



# Electricity Market Design with Renewable Energy: A Comparison of the United States and Europe

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# Outline

- Background
  - Renewable energy levels
  - Drivers of electricity prices
- Support schemes for renewables
  - Most common support mechanisms in Europe and the United States
- Short-term electricity market operations
  - Comparison of European and U.S. markets
- Long-term electricity market design
  - Different approaches to resource adequacy
  - Comparison of European and U.S. markets
- Recommendations and conclusions

# Literature on US-European Electricity Markets

Green R. (2008). “Electricity Wholesale Markets: Designs Now and in a Low-carbon Future.” *The Energy Journal* 29(2): 95-124.

Haas R. et al. (2008). “Promoting Electricity from Renewable Energy Sources – Lessons Learned from the EU, United States, and Japan”. in: *Competitive Electricity Markets: Design, Implementation, Performance*, Elsevier Global Energy Policy and Economics Series, 1<sup>st</sup> Ed., Editor: F.P. Sioshansi, p. 419-468.

Imran K., I. Kockar (2014). “A technical comparison of wholesale electricity markets in North America and Europe.” *Electric Power Systems Research* 108: 59-67.

Pollitt M.G., K.L. Anaya (2016). “Can current electricity markets cope with high shares of renewables? A comparison of approaches in Germany, the UK and the State of New York.” *The Energy Journal* 37(2): 69-88.

Conejo A. J., R. Sioshansi (2018). “Rethinking restructured electricity market design. Lessons learned and future needs.” *Electrical Power and Energy Systems* 98: 520-530.

*We provide an updated review and comparison of electricity market designs, with specific focus on resource adequacy with more renewables.*

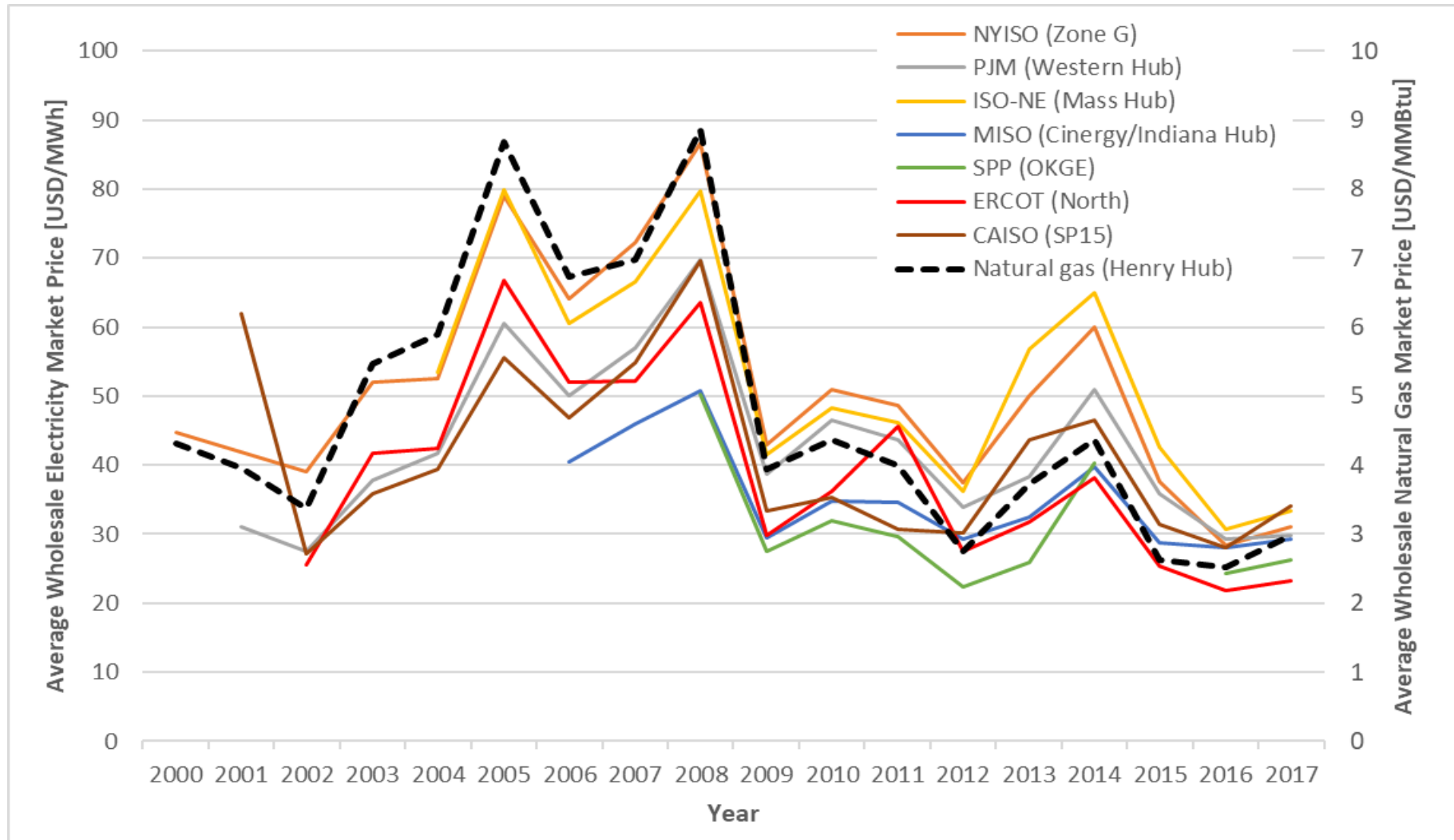
# Renewable Electricity in U.S. and Europe

| Technology  | United States |             | Europe (EU-28) |             |
|-------------|---------------|-------------|----------------|-------------|
|             | 2005          | 2016        | 2005           | 2016        |
| Hydro [%]   | 6.7           | 6.5         | 10.4           | 10.8        |
| Wind [%]    | 0.4           | 5.5         | 2.1            | 9.6         |
| Solar [%]   | 0.0           | 1.7         | 0.0            | 3.4         |
| Biomass [%] | 1.3           | 1.5         | 1.3            | 2.8         |
| Other [%]   | 0.4           | 0.4         | 1.0            | 3.0         |
| Total [%]   | <b>8.8</b>    | <b>15.6</b> | <b>14.8</b>    | <b>29.6</b> |
| Total [TWh] | 358.2         | 640.3       | 490.3          | 959.4       |

Sources: U.S. DOE (2018) and Eurostat (2018).

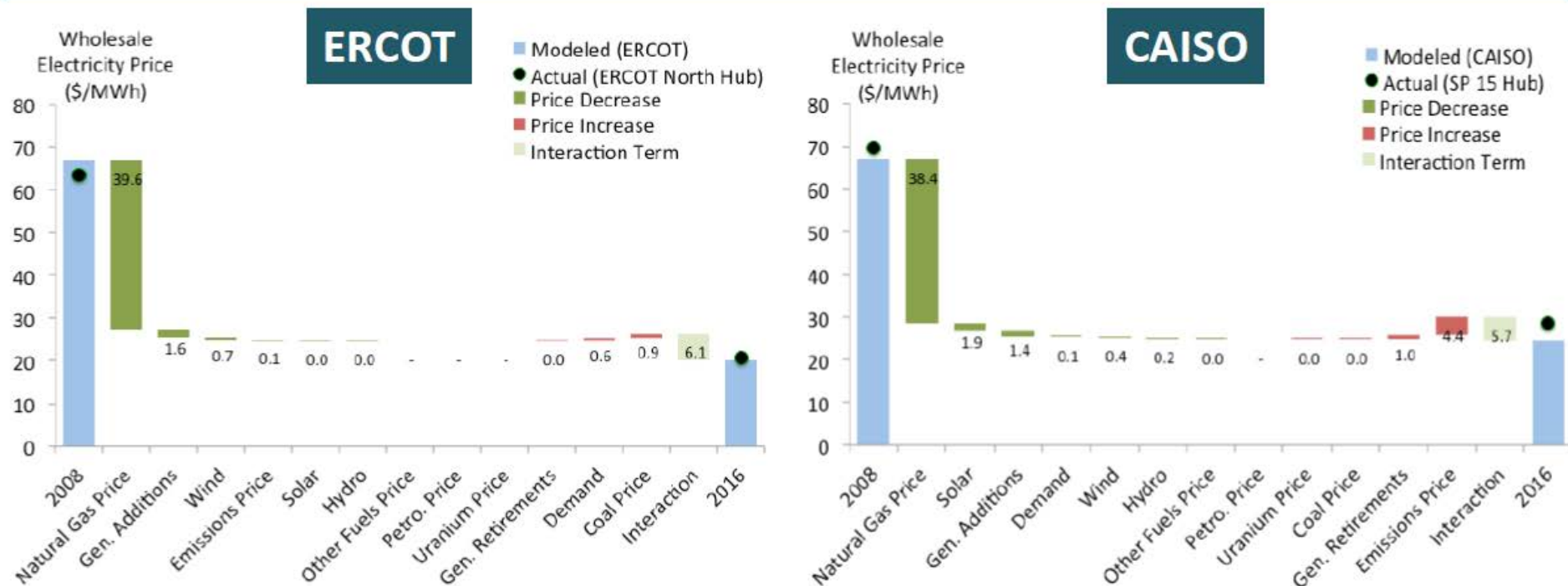
- About twice as much renewables in Europe compared to United States; similar growth rates
- Hydropower still the largest renewable electricity resource, followed by wind power

