

# Bringing It All Together: Impacts of VRE on Wholesale Prices & Market Revenue Now and in the Future

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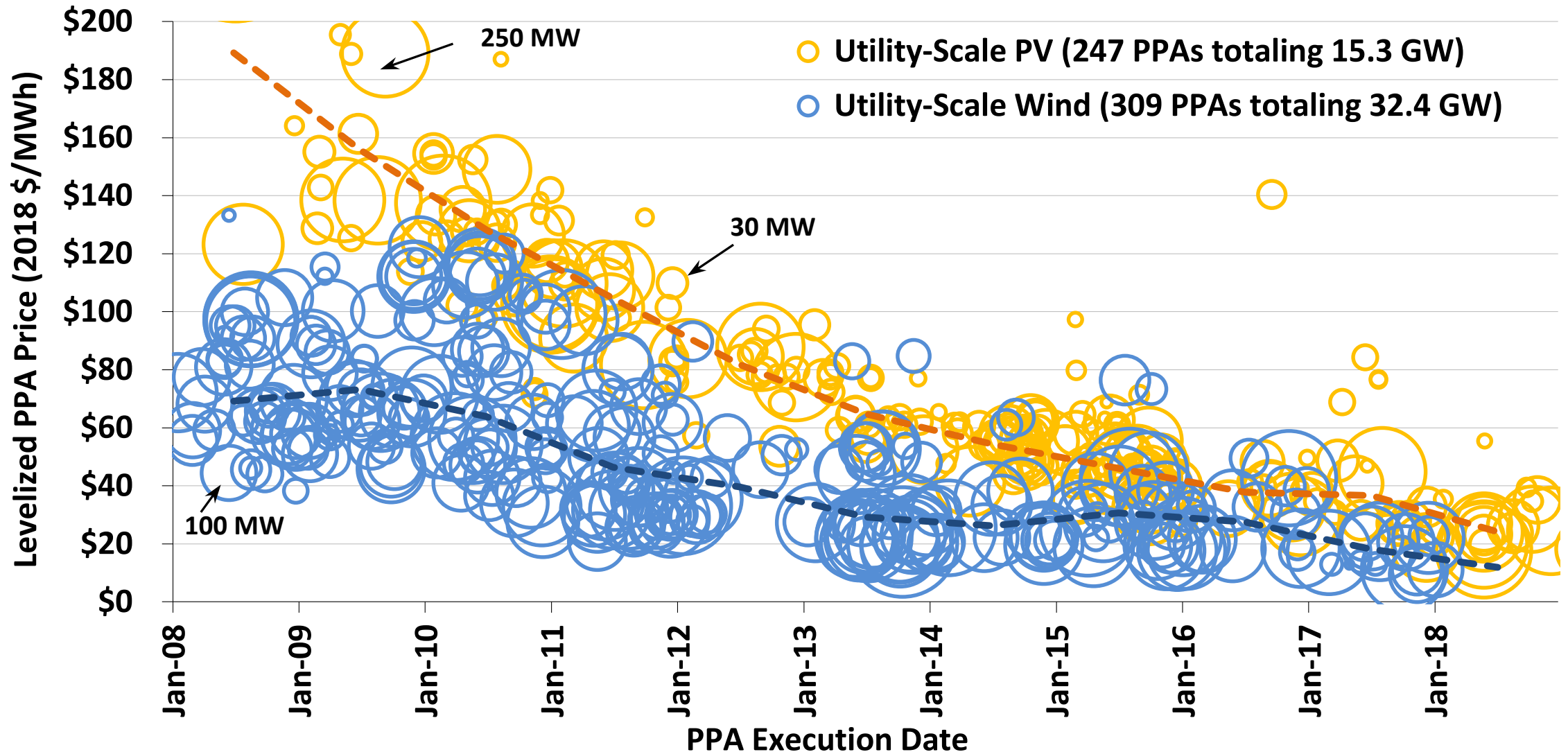
Lawrence Berkeley National Laboratory

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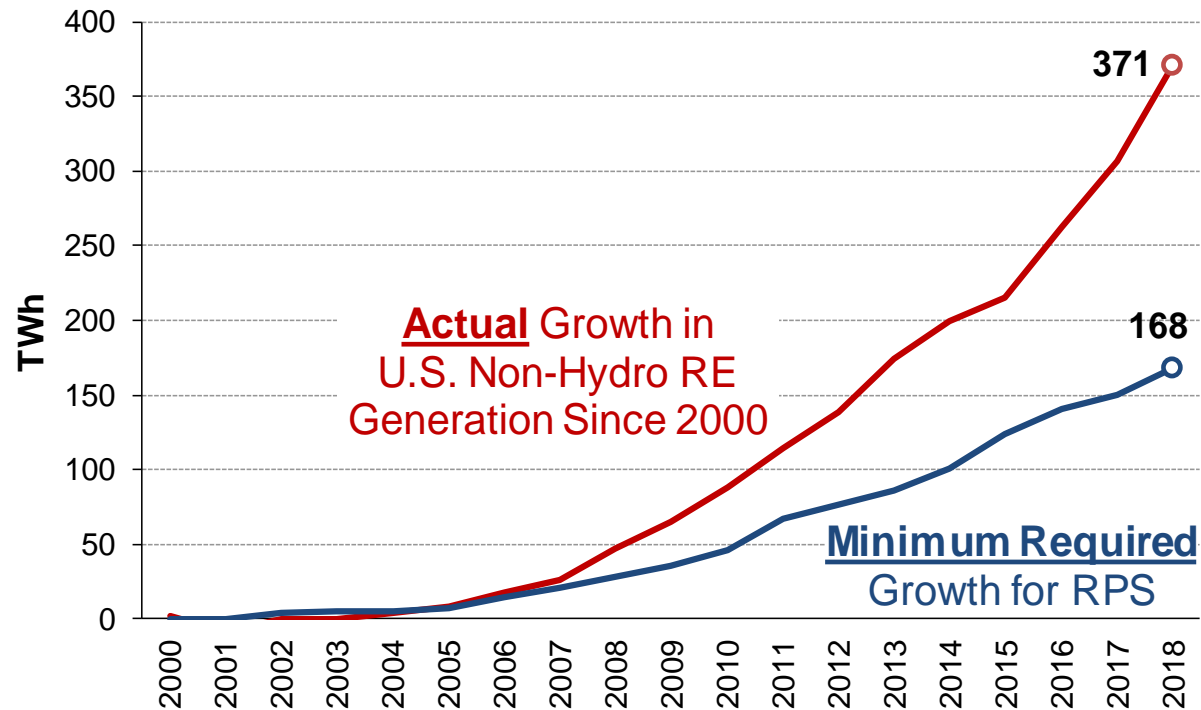
The work described here was funded by the Office of Energy Efficiency and Renewable Energy and the Office of Electricity of the U.S. Department of Energy

# Good News: Cost of Wind and Solar Continue to Decline...

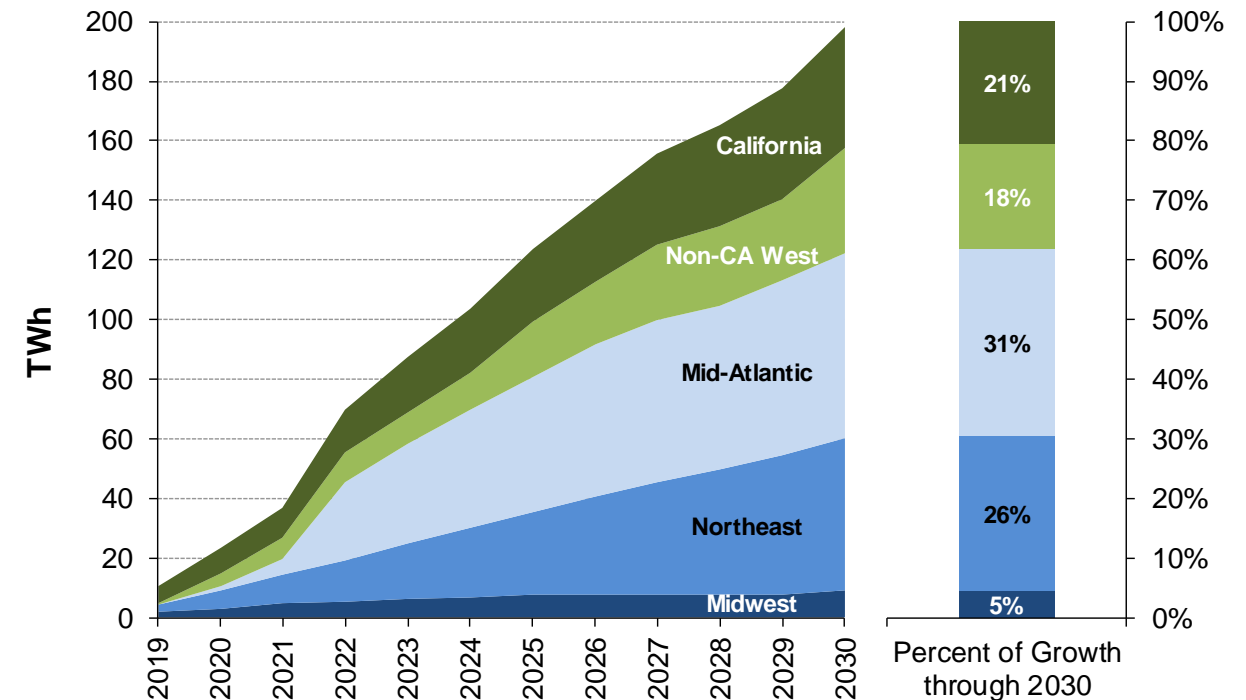


# ... and State Clean Energy Policies Are Strengthening

## Past Renewable Energy Growth

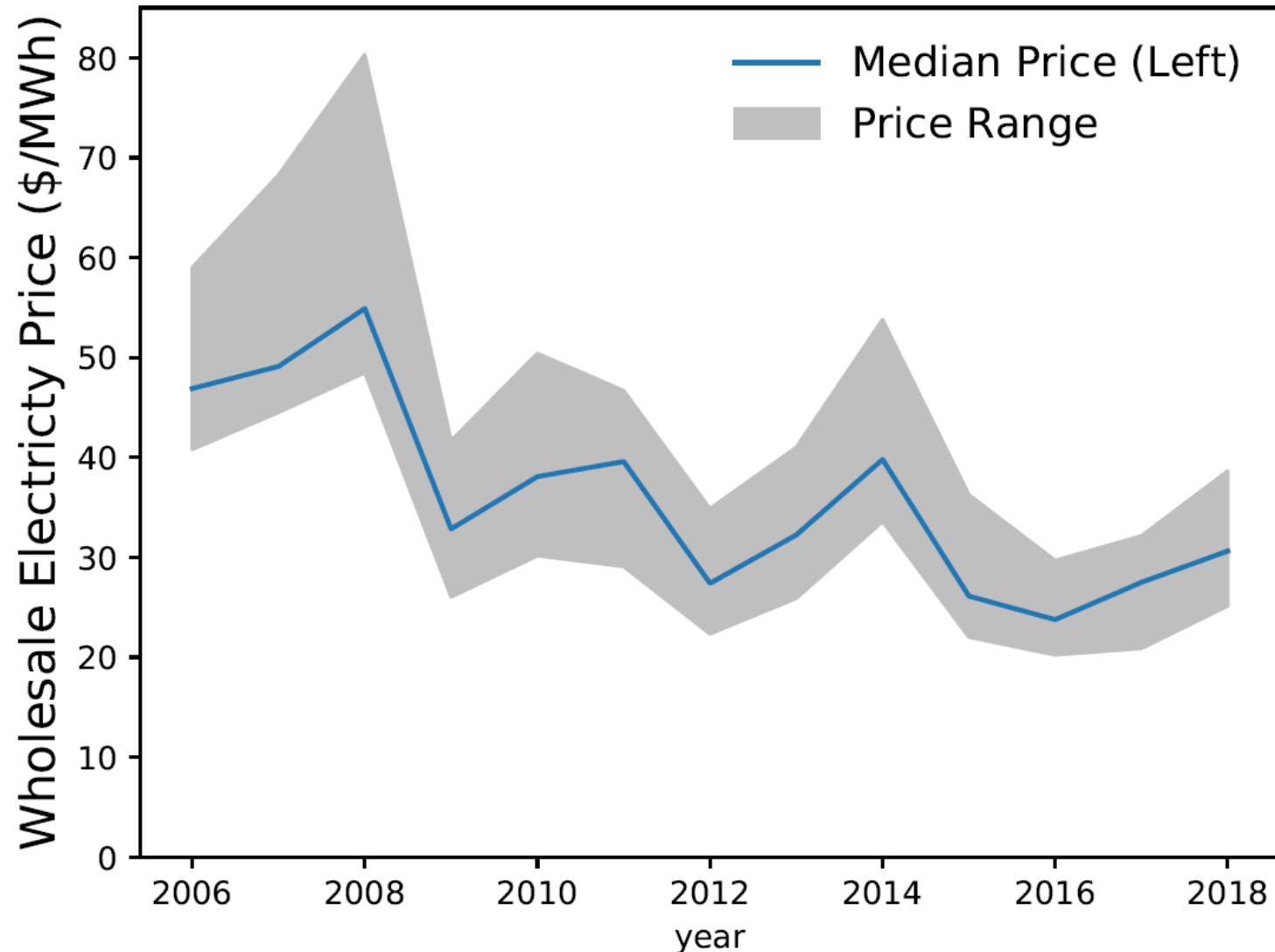


## Future RPS Demand Relative to Supply



States that have significantly increased RPS (or CES) policies in 2018-2019:  
**CA, CT, DC, MA, MD, NJ, NM, NV, PR, WA**

