Energy Markets
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Status, Directions and Challenges

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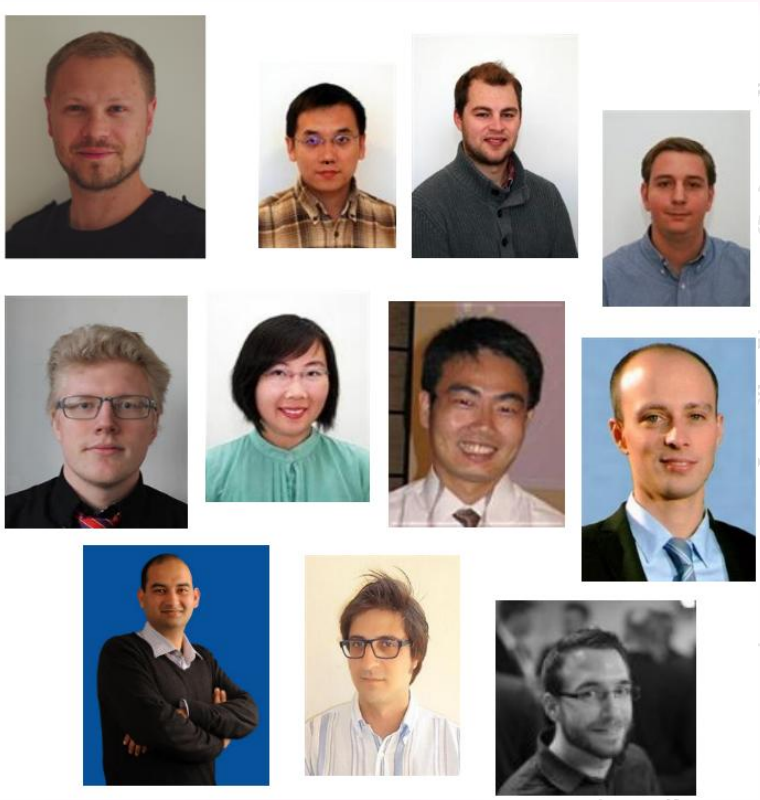
Outline

- **Our European context**
  - Renewable energy deployment and integration
  - Planned evolution of electricity markets
- **Identified issues and proposal paths of investigation**
  - Predictability
  - Market design
  - Coordination issues
- **The grand challenge**