# Electricity and Natural Gas Prices in the U.S.



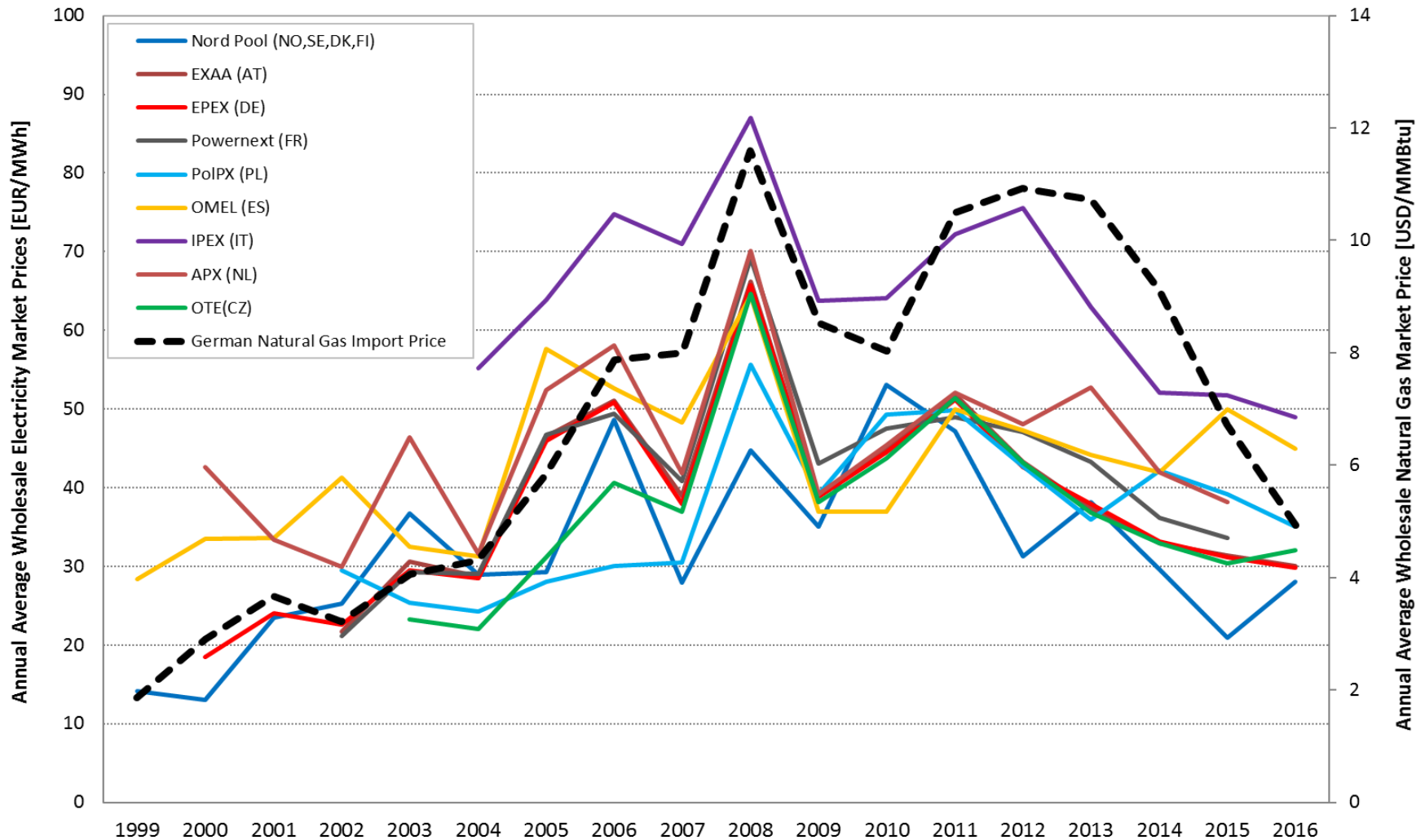
# What drove down prices in CAISO and ERCOT?

Natural gas price decline is the dominant driver in reduced average annual wholesale prices from 2008 to 2016 in ERCOT and CAISO; VRE impacts are modest, in part due to relatively flat supply curve



Analysis based on simple supply curve model to estimate wholesale prices in 2016 and 2008 and factors that drove down prices over this period.

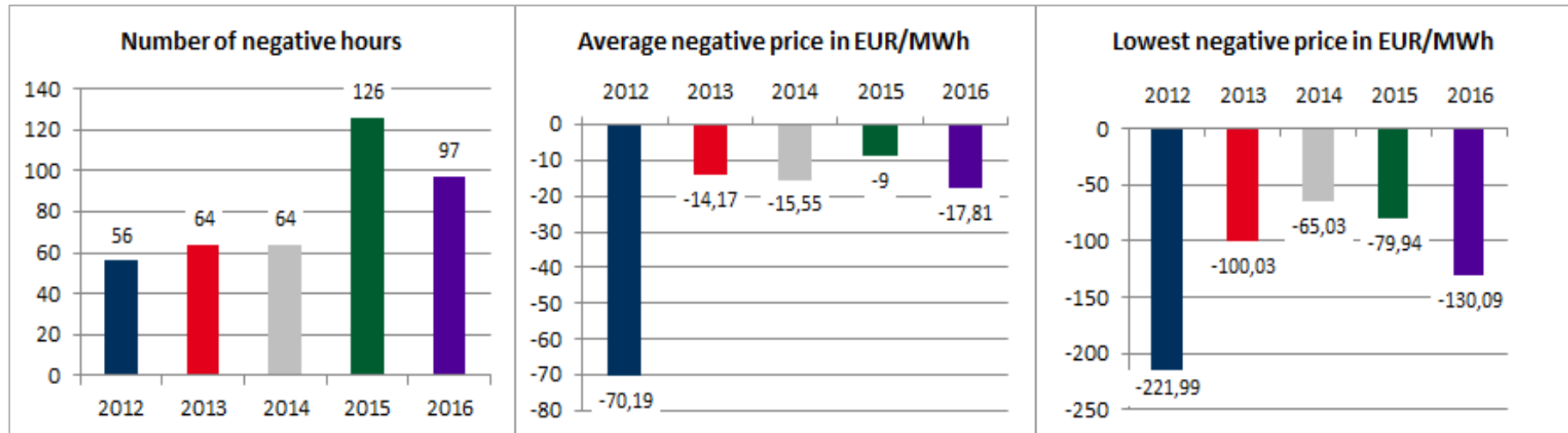
# Electricity and Natural Gas Prices in Europe



