

# Uncertainty of wind power forecasts and optimizing the use of weather intelligence

29.09.2016

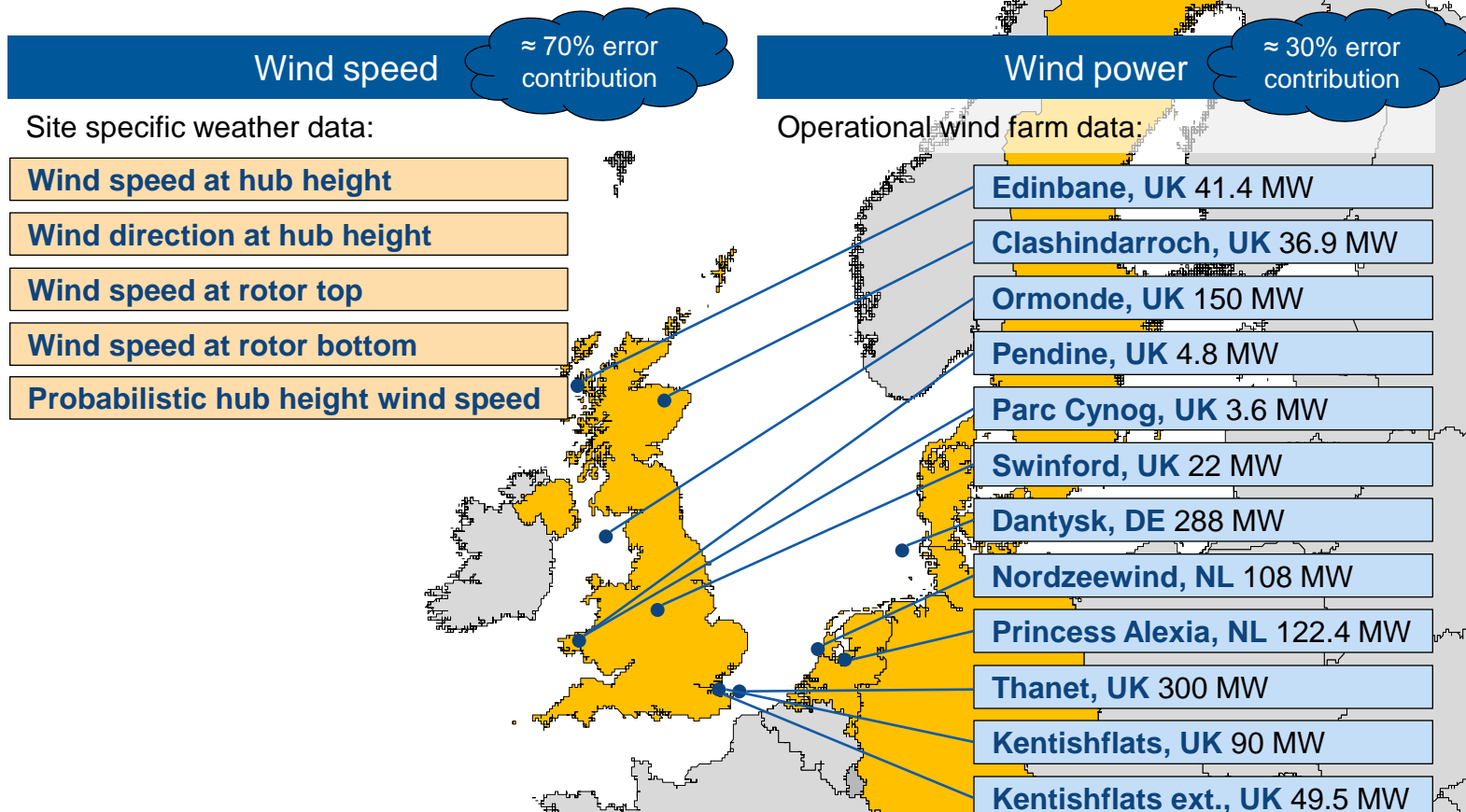
Dr. Tilman Koblitz

Short-Term Forecasting & Optimization  
Vattenfall Energy Trading

# Wind Power Forecast

Dataset for current study (2013-2016):

- Production data from 3.2 GW in 3 countries (UK, NL & DE)
- SCADA data from 12 wind farms (415 turbines)



# Agenda

Uncertainty of wind power forecasts and optimizing the use of weather intelligence



- **Wind power forecast & atmospheric stability**
- Probabilistic wind power forecasts

# Wind Power Forecast & Atmospheric Stability

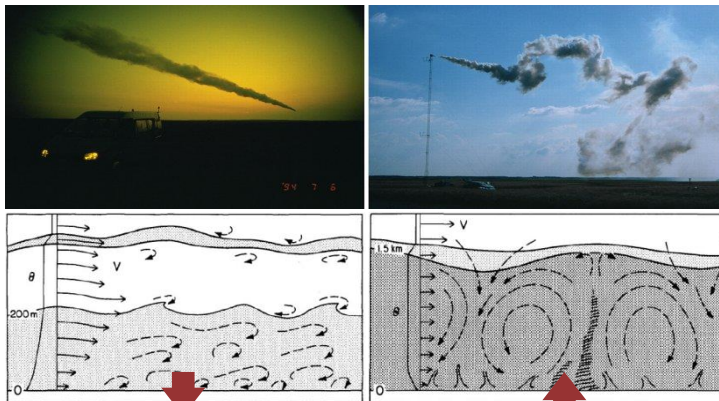
Effect of atmospheric stability on a wind turbine



