

# The role and value of wind power forecasts in electricity markets

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- A map of Europe showing a detailed power grid network. The grid consists of numerous nodes (small circles) connected by lines, representing transmission lines. The map is overlaid with a semi-transparent blue and pink color gradient.
- **Publication news**
  - **An introductory anecdote**
  - **Power system operations through electricity markets**
  - **Forecasts in electricity markets**
  - **Outlook**

International Series in  
Operations Research & Management Science

Juan M. Morales · Antonio J. Conejo  
Henrik Madsen · Pierre Pinson  
Marco Zugno

# Integrating Renewables in Electricity Markets

Operational Problems



 Springer

- Available by the end of the year 2013
- Published by **Springer, International Series in Operations Research and Management Sciences**
- Covers the more mathematical aspects of renewables in electricity markets

Submitted to the *Statistical Science*

# Wind Energy: Forecasting Challenges for its Operational Management

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➤ *Abstract.* Renewable energy sources, especially wind energy, are to play a larger role in providing electricity to industrial and domestic consumers. This is already the case today for a number of European countries, closely followed by the US and high growth countries, e.g., Brazil, India and China. There exist a number of technological, environmental and political challenges linked to supplementing existing electricity generation capacities with wind energy. Here, mathematicians and statisticians could make a substantial contribution at the interface of meteorology and decision-making, in connection with the generation of forecasts tailored to the various operational decision problems involved. Indeed, while wind energy may be seen as an environmentally friendly source of energy, full benefits from its usage can only be obtained if one is able to accommodate its variability and limited predictability. Based on a short presentation of its physical basics, the importance of

*Invited paper in **Statistical Science** for special issue “Mathematics of Planet Earth”, to appear in December 2013.*



# 1. An introductory anecdote

# Go' morgen Danmark, og God Jul!

## Elspot market overview

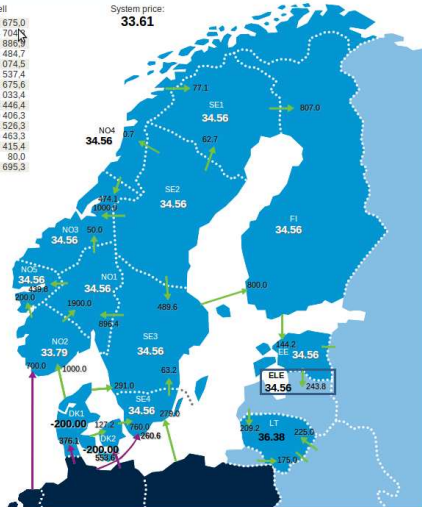
25-12-2012 Resolution 06-07 Currency EUR Capacities Flow Area Prices  
ITVC ITVC

### Elspot volumes

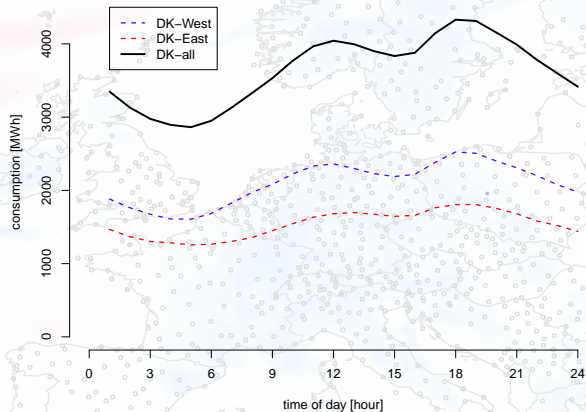
	Buy	Sell
NO1	4 981.6	2 675.0
NO2	3 604.8	4 704.9
NO3	2 411.0	895.9
NO4	1 934.2	2 484.7
NO5	1 714.3	1 074.5
DK1	1 119.2	2 537.4
DK2	1 042.8	1 675.6
SE1	1 366.2	2 033.4
SE2	1 893.4	3 446.4
SE3	9 553.7	10 406.3
SE4	2 223.1	1 526.3
FI	6 926.1	5 463.3
EE	315.8	415.4
ELE	323.8	80.0
LT	695.3	695.3

System price:  
**33.61**

- 25 December 2012, between 6:00 and 7:00 in the morning
- The day-ahead electricity price is negative, and at the lowest cap value
- The system price is used for the neighboring countries...

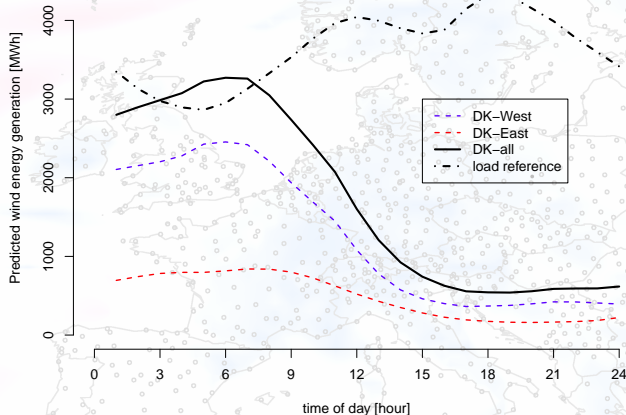


- Consumption seems to be normal for that period of the year
- Then we should look at the production side
- Could this result from our ambitious targets for wind power integration in Denmark?



