Analytics and Forecasting for Renewable Energy Generation

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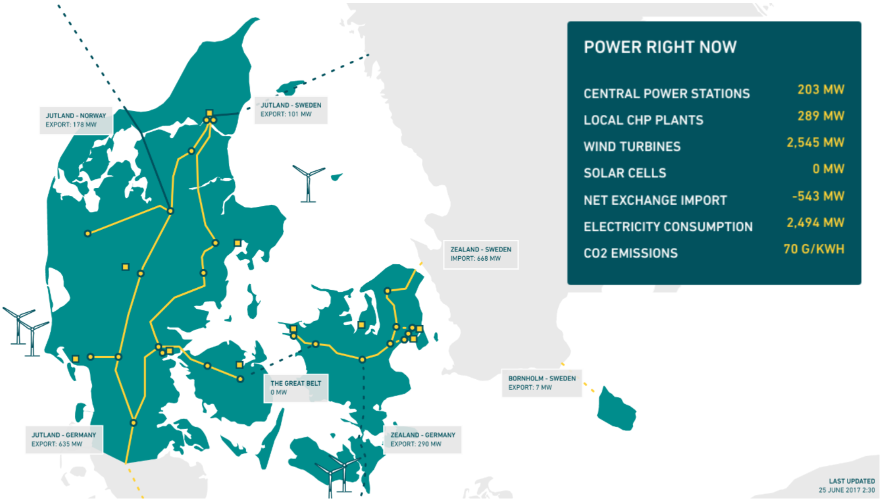
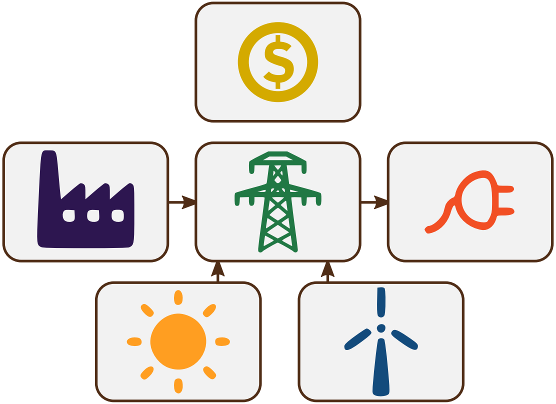
3 May 2019

Power right now: 25 June 2017, 2.30am



Denmark's objective: 100% renewable-based energy system by 2050(!)

Context: Renewables in power systems and markets



- Forecast information is widely used as input to several decision-making problems:
  - definition of **reserve** requirements (i.e., backup capacity for the system operator)
  - **unit commitment** and **economic dispatch** (i.e., least costs usage of all available units)
  - coordination of renewables with **storage**
  - design of optimal **trading** strategies
  - optimal **maintenance planning** (especially for offshore wind farms)

The *MIT Technology Review*

- The **MIT Technology Review**:
  - founded at MIT in 1899
  - daily review/analysis of technological innovation worldwide
  - *impact*: 580.000 members and 2.400.000 website visitors per month!

- The **10 breakthrough technologies 2014**:
  - genome editing
  - microscale 3D printing
  - neuromorphic chips
  - brain mapping
  - etc.
  - **renewable energy analytics (!)**, and more particularly forecasting and uncertainty assessment

[See link:
MIT Technology Review - Smart Wind and Solar Power]

Outline

- **Variability** and **uncertainty** in power generation at various time scales
- **Where are we coming from** and **status quo** in forecasting
- Some **perspectives** with forecasting in the management of next generation energy systems

1. **Variability and uncertainty in power generation at various time scales**

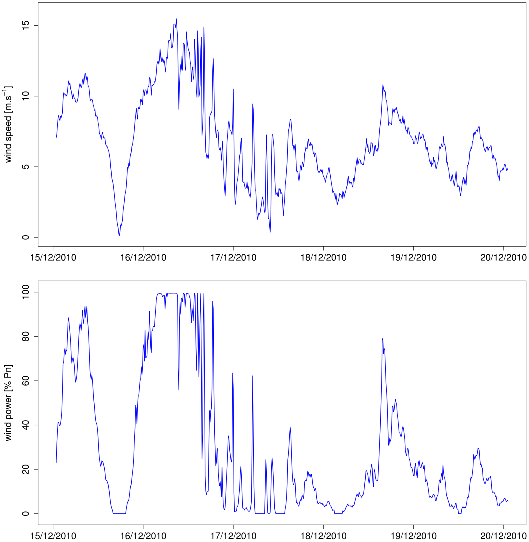
Horns Rev, Denmark

Wind variability: from one minute to the next

- Large wind variations (especially offshore) yield intense power fluctuations!

