How Much Are Wind, Solar, and Other Factors Driving Changes in Wholesale Power Prices?

An Historical Analysis—2008 through 2017

Andrew Mills, Dev Millstein, Ryan Wiser, Jo Seel, Juan Pablo Carvallo, Seongeun Jeong, Will Gorman

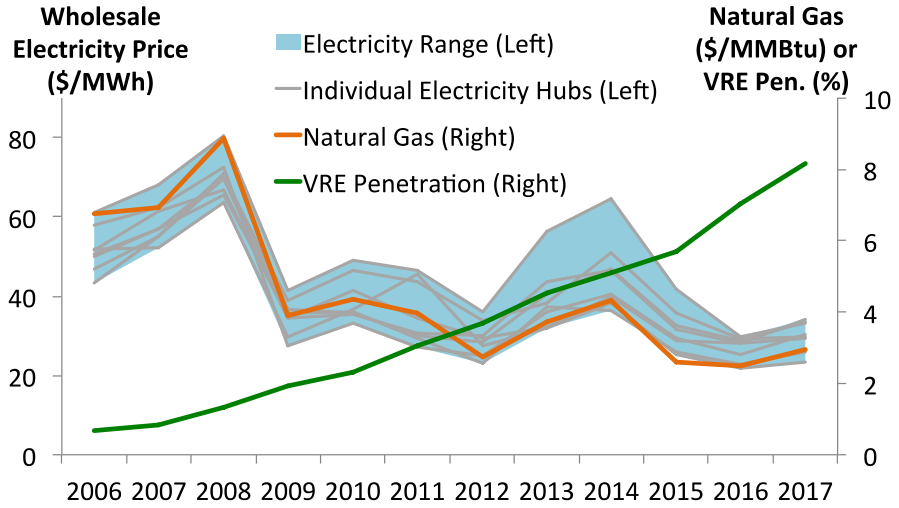
Lawrence Berkeley National Laboratory

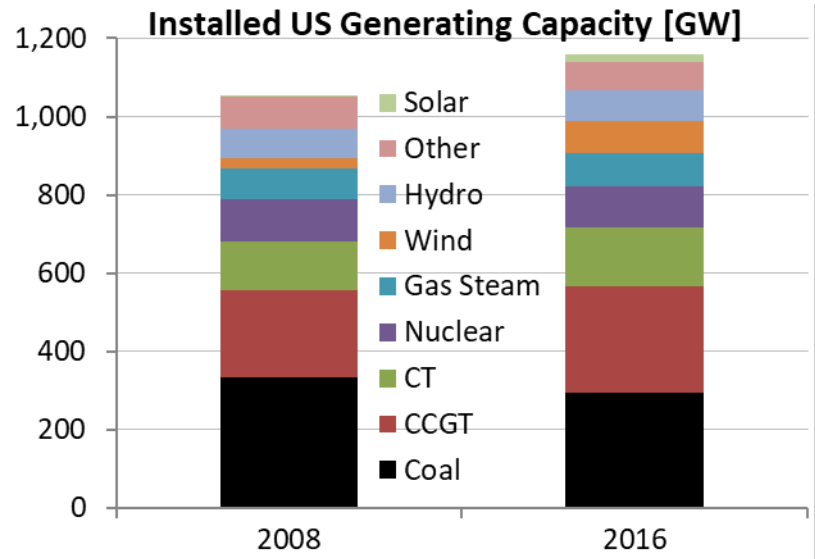
Energy Systems Integration Group

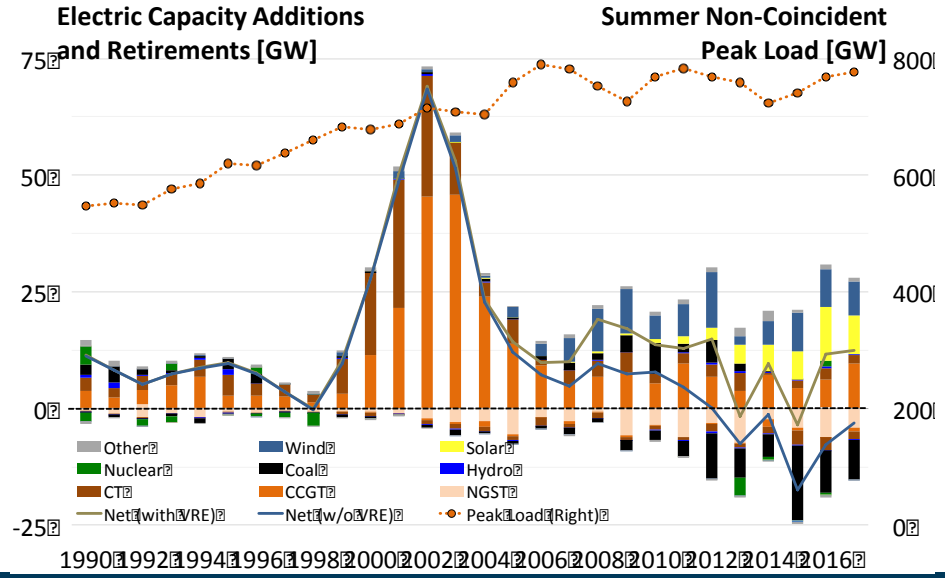
Spring Technical Workshop, March 2019

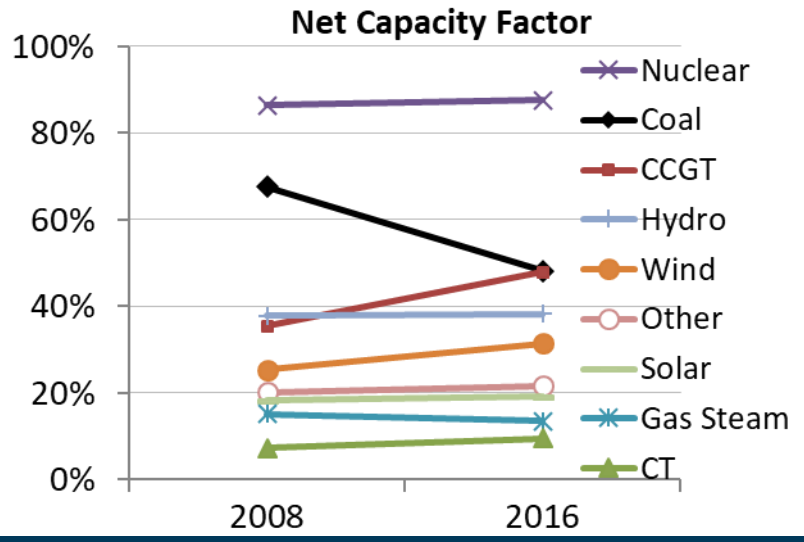
The work described here was funded by the Office of Electricity and the Office of Energy Efficiency and Renewable Energy of the U.S. Department of Energy

