NREL
NATIONAL RENEWABLE ENERGY LABORATORY

Drivers for the Value of Demand Response under Increased Levels of Wind and Solar Power

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Value of Demand Response

To whom?

To begin to answer the question, measure maximum possible value to the power system.

→ operational zero-cost resource

→ estimate capacity value and compare to alternatives

Sources of Value

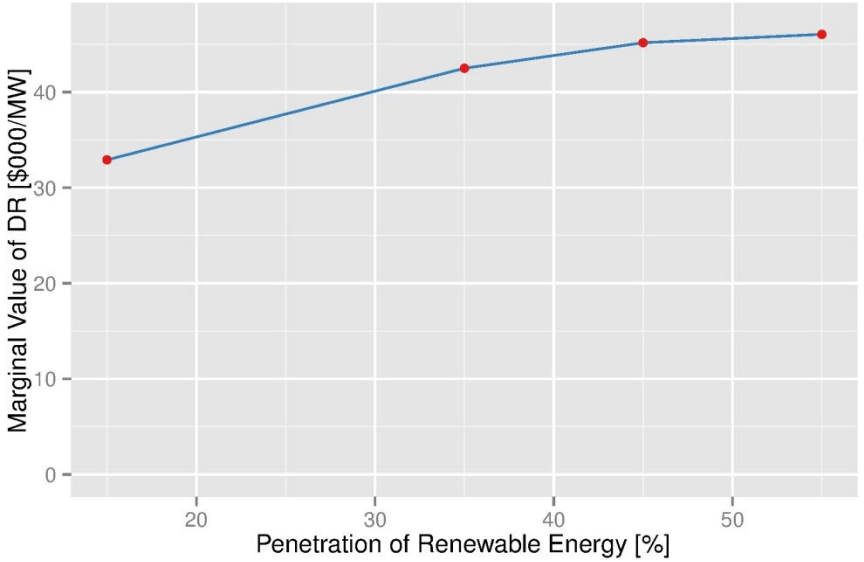
Product Type	General Description	Physical Requirements: How fast to respond	Length of response	Time to fully respond	How often called
Regulation	Response to random unscheduled deviations in scheduled net load	30 seconds	Energy neutral in 15 minutes	5 minutes	Continuous within specified bid period
Flexibility	Additional load following reserve for large un-forecasted wind/solar ramps	5 minutes	1 hour	20 minutes	Continuous within specified bid period
Contingency	Rapid and immediate response to a loss in supply	1 minute	≤ 30 minutes	≤ 10 minutes	≤ Once per day
Energy	Shed or shift energy consumption over time	5 minutes	≥ 1 hour	10 minutes	1-2 times per day with 4-8 hour notification
Capacity	Ability to serve as an alternative to generation	Top 20 hours coincident with balancing authority area system peak			

Categories of Demand Response

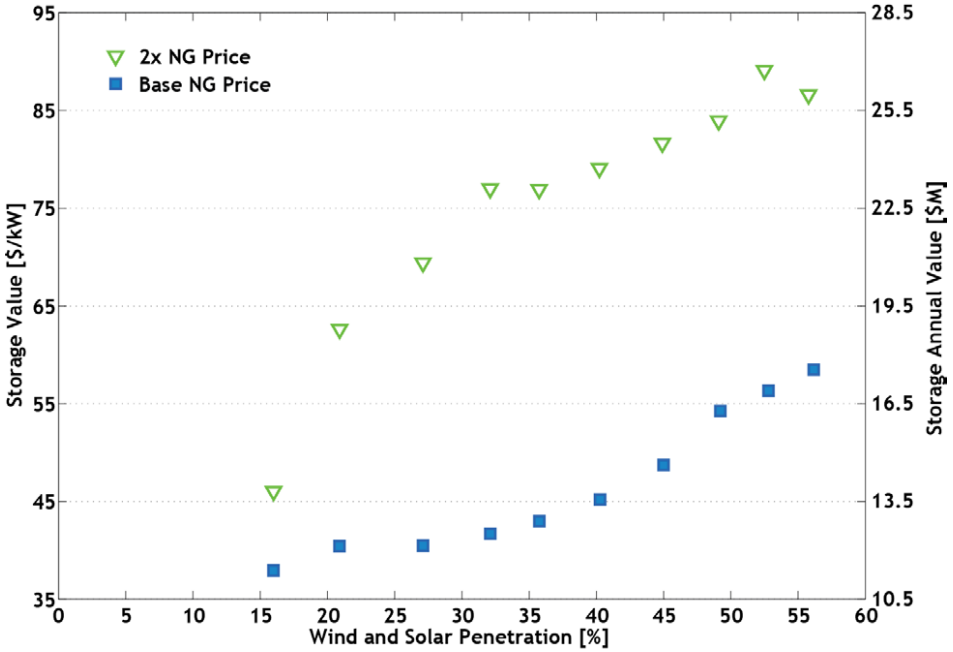
	End-Use	Energy	Regulation	Contingency	Flexibility
STORAGE	Residential Heating	Shed	X	X	X
	Commercial Cooling	Shift (6a-6p)	X	X	x
	Commercial Heating	Shift (3a-7p)	X	X	X
	Residential Cooling	Shift (6a-6p)	X	X	X
	Residential Water Heating	Shift	X	X	X
	Data Centers	Shift		X	
SCHEDULED	Wastewater Pumping	Shift			
	Agricultural Pumping	Shift		X	
	Municipal Pumping	Shift			
	Refrigerated Warehouses	Shift			
SHED	Commercial Lighting		X	X	X
	Commercial Ventilation		X	X	X
	Outdoor Lighting		X	X	X

Value as a Function of Wind and Solar Penetration: Energy Shifting in the Colorado Test System

For grocery story refrigeration DR in an hour-ahead market, we see value increasing with wind and solar penetration.



