Impacts of Variable Renewable Energy (VRE) on Wholesale Power Markets

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Presentation Based on Two Recent / Ongoing Berkeley Lab Research Efforts

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Impacts of Variable Renewable Energy on Bulk Power System Assets, Pricing, and Costs

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Impacts of High Variable Renewable Energy Futures on Electric-Sector Decision Making

Authors:

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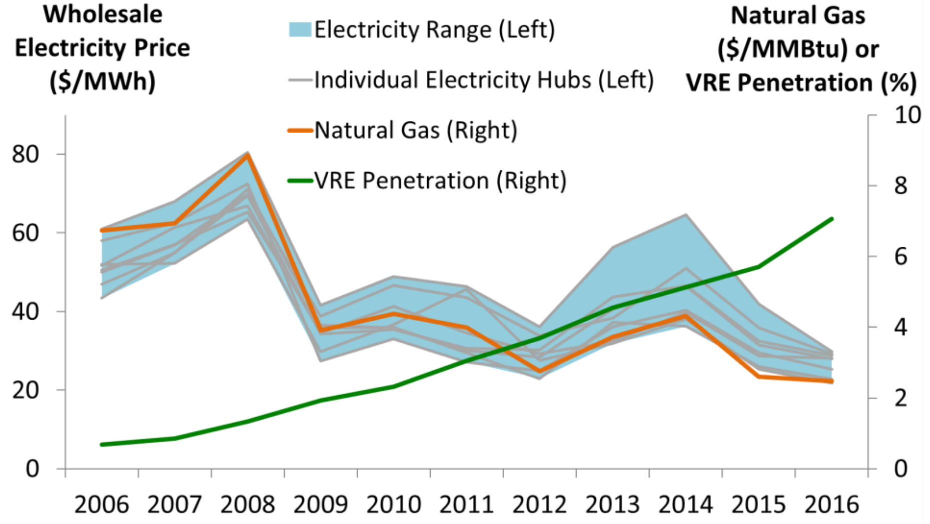
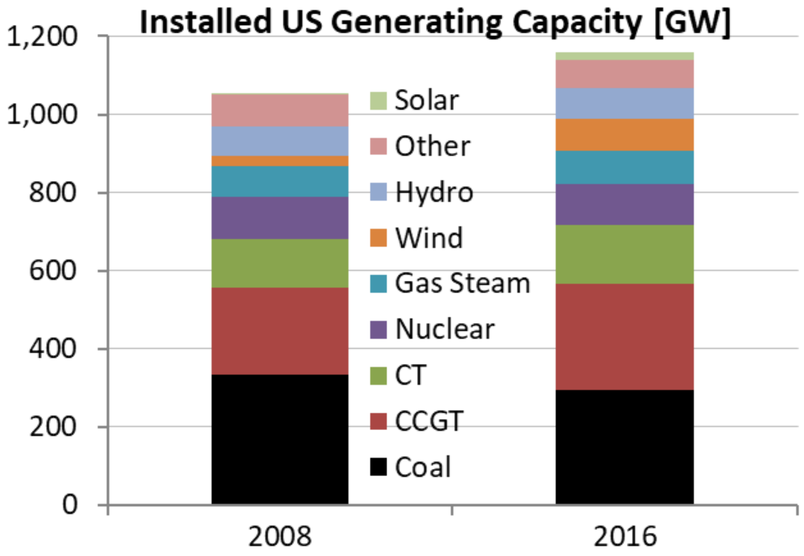
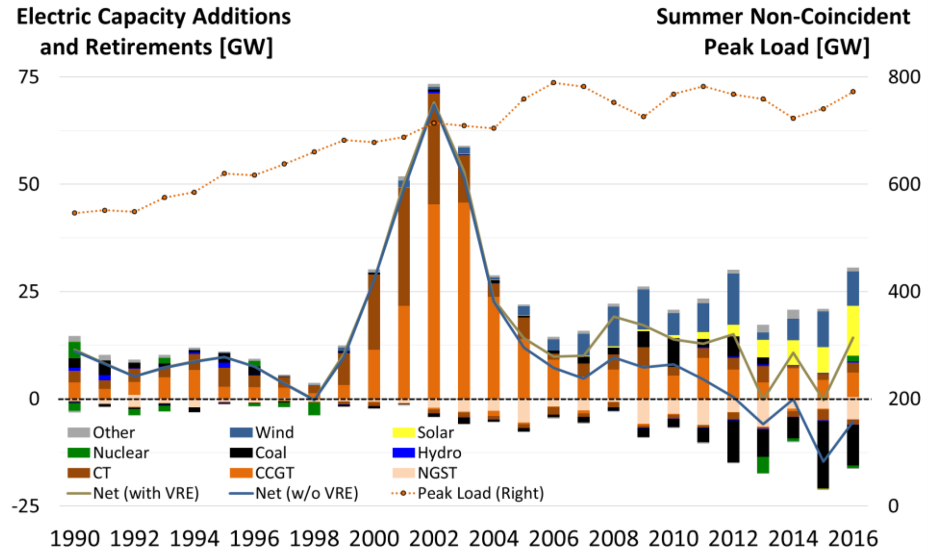
Forthcoming

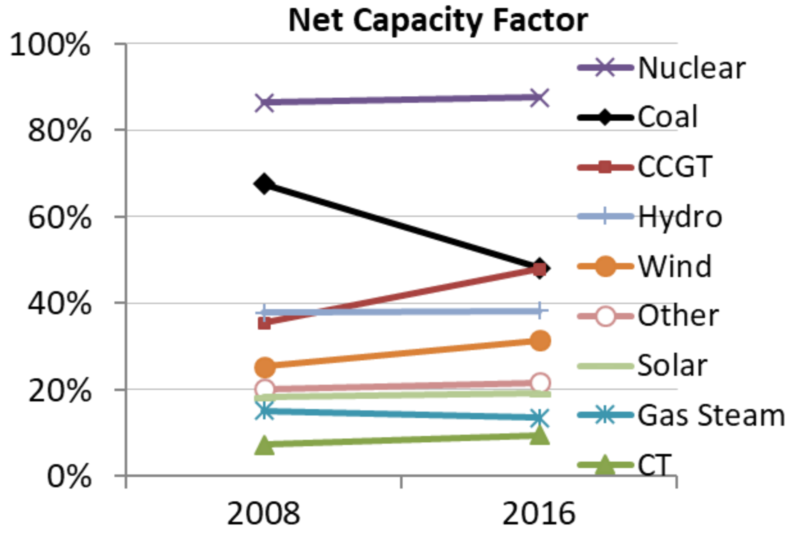
This project is funded by the Office of Energy Efficiency and Renewable Energy (Strategic Programs Office) of the U.S. Department of Energy

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

<u>Pertinent Baseline Questions</u>

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

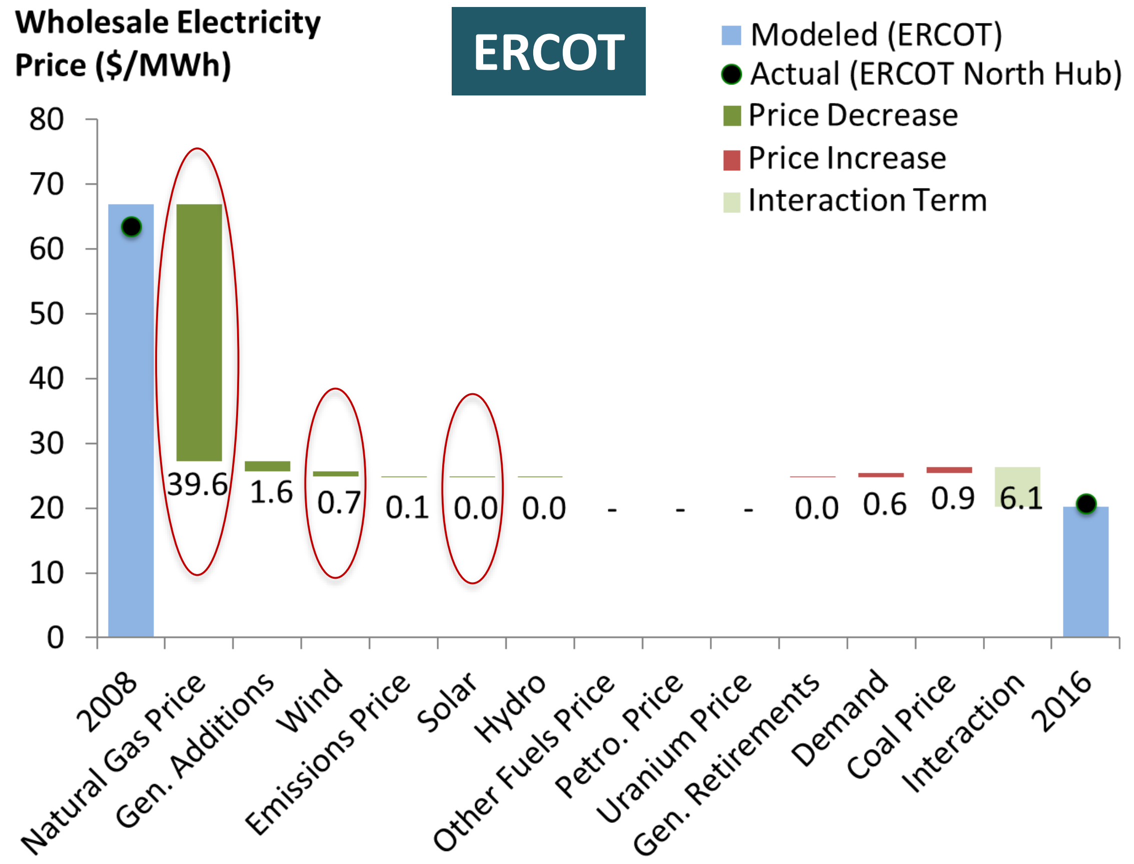
(2) **How might the impacts grow** in the future?

