



Electrical Engineering and
Systems Technology

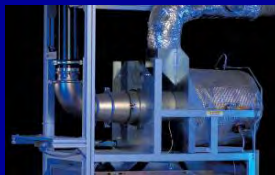
for the Use of
Renewable Energies

and Decentral
Energy Supply

Applications oriented Research
and Development

Institut für Solare
Energieversorgungstechnik
Verein an der
Universität Kassel e.V.

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Reduction of Wind Power Variability by Aggregation of Wind Farms to Large Interconnected Offshore Grids

Risø, 26.02.2009

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advancing energy systems



Outline

(1) Introduction

(2) Model description

(3) Case study: German offshore scenario 2020

(4) Conclusion and outlook

Introduction

Operation and control of the electric power system including a high share of offshore wind energy.

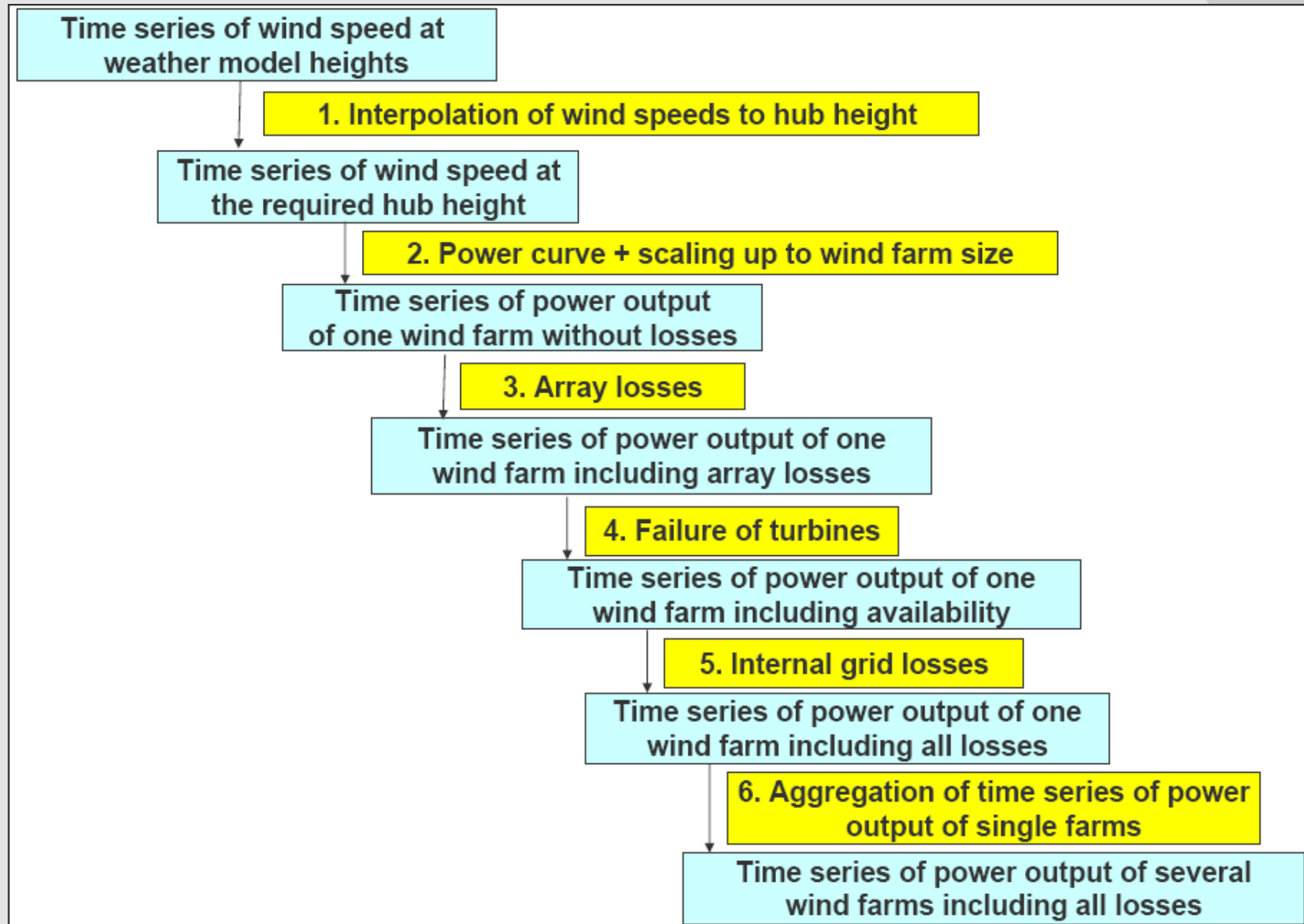
Important future challenges in reducing the feed-in fluctuations of distributed wind farms.

Adequate aggregated time series of future power feed-in are needed for the few offshore connection points

Investigations concerning ...