## Predicted wind power generation: 25 December 2012

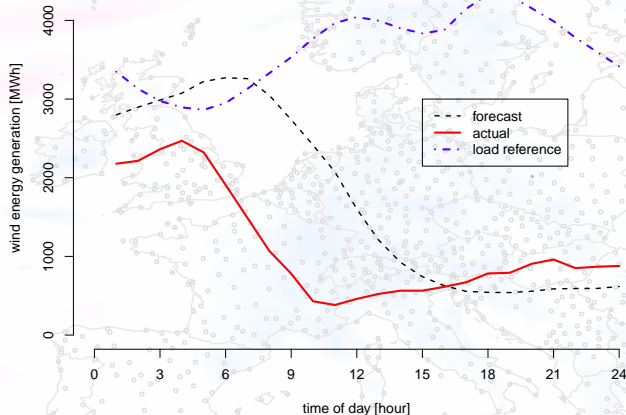
- The wind power forecasts was very high...
- Actually, it was predicted we would have more wind power generation than needed...





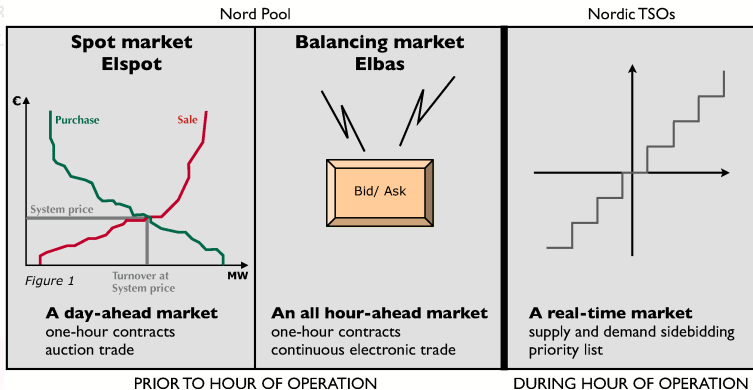
# Actual wind power generation: 25 December 2012

- This is not what exactly happened in practice
- **Balancing volume: 18 684 MWh(!)**
- This represents:
  - 45% of the daily predicted energy generation
  - (roughly) the yearly electricity consumption of 4000 Danish households)



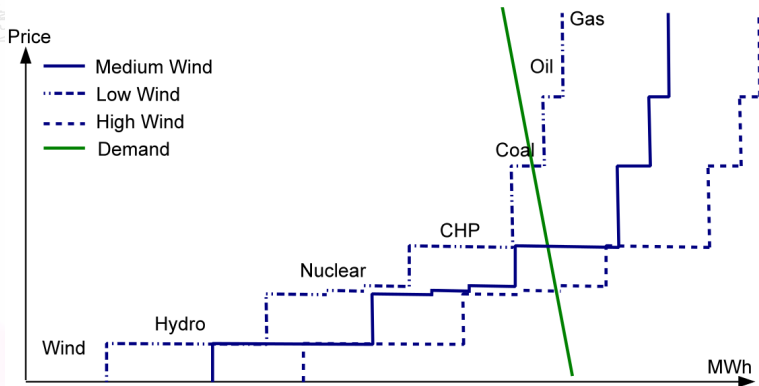


## 2. Power system operations through electricity markets



- **Elspot** - Bids/offers proposed before noon for hourly delivery periods over the following day
- **Elbas** - Trading takes place every day round the clock until one hour before delivery
- **Balancing** - Settlement of deviations between bids/offers and actual production/consumption

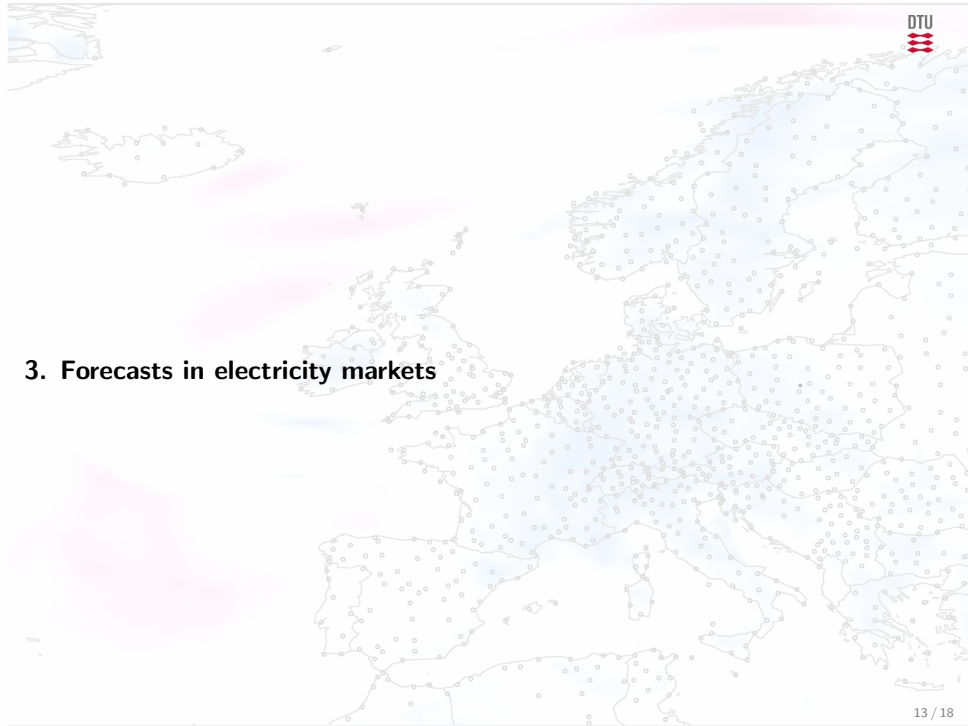
# The merit-order effect (day-ahead)