# VRE Impacts on Wholesale Electricity Prices

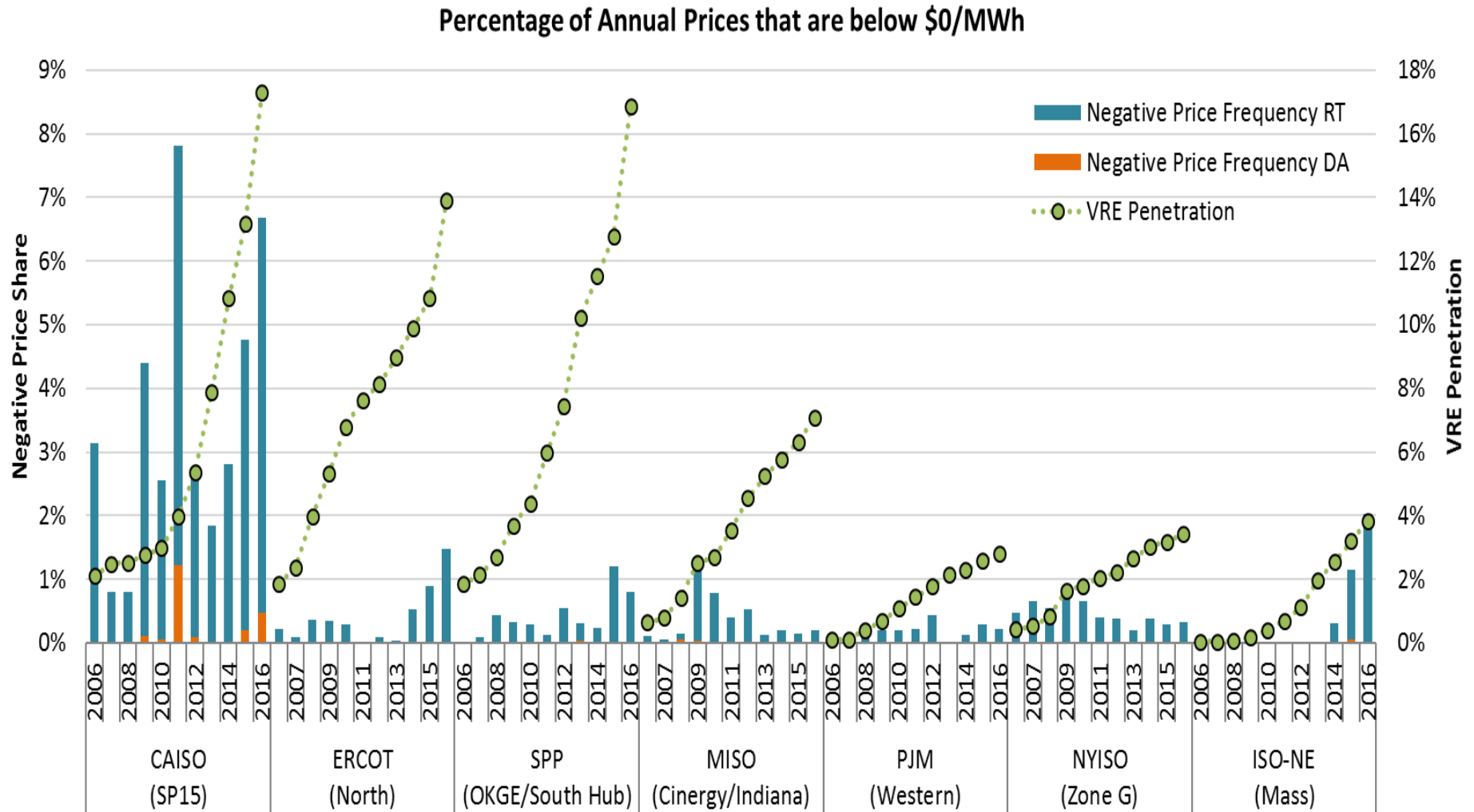
- The merit order effect reduces electricity prices
  - Empirical literature indicates a larger effect in Europe than the U.S.
- The occurrence of negative prices has also increased with higher VRE penetration levels

## Negative prices in German electricity market





# Negative Prices and VRE in U.S. Markets



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# VRE Support Schemes and Carbon Policies

## ■ Europe

- Green certificates
- Feed-in tariffs
- Feed-in premiums
- Auction schemes

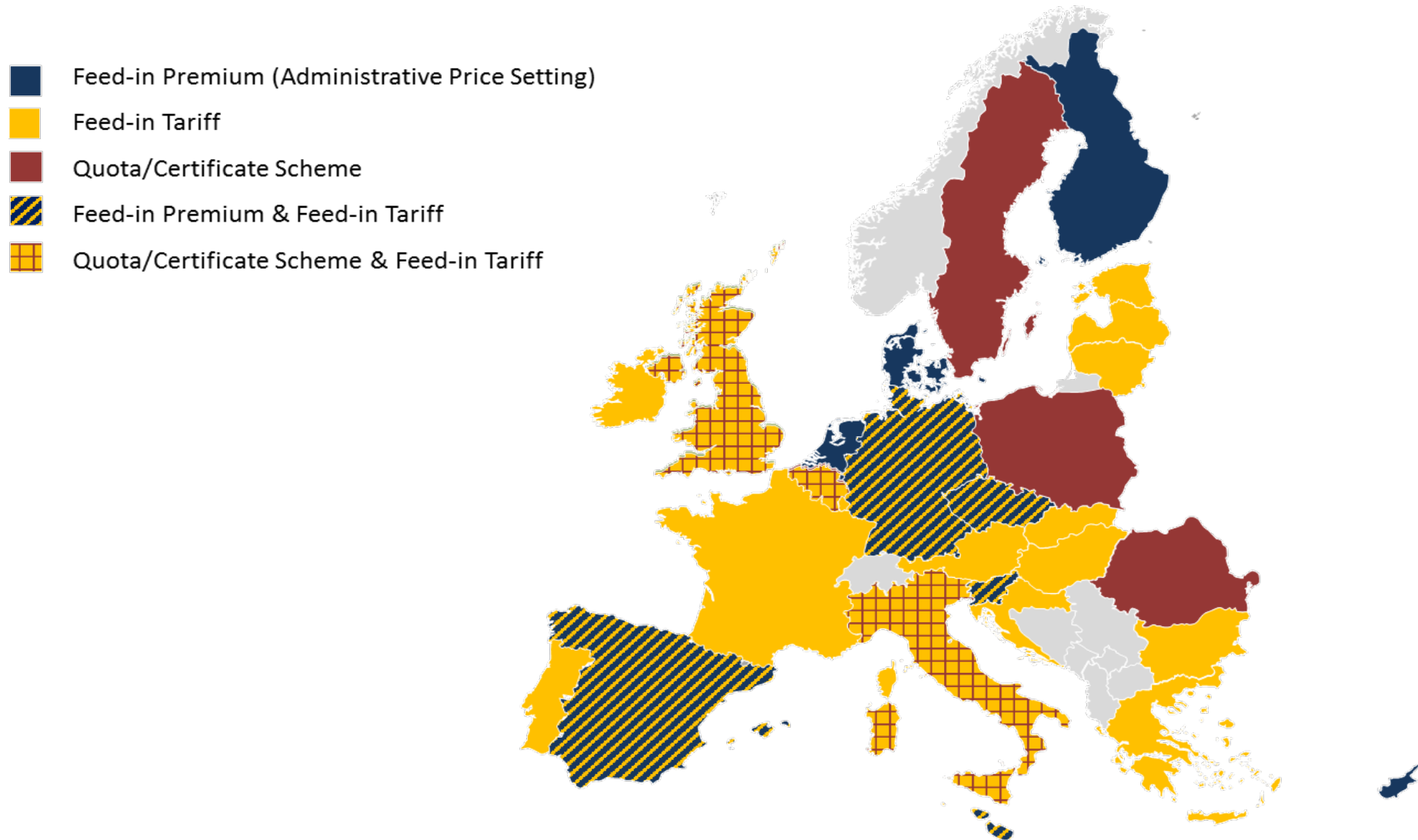
## ■ United States

- Renewable portfolio standards (state)
- Renewable portfolio goals (state)
- Production tax credits (federal)
- Investment tax credits (federal)