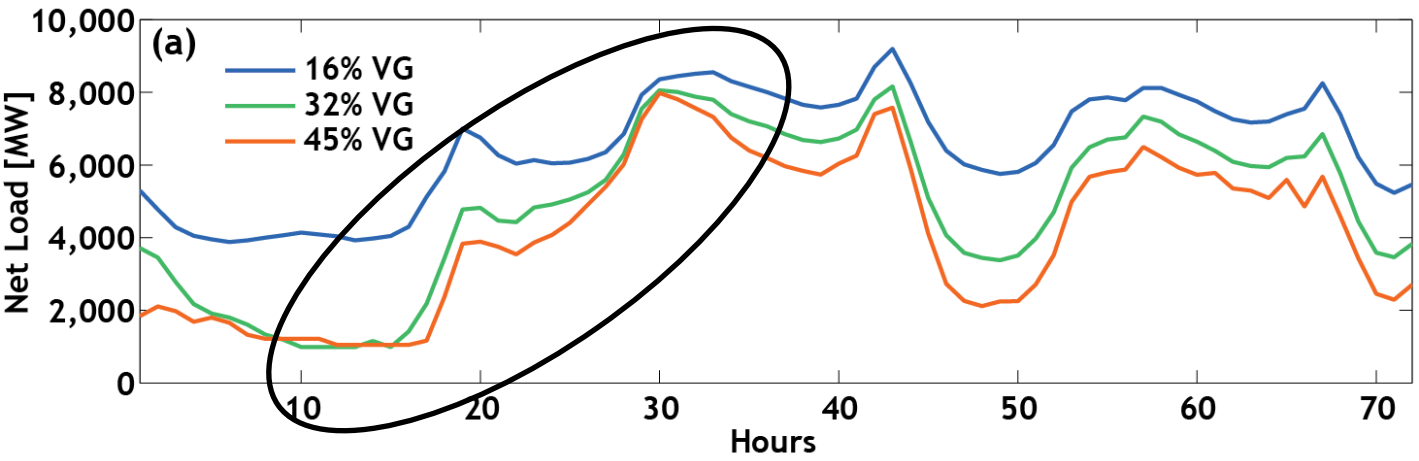
(O'Connell et al. 2015)

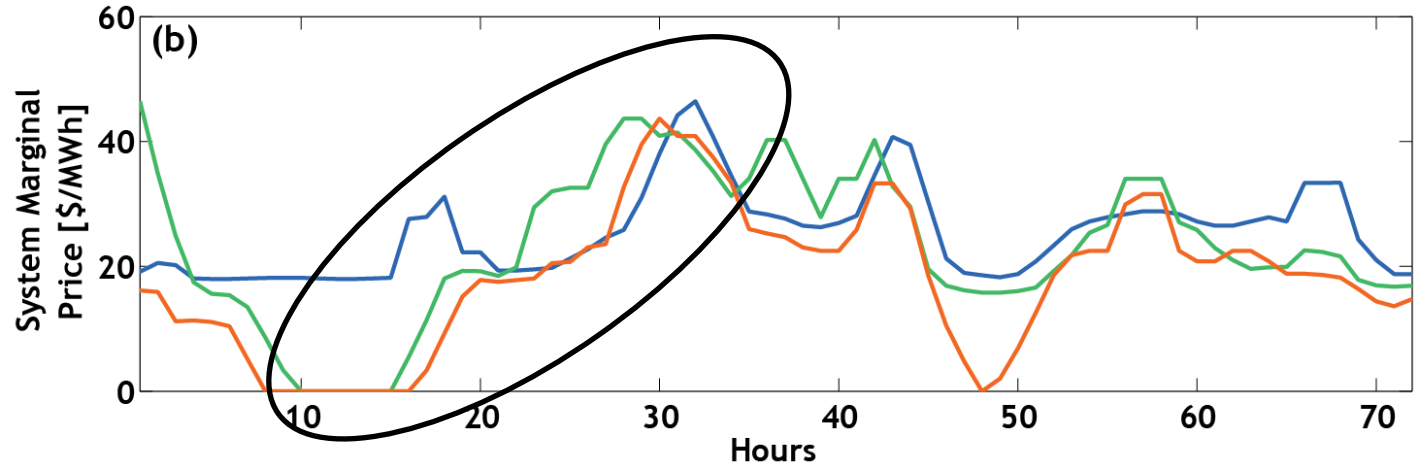


(Denholm et al. 2013)

This is in line with what we have seen for storage.

