GE
Energy

Western Wind & Solar Integration Study

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(Speaking for a large team at GE, NREL, 3TIER, Northern Arizona University, Exeter, SUNY/Clean Power Research)

A national laboratory of the U.S. Department of Energy
Office of Energy Efficiency & Renewable Energy

National Renewable Energy Laboratory

Innovation for Our Energy Future

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What did we model?

- We don't expect 35% renewables by 2017 but needed a realistic baseline of the power system
- Modeled WECC power system for the year 2017 three times, with load and weather data from 2004, 2005, 2006
  - Important to use time-synchronous load and weather data to capture load/weather correlations
- Fixed targets for wind and solar independently

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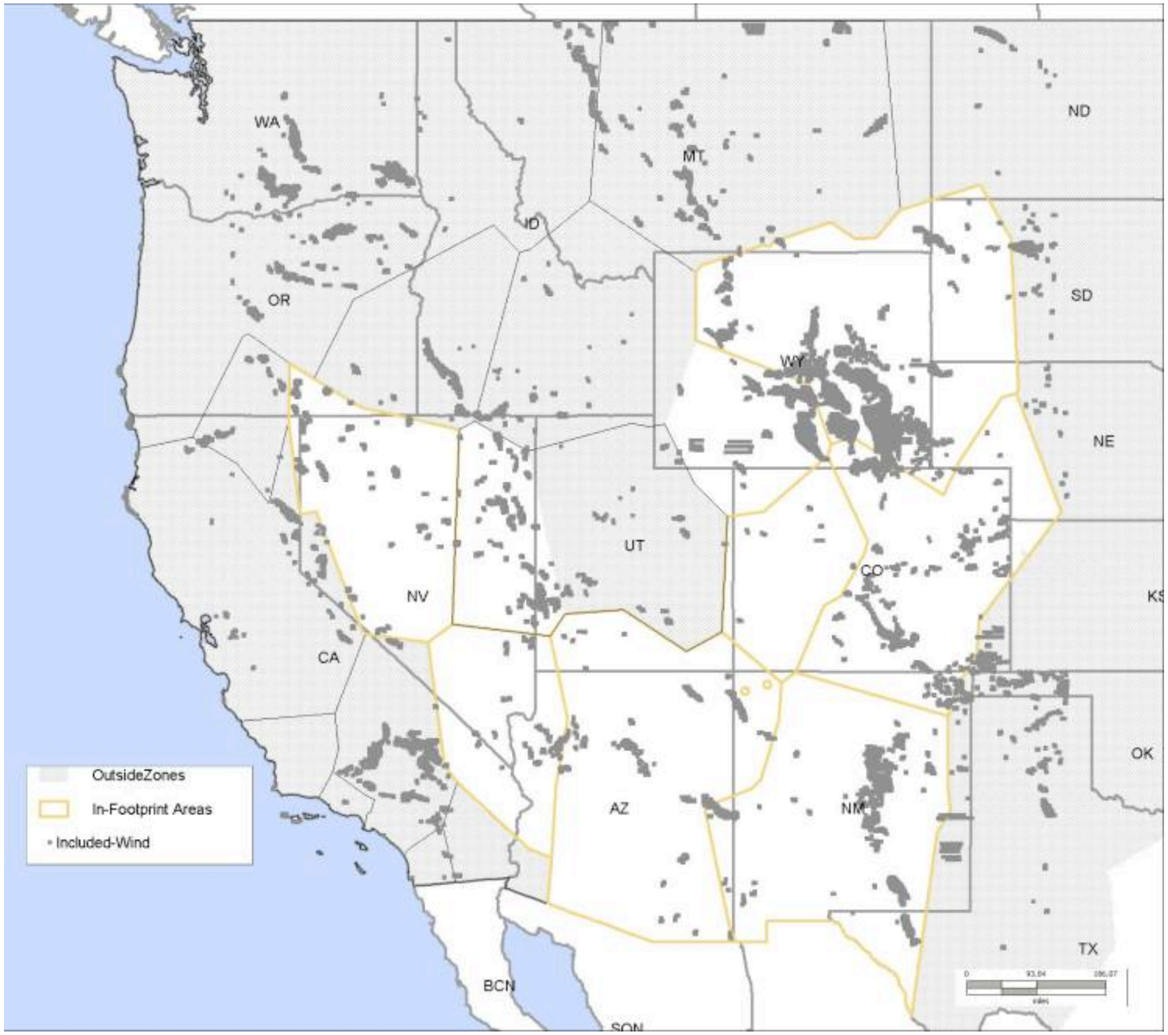
Wind data

- 3TIER Group: 10 minute wind power output for 2004, 2005, and 2006 for 960 GW of wind sites in WECC.
- Power profiles were based on Vestas V90 3MW turbine at 100m height.
- Hourly day-ahead power output forecasts.



http://www.nrel.gov/wind/integrationdatasets

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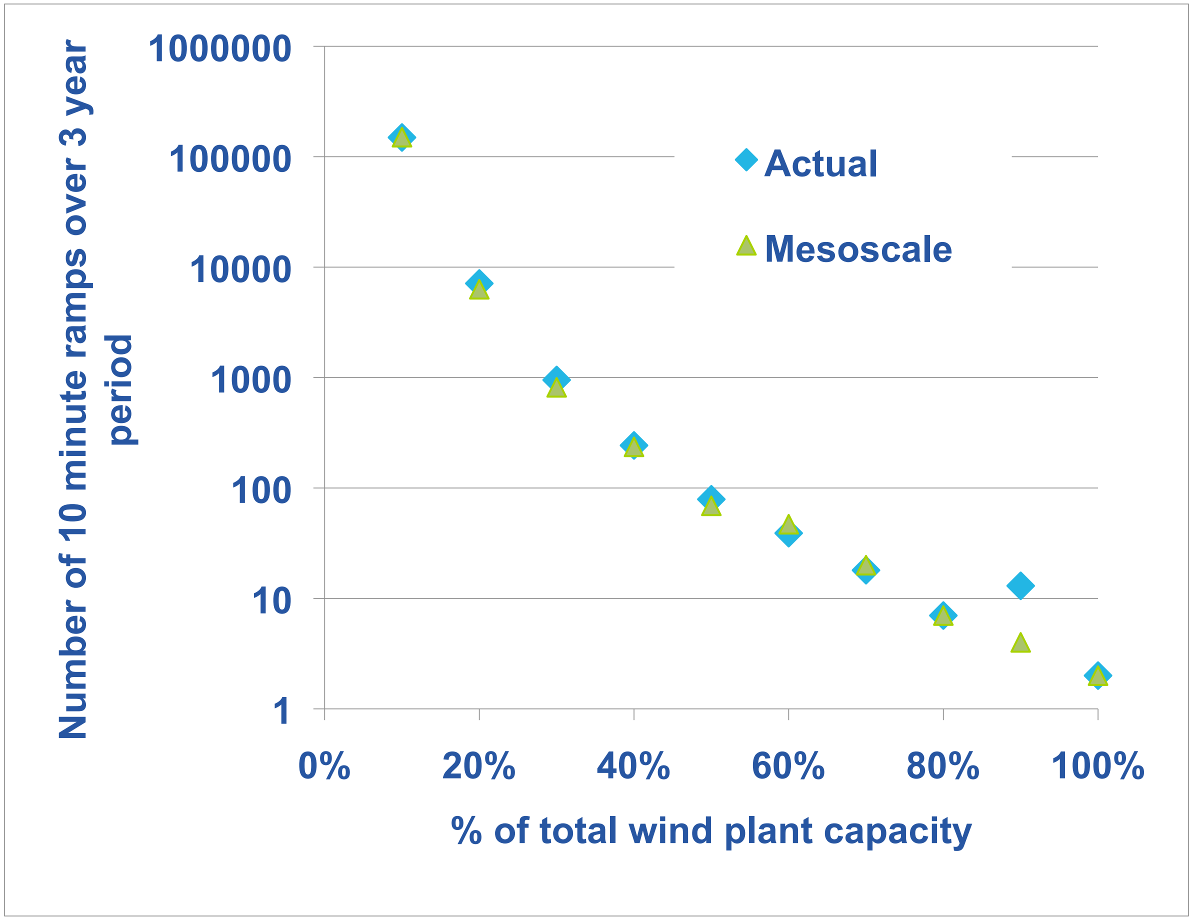

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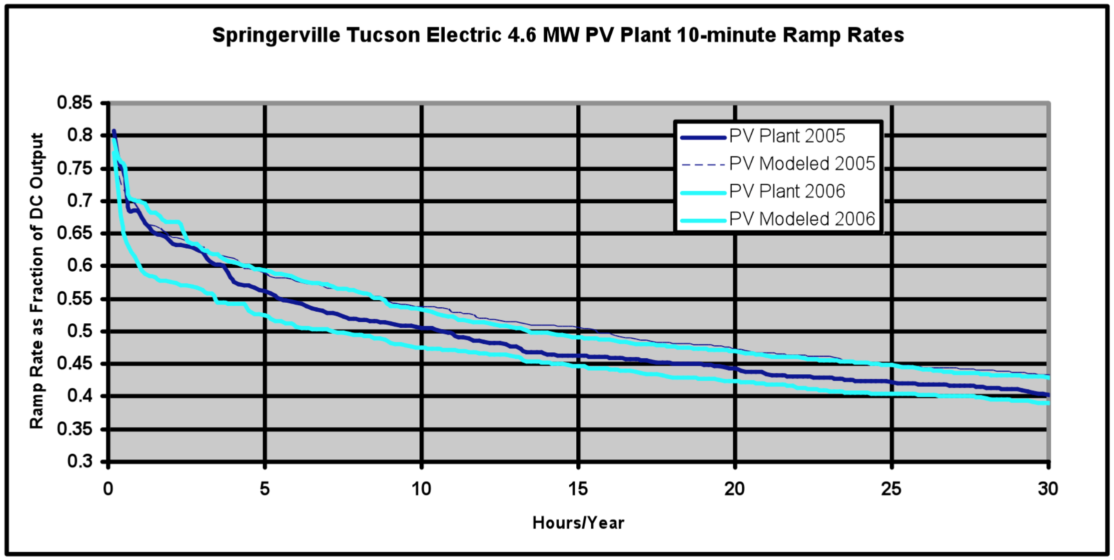
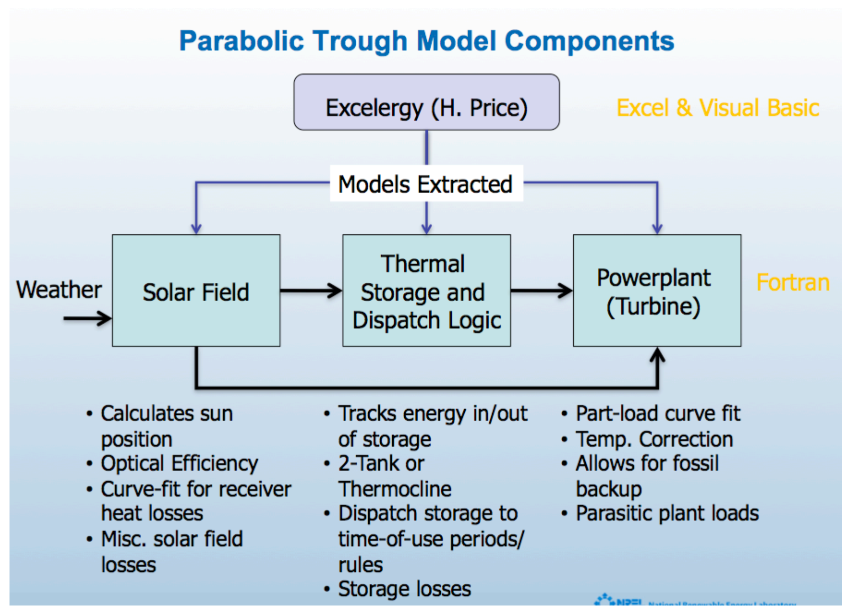
Solar datasets



Satellite cloud cover model produced 10 km hourly solar irradiance. Variability was added based on PV plant output. Distributed, rooftop PV was modeled due to lack of data from centralized PV plants.

CSP was modeled with 6 hours thermal storage which eliminated the need to model 10 min CSP output. Initially the thermal storage dispatch was based on SCE's load shape.



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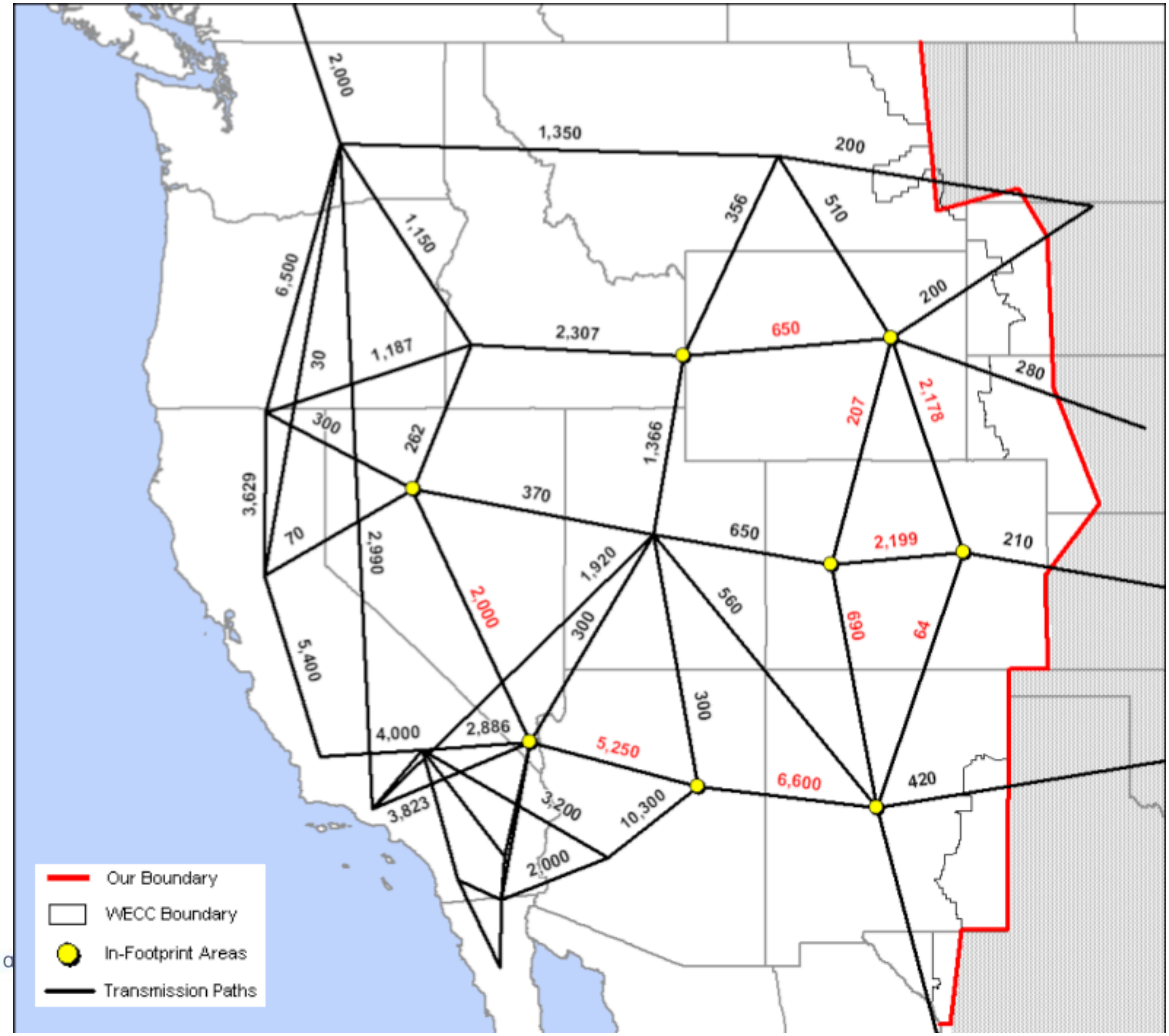
Inter-area Transmission Path Ratings



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Scope of this study

- Operational impact study, not a transmission planning study.
- Not a full-blown reliability analysis. We do a capacity value analysis to look at contributions to resource adequacy.
- Not a full cost-benefit analysis. Doesn't look at cost of generation, but rather operational costs savings.
- Does not optimize the balance of generation to meet 2017 load, but rather assumes a business-as-usual portfolio in addition to the renewables
- Economic commitment and dispatch of generators. Did not model bilateral contracts.
- Does not include Canadian wind and solar resources
- Only distributed generation (not centralized) PV is included
- Considered inter-state, not intra-state transmission buildouts
- Did not include increased wear and tear due to cycling of thermal units. Did include impact on heat rate and emissions

Assumptions

- 2017 nominal dollars
- $30/ton carbon cost
- $2/MBTU coal, $9.5/MBTU natural gas
- Except where noted, extensive balancing area cooperation
- Economic commitment and dispatch of generators, while respecting transmission limits and generator cycling capabilities and minimum turndowns
- Business-as-usual capacity expansion of 24GW to meet 2017 load is assumed
- Contingency reserves: 6% of load, half of which is spinning and half is non-spin
- Subhourly modeling is based on 5 min economic dispatch