Who are we? - The Energy Analytics & Markets group

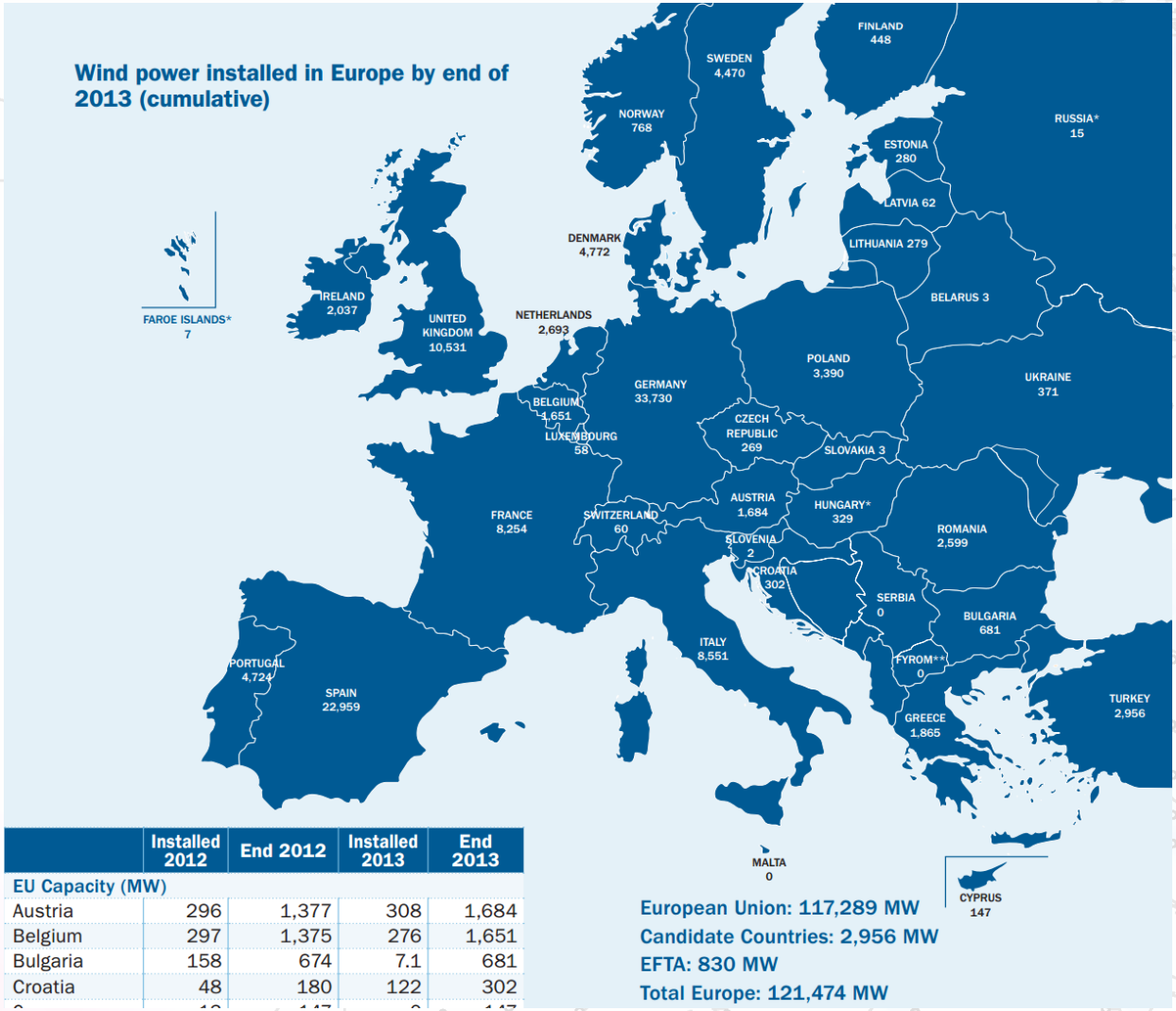
- One of the 5 groups of the Center for Electric Power and Energy, Dpt. of Electrical Engineering



- **Resources:**
  - *Faculty:* 1 Prof. and 1 Assoc. Prof.
  - *Junior:* 2 Post-doctoral fellows, 6 Ph.D. students (+5 others outside of DTU Elektro), 1 research assistant
  - + student helpers, and Ph.D. guests from, e.g., Johns Hopkins (US), Strathclyde (UK), Tsinghua (China), etc.
- **Projects** (active in 2014):
  - **EU:** EcoGrid EU, WIRE, BestPaths
  - **Danish:** iPower, EaseWind, 5s, CITIES
  - **Danish-Chinese:** PROAIN
  - **and...:** EPRI (US), EDF (France)
- **Education:** 1 new course in 2014 - "31761- Renewables in Electricity Markets"

1. **Our European context**

Wind power in Europe



	Installed 2012	End 2012	Installed 2013	End 2013
EU Capacity (MW)				
Austria	296	1,377	308	1,684
Belgium	297	1,375	276	1,651
Bulgaria	158	674	7.1	681
Croatia	48	180	122	302

Total: 121,474 MW (Dec. 2013, *source: European Wind Energy Association - EWEA*)

Worldwide: 318 GW for wind energy, and 135 GW for solar energy

The Internal Energy Market

- Grid operators and power exchanges from 14 EU Member States plus Norway inaugurated on February 4 a pilot project for joint electricity trading, so-called *day-ahead market coupling*

- **Overall objectives:**
  - harmonize European electricity markets and strengthen competition
  - improve liquidity, transparency and efficiency in the power markets across Europe
  - social welfare optimisation

- **In practice:**
  - flow-based coupling of *day-ahead markets*
  - standardization of (also new) products for *intra-day markets* and new matching algorithms
  - target model for *balancing*? co-existence with new intra-day solutions?

