# Electricity Markets and Renewable Energy: United States vs. Europe

***Audun Botterud***

Center for Energy, Environmental, and Economic Systems Analysis
Energy Systems Division
Argonne National Laboratory
abotterud@anl.gov

Visiting Researcher, Energy Economics Group, TU Wien

Visiting Scholar, MIT Energy Initiative, Massachusetts Institute of Technology
http://botterud.mit.edu/

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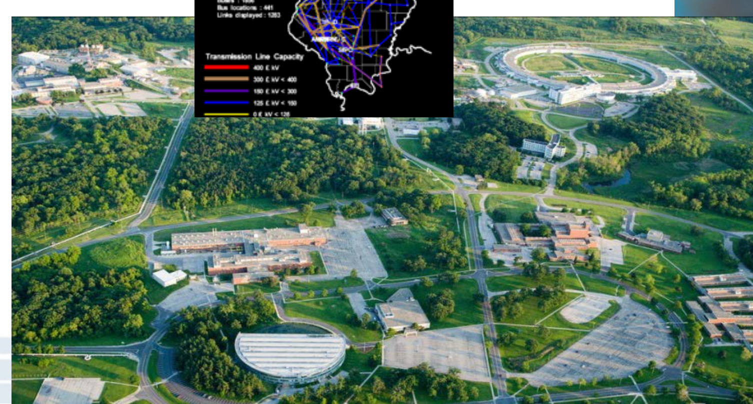
# Argonne is America's First National Laboratory and one of the World's Premier Research Centers

- Founded in 1943, designated a national laboratory in 1946
- Part of the U.S. Department of Energy (DOE) laboratory complex
  - 17 DOE National Laboratories
- Managed by UChicago Argonne
  - About 3,400 full-time employees
  - 6,000+ facility users
  - About $800M budget
  - Main site: 1500-acre site in Illinois, southwest of Chicago
- Broad research and development portfolio
- Numerous sponsors in government and private sector
- 3 Nobel Prize Winners

# Center for Energy Environmental and Economic Systems Analysis (CEEESA): Overview of Grid Research

- **Power Systems Analysis**
  - Unit Commitment and Economic Dispatch
  - Hydro-Thermal Coordination
  - Power Flow Analysis, Congestion Management
- **Renewables (Wind and Solar) Integration**
  - Stochastic Generation Expansion Plan
  - Wind and Solar Forecasting
- **Battery Energy System Analysis**
  - Energy Arbitrage, Load Leveling
  - Frequency Regulation, Operating Reserves
- **Smart and Resilient Grids**
  - Dynamic Line Ratings
  - Controlled Cascading
  - Power System Restoration
  - Cyber Security
- **Micro Grids**
  - Distributed Generation Management
  - Islanding with Mutiple Micro Grids
- **Energy in Buildings**
  - Energy Efficiency, Demand Response
  - Building/Grid Interaction


# Renewable Electricity Generation in United States

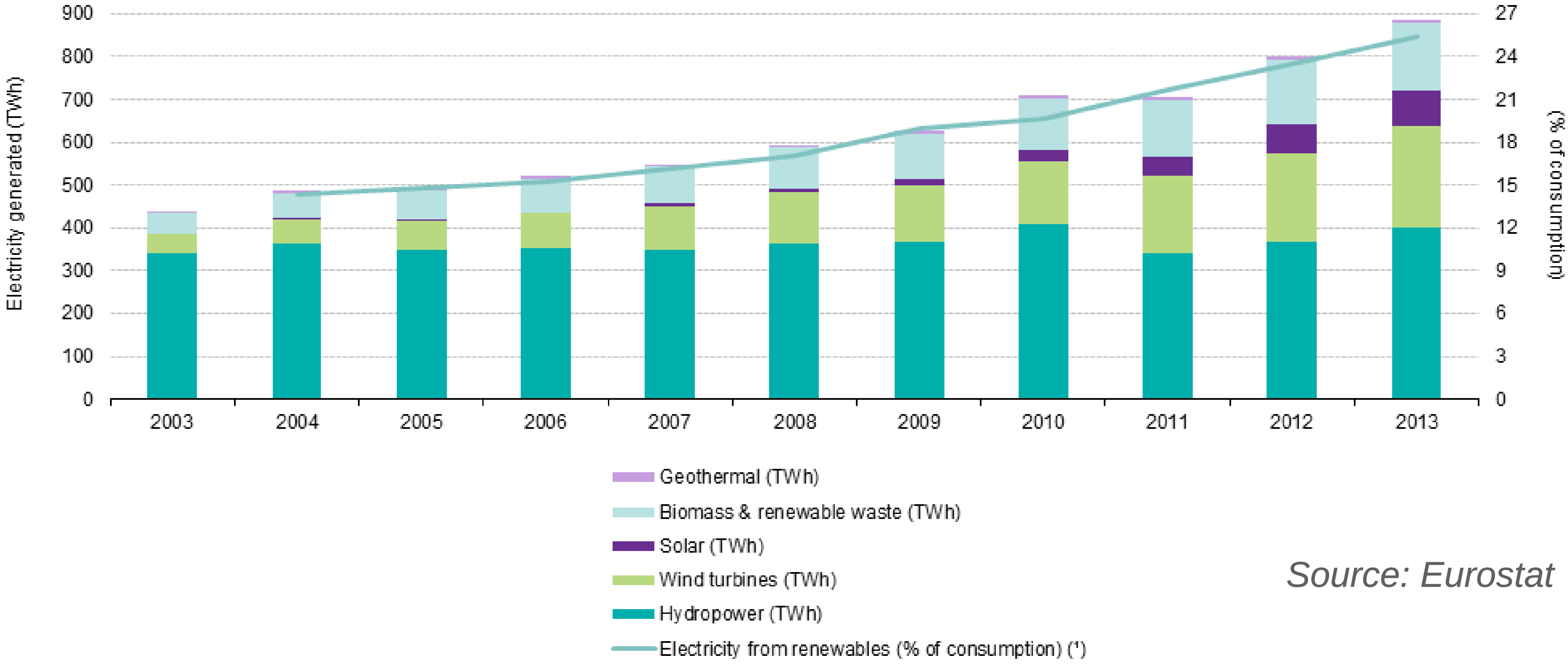
| | Hydropower | Solar[1] | Wind | Geothermal | Biomass | Total Renewables |
|---|---|---|---|---|---|---|
| 2004 | 6.7% | 0.0% | 0.4% | 0.4% | 1.3% | 8.8% |
| 2005 | 6.7% | 0.0% | 0.4% | 0.4% | 1.3% | 8.8% |
| 2006 | 7.1% | 0.0% | 0.7% | 0.4% | 1.3% | 9.5% |
| 2007 | 5.9% | 0.0% | 0.8% | 0.4% | 1.3% | 8.5% |
| 2008 | 6.2% | 0.1% | 1.3% | 0.4% | 1.3% | 9.3% |
| 2009 | 6.9% | 0.1% | 1.9% | 0.4% | 1.4% | 10.6% |
| 2010 | 6.3% | 0.1% | 2.3% | 0.4% | 1.4% | 10.4% |
| 2011 | 7.8% | 0.2% | 2.9% | 0.4% | 1.4% | 12.6% |
| 2012 | 6.8% | 0.3% | 3.4% | 0.4% | 1.4% | 12.4% |
| 2013 | 6.6% | 0.5% | 4.1% | 0.4% | 1.5% | 13.1% |
| 2014 | 6.3% | 0.8% | 4.4% | 0.4% | 1.6% | 13.5% |

Sources: EIA, LBNL, SEIA/GTM

*Source: NREL*

- Total Renewable Generation 2014: 554 TWh (13.5%) in 2014

# Renewable Electricity Generation in Europe (EU-28)



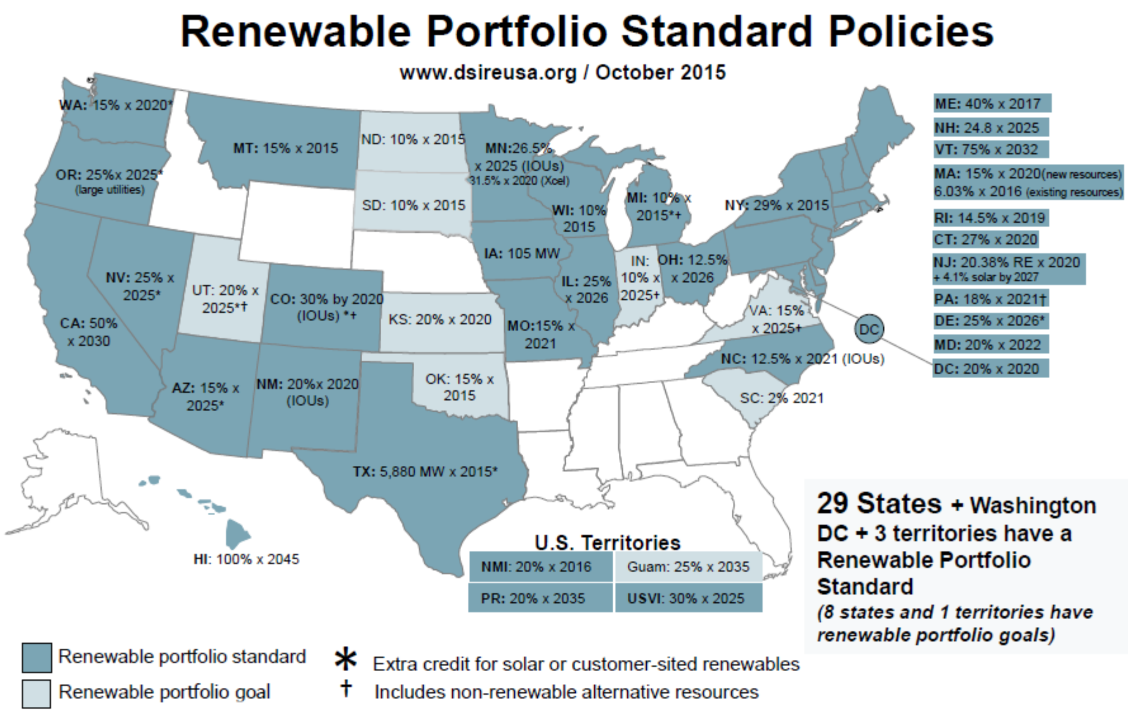

*Source: Eurostat*

(¹) 2003: not available.
*Source:* Eurostat (online data codes: nrg_105a and tsdcc330)

