GE
Energy

Western Wind & Solar Integration Study

TRC Conference Call
February 25, 2009

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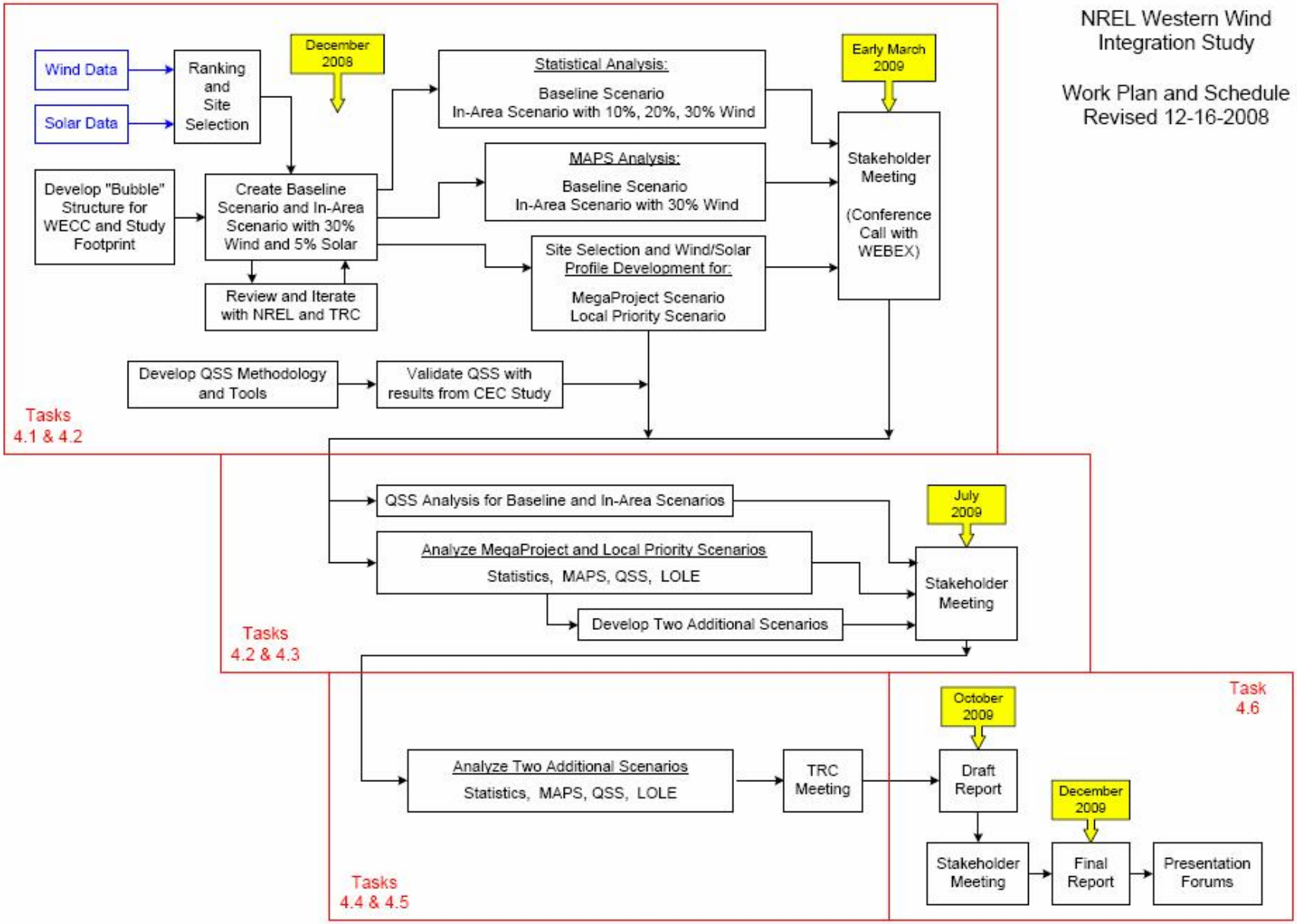
Work Plan


NREL Western Wind Integration Study
Work Plan and Schedule Revised 12-16-2008
Wind Data
Solar Data
Ranking and Site Selection
December 2008
Develop "Bubble" Structure for WECC and Study Footprint
Create Baseline Scenario and In-Area Scenario with 30% Wind and 5% Solar
Review and Iterate with NREL and TRC
Statistical Analysis:
Baseline Scenario
In-Area Scenario with 10%, 20%, 30% Wind
MAPS Analysis:
Baseline Scenario
In-Area Scenario with 30% Wind
Site Selection and Wind/Solar Profile Development for:
MegaProject Scenario
Local Priority Scenario
Early March 2009
Stakeholder Meeting
(Conference Call with WEBEX)
Develop QSS Methodology and Tools
Validate QSS with results from CEC Study
Tasks 4.1 & 4.2
QSS Analysis for Baseline and In-Area Scenarios
Analyze MegaProject and Local Priority Scenarios
Statistics, MAPS, QSS, LOLE
Develop Two Additional Scenarios
July 2009
Stakeholder Meeting
Tasks 4.2 & 4.3
Analyze Two Additional Scenarios
Statistics, MAPS, QSS, LOLE
TRC Meeting
Tasks 4.4 & 4.5
October 2009
Draft Report
Stakeholder Meeting
December 2009
Final Report
Presentation Forums
Task 4.6

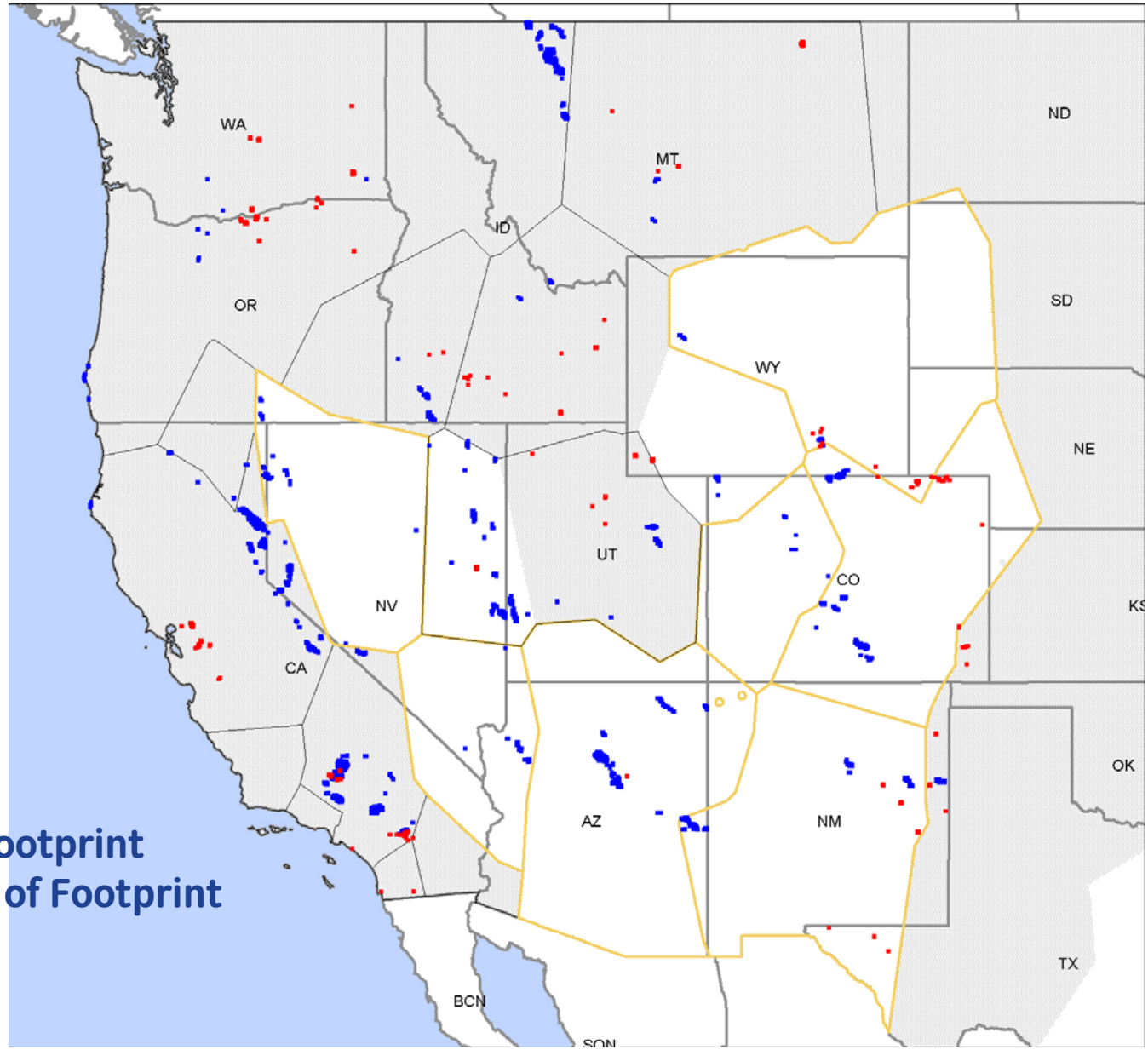
Progress Since August 2008 Stakeholder Meeting

- Received New Wind Data
- Revised In-Area Selection
- Revised Statistical Analysis on In-Area Scenario
- Revised MAPS Analysis on In-Area Scenario
- Revised Mega Project Scenario
- Revised Local Priority Scenario
- QSS Algorithm Development & Test

Revised In-Area Selection

- New Wind Data
- Additional Exclusions Based on Proximity to Recreation Areas
- Site Selection Includes Average of 3 Year's Capacity Factors
- In-Footprint Redefined to Better Match WestConnect
  - Include SW Wyoming, Eastern Nevada
- Site Selection Based on State Boundaries not Transmission Areas
  - Each Site Then Assigned to an In-State Transmission Area
- Four In-Area Scenarios
  - Baseline – Preselected Wind Only
  - 10% Wind – 10% Wind, 1% Solar In Footprint
    (10% Wind, 1% Solar Out of Footprint)
  - 20% Wind – 20% Wind, 3% Solar In Footprint
    (10% Wind, 1% Solar Out of Footprint)
  - 30% Wind - 30% Wind, 5% Solar In Footprint
    (20% Wind, 3% Solar Out of Footprint)

Wind Selected for 30% In-Area Scenario



30% Wind In Footprint
20% Wind Out of Footprint

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30% In-Area Scenario Energy Summary

In Footprint

Areas	Load Energy (GWh)	Wind Energy (GWh)	Wind # Sites (Used/Available)	CSP with Storage Energy (GWh)	CSP with Storage # Sites (Used/Available)	PV Energy (GWh)	PV # Sites (Used/Available)	Total Renewable Energy (GWh)	
Arizona	99,437	29,897	374 / 1091	3,735	10 / 38	1,548	10 / 16	35,180	
Colorado East	61,372	18,453	188 / 1673	2,252	7 / 58	1,038	7 / 13	21,743	
Colorado West	8,708	2,622	30 / 68	564	2 / 8	151	1 / 11	3,337	
New Mexico	31,260	9,382	93 / 3062	1,421	4 / 35	473	3 / 19	11,276	
Nevada	57,505	17,290	235 / 1591	2,161	6 / 45	773	5 / 10	20,224	
Wyoming	27,697	8,414	78 / 8912	0	0 / 0	420	3 / 10	8,834	
In Footprint	**285,979**	**86,058**	**998 / 16397**	**10,133**	**29 / 184**	**4,403**	**29 / 79**	**100,594**	**35.2 %**

Out of Footprint

Areas	Load Energy (GWh)	Wind Energy (GWh)	Wind # Sites (Used/Available)	CSP with Storage Energy (GWh)	CSP with Storage # Sites (Used/Available)	PV Energy (GWh)	PV # Sites (Used/Available)	Total Renewable Energy (GWh)	
COB	1,759	394	6 / 155	294	1 / 22	142	1 / 2	830	
Idaho East	6,907	1,406	26 / 185	0	0 / 0	142	1 / 8	1,548	
Idaho Southwest	17,962	3,658	50 / 448	0	0 / 0	132	1 / 5	3,790	
Montana	14,143	2,873	35 / 1194	0	0 / 0	127	1 / 14	3,000	
Northern California	128,935	25,812	393 / 472	2,726	8 / 26	1,117	8 / 30	29,655	
Northwest	178,359	35,733	431 / 3195	0	0 / 0	1,645	13 / 54	37,378	
Southern California	224,197	44,890	483 / 1916	8,957	23 / 85	2,050	13 / 39	55,897	
Utah	38,022	7,658	91 / 554	937	3 / 24	303	2 / 14	8,898	
Out of Footprint	**610,284**	**122,424**	**1515 / 8119**	**12,914**	**35 / 157**	**5,658**	**40 / 166**	**140,996**	**23.1 %**

30% In-Area Scenario Power Summary

In Footprint

	Load		Wind			CSP with Storage			PV			Total Renewable		
	Minimum	Maximum	Rating	Penetration		Rating	Penetration		Rating	Penetration		Rating	Penetration	
Areas	(MW)	(MW)	(MW)	% Min	%Max	(MW)	% Min	% Max	(MW)	% Min	% Max	(MW)	% Min	% Max
Arizona	6,995	23,051	11,220	160%	49%	1,000	14%	4%	1,000	14%	4%	13,220	189%	57%
Colorado East	4,493	11,589	5,640	126%	49%	700	16%	6%	700	16%	6%	7,040	157%	61%
Colorado West	712	1,526	900	126%	59%	200	28%	13%	100	14%	7%	1,200	169%	79%
New Mexico	2,571	5,320	2,790	109%	52%	400	16%	8%	300	12%	6%	3,490	136%	66%
Nevada	3,863	12,584	7,050	183%	56%	600	16%	5%	500	13%	4%	8,150	211%	65%
Wyoming	2,369	4,016	2,340	99%	58%	0	0%	0%	300	13%	7%	2,640	111%	66%
In Footprint	**21,249**	**58,087**	**29,940**	**141%**	**52%**	**2,900**	**14%**	**5%**	**2,900**	**14%**	**5%**	**35,740**	**168%**	**62%**

Out of Footprint

	Load		Wind			CSP with Storage			PV			Total Renewable		
	Minimum	Maximum	Rating	Penetration		Rating	Penetration		Rating	Penetration		Rating	Penetration	
Areas	(MW)	(MW)	(MW)	% Min	%Max	(MW)	% Min	% Max	(MW)	% Min	% Max	(MW)	% Min	% Max
COB	138	294	180	131%	61%	100	73%	34%	100	73%	34%	380	276%	129%
Idaho East	460	1,365	780	170%	57%	0	0%	0%	100	22%	7%	880	191%	64%
Idaho Southwest	1,188	3,592	1,500	126%	42%	0	0%	0%	100	8%	3%	1,600	135%	45%
Montana	1,149	2,337	1,050	91%	45%	0	0%	0%	100	9%	4%	1,150	100%	49%
Northern California	10,297	28,319	11,790	114%	42%	800	8%	3%	800	8%	3%	13,390	130%	47%
Northwest	14,278	30,953	12,930	91%	42%	0	0%	0%	1,300	9%	4%	14,230	100%	46%
Southern California	9,557	26,864	14,490	152%	54%	2,300	24%	9%	1,300	14%	5%	18,090	189%	67%
Utah	2,263	7,274	2,730	121%	38%	300	13%	4%	200	9%	3%	3,230	143%	44%
Out of Footprint	**46,328**	**119,696**	**45,450**	**98%**	**38%**	**3,500**	**8%**	**3%**	**4,000**	**9%**	**3%**	**52,950**	**114%**	**44%**

$$\text{Penetration} = \frac{\text{Wind Plant MW Rating}}{\text{Load MW}}$$

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Statistical Analysis on In-Area Scenario

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

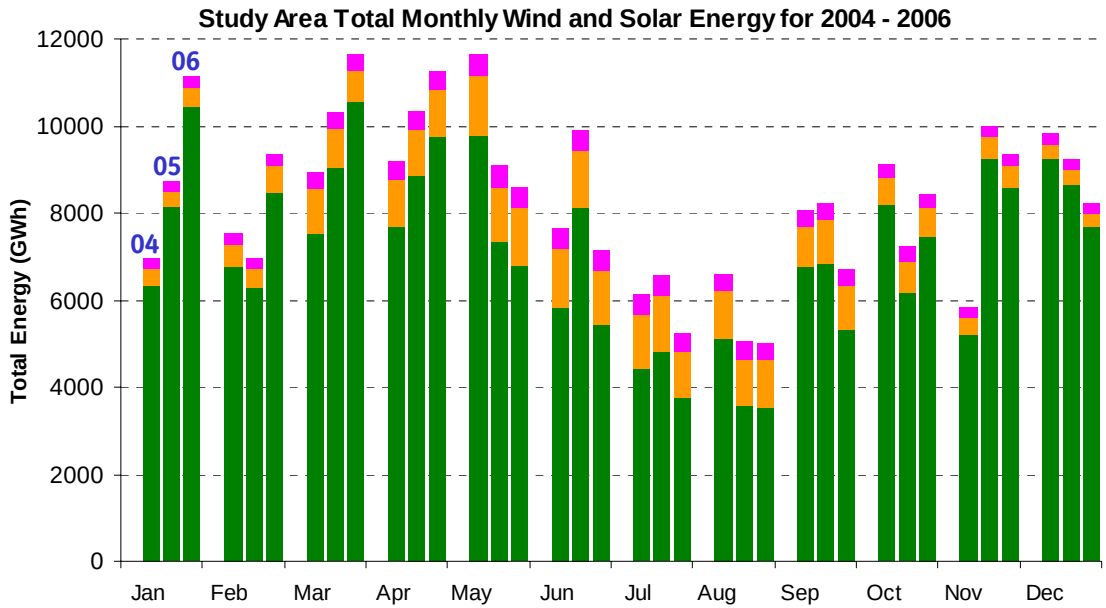
- Net load is the instantaneous system consumer load, minus the generation output of wind and solar
- Net load is the amount of generation required from dispatchable units
- The statistical analysis highlights net load, instead of the wind or solar output in isolation, because some amount of the variations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

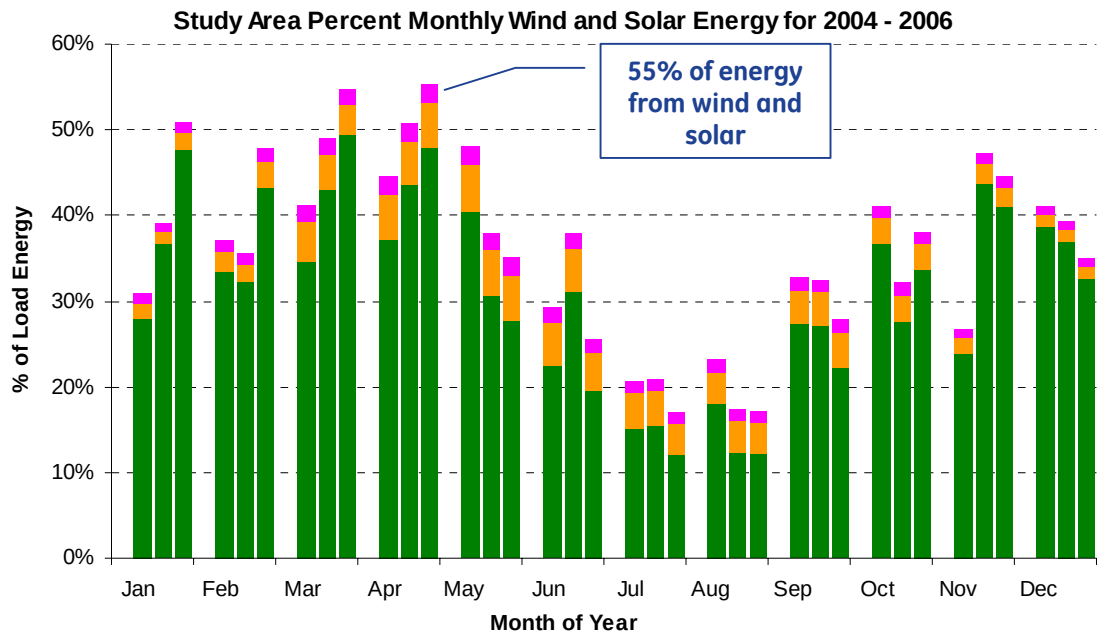
Key issues are:

- 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

Study Area Monthly Energy from Wind and Solar for 2004 - 2006
(30% In Area Scenario)





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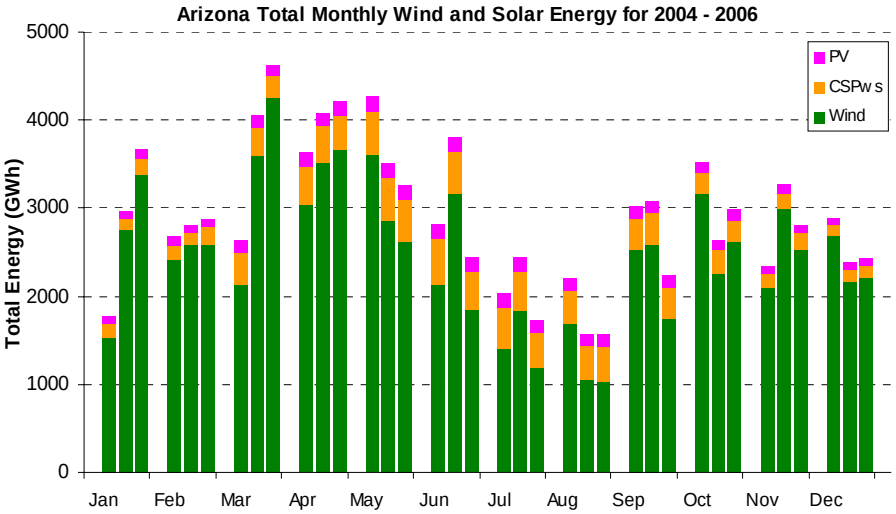
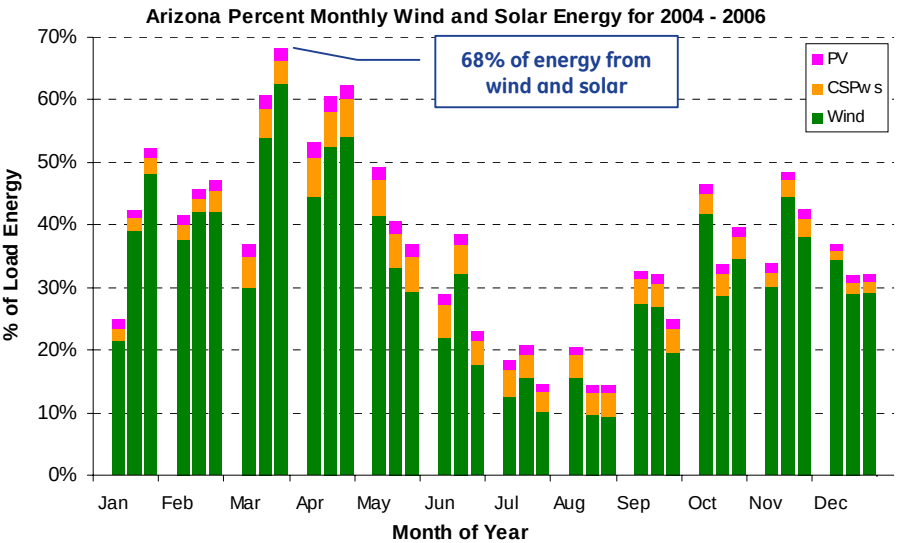
State Monthly Energy from Wind and Solar for 2004 - 2006

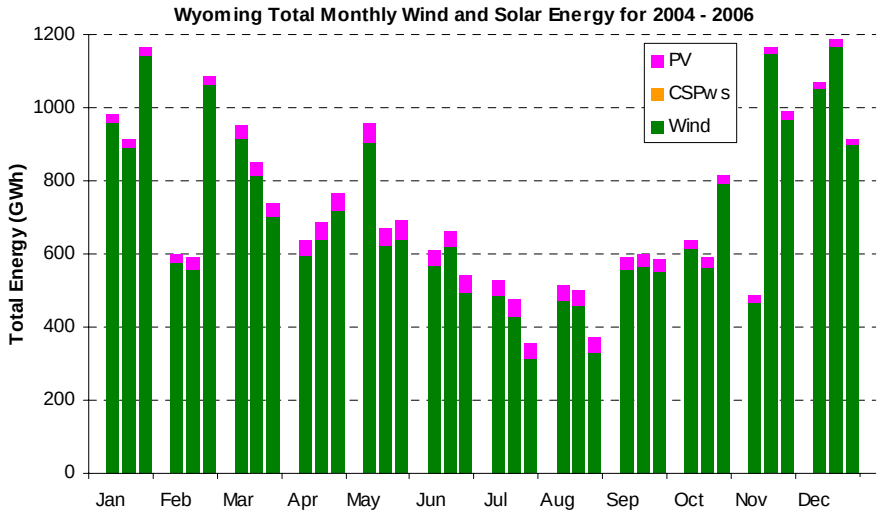
(30% In Area Scenario)

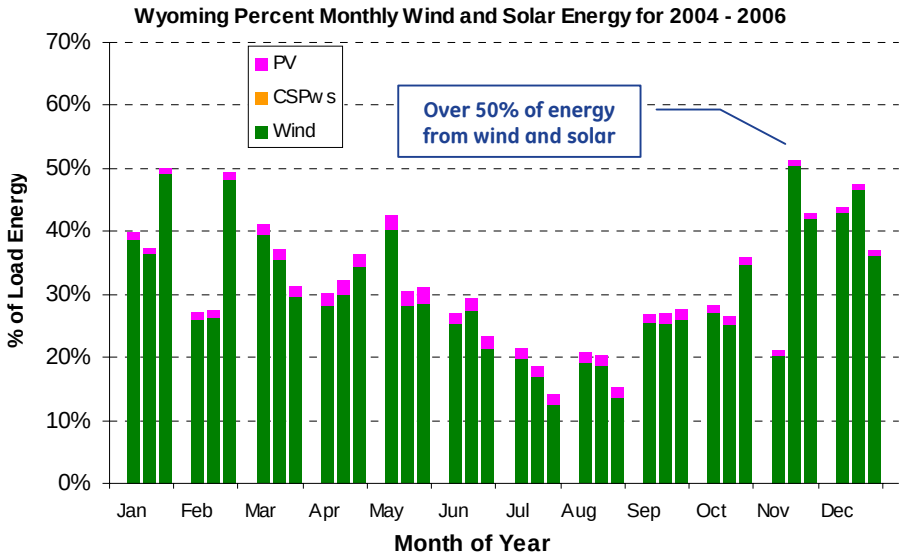
Arizona





Wyoming





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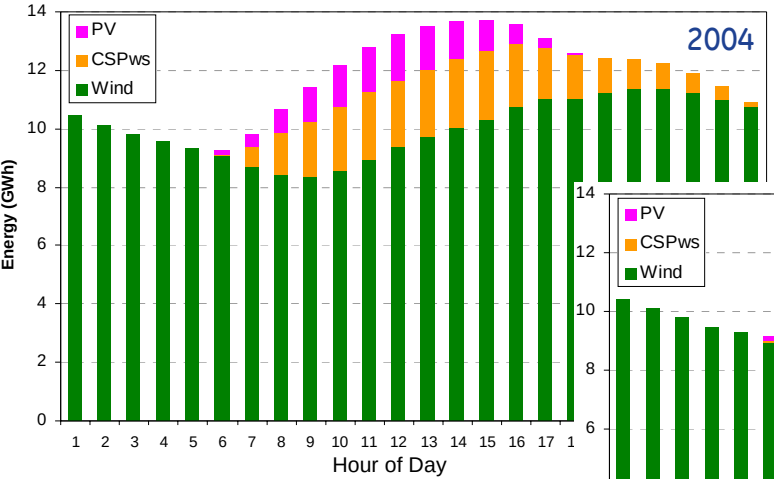
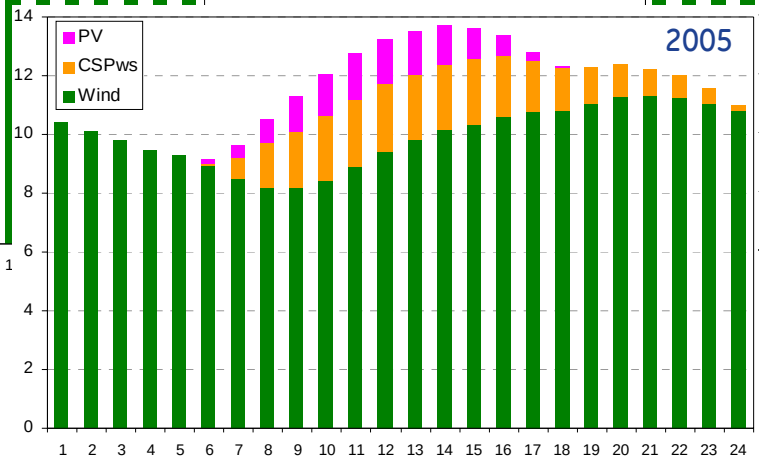
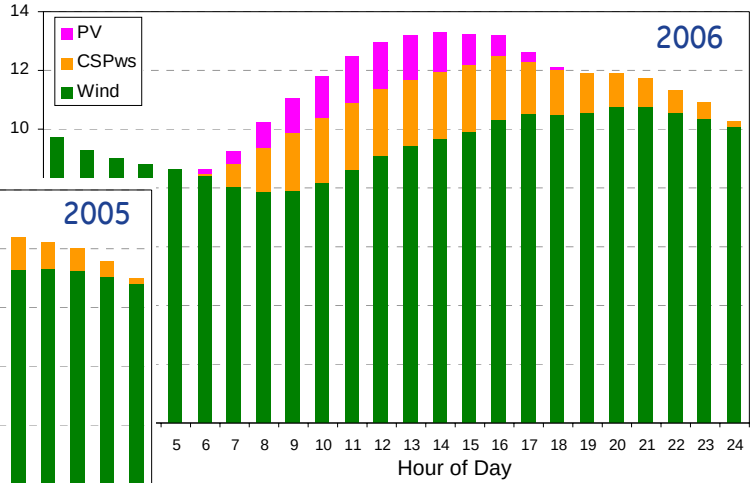
Study Area Average Daily Energy from Wind and Solar for 04 - 06