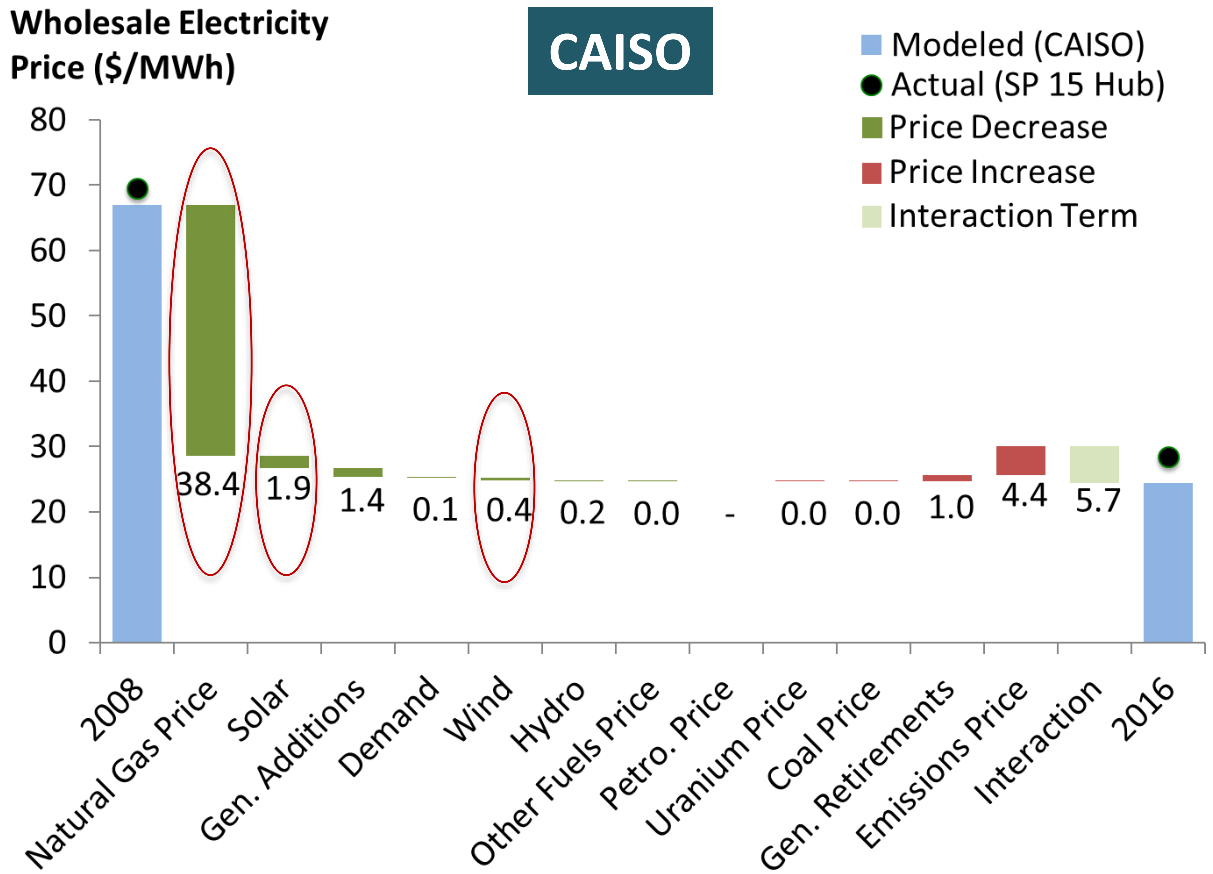
(3) What **affects** might these changes have **on market design, and various supply- & demand-side assets**, including VRE?

Part 1:
Historical Observed Impacts of VRE on U.S. Wholesale Power Prices and Plant Retirements

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 2016, in part due to relatively flat supply curve





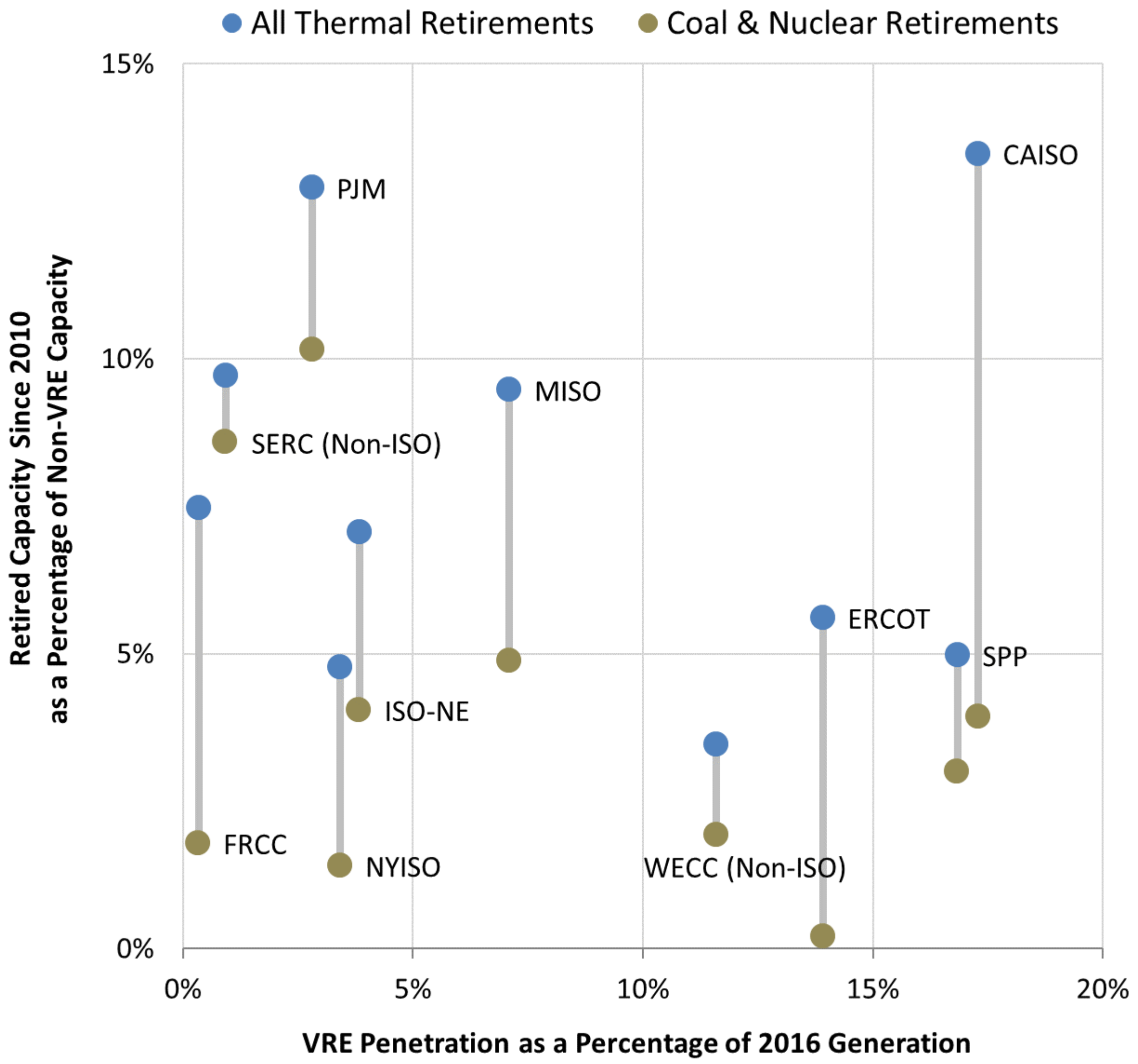
Used simple fundamental "supply curve" model to estimate wholesale prices in 2016 and 2008; see details in full report and appendix

VRE Has Not Been a Primary and Widespread Driver for Thermal-Plant Retirements Thus Far

Based on simple correlations, the strongest predictors of regional retirement variations include SO_2 emissions rates, planning reserve margins, variations in load growth / contraction, and the age of thermal plants.

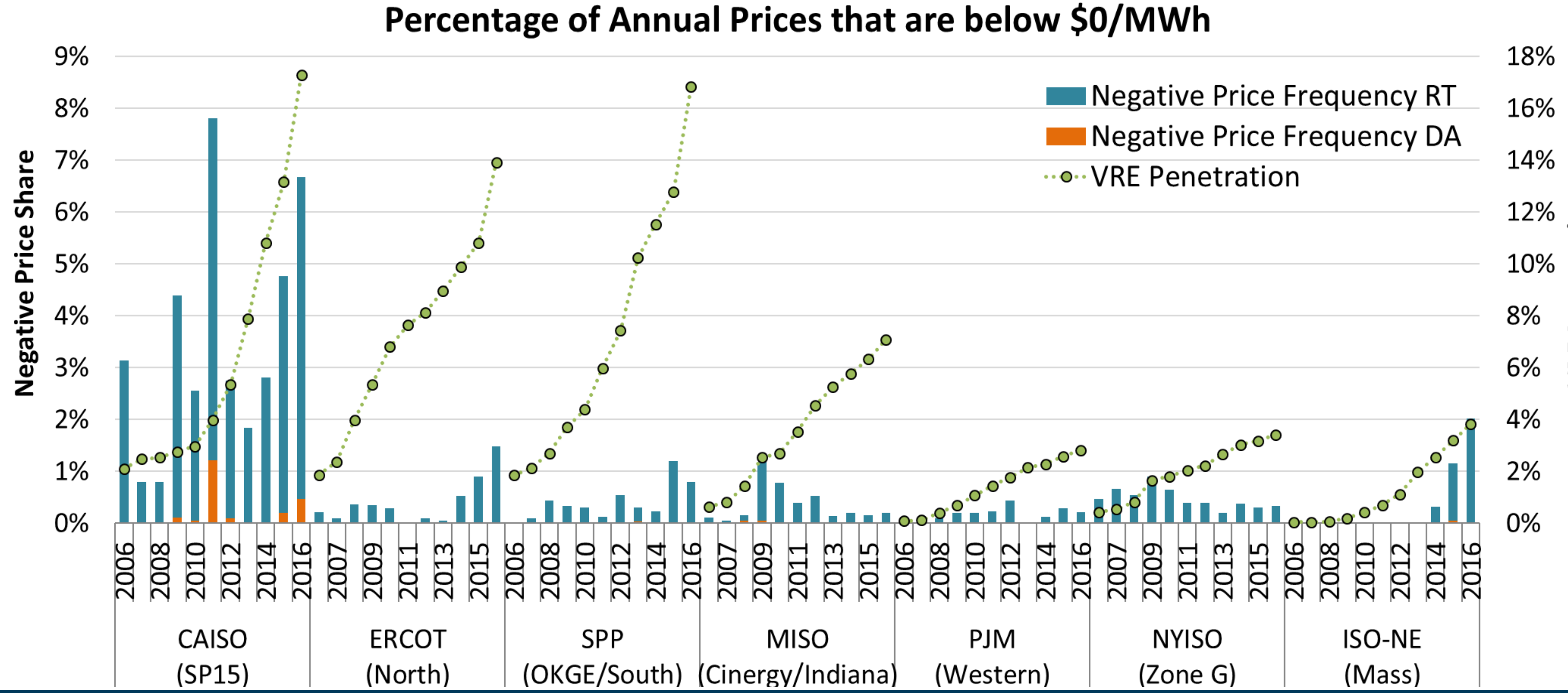
Additional predictors include the ratio of coal to gas prices and delivered natural gas prices.

Other factors appear to play lesser roles: VRE penetration, recent non-VRE additions, and whether the region hosts an ISO.