- Total Renewable Generation 2013: 890 TWh (25.4%) in 2013

# Subsidy Schemes for Renewables

- United States
  - Direct support for renewables
    - Production/Investment tax credits (Federal)
    - Renewable portfolio standards (State)
  - Climate change policies
    - EPA’s Clean Power Plan (stayed by Supreme Court)
    - Regional cap and trade programs




- Europe
  - Direct support for renewables
    - Feed-in tariffs for wind and solar
      - Fixed to premium tariffs and auctions
    - Green certificates
  - Climate change policies
    - European Emissions Trading System (ETS)

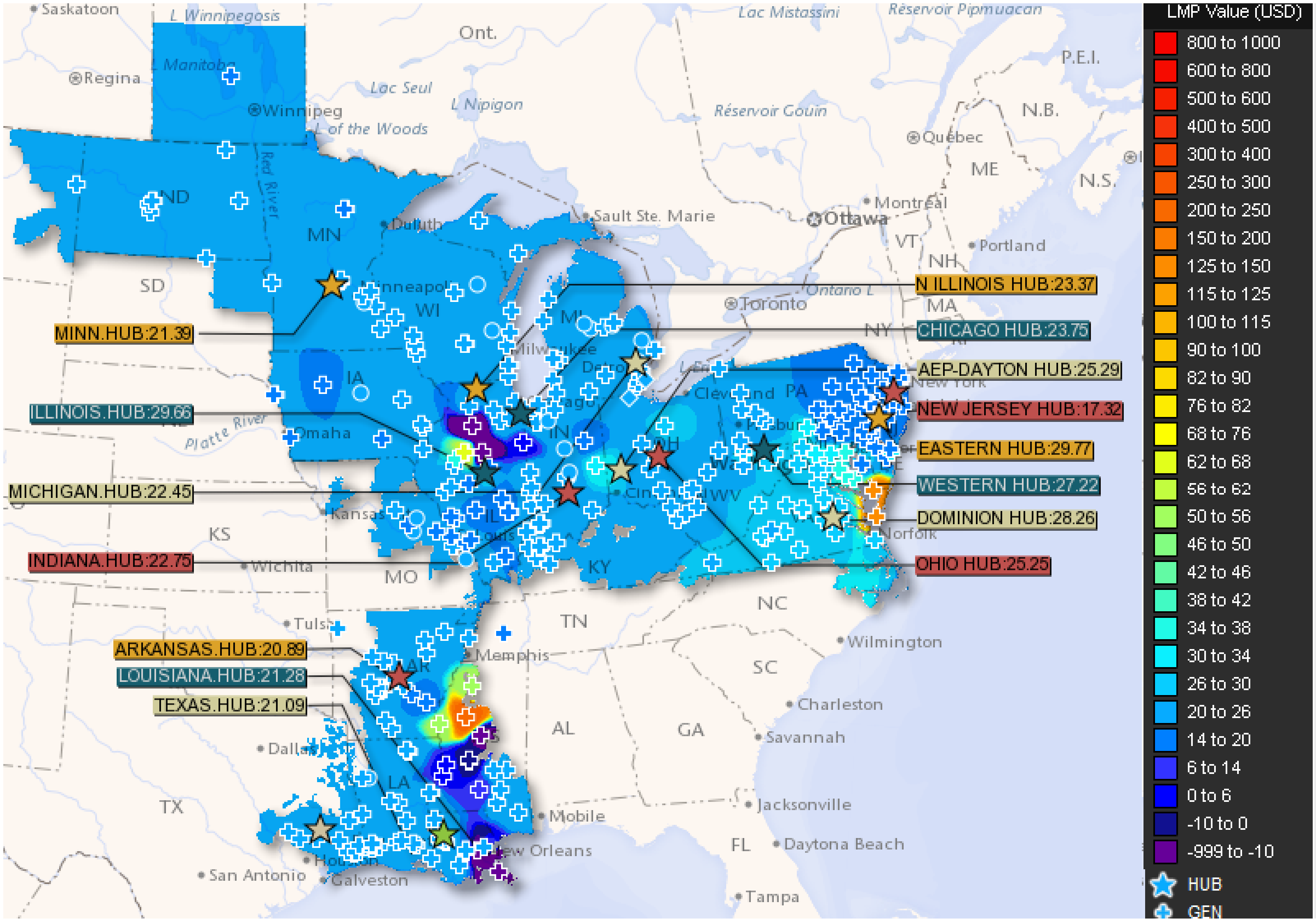
*Source: DSIRE*

# The General Structure of Electricity Markets

- United States
  - Build into existing system operators (ISOs)
    - Emphasize physics of the power system
    - Short-term system operation
    - ISOs do not own transmission system
  - Market design elements (United States)
    - Day-ahead market (ISO - hourly)
    - Real-time market (ISO - 5 min)
    - Complex bids/ISO UC
    - Locational marginal prices
    - Co-optimization of energy and reserves
  - Variable Renewable Energy (VER)
    - “Dispatchable” VER

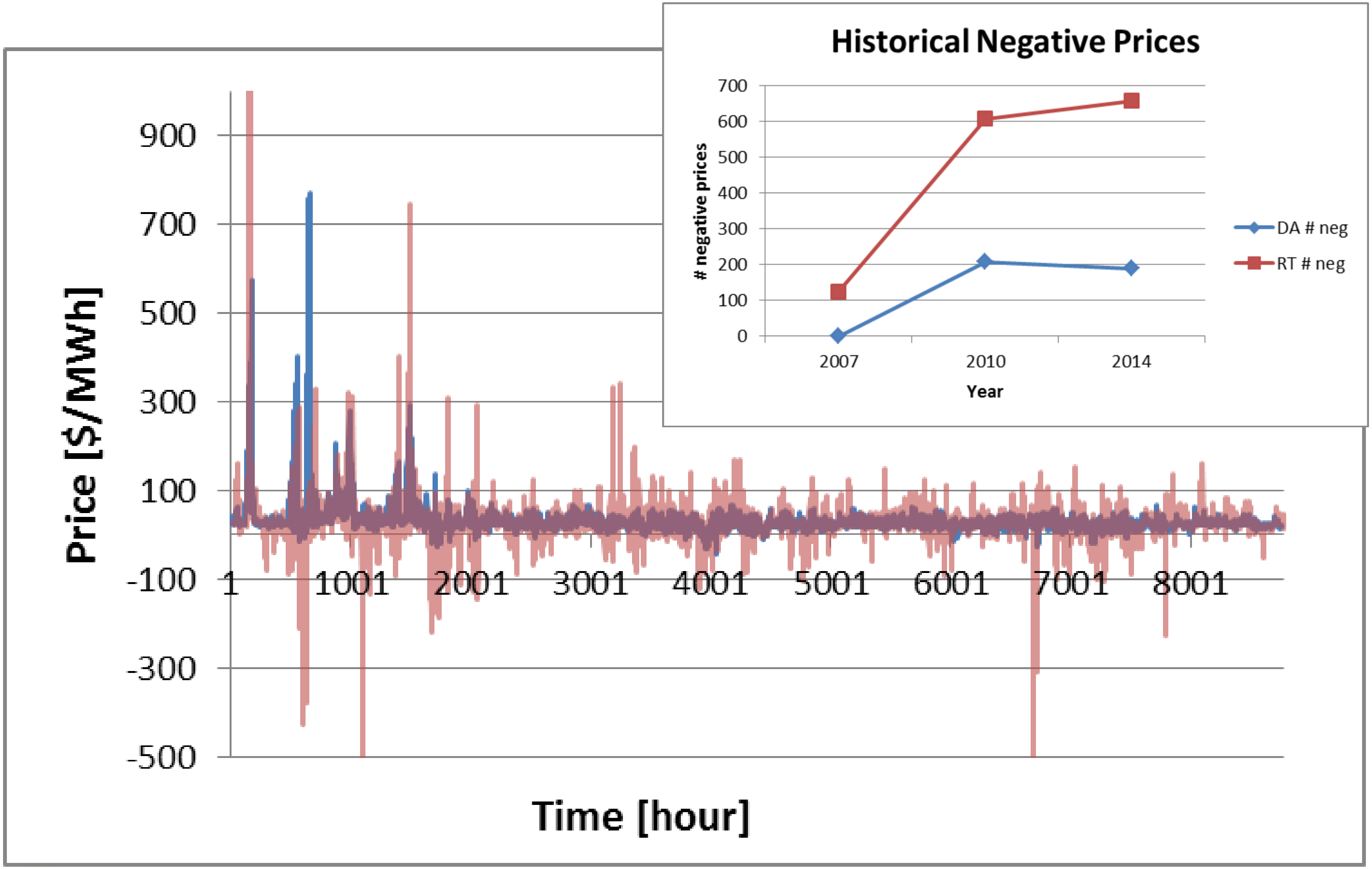
- Europe
  - Introduced new power exchanges (PXs)
    - Emphasize markets and economics
    - Includes long-term contracts
    - TSOs typically own transmission system
  - Market design elements (Europe)
    - Day-ahead market (PX)
    - Real-time balancing (TSO)
    - Simple bids/generator UC
    - Zonal pricing/market coupling
    - Sequential reserve and energy markets
  - Variable renewable energy (VER)
    - VER as “must-take”