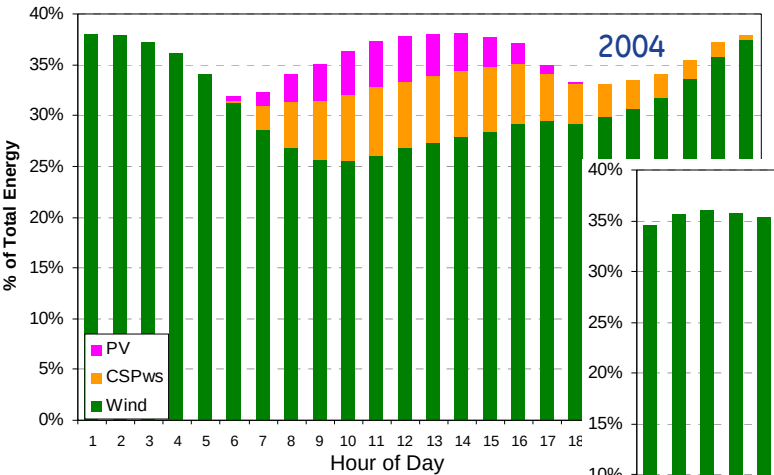
(30% In Area Scenario)

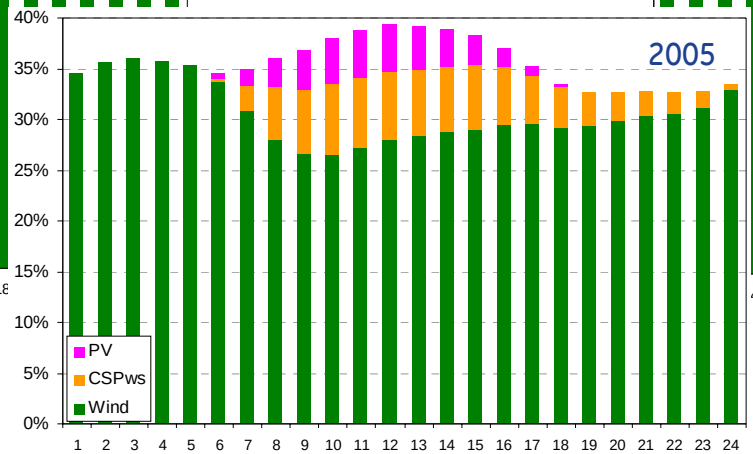


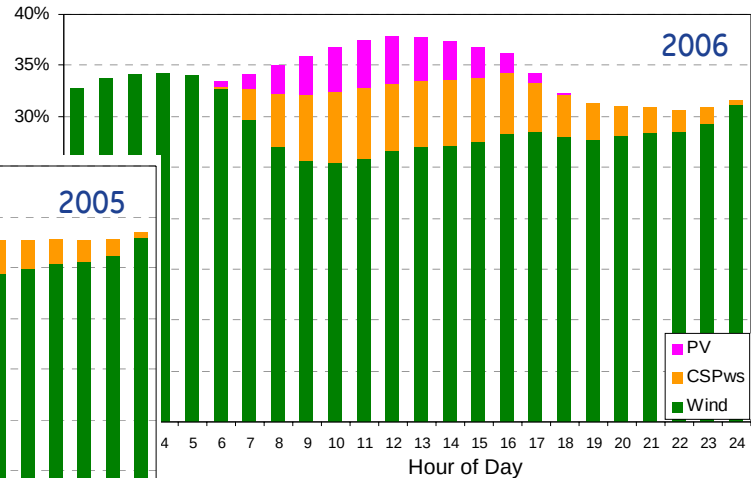




Study Area Average Energy by hour, from Wind and Solar

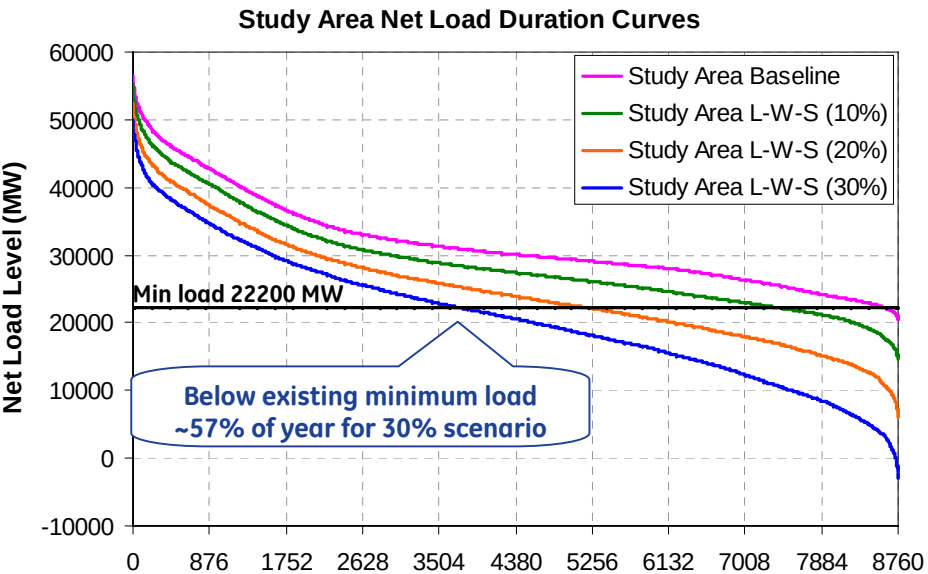


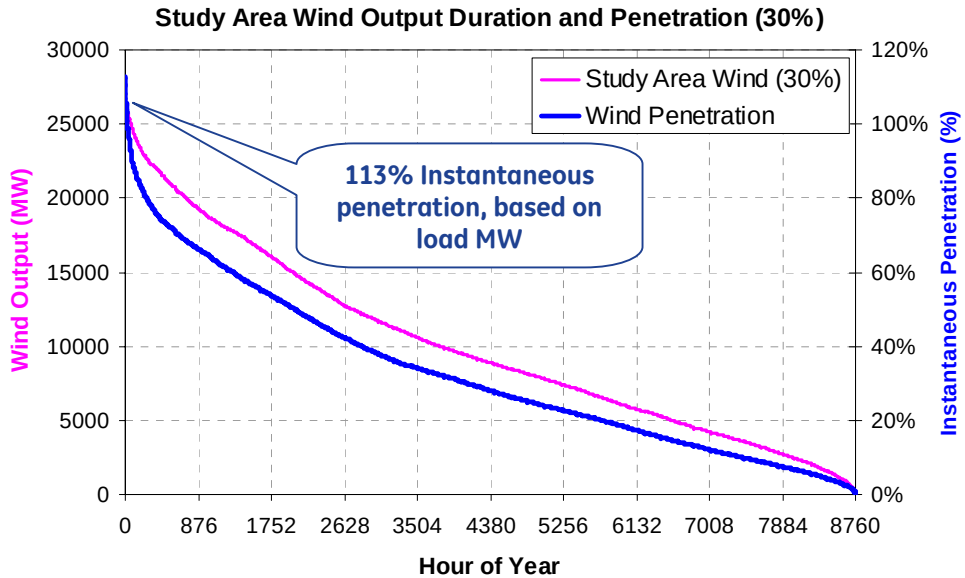


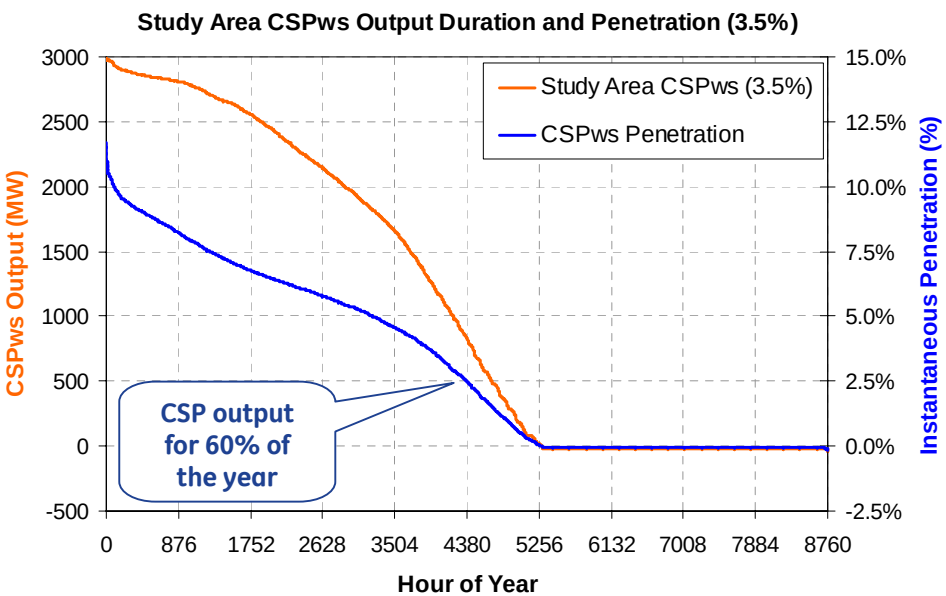


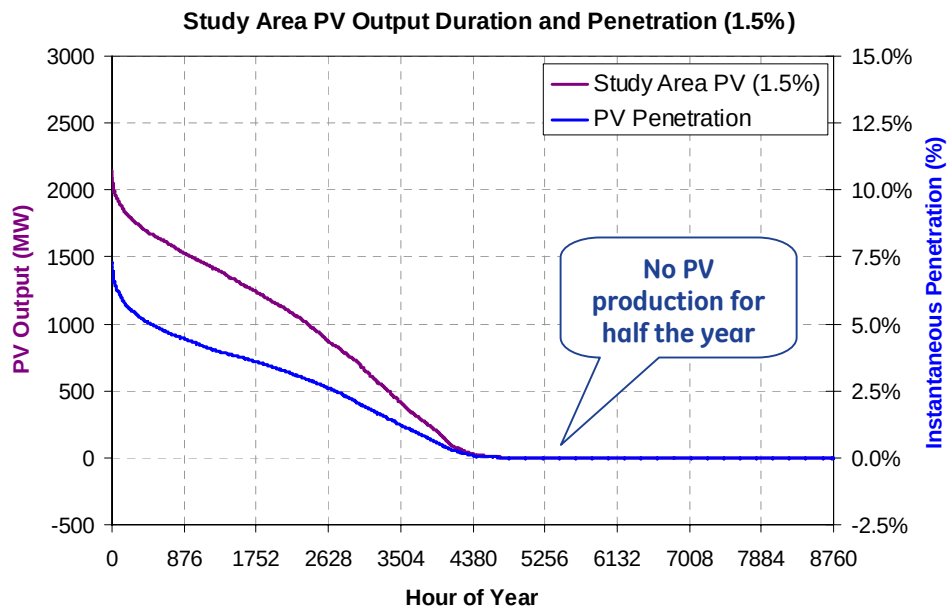
Study Area Average Percent Energy by hour, from Wind and Solar

Net Load Duration, Wind and Solar Penetration Over Year 2006

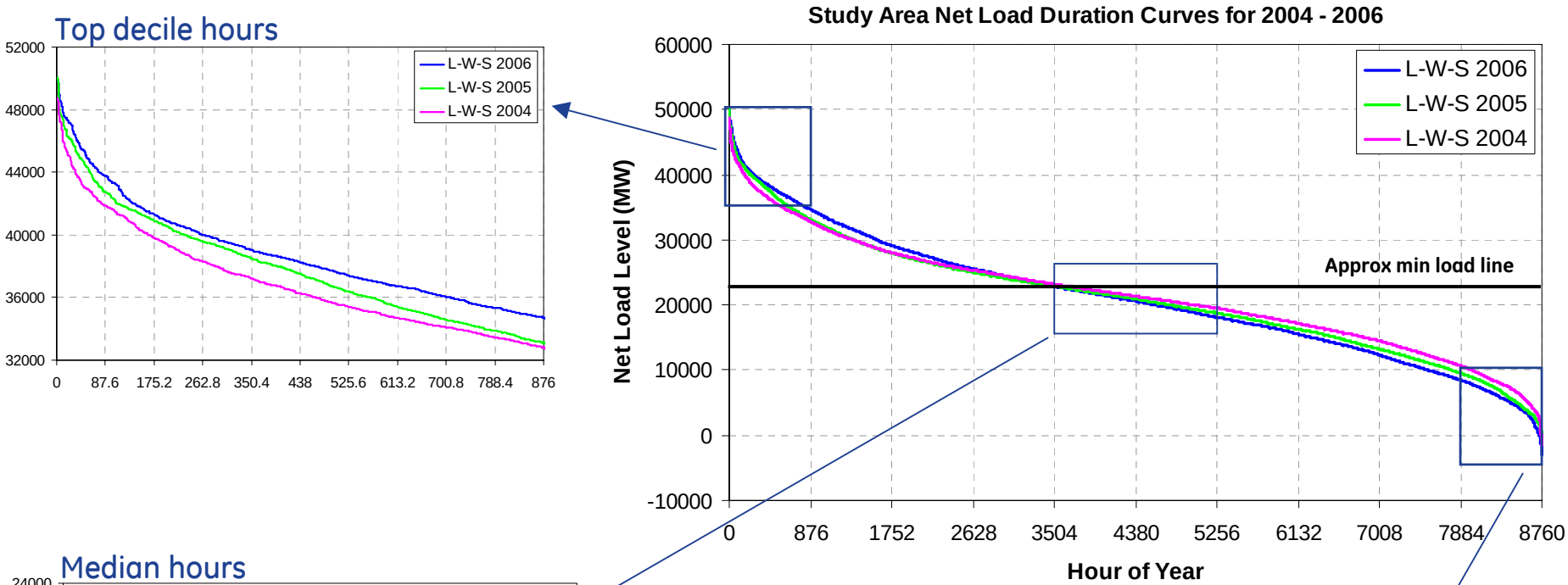


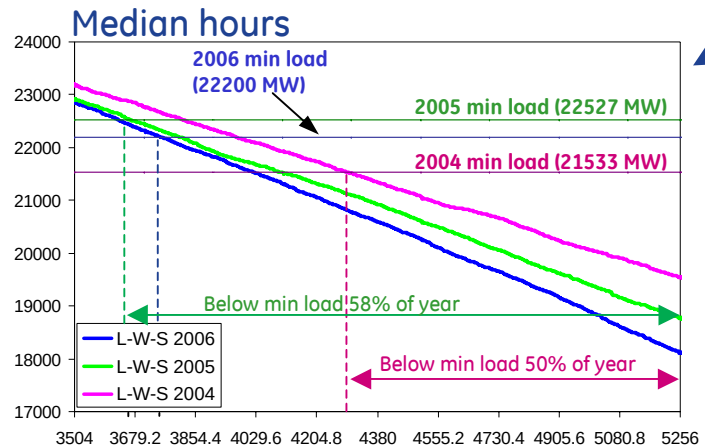


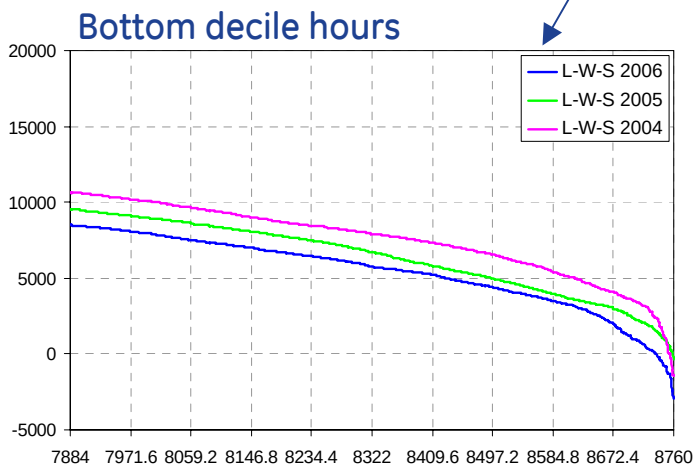




Study Area Net Load Duration for 2004 - 2006
(30% In Area Scenario)







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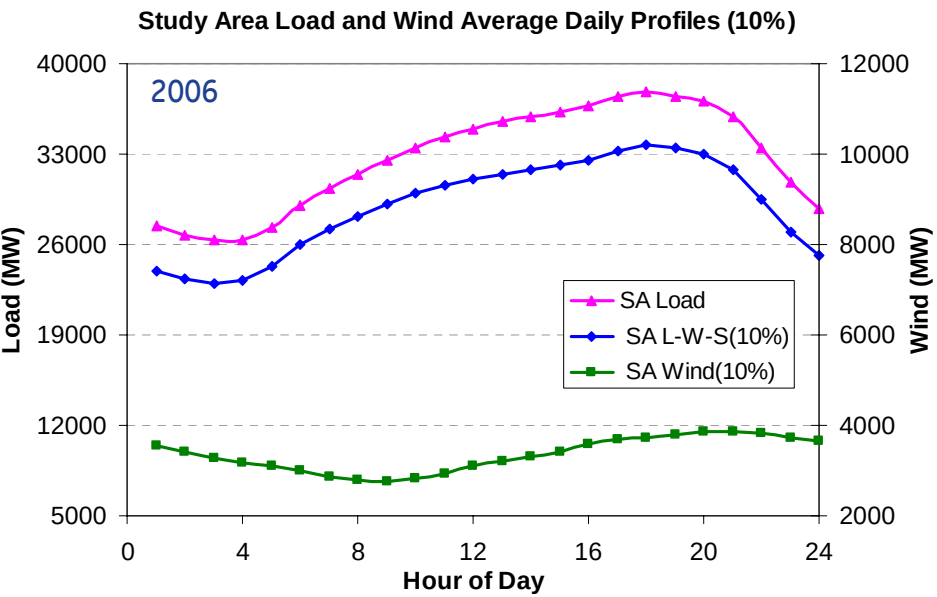
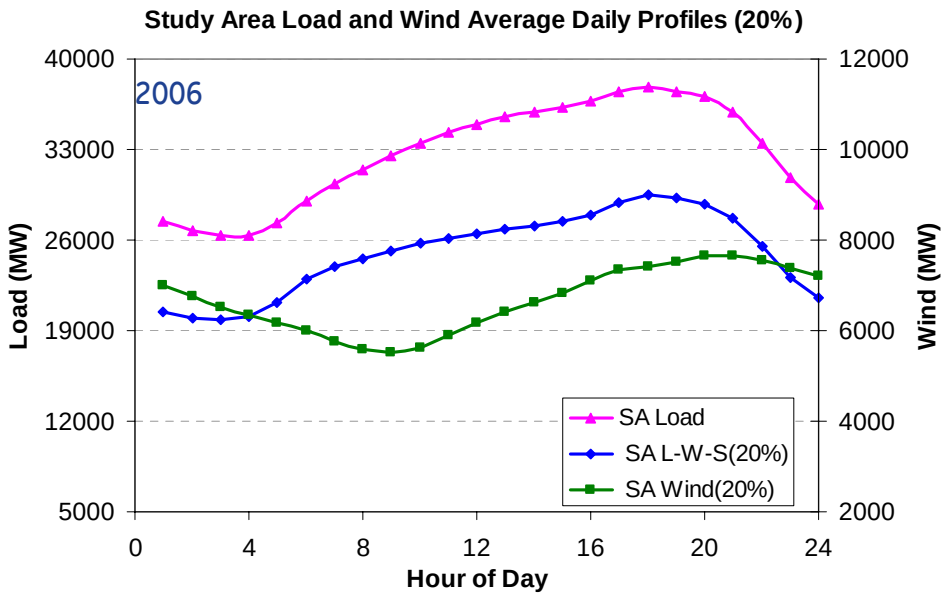
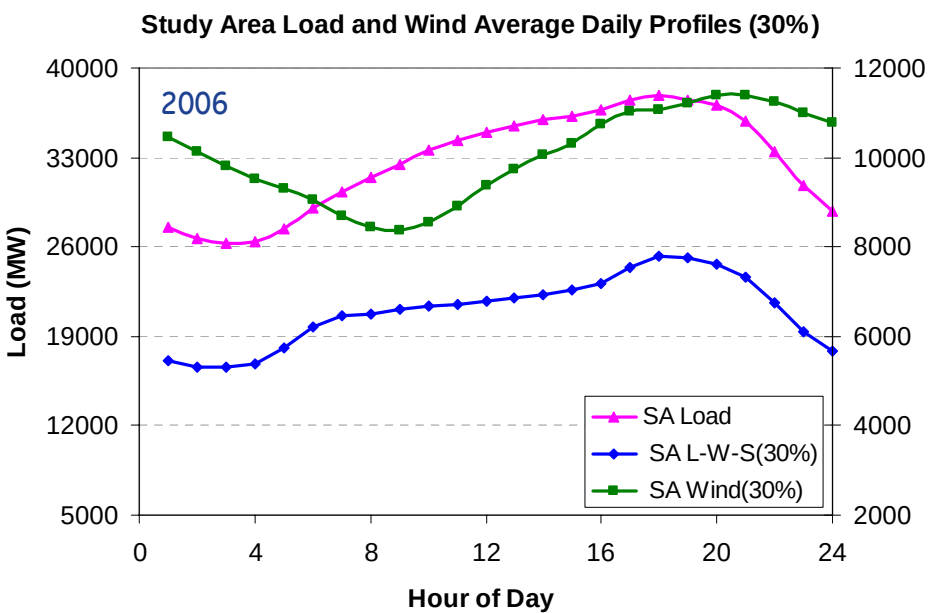
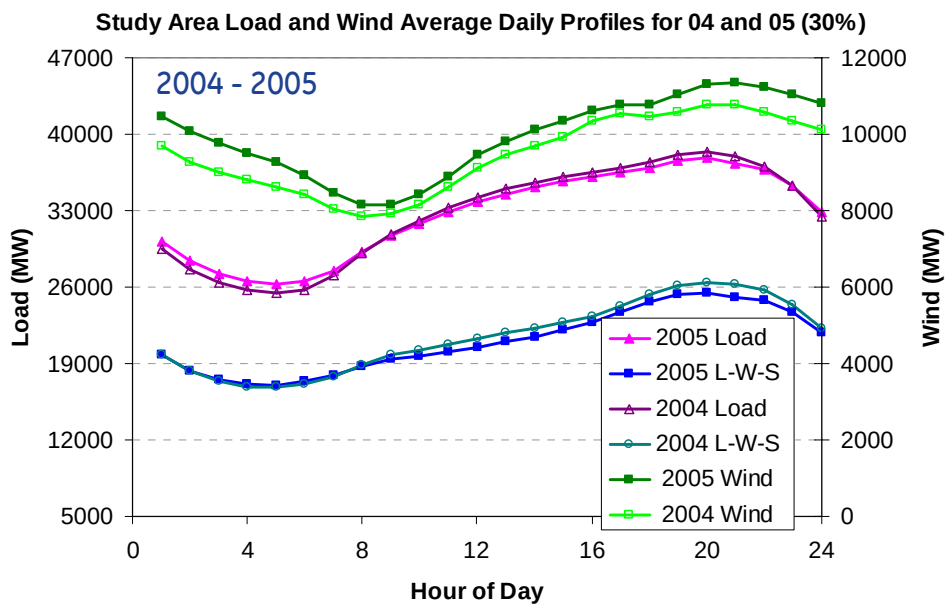
Study Area Load and Wind Average Daily Profiles

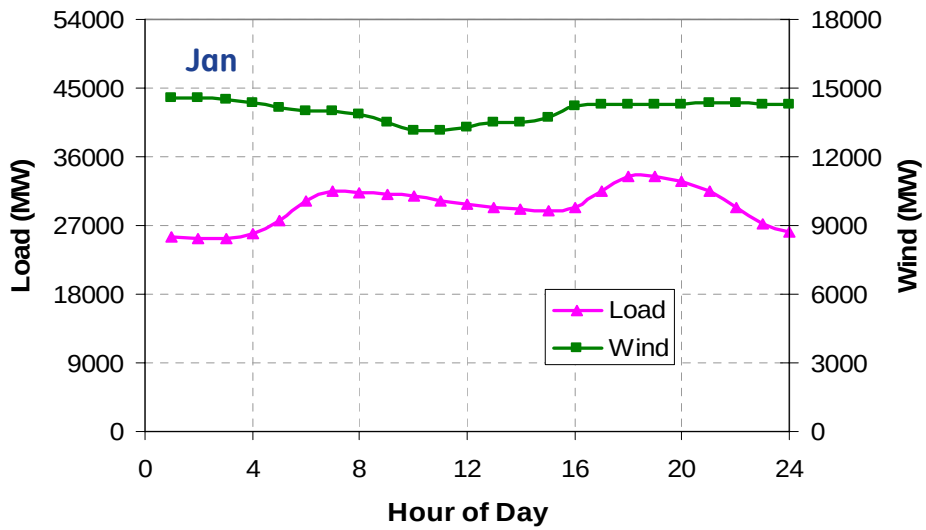


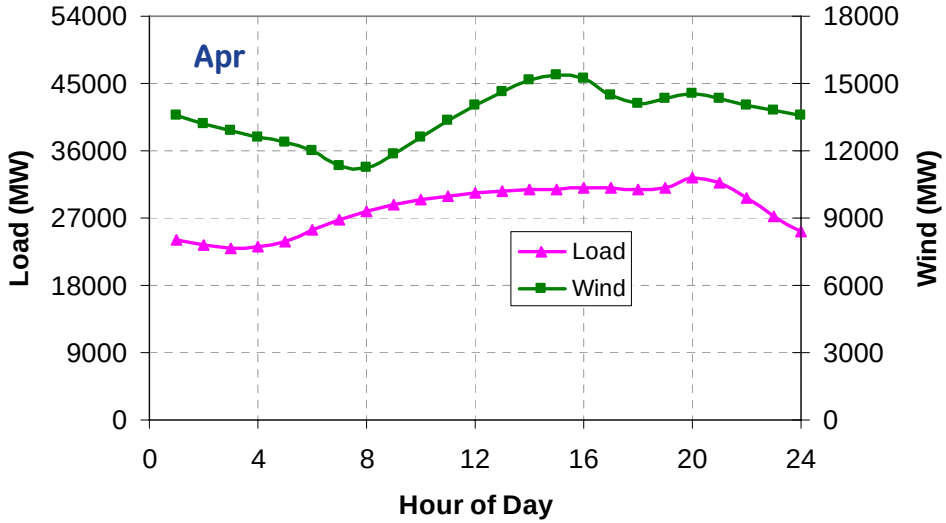


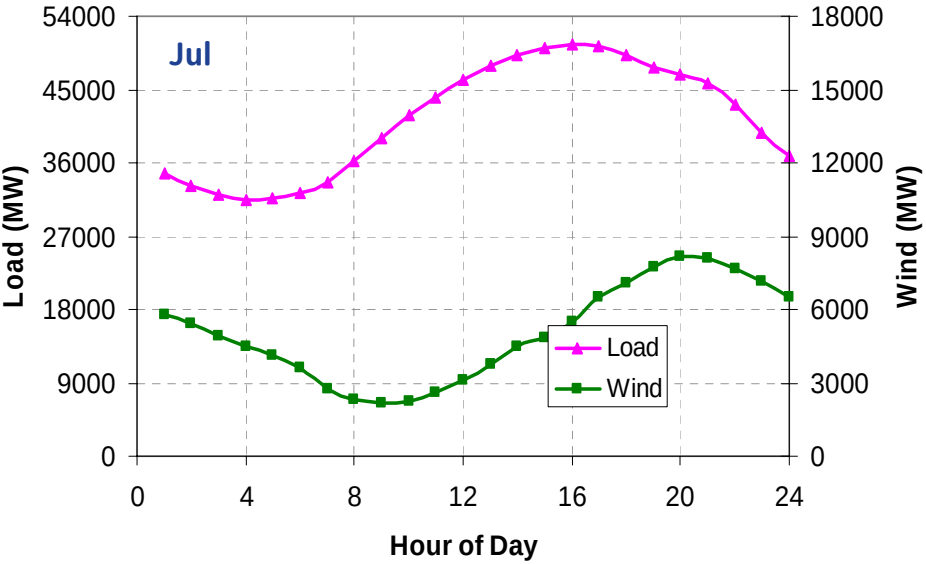


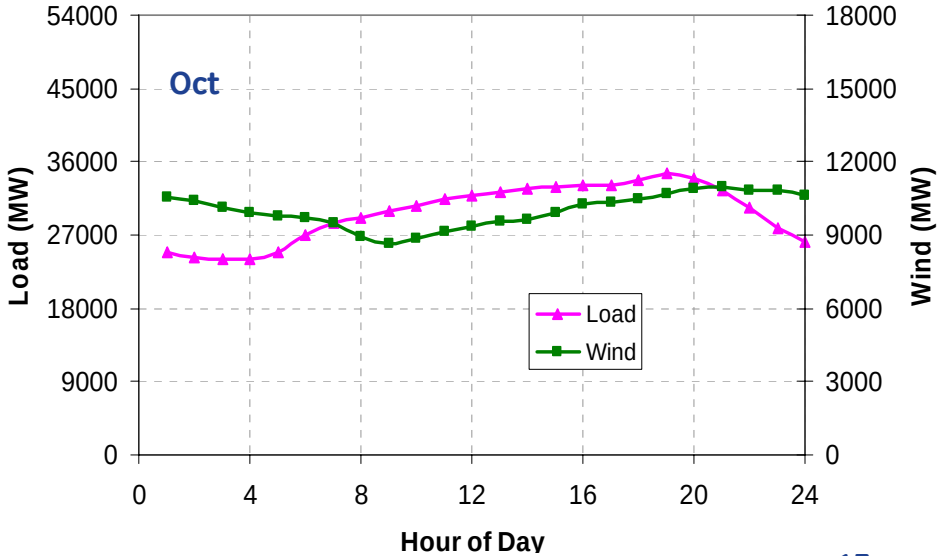


Study Area Load and Wind Average Daily Profiles By Seasonal Month for 2006
(30% In Area Scenario)

