Impact of Wind, Solar, and Other Factors on Wholesale Power Prices

An Historical Analysis—2008 through 2017

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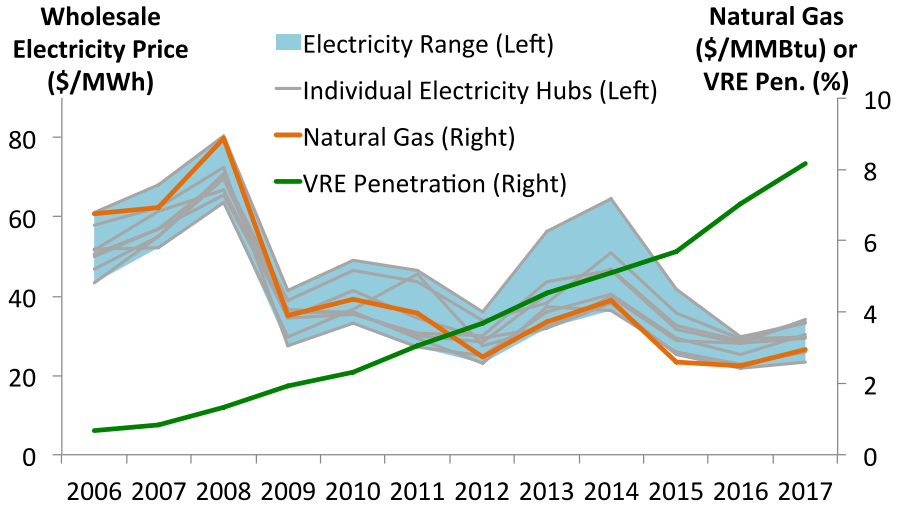
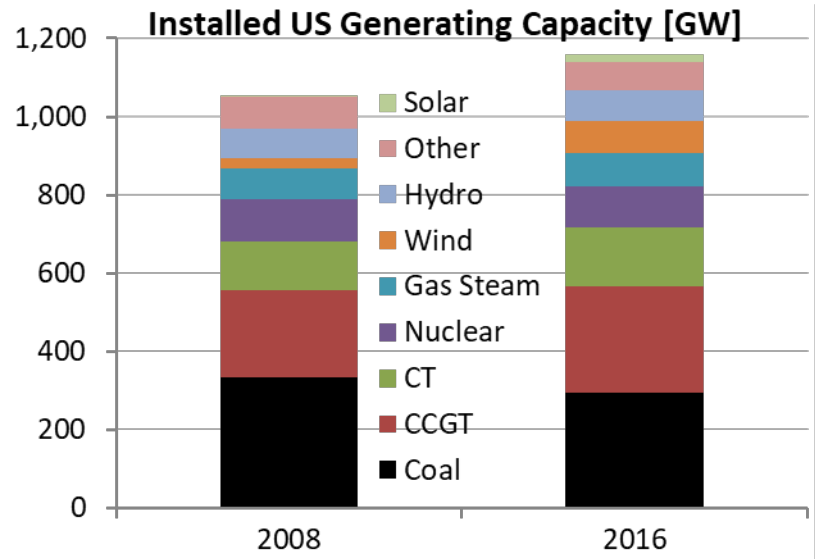
Report Briefing

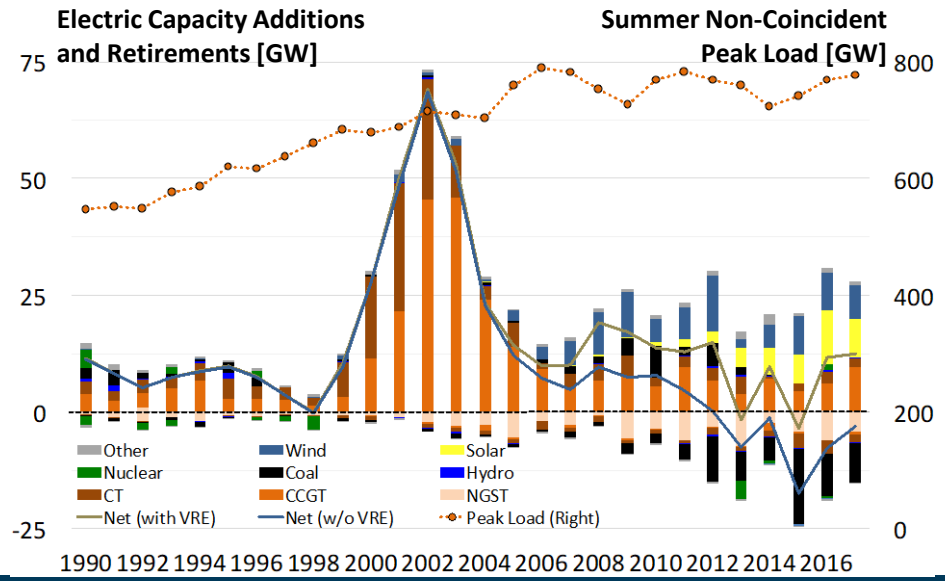
November 2019

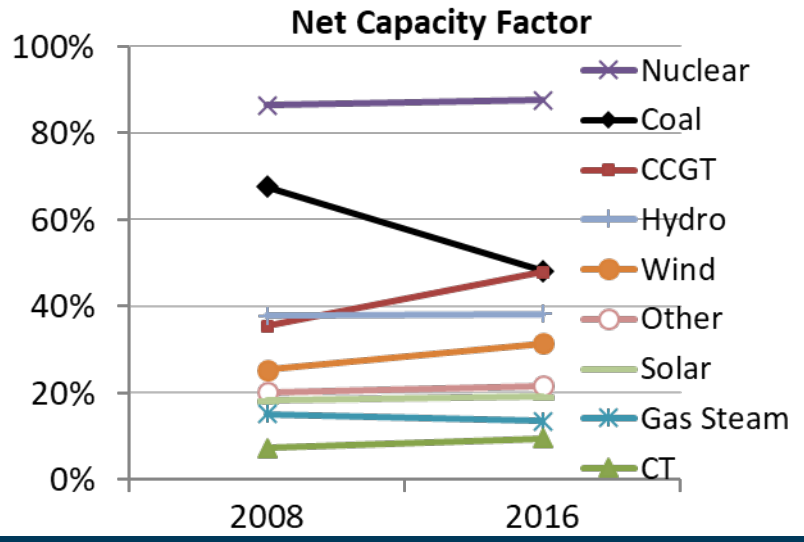
The work described here was funded by the Office of Electricity and the Office of Energy Efficiency and Renewable Energy of the U.S. Department of Energy

Wholesale Power Pricing and the Composition and Operation of the Bulk Power System have Changed in Recent Years









Concerns raised that VRE is a primary cause of these trends, in part motivating wholesale market design changes and policy support for at-risk resources

Pertinent Baseline Questions

(1) To what degree **has VRE contributed to these trends**?

(2) **How might the impacts grow** in the future?

(3) What **effects** might these changes have **on market design, and various supply- & demand-side assets**, including VRE?

Analysis Builds from Past Work, and May Inform Variety of Contemporary Discussions in the Electric Sector

PLANNING AND INVESTMENT DECISIONS

- Trends in annual average wholesale prices impact inflexible baseload generation assets
- Temporal variations in wholesale prices impact value of flexible supply, demand, and storage assets
- Geographic variations help inform power plant planning and siting by signaling high- and low- value locations
- Geographic variations in prices help illustrate the value of transmission expansion in order to reduce congestion

POLICY AND MARKET DESIGN DECISIONS

- To the degree wholesale price impacts are affected by policy, might inform policy reform and ISO market design
- May inform policy and market discussions related to 'premature' retirement of thermal plants
- May suggest changes to market design, especially if reflective of an inability to access extant flexibility
- Altered pricing patterns impact market value of VRE, affecting competitiveness and informing VRE policy

Average Market-Wide Price Impacts: Summary of Existing Literature

Study	Applicable Region	Period	Average VRE Penetration (% of demand)	Decrease in Average Wholesale Power Energy Price from Average VRE
Woo et al. (2011)	ERCOT	2007-2010	Wind: 5.1%	Wind: $2.7/MWh (ERCOT North) Wind: $6.8/MWh (ERCOT West)
Woo et al. (2013)	Pacific NW (Mid-C)	2006-2012	N/A	Wind: $3.9/MWh
Woo et al. (2014)	CAISO (SP15)	2010-2012	Wind: 3.4% Solar: 0.6%	Wind: $8.9/MWh Solar: $1.2/MWh
Woo et al. (2016)	CAISO (SP15)	2012-2015	Wind: 4.3% Solar: 2.6%	Wind: $7.7/MWh Solar: $2.1/MWh
Gil and Lin (2013)	PJM	2010	Wind: 1.3%	Wind: $5.3/MWh
Wiser et al. (2016)[a]	Various regions	2013	RPS energy: 0%-16% depending on the region	RPS energy: $0 to $4.6/MWh depending on the region
Craig et al. (2018)	CAISO	2013-2015	Distributed solar: ~5%	Distributed solar: < $1/MWh
Tsai and Eryilmaz (2018)	ERCOT	2014-2016	Wind: 11%	Wind: $8 to $12/MWh
Quint and Dahlke (2019)	MISO	2014-2016	Wind: 6%	Wind: $6.7/MWh
Jenkins (2017)[b]	PJM	2008-2016	N/A	Wind: $1 to $2.5/MWh
Wiser et al. (2017)[b]	CAISO	2008-2016	Solar: ↑ 9.5% 2008-2016 Wind: ↑ 3.3% 2008-2016	Solar: $1.9/MWh Wind: $0.4/MWh
Wiser et al. (2017)[b]	ERCOT	2008-2016	Wind: ↑ 10.8% 2008-2016 Solar: ↑ 0.3% 2008-2016	Wind: $0.7/MWh Solar: $0/MWh
Haratyk (2017)[b]	Midwest	2008-2015	Wind: ↑ 9% 2008-2015	Wind: $4.6/MWh
Haratyk (2017)[b]	Mid-Atlantic	2008-2015	N/A	Wind: $0/MWh
Bushnell and Novan (2018)[b]	CAISO	2012-2016	Utility-scale solar: ↑ 8.3% 2012-2016	Solar: $5.2/MWh

See also: Makovich and Richards (2017), Hibbard, Tierney, and Franklin (2017), Hogan and Pope (2017)

Low marginal-cost generation (and negative bidding) push the supply curve out, reducing wholesale prices at least in the near term; a number of studies have used historical prices to estimate this VRE "merit order" effect

Overview

Impacts of VRE on average market-wide wholesale prices

- Validation of simple supply curve model
- Contributors to price decline between 2008-2017 and impacts since 2012
- Outlook to 2022 building on EIA and other projections