# Congestion Management and Locational Marginal Prices (US)



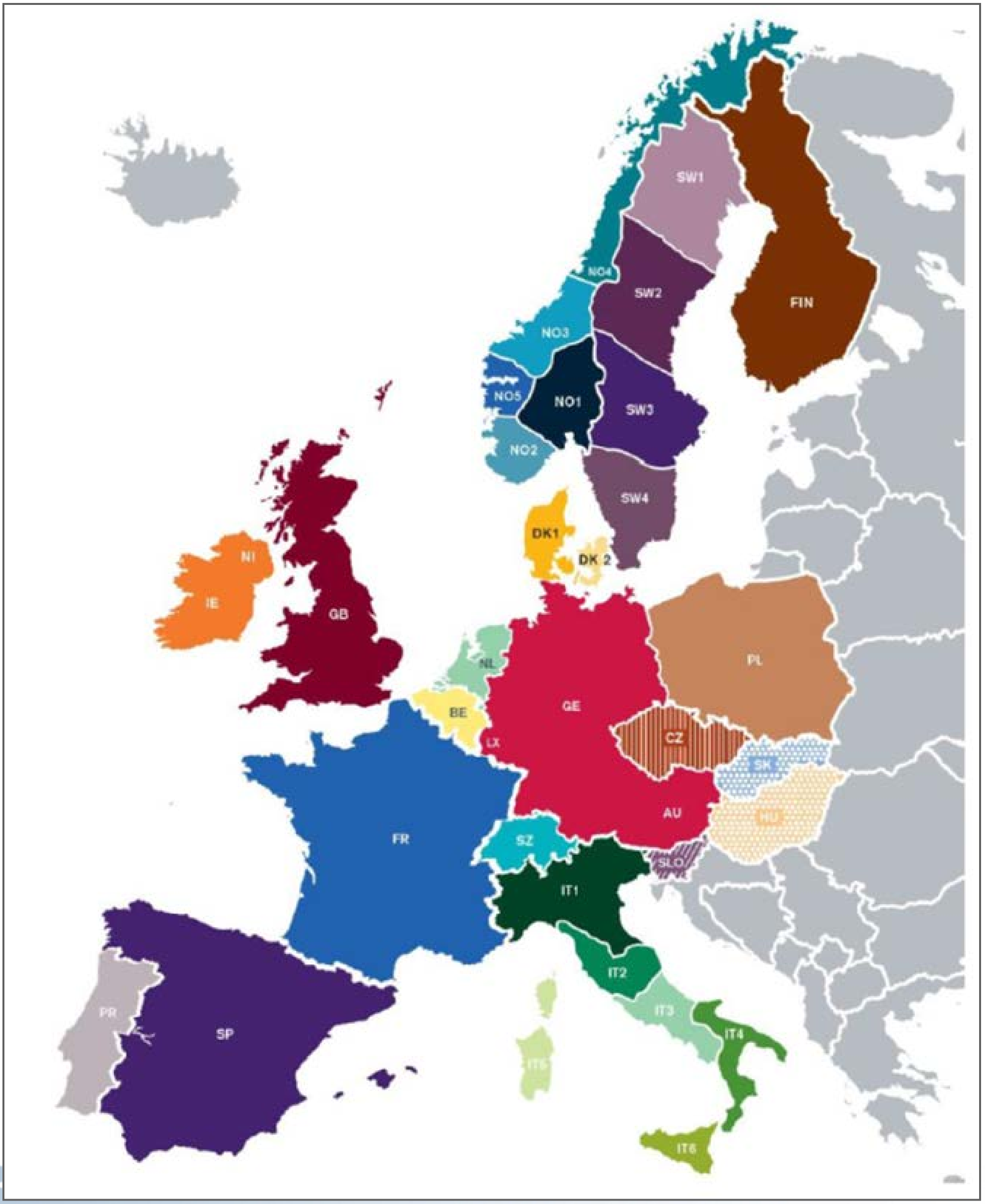

Nov 18 2015, 8.30am

# Wind Power Influences Electricity Prices Today: Day-ahead and Real-time Prices at Node in Illinois (2014)




*Prices in Illinois PJM Node: 4 QUAD C18 KV QC-1*

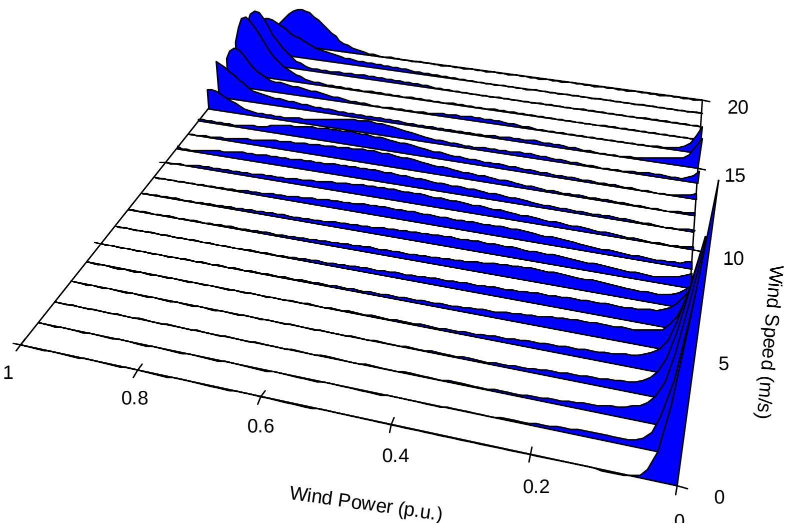
# Price Zones in European Day-Ahead Markets




*Courtesy:*
*Hans Auer*

# Improved Market Operations with Renewables

- How do we best address increasing uncertainty and variability in system/market operations?
- Forecasting of wind and solar power
  - Importance of estimating forecast uncertainty (e.g. conditional kernel density estimation)
- Improved operating reserve strategies
- Stochastic unit commitment
  - Minimizes expected cost across uncertainties
  - Implicit operating reserves
  - Most studies show significant benefits
  - Several challenges for real-world implementation
    - Uncertainty quantification
    - Computational aspects
    - Pricing and market implementation
  - Limited industry applications so far




*Bessa et al. Renewable Energy*, 40(1): 29-39, *2012.*

| Study | Stochastic UC Cost Savings |
|---|---|
| Gröwe et, al. (1995) | 1.6% |
| Takriti et. al. (1996, 2000) | 0.4-4.0% |
| Tuohy et. al. (2008) | 0.6% |
| Wang et. al. (2008) | 1.3% |
| Pappala et. al. (2009) | 2.8-3.8% |
| Ruiz et. al. (2009, 2010) | 0.8-1.8% |
| Constantinescu et. al. (2011) | 1.0% |
| Wang et al. (2011) | 2.9 % |
| Zhou et al. (2013) | 1.7 % |
| Papavasiliou and Oren (2013a,b) | 1.9-5.4% |

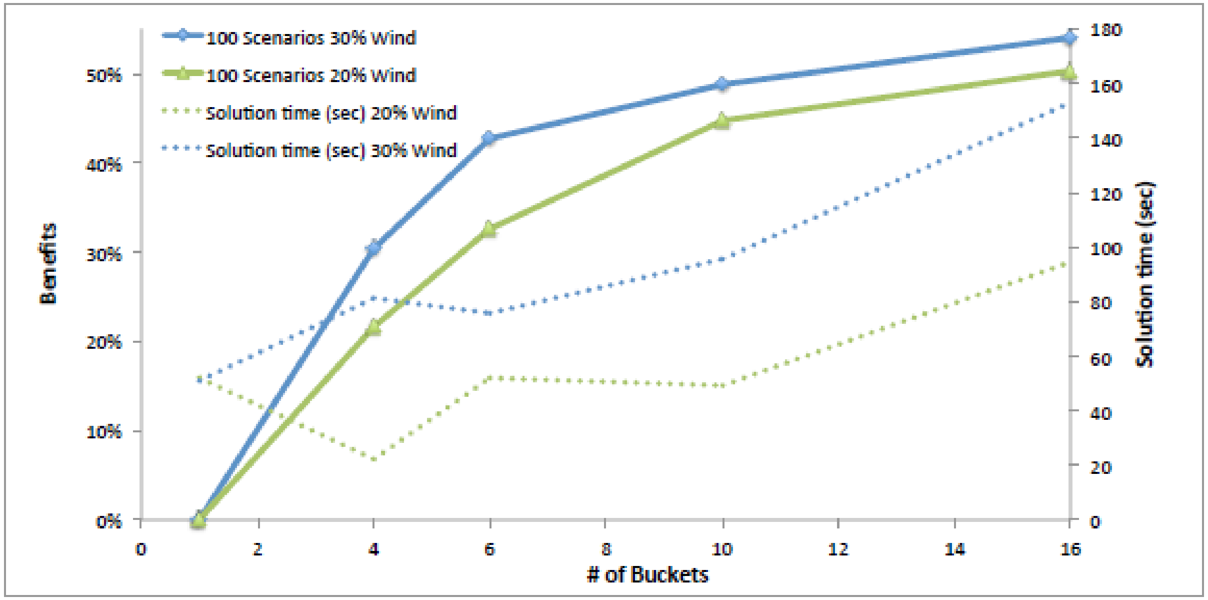
*Zhou et al. forthcoming*

# An Improved Stochastic Unit Commitment Formulation

- Traditional two-stage stochastic unit commitment model
  - Unit commitment decisions are the same across all scenarios.
- New improved approach
  - Unit commitment decisions depend on wind forecast level (“bucket”) and time segments, i.e., more flexible solutions, approaching a multi-stage formulation.

| Expected cost savings compared to two-stage model | |
|---|---|
| 6-bus | 0.8% |
| 24-bus | 1.4% |
| 118-bus | 0.4% |

Expected cost benefit* and solution time (6-bus)



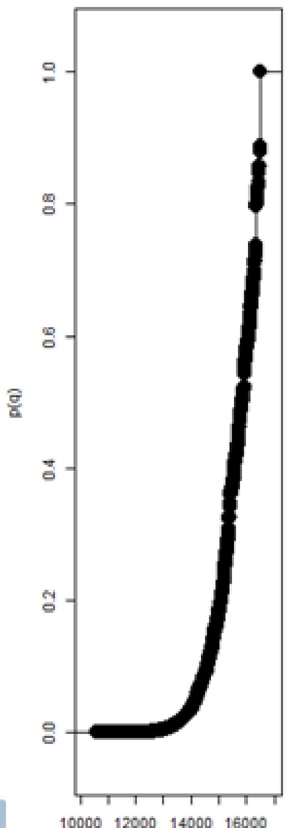

* Percent of multi-stage benefit on 2-stage.

