GE
Energy

Western Wind & Solar Integration Study

Statistical Analysis

Lavelle Freeman

Stakeholder Meeting
August 14, 2008

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Time Series Plots and Daily Profiles

Net Load Concepts

In this next set of slides, we will show how wind and load interact to create net load

- Net Load is the instantaneous system consumer load, minus the generation output of wind and solar
- Net load is the amount of generation required from dispatchable units
- The statistical analysis highlights net load, instead of the wind or solar output in isolation, because some amount of the variations in load, wind and solar tend to cancel

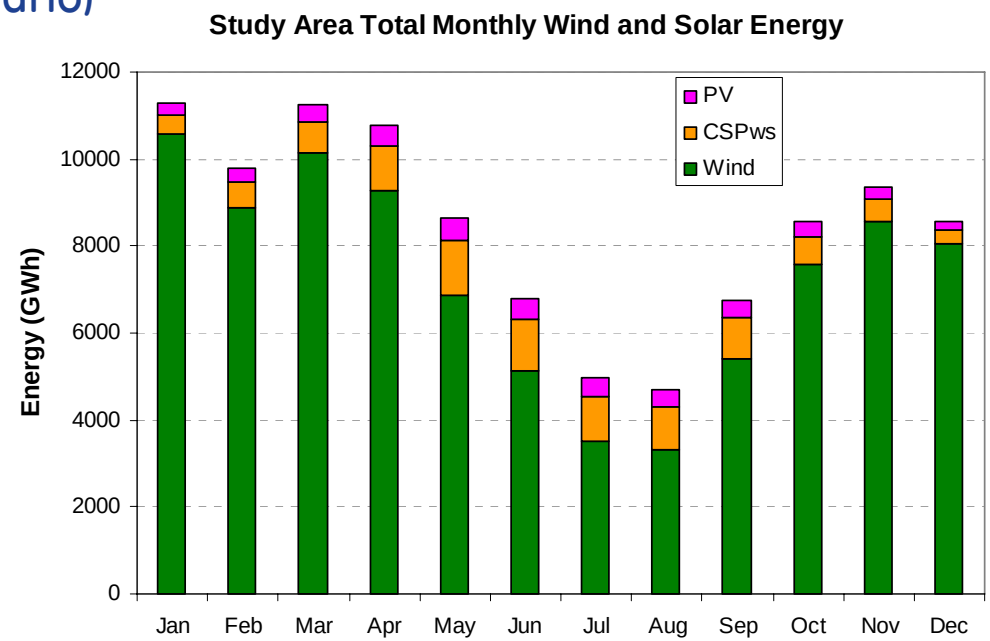
Key issues are:

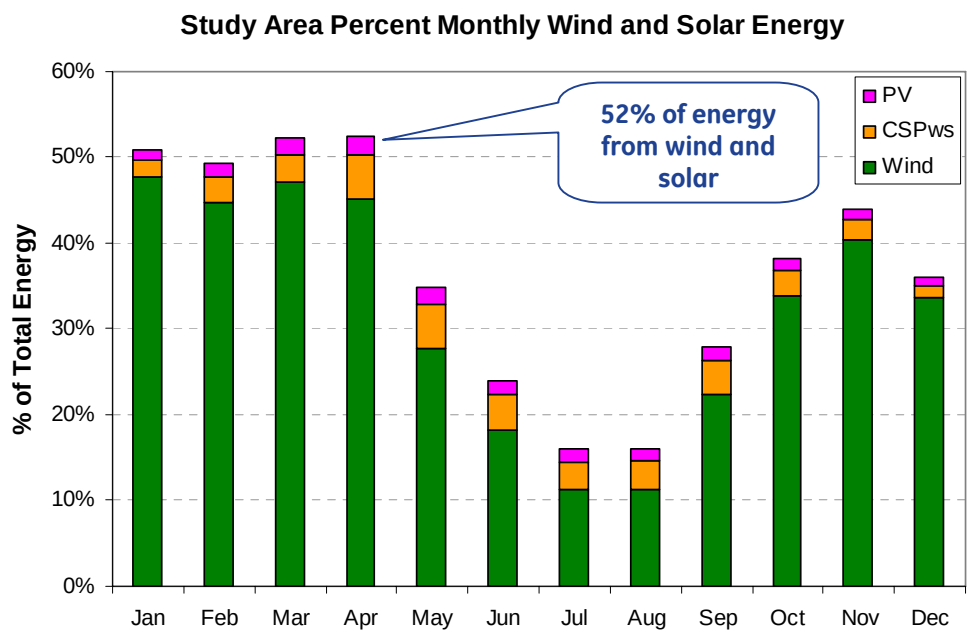
- Coincidence of load, wind and solar
- Impacts on net load peaks and valleys
- Increases in ramp rates

Net load is also called “Load-Wind-Solar” or L-W-S in parts of this presentation

Duration and Penetration

Monthly Energy from Wind and Solar
(30% In Area Scenario)





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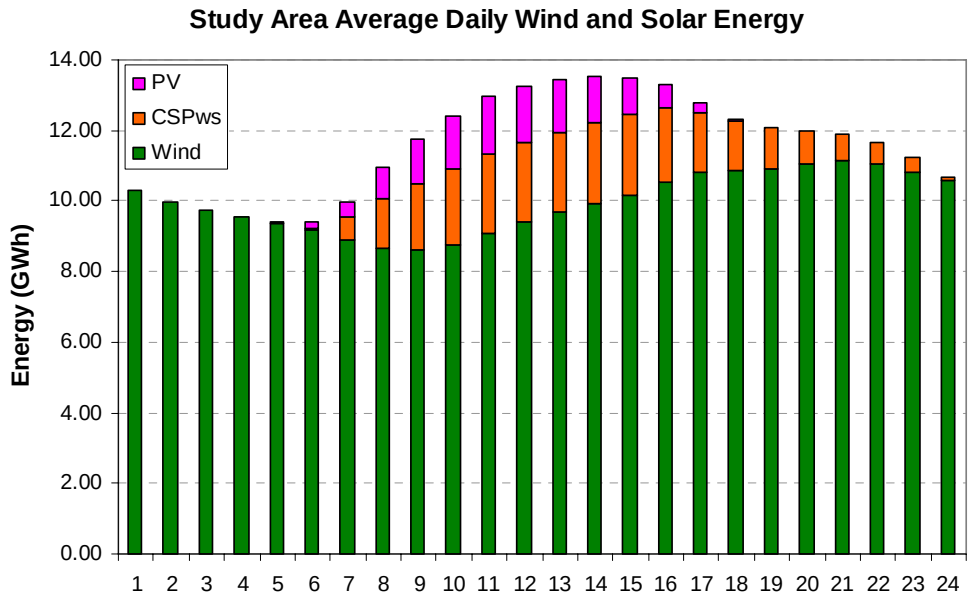
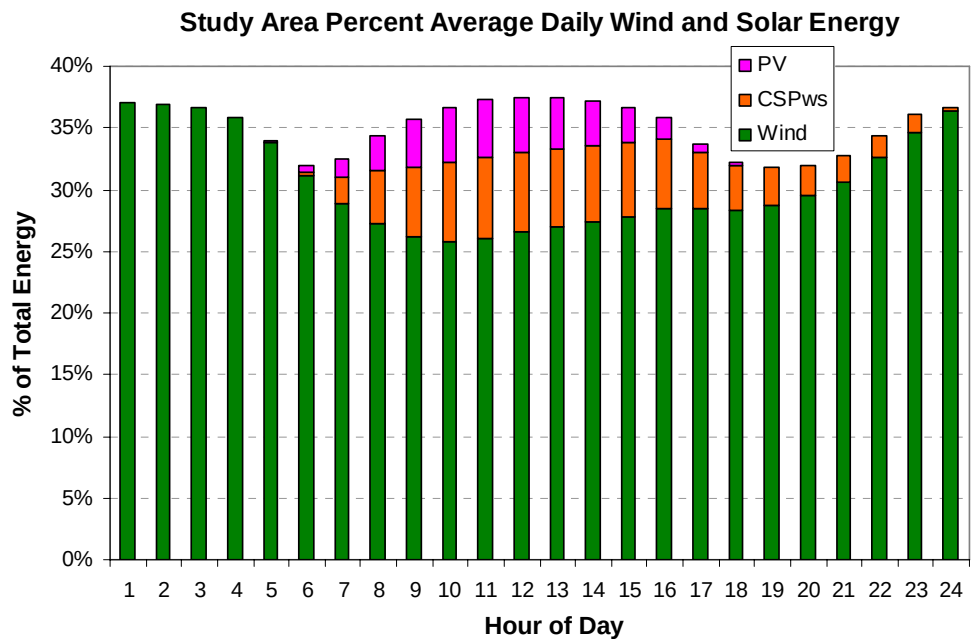
Average Hourly Energy from Wind and Solar Over Entire Year
(30% In Area Scenario)





Solar tends to complement wind variation over the day

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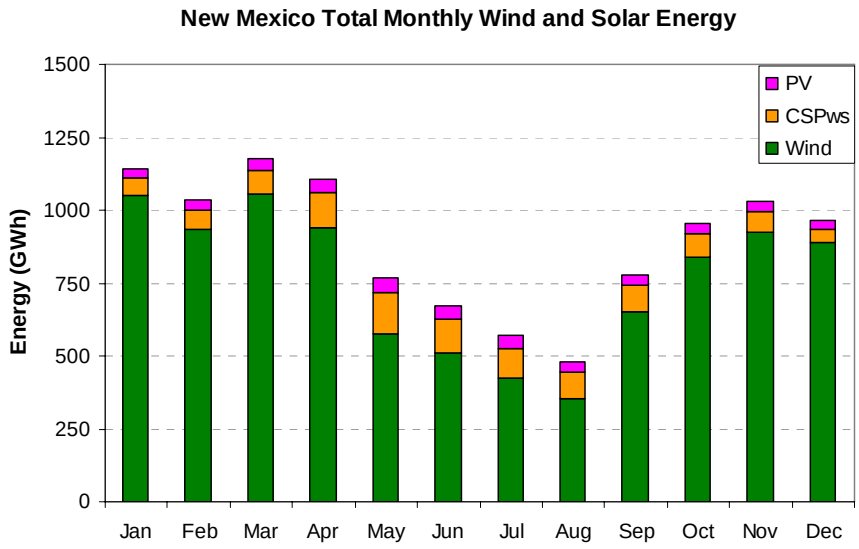
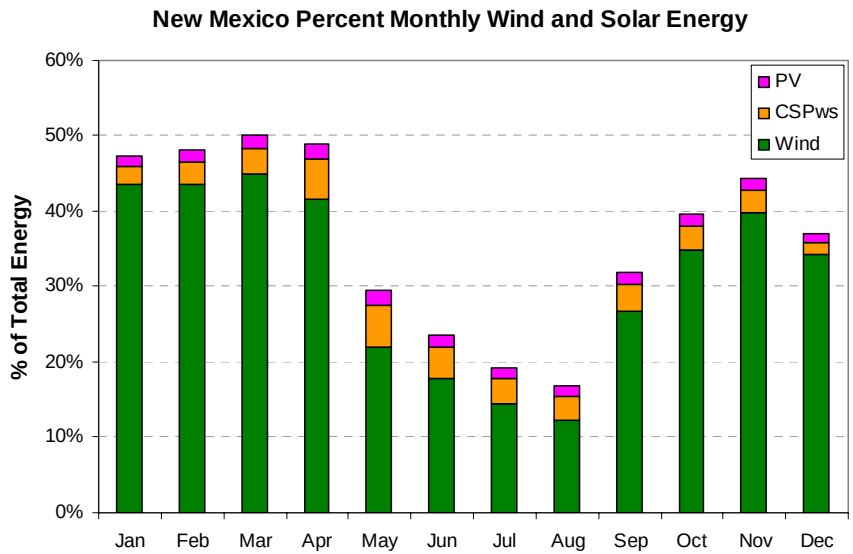
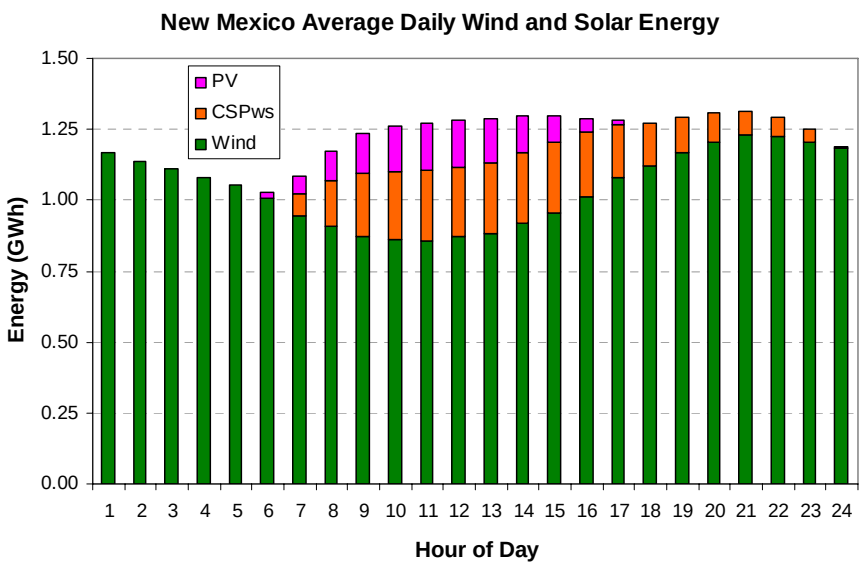
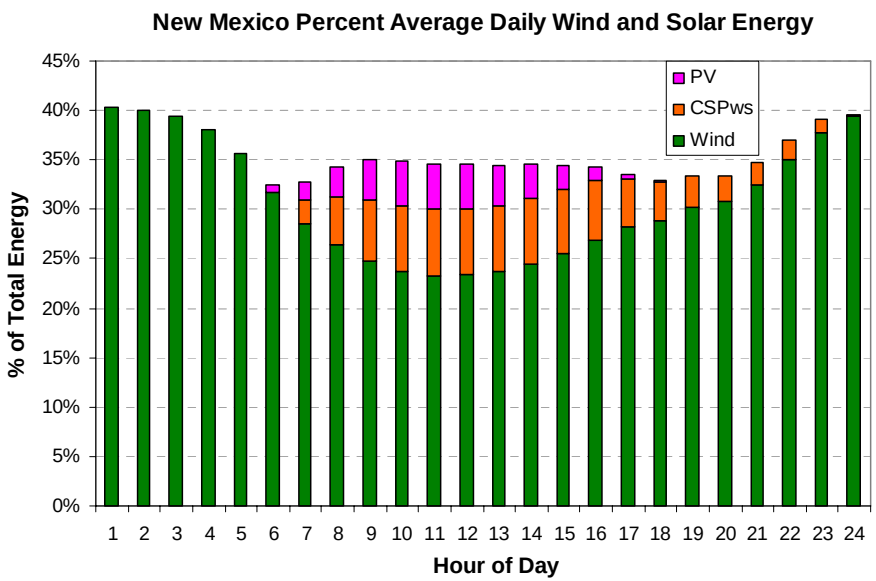
New Mexico Monthly Energy and Average Hourly Energy (Over Entire Year) from Wind and Solar (30% In Area Scenario)



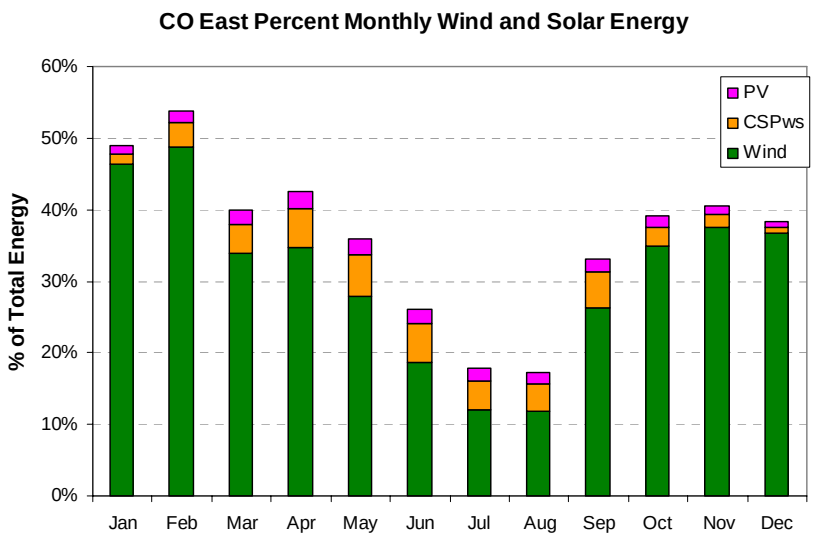


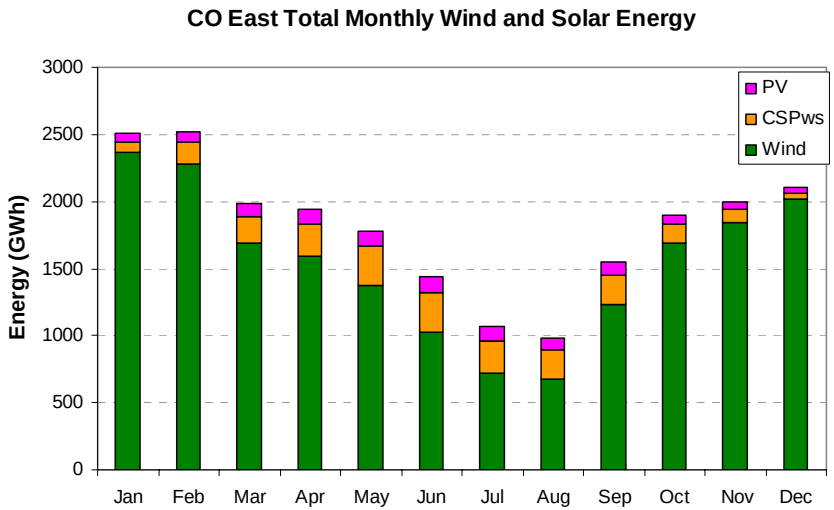


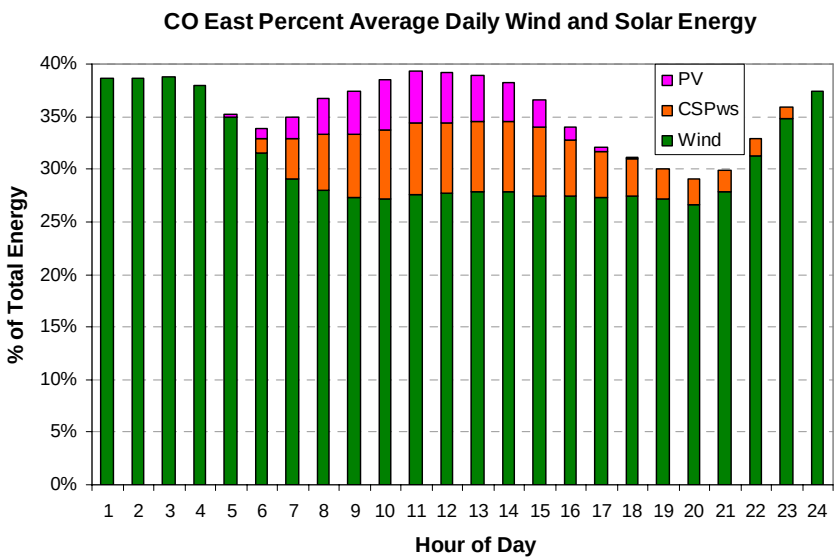


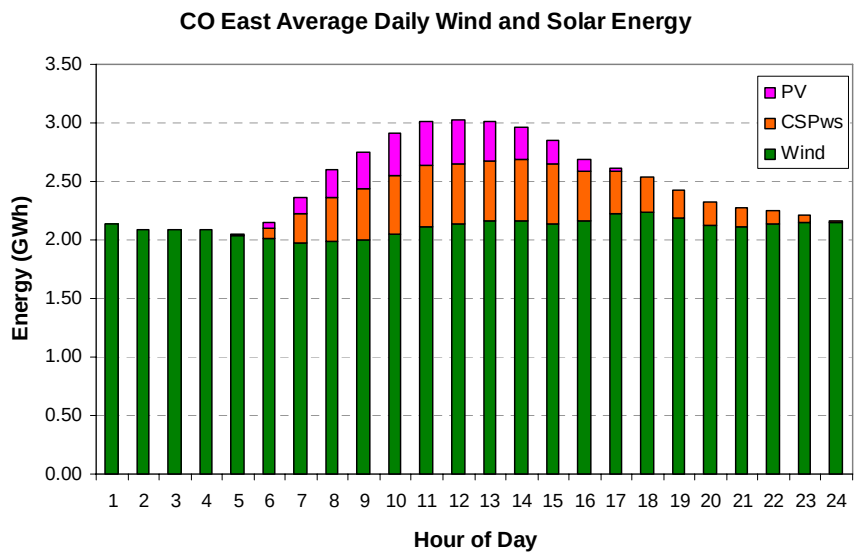
imagination at work

Colorado East Monthly Energy and Average Hourly Energy (Over Entire Year) from Wind and Solar (30% In Area Scenario)