Intuition for Value Increasing with VG: Variability



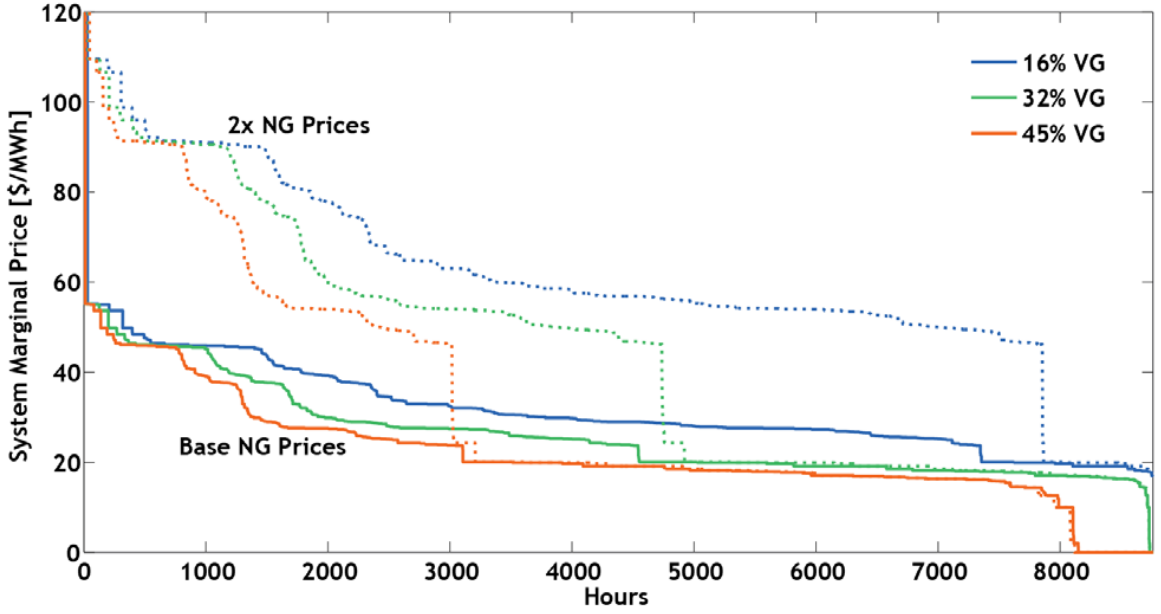


Net load and system marginal price for three variable generation (VG) penetrations during three spring days beginning April 5.

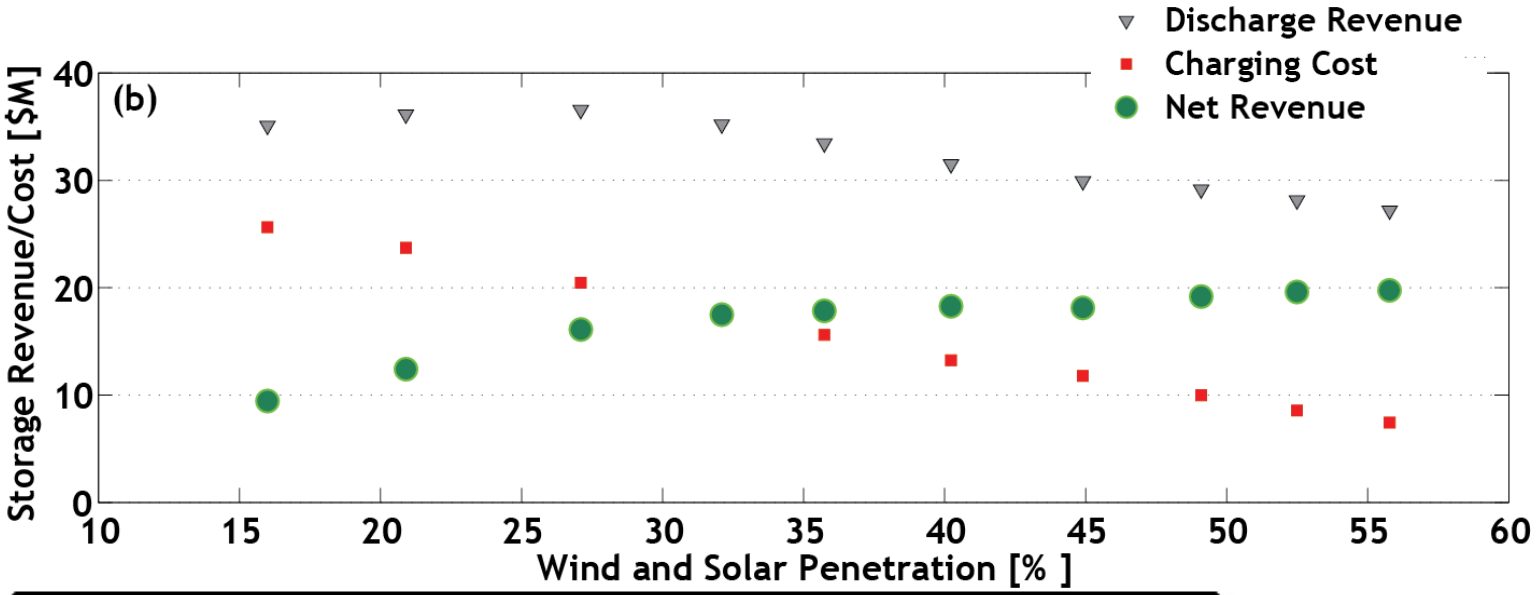
Increased variability creates arbitrage opportunities.

(Denholm et al. 2013)

Intuition for Value Increasing with VG: Variability



Results for storage (analogous, although less constrained than DR), show charging costs decreasing faster than discharging revenue (Denholm et al. 2013).