- **Simulation of power output from grouped offshore wind farms**
- **characteristics of short-term fluctuations depending on cluster size**

General method of time series generation



Case Study: **Future offshore wind power scenario in Germany**

Region: German North Sea and German Baltic Sea

Scenario: 20 GW of offshore wind farms

**Numerical weather model: local model of the German
Weather Service (DWD)**

Type of data: Analysis

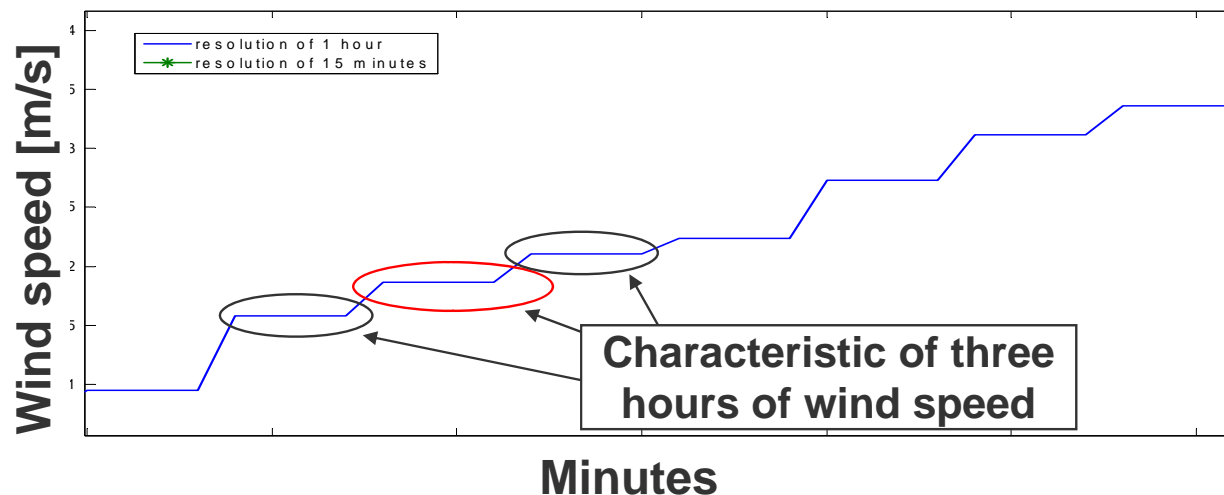
Spatial resolution: 7 x 7 km

Temporal resolution: 1 hour

Year: 2004-2007

Simulation of a wind speed time series with a temporal resolution of 15 min

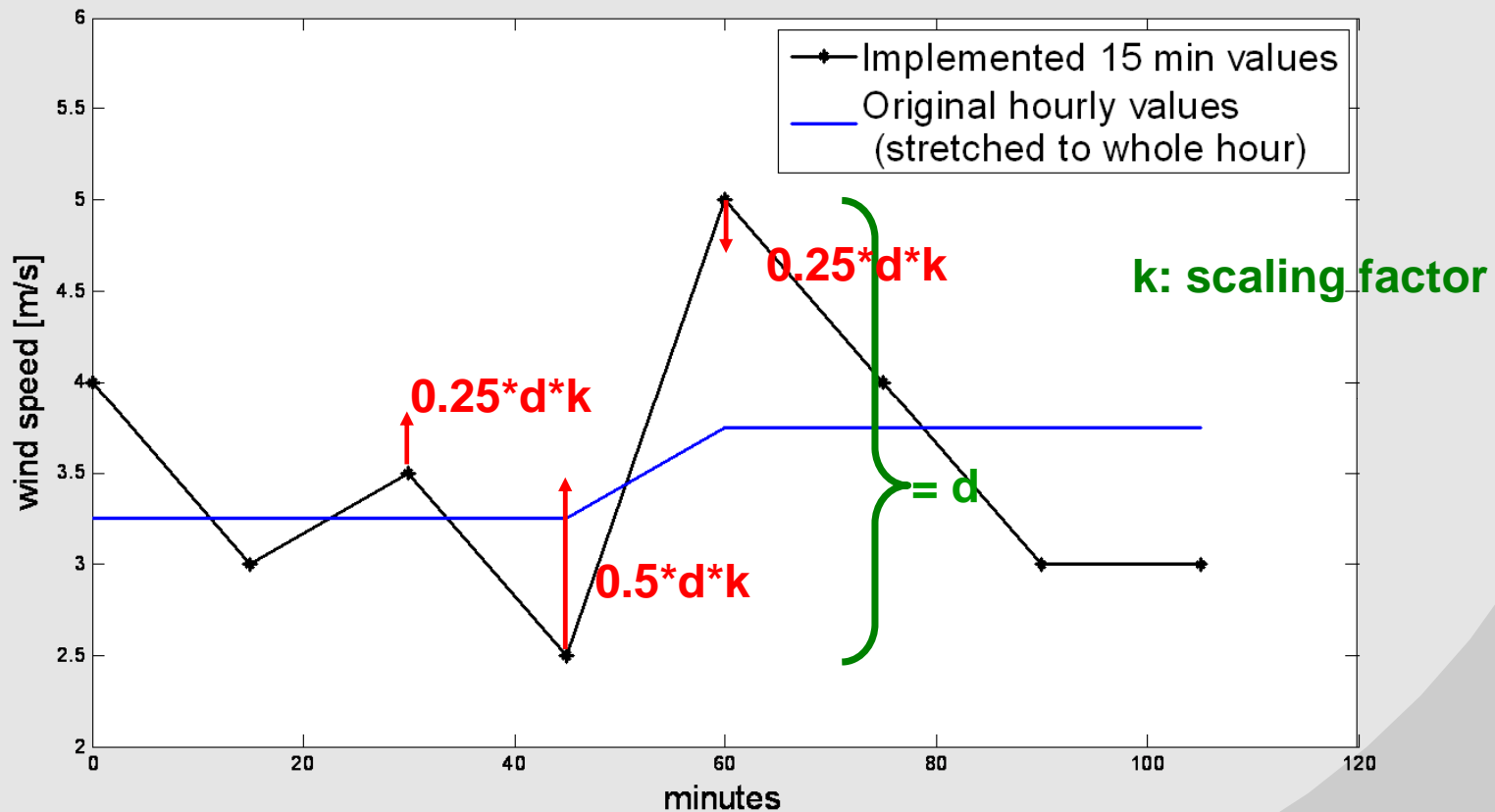
1. DWD model data have hourly resolution, but 15 min resolution needed for grid calculations
2. FINO 1 data are used to simulate a 15 min time series based on DWD hourly data
3. Transforming a single hourly value into four 15 minute values
 - Implementing 15min measurements when their average value (moving average) is (almost) equal to the hourly DWD value.
 - To avoid non-realistic dynamics, synchronous investigations of the previous and following hour



