Resource Adequacy with Increasing Shares of Wind and PV-Generation: A Comparison of European and U.S. Electricity Market Designs

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Outline

1. Introduction/Background
   - Key questions addressed
   - Developments in electricity market prices in recent years
2. Variable renewable electricity generation in Europe and the United States
   - Penetration levels for renewable generation technologies
   - Support schemes for renewable generation technologies
   - Impacts of renewable electricity generation on wholesale market prices
3. Short-term electricity market operations
   - Comparison of European and U.S. markets
4. Long-term electricity market design
   - Different approaches to resource adequacy
   - Comparison of European and U.S. markets
5. Conclusions and recommendations

Key Questions (Intro_1/5)

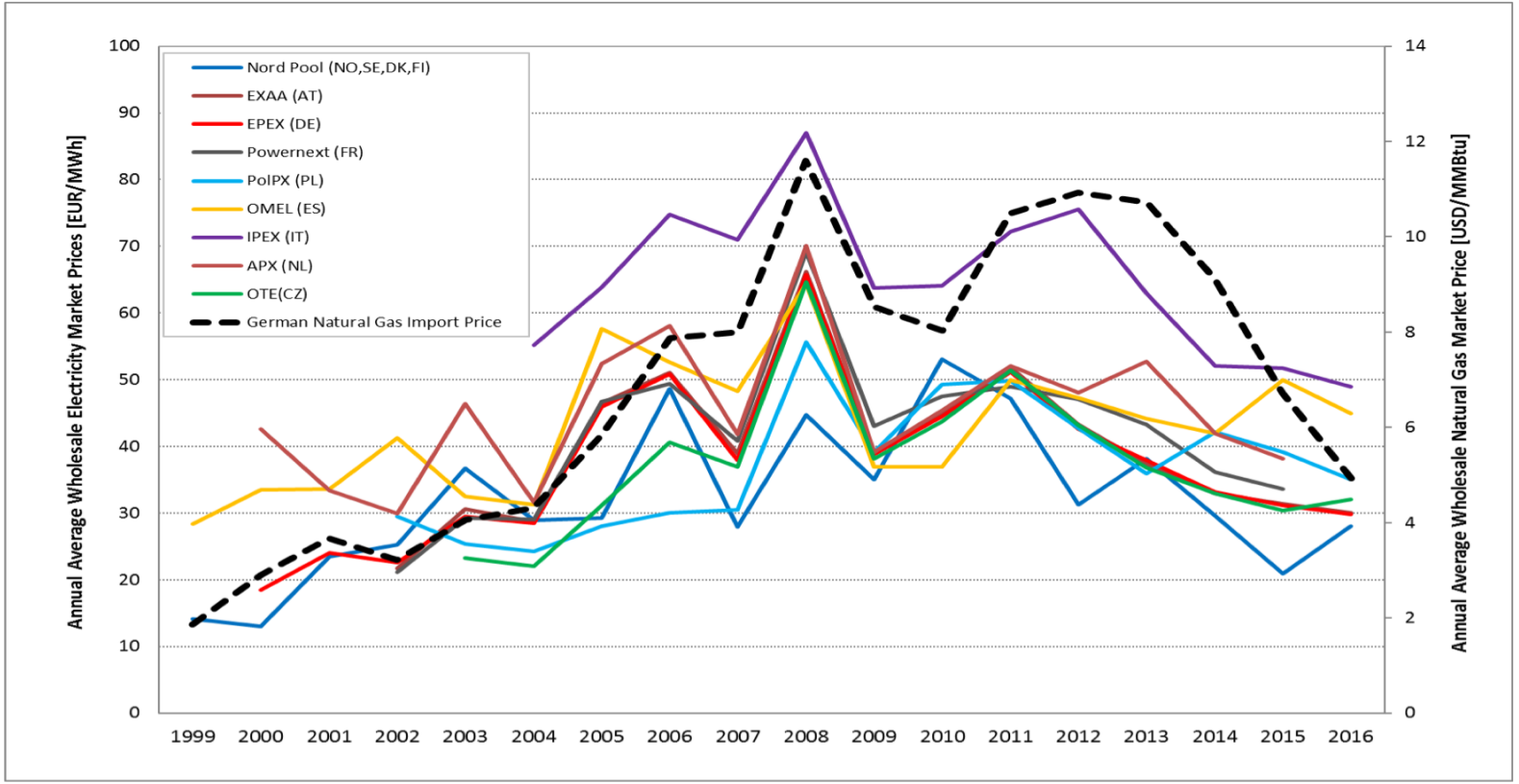
- What are differences and similarities in electricity market design in Europe and the United States?
- How does the rapid increasing in wind and PV generation impact electricity markets in the short- and long-term?
  - Wind and PV penetrations levels
  - Support schemes for variable renewable electricity (VRE)
  - Treatment / Implications of renewables in electricity market operations
- What are the pros and cons of the key electricity market design characteristics in Europe and Unites States?
- What are the possible electricity market design options for resource adequacy?
- Recommendations for improvements in electricity market design (general, Europe and U.S. specific)

Literature: European - U.S. Electricity Markets (Intro_2/5)

- 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 Source – Lessions Learned from the EU, United States, and Japan”. in: Competitive Electricity Markets: Design, Implementation, Performance, Elsevier Global Energy Policy and Economics Series, 1st 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.