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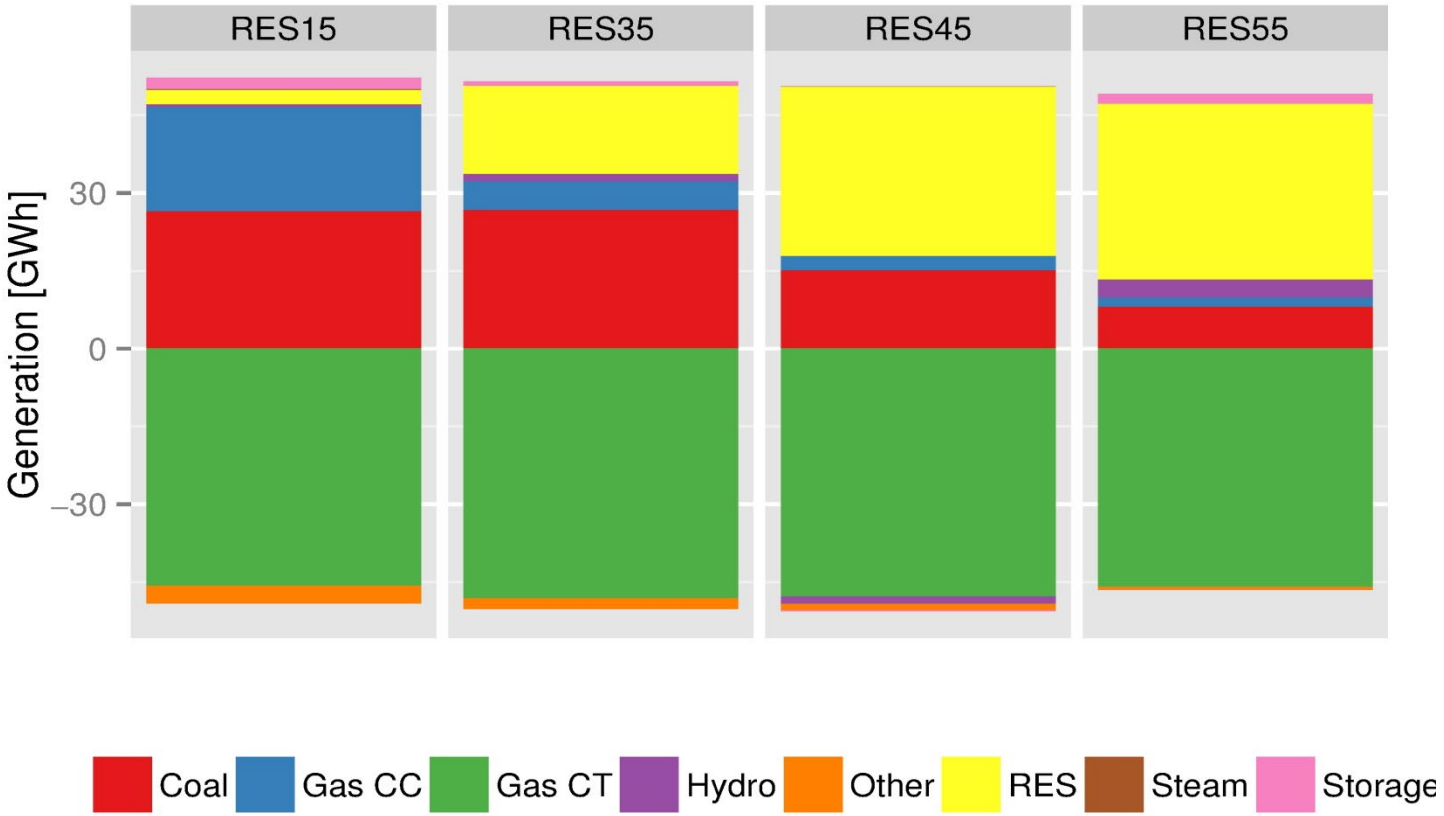
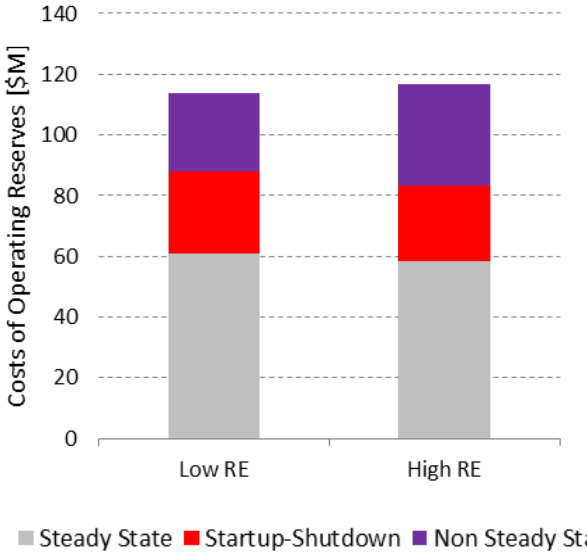
With increasing VG, DR switches from enabling less expensive thermal generator to reducing curtailment of renewables