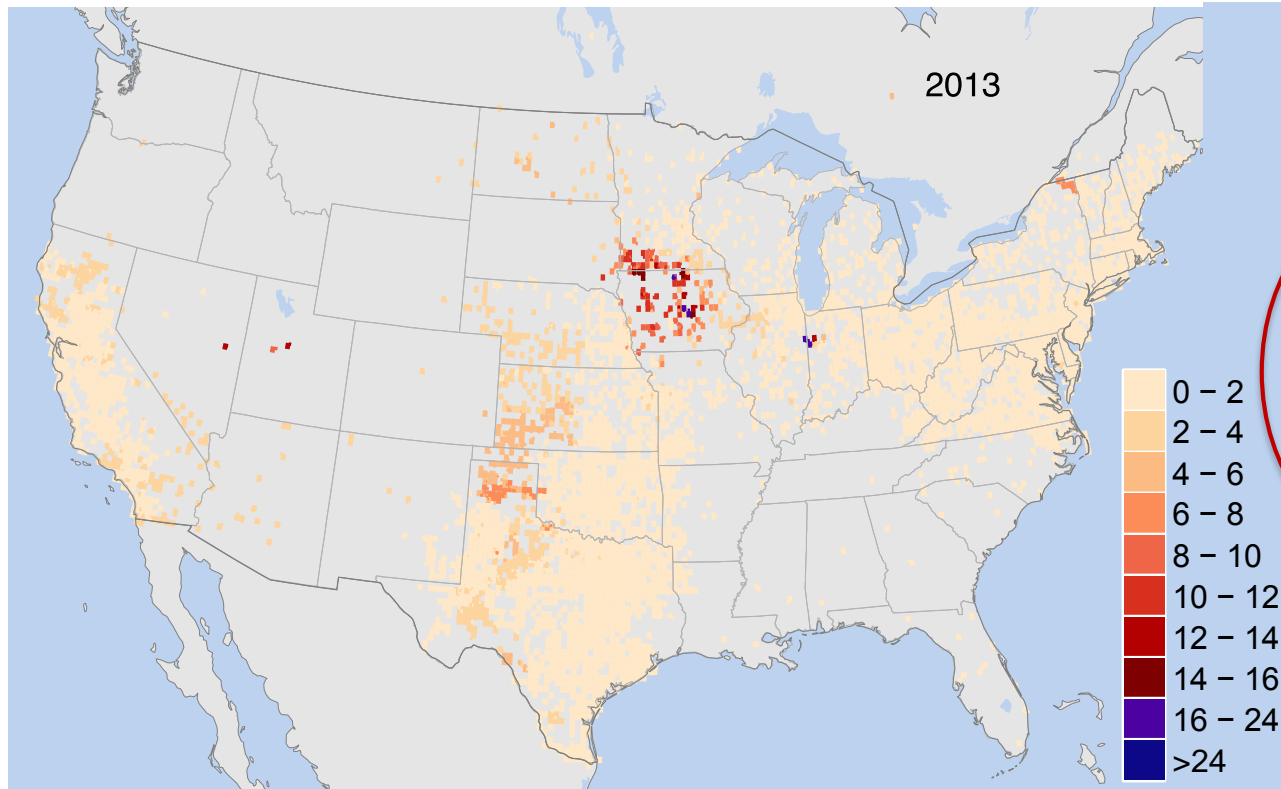
# But Relative Economics of VRE Is Also Dictated by Average Wholesale Power Prices (which have declined)...



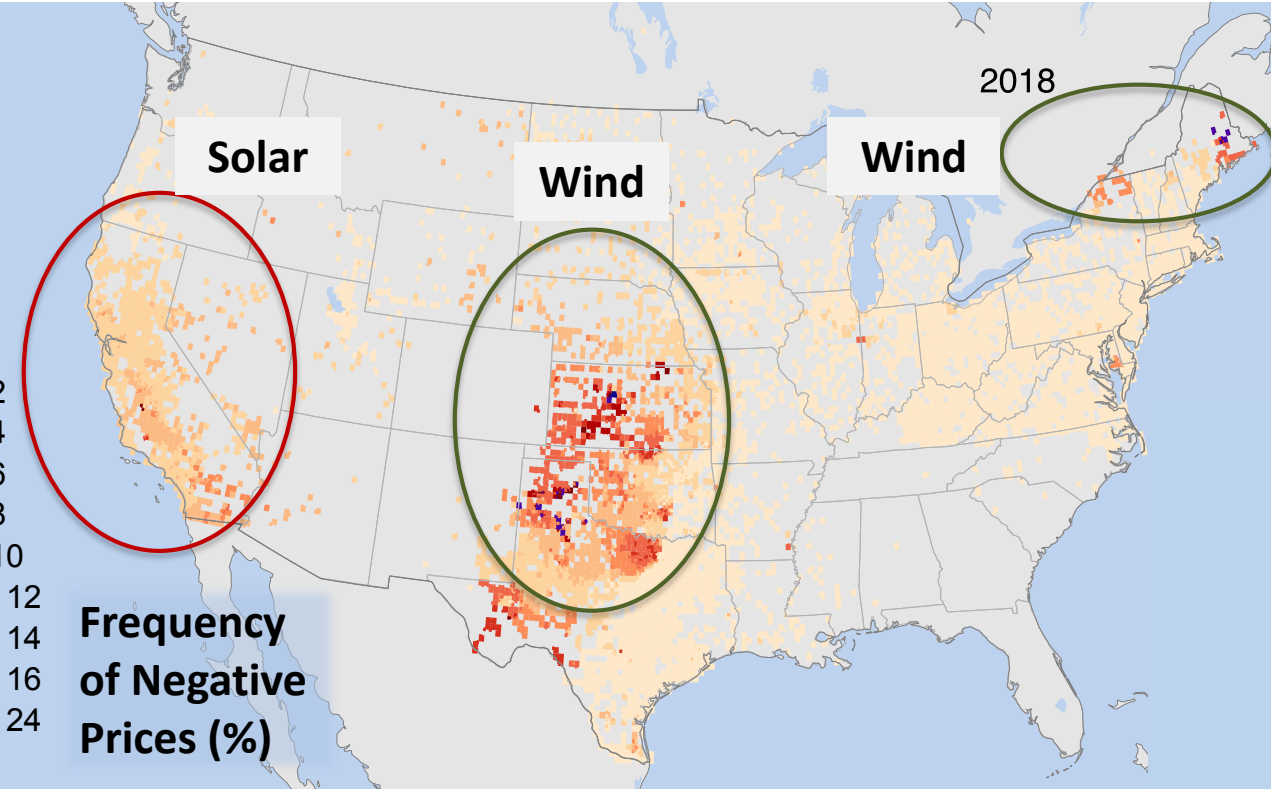
*Note: Range is 10<sup>th</sup> to 90<sup>th</sup> percentile across 60,000+ pricing nodes*

# ... and More Specifically, by the Wholesale Market Value of VRE, Considering Temporal and Geographic Pricing Trends

## Negative Prices, 2013



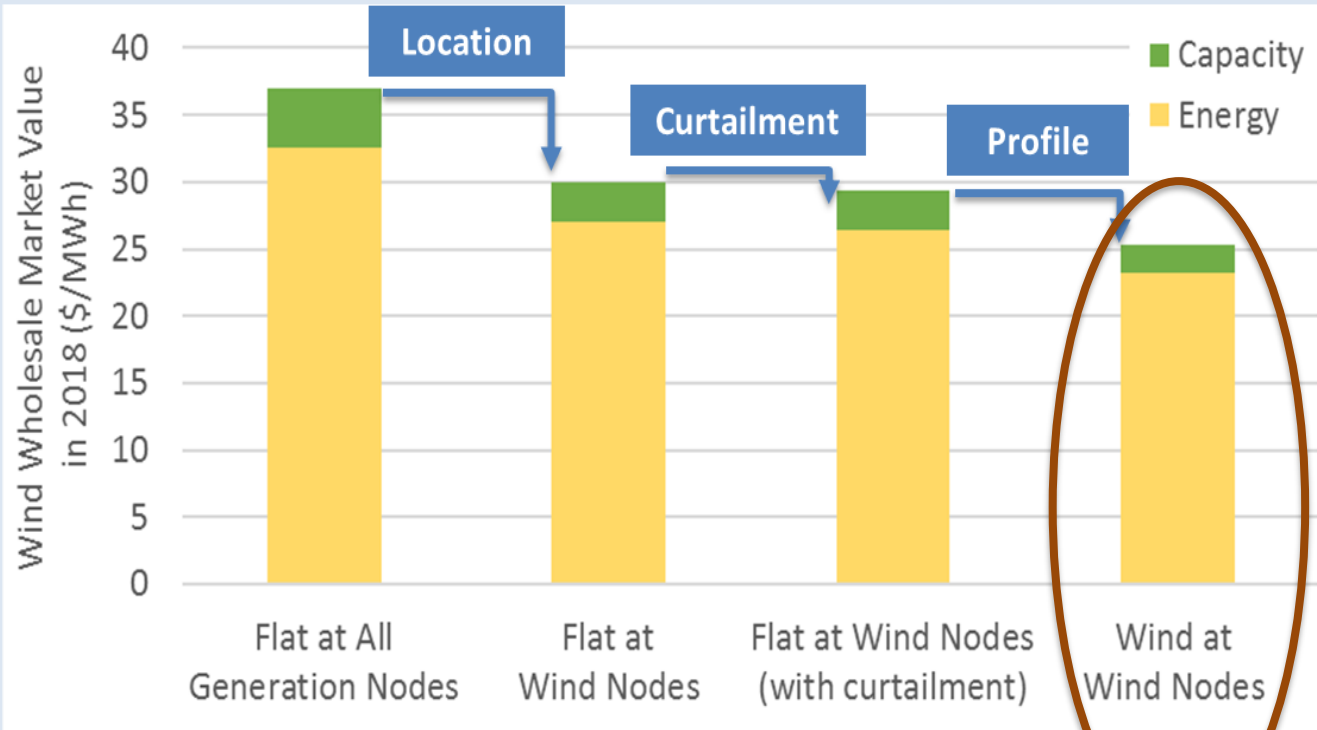
## Negative Prices, 2018



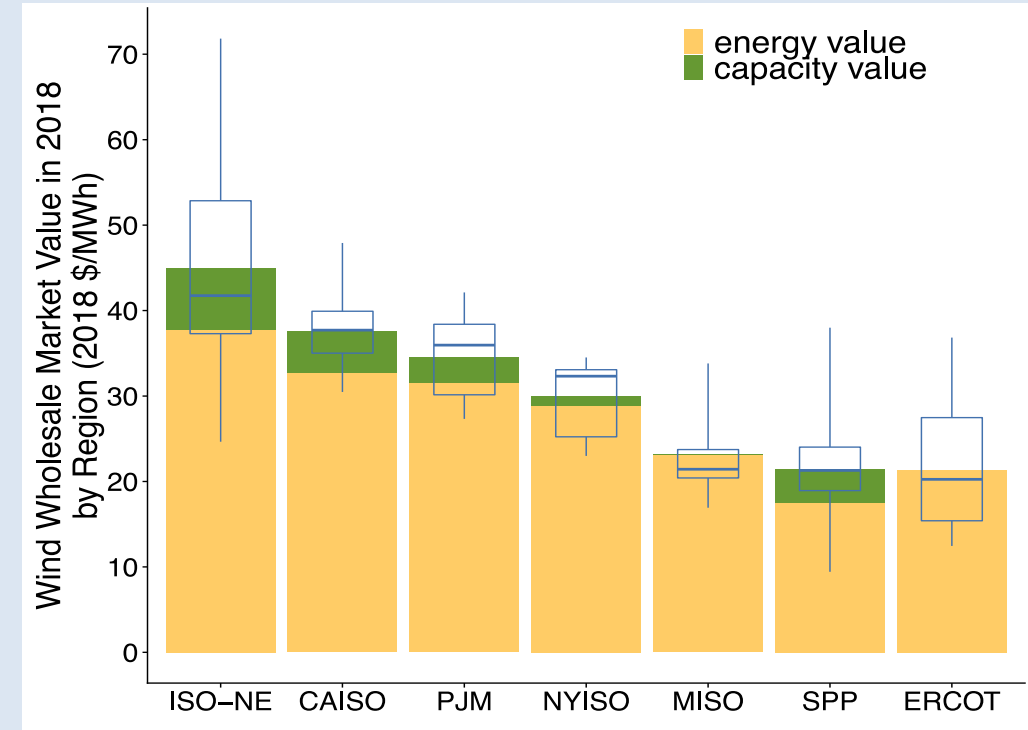
Higher frequency of negative prices in certain areas, seemingly driven in significant measure by wind and solar growth