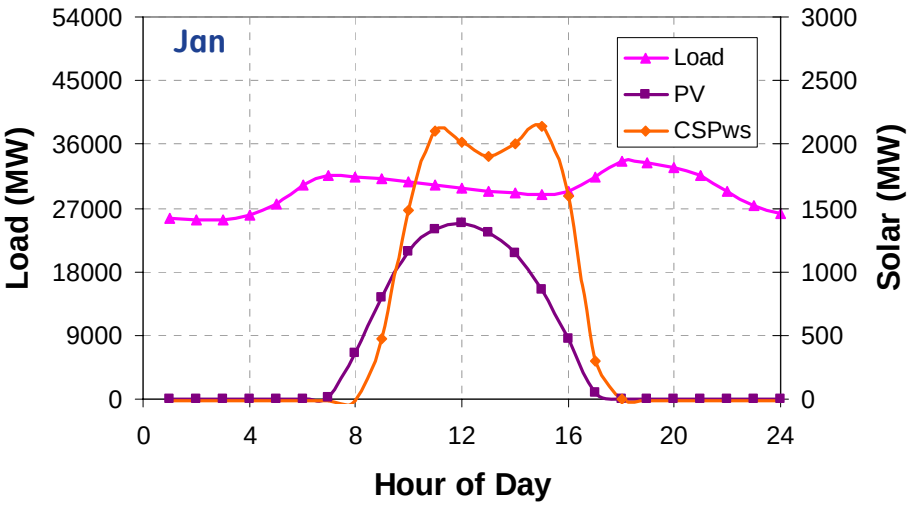


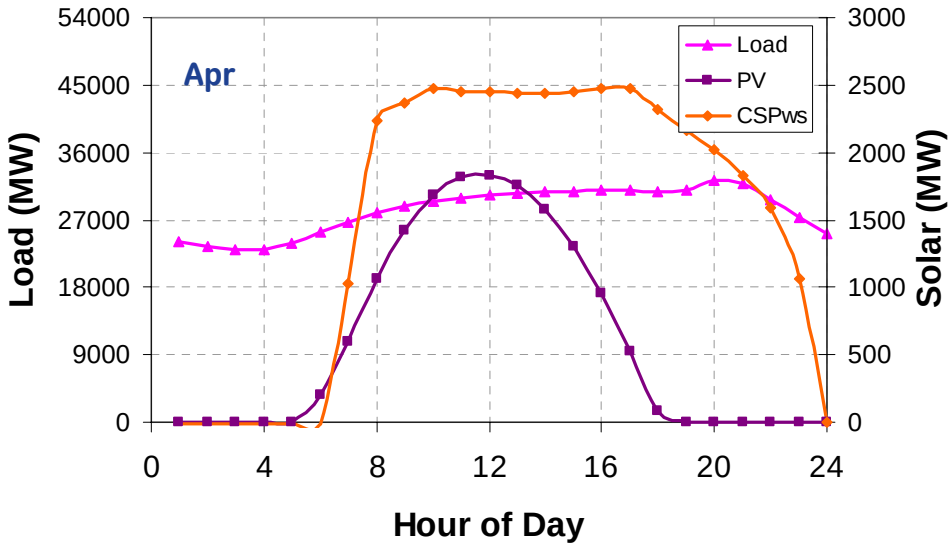


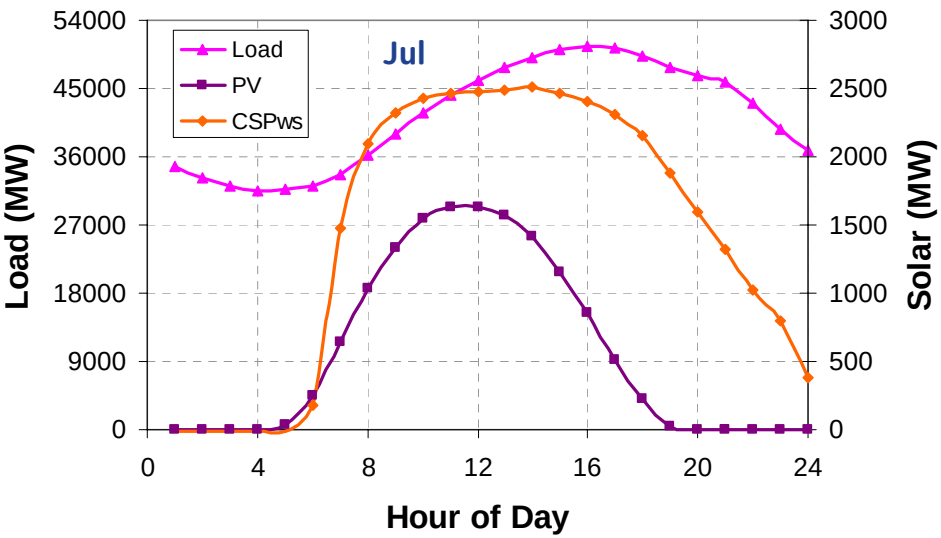


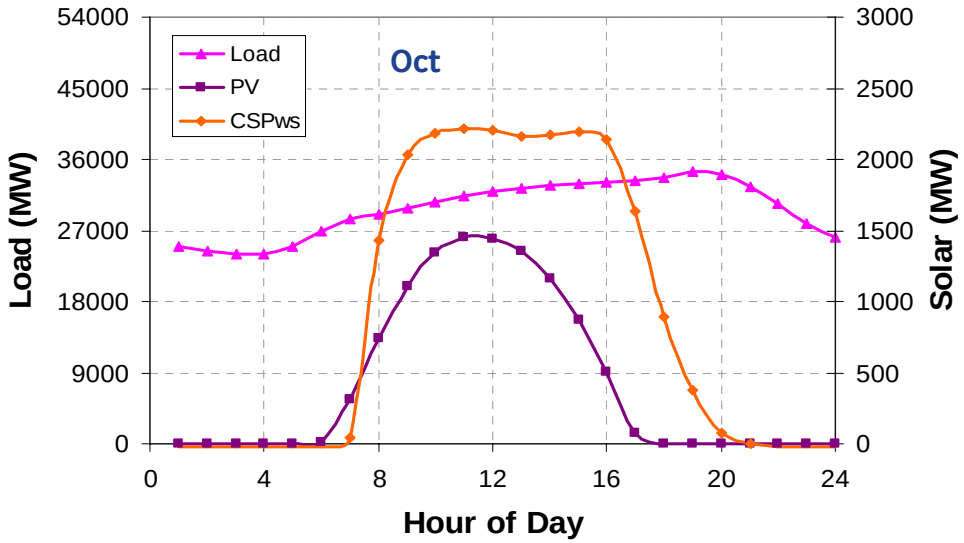


Study Area CSPws and PV Average Daily Profiles By Seasonal Month for 2006
(30% In Area Scenario)









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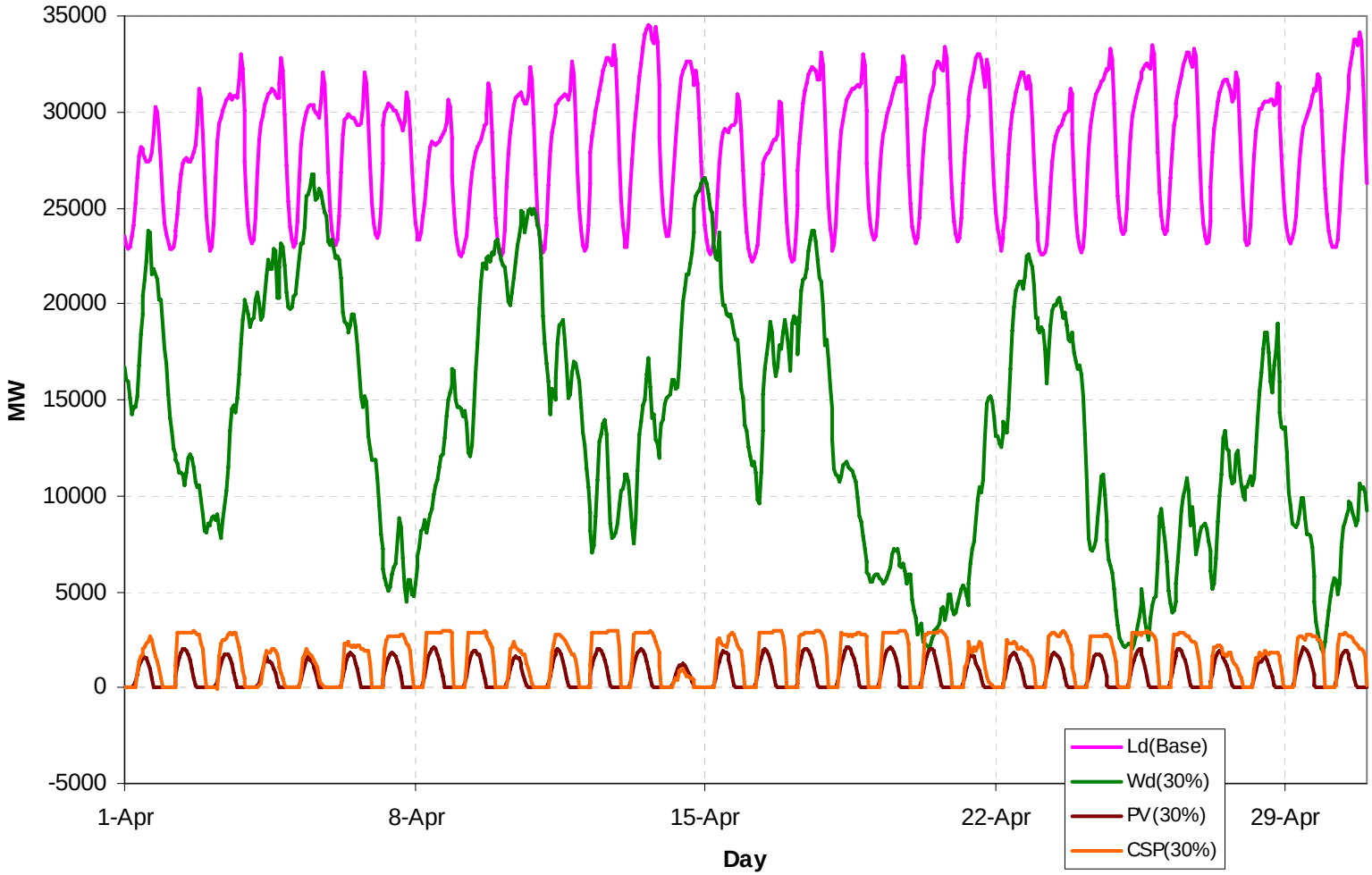
Study Area Total Load, Wind and Solar Variation Over Month of April (30% in Area Scenario)



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

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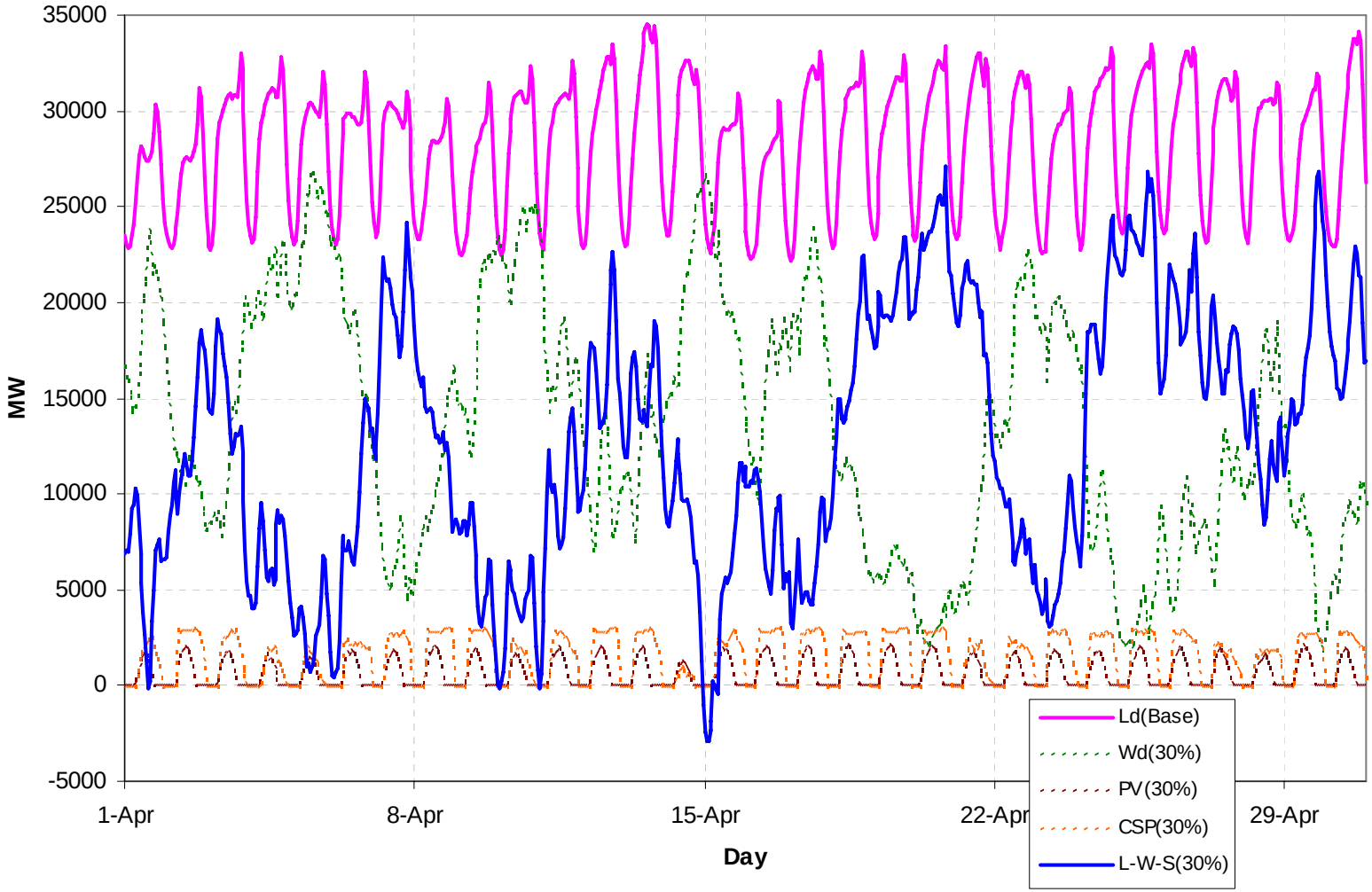
Study Area Total Load, Wind and Solar Variation Over Month of April (30% in Area Scenario)



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

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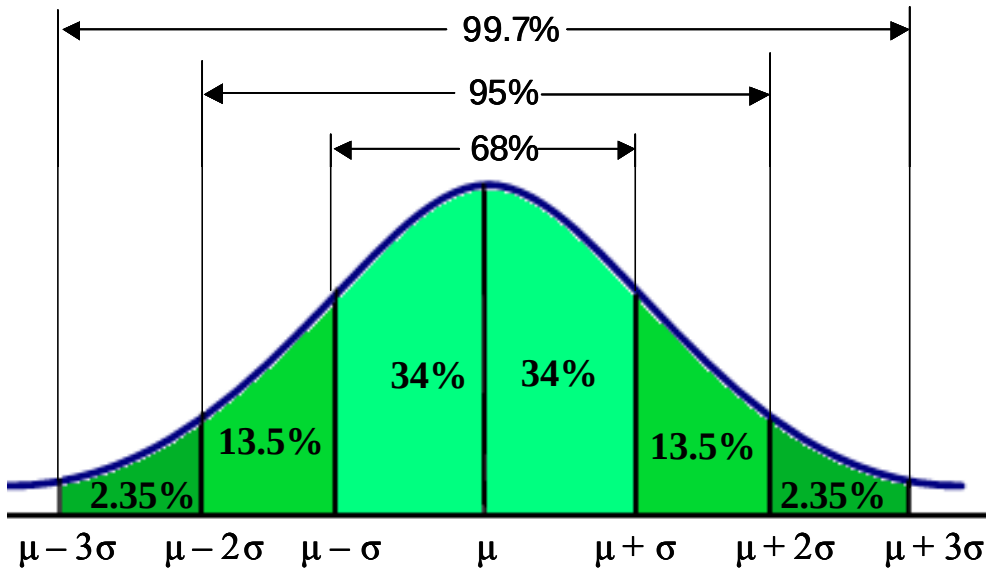
Period-to-Period Variability Analysis

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



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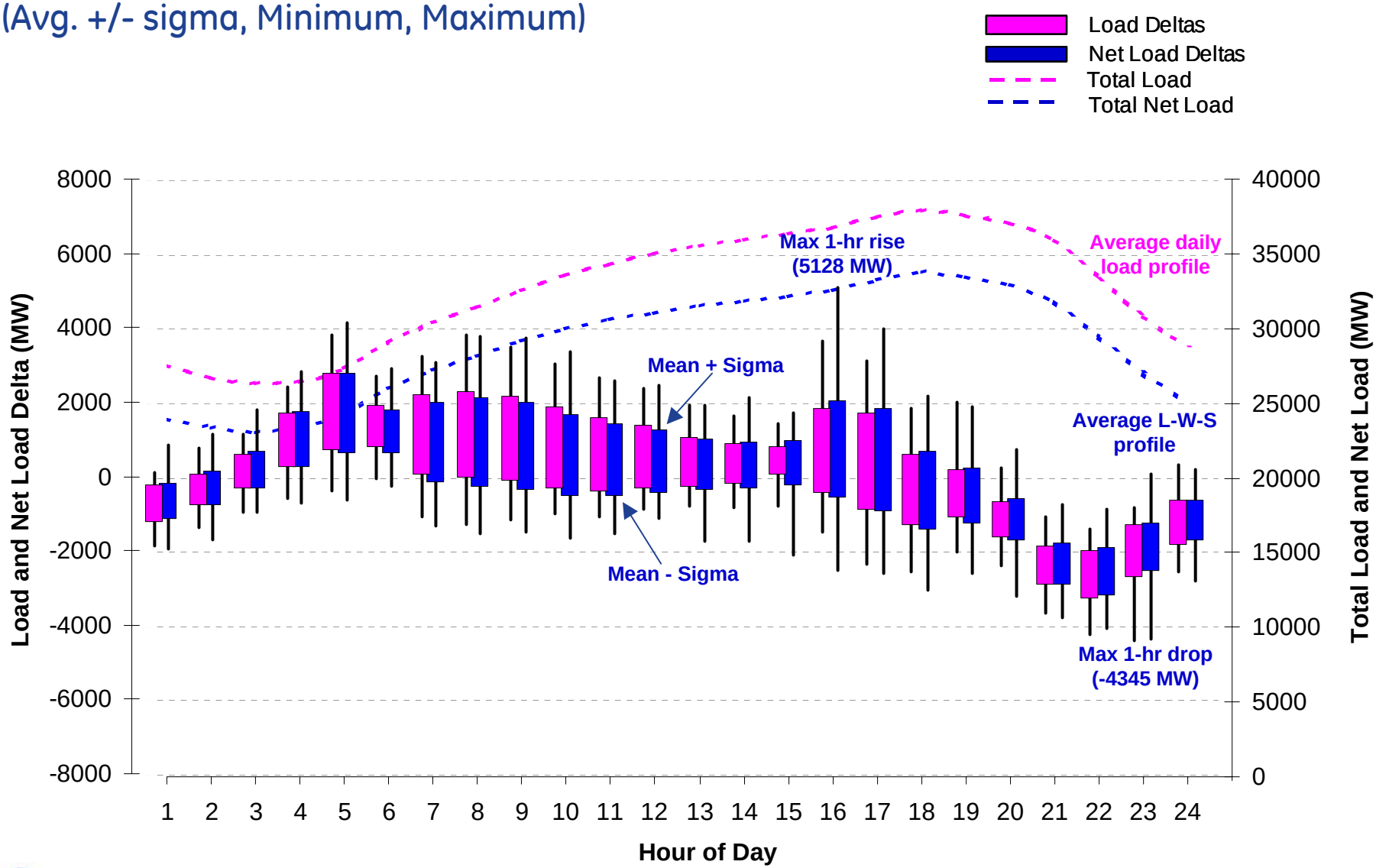
Study Area Average Daily Profile of Deltas Over Year 2006

(10% In Area Scenario)

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



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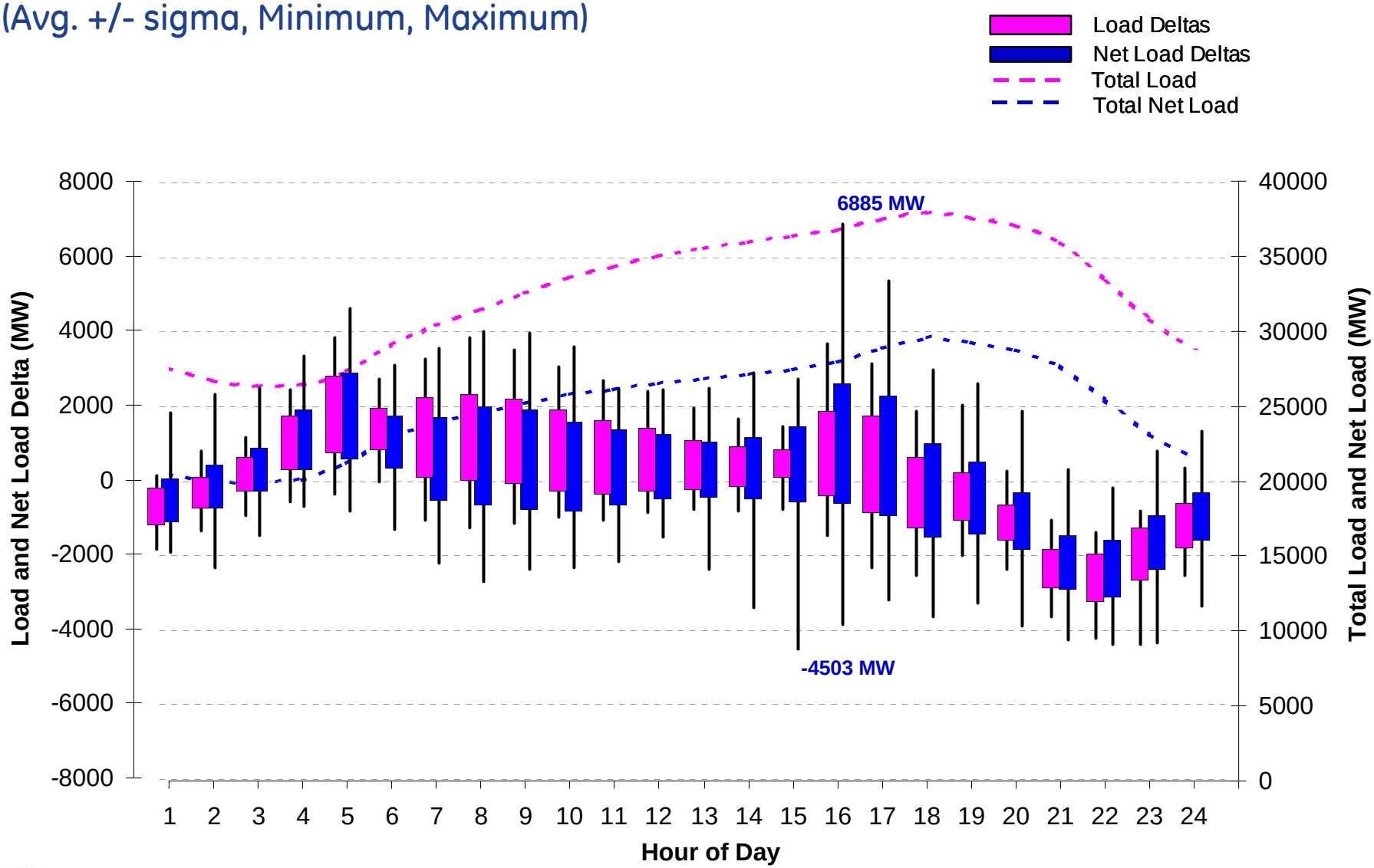
Study Area Average Daily Profile of Deltas Over Year 2006

(20% In Area Scenario)

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

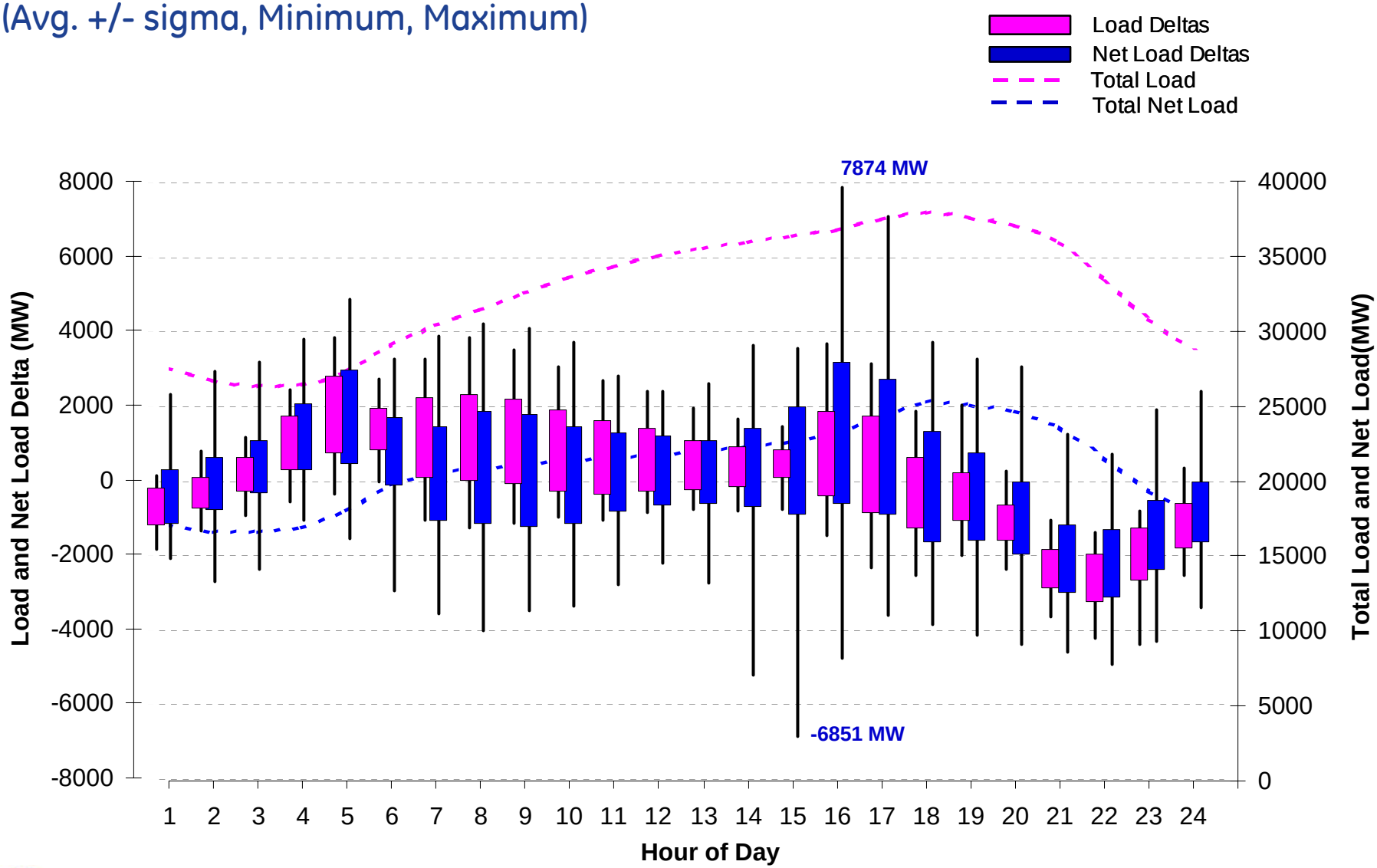


imagination at work

Study Area Average Daily Profile of Deltas Over Year 2006

(30% In Area Scenario)