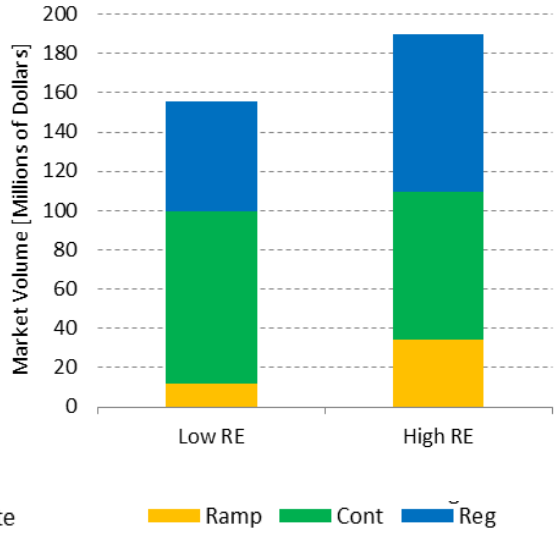


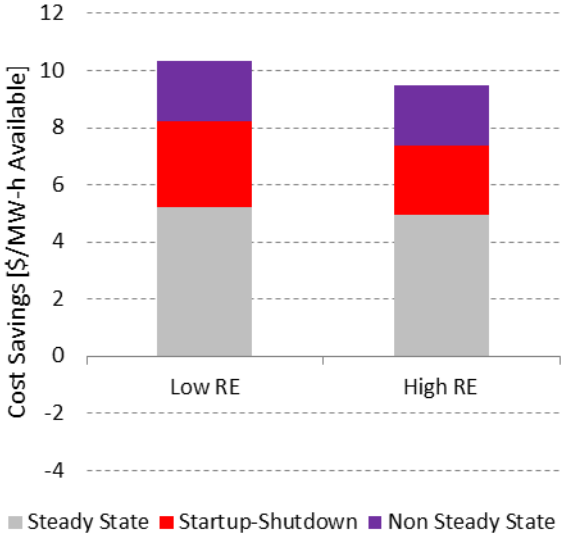
(O'Connell et al. 2015)

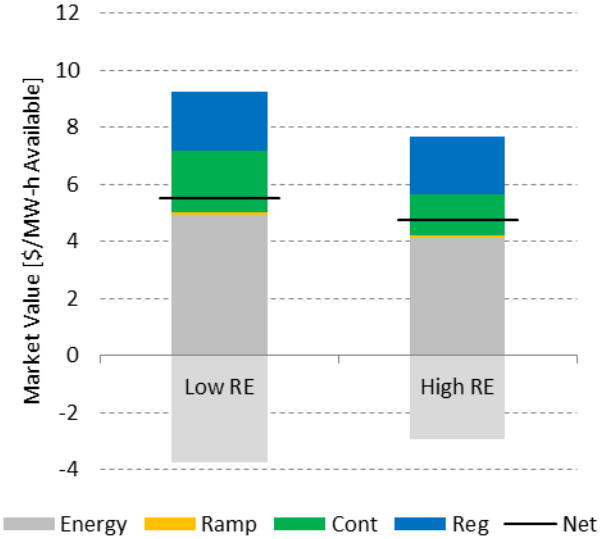
Value as a Function of Wind and Solar Penetration: Operating Reserves in Western Interconnection Model

Total volume of reserve market increases in Western Interconnection Model going from 14% to 33% renewables.





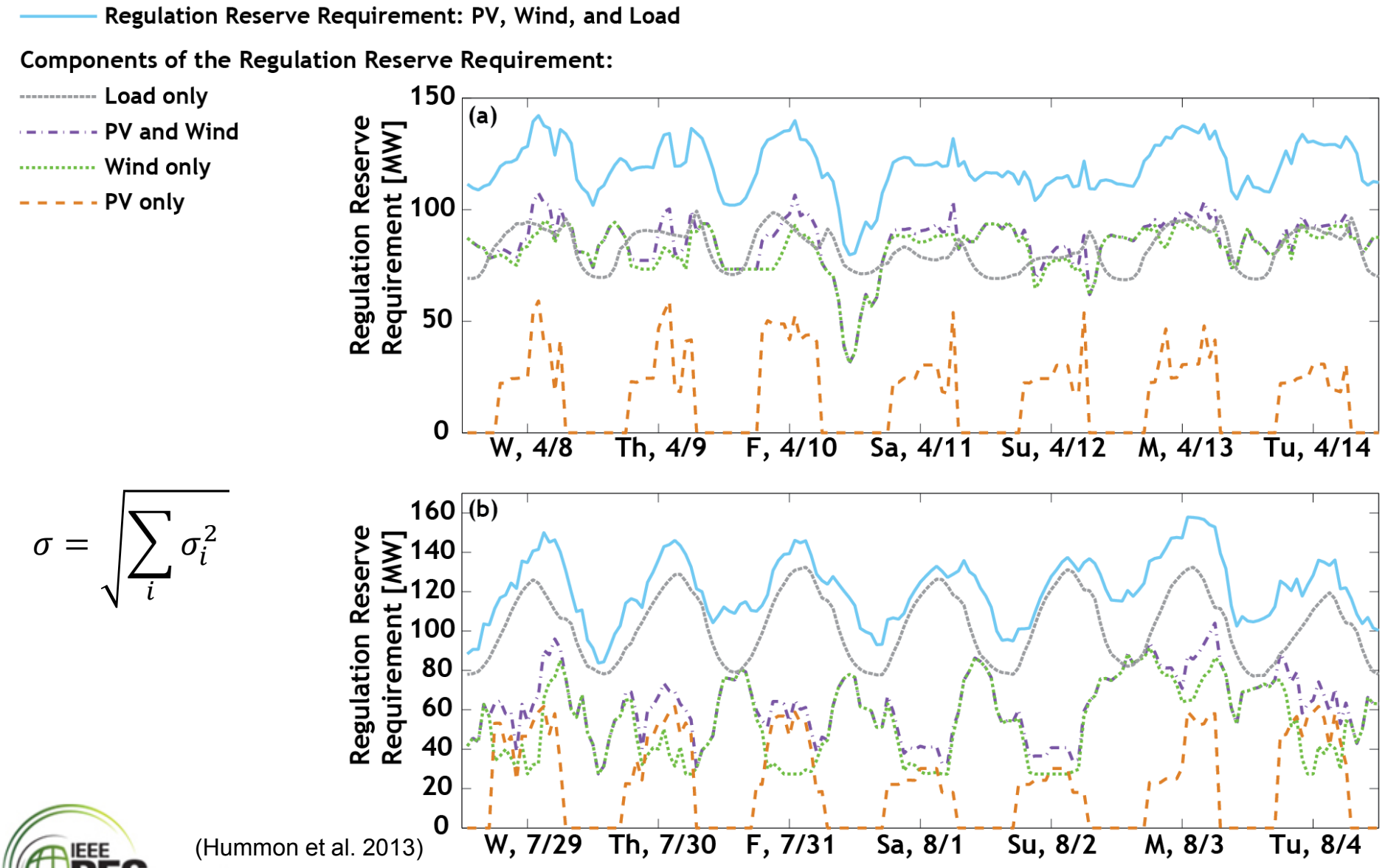




However, per-unit value of DR does not necessarily increase in that circumstance.

