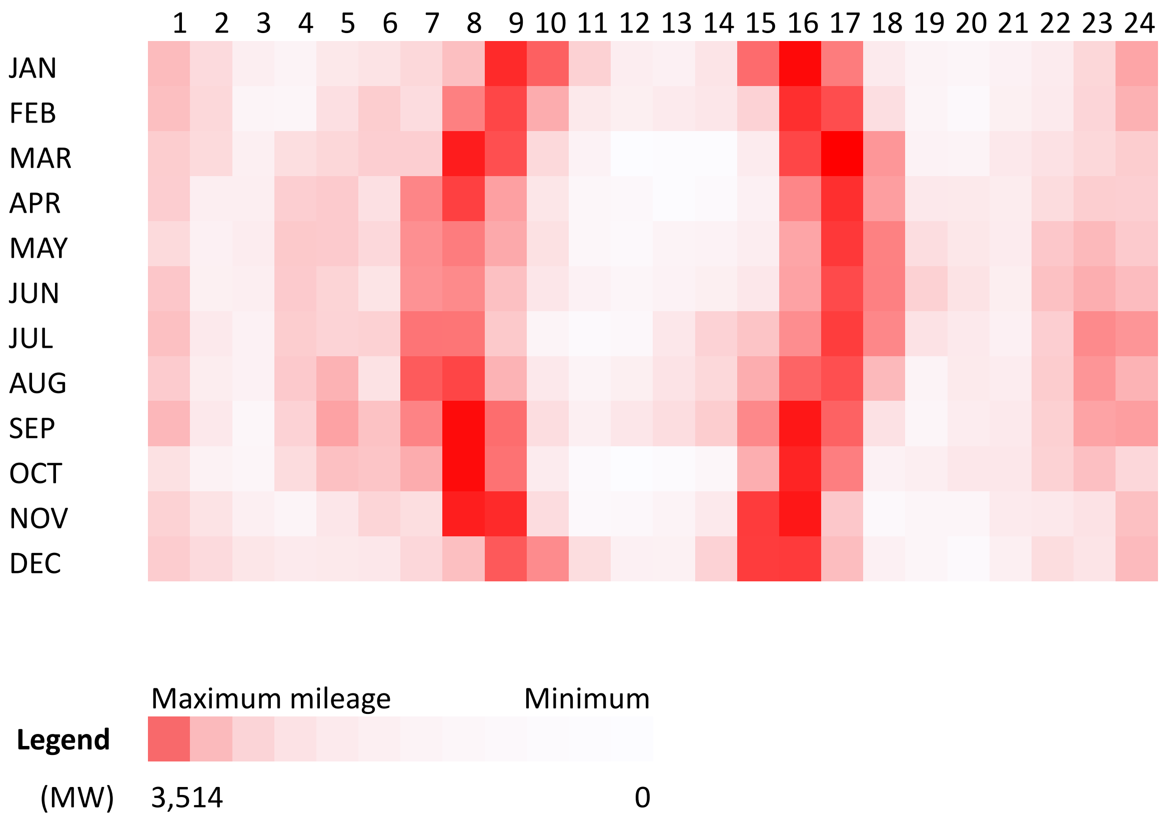
System Pmin – Interchange as a solution



Results showed larger amount of ramp at the interties under a highly inflexible system, operational feasibility and costs need to be studied

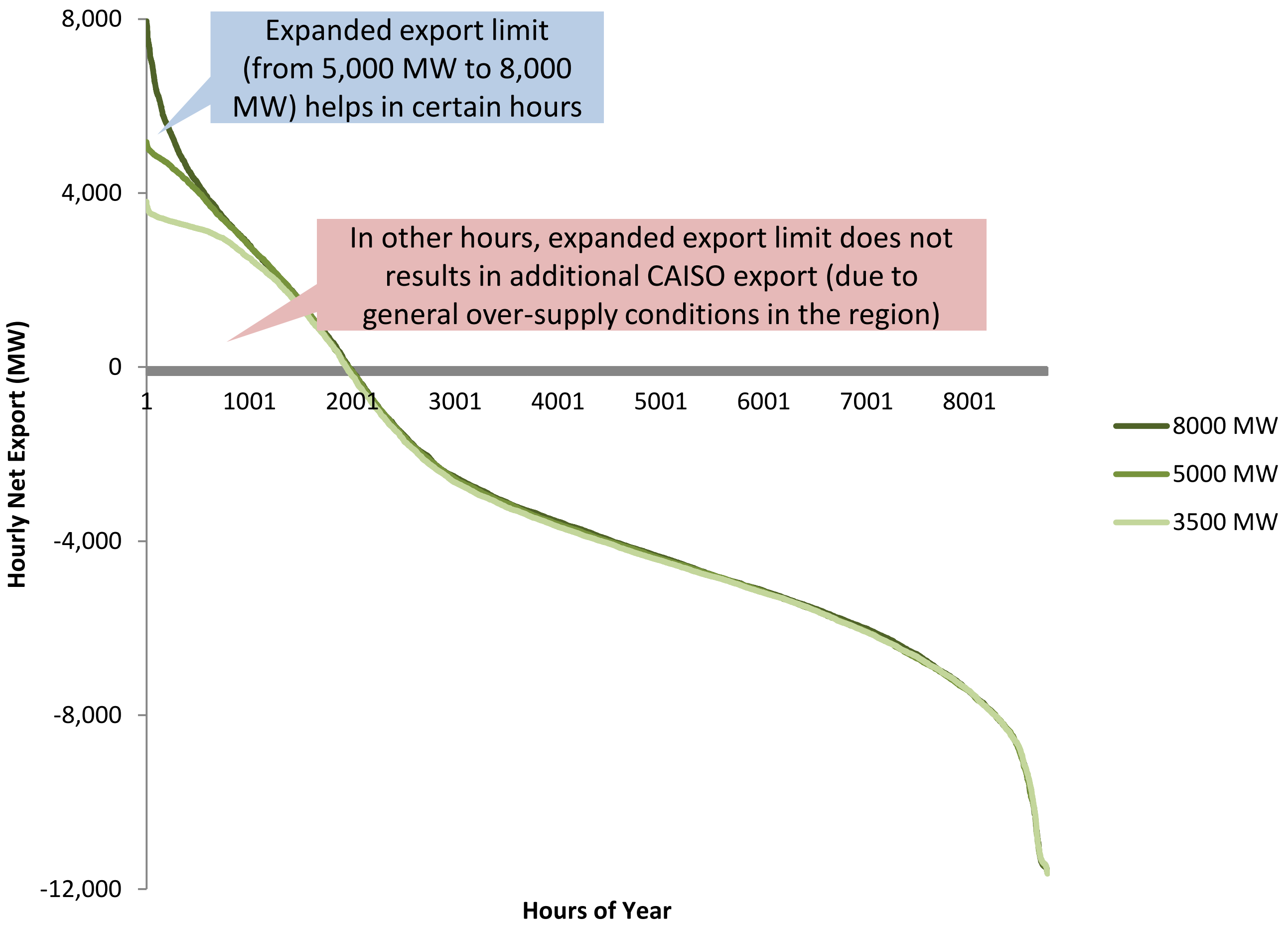
System Pmin – Interchange as a solution

Average Hourly Net Import Mileage by Month – System Pmin + 4,000 MW (SC_11)



Results showed larger amount of ramp at the interties – following a clear, consistent diurnal pattern – under a highly inflexible system

Net Export Cases – Net Export Duration Curves



Results show expanded limit utilized to export excess CAISO supply in some hours, but not others (when neighbors also have over-supply)