SPP Future Fuel Mix Study Results

Resource & Energy Adequacy Leadership Team

02/21/2024

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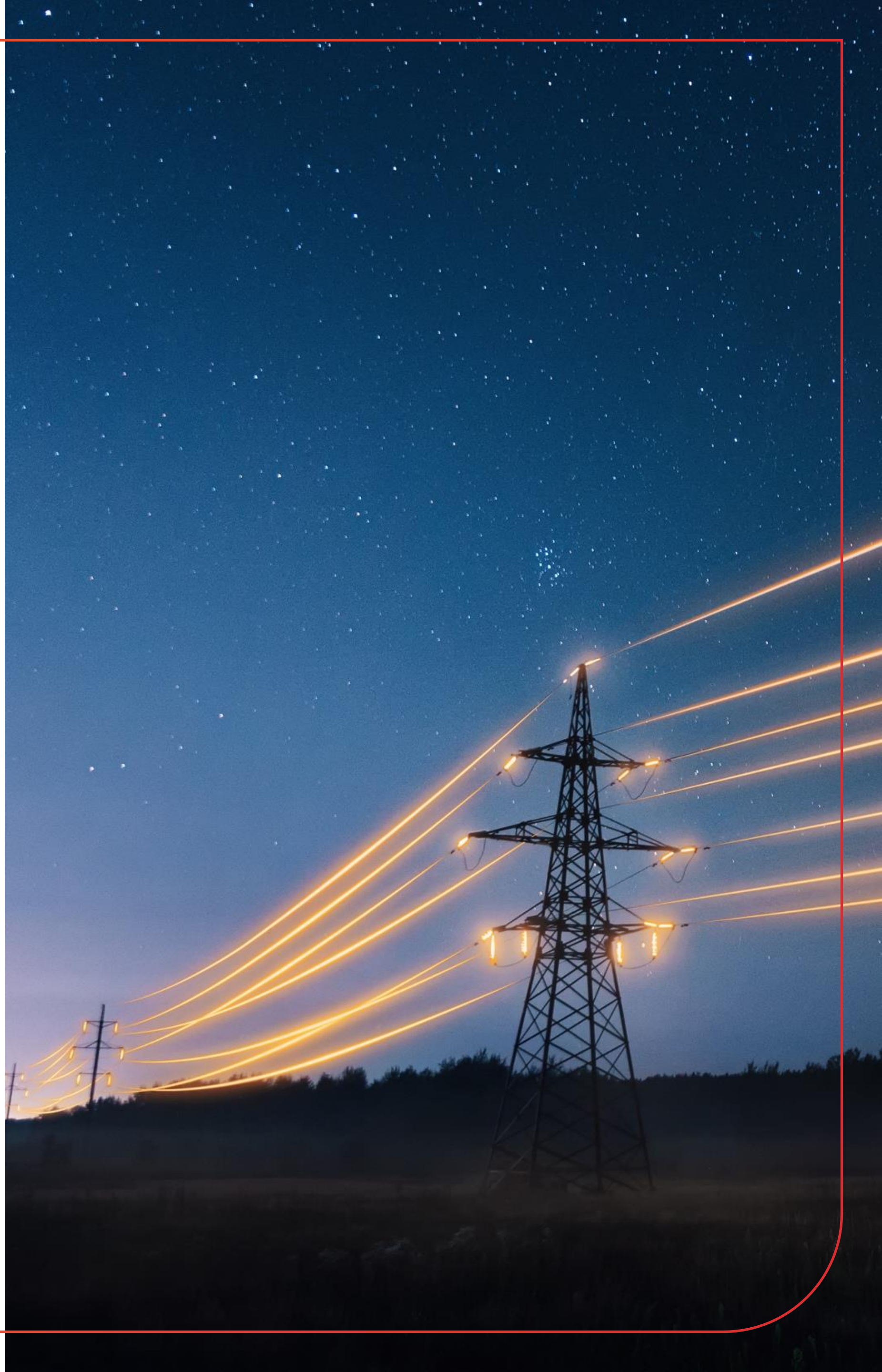
ASTRAPÉ CONSULTING
innovation in electric system planning



Methodology

Study Objectives

- Calculate the System Annual, Summer, and Winter Effective Load Carrying Capability (ELCC) using 0.1 LOLE metric for various high renewable penetration scenarios
  - Determine if LOLE remains a viable metric for high renewable penetration by evaluating the Normalized EUE for each scenario
- Using appropriate metric (NEUE vs. LOLE), determine seasonal Planning Reserve Margins (PRM) at each high renewable penetration scenario
- Using appropriate metric (NEUE vs. LOLE), determine the seasonal solar, wind, storage, and demand response ELCCs at each high renewable penetration scenario
- Develop ELCC surfaces for solar, wind, and storage

Scenarios Modelled

- 6 scenarios of renewables penetration provided by SPP
- Technologies modeled are Wind, Solar, Storage and Demand Response (DR)
- Solar was incremented up differently for each zone
- DR amounts for Scenarios 1 and 2 reflect actual DR amounts

Scenario	Wind (MW)	Solar (MW)	Storage (MW)	Demand Response (MW)
1	40,000	10,000	5,000	2,200
2	40,000	20,000	5,000	2,200
3	52,000	20,000	5,000	3,000
4	59,000	24,000	10,000	3,000
5	60,000	30,000	10,000	5,000
6	60,000	30,000	20,000	5,000

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Scenario Assumption

- Scenarios 1 and 6 were run to measure sensitivity impacts at both extremes of renewable penetration (i.e., S1 and S6)
- Scenarios 2 – 5 were intermediate steps that bridge the renewable penetration in Scenarios 1 and 6
- Cold weather outage adjustments were modeled at a flat 50%
- Scenarios 3-6 were run with Demand response (DR) constraints on the maximum number of calls and dispatch capacity at different time periods

Astrapé and SERVM

- **Strategic Energy Risk Valuation Model (SERVM)**
  - Multi-area reliability and economic simulation tool for the bulk electric system
  - Originally developed/patented in 1980s by Southern Company
  - Owned/licensed by Astrapé Consulting with 15+ years of ongoing development
  - Capable of hourly and sub-hourly chronological resource commitment and dispatch
- **Types of Resource Adequacy Studies**
  - LOLE Analyses
  - Reserve Margin Analyses
  - **ELCC Analyses**
  - Renewable Integration Analyses
  - Resiliency Analyses

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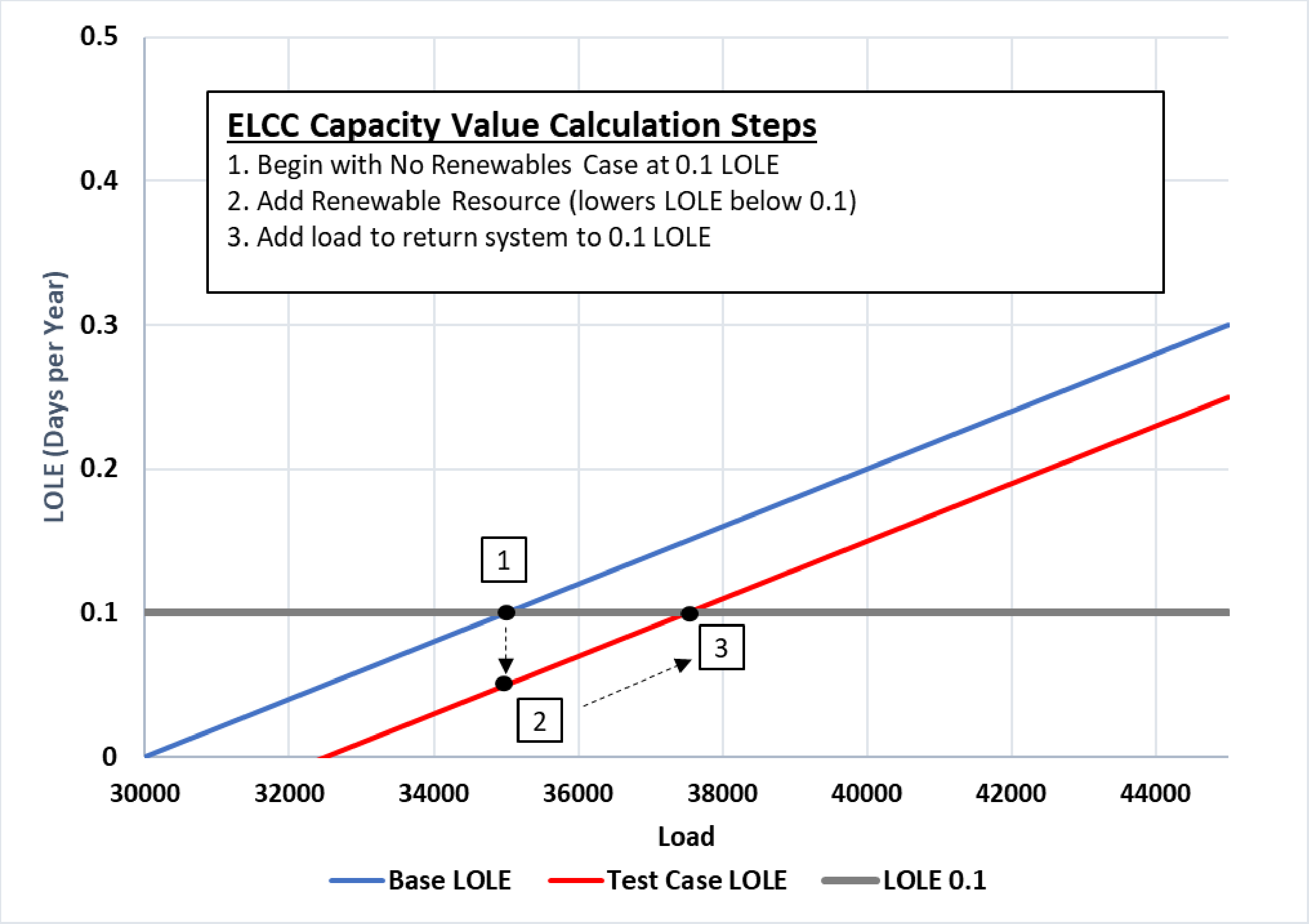
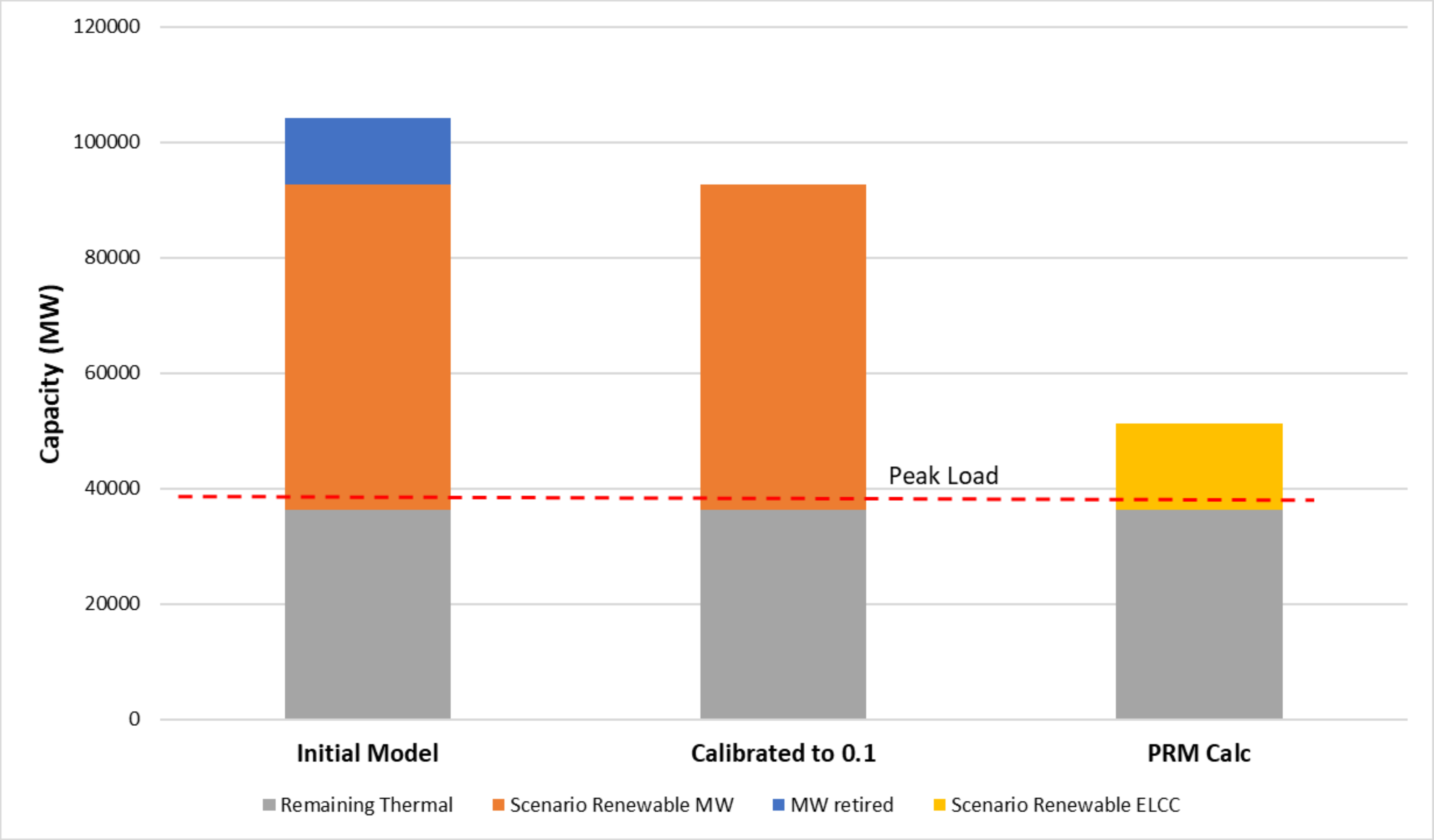
Calculating ELCC

ELCC is derived as the equivalent capacity value divided by the nominal value

Within SERVM, either Equivalent Capacity or Load Equivalent methods are typically used.