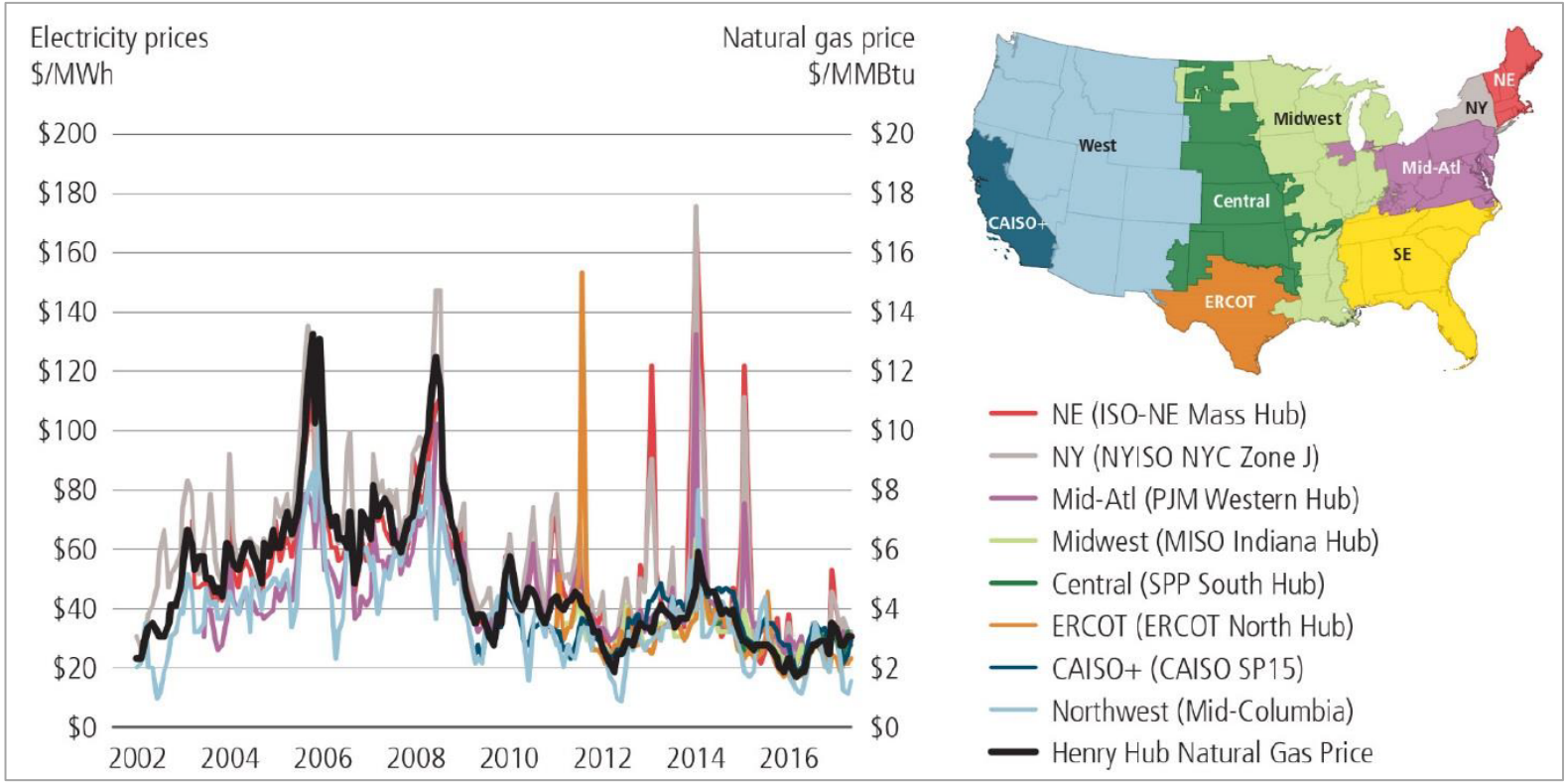
We provide an updated review and comparison of electricity market designs, with specific focus on resource adequacy with increasing renewable generation…

Electricity and Natural Gas Prices in Europe (Intro_3/5)