Monthly penetration levels can be much higher or lower than 35%

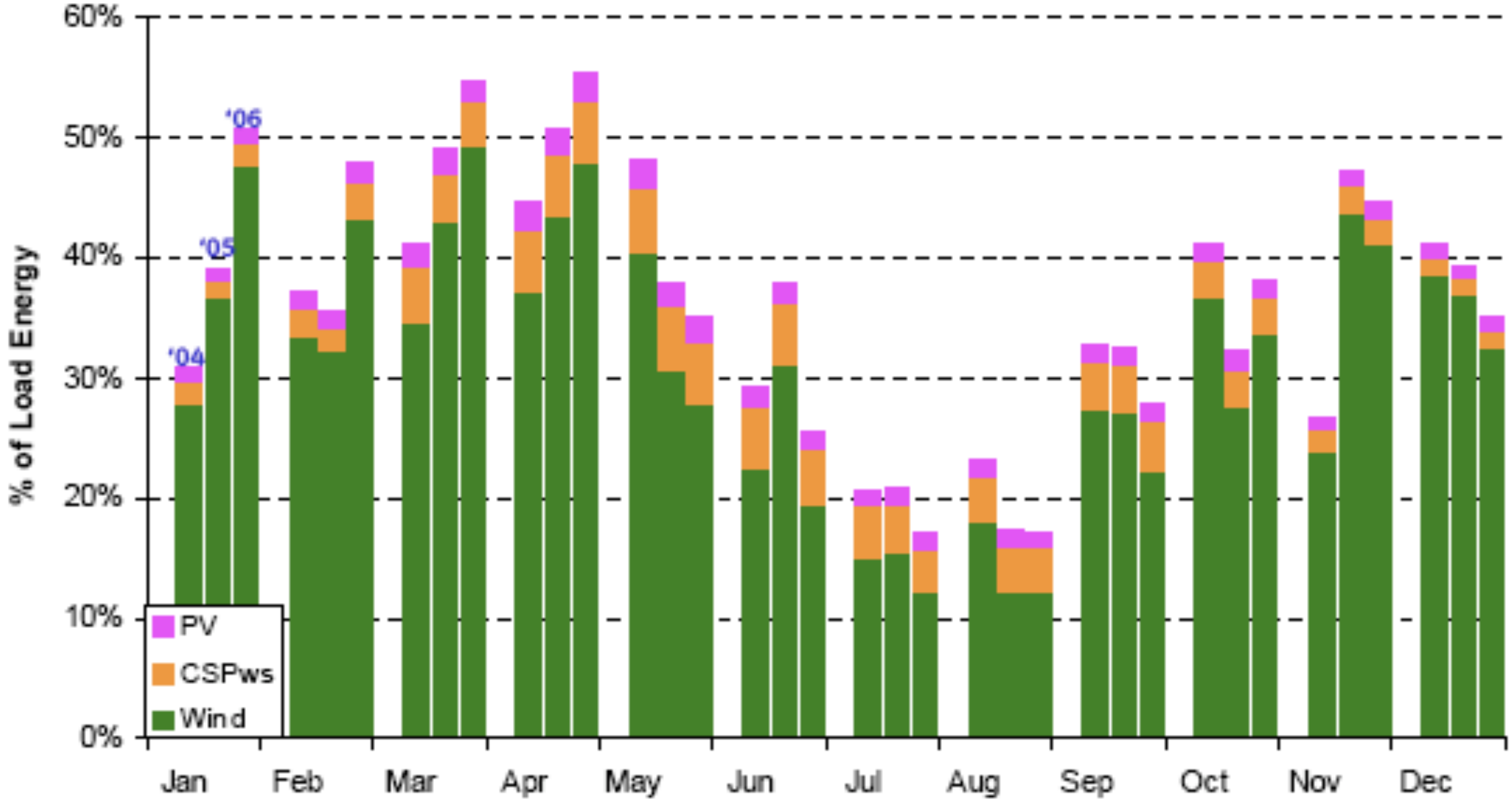

Figure 4.3 Total In-Footprint Monthly Energy from Wind and Solar for 2004 – 2006 (30% In Area Scenario)

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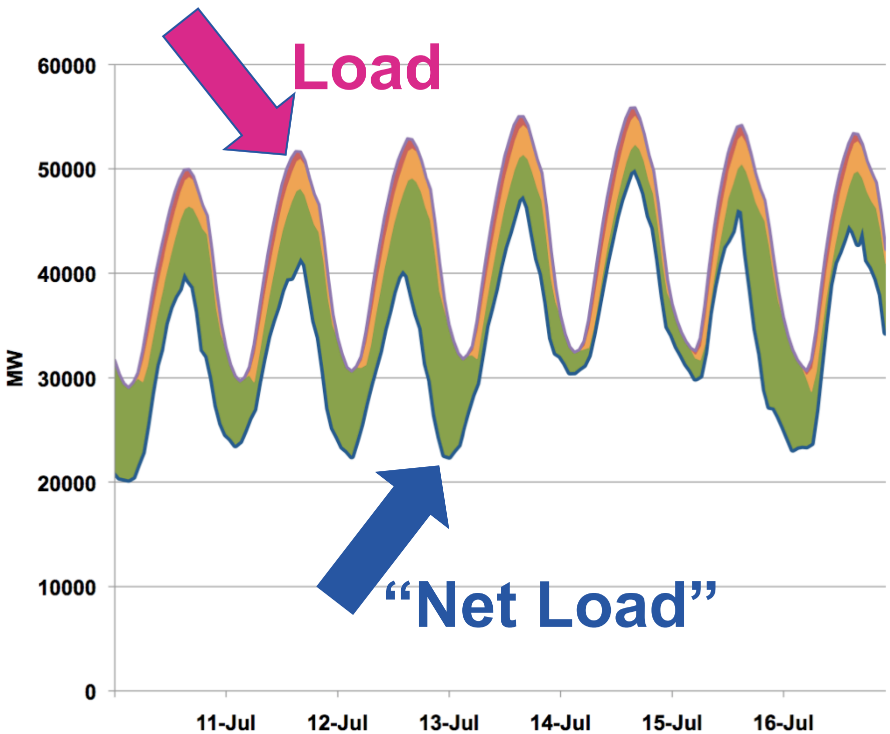
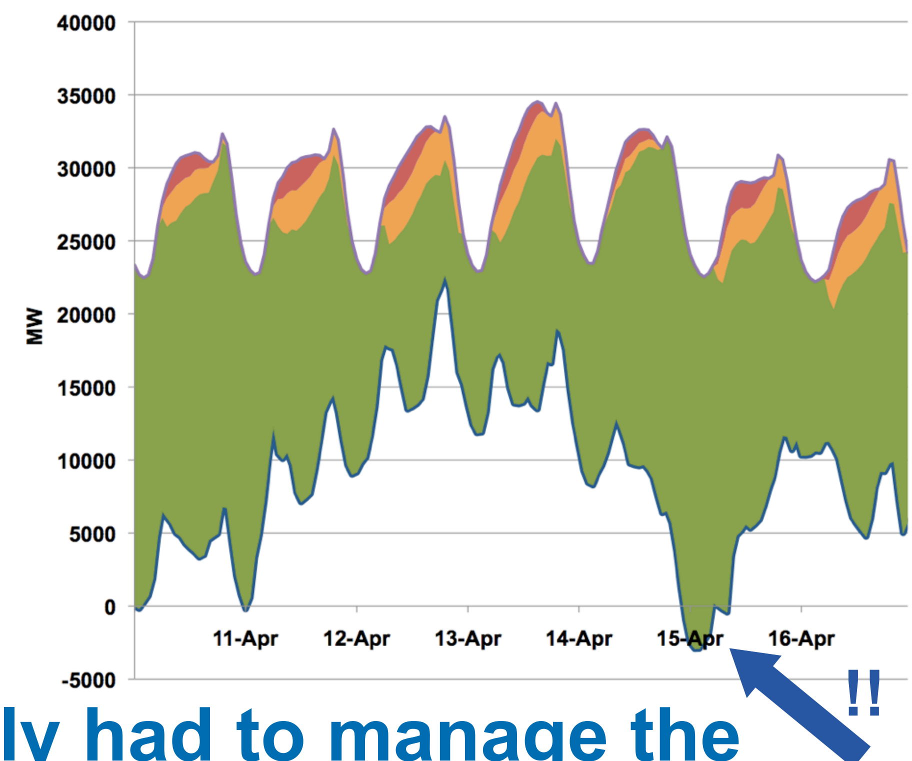
How does the system operate with 35% renewables?

July 2006 – a tame week



April 2006 – the worst week of 3 years



The operator formerly had to manage the pink load trace but now has to manage the blue net load trace

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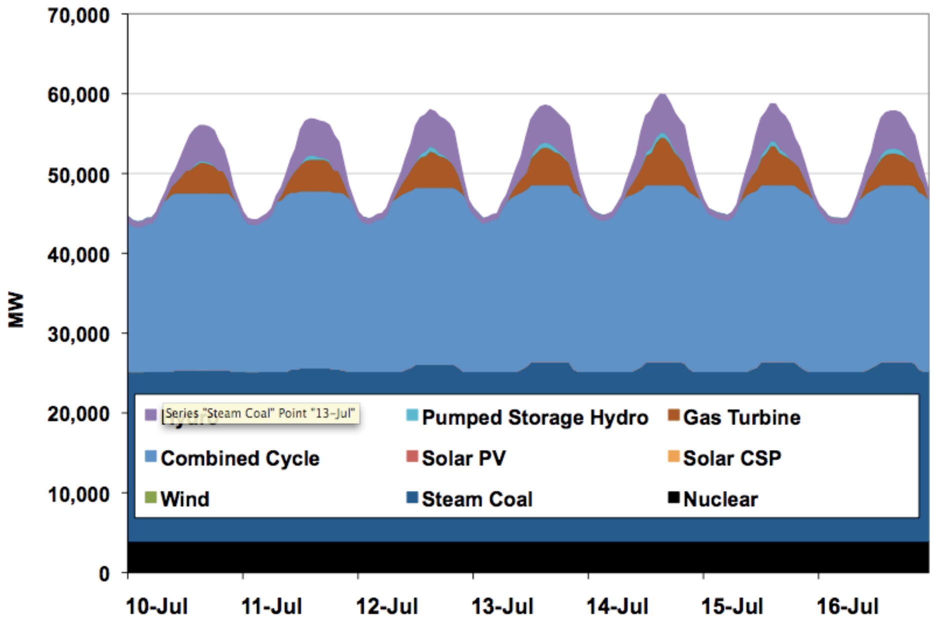
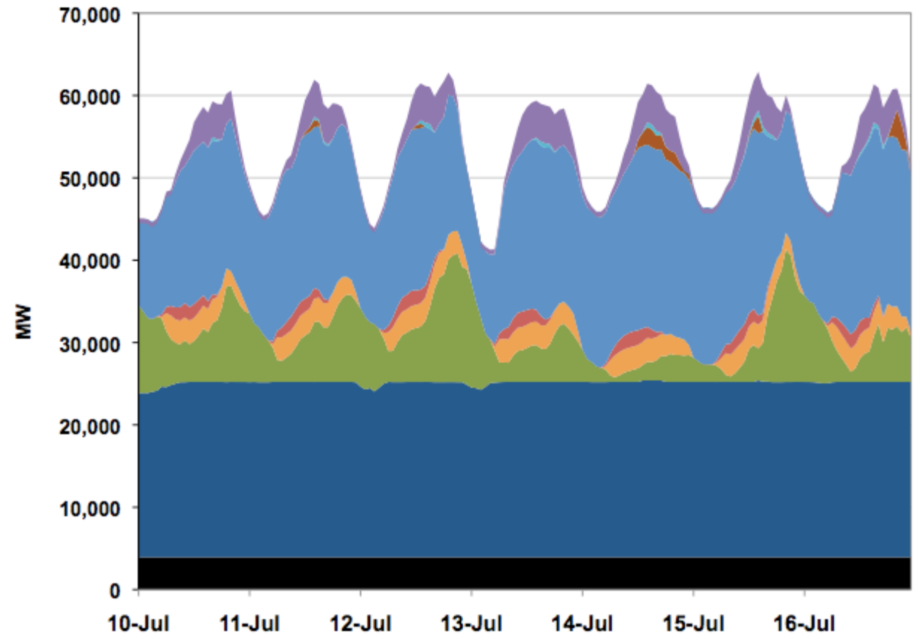
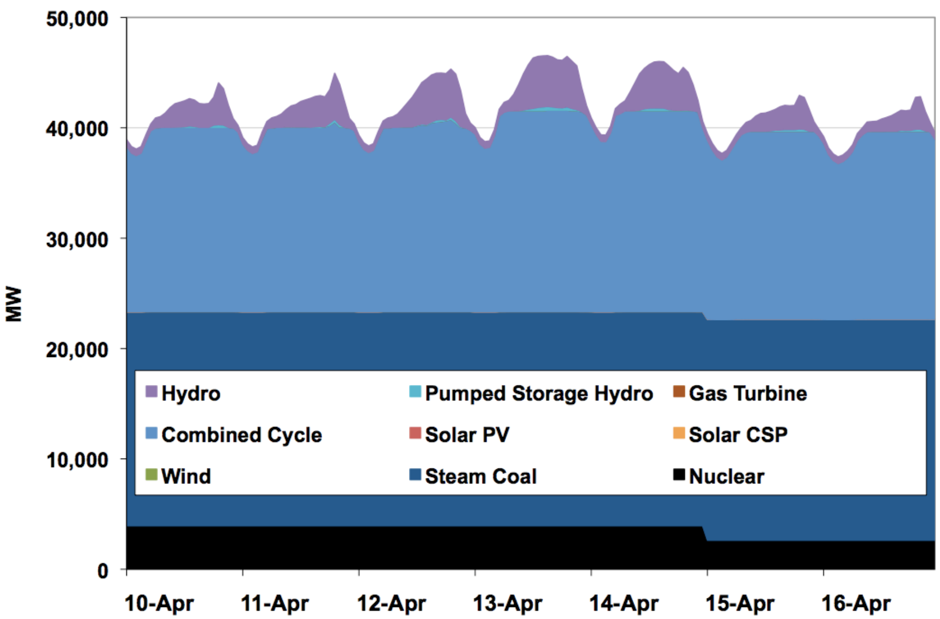
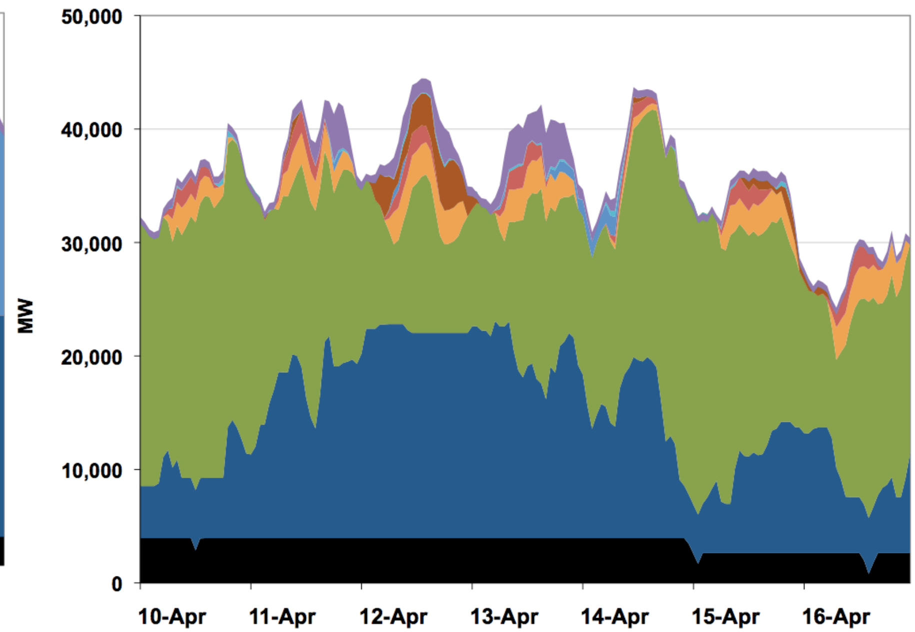
Operations during these weeks









What generation gets displaced?

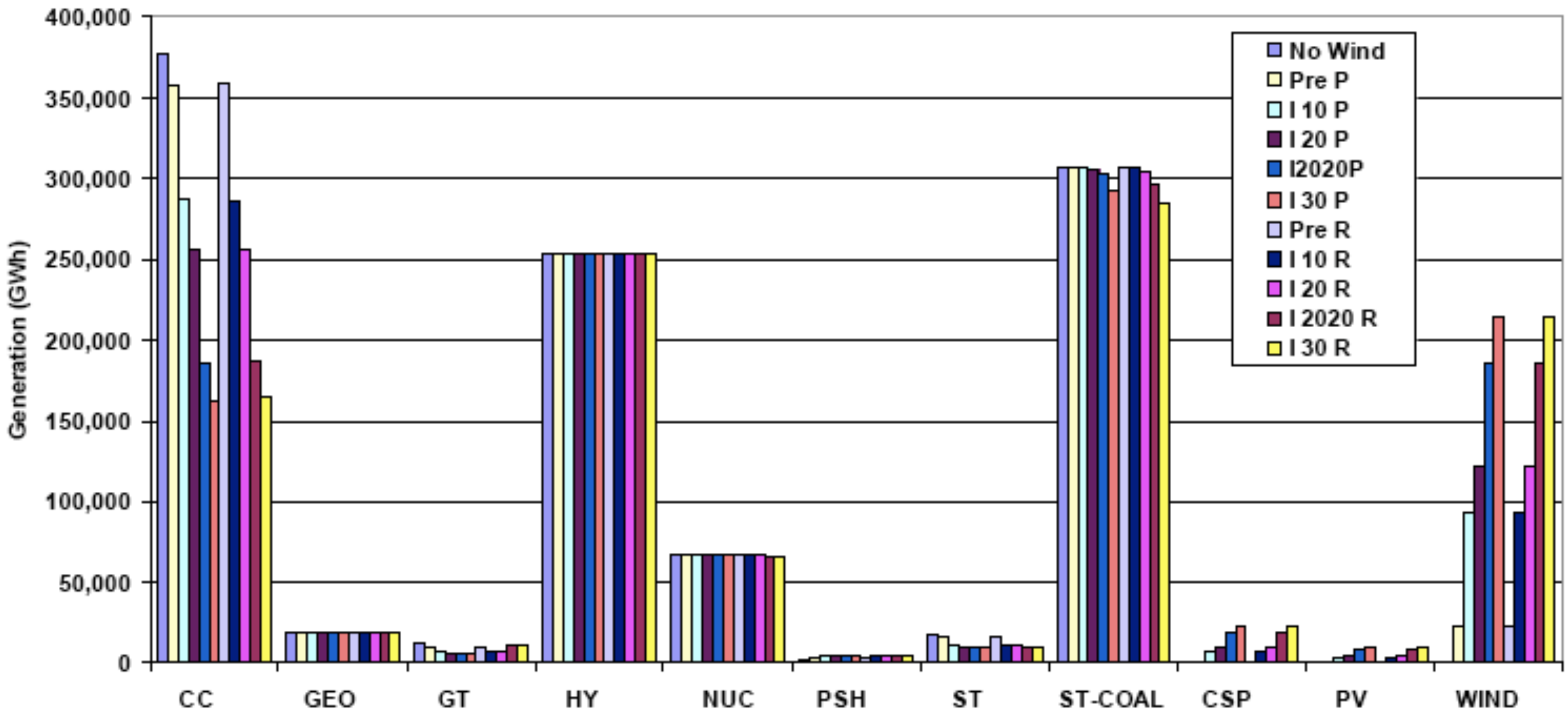


Figure 6.3 Generation by type - WECC – 2006

Assuming $9.5/MBTU gas price and $30/ton CO2 in 2017, gas units are mostly displaced. Coal starts to be displaced at higher penetration levels.