Negative Prices at Many Large Trading Hubs are Rare, but Increasing in Some Areas with VRE

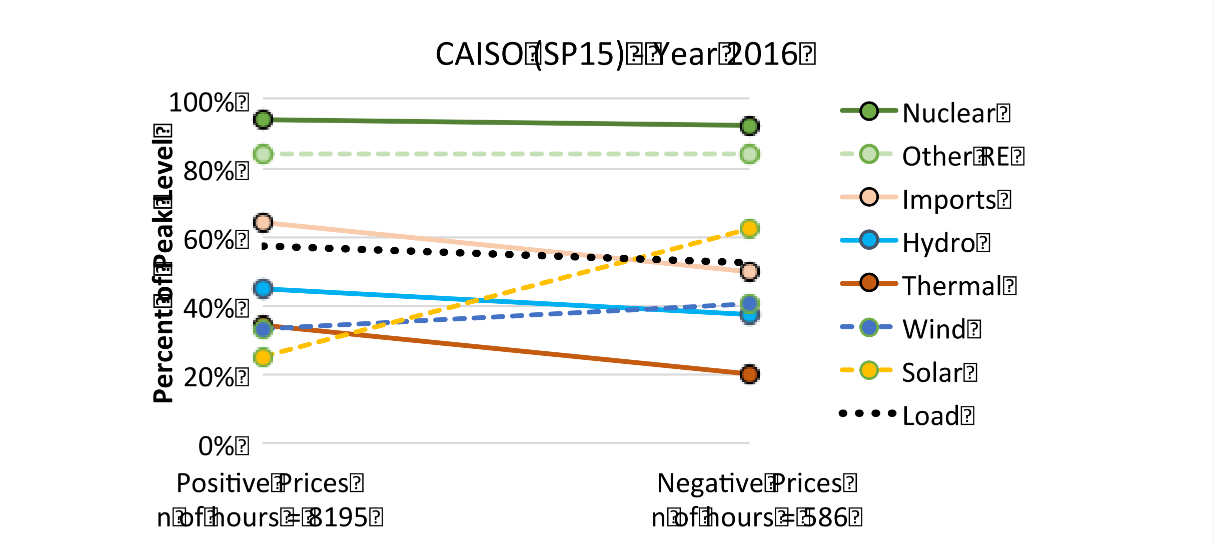
CAISO is unique in high frequency of negative prices (real time prices 6% lower in 2015 due to negative prices, 3% in 2016); VRE appears to play a role, but not exclusively

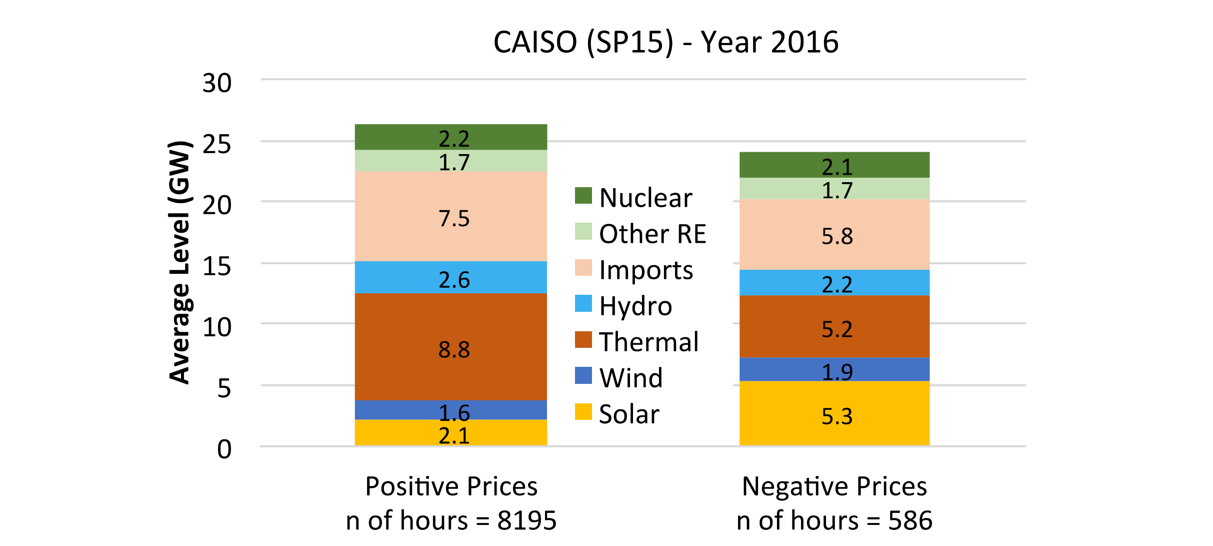


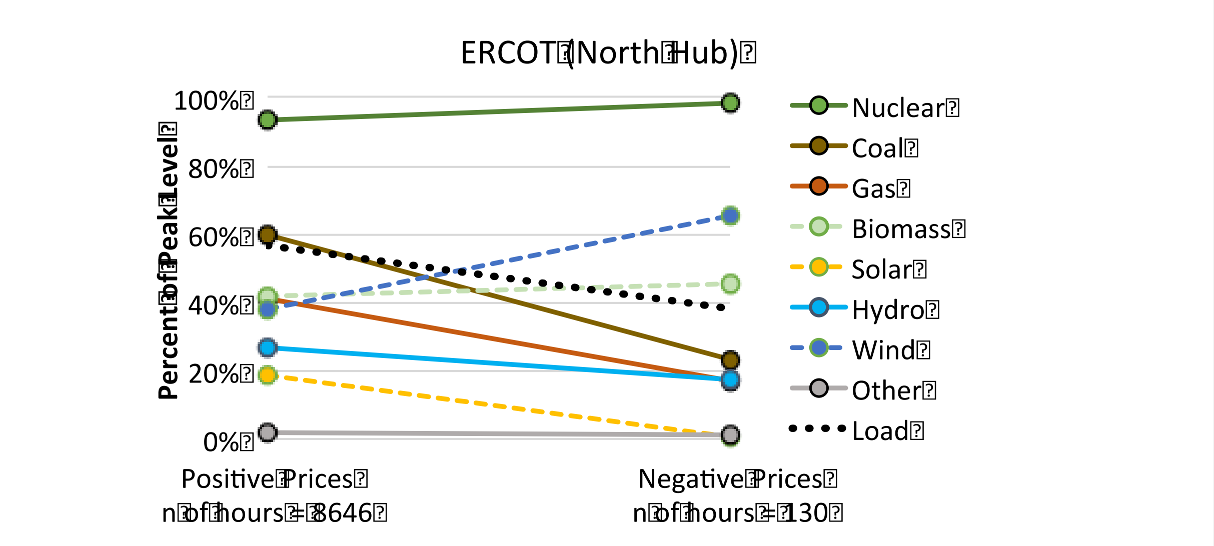
Focuses on selected major trading hubs

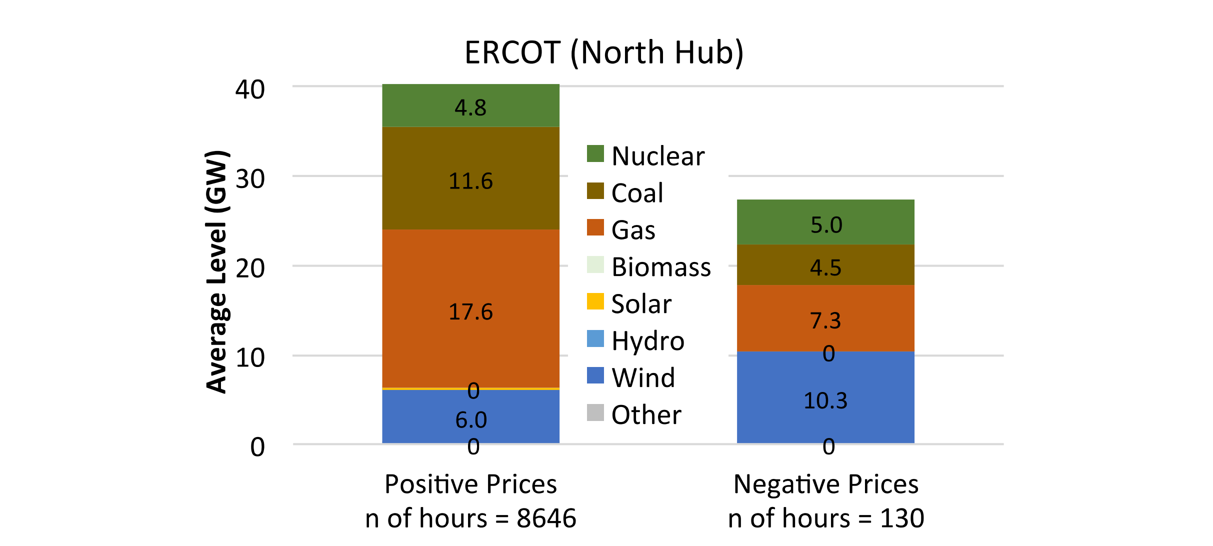
Negative prices almost non-existent in day-ahead market (though lower average real-time prices may also lower average day-ahead prices)

VRE and Other Inflexible Generation Contribute to Negative Price Events, Often in Concert w/ Low Load & Constrained Transmission







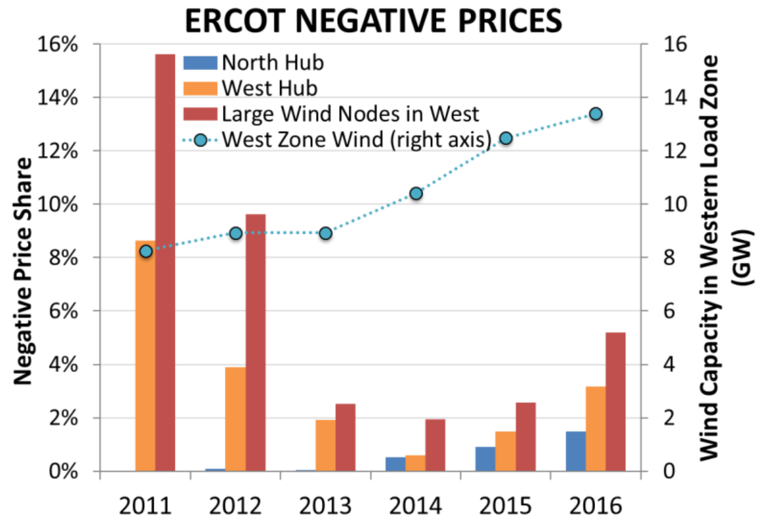


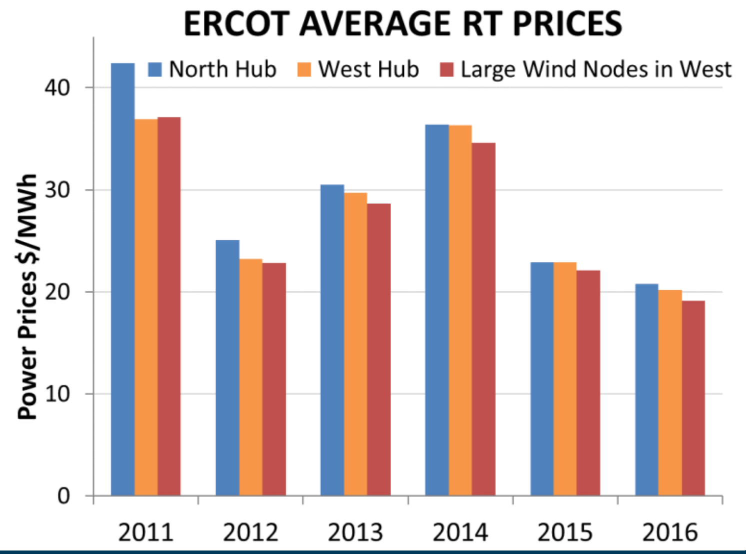
Focuses on selected major trading hubs

Larger Impacts In Constrained Pricing Zones: Focus on West Texas and Northern Illinois