# Geographic and Temporal Variations in Wholesale Prices Are Impacting 'Market Value' (energy + capacity) of Wind

## National 2018 Avg. Wholesale Market Value of Wind

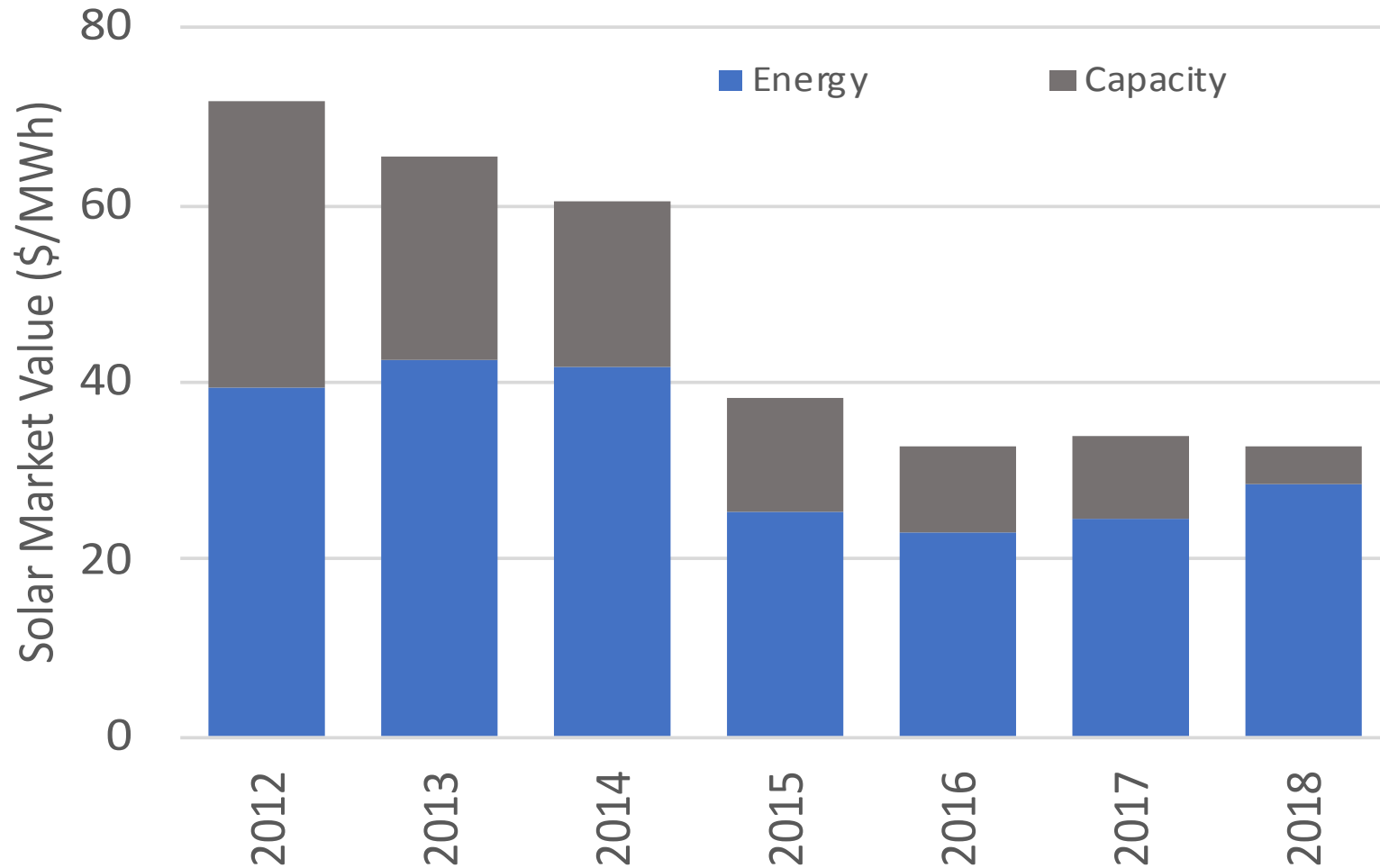


## Regional 2018 Market Value of Wind



Notes: Bars show averages. Box and whiskers show median, 25<sup>th</sup>/75<sup>th</sup> percentiles, min/max

# Changes in Diurnal and Seasonal Price Patterns Are Impacting the 'Market Value' of Solar Energy in California

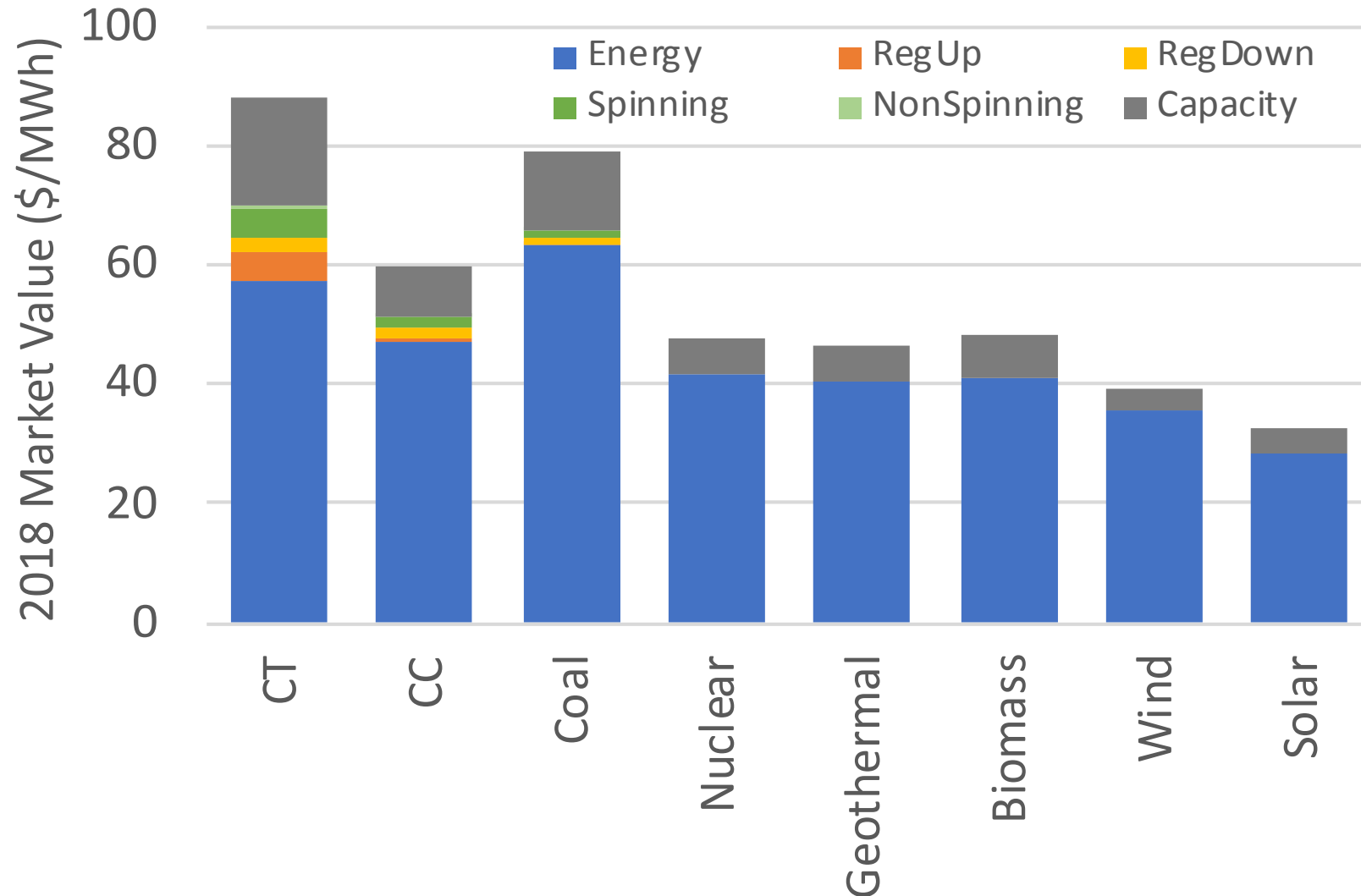


In largest U.S. solar market, wholesale market value—inclusive of energy and capacity—has declined since 2012

Some stabilization in value since 2015, with natural gas price increases yielding increased energy value since 2016, but continued reduction in capacity value



# 2018 Market Value (energy, capacity, AS) Comparison in CAISO across all Resources, with Typical Dispatch Patterns



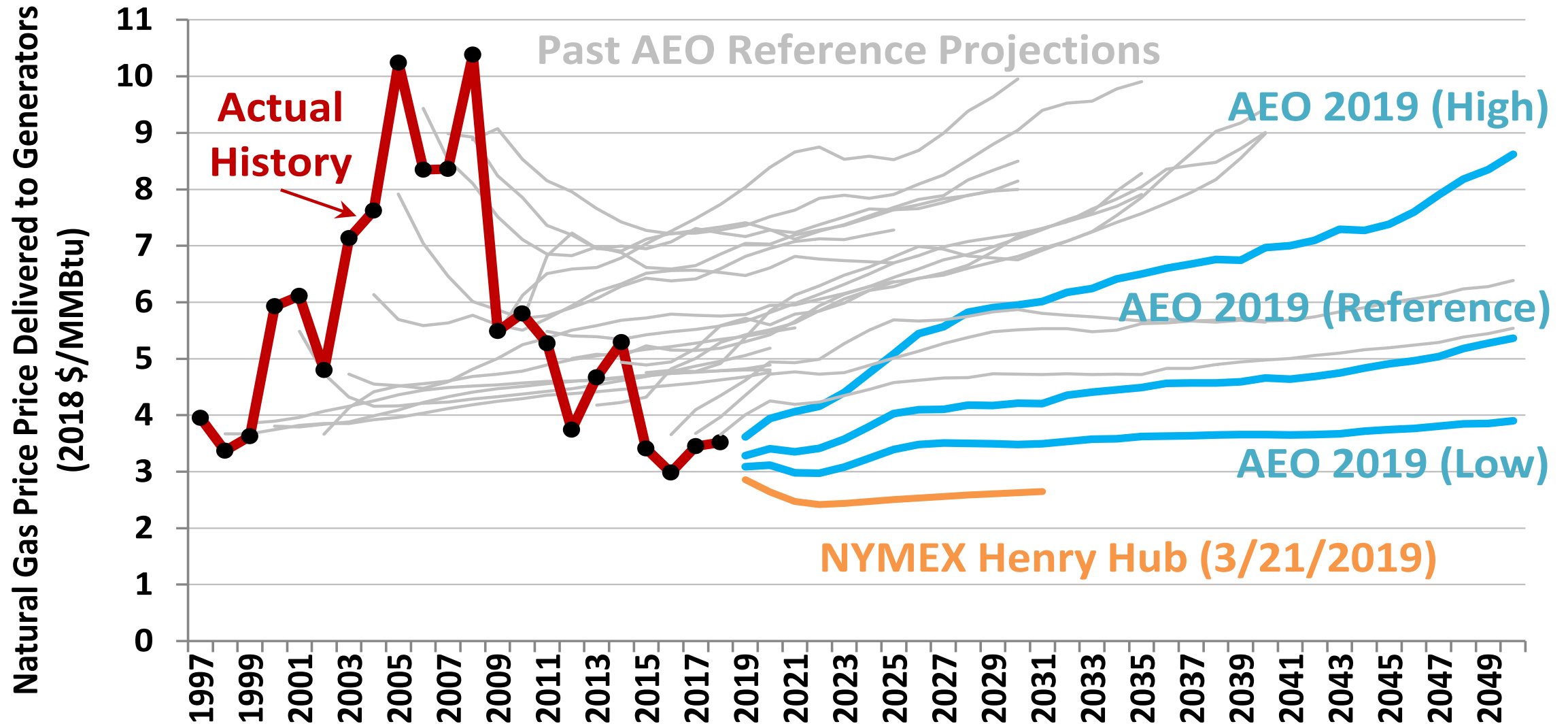
Wholesale market value in 2018 of solar and wind in CAISO (in \$/MWh terms) is lower than other generation technologies, given temporal profiles of wholesale prices and 'typical' dispatch and output patterns



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**Understanding the future economics of VRE requires not only forecasting LCOE, but also average wholesale prices and the geographic and temporal patterns of those prices**