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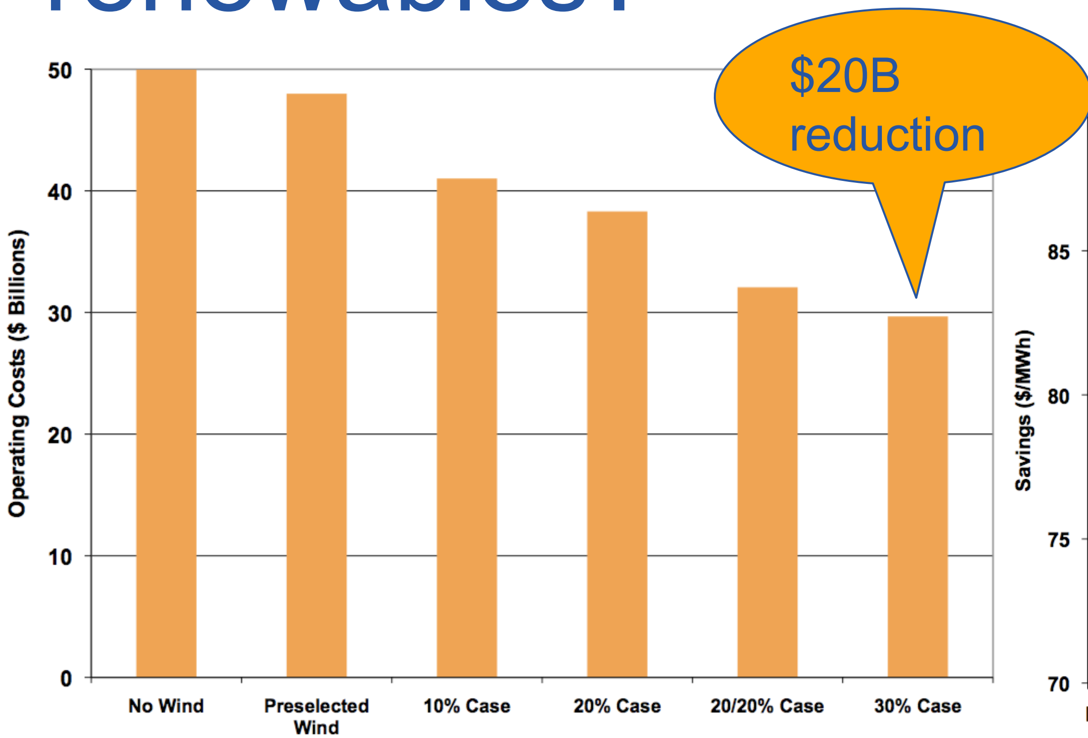
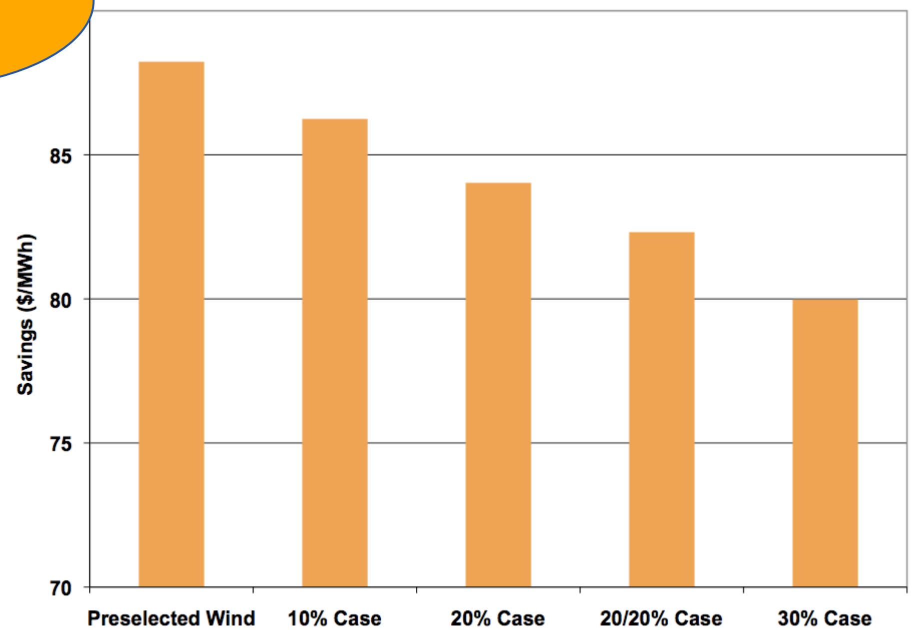
What are some of the benefits of 35% renewables?





WECC saves 40% in fuel and emissions costs

This does not include any capital costs, including payments to wind and solar generators. Presumably some of this would be used to recover other capital costs. 2017$ with $9.5/MBTU gas and $30/ton CO2 assumed.

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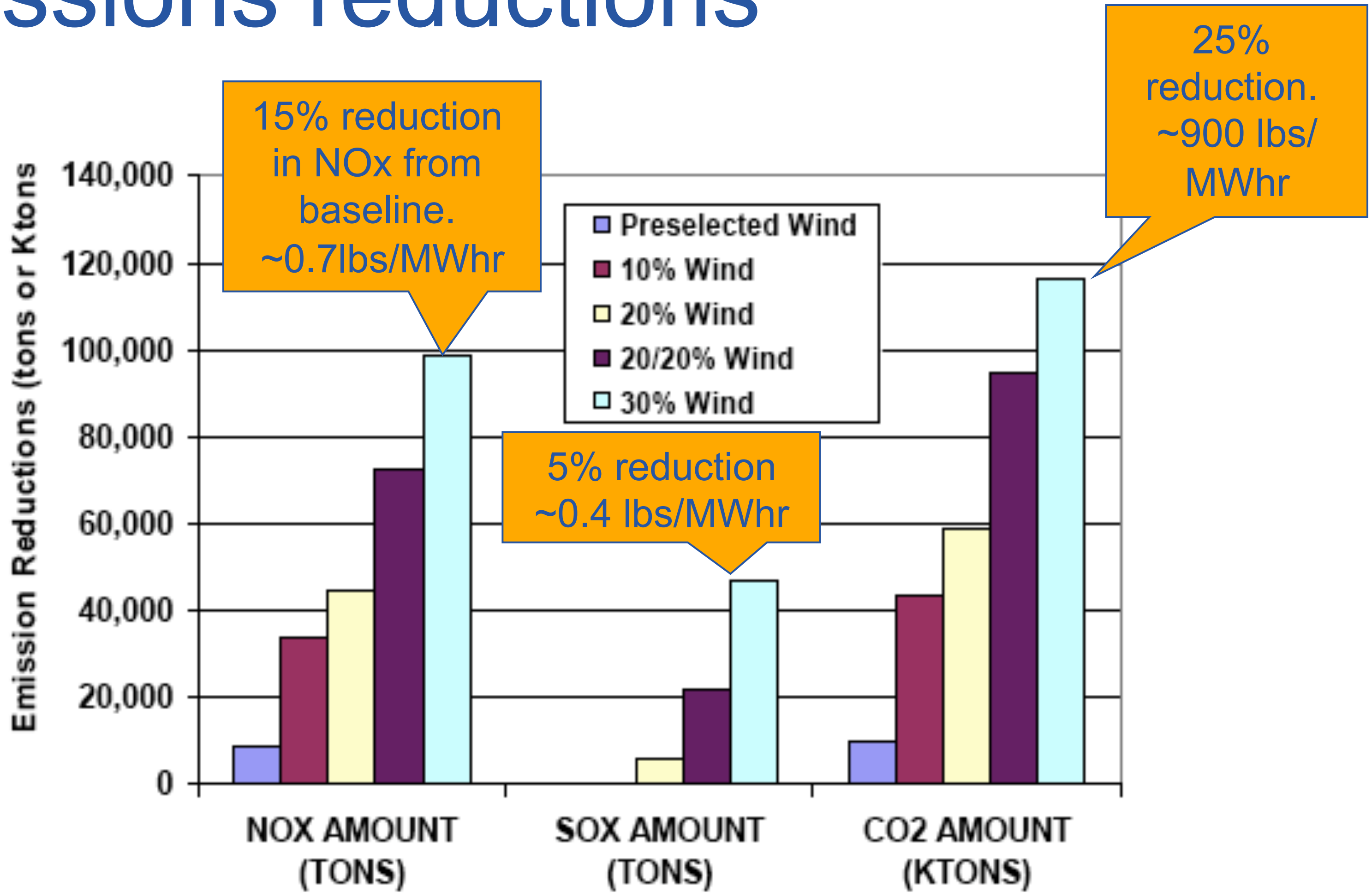
Emissions reductions



Assuming $9.5/MBTU gas, renewables mostly displace gas. Coal starts to be displaced at higher penetration levels.

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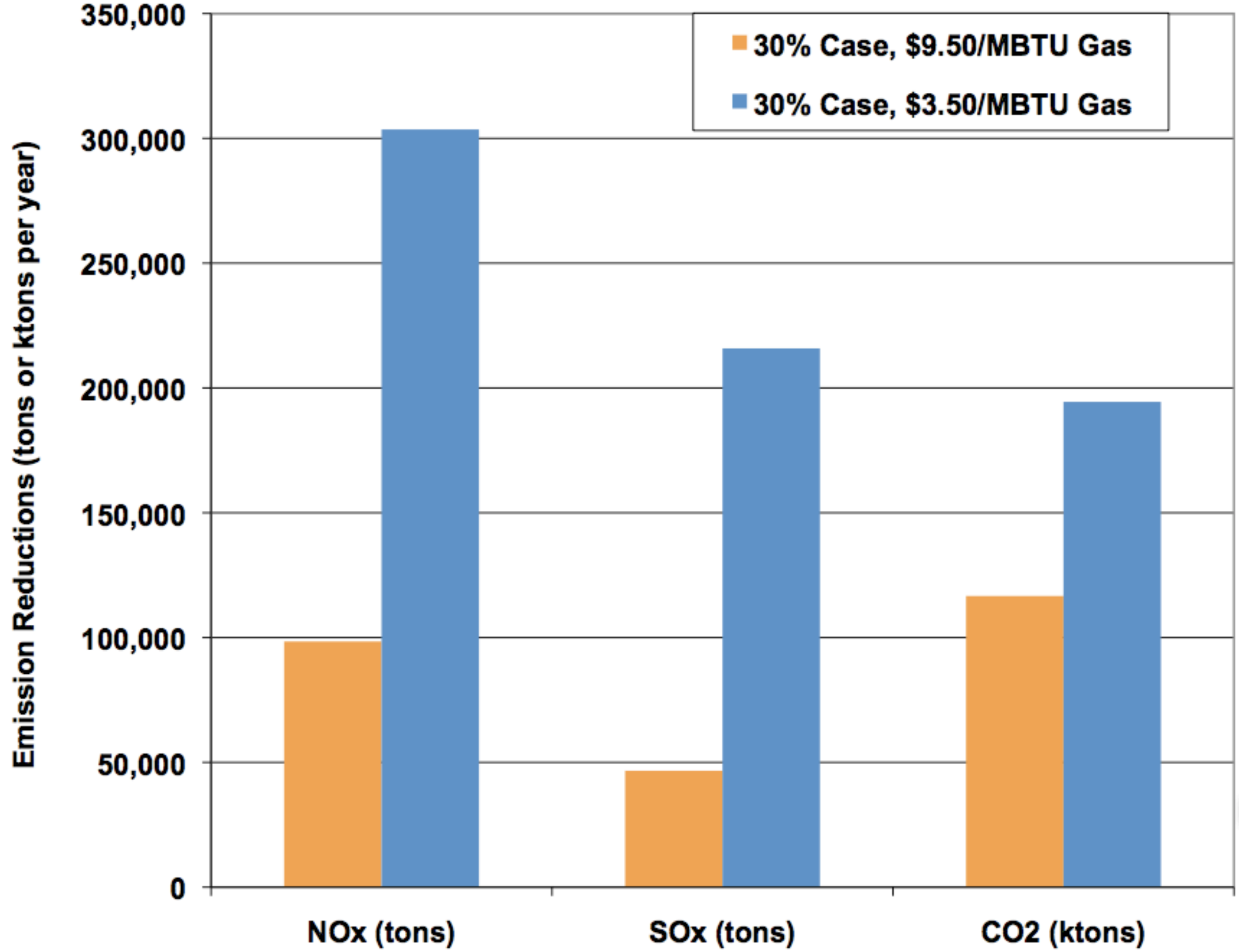
Emissions Depend on the Price of Gas



At $3.5/MBTU gas, coal is displaced, resulting in greater emissions reductions

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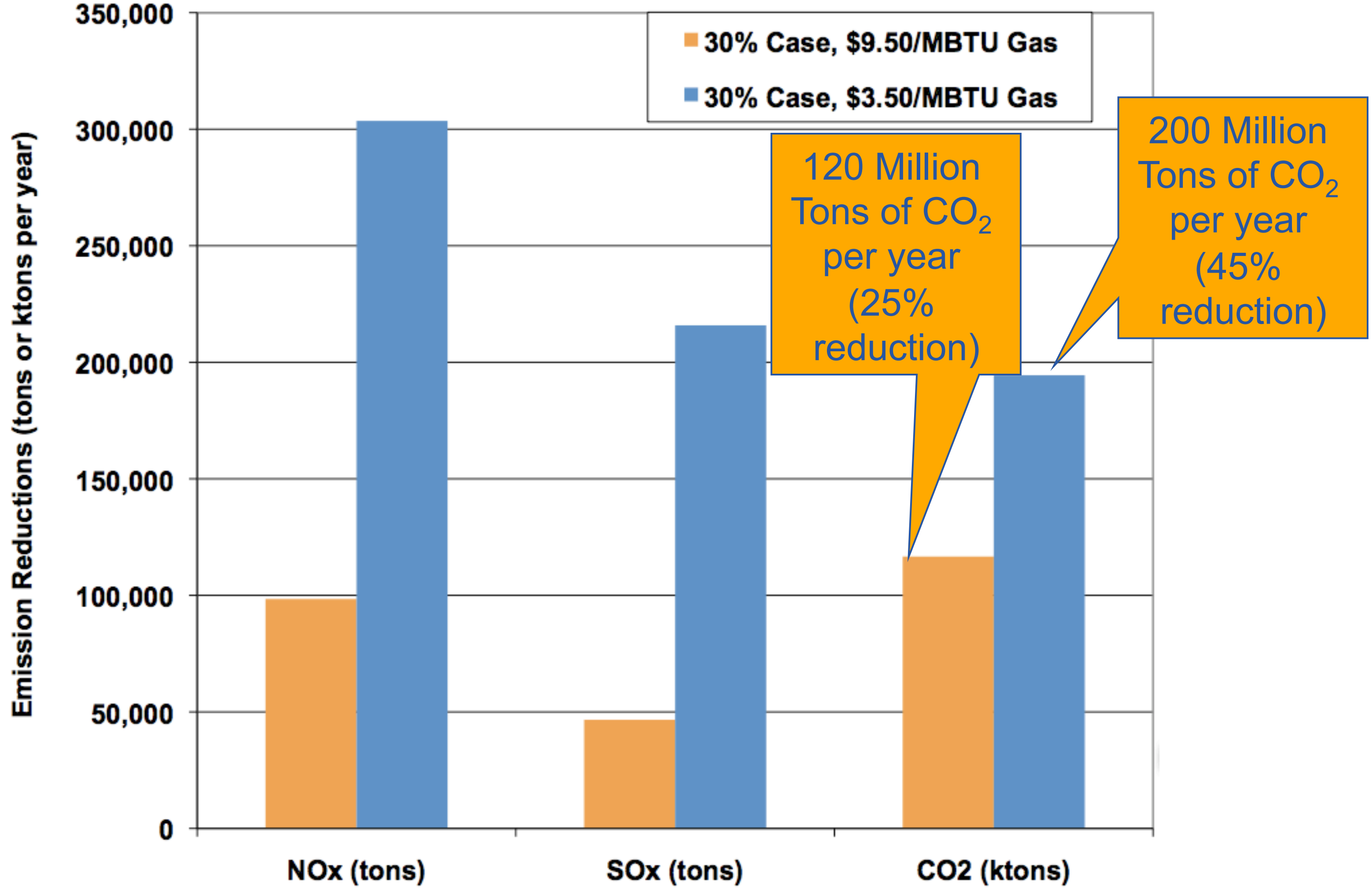

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Variability can help or hurt you