(Ma et al. In Prep.)

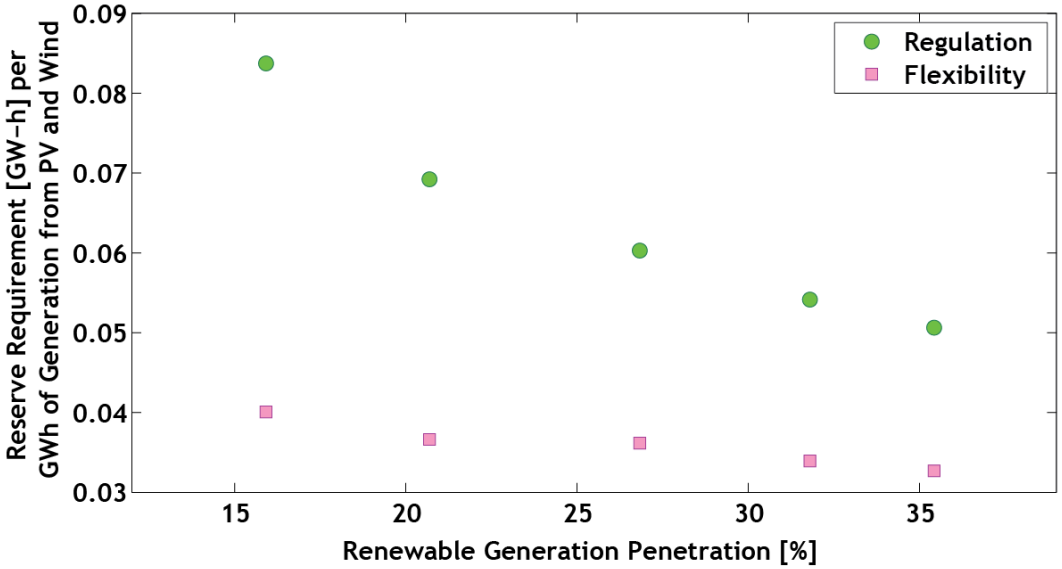
Intuition for Value Increasing with VG: Uncertainty



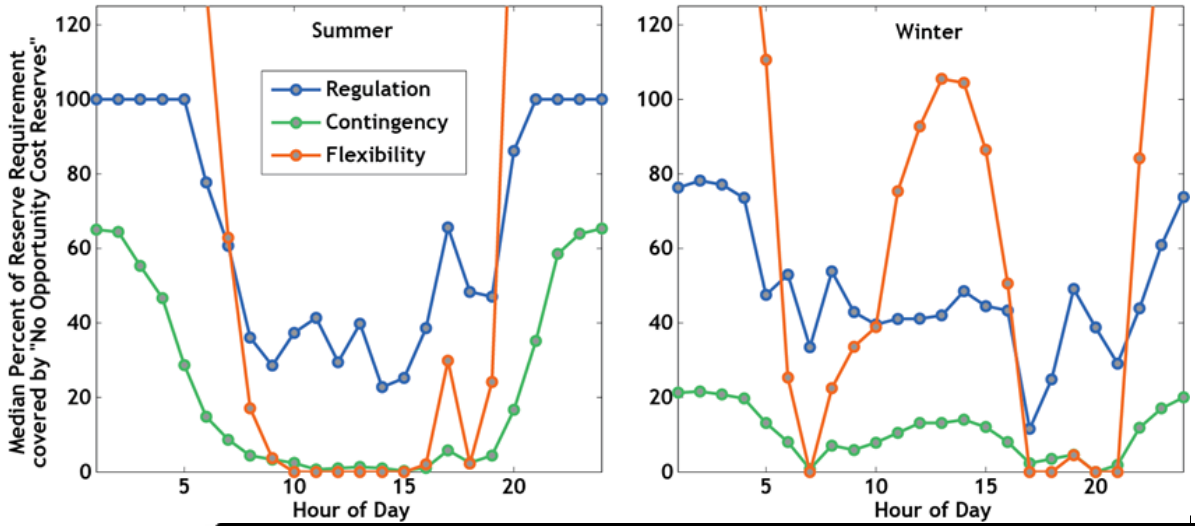
$$\sigma = \sqrt{\sum_i \sigma_i^2}$$

(Hummon et al. 2013)