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

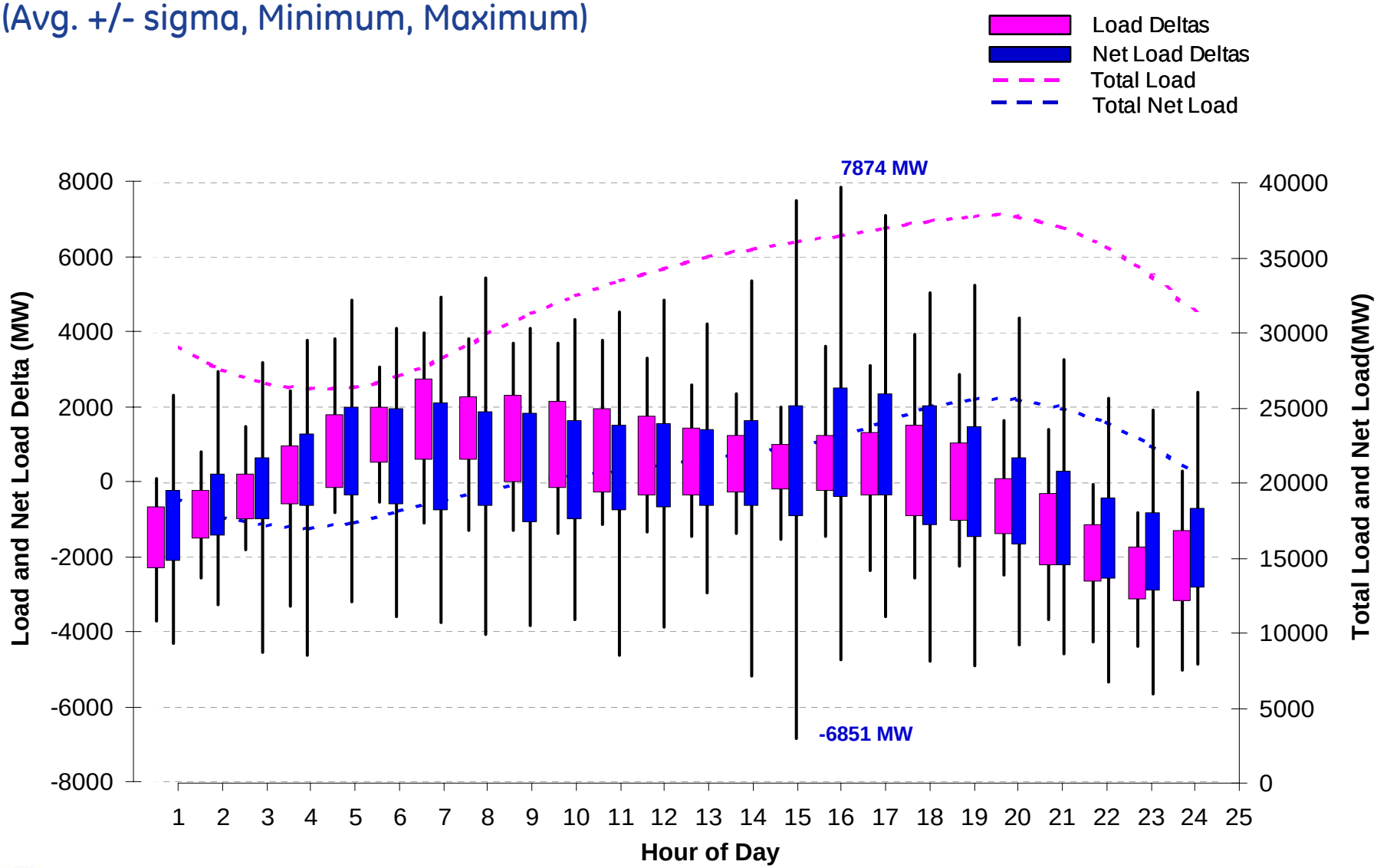


imagination at work

Study Area Average Daily Profile of Deltas Over 2004- 2006

(30% In Area Scenario)

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

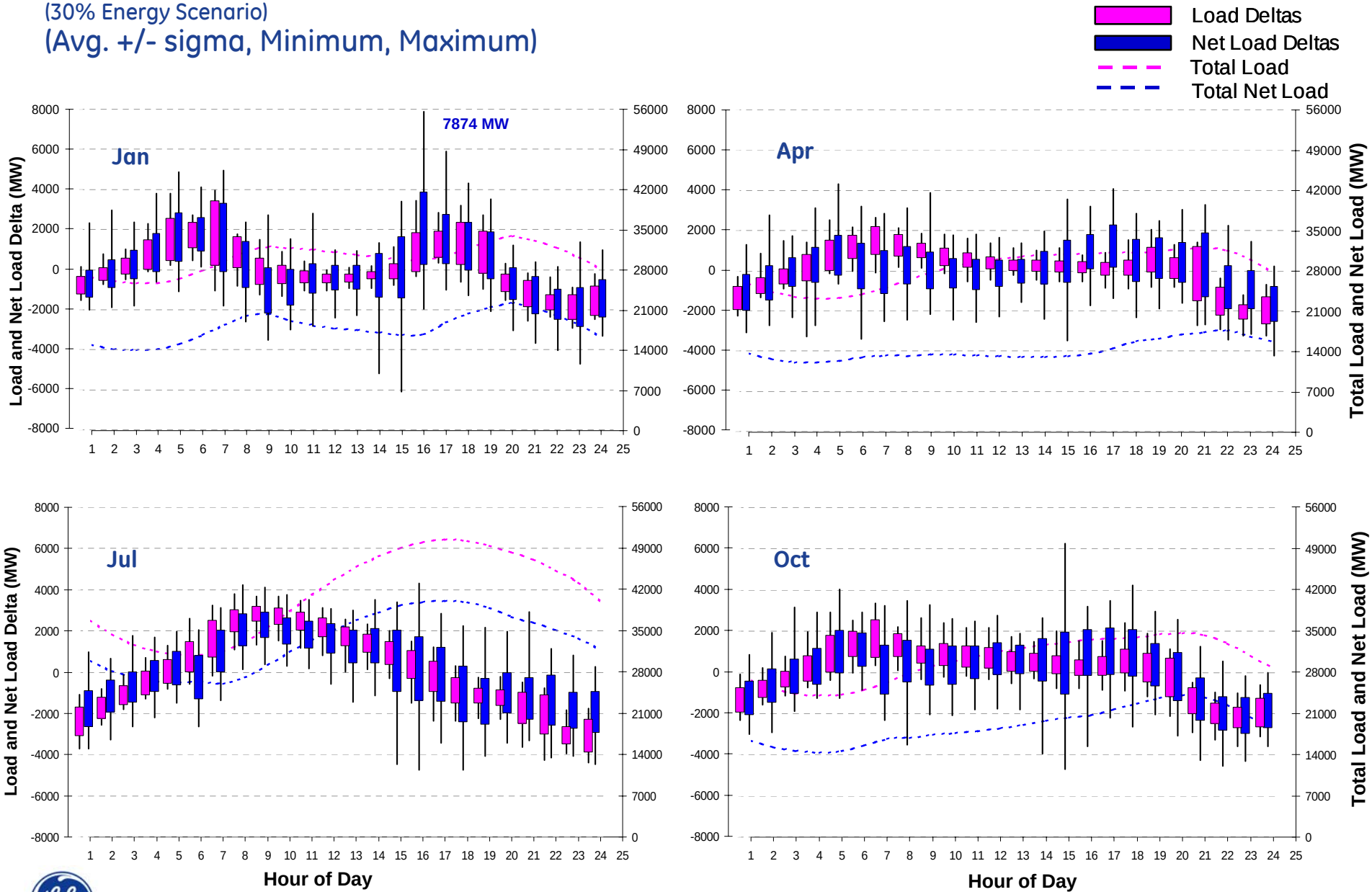


imagination at work

Study Area Average Daily Profile of Deltas by Seasonal Month for 2004-2006

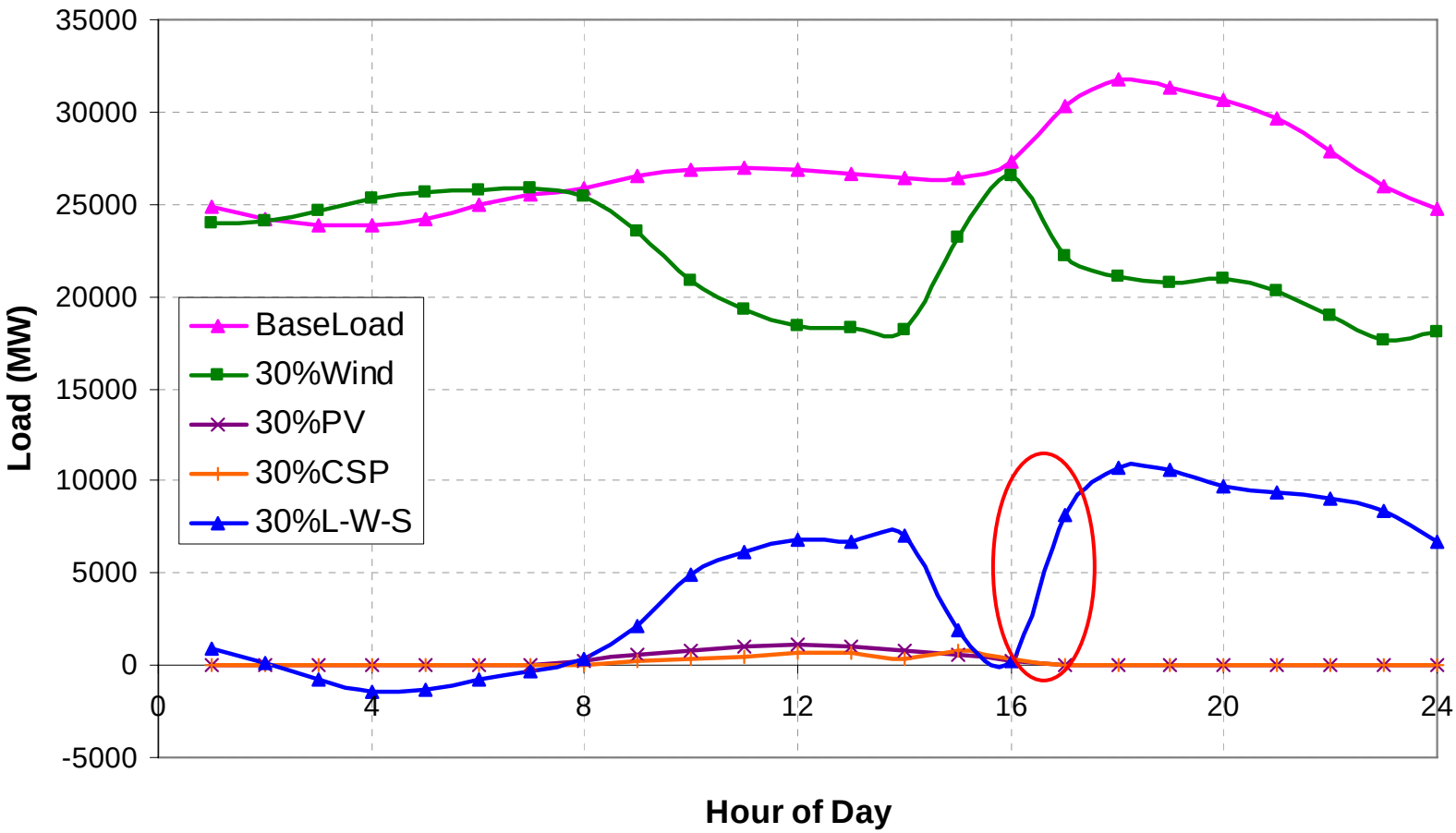
(30% Energy Scenario)

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



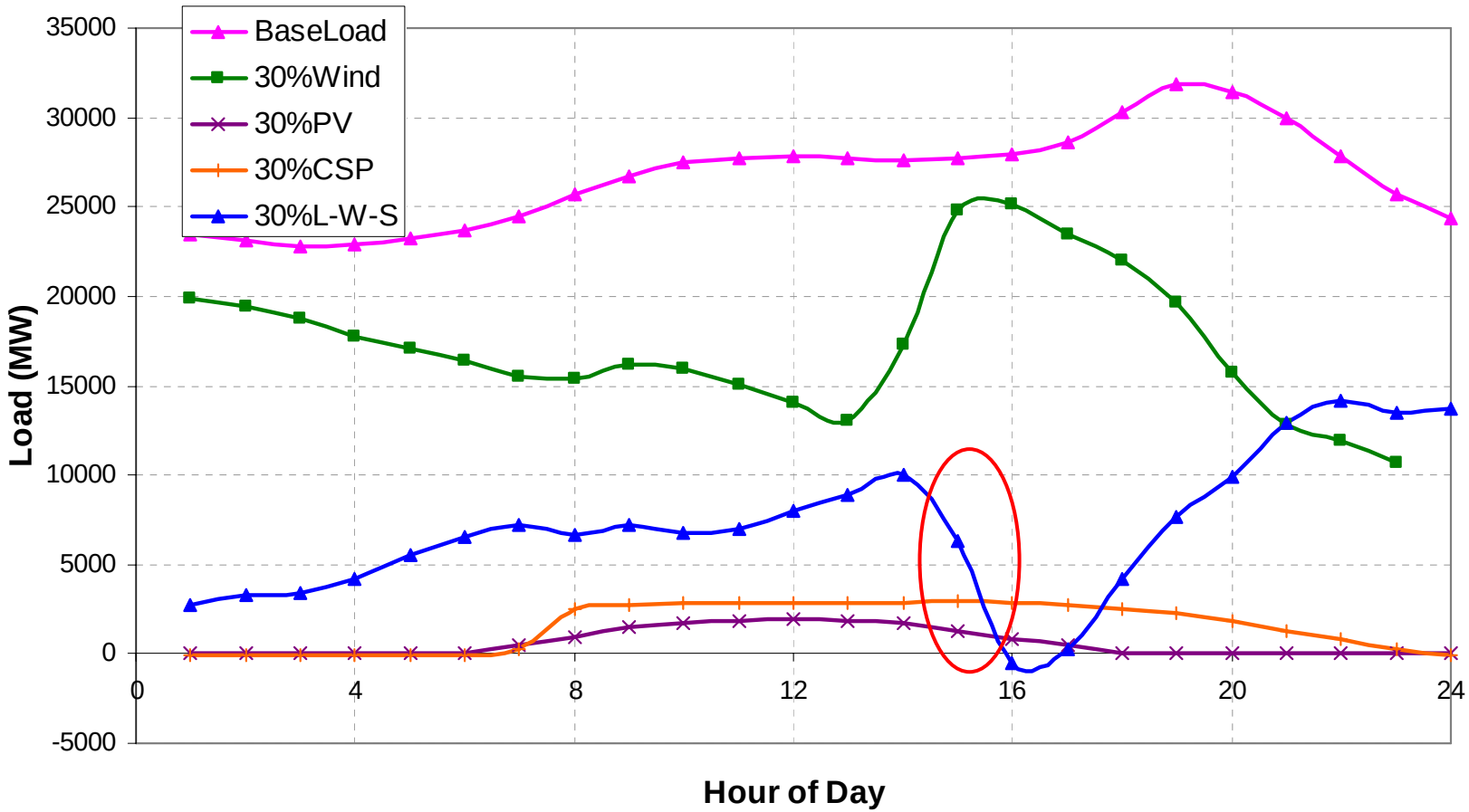
imagination at work

Study Area Total Load, Wind and Solar Variation on Maximum Positive L-W-S Delta Day - Jan 1 2006 for (30% In Area Scenario)



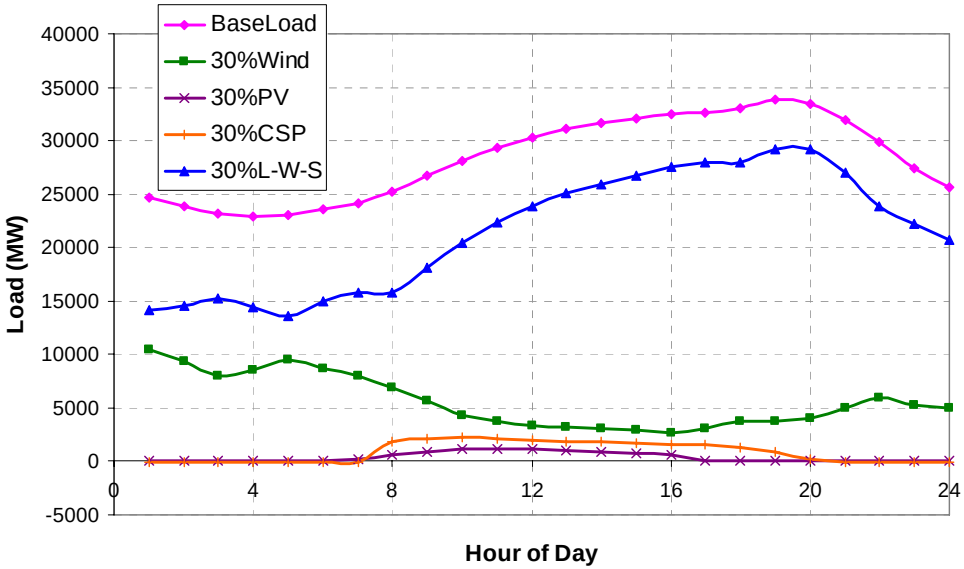
imagination at work

Study Area Total Load, Wind and Solar Variation for Maximum Negative L-W-S Delta Day - Mar 26th 2006 (30% In Area Scenario)



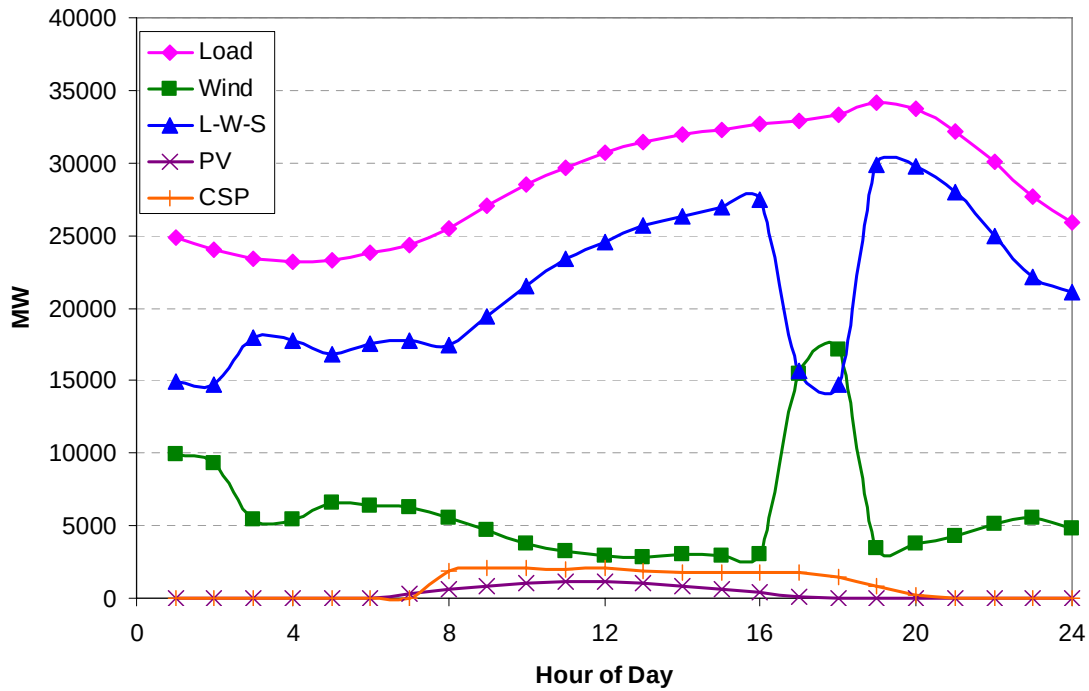
imagination at work

Study Area Total, Load Wind, Solar and Net Load for Oct 8th 2006 (30% In-Area Scenario)



