
- HOME
- COMMITTEES
- KEYNOTE SPEAKERS
- BANQUET SPEAKERS
- PANEL SPEAKERS
- SESSION SPEAKERS
- GENERAL INFORMATION
- TOPICS
- SUBMIT YOUR PAPER
- PROGRAM
- IMPORTANT DATES
- SUPPORTING INSTITUTES & SPONSORS
- REGISTRATION
- ABOUT BOSTON
- CONTACT US

**Welcome to AEAB2019-Applied Energy Symposium: MIT A+B.**

The IPCC report "Global Warming of 1.5°C" (Oct. 2018) issued a dire warning that unless CO2 emissions are halved by 2030, devastating changes will occur on land and in ocean irreversibly and sooner than expected. Time is running out for transitioning to new energy systems globally. Logic and numbers show that the world must take a two-step approach: (A) deploy existing, industrially proven technologies, namely solar, wind and nuclear base load at an unprecedented scale and pace, from now to 2050 -- when a house catches fire, firemen must run to the closest hydrants and stop disputing which water stream would be purer; and (B) develop new concepts and technologies that may replace the dirtier parts of (A) post-2050, at terawatt scale.

The Applied Energy "A+B" symposium (AEAB2019) is dedicated to the accelerated deployment of (A), and new concepts and emerging technologies for (B). For (A), reducing capital and operating costs, managing social dynamics, and minimizing environmental impact while maintaining extreme productivity are key; automation, artificial intelligence, social mobilization, governmental actions and international coordination will provide essential boosts. For (B), we seek new concepts and emerging technologies (e.g. in energy storage, superconducting transmission, etc.) that stand a chance to scale to terawatts within 30 years.

AEAB2019 consists of a three-day symposium on May 22-24, 2019, at Massachusetts Institute of Technology, Cambridge, USA. All presentations (with the author's permission) will be video recorded and posted on YouTube or other open sources for public dissemination. Outstanding presentations will be recommended by the session chair and scientific committee to be further considered for publication in a special issue of Applied Energy (journal Impact Factor 7.9, please find more information at https://www.journals.elsevier.com/applied-energy).

To be invited to present at this symposium, please upload a .zip file (<200MB) containing a video or voice file (≤10 min) or a Powerpoint presentation (≤30 slides) or a traditional abstract (≤6 pages), with up to 3 supplemental PDF files, that explain how and why your work matters to A or B. The manuscript will be reviewed by symposium organizers for acceptance to the conference. Examples of topics include, but are not limited to, the following:

- Renewable energy: Solar energy (A or B), wind energy (A or B), bioenergy (A or B), geothermal energy (A or B) and other renewables.
- Nuclear energy: Shipyard constructed floating reactors (A), small modular reactors (A or B), fast reactors (B).
- Clean energy conversion technologies: Conversion of petroleum/gas/coal to high-valued materials and chemicals (A), hybrid energy systems, such as the combination of intermittent renewable energies and nuclear heat storage for load following, chemicals/materials/fuel production (A or B), multienergy carrier energy systems (A or B).
- Mitigation technologies: Carbon capture and sequestration (B), nuclear waste (A), solar waste (A), battery waste (A), reduced-CO2 production of cement, bulk metals and chemicals (A or B).
- Intelligent energy systems: smart grids (A), ultra-efficient/superconducting power transmission (B), wireless power transmission (B); electrification of transportation and industrial production, such as electric cars/trucks (A or B), electrified air flight (A or B).
- Energy storage: Pumped hydro/compressed air (A), thermal energy storage (A or B), grid-scale batteries (A or B), distributed energy storage (A or B).
- Sustainability of energy systems: Environmental monitoring (A), social mobilization (A), consensus building

- PROGRAM
- IMPORTANT DATES
- SUPPORTING INSTITUTES & SPONSORS
- REGISTRATION
- ABOUT BOSTON
- CONTACT US

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- Sustainability of energy systems: Environmental monitoring (A), social mobilization (A), consensus building
(A), governmental policy making (A), international coordination (A).

Given the grave urgency of our mission, we ask authors to be earnest, practical and in a problem-solving mode in their presentations. Creativity will be highly valued.

Details and updated information are available at www.applied-energy.org/aeab2019. If you have questions regarding this conference or submission, please contact Conference Organization Chair Dr. Ray (Zhenhua) Rui at MIT (aeab2019@applied-energy.org).