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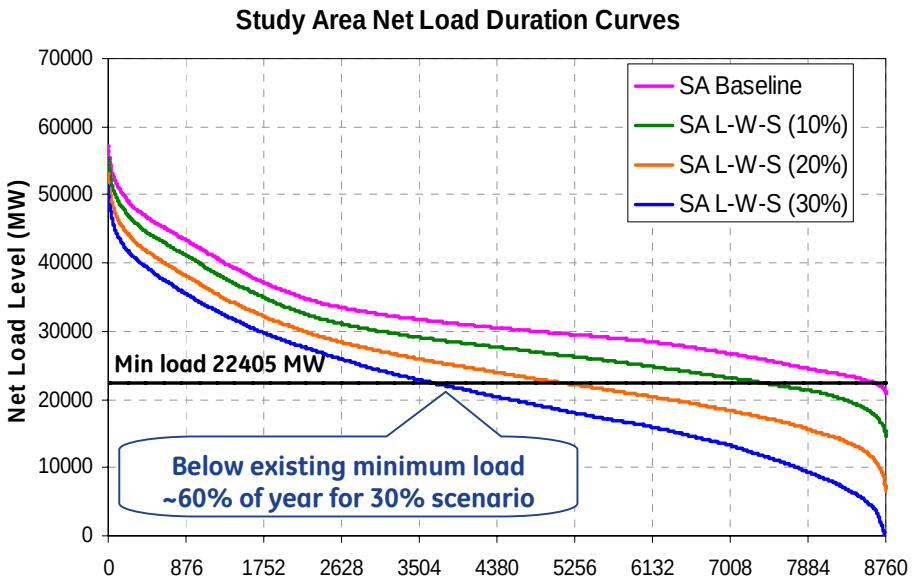
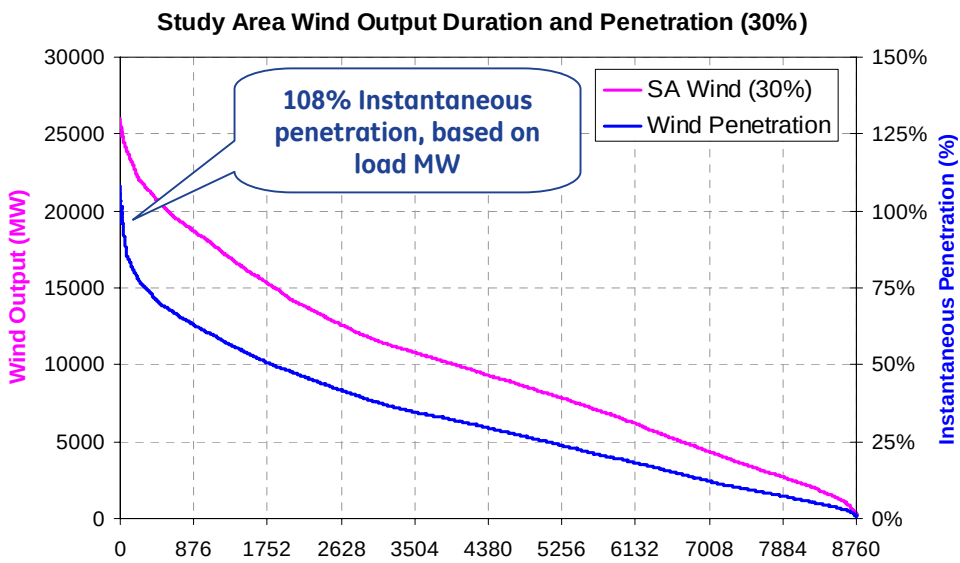
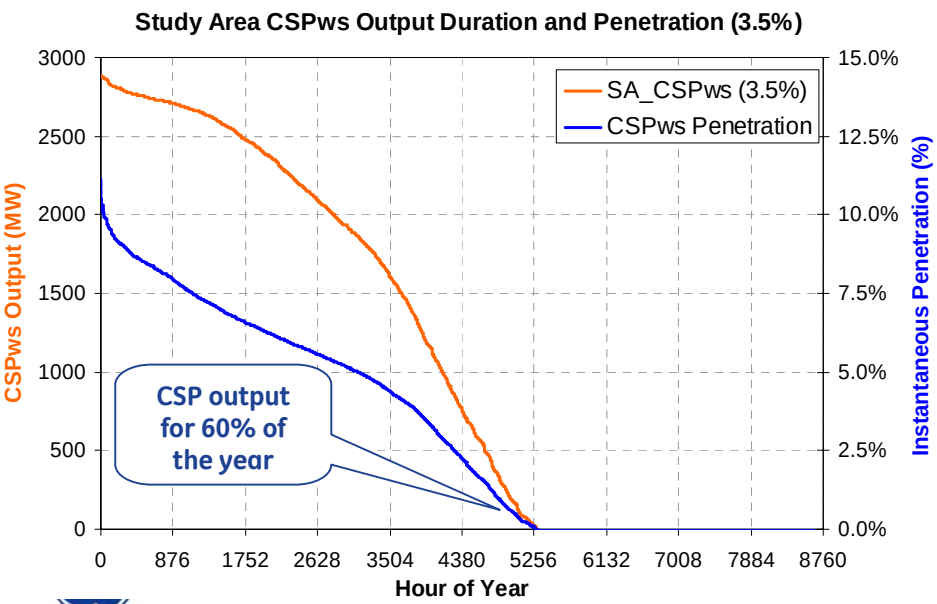
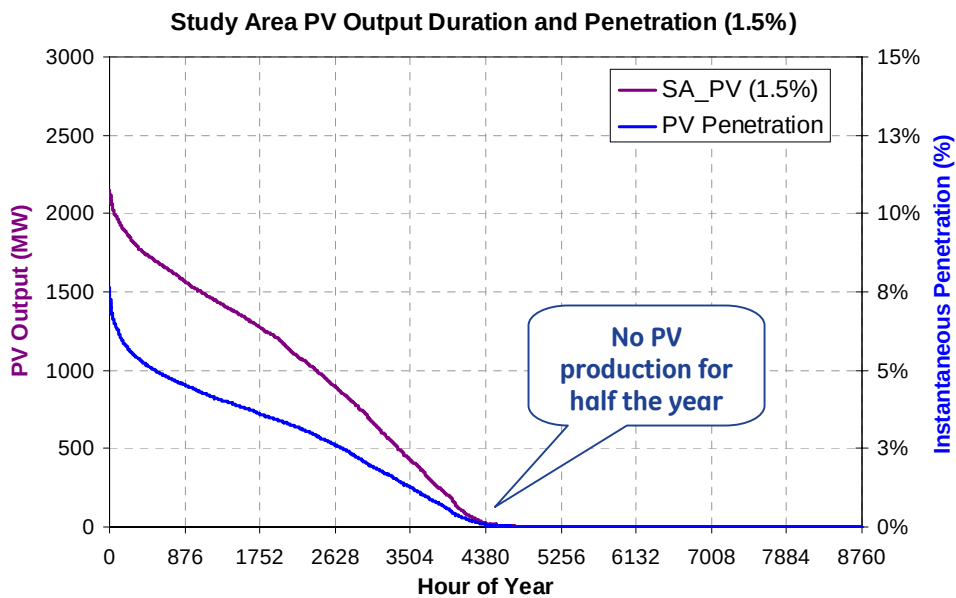
Net Load Duration, Wind and Solar Penetration Over Entire Year
(30% In Area Scenario)

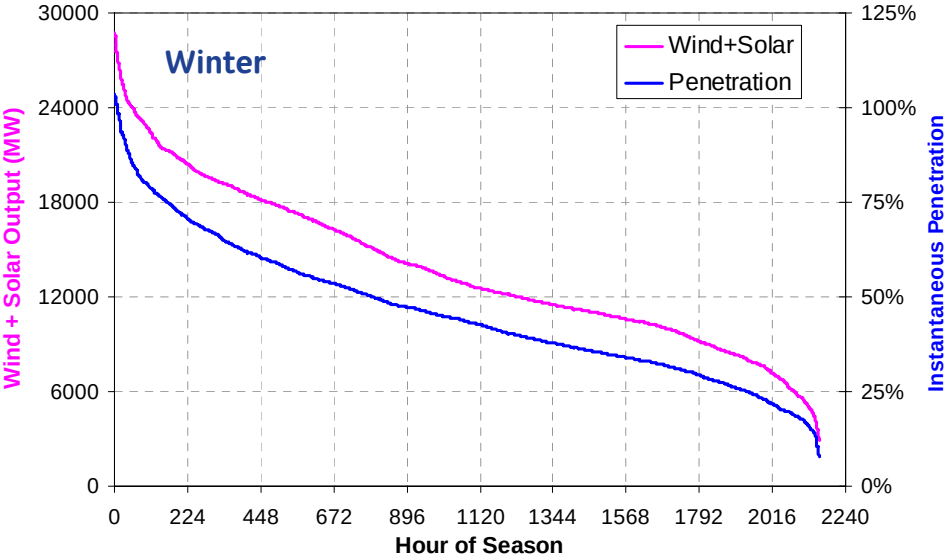


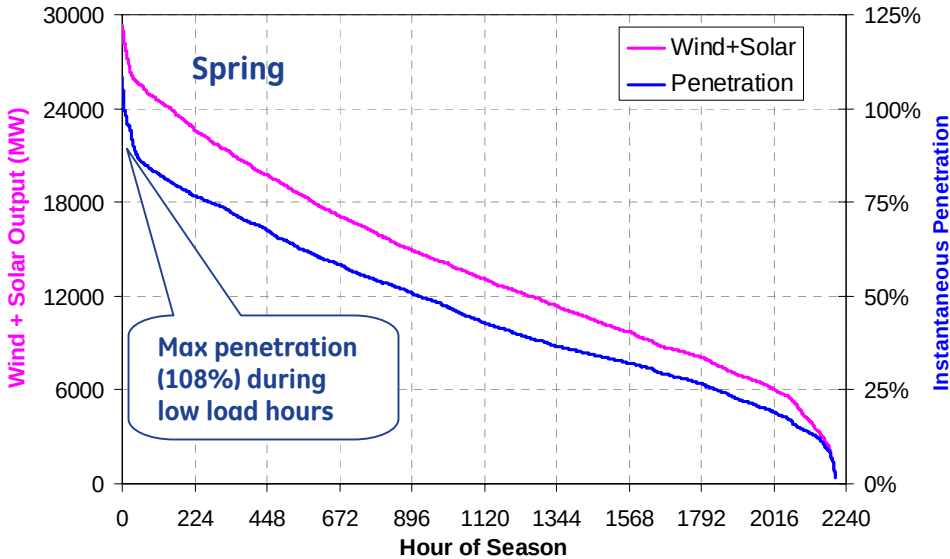


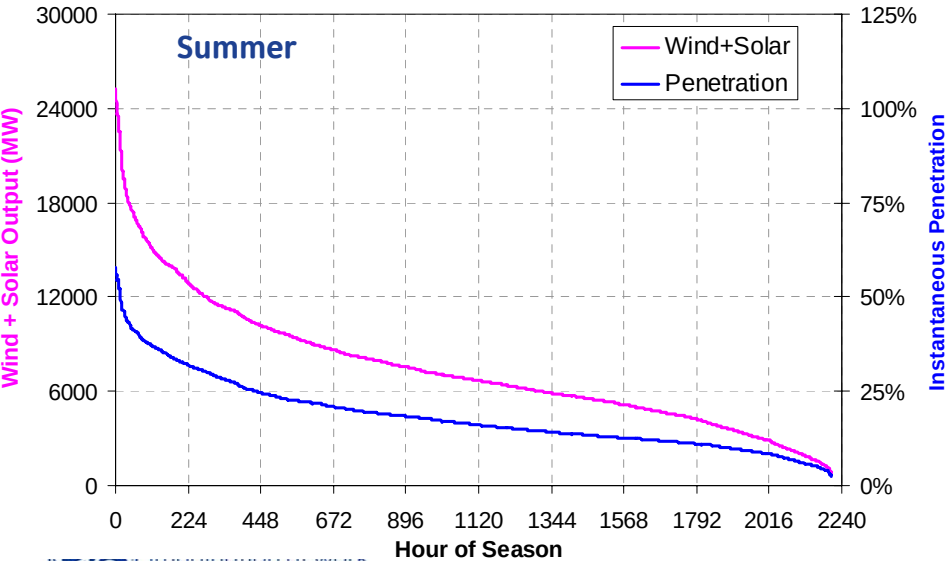


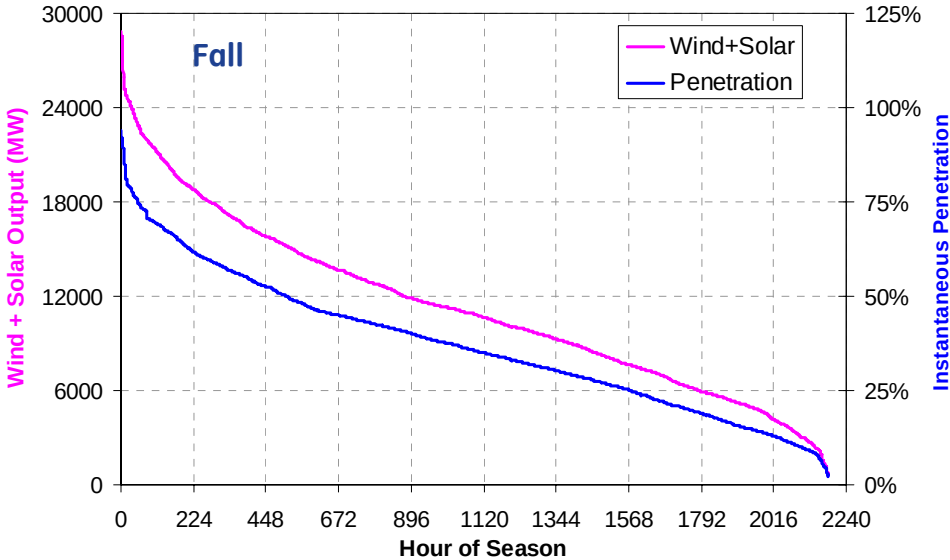


Study Area Wind+Solar Duration and Penetration by Seasonal Month (30% In Area Scenario)

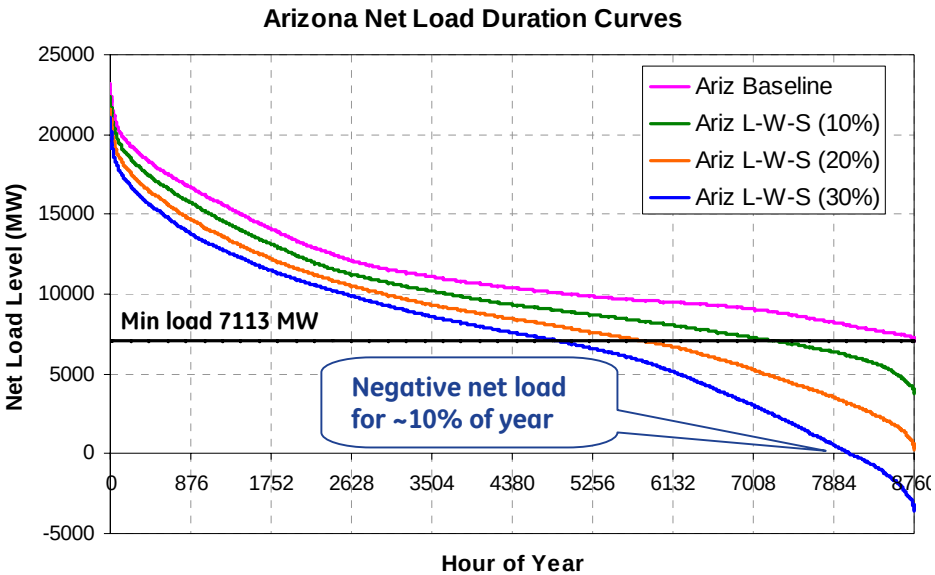


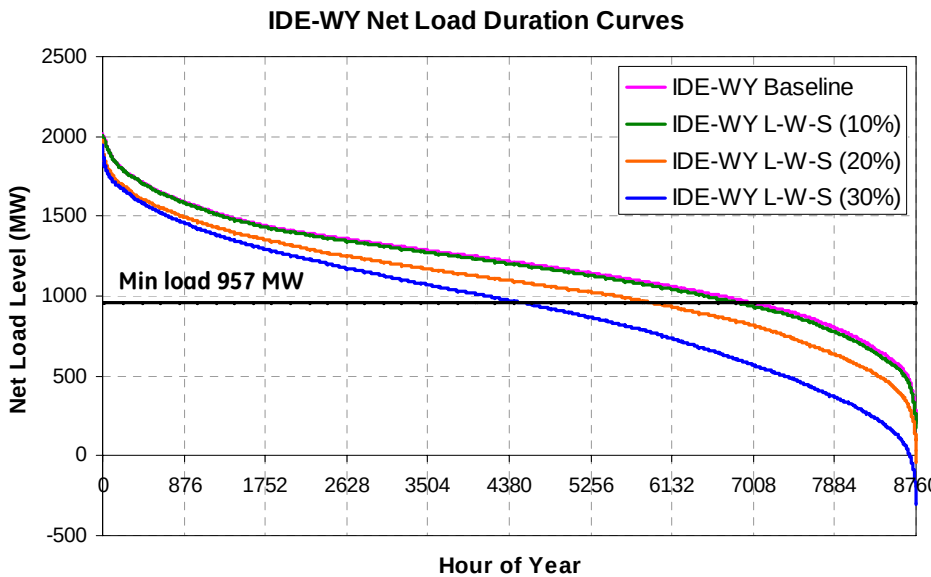


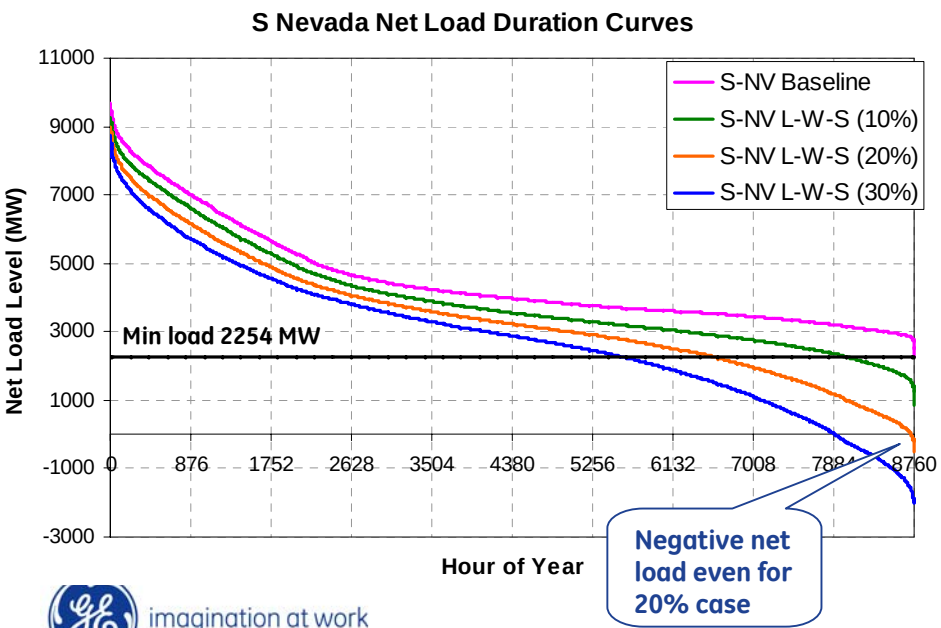


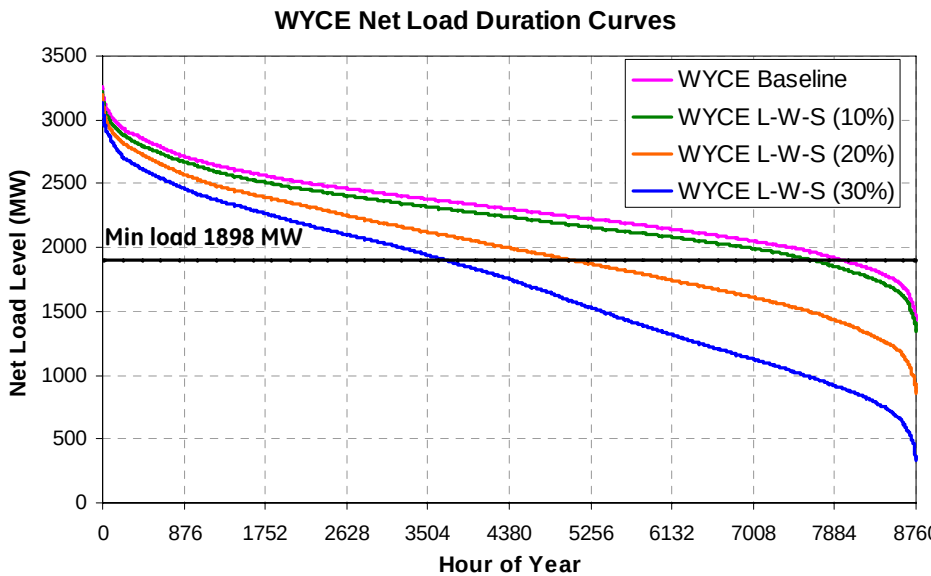


Net Load Duration, Wind and Solar Penetration Over Entire Year
(30% In Area Scenario)