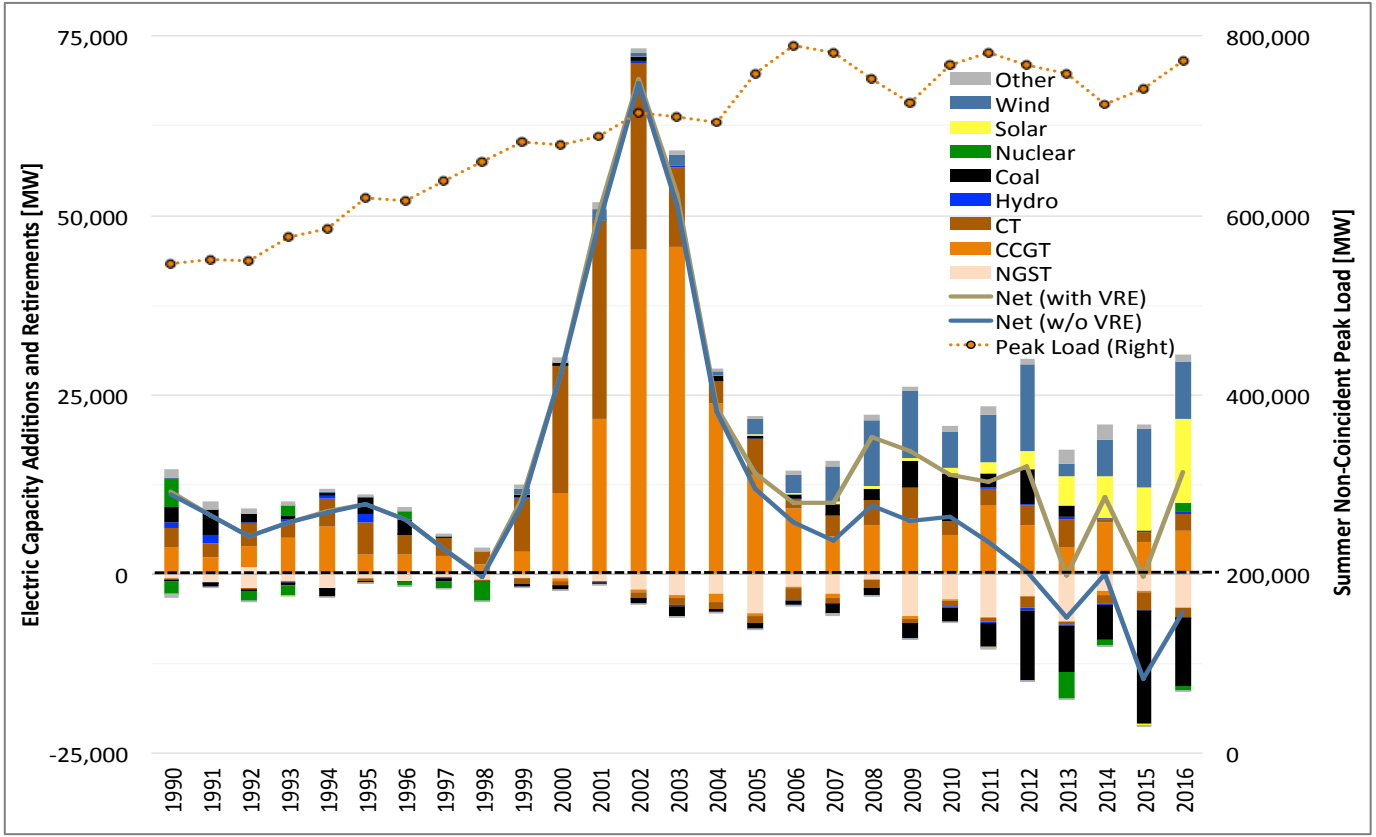
Sources: EEG-EEMD (2017) and BAFA (2017)

Electricity and Natural Gas Prices in the U.S. (Intro_4/5)



Source: DOE Staff Report (2017)

U.S. Capacity Additions and Retirements (Intro_5/5)



Wiser et al. , LBNL/ANL Report, Nov. 2017

Renewable Electricity in U.S. and Europe (Ren_1/6)

Technology	United States		Europe (EU-28)	
	2005	2015	2005	2015
Hydro	6.7	6.1	10.7	10.9
Wind	0.4	4.6	2.1	8.9
Solar	0	1.1	0.0	3.4
Biomass	1.3	1.6	1.4	2.8
Other	0.4	0.4	1.0	2.9
Total [%]	8.8	13.8	15.2	28.8
Total [TWh]	358.2	567.3	490.5	972.2

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

Renewable Policy

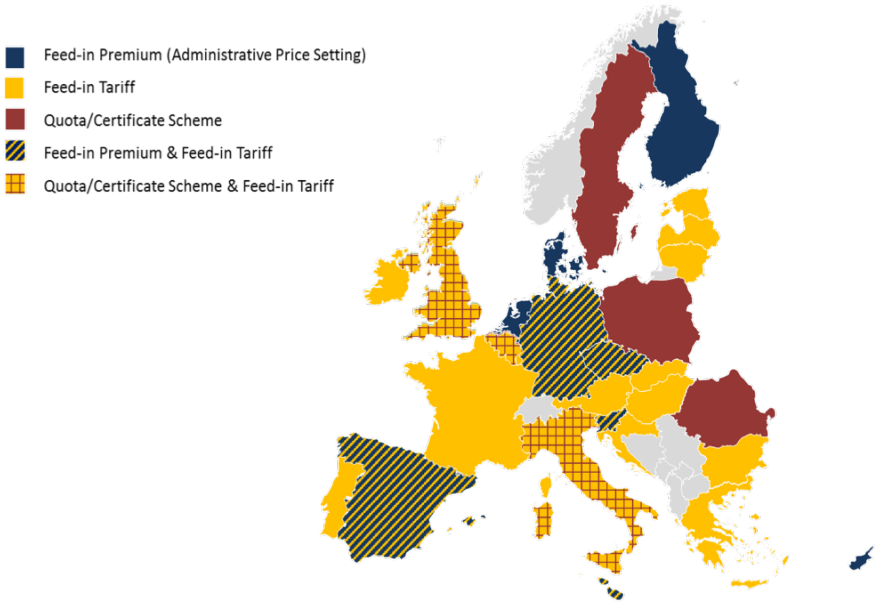
- Europe: Green certificates, Feed-in tariffs, Feed-in premiums, Auction schemes
- United States: Renewable portfolio standards (state), Renewable portfolio goals (state), Production tax credits (federal), Investment tax credits (federal)