Methodology for Initial Calibration and PRM Determination



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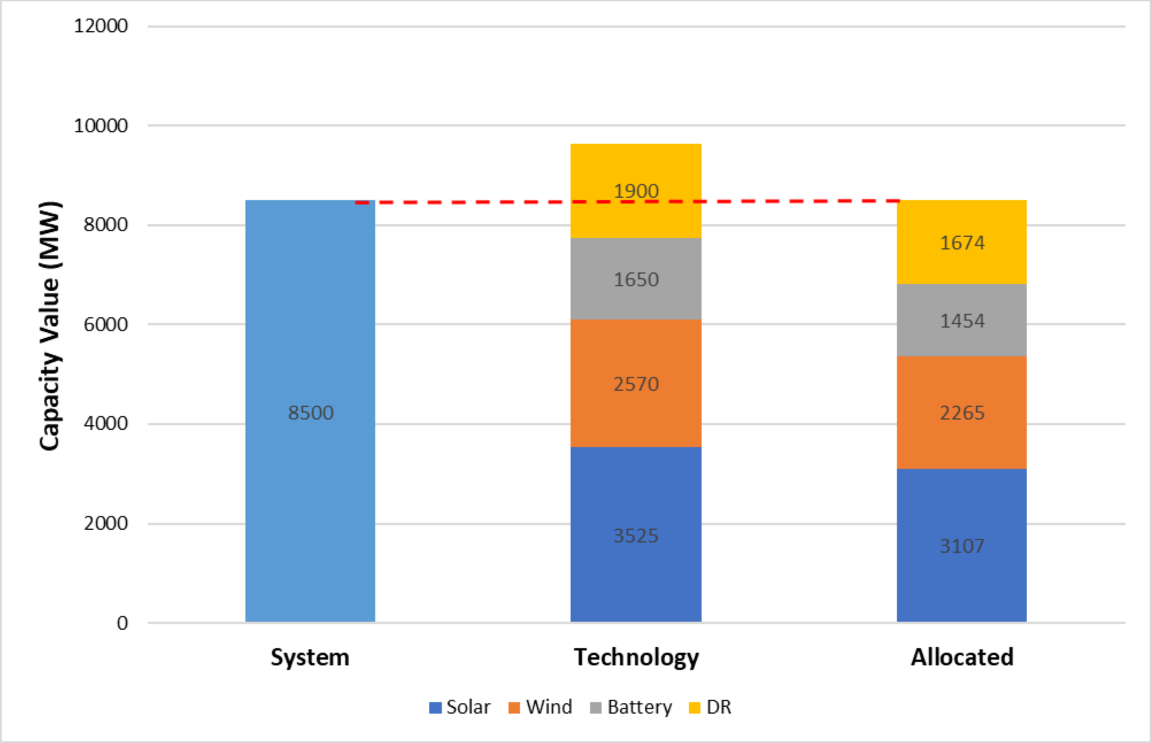
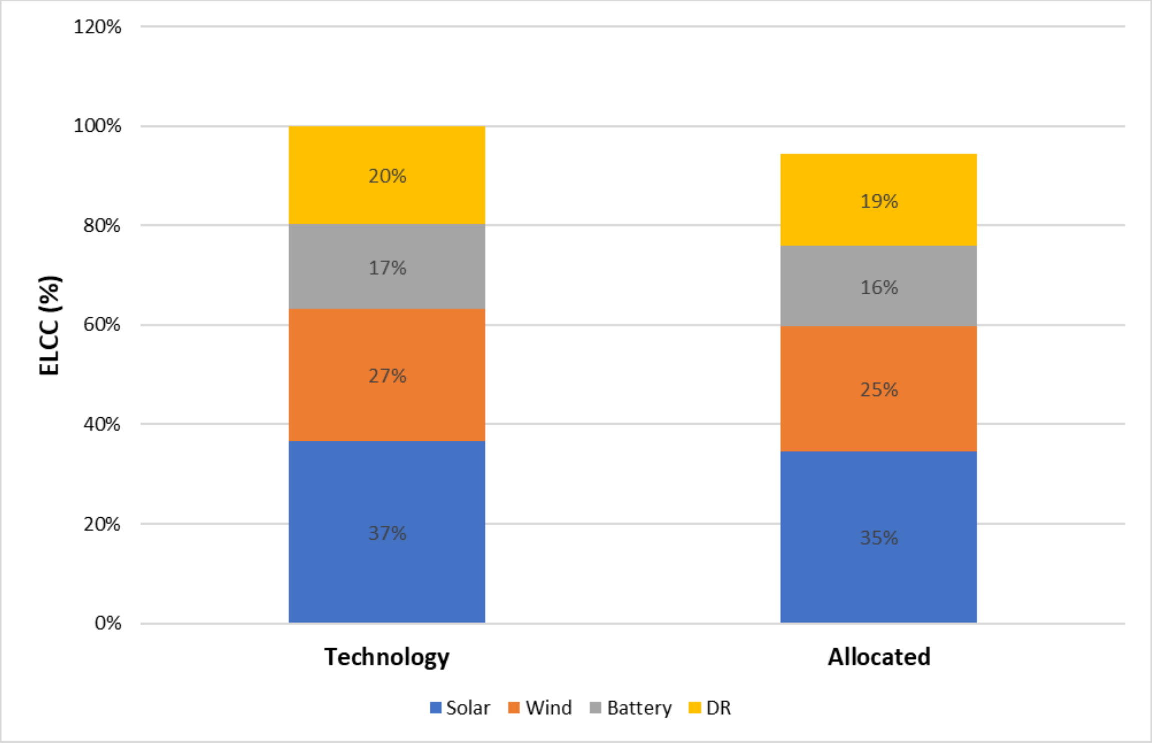
Methodology for Technology Specific ELCC



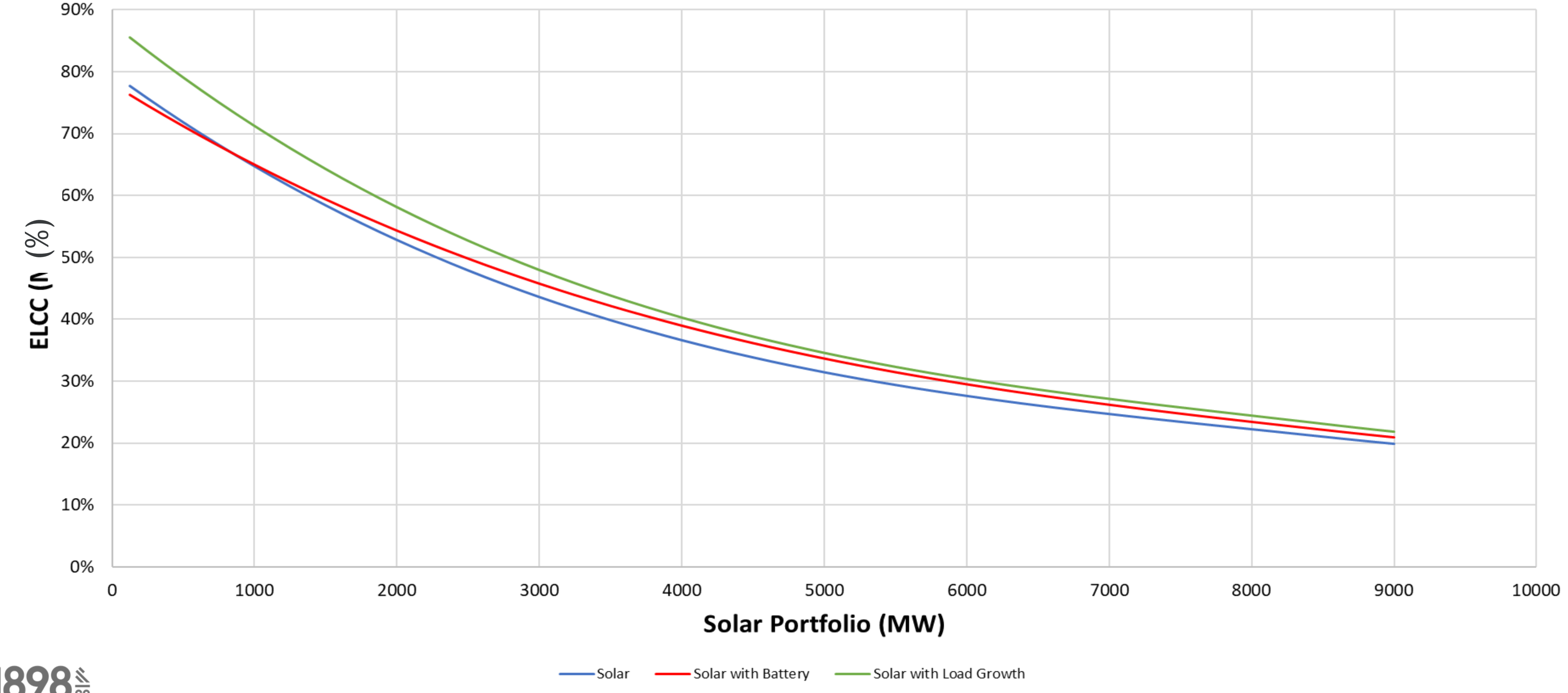


Challenges of Calculating ELCC

Challenges of Calculating ELCC

- Dynamic Nature of ELCC
  - Penetration of resources
  - Load growth of underlying system
  - Penetration of other technologies