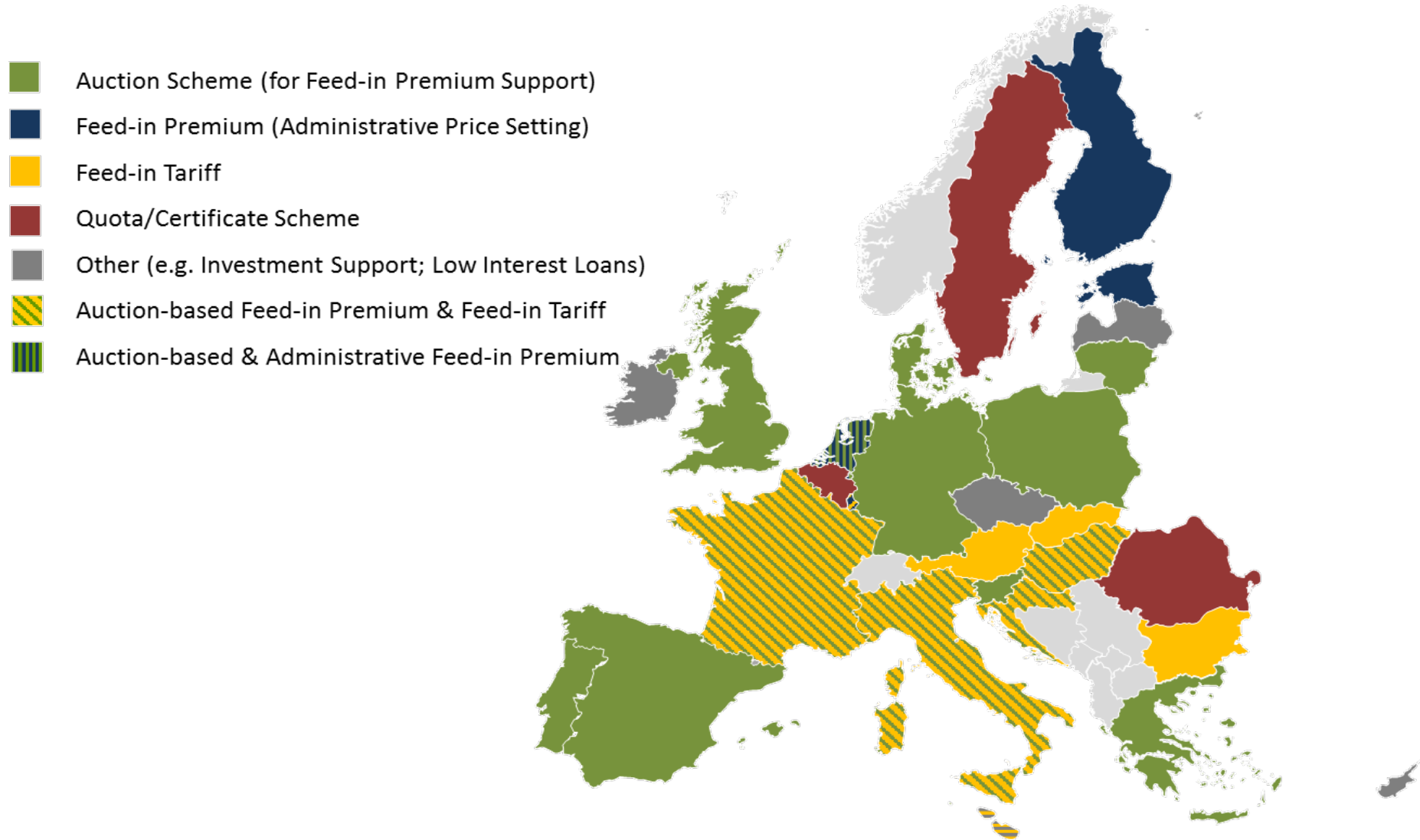
## ■ Carbon policies

- European emissions trading system (ETS)
- Regional emissions trading in U.S. (Northeast and California)
- Low carbon prices in recent years

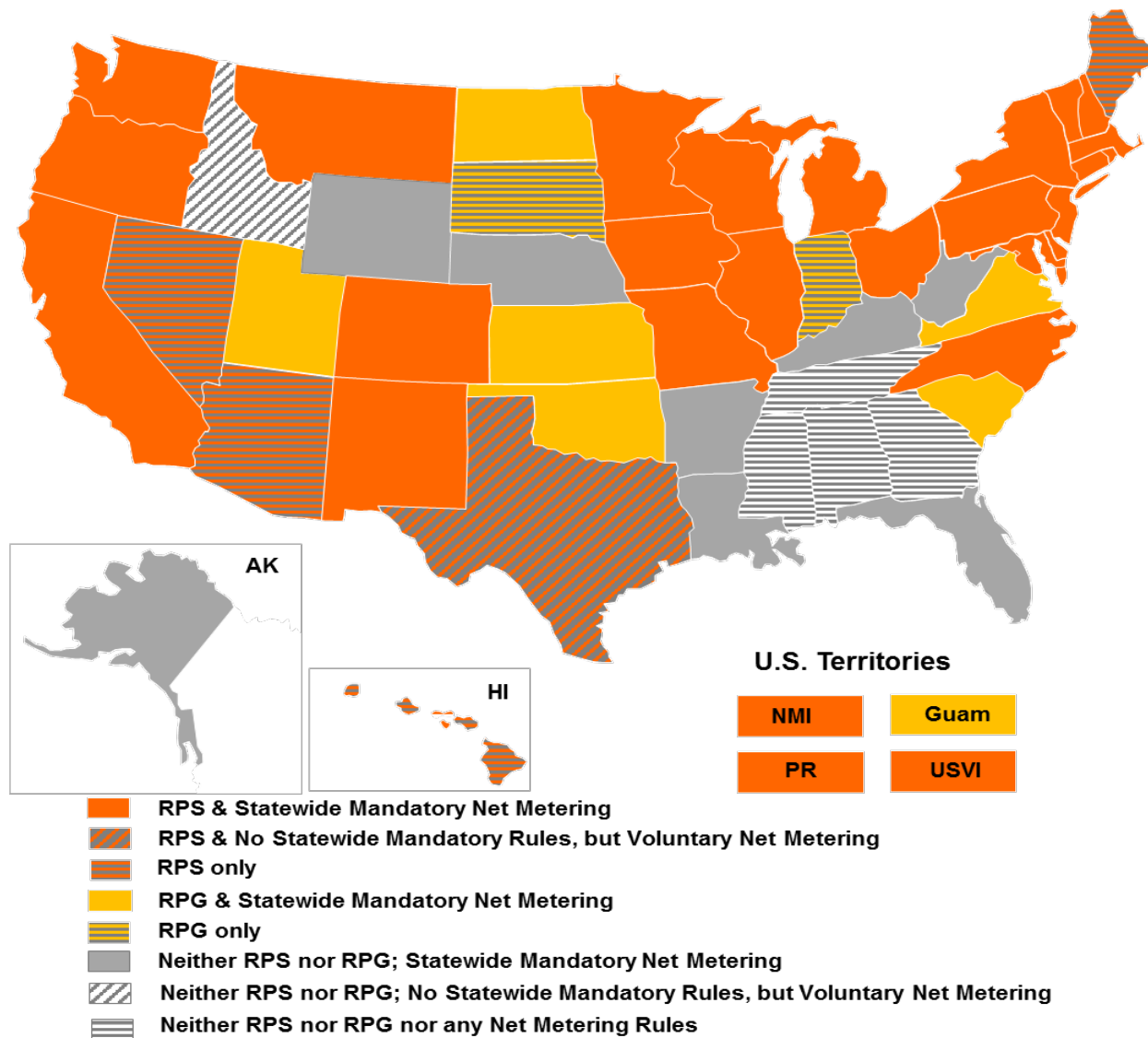
# VRE Support Schemes in Europe (2005)