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

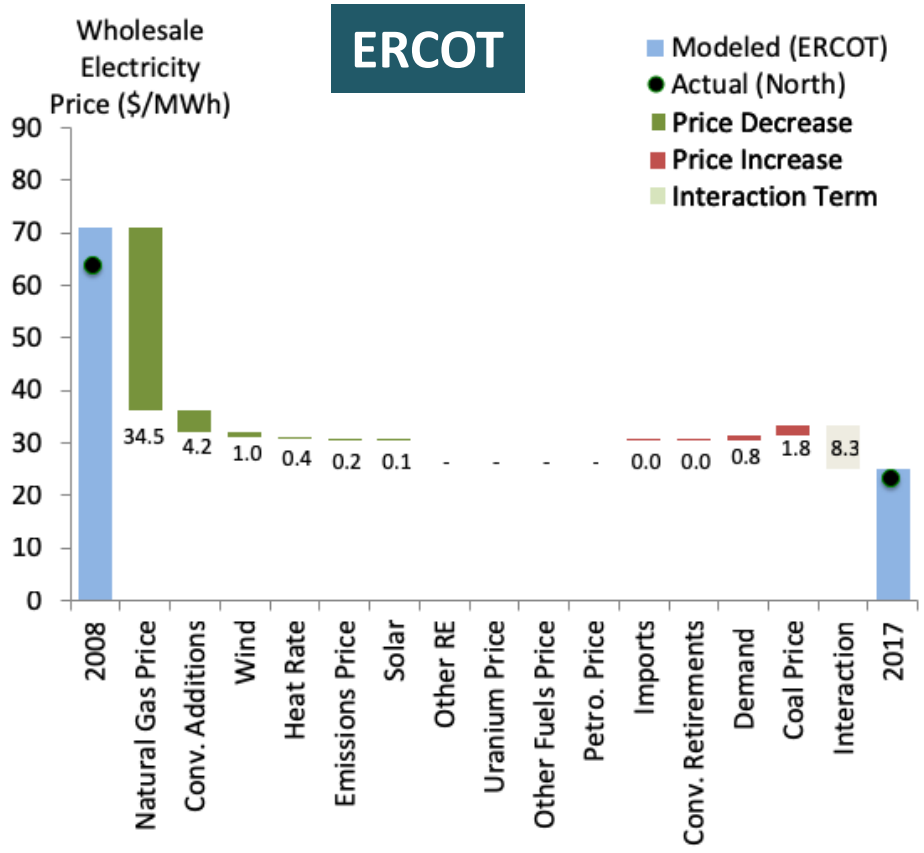
Study	Applicable Region	Time Period	Average VRE Penetration (% of demand)	Decrease in Average Wholesale Power Energy Price from Average VRE
Woo et al. 2011	ERCOT	2007-2010	Wind: 5.1%	Wind: $2.7/MWh (ERCOT North) Wind: $6.8/MWh (ERCOT West)
Woo et al. 2013	Pacific NW	2006-2012	N/A	Wind: $3.9/MWh
Woo et al. 2014	CAISO	2010-2012	Wind: 3.4% Solar: 0.6%	Wind: $8.9/MWh Solar: $1.2/MWh
Woo et al. 2016	CAISO	2012-2015	Wind: 4.3% Solar: 2.6%	Wind: $7.7/MWh Solar: $2.1/MWh
Gil and Jin 2013	PJM	2010	Wind: 1.3%	Wind: $5.3/MWh
Wiser et al. 2016	Various	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	DG Solar: ~5%	DG Solar: < $1/MWh
Tsai and Eryilmaz 2018	ERCOT	2014-2016	Wind: 11%	Wind: $8-12/MWh
Quint and Dahlke 2019	MISO	2014-2016	Wind: 6%	Wind: $6.7/MWh
Jenkins 2017	PJM	2008-2016	N/A	Wind: $1-2.5/MWh
Wiser et al. 2017	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	ERCOT	2008-2016	Wind: ↑ 10.8% 2008-2016 Solar: ↑ 0.3% 2008-2016	Wind: $0.7/MWh Solar: $0/MWh
Haratyk 2017	Midwest	2008-2015	Wind: ↑ 9% 2008-2015	Wind: $4.6/MWh
Haratyk 2017	Mid-Atlantic	2008-2015	N/A	Wind: $0/MWh
Bushnell and Novan 2018	CAISO	2012-2016	Utility-Scale Solar: ↑ 8.3% 2012-2016	Solar: $5.2/MWh

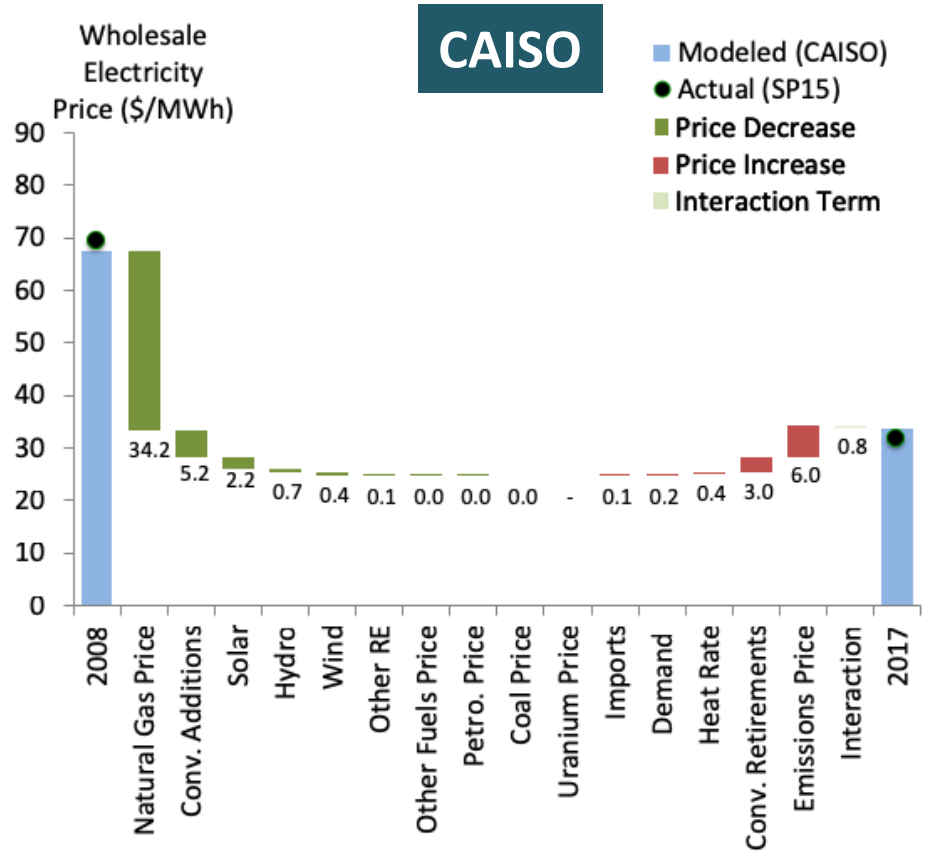
See also: Makovich and Richards (2017), Hibbard, Tierney, and Franklin (2017), Hogan and Pope (2017)