- On the day-ahead market, wind acts as a **stochastic driver** since having the lowest short-run marginal cost, with quantities based on forecasts (13-37 hours ahead)



### 3. Forecasts in electricity markets

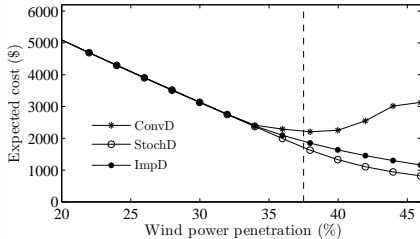


- **Partners:** DTU (lead), Copenhagen Business School, Copenhagen University, Danish Energy Association, Energinet.dk, NTNU (S.-E. Fleten), University of Castilla La Mancha (A. Conejo)
- **Adv. Board:** B. Hobbs (J. Hopkins), A. Siddiqui (UCL), E. Ela (NREL/UCD)
- **Vision:** *Proposal and benchmarking of new approaches to market design allowing for a very large penetration of stochastic power generation, while respecting power system operations constraints and stimulating a healthy environment for investment.*
- **In practice, some of the key aspects include**
  - *market-clearing mechanisms*
  - *plurality of markets (energy, capacity, ancillary services) possibly co-optimized*
  - *enabling and rewarding the more pro-active role of electricity demand*
  - *assessing impact on investment and our future power system*
  - *bridging the gap between "theoretical proposals" and practical implementation*
- **More generally:** foster and develop cutting-edge electricity market expertise to support education, industry and increase in social welfare

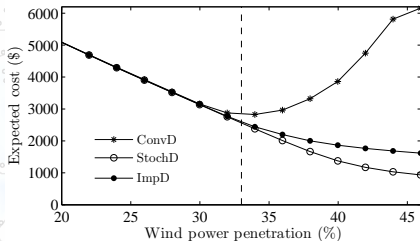
- Day-ahead market-clearing insures an **optimal match of production and demand**, a fair amount of time prior to operations, **regardless of the 'nature' of offers/bids**
- With increased variability and uncertainty to be dealt with, the system should be placed in a state permitting to optimally cope 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*
- These are current research problems...

## Illustration: costs of power system operation

- **Representative 24-bus system** (IEEE RTS, Grigg *et al.* (1999)), with total demand of 2GW and various types of generators (2 wind farms, for simplicity)
- Realistic unit characteristics (also, Bouffard *et al.* (2005)) 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



$\rho = 0.35$



$\rho = 0.75$



- Renewable energy (here, wind) **forecasts are gaining increasing importance** in electricity markets
- **Evolutions in market designs** may heavily influence the role and value of these forecasts, e.g., in case of US or European types of electricity markets....
- In all cases, probabilistic forecasts comprise an **optimal input** to design of offering strategies and market clearing...
- here discussed for wind only, though also valid for solar and wave energy, load, demand-response potential, etc.
- **Future research** on forecasting and electricity markets should focus on
  - coupling *in time* (day-ahead and real-time stages)
  - coupling *in space* (e.g., flow-based, dynamic zonal pricing)
  - coupling of *energy and ancillary services*

Thanks for your attention!



Pierre Pinson



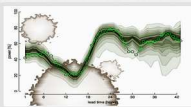
### Large-scale integration of renewable energy

#### Books



In an effort to disseminate our work to students, researchers and practitioners, some collaborators and I have been focusing on producing books that would gather knowledge in renewable energy, forecasting, and electricity markets. For a

#### Wind power forecasting



It is not possible to decide on the level of wind energy to be produced in the coming minutes or days – one relies on nature and the weather. Ways have to be found to optimally assimilate this energy generation in the system. Wind power modulation and forecasting is recognized as a net-

#### A little toy...



If you wonder how future renewable energy forecasting may look, let me invite you to look at this toy forecasting system, which we will make evolve as new features are to become available.