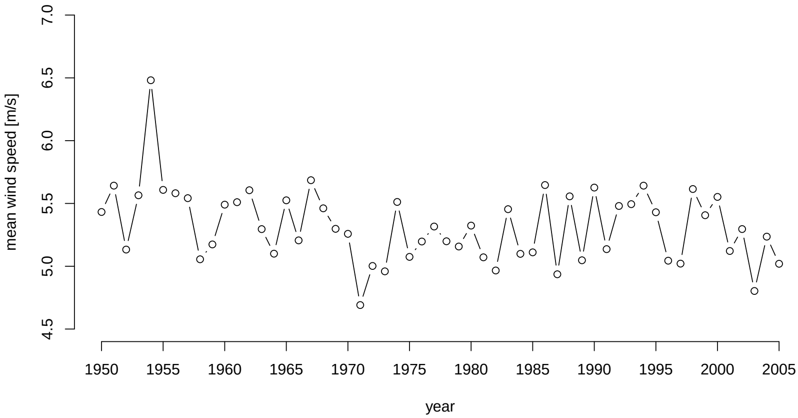
- These are particularly important for:
  - *control* of wind farms output
  - *balancing* of power generation and consumption at the grid level
  - etc.

- Same goes for solar power with (various types) of cloud passages



Wind variability - from year to year

- Wind resource assessment is somewhat based on the assumption such that average wind is constant from one year to the next
- Seasonal to yearly variability is crucial for optimal planning of the generation mix

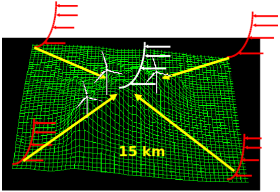


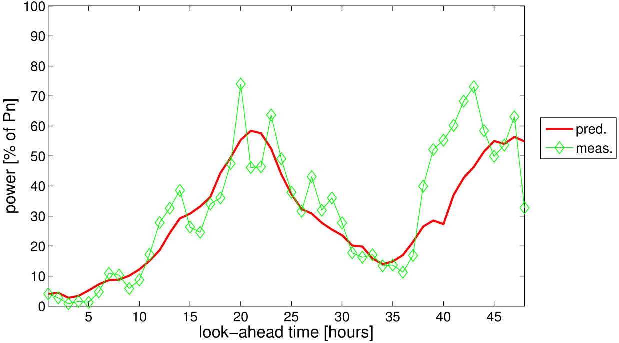
yearly average wind speed at Schiphol airport over 55 years

2. **Where are we coming from and status quo**

A traditional view on renewable (wind here) energy forecasting

The wind power forecasting problem is defined for a single location...



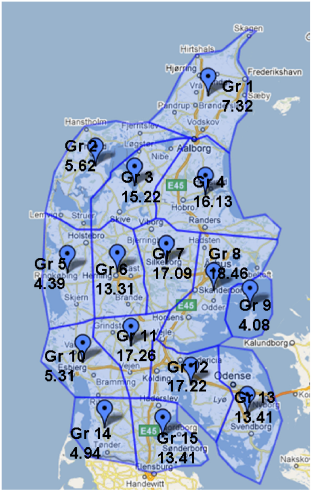


... or, if several locations, by considering each of them individually

Wind farms as a network of sensors

Many works showed that **forecast quality could be significantly improved:**

- by using data at offsite locations (i.e., other wind farms)
- based on spatio-temporal modelling (and the likes)

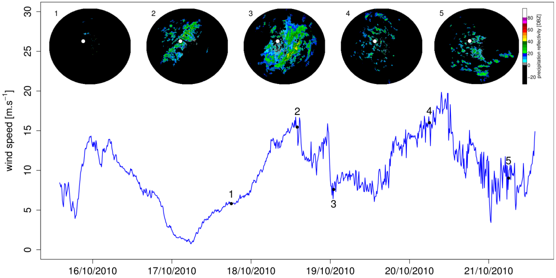


improvement of 1-hour ahead forecast RMSE

- A Danish example...
- Accounting for spatio-temporal effects allows for the correction of aggregated power forecasts **for horizons up to 8 hours ahead**
- Largest improvements at **horizons of 2-5 hours ahead**

Do not forget the role of remote sensing e.g. Radar@Sea

- X-band weather radars (DHI, range: 60kms) were installed at Horns Rev in 2009/2010