**Important Dates**

Submission deadline: March 10, 2019
Review: Feb 26 – March 20, 2019
Notification of acceptance: March 20, 2019
Conference: May 22 - 24, 2019
Conference Registration and MIT Campus Tour: May 22, 2019

We look forward to meeting you at MIT in Boston, USA.
Chairs of AEAB2019

| | |
|---|---|
| Prof. Ju Li<br>Massachusetts of Institute of Technology | Prof. J. Yan<br>Editor-in-chief of Applied Energy |

# Resource adequacy with increasing shares of wind and solar power: a comparison of European and U.S. electricity market designs

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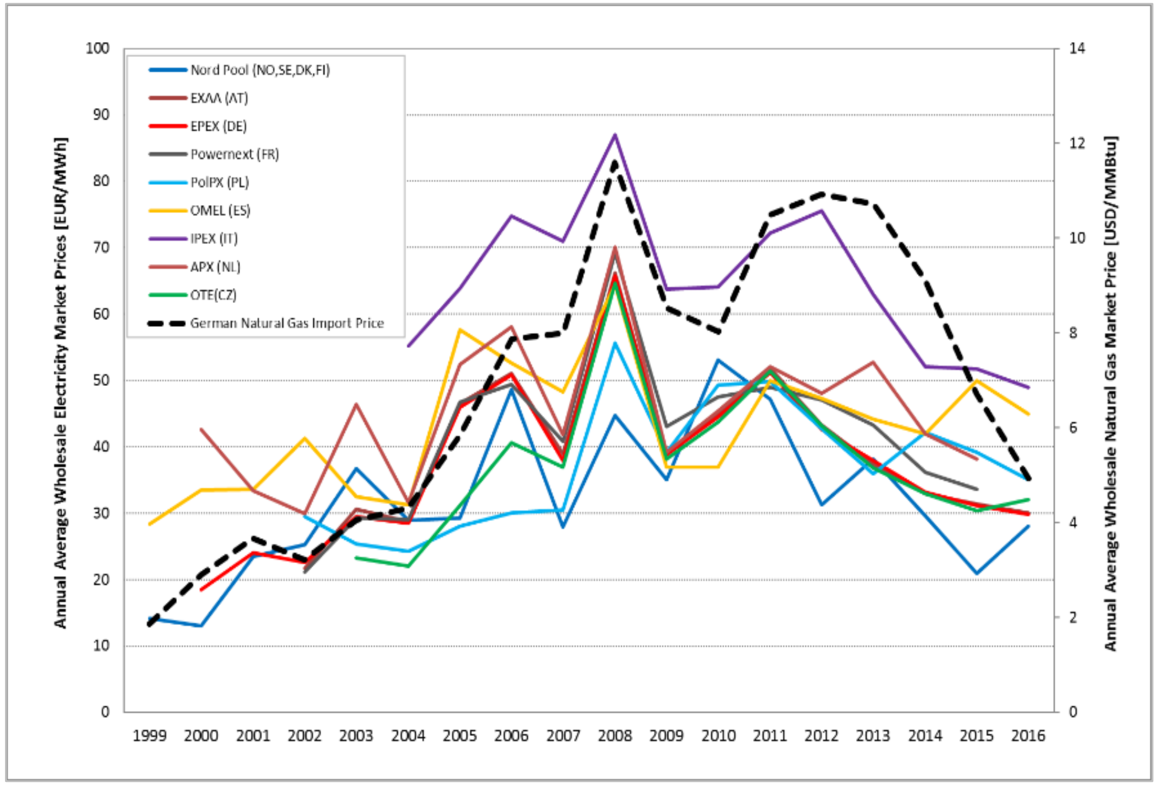
## KEY QUESTIONS

- How does rapidly increasing wind and PV generation impact electricity markets in the short- and long-term?
- Have wind and PV generation been the (only) drivers for wholesale electricity market price decreases in recent years?
- What are the pros and cons of the key electricity market design characteristics in Europe and the U.S. (for hosting high shares of wind and PV generation)?
- What are the possible electricity market design options for resource adequacy?
- What are the recommendations for improvements in electricity market design (general, Europe, U.S.) supporting further increasing wind and PV generation?