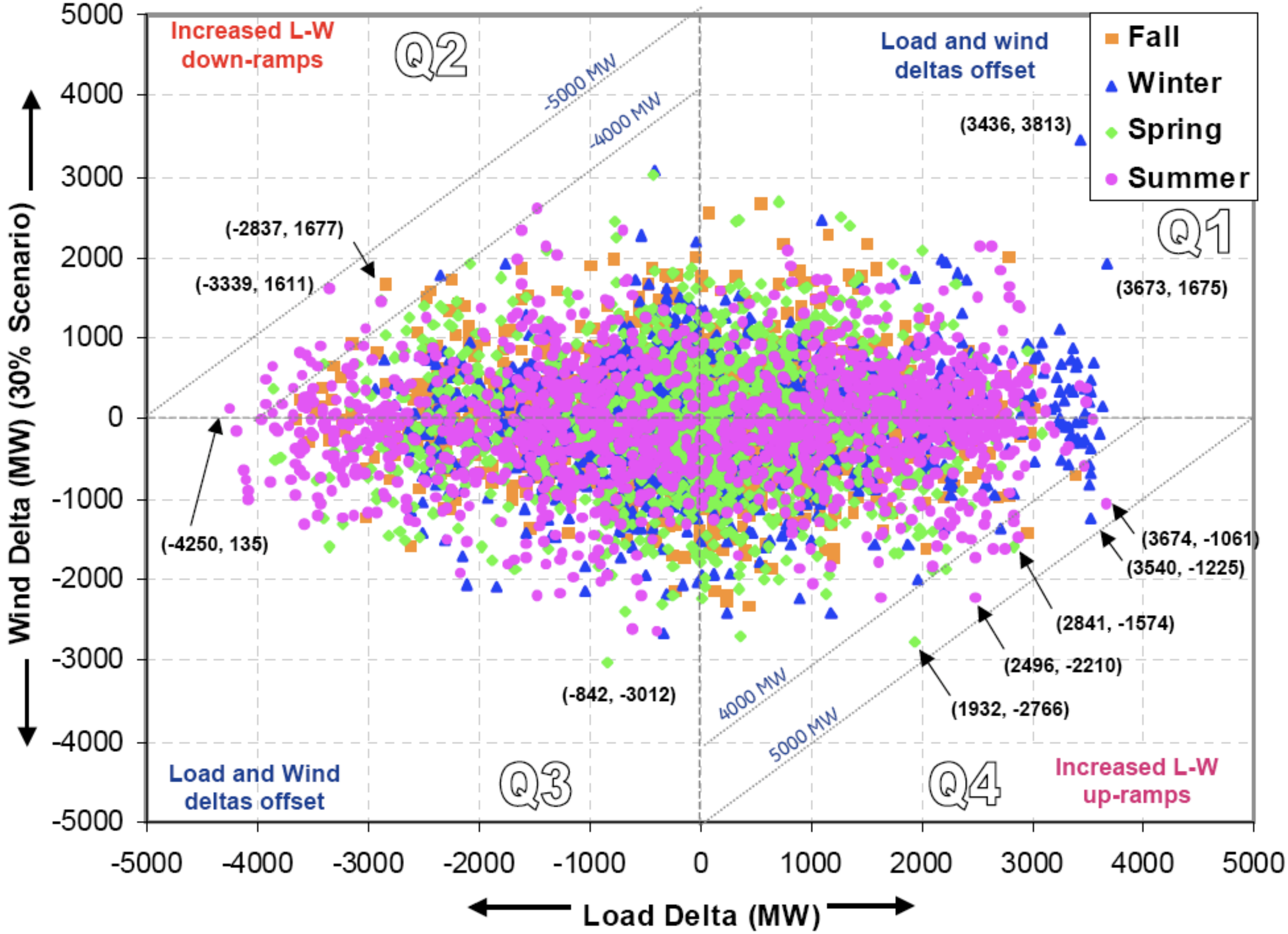
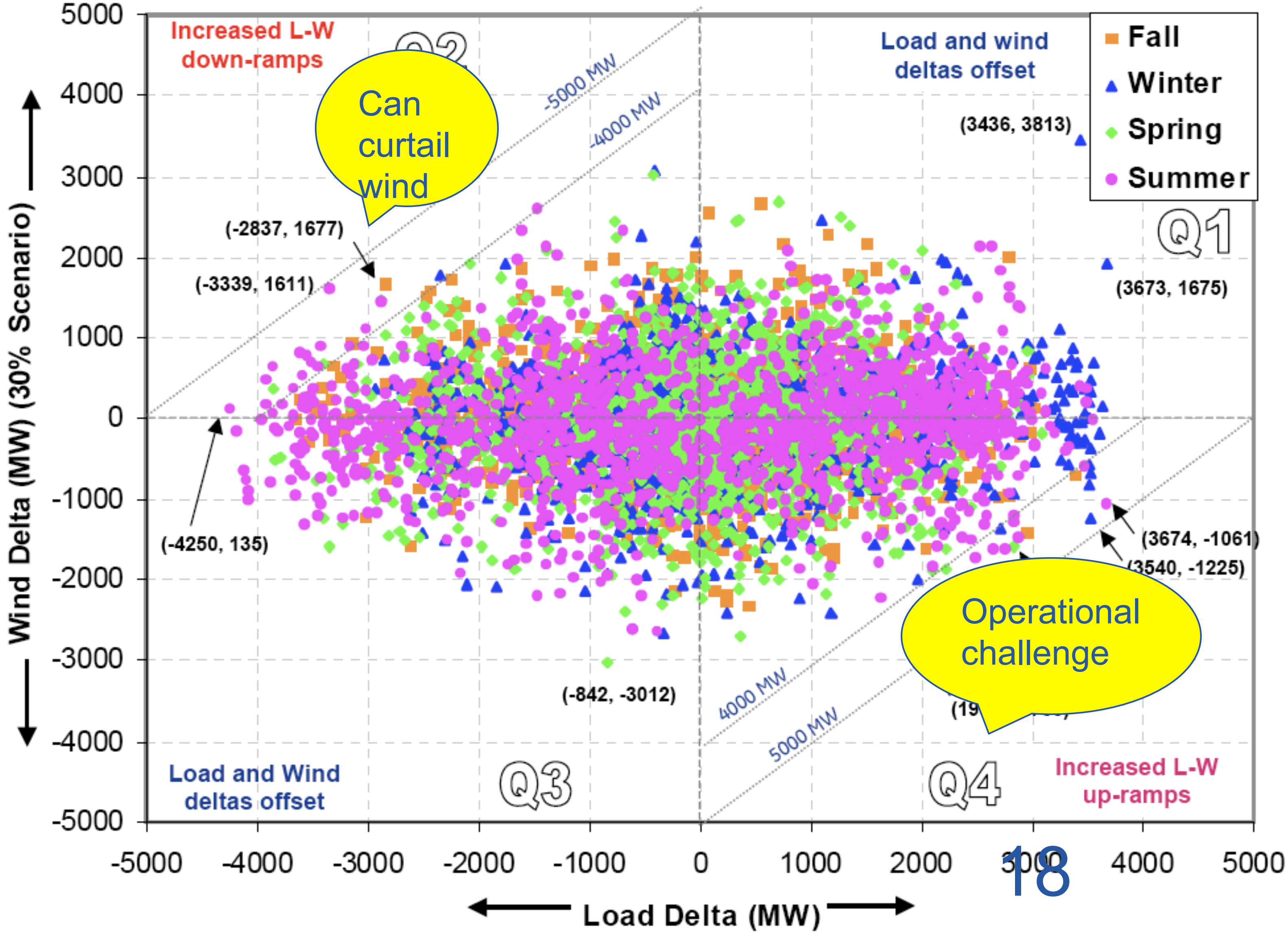


Figure 5.2 2006 Study Footprint Wind Deltas vs. Load Deltas by Season for 30% LP Scenario

Variability can help or hurt you



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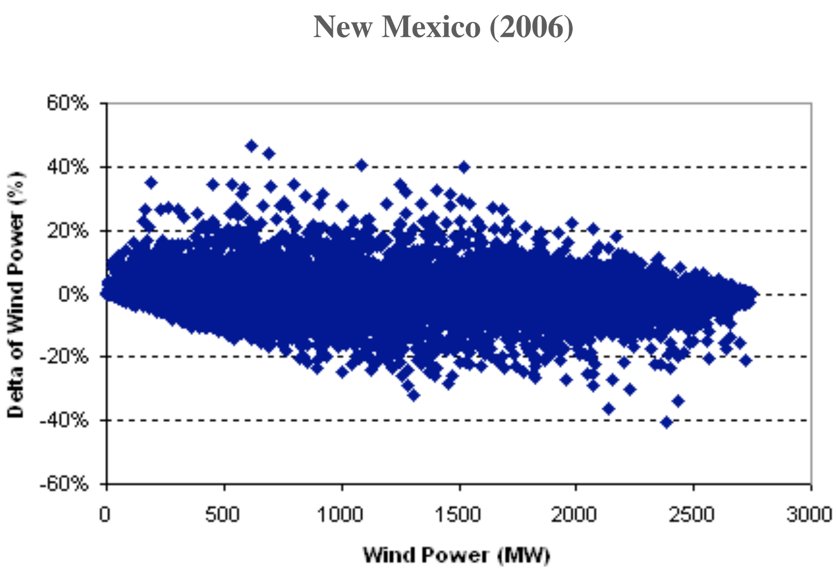
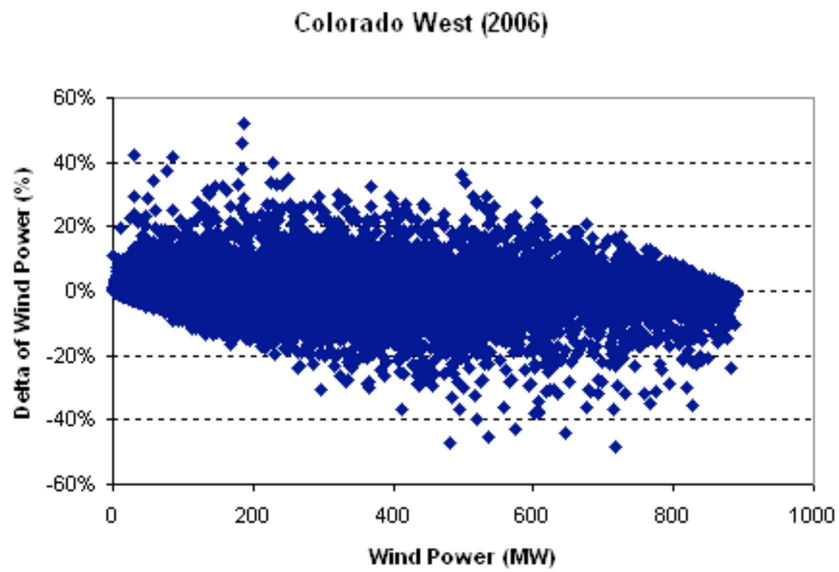
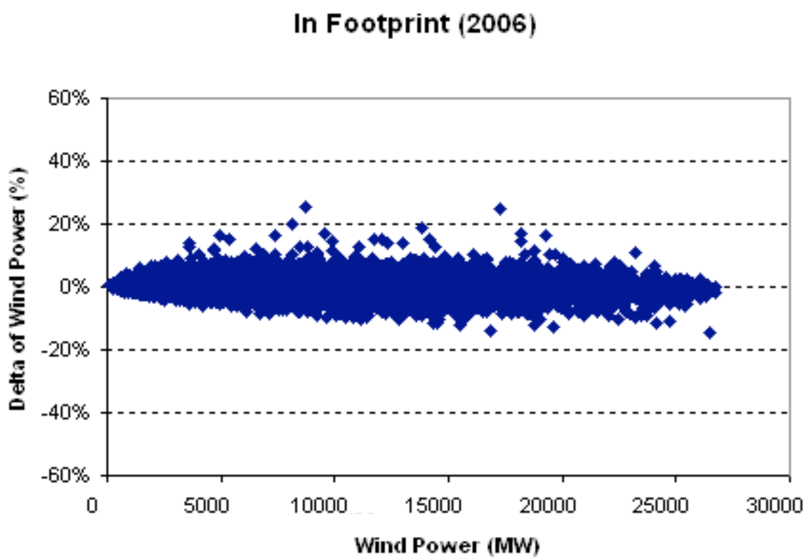
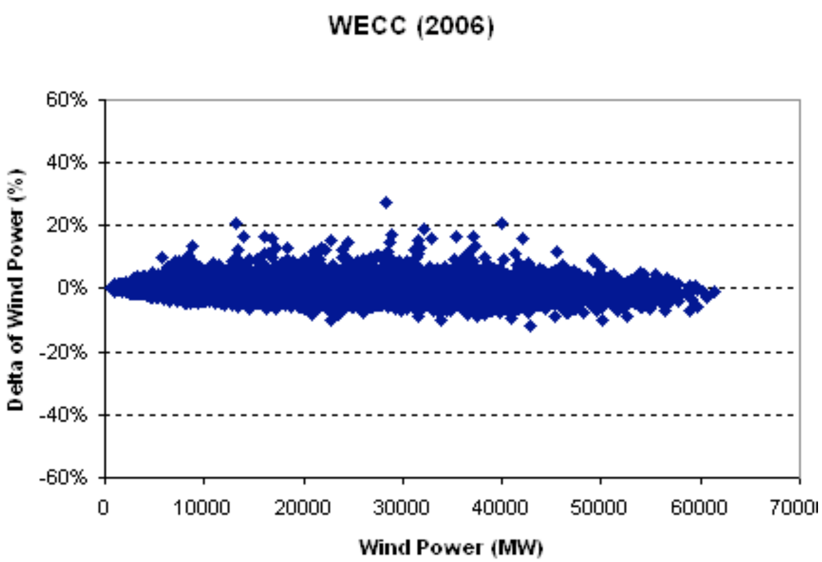
Benefits of Balancing Area cooperation: Geographic diversity mitigates variability

(30% In-Area Scenario)

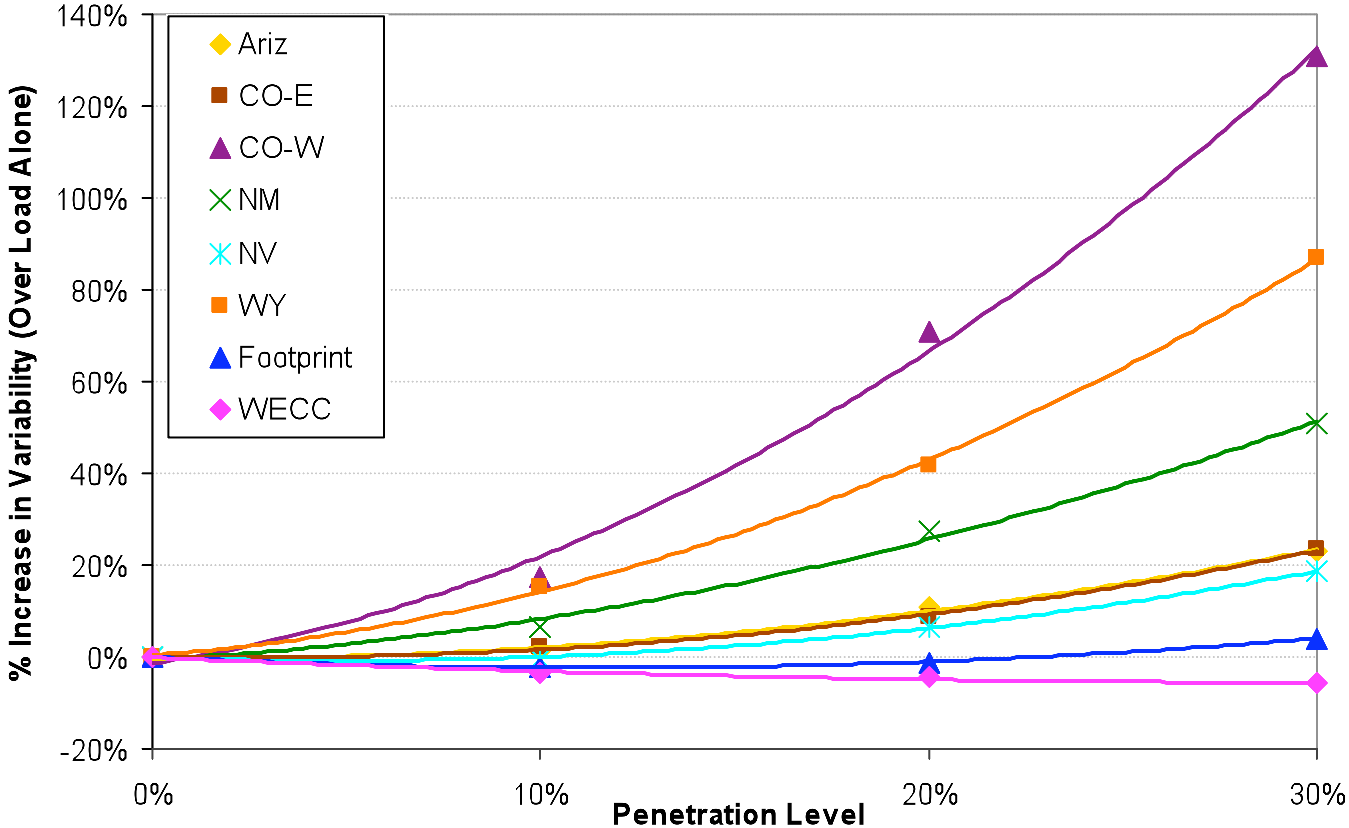








Balancing Area cooperation reduces net load variability



Net load variability increases with increasing penetration of wind. Geographic diversity mitigates this increase on a WestConnect and WECC basis