Major trading hubs do not reveal the full story

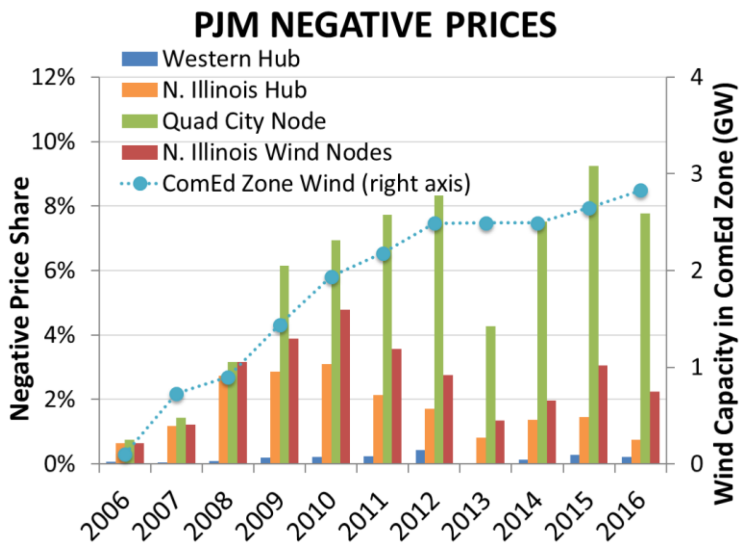
Transmission limits between where generation is located and load centers can lead to congestion and a higher prevalence of negative prices

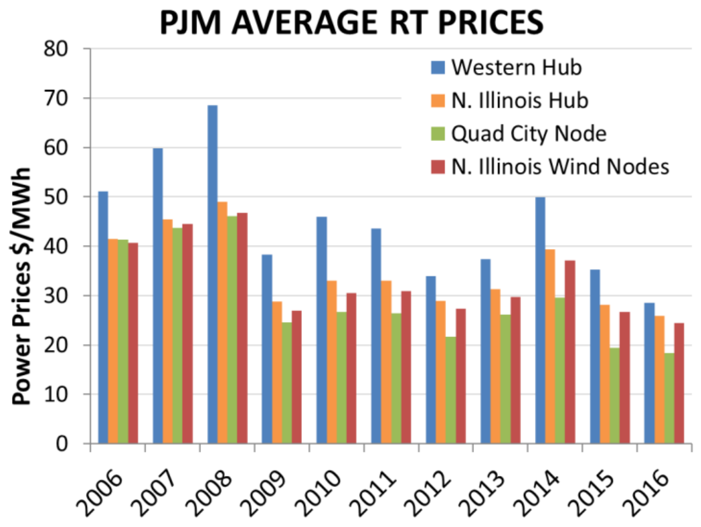




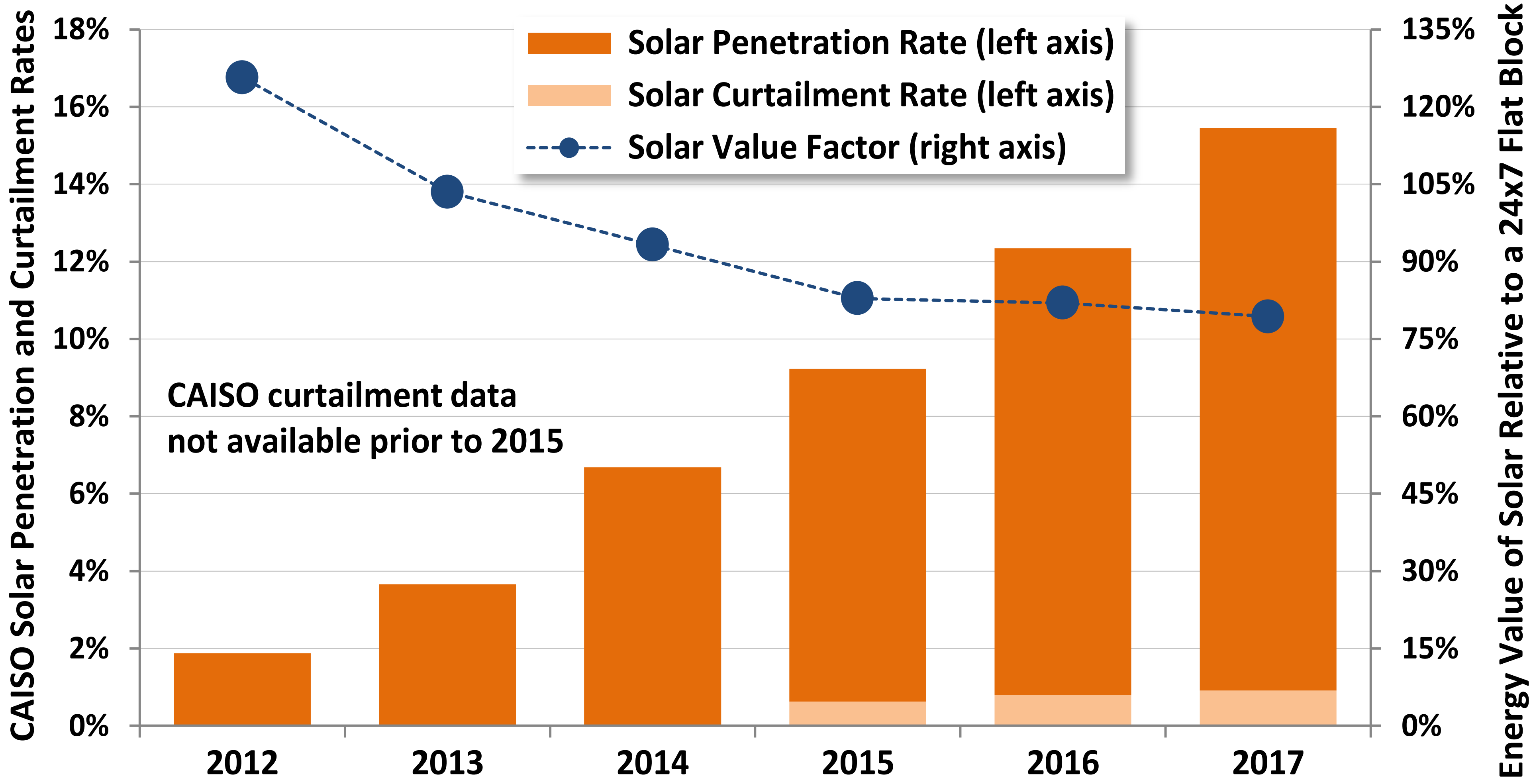
Negative prices more common in W. Texas and Quad City

Average annual prices also lower in constrained zones





Changes in Price Patterns from VRE Beginning to Impact 'Market Value' of VRE in Some Locations



- In largest US solar market, relative wholesale market energy value has declined by ~50%-points since 2012
- Some stabilization in "value factor" since 2015
- Overall decreasing wholesale prices have also lowered market value

Part II:

Future Impacts of VRE on Wholesale Prices, and Related Impacts on 'Market Value' of VRE and Net Revenue of non-VRE Generation Technologies (and Other Demand- and Supply-Side Investments)

-- draft results --

Research Objective

Will electric-sector decisions based on past assumptions still achieve their intended objective in high VRE futures given impacts of VRE on wholesale power markets?

Demand-Side Decisions	Supply-Side Decisions
Choice of Energy Efficiency Portfolios	Incentives for Nuclear Revenue Sufficiency, Flexibility Retrofits
Appliance Standards Promoting Electric or Gas Water Heaters	Investing in Combined Cycle Gas Turbines or Reciprocating Engines
Location Choices of EV Charging Infrastructure	Cost-Effectiveness of Energy Storage and Capability Selection
Advanced Commodity Production Processes	Hydropower Relicensing under Alternate Water Flow Regimes
Demand Response Service Design	
Retail Rate Design	

Impacts on VRE Assets

- Shifts in location to areas that are better aligned with high-priced hours
- Change in project design to maximize value instead of energy production
  - solar: higher ILR, SW orientation
  - wind: larger rotors, taller towers
  - VRE + storage
- Change in investments decisions between wind and solar
- Change in operations and contractual structures, allocation of pricing risks

For this presentation, focus on possible impacts on wholesale electricity prices, and on related market value of VRE and net revenue of non-VRE generation assets

Research Design for Assessment of Wholesale Market Outcomes in 2030

Four Regions

ERCOT | SPP | CAISO | NYISO

Low VRE in 2030

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

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)

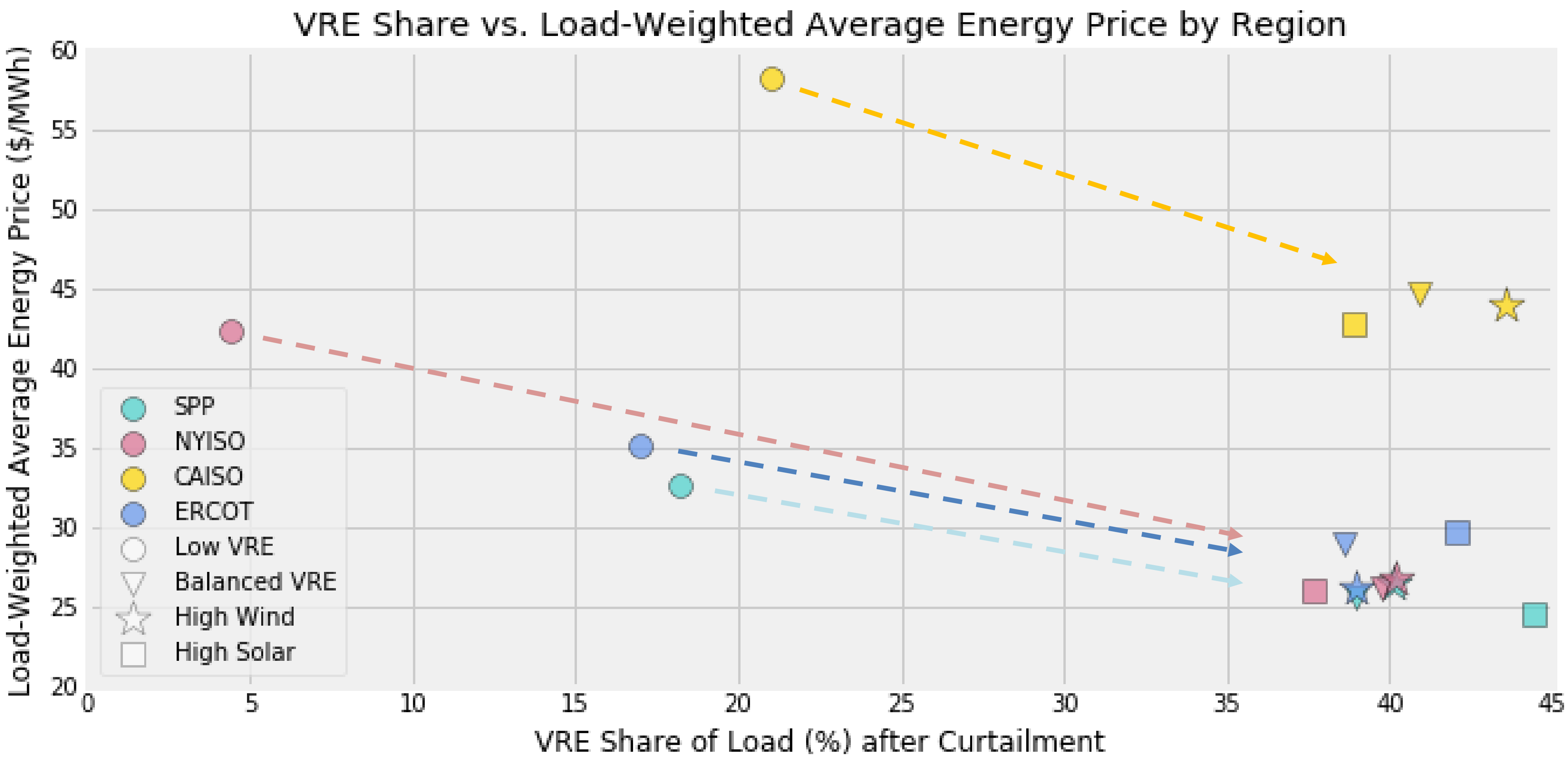
LCG UPLAN and Gen-X Models

- Capacity expansion model (Gen-X) to establish non-VRE 2030 generation portfolio based on social cost minimization
- Market simulation model (UPLAN) co-optimizes hourly energy and ancillary service prices; extract capacity prices and CO_2 emissions
- Market designs assumed to be roughly similar to those in place today in each region
- Limit price distortion through leakage to neighboring markets; limit price effects that are primarily transmission congestion related