## Wind speed

stable

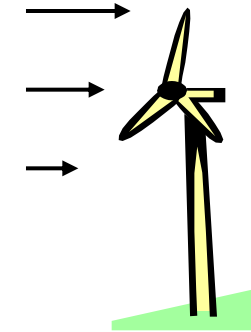
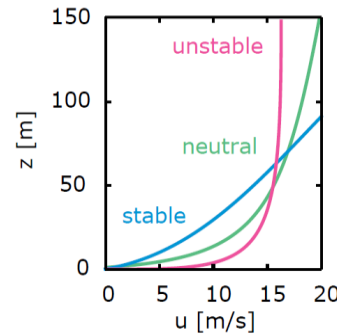
unstable



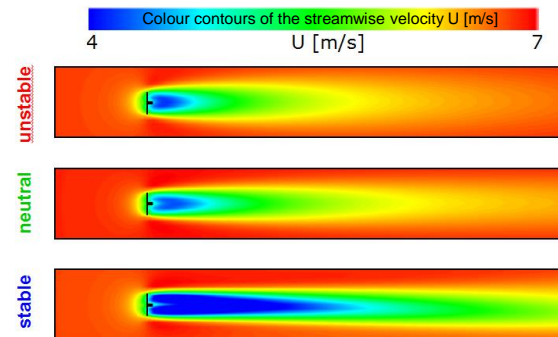
heat flux

Sources: Dr. Torben Mikkelsen, Risø DTU, Dr. Thomas Ellermann, National Environmental Research Institute; Kaimal and Finnigan 1994

## Wind power



Wind turbine wake modelled with CFD (EllipSys3D - DTU):



# Wind Power Forecast & Atmospheric Stability

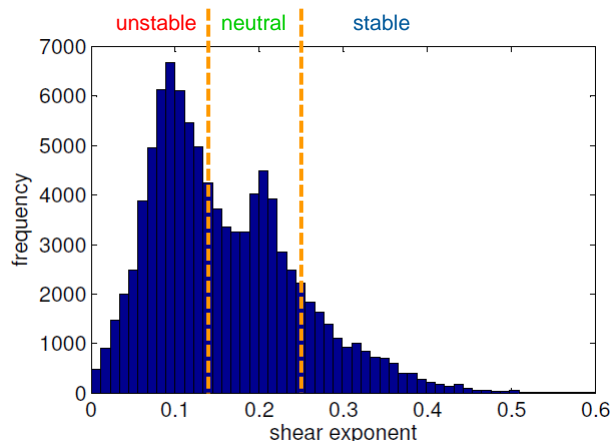
Effect of atmospheric stability on a wind farm