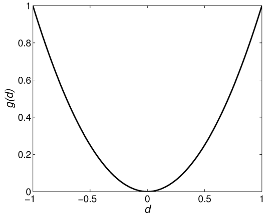


- Supplemented by the DMI C-band radar (range: 240kms) at Rømø, they were used for
  - monitoring of weather conditions (safety)
  - analysis of meteorological episodes (climatology)
  - improving short-term forecasts
  - better control for episodes with intense fluctuations
  - ... and environmental studies (e.g. bird counts)

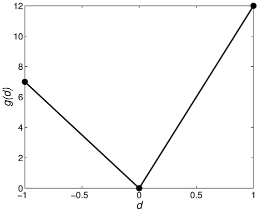
... in 2015, DONG Energy decided to invest in dual-doppler radar systems for offshore wind conditions in the UK (BEACon - Westermough Rough, 210MW)!

Different loss functions

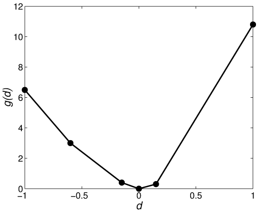
- Forecasters and forecast users have different loss functions
- Actually, each forecast user has its own cost function
  (that he does not necessarily know...!!)



Forecaster



Trader (wind power only)



Portfolio manager

- **So... What is the best forecast in such a case??**

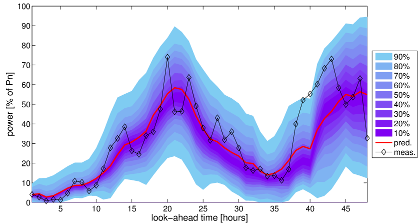
Renewable energy analytics in a probabilistic framework

- **Modelling**, **forecasting**, and **decision-making** ought to be thought of in a probabilistic framework

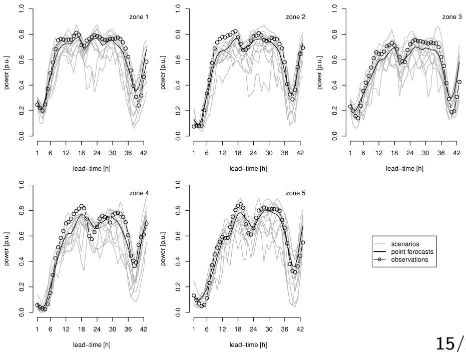
- Relevant forecast products:

  1. quantile forecasts
  2. prediction intervals
  3. density forecasts
  4. forecast trajectories (/paths, scenarios, etc.)
  5. risk indices (broad audience, mainly)

Density forecasts: (*ex:* wind farm in Denmark)

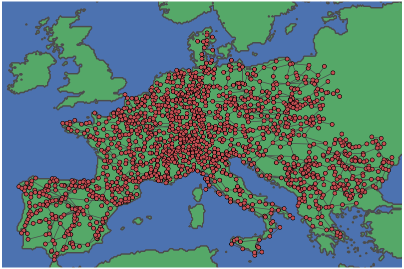


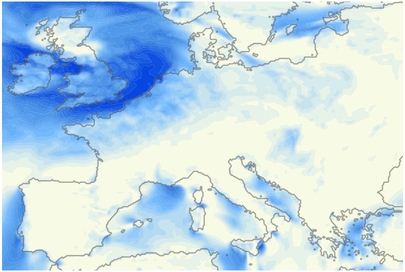
Space-time scenarios: (*ex:* 5 areas in Denmark)

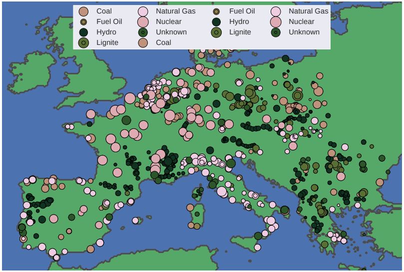


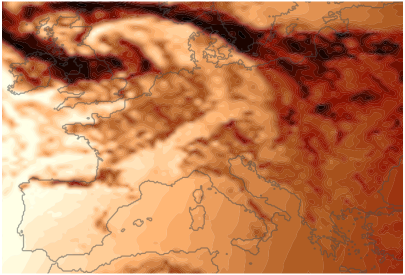
Scaling it up

Ultimately, we would like to predict all wind power generation, also solar and load, at the scale of a continental power system, e.g. the European one





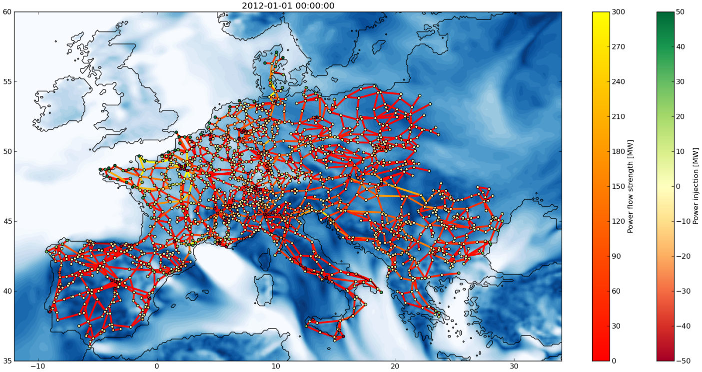




RE-Europe dataset, available at `zenodo.org`

The big picture...