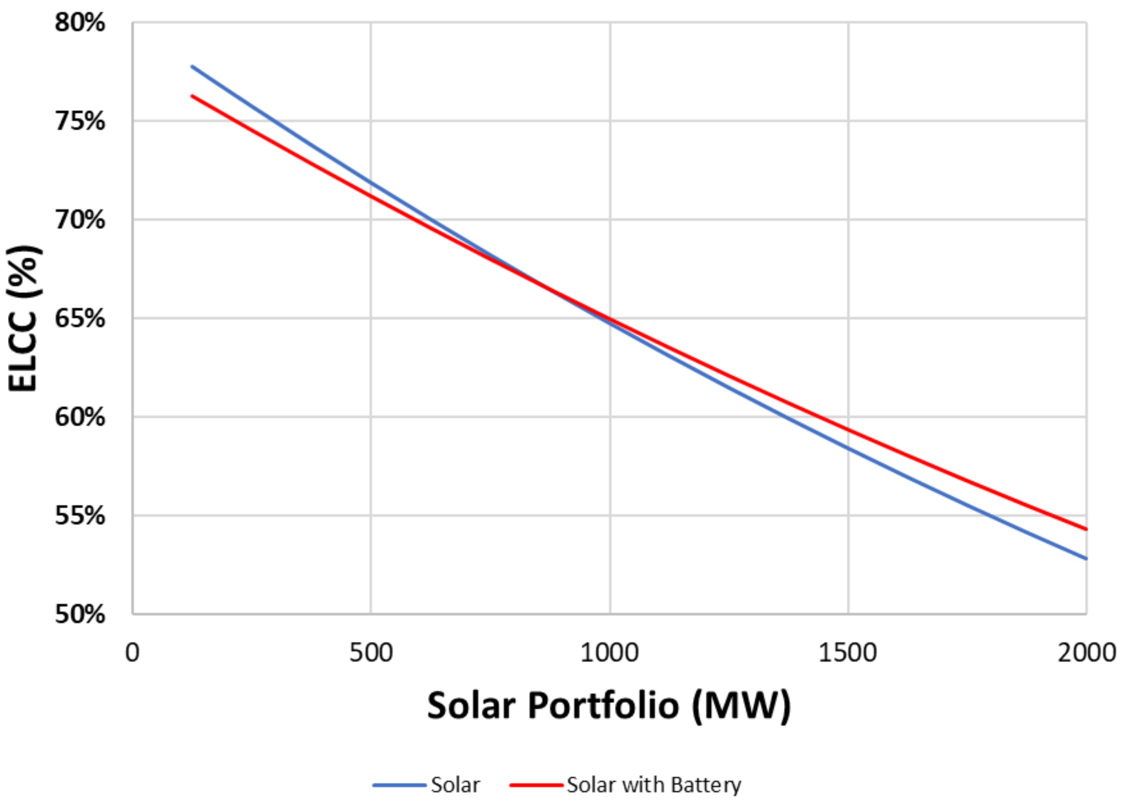
Dynamic Nature of ELCC

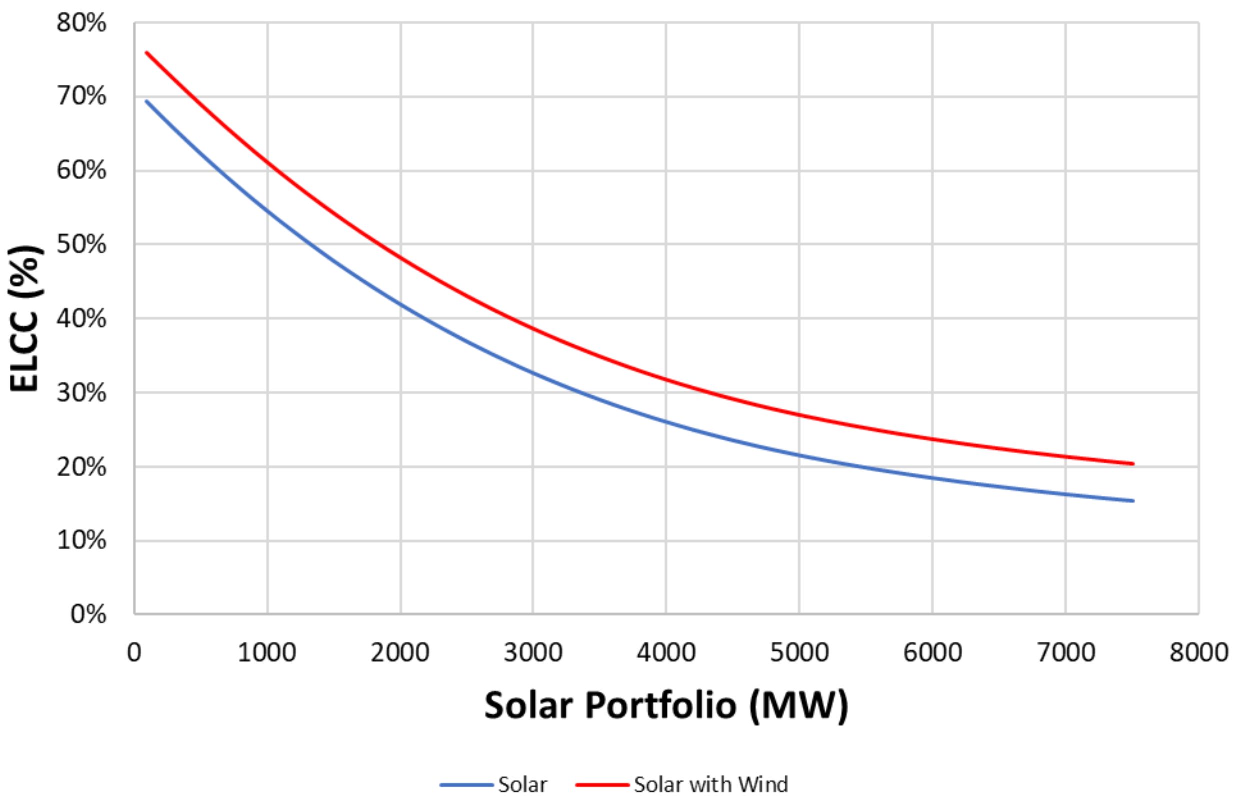


Challenges of Calculating ELCC

- Dynamic Nature of ELCC
- Synergistic/Antagonistic Nature of Mixed Portfolios
  - Some technologies work together (synergistically) such that the combined capacity value is greater than the sum of the individual capacity values.
  - Some technologies work against one another (antagonistically) such that the combined capacity value is less than the sum of the individual capacity values.

Antagonistic/Synergistic Effects





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Challenges of Calculating ELCC

- Dynamic Nature of ELCC
- Synergistic/Antagonistic Nature of Mixed Portfolios
- Allocation of Synergistic Benefits
- Multi-Dimensional Nature of Problem

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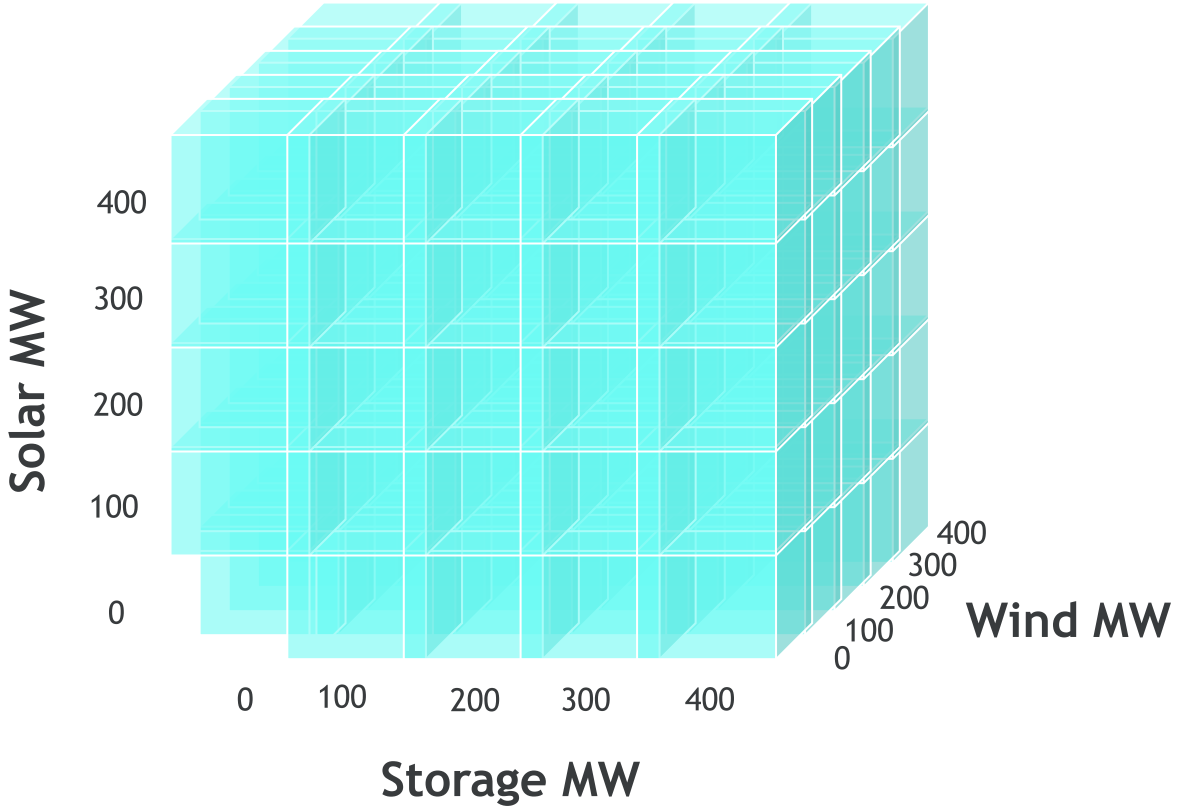
Multi-Dimensional Problem

Dimensional Interactions

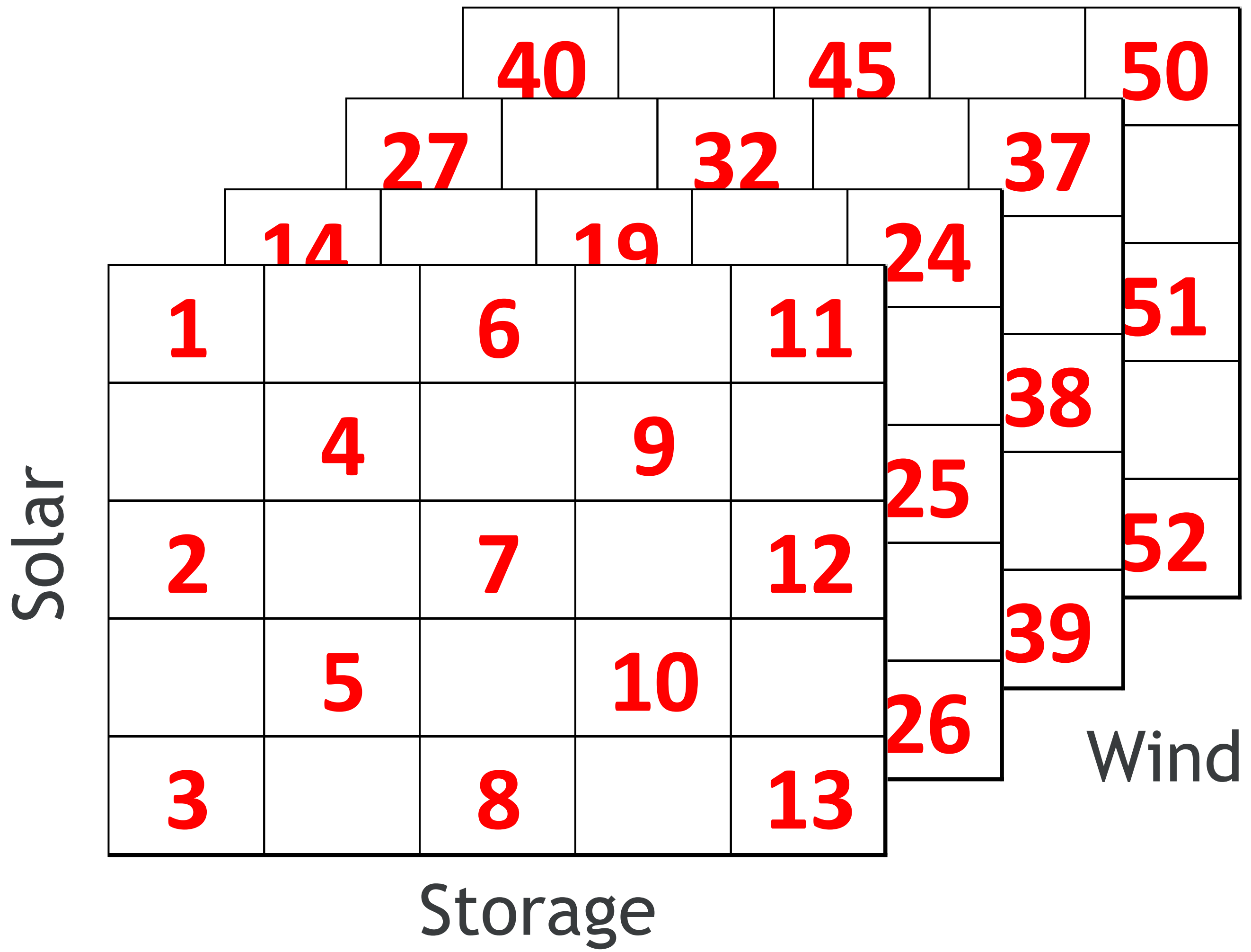
1. Solar
2. Wind
3. Storage
4. Demand Response
5. Load Growth



ELCC Surfaces

Development of ELCC Surfaces

- Using SERVM, develop 3-D Sparse Matrix of Capacity Values
  - Total number of scenarios may vary
  - Actual SERVM ELCC simulations would be performed for each of the numbered cells.