Two cases for High VRE scenarios: with 'balanced' capacity equilibration and without (focus here is with equilibration)

Performed "marginal" assessment of wholesale market value using marginal prices; assumes limited 'effect mitigation'

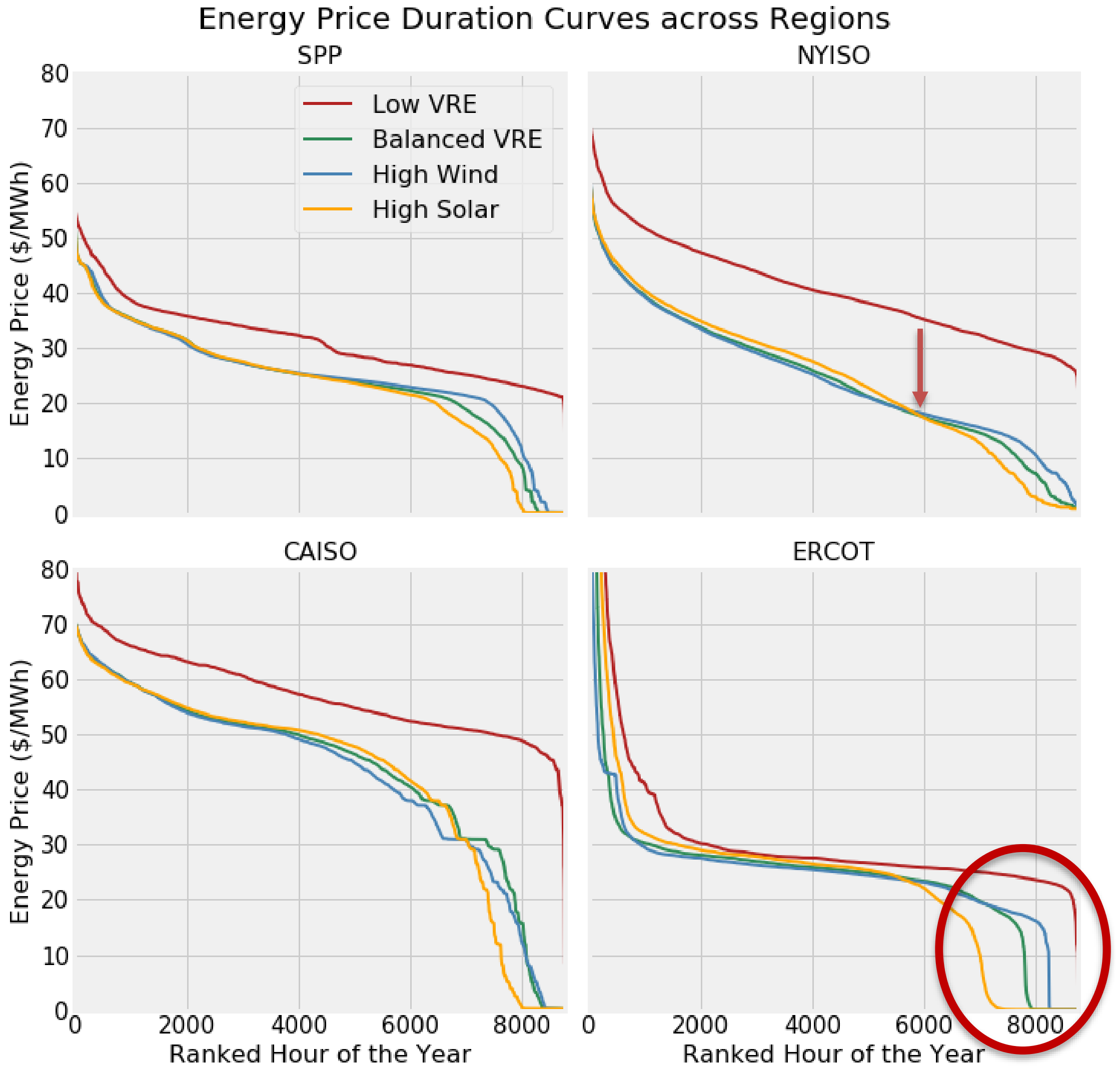
Increasing VRE to ≥40% is Projected to Decrease Average Annual Wholesale Energy Prices by $5-16/MWh

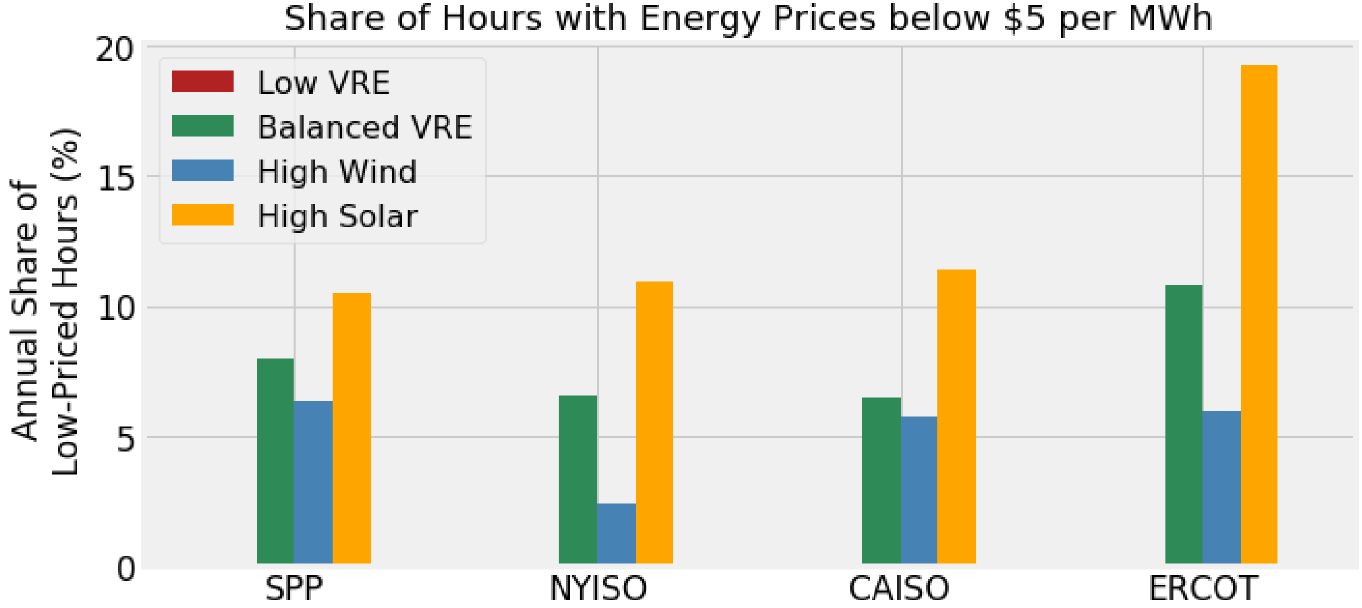


Avg. reduction in energy price of \$0.2-\$0.85/MWh for each % of VRE penetration *(consistent with past literature)*

Reduction similar without capacity equilibration in most scenarios

Signals for Flexibility: Low Energy Prices Become More Common under High VRE Scenarios

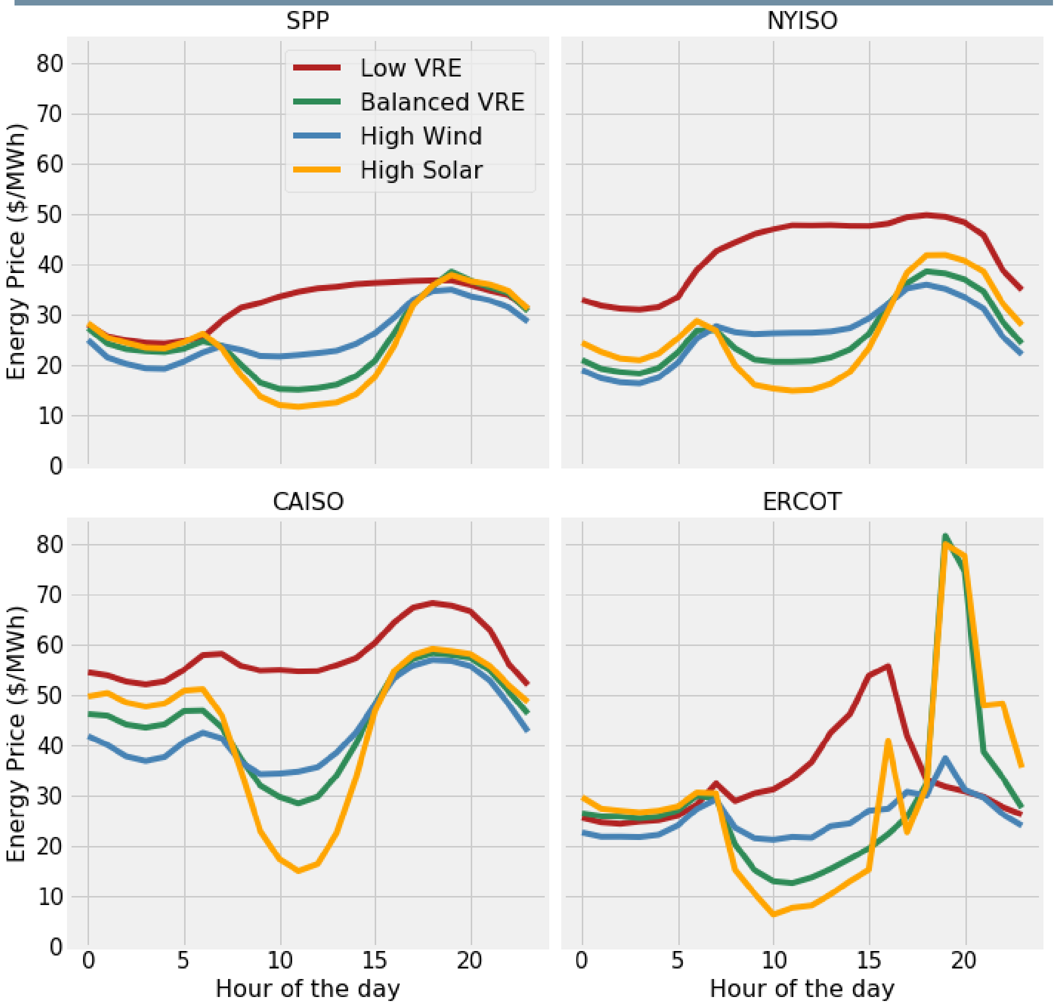




- In some regions, the shape of the price distribution curve does not change dramatically but is merely shifted downwards (e.g. NYISO)
- Other regions feature a more pronounced ‘cliff’, featuring a dramatic increase in hours with very low prices (e.g. ERCOT)
- Low prices driven by **solar** more than **wind**