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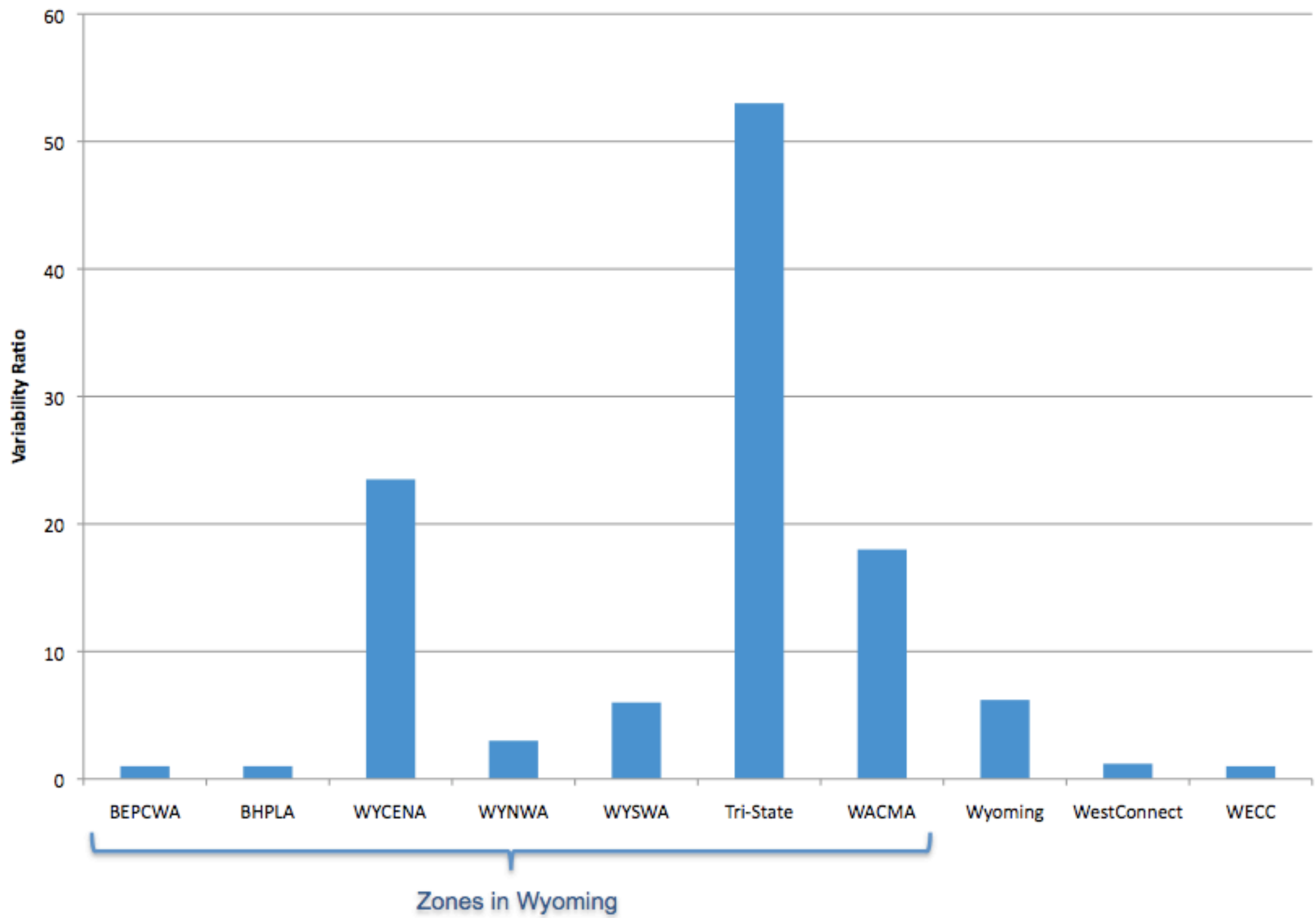
Variability Decreases with Larger Footprints



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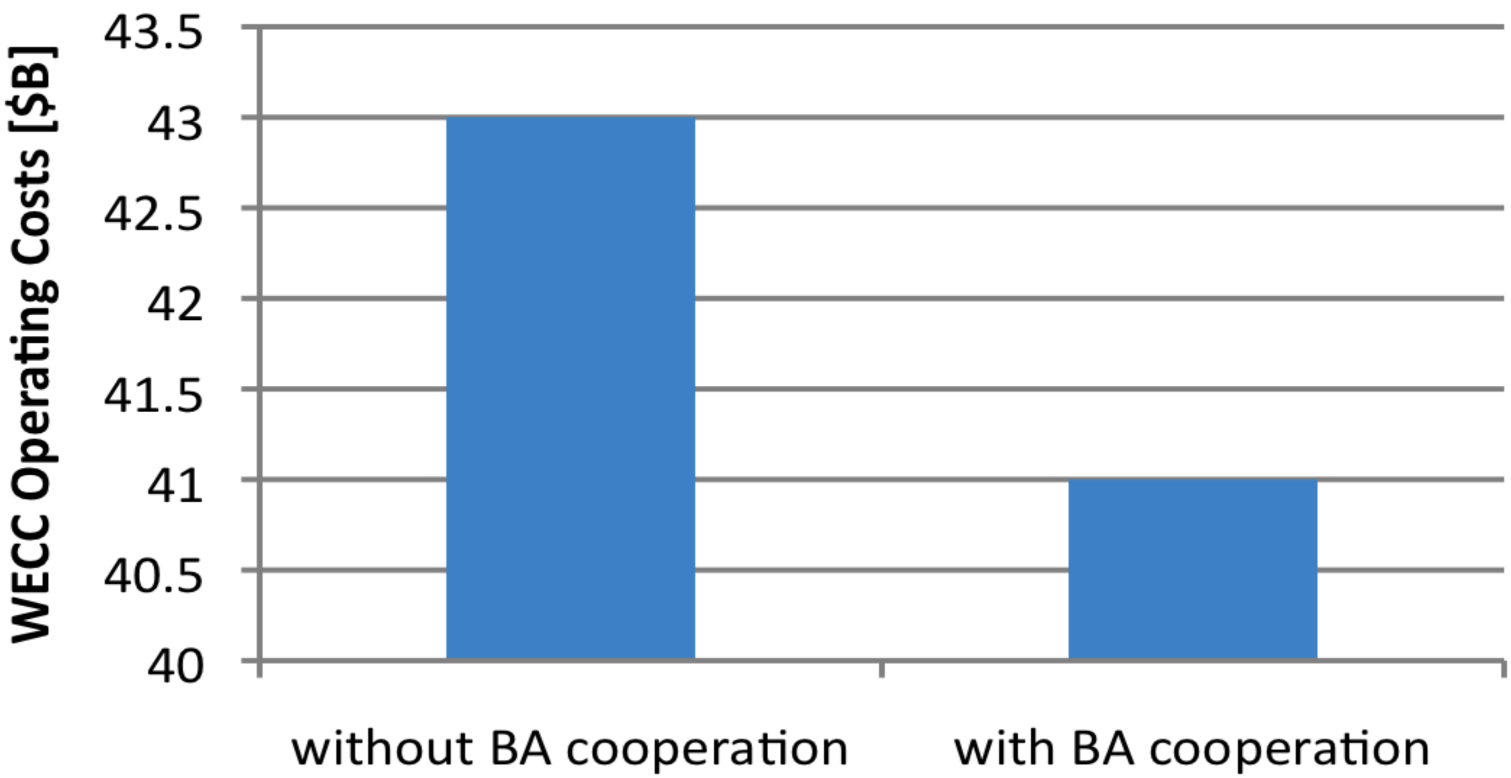
WECC can save money just by holding reserves in 5 regions as opposed to many smaller zones



Annual WECC operating costs at 10% case. Left – 106 zones; Right – 5 regions. Saving is about $2 billion/year

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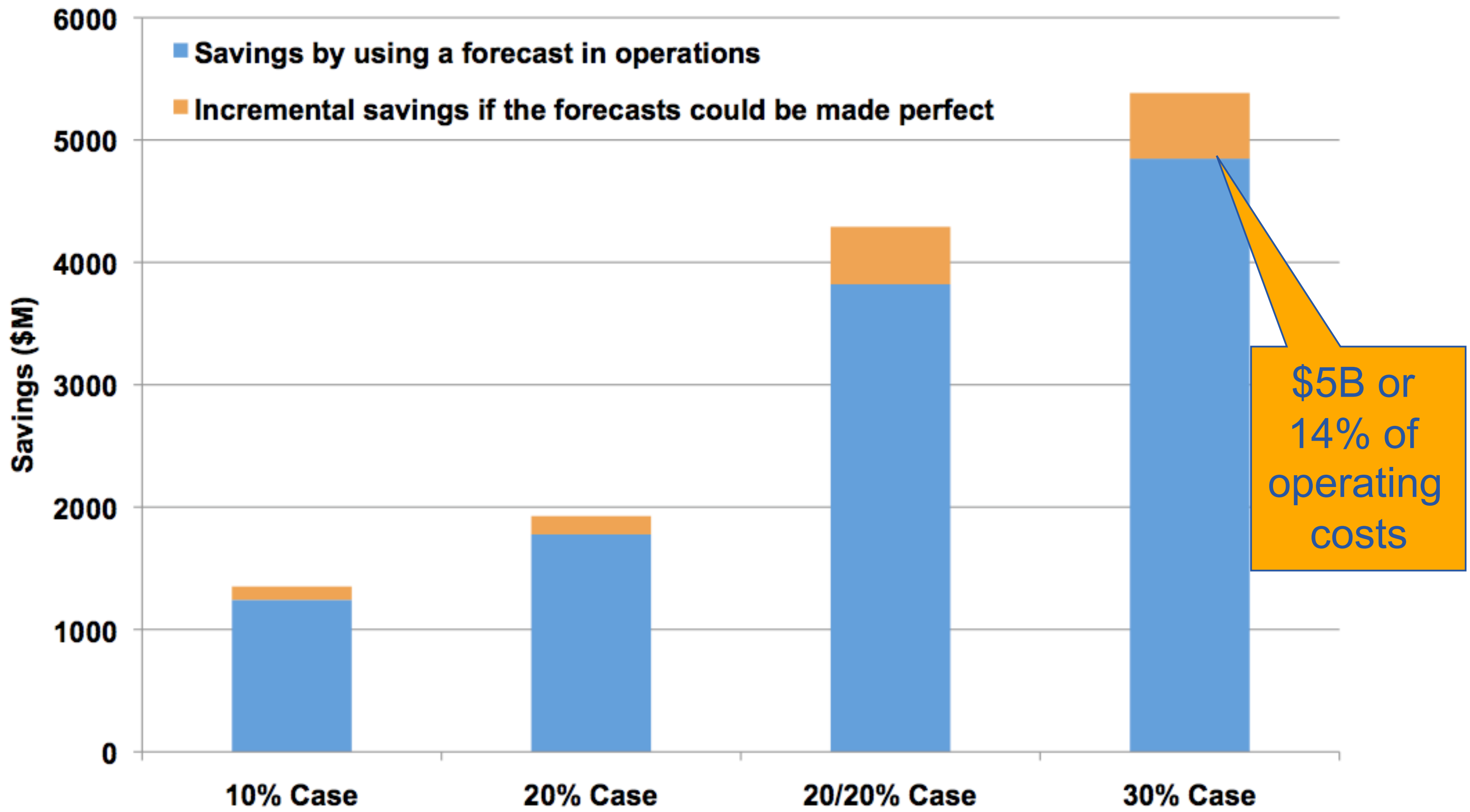
Incorporation of wind/solar forecasts is essential



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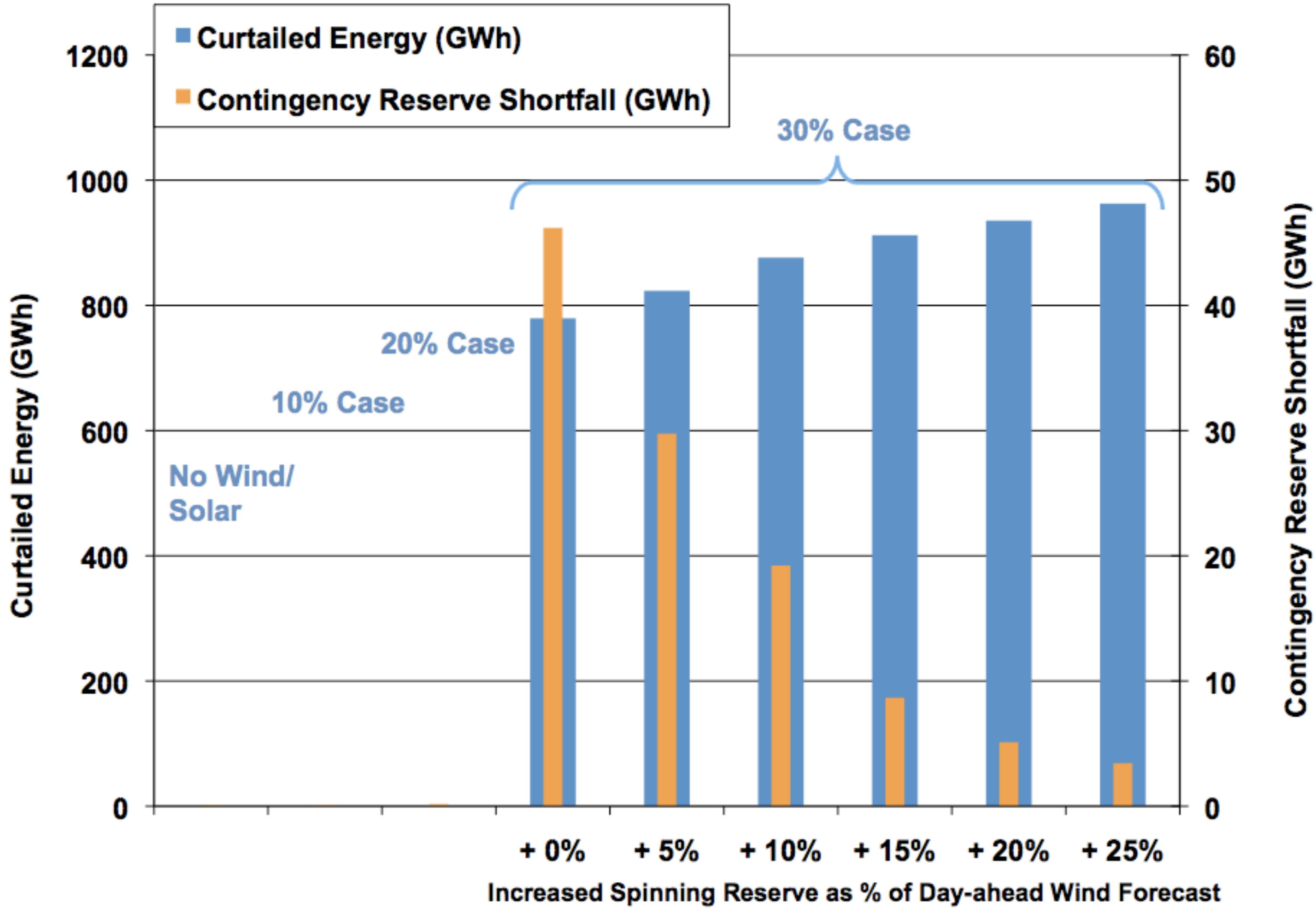
Impact of Uncertainty on Operations

- Wind forecast error is moderate when aggregated across WestConnect or WECC.
- As a result, the benefit of making a forecast perfect is relatively small compared to the benefit of using a forecast in operations.
- However, even with these moderate *average* forecast errors, the largest forecast errors can be nearly half of the installed wind capacity.
- Large under-forecasts can lead to curtailment of wind. Large over-forecasts of wind can lead to contingency reserve shortfalls.

Forecast error drives contingency reserve shortfalls



There are 89 hours (1% of hours) of contingency reserve shortfalls

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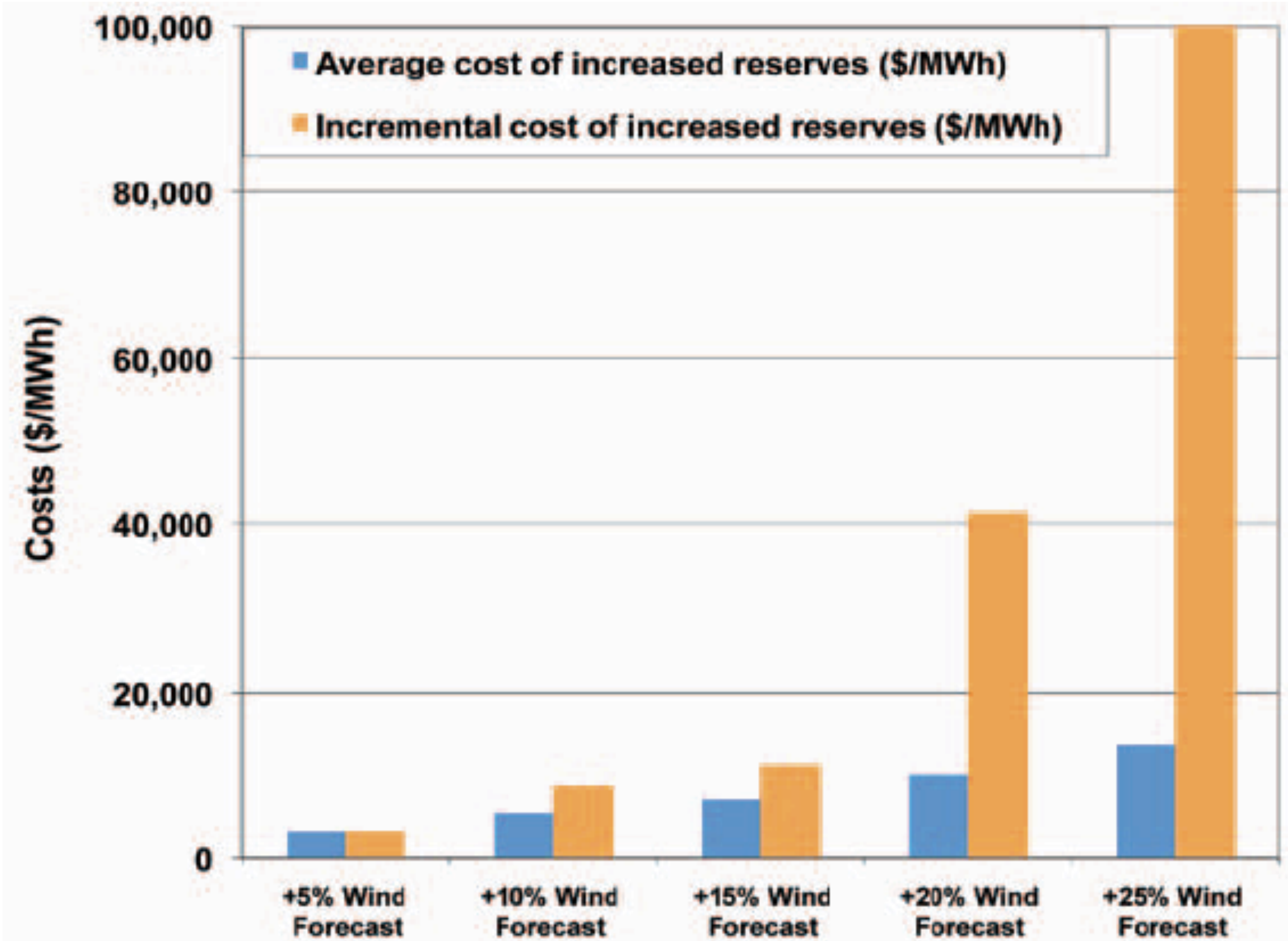