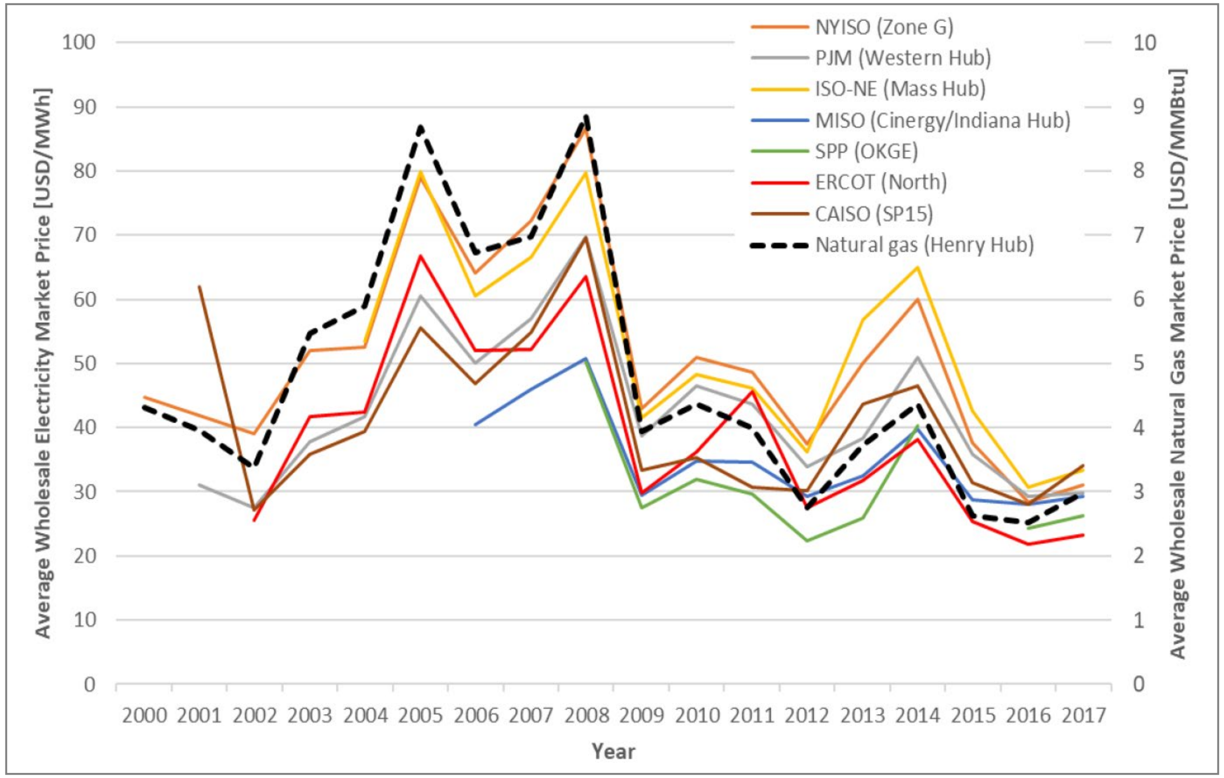
# ELECTRICITY & NATURAL GAS PRICES IN EUROPE & U.S.

## Europe (1999-2016)




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

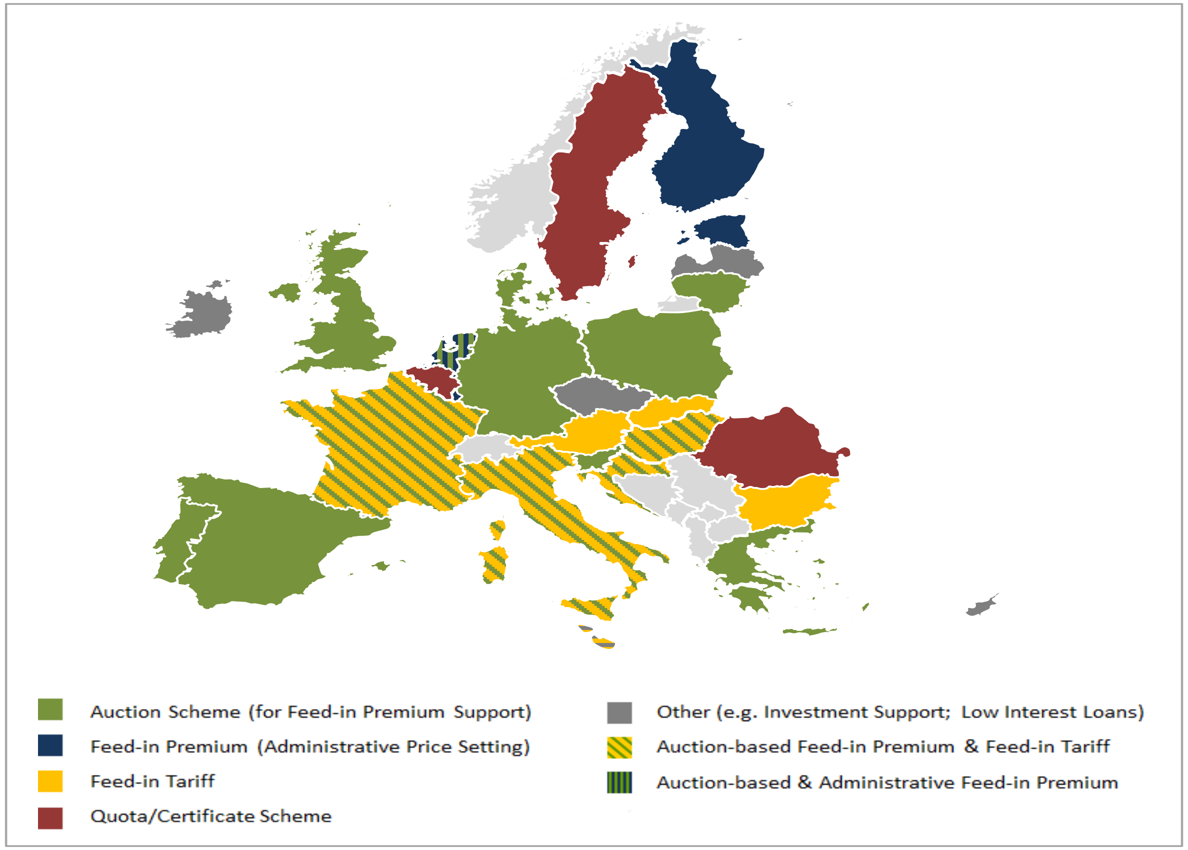
## U.S. (1999-2016)