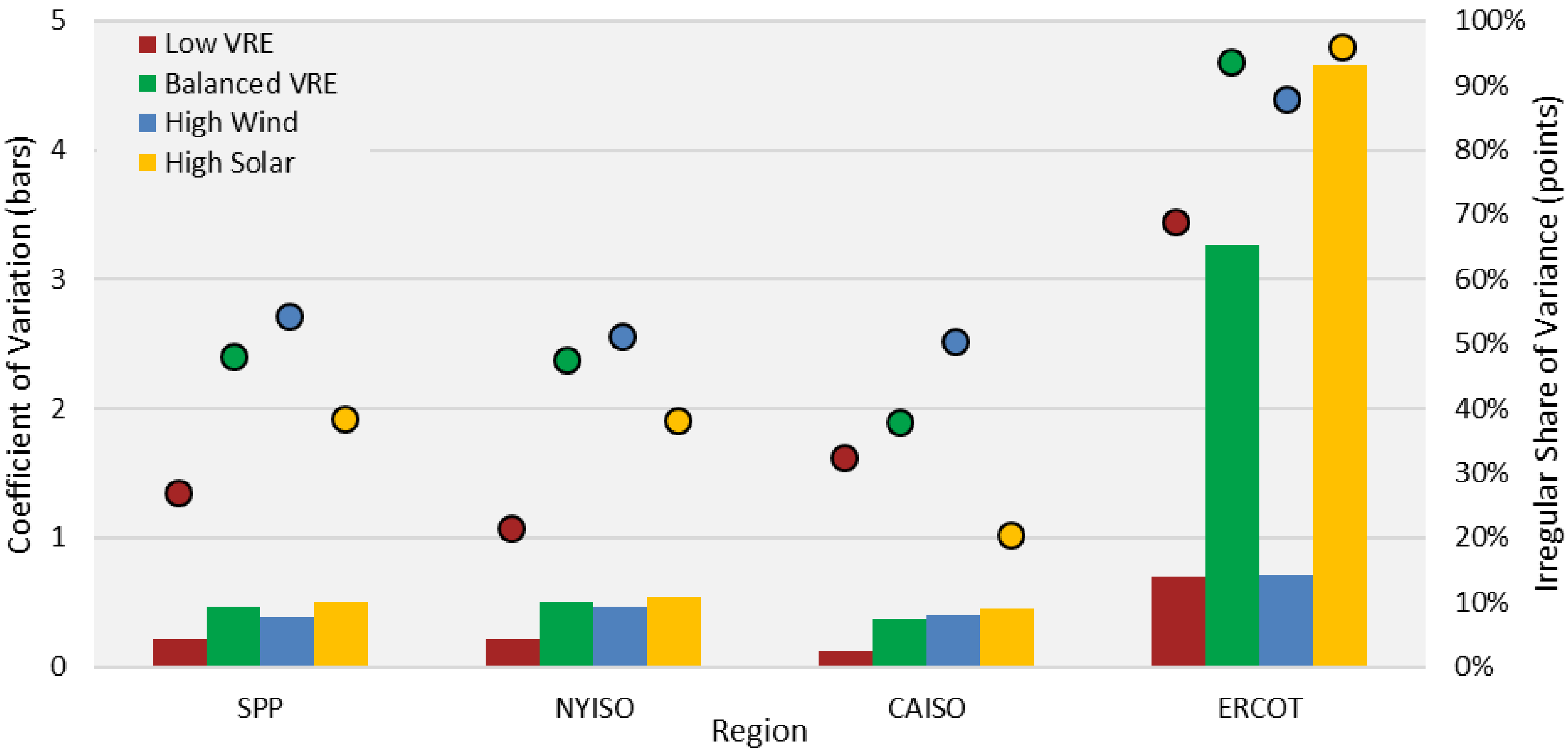
High VRE Significantly Alters Diurnal Price Profiles, Particularly With High Solar

Mean Diurnal Profiles for Weekdays



- Substantial decrease in prices in the middle of the day in **solar** scenarios across all regions
- Diurnal profiles vary by season
  - **Morning:** **wind** vs **low VRE** scenario in CAISO:
    - -$25/MWh in Spring, -$10/MWh in Fall & Winter
  - **Afternoon:** **solar** vs **low VRE** scenario in NYISO:
    - -$30/MWh in Spring & Summer, -$15/MWh in Winter
  - **Evening:** **balanced** / **solar** vs **low VRE** in ERCOT:
    - +$180/MWh in Summer (driven by few high-priced hours), +$5/MWh in Winter
- Price peaks remain across most seasons in the early evening at levels similar to **low VRE** scenario

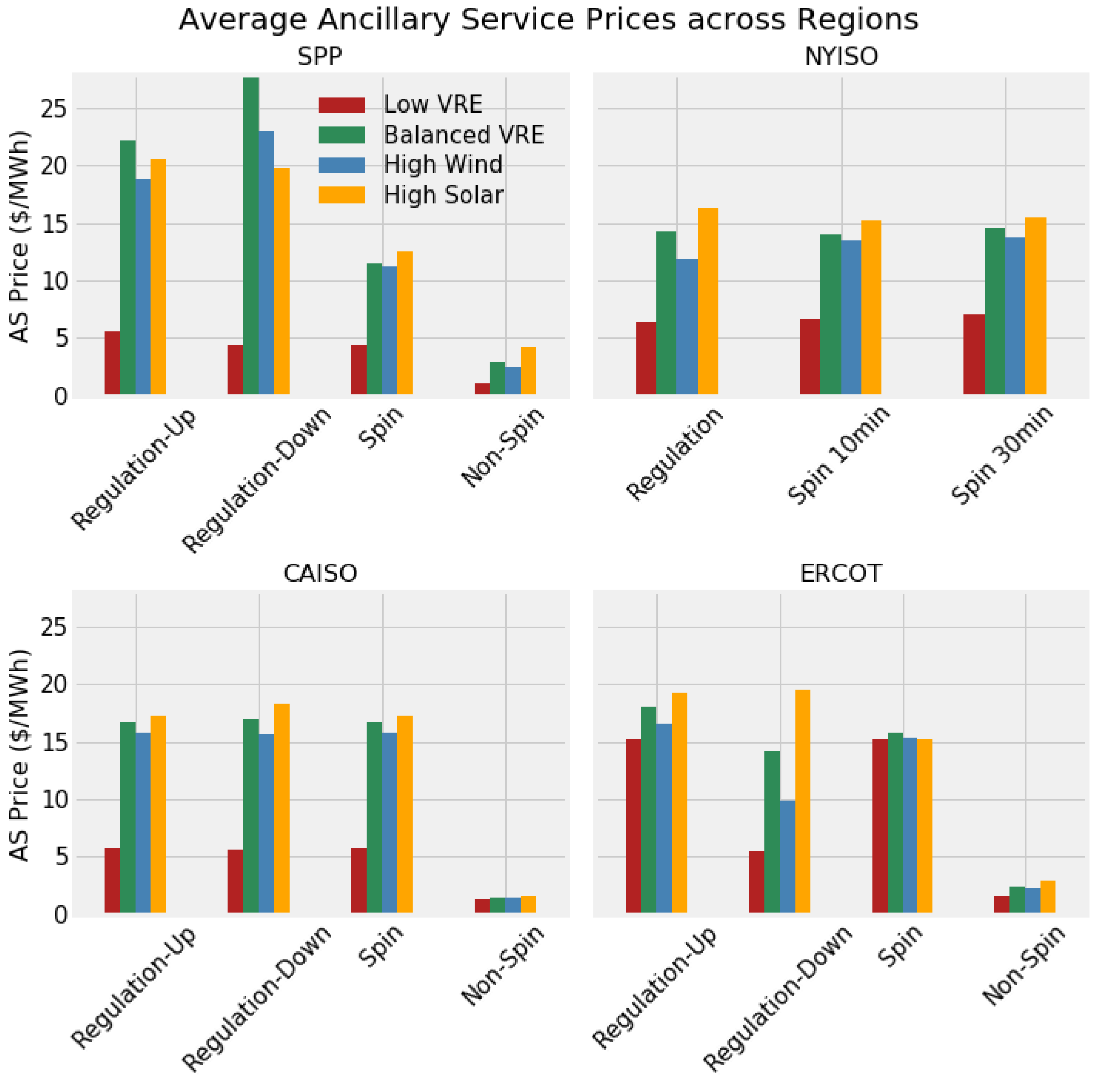
High VRE Increases Price Volatility; Prices Are Most Irregular with High Wind



Coefficient of Variation is normalized standard deviation of prices to facilitate cross-region comparison

- Absolute price volatility increases with VRE, affected by **solar** more than **wind**
- Volatility created by **solar** is—to a greater extent—explained by regular diurnal, weekly, and seasonal shifts; **wind** has greater 'irregular' volatility
- High volatility in ERCOT in part due to few high priced hours ($1000-$9000/MWh) due to Operating Reserve Demand Curve

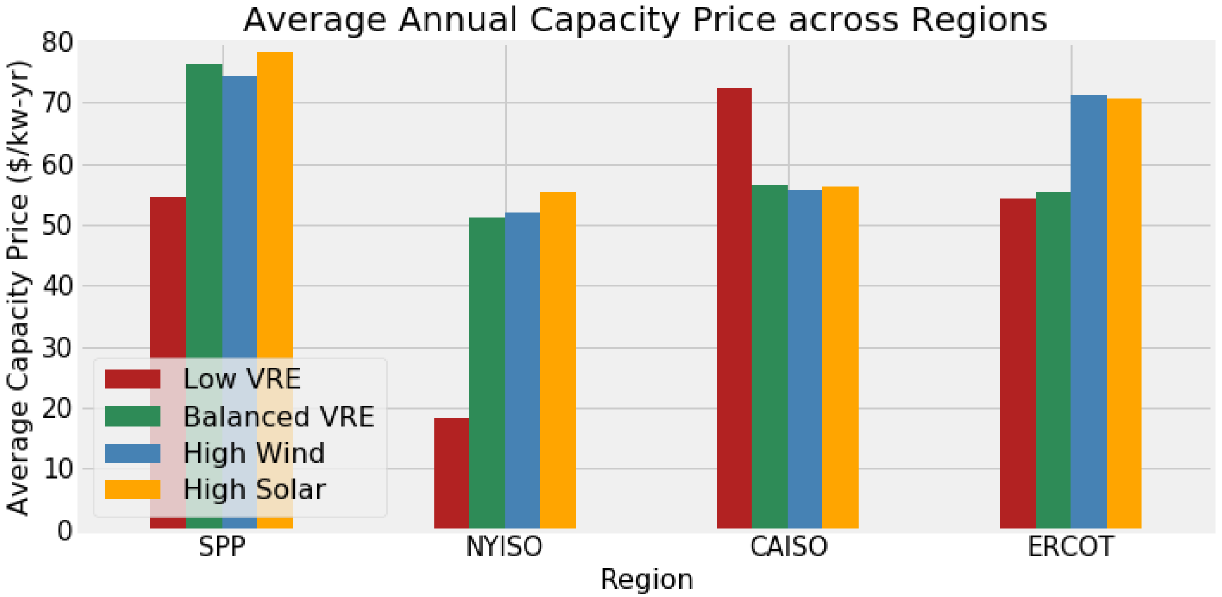
High VRE Leads to an Increase in Ancillary Service Prices