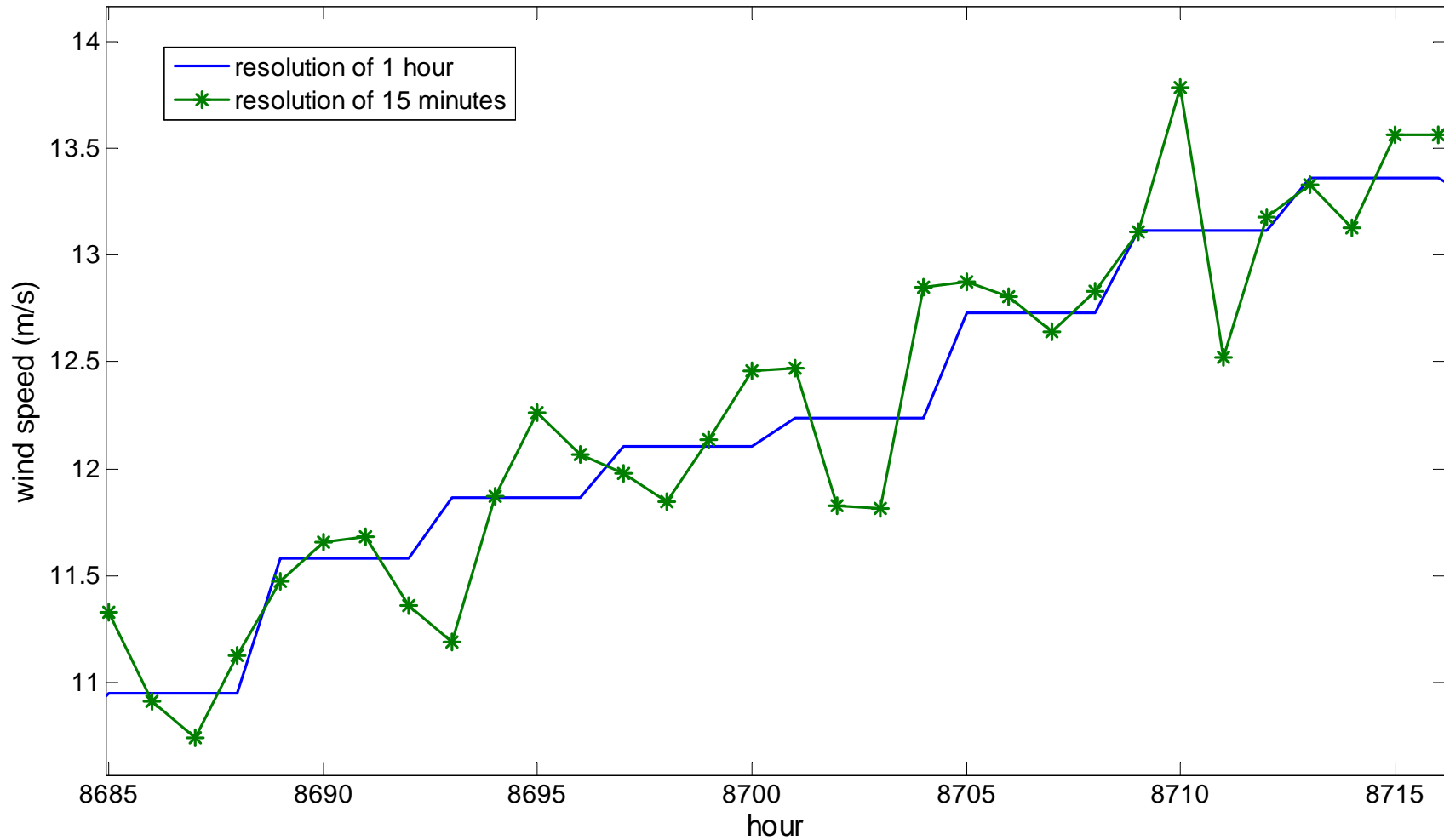
Challenge I

- Unrealistic fluctuations between the last and the first 15 min value of two subsequent hourly periods