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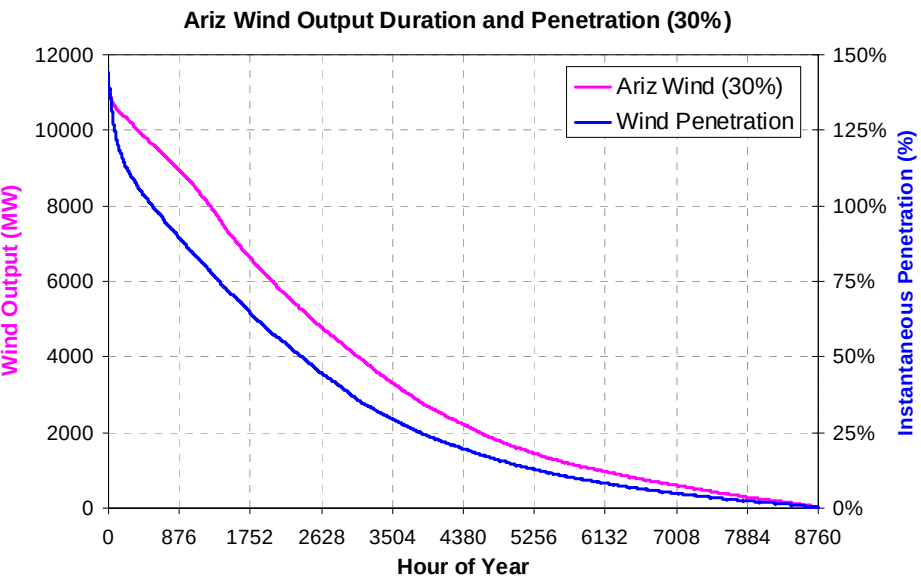
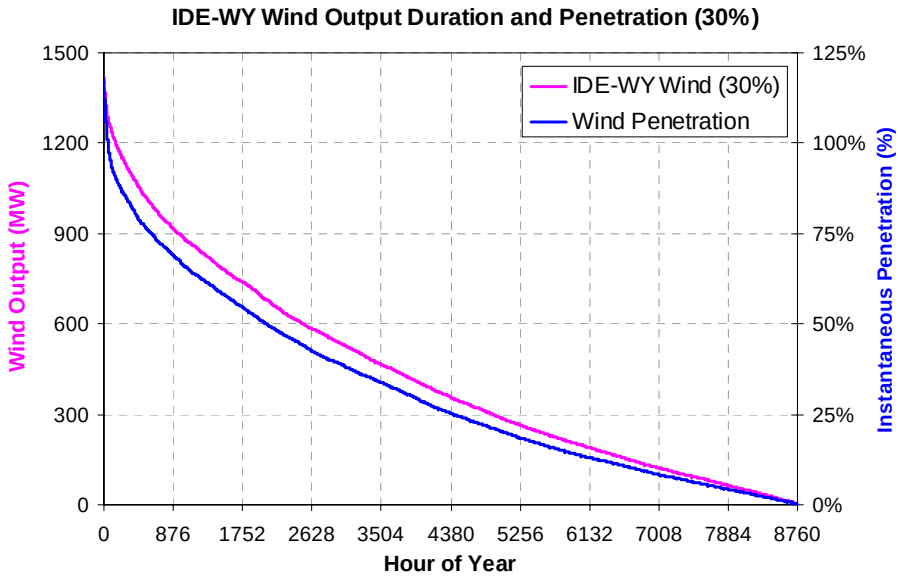
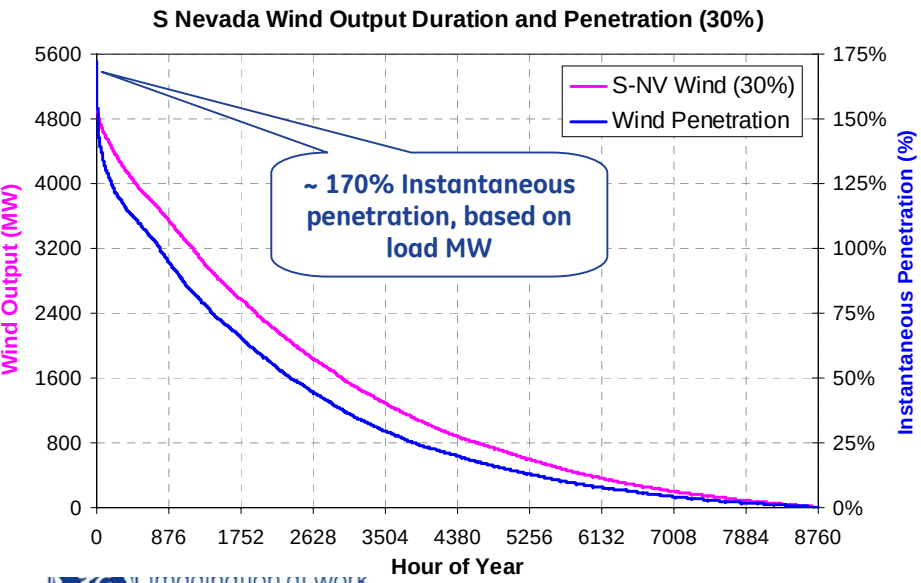
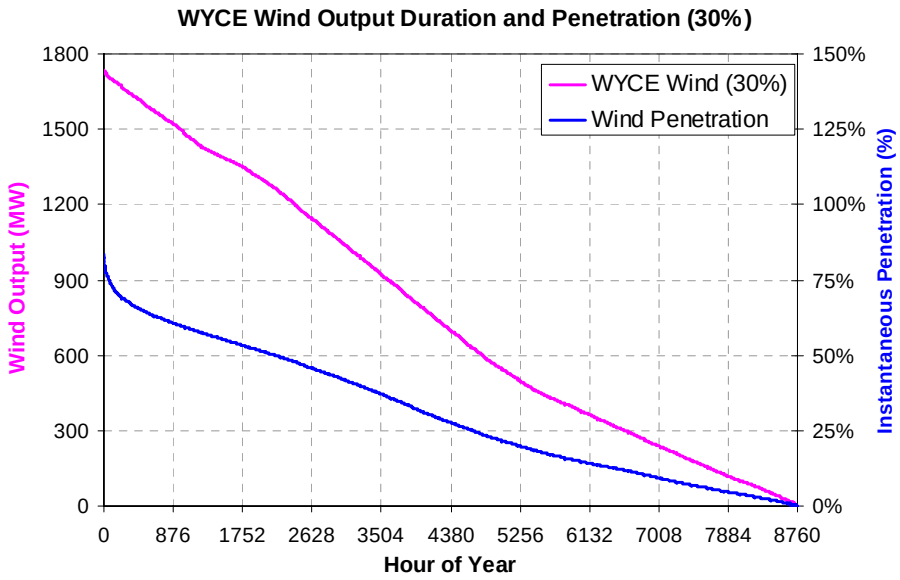
Wind Duration and Penetration Over Entire Year for Selected Areas (30% In-Area Scenario)





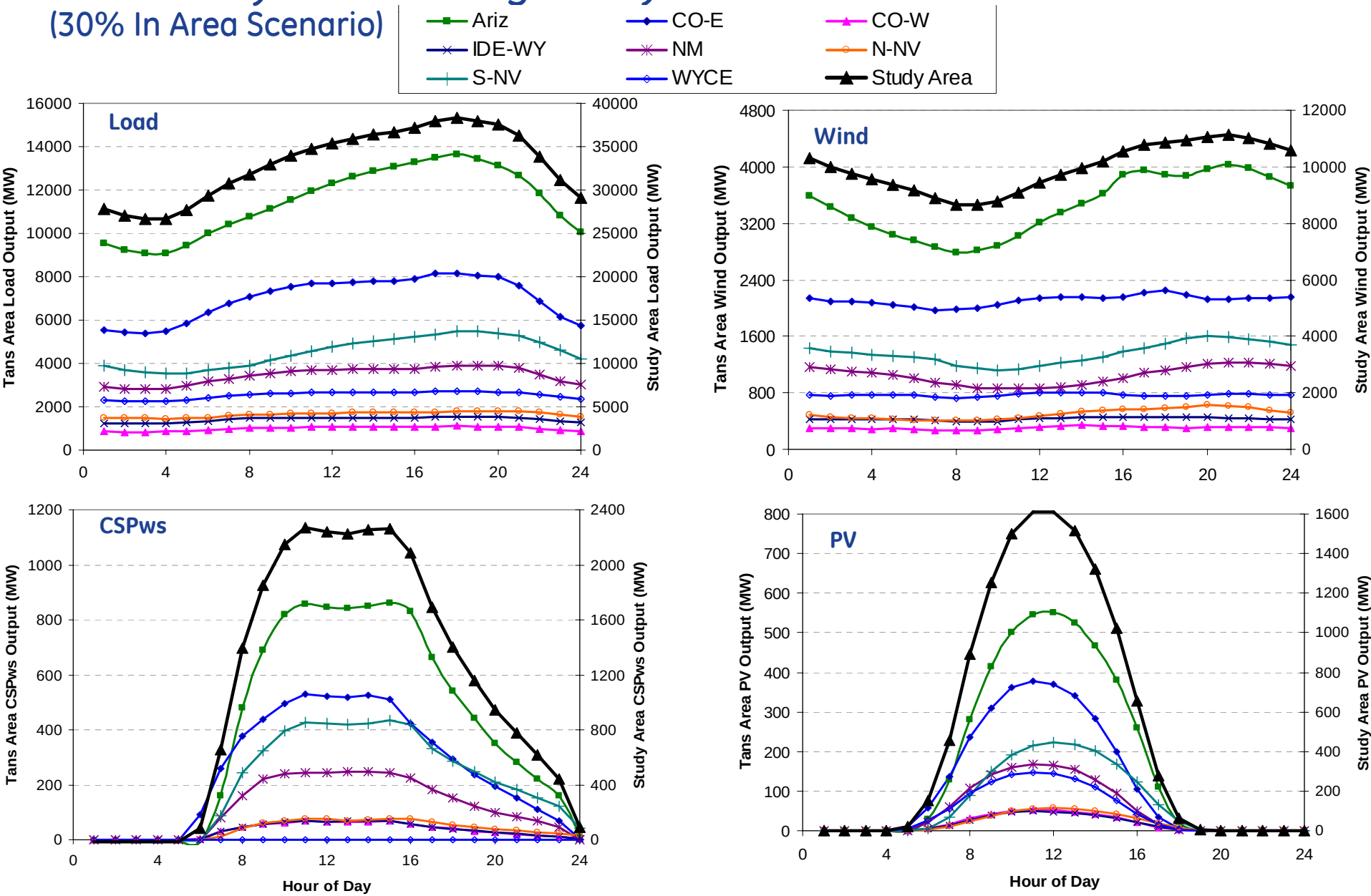




Average Daily Profiles

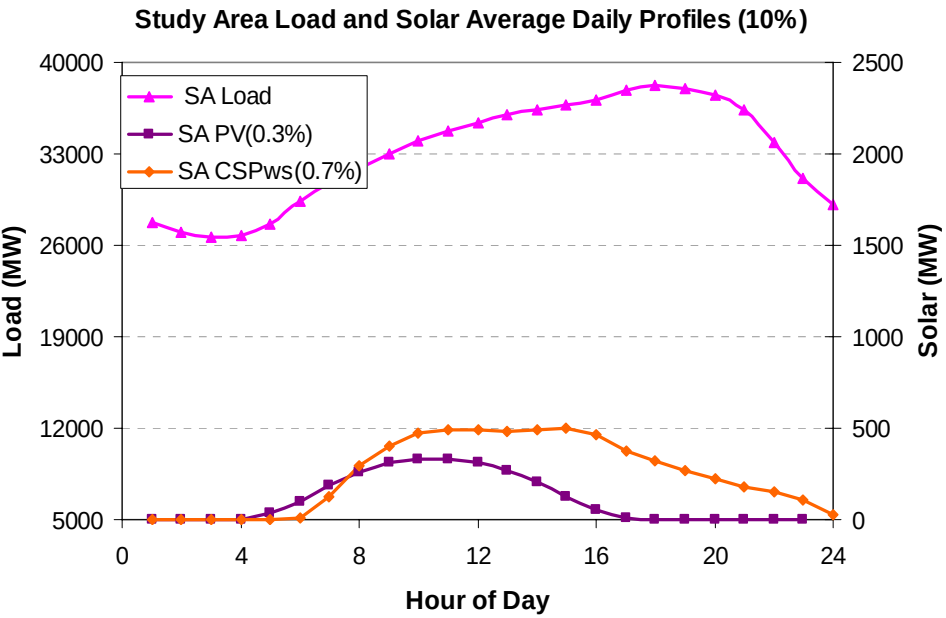
All In-Study Area Average Daily Profiles Over Entire Year

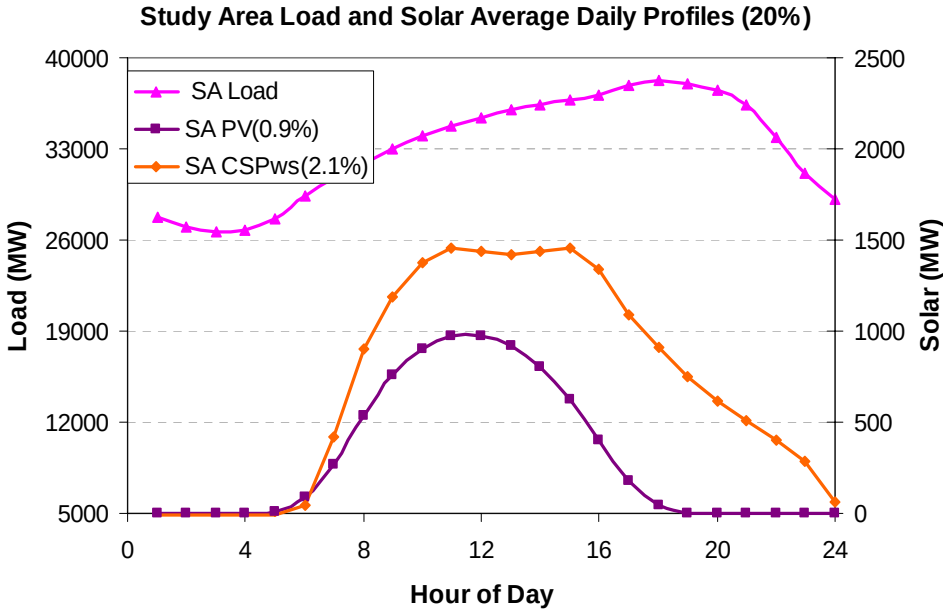
(30% In Area Scenario)

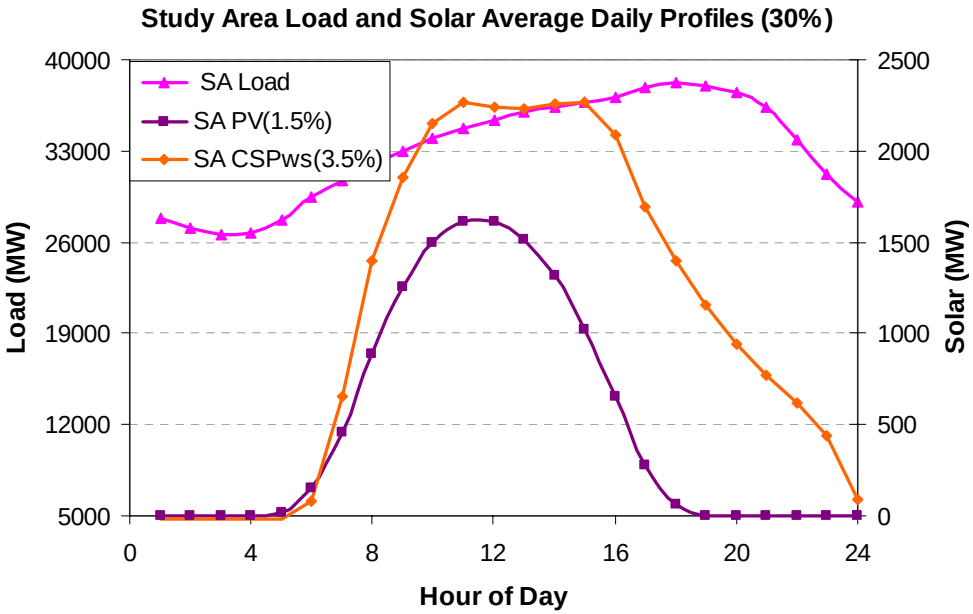


Note: Study Area totals (black trace) plotted on right scale

Study Area Total CSPws and PV Daily Profiles Over Entire Year







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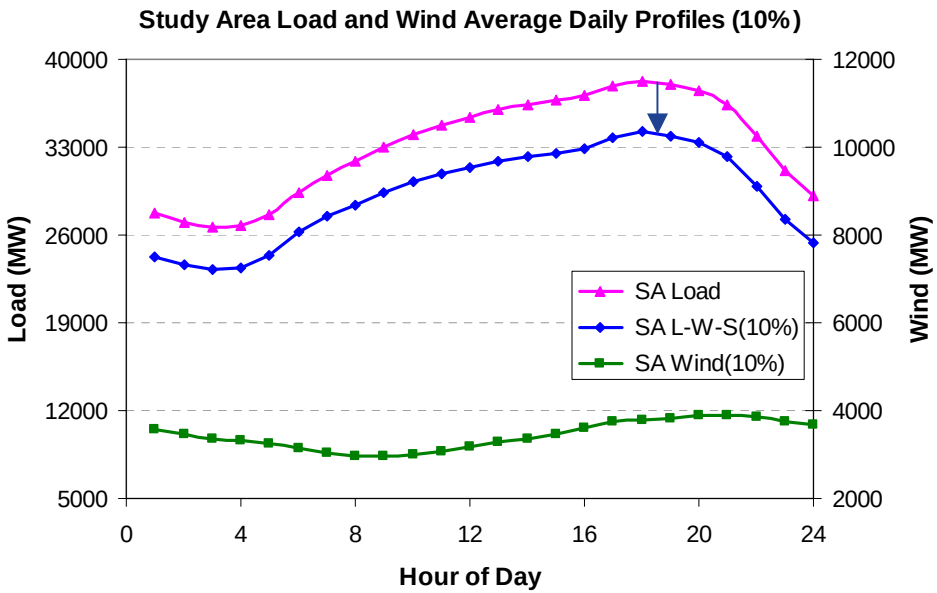
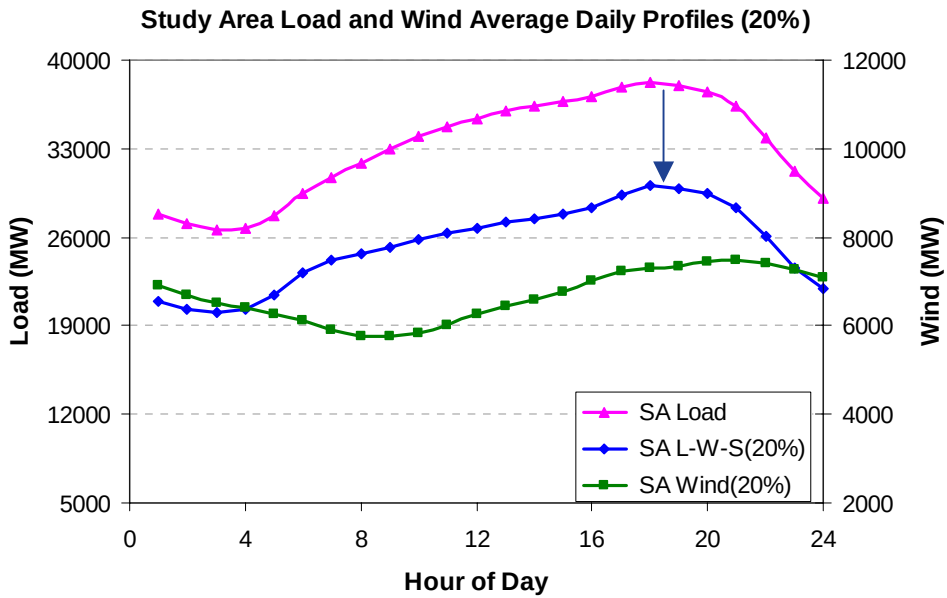
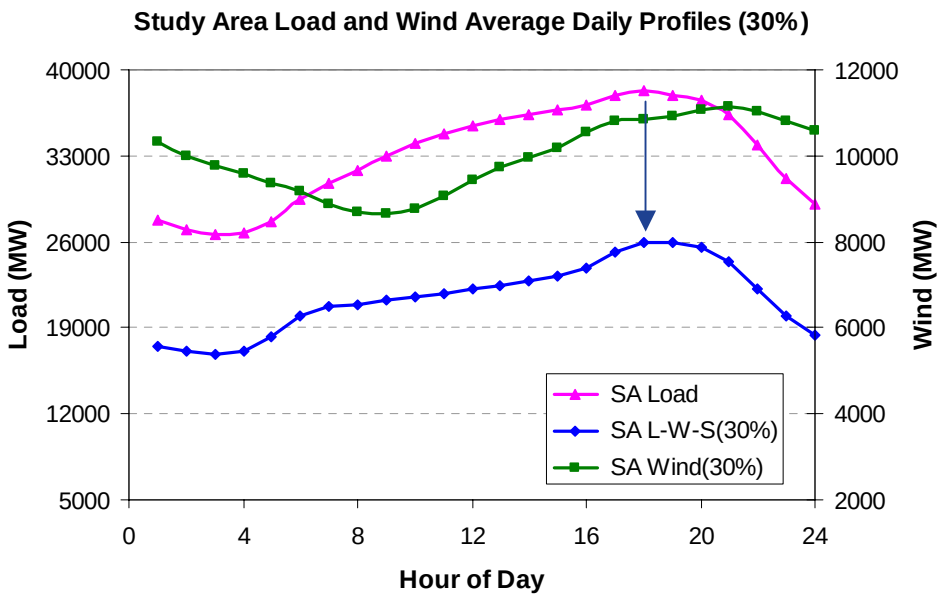
Study Area Load and Wind Average Daily Profiles Over Entire Year







Increasing amounts of wind & solar progressively push net load to lower values

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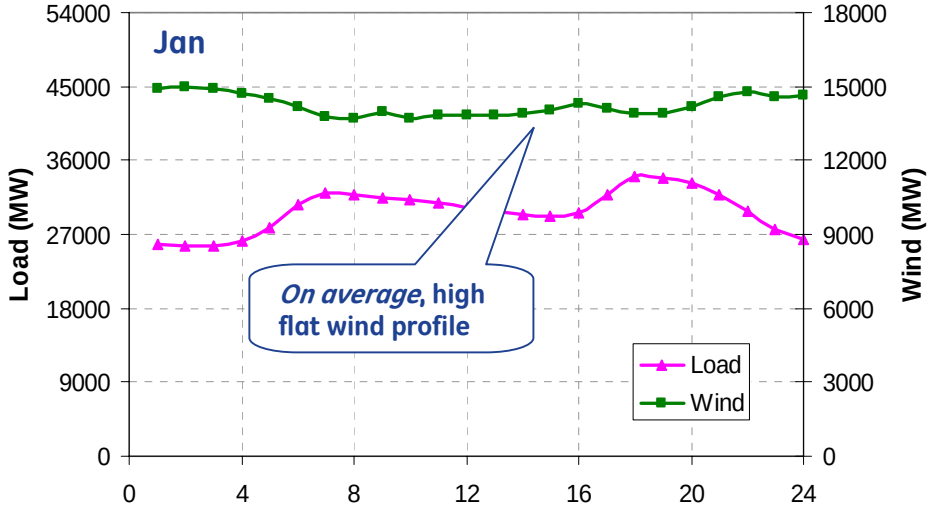
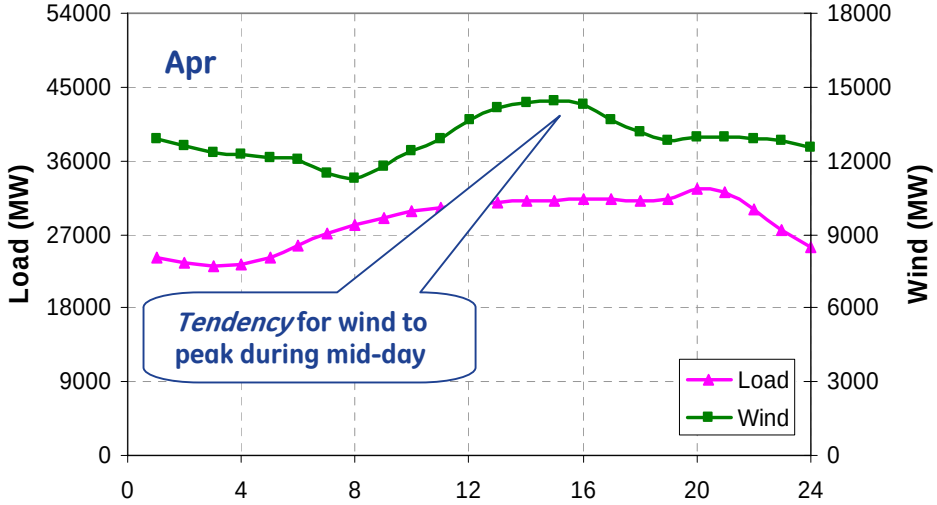
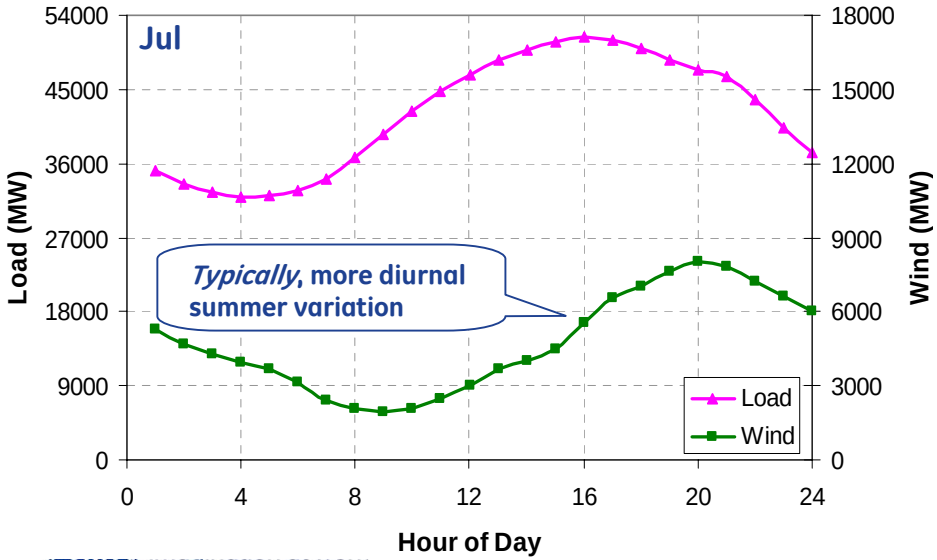
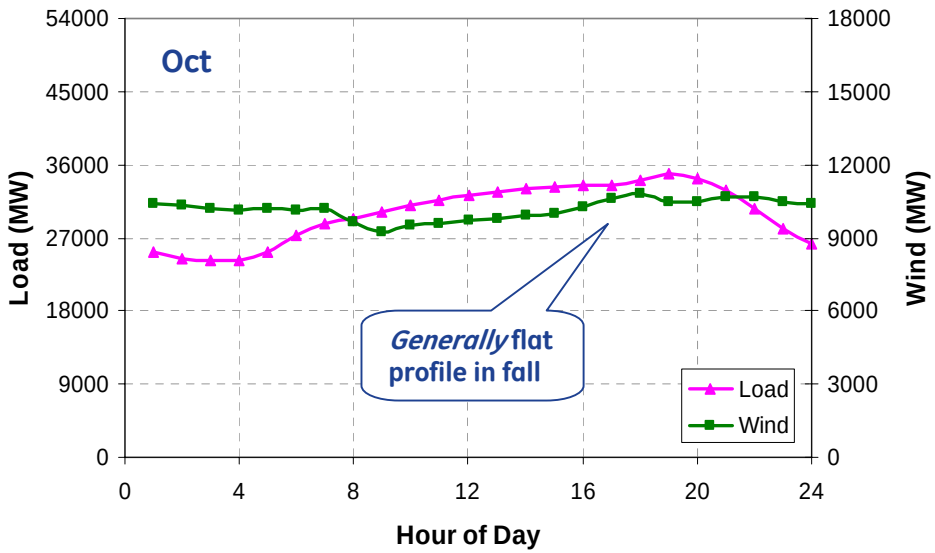
Study Area Load and Wind Average Daily Profiles By Seasonal Month (30% In Area Scenario)