Carbon Policy (low carbon prices in recent years)

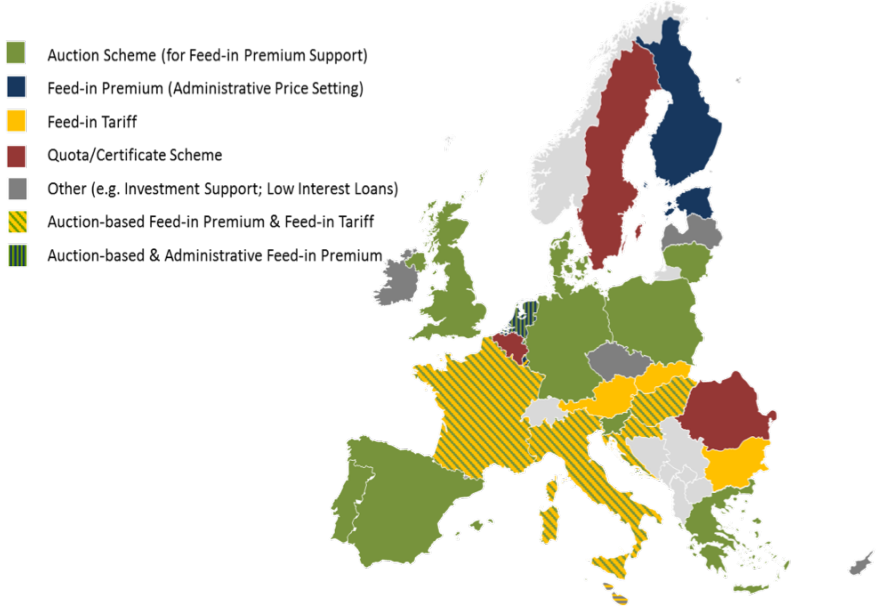
- European emissions trading system (ETS), Regional emissions trading in U.S. (Northeast and California)

Renewable Support Schemes in Europe (2012/2017) (Ren_2/6)

2012

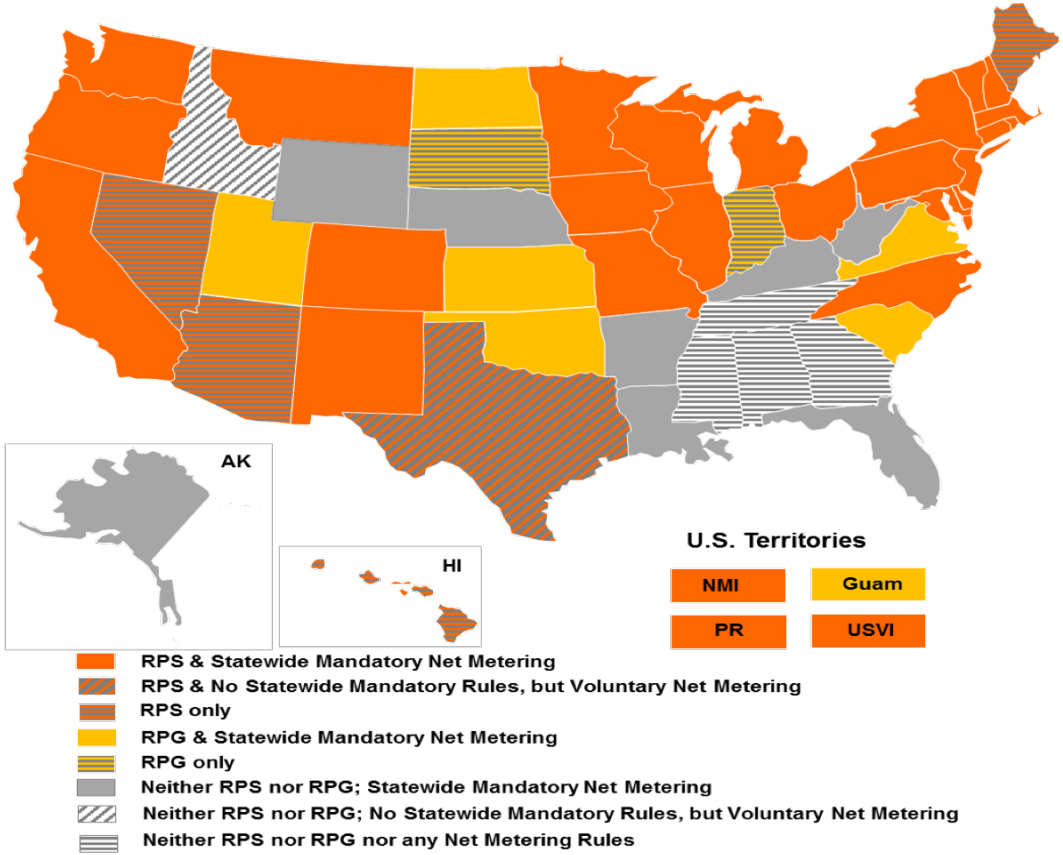


2017



Source: EEG Green-X (2017)