C. Uckun, A. Botterud, J. Birge, “An Improved Stochastic Unit Commitment Formulation to Accommodate Wind Uncertainty,” *IEEE Transactions on Power Systems,* in press.

# Dynamic Operating Reserve Demand Curves (ORDCs)

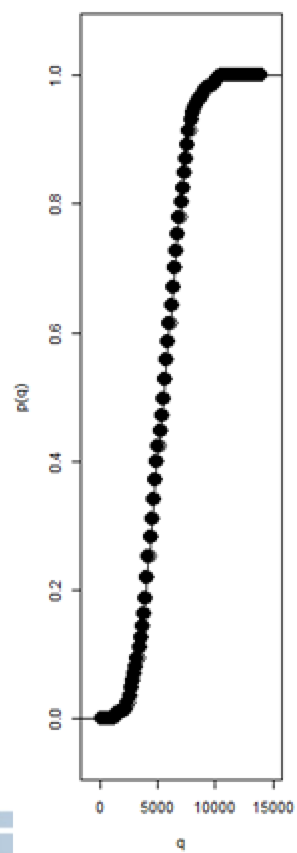
- Concept
  - Consider the uncertainties from load and supply (thermal outages and wind fcst. uncertainty)
  - Estimate the risk of supply shortage for system
  - Link the expected cost of this risk to the price to pay for reserves (Hogan 2005)

*Thermal generators*




+

*Wind power*

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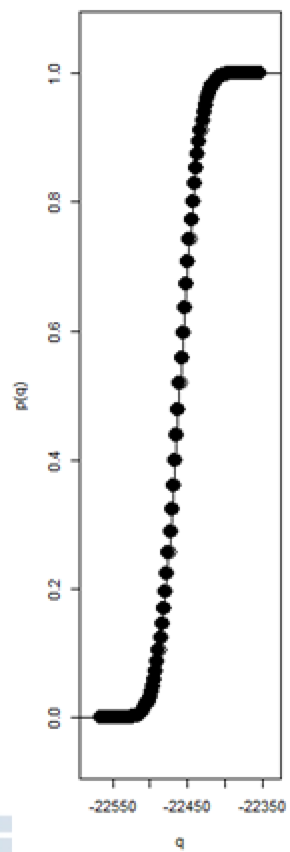
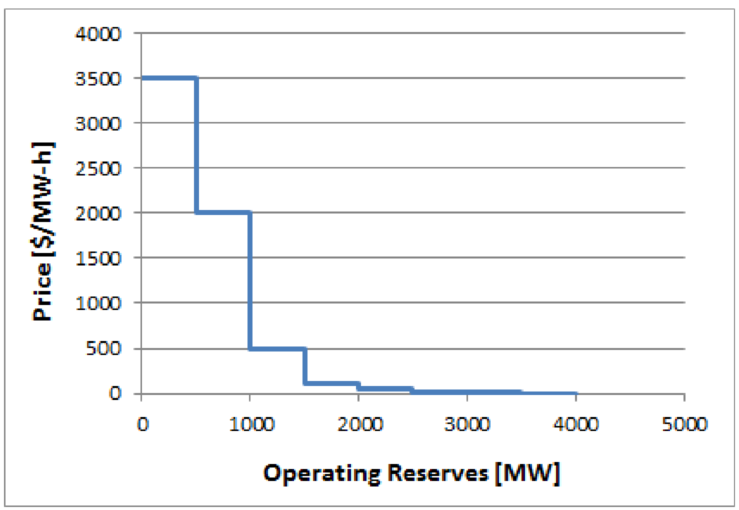
*Load*




→

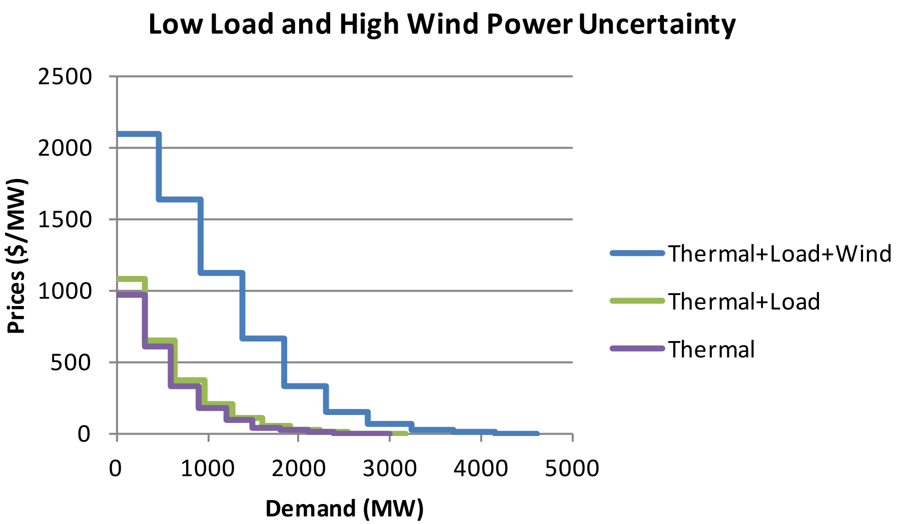
Value of Lost Load

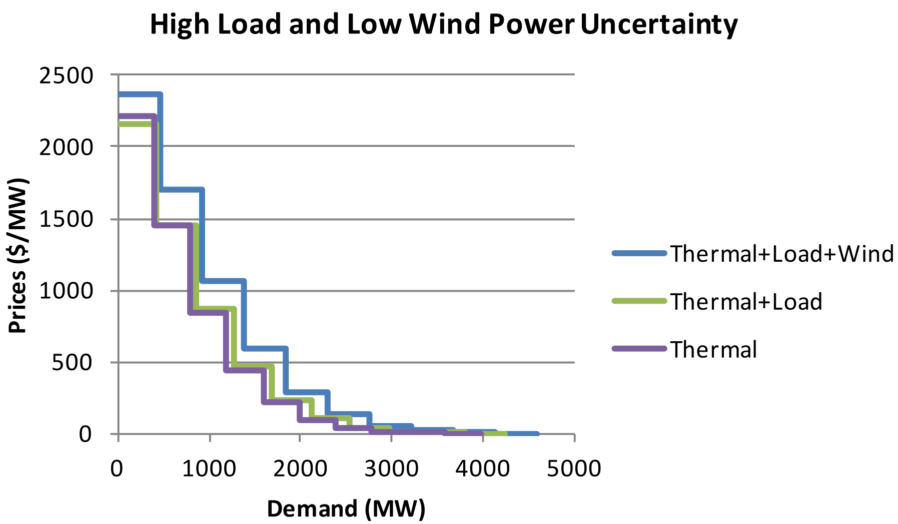
↓



# ORDCs Depend on the Status of the System

- Demand for operating reserves is dynamic and varies by situation (e.g. wind power forecast uncertainty)



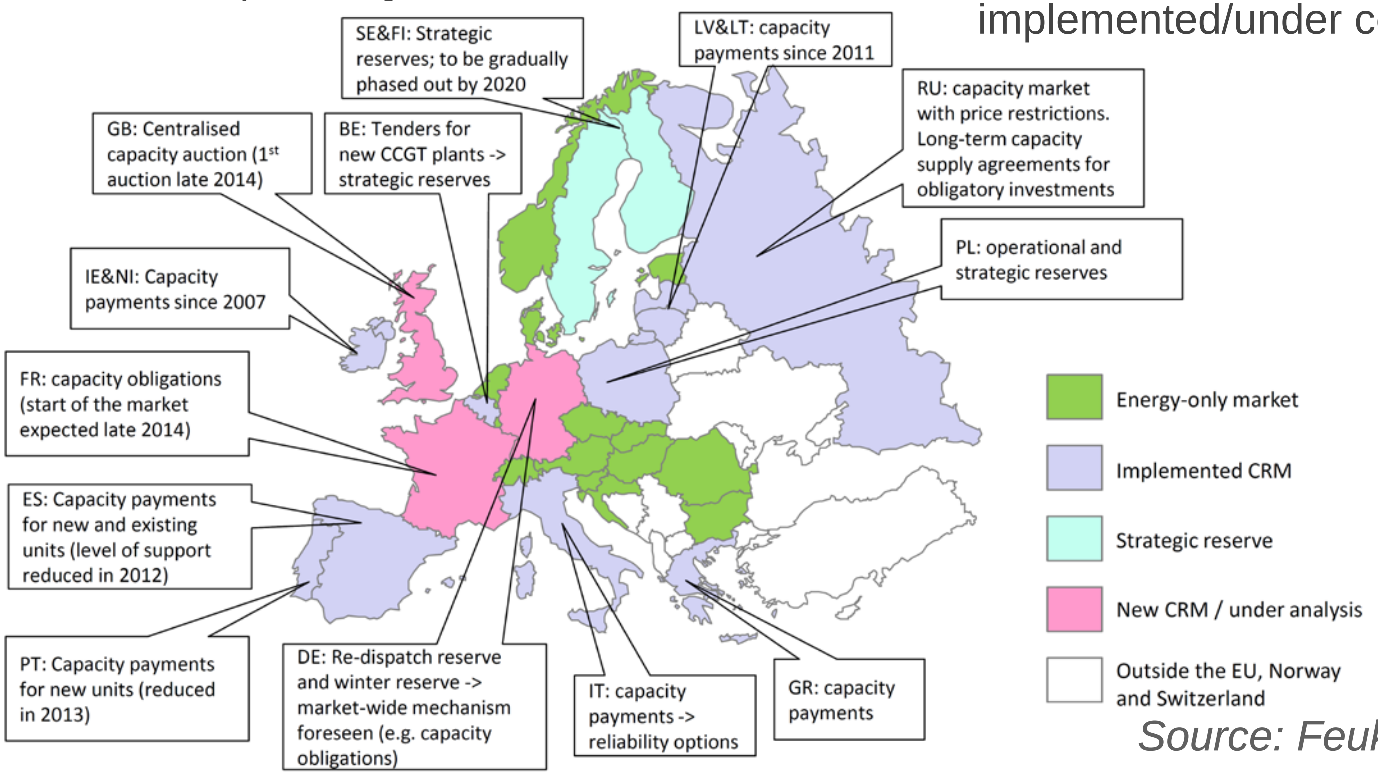




- Advantages of the dynamic ORDC approach
  - Adds flexibility to the scheduling/dispatch process (co-optimization of energy and reserves)
  - Gives higher prices for energy and reserves in most hours, fewer extreme price spikes
  - Stabilizes revenue stream for thermal generators
  - Better reflects wind power forecast uncertainty in prices
  - "Static" ORDCs implemented in ERCOT/Texas market in 2014