A few important questions

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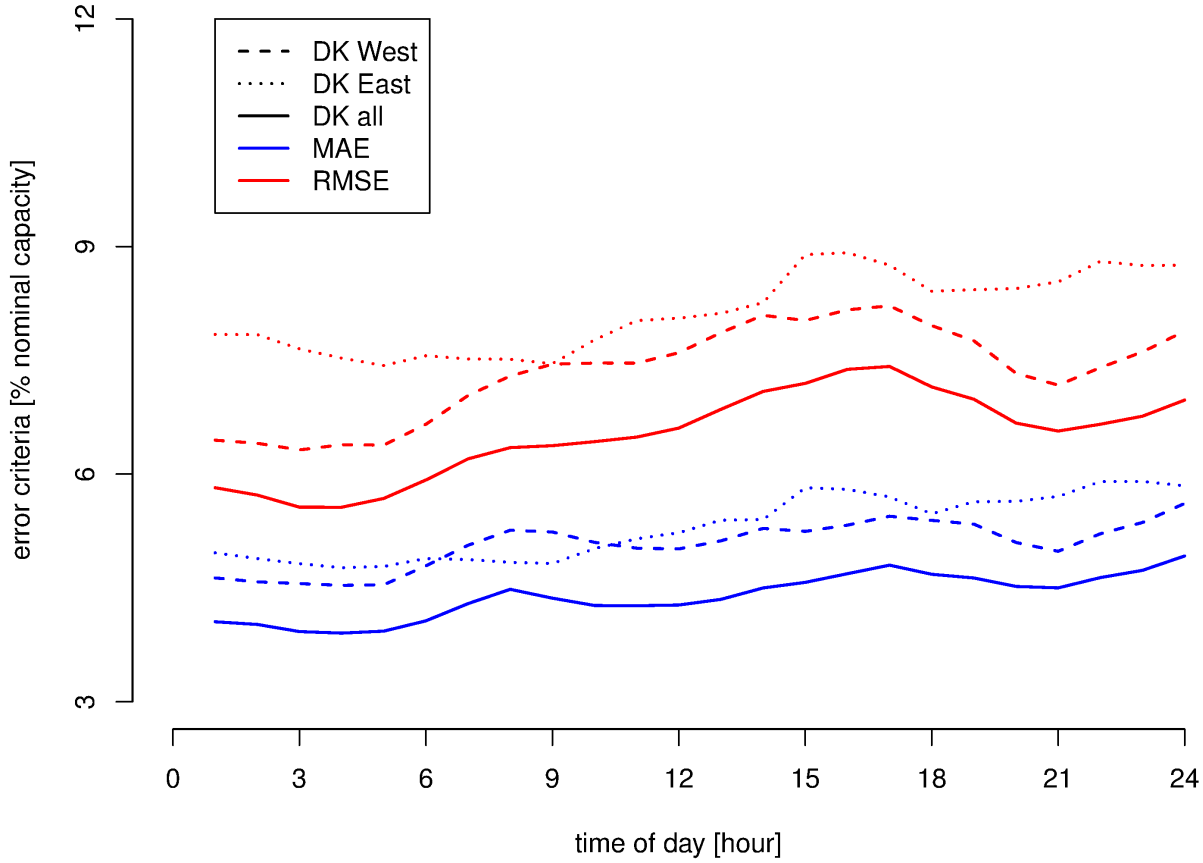
- *Can we continuously integrate more renewable energy generation into such electricity markets?*
- *Are they fundamental changes to consider?*
- *How are we contributing to that?*