Renewable Support Schemes in the U.S. (2017) (Ren_3/6)



Data source: DSIRE (2017)

Indirect Enablers & Voluntary Schemes (Ren_4/6)

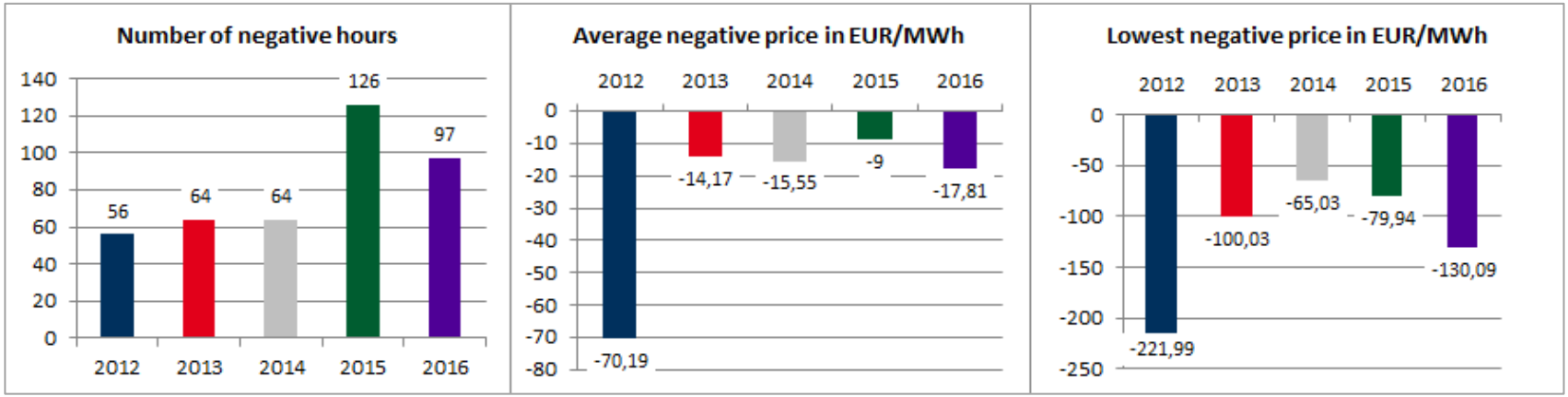
- Net Metering
  - In majority of U.S. states
  - In several European countries
- Local Energy Sharing
  - Solar PV community
  - Microgrids
- Corporate interest in renewable electricity
  - Purchasing of VER by corporations (*e.g. Google 100% renewable*)
  - Green electricity offered by food retailers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

Renewable Impact on Wholesale Electr. Prices (Ren_5/6)

- The merit order effect reduces electricity prices
  - Empirical literature indicates a larger effect in Europe (5-13 €/MWh) than the U.S. (0-9 $/MWh)

- The occurrence of negative prices has also increased in Europe and the U.S. with higher VRE penetration levels

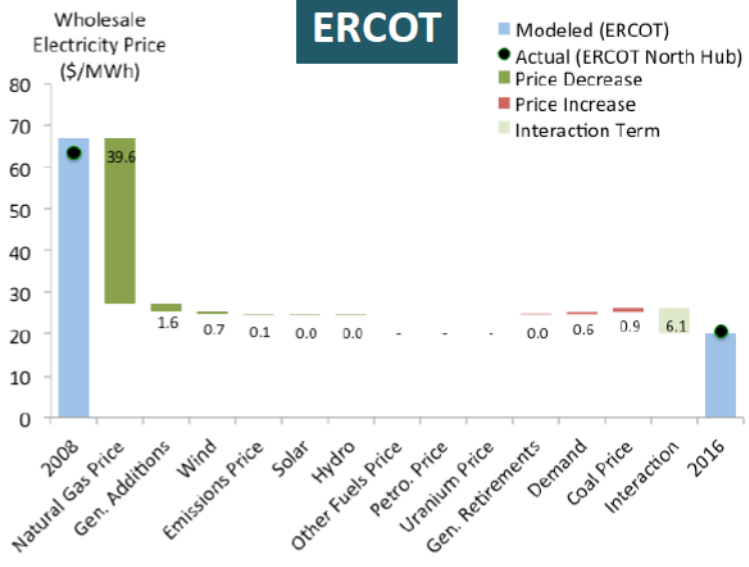
Negative prices in German electricity market

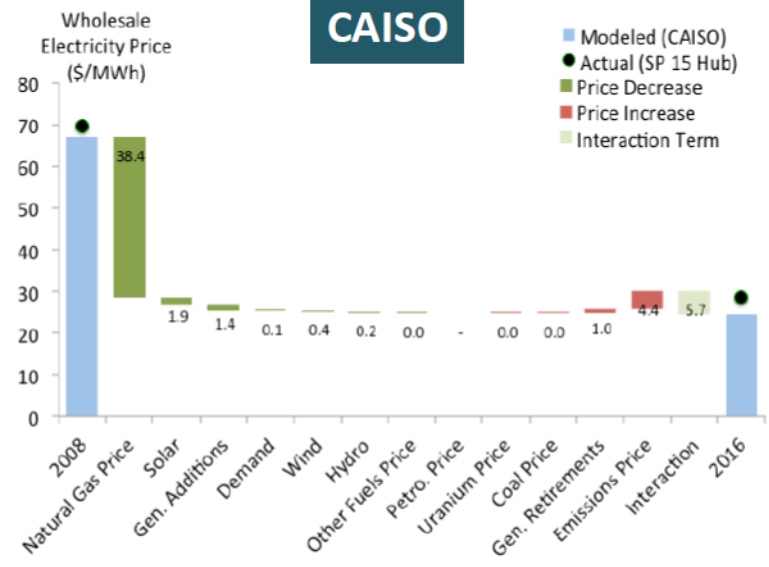


Source: Energy Brainpool (2017)