Reserve requirement increases with wind and solar, but declines per unit of VG

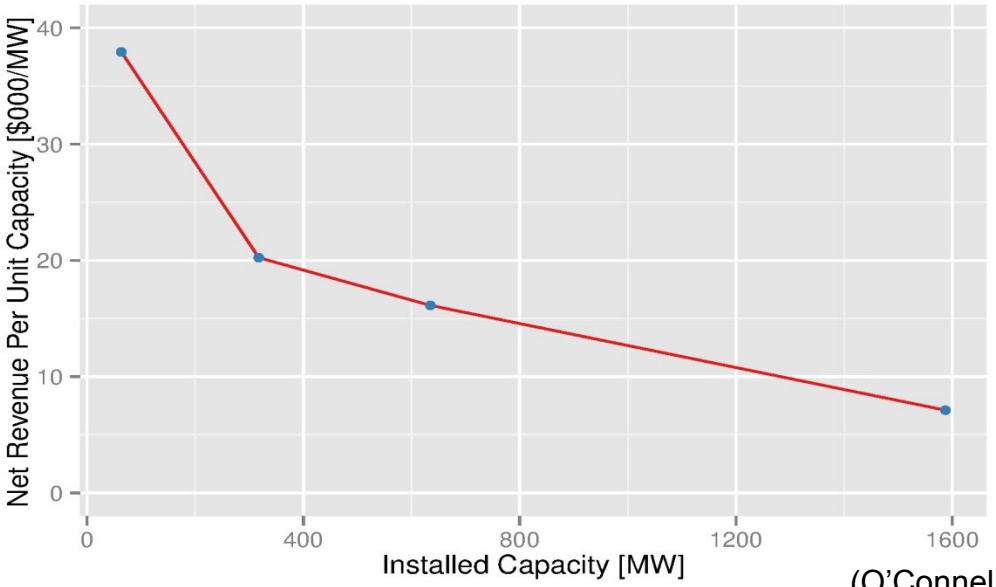


Reserves can sometimes be provided at no opportunity cost; prevalence is highly system-dependent



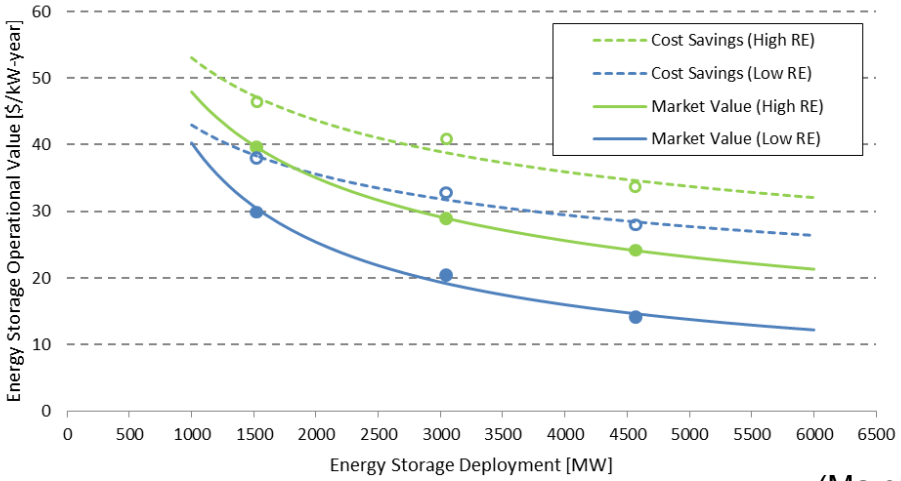
Colorado Test System

Value of DR is very sensitive to amount of DR supply



(O'Connell et al. 2015)

Analogous to storage

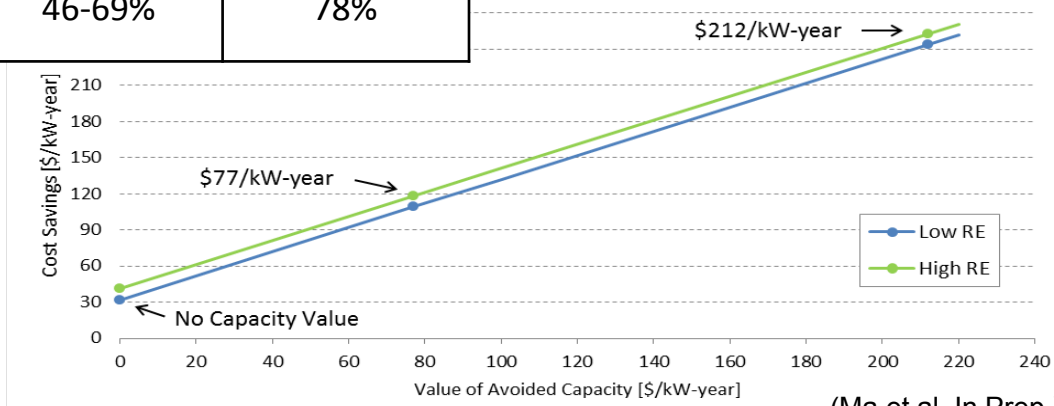


(Ma et al. In Prep.)

Conjecture: Capacity value is hard to measure, depends greatly on system, and is quite important

	Winter System 1 (AVA)	Winter System 2 (PSE)	Summer System 1 (LDWP)	Summer System 2 (NEVP)
Commercial Heating	35-41%	27-35%	4%	N/A
Data Centers	67-73%	52-60%	47-80%	78%
Municipal Pumping	14-18%	20-29%	29-39%	41-47%
Residential Cooling	N/A	N/A	35-55%	N/A
Residential Water Heating	24-43%	27-38%	13-22%	25-27%
Waste Water Pumping	36%	52%	46-69%	78%

(Nolan et al. 2014)



(Ma et al. In Prep.)