Development of ELCC Surfaces

- Develop 3-D Sparse Matrix of Capacity Values
- Expand/Trend/Smooth
  - Uses radial basis function interpolation
  - Creates dense matrix of capacity values
  - Generates capacity value surfaces

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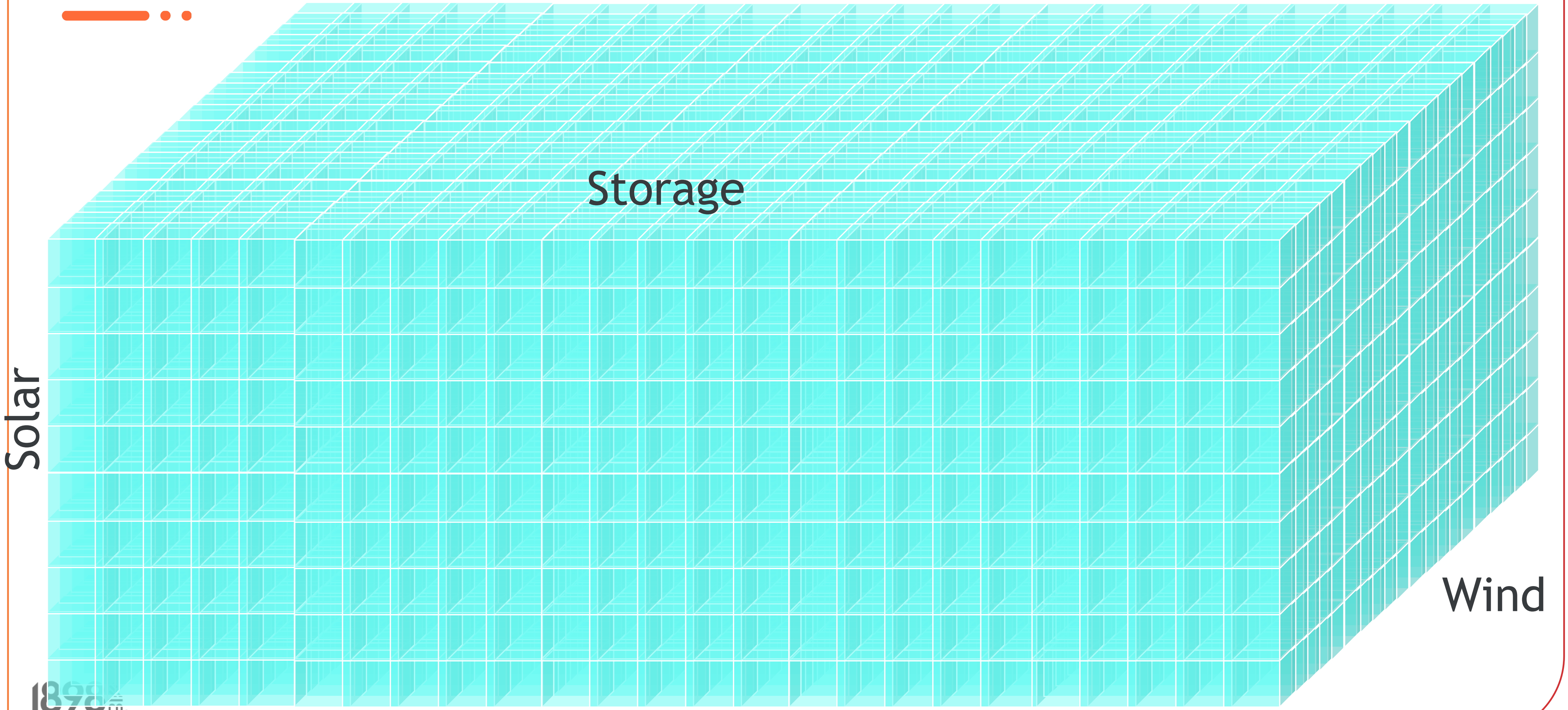
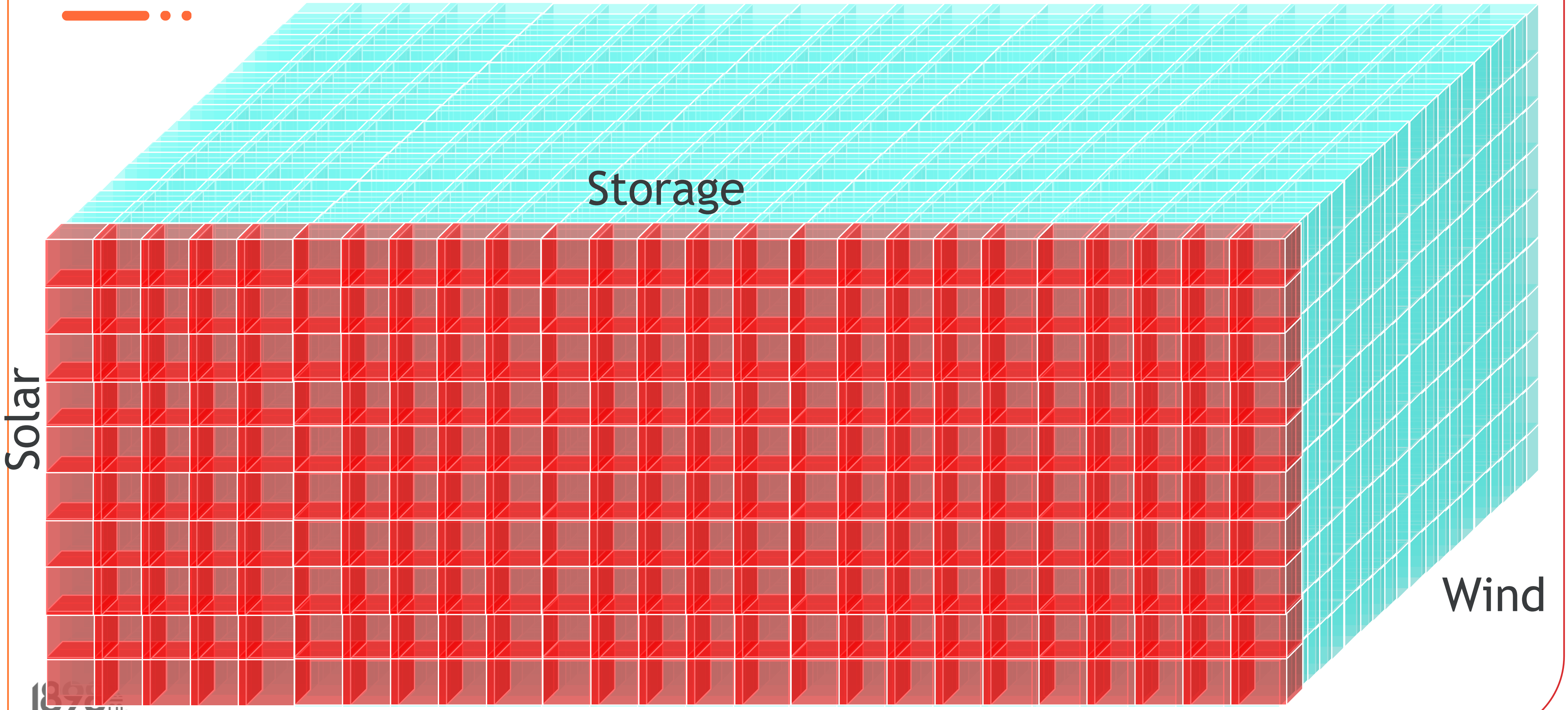
Dense Matrix



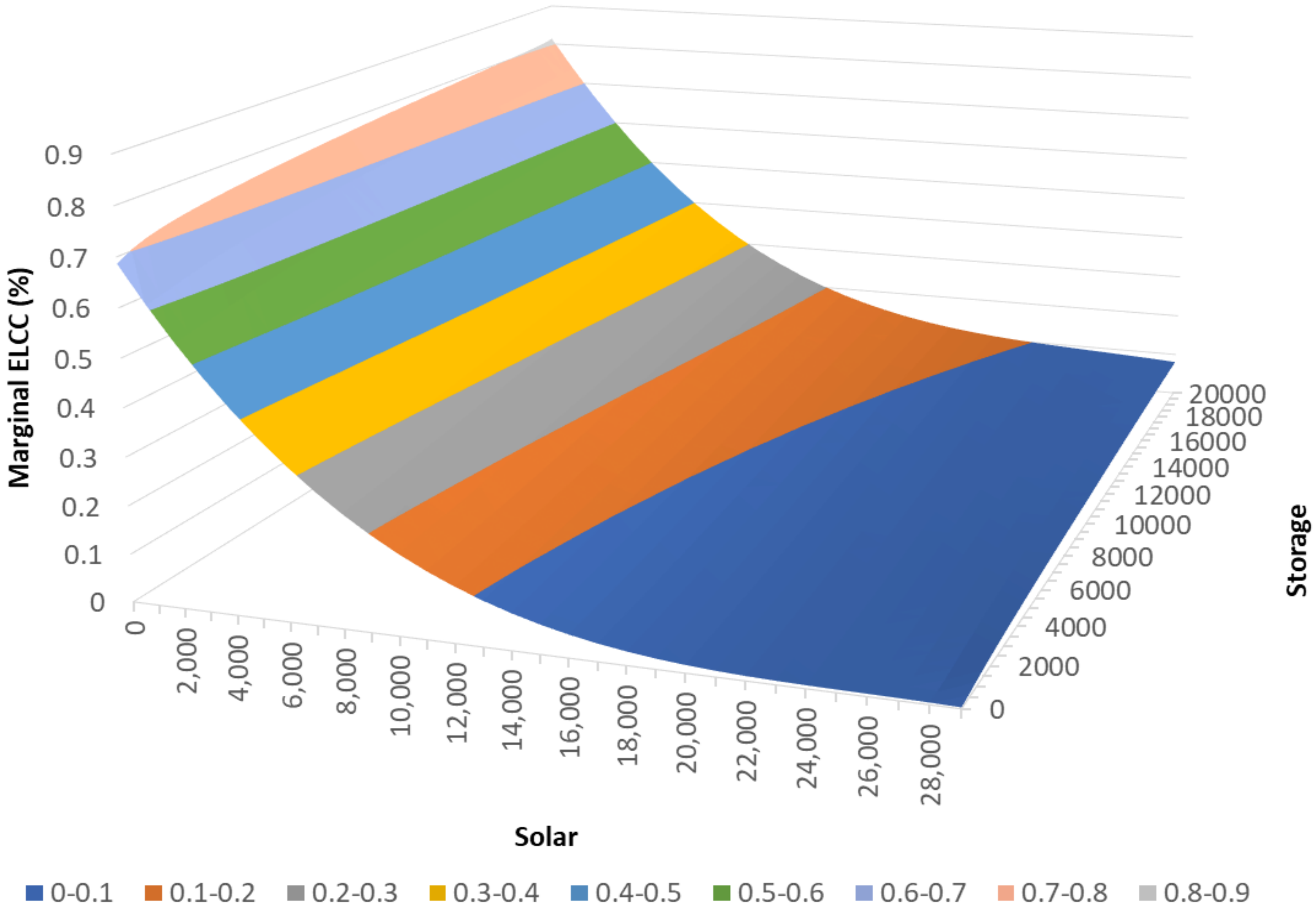
Dense Matrix - Slice across two variables



Development of ELCC Surfaces

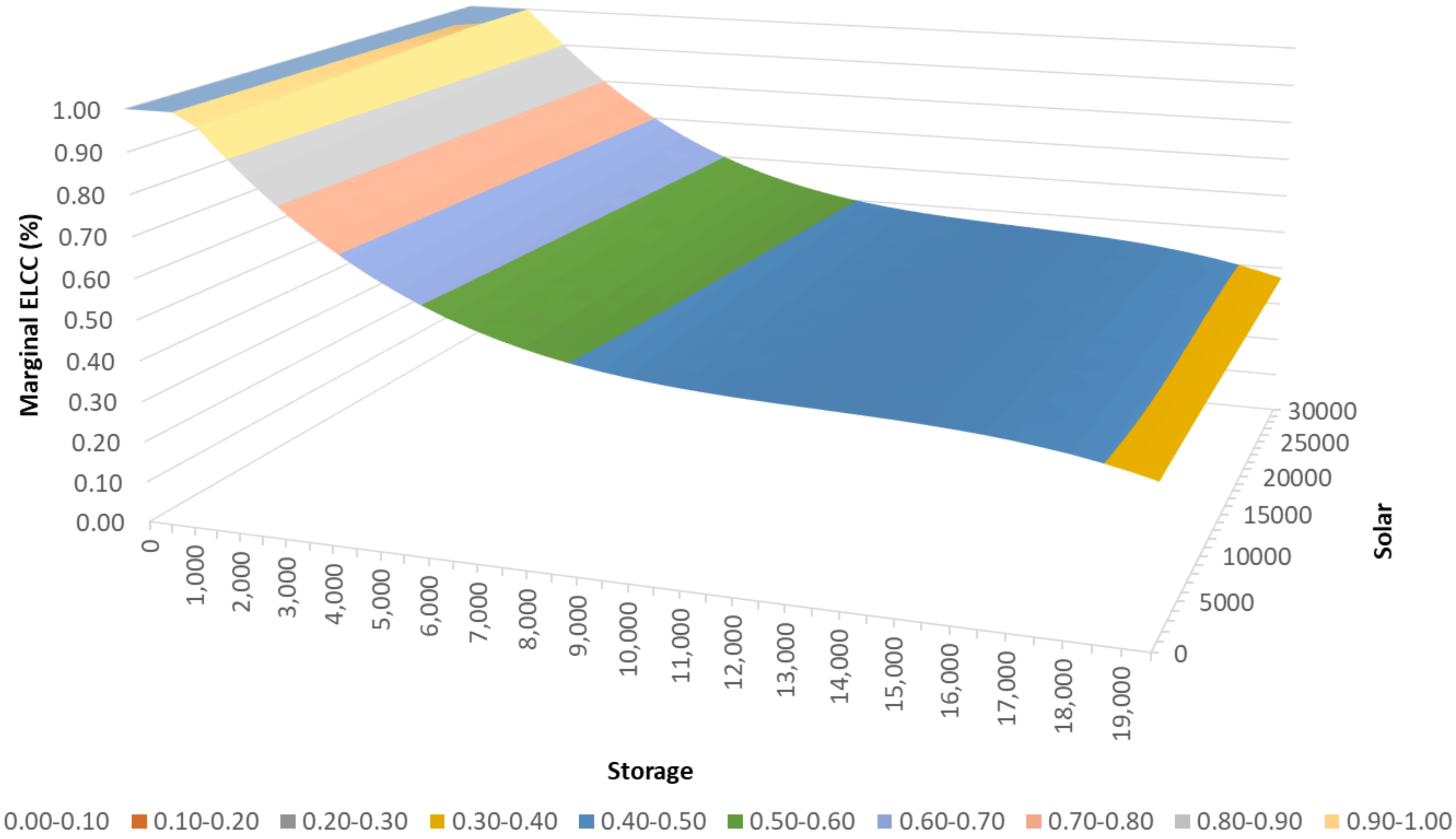
- Develop 3-D Sparse Matrix of Capacity Values
- Expand/Trend/Smooth
  - Creates dense matrix of capacity values
  - Generate capacity value surfaces
- Calculate Average and Marginal ELCCs
  - From the portfolio surfaces, generate average and marginal ELCC technology values