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

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

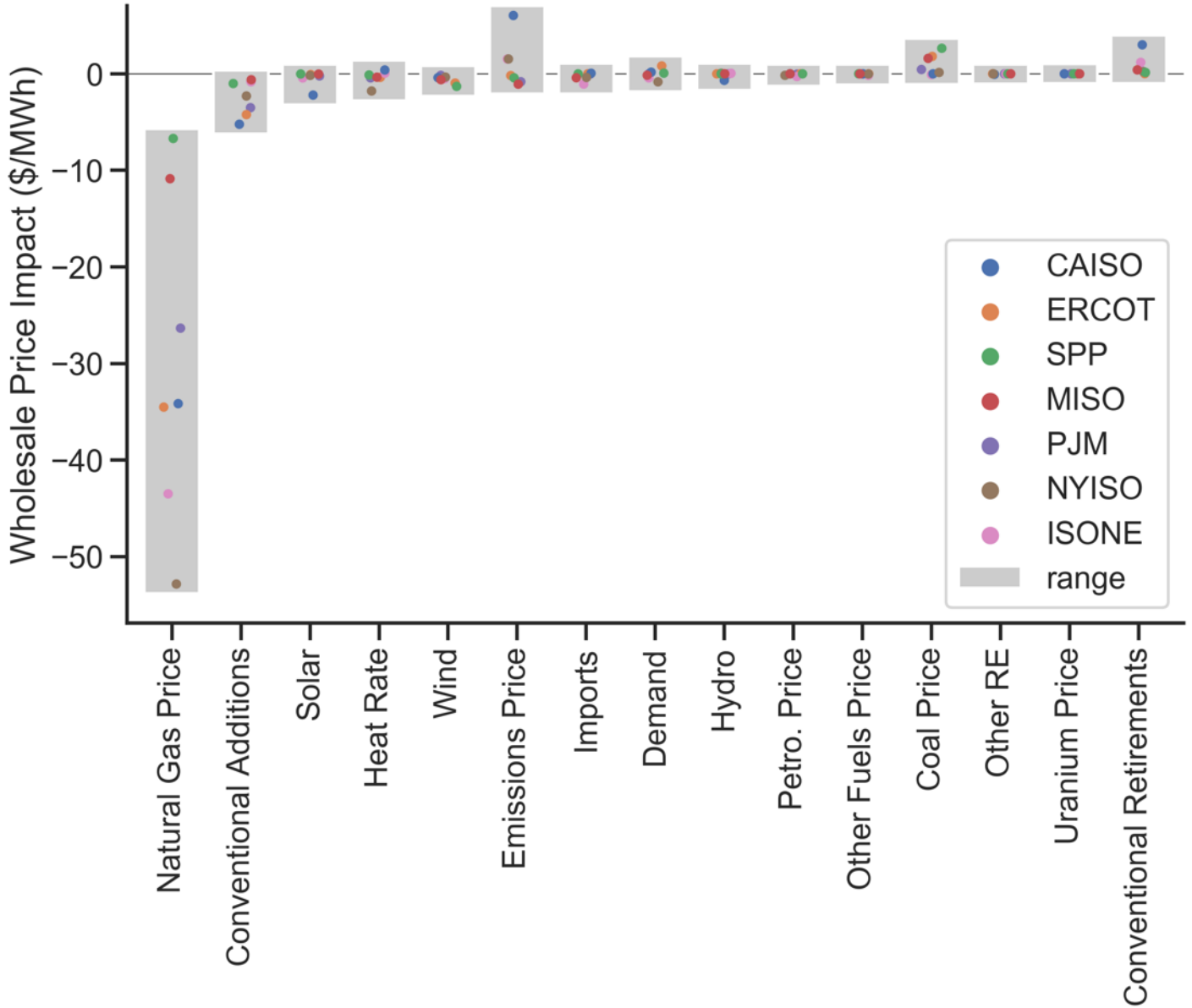
Analysis shows limited VRE impacts on average annual market-wide wholesale prices from 2008 to 2017, in part due to relatively flat supply curve



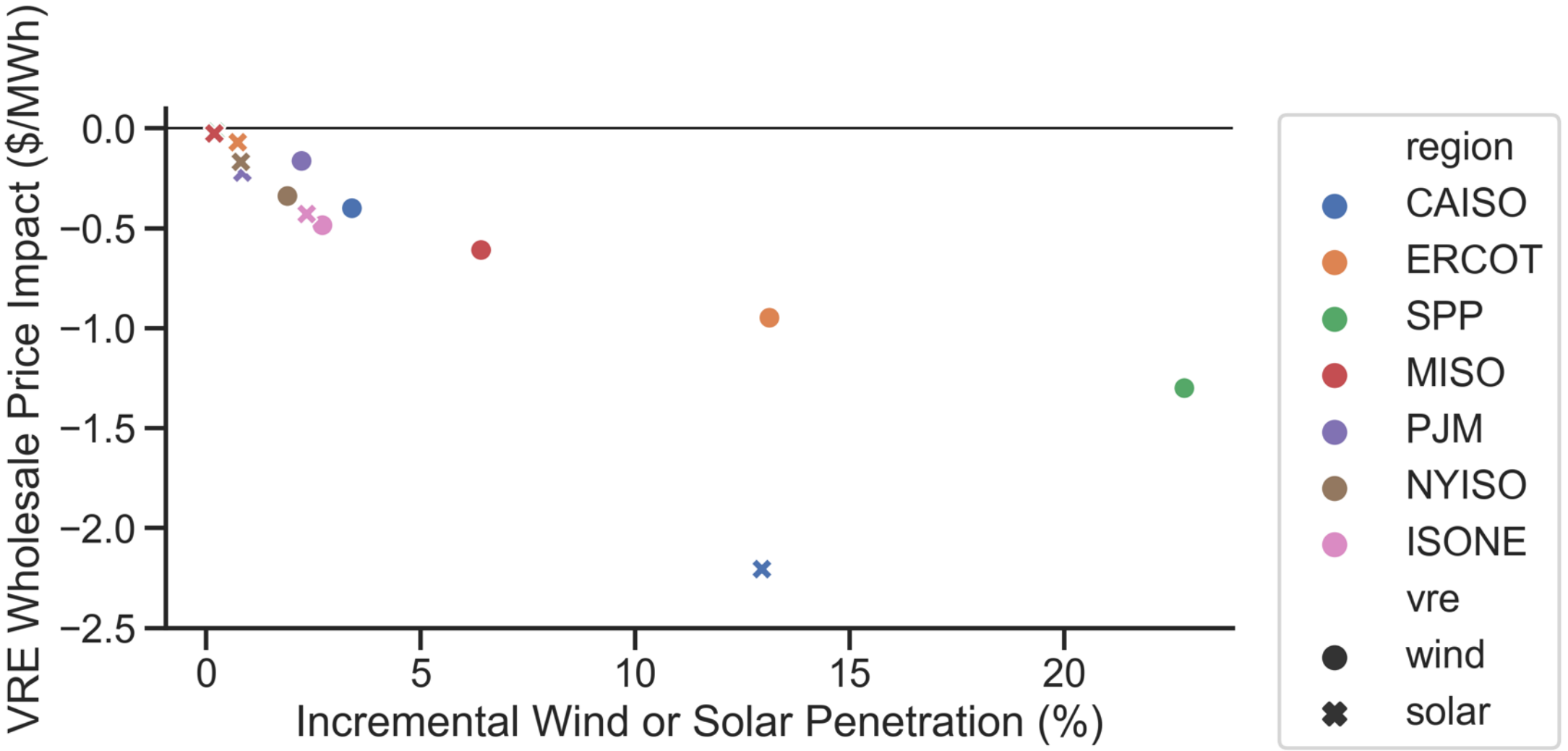


Used simple fundamental "supply curve" model to estimate wholesale prices in 2017 and 2008