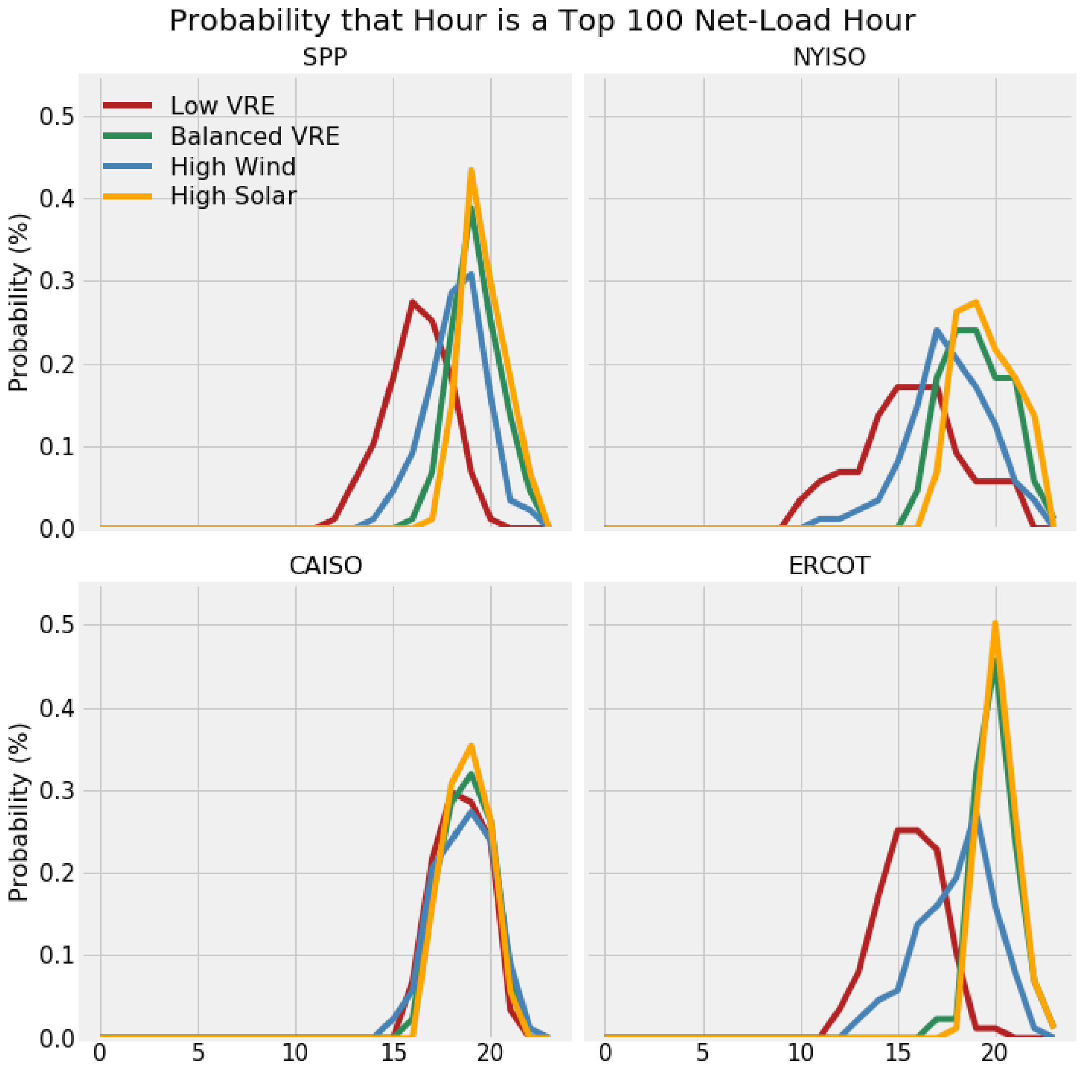


- Average prices for regulation (up and down) and spinning reserves increase by 2-4x across most regions in high VRE futures, to $15-$20/MWh; non-spinning reserves remain at lower prices
- High **solar** often leads to the strongest increase in AS prices, but **balanced** and **wind** scenarios reach higher levels in SPP for downward regulation
- Diurnal AS price profiles and their peaks can change significantly, as do price ranges

Increases for regulation reserve requirements with VRE are consistent with previous region-specific studies (an increase of 1-1.5% of hourly VRE generation); assumes that VRE does not provide AS, new storage excluded

High VRE Can Impact Capacity Prices; Pronounced Shift In Timing of Peak Periods

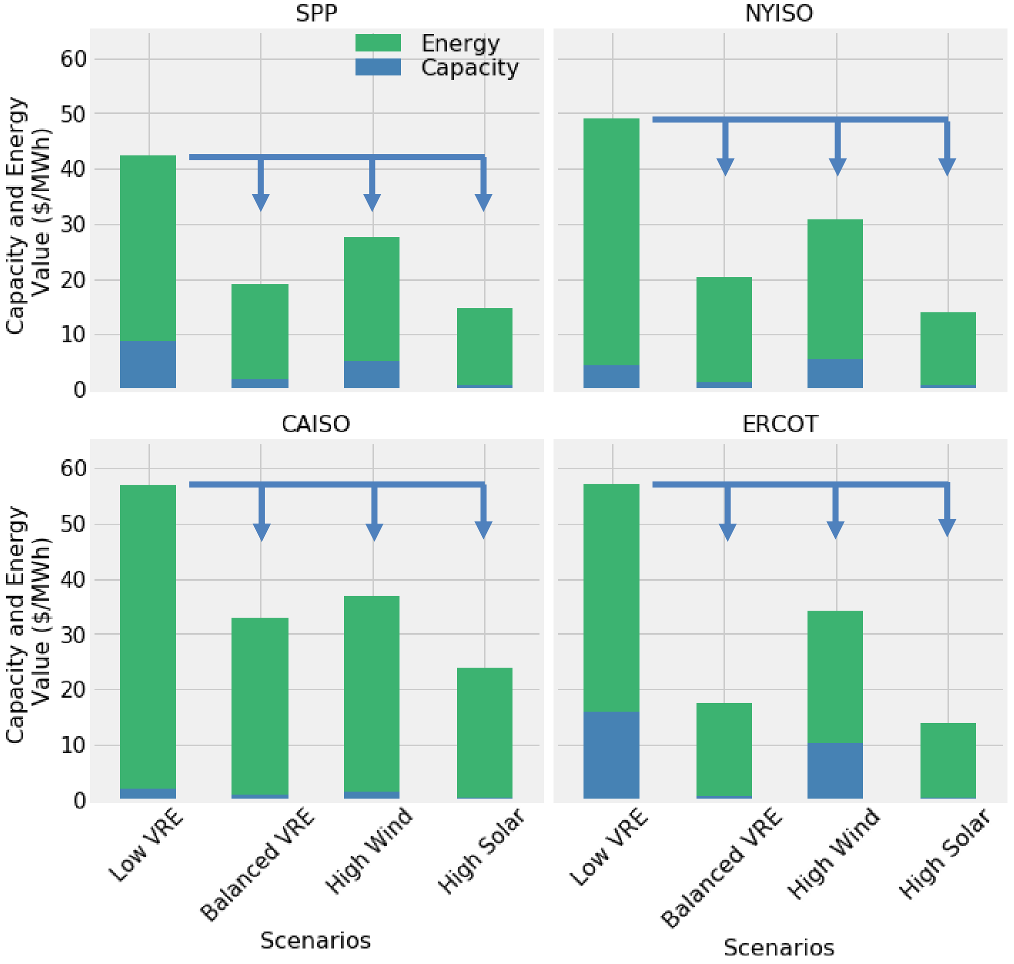




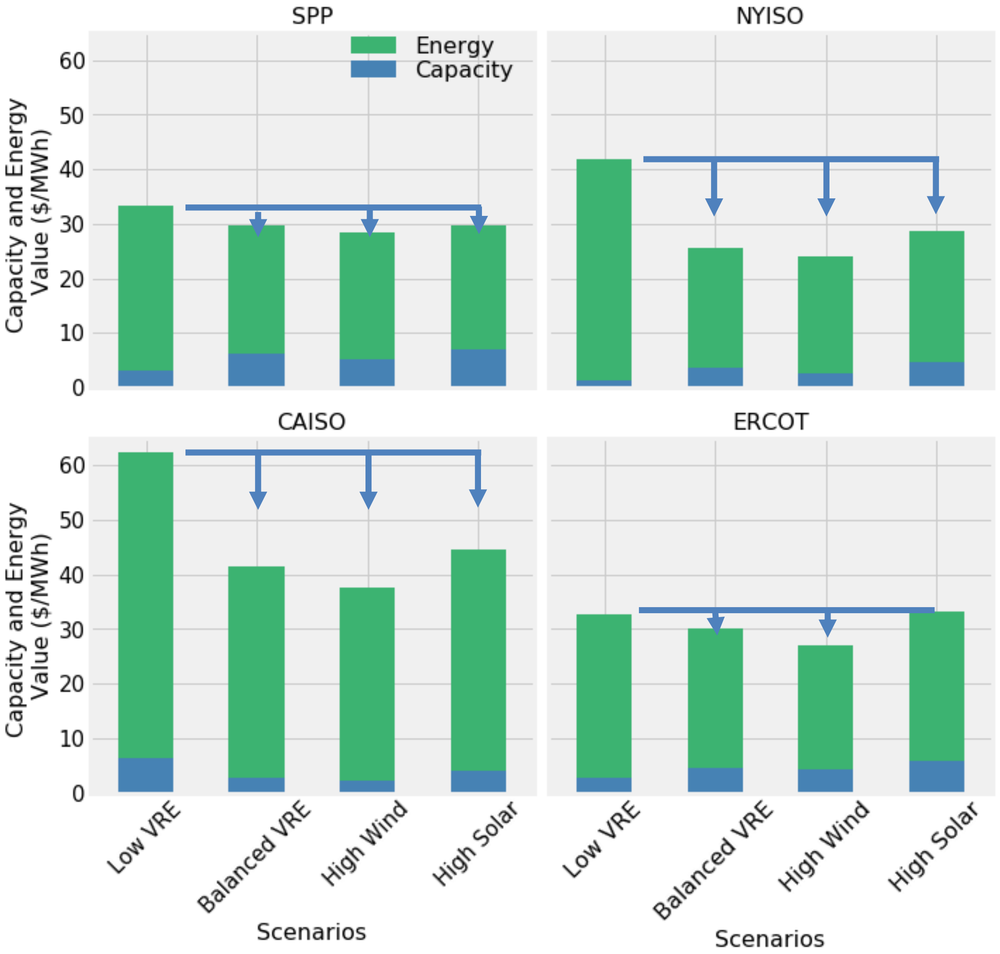
- Mixed trends in annual average capacity prices due to VRE
- Depending on region, top net-load hours are concentrated over fewer hours of the day and pushed later into the evening, especially in solar scenarios
- Top net-load hours are spread over more summer & fall months in the high VRE scenarios in comparison to the low VRE scenario

VRE Impacts on Wholesale Prices Leads to a Decline in VRE Energy and Capacity Value with Increasing Penetration

Energy and Capacity Value for Solar



Energy and Capacity Value for Wind



Solar more valuable than wind at low penetration, but suffers more from energy and capacity value decline