# Forecasting Wholesale Prices Is a Tough Business: Let's Start with Our (In)Ability to Forecast Natural Gas Prices



# Assessment of Possible Wholesale Market Outcomes in 2030 Under High Variable Renewable Energy (VRE) Futures

Four Regions: Modeled with LCG UPLAN and Gen-X Models

ERCOT

SPP

CAISO

NYISO

## Low VRE in 2030

- **Low VRE** future with wind and solar shares frozen at 2016 levels

Impacts on wholesale electricity prices

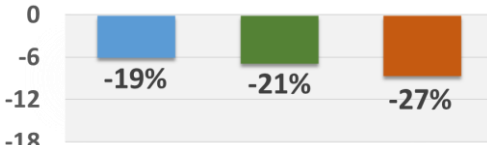
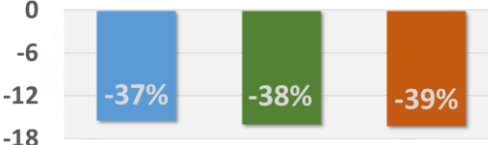
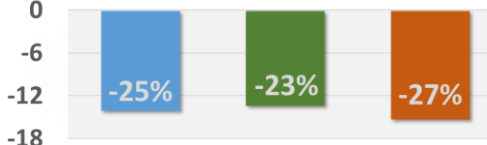
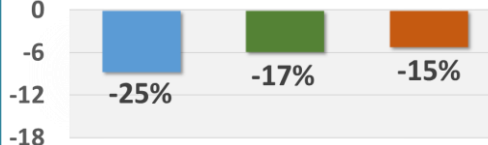
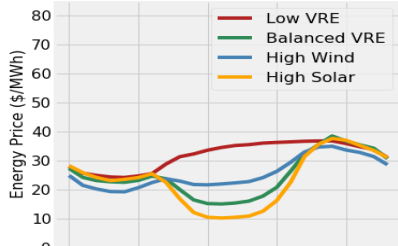
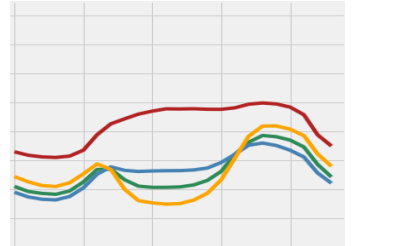
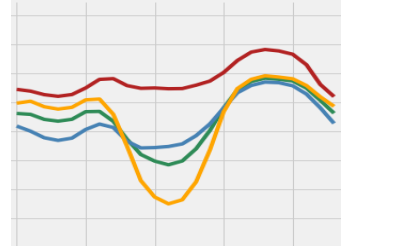
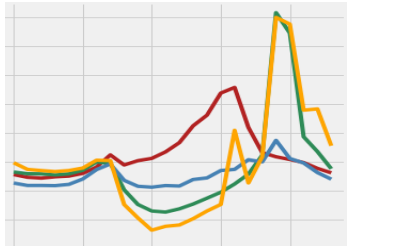
## High VRE in 2030

- **Balanced VRE** (20% Wind, 20% Solar)
- **High Wind** (30% Wind and at least 10% Solar)
- **High Solar** (30% Solar and at least 10% Wind)

Impacts on 'market value' of wind and solar

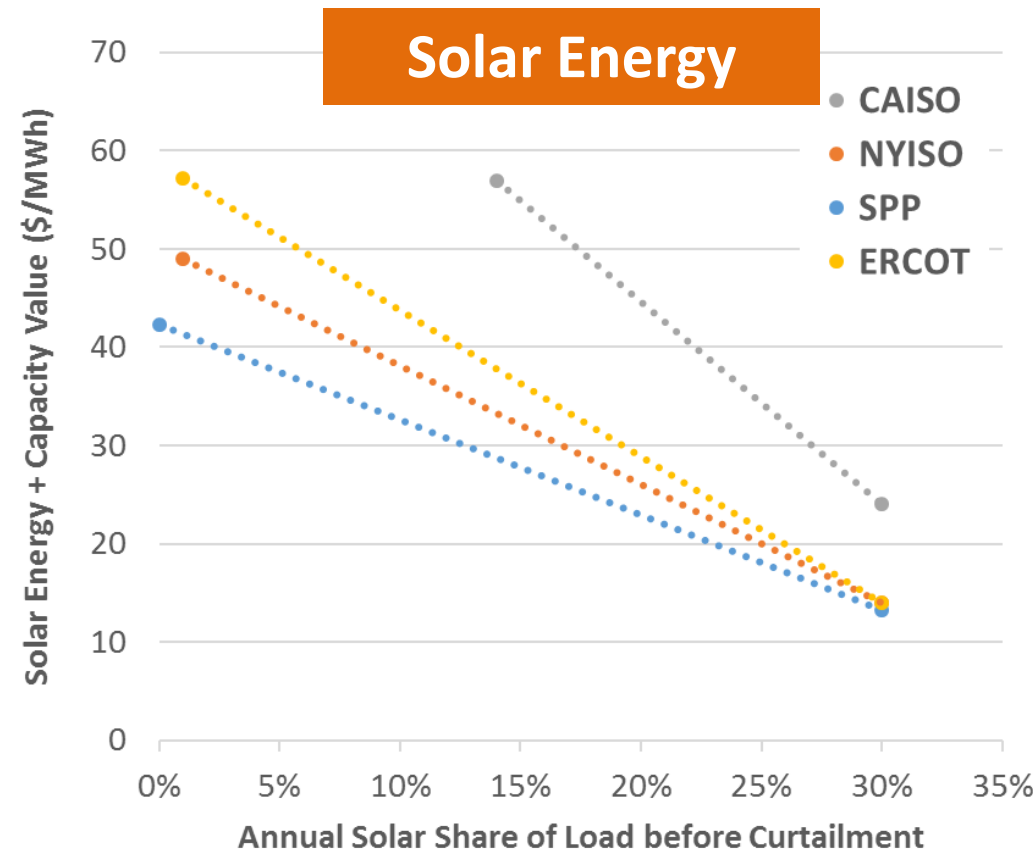
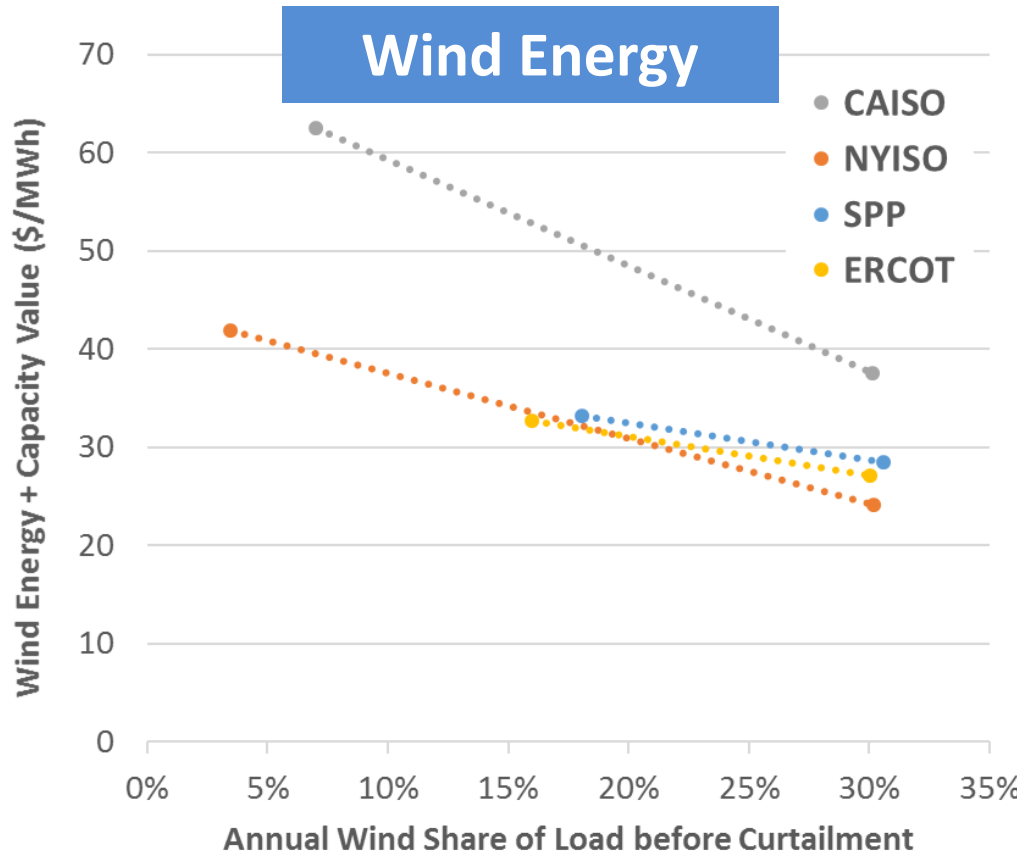
# Wholesale Price Effects of 40-50% Wind & Solar

(**Wind:** 30% wind & 10+% solar | **Balanced:** 20% wind & 20% solar | **Solar:** 30% solar & 10+% wind)

Impacts in 2030 relative to baseline with 2016 wind & solar shares	Southwest Power Pool 2016: 18% wind & 0% solar			NYISO (New York) 2016: 3% wind & 1% solar			CAISO (California) 2016: 7% wind & 14% solar			ERCOT (Texas) 2016: 16% wind & 1% solar		
	Wind	Balanced	Solar	Wind	Balanced	Solar	Wind	Balanced	Solar	Wind	Balanced	Solar
Lower Average Prices [\$/MWh]												
More Hours <\$5/MWh In baseline: 0% of all hours	6%	8%	13%	2%	7%	11%	6%	7%	11%	6%	11%	19%
Changes in Diurnal Price Profile red baseline shows 2016 wind & solar shares												
More Price Variability	1.8x	2.1x	2.5x	2.1x	2.3x	2.5x	3.0x	2.9x	3.4x	1x	4.7x	6.6x
Higher AS Prices Regulation Down	5x	6x	9x	2x	2x	3x	3x	3x	3x	2x	3x	4x
Change in Timing of Top Net-Load Hours	Shift from 4pm to 7pm			Shift from 3pm to 5-7pm			No further shift 7pm			Shift from 3pm to 6-8pm		

# VRE Impacts on Wholesale Prices Lead to a Decline in Market Value (energy + capacity) with Increasing Penetration

Wind value in 2030 declines with penetration; solar more valuable than wind at low penetration, but suffers more from value decline