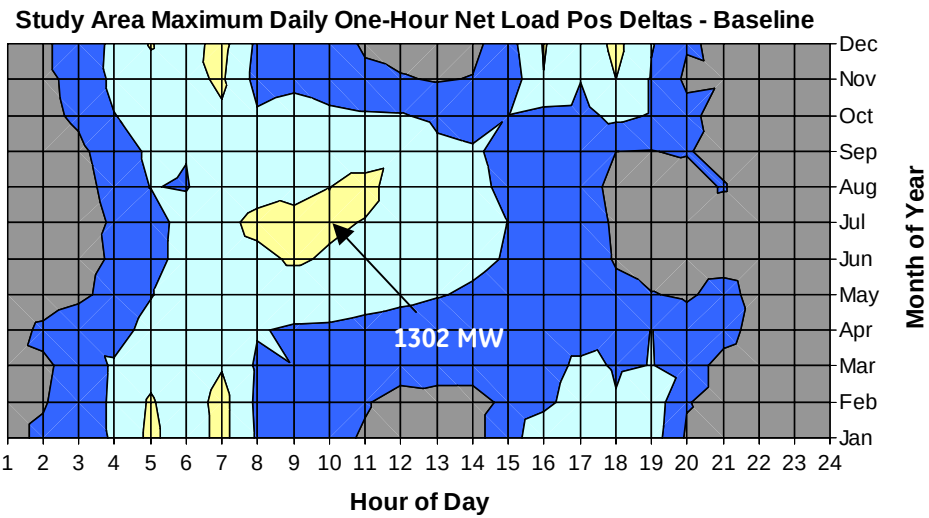
With new data

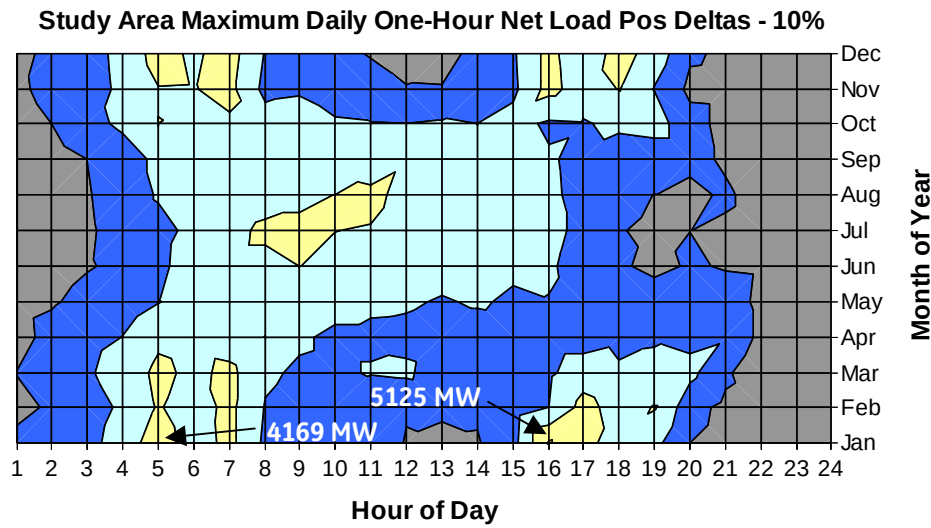
With old Data

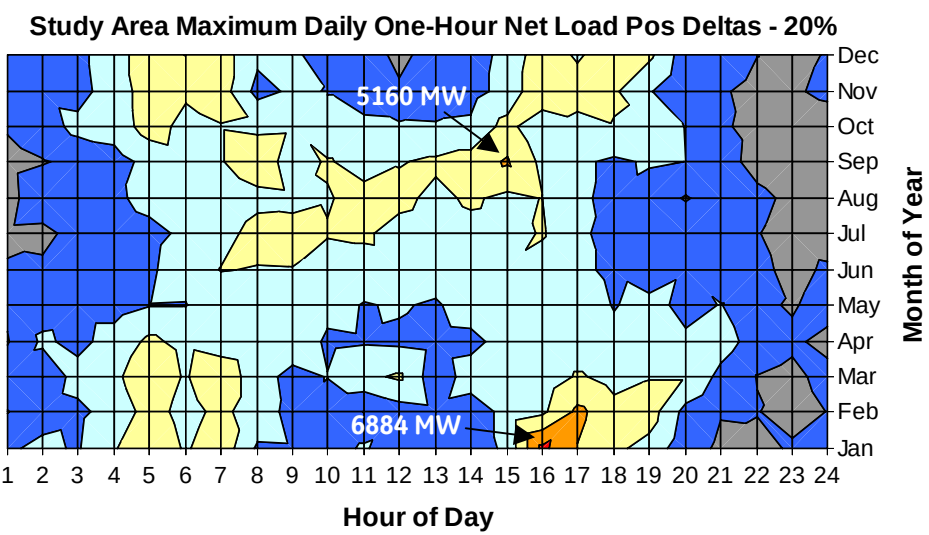


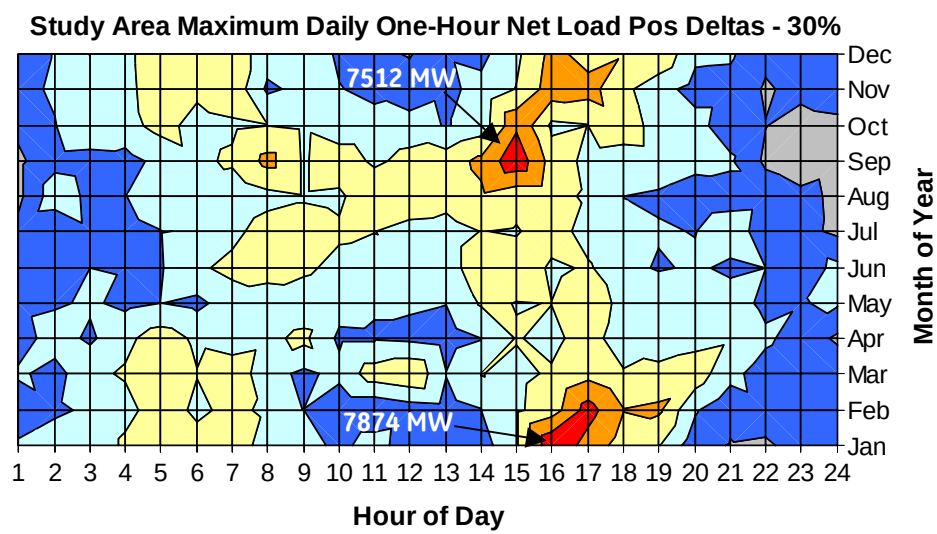
imagination at work

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







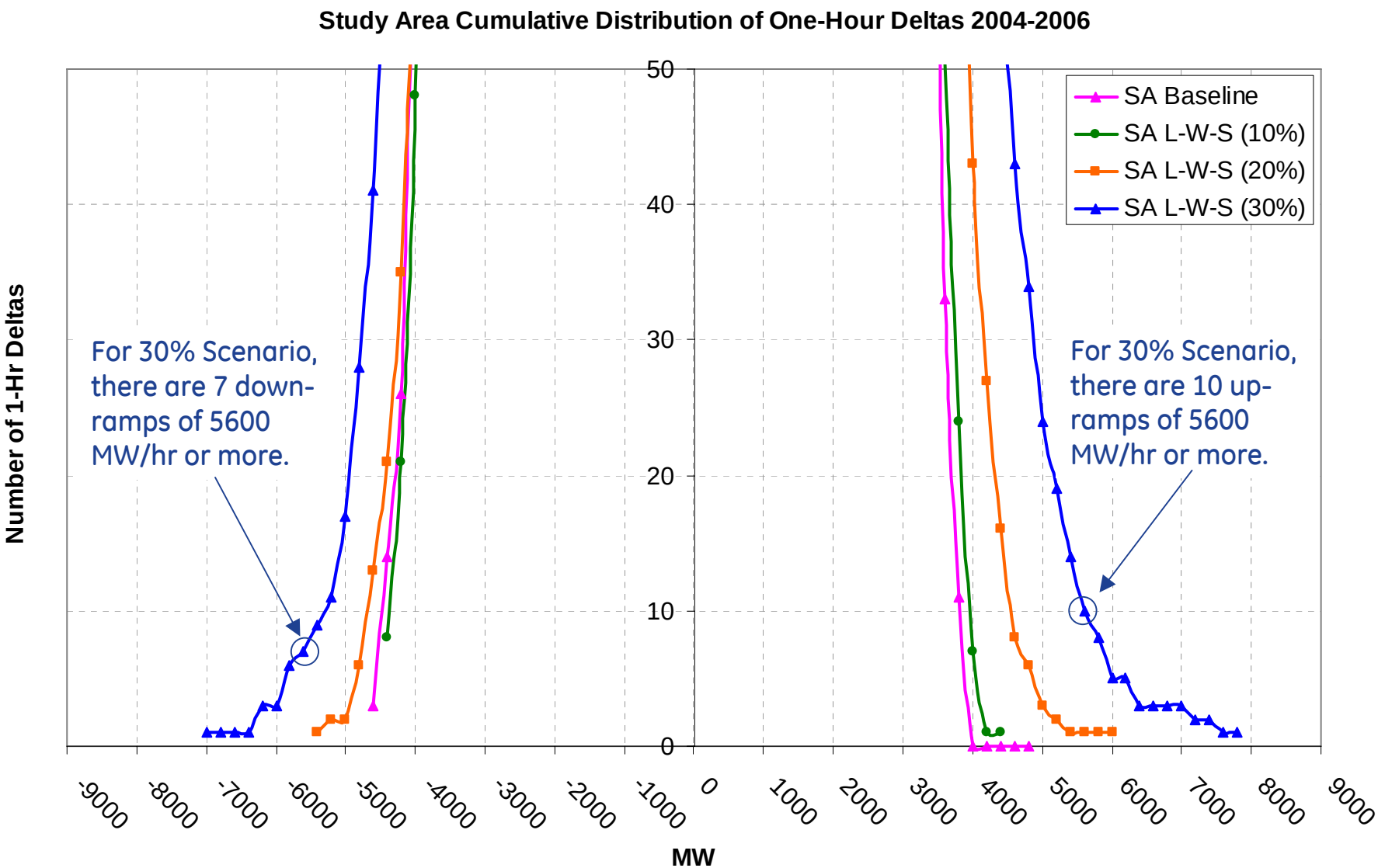


-1000-500 | 500-2000 | 2000-3500 | 3500-5000 | 5000-6500 | 6500-8000

imagination at work

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

Distribution of Extreme Hourly Net Load Deltas 2004 – 2006



imagination at work

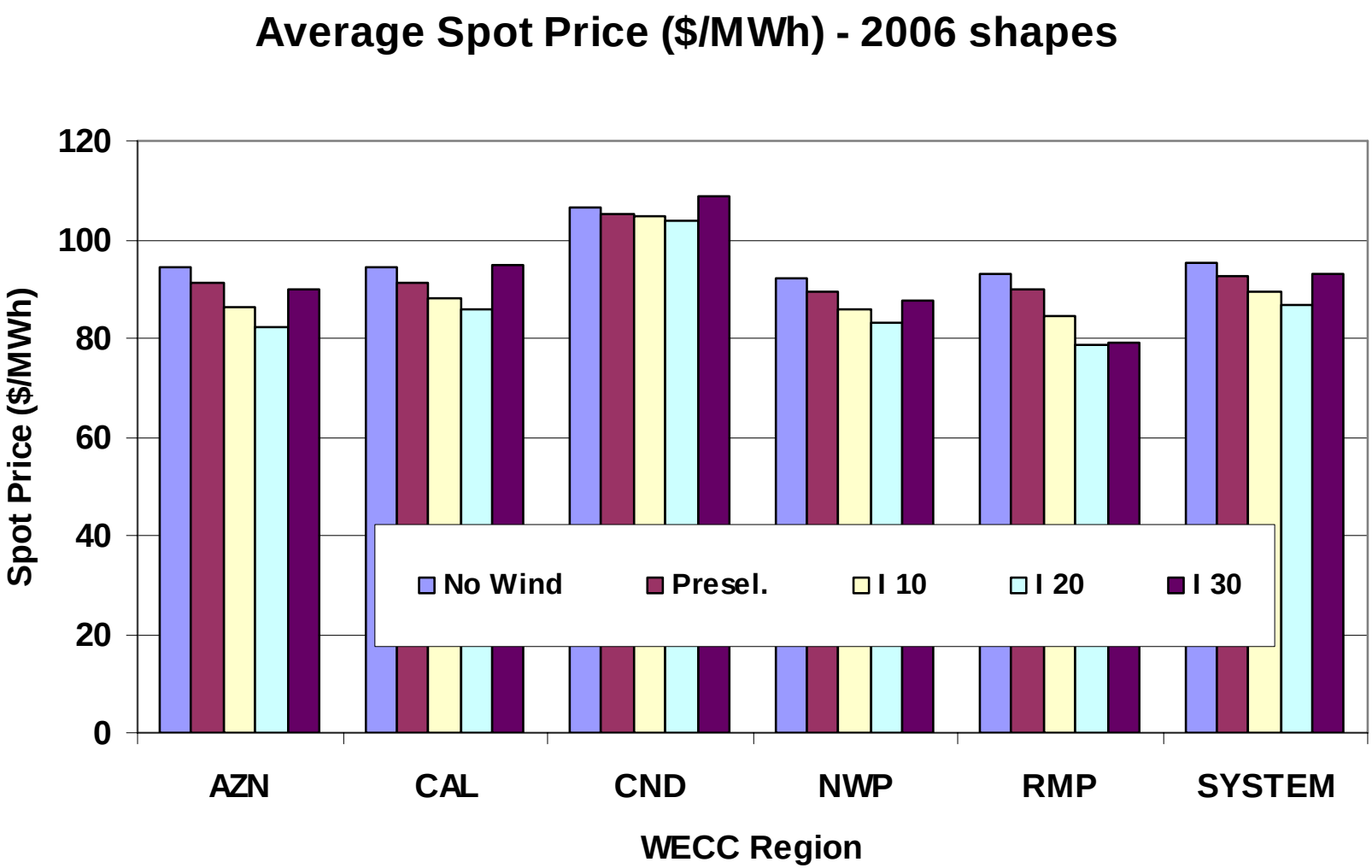
Summary Statistics for 2004 - 2006

Sigma (MW)	Ariz		CO-E		CO-W		NM		NV		WYCE		In FP	
Load-alone	660.4		341.4		35.1		164.2		302.2		89.6		1472.9	
Baseline (Existing)	659.7		349.7		35.1		170.9		301.3		104.7		1466.8	
10% Scenario	658.6	-0.2%	351.3	0.5%	42.5	21.0%	173.0	1.3%	301.3	0.0%	104.2	-0.4%	1420.5	-3.2%
20% Scenario	716.5	8.6%	381.6	9.1%	64.2	82.9%	208.1	21.8%	329.8	9.5%	130.4	24.6%	1427.8	-2.7%
30% Scenario	794.2	20.4%	446.9	27.8%	88.8	152.9%	246.6	44.3%	378.1	25.5%	176.0	68.2%	1500.2	2.3%
Max Neg Delta(MW)	**Ariz**		**CO-E**		**CO-W**		**NM**		**NV**		**WYCE**		**In FP**	
Load-alone	-2134		-1339		-180		-1307		-1344		-337		-4911	
Baseline (Existing)	-2131		-1408		-180		-1352		-1342		-503		-5042	
10% Scenario	-2444	14.7%	-1422	1.0%	-221	22.6%	-1346	-0.4%	-1345	0.3%	-516	2.7%	-4766	-5.5%
20% Scenario	-3321	55.8%	-1706	21.2%	-430	138.8%	-1373	1.6%	-2245	67.3%	-677	34.7%	-5326	5.6%
30% Scenario	-4662	118.8%	-2587	83.8%	-562	212.3%	-1639	21.3%	-3202	138.7%	-1084	115.8%	-6851	35.9%
Max Pos Delta(MW)	**Ariz**		**CO-E**		**CO-W**		**NM**		**NV**		**WYCE**		**In FP**	
Load-alone	1944		1341		148		1212		1391		498		3908	
Baseline (Existing)	1948		1342		148		1169		1400		475		3972	
10% Scenario	2233	14.7%	1431	6.6%	201	36.0%	1151	-1.6%	1418	1.3%	477	0.4%	5125	29.0%
20% Scenario	3114	59.9%	1550	15.4%	351	137.2%	1228	5.0%	1710	22.2%	741	56.0%	6885	73.3%
30% Scenario	4235	117.4%	2099	56.3%	560	278.4%	1678	43.6%	2095	49.6%	1063	123.8%	7875	98.2%
No. Rises > 3*Load-Sigma	**Ariz**		**CO-E**		**CO-W**		**NM**		**NV**		**WYCE**		**In FP**	
Load-alone	0		26		55		53		11		186		0	
Baseline (Existing)	0		28		55		84		11		304		0	
10% Scenario	13		38		268		103		30		265		1	
20% Scenario	90		123		1325		313		128		647		16	
30% Scenario	197		364		2521		683		302		1596		58	
No. Drops > 3*Load-Sigma	**Ariz**		**CO-E**		**CO-W**		**NM**		**NV**		**WYCE**		**In FP**	
Load-alone	10		26		56		19		16		24		3	
Baseline (Existing)	9		42		56		49		15		186		2	
10% Scenario	18		58		287		62		34		183		3	
20% Scenario	110		139		1299		340		114		600		13	
30% Scenario	247		363		2579		728		292		1531		40	

MAPS Analysis on In-Area Scenario

Study Assumptions

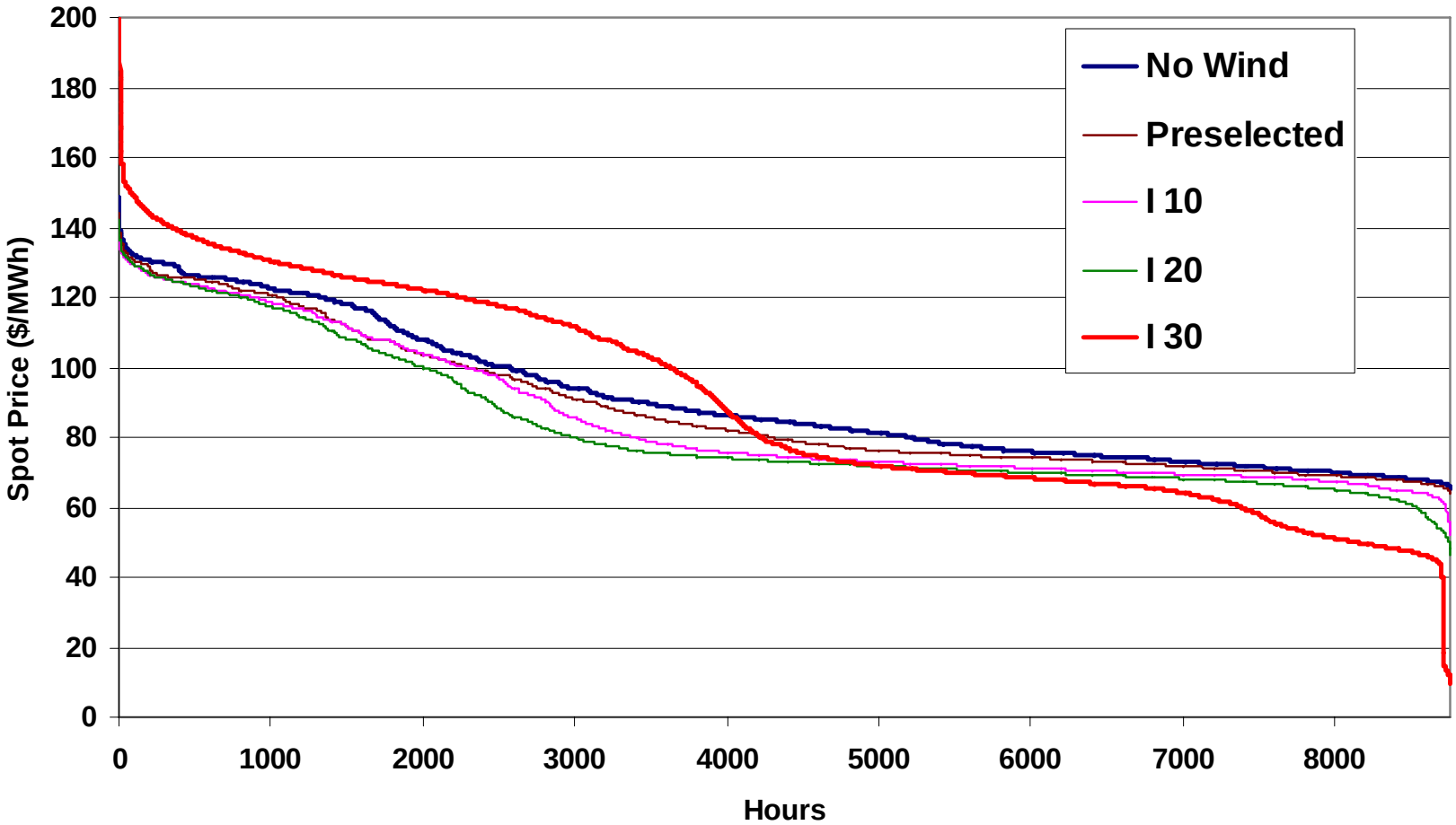
- 2017 Fuel Prices
  - Coal ~ $2.00/MBtu
  - Natural Gas ~$8.00/MBtu
- Carbon Tax
  - $30/ton
- Energy Velocity Database
  - ~24 GW capacity added 2009-2017 timeframe to maintain reserve margins (~11GW not in plans)
- NERC ES&D Peak Load Projections



All of WECC

imagination at work

Spot Price Duration Curve - 2006



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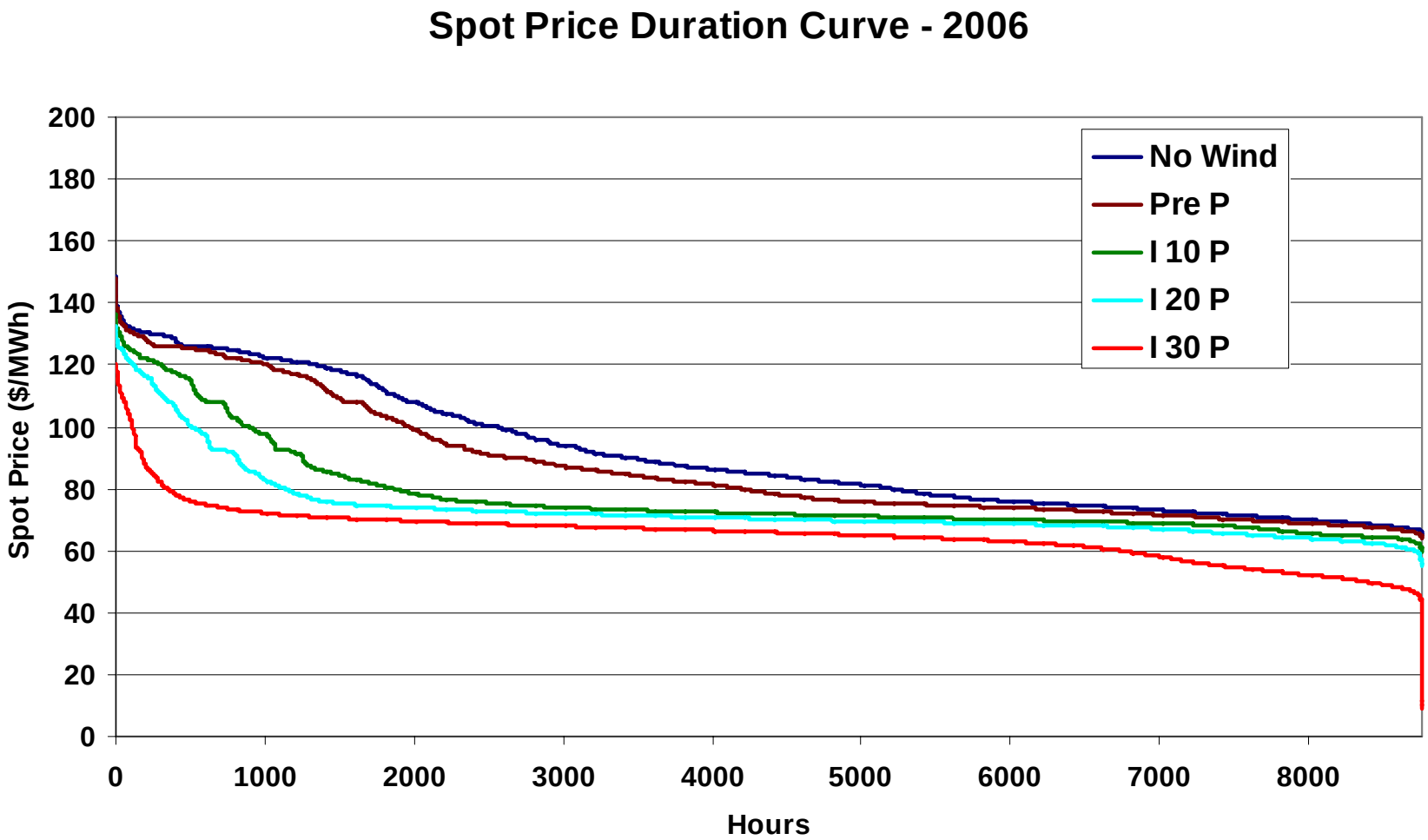

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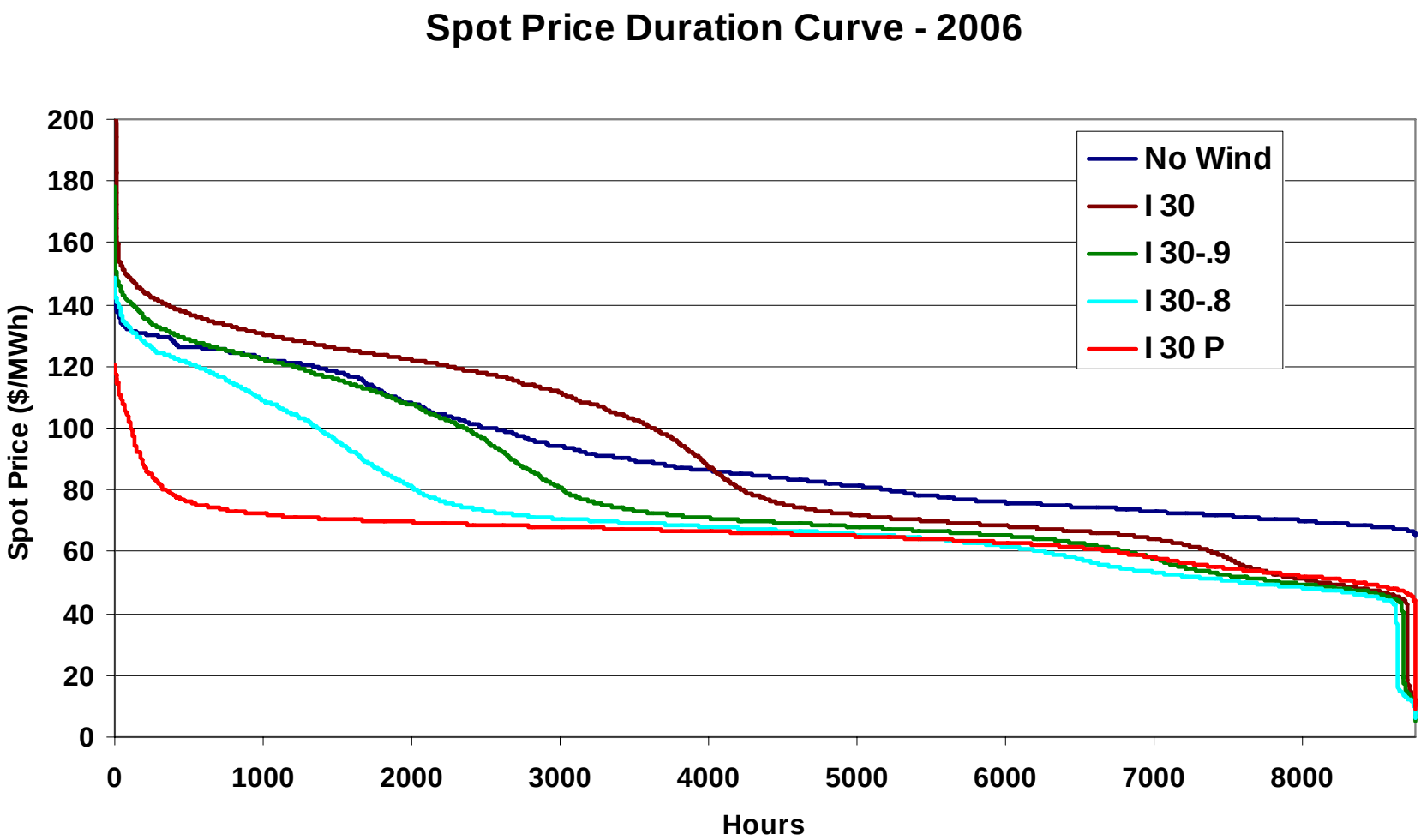

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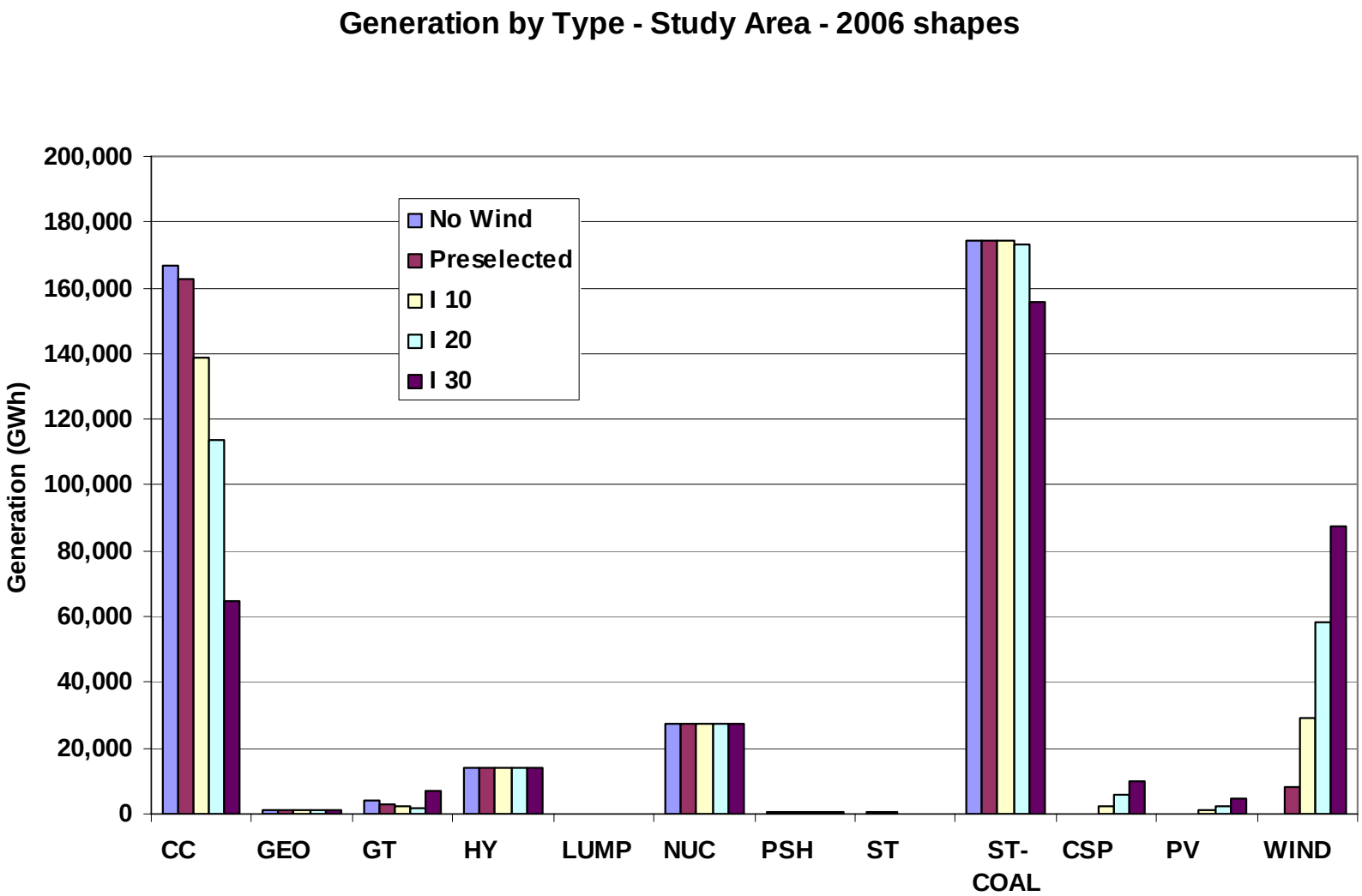
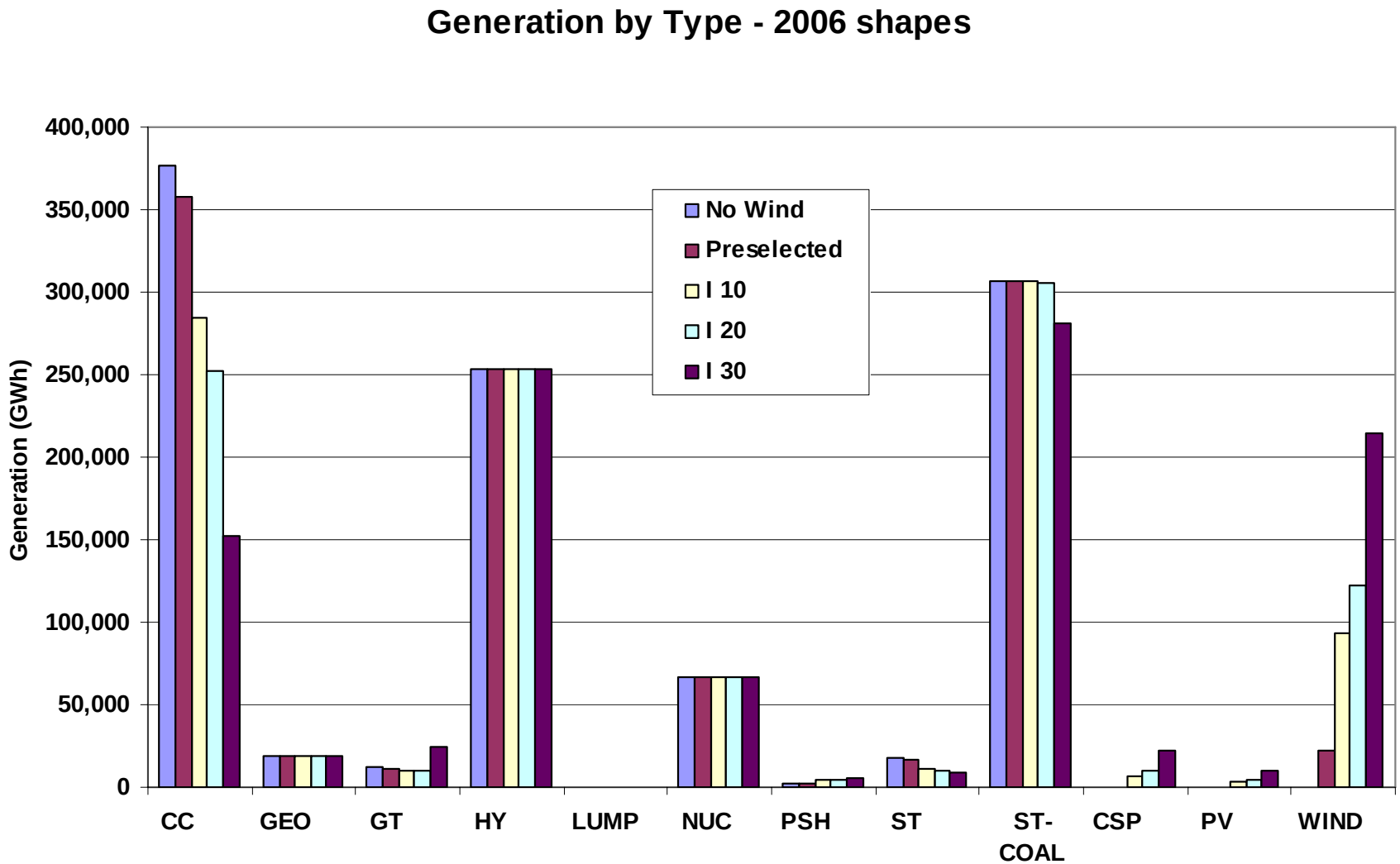