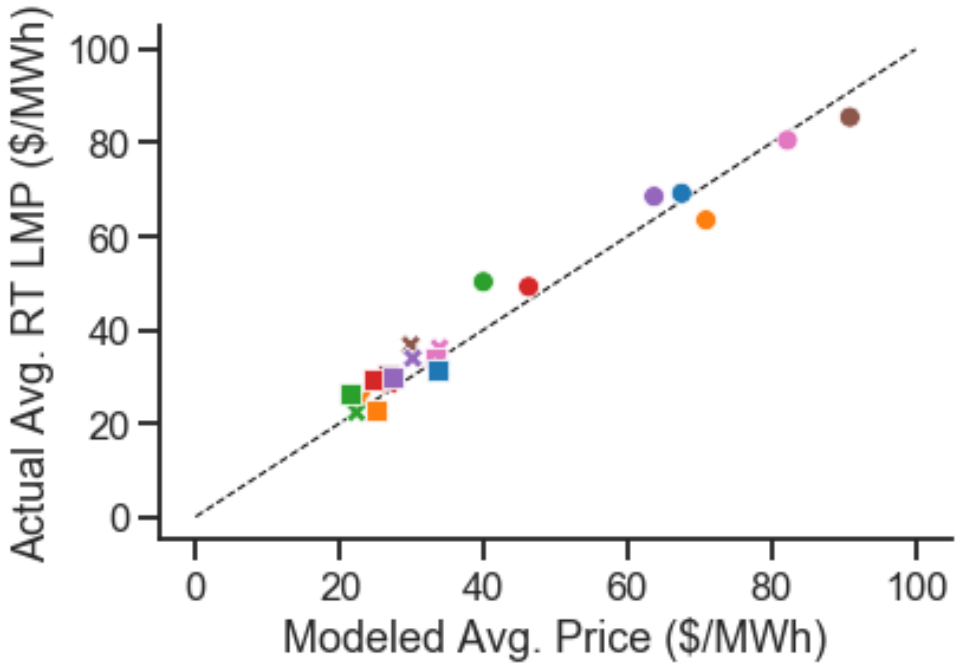
Impacts of VRE on geographic and temporal pricing variability

- Variation in prices across the U.S.
- Impact of wind on prices
- Impact of solar on prices in California
- Reduction in frequency of negative prices with transmission expansion

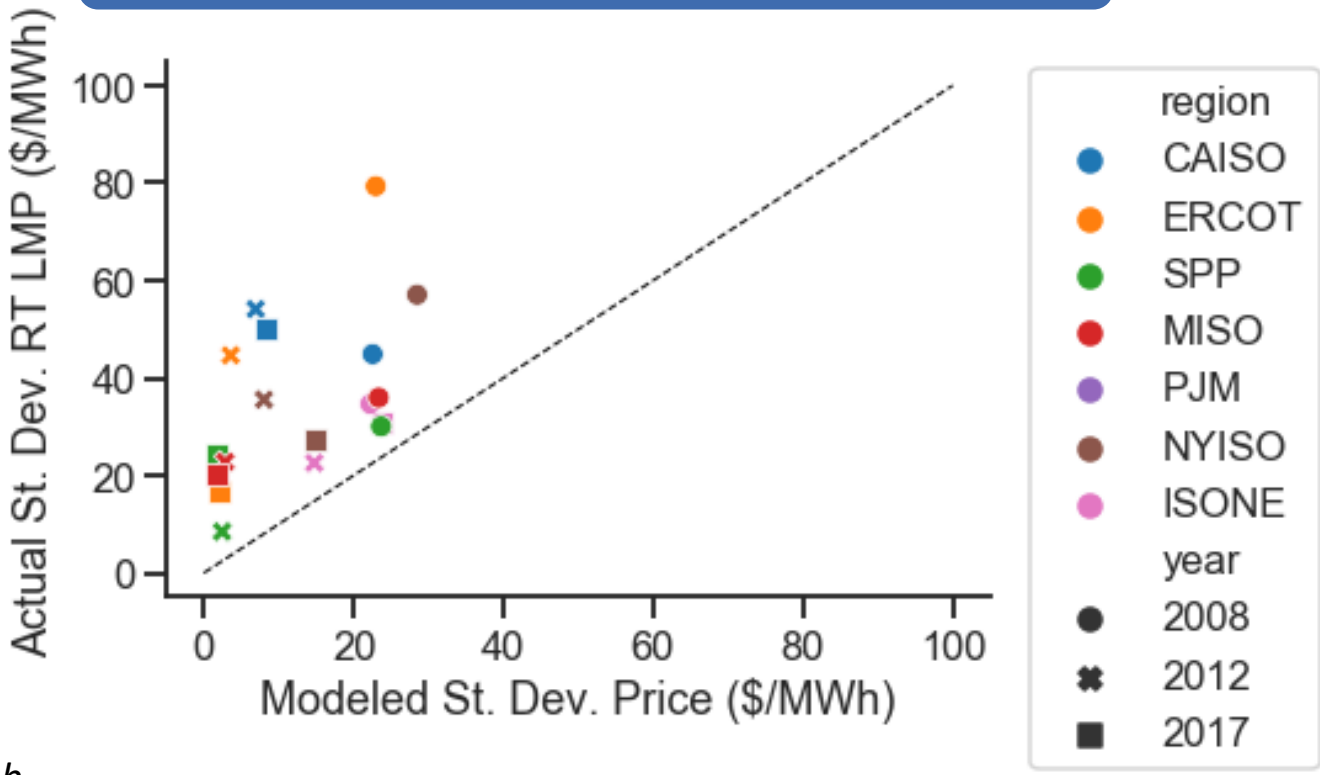
Notes: We focus only on energy and congestion pricing and mostly on the real-time market, not capacity and AS or the day-ahead market; we do not address cost of VRE, or implications for reliability

Validation of Simple Supply Curve Model

Annual Average Wholesale Price



Variability in Hourly Prices

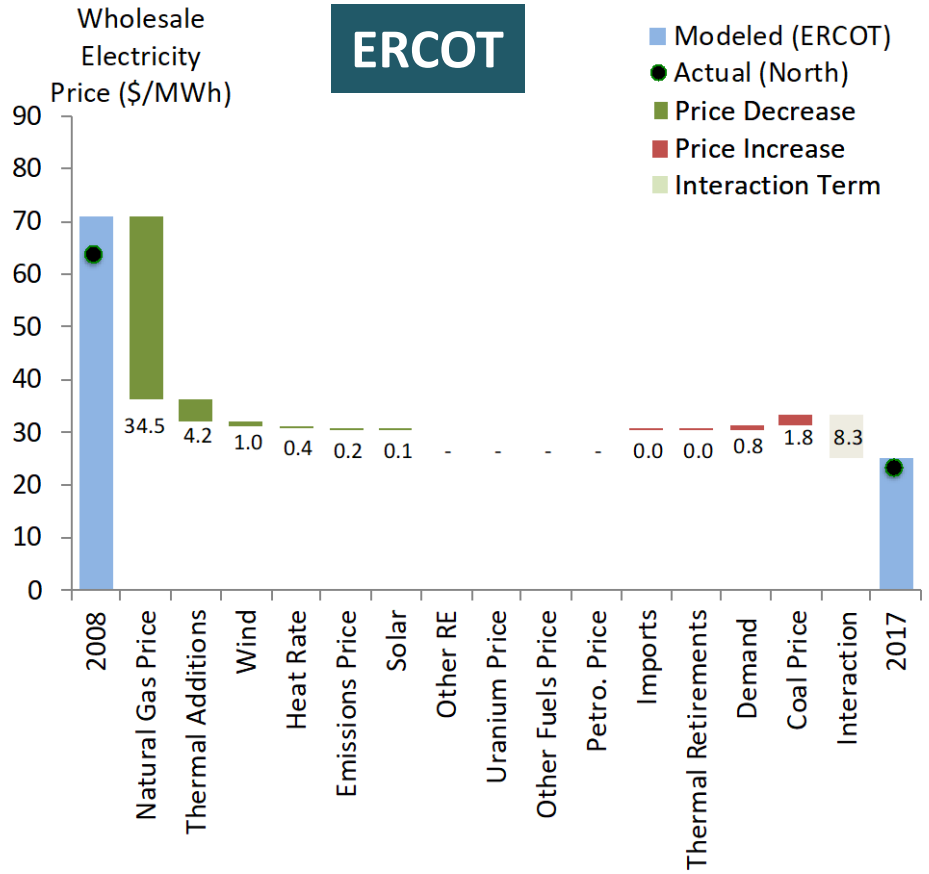


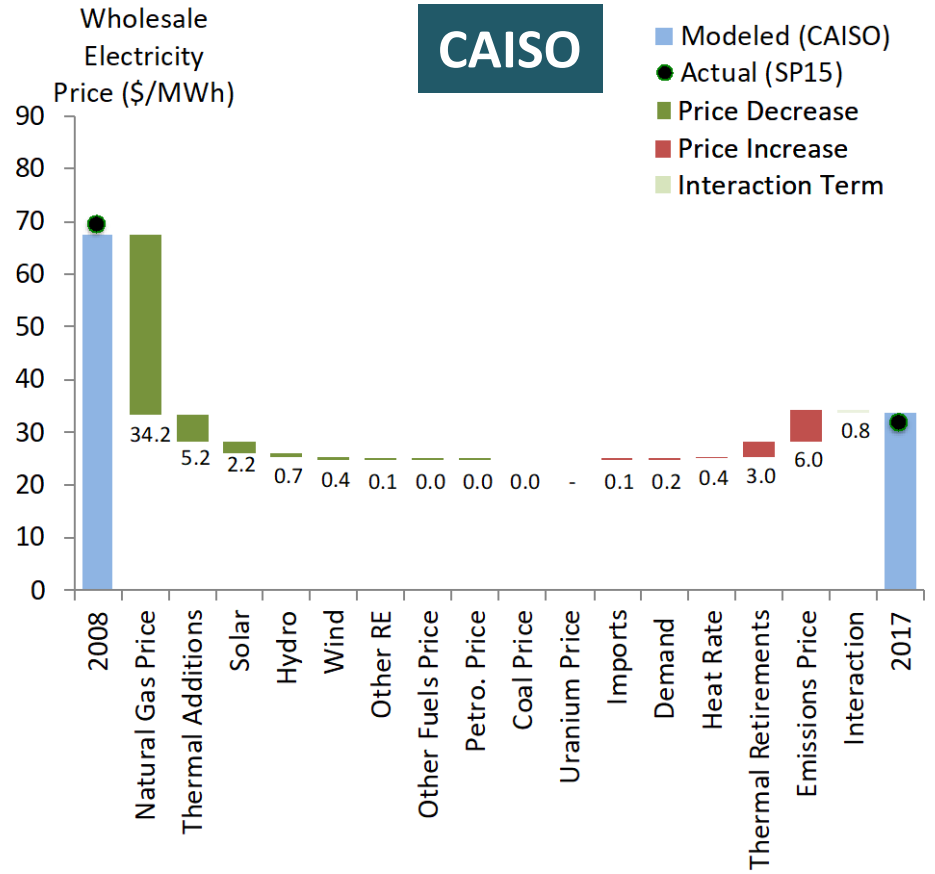
*"Actual" is based on hourly average of **real-time** price at major hub*

Model captures variation in annual average prices across all seven U.S. markets; understates variability in hourly real-time prices.