- The **"grand forecasting challenge"**: predict *renewable power generation*, *dynamic uncertainties* and *space-time dependencies* at once for the whole Europe...!



- **Many relevant applications:**
  - Monitoring and forecasting of the complete **"Energy Weather"** over Europe, with consistent information for all agents
  - Uncertainty-aware management of energy systems
  - Input to operational coordination problems (market coupling, reserve sharing, etc.)

3. **Some perspectives with forecasting in the management of next generation energy systems**

Sharing is caring...

[Taken from moneycrashers.com, Brian Martucci]

- *Sharing* is part of human nature and a source of happiness
- *Sharing* is a basis for the development of new business models (*'access economy'* and *'collaborative commons'*)
  - crowdfunding
  - crowdsourcing
  - car pooling, shared property, etc.

There is one thing we do not really share in electricity energy systems... **data** and **forecasts**(!)

Sharing data and forecasts: motivations

- Today, most markets are cleared (and operations settled) based on forecasts

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Sharing wind power forecasts in electricity markets: A numerical analysis

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H I G H L I G H T S

- Information sharing among different agents can be beneficial for electricity markets.
- System cost decreases by sharing wind power forecasts between different agents.
- Market power of wind producer may increase by sharing forecasts with market operator.
- Extensive out-of-sample analysis is employed to draw reliable conclusions.

A R T I C L E I N F O

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A B S T R A C T

In an electricity pool with significant share of wir
wind power units are generally scheduled in a c
Then, a real-time market is cleared given the update
to adjust power imbalances. This sequential market
challenges such as severe power shortage in real-t
ahead market. To overcome such situations, severa
resources to the system. In this paper, we address a
ing in which market players share their own wind p
solution may improve the functioning of sequen
informed day-ahead schedules, which reduces the
This paper numerically evaluates the potential valu
of system cost reduction. Besides, its impact on each
this study is based on a stochastic two-stage market
us to gain further insights into information sharing

1

Impact of Public Aggregate Wind Forecasts on Electricity Market Outcomes

Lazaros Exizidis, *Student Member, IEEE,* Jalal Kazempour, *Member, IEEE,* Pierre Pinson, *Senior Member, IEEE,* Zacharie De Grève, *Member, IEEE,* and François Vallée, *Member, IEEE*

***Abstract*—Following a call to foster a transparent and more competitive market, member states of the European transmission system operator are required to publish, among other information, aggregate wind power forecasts. The publication of the latter information is expected to benefit market participants by offering better knowledge of the market operation, leading subsequently to a more competitive energy market. Driven by the above regulation, we consider an equilibrium study to address how public information of aggregate wind power forecasts can potentially affect market results, social welfare as well as the profits of participating power producers. We investigate, therefore, a joint day-ahead energy and reserve auction, where producers offer their conventional power strategically based on a complementarity approach and their wind power at generation cost based on a forecast. In parallel, an iterative game-theoretic approach (diagonalization) is incorporated in order to investigate the existence of an equilibrium for various values of aggregate forecast. As anticipated, variations in public forecasts will affect market results and, more precisely, under-forecasts can mislead power producers to make decisions that favor social welfare, while over-forecasts will cause the opposite effect. Furthermore, energy and reserve market prices can also be affected by deviations in aggregate wind forecasts altering, inevitably, the profits of all power producers.**

***Index Terms*—Wind power, aggregate forecasts, public data, equilibrium, game theory.**

Notation:

Sets:

$\mathcal{G}$	Set of all conventional power units.
$\mathcal{G}_{\mathcal{J}}$	Set of conventional power units belonging to producer $\mathcal{J}$.
$\mathcal{W}$	Set of all wind power units.
$\mathcal{W}_{\mathcal{J}}$	Set of wind power units belonging to producer $\mathcal{J}$.

Indices:

$\mathcal{J}$	Index for producers.
i	Index for conventional units.
b	Index for generation blocks of conventional units.
d	Index for demands.
l	Index for wind power units.
ω	Index for wind power generation scenarios.
s	Index for real-time market price scenarios.