*Zhou and Botterud, IEEE Trans. Power Systems, 29(1): 160-171, 2014.*

# Resource Adequacy and Capacity Mechanisms

- United States
  - Capacity markets
    - PJM, NE-ISO, NYISO, MISO
  - Capacity obligations
    - CA-ISO
  - Energy Only
    - ERCOT/Texas
  - Integrated resource planning
- Open questions
  - Do we need specific resource adequacy mechanisms?
  - Do we need to incentivize capacity with specific attributes?
- Europe
  - Multiple solutions implemented/under consideration




*Source: Feuk 2015*

# Centralized Generation Expansion: Formulation

## ORDC

Expansion (Integer) → $u_i$

Commitment (Integer) → $y_{i,t}$, $x_{i,t}$, $z_{i,t}$

$$\min \sum_{i \in I} u_i \cdot (C_i + F_i) \cdot \overline{P_i} + \sum_{i \in I} \sum_{t \in T} MC_i \cdot g_{i,t} + SUC_i \cdot y_{i,t} + SDC_i \cdot x_{i,t} + NLC_i \cdot z_{i,t} \cdot \overline{P_i}$$
$$+ \sum_{t \in T} VOLL \cdot es_t - PTC \cdot wg_t - \sum_{t \in T} RBS_t[Rs_t] + RBNS_t[Rns_t]$$

## Reserve Scarcity Pricing (FRSP) / Capacity Payment (CP)

$$\min \sum_{i \in I} u_i \cdot (C_i + F_i - CP) \cdot \overline{P_i} + \sum_{i \in I} \sum_{t \in T} MC_i \cdot g_{i,t} + SUC_i \cdot y_{i,t} + SDC_i \cdot x_{i,t} + NLC_i \cdot z_{i,t} \cdot \overline{P_i}$$
$$+ \sum_{t \in T} ESC \cdot es_t + SRSC \cdot srs_t + NRSC \cdot nrs_t$$

$$\sum_{i \in I} rs_{i,t} + wr_t + rss_t = RRs_t \quad \forall \ t \in T$$
$$\sum_{i \in I} (rs_{i,t} + rns_{i,t}) + wr_t + rnss_t = RRs_t + RRns_t \quad \forall \ t \in T$$

Shadow Price →

**Reserve targets are based on ORDC results.**
**Spin: $15/MW-h**
**Non-Spin: $.01/MW-h**

**Energy/reserve prices in each period are set equal to the marginal cost/benefit of their provision**

*Levin and Botterud 2015, Energy Policy, 87: 392-406,2015.*

# Centralized Generation Expansion: Formulation

## Load Balance

$$\sum_{i \in I} g_{i,t} + wg_t + es_t = D_t$$

→ LMP
Shadow Price

## Thermal Output

$$g_{i,t} + rs_{i,t} \leq z_{i,t} \cdot \overline{O_i} \quad \forall\, i \in I, t \in T$$

$$g_{i,t} \geq z_{i,t} \cdot \underline{O_i} \quad \forall\, i \in I, t \in T$$

## Ramping

$$g_{i,t} \leq g_{i,t-1} + z_{i,t} \cdot RU_i \quad \forall\, i \in I, t \in T \neq 1$$

$$g_{i,t} \geq g_{i,t-1} - z_{i,t-1} \cdot RD_i \quad \forall\, i \in I, t \in T \neq 1$$

## Unit Reserves

$$rs_{i,t} \leq z_i \cdot \overline{P_i} \cdot SPR_i \quad \forall\, i \in I, s \in S, t \in T$$

$$rns_{i,t} \leq (u_i - z_i) \cdot \overline{P_i} \cdot NSR_i \quad \forall\, i \in I, s \in S, t \in T$$

## Wind Balance

$$wg_t + wr_t + wc_t = W_t \quad \forall\, t \in T$$

## Unit Commitment

$$z_{i,t} = z_{i,t-1} + y_{i,t} - x_{i,t} \quad \forall\, i \in I, t \in T \neq 1$$

$$z_{i,t} \leq u_i \quad \forall\, i \in I, t \in T$$

$$x_{i,t},\ y_{i,t},\ z_{i,t} \geq 0 \quad \forall\, i \in I, t \in T$$

- **Integer variables for expansion and commitment**
- **Significant reduction in computation time (up to 5000x*)**
- **Enables solving for full year of operations (8760 hourly periods)**

* B. Palmintier and M. Webster, "Impact of unit commitment constraints on generation expansion planning with renewables," in *2011 IEEE Power and Energy Society General Meeting*, 2011, pp. 1–7.

# Generation Expansion and Capacity Adequacy in ERCOT

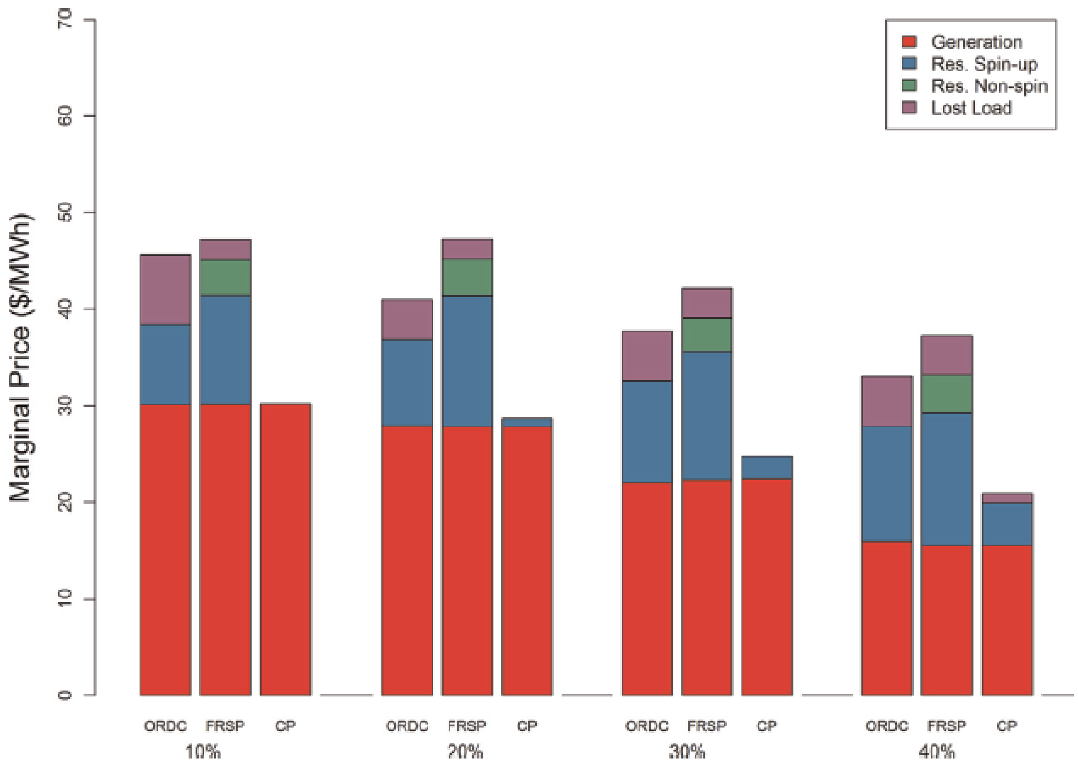
- Model three different market polices to value reserves, energy and capacity
  - 1) Energy Only with Operating Reserves Demand Curve (ORDC)
    - Implemented in ERCOT
  - 2) Energy Only with Fixed Reserves Scarcity Pricing (FRSP)
    - Used in most U.S. markets
    - $100/MW-h for spin-up shortage, $500/MW-h total reserve shortage
  - 3) Capacity Payments (CP)
    - $40/kW-year
    - No reserve scarcity pricing

- Case Study of ERCOT market in Texas
  - 4 thermal unit types (Nuclear, Coal, NGCC, NGCT)
  - 2013 ERCOT wind and load profile
  - 2024 total load projection (15% growth)
  - Wind varies from 10% to 40% of total demand
  - Model finds optimal generation expansion and dispatch

| Parameter | Value |
|---|---|
| Peak Load (MW) | 77,471 |
| Existing Generation Capacity (MW) | 73,380 |
| Nuclear | 4,400 |
| Coal | 19,500 |
| NGCC | 43,600 |
| NGCT | 5,880 |
| Maximum Wind Resource Capacity Factor | 33.0% |