→ “Trend”-smoothing, s.t. all fluctuations show same characteristics



Simulation of the time series with a resolution of 15 Minutes

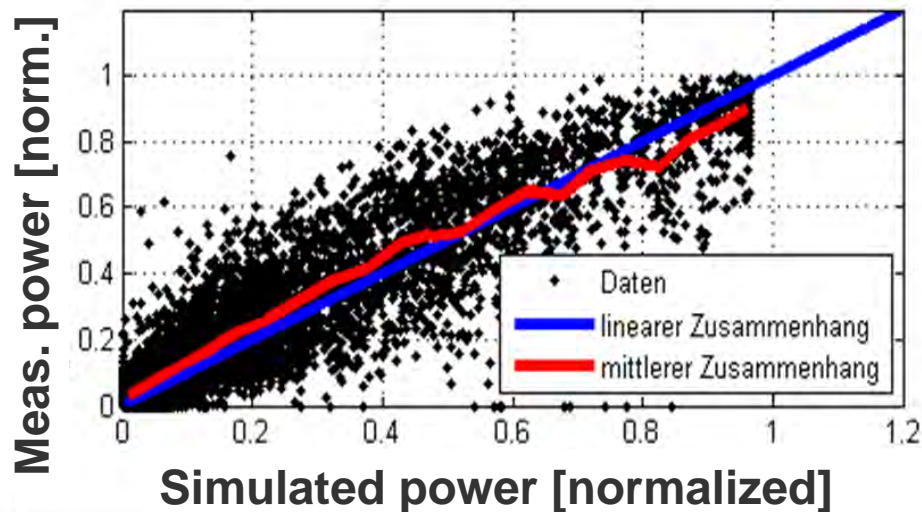
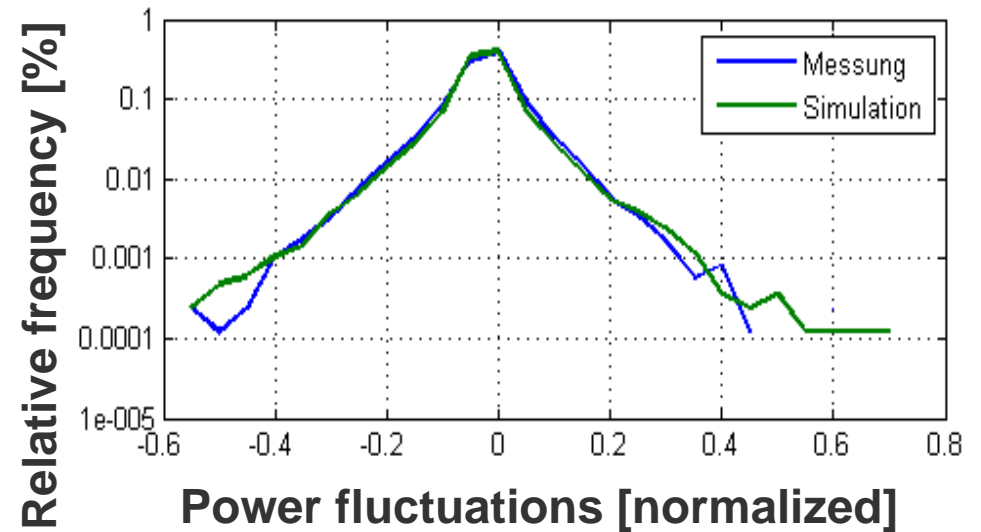
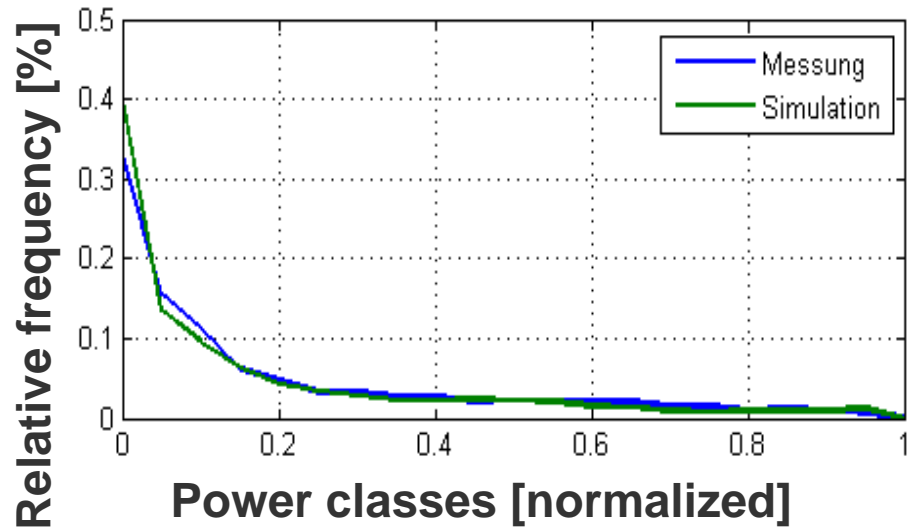


Challenge II

- a) Wind speed and the resultant wind power fluctuate more like an anemometer and not like a wind farm.
- b) No data of an offshore wind farm were available to investigate the power fluctuations and finally to validate the whole model.