Dramatic Drop in Annual Average Wholesale Prices Has Been Driven By Natural Gas Prices: ERCOT and CAISO

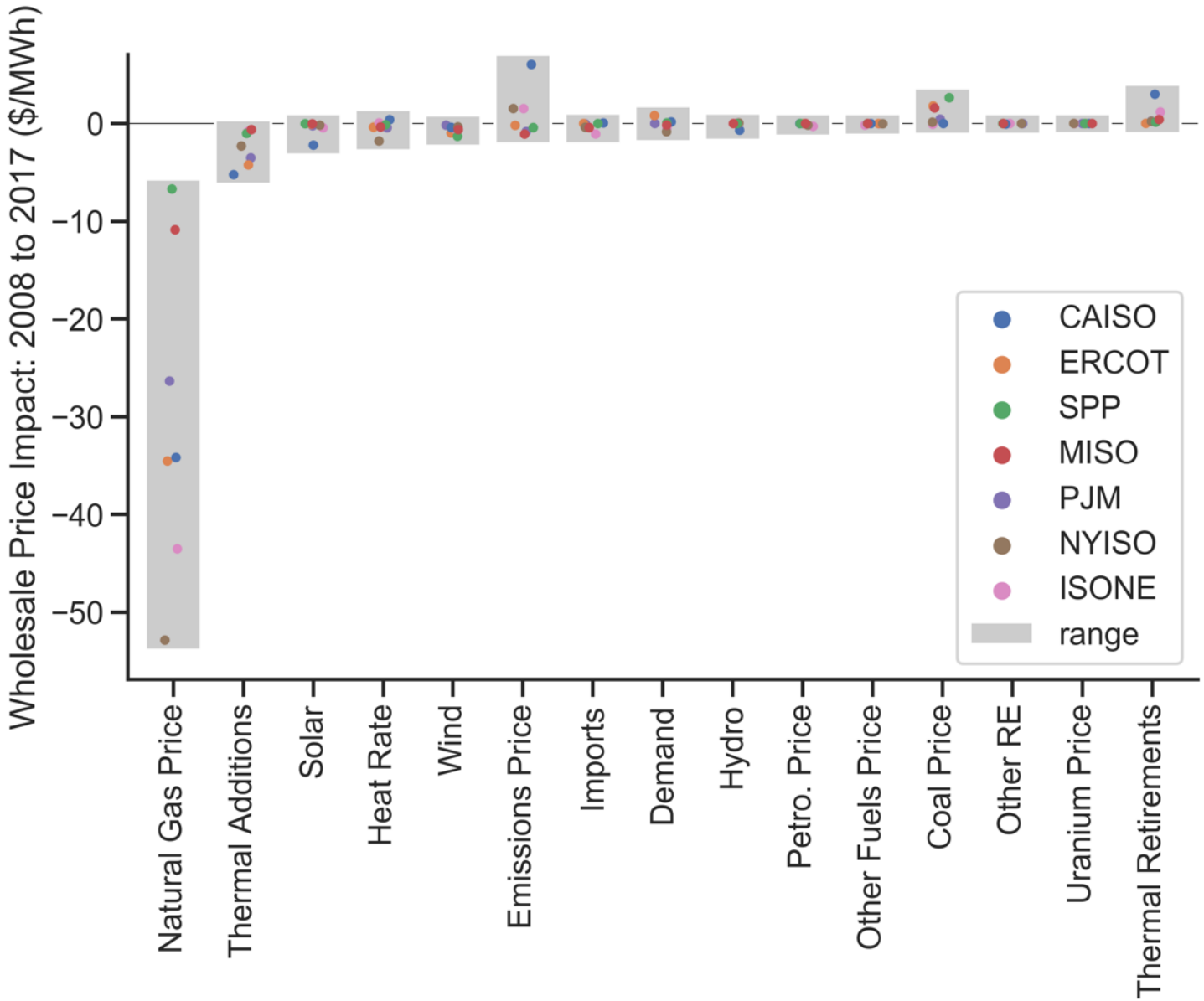
Analysis shows limited VRE impacts on average annual market-wide wholesale prices from 2008 to 2017, in part due to relatively flat supply curve



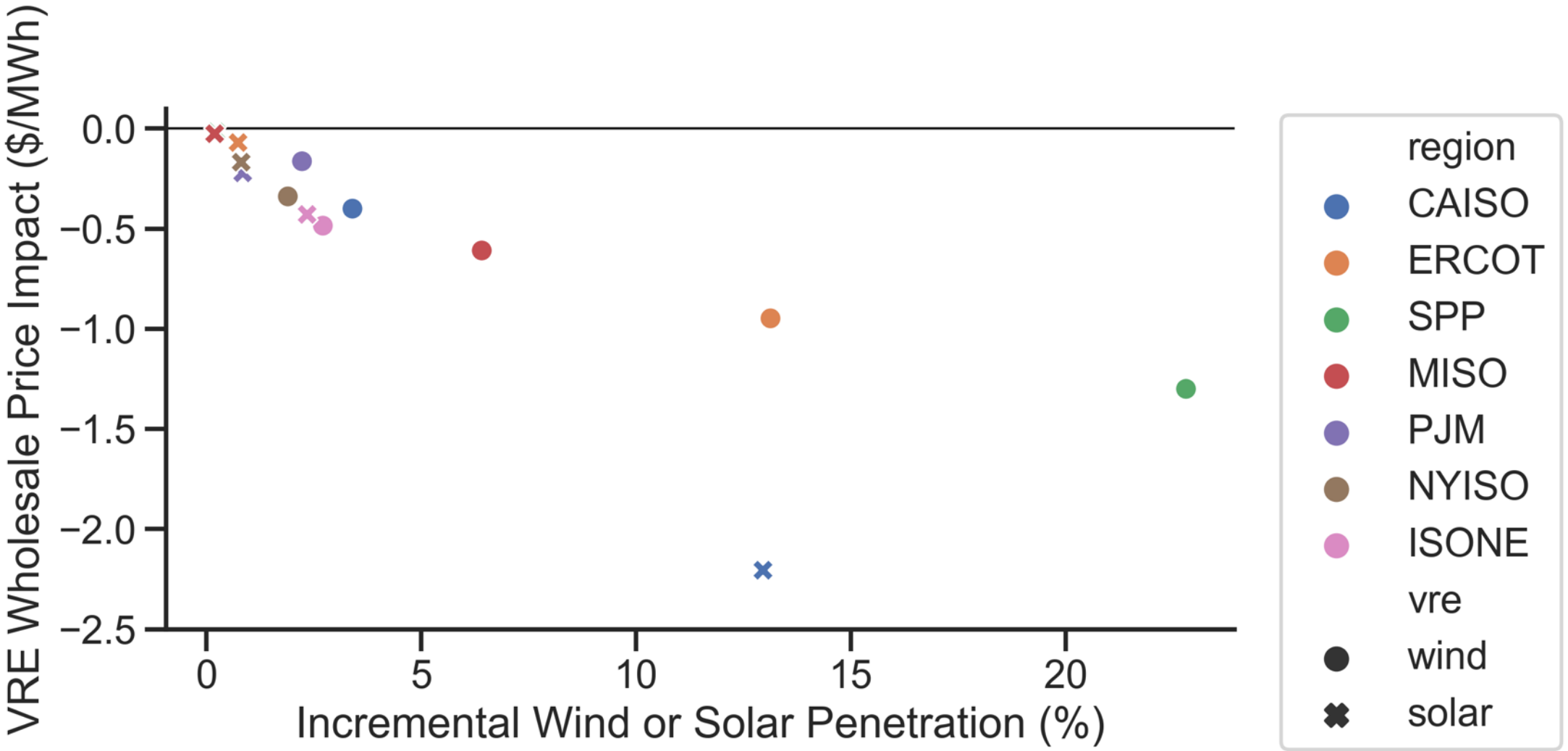


Used simple fundamental "supply curve" model to estimate wholesale prices in 2017 and 2008

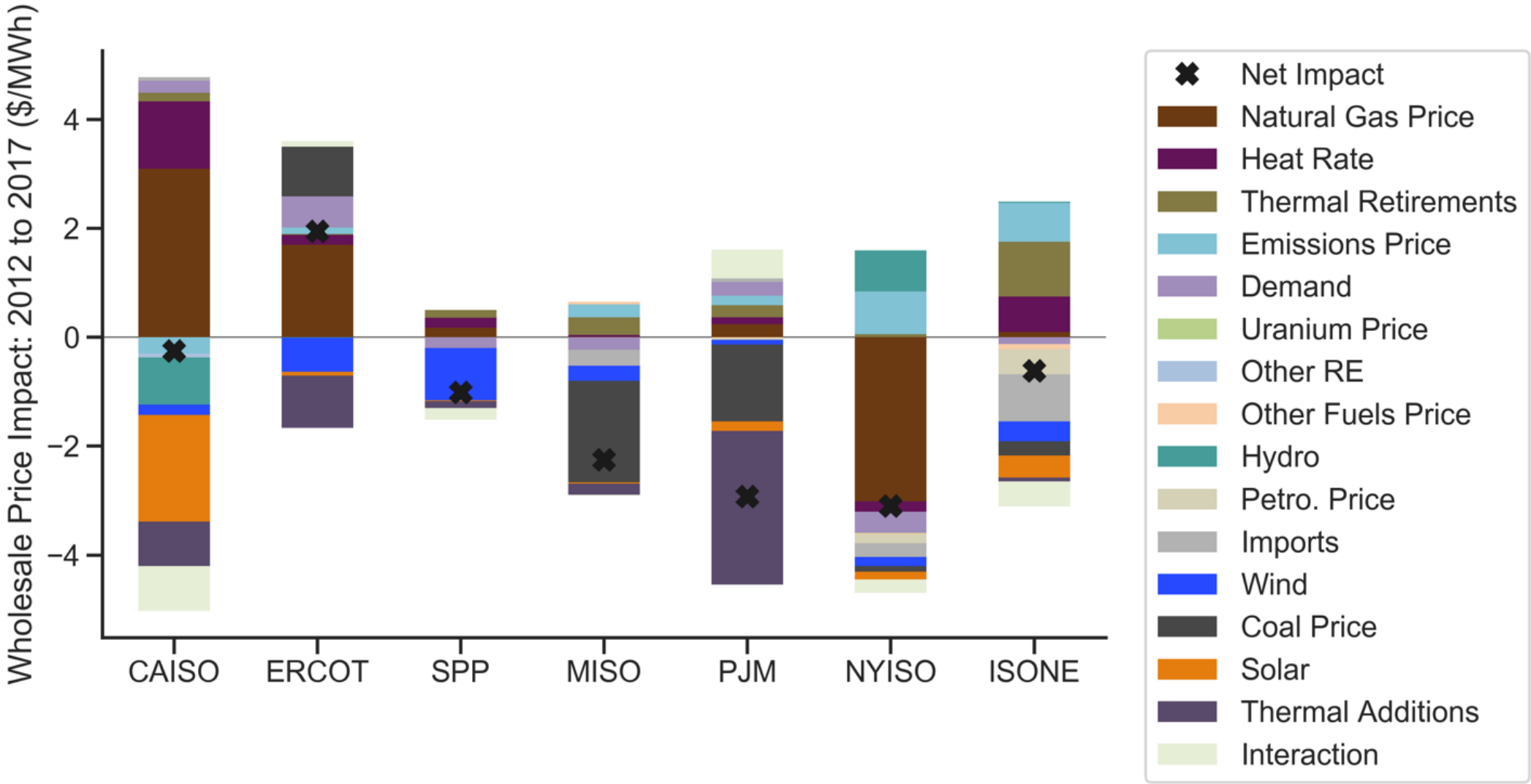
Based on Supply-Curve Model, Natural Gas Is Greatest Driver of Annual Average Wholesale Prices Across All Markets



Higher Shares of Wind or Solar Lead to a Greater Impact on Average Wholesale Prices, Especially for Solar in California