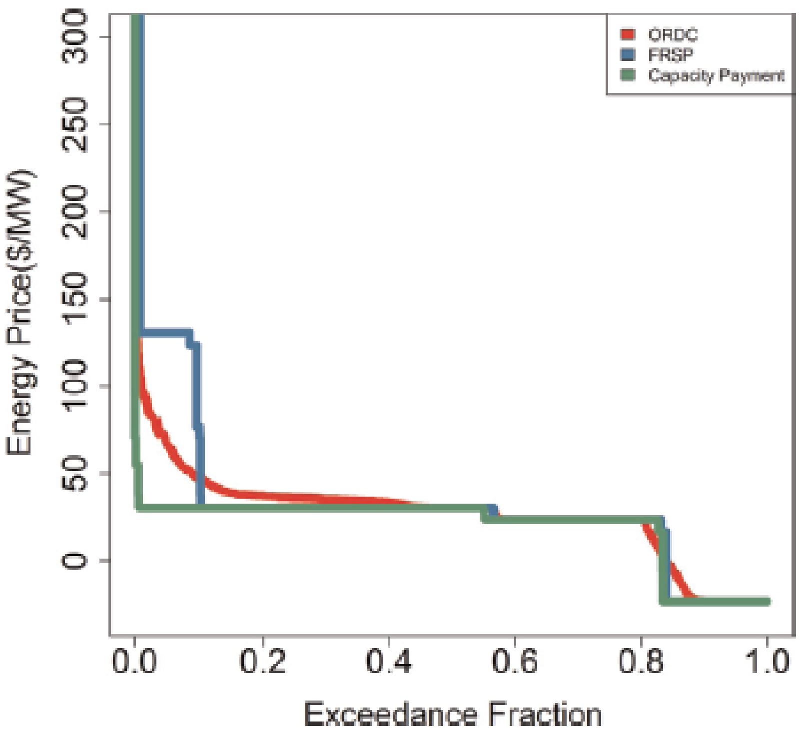
# ERCOT Study Results: Prices

Average energy price



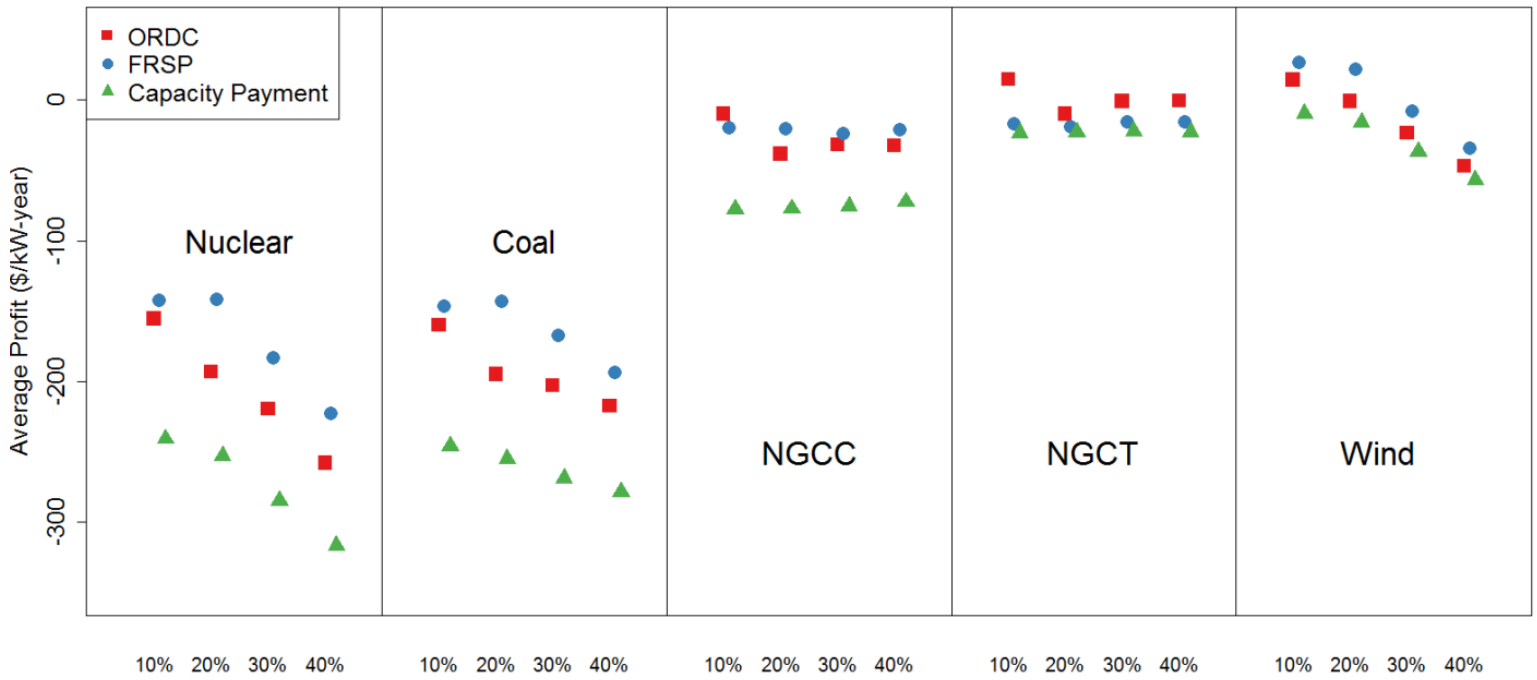

*Wind penetration level*

Energy price duration at 40% wind




ORDC – operating reserve demand curve
FRSP – fixed reserve scarcity pricing
CP – capacity payment

# ERCOT Study Results: Generator Profits



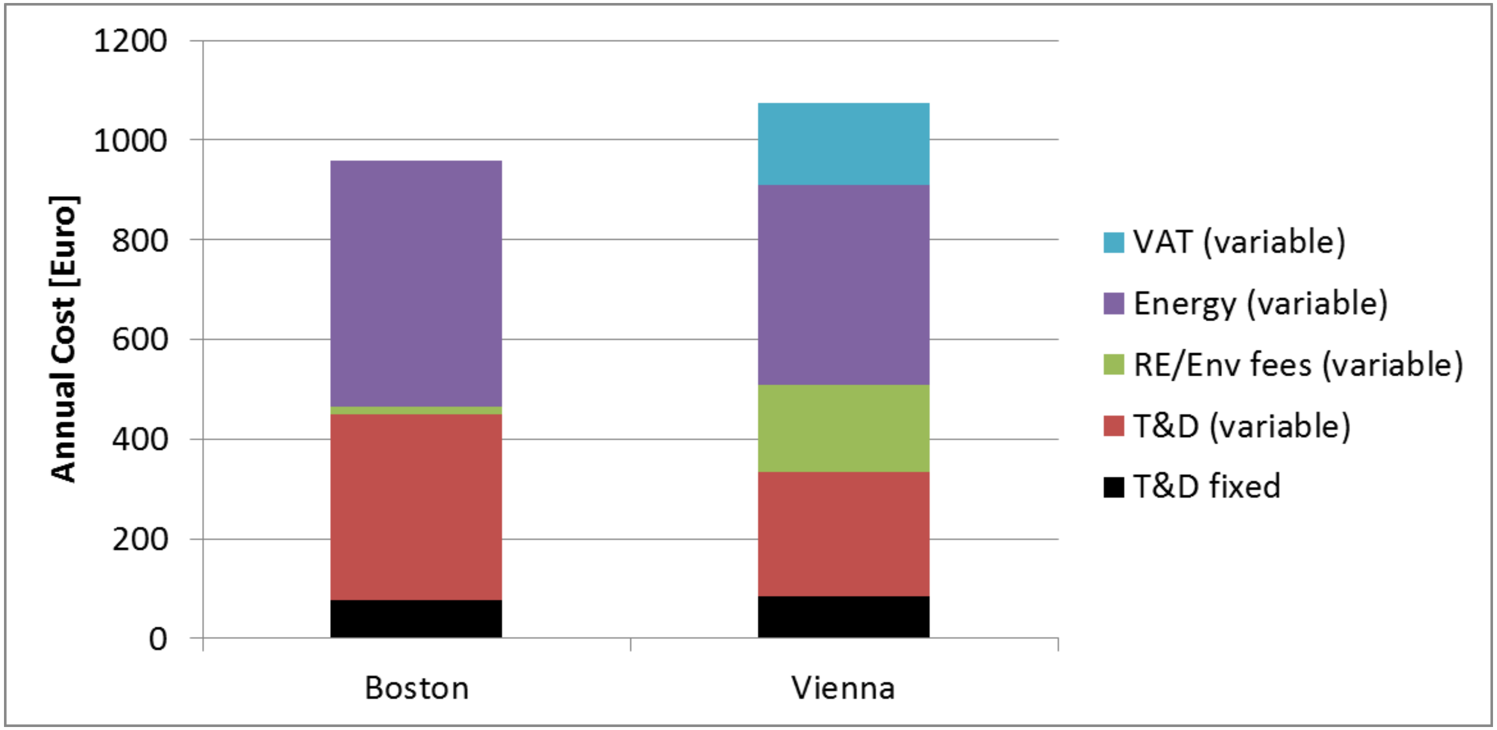

- Optimal investment choice (NGCT) breaks even under all mechanisms
  - For all wind penetration levels
- Gas units (NGCC, NGCT) receive additional revenues from providing reserves
- Base load units (nuclear, coal, wind) profits decrease with increasing wind
  - More exposed to lower off-peak prices
- An advantage of ORDC is the more stable prices (less risk)

*Levin and Botterud 2015, Energy Policy, 87: 392-406,2015.*

# *Distributed Generation and End-User Tariffs*

- "Net metering" a very hotly debated topic

- Example: Residential customer bills in Boston and Vienna
  - Annual consumption: 5000 kWh



# Hydropower and Energy Storage

- Hydropower in Europe
  - Hydropower flexibility perfect for integration of wind and solar

**Norway Wants to Be Europe's Battery**

A new HVDC line will let Europe store more wind energy in Norway's hydropower system

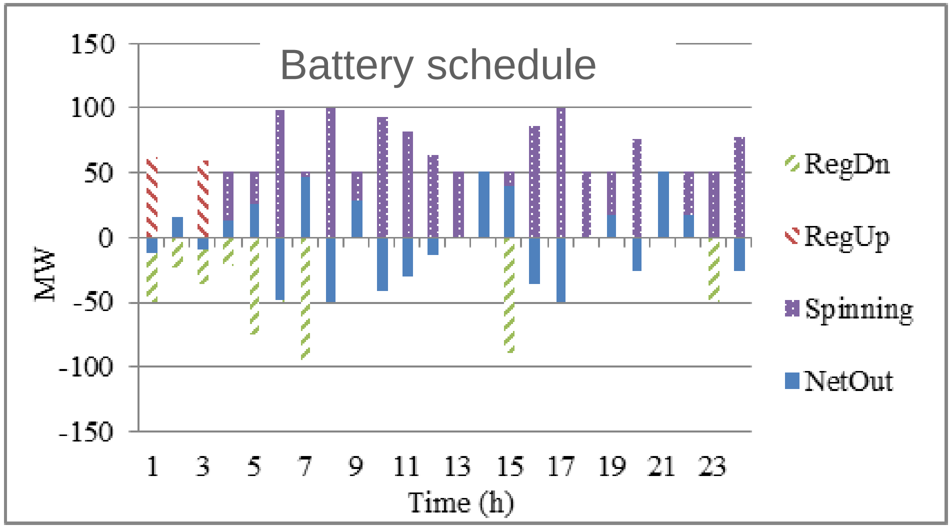
By Peter Fairley
Posted 21 Oct 2014 | 19:00 GMT