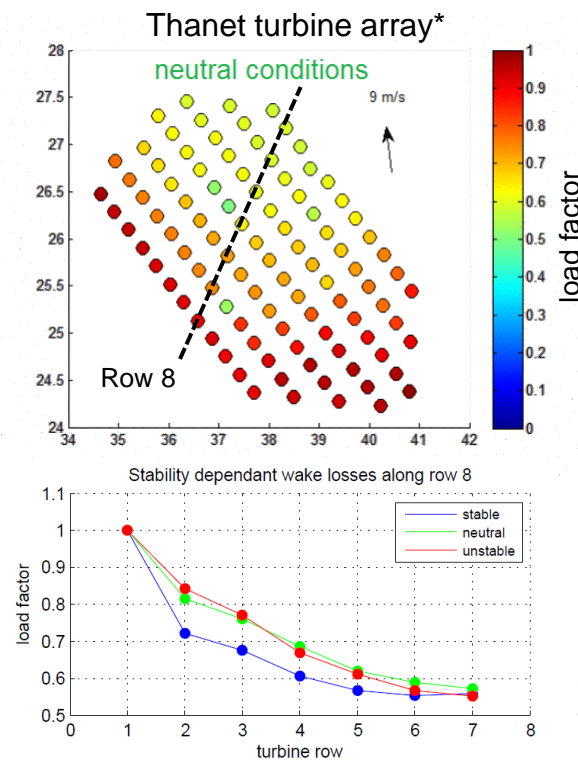
Wind speed

Shear exponent:  $\alpha = \frac{u_{180} - u_{21m}}{u_{70m}}$

Day-ahead wind shear distribution - Thanet, UK



Wind power



\*Based on 1year of SCADA data

# Wind Power Forecast & Atmospheric Stability

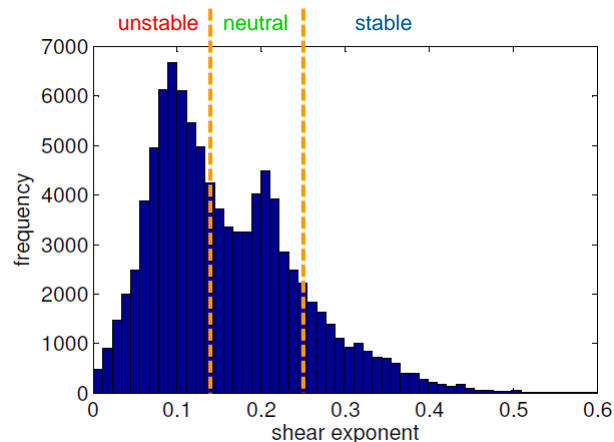
Effect of atmospheric stability on a wind farm



Wind speed

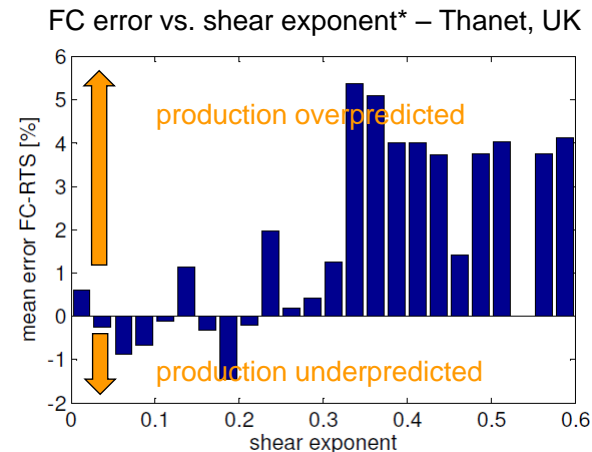
Shear exponent: 
$$\alpha = \frac{u_{180} - u_{21m}}{u_{70m}}$$

Day-ahead wind shear distribution - Thanet, UK



Wind power

- Day-ahead forecast error vs. atmospheric stability at Thanet, UK:



\*Based on 21 months of data

# Wind Power Forecast & Atmospheric Stability

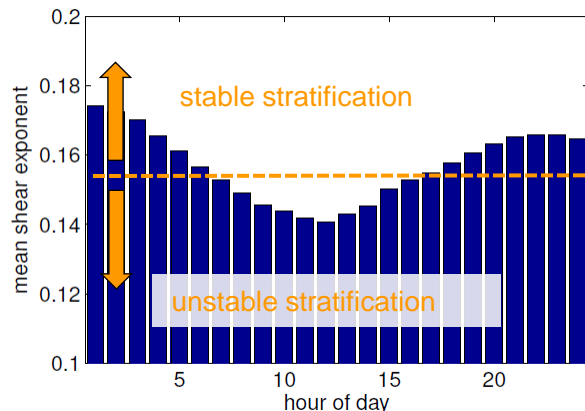
Effect of atmospheric stability on a wind farm



Wind speed

Shear exponent: 
$$\alpha = \frac{u_{180} - u_{21m}}{u_{70m}}$$

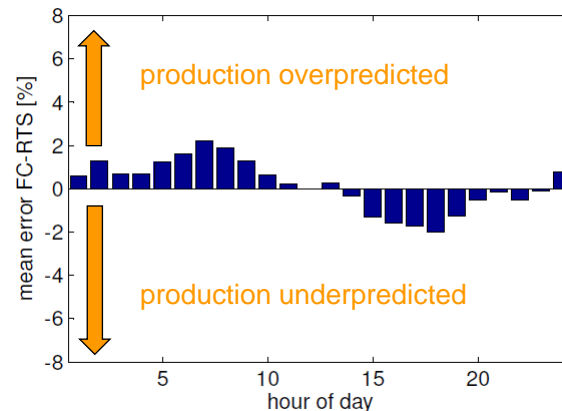
Day-ahead wind shear distribution - Thanet, UK



Wind power

- Day-ahead forecast error vs. time of day at Thanet, UK

FC error vs. time of day – Thanet, UK



Bias corrected model	Wind power MAE	Wind power RMSE
Improvement	- 0.54 %	- 0.64 %

# Wind Power Forecast & Atmospheric Stability

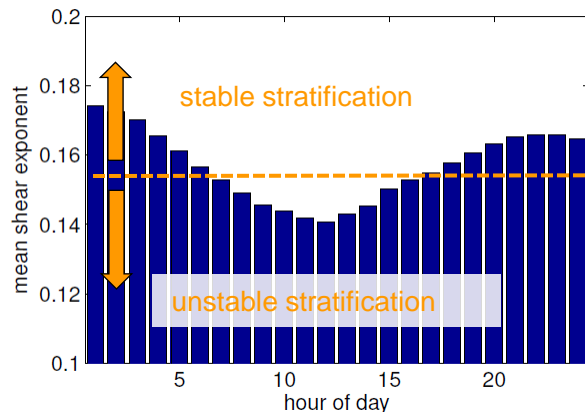
Effect of atmospheric stability on a wind farm