# VRE Support Schemes in Europe (2017)



# VRE Support Schemes in United States (2017)



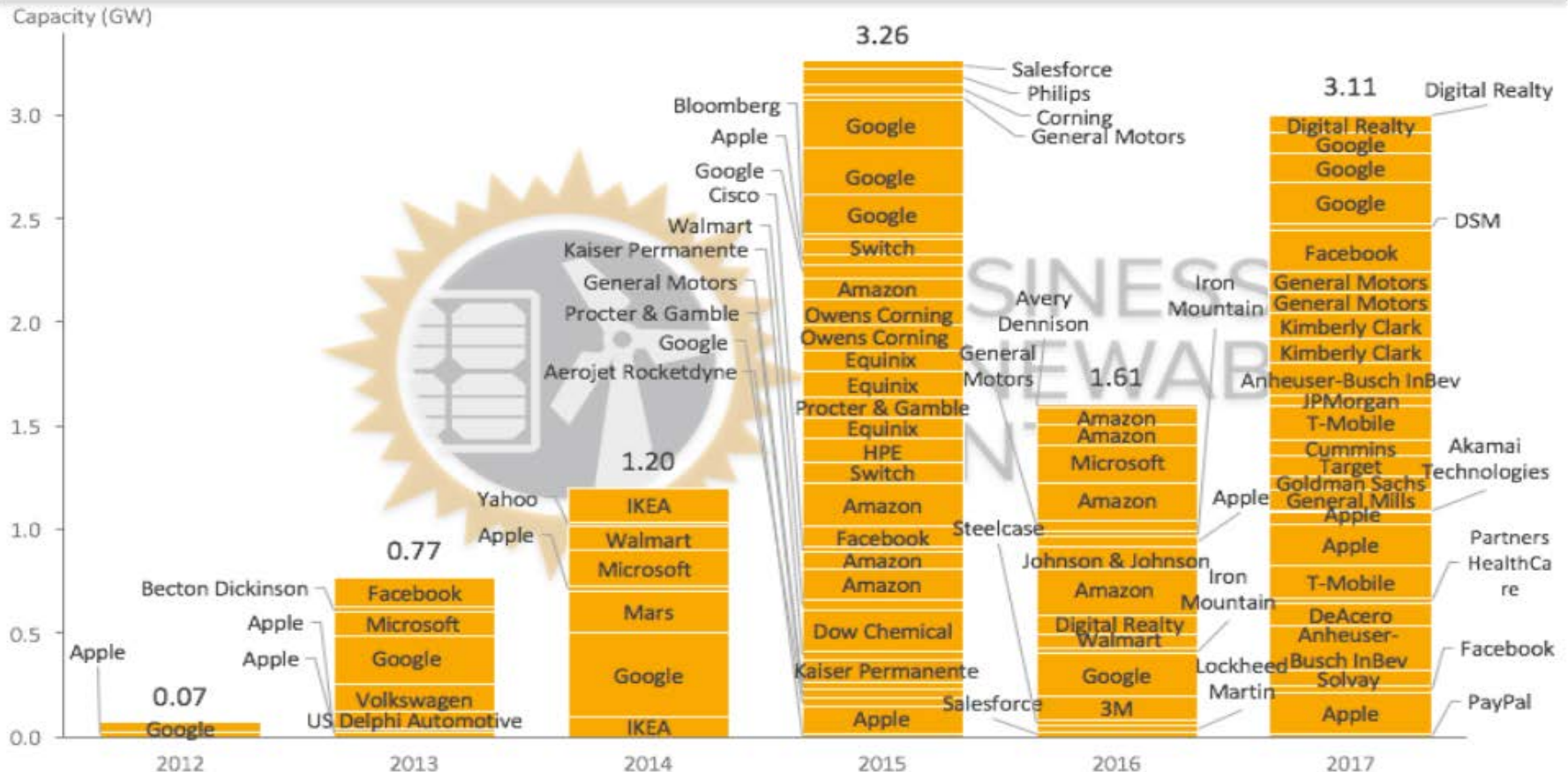
# VRE Indirect Enablers and Voluntary Schemes

- Net Metering
  - In majority of U.S. states
  - In several European countries
- Local Energy Sharing
  - Community solar
  - Microgrids
- Community choice aggregation
  - At city and county level in the United States
  - Often a high fraction of VRE
- Corporate interest in renewable electricity
  - Green electricity offered by food retailers in Europe
  - Purchasing of VER by corporations (e.g. Google 100% renewable)

# Corporate Renewables Deals in U.S./Mexico



## Corporate Renewable Deals 2012 – 2017



Publicly announced contracted capacity of corporate Power Purchase Agreements, Green Power Purchases, Green Tariffs, and Outright Project Ownership in the US and Mexico, 2012-2017. Excludes on-site generation (e.g., rooftop solar PV) and deals with operating plants. Last updated: January 5, 2018.

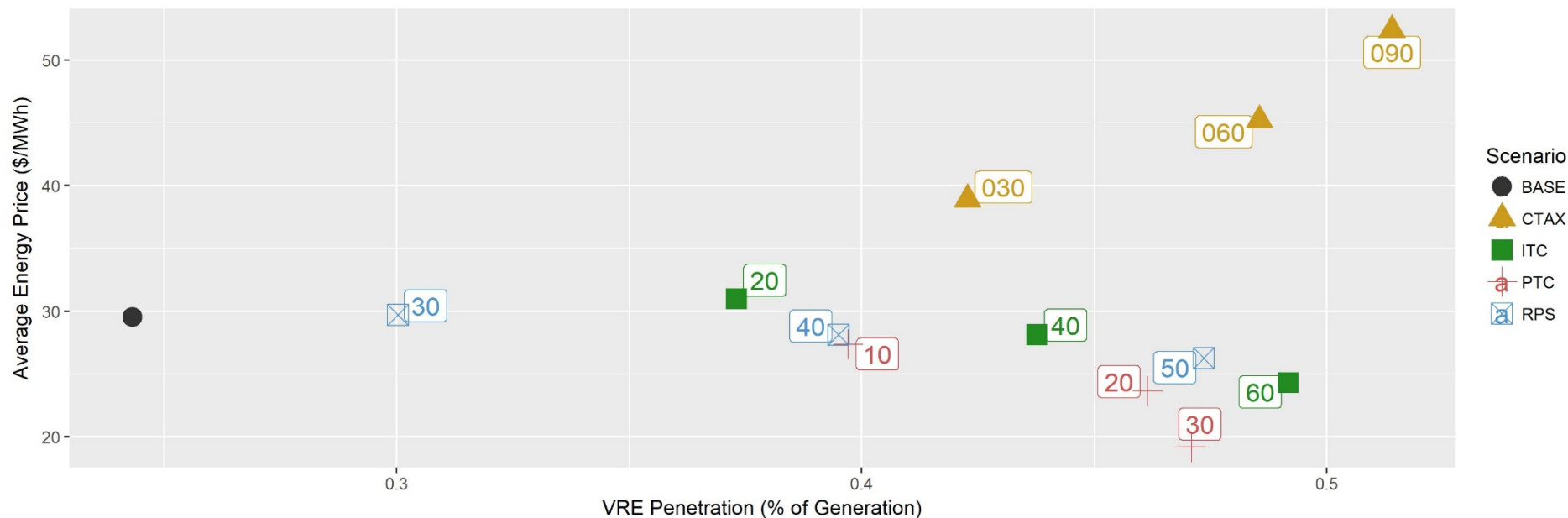
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For more information, please visit <http://www.businessrenewables.org/> or contact [BRC@RMI.org](mailto:BRC@RMI.org)



# VRE Support Schemes Influence Market Prices

VRE Penetration and Market Prices with Different Policies (“ERCOT-like system”)



| Policy                       | Abbreviation | Metric            | Scenario Range |
|------------------------------|--------------|-------------------|----------------|
| Carbon Tax                   | CTAX         | \$/ton            | \$30-\$90      |
| Investment Tax Credit        | ITC          | % of capital cost | 20%-60%        |
| Production Tax Credit        | PTC          | \$/MWh            | \$10-\$30      |
| Renewable Portfolio Standard | RPS          | % of generation   | 30%-50%        |

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# Electricity Markets in United States and Europe

## ■ United States

- Build into existing system operators (ISOs)
  - Short-term system operation
  - ISOs do not own transmission system
  - ***Emphasize physics of the power system***
- Short-term market operations
  - Day-ahead market (ISO - hourly)
  - Real-time market (ISO - 5 min)
  - Complex bids/ISO UC
  - Locational marginal prices
  - Co-optimization of energy and operating reserves
  - ***Centralized control through ISO***

## ■ Europe

- Introduced new power exchanges (PXs)
  - Include long-term contracts
  - TSOs typically own transmission system
  - ***Emphasize markets and economics***
- Short-term market operations
  - Day-ahead and intraday markets (PX)
  - Real-time balancing markets (TSO)
  - Simple bids/generator UC
  - Zonal pricing/market coupling
  - Sequential reserve and energy markets
  - ***Decentralized balancing through balance responsible parties***

***Who should solve the optimization problem?***

# Electricity Markets in United States and Europe

## ■ United States

- Variable renewable energy
  - Intermittent policy support
  - Tax credits, renewable portfolio standards
  - ***“Dispatchable” VER***
- Retail competition
  - Retail choice in some states