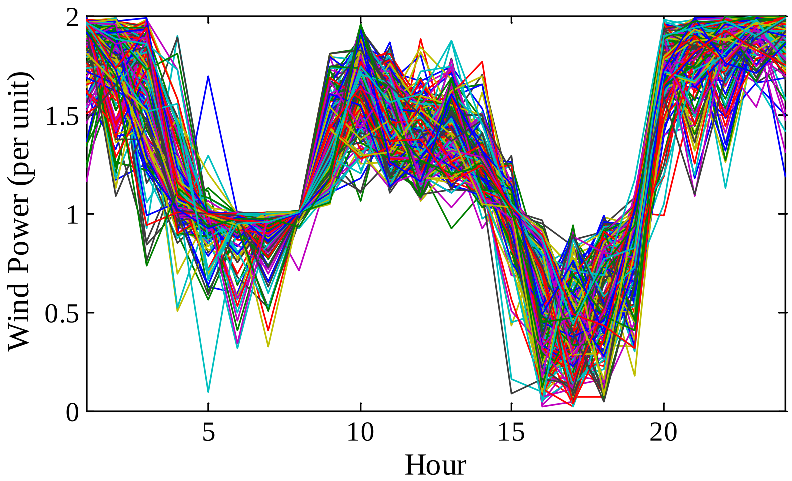
- United States
  - Hydropower flexibility in the West constrained since dams serve multiple purposes

- Energy Storage
  - Battery storage receiving substantial attention to provide flexibility to the evolving grid
    - E.g. Joint Center for Energy Storage Research (JCESR) at Argonne
  - Pumped storage hydro still the main grid storage technology (95% in the United States)

# Energy Storage for System-Wide Scheduling

- A stochastic day-ahead unit commitment model with energy storage and wind power
  - IEEE RTS system: 2656 MW load, 15%-30% wind power (345-690 MW)
  - Battery: 50MW/150MWh (3 hours), 10% loss in each direction




Average day-ahead cost savings from battery:

| Wind % | Total Cost with Battery ($) | Total Cost without Battery ($) | Cost Savings ($) | Cost Savings (%) |
|---|---|---|---|---|
| 15% | 806,287 | 930,440 | 124,154 | 13.3% |
| 20% | 765,307 | 887,480 | 122,173 | 13.8% |
| 25% | 733,779 | 849,963 | 116,184 | 13.7% |
| 30% | 712,808 | 827,570 | 114,762 | 13.9% |

NPV of cost savings from battery at 25% wind: $1200/kWh-capacity
(@5500 cycles/5 year lifetime, 8% interest)

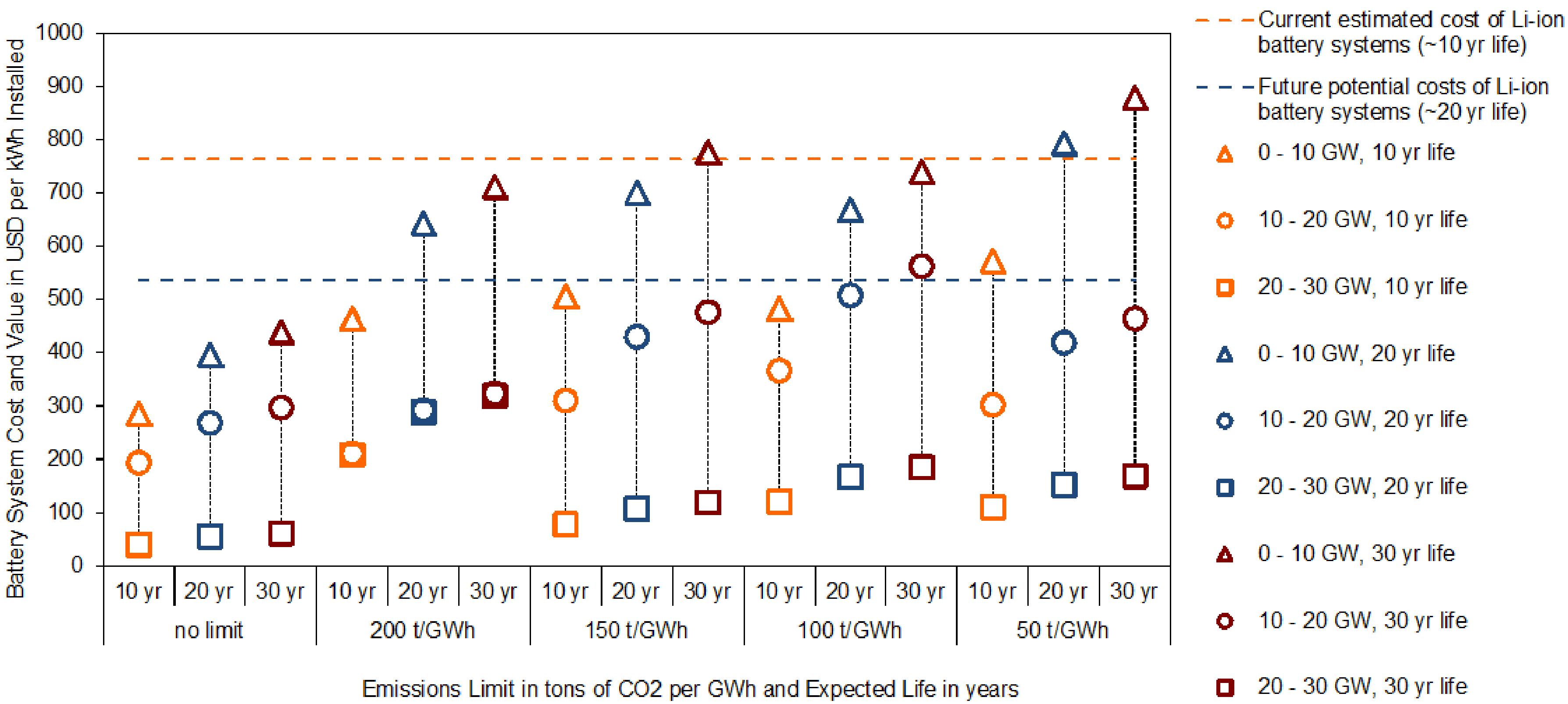
Note: small, high cost system.

*Source: Li et al., in press.*

# What is the Value of Battery Storage to the Future Grid?

- Optimal expansion with emissions targets and operational constraints (IMRES model)
  - Wind, solar, and load data for ERCOT/Texas for 2035, greenfield expansion
  - Increasingly stringent emissions targets (today 600 $tCO_2$/GWh)
  - Different energy storage levels (2 hr storage, 20% roundtrip losses, 10% interest)

**Estimated benefits (avoided generation costs) and costs of energy storage**



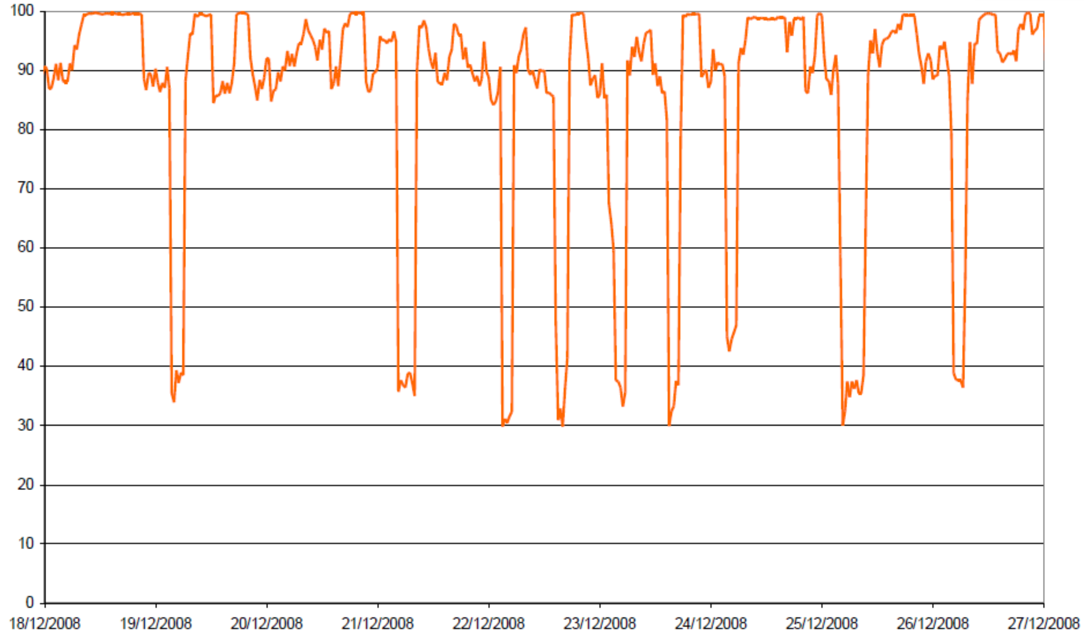

*de Sisternes, Jenkins, Botterud, in review..*

# Nuclear Power: A Source of Flexibility?

- Nuclear shut-downs
  - Primarily due to economics (US)
  - Public resistance (Europe)

- Importance of nuclear flexibility with increasing renewable penetration levels
  - United States: Nuclear energy is baseload
  - Europe: Flexible nuclear operations (e.g. France, Germany)