Drivers for Wholesale Price Decreases in the U.S. (Ren_6/6)

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





Wiser et al. , LBNL/ANL Report, Nov. 2017

Comparison: Short-term Market Operations (Short_1/2)

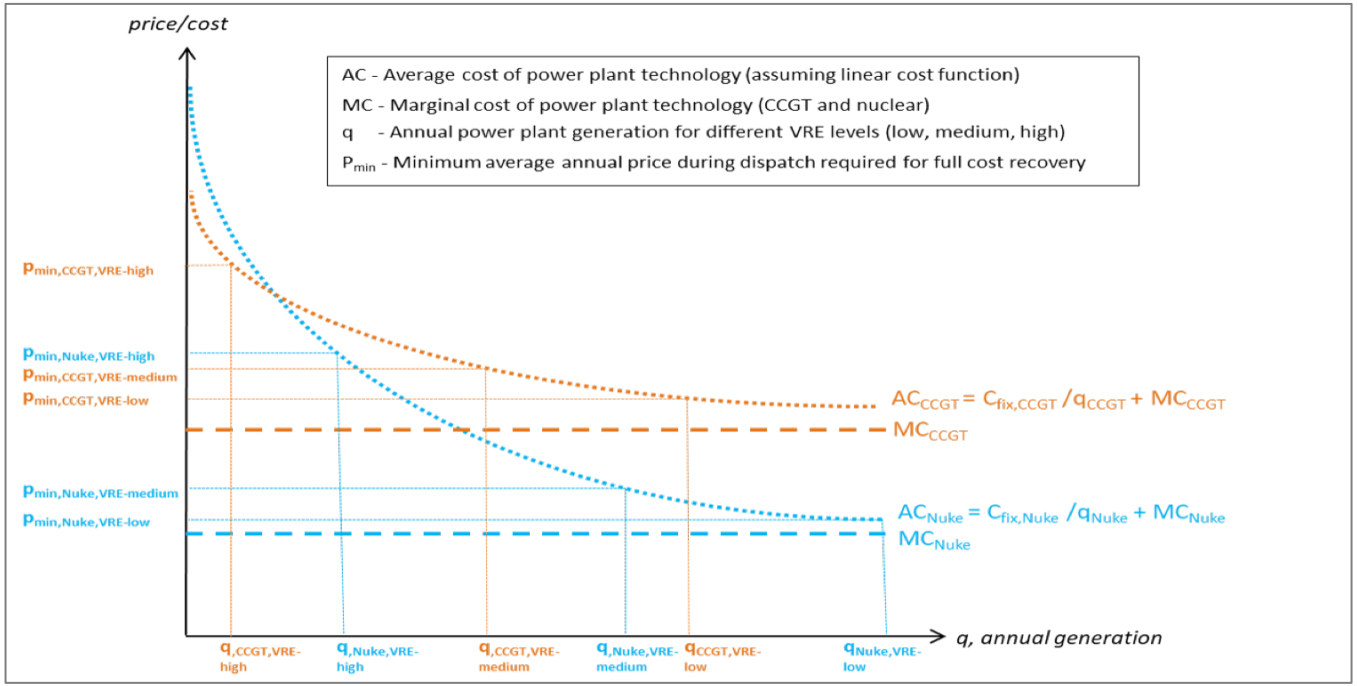
United States

- 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*
  - *More centralized control through ISO*
- Variable renewable energy
  - Intermittent policy support
  - Tax credits, renewable portfolio standards
  - *"Dispatchable" VER*
- Retail competition
  - Retail choice in some states

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*
  - *Market based, decentralized balancing through balance responsible parties*
- Variable renewable energy
  - Strong policy support
  - Feed-in tariffs - premiums, tenders/auctions
  - *VER as "must-take"*
- Retail competition
  - Retail choice in all countries