In Footprint

imagination at work



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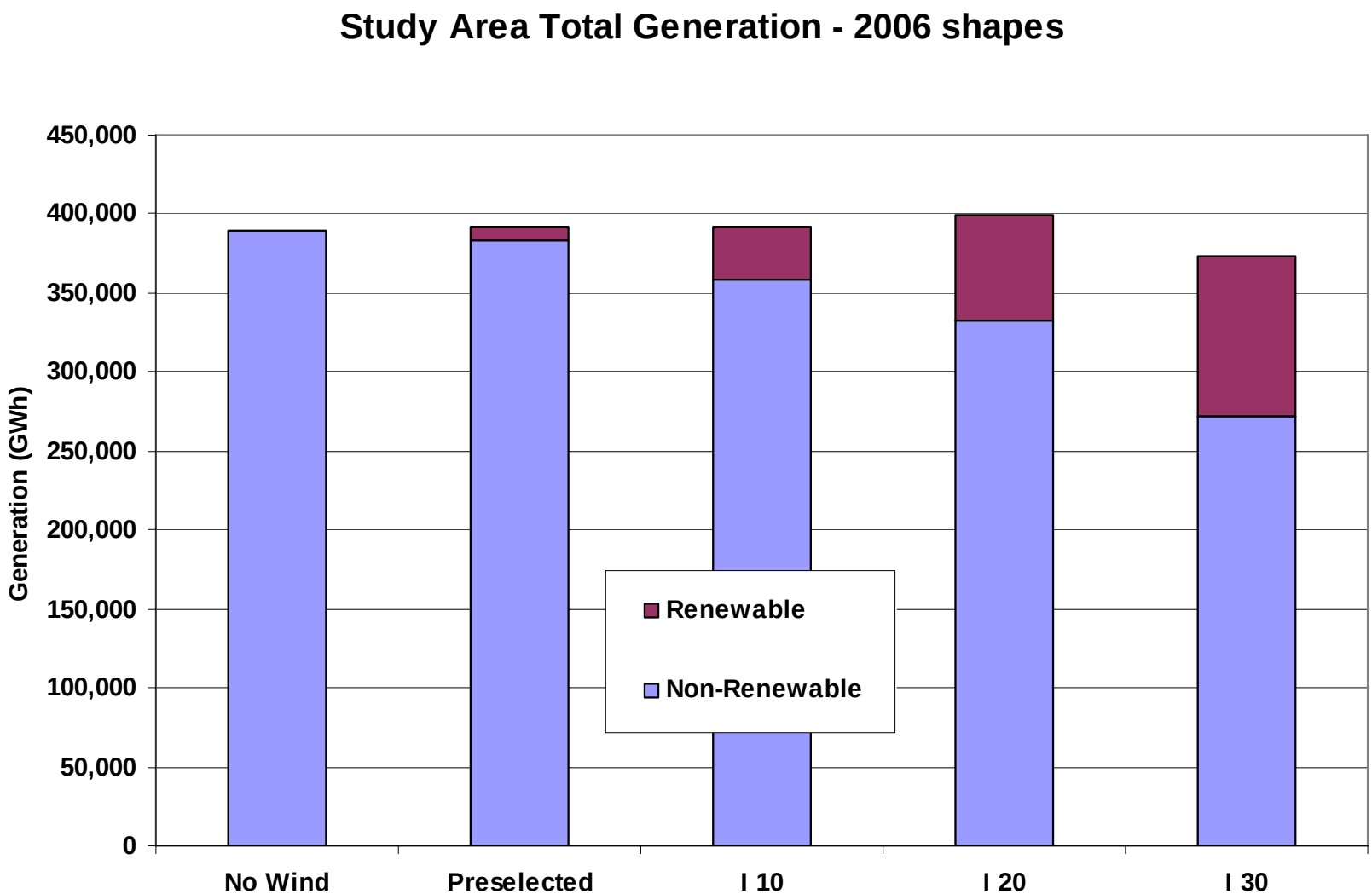
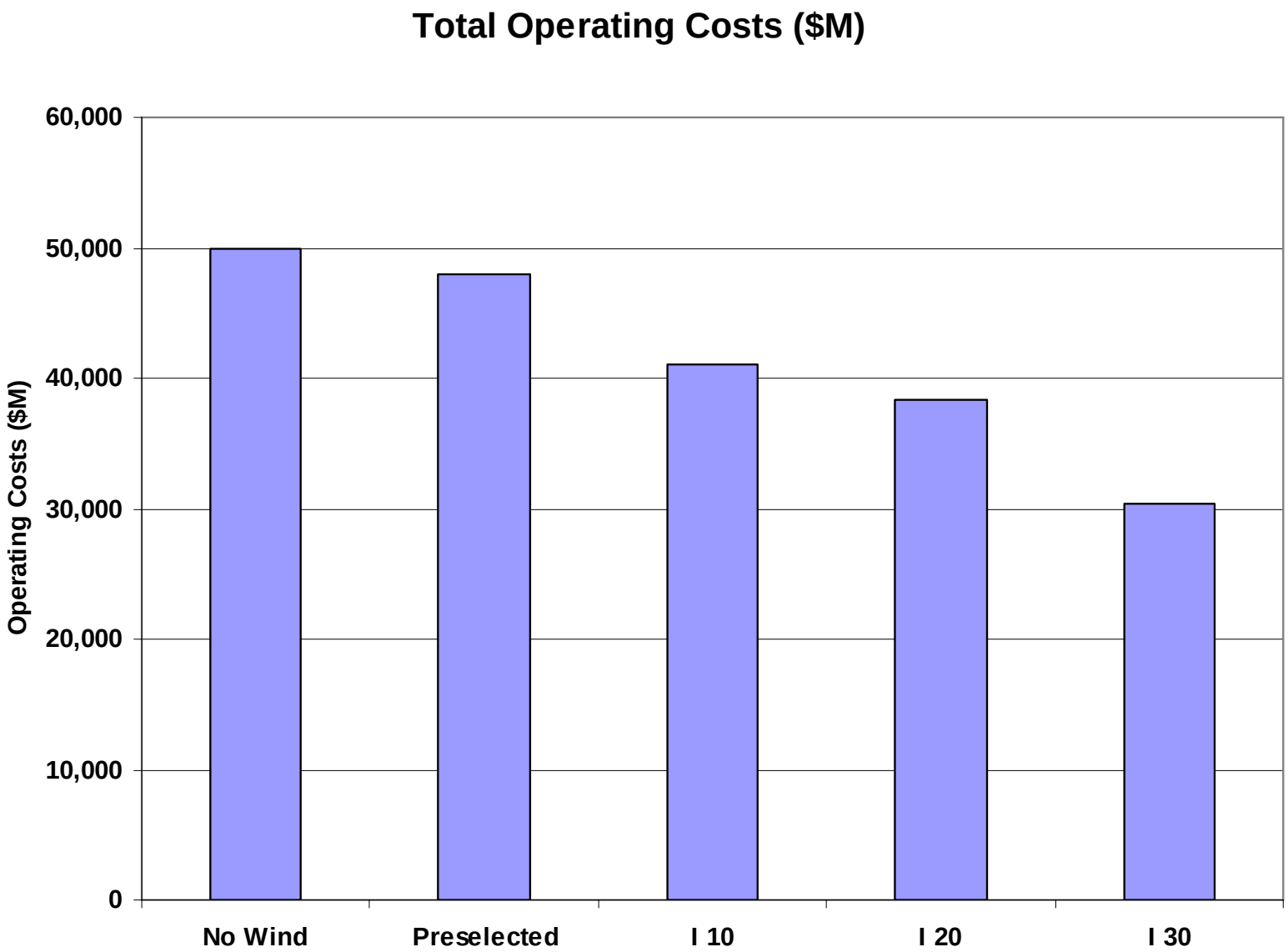


In Footprint

imagination at work



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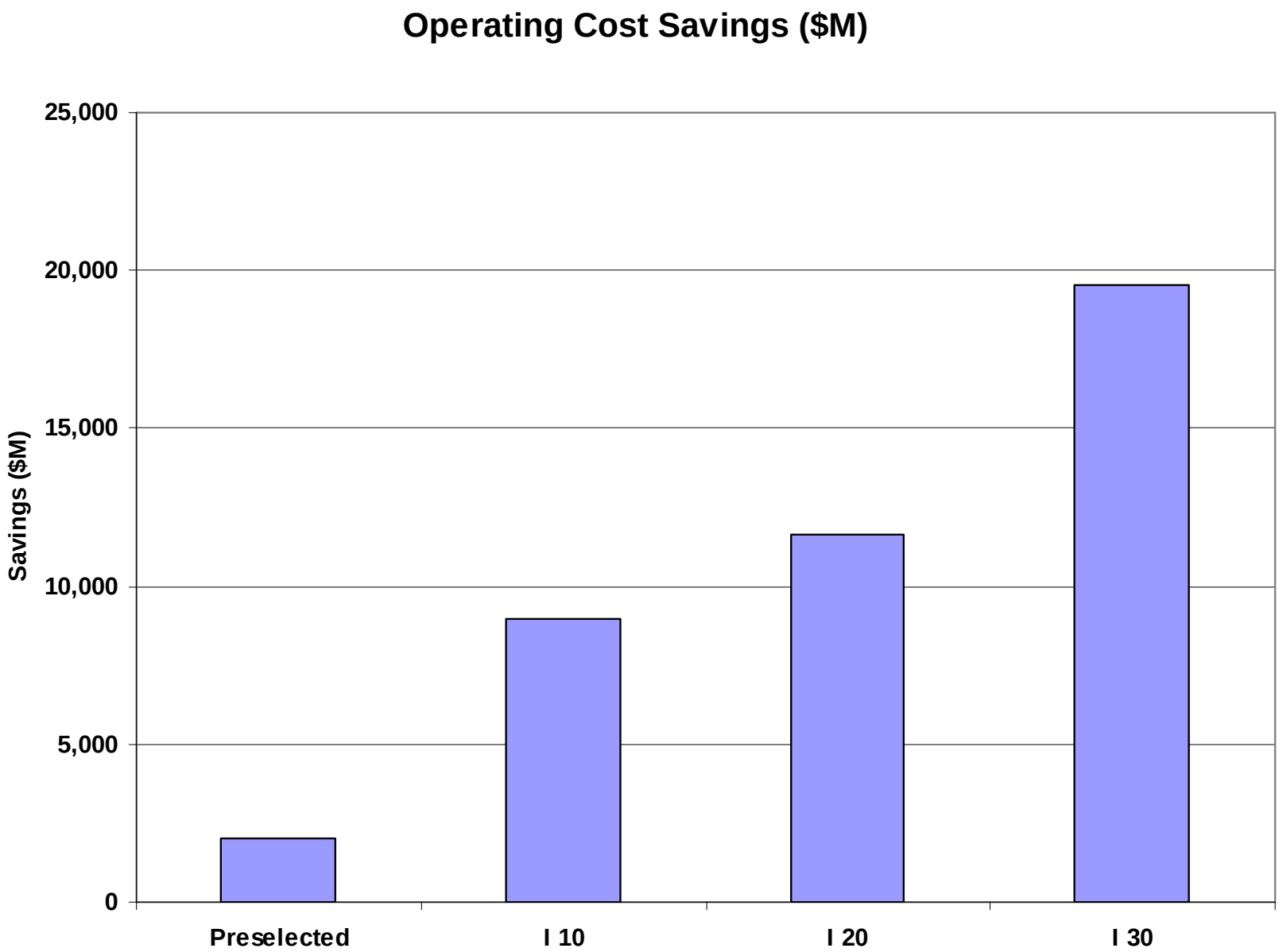

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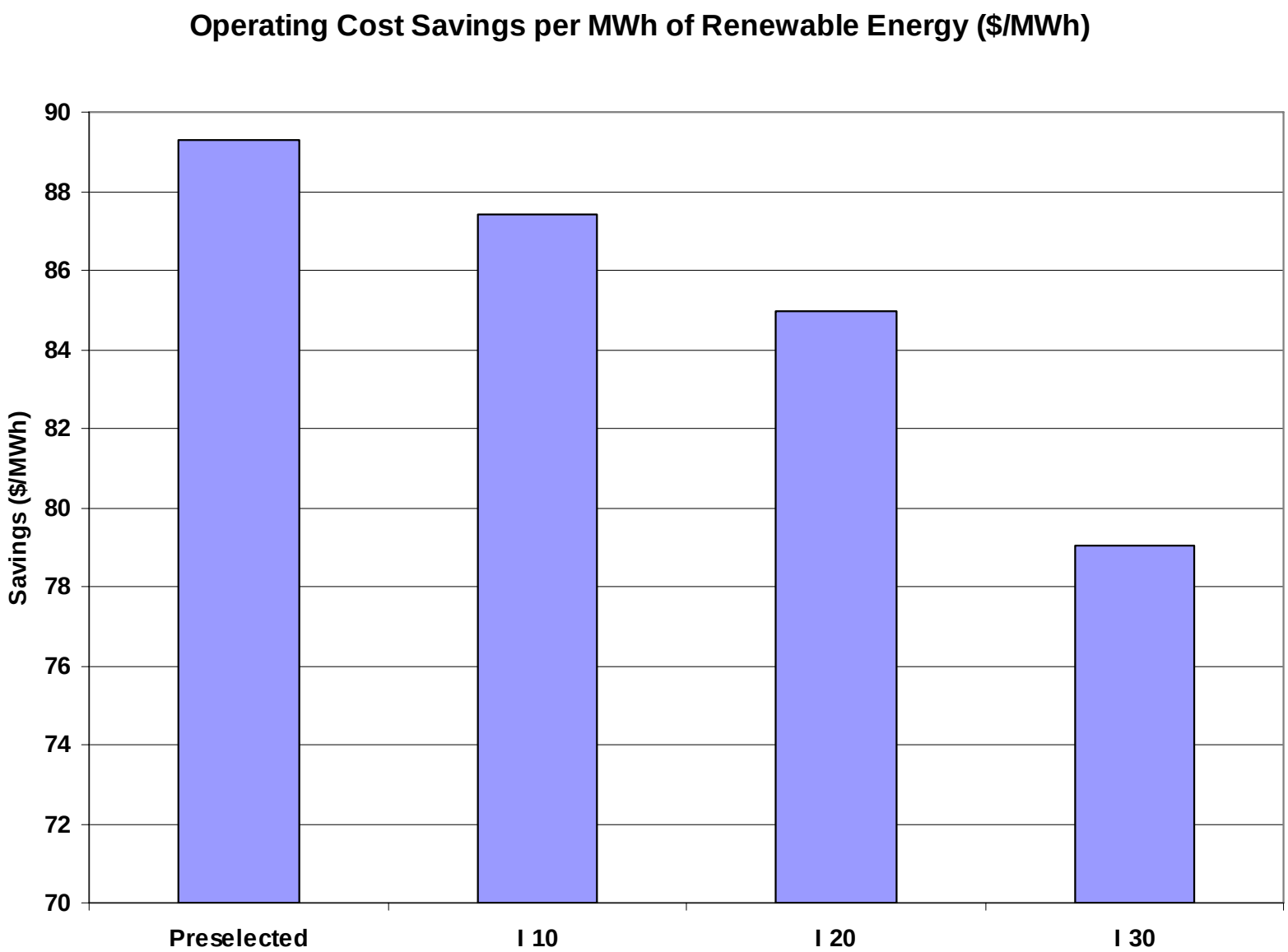
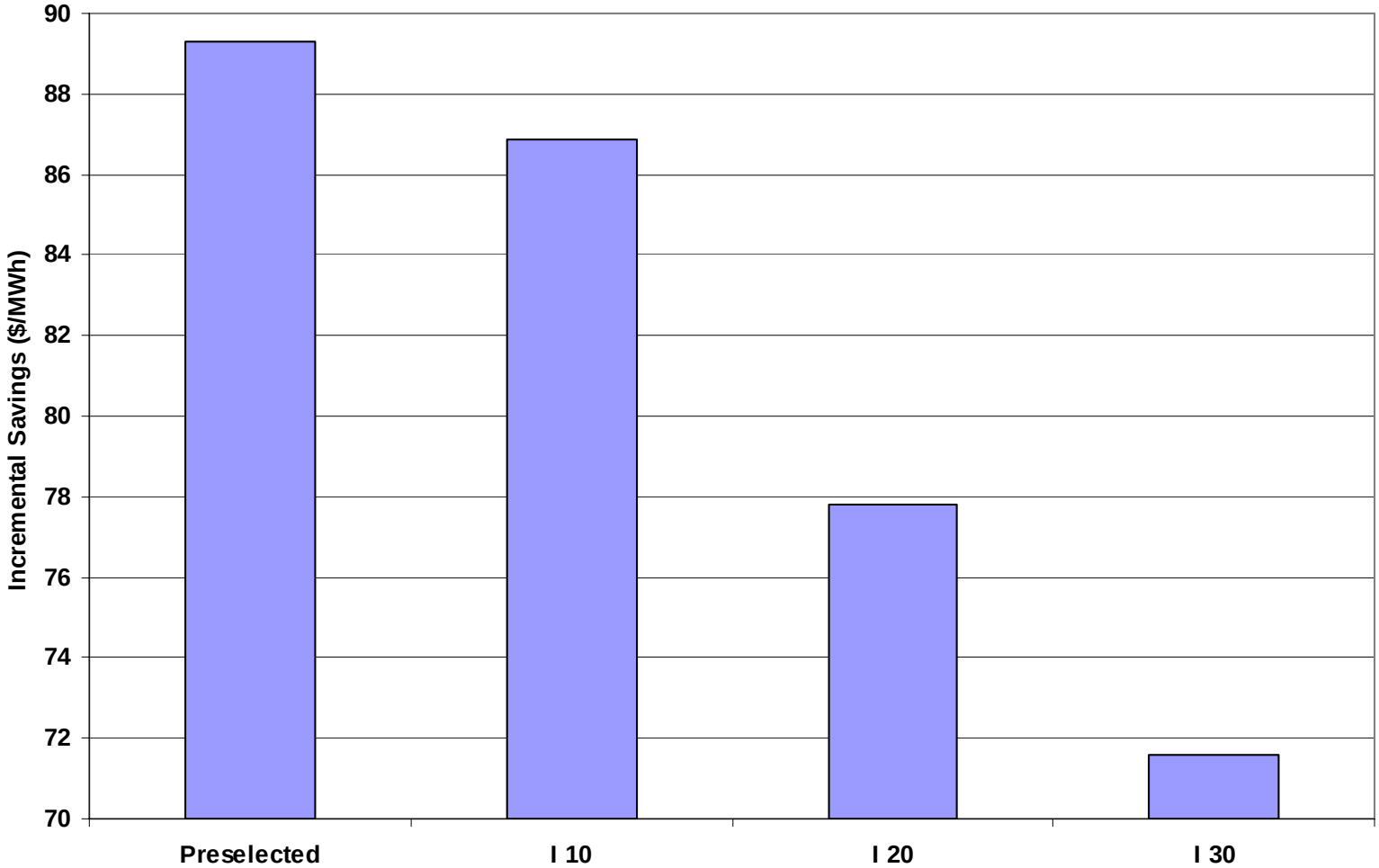


imagination at work

All of WECC

Incremental Savings per Incremental Renewable Energy ($/MWh)



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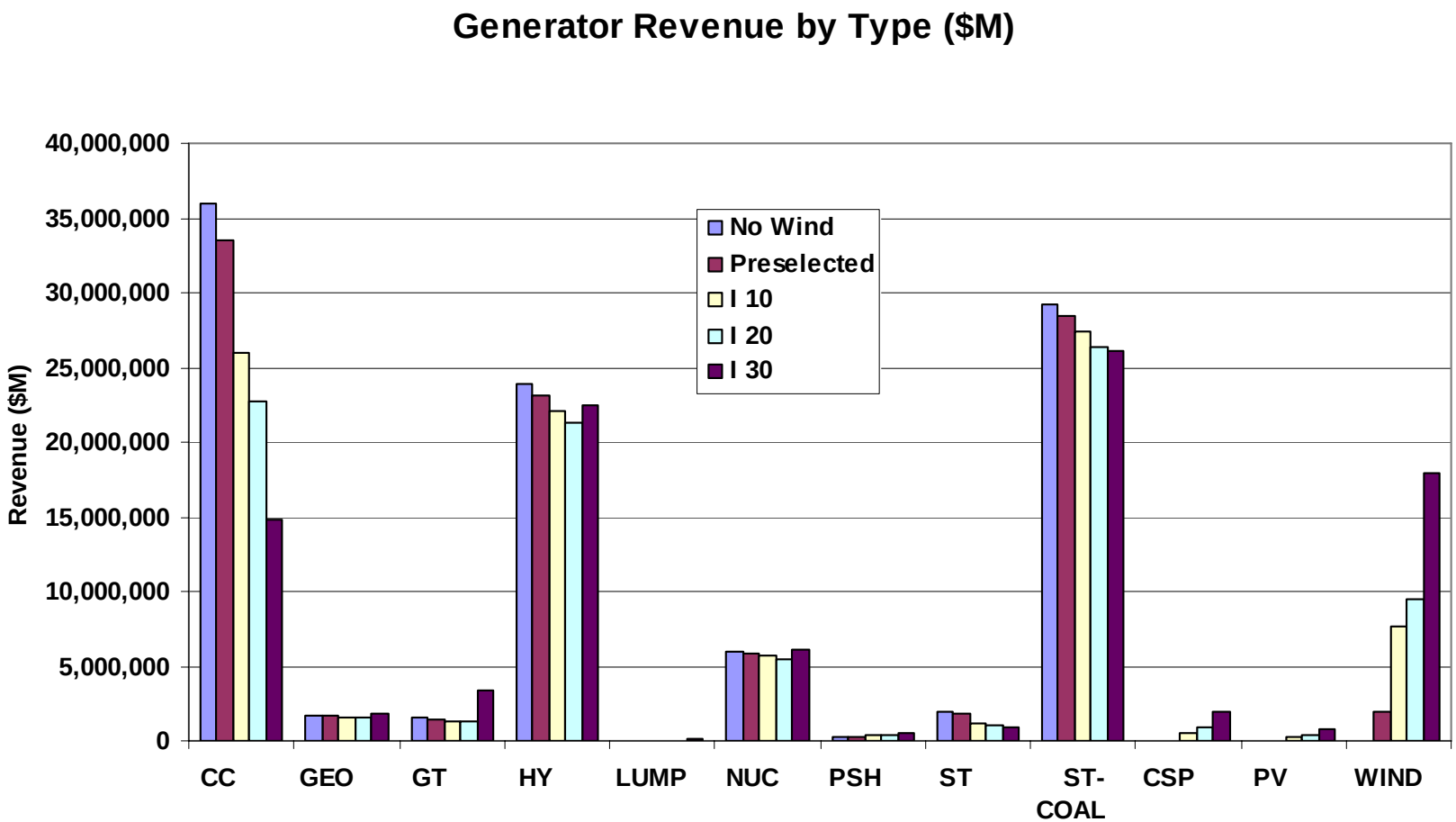

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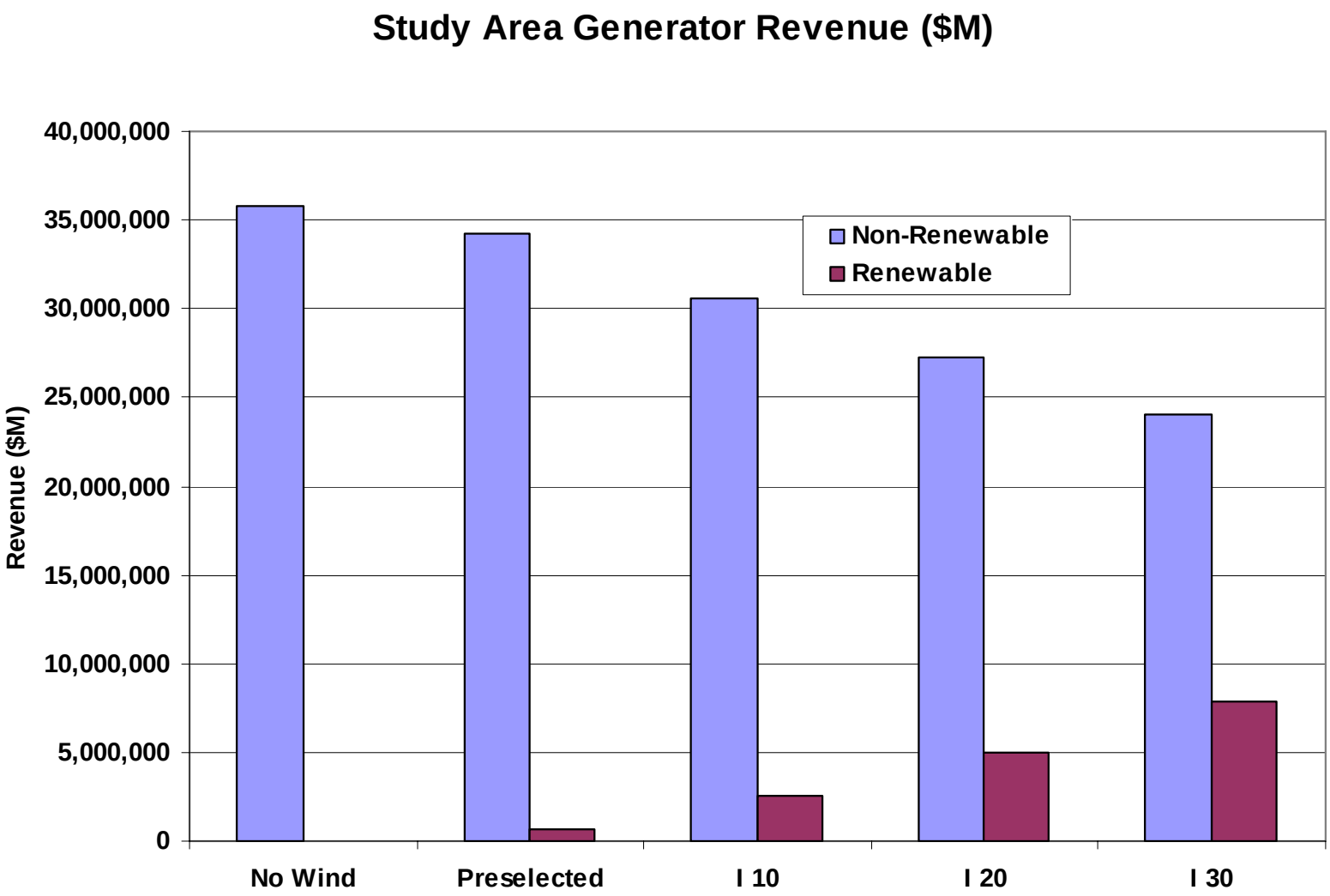
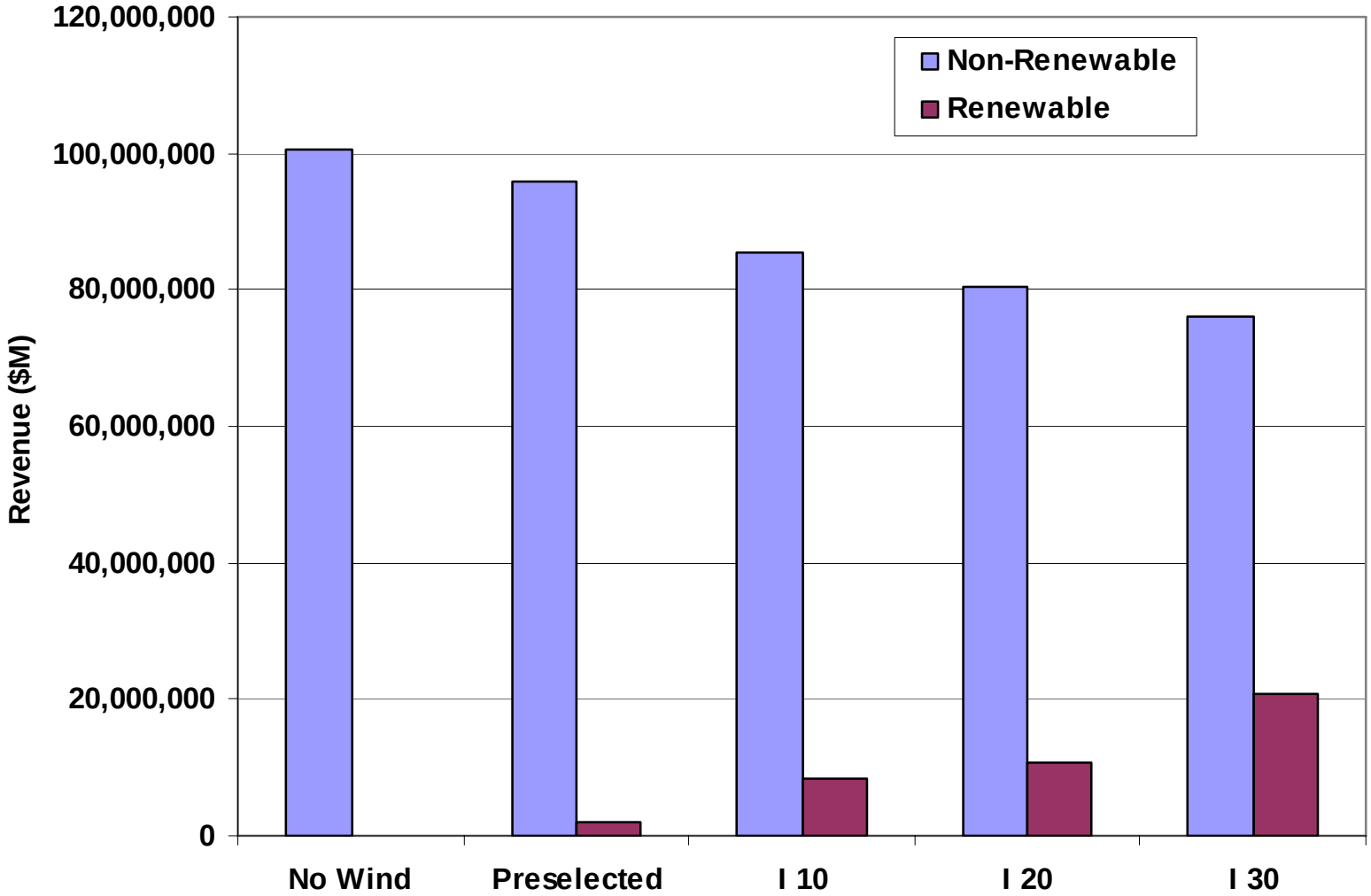


In Footprint

imagination at work

Generator Revenue ($M)