*Data Sources: Data Source: ABB Velocity Suite and U.S. EIA*

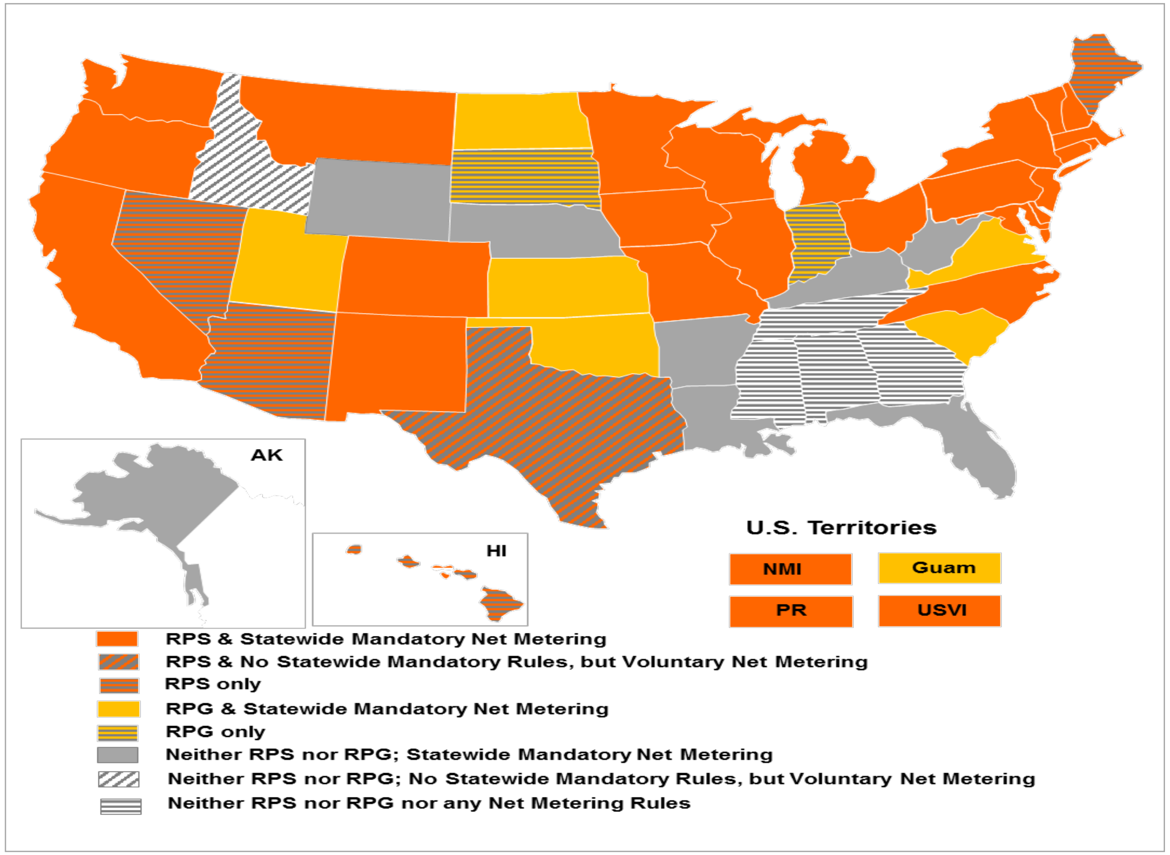
# RENEWABLE SUPPORT SCHEMES IN EUROPE & U.S.