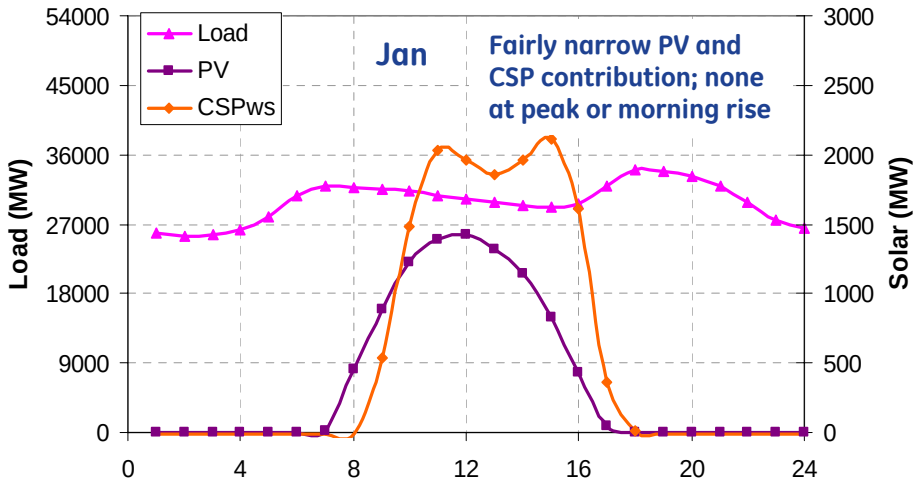


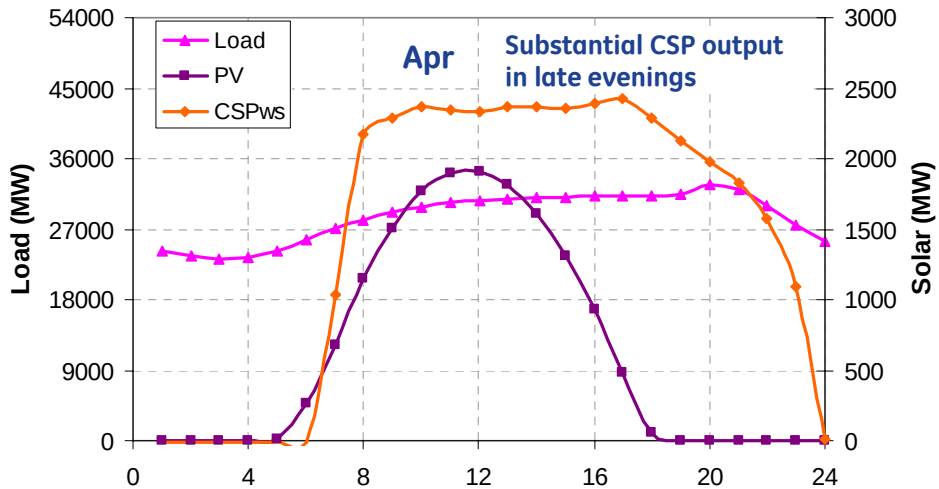


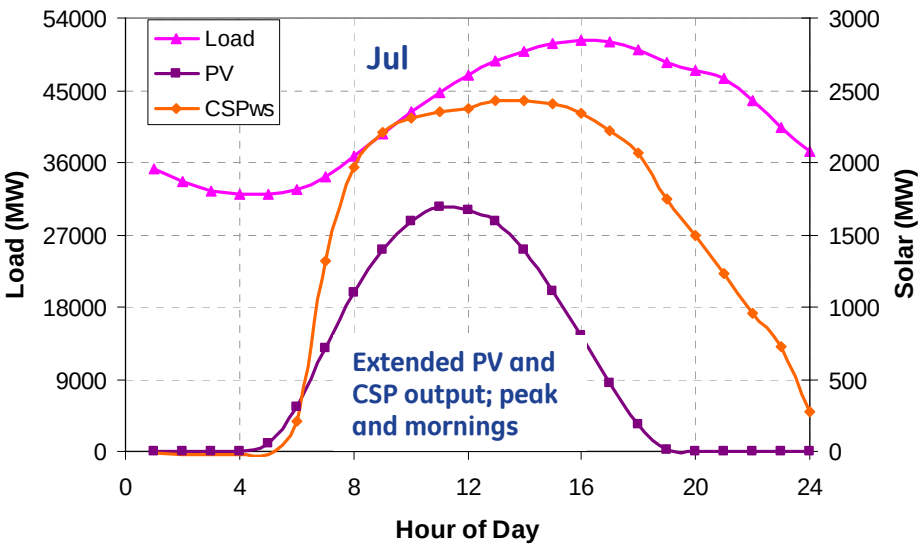


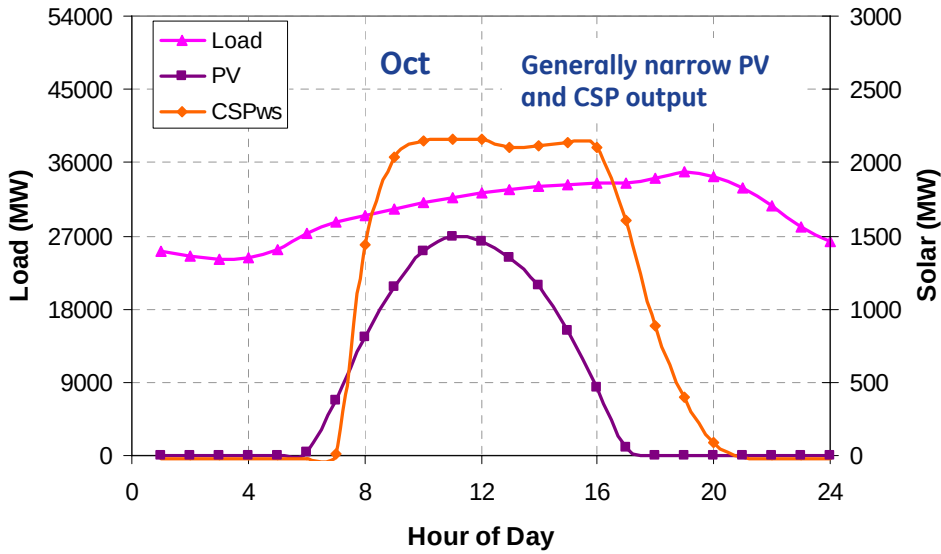


Study Area CSPws and PV Average Daily Profiles By Seasonal Month (30% In Area Scenario)

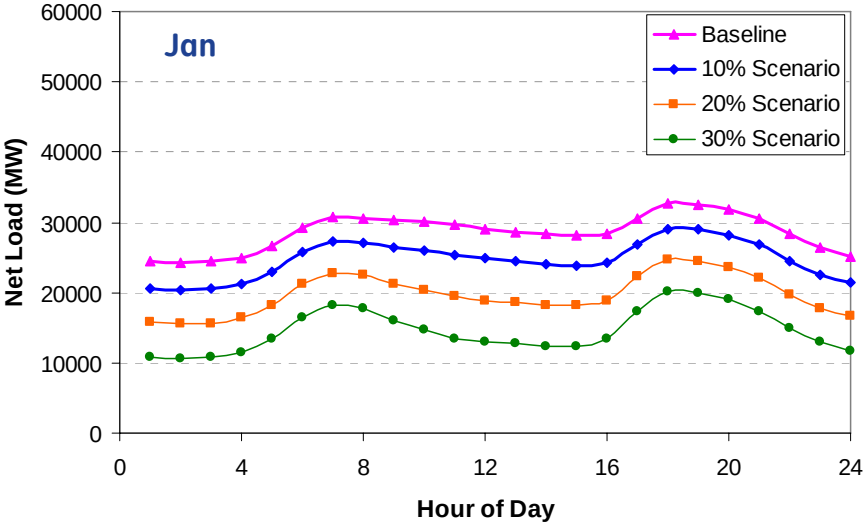


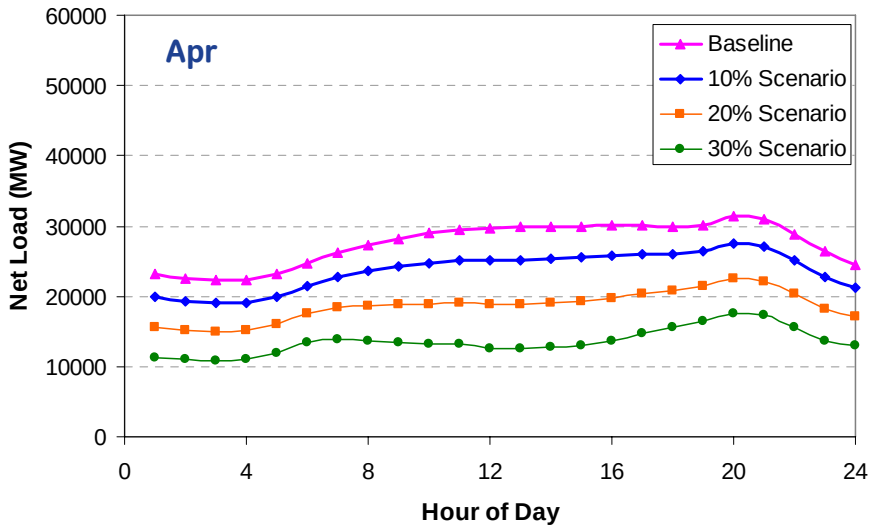


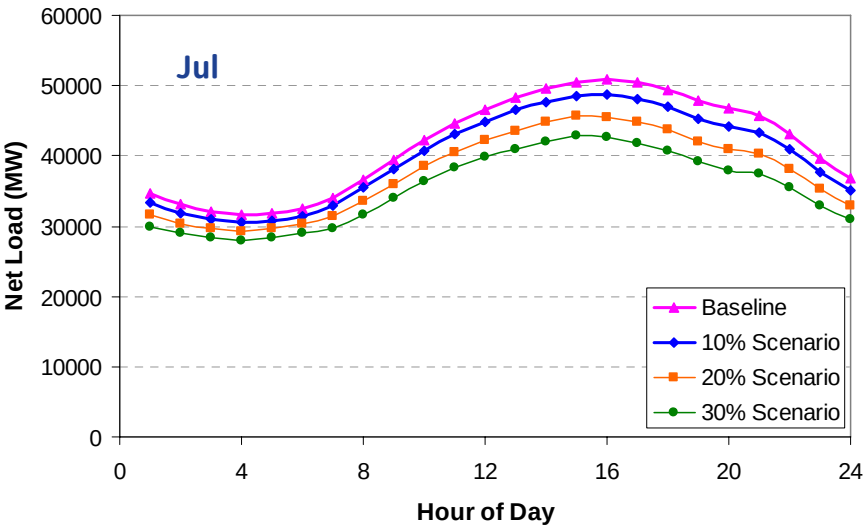


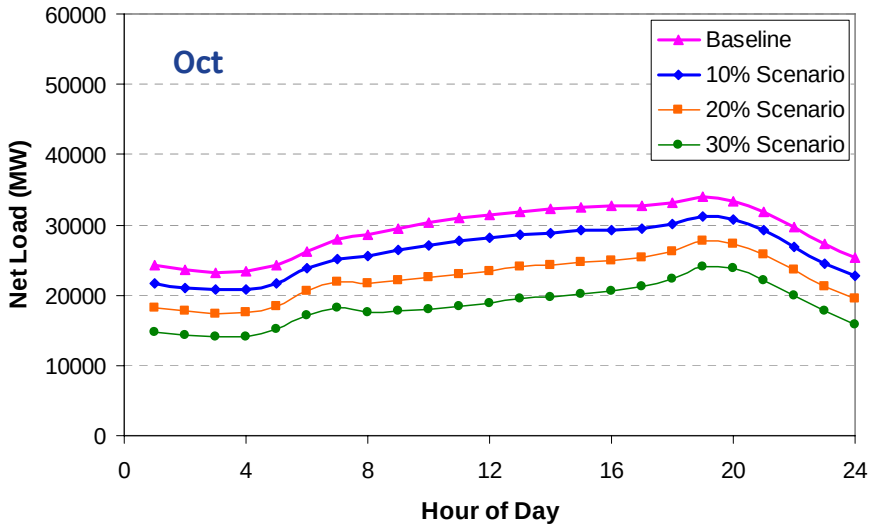


Study Area Net Load Average Daily Profiles By Seasonal Month
(30% In Area Scenario)









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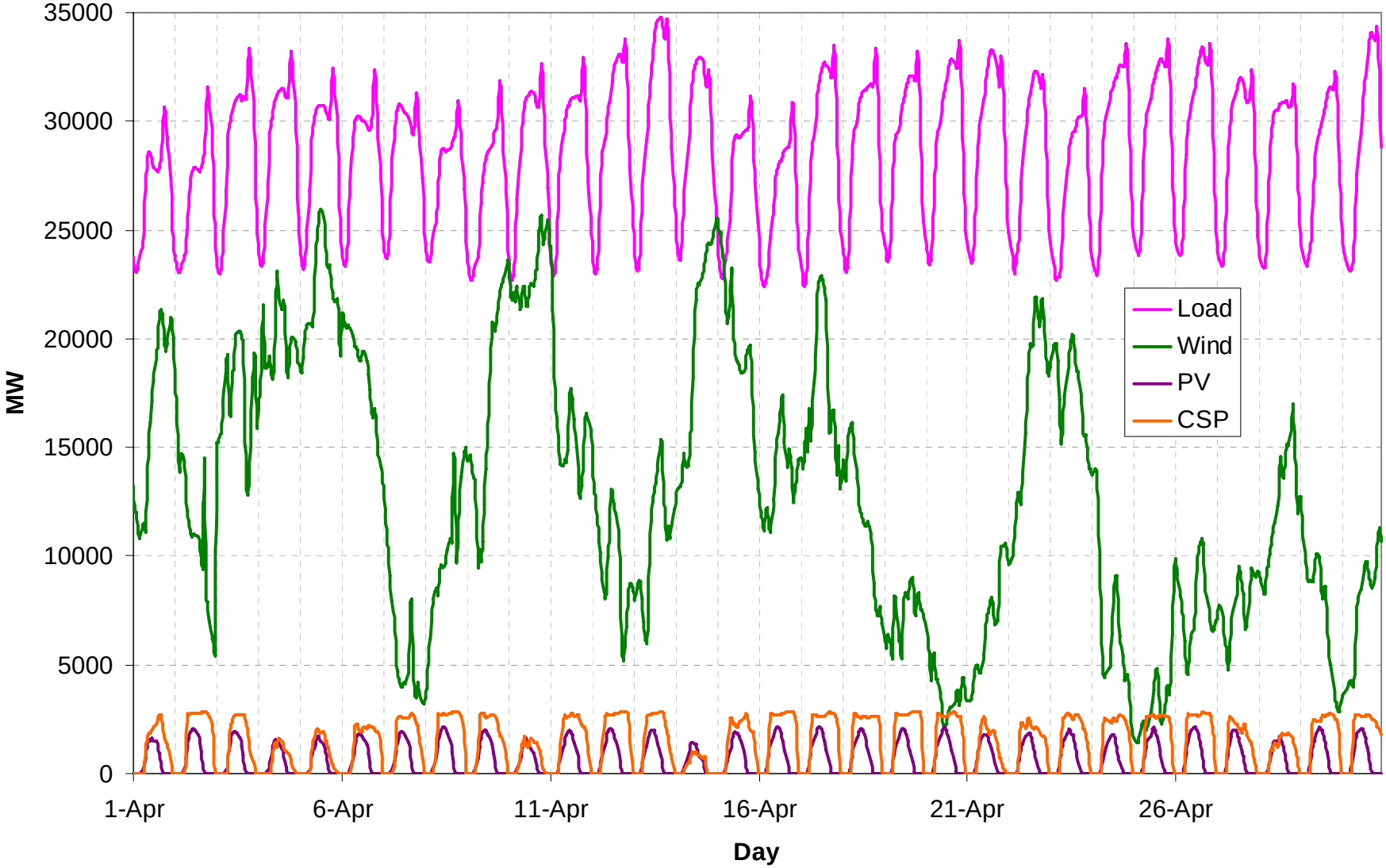
Net load driven down proportionally across scenarios

Profiles for Selected Periods

Study Area Total Load, Wind and Solar Variation Over Month of April
(30% In Area Scenario)



Load, wind, and solar have distinct variability characteristics during the day, and over a month/season/year

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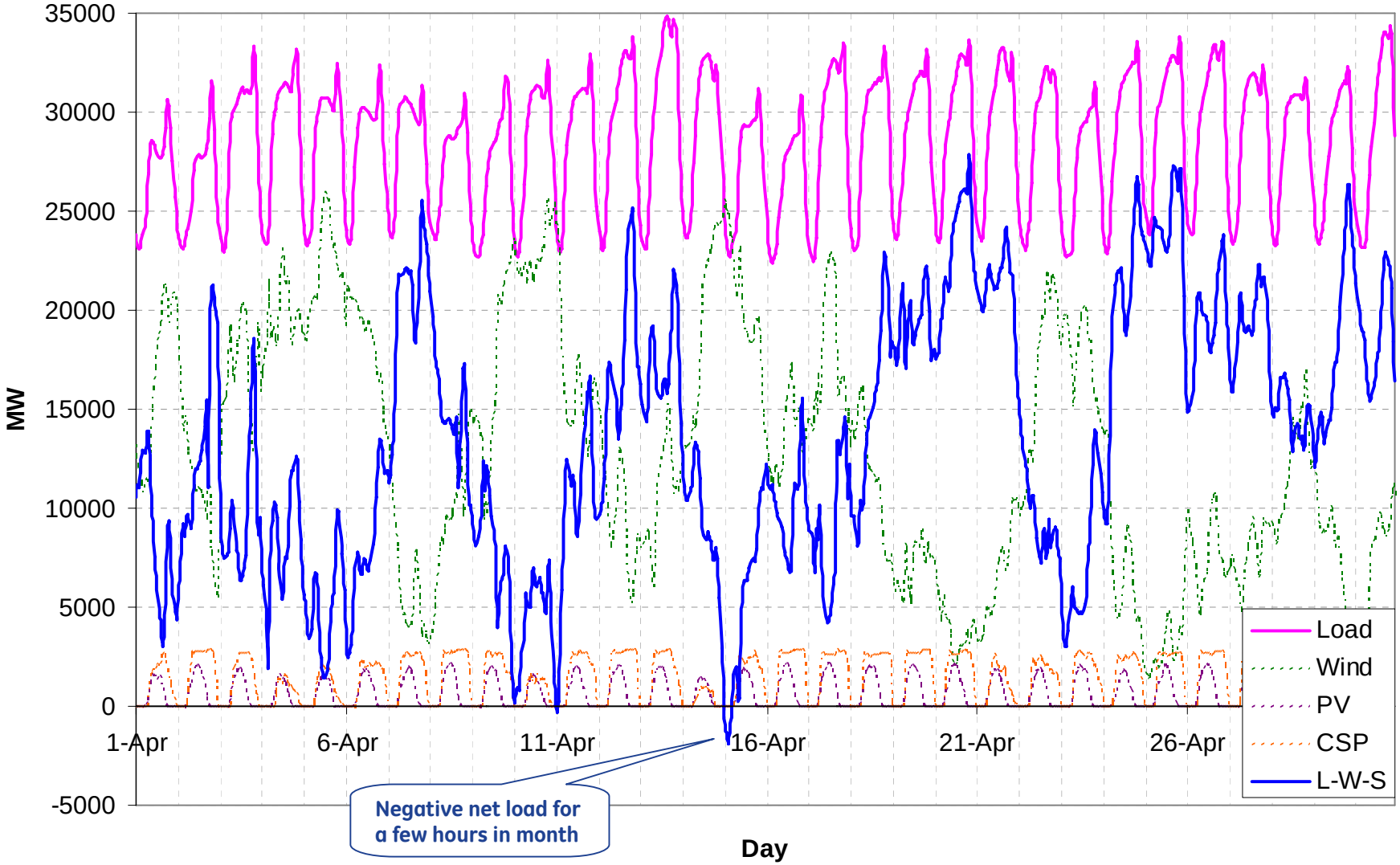
Study Area Total Load and Net Load (L-W-S) Variation Over Month of April (30% In Area Scenario)



Substantial increase in net load variability (over load), driven largely by wind variation