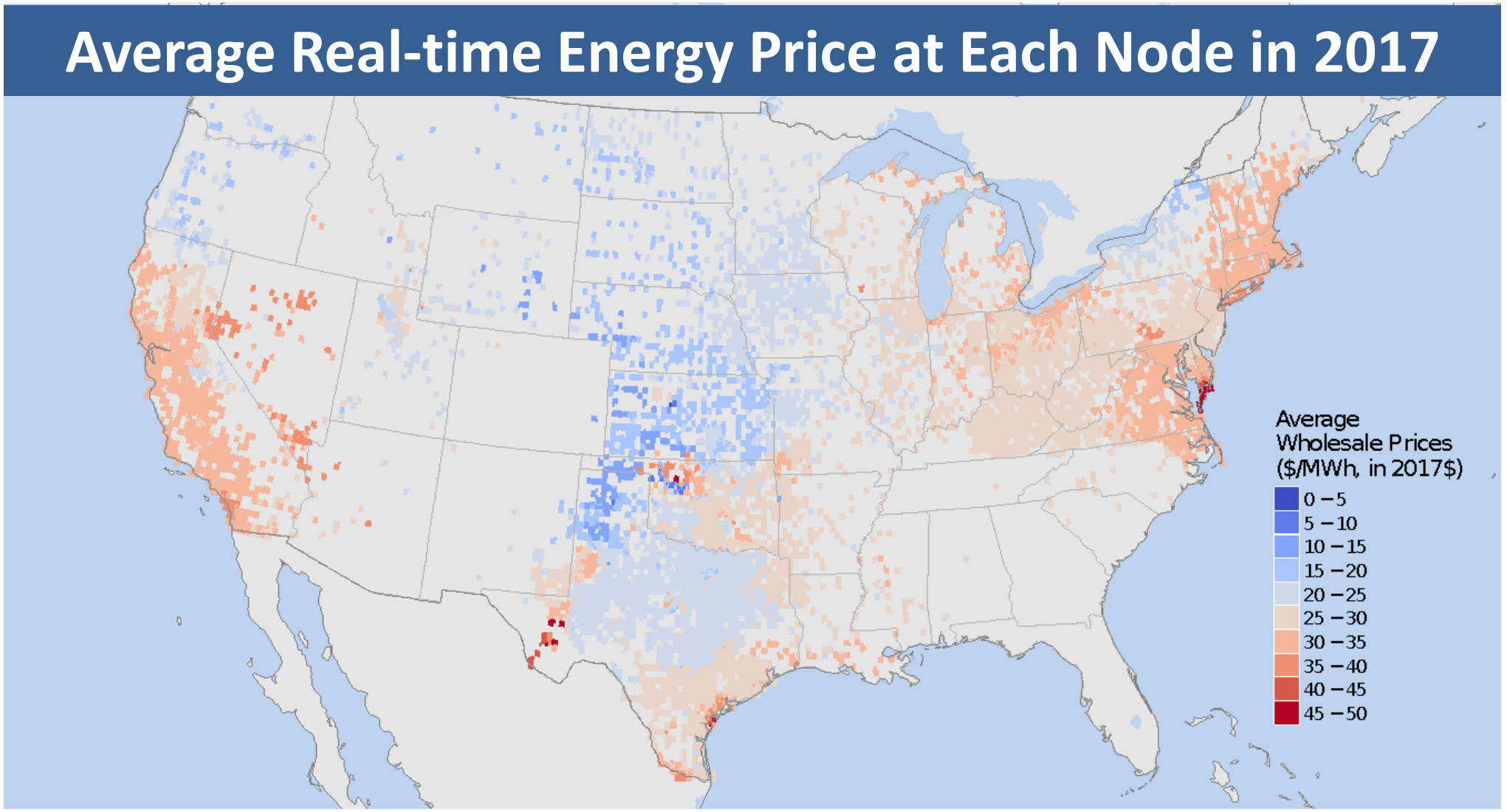
Based on Supply-Curve Model, Natural Gas Is Greatest Driver of Annual Average Wholesale Prices Across All Markets



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



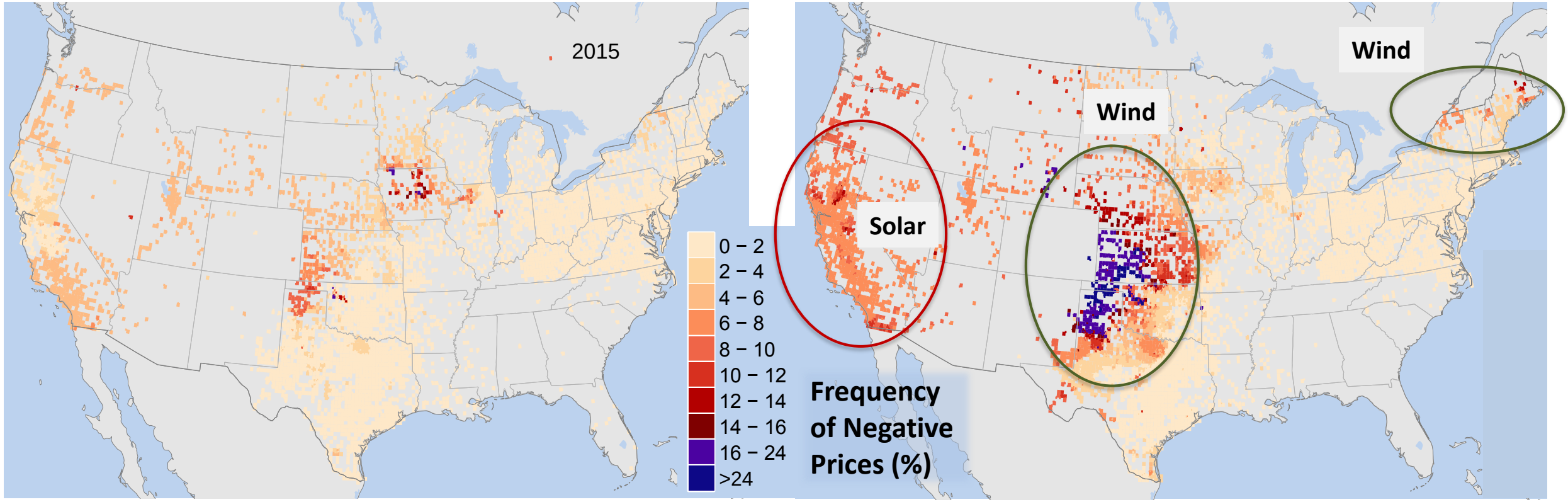
Market-Wide Average Prices Tell Only Part of the Story:
Thousands of Pricing Nodes, Each with Different Pricing Patterns