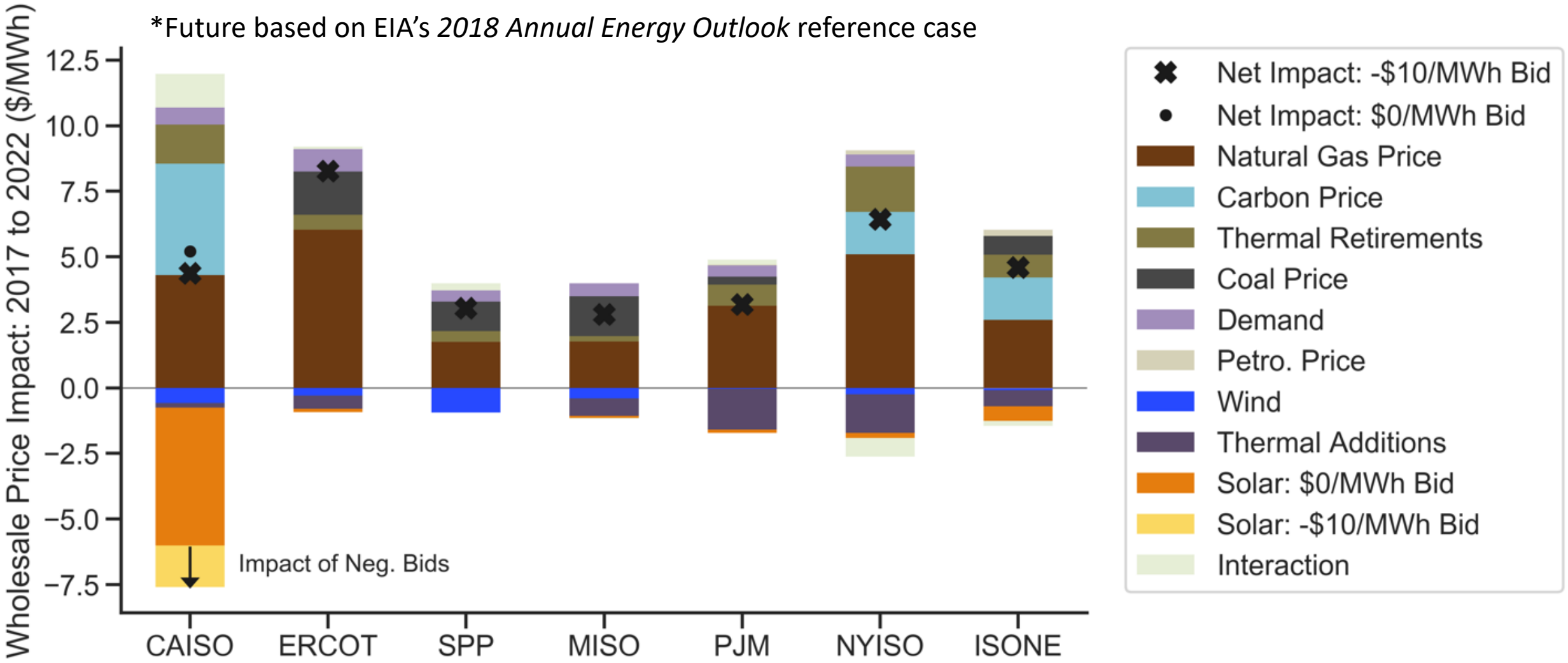


Prices Are Largely Stable Between 2012 and 2017; Decrease in Prices from VRE Are Offset by Other Impacts



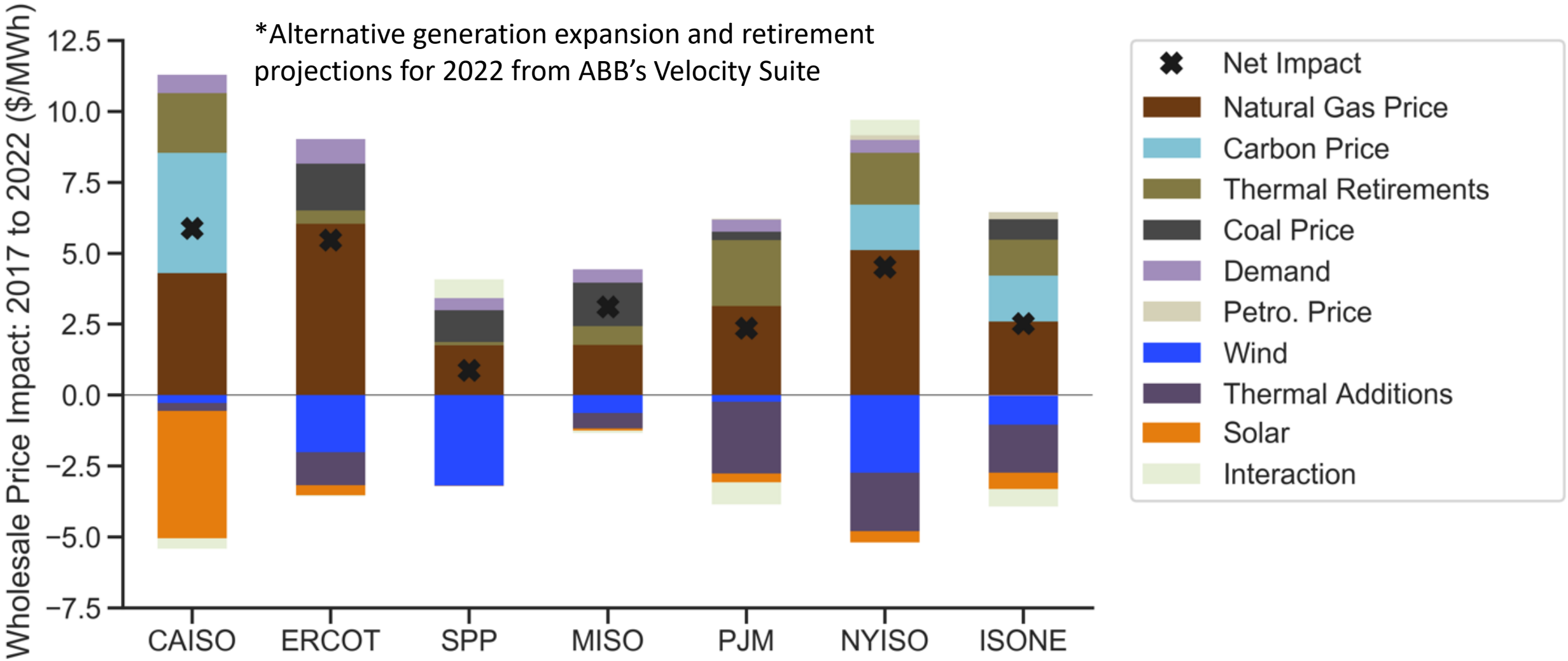
Outlook to 2022 Has VRE Impacts On Par with Impacts of Other Generation Expansion, Except for Solar in California

*Future based on EIA's *2018 Annual Energy Outlook* reference case



Alternative Projections Find Relatively Smaller Impacts of Solar in CAISO and Greater Impacts of Wind in SPP, NYISO, and ERCOT

*Alternative generation expansion and retirement projections for 2022 from ABB's Velocity Suite