**Figure E.1: Example of a typical power history during a cycle in a EDF reactor (in % of the rated power)**

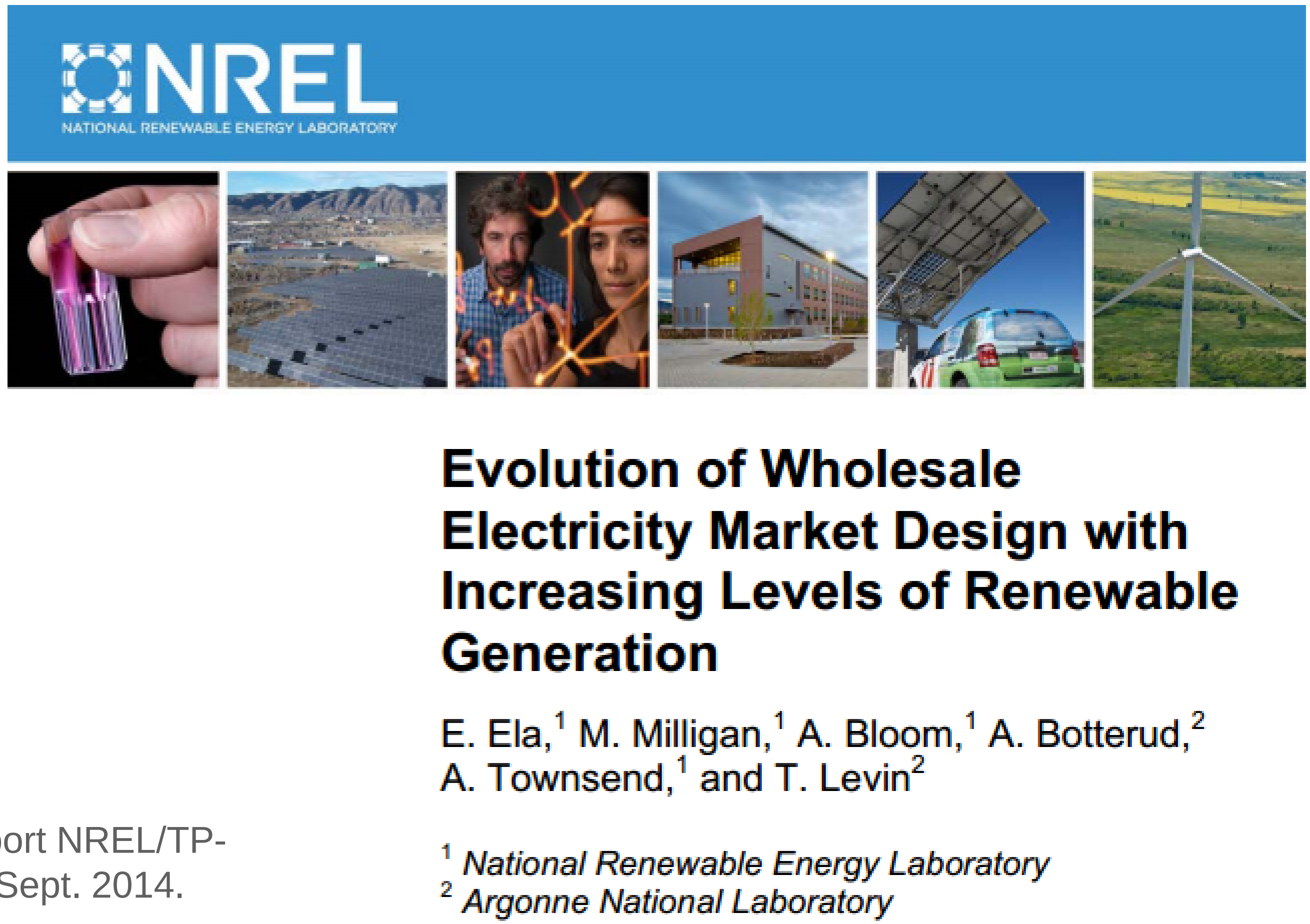



Courtesy of Électricité de France (EDF)

*Source: NEA, 2011*

# Electricity Market Design with Renewable Energy

- Review of current and proposed market designs
  - How to achieve capacity adequacy and revenue sufficiency in the long-run?
  - How to ensure and incentivize flexibility in short-run operations?


NREL
NATIONAL RENEWABLE ENERGY LABORATORY

**Evolution of Wholesale Electricity Market Design with Increasing Levels of Renewable Generation**


E. Ela,[1] M. Milligan,[1] A. Bloom,[1] A. Botterud,[2]
A. Townsend,[1] and T. Levin[2]

[1] *National Renewable Energy Laboratory*
[2] *Argonne National Laboratory*


Technical Report NREL/TP-5D00-61765, Sept. 2014.

# Concluding Remarks

- Electricity markets and renewable energy
  - Fundamental challenges the same in Europe and United States: uncertainty and variability
  - Implications for operations, planning, and markets
  - Flexibility is key, but solutions differ
  - More advanced electricity markets in the US, more support for renewables in Europe
  - Physical complexity vs. economic transparency in market design

- Many solutions to variable renewable energy integration challenges
  - Supply flexibility, demand response, energy storage
  - Forecasting, operational practices, market design
  - No silver bullet: Ideally, the most cost effective solutions should prevail
  - Lessons can be learned from both Europe and the United States


# Acknowledgements and References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| | |
|---|---|
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| – Todd Levin | Argonne National Laboratory |
| – Fernando de Sisternes | Argonne National Laboratory |
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| – Hans Auer | TU Wien, Austria |
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# References I

## Wind Power Forecasting


Monteiro C., Bessa R., Miranda V., Botterud A., Wang J., Conzelmann G., "Wind Power Forecasting: State-of-the-Art 2009," Report ANL/DIS-10-1, Argonne National Laboratory, Nov.2009.

Ferreira C., Gama J., Matias L., Botterud A., Wang J., "A Survey on Wind Power Ramp Forecasting," Report ANL/DIS 10-13, Argonne National Laboratory, Dec. 2010.

Bessa R.J., Miranda V., Botterud A., Wang J., "'Good' or 'Bad' Wind Power Forecasts: A Relative Concept," *Wind Energy*, Vol. 14, No. 5, pp. 625-636, 2011.

Bessa R.J., Miranda V., Botterud A., Wang J., Constantinescu E.M., "Time Adaptive Conditional Kernel Density Estimation for Wind Power Forecasting," *IEEE Transactions on Sustainable Energy*, Vol. 3, No. 4, pp. 660-669, 2012.

Bessa R.J., Miranda V., Botterud A., Zhou Z., Wang J., "Time-Adaptive Quantile-Copula for Wind Power Probabilistic Forecasting," *Renewable Energy*, Vol. 40, No. 1, pp. 29-39, 2012.


## Unit Commitment, Economic Dispatch, Operating Reserves with Wind and Solar Power


Wang J., Botterud A., Bessa R., Keko H, Carvalho L., Issicaba D., Sumaili J., Miranda V., "Wind Power Forecasting Uncertainty and Unit Commitment," *Applied Energy*, Vol. 88, No. 11, pp. 4014-4023, 2011.

Valentino L., Valenzuela V., Botterud A., Zhou Z., Conzelmann G., "System-Wide Emissions Implications of Increased Wind Power Penetration," *Environmental Science and Technology*, Vol. 46, No. 7, pp. 4200–4206, 2012.

Zhou Z., Botterud A., Wang J., Bessa R.J., Keko H., Sumaili J., Miranda V., "Application of Probabilistic Wind Power Forecasting in Electricity Markets," *Wind Energy*, Vol. 16, No. 3, pp. 321-338, 2013.

Zhou Z., Botterud A., "Dynamic Scheduling of Operating Reserves in Co-optimized Electricity Markets with Wind Power," *IEEE Transactions on Power Systems*, Vol. 29, No. 1, pp.160-171, 2014.

Wu J., Botterud A., Mills A., Zhou Z., Hodge B-M., Heaney M., "Integrating Solar PV in Utility System Operations: Analytical Framework and Arizona Case Study," *Energy*, Vol. 85, pp. 1-9, 2015.

# References II

## Generation Expansion and Resource Adequacy with Wind Power


Jin S., Botterud A., Ryan S.M., "Impact of Demand Response on Thermal Generation Investment with High Wind Penetration," *IEEE Transactions on Smart Grid*, Vol. 4, No. 4, pp. 2374-2383, 2013.

Jin S., Botterud A., Ryan S.M., "Temporal vs. Stochastic Granularity in Thermal Generation Capacity Planning with Wind Power," *IEEE Transactions on Power Systems*, Vol. 29, No. 5, pp. 2033-2041, 2014.

Levin T., Botterud A., "Capacity Adequacy and Revenue Sufficiency in Electricity Markets with Wind Power," *IEEE Transactions on Power Systems*, Vol. 30, No. 3, pp. 1644-1653, 2015.

Levin T., Botterud A., ""Electricity Market Design for Generator Revenue Sufficiency with Increased Variable Generation," Energy Policy, Vol. 87, pp. 392–406, 2015.


## Electricity Market Design with Renewable Energy


Ela E., Milligan M., Bloom A., Botterud A., Townsend A., Levin T., "Evolution of Wholesale Electricity Market Design with Increasing Levels of Renewable Generation," Technical Report NREL/TP-5D00-61765, National Renewable Energy Laboratory, Sep. 2014.


## Energy Storage Analysis


N. Li, Uckun C., Constantinescu E., Birge J.R., Hedman K.W., Botterud A., "Flexible Operation of Batteries in Power System Scheduling with Renewable Energy", *IEEE Transactions on Sustainable Energy*, in press.

F. de Sisternes, J. Jenkins, A. Botterud, "The contribution of energy storage to climate change mitigation in the electricity sector," *Working Paper*, revised, Mar. 2015.


## Wind Power Project Website with Additional Publications and Information

http://ceeesa.es.anl.gov/projects/windpowerforecasting.html

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# Electricity Markets and Renewable Energy: United States vs. Europe

***Audun Botterud***

Center for Energy, Environmental, and Economic Systems Analysis
Energy Systems Division
Argonne National Laboratory
abotterud@anl.gov

Visiting Researcher, Energy Economics Group, TU Wien

Visiting Scholar, MIT Energy Initiative, Massachusetts Institute of Technology
http://botterud.mit.edu/

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