## Europe (2017; 29.6% RES-E)




Source: EEG Green-X (2017)

## U.S. (2017, 15.6% RES-E)




Data Source: DSIRE (2017)

# DRIVERS FOR ELECTRICITY PRICE DECREASES IN EUROPE & U.S.

## Europe

- Merit Order Effect: 5-13 €/MWh (Praktiknjo/Erdmann (2016))
- VRE mainly responsible for price decline at least since 2011/2012
- Price decline 0-1 €/MWh in relative terms for 1% VRE increase (Welisch et al (2016))

**Merit order effect estimates of wind and PV in Germany, 2006–2012**

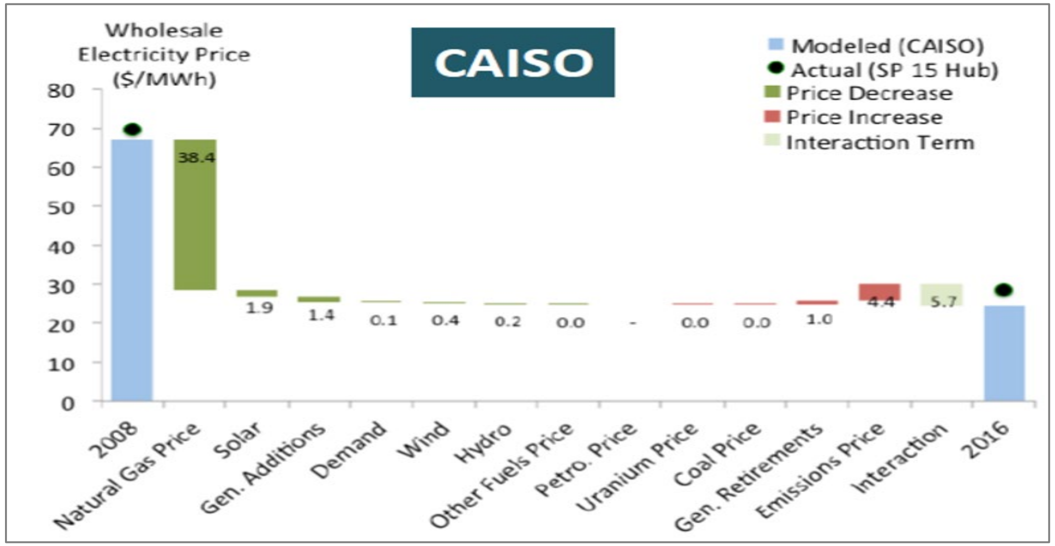
| | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 |
|---|---|---|---|---|---|---|---|
| | Euros/MWh | | | | | | |
| Sensfuß et al. (2008) | -7.8 | | | | | | |
| Weigt (2009) | -6.2 | -10.4 | -13.0 | | | | |
| vbw (2011) | | | | | -8.0 | | |
| Sensfuß (2012) | | -5.8 | -5.3 | -6.0 | -5.2 | -8.7 | -8.9 |
| Speth, Stark (2012) | | | | | -5.6 | -5.6 | |
| Cludius et al. (2013) | | | -10.8 | -7.8 | -6.0 | -7.7 | -10.1 |

Data source: Federal Ministry of Economic Affairs and Energy (2014), p. 38.

*Source: Praktiknjo/Erdmann (2016)*

## U.S.

- Merit Order Effect: 0-9 $/MWh (Wiser et al (2017))
- But: 5% VRE contribution only to overall price decline between 2008-2016 (85-90% gas)




*Source: Wiser et al (2017)*

In addition, we frequently have been observing negative electricity market prices in recent years, both Europe & the U.S.

# COMPARISON: SHORT-TERM MARKET OPERATIONS

## Europe

Indroduced 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 decentralised balancing through balance responsible parties**

Variable renewable energy
- Strong policy support
- Feed-in tariffs/premiums, tenders/auctions
- **VRE as „must-take“**