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

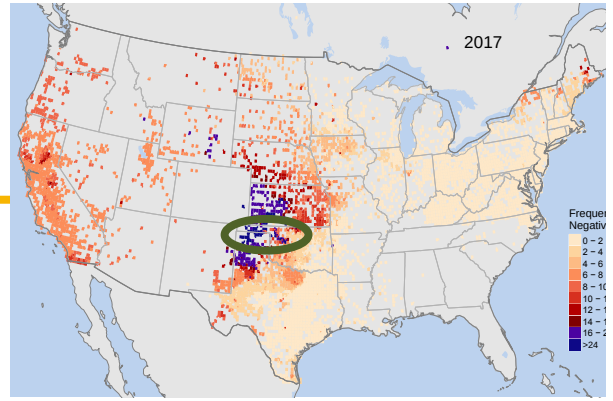
Negative prices, 2015

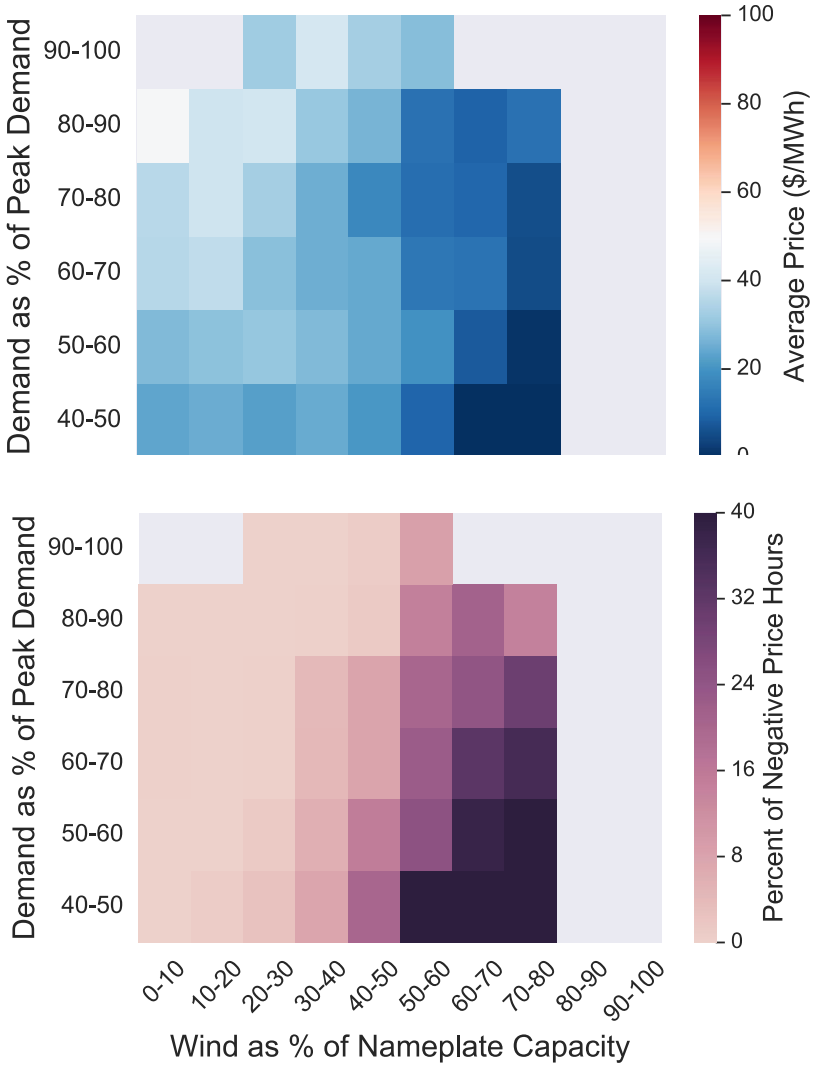
Negative prices, 2017



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

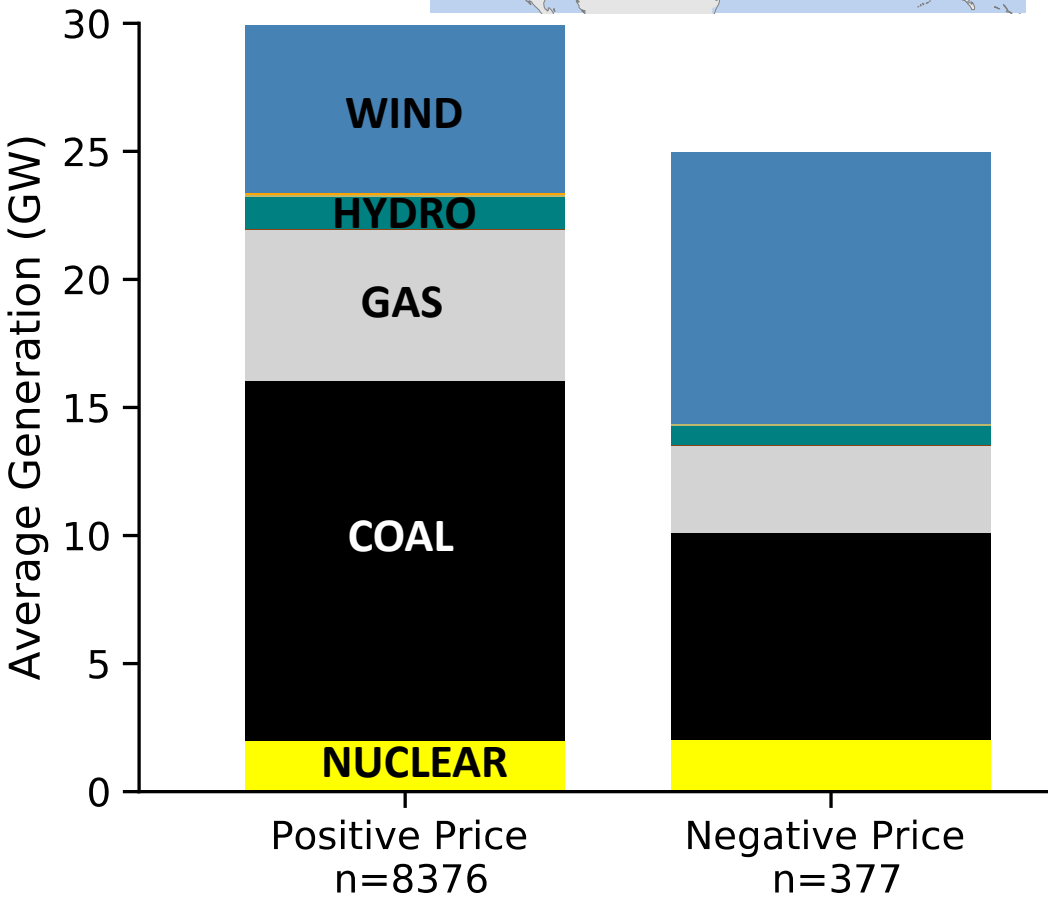
Illustrating the Impact of Wind Power: Oklahoma Hot Spot, 2017