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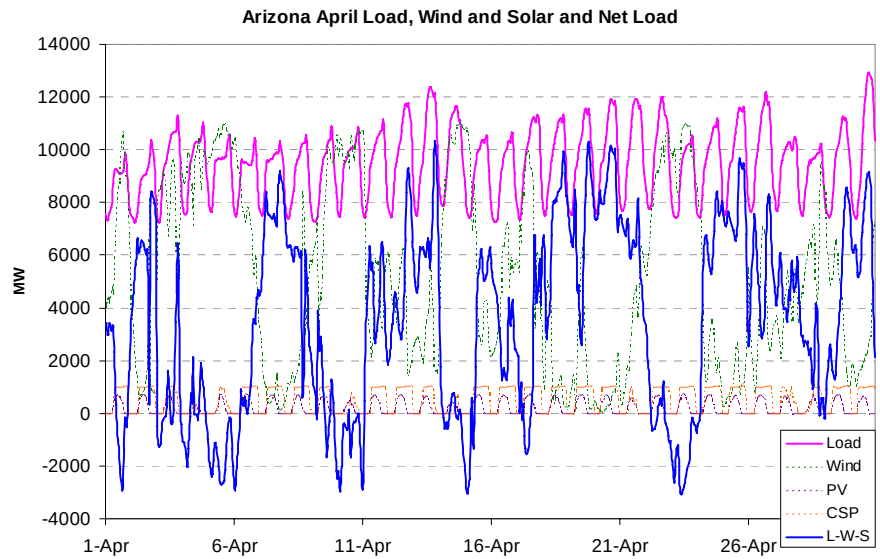
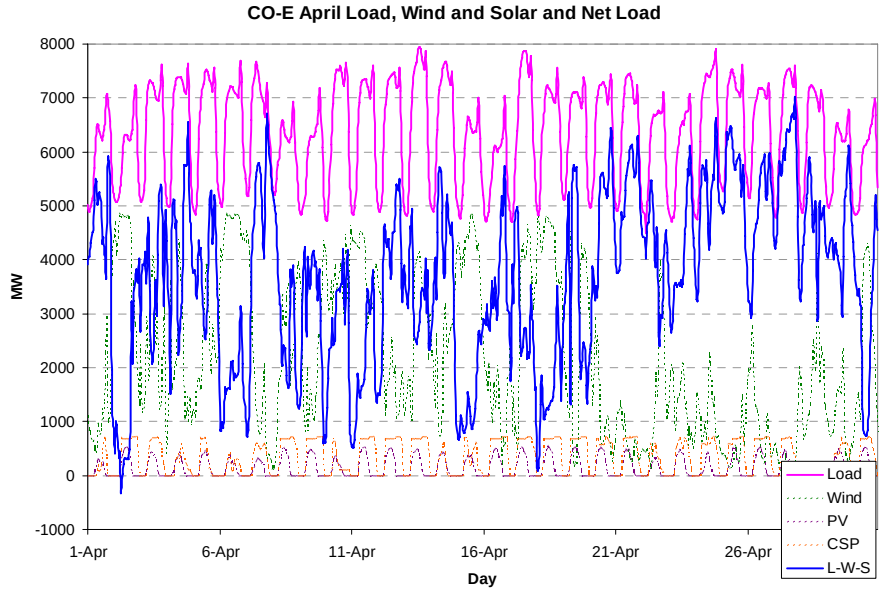
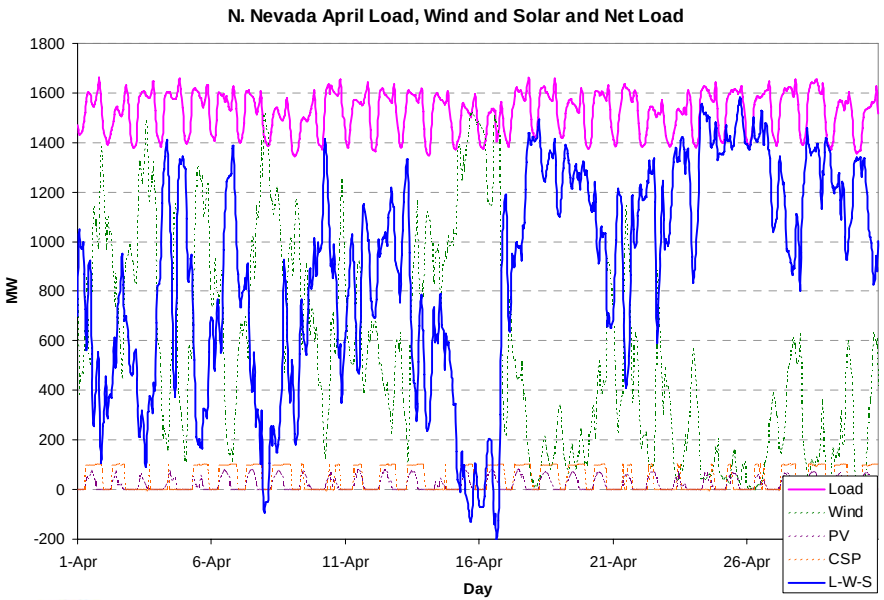
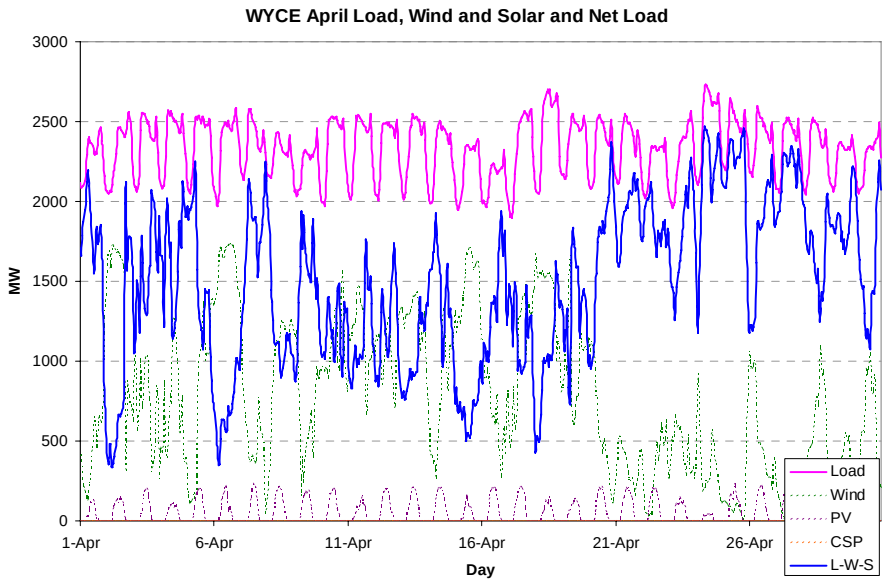
Load and Net Load (L-W-S) Variation Over Month of April for Selected Areas
(30% In Area Scenario)





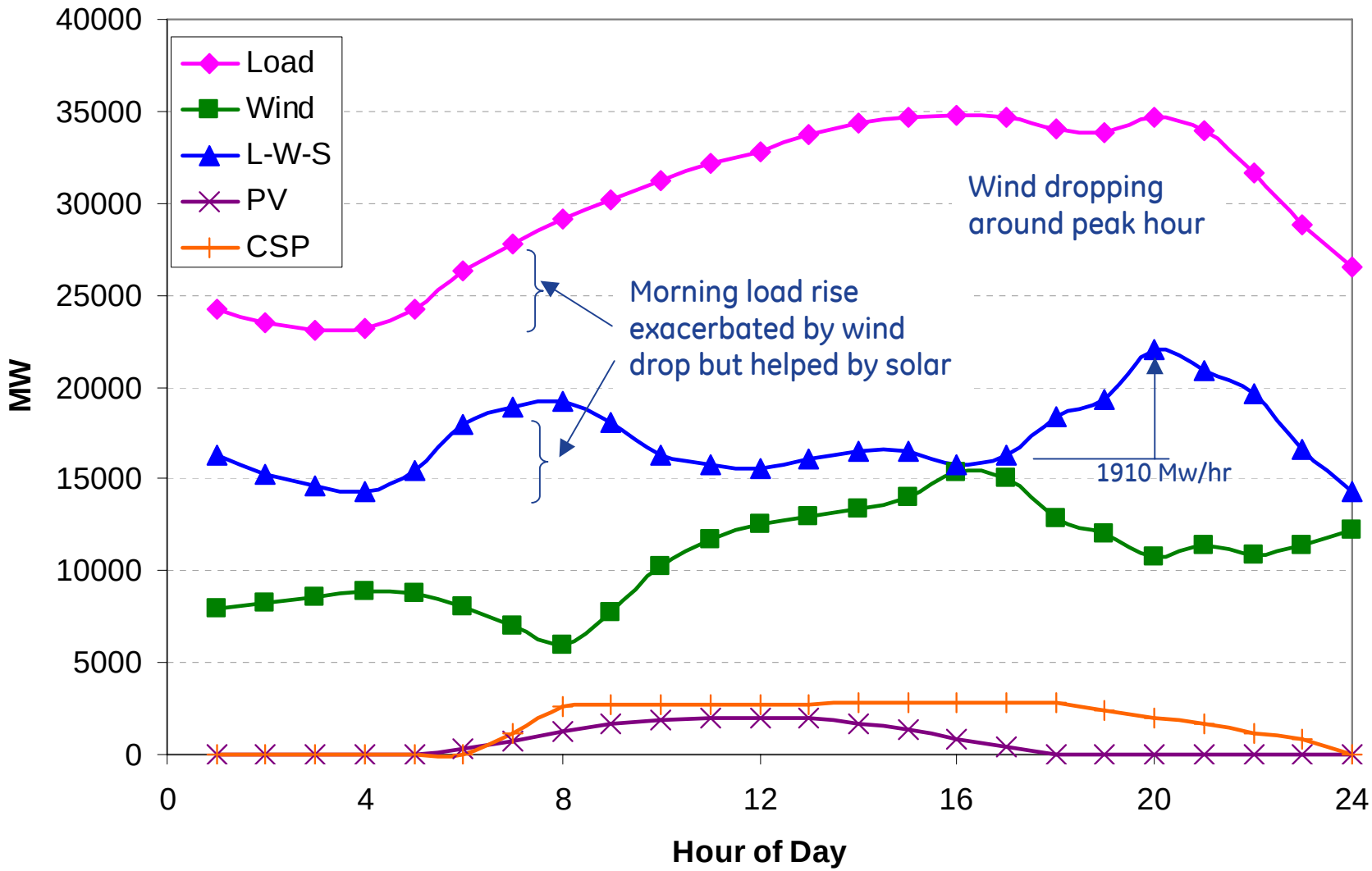




imagination at work

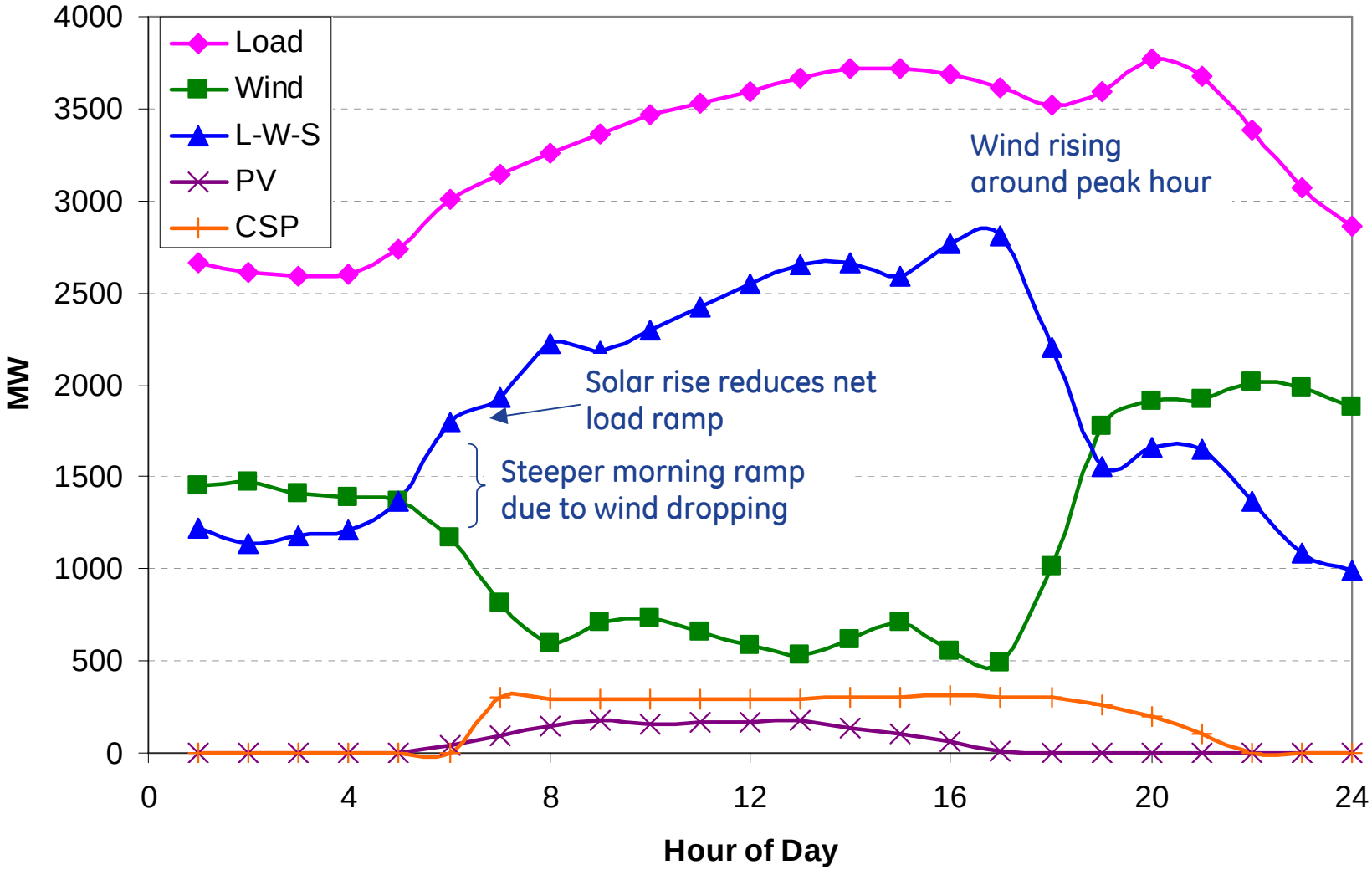
Variability can be very different across areas

Study Area Total Load Wind, Solar and Net Load for Typical Spring Day April 13th (30% In Area Scenario)



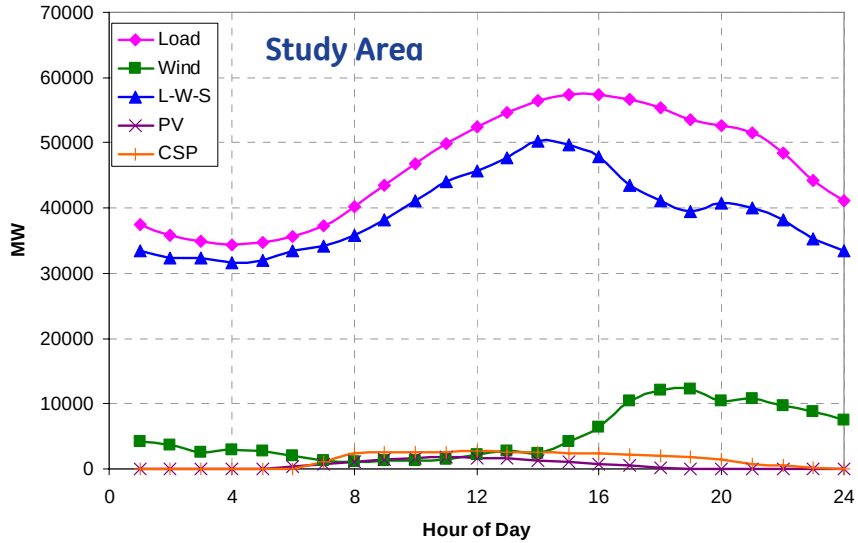
imagination at work

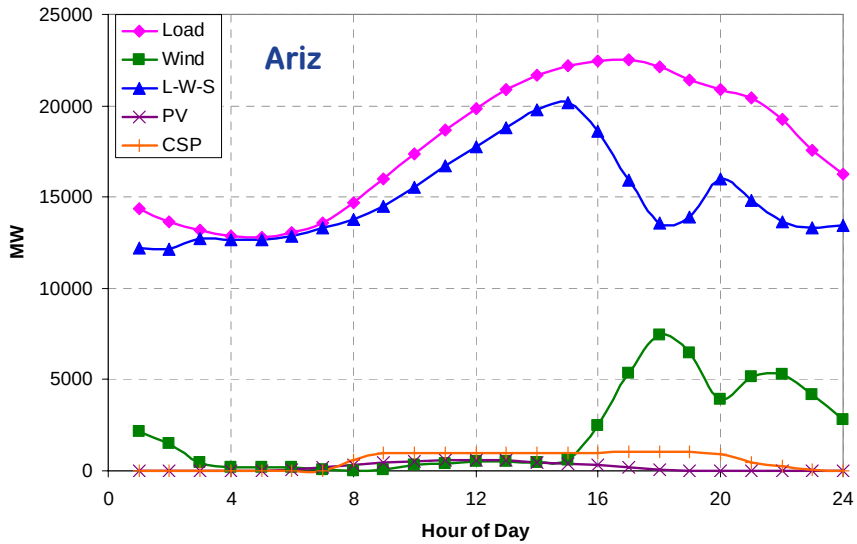
New Mexico Total Load Wind, Solar and Net Load for Typical Spring Day April 13th (30% In Area Scenario)

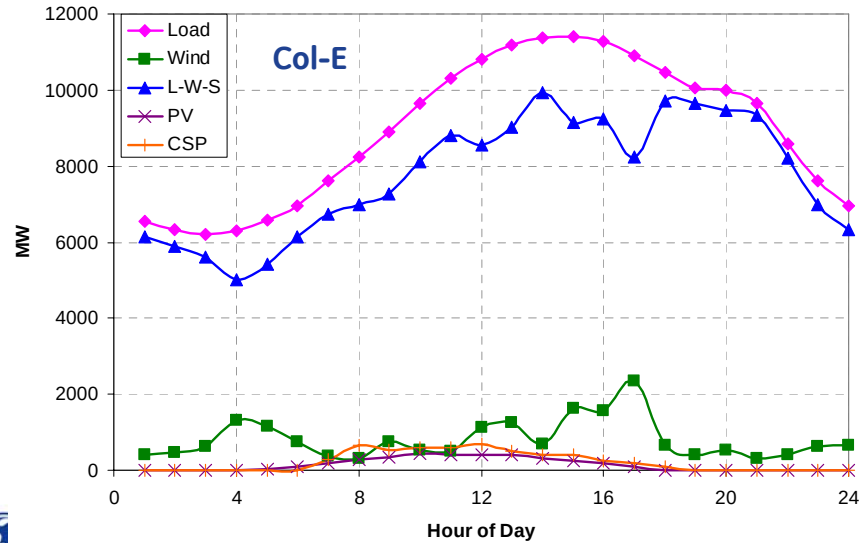


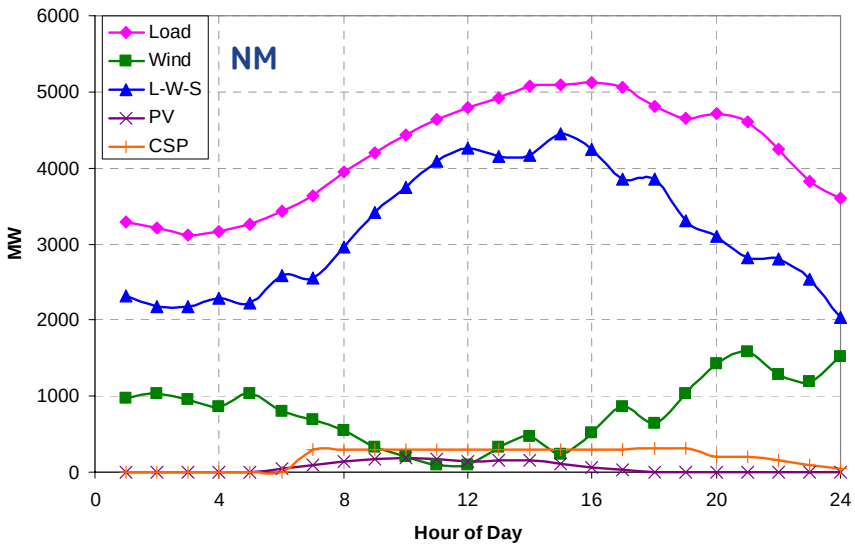
imagination at work

Load Wind, Solar and Net Load for Study Area Peak Load Day
July 24th (30% In Area Scenario)