Example -Solar Marginal Summer as a Function of Zero Penetration Wind



Wind penetration fixed

Example -Storage Marginal Summer as a Function of 40GW Wind



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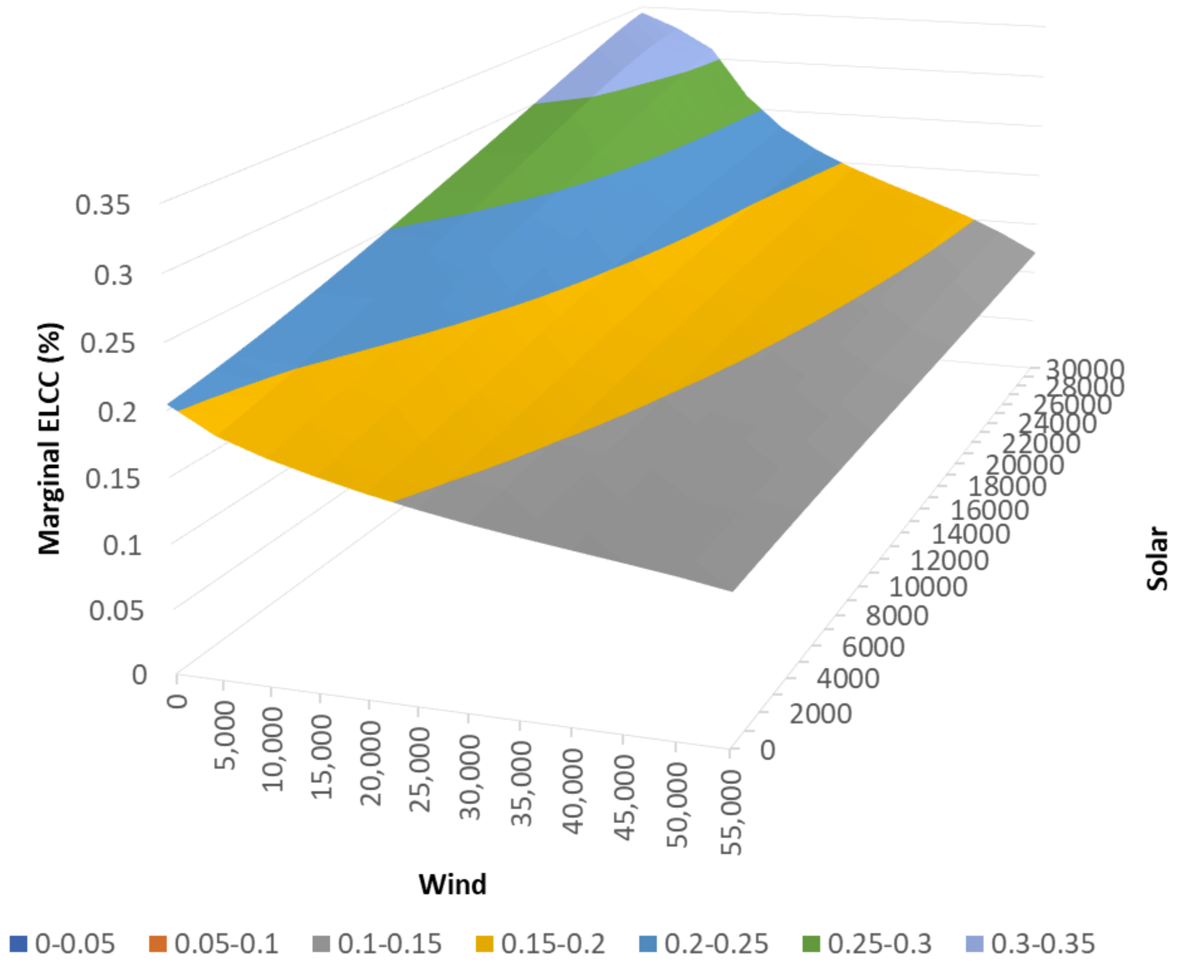
Example -Wind Marginal Summer as a Function of 10GW Storage



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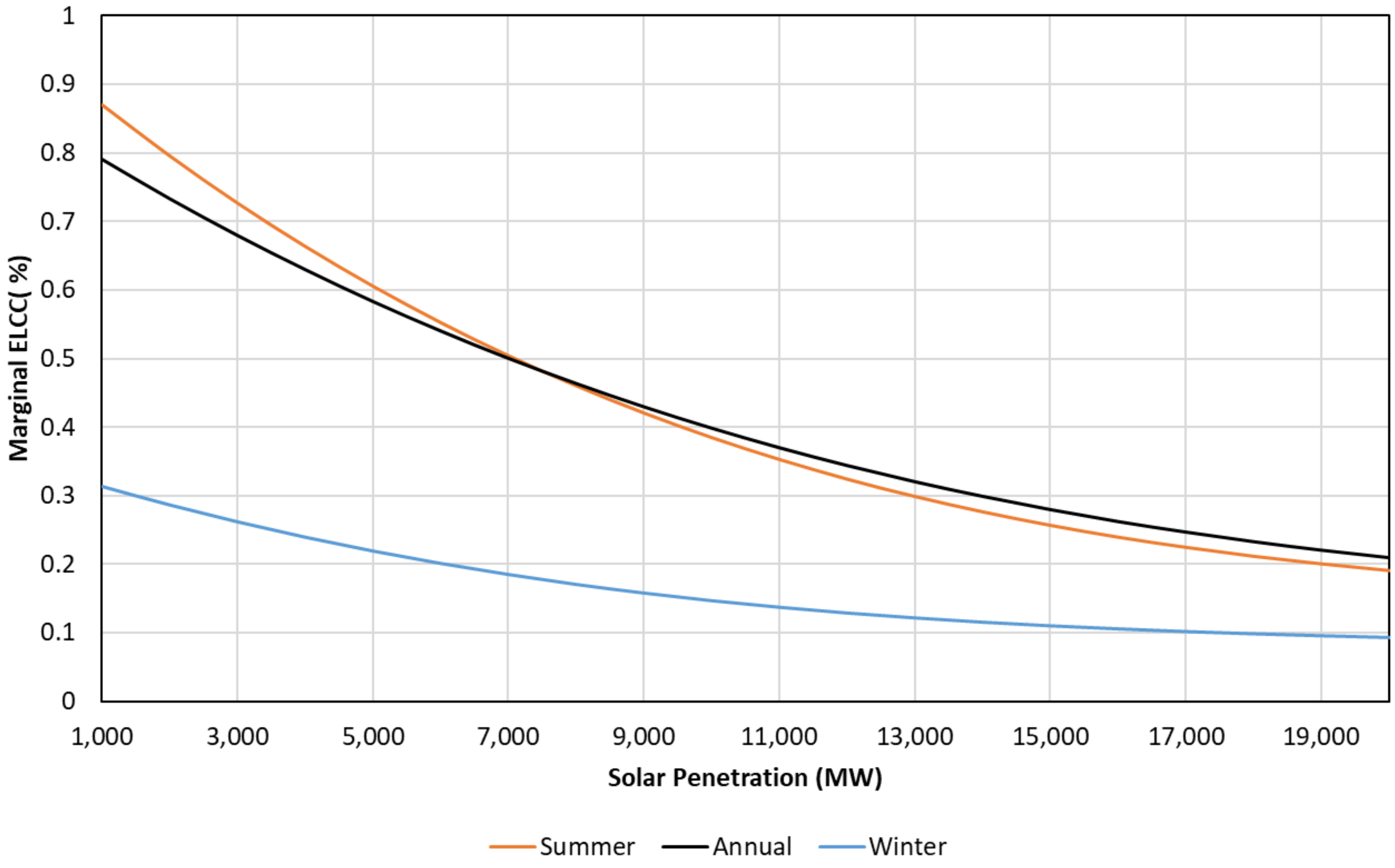
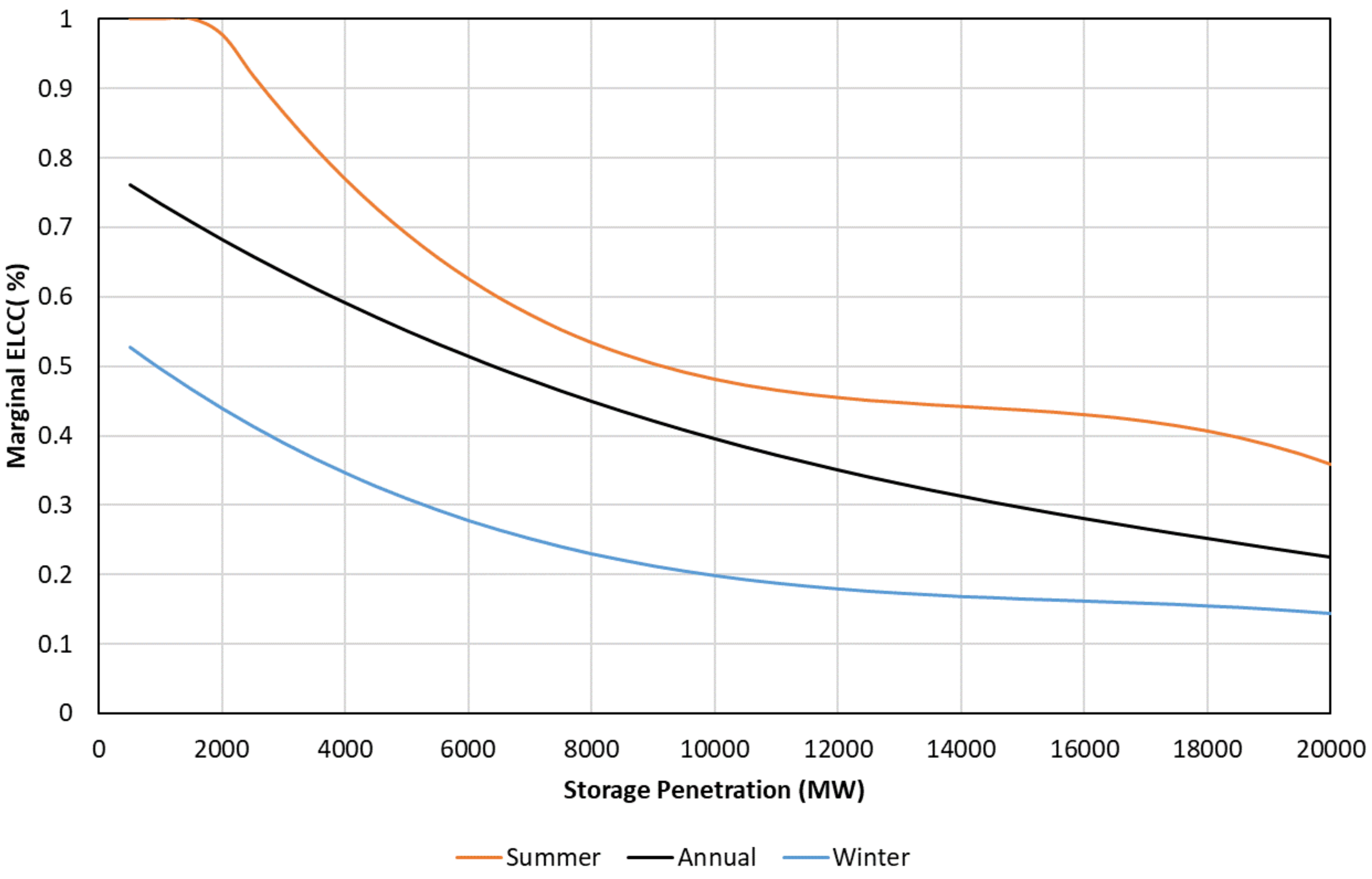
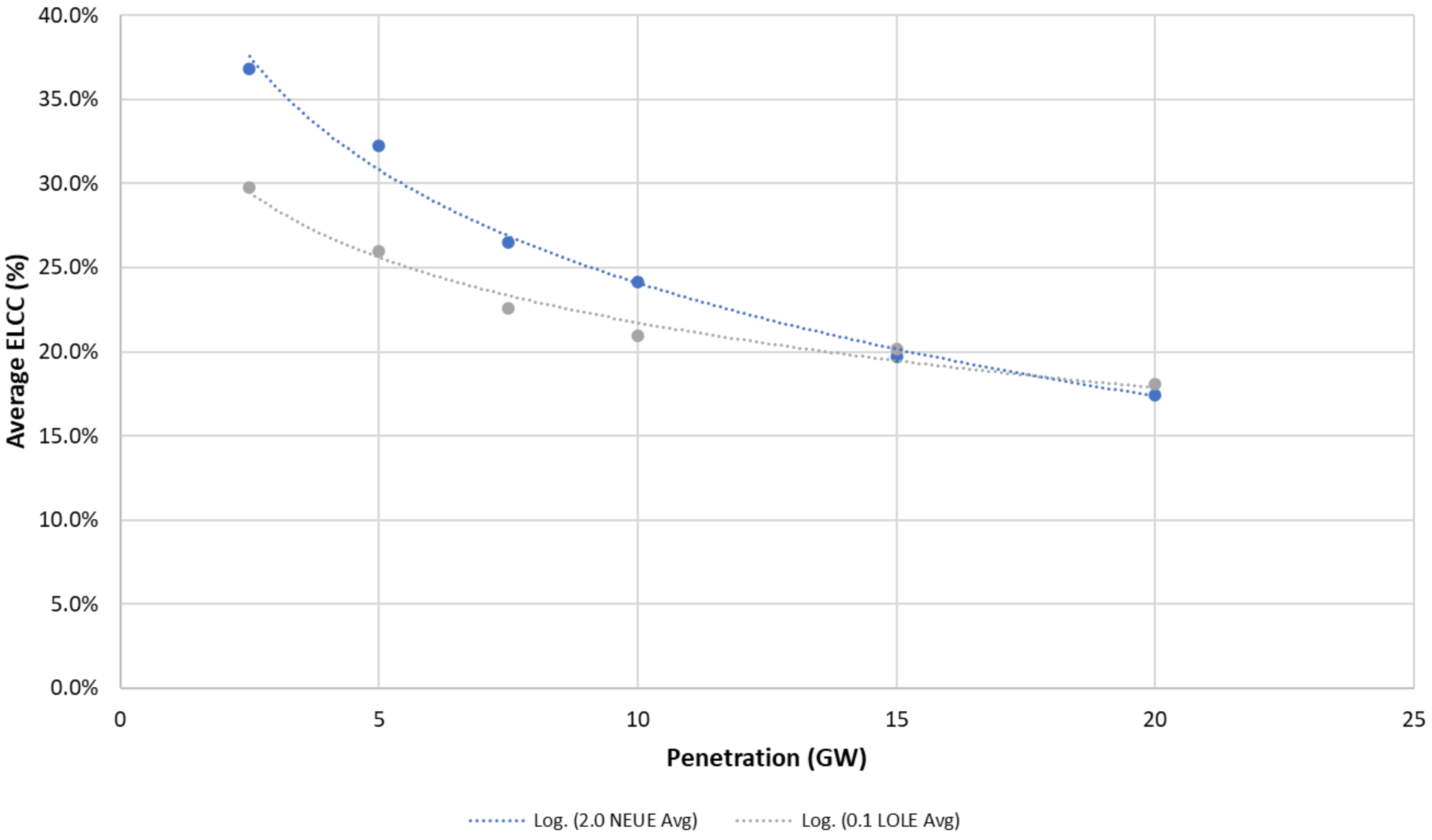
Example -Solar Marginal at 30GW Wind and 10GW Storage