Wind value declines by **14-42%** in **High Wind** scenarios

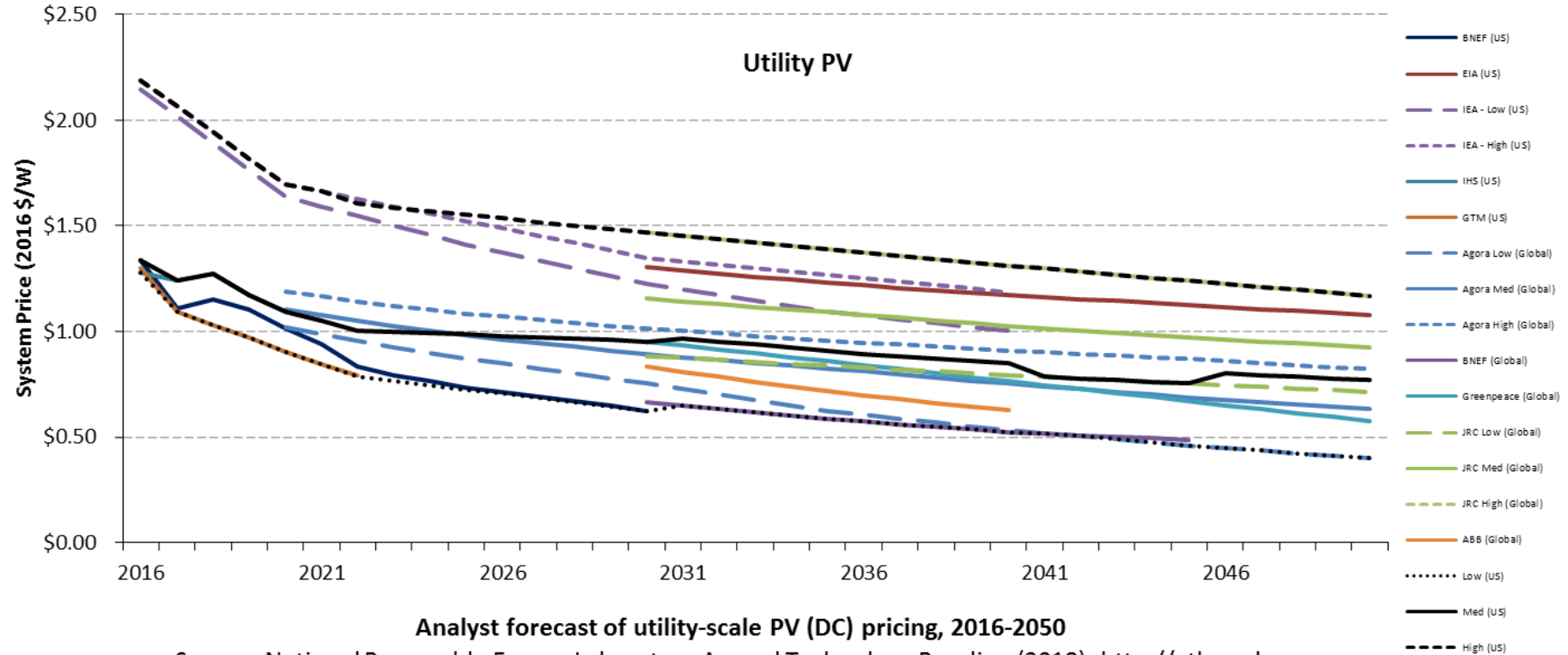
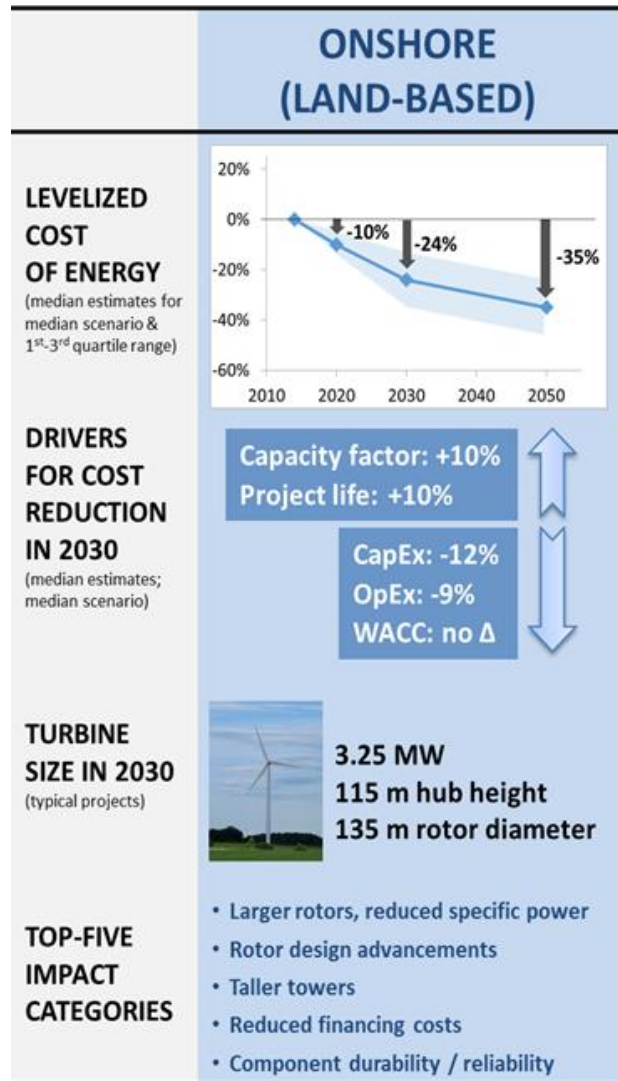
Solar value declines by **58-76%** in **High Solar** scenarios

*Carbon prices boost value in CAISO*

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# Maintaining Economic Competitiveness as Wind and Solar Penetrations Increase: *What Are the Options?*

# One Option for Maintaining Economic Competitiveness: Continuing to Press Downward on Wind and Solar Costs





# Other Options for Maintaining Economic Competitiveness: Boosting the Market Value of VRE as Penetrations Increase

## System-friendly VRE

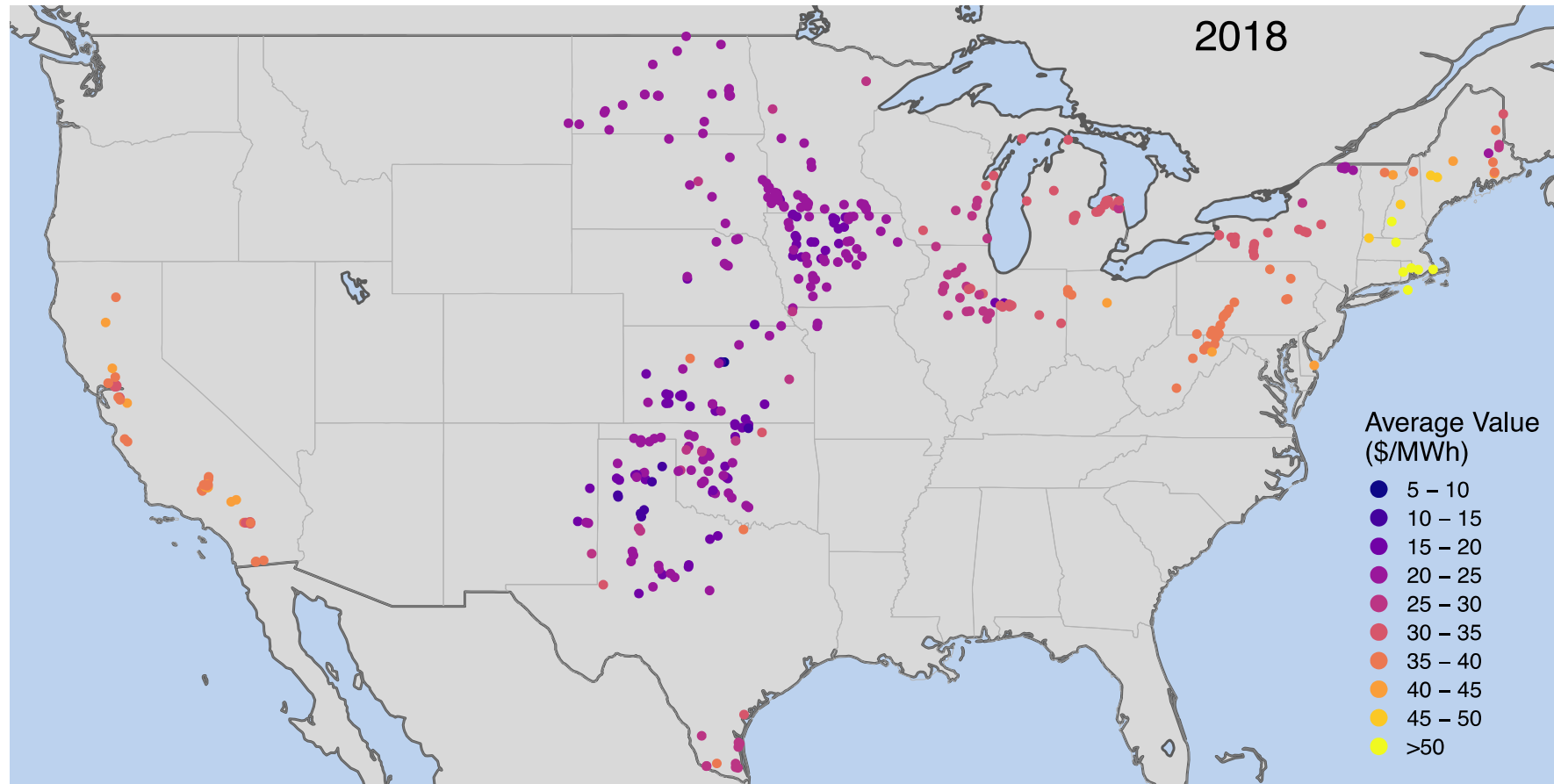
- Optimized siting / diversity
- Technology choice and design
- Ancillary services provision
- Hybridized with storage

## VRE-friendly System

- *Wholesale market design*
- *Generation flexibility*
- *Demand flexibility*
- *Electricity storage*
- **Electricity transmission**

# Other Options for Maintaining Economic Competitiveness: Find the Right Location... to Enhance Market Value

## Example: Wholesale Market Value of Wind in 2018 (energy & capacity)

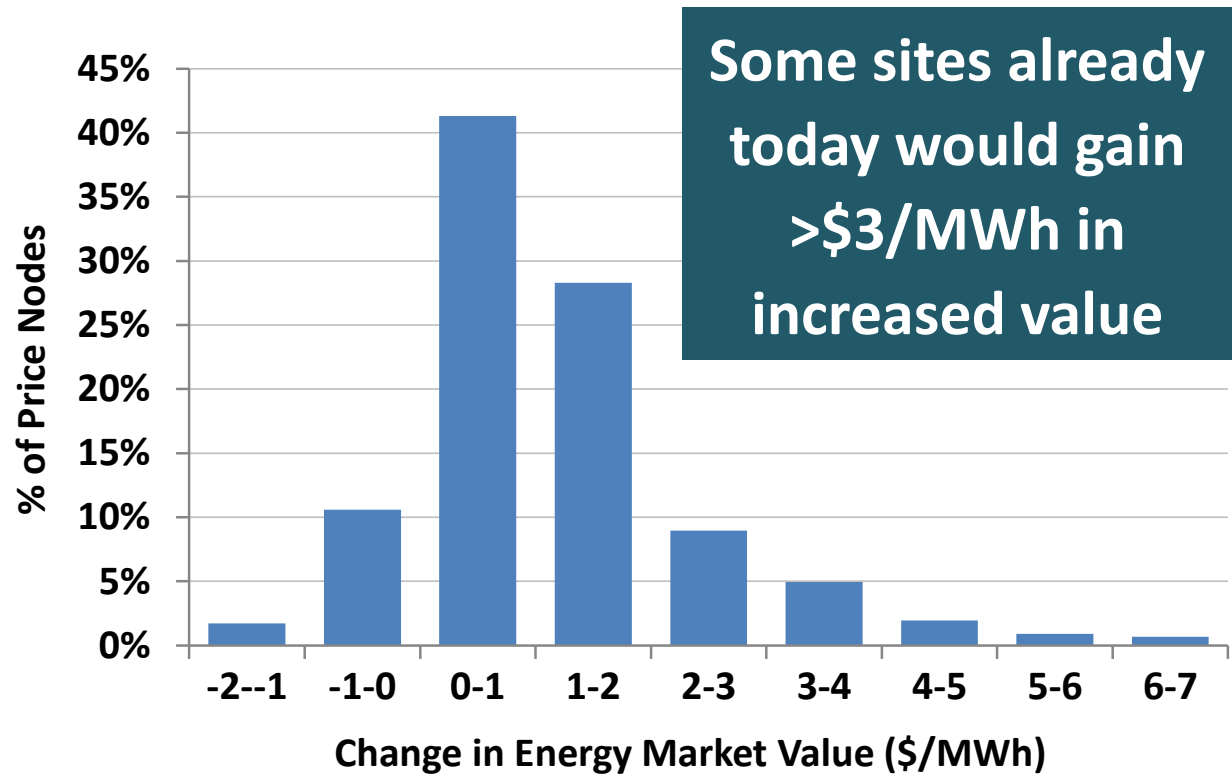


**Practical Example:** the region with the greatest expansion in wind in its queue in 2018 – PJM, a relatively high-value region; of course, must also consider relative cost of wind in each region and so compare value to cost in making decisions