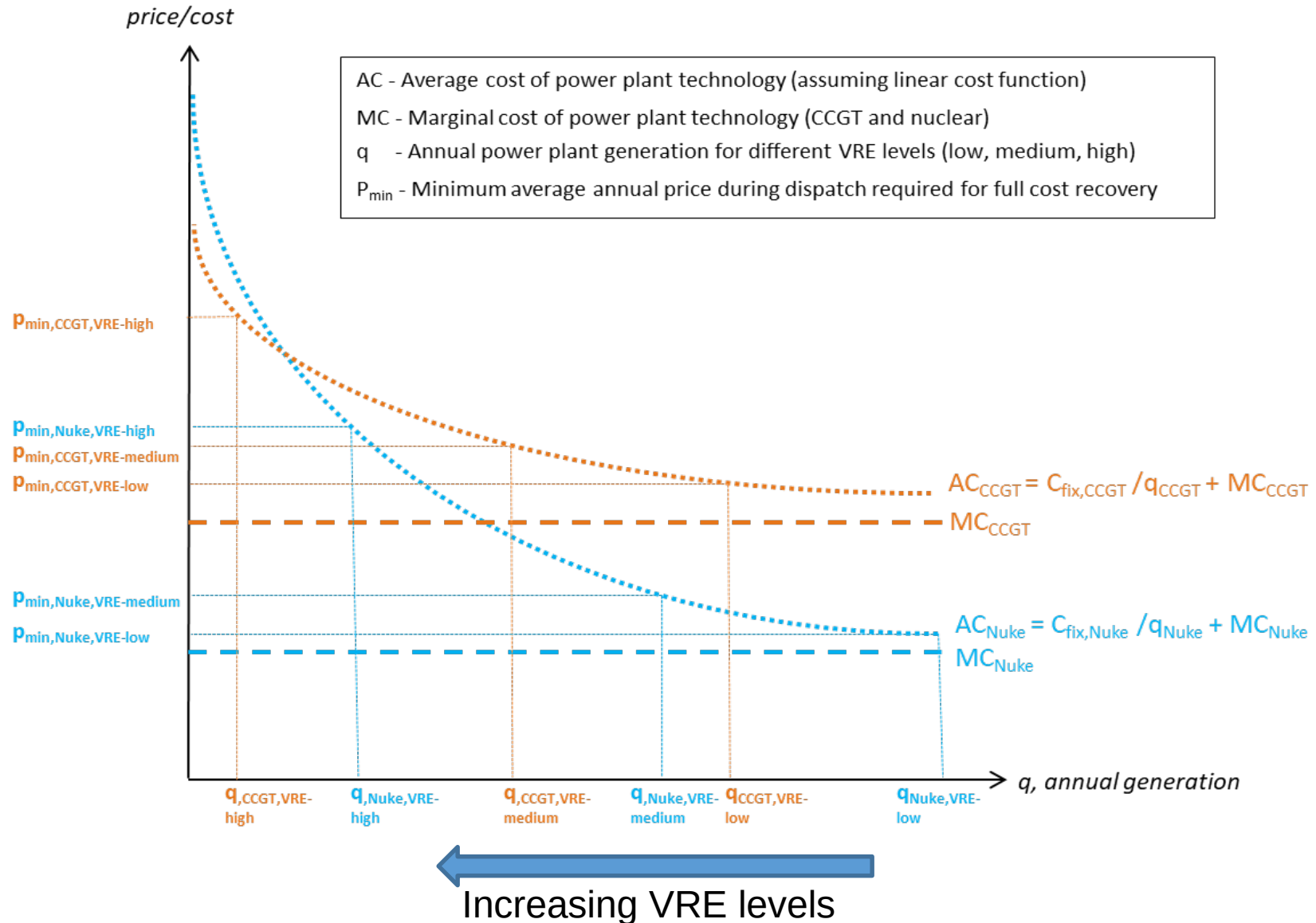
## ■ Europe

- Variable renewable energy
  - Strong policy support
  - Feed-in tariffs - premiums, tenders/auctions
  - ***VER as “must-take”***
- Retail competition
  - Retail choice in all countries

# Outline

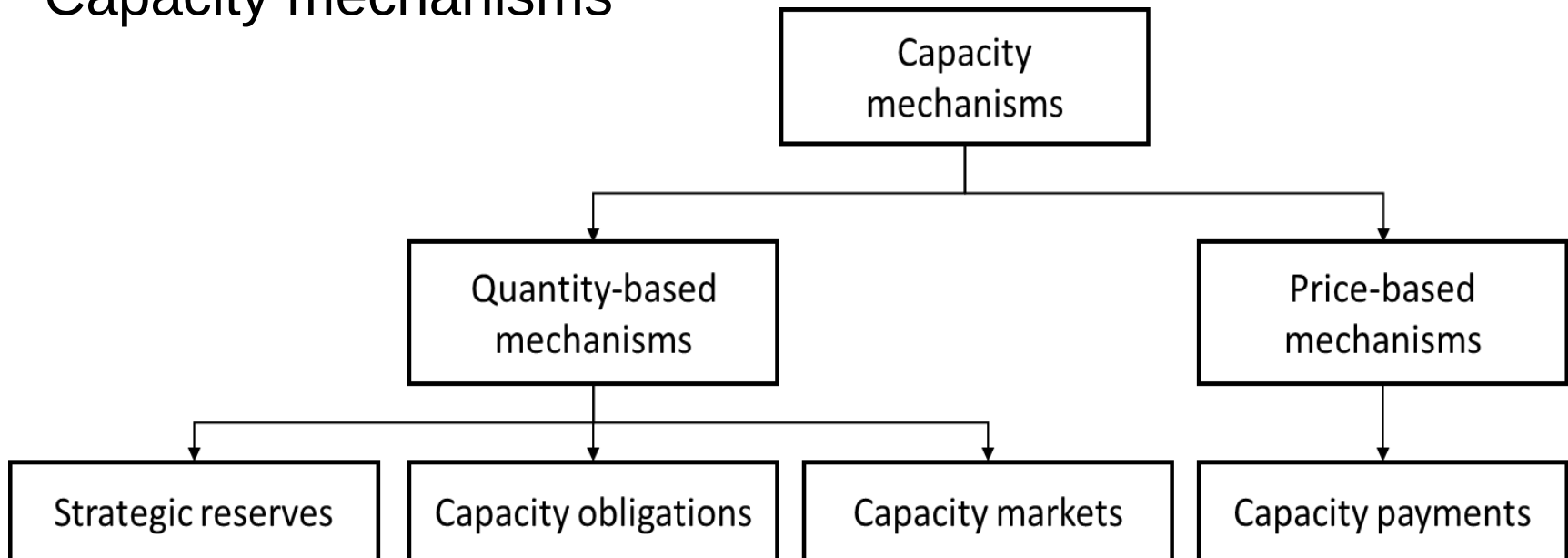
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# The Revenue Sufficiency Challenge with VRE



# Resource Adequacy Paradigms

- Energy only market
  - Prices in energy (and reserves) markets provide investment incentives
  - Importance of scarcity rents
  - Provides the best performance incentives
- Capacity mechanisms