Variables:

$p^{\mathrm{G}}_{i,b}$	Scheduled generation for the b-th block of the i-th conventional unit [MW].
r^{U}_{i}	Committed upward reserve from the i-th conventional unit [MW].
r^{D}_{i}	Committed downward reserve from the i-th conventional unit [MW].
λ^{DA}	Energy price [\$/MWh].
μ^{U}	Price of capacity for committed upward reserve [\$/MWh].
μ^{D}	Price of capacity for committed downward reserve [\$/MWh].
$\alpha^{\mathrm{G}}_{i,b}$	Price offer for the b-th block of the i-th unit [\$/MWh].
p^{D}_{d}	Scheduled consumption for the d-th demand [MW].
p^{W}_{l}	Scheduled wind power generation for the l-th wind power unit [MW].
$p^{\mathrm{W,RT}}_{l,\omega}$	Power sold/bought in the real-time market by the l-th wind power unit under scenario ω [MW].

Parameters:

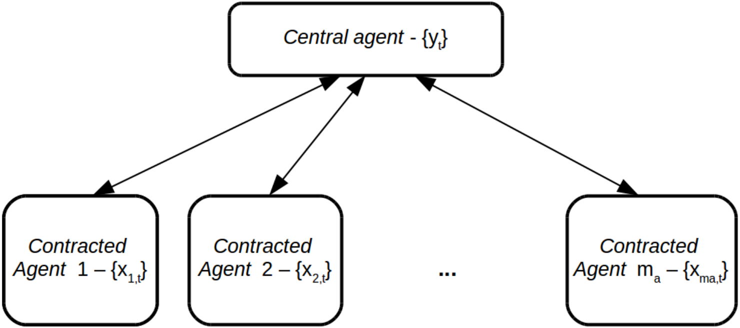
$C^{\mathrm{G}}_{i,b}$	Marginal cost of the b-th block of the i-th unit

- Wouldn't exchange of forecasts (and data) improve market outcomes?

Alternative setup: distributed learning

- In most cases, market players do not want to share their data - even though models and forecasts would highly benefit from that!
- one may design **distributed learning algorithms** that are **privacy-preserving**

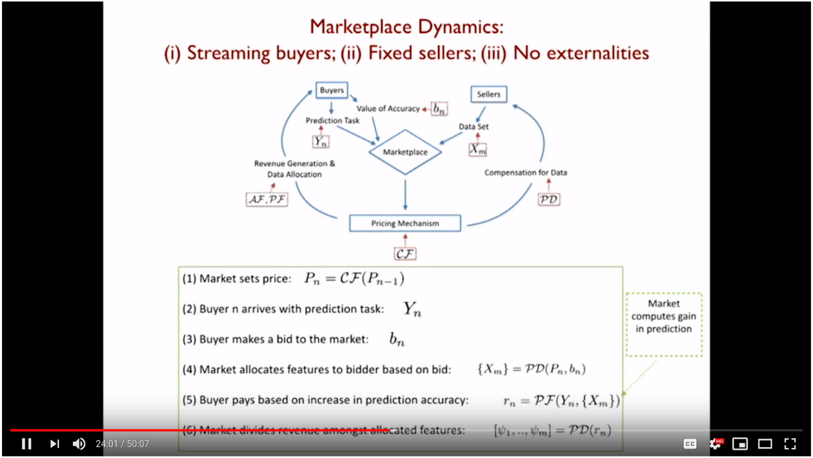
- Example setup, with a *central* and *contracted agents*:



- Distributed learning, optimization, etc. is to **play a key role** in future energy analytics

Towards data (or information) markets...?

- Quite a few in academia are looking at the design of data markets



Princeton Day of Optimization 2018: A Marketplace for Data An Algorithmic Solution by Munther Dahleh

- And it may be that applications in electricity markets and for the management of next generation energy systems are very promising!

Concluding remarks

- Renewable energy generation is a **nonlinear, bounded and nonstationary** stochastic processes, with complex space-time dependencies

- There is a lot of room for improving modelling and forecast methodologies

- **High-dimensional (multivariate) probabilistic forecasting** is currently one of the key topics of interest
  - modelling for predictive marginals
  - dependency structures
  - forecast verification challenges

- **Distributed learning** and **data markets** potentially have a bright future, since
  - high quantity of distributed data is being collected
  - valuable information is spread in terms of localization and ownership
  - the value of information might become higher than the value of energy itself(!)

- Design of, and pricing in, distributed computation and data sharing markets may not be straightforward though

Thanks for your attention!