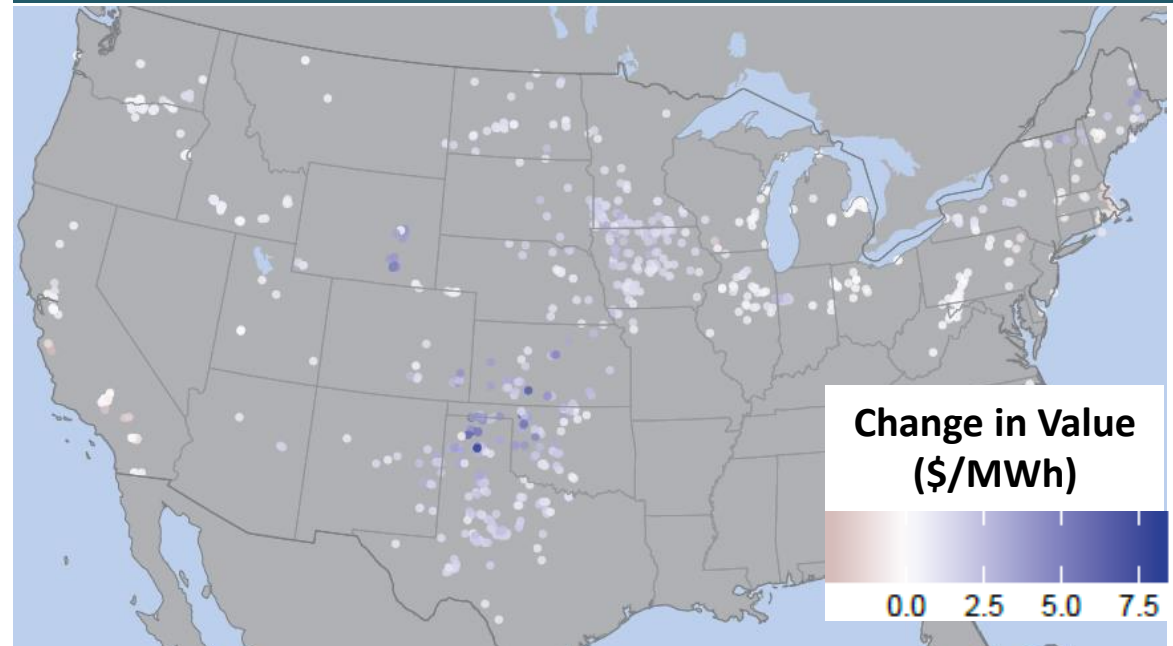
**Other options:**  
resource diversity

# Other Options for Maintaining Economic Competitiveness:

## Tech Choice: e.g., Large Rotors /Tall Towers Increase Wind Value



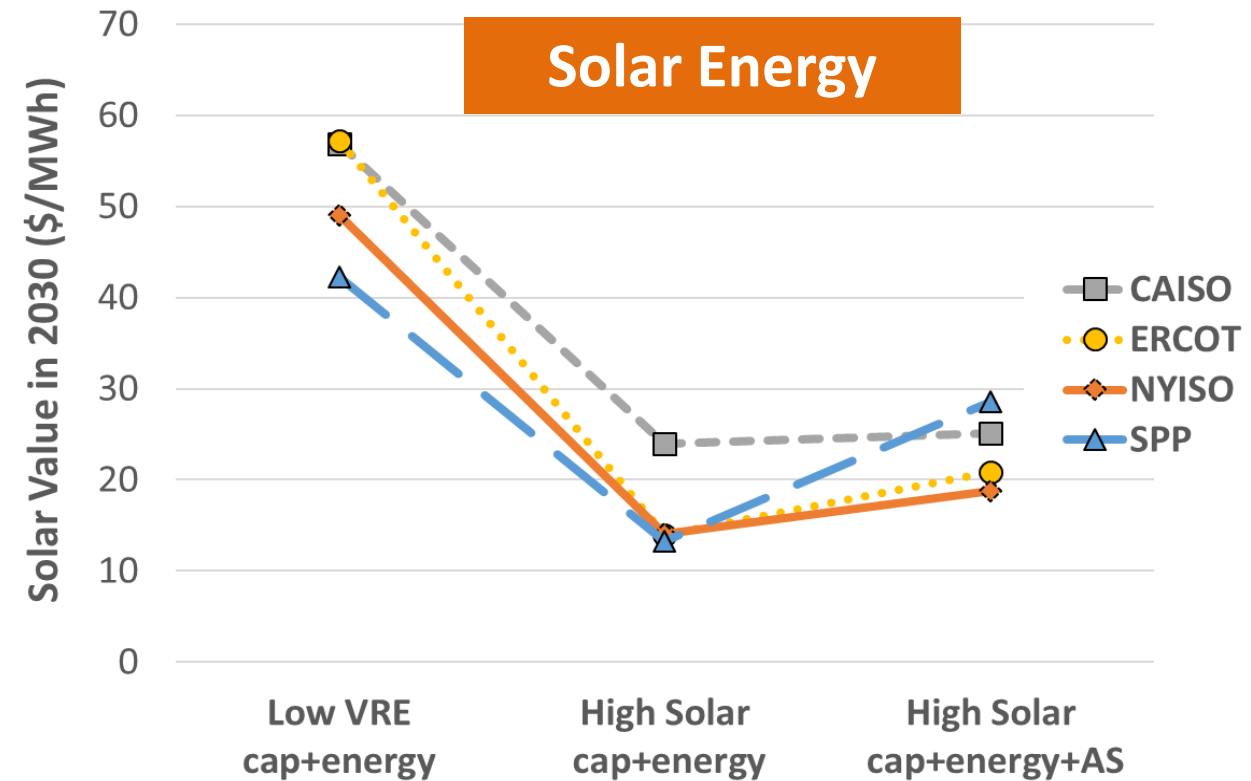
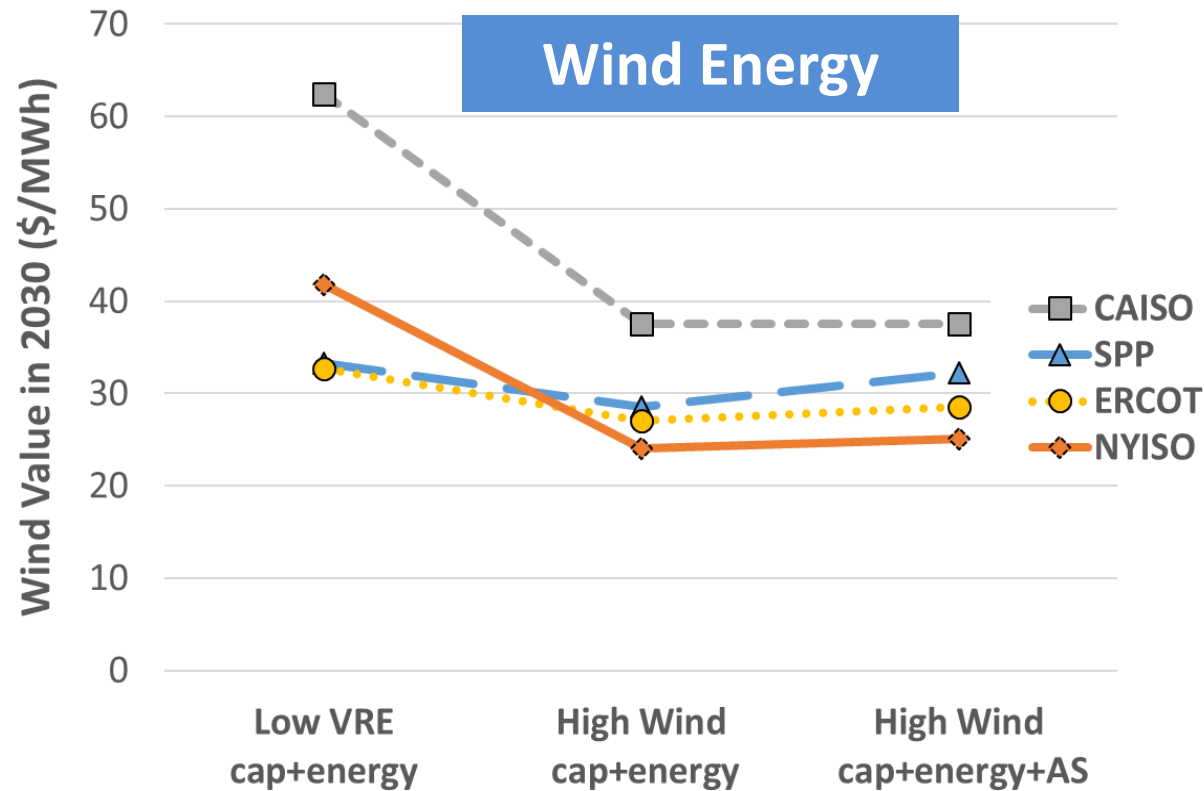
Map shows change in 2017 wholesale market value at project sites if existing turbines were replaced with turbines with higher hub heights (115 m) and lower specific power (150 W/m<sup>2</sup>)



Literature finds that low-specific power and high-hub height turbines can boost market value by 8-30% (\$3-15/MWh) at higher wind penetrations

PV options: oversizing DC array relative to inverter, SW orientation

# Other Options for Maintaining Economic Competitiveness: Wind and Solar Providing Ancillary Services (AS)

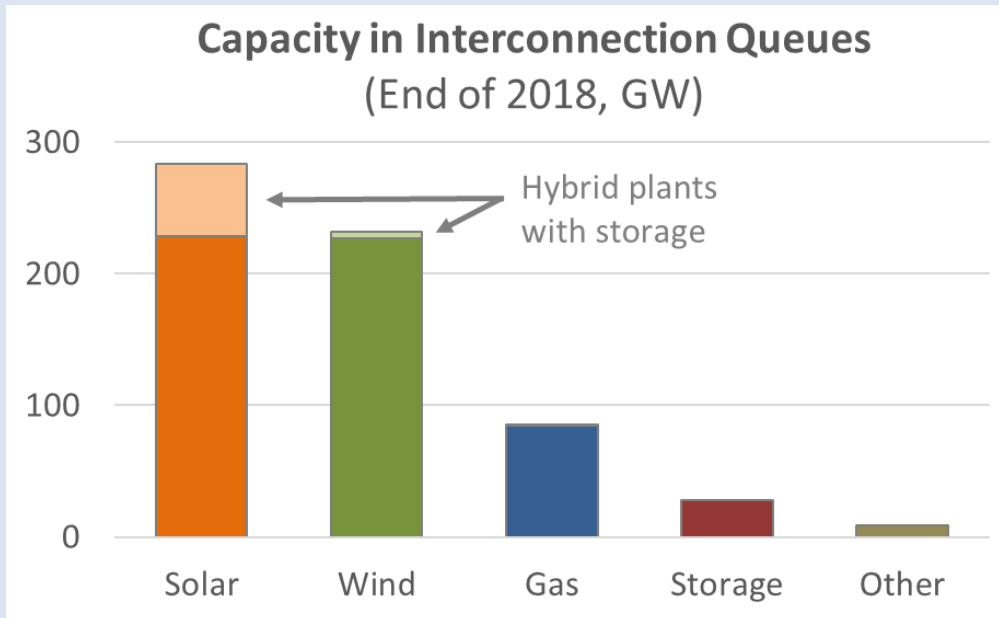


**Wind and solar can boost value by delivering AS, but markets are thin and value increase is likely relatively modest at least at medium penetration levels**  
*(could be higher at higher penetrations, if inclusive of upward reserves, if de-commit thermal units; but likely lower with storage and VRE providing reserves)*

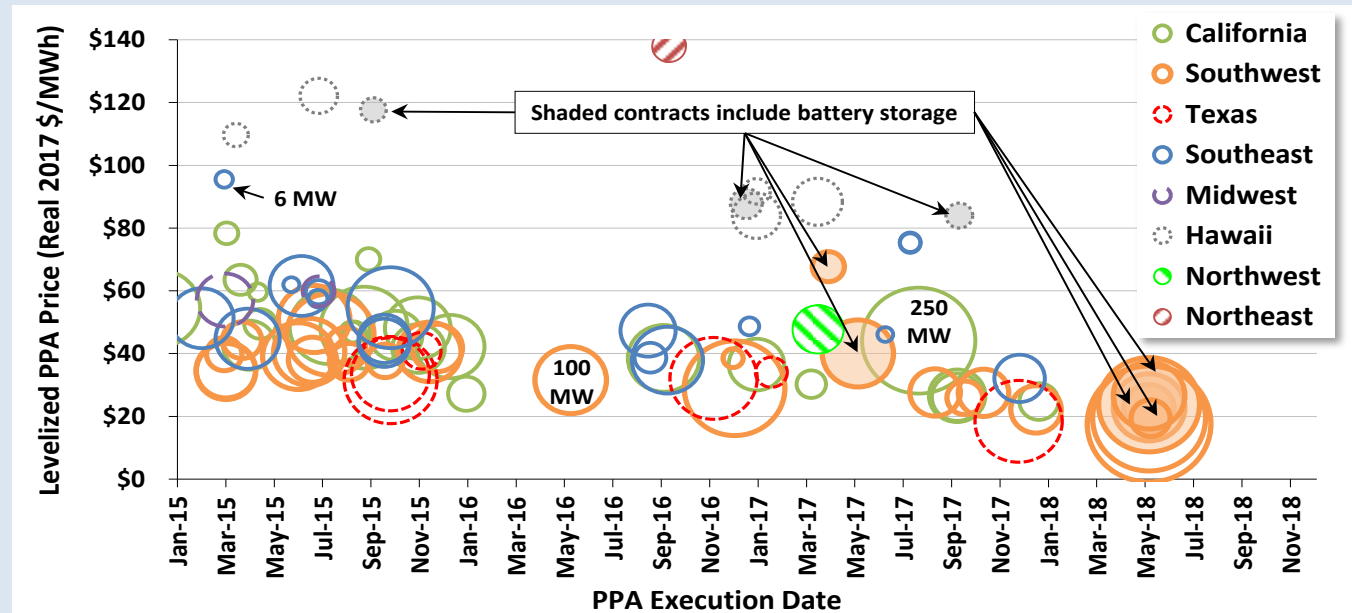
# Other Options for Maintaining Economic Competitiveness: Hybrid Plants w/ Storage (or Simply Stand-Alone Storage)

With declines in storage costs and ITC, Solar + Storage set to become more common