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

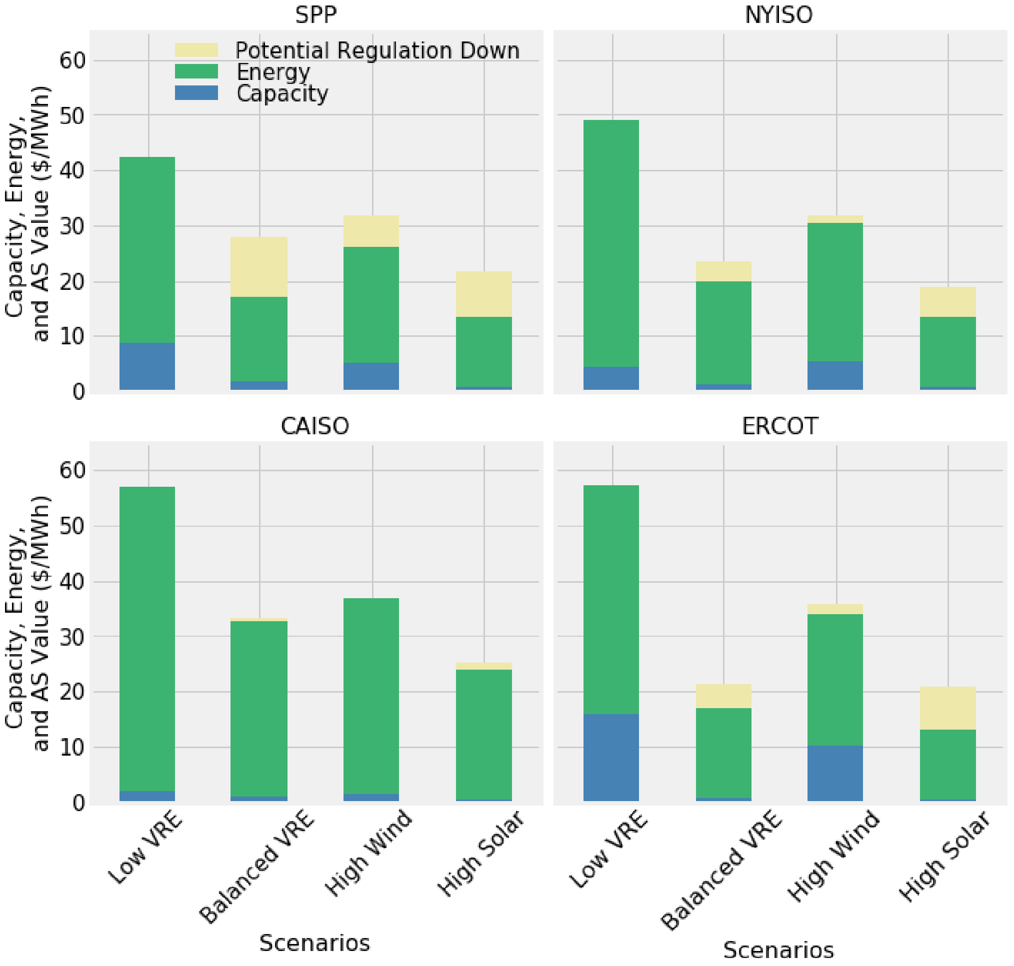
Wind value declines by **14-42%** in **High Wind** scenarios

Carbon prices boost value in CAISO

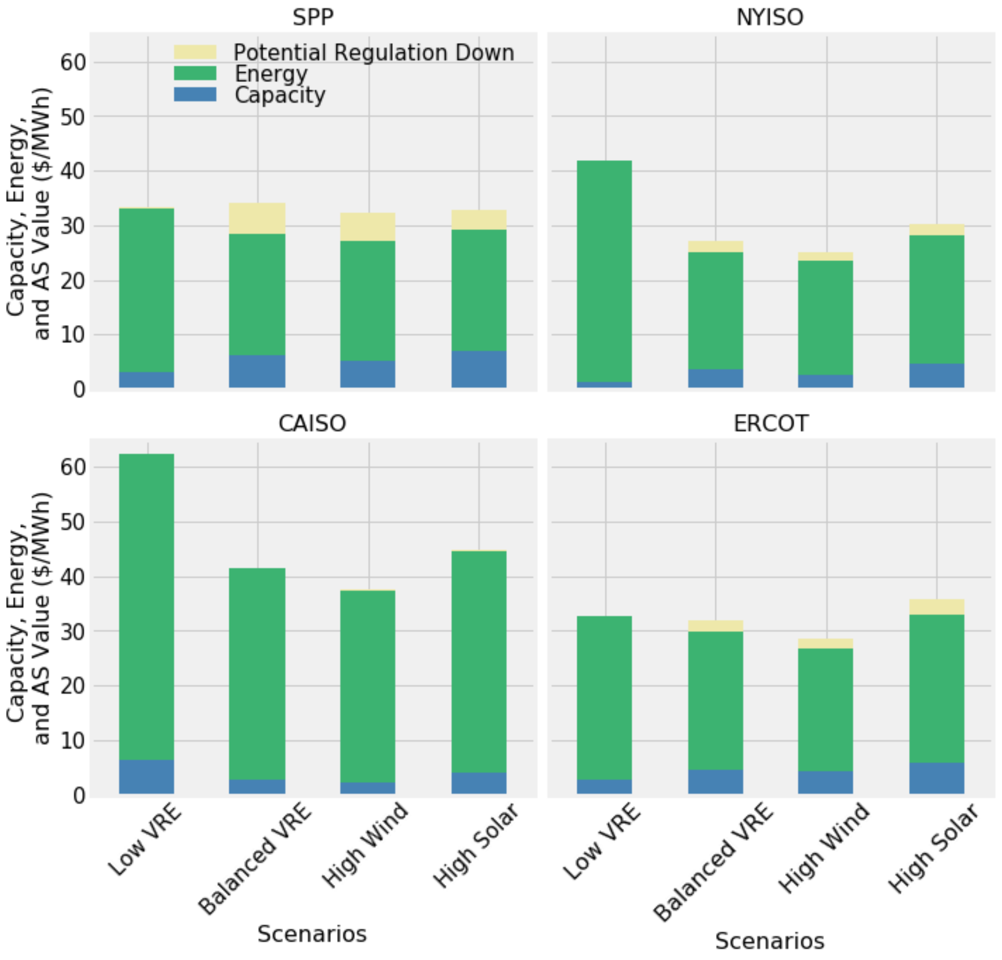
Some VRE May Boost Value by Participating in AS Market

(But Market Size is Limited, and Value Increase Not Enough to Compensate for Value Decline)

Energy, Capacity, and AS Value for Solar



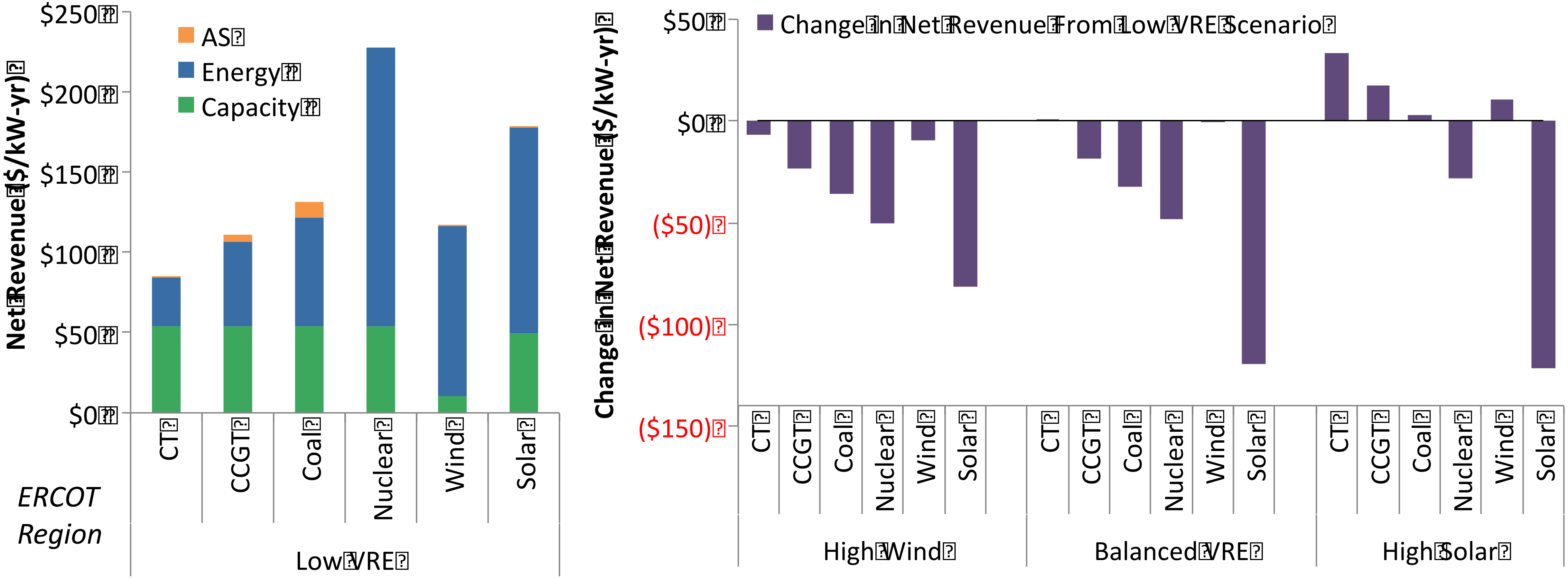
Energy, Capacity, and AS Value for Wind



- Assumes 20% of hourly wind & solar can bid into *Reg-Down* market
- Generation that participates in *Reg-Down* forgoes *Energy* revenue → only participates when *Reg-Down > Energy* (energy revenue therefore decreases)
- Total value increases by 49% in most-extreme case for solar, 15% for wind

VRE Impacts on Wholesale Prices Reduces Revenue & Profits of Nuclear & Coal; Flexible Gas Less Exposed

Representative plants dispatched against wholesale prices from LCG to estimate schedules and revenue



Capacity and AS make up 50% of coal plant net revenue in Low VRE, increases to 60-80% with high VRE

Conclusions and Implications

- Growth in VRE can decrease overall average wholesale market prices
- However, recent decrease in average wholesale prices due to changing natural gas prices (~$40/MWh in CAISO and ERCOT) far exceeds past effect of VRE (<$0.7-2.3/MWh in CAISO and ERCOT) or projected effects with 40% VRE ($5-16 in CAISO and ERCOT)
- Beyond impacts to average prices, more consequential may be relative shifts in energy, AS, and capacity market prices and shifting temporal and geographic pricing patterns:
  - Growth in frequency of very low priced periods
  - Changing diurnal patterns especially with high solar
  - Increase in irregularity of wholesale prices especially with high wind
  - More-severe impacts of VRE on prices in transmission constrained locations
- Changes affect the value of VRE, the value of other supply- & demand-side resources, the relative contribution of energy, capacity and AS… and have implications for market design
- Magnitude and importance of these shifts depends on what other disruptions might be on the horizon, some of which may mitigate the effects of VRE…

Next Steps

- Extend historical-impacts analysis:
  - Additional ISO regions, and more geographic detail
  - Peek-ahead towards prospective impacts in near term
- Analyze VRE impacts on supply- and demand-side decisions:
  - Demand-side decisions
  - Non-VRE supply-side decisions
  - VRE location, design, and operation decisions
- Market design implications… will leave those for others!

Questions?

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