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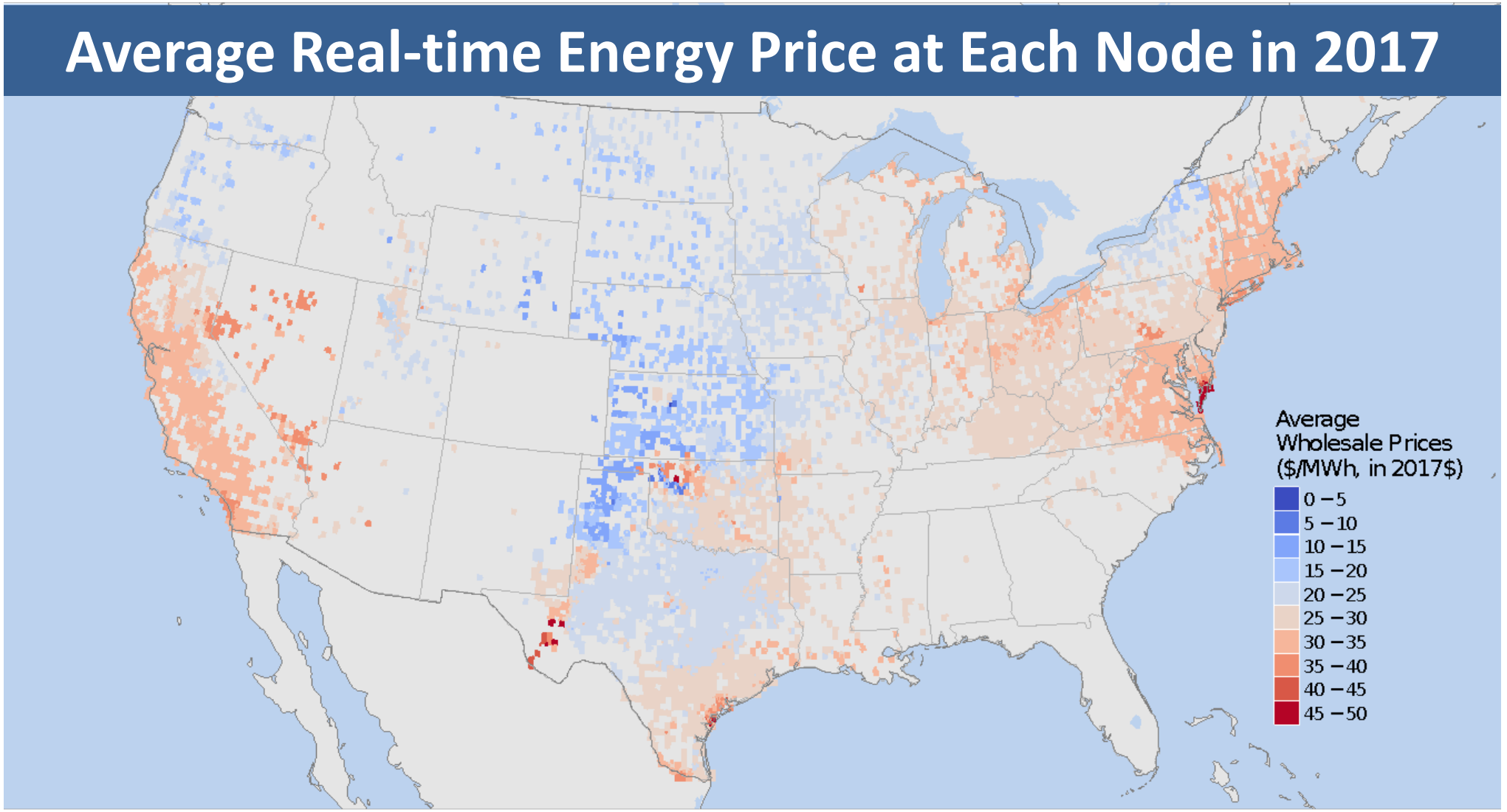
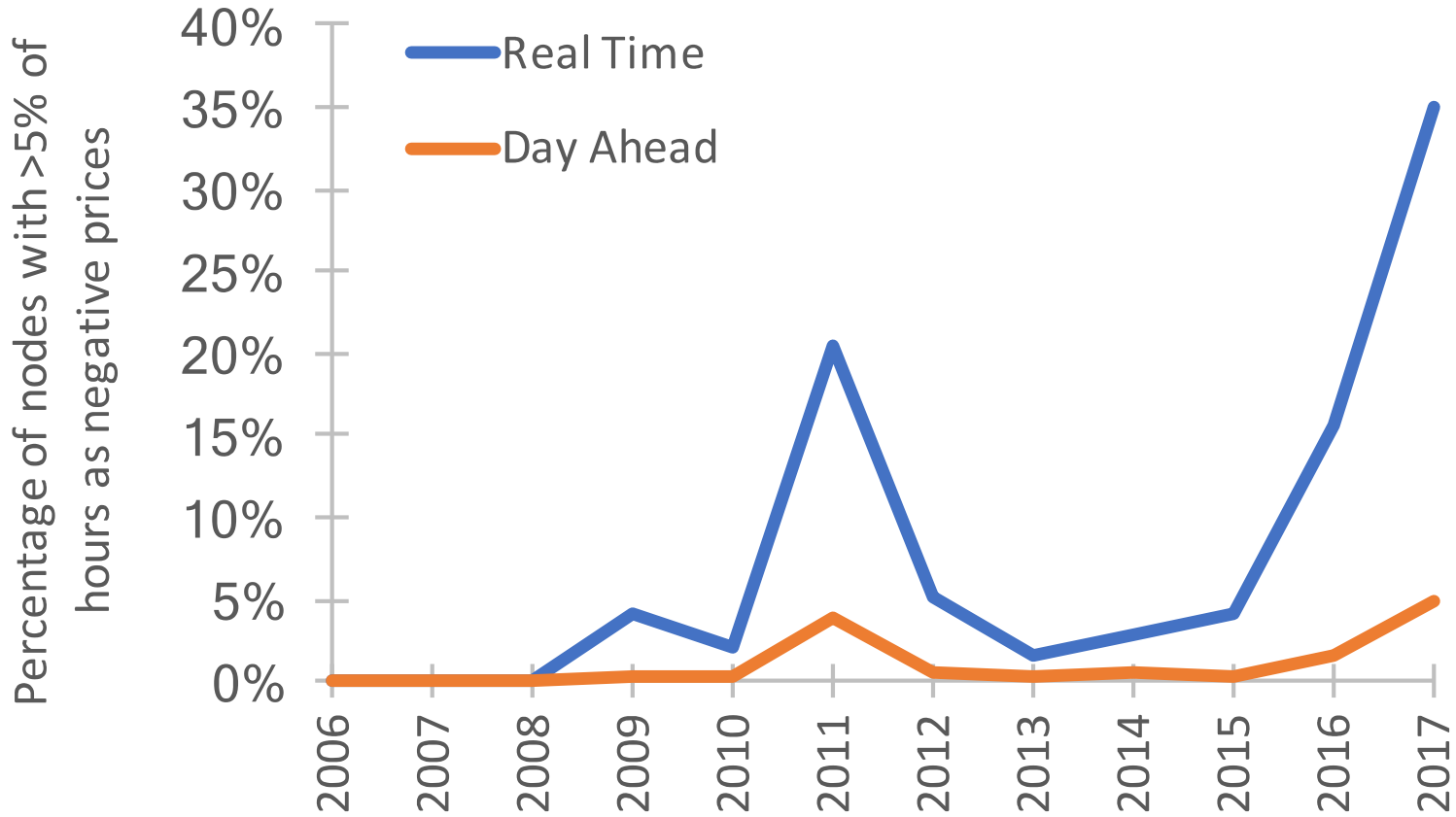
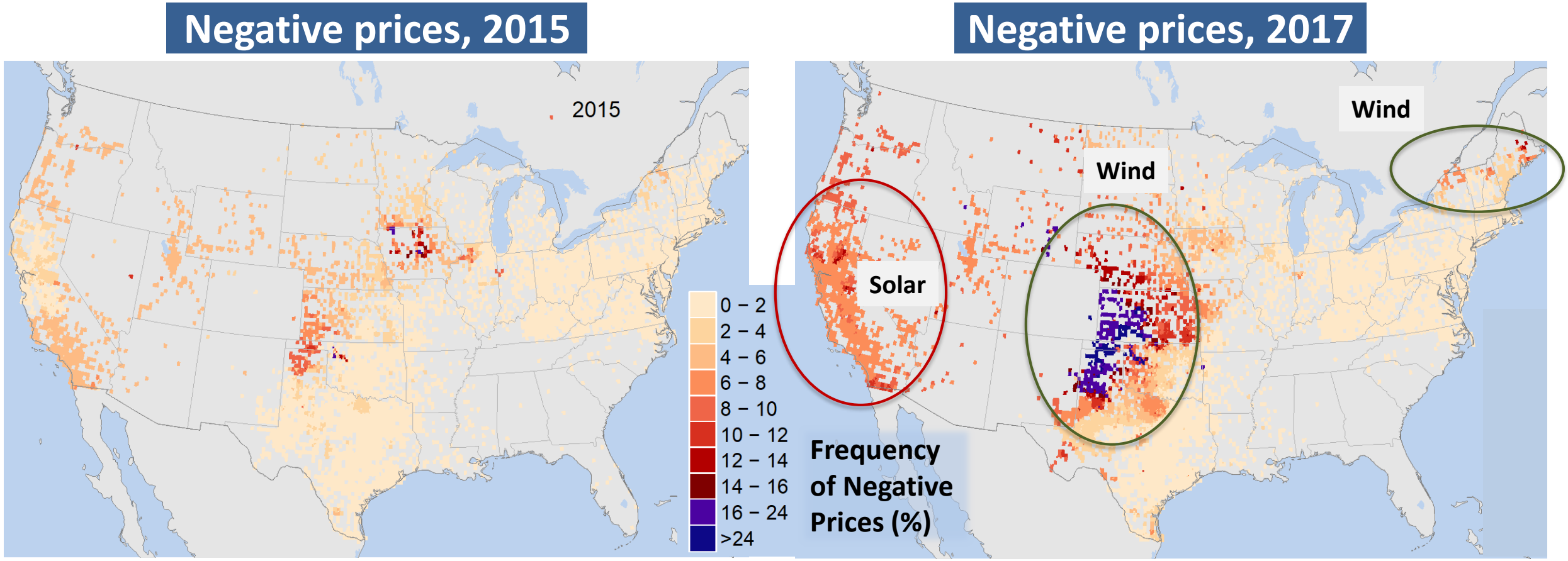
Market-Wide Average Prices Tell Only Part of the Story:
Thousands of Pricing Nodes, Each with Different Pricing Patterns



Negative Prices are Occurring at an Increasing Share of Nodes in the U.S

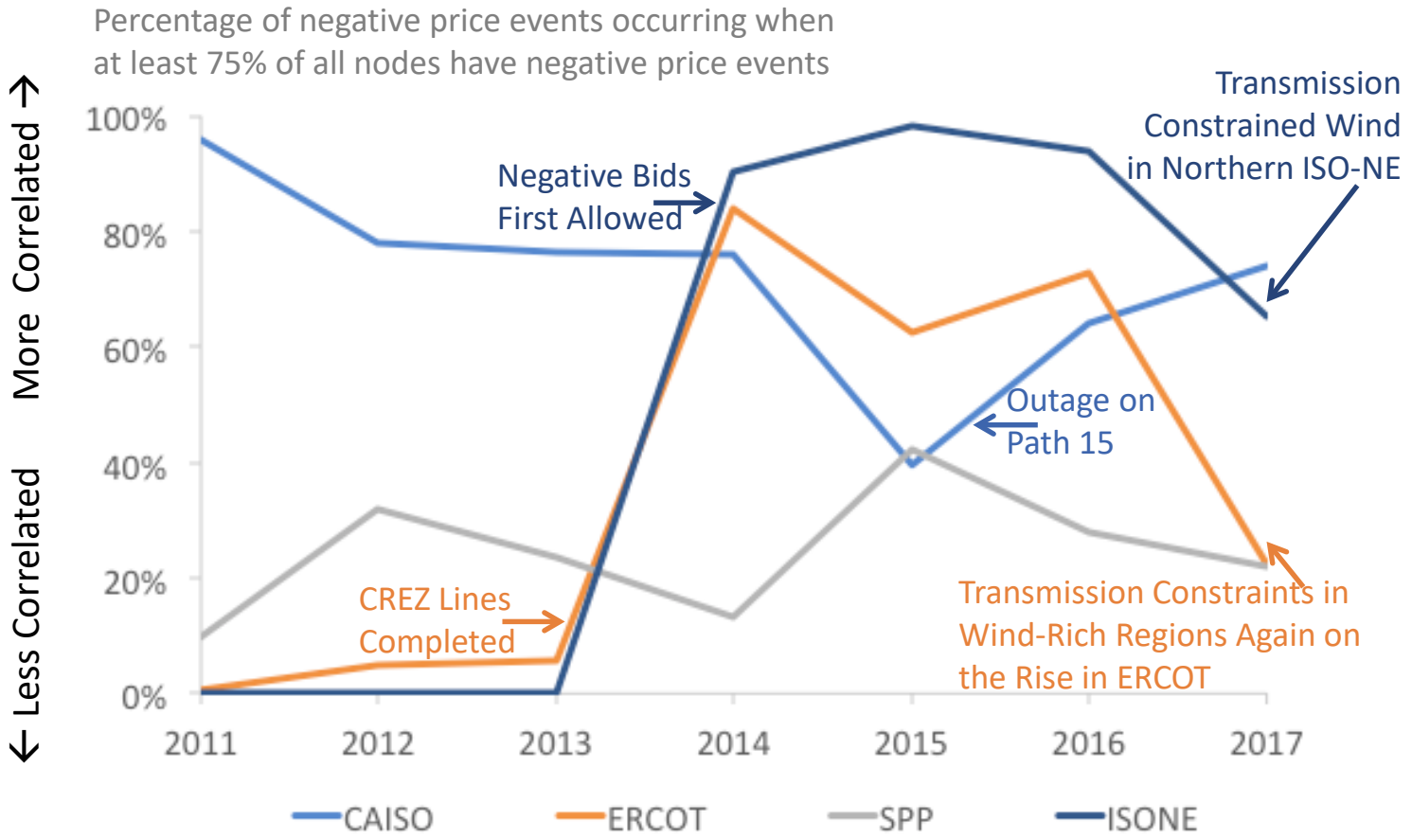


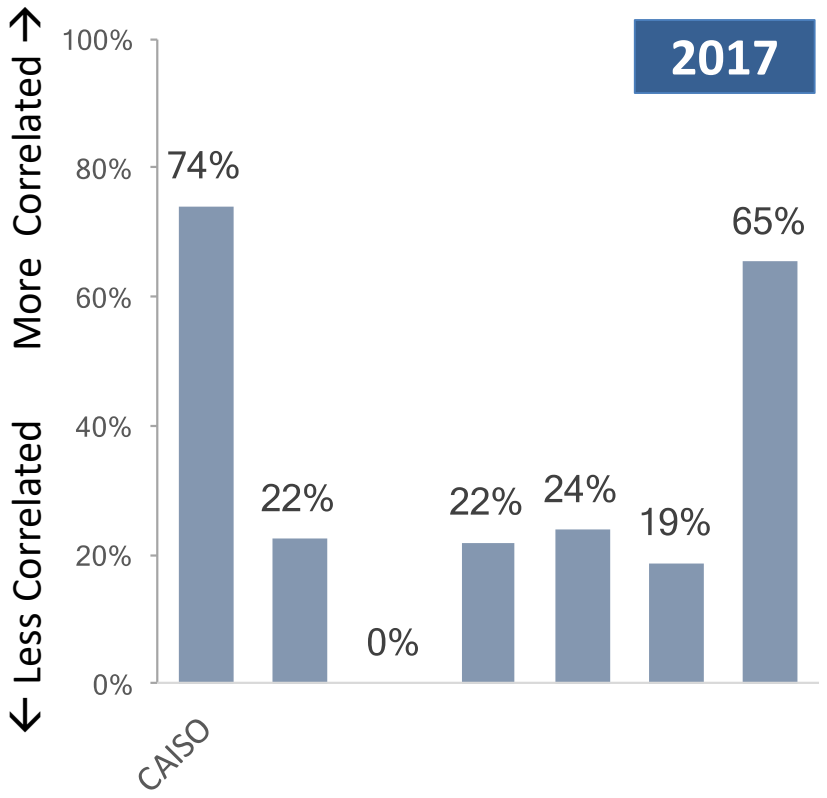
Higher Frequency of Negative Prices in Constrained Areas, Seemingly Driven in Significant Measure by VRE Growth