- Using the model to simulate the power time series of an *onshore* wind farm using typical onshore parameters and wind measurements from the ISET wind measuring network.
- Development of a smoothing method (block average) for the implemented wind speed time series, s.t. the simulation shows the same characteristics as a large wind farm close to the shore.
- Validation of the whole model for onshore conditions.

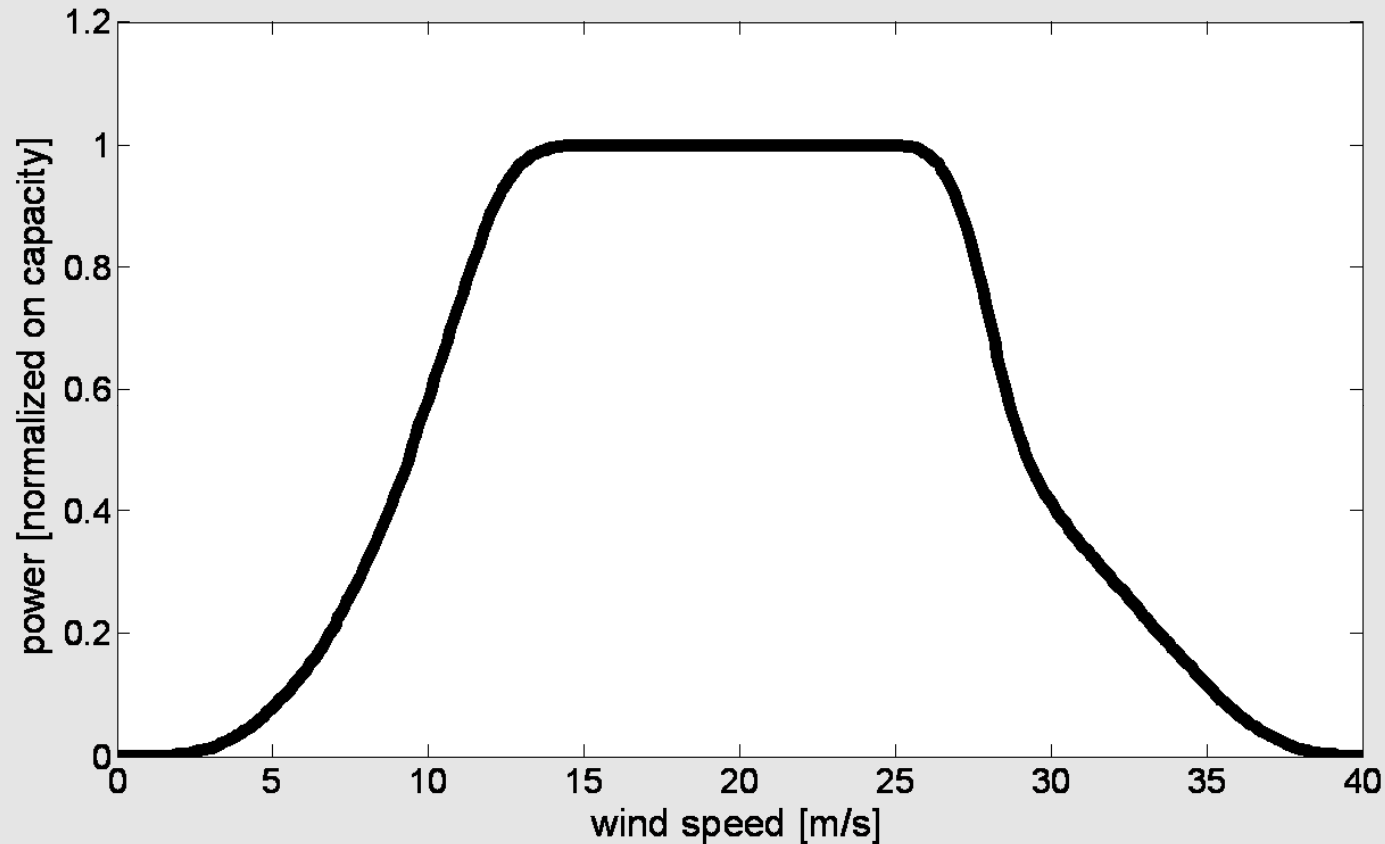
Validation of the whole model for onshore conditions



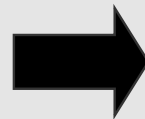
The simulation of onshore power time-series is satisfactory