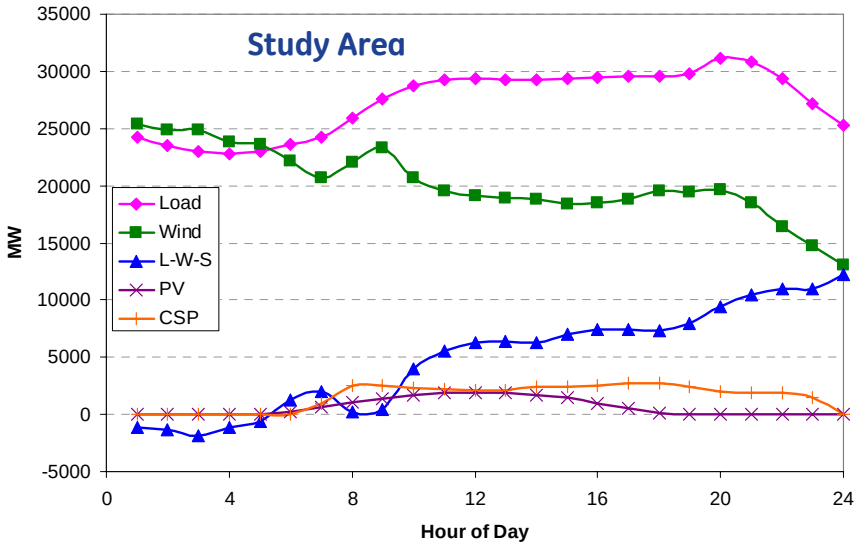


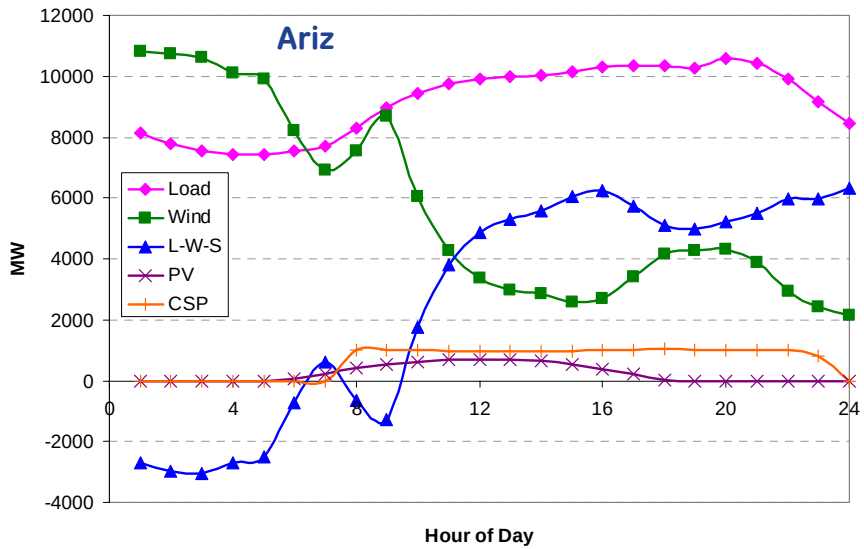


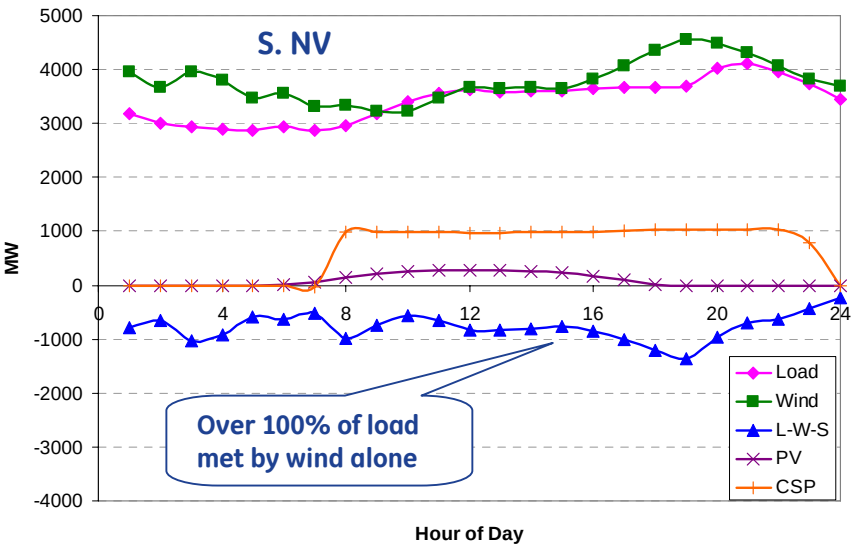


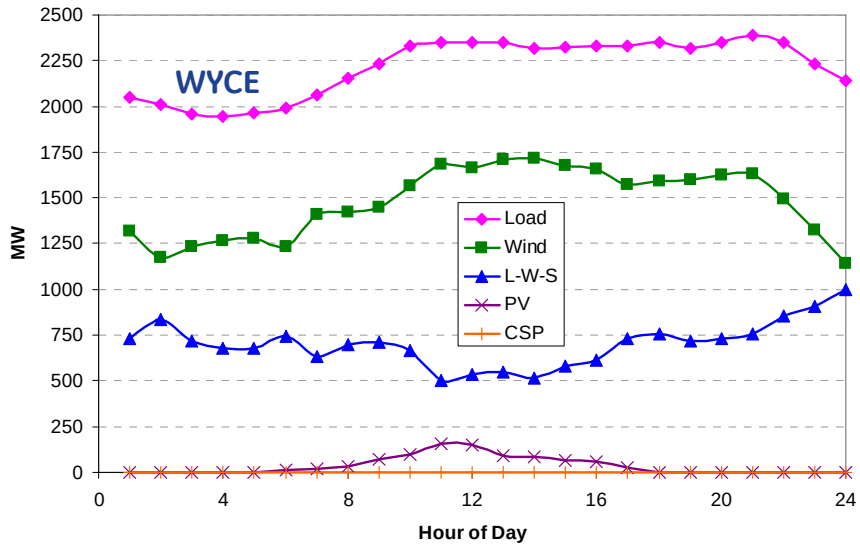
imagination at work

Load, Wind, Solar and Net Load for Study Area Minimum Net Load Day April 15th (30% In Area Scenario)









imagination at work

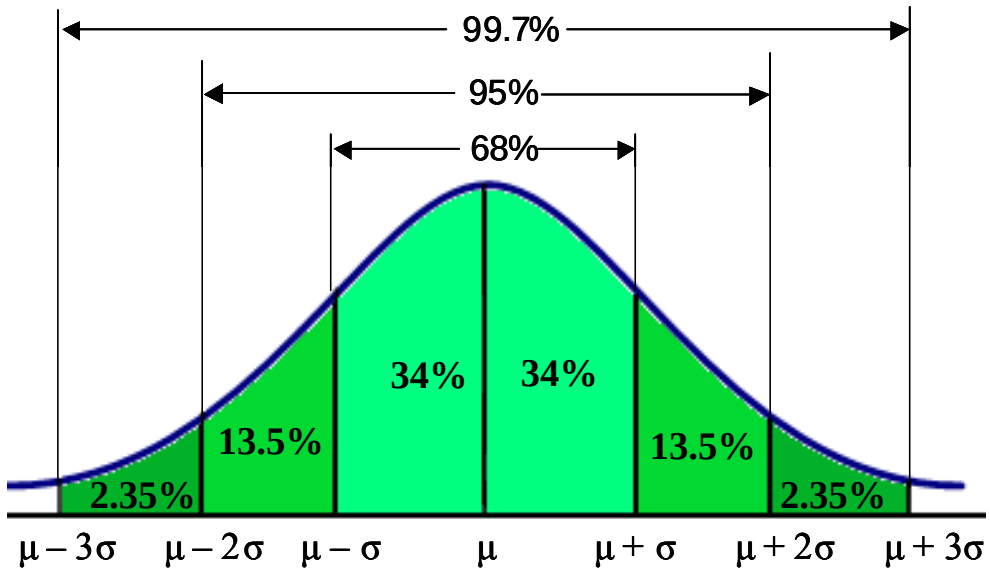
Period-to-Period Variability Analysis

Variability Analysis - Deltas

Statistics used to characterize variability:

- Delta (Δ) – The difference between successive data points in a series, or period-to-period ramp rate.
  - Positive delta is a rise or up-ramp
  - Negative delta is a drop or down-ramp
- Mean (μ) – The average of the deltas (typically zero within a diurnal cycle)
- Sigma (σ) – The standard deviation of the deltas; measures spread about the mean

For a normal distribution of deltas, σ is related to the percentage of deltas within a certain distance of the mean

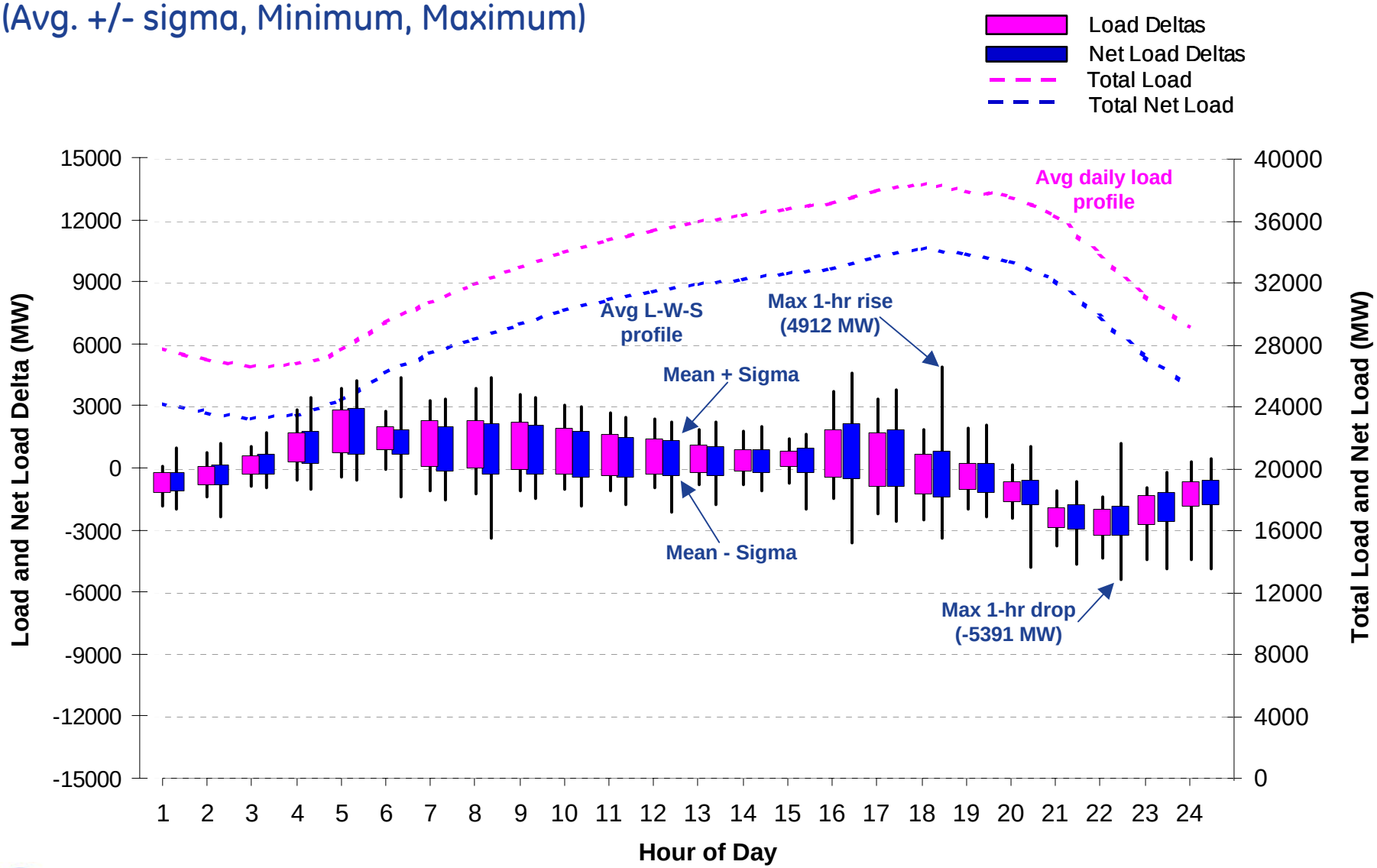


imagination at work

Study Area Average Daily Profile of Deltas Over Entire Year

(10% In Area Scenario)

(Avg. +/- sigma, Minimum, Maximum)



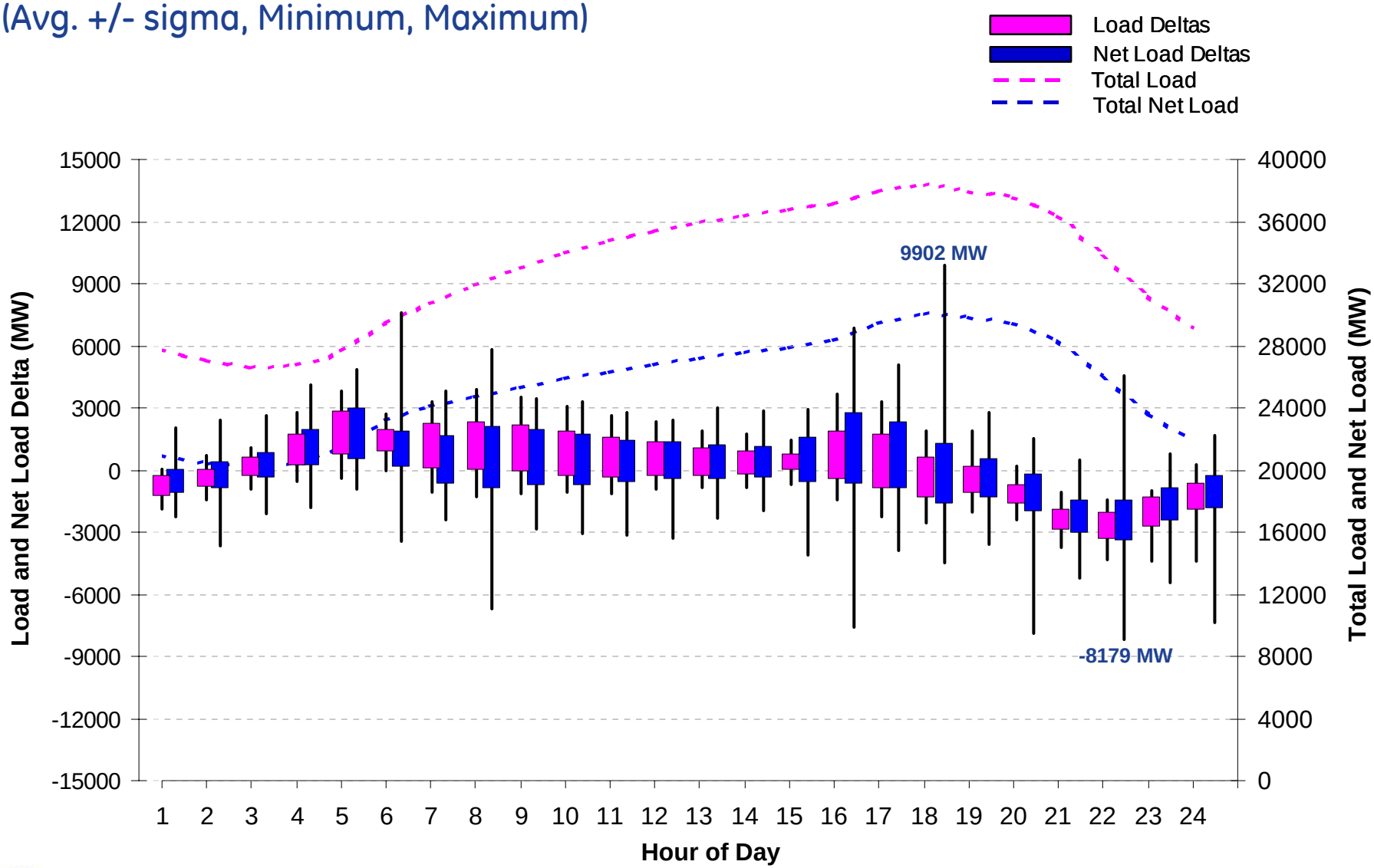
imagination at work

Limited incremental variability

Study Area Average Daily Profile of Deltas Over Entire Year

(20% In Area Scenario)

(Avg. +/- sigma, Minimum, Maximum)



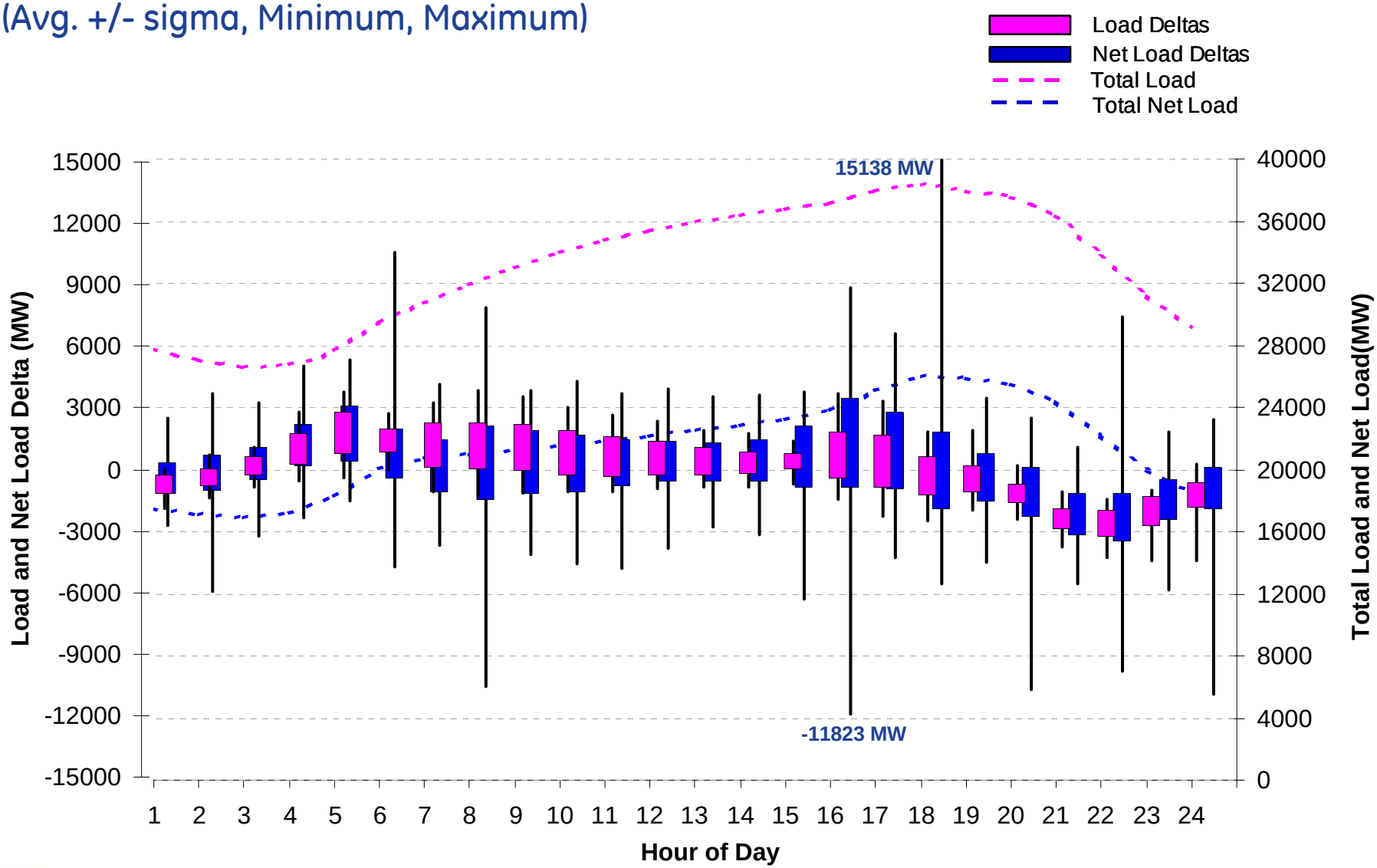
imagination at work

More incremental variability; Larger max hourly deltas

Study Area Average Daily Profile of Deltas Over Entire Year

(30% In Area Scenario)

(Avg. +/- sigma, Minimum, Maximum)



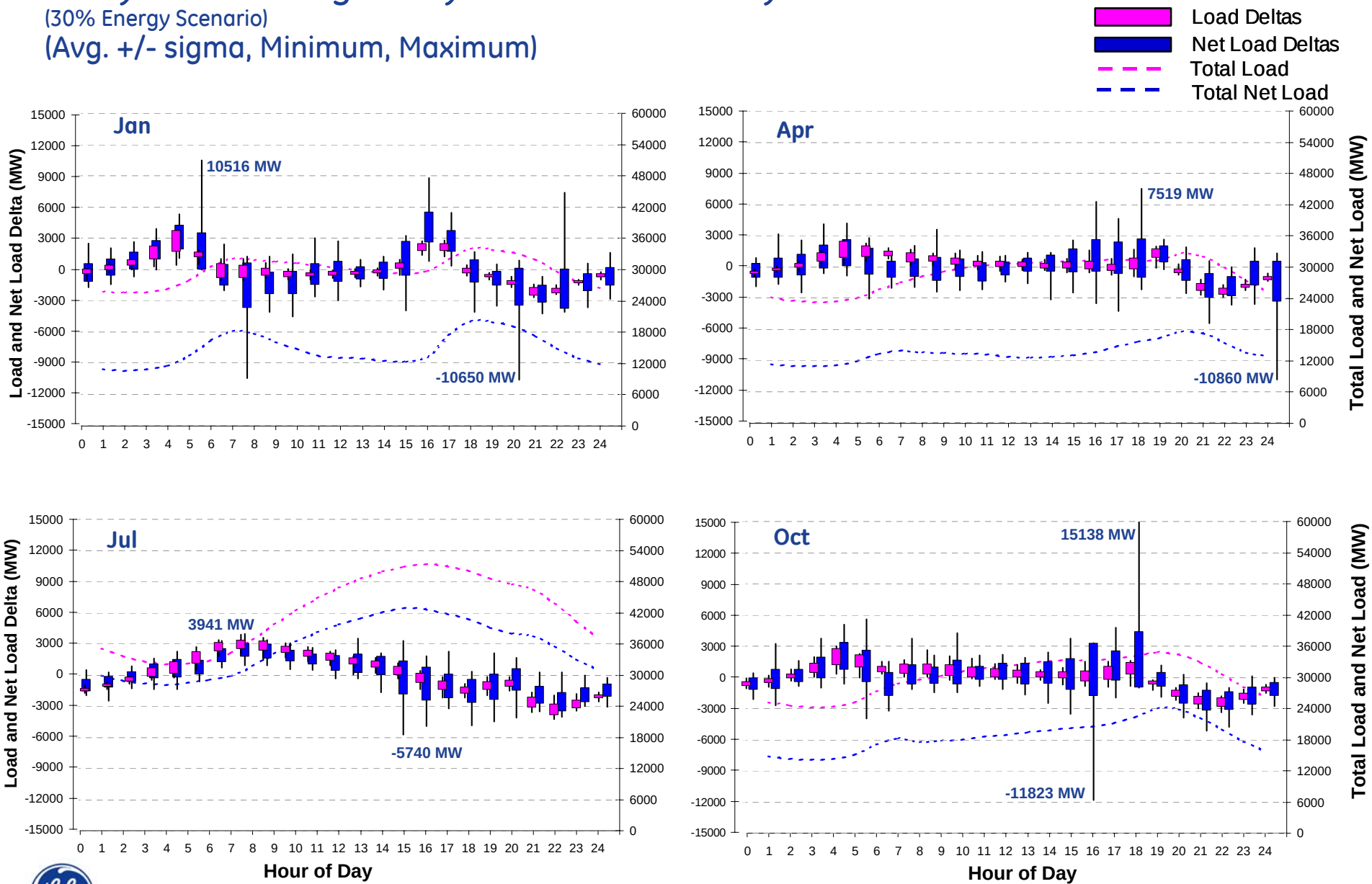
imagination at work

Significant increase in variability and max hourly deltas

Study Area Average Daily Profile of Deltas by Seasonal Month

(30% Energy Scenario)

(Avg. +/- sigma, Minimum, Maximum)