Example -Storage Marginal at 30GW Wind and 15GW Solar



Example -Storage ELCC with Alternative Reliability Metrics (2.0 NEUE vs 0.1 LOLE)



Pulling Results from Dense Matrix

- Choose a solar/wind/storage penetration (i.e., a single point within the dense matrix range)
- Develop average and marginal ELCCs using integration method
  - Divide technology penetrations into small increments or steps
  - Calculate portfolio capacity values at each step
  - Allocate synergies across technologies between steps to get marginal capacity values (delta method)
  - Integrate steps for each technology to get average capacity value (multiple delta method steps)

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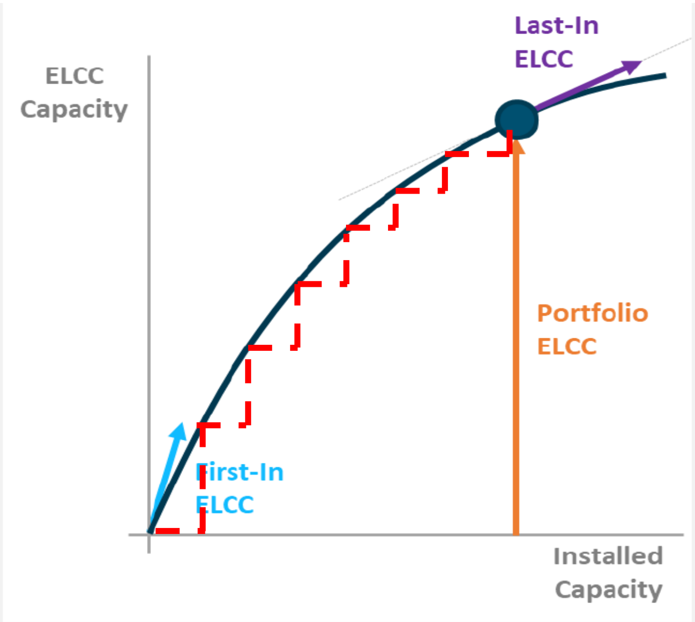
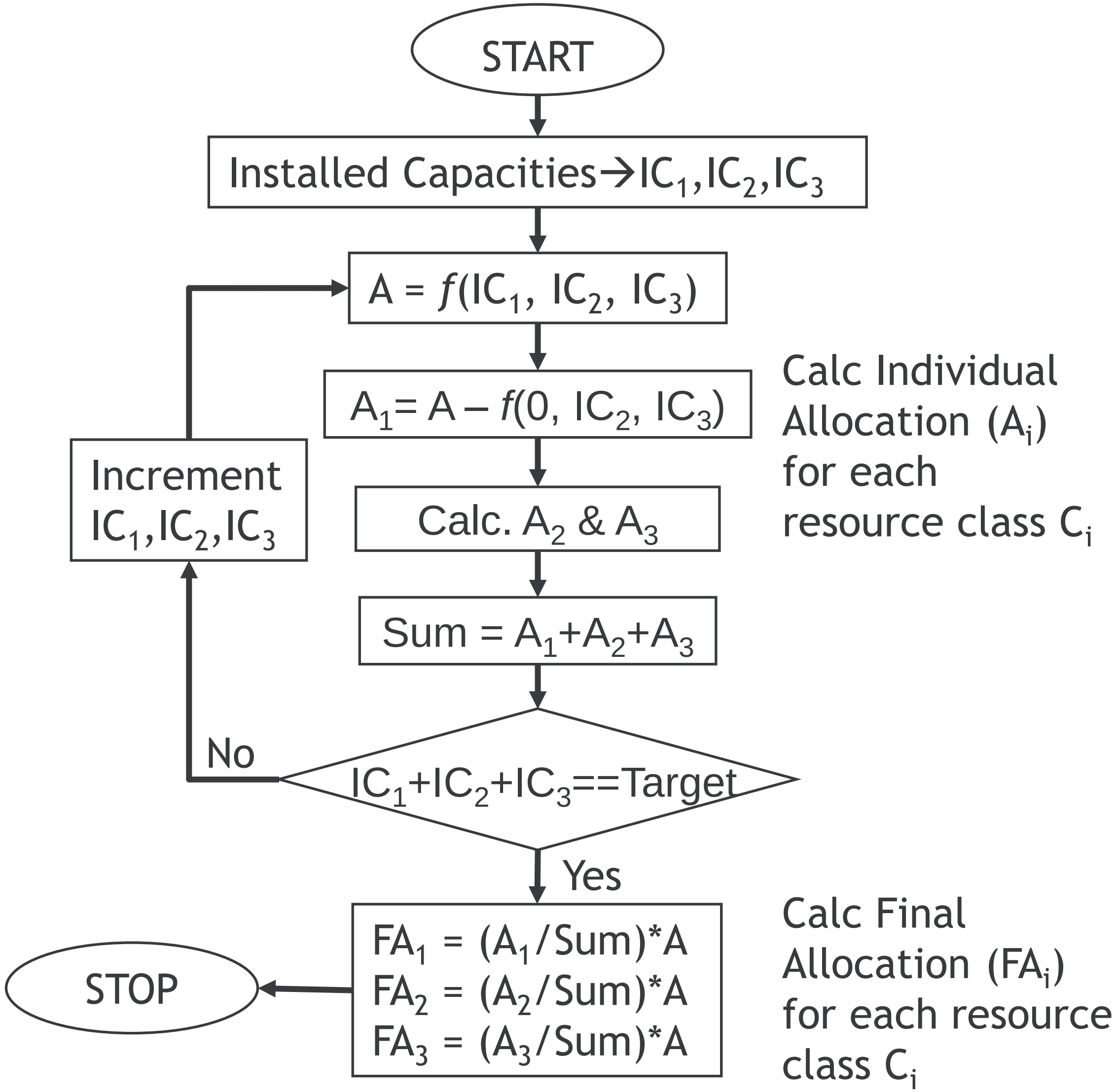
Integration Method for Average ELCC

- Integrates along the curve of the portfolio ELCC, from origin to installed capacity
- Captures the non-linear nature of the ELCC curve as installed capacity rises for different resource classes





System Reliability Results

Annual Loss of Load Expectation (LOLE)

Scenario	Retirements @ ~0.1 Annual LOLE			Corresponding Seasonal Metrics Under Annual Assumptions					
	Annual			Winter			Summer		
	Retire (MW)	NEUE (PPM)	EUE (MWh)	LOLE	NEUE (PPM)	EUE (MWh)	LOLE	NEUE (PPM)	EUE (MWh)
S1	11,500	1.91	577	0.03	1.22	368	0.07	0.69	209
S2	15,700	3.10	937	0.05	2.69	813	0.03	0.41	124
S3	18,350	2.82	853	0.05	2.09	631	0.05	0.73	222
S4	23,000	5.63	1,702	0.09	5.36	1,622	0.02	0.27	80
S5	24,900	4.92	1,487	0.10	4.87	1,473	0.00	0.05	14
S6	26,100	7.36	2,226	0.10	7.08	2,140	0.00	0.28	86

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Annual Normalized Expected Unserved Energy (NEUE)

Scenario	Retirements @ ~2ppm Annual NEUE			Corresponding Seasonal Metrics Under Annual Assumptions					
	Annual			Winter			Summer		
	Retire (MW)	LOLE	EUE (MWh)	LOLE	NEUE (PPM)	EUE (MWh)	LOLE	NEUE (PPM)	EUE (MWh)
S1	11,500	0.10	577	0.03	1.22	368	0.07	0.69	209
S2	14,650	0.05	590	0.04	1.89	571	0.01	0.06	18
S3	18,000	0.08	651	0.04	1.64	495	0.04	0.52	157
S4	21,000	0.04	559	0.04	1.85	559	0.00	0.00	0
S5	22,800	0.04	591	0.04	1.96	591	0.00	0.00	0
S6	24,500	0.05	636	0.05	2.07	626	0.00	0.03	10

Annual Loss of Load Hours (LOLH)

Scenario	Retirements @ ~0.1 LOLE				Retirements @ 2 PPM NEUE					
	Annual		Winter		Annual			Winter		
	LOLH	Event Duration (Hours)	LOLH	Event Duration (Hours)	LOLE	LOLH	Event Duration (Hours)	LOLE	LOLH	Event Duration (Hours)
S1	0.30	3.03	0.77	7.20	0.10	0.33	2.87	0.04	0.24	6.45
S2	0.37	3.87	0.53	4.90	0.05	0.25	4.55	0.05	0.24	5.29
S3	0.36	3.59	0.57	5.09	0.08	0.28	3.64	0.05	0.25	5.22
S4	0.53	4.42	0.53	5.03	0.04	0.22	5.54	0.04	0.22	5.61
S5	0.49	4.55	0.48	4.69	0.04	0.21	4.64	0.04	0.21	4.64
S6	0.58	4.78	0.56	5.12	0.05	0.20	4.10	0.05	0.20	4.21

Annual & Seasonal Expected Unserved Energy

- Annual and Winter NEUE's increase with more renewable penetration.
- This finding suggests calibrating to a 0.1 LOLE does not provide enough reliability and that NEUE of 2 PPM should be the reliability metric.
- Summer NEUE stay below 2.0 PPM for all scenarios except Scenario 6. This suggests that for Scenarios 1 – 5 LOLE of 0.1 provides enough reliability and 0.1 LOLE to be the reliability metric to determine PRM and ELCC.