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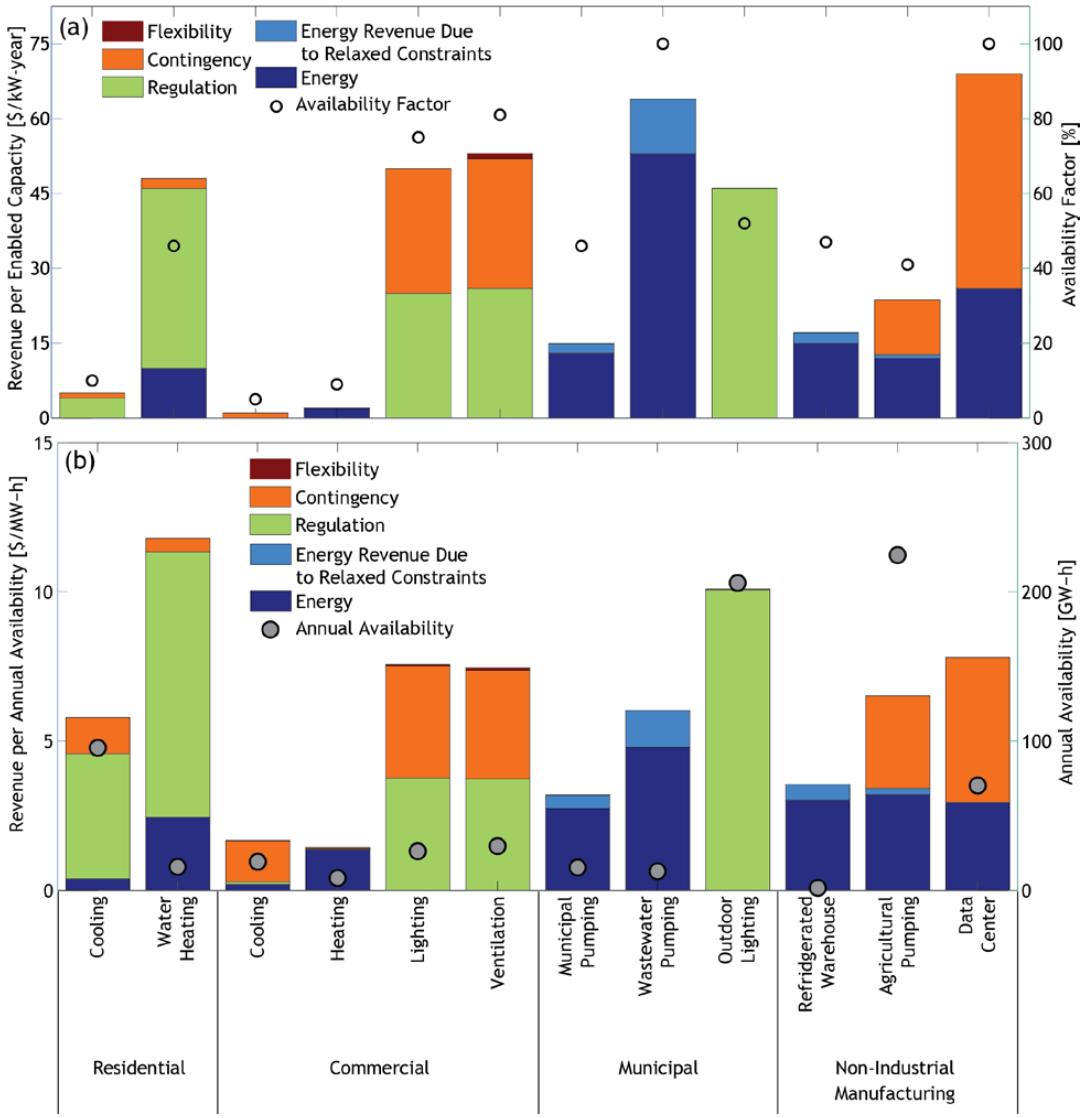
Order of Magnitude Value of DR

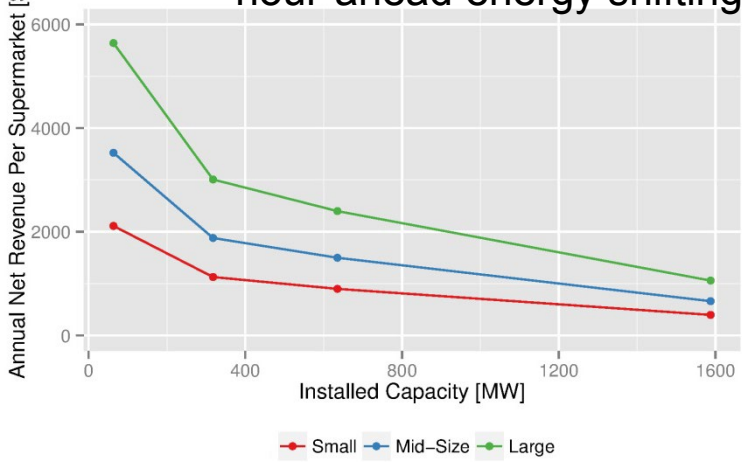


(Hummon et al. 2013)

Examples: Summer peaking

- 5 kW residential A/C, 40% CV: $25-450/unit-yr
- 4.5 kW residential water heater, 20% CV: $200-400/unit-yr

Colorado Test System, hour-ahead energy shifting



(O'Connell et al. 2015)

Conclusions

- Wind and solar variability and uncertainty provide additional opportunities for DR
- DR value is highly dependent on amount of DR supply
- DR value is also dependent on its capacity value, which is hard to measure and system-dependent
- Thus far, order of magnitude estimates of DR value show significant potential, but are very case-dependent

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Other collaborators: Brendan Kirby, Mark O'Malley, Sheila Nolan

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