2. **Identified issues and proposal paths of investigation**

A key issue: predictability of renewable energy generation

Error criteria for 2011 - Danish wind power generation

- *MAE:* Mean Absolute Error
- *RMSE:* Root Mean Square Error
- *Lead times:* between 12 and 36 hours ahead
- *Over the year:* **1 336 179 MWh** to be balanced (roughly, the yearly consumption of 300 000 Danish households)



- Same applies for other renewable energy sources (e.g., solar) and other countries...
- Space-time characteristics of preduicatbility motivates *coordination*

Temporal coupling: day-ahead and balancing

- Day-ahead market-clearing insures an **optimal match of production and demand**, a fair amount of time prior to operations, **regardless of the 'nature' of offers/bids**

- With increased variability and uncertainty to be dealt with, the system should be placed in a state permitting to optimally cope with **whatever could realistically happen**

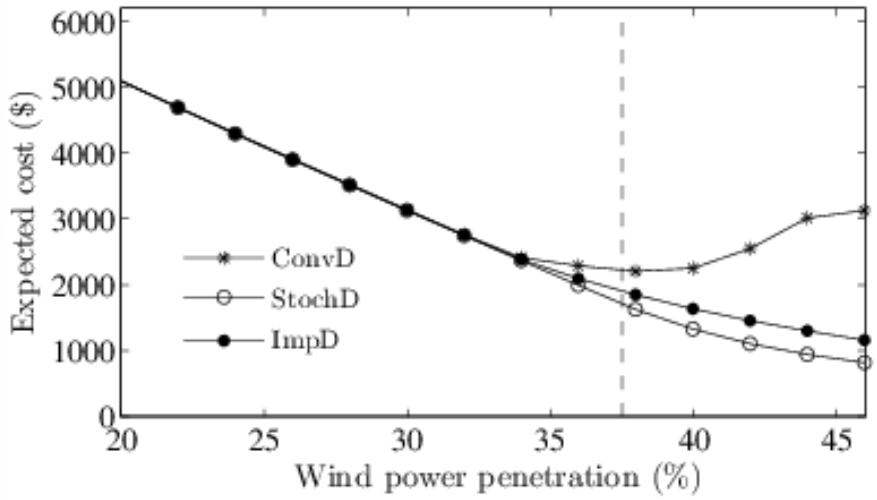
- The alternative schools of thoughts:
  - *Conventional sequential market-clearing(s)*, where day-ahead aspects and balancing are decoupled
  - *Stochastic optimization*, accounting for expected costs of balancing

- The more practical, and still efficient, solutions:
  - *Conventional market-clearing with improved dispatch of stochastic production*
  - *Robust optimization based dispatch*
  - *Auctions with probabilistic offering*, etc.

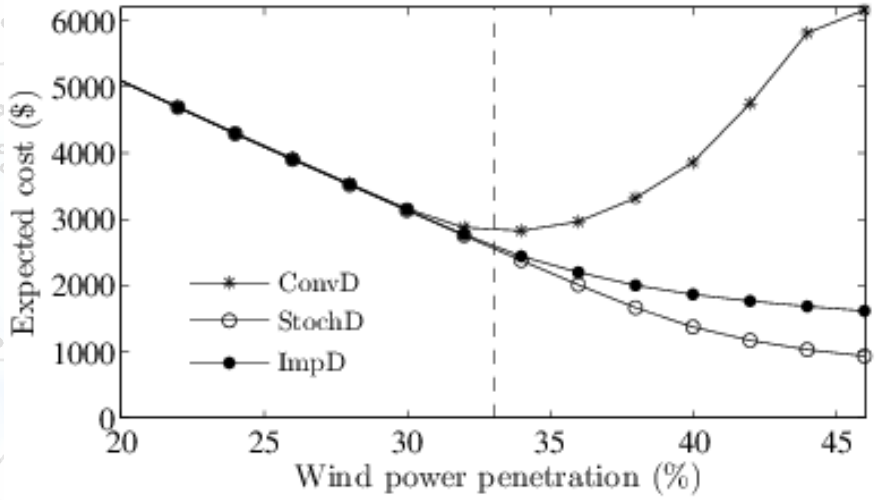
- These are current research problems...