Retail competition
- Retail choice in all countries

## U.S.

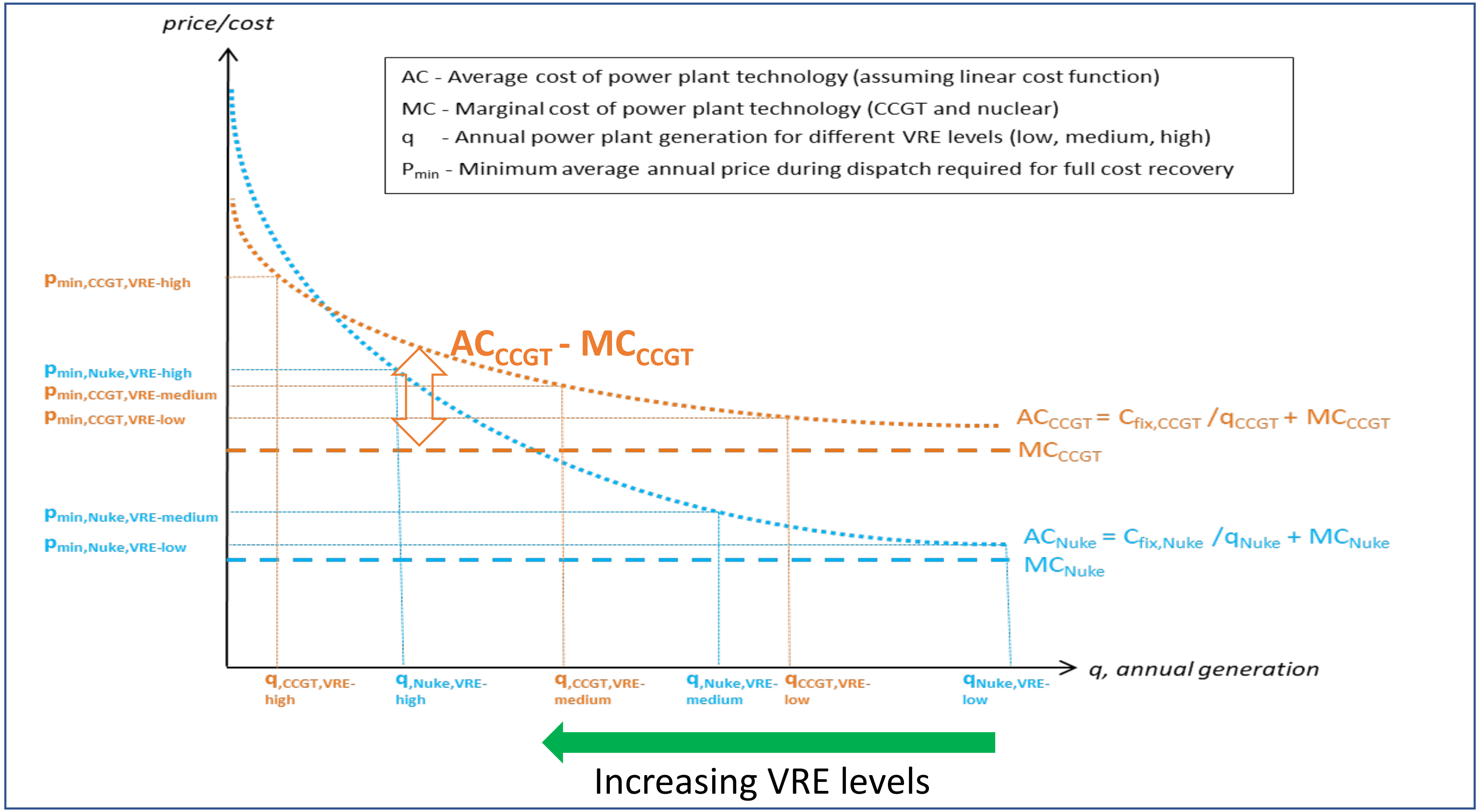
Build into existing system operators (ISOs)
- Short-term system operation
- ISOs do not own transmission system
- **Emphasize physics of the power system**