Wind speed

Shear exponent: 
$$\alpha = \frac{u_{180} - u_{21m}}{u_{70m}}$$

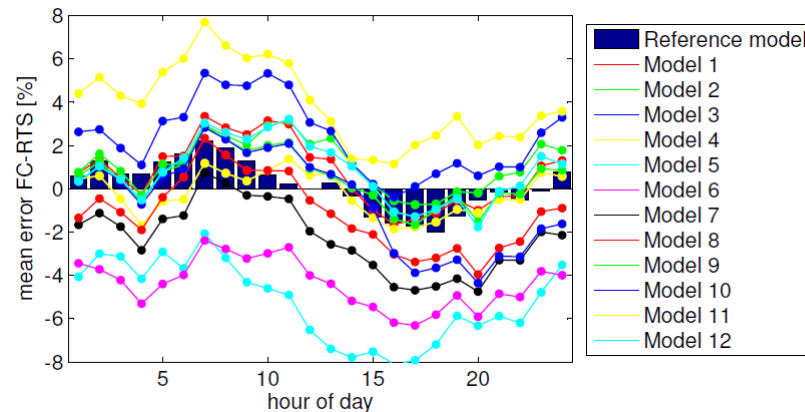
Day-ahead wind shear distribution - Thanet, UK



Wind power

- Day-ahead forecast error vs. time of day at Thanet, UK
- Benchmark results: day-ahead forecast of 12 different models over a period of 6 months

FC error vs. time of day – Thanet, UK



Bias corrected model	Wind power MAE	Wind power RMSE
Improvement	-0.54 %	-0.64 %



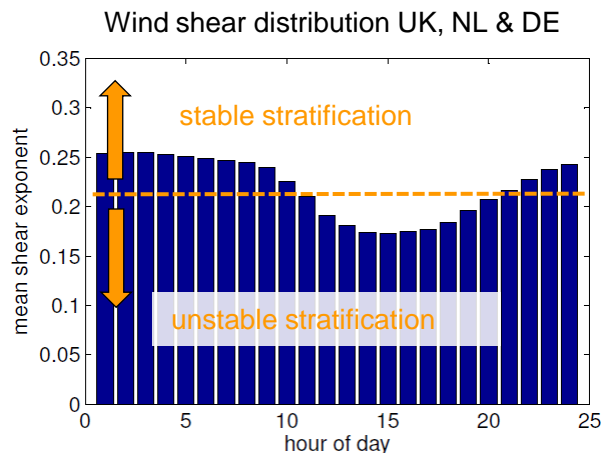
# Wind Power Forecast & Atmospheric Stability

Effect of atmospheric stability on a wind portfolio



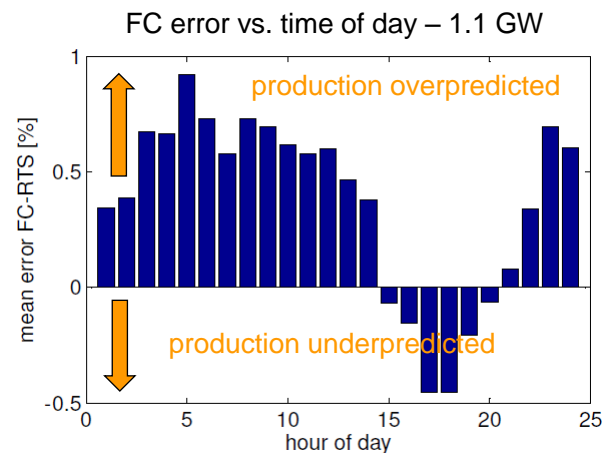
## Wind speed

- Day-ahead shear index forecast over time of day across different geographical locations and heights



## Wind power

- Day-ahead forecast error vs. time of day for 1.1 GW of installed capacity in NL, UK & DE



Bias corrected model	Wind power MAE	Wind power RMSE
Improvement	-2.01 %	-3.34 %

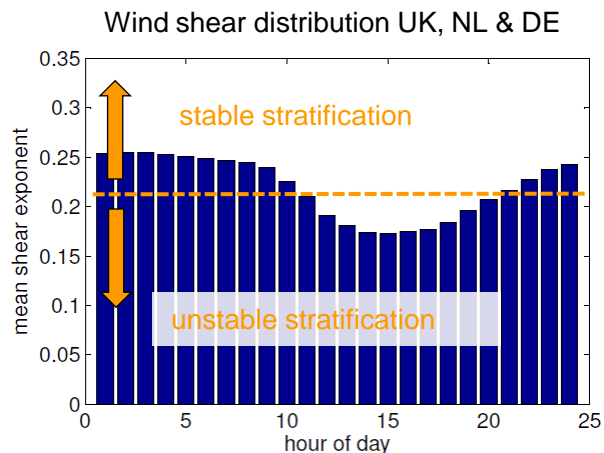
# Wind Power Forecast & Atmospheric Stability