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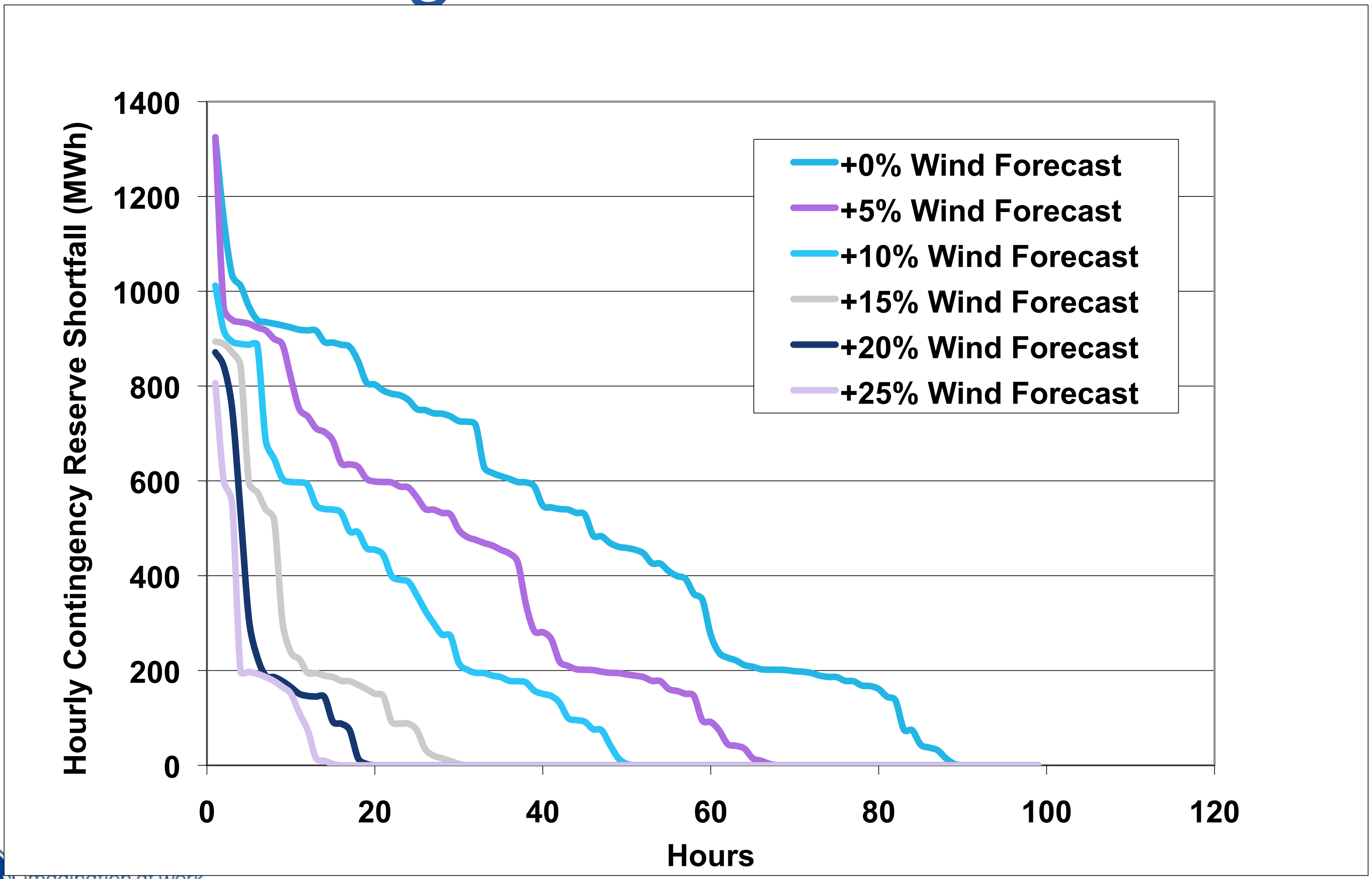
Demand response as an alternative to increasing reserves



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Sources of Flexibility to Deal with Contingency Reserve Shortfalls

- Increase spinning reserve for every 8760 hours of the year – this is expensive
- Demand response to address the 89 hours of the year – this was found to be effective and yielded significant savings over increased spinning reserves
- There are other options not modeled here, including better prediction of when shortfalls are likely to occur and adding quick-start generation or more reserves

Reserve Requirements

- System must carry reserves to cover contingencies *and* most net load variations
- Relationship between load and wind levels and net load variability is complex
- Statistical expectation of variability can be distilled to some simple approximate rules:

	Load Only	30% LP Scenario		
	(% of load)	Load Term (% of load)	Wind Term (% of wind production)	up to (% of wind nameplate)
Footprint	1.3	1.1	5	47
Arizona	2.2	2.2	5.6	36
Nevada	2.1	1	10.7	54
Colorado East	2.4	2	5.7	68
New Mexico	2	3.1	3.5	70
Wyoming	1.3	2.7	8.7	33
Colorado West	1.8	3.1	7.3	100

- Contingency reserves are 3% of load; no change
- Average requirement to cover *variability* is roughly double:
  - ~425 MW vs ~850 at footprint
  - Requirements roughly double for reserves by area (vs. footprint)

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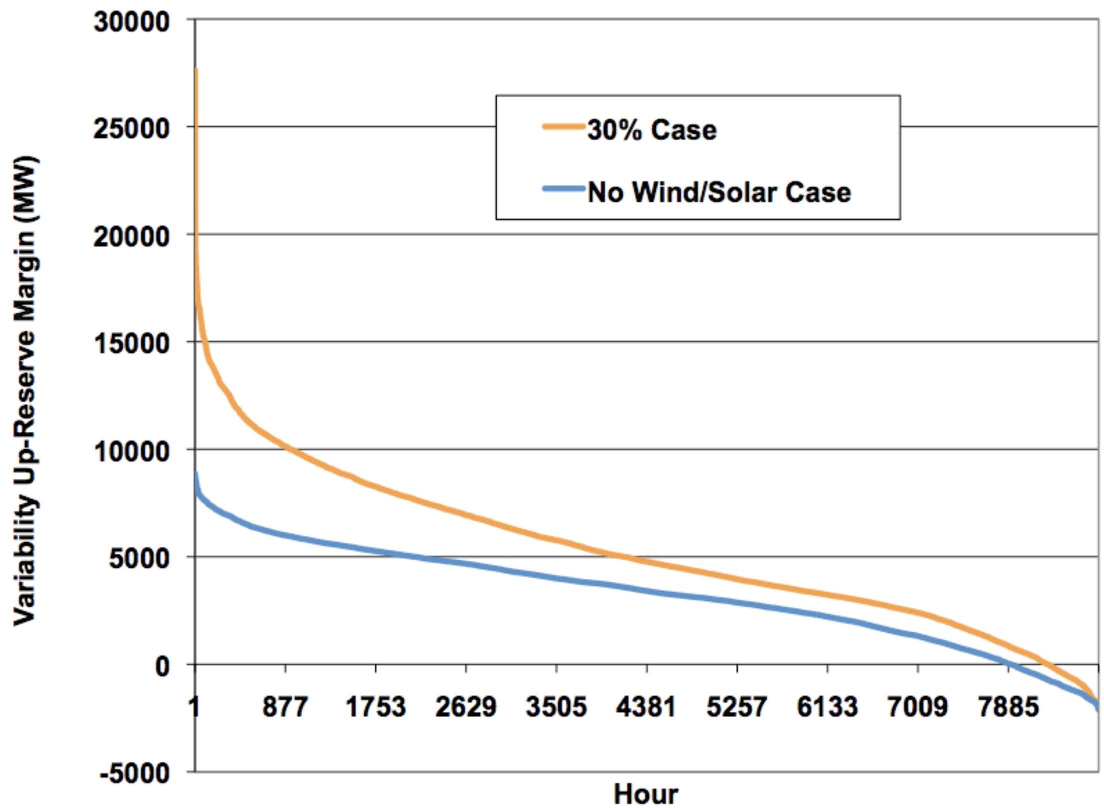
Variability Reserves

- Variability requirements increase with wind and solar.
- However, displacement of other generation tends to increase the amount of up reserves online.
- **Additional reserves do not need to be committed to cover the increased variability reserve requirement**



• If utilities want to be conservative, they can commit units to provide 5% of wind for reserve, at a cost of ~$0.25/MWhr. The above results suggest this is not necessary.

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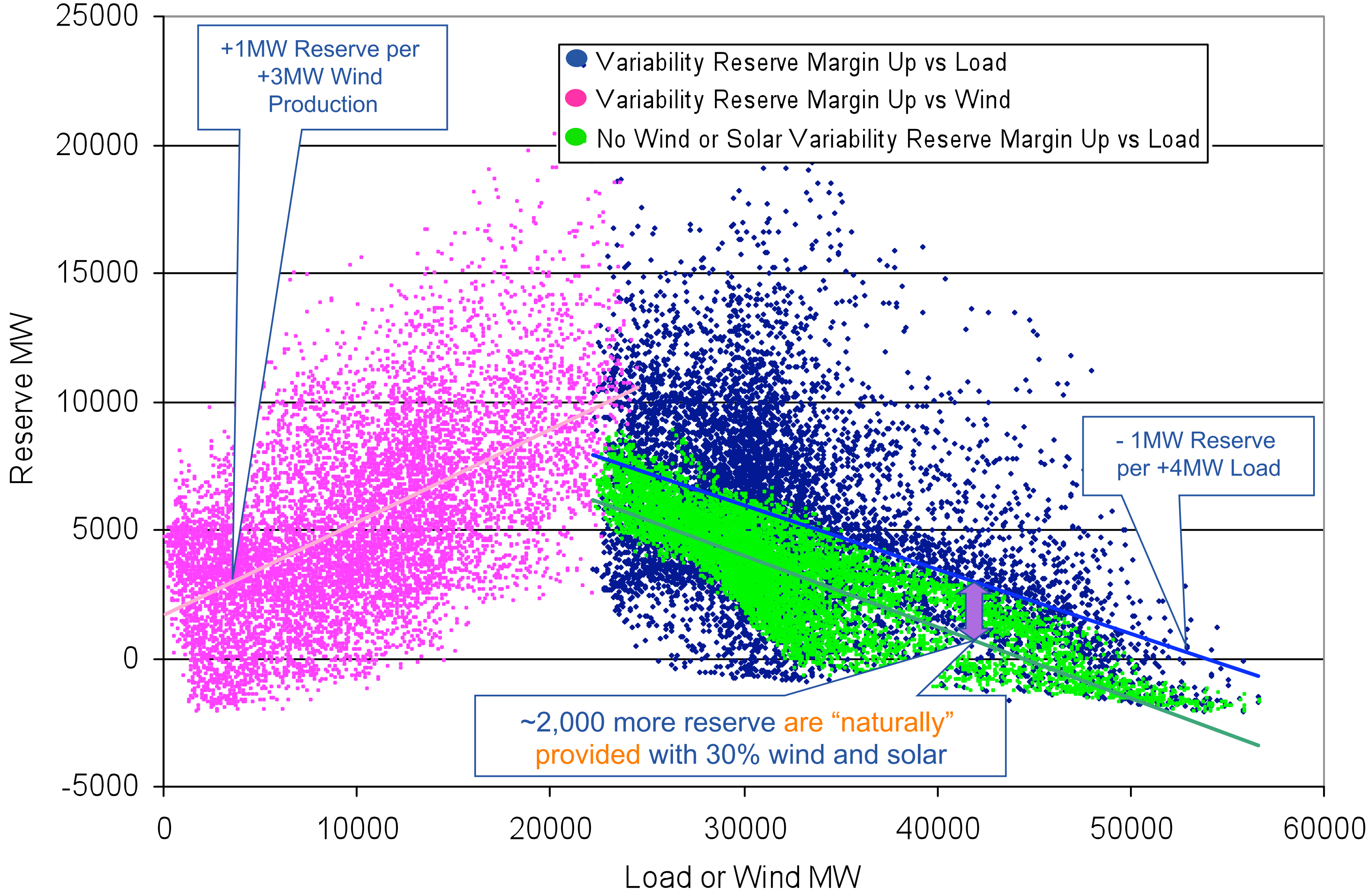
Variability Reserve Margins



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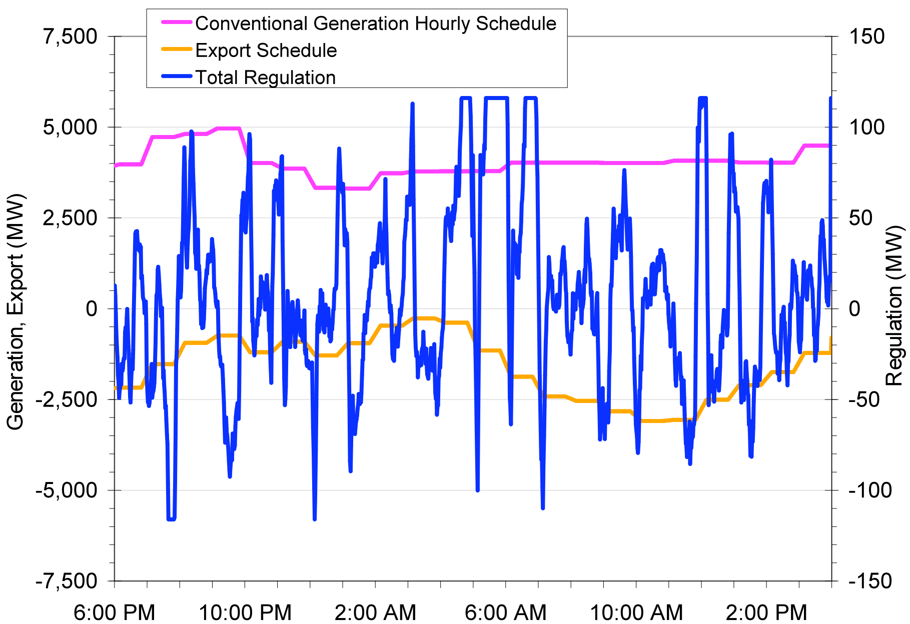
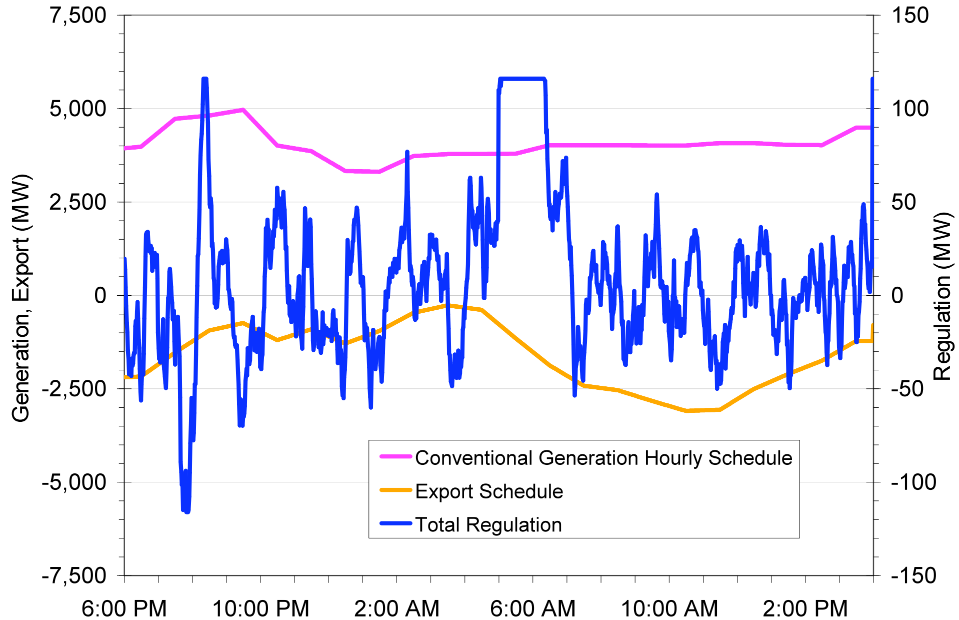
The Impact of Sub-hourly Scheduling on Regulation





Local Priority, 30% Wind

Regulation impact of hourly schedules is significantly higher than impact of wind and solar variability