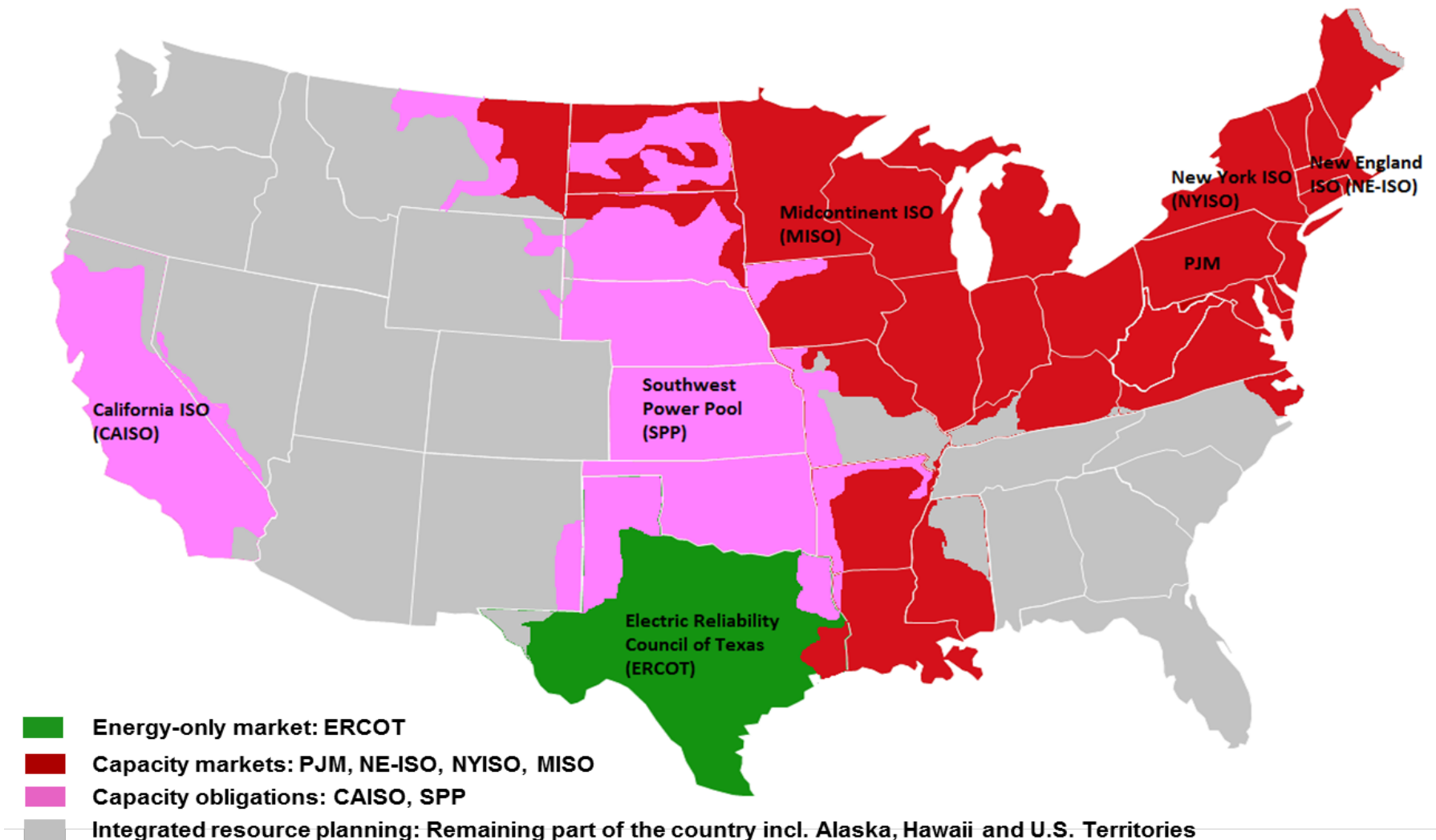


# Resource Adequacy: Current Status in Europe





# Resource Adequacy: Current Status in U.S.



# Capacity Mechanisms

- Capacity payments
  - Pros: Stable revenues for generators
  - Cons: May not achieve desired reliability level, may result in over/under compensation
- Capacity markets
  - Pros: Target level of reliability achieved, limited market intervention
  - Cons: Uncertain revenues for generators, hard to determine demand
- Capacity obligations
  - Pros: Can address flexibility requirements
  - Cons: High degree of centralized planning
- Strategic reserves
  - Pros: High level of control for system operator (owning the reserve)
  - Cons: High degree of market intervention

# Limited Assessment of U.S. Capacity Markets



United States Government Accountability Office  
Report to Congressional Committees

December 2017

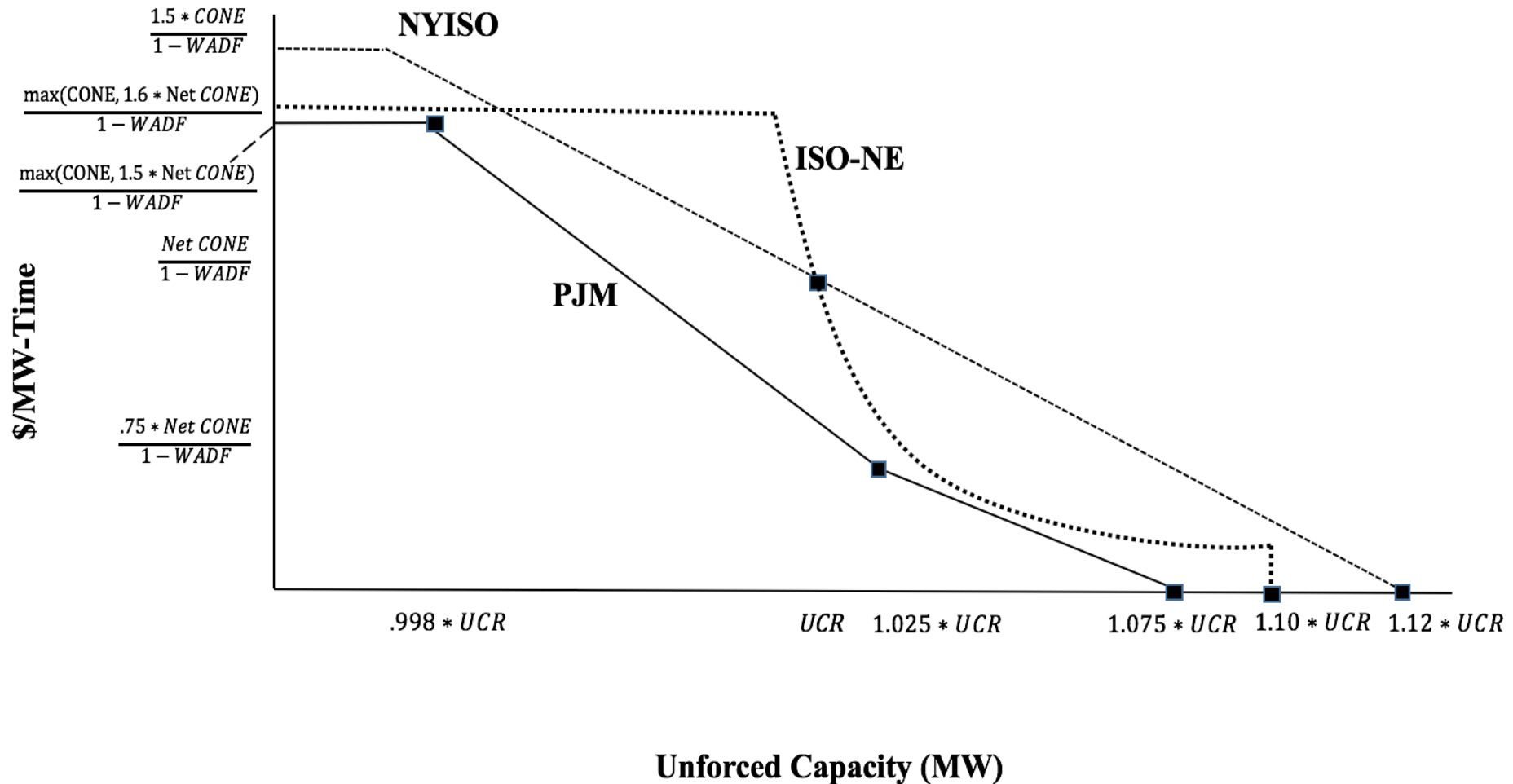
## ELECTRICITY MARKETS

Four Regions Use  
Capacity Markets to  
Help Ensure  
Adequate Resources,  
but FERC Has Not  
Fully Assessed Their  
Performance

- \$51 billion paid in four U.S. capacity markets, 2013-2016
- Lack of performance goals for capacity markets
- Frequent re-design of capacity markets (e.g. two-tiered markets)
- Capacity markets receive limited focus in the research domain

# Differences in U.S. Capacity Market Designs

Comparison of demand curves for capacity auctions. *Figure not to scale.*



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# Towards Improved Electricity Markets with VRE: General Recommendations

- Gradual removal of technology specific subsidy schemes for clean energy
- Adequate pricing of carbon/other environmental externalities as a market compatible incentive scheme for clean energy resources
- Improved price formation in energy and reserves markets, particularly during scarcity situations
- Improved incentives for system flexibility from supply, demand and energy storage
- Move day-ahead markets closer to the operating day
- Enable participation of distributed energy resources and demand response in electricity markets
- Reduce reliance on explicit capacity mechanisms to incentivize investments

# Specific Recommendations for Europe and US

## Europe

- **Improved representation of transmission in market clearing**
- Better coordination between TSOs
- Imbalance netting to avoid opposite activation of reserves
- Shortening timeframes in intraday markets
- **Higher frequency of real-time dispatch and market clearing**
- **Co-optimization of energy and reserves**
- Economic dispatch of renewable resources
- Further develop retail competition

## United States

- **Increased liquidity and transparency in long-term contracts**
- **Implementation of intraday markets for market-based balancing**
- Higher time resolution of settlements in real-time energy and reserve markets
- Further refinements of products in ancillary services markets
- Full co-optimization of energy and reserves in all regional U.S. markets
- Better coordination between regional capacity, energy, and reserves markets
- **Open up for retail competition in larger parts of the country**

# Concluding Remarks

- The impacts of VRE on electricity markets are more visible in European compared to U.S. electricity markets
- U.S. electricity markets better aligned with physics of the power grid: more centralized coordination and control
- European electricity markets more focused on economics: power exchanges also include long-term contracts
- No single solution: lessons to be learned in both directions
- How much of the “optimization problem” should be solved by system operators vs. market participants?
- Getting the price formation in short-term energy/reserve markets is the key challenge
- Capacity mechanisms only as a back-up



# Acknowledgements

## ■ Collaborators

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- Todd Levin                      Argonne National Laboratory
- Andrew Mills                      Lawrence Berkeley National Laboratory
- Ryan Wiser                      Lawrence Berkeley National Laboratory
- Conleigh Byers                      Massachusetts Institute of Technology