Maps show frequency of negative hourly prices in real-time market, demonstrating growing geographic extent and frequency of negative pricing

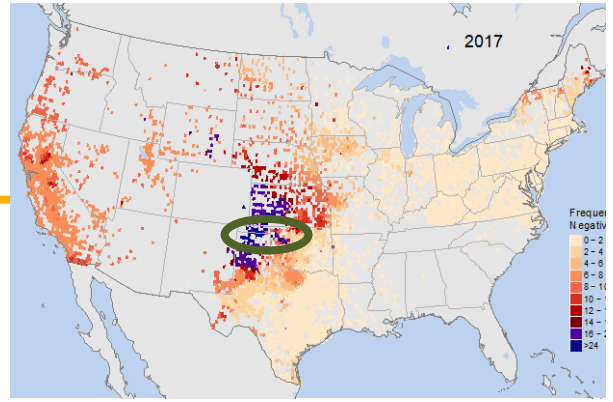
Negative Prices Are Widespread and Correlated In Some Markets and Independent in Other Markets

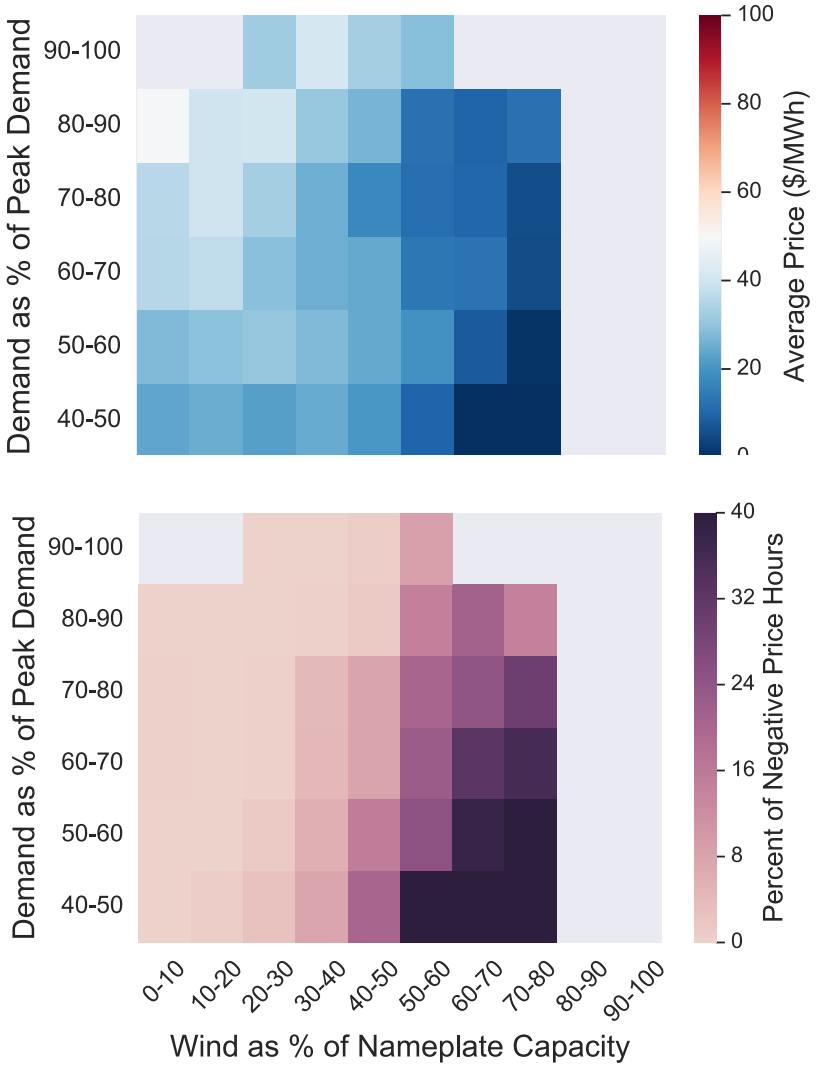




Highly correlated negative prices across an ISO footprint reflect system-wide issues that cannot be mitigated by internal transmission expansion (e.g., CAISO in 2011). Transmission expansion may mitigate less correlated negative prices.

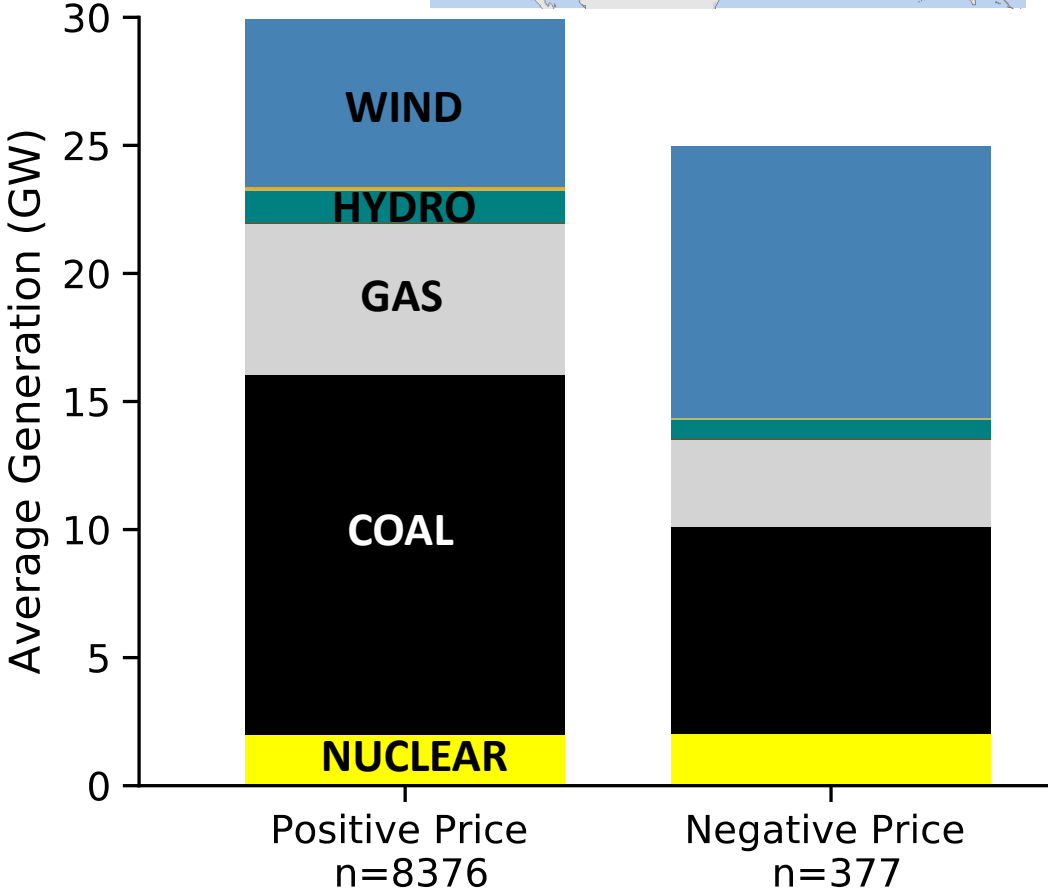
Illustrating the Impact of Wind Power: Oklahoma Hot Spot, 2017