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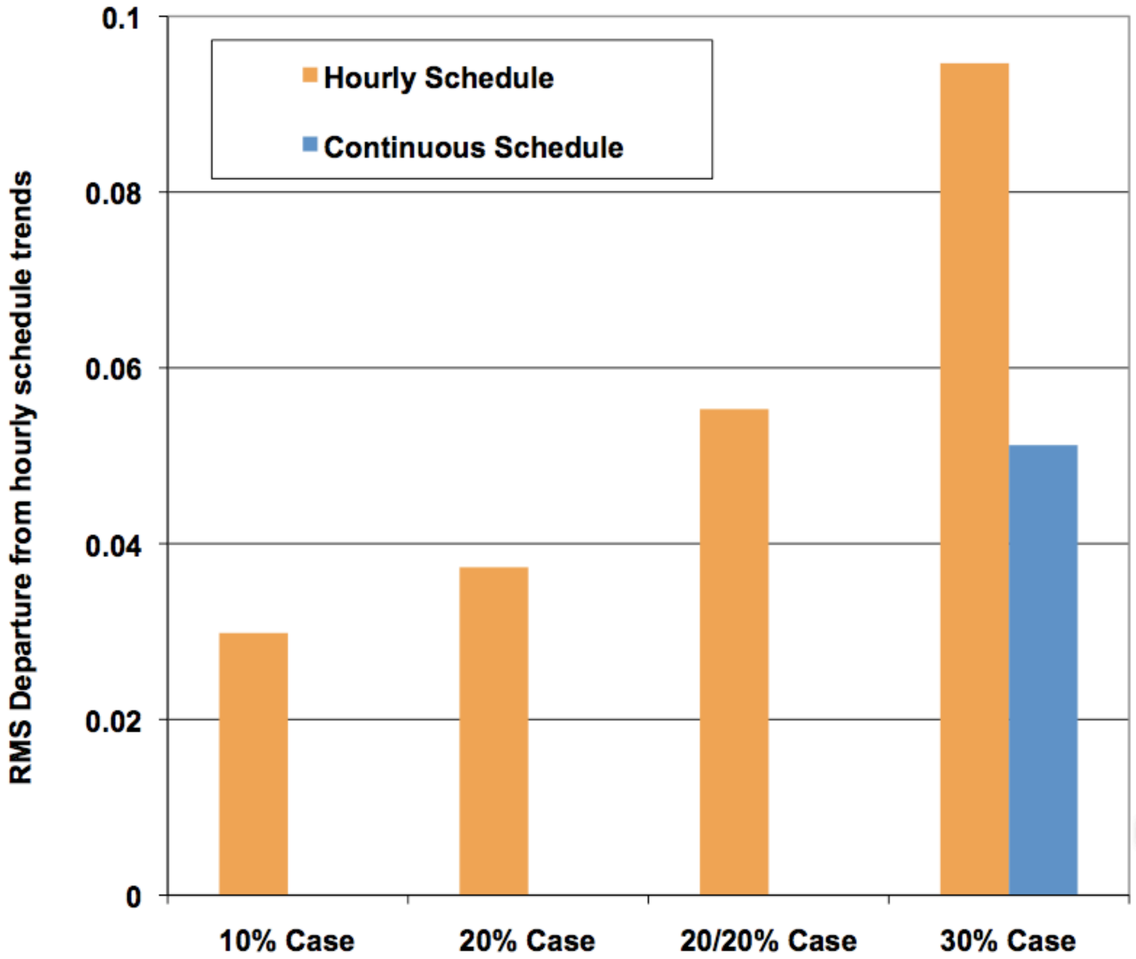
Subhourly scheduling reduces fast maneuvering duty of regulating units



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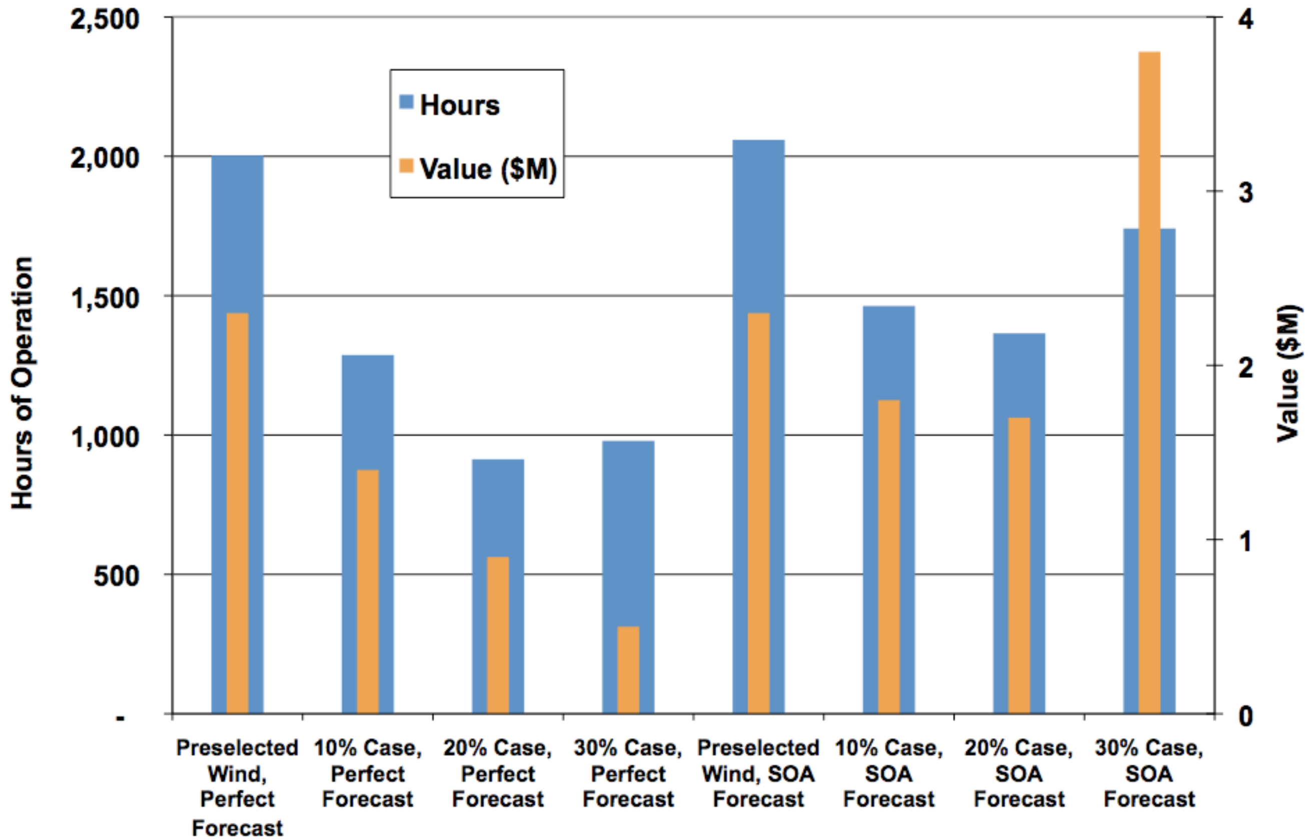
Do we need storage?

- We evaluated storage for price arbitrage. We did not evaluate storage for ancillary services.
- Increased wind and solar increased use of existing pumped hydro storage (PSH) slightly.
- We decreased pumping costs to increase use of PSH but overall production cost increased.
- We added a 100 MW PSH in Arizona and gave it perfect foresight of when to pump and when to generate.

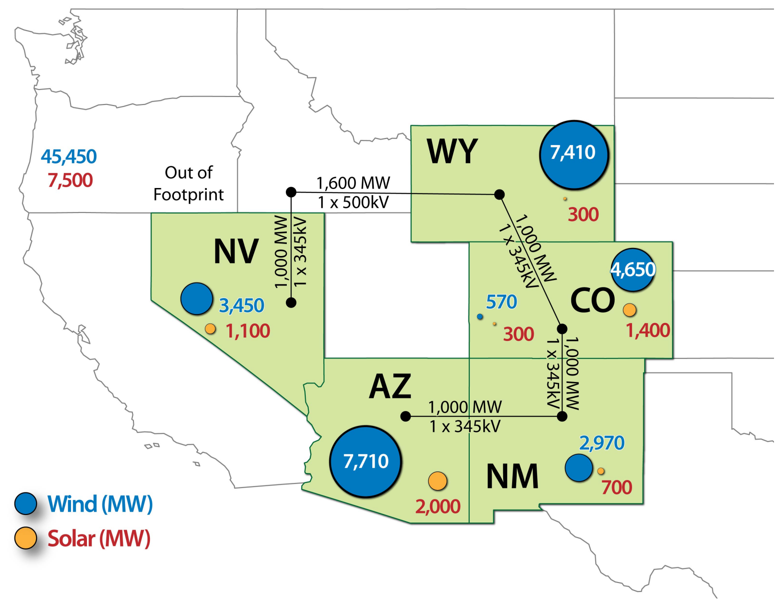
Price arbitrage value of PSH does not justify costs



At high penetrations, especially with imperfect forecasts, value and use of storage increases. However, this price arbitrage value alone won't justify it. We have not evaluated use of storage to provide reserves.

Do we need to build more inter-state transmission?

- Absolutely need some amount of intra-state transmission to bring resources to load. However, we do not find much *operational* difference between the 3 scenarios.
- Wind/solar displace other generation, freeing up transmission capacity. If this freed up capacity can be used for wind/solar, then less new transmission will need to be built.



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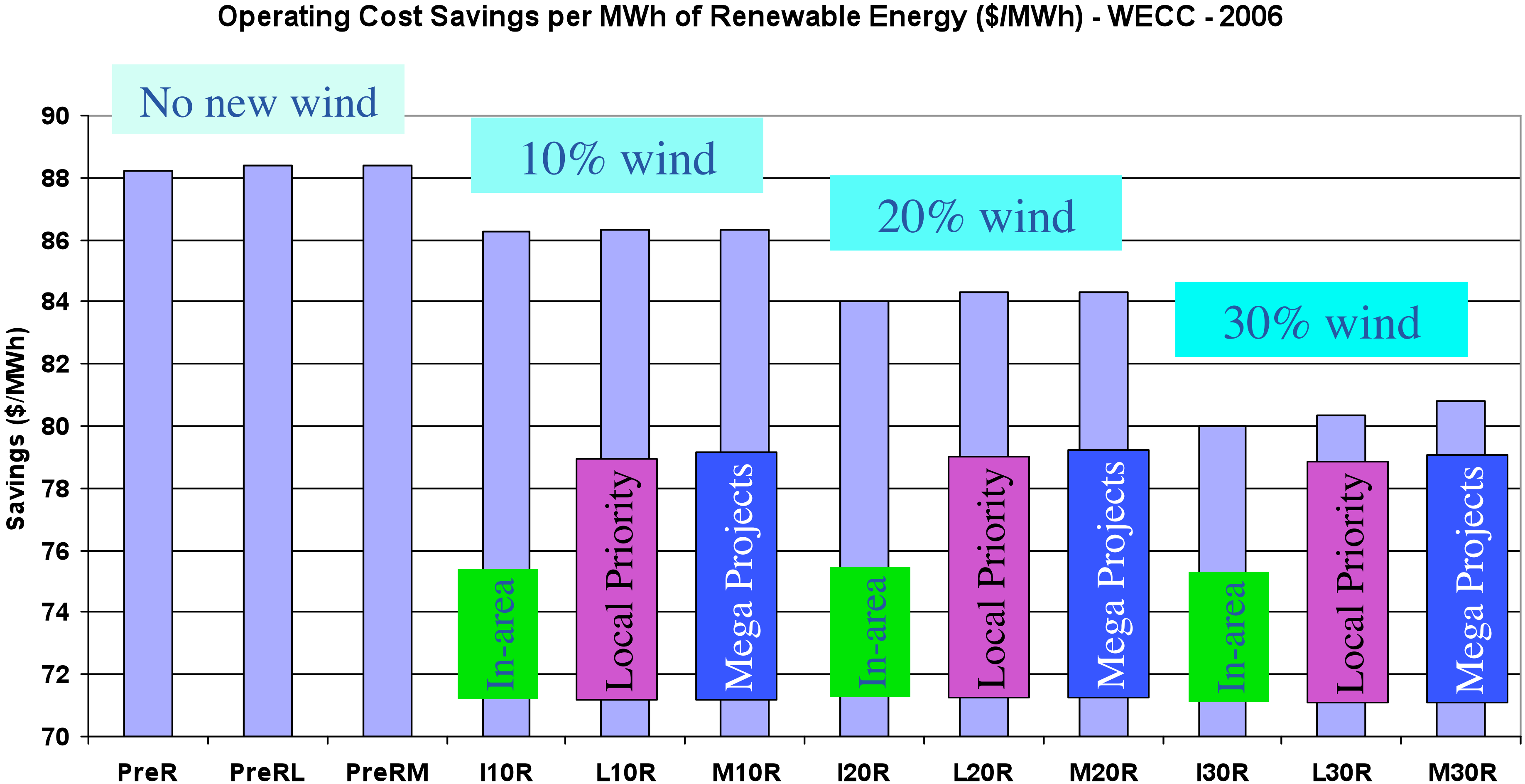
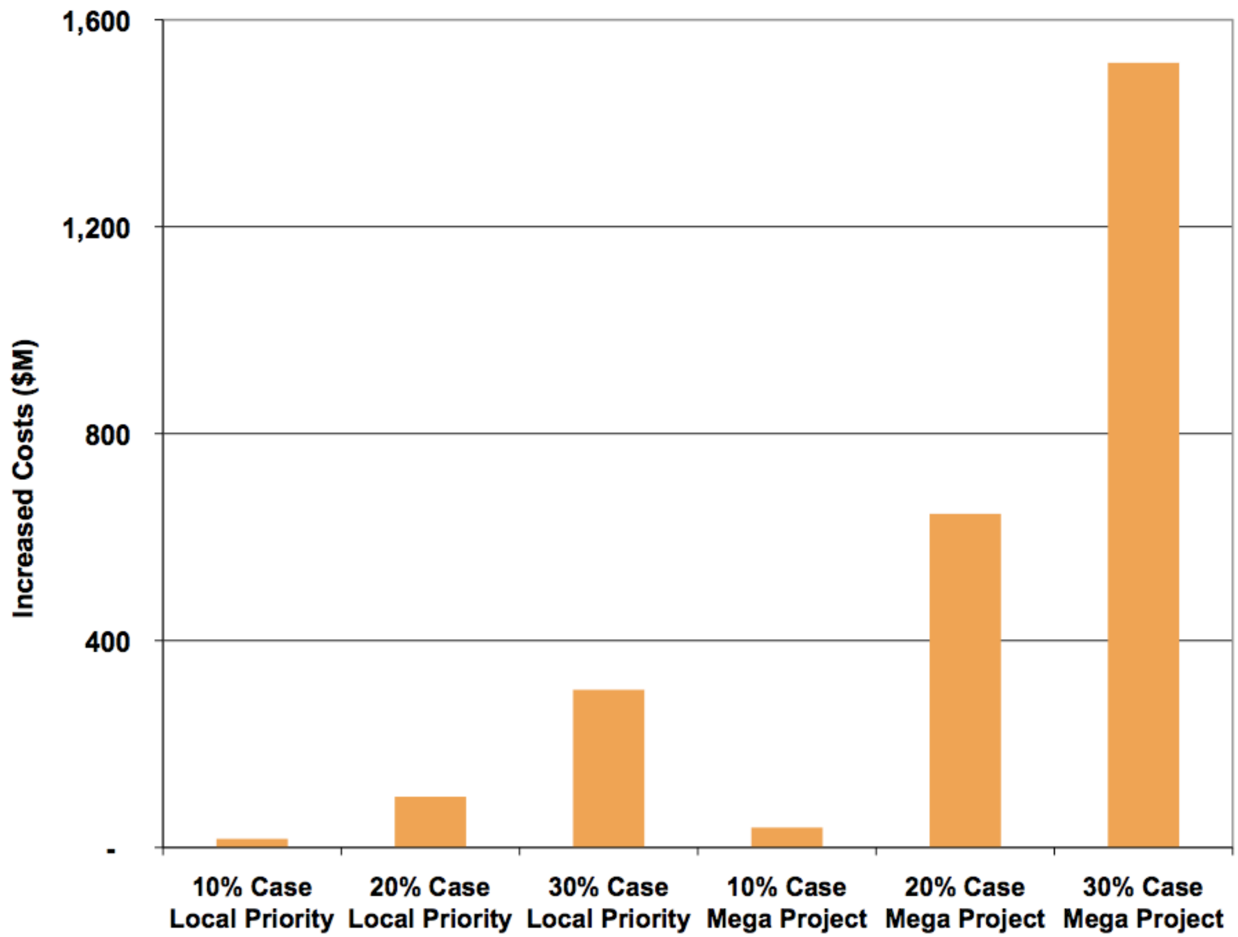
Not much difference *operationally* between the scenarios



Note axes: Difference between scenarios is small

Do we need long distance transmission?