Illustration: costs of power system operation

- **Representative 24-bus system**, with total demand of 2GW and various types of generators (2 wind farms, for simplicity)
- Realistic unit characteristics and load, while varying wind power penetration and spatial correlation
- Energy-only **Market-clearing:** *conventional*, *stochastic optimization*, *conventional with improved dispatch of stochastic power generation*
- Costs of power system operation highly impacted by market-clearing approach



$\rho = 0.35$

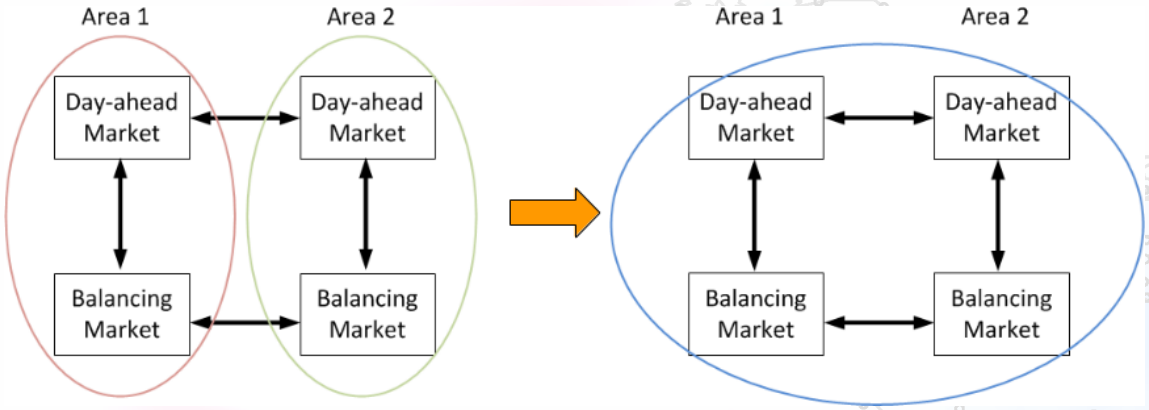


$\rho = 0.75$

Morales JM, Zugno M, Pineda S, Pinson P (2014). Electricity market clearing with improved scheduling of stochastic production. *EJOR* 235(3): 765-774

Spatial coupling: cross-border balancing

Policy options for balancing market integration:

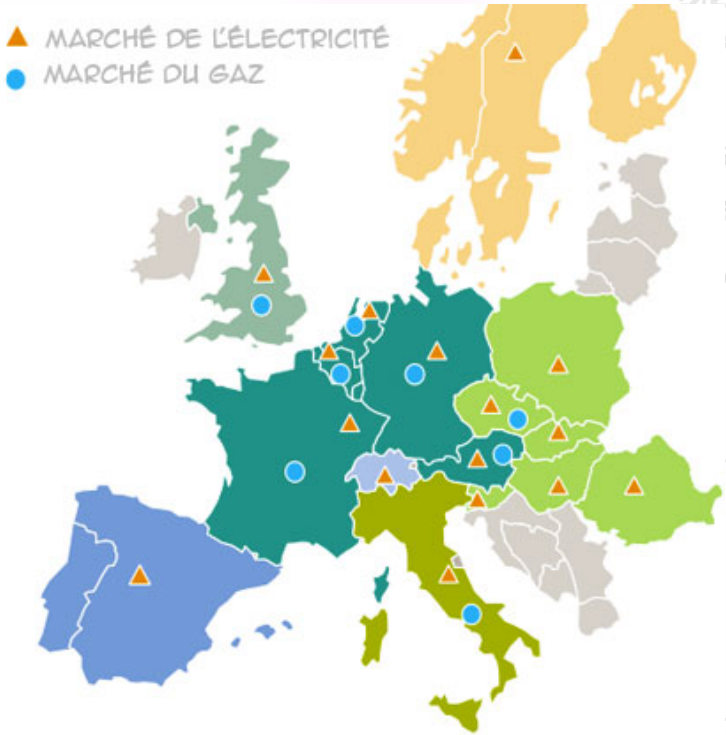


- *Option A:* voluntary cooperation
- *Option B:* Minimum harmonization
- *Option C:* Mandatory exchange of balancing power
- *Option D:* Single European balancing market ("Super TSO")

→ *Necessary balance between optimality and feasibility...*

Ongoing activities (in Denmark at least...)