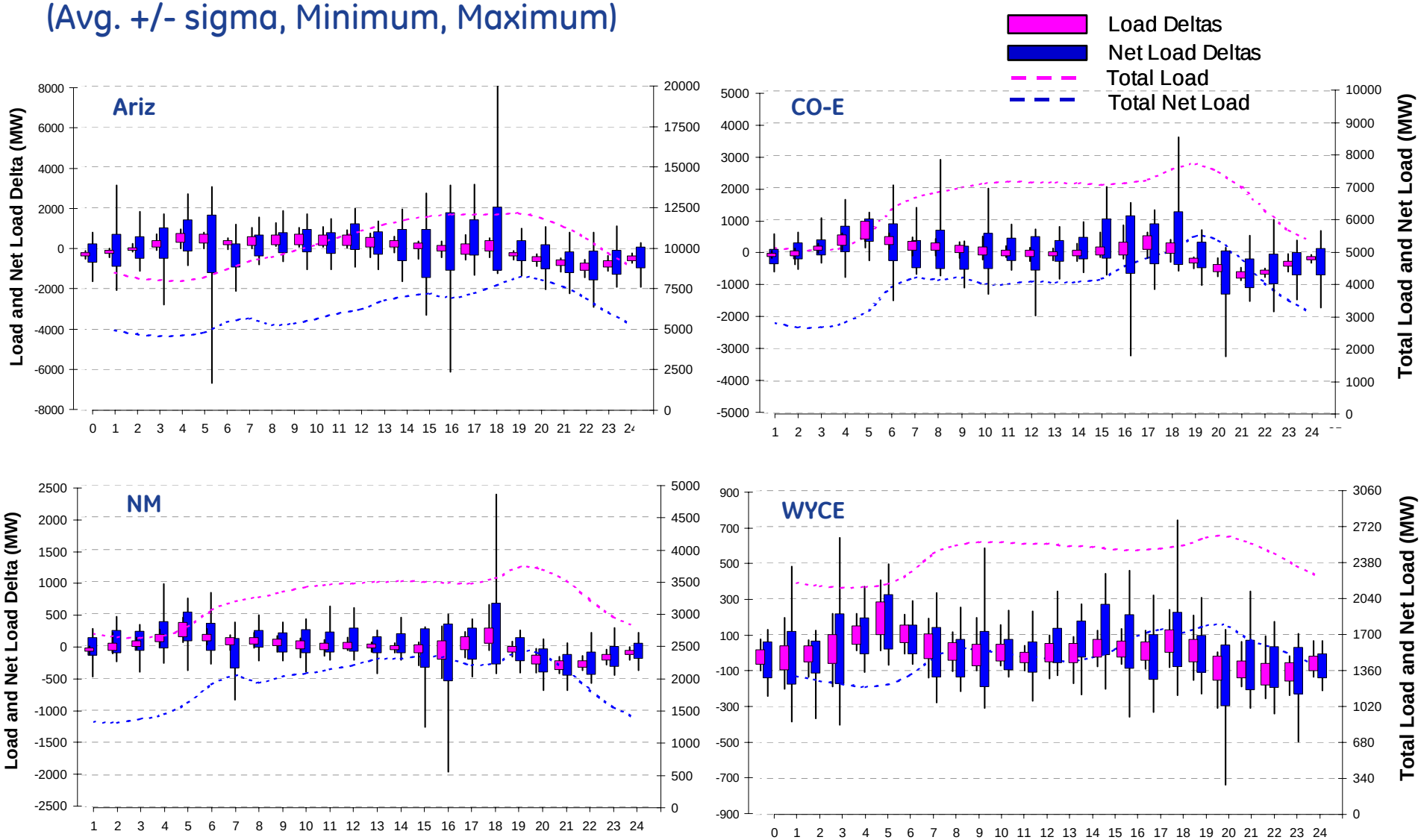


imagination at work

Average Daily Profile of Deltas for Selected Areas in October/Fall

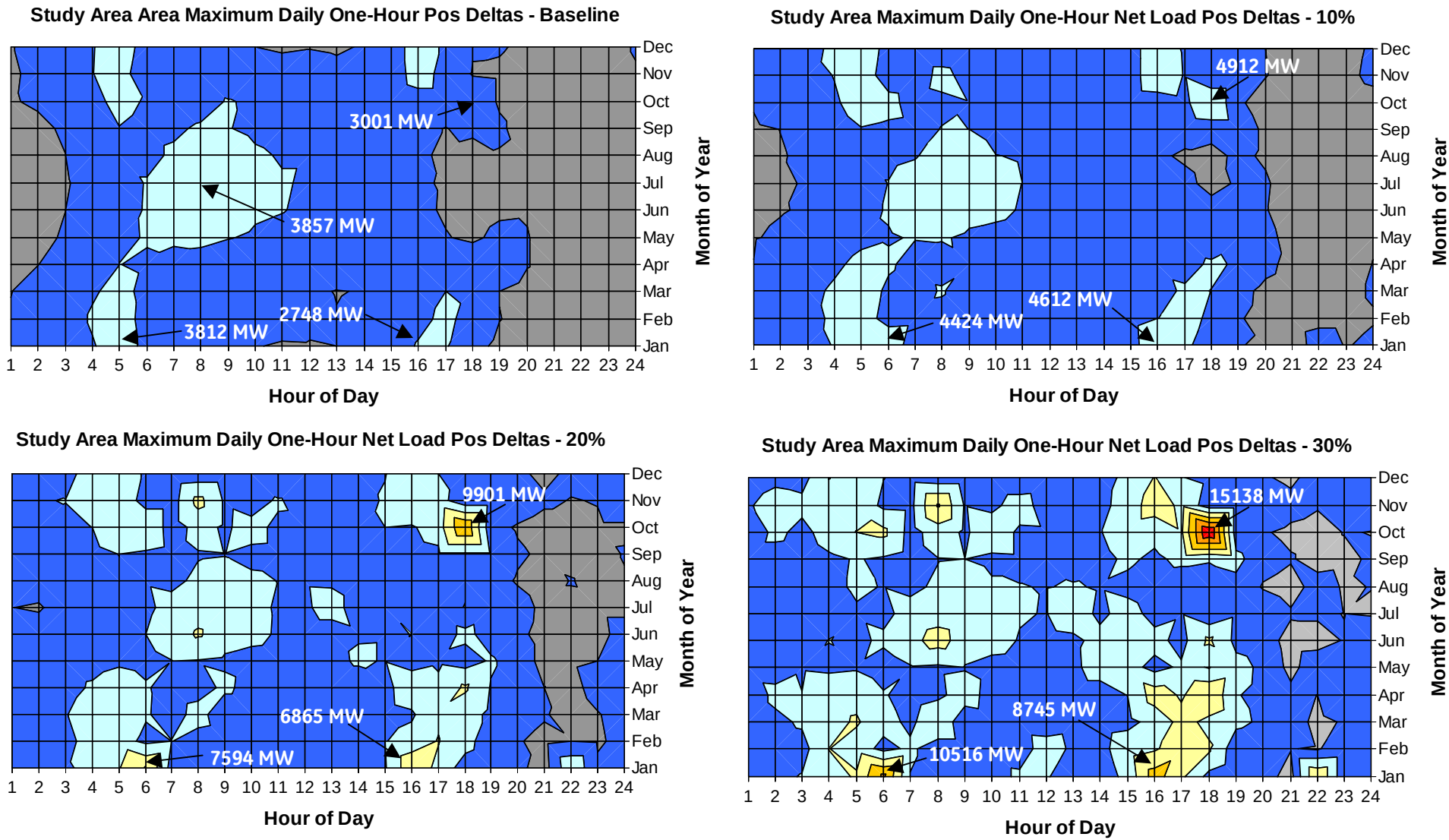
(30% In Area Scenario)

(Avg. +/- sigma, Minimum, Maximum)



imagination at work

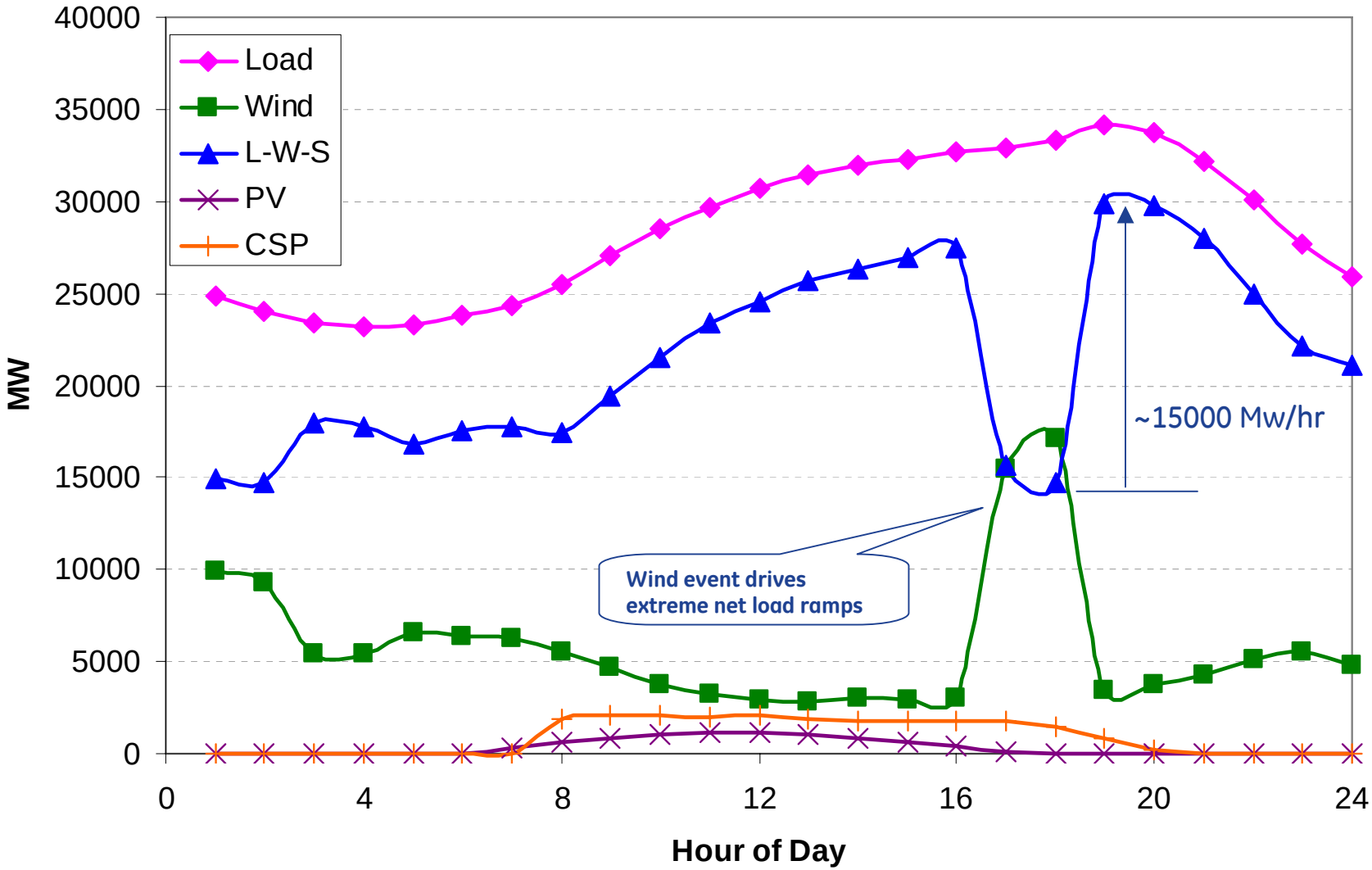
Timing of Maximum Daily 1-Hr Positive Deltas for Study Area



imagination at work

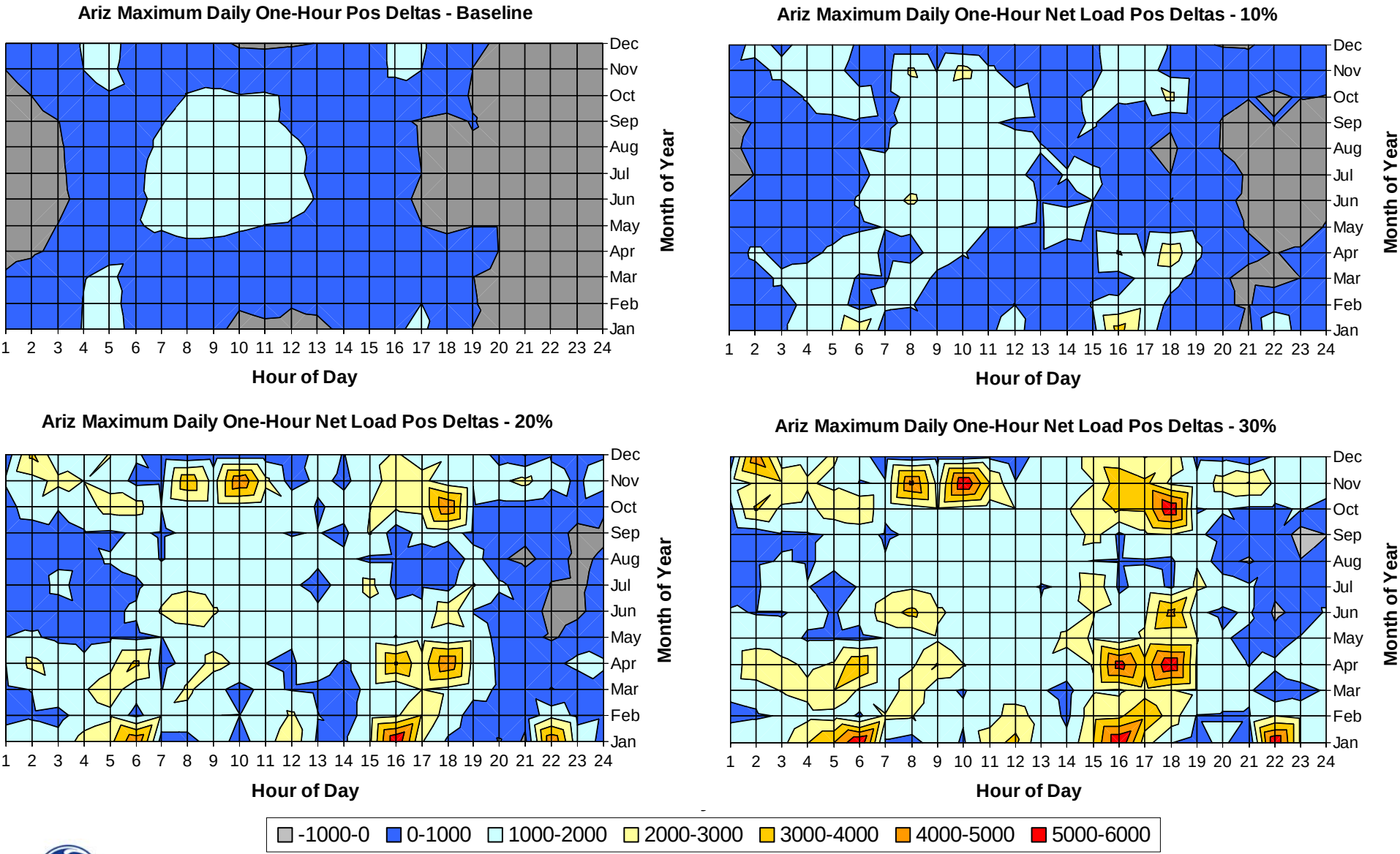
Impact of wind and solar on extreme deltas more pronounced in evening hours during winter, spring and fall

Study Area Total, Load Wind, Solar and Net Load for Oct 8th
(30% In-Area Scenario)



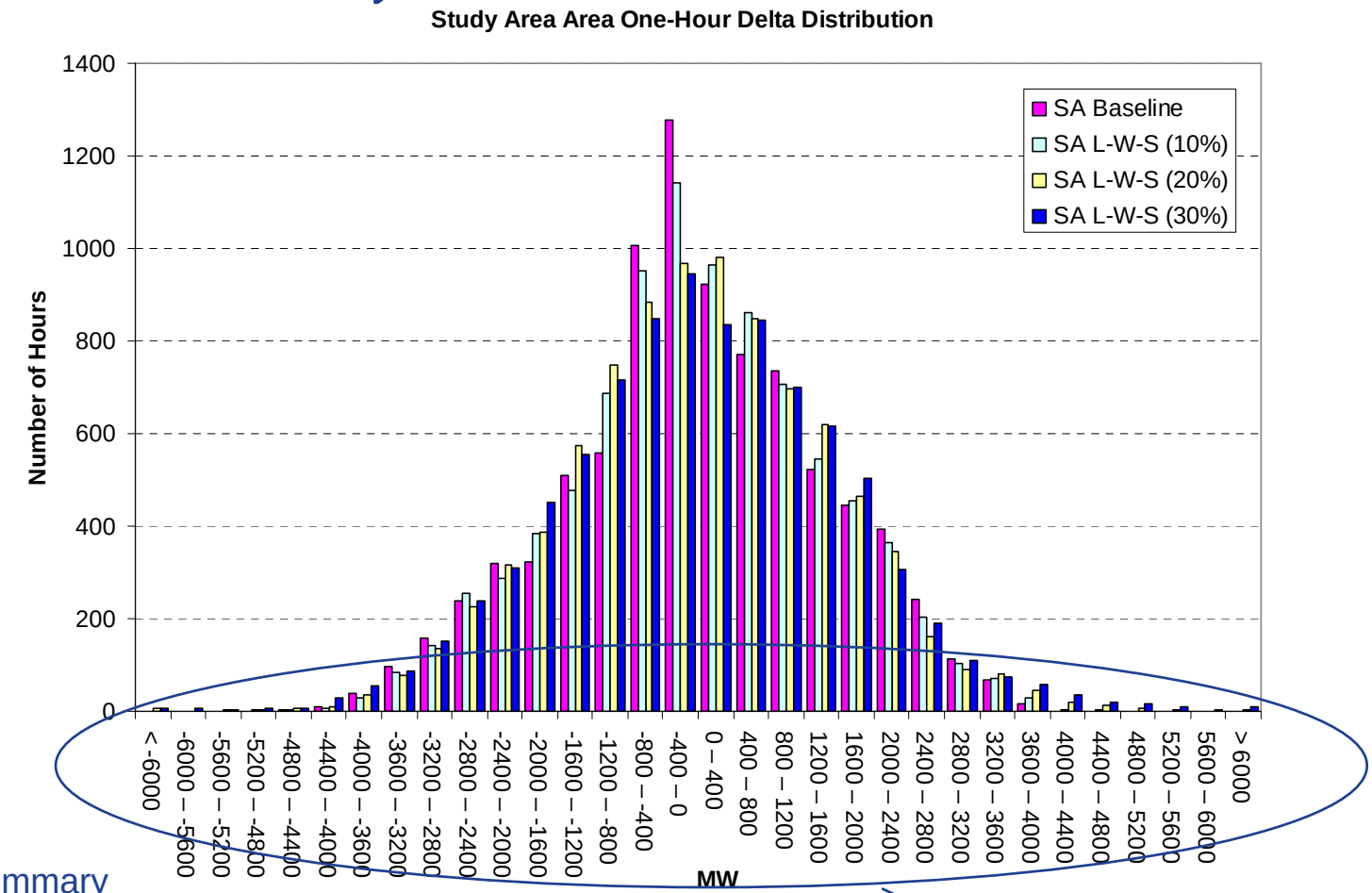
imagination at work

Timing of Maximum Daily 1-Hr Positive Deltas for Arizona
(30% In-Area Scenario)



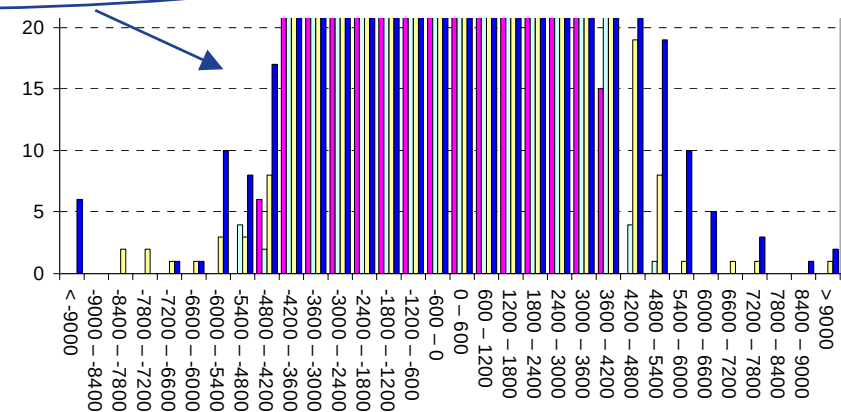
imagination at work

Distribution of Hourly Net Load Deltas

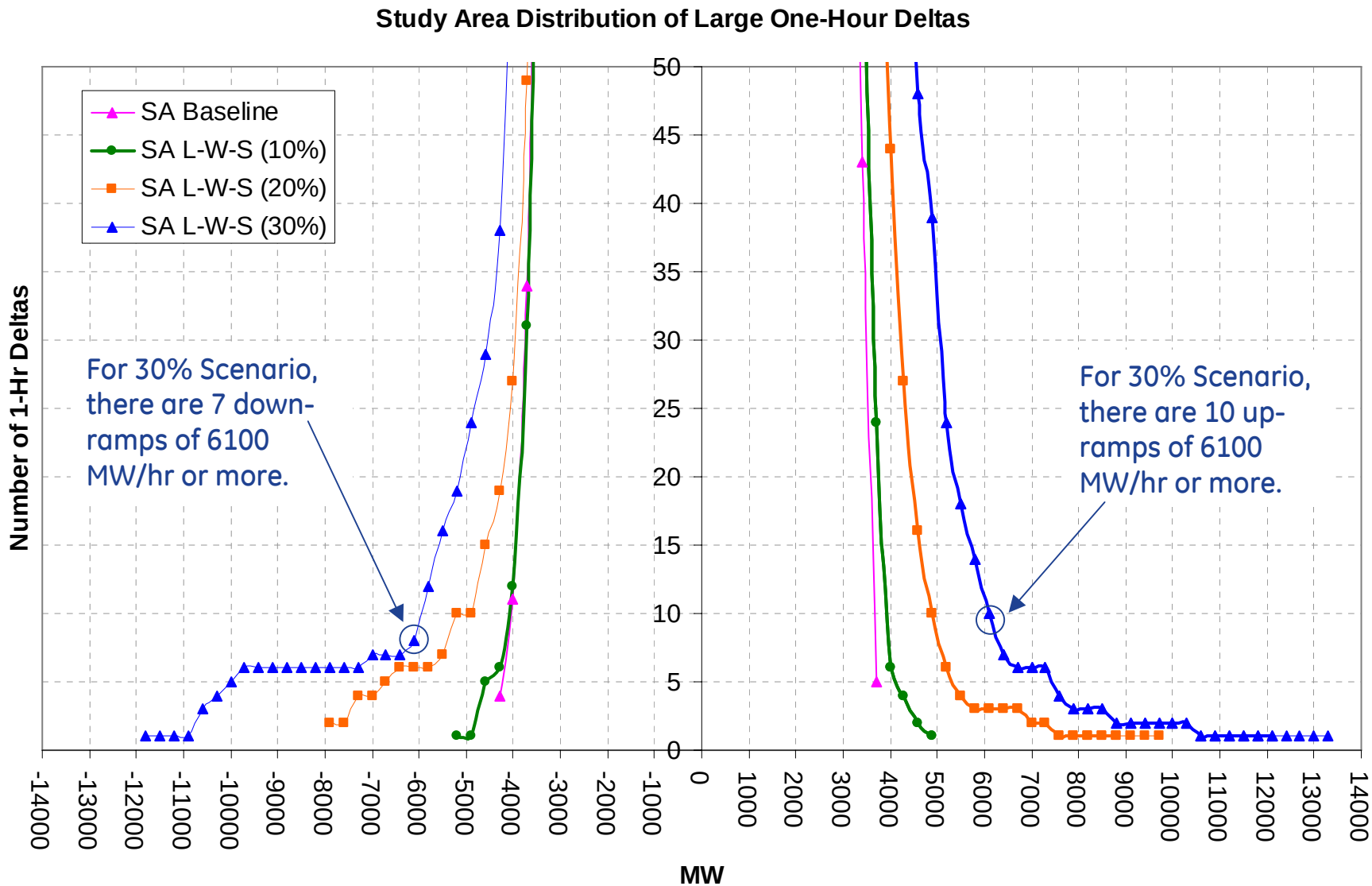


Statistical Summary

	Baseline	10% In Area	20% In Area	30% In Area
Sigma (MW)	1450.5	1438.8	1506.5	1645.1
Max Pos Delta (MW)	3857.7	4912.2	9901.6	15138.1
Max Neg Delta (MW)	-4415.7	-5391.0	-8178.9	-11823.1
No. $> \mu + 3\sigma$	0	4 (.046%)	19 (.21%)	38 (.43%)
> 4200 MW	0	5	31	80