We can start integrating up to the 20% case before interstate transmission is commissioned, assuming wind/solar can fully utilize existing transmission and sufficient intra-state transmission

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High penetrations lead to cycling off of coal plants

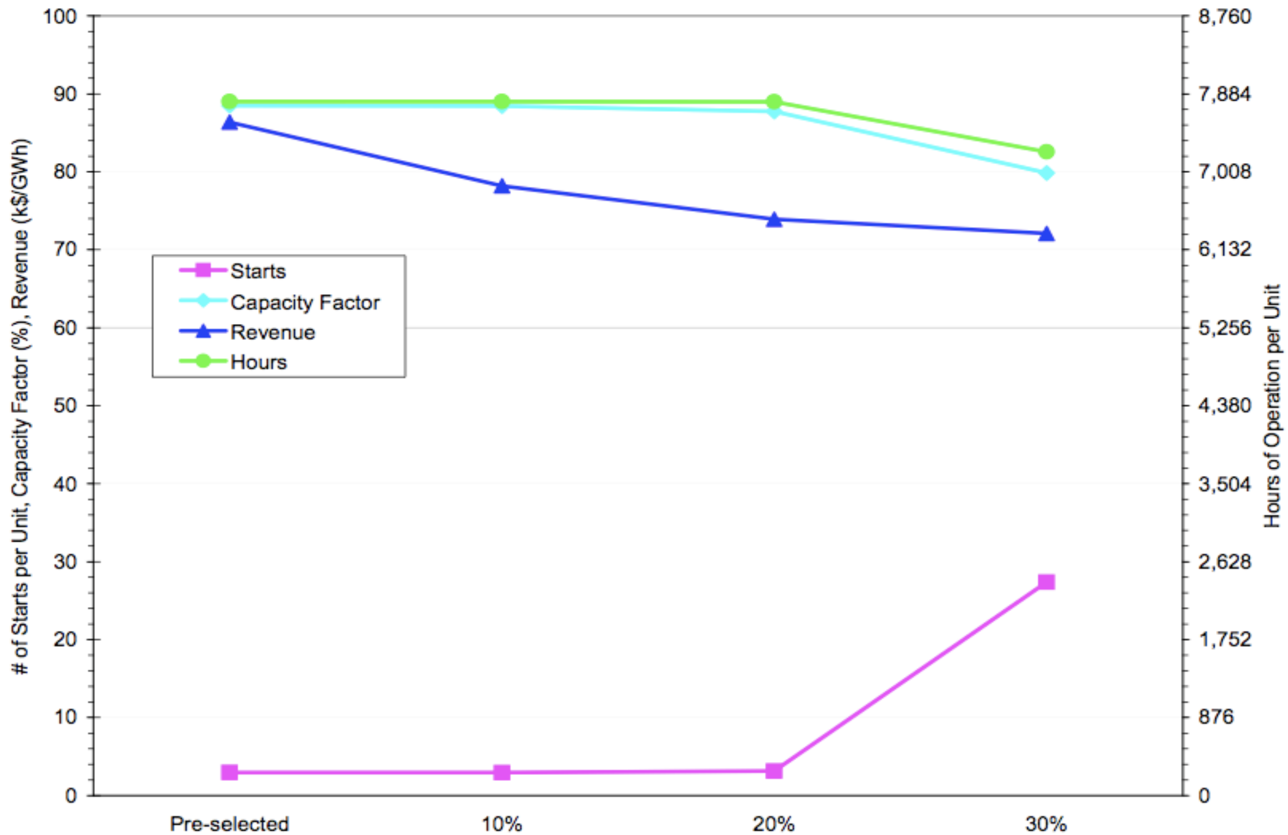

Figure 6.10 Coal plant statistics, Local Priority scenario

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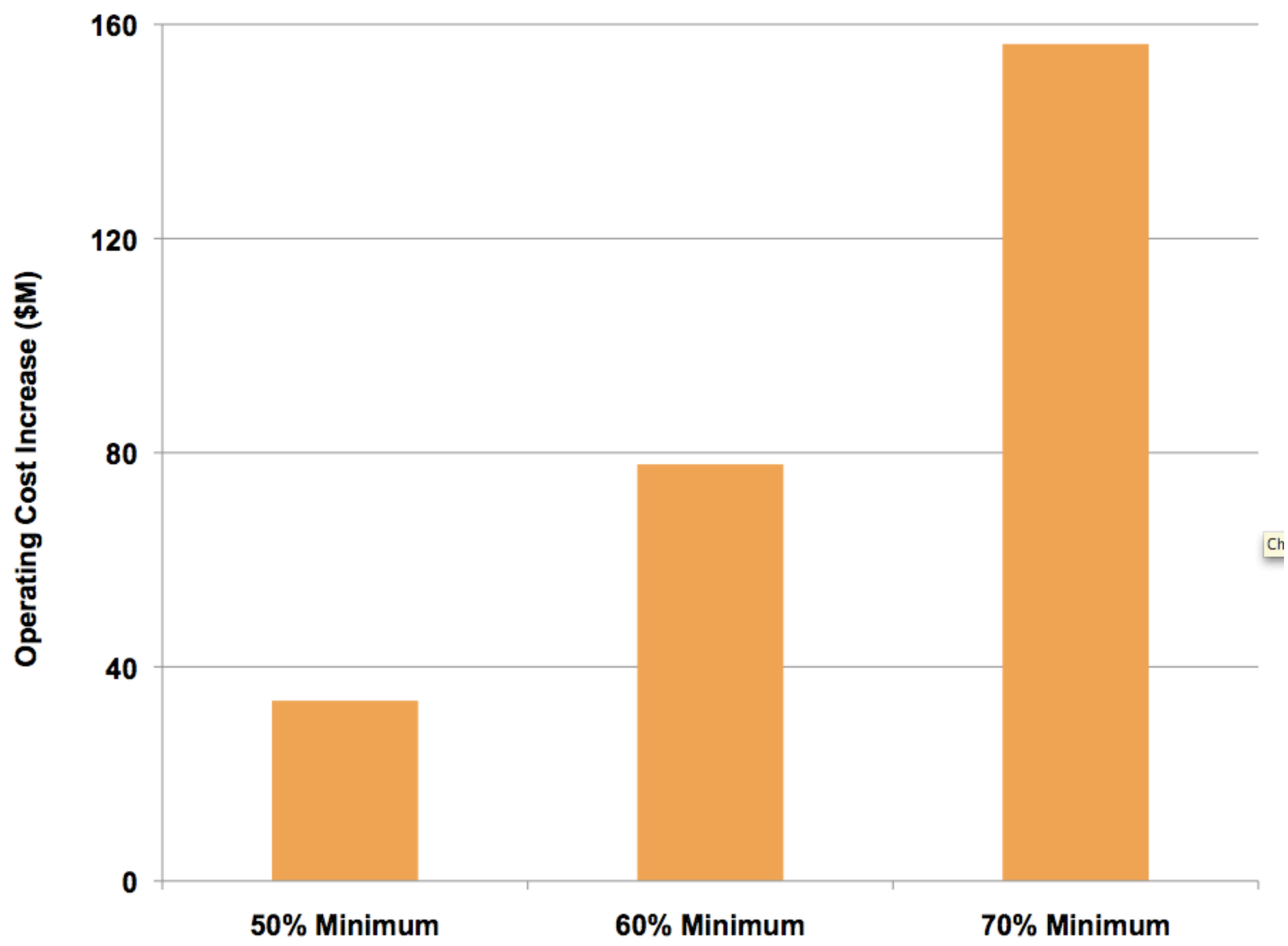
How do coal constraints affect these results?

Increased costs if coal minimum generation increased from 40%



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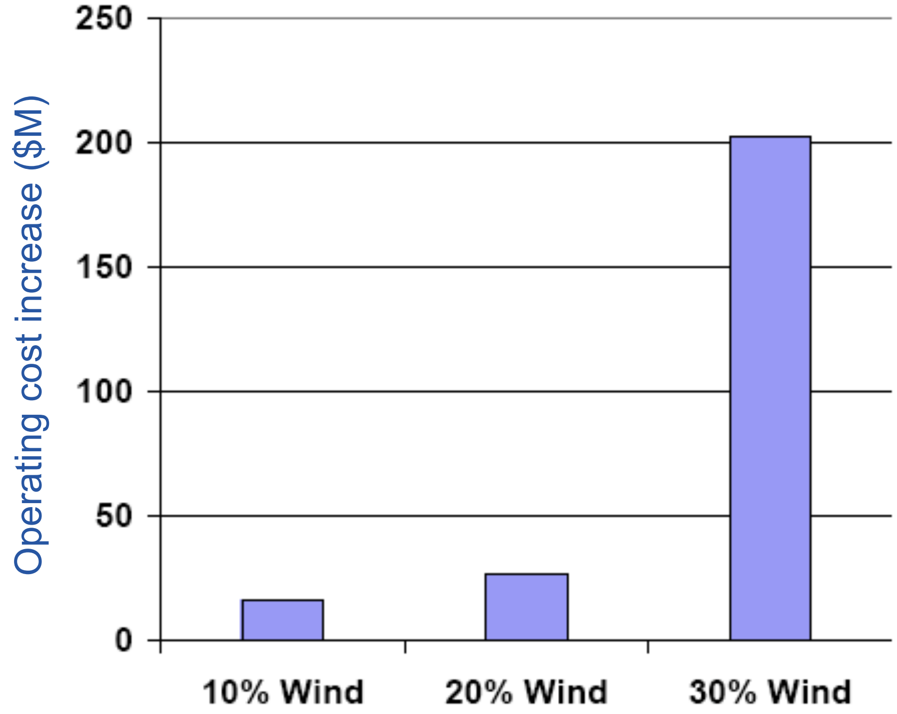
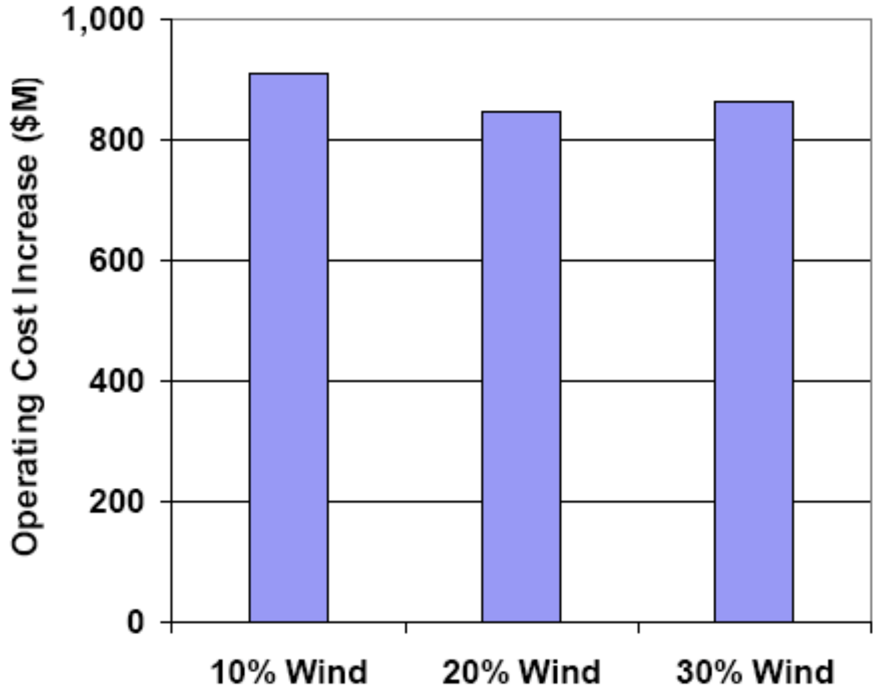
How do hydro constraints affect these results?

Cost if you dispatch hydro to load only, not net load



Cost increase if hydro output kept flat over the year



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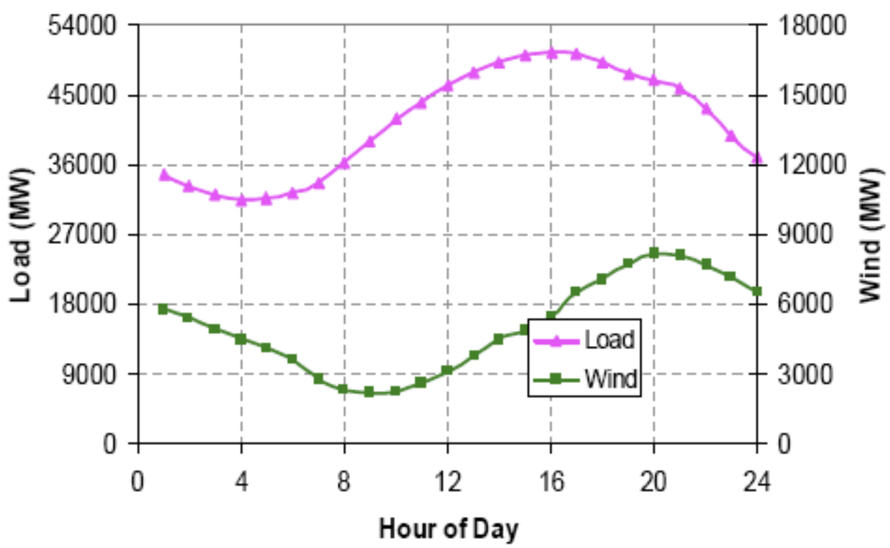
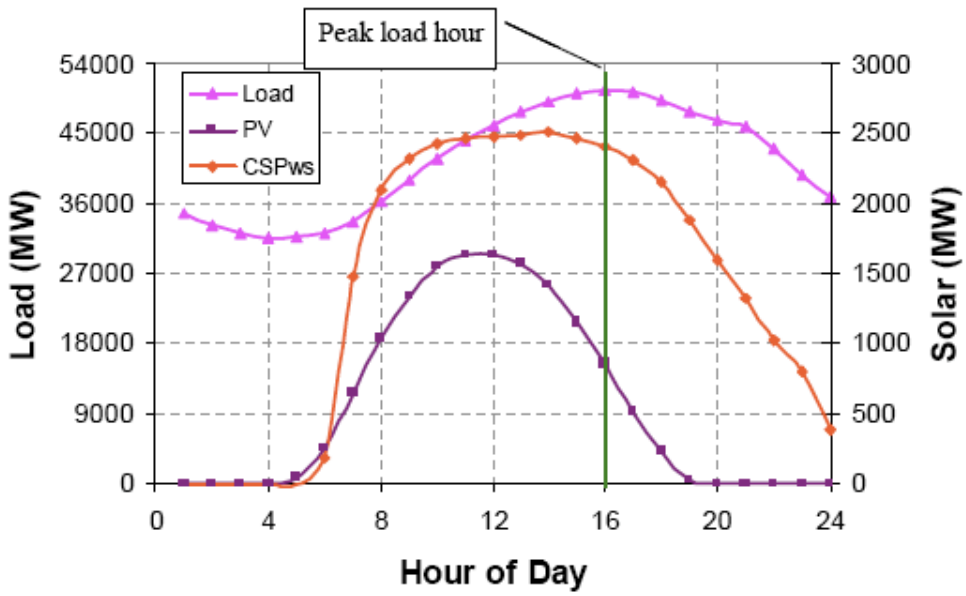
How much capacity value do renewables provide at these penetration levels?

Wind: 10-15%
PV: 25-30%
CSP with storage: 90-95%





PV was based on DC rating with losses of 23%

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It is feasible for WestConnect to accommodate 30% wind/5% solar

Assuming the following changes to current practice can be made:

- Substantially increase Balancing Area cooperation or consolidation, real or virtual
- Increase the use of sub-hourly scheduling for generation and interchanges
- Increase utilization of transmission
- Enable coordinated commitment and economic dispatch of generation over wider regions
- Use state of the art wind/solar forecasts in unit commitment/operations
- Increase the flexibility of dispatchable generation where appropriate
- Commit additional operating reserves as appropriate
- Target new or existing demand response programs to accommodate increase variability and uncertainty
- Require wind plants to provide down reserves

Summary of Key Findings

- We find it feasible for WestConnect to accommodate 30% wind and 5% solar
- What makes this possible?
  - Extensive balancing area cooperation
  - Subhourly economic dispatch
- What are the benefits?
  - Reductions of 40% in annual operating costs and 25-45% CO_2 emissions
- What factors have a large impact on the economics of accommodating wind and solar?
  - Use of forecasts in unit commitment
  - Renewable energy penetration in the *rest of WECC* affects performance and economics
  - Operating costs increase with more hydro/coal plant constraints
  - Different transmission/geographic scenarios do NOT have much impact
- Do we need long distance transmission?
  - We can start integrating lower penetrations of wind/solar before long distance transmission is commissioned

Summary of Key Findings 2

- Do we need more reserves or storage?
  - Load is always met but there are contingency reserve shortfalls using the WECC rules of 3% of load
    - Demand response is a more cost-effective option to meet the contingency reserve shortfalls than increasing operating reserves
  - Reserve requirement for net load variability (load following) increases but the system naturally provides these, so more reserves do not need to be committed.
  - Additional storage is not justified based solely on price arbitrage. Did not examine the economics of storage for reserves
- How often is wind curtailed?
  - On the order of 1% or less of total wind energy
- What capacity value do wind, PV and CSP provide?
  - Wind provides 10-15%, PV provides 25-30%, CSP provides 90-95%

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Next Steps

- More detail on non-renewable portfolio
- Changes in non-renewable portfolio
- Reserve requirements and strategies
- Load participation/demand response
- Fuel sensitivities
- Forecasting
- Rolling unit commitment
- Transmission planning and reliability
- Hydro flexibility

30% In-Area Scenario Energy Summary

In Footprint

	Load	Wind		CSP with Storage		PV		Total Renewable	
Areas	**Energy (GWh)**	**Energy (GWh)**	**# Sites (Used/Available)**	**Energy (GWh)**	**# Sites (Used/Available)**	**Energy (GWh)**	**# Sites (Used/Available)**	**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

	Load	Wind		CSP with Storage		PV		Total Renewable	
Areas	**Energy (GWh)**	**Energy (GWh)**	**# Sites (Used/Available)**	**Energy (GWh)**	**# Sites (Used/Available)**	**Energy (GWh)**	**# Sites (Used/Available)**	**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% Wind, 5% Solar In Footprint
20% Wind, 3% Solar Out of Footprint

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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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Scenario Overview

In Area

Area	Load Minimum (MW)	Load Maximum (MW)	10% Wind Rating (MW)	1% Solar Rating (MW)	20% Wind Rating (MW)	3% Solar Rating (MW)	30% Wind Rating (MW)	5% Solar Rating (MW)
Arizona	6,995	23,051	3,600	400	7,350	1,200	11,220	2,000
Colorado East	4,493	11,589	2,040	300	3,780	800	5,640	1,400
Colorado West	712	1,526	300	0	600	200	900	300
New Mexico	2,571	5,320	1,080	200	1,920	400	2,790	700
Nevada	3,863	12,584	2,340	200	4,680	700	7,050	1,100
Wyoming	2,369	4,016	930	100	1,620	100	2,340	300
In Footprint	21,249	58,087	10,290	1,200	19,950	3,400	29,940	5,800

Local Priority

Area	Load Minimum (MW)	Load Maximum (MW)	10% Wind Rating (MW)	1% Solar Rating (MW)	20% Wind Rating (MW)	3% Solar Rating (MW)	30% Wind Rating (MW)	5% Solar Rating (MW)
Arizona	6,995	23,051	2,850	400	5,250	1,200	7,710	2,000
Colorado East	4,493	11,589	2,190	300	3,870	800	4,650	1,400
Colorado West	712	1,526	210	0	450	200	570	300
New Mexico	2,571	5,320	1,350	200	2,100	400	2,970	700
Nevada	3,863	12,584	1,350	200	2,490	700	3,450	1,100
Wyoming	2,369	4,016	1,650	100	4,020	100	7,410	300
In Footprint	21,249	58,087	9,600	1,200	18,180	3,400	26,760	5,800

Mega Project

Area	Load Minimum (MW)	Load Maximum (MW)	10% Wind Rating (MW)	1% Solar Rating (MW)	20% Wind Rating (MW)	3% Solar Rating (MW)	30% Wind Rating (MW)	5% Solar Rating (MW)
Arizona	6,995	23,051	810	400	1,260	1,800	1,890	2,600
Colorado East	4,493	11,589	2,010	300	2,400	400	2,490	1,200
Colorado West	712	1,526	60	0	90	0	90	200
New Mexico	2,571	5,320	1,860	400	2,700	1,000	4,350	1,000
Nevada	3,863	12,584	570	100	1,020	200	1,440	600
Wyoming	2,369	4,016	3,390	0	8,790	0	13,770	100
In Footprint	21,249	58,087	8,700	1,200	16,260	3,400	24,030	5,700