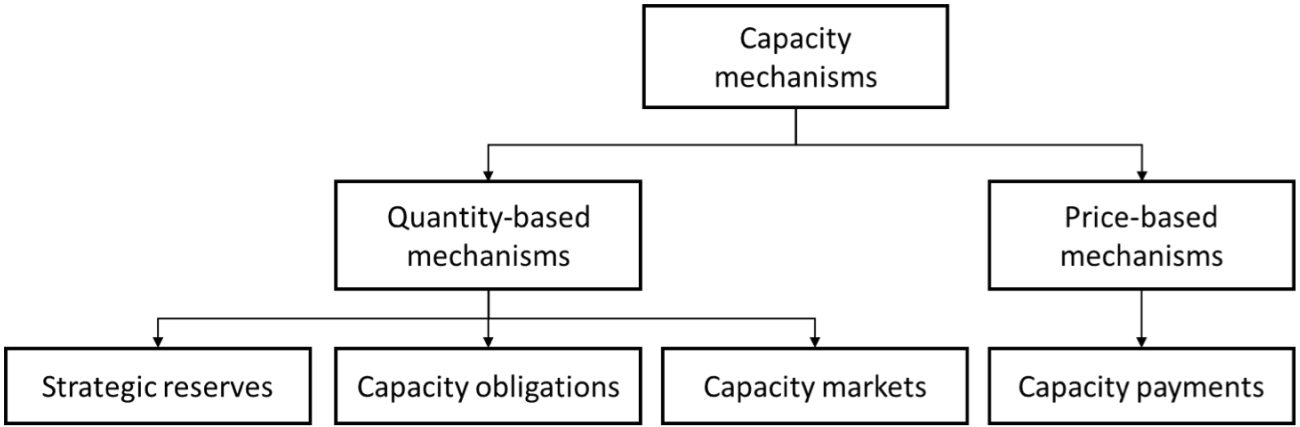
Revenue Sufficiency Challenge with Renewables (Short_2/2)



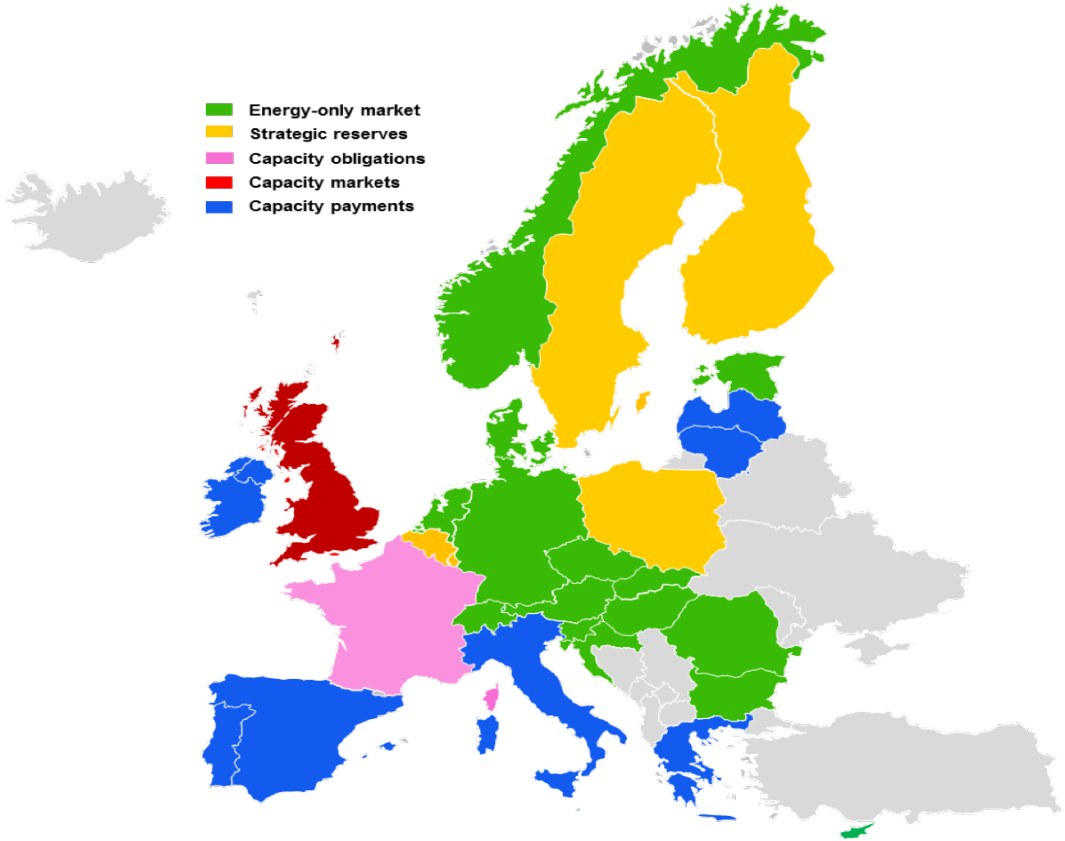
- Several ways to close the AC-MC gap
  - Scarcity pricing, demand response, higher offer prices in energy market
  - Capacity mechanisms

Resource Adequacy Paradigms (Long_1/3)