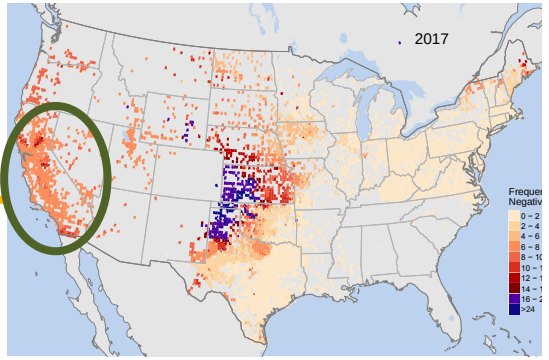


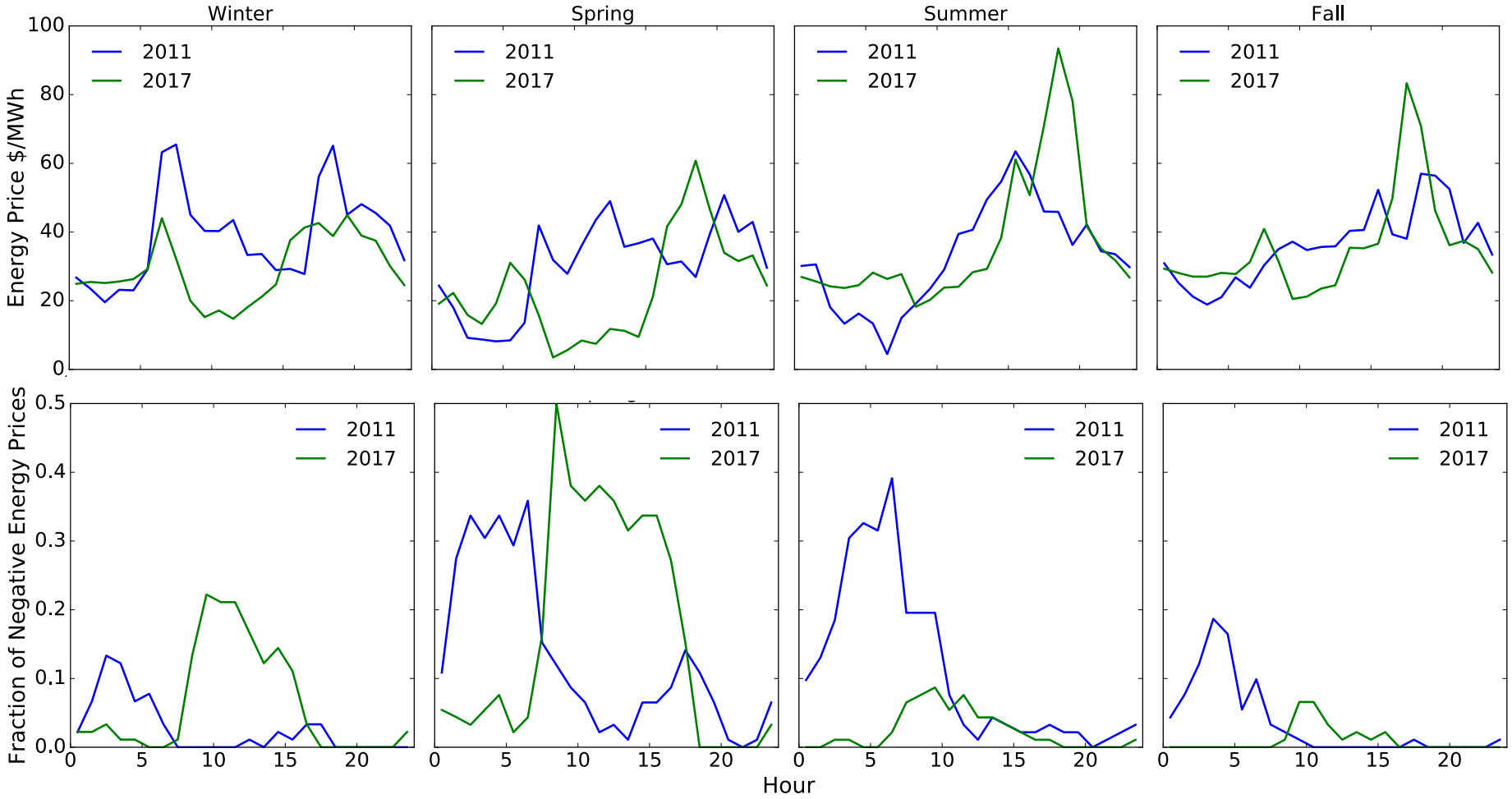
Average prices

Negative prices



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

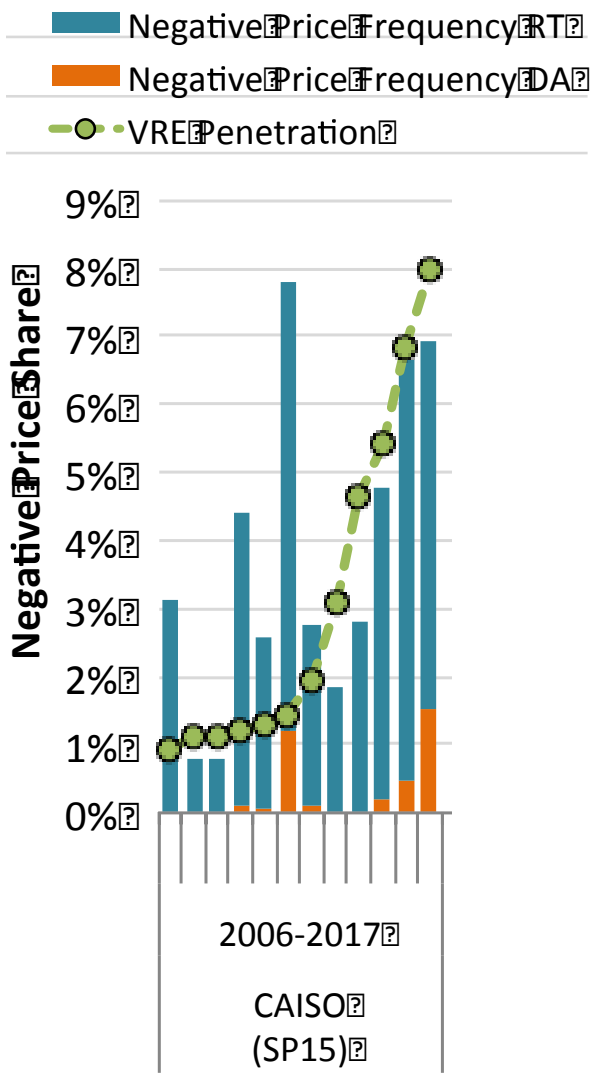




Average diurnal prices

Frequency of negative prices

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

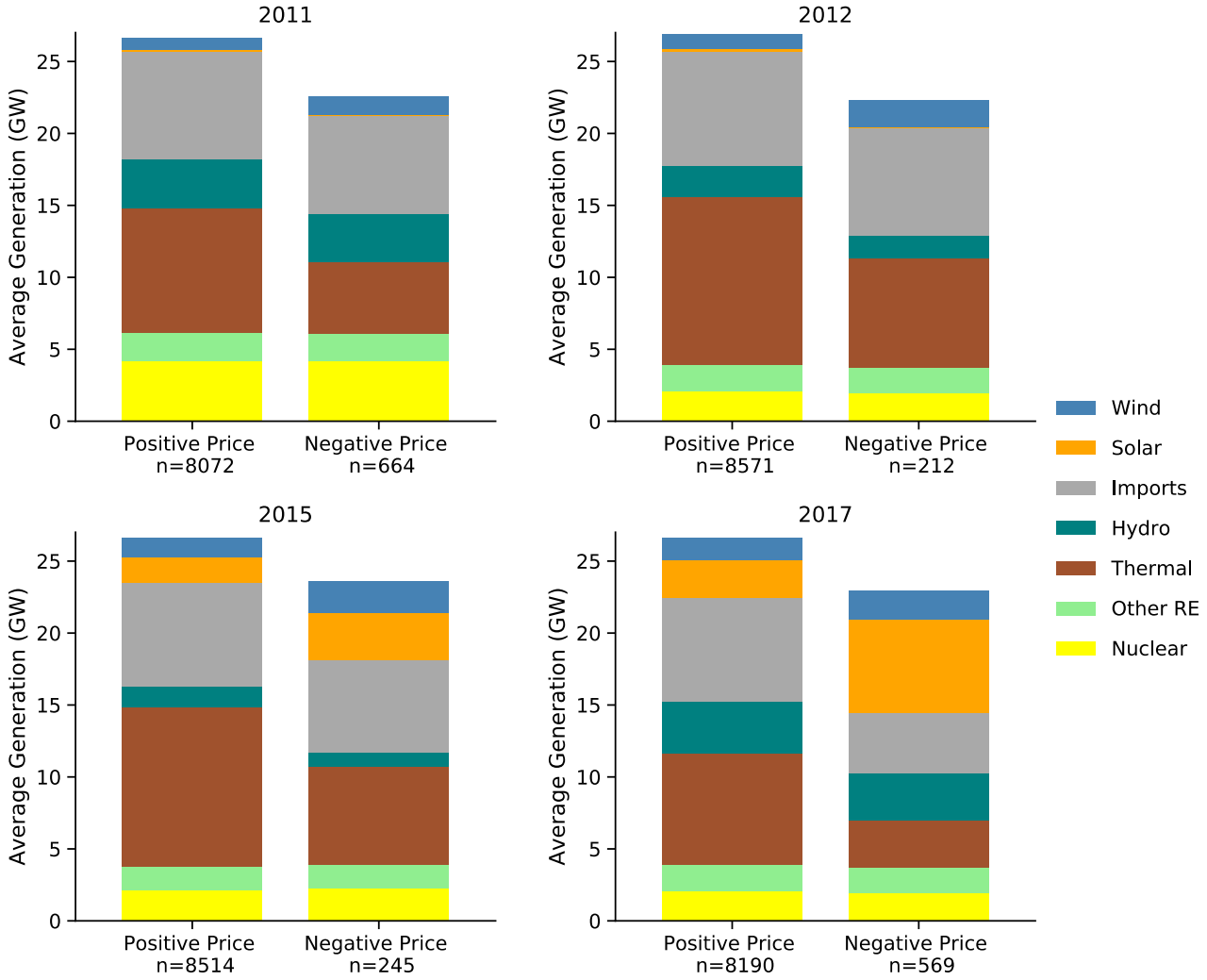


Contributing to negative prices:

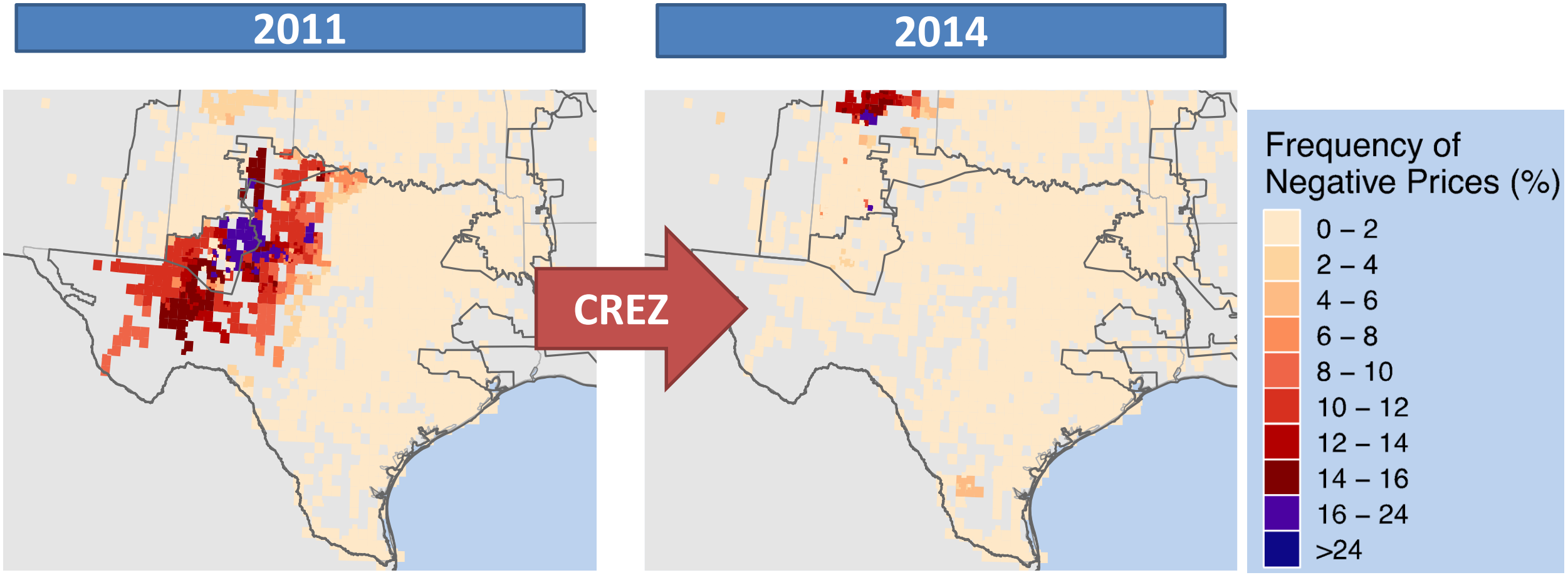
- high hydro in 2011 / '17
- inflexible nuclear
- must-run thermal

Mitigating negative prices:

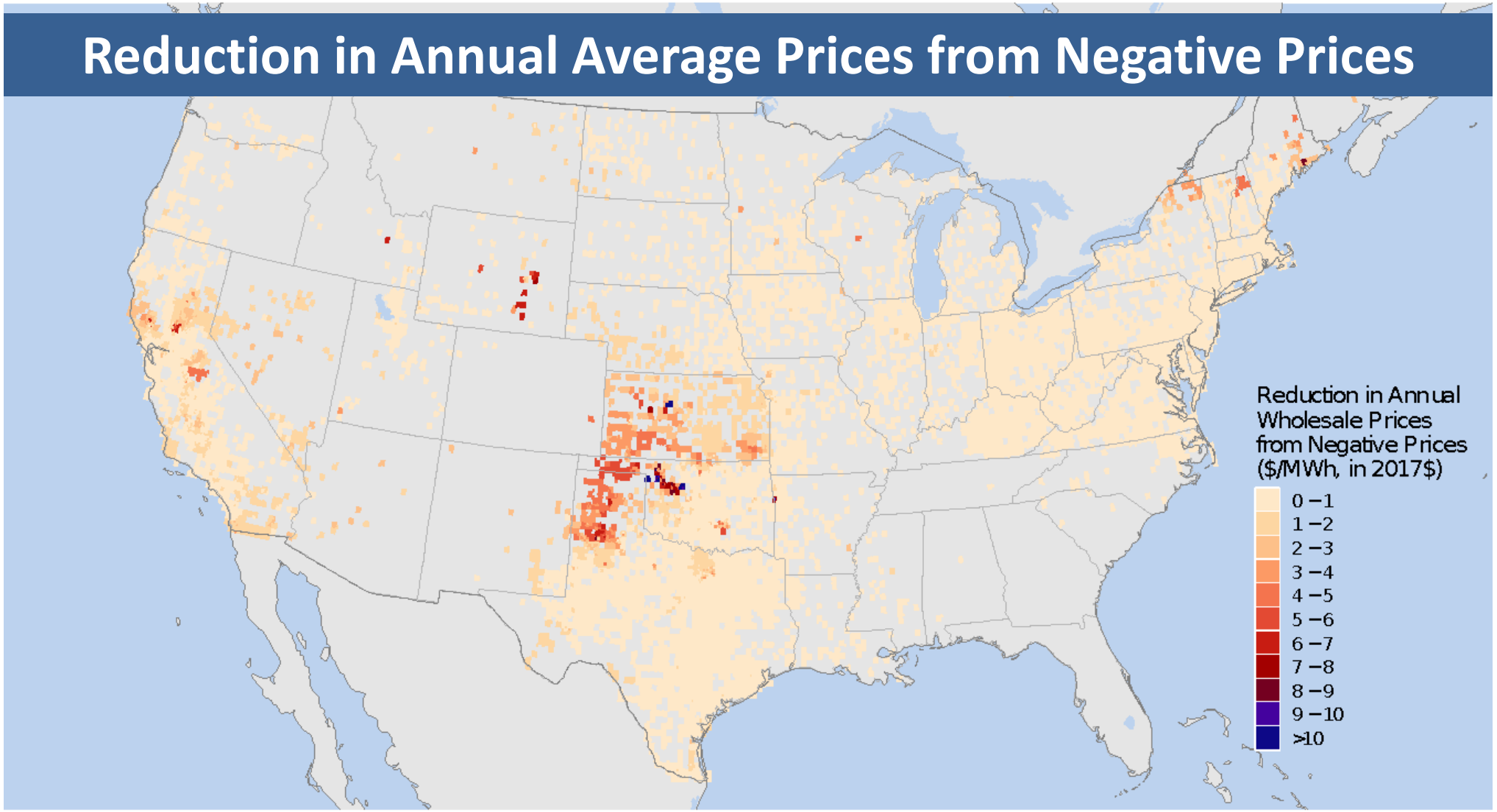
- nuc retirement in 2012
- more responsive imports by 2017
- more responsive thermal by 2017