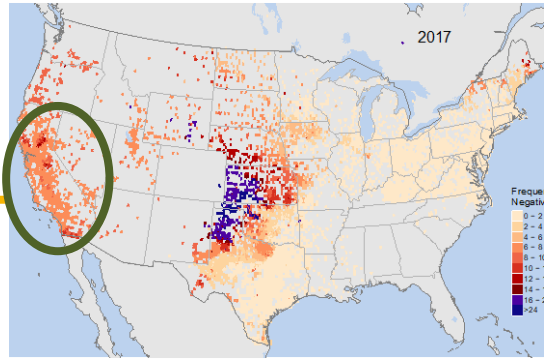


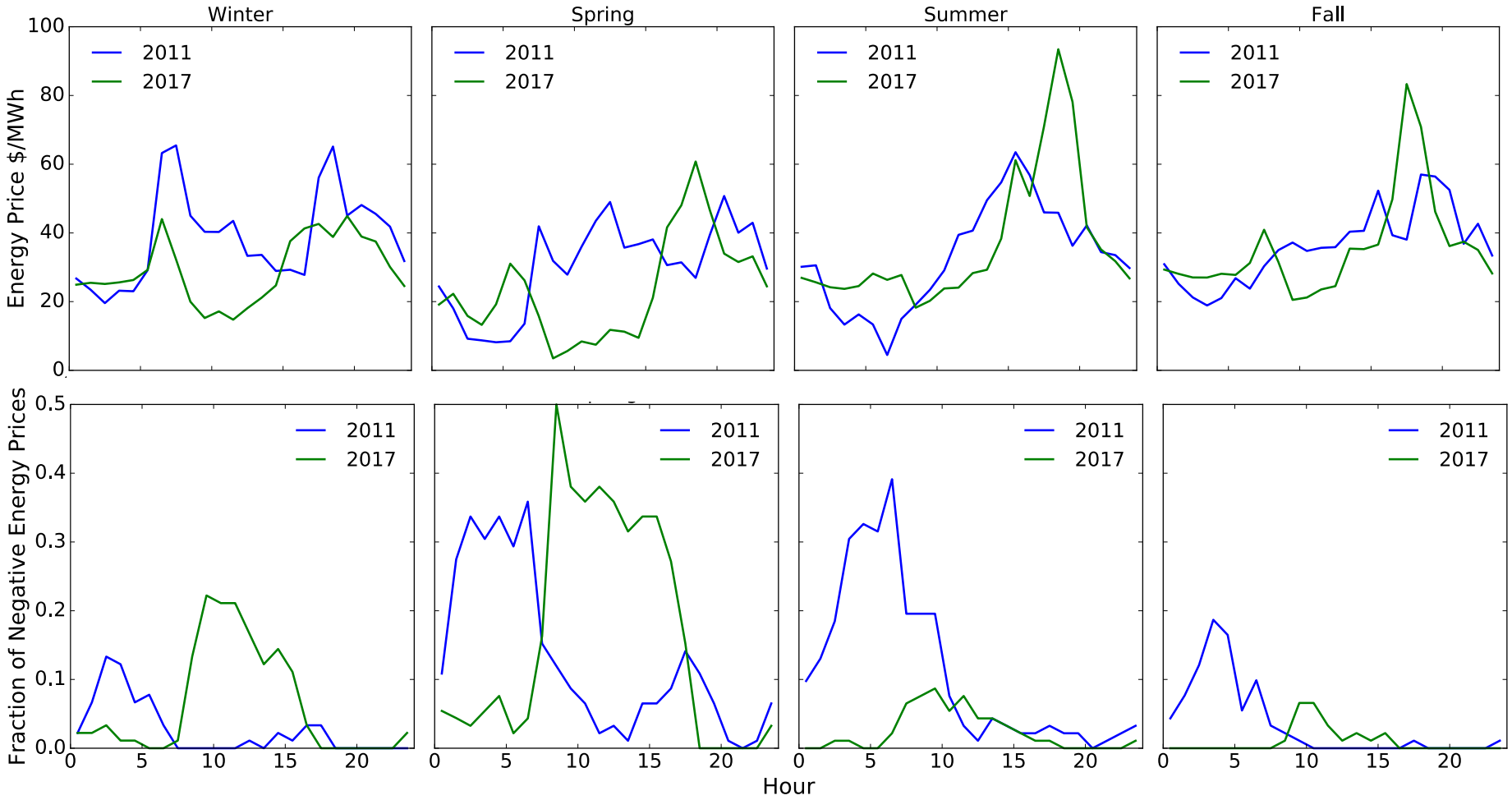
Average prices

Negative prices



Illustrating the Impact of Solar Power: California Hot Spot, 2017

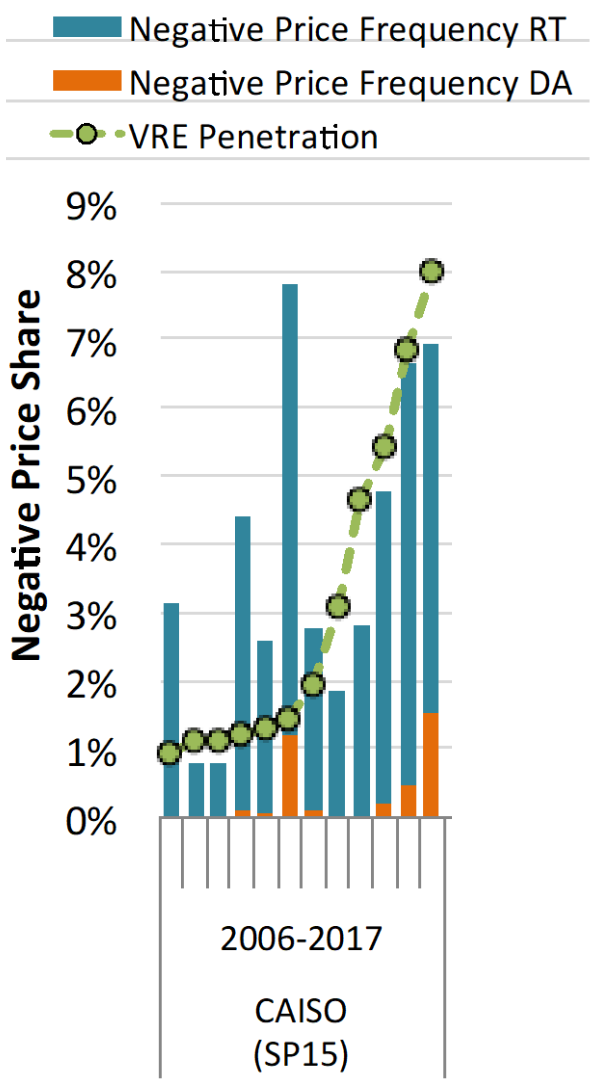




Average diurnal prices

Frequency of negative prices

It's Not All About Wind, Solar, and Load: Continuing the California Example

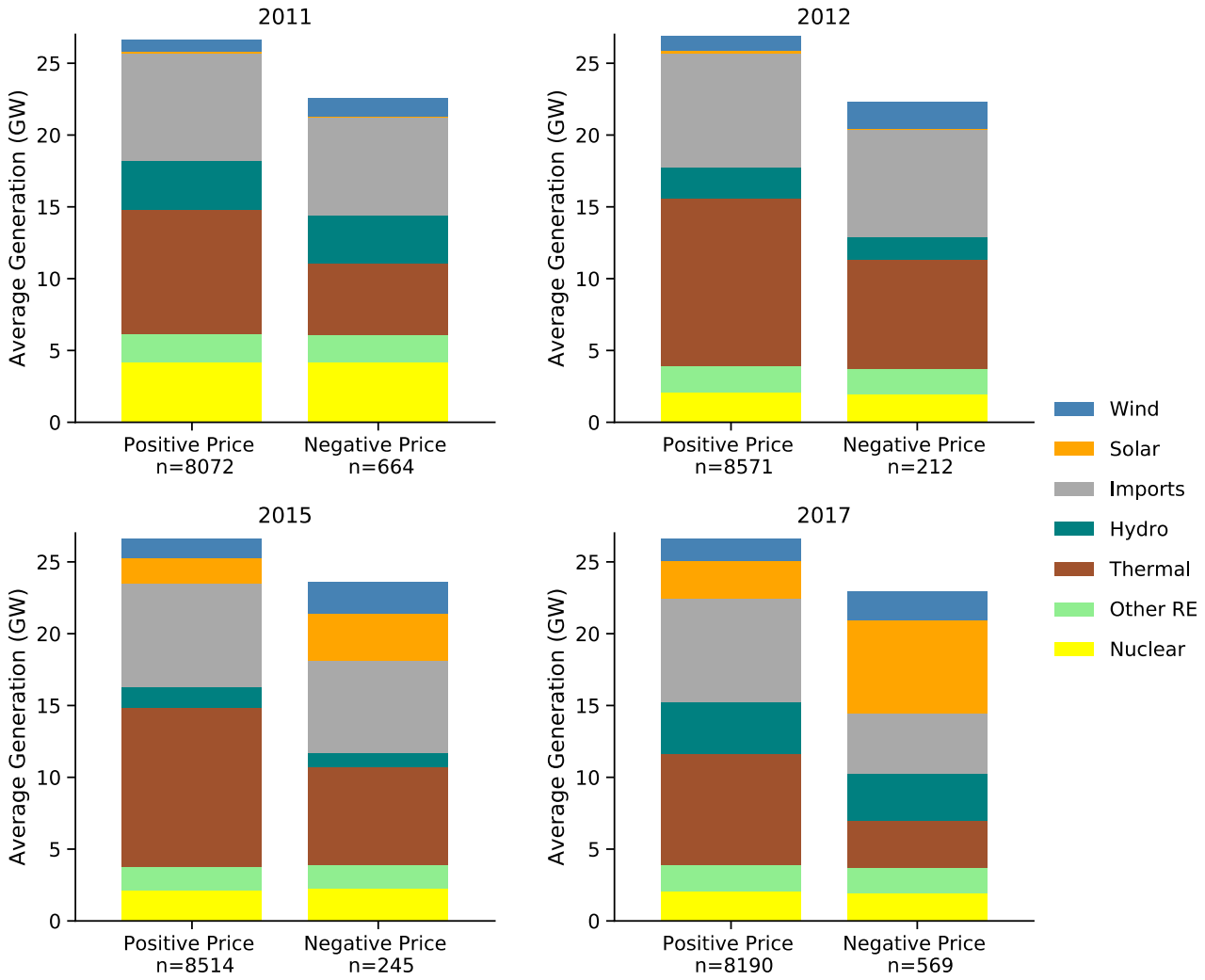


Contributing to negative prices:

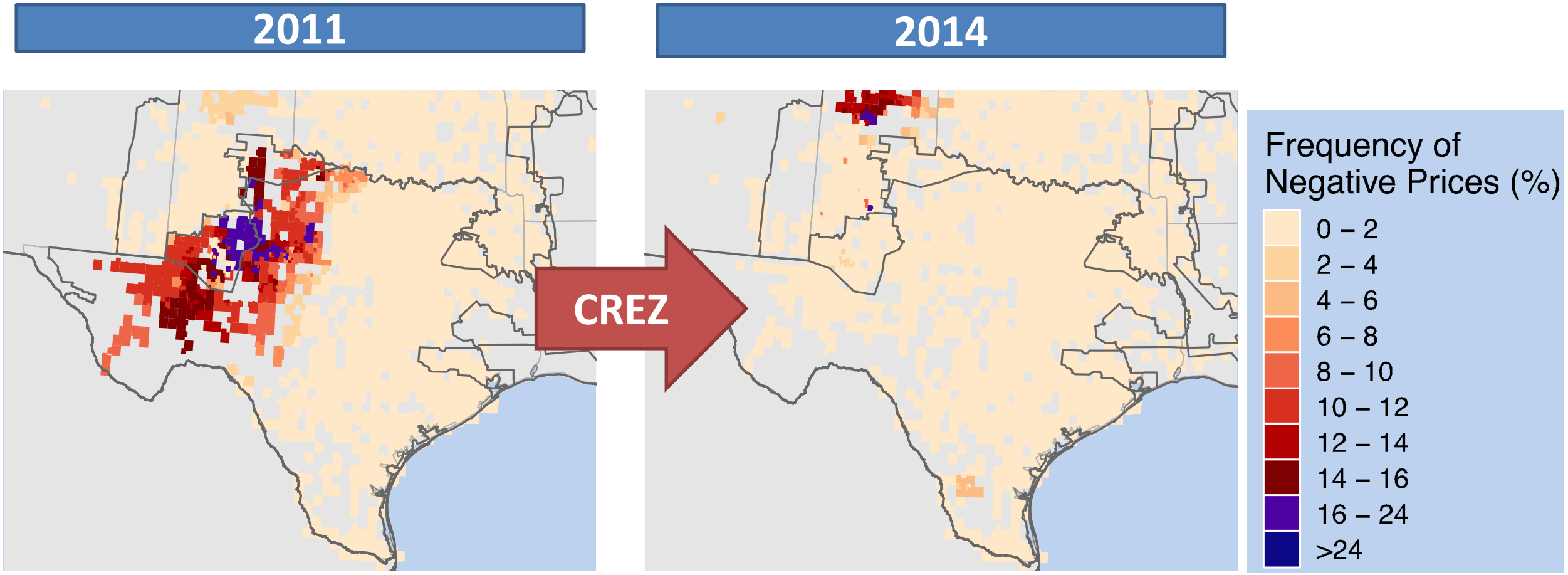
- high hydro in 2011 / '17
- inflexible nuclear
- must-run thermal

Mitigating negative prices:

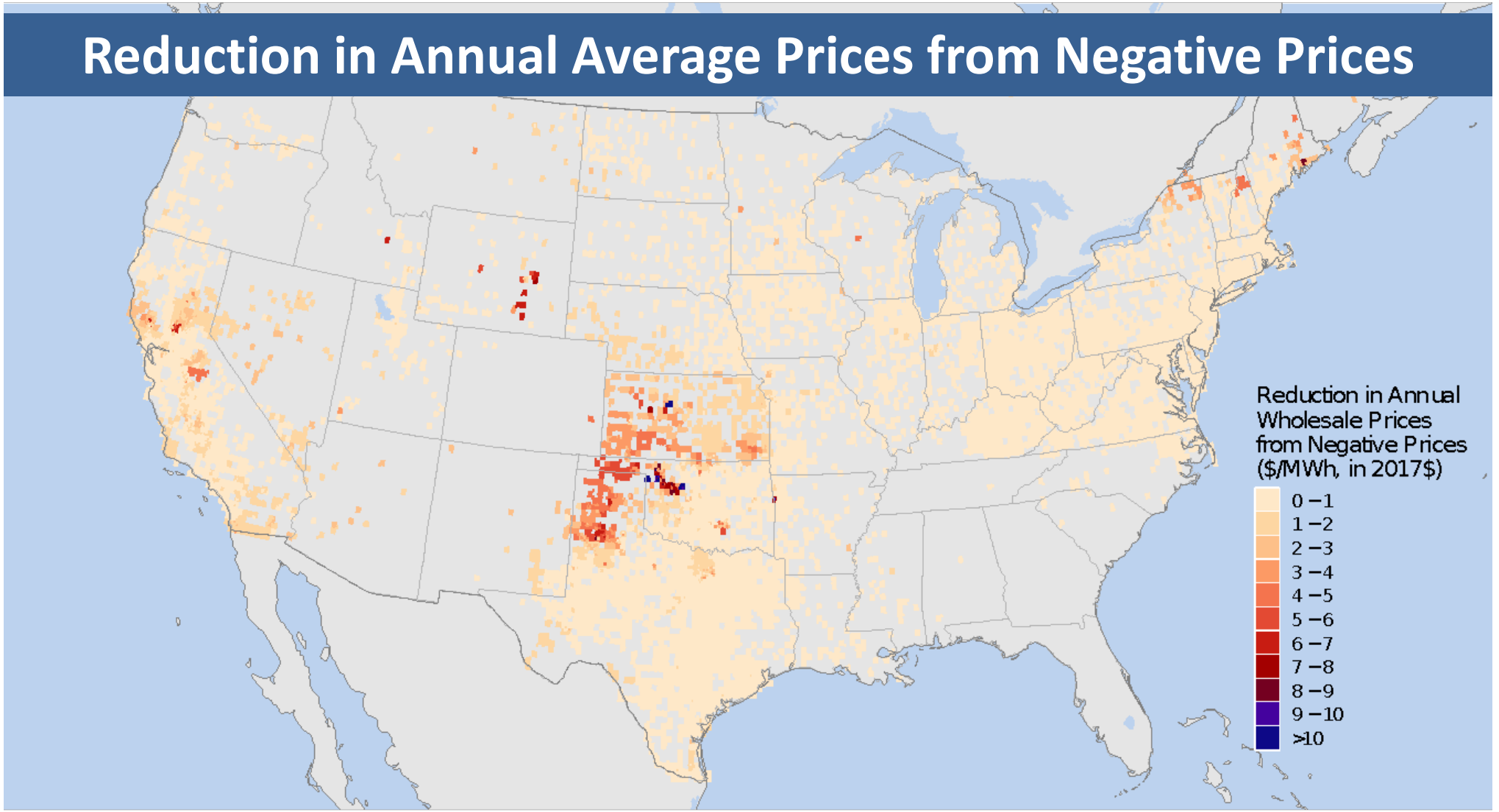
- nuc retirement in 2012
- more responsive imports by 2017
- more responsive thermal by 2017



Widespread Negative Pricing Need Not Always Be Permanent: Transmission Matters

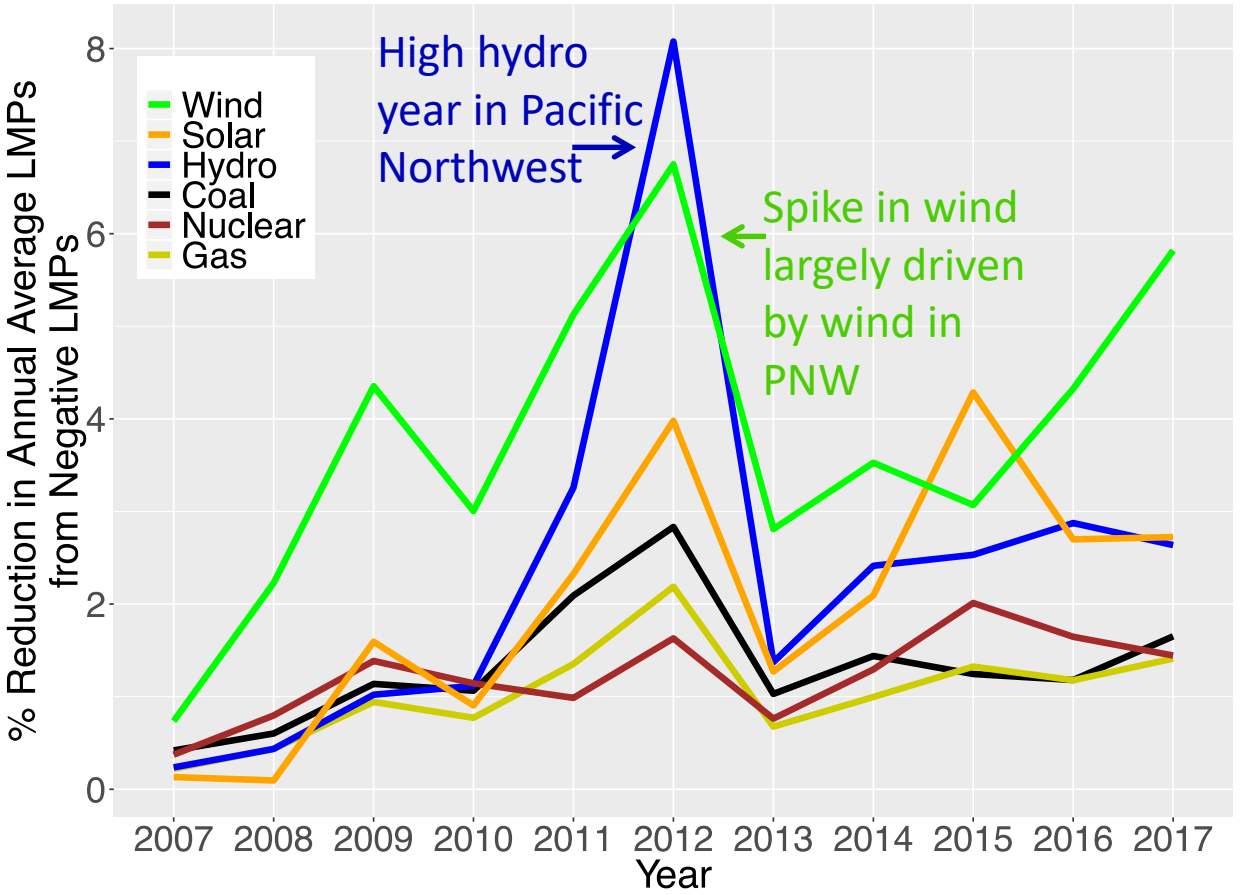


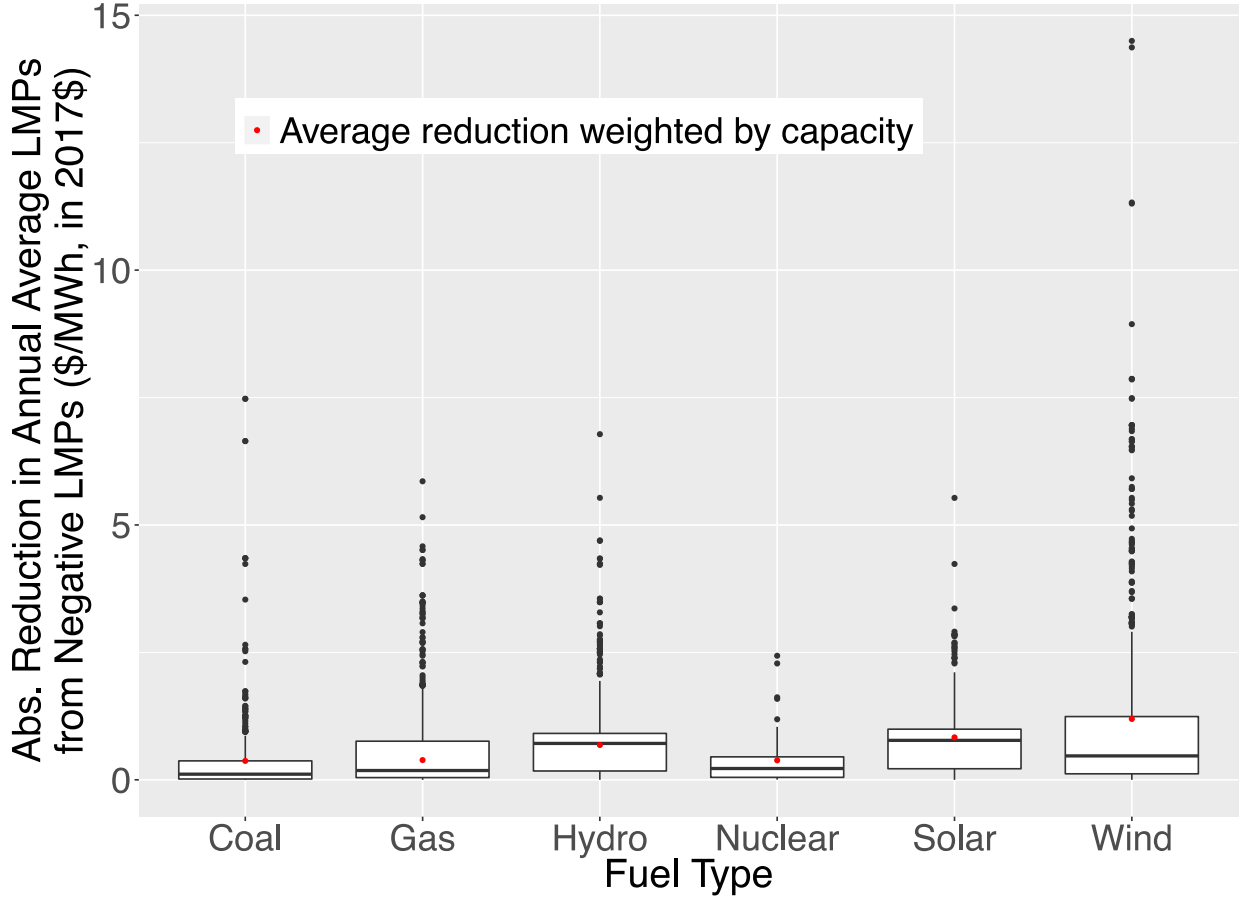
How Much Does it Matter? Impact of Negative Pricing on Annual Average Wholesale Prices



What Generation Technologies Are Facing the Brunt of the Negative-Price Impact So Far?

Reduction in Annual Average Prices from Negative Prices, by Plant Type





Note: represents annual averages at pricing nodes; does not consider ability to dispatch around low-priced hours

Conclusions

- Decrease in *market-wide average* wholesale prices since 2008 is largely due to changing natural gas prices; historical effect of VRE is limited, in part due to flat supply curve
- Beyond impacts to market-wide average prices, more consequential are the impacts of wind and solar on temporal and geographic pricing patterns
- The frequency of negative wholesale prices is on the rise, in part driven by wind and solar, with wind-related impacts often also due to transmission constraints
- Negative pricing has had a much-greater impact on wind and solar assets than other generation assets thus far, but some spillover impacts are apparent
- Magnitude and importance of these shifts in the longer term depend on what other disruptions occur, including efforts to actively mitigate the grid-effects of wind and solar

Questions?

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  - Dev Millstein
  - Joachim Seel

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This work is funded by the Office and Electricity and the Office of Energy Efficiency and Renewable Energy of the U.S. Department of Energy