Effect of atmospheric stability on a wind portfolio



## Wind speed

- Day-ahead shear index forecast over time of day across different geographical locations and heights



## Wind power

- Relative improvement of shear corrected day-ahead model vs. uncorrected model

Bias corrected model	Wind power MAE	Wind power RMSE
Clashindarroch UK	-1.60 %	-1.80 %
Edinbane UK	-0.19 %	-0.62 %
Kentishflats UK	-3.48 %	-2.65 %
Kentishflats ext. UK	-3.49 %	-4.58 %
Ormonde UK	-0.33 %	-0.50 %
Parc Cynog UK	-1.91 %	-0.93 %
Pendine UK	-0.84 %	-1.06 %
Swinford UK	-1.65 %	-1.45 %
Thanet UK	-0.56 %	-0.70 %
Nordzeewind NL	-6.02 %	-11.08 %
Zuidlob NL	-1.11 %	-2.03 %
Dantysk DE	-0.71 %	-1.77 %
<b>All</b>	<b>-2.01%</b>	<b>-3.34%</b>

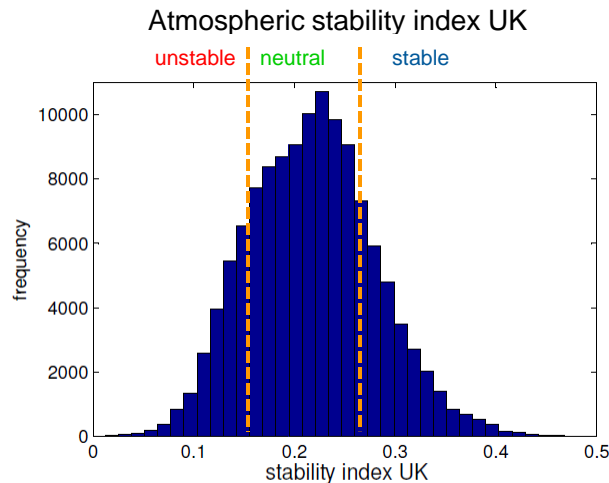
# Wind Power Forecast & Atmospheric Stability

Effect of atmospheric stability on the UK power market



## Stability index UK

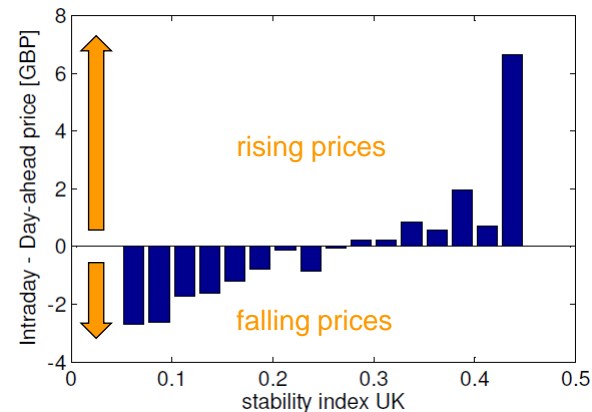
- Day-ahead atmospheric stability index UK
- Calculated from day-ahead forecasts across different geographical locations & heights



## UK Power Market

- Intraday minus day-ahead (spot) price\*1 vs. stability index UK

Power price\*1 vs. atmospheric stability index UK



\*1: based on 18 months of UK market data (01/2015-06/2016)

# Agenda

Uncertainty of wind power forecasts and optimizing the use of weather intelligence



- Wind power forecast & atmospheric stability
- **Probabilistic wind power forecasts**

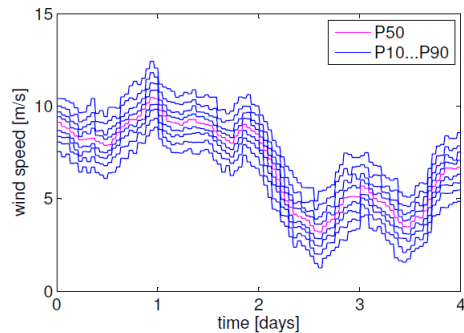
# Probabilistic Wind Power Forecast

Effect of probabilistic forecast on a Wind Turbine



## Wind speed

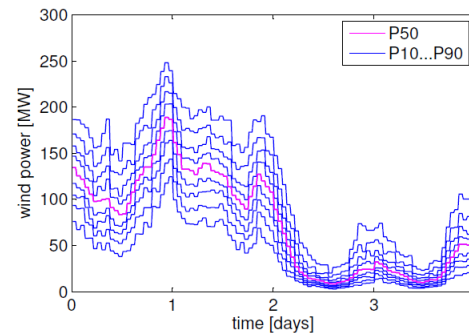
Day-ahead prob. Wind speed FC – Thanet, UK