Seasonal Reliability Metrics

Scenario	Retirements @ 2ppm Winter NEUE		Retirements @ 0.05 Summer LOLE		
	Retired (MW)	LOLE	Retire (MW)	EUE (MWh)	NEUE (PPM)
S1	12,365	0.04	11,150	136	0.45
S2	14,734	0.05	16,034	149	0.49
S3	18,536	0.05	18,268	207	0.68
S4	21,145	0.04	23,530	188	0.62
S5	22,819	0.04	26,450*	191	0.63
S6	24,446	0.05	28,150*	619	2.05

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Loss of Load Hours

Scenario	Annual @ 2ppm NEUE			Winter @ 2ppm NEUE			Summer @ 0.05 LOLE		
	LOLE	LOLH	Event Duration (Hours)	LOLE	LOLH	Event Duration (Hours)	EUE (MWh)	LOLH	Event Duration (Hours)
S1	0.10	0.33	2.87	0.04	0.24	6.45	136	0.10	1.96
S2	0.05	0.25	4.55	0.05	0.24	5.29	149	0.09	1.85
S3	0.08	0.28	3.64	0.05	0.25	5.22	207	0.10	2.04
S4	0.04	0.22	5.54	0.04	0.22	5.61	188	0.07	1.48
S5	0.04	0.21	4.64	0.04	0.21	4.64	191	0.08	1.63
S6	0.05	0.20	4.10	0.05	0.20	4.21	619	0.14	2.74

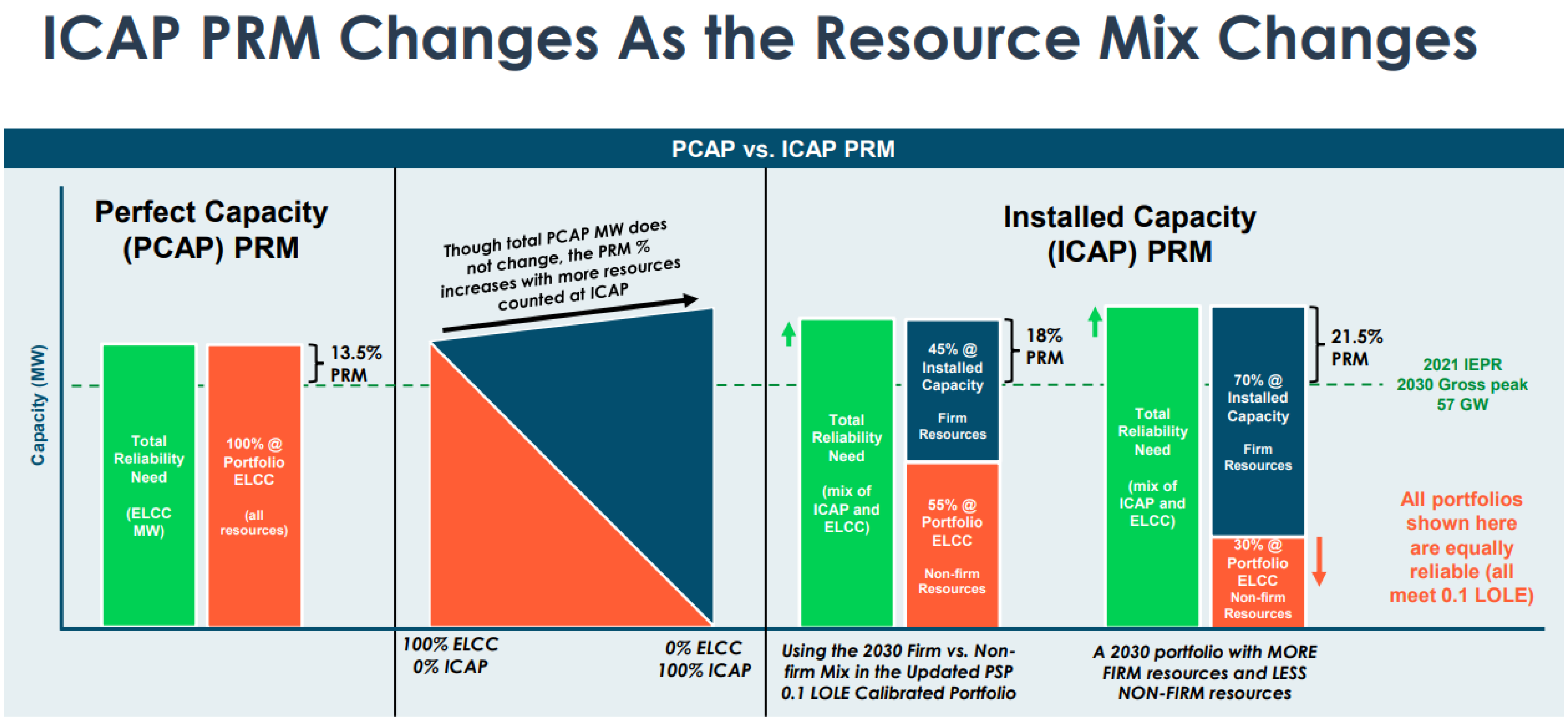
System ELCC Summary

Scenario	Renewables Nameplate Capacity (MW)	Winter @ 2ppm NEUE	Summer @ 0.05 LOLE
S1	57,200	24.4%	28.6%
S2	67,200	21.7%	30.1%
S3	80,000	21.7%	28.0%
S4	96,000	19.9%	27.5%
S5	105,000	19.5%	27.3%
S6	115,000	18.8%	26.4%

Non-Coincident Peak Planning Reserve Margin

Scenario	Renewables Nameplate Capacity (MW)	Winter @ 2ppm NEUE	Summer @ 0.05 LOLE
S1	57,200	40.0%	20.3%
S2	67,200	36.2%	18.5%
S3	80,000	34.0%	18.4%
S4	96,000	32.1%	16.2%
S5	105,000	31.4%	15.0%
S6	115,000	29.7%	15.1%

Why PRM Drops with more renewables…



Source: https://www.cpuc.ca.gov/-/media/cpuc-website/divisions/energy-division/documents/integrated-resource-plan-and-long-term-procurement-plan-irp-ltpp/2022-irp-cycle-events-and-materials/20220729-updated-fr-and-reliability-mag-slides.pdf

Key Takeaways

- Calibrating to NEUE of 2 PPM vs LOLE of 0.1 depends on NEUE results by season – more than 2 PPM suggests NEUE is the correct metric for calibration and ELCC and PRM development. Said differently, if a portfolio calibrated with 0.2 PPM requires fewer retirements than a portfolio calibrated with 0.1 LOLE, NEUE of 2 PPM should be the driving reliability metric.
- Initially, retirement needs are less in summer than in winter, i.e., summer is less reliable than winter and more capacity is needed. This flips for S3 – S6, when winter has less retirements.
- Consistent with slide 33, LOLE declines with more renewables at NEUE is fixed at 2 PPM.
- System ELCC's decrease with more renewables.
- PRM's decrease with more renewables.

Technology Specific ELCC Results

Scenario 6 Portfolio ELCC Allocation

Technology	Nameplate Capacity Removed (MW)	Winter @ 2ppm NEUE			
		Last-In		Adjusted to System ELCC	
		Perfect CT (MW)	ELCC	Perfect CT (MW)	ELCC
Solar	30,000	5,683	18.9%	4,857	16.2%
Wind	60,000	14,555	24.3%	12,438	20.7%
Storage	20,000	3,859	19.3%	3,298	16.5%
DR	5,000	1,186	23.7%	1,014	20.3%
Total	**115,000**	**25,283**	**--**	**21,606**	**18.8%**

$$\text{Adjusted ELCC} = \frac{System\ ELCC * Last\ In\ ELCC}{\Sigma\ Last\ In\ ELCC}$$

System ELCC	21,606

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Solar ELCC

Scenario	Nameplate Capacity Removed (MW)	Winter @ 2ppm NEUE	Summer @ 0.05 LOLE*
S1	10,000	18.5%	57.4%
S2	20,000	15.3%	41.5%
S3	20,000	15.4%	43.4%
S4	24,000	15.8%	40.5%
S5	30,000	14.2%	36.3%
S6	30,000	16.2%	34.9%

*Estimated results based on trending

Wind ELCC

Scenario	Nameplate Capacity Removed (MW)	Winter @ 2ppm NEUE	Summer @ 0.05 LOLE*
S1	40,000	25.8%	19.7%
S2	40,000	23.6%	18.1%
S3	52,000	22.5%	16.5%
S4	59,000	21.7%	16.5%
S5	60,000	21.1%	16.6%
S6	60,000	20.7%	18.4%

*Estimated results based on trending

Storage ELCC

Scenario	Nameplate Capacity Removed (MW)	Winter @ 2ppm NEUE	Summer @ 0.05 LOLE*
S1	5,000	17.5%	43.6%
S2	5,000	21.8%	77.7%
S3	5,000	24.6%	71.2%
S4	10,000	19.1%	61.1%
S5	10,000	20.7%	59.5%
S6	20,000	16.5%	41.8%

*Estimated results based on trending

Demand Response ELCC

Scenario	Nameplate Capacity Removed (MW)	Winter @ 2ppm NEUE	Summer @ 0.05 LOLE*
S1	2,200	41.9%	19.7%
S2	2,200	43.3%	62.0%
S3	3,000	44.6%	55.0%
S4	3,000	20.0%	25.8%
S5	5,000	29.0%	39.2%
S6	5,000	20.3%	22.0%

*Estimated results based on trending

Key Takeaways

- Solar, storage, and demand response summer ELCC values are generally higher than winter values.
- Wind winter ELCC values are generally higher than summer values.
- Solar ELCC values drop in S5 and S6 when additional renewable nameplate is added to the system.
- Results show that winter ELCC values (at lower ELCC's) tend to be less sensitive to high renewable penetration.

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Conclusions and Recommendations

Conclusions & Recommendation

- The existing 0.1 LOLE reliability target continues to contribute to increased EUE and unacceptable reliability.
- As renewable capacity increases, the winter season becomes dominant.
- Implementing reliability metrics separated by season, 2.0 NEUE winter & 0.05 LOLE summer, allow us to meet the annual LOLE/EUE target at this time.
- The last-in allocation methodology may allocate more accreditation than appropriate to certain technology types due to synergies between resources.
- Currently, there is no existing NEUE standard. This evaluation utilizes 2.0 NEUE which roughly represents current state. Additional studies are required to confirm the appropriate level of NEUE to utilize as a reliability standard.
- This evaluation suggests NEUE is a more appropriate reliability standard in the winter season given the nature of event types.