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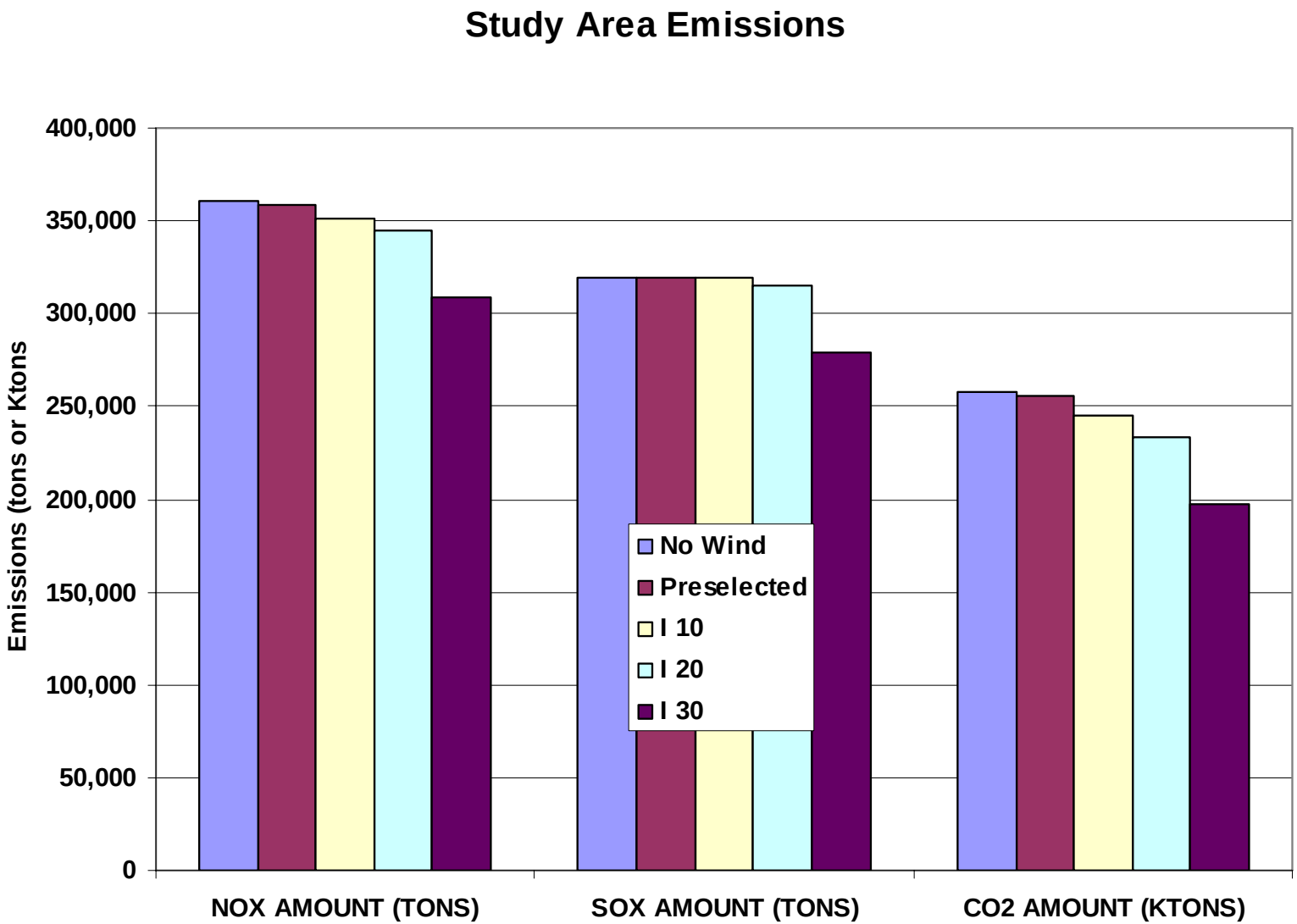
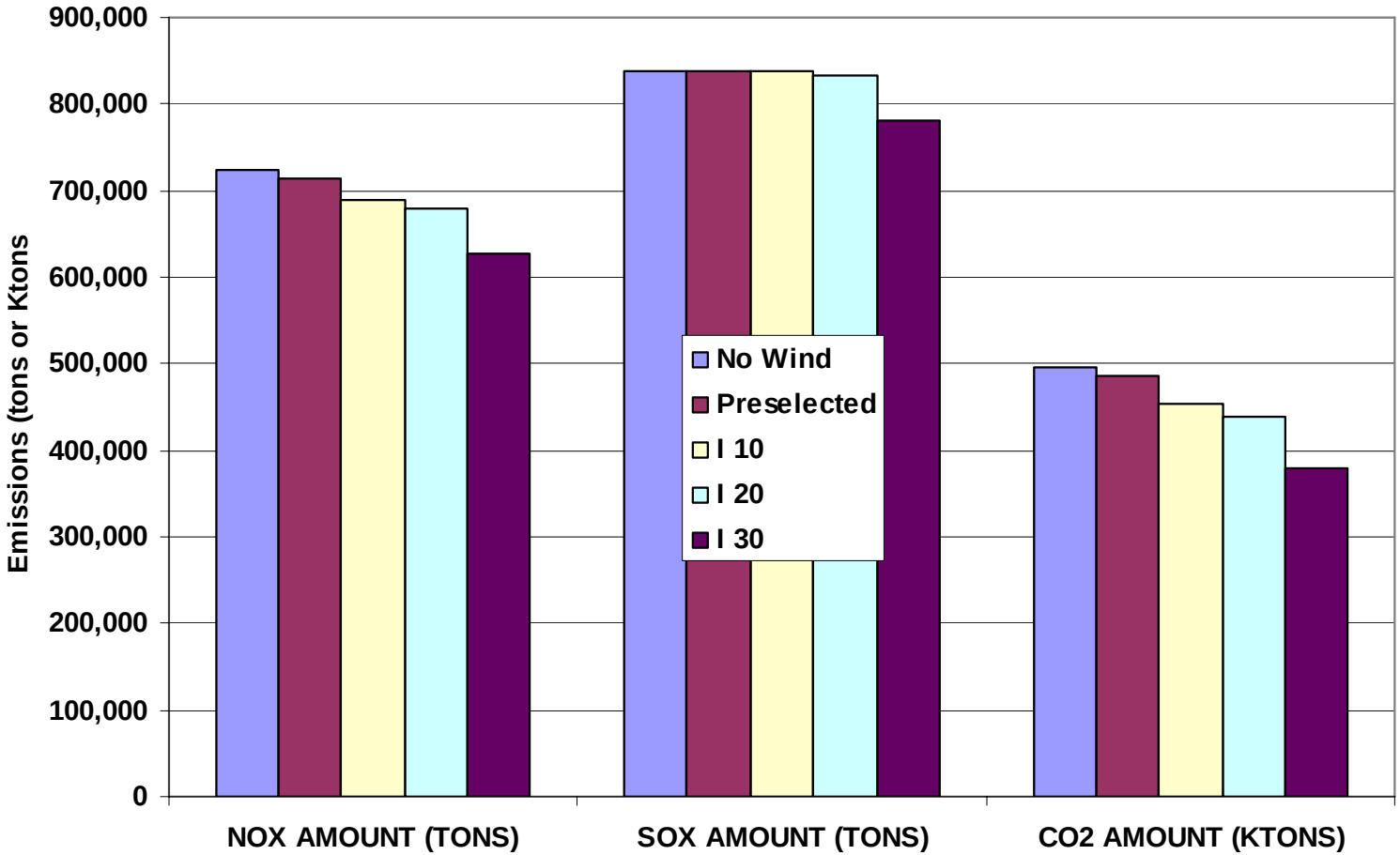


In Footprint

imagination at work

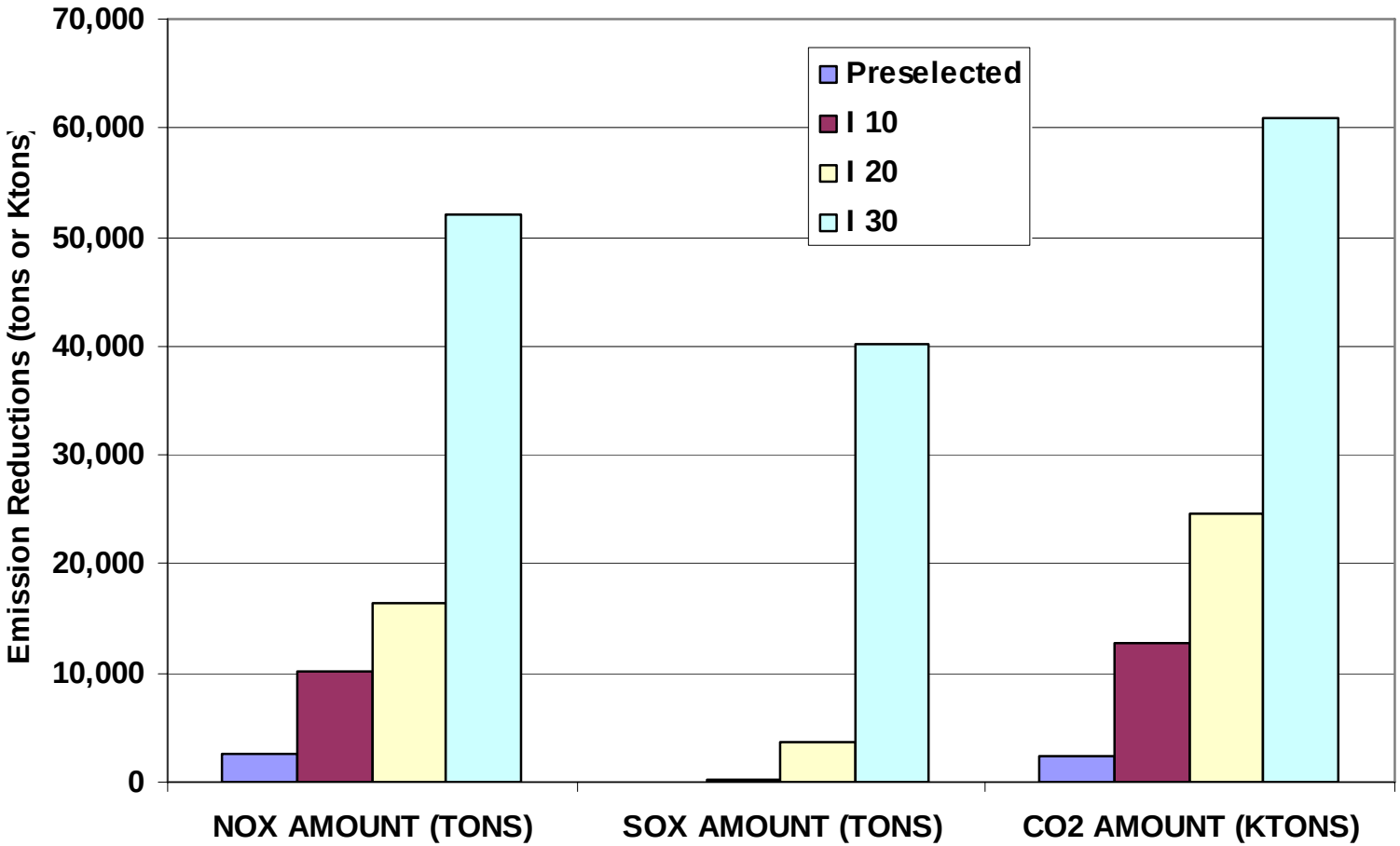
Total Emissions



All of WECC

imagination at work

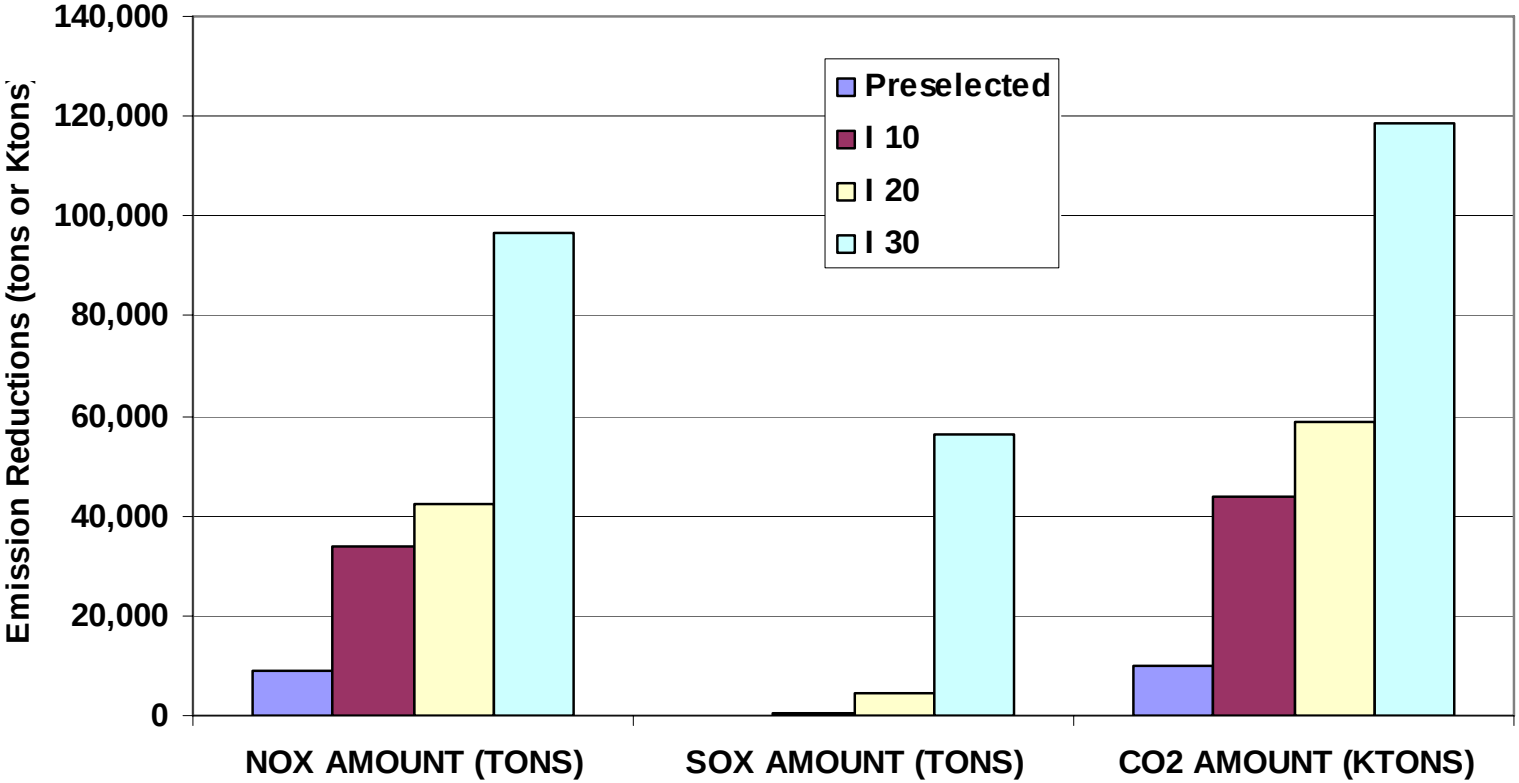
Study Area Emission Reductions



In Footprint

imagination at work

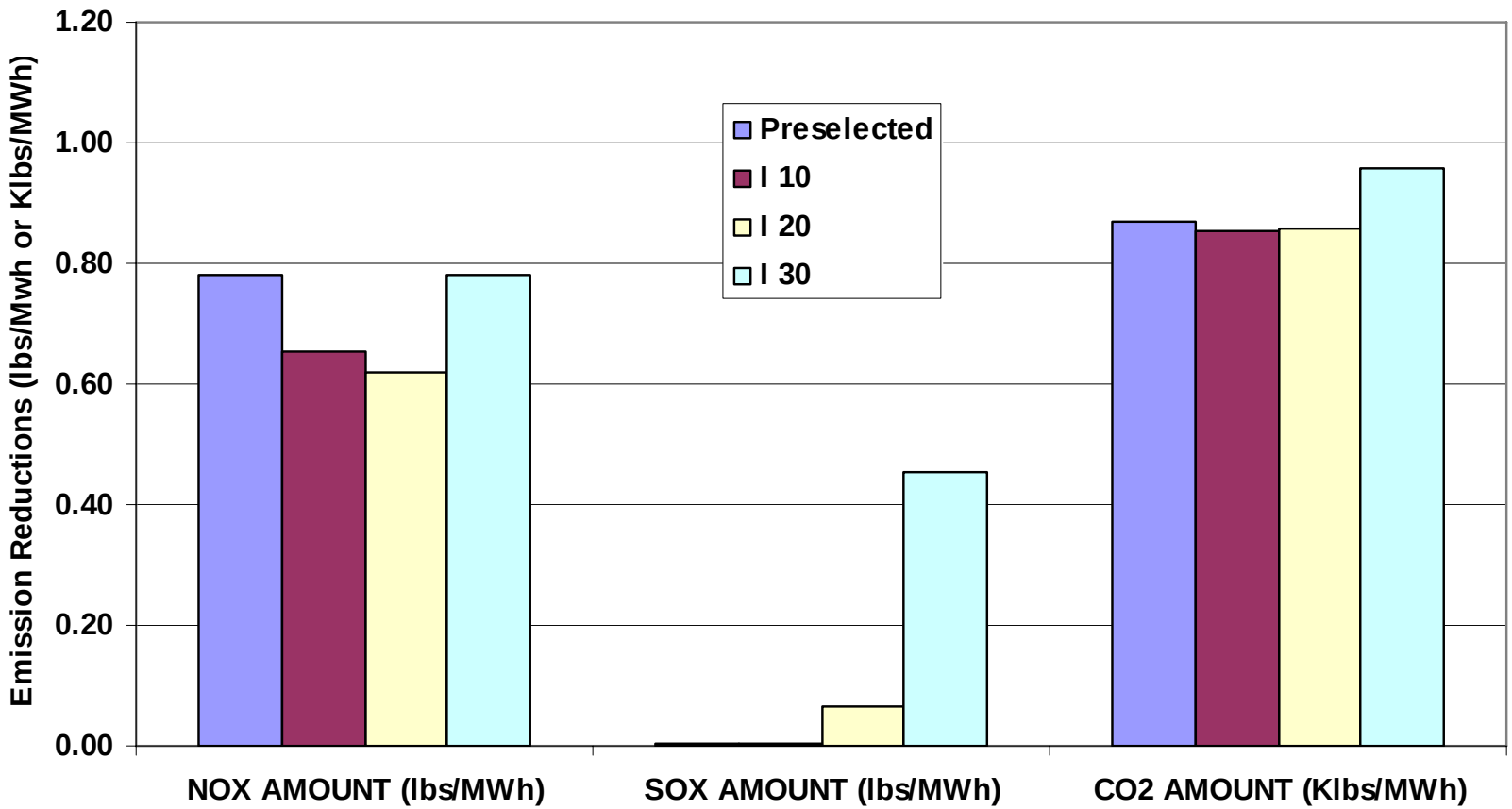
Total Emission Reductions



All of WECC

imagination at work

Total Emission Reductions per MWh of Renewable Generation



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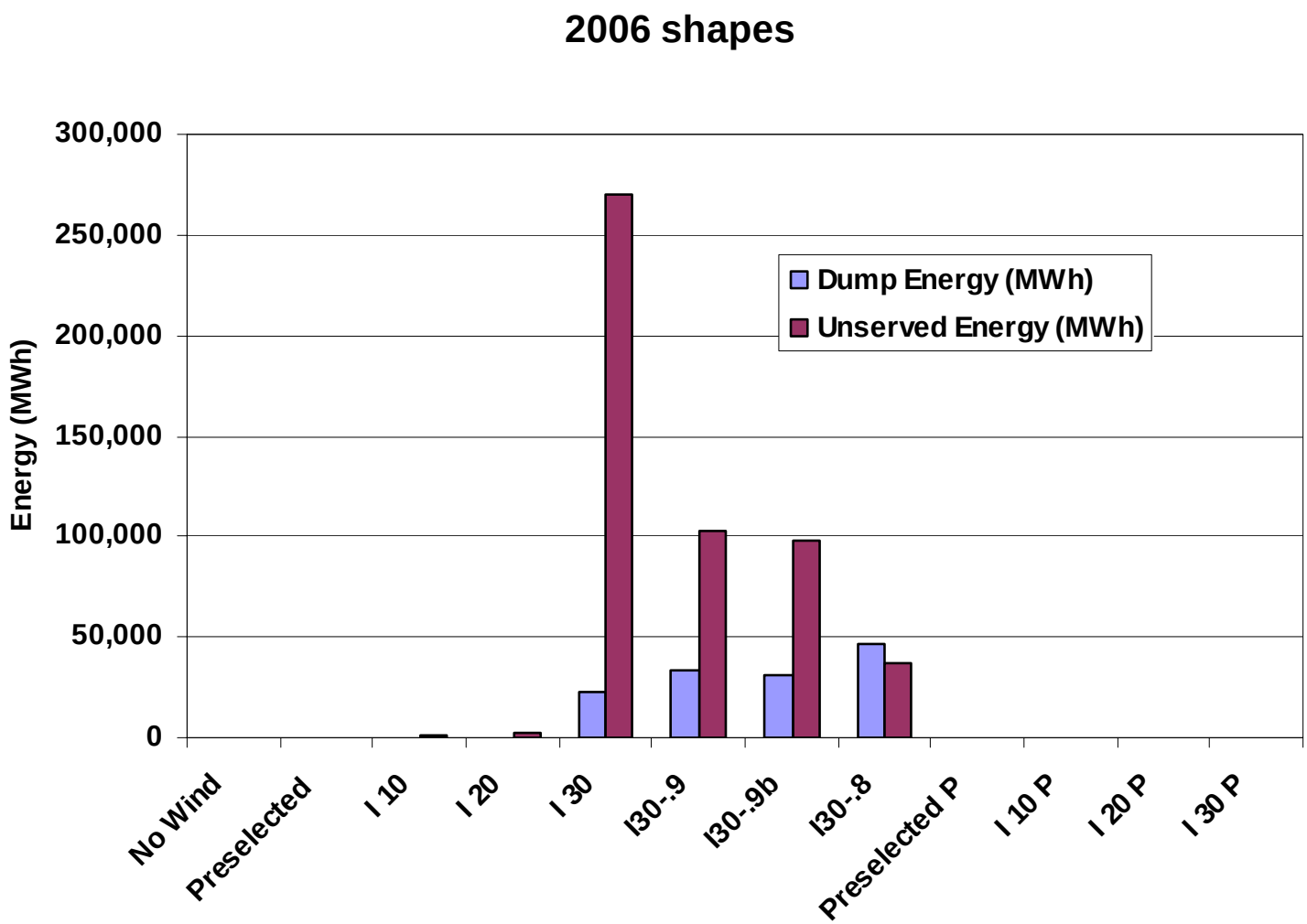

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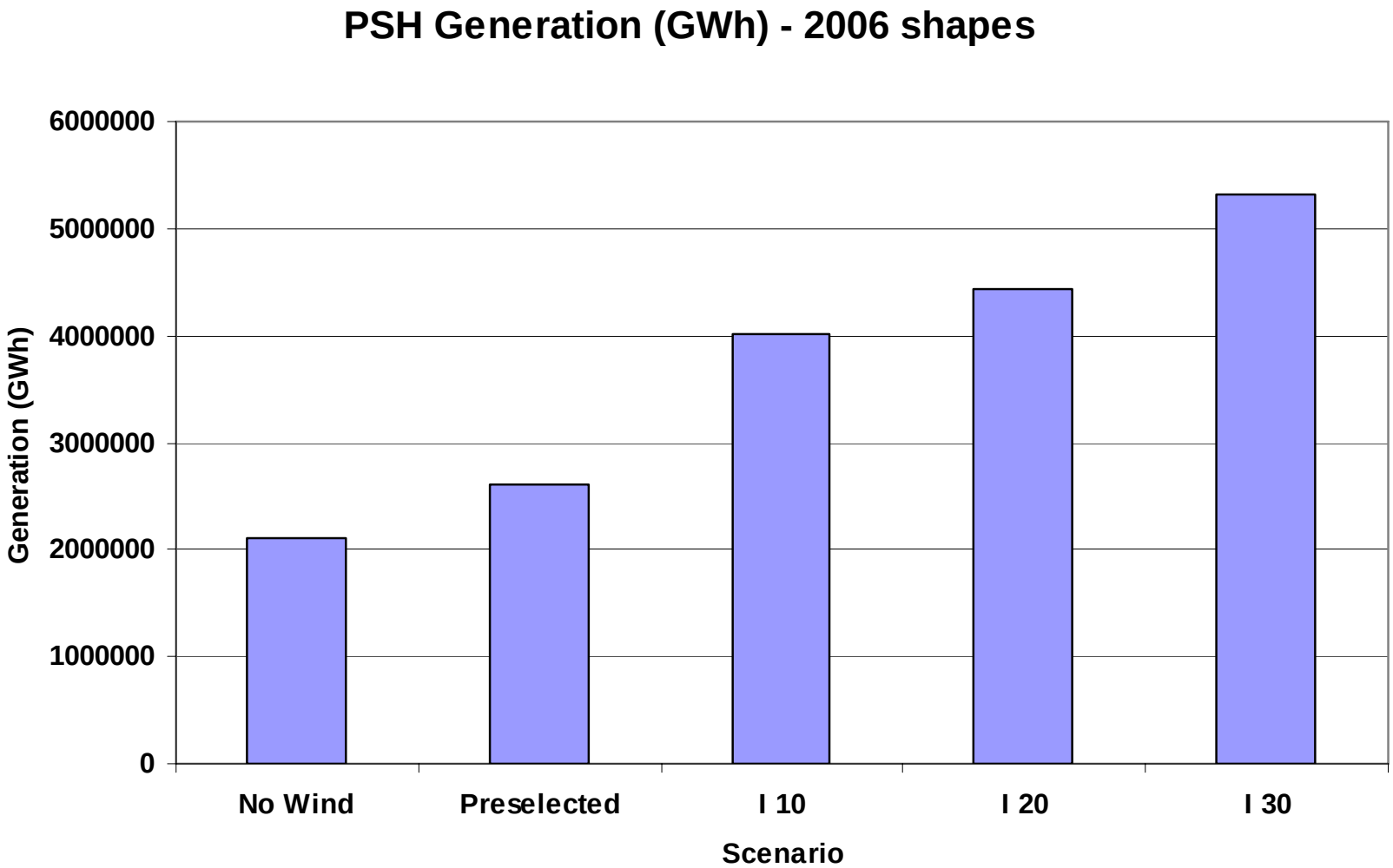

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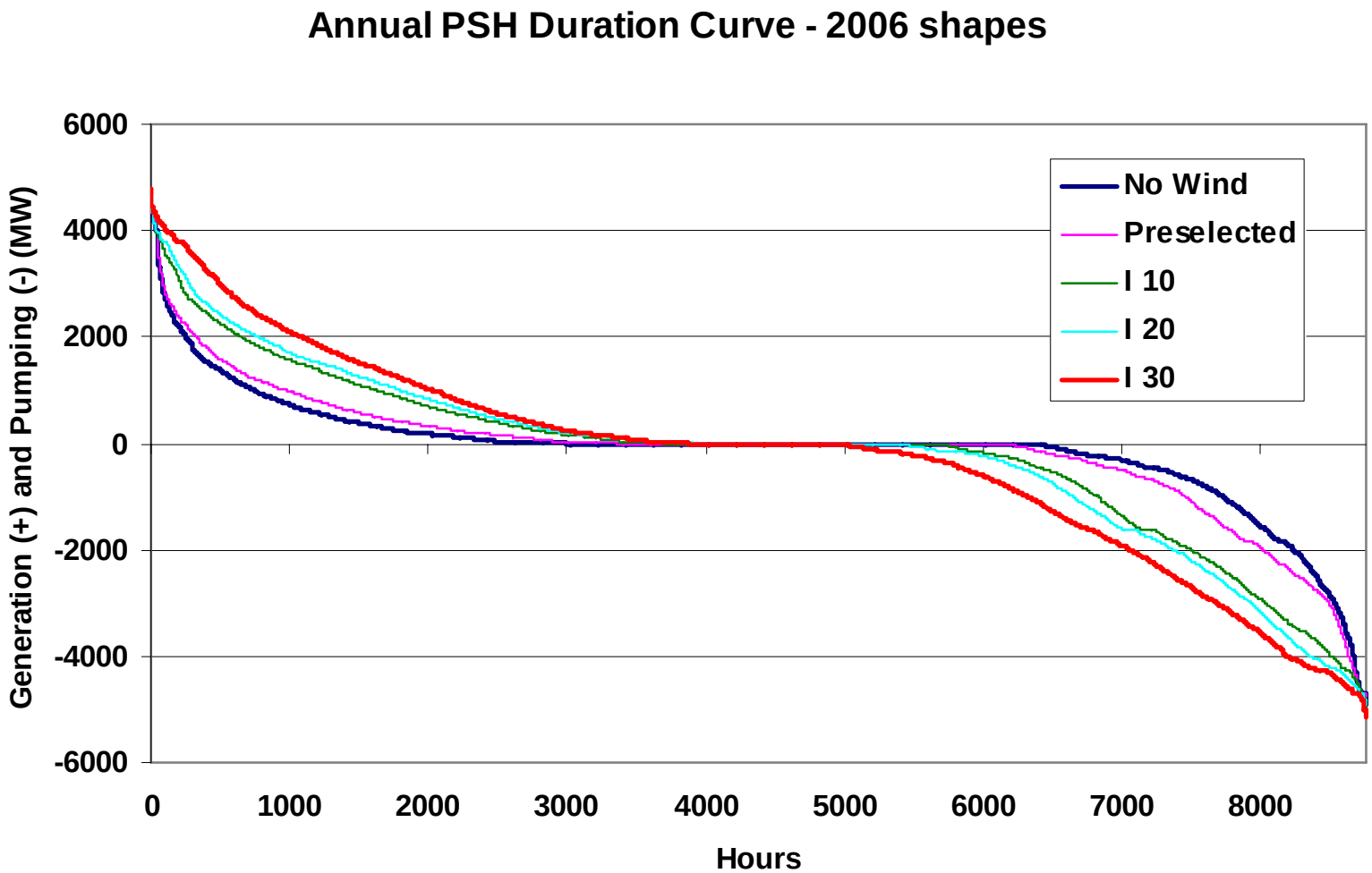

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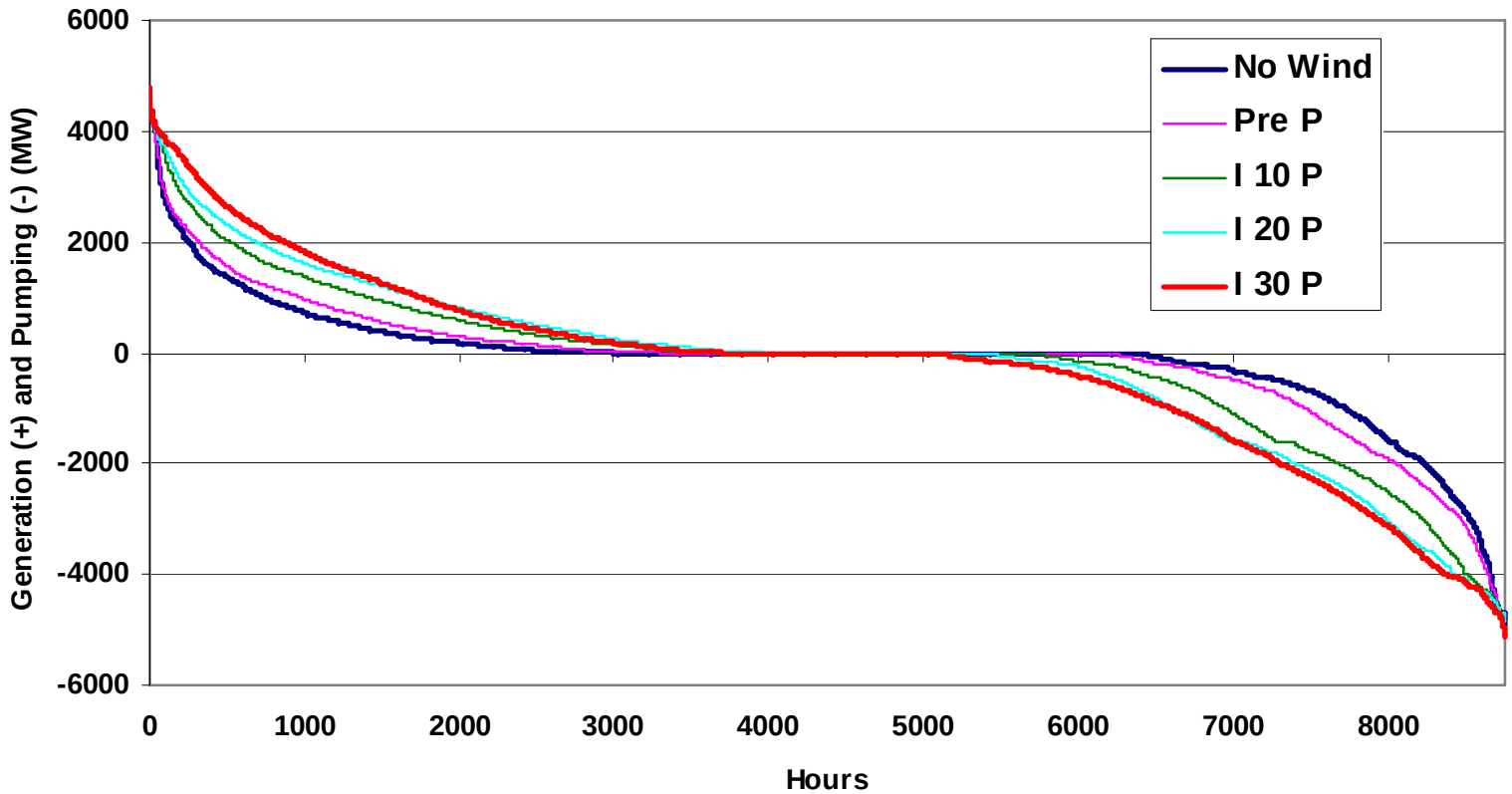
Annual PSH Duration Curve - 2006 shapes



All of WECC

imagination at work

Variations on In-Area Scenario

- Algorithm displaces less valuable sites from one area, making it a net importer, with the energy from more valuable sites in another area, making it a net exporter.
- Total renewable energy is held constant.
- Costs of generation equipment, new transmission and losses are minimized.
- Site selection and transmission reinforcements from algorithm are manually adjusted to reflect practical constraints.