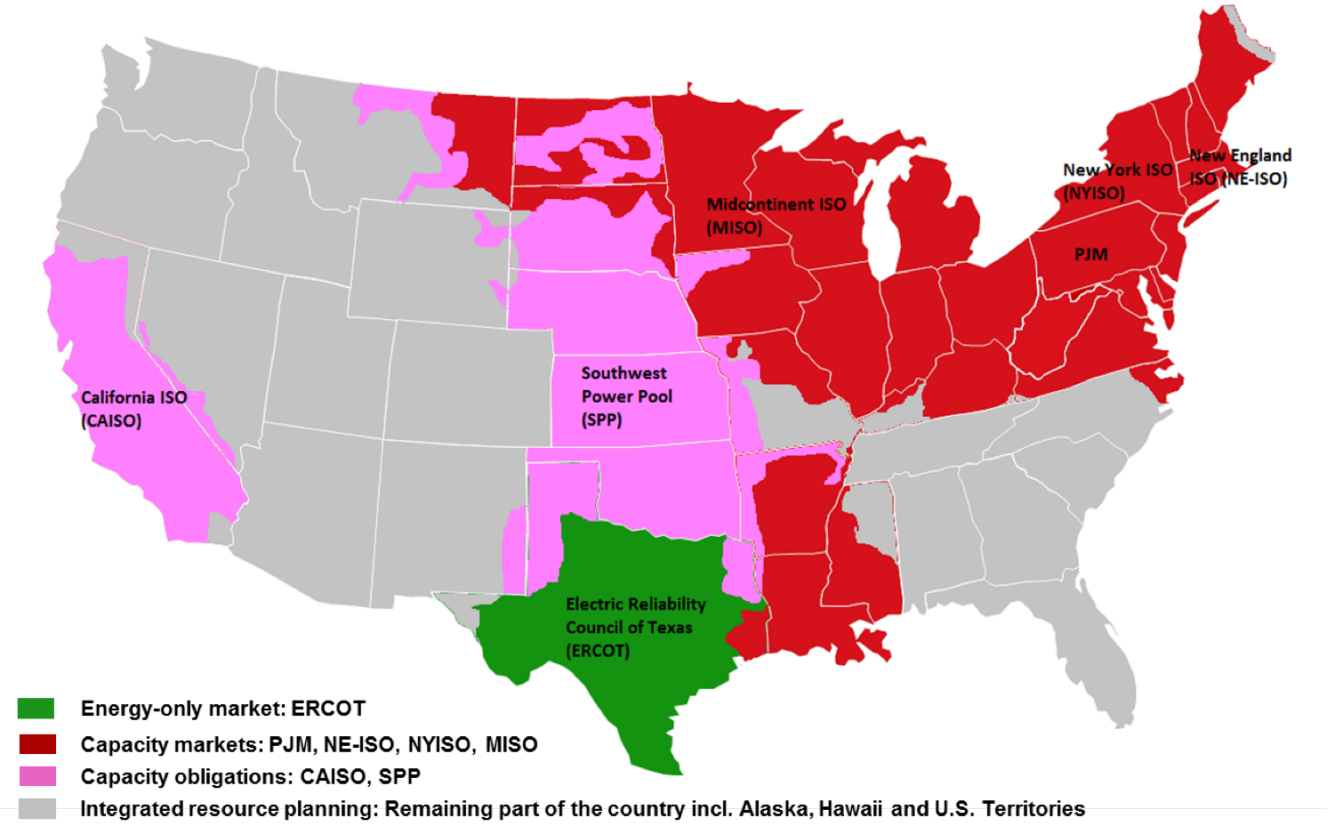
- Energy only market
  - Prices in energy (and reserves) markets provide investment incentives
  - Importance of scarcity rents
- Capacity mechanisms



Resource Adequacy: Current Status in Europe (Long_2/3)



Resource Adequacy: Current Status in U.S. (Long_3/3)



Recommendations for Improved Market Design (Concl_1/2)

General electricity market improvements

- Gradual removal of technology specific subsidy schemes for clean energy
- Adequate pricing of carbon and 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
- Move day-ahead markets closer to the operating day
- Improved incentives for system flexibility from supply, demand and energy storage
- Enable participation of distributed energy resources and demand response in electricity markets
- Reduce reliance on explicit capacity mechanisms to incentivize investments

Specific improvements for Europe

- Improved representation of transmission in market clearing to better reflect congestion in prices
- Imbalance netting to avoid opposite activation of frequency reserves in neighboring zones
- Shortening timeframes in intraday market
- Higher frequency of real-time dispatch and market clearing
- Co-optimization of energy and reserves instead of sequential/separate markets
- Economic dispatch of renewable resources
- Better coordination between TSOs
- Further develop retail competition, notably in terms of introducing more flexible and variable pricing/tariff products

Specific improvements for 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, along with innovations in flexible pricing/tariff design

Concluding Remarks (Concl_2/2)

- The impacts of variable renewable generation 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 markets: power exchanges also include long-term contracts
- How much of the “optimization problem” should be solved by system operators vs. market participants?
- No single solution: lessons to be learned in both directions
- Getting the price formation in short-term energy/reserve markets is the key challenge; capacity mechanisms only should be a back-up mechanism

- Collaborators
  - Audun Botterud — Massachusetts Institute of Technology (MIT)
  - Todd Levin — Argonne National Laboratory (ANL)
  - Andrew Mills — Lawrence Berkeley National Laboratory (LBNL)
  - Ryan Wiser — Lawrence Berkeley National Laboratory (LBNL)

- MIT International Policy Lab

- References

  - Botterud A. and H. Auer, “Resource Adequacy with Increasing Shares of Wind and Solar Power: A Comparison of European and U.S. Electricity Market Designs,” working paper.

  - Wiser R., Mills A.D., Seel J., Levin T., Botterud A., “Impacts of Variable Renewable Energy on Bulk Power System Assets, Pricing, and Costs,” Technical Report LBNL-2001082,” Nov. 2017.

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