## Interconnection Queues



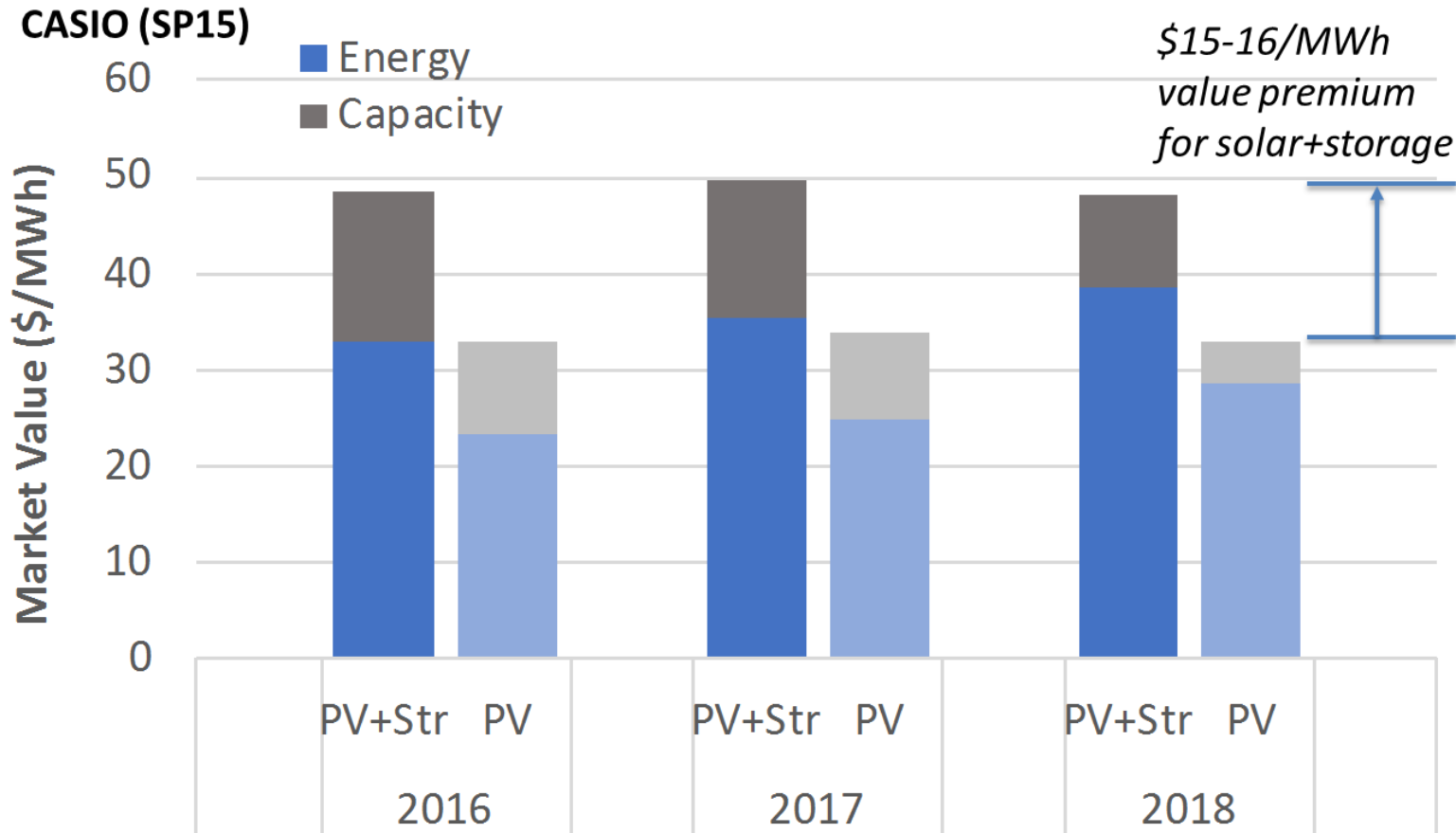
## Price of Solar + Storage



# Other Options for Maintaining Economic Competitiveness:

## Hybrid Plants w/ Storage: Energy + Capacity Value

~\$15/MWh recent (energy + capacity) value premium in CAISO for Solar + Storage (4 hour duration storage, sized at 25% of PV capacity), compared to ~\$5-10/MWh additional costs

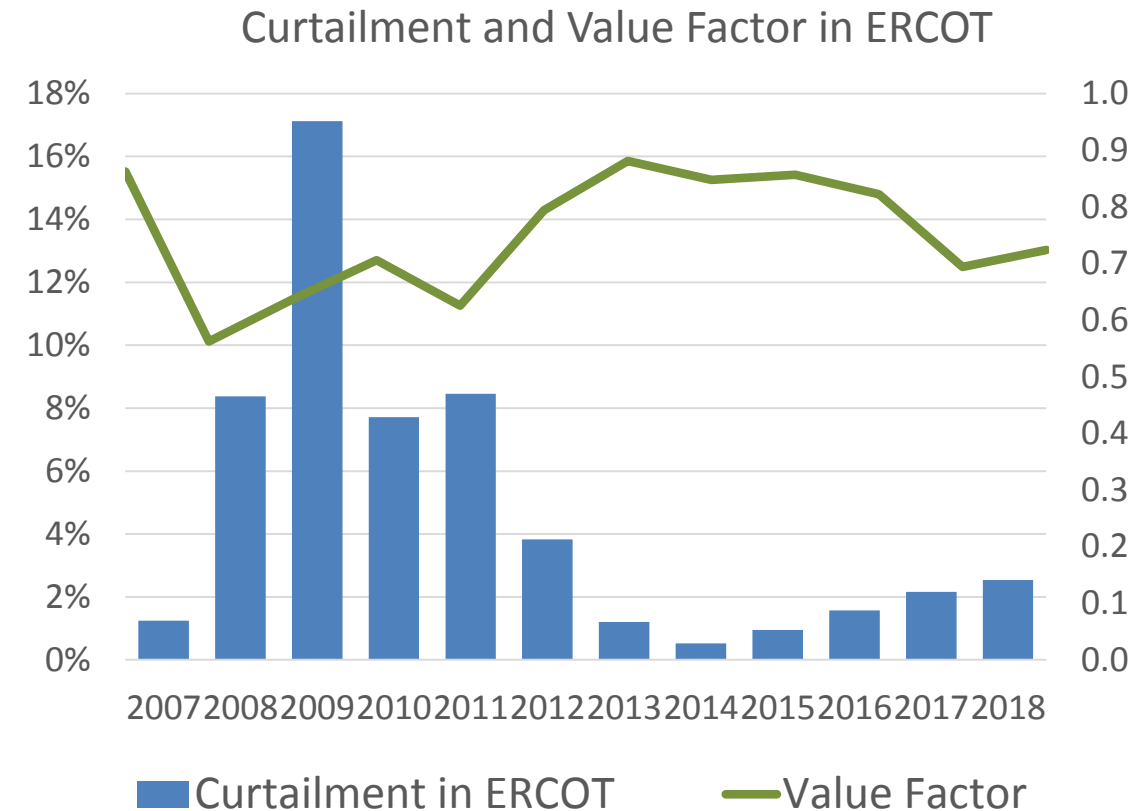
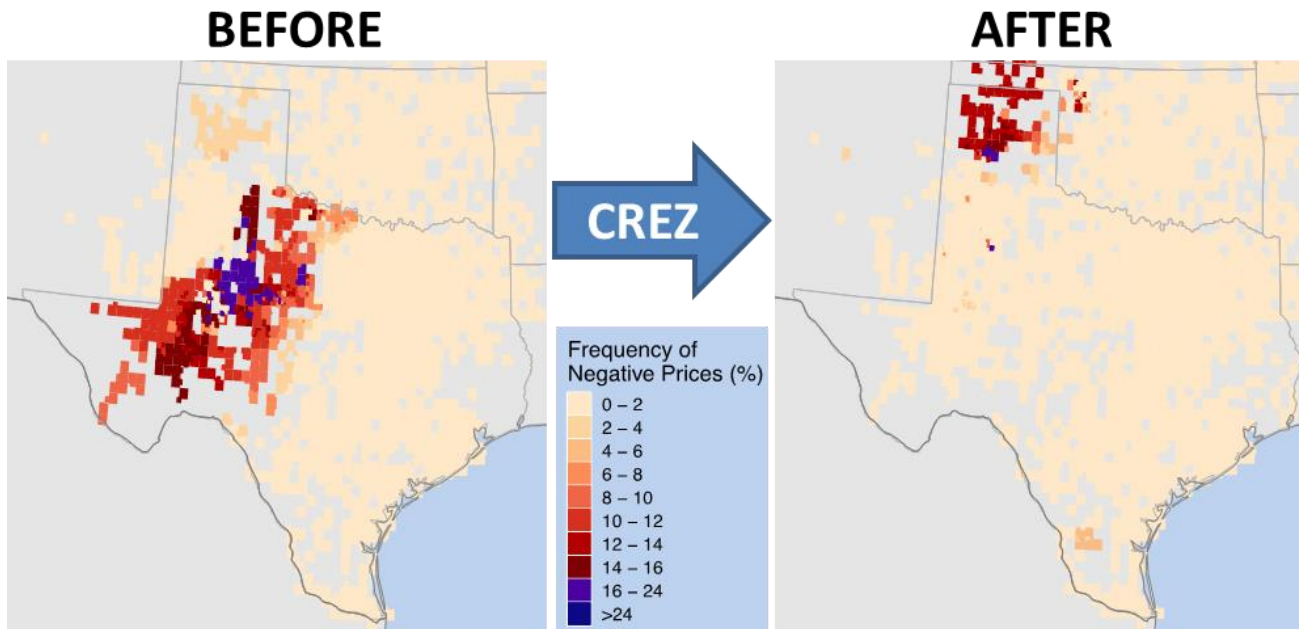


- 4 hour duration battery
- Battery sized to 25% of PV nameplate capacity
- 81% roundtrip efficiency
- Storage charges from solar only (not from grid)
- Storage dispatch otherwise maximizes hourly average real-time market revenue, with perfect foresight
- Solar+storage gets solar capacity credit plus 100% of storage nameplate
- Assumes can fully deliver solar and storage combined (125% of solar)



# Other Options for Maintaining Economic Competitiveness: Transmission to Reduce Congestion and Move VRE to Load

Transmission quickly reduced the frequency of negative prices in West Texas, decreasing wind curtailment, increasing wind value, and enabling an additional ~12 GW of wind

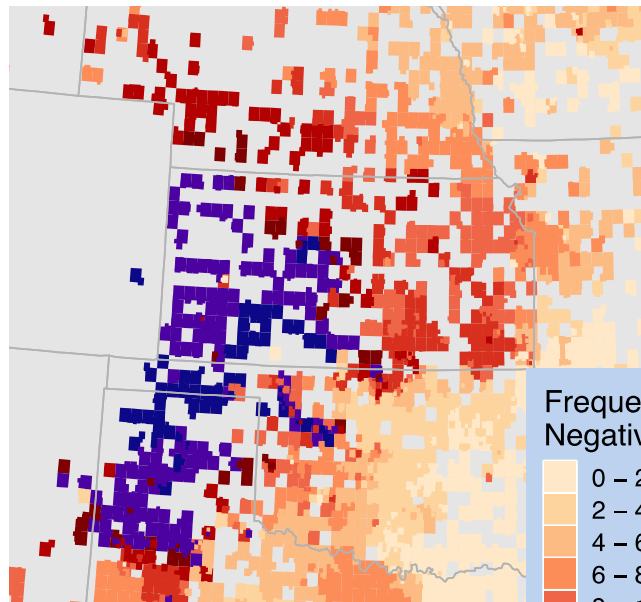




# Other Options for Maintaining Economic Competitiveness: Transmission to Reduce Congestion and Move VRE to Load

Transmission also reduced the frequency of negative prices and curtailment in the Southwest Power Pool (SPP), increasing wind value, just from 2017 to 2018