Appendix

Winter NEUE

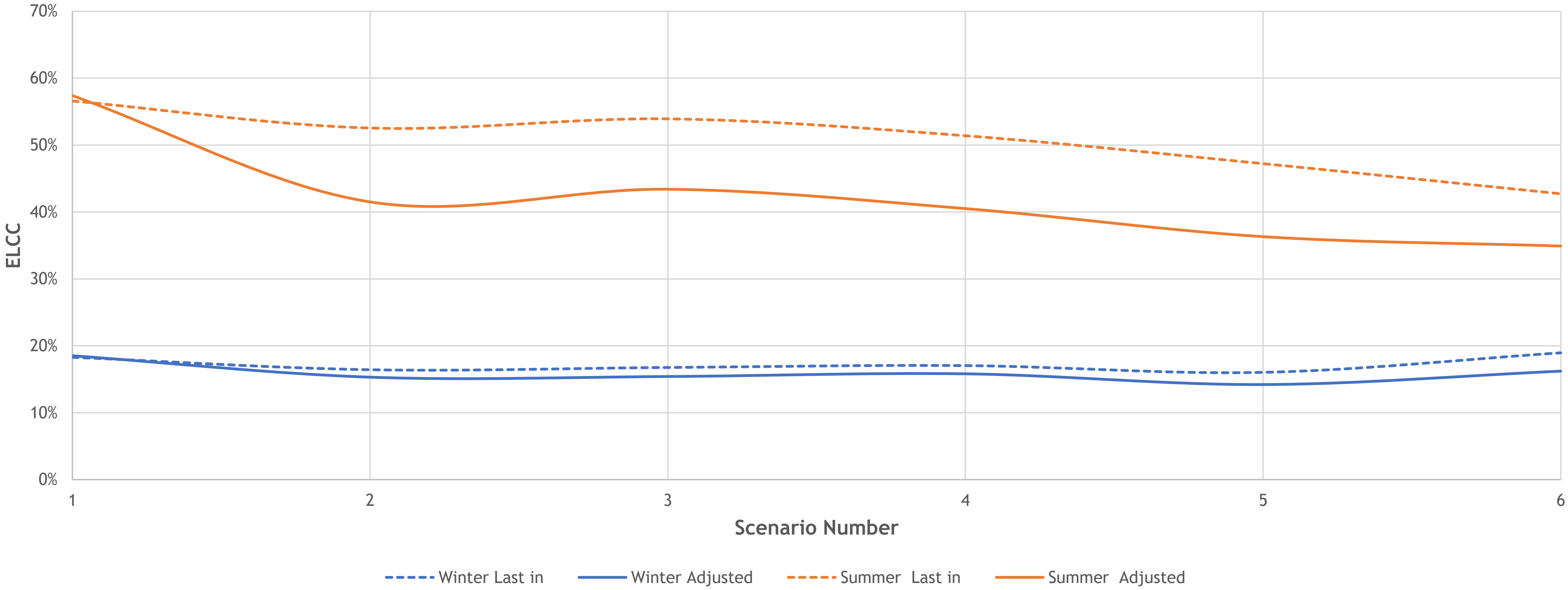
Scenario	Retirements @ 2ppm Winter NEUE		Corresponding Seasonal Metrics			
	Winter		Annual		Summer	
	Retired (MW)	LOLE	LOLE	NEUE (PPM)	LOLE	NEUE (PPM)
S1	12,365	0.04	0.17	1.75	0.14	1.62
S2	14,734	0.05	0.05	1.95	0.01	0.06
S3	18,536	0.05	0.11	2.93	0.07	0.89
S4	21,145	0.04	0.04	1.85	0	0
S5	22,819	0.04	0.04	1.96	0	0
S6	24,446	0.05	0.05	2.10	0	0.03

Summer LOLE

Scenario	Retirements @ 0.05 Summer LOLE			Corresponding Seasonal Metrics Under Summer Assumptions					
	Summer			Annual			Winter		
	Retire (MW)	EUE (MWh)	NEUE (PPM)	LOLE	EUE (MWh)	NEUE (PPM)	LOLE	EUE (MWh)	NEUE (PPM)
S1	11,150	136	0.45	0.07	371	1.23	0.02	234	0.77
S2	16,034	149	0.49	0.10	937	3.10	0.05	813	2.69
S3	18,268	207	0.68	0.10	853	2.82	0.05	631	2.09
S4	23,530	188	0.62	0.17	2,364	7.82	0.12	2,185	7.23
S5	26,450*	191	0.63	0.23	3,162	10.46	0.18	2,971	9.82
S6	28,150*	619	2.05	0.13	2,348	7.77	0.08	1,729	5.72

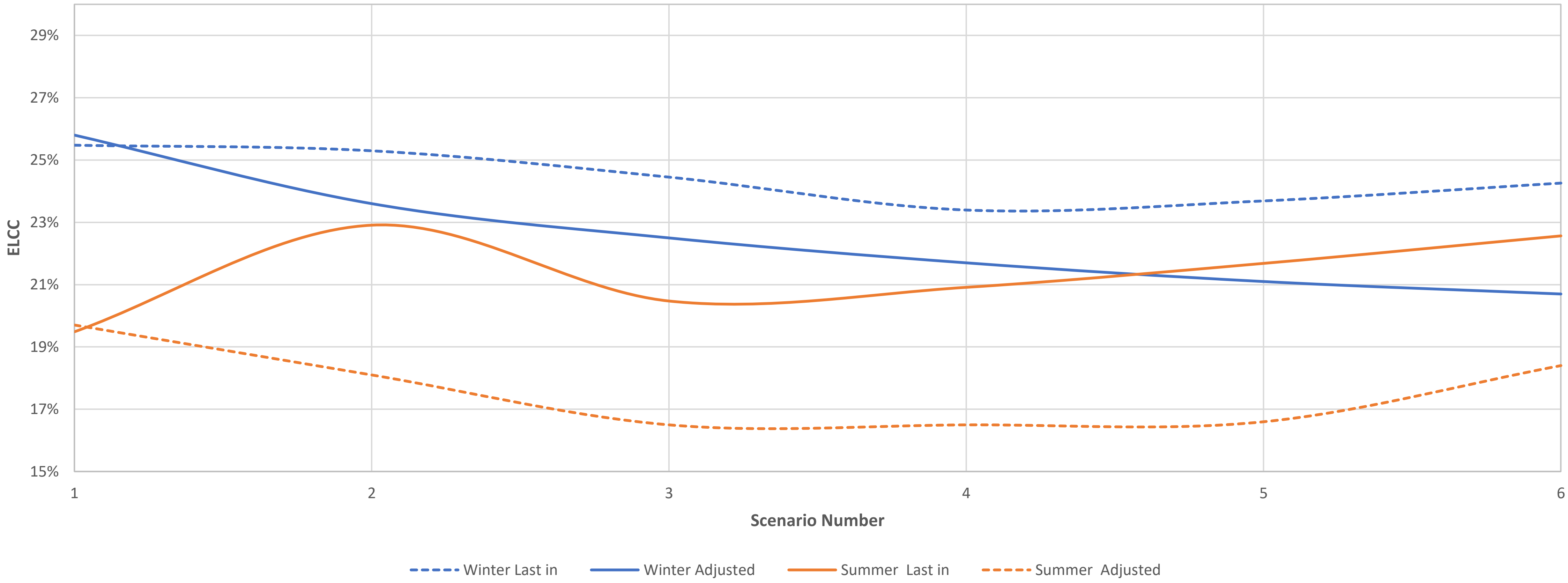
* Includes negative generation

Solar ELCC



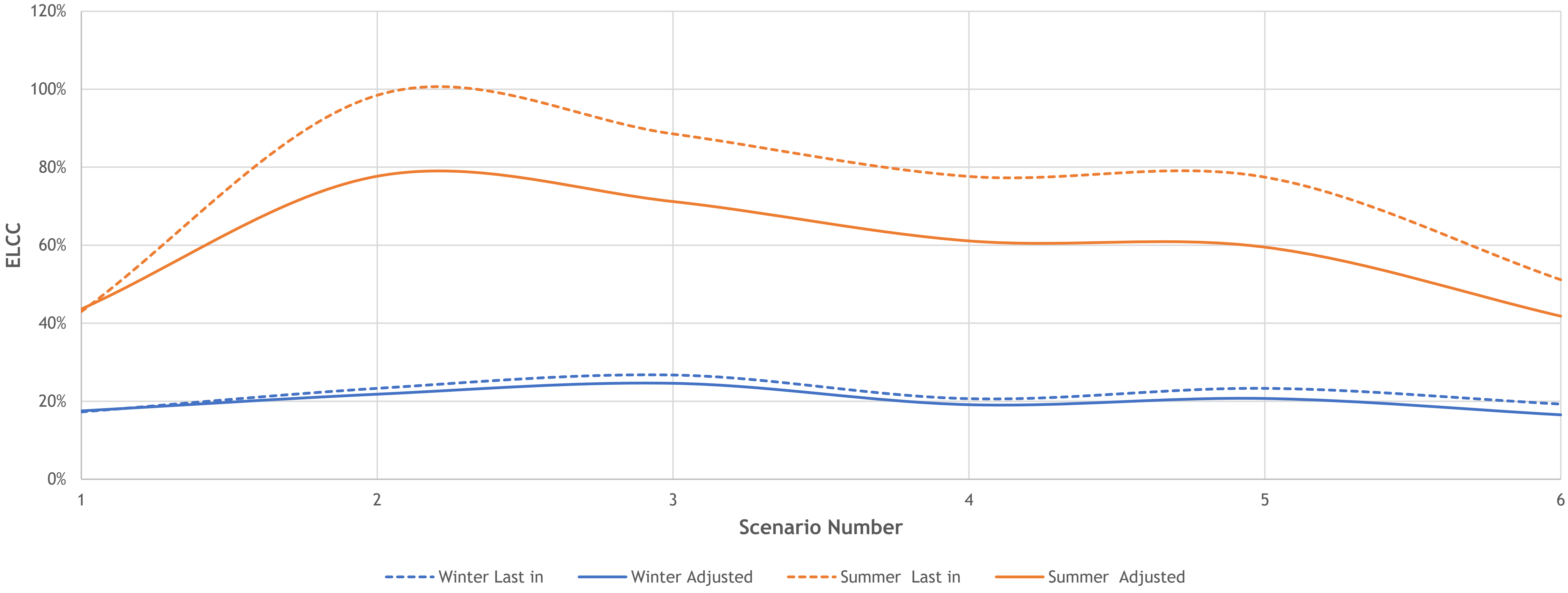
70%
60%
50%
40%
30%
20%
10%
0%
ELCC
1
2
3
4
5
6
Scenario Number
Winter Last in
Winter Adjusted
Summer Last in
Summer Adjusted

Wind ELCC



29%
27%
25%
23%
21%
19%
17%
15%
ELCC
1
2
3
4
5
6
Scenario Number
Winter Last in
Winter Adjusted
Summer Last in
Summer Adjusted

Storage ELCC



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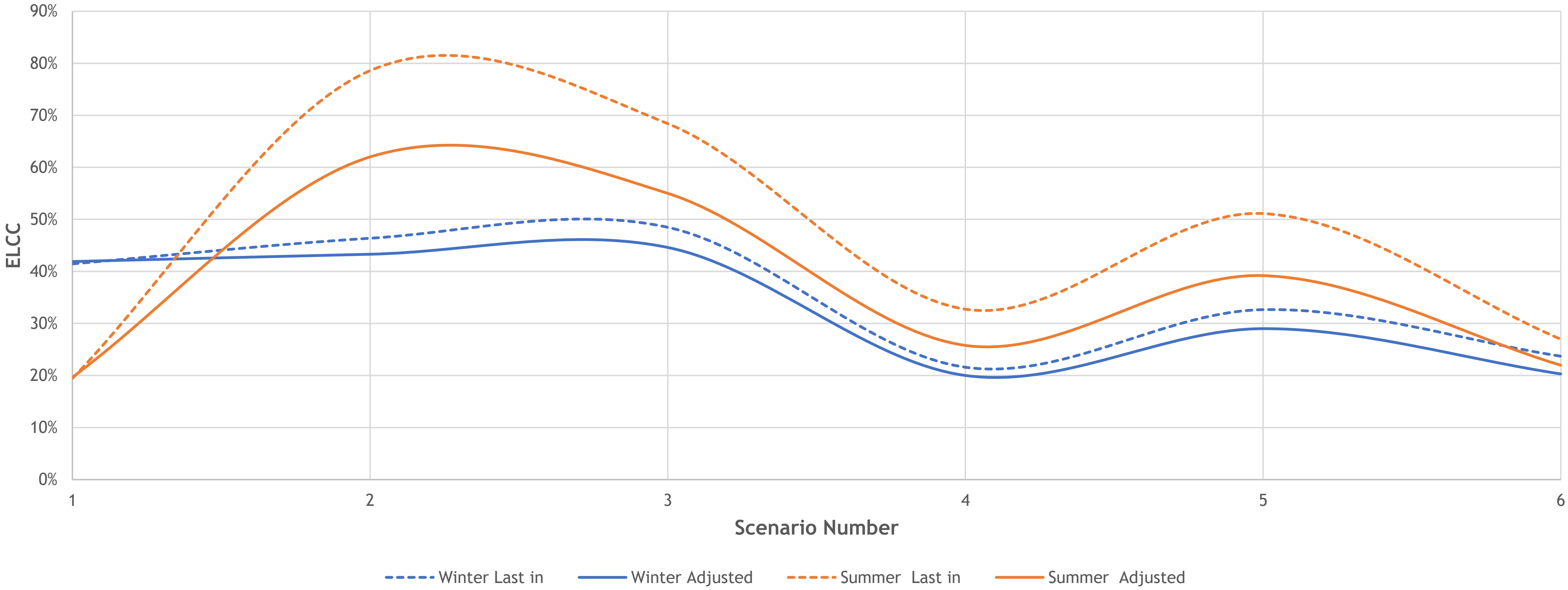
Demand Response ELCC



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