## ■ MIT International Policy Lab

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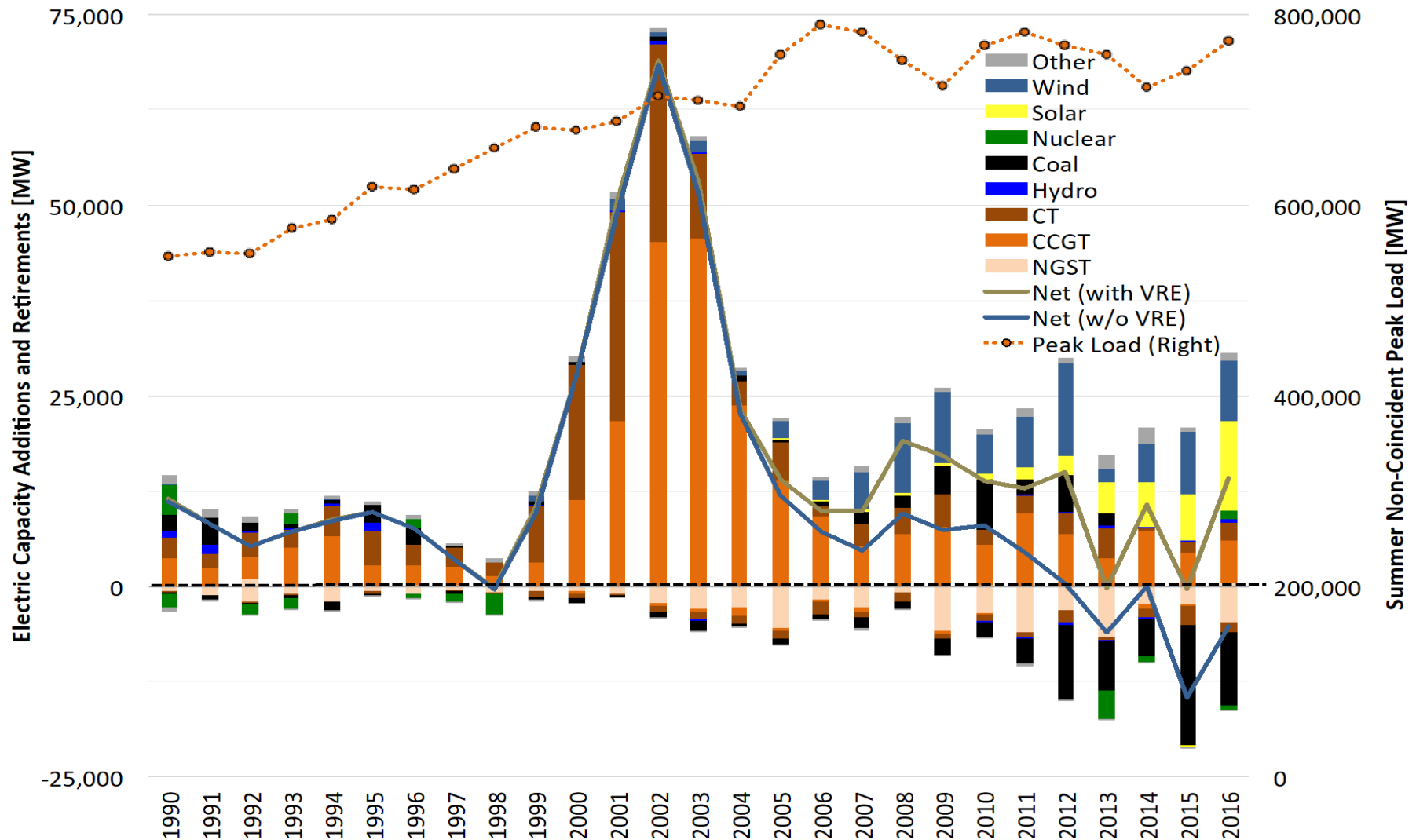
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# Key Issues Addressed in Paper

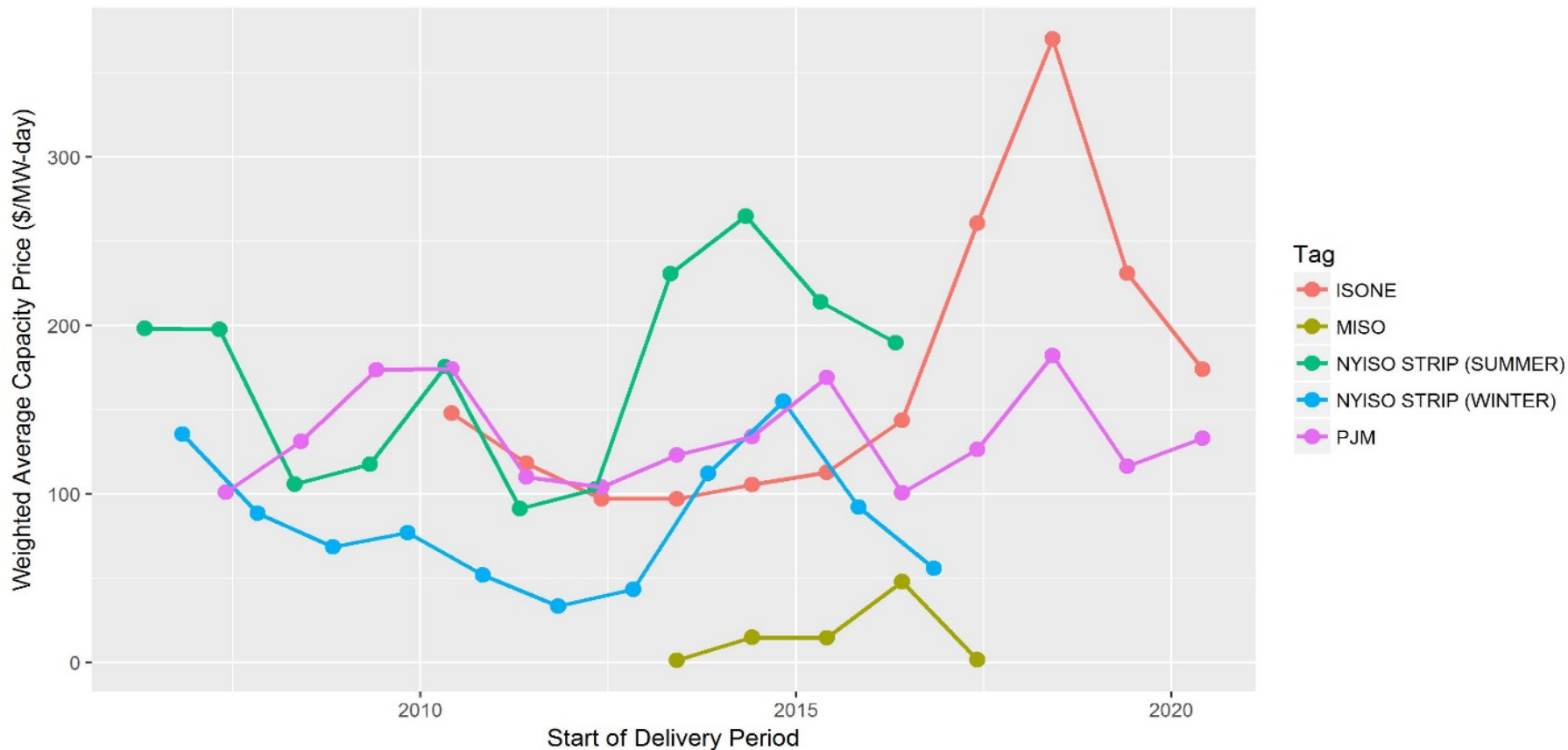
- What are differences and similarities in electricity market design in Europe and the United States?
- How does the rapid increase in wind and solar resources impact electricity markets in the short- and long-term?
  - Wind and solar penetrations levels
  - Support schemes for variable renewable electricity (VRE)
  - Treatment of renewables in electricity market operations
- Summarize key electricity market design characteristics in Europe and United States
- Electricity market design options for resource adequacy
- Recommendations for improvements in electricity market design (general, Europe and US specific)

# U.S. Capacity Additions and Retirements



# Capacity Market Price Trends

**Historical capacity prices.** The Limited number of data points, differences in market rules across markets, and changes in market rules within markets make it difficult to identify clear trends in the prices.



# Negative Prices in PJM Node 2014 (West Illinois)