- **Lead projects (selection):**
  - *CITIES* (supported by Danish Strategic Research Council)
  - *'5s' - Future Electricity Markets* (supported by Danish Strategic Research Council)
  - *BestPaths* (EU FP-7)
  - *EcoGrid EU* (EU FP-7)
  - *'BPES' - Balancing Power Energy System* (supported by ForskEL/EERA)

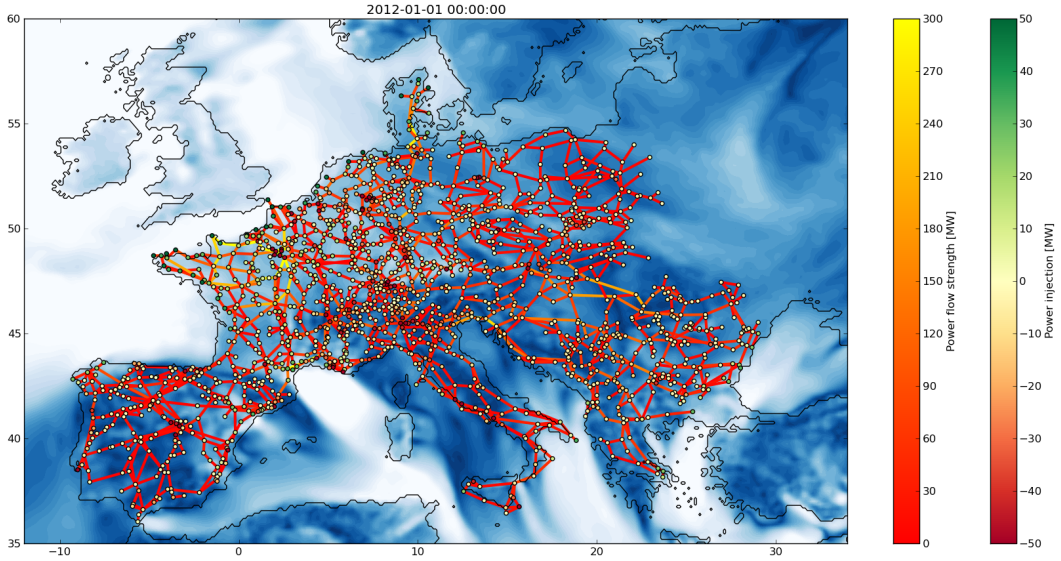


Ex: GDF-Suez in Power and Gas markets in Europe...

- The **core reseach themes** include
  - *market-clearing mechanisms*, optimally embedding forecast information and accounting for network dynamics and controls (e.g., with HVDC)
  - *plurality of markets* (energy, capacity, ancillary services) possibly co-optimized
  - enabling and rewarding the more *pro-active role of electricity demand*
  - optimizing *synergies between energy carriers* (e.g., electricity and gas)
  - *bridging the gap* between "theoretical proposals" and practical implementation

3. **The grand challenge**

EU-wide forecasting and market integration



- **Looking at the big picture:**
  - Insure consistency in forecast input to electricity markets
  - Optimally embed advanced forecast information (e.g., space-time trajectories)
  - Allow for optimal coordination at all market stages...

- **New probablistic market mechanisms**
  - Proposing new types of auctions (for forward markets) with probabilistic offers, on both demand and supply side
  - The cost of handling uncertainty is anticipated and defines an "uncertainty rent" for the system operator

- **Energy and services:** Novel joint markets, permitting to better reward various players for their support to power system operations

Thanks for your attention!