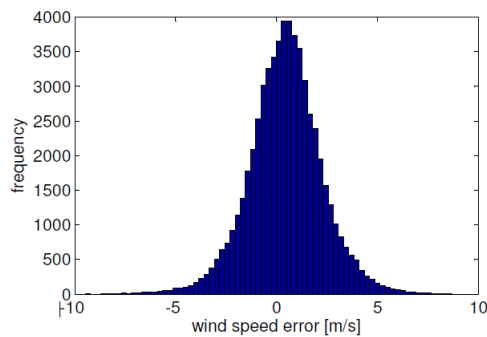
Forecast

## Wind power

Day-ahead prob. wind power FC – Thanet, UK

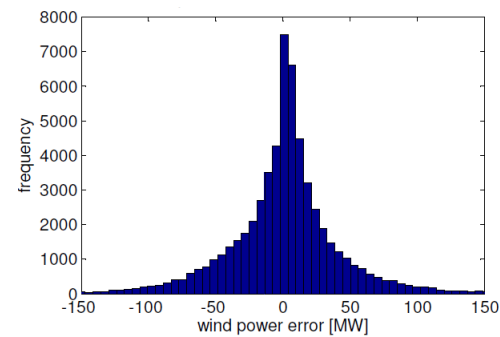


Day-ahead wind speed error – Thanet, UK



Error distribution

Day-ahead wind power error – Thanet, UK



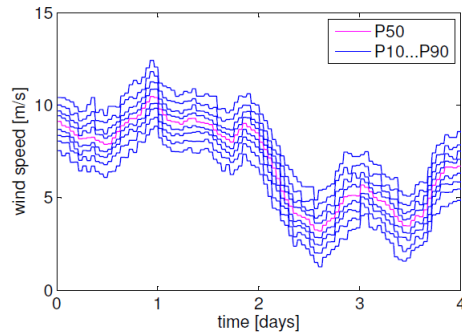
# Probabilistic Wind Power Forecast

Effect of probabilistic forecast on a Wind Turbine / Wind Farm



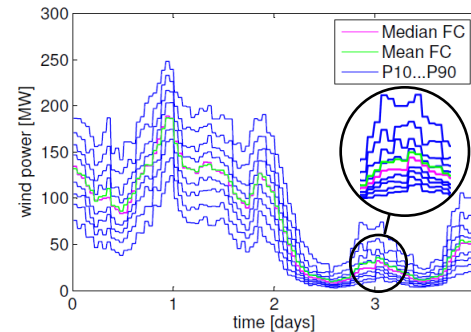
## Wind speed

Day-ahead prob. Wind speed FC – Thanet, UK



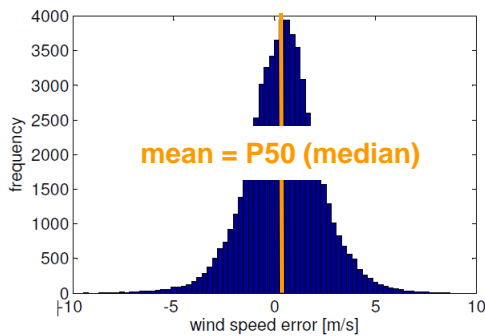
## Wind power

Day-ahead prob. wind power FC – Thanet, UK



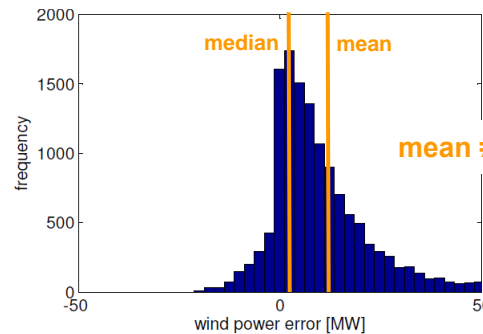
Forecast

Day-ahead wind speed error – Thanet, UK

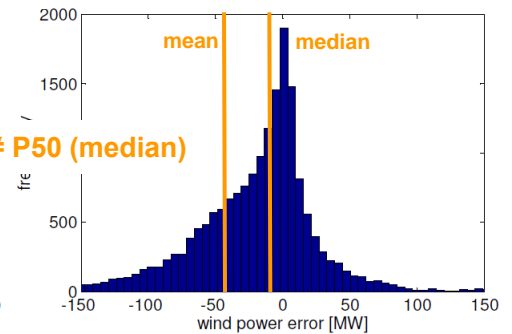


Error distribution

Day-ahead wind power error (ws < 10 m/s)



Day-ahead wind power error (ws > 10 m/s)



# Probabilistic Wind Power Forecast

## Effect of probabilistic forecast on a Wind Portfolio



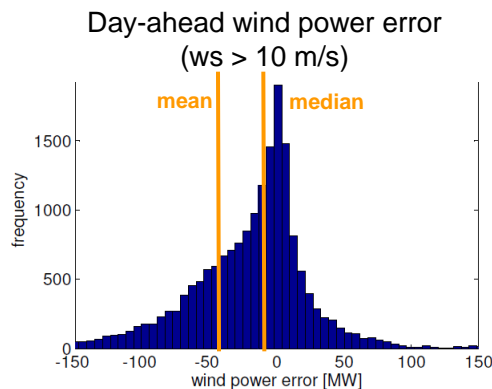
### Wind power

- For asymmetric distributions the median can differ significantly from the mean:

- Median (P50) minimizes MAE
- Mean minimizes RMSE

- Relative KPI difference of mean vs. median day-ahead forecast model:

Mean vs. median model per park	Wind power MAE	Wind power RMSE
Clashindarroch UK	-0.21%	-1.85%
Edinbane UK	+1.26%	-2.51%
Kentishflats UK	+1.45%	-0.88%
Ormonde UK	+2.57%	-2.21%
Parc Cynog UK	+2.18%	-0.08%
Pendine UK	+1.29%	-1.02%
Swinford UK	+0.66%	-1.46%
Thanet UK	+2.66%	-1.22%
Nordzeewind NL	+3.06%	-1.04%
Zuidlob NL	+0.79%	-1.89%
Dantysk DE	+2.41%	-1.17%
<b>All</b>	<b>+2.63%</b>	<b>-1.22%</b>



Forecast

Error distribution

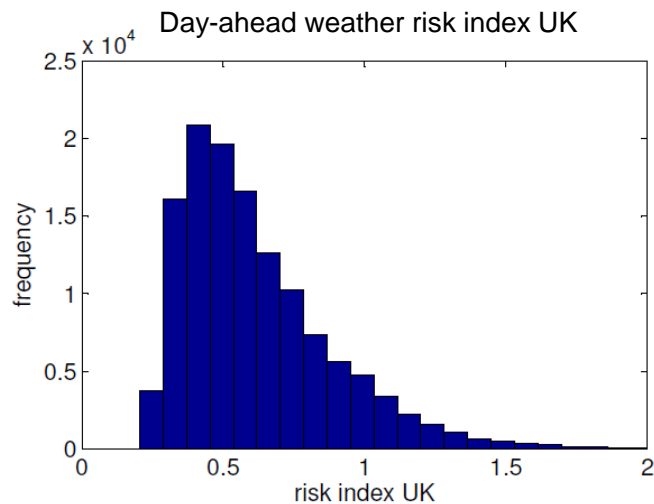
# Probabilistic Wind Power Forecast

## Probabilistic forecasts and the UK Power Market



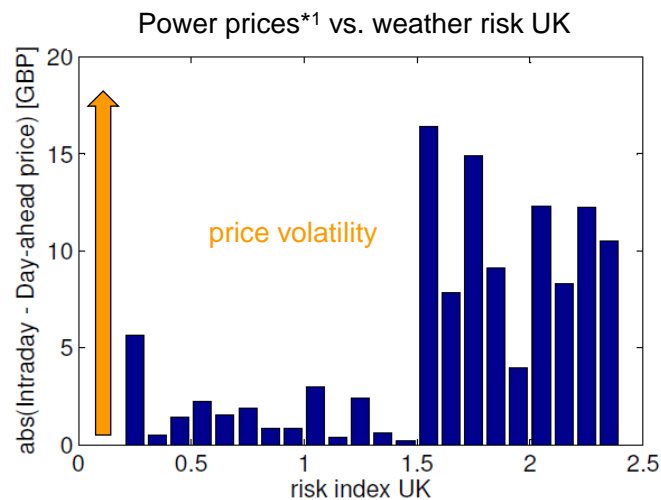
### Wind speed

- Day-ahead risk index:  $\frac{P_{90}-P_{10}}{P_{50}}$
- Calculated from forecasts across different geographical locations & heights



### Wind power

- Absolute difference between intraday and day-ahead (spot) price\*1 vs. risk index UK



\*1: based on 18 months of UK market data (01/2015-06/2016)



# Conclusions & Contact



## Atmospheric stability:

- Day-ahead wind shear forecast can be used as proxy for atmospheric stability
- Effect of atmospheric stability is evident from wind turbine to energy market
- Implementation into forecast models improves accuracy

## Probabilistic forecasts:

- The choice of mean vs. median forecast determines which KPI is minimized
- Day-ahead weather risk can be linked to forecast error and hence market price volatility

## Contact for questions:

- Dr. Tilman Koblitz [tilman.koblitz@vattenfall.com](mailto:tilman.koblitz@vattenfall.com)