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“ VRE**

Retail competition
- Retail choice in some states

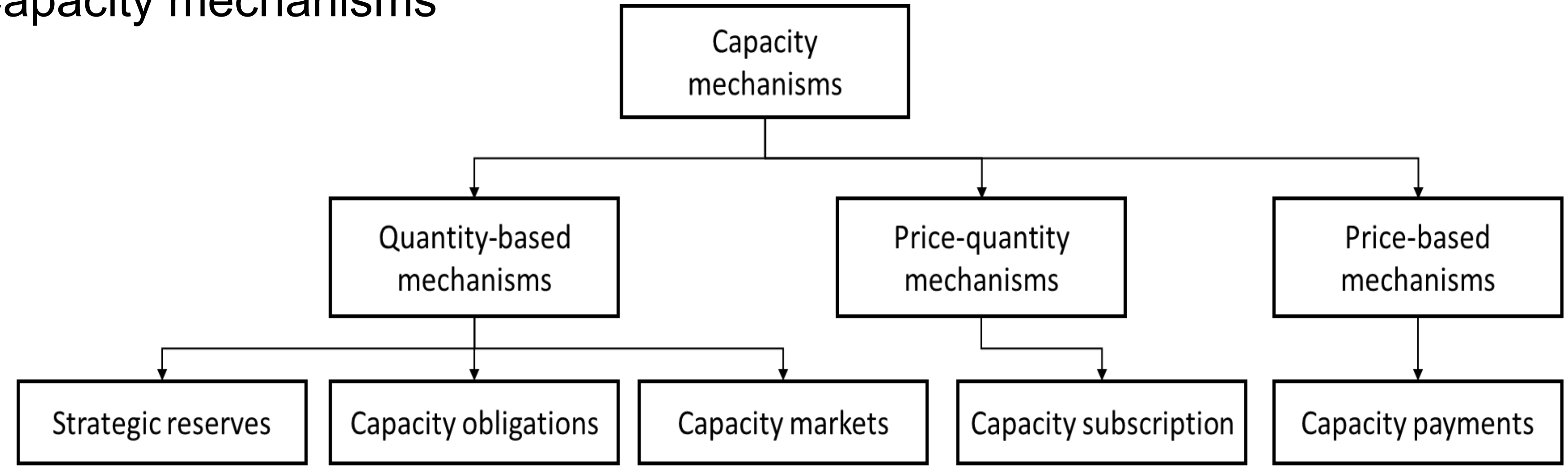
# THE REVENUE SUFFICIENCY CHALLENGE WITH INCREASING VRE



## RESOURCE ADEQUACY PARADIGMS

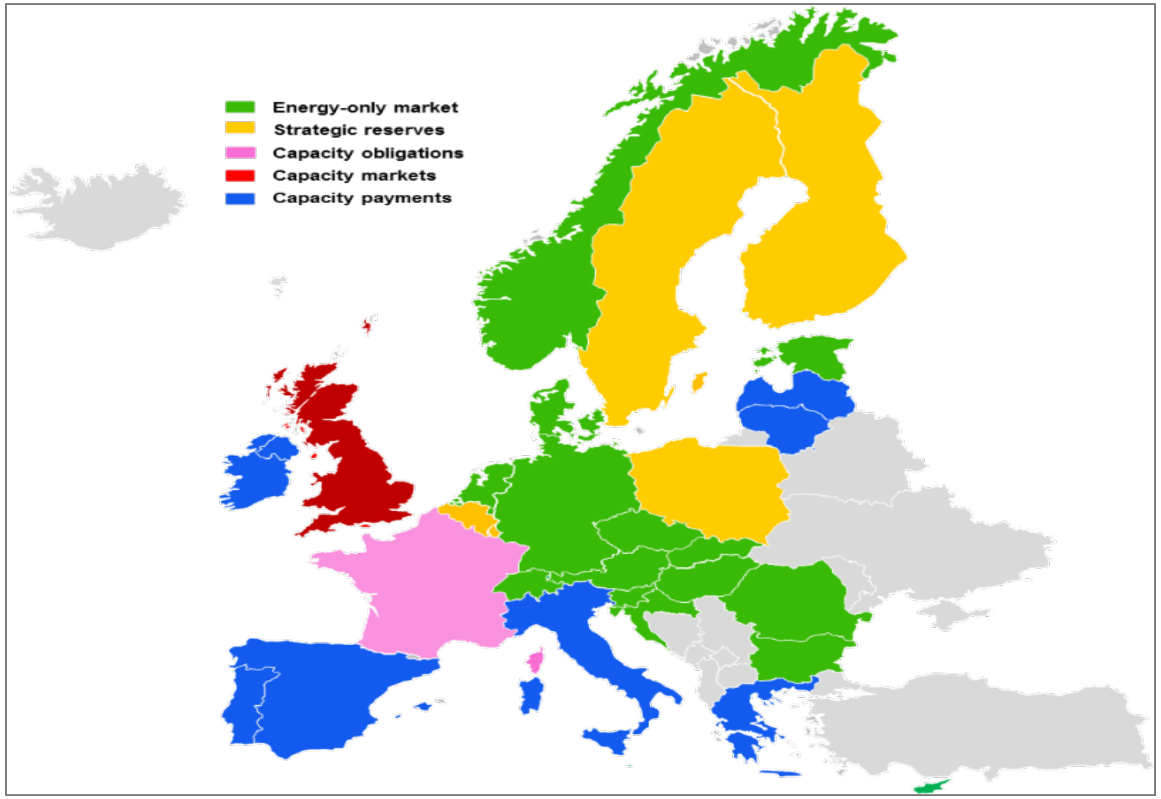
Several ways to close the gap between Average Cost (AC) and Marginal Cost (MC):

- Energy-only market
  - Prices in energy (and reserves) markets provide investment incentives
  - Importance of scarcity rents (higher offer prices in energy market)
  - Exploitation of several existing flexibilities in the electricity system
- Capacity mechanisms