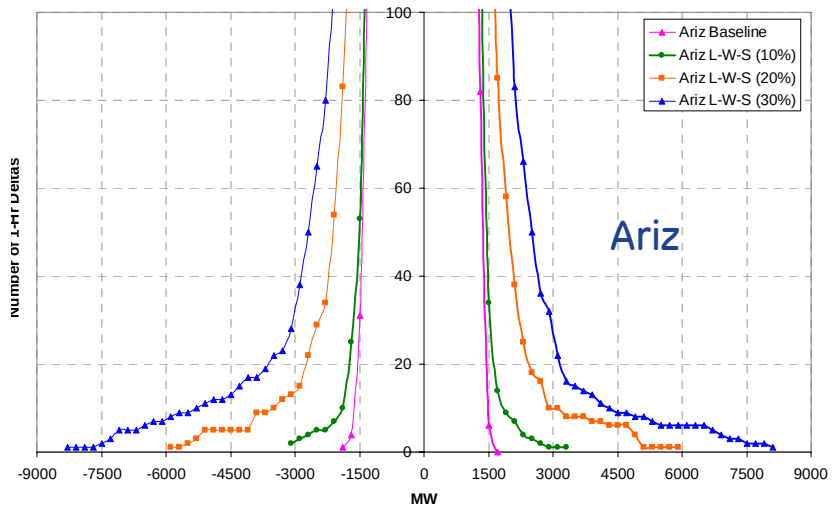


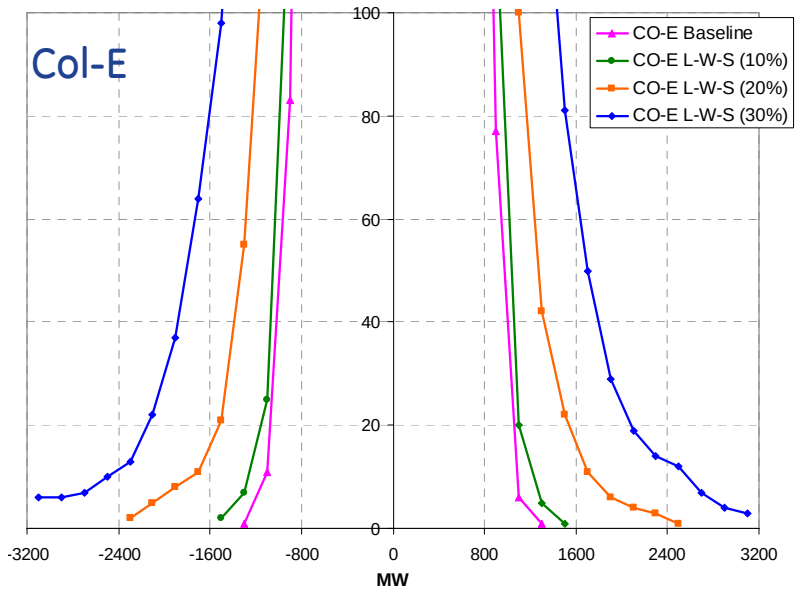
Distribution of Extreme Hourly Net Load Deltas

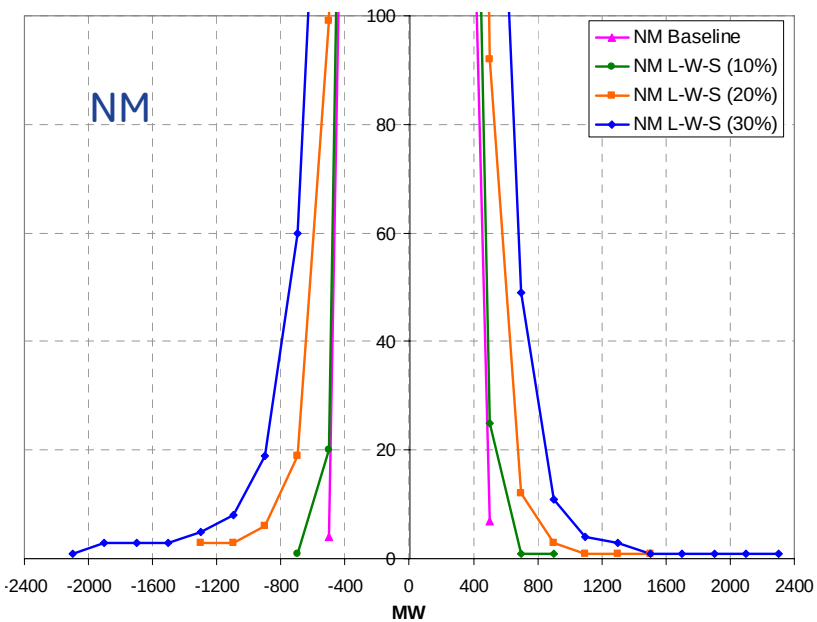


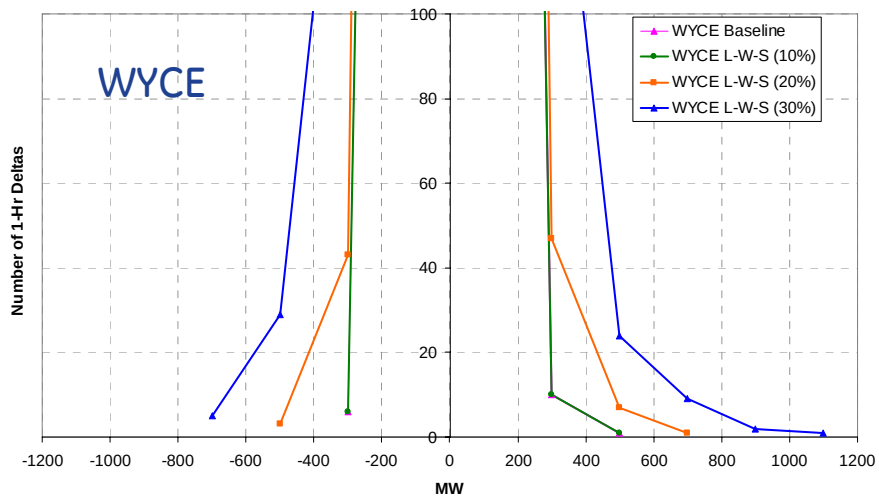
imagination at work

Distribution of Extreme Hourly Net Load Deltas for Selected Areas







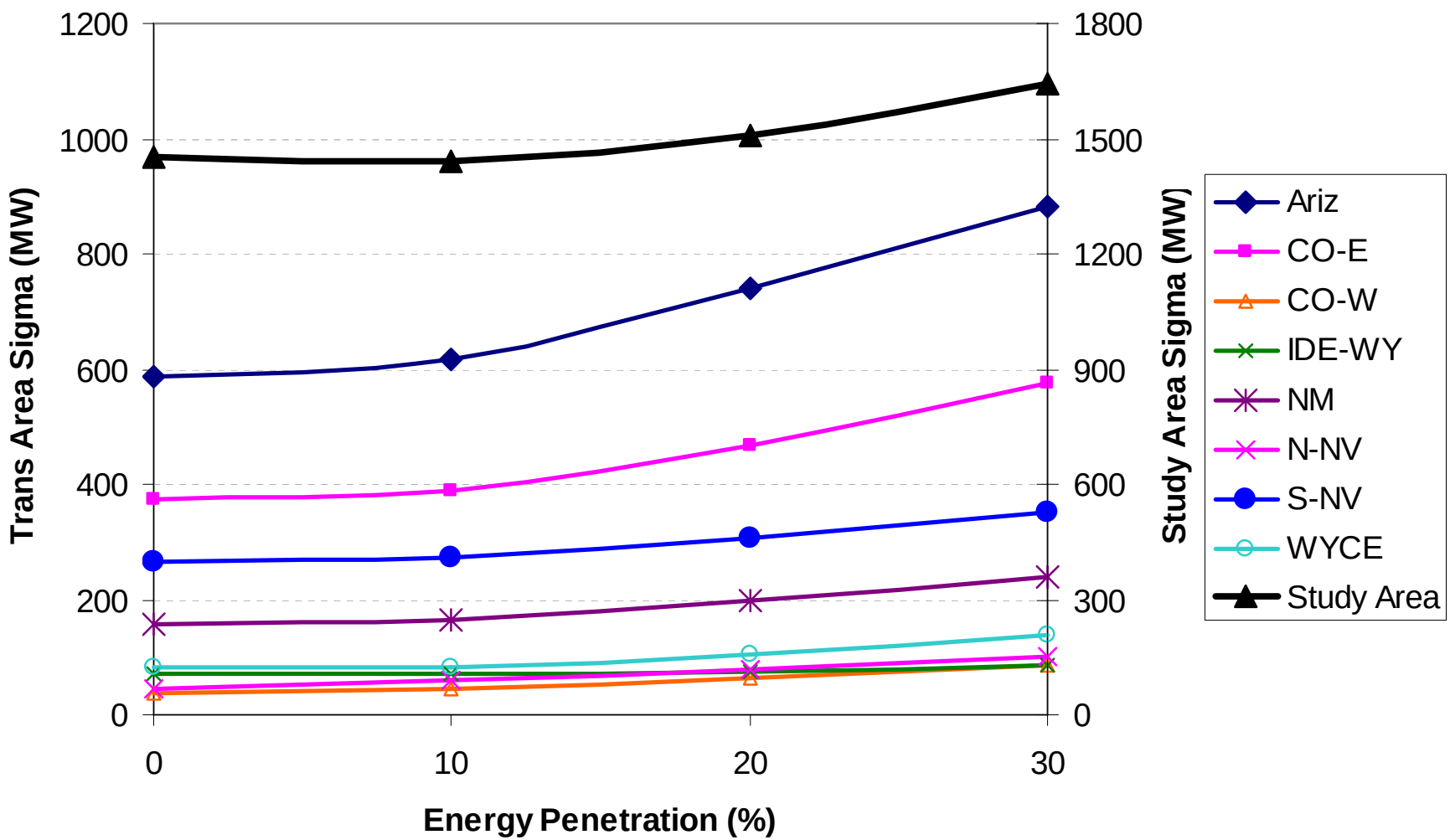


imagination at work

Summary Statistics

Area:	Ariz		CO-E		CO-W		IDE-WY		NM		N-NV		S-NV		WYCE		In Study Foot Print		Out of Footprint	
	Val	% Incr	Val	% Incr	Val	% Incr	Val	% Incr	Val	% Incr	Val	% Incr	Val	% Incr	Val	% Incr	Val	% Incr	Val	% Incr
Sigma (MW)																				
Load-alone	585.6		367.5		37.5		48.8		150.4		44.2		264.8		70.6		1453.7		3026.0	
Baseline (Existing)	585.2		372.4		37.5		70.6		155.5		44.2		264.8		82.6		1450.5		3033.6	
10% In Area Scenario	615.4	5%	390.4	5%	43.6	16%	70.8	0%	166.0	7%	58.4	32%	271.7	3%	81.9	-1%	1438.8	-1%	2963.1	-2%
20% In Area Scenario	737.1	26%	465.5	25%	64.1	71%	75.3	7%	198.8	28%	78.8	78%	304.4	15%	102.9	25%	1506.5	4%	2963.2	-2%
30% In Area Scenario	875.9	50%	577.2	55%	84.1	125%	84.0	19%	239.2	54%	101.7	130%	347.5	31%	137.2	66%	1645.1	13%	3013.7	-1%
Max Neg Delta(MW)																				
Load-alone	-2072		-1339		-180		-165		-532		-162		-1109		-247		-4294		-9268	
Baseline (Existing)	-2070		-1355		-180		-430		-599		-162		-1109		-340		-4416		-9149	
10% In Area Scenario	-3133	51%	-1600	18%	-228	27%	-435	1%	-727	21%	-246	52%	-1076	-3%	-332	-3%	-5391	22%	-9335	2%
20% In Area Scenario	-5924	186%	-2451	81%	-432	140%	-477	11%	-1382	131%	-409	153%	-1726	56%	-550	62%	-8179	85%	-9335	2%
30% In Area Scenario	-8410	306%	-3749	177%	-617	243%	-499	16%	-2188	265%	-636	292%	-2598	134%	-892	162%	-11823	168%	-12331	35%
Max Pos Delta(MW)																				
Load-alone	1604		1341		147		231		621		172		1151		389		3877		8661	
Baseline (Existing)	1602		1313		147		329		670		172		1151		520		3858		8793	
10% In Area Scenario	3419	113%	1667	27%	189	28%	329	0%	986	47%	263	53%	1107	-4%	553	6%	4912	27%	9451	7%
20% In Area Scenario	6070	279%	2637	101%	433	193%	350	6%	1639	145%	447	160%	1521	32%	815	57%	9902	157%	9451	7%
30% In Area Scenario	8182	411%	3801	189%	697	373%	388	18%	2348	250%	668	288%	2132	85%	1145	120%	15138	292%	11704	33%
No. Rises > 3*(σ_{Load})																				
Load-alone	0		9		15		21		17		5		7		50		0		0	
Baseline (Existing)	0		6		15		207		15		5		7		101		0		0	
10% In Area Scenario	10		20		59		211		56		155		14		92		4		2	
20% In Area Scenario	74		99		334		268		144		395		62		200		26		2	
30% In Area Scenario	164		228		622		355		251		654		138		460		62		14	
No. Drops > 3*(σ_{Load})																				
Load-alone	2		7		17		4		10		14		9		7		0		1	
Baseline (Existing)	2		11		17		186		15		14		9		53		2		1	
10% In Area Scenario	18		23		80		187		48		114		19		55		6		2	
20% In Area Scenario	108		124		358		243		143		406		47		188		18		2	
30% In Area Scenario	189		279		654		354		271		701		124		429		35		8	

Net Load Variability with Increasing W+S Penetration

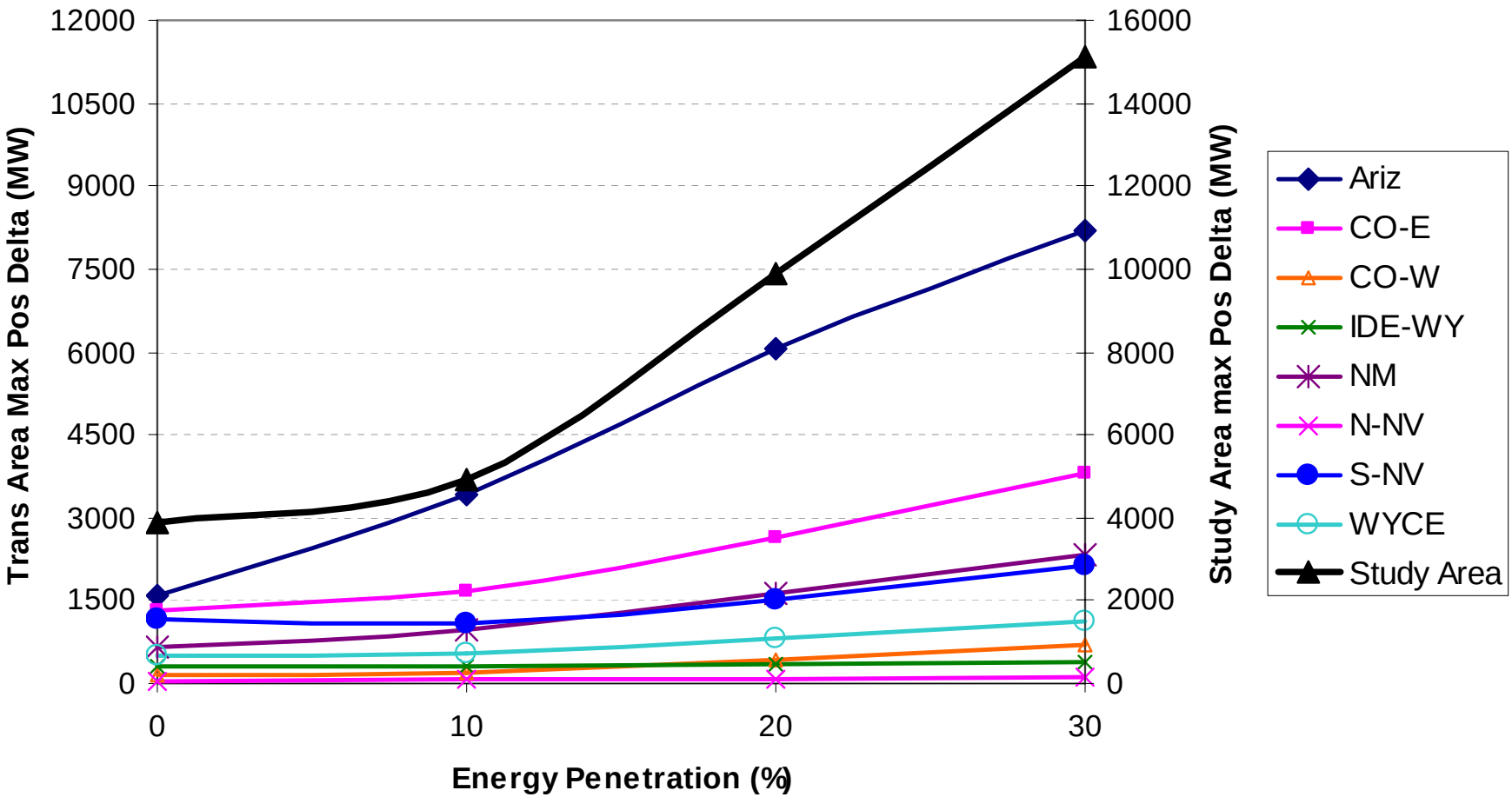


Linear increase in variability (sigma) over baseline, faster high load areas

imagination at work

Note: Study Area totals (black trace) plotted on right scale

Change in Max Delta (1-Hr Rise) with W+S Penetration



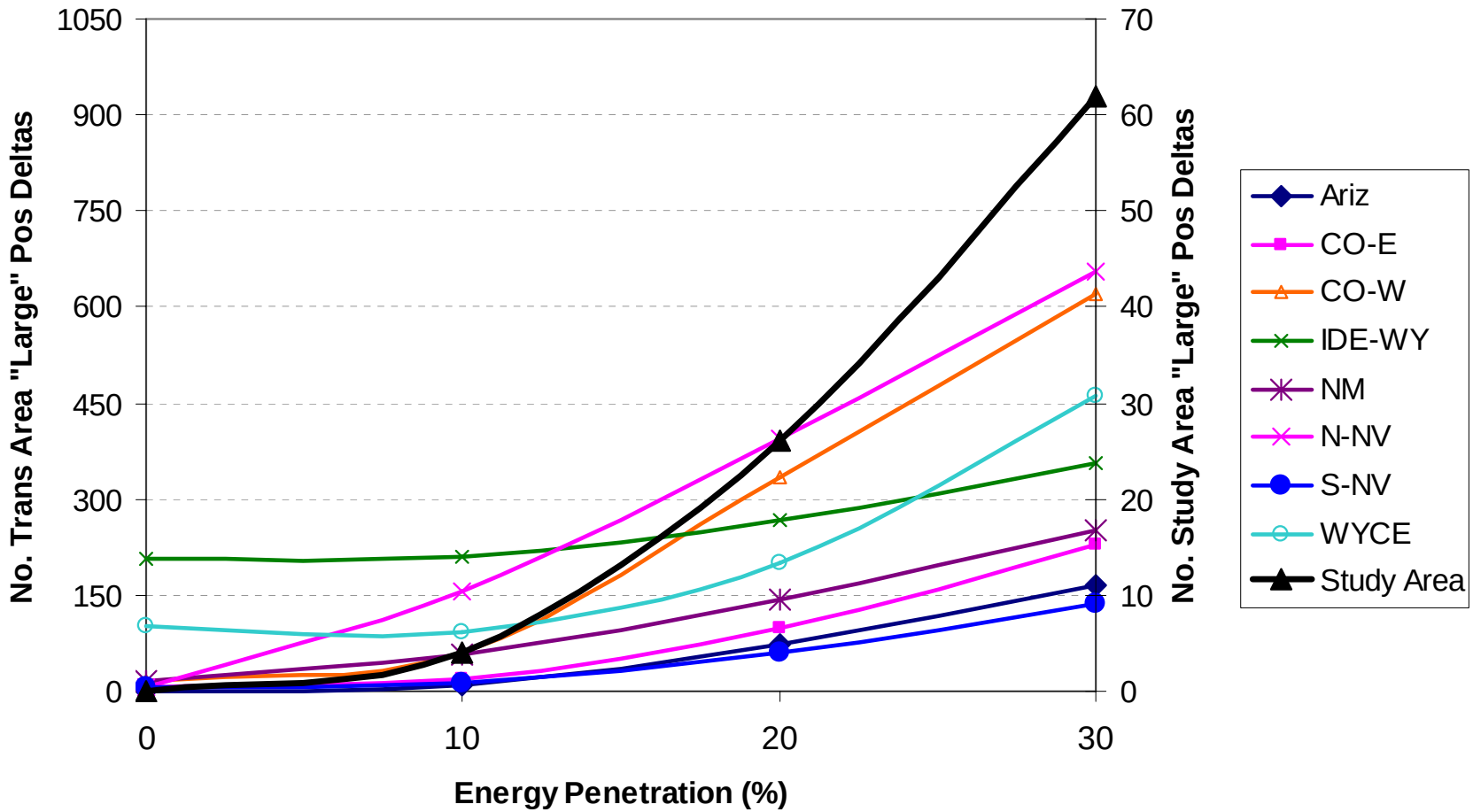
Size of largest deltas increases faster for high load areas
Max changes reduced by spatial/temporal diversity

imagination at work

Note: Study Area totals (black trace) plotted on right scale

Change in No. "Large" Deltas with W+S Penetration

("Large" Delta is defined as > $T + 3*\sigma_{Load}$)



Areas with the least load experience more rapid increases

imagination at work

Note: Study Area totals (black trace) plotted on right scale