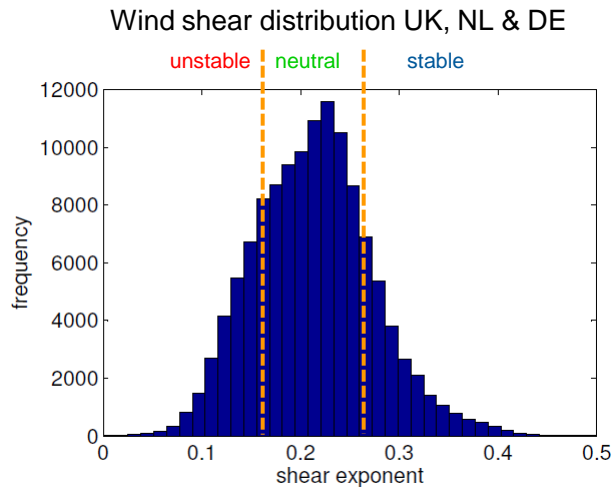
# Backup A

## Effect of atmospheric stability on a wind portfolio



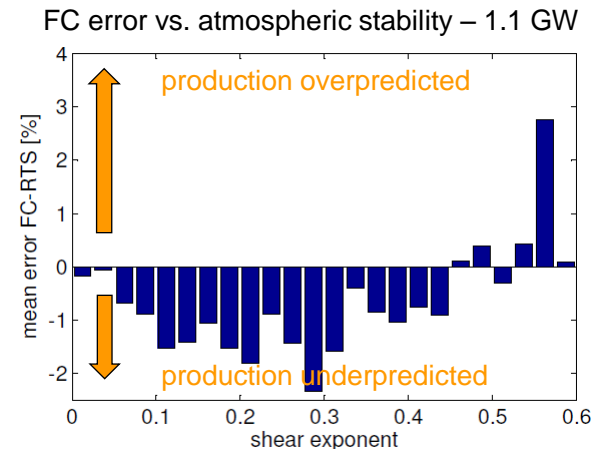
### Wind speed

- Day-ahead shear index forecast across different geographical locations and heights



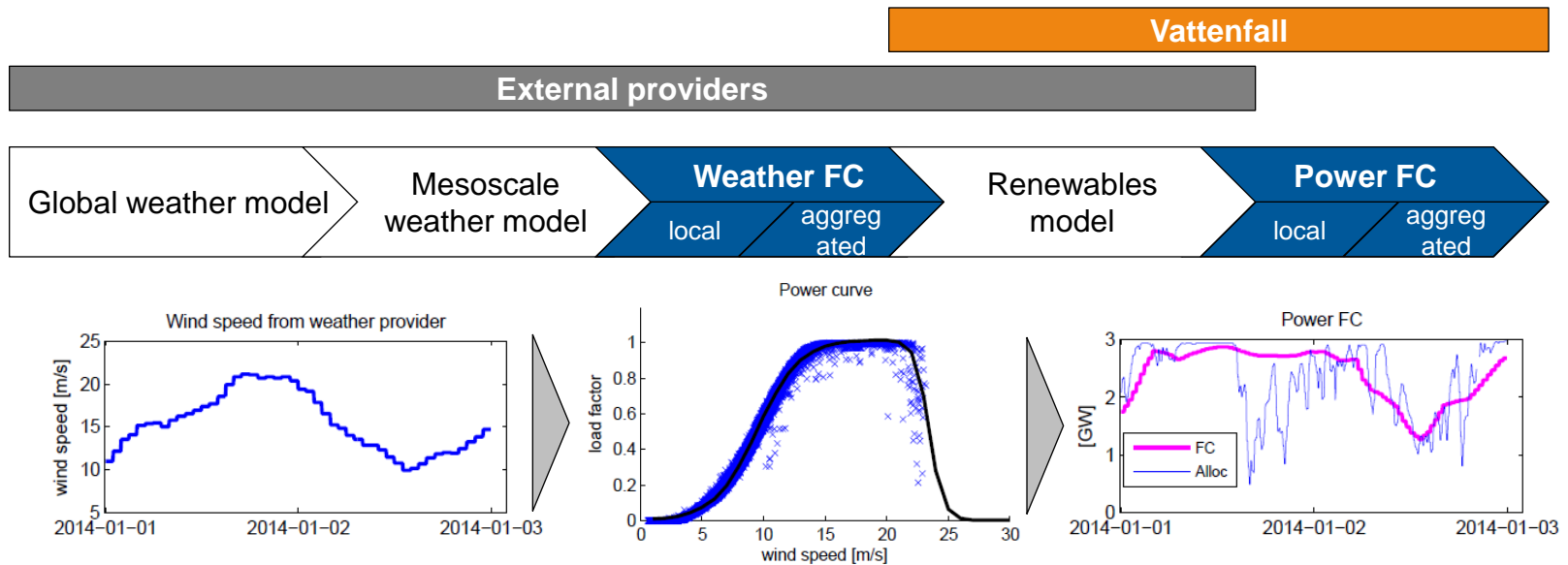
### Wind power

- Day-ahead forecast error of 1.1 GW of installed capacity in UK, NL & DE



# Backup B

## Current wind power forecast process



Forecast accuracy:		
	Wind speed MAE*1	Power NMAE*1
Market benchmark*1	0.6-2.2 m/s	4-25%
Power error contribution*2	≈ 70%	≈ 30%

\*1: Data from 2015 weather & power production benchmark project within Vattenfall  
 \*2: Note that accuracy values are indications.

### Definitions:

- 'Day-ahead' in this study refers to data that is available at 9am the previous day for the period 00:00-24:00 the following day
- To quantify forecast errors and potential improvements a reference forecast model is used which is based based on a power curve model using hub height P50 wind speed as input