Theoretical power curve for the scenario 2020

Combination of power curves with storm cut-out and power control

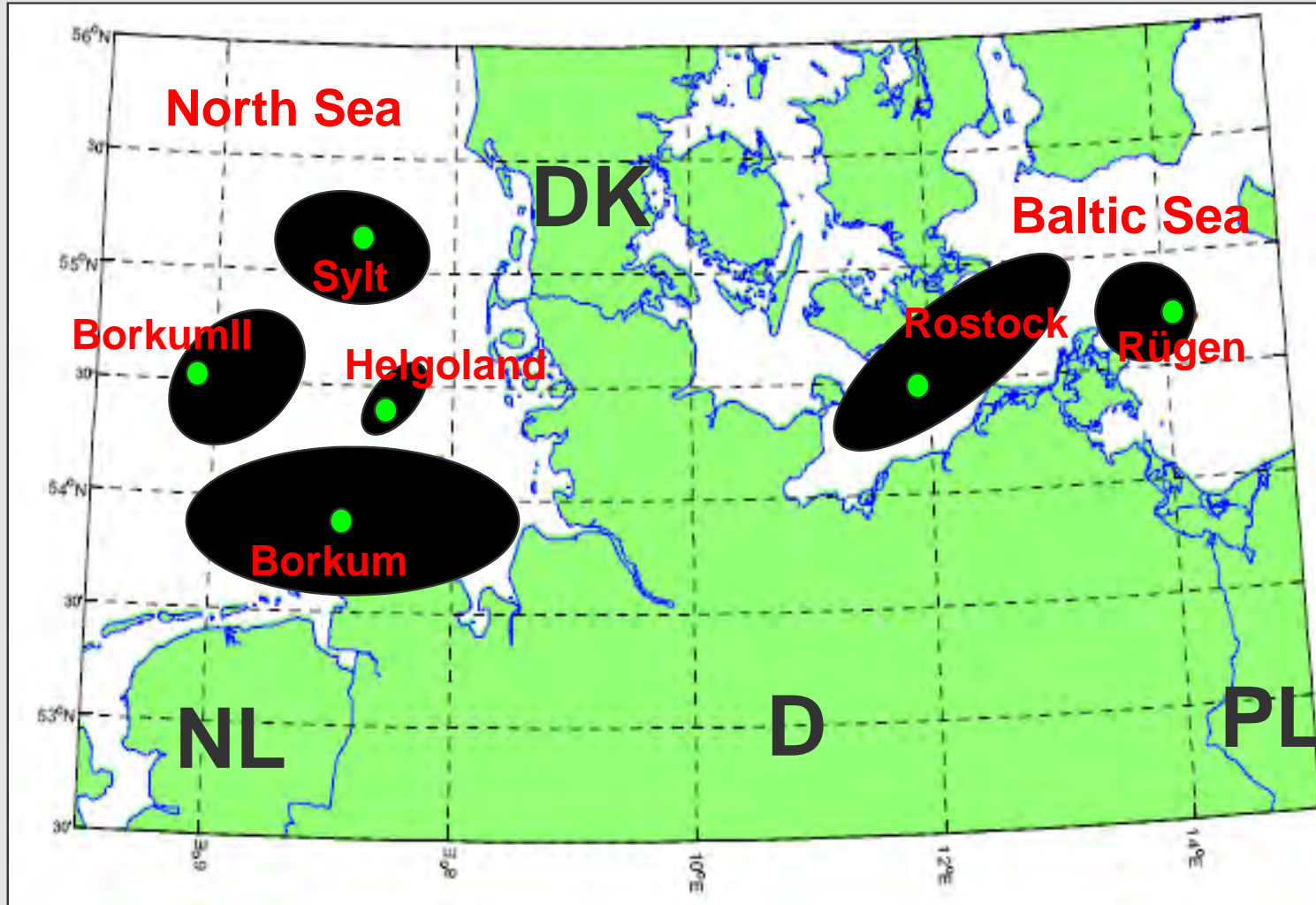


- Spatial distributed wind turbines
- 15 minute average wind speed values



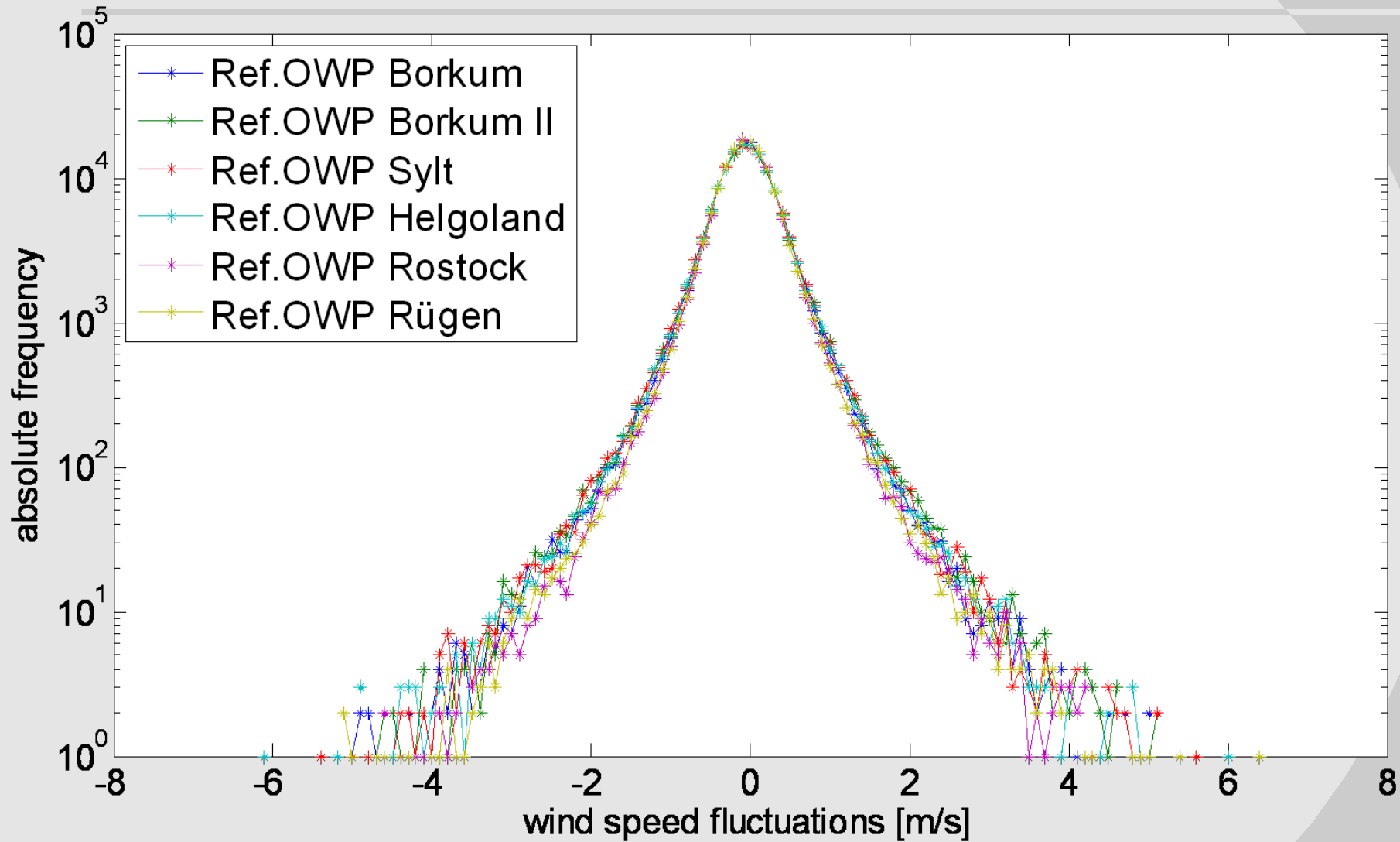
Smoothing of the power curve
using parameters gained from
onshore validation