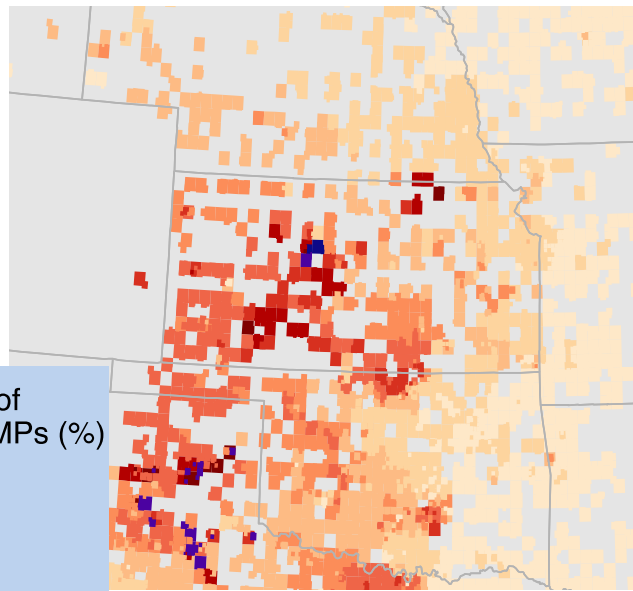
2017



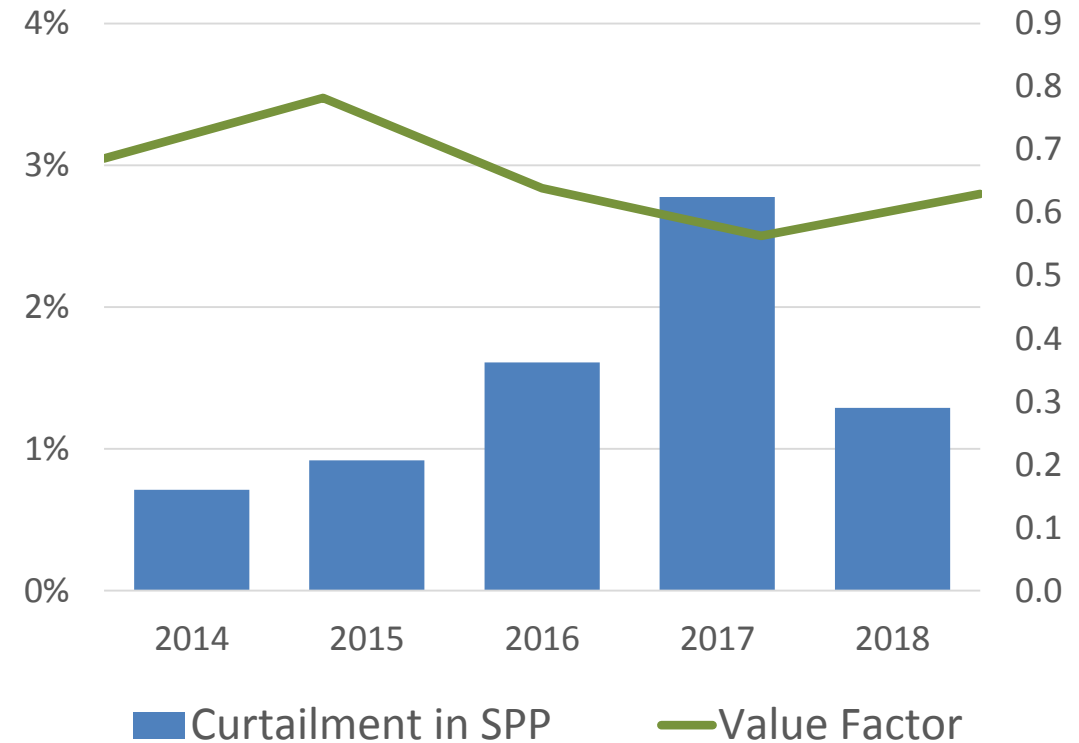
Frequency of Negative LMPs (%)

0 - 2  
2 - 4  
4 - 6  
6 - 8  
8 - 10  
10 - 12  
12 - 14  
14 - 16  
16 - 24  
>24

2018

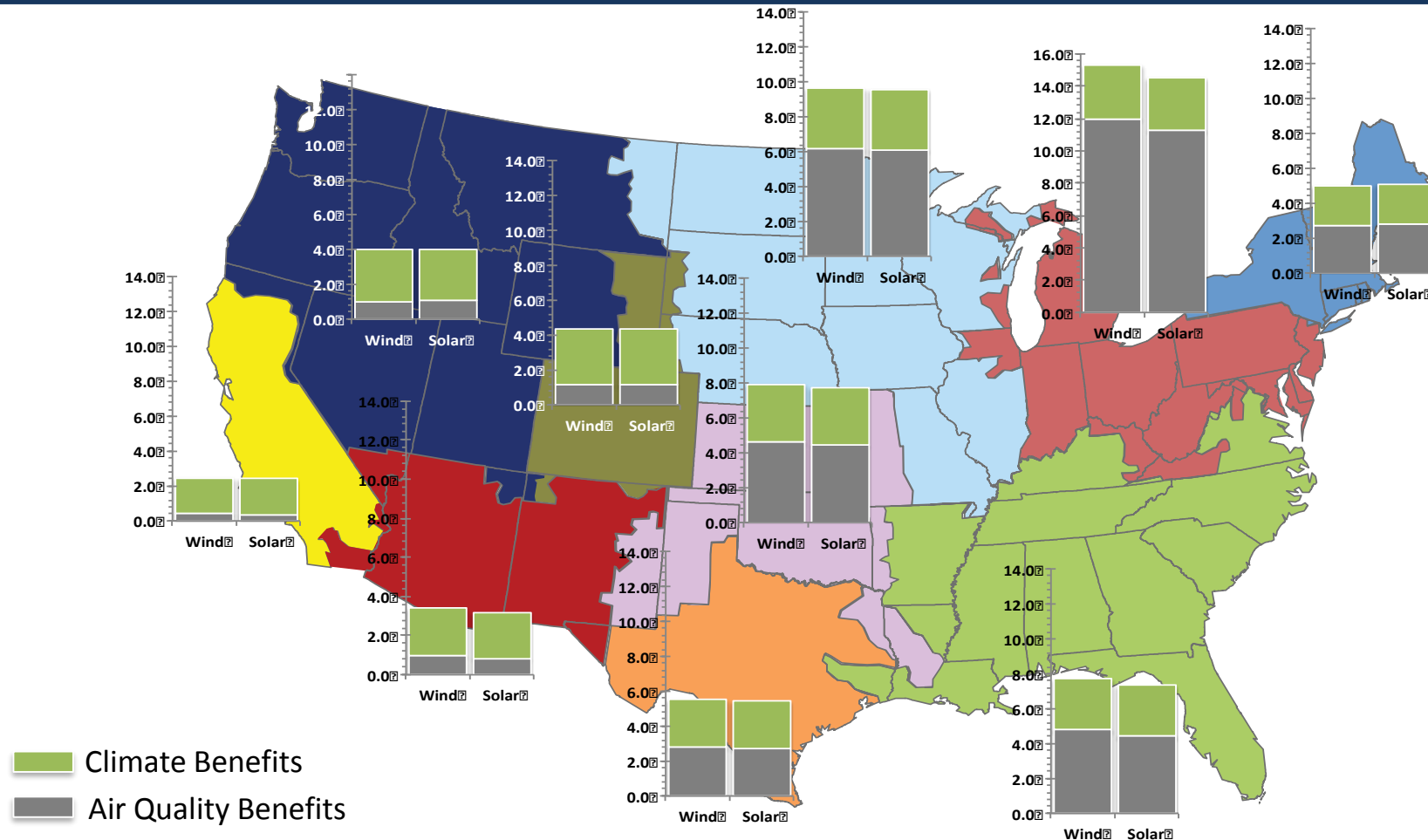


Curtailment and Value Factor in SPP



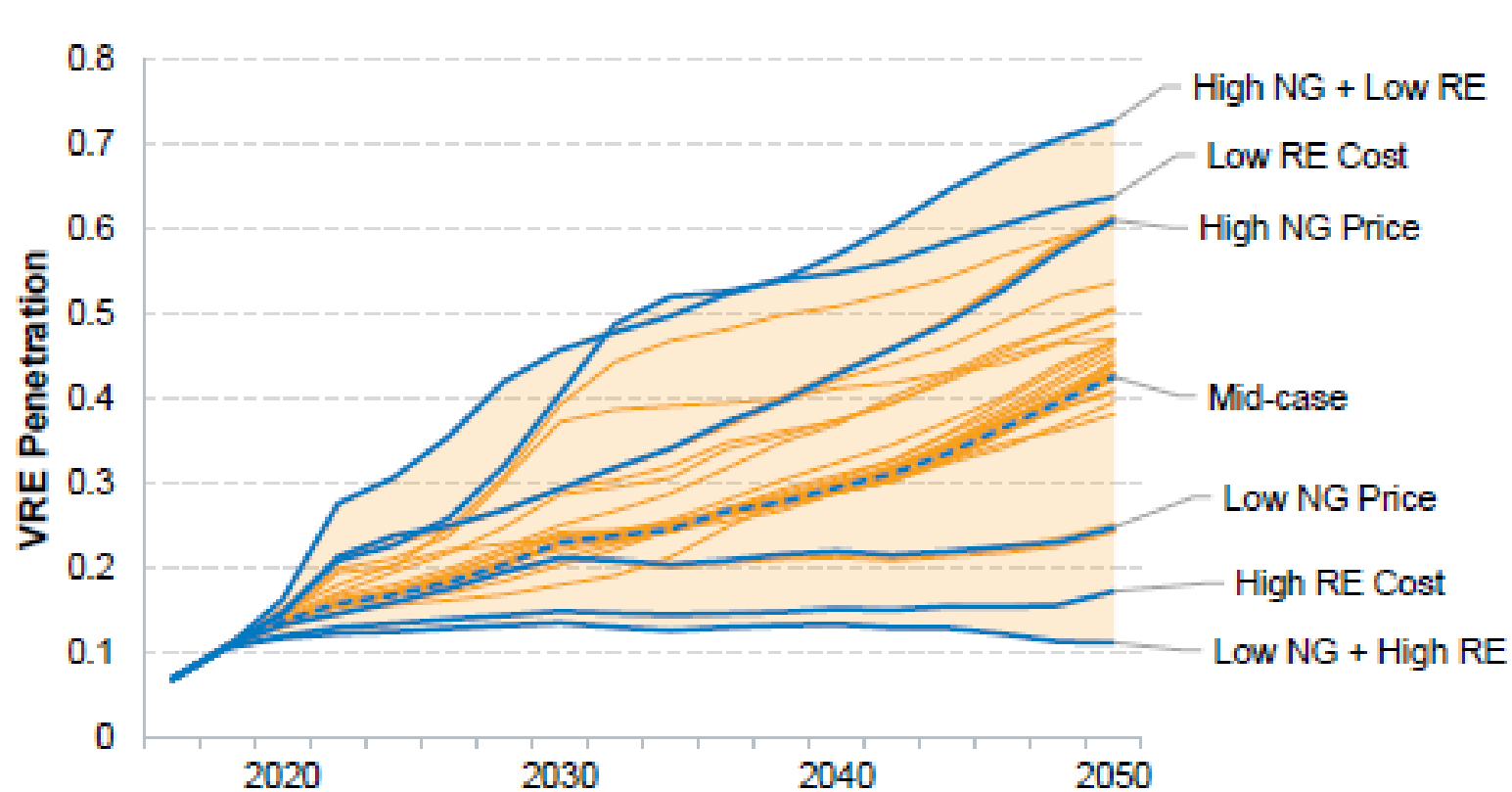
# Other Options for Maintaining Economic Competitiveness: Monetization of External Health and Environmental Costs

## Marginal Avoided Air Pollution and Climate Damages from Wind (¢/kWh)

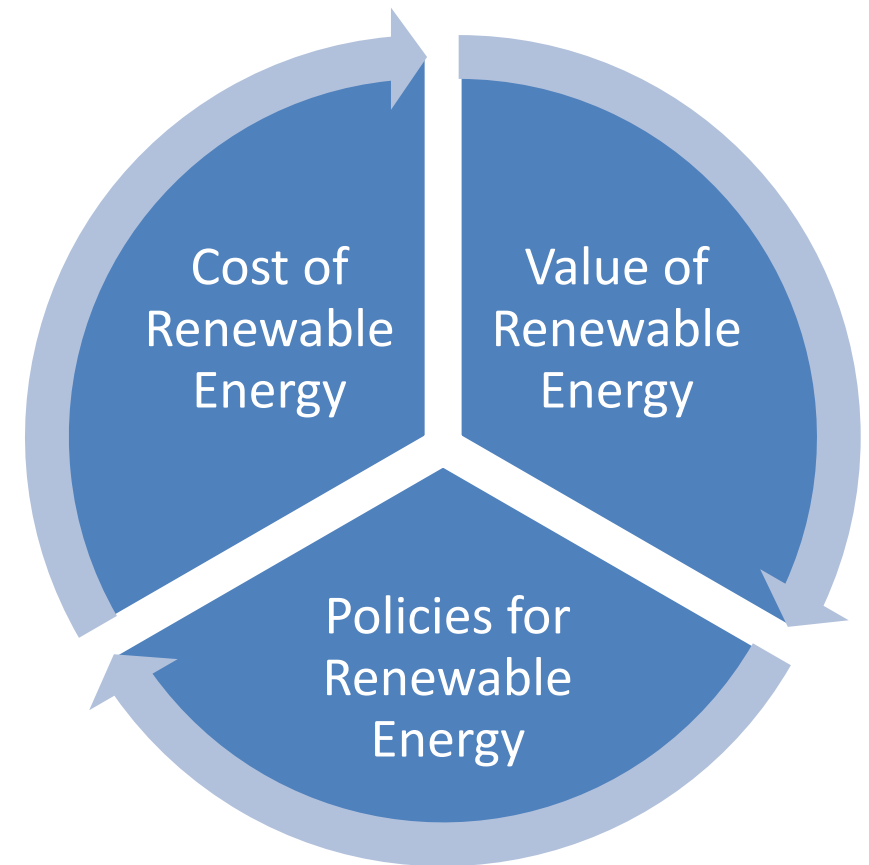


# There Are No Actual Data About Future VRE Deployment

The future is uncertain, but VRE growth will be influenced by the impact of VRE on wholesale prices, and measures taken to reduce price suppression and value deflation



Source: NREL (2018)



# Questions?

## ◆ Contact the Presenter

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Download all of our work at:

<http://emp.lbl.gov/reports/re>

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