Widespread Negative Pricing Need Not Always Be Permanent: Transmission Matters

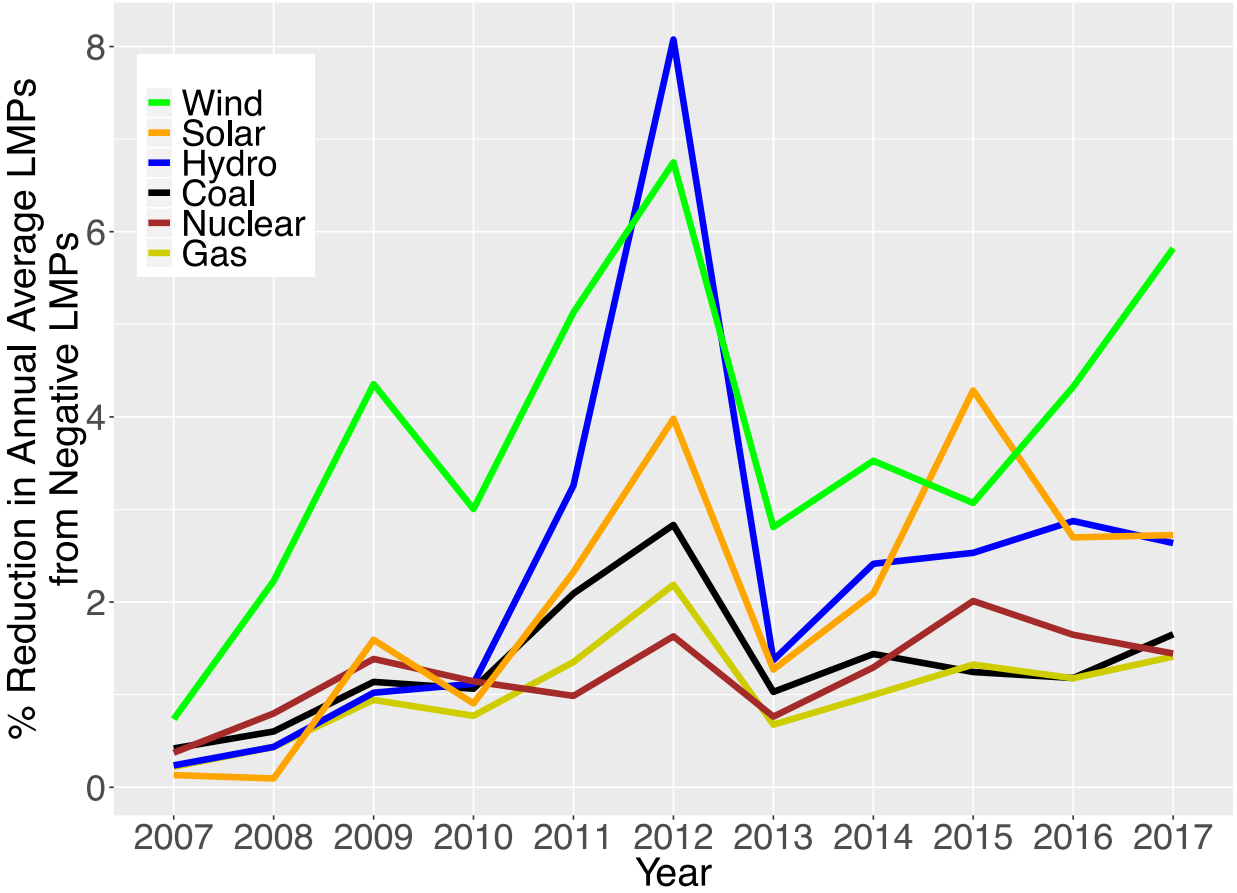


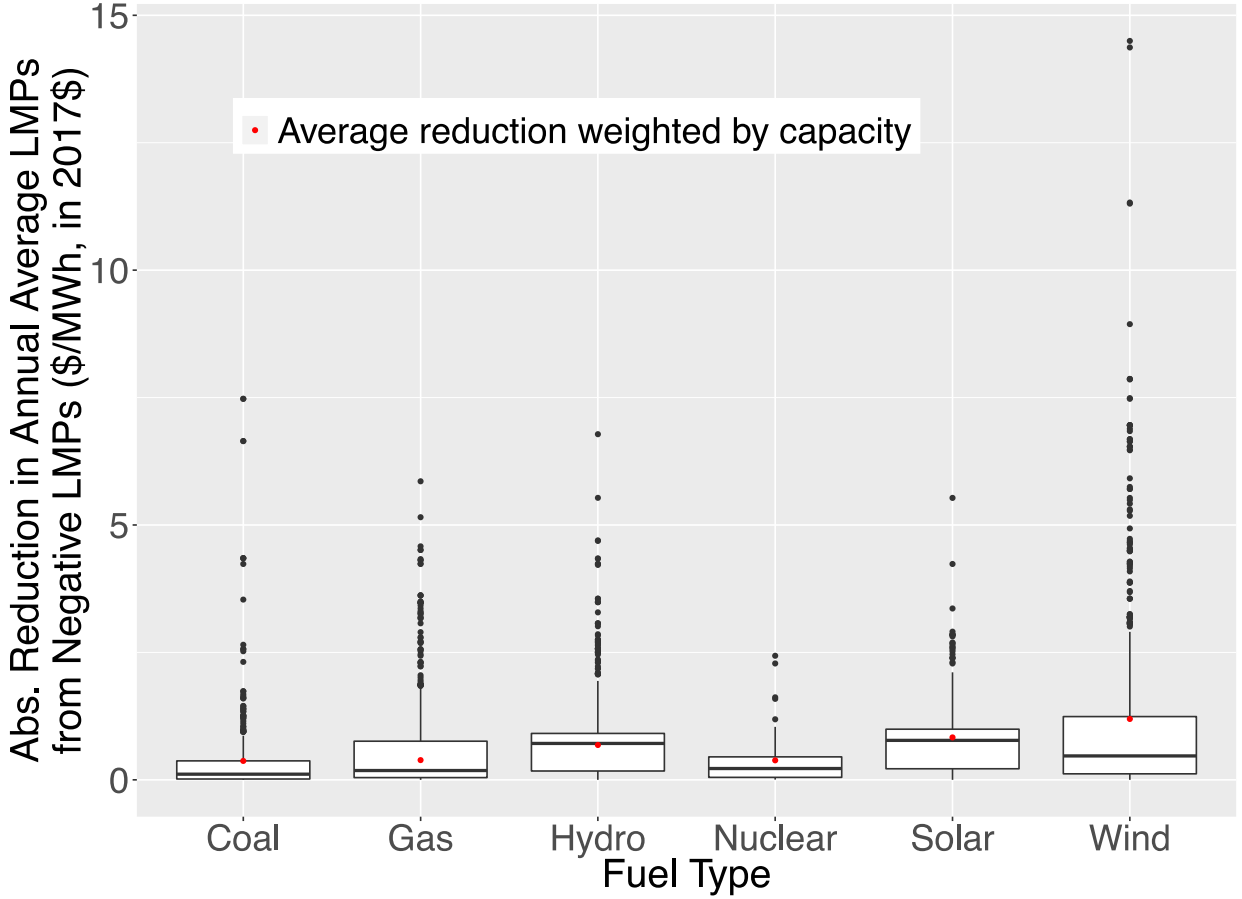
How Much Does it Matter? Impact of Negative Pricing on Annual Average Wholesale Prices



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?

- Contact the presenter
  - Andrew Mills
  - admills@lbl.gov
  - 510-486-4059
- Project team at Lawrence Berkeley National Laboratory:
  - Ryan Wiser
  - Dev Millstein
  - Joachim Seel

Download all of our work at:

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

Follow the Electricity Markets & Policy Group on Twitter:

@BerkeleyLabEMP

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

Simple Supply-Curve Model to Quantify the Drivers of Average Wholesale Prices

- Hourly prices estimated from the intersection of supply and demand, then averaged over the year
- Supply curves are based on individual thermal unit capacity, heat rate, and fuel cost (natural gas cost varies daily, other fuel costs are constant for the year)
  - Simple supply curve ignores numerous real constraints on thermal unit dispatch
- Demand is the hourly load less hourly wind, solar, hydro, and import profiles
- Relative contribution of factors to observed price decline is estimated by keeping all factors at 2017 levels, then changing one at a time to 2008 levels
- Interaction term: Non-linear relationships between factors and wholesale prices means that the sum of individual contributions is not the same as change in prices when changed simultaneously
- Additional details in Appendix A: https://emp.lbl.gov/publications/impacts-variable-renewable-energy