Mega Project scenario - maximum cost benefit

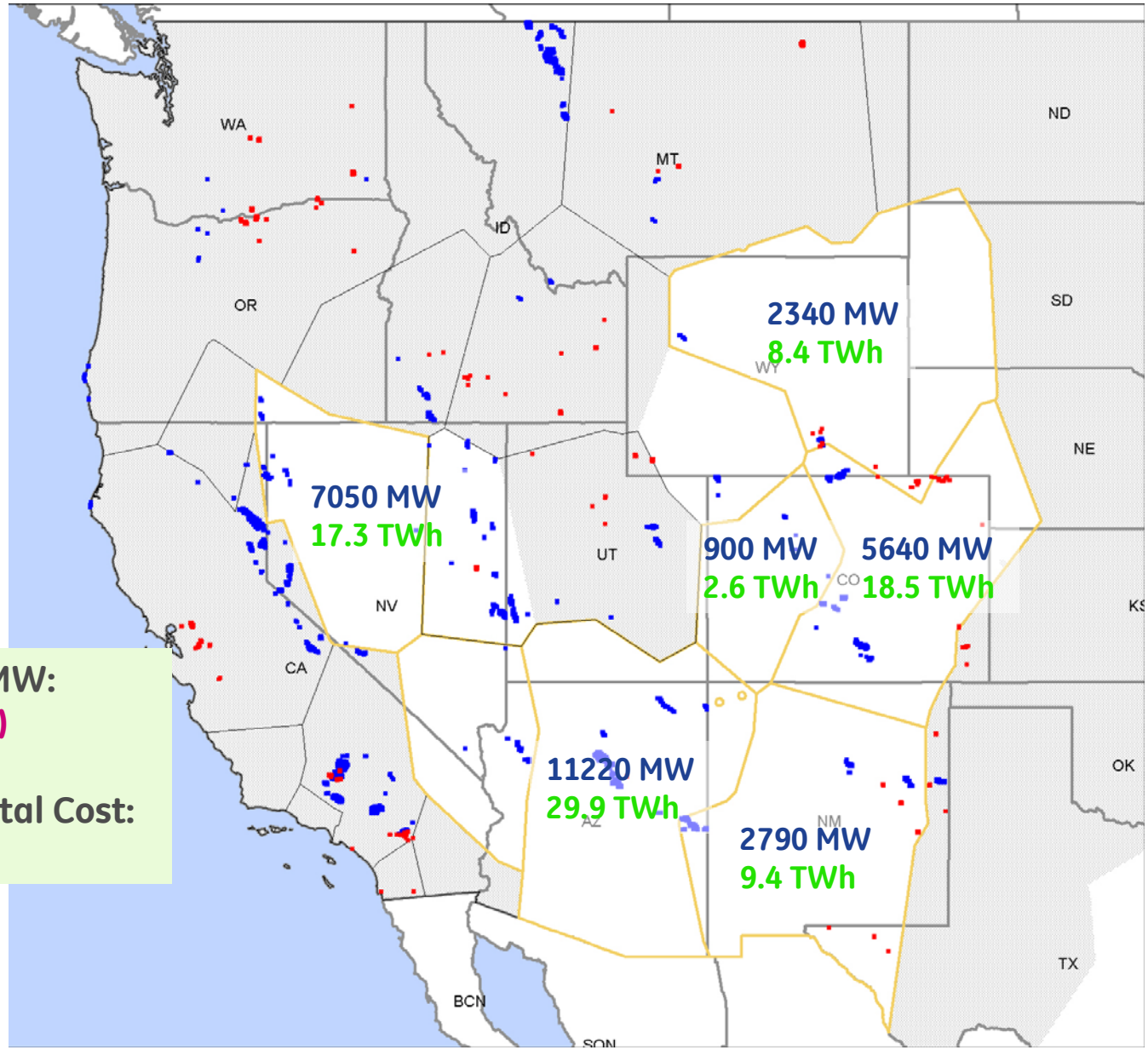
Local Priority scenario – approximate local benefits (e.g., jobs, taxes) by reducing cost of capital in importing areas

Other scenarios - TBD

In-Area Scenario – Wind Sites

Legend:

Wind MW
Annual Energy

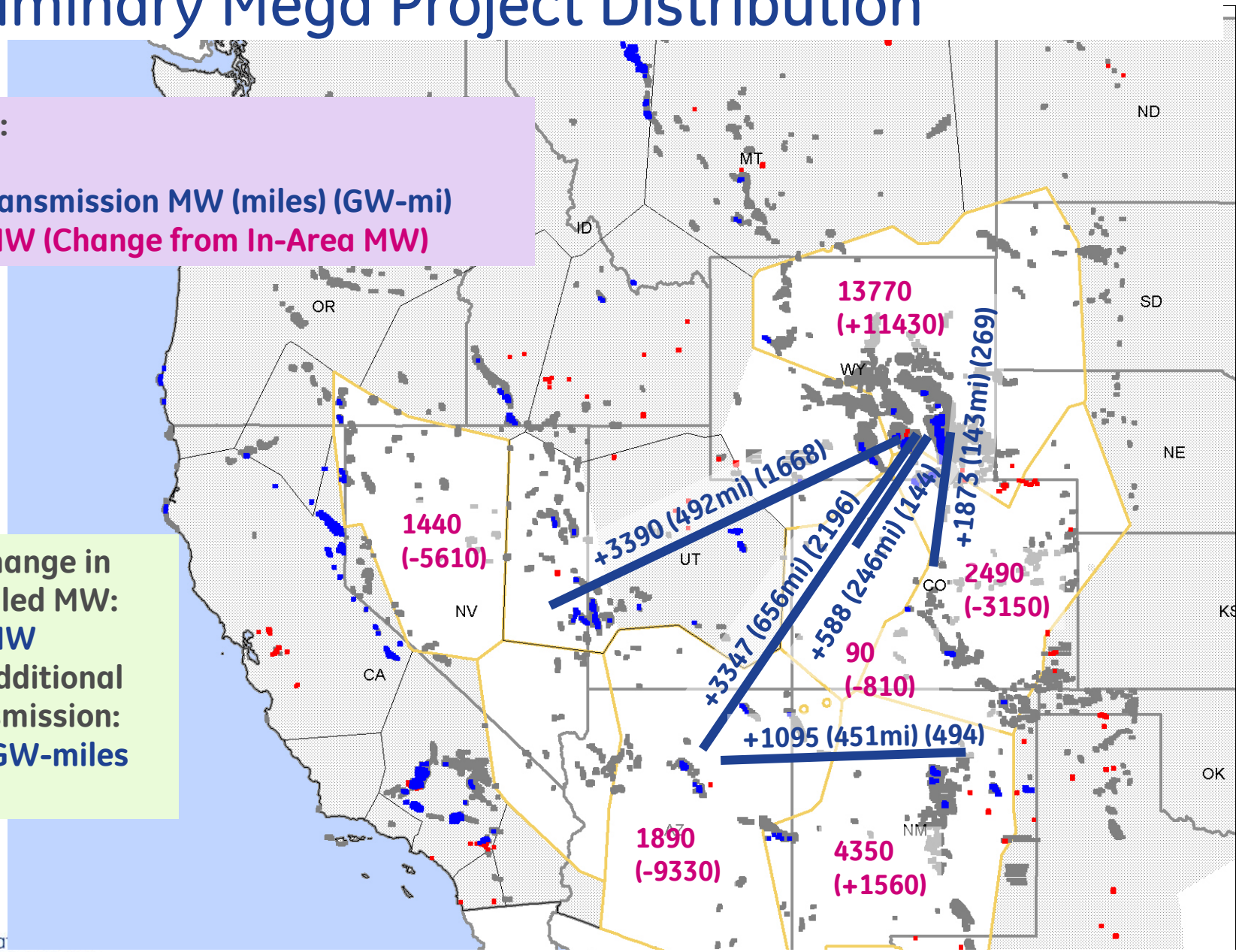


Total Installed MW:
29940 (998 sites)

Total Wind Capital Cost:
$59.9 B

imagination at work

Preliminary Mega Project Distribution



Legend:

New Transmission MW (miles) (GW-mi)
Wind MW (Change from In-Area MW)

Total Change in Installed MW:
- 5910 MW
Total Additional Transmission:
~ 4771 GW-miles

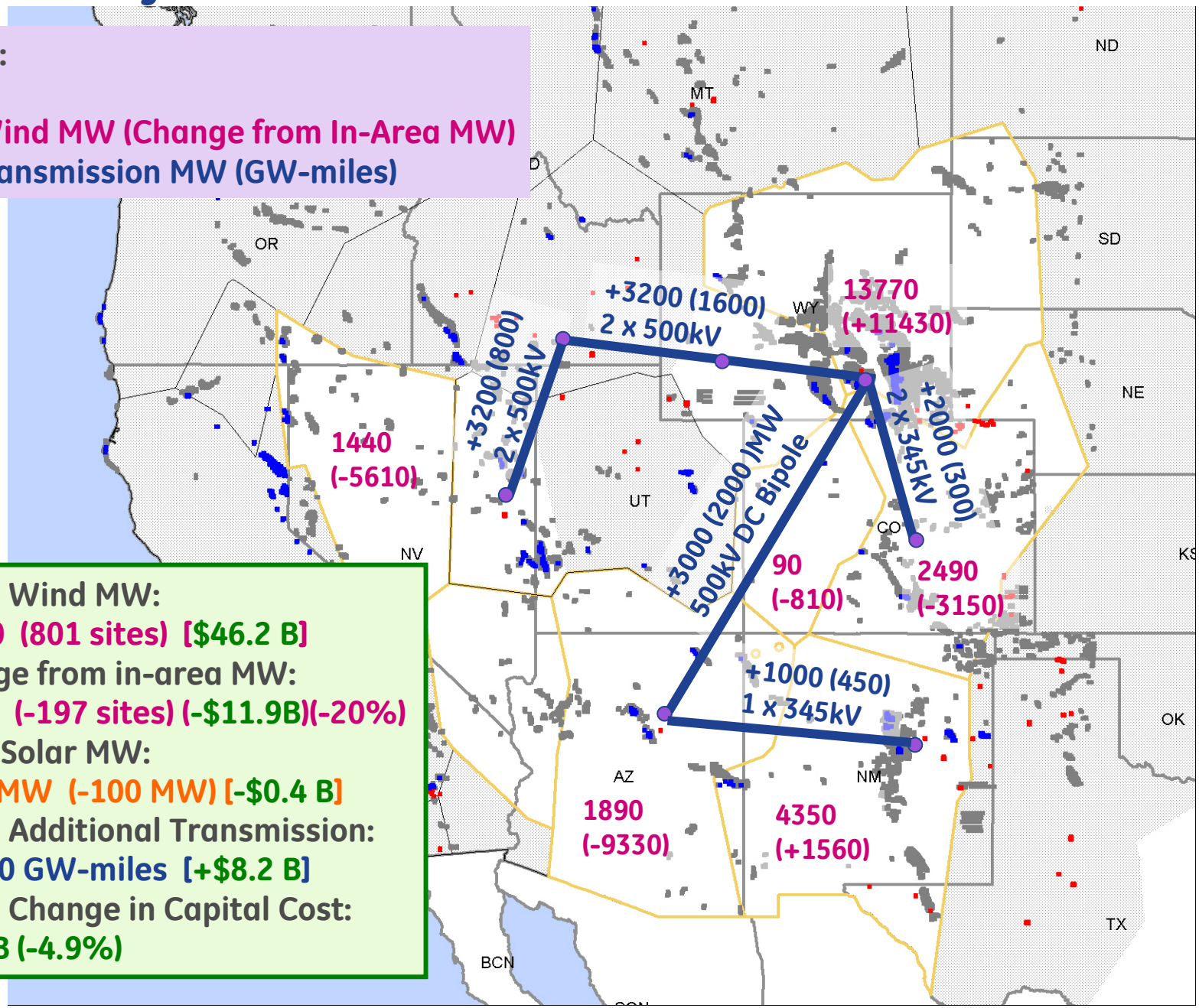
Rationalize Site Distribution & Transmission

- Refine distribution identified by global algorithm to rational components
- Use whole 30 MW wind plants
- Use whole 100 MW solar plants
- Use typical transmission rating
  - 345 or 500 kV AC for bulk interties
    - 1000 or 1600 MW/circuit, respectively
    - Select kV to match voltage level in vicinity
  - HVDC for long distance and high power
    - i.e. > 2 circuits of EHV AC
  - Select in-footprint routes
  - Disregard/consolidate small incremental ties to local transmission voltage level (e.g. 230kV/400 MW)

Mega Project Scenario – Limited Transmission

Legend:

Final Wind MW (Change from In-Area MW)
New Transmission MW (GW-miles)

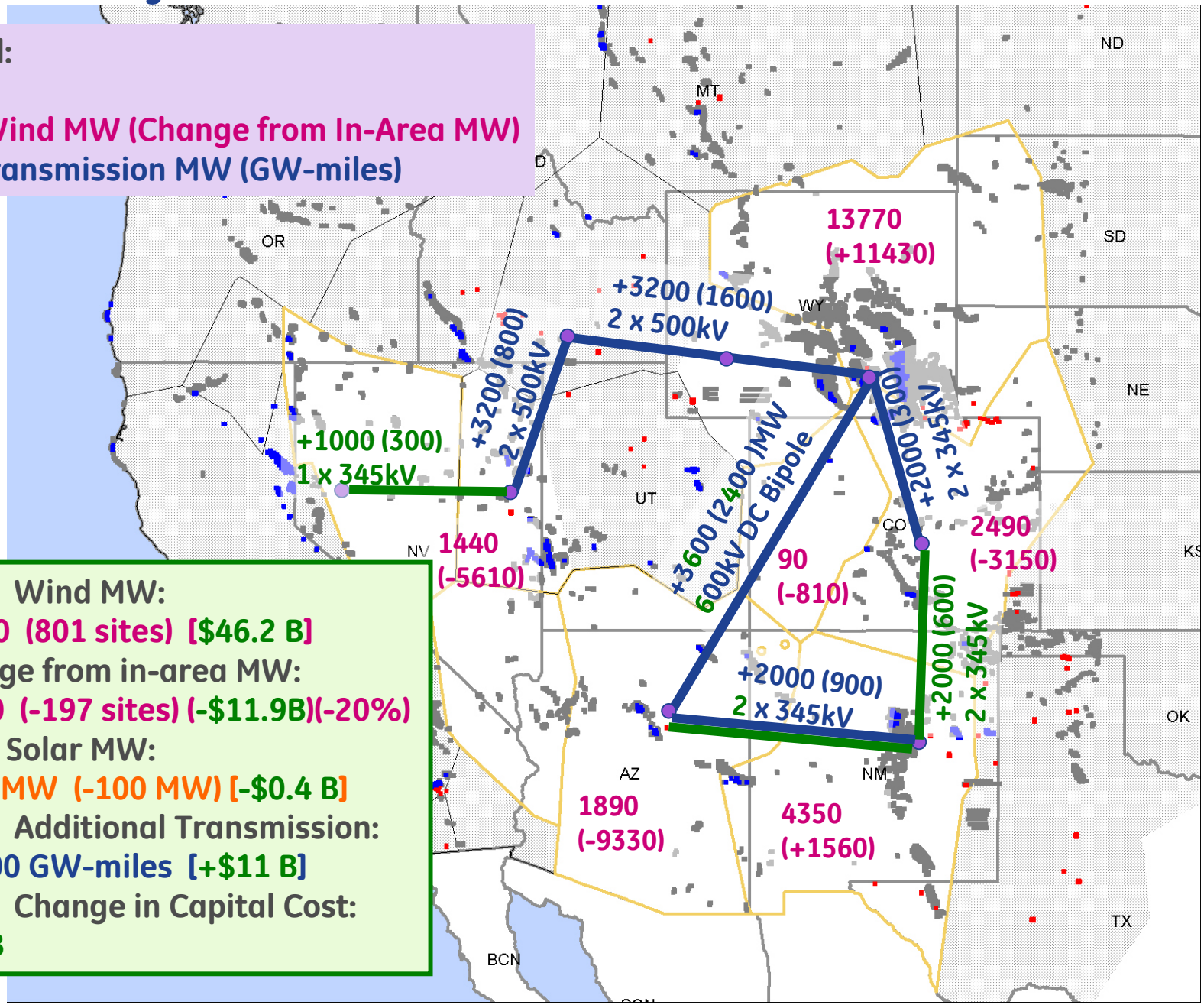


Total Wind MW:
24040 (801 sites) [$46.2 B]
Change from in-area MW:
-5940 (-197 sites) (-$11.9B)(-20%)
Total Solar MW:
5700 MW (-100 MW) [-$0.4 B]
Total Additional Transmission:
+ 5200 GW-miles [+$8.2 B]
Total Change in Capital Cost:
-$4.1B (-4.9%)

Mega Project Scenario – More Transmission

Legend:

Final Wind MW (Change from In-Area MW)
New Transmission MW (GW-miles)

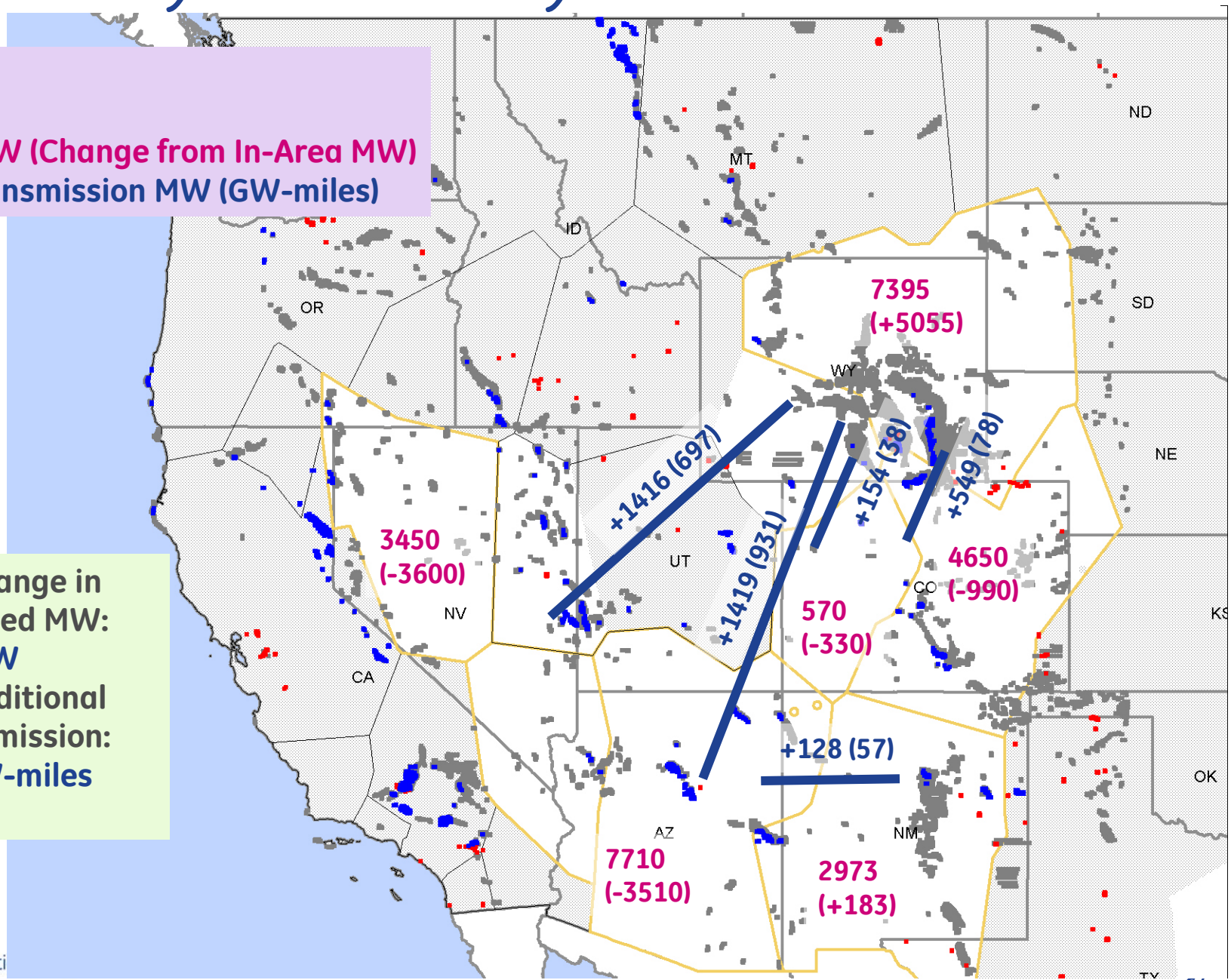


Total Wind MW:
24040 (801 sites) [$46.2 B]
Change from in-area MW:
-5940 (-197 sites) (-$11.9B)(-20%)
Total Solar MW:
5700 MW (-100 MW) [-$0.4 B]
Total Additional Transmission:
+ 6900 GW-miles [+$11 B]
Total Change in Capital Cost:
- $1B

Preliminary Local Priority Distribution

Legend:

Wind MW (Change from In-Area MW)
New Transmission MW (GW-miles)



Total Change in Installed MW:
-3192 MW
Total Additional Transmission:
1890 GW-miles

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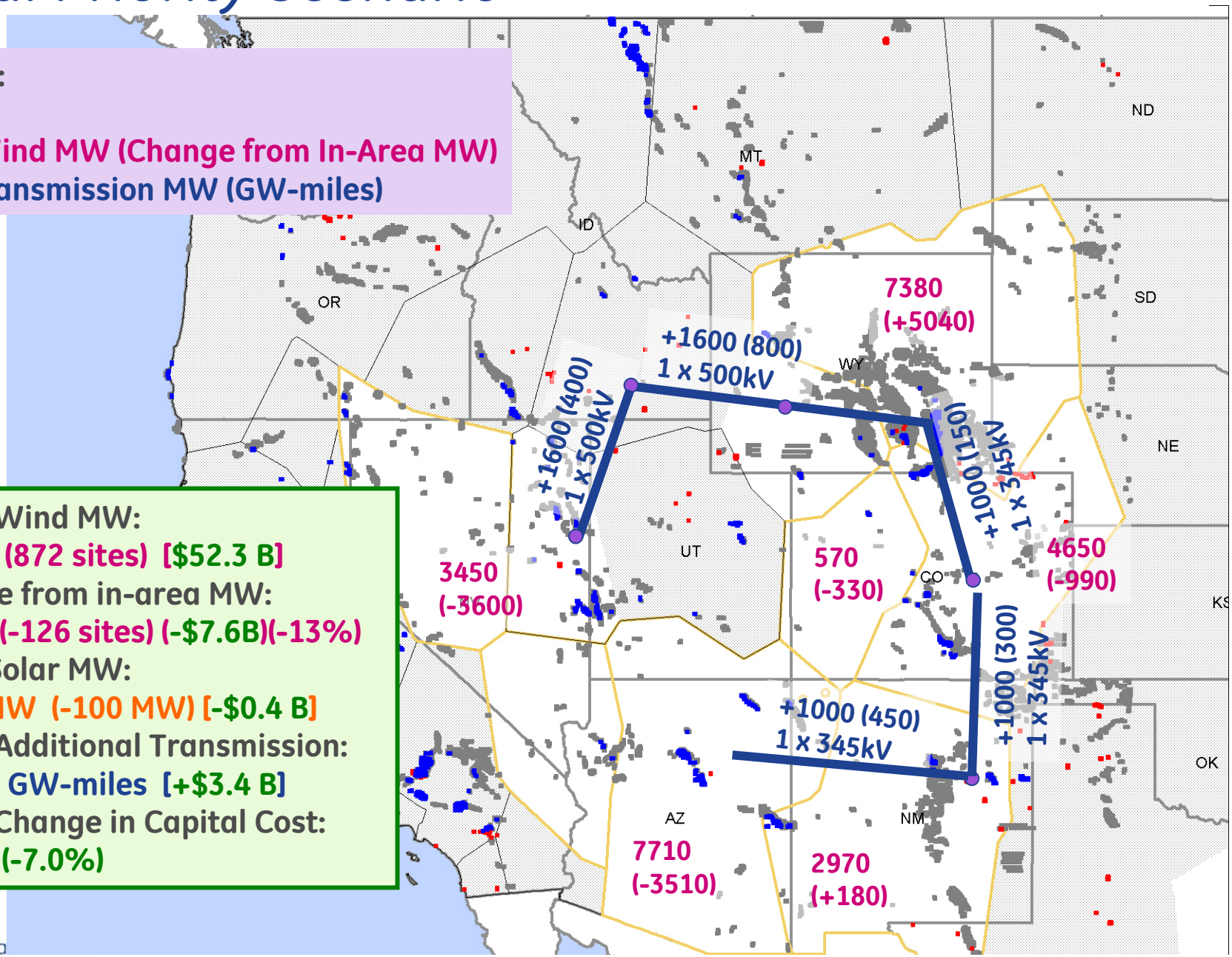
Local Priority Scenario

Legend:

Final Wind MW (Change from In-Area MW)
New Transmission MW (GW-miles)



Total Wind MW:
26160 (872 sites) [$52.3 B]
Change from in-area MW:
-3780 (-126 sites) (-$7.6B)(-13%)
Total Solar MW:
5700 MW (-100 MW) [-$0.4 B]
Total Additional Transmission:
+ 2100 GW-miles [+$3.4 B]
Total Change in Capital Cost:
-$4.2B (-7.0%)

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