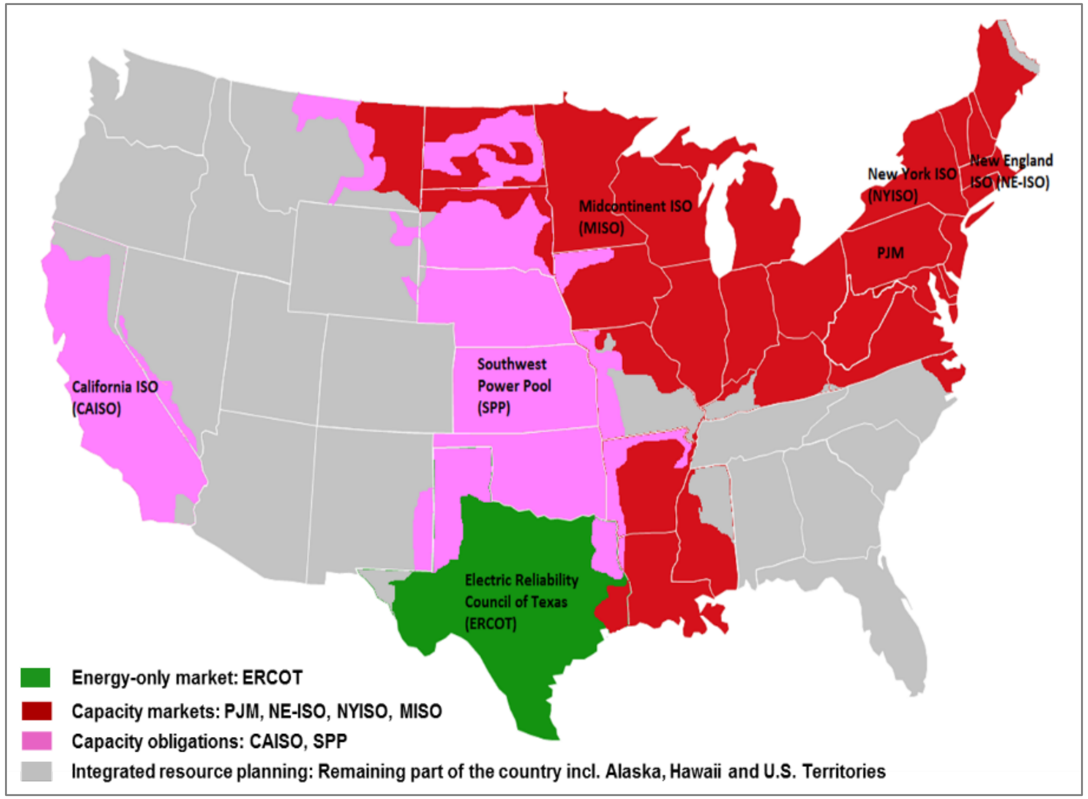
# CAPACITY MECHANISMS: CURRENT STATUS IN EUROPE & U.S.

## Europe (2017)




*Source: EEG-EEMD (2017)*

## U.S. (2017)




*Source: IRC – ISO/RTO Council (www.isorto.org); own research*

# CAPACITY SUBSCRIPTION

The idea *(Doorman 2005)*

- Consumers buy the capacity they need under system scarcity
- Generators (and storage) receive capacity payments accordingly
- System operator limits consumer demand during scarcity
- A practical implementation of "priority service" *(Chao and Wilson 1987)*

Several advantages *(Doorman and De Vries 2017)*

- Consumers pay directly for the scarce resource: generation capacity
- Capacity adequacy moves in the direction of a private good (economically efficient rationing)
- Capacity price and quantity reflecting consumer preferences
- Reduced risk for consumers and producers

Challenges

- Cost of controlling loads at consumer level (load limiting devices)

## GENERAL RECOMMENDATIONS FOR IMPROVED MARKET DESIGN

- **Gradually remove technology specific subsidy schemes for VRE generation**
- **Adequate pricing of carbon and other environmental externalities in a more market-compatible manner**
- **Improve price formation in energy and reserve markets, particularly during scarcity conditions**
- Move day-ahead markets closer to the operating day
- Improve incentives for provision of system flexibility
- Remove barriers for supply, demand and energy storage technologies to enable competition in several market segments
- Enable participation of distributed generation and demand response
- Reduce reliance on explicit capacity mechanisms to incentivize investments (if still needed, use more market-based designs like capacity subscriptions)

# SPECIFIC RECOMMENDATIONS FOR IMPROVED MARKET DESIGN

## 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 time resolution of real-time dispatch and market clearing**
- **Co-optimization of energy and reserves instead of sequential/separate markets**
- **Economic dispatch of VRE**
- Better coordination between TSOs to reduce dispatch needs
- Further develop retail competition, notably in terms of more flexible and variable pricing/tariff products

## U.S.

- **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 service markets
- Full co-optimization of energy and reserves in all regional U.S. markets
- Better coordination between regional capacity, energy, and reserve markets
- **Open up for retail competition in larger parts of the country, along with innovations in flexible pricing/ tariff design**

## CONCLUDING REMARKS

- The impact of variable renewable generation on electricity markets is more visible in European compared to U.S. electricity markets.
- U.S. electricity markets better aligned with physics of the transmission grid: more centralized coordination and control.
- European electricity markets more focused on market clearing via power exchanges (including also long-term contracts).
- One of the key questions: 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 should be a back-up only (and if needed, preference for a more market-based approach like capacity subscriptions).
- No single solution: lessons to be learned in both directions!

# Acknowledgements / References

## Collaborators

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

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