Offshore Clusters



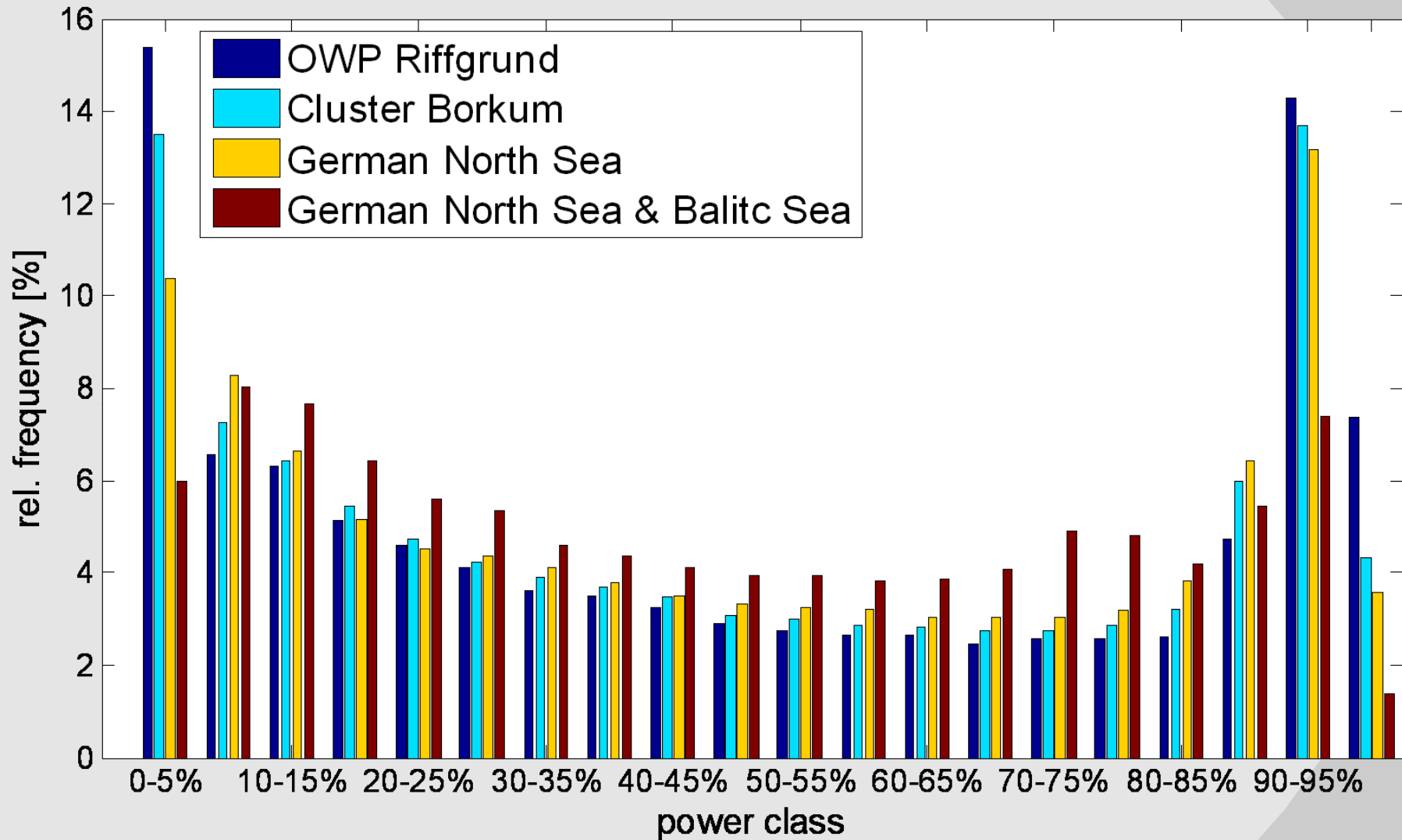
- Offshore-Cluster
- Reference-OWP

Wind speed fluctuations



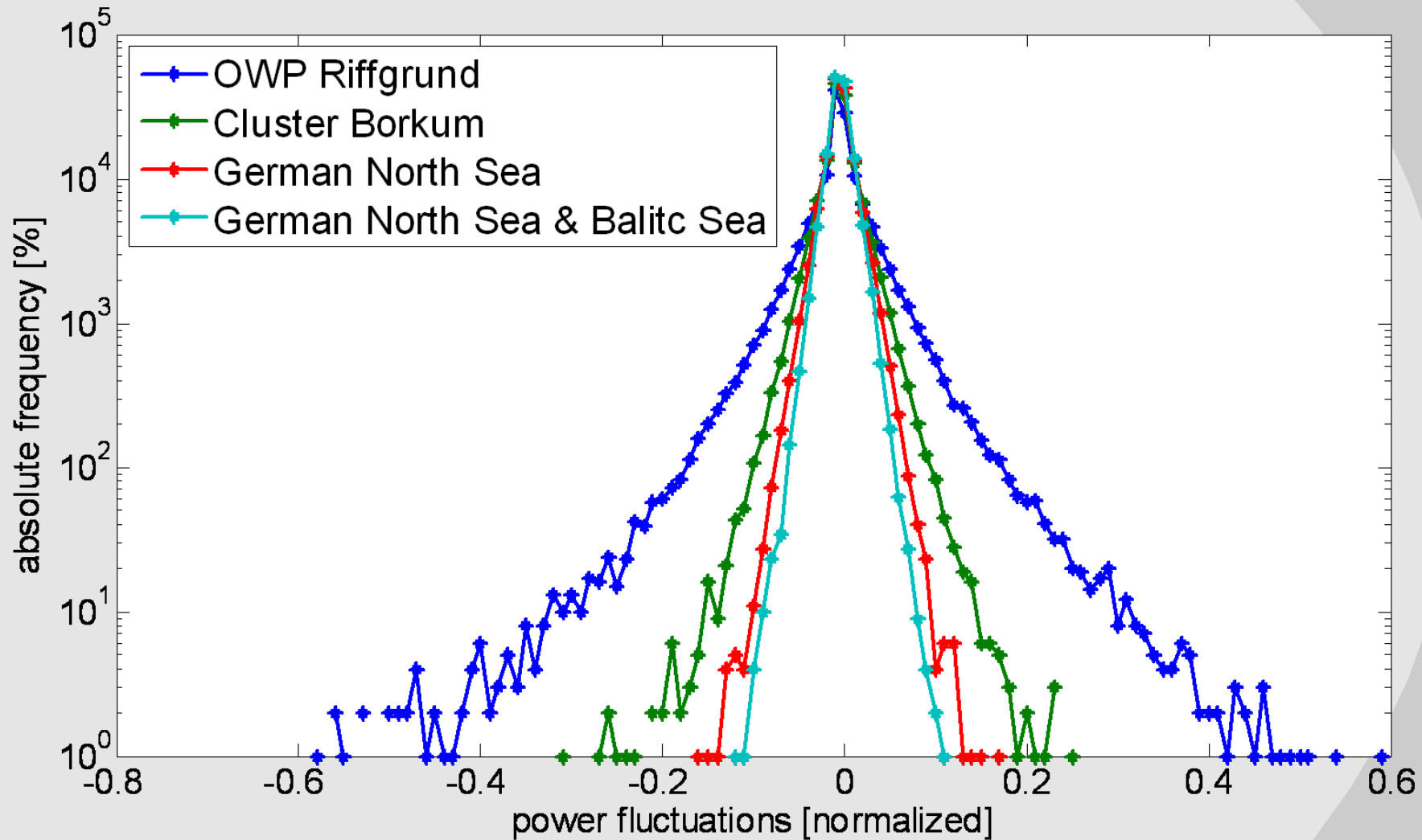
- ➔
- All wind speed time-series at the reference OWPs show similar characteristics.
 - Less fluctuation in the Baltic Sea but also significant part of highest fluctuations at the reference OWP of Cluster “Rügen” (further studies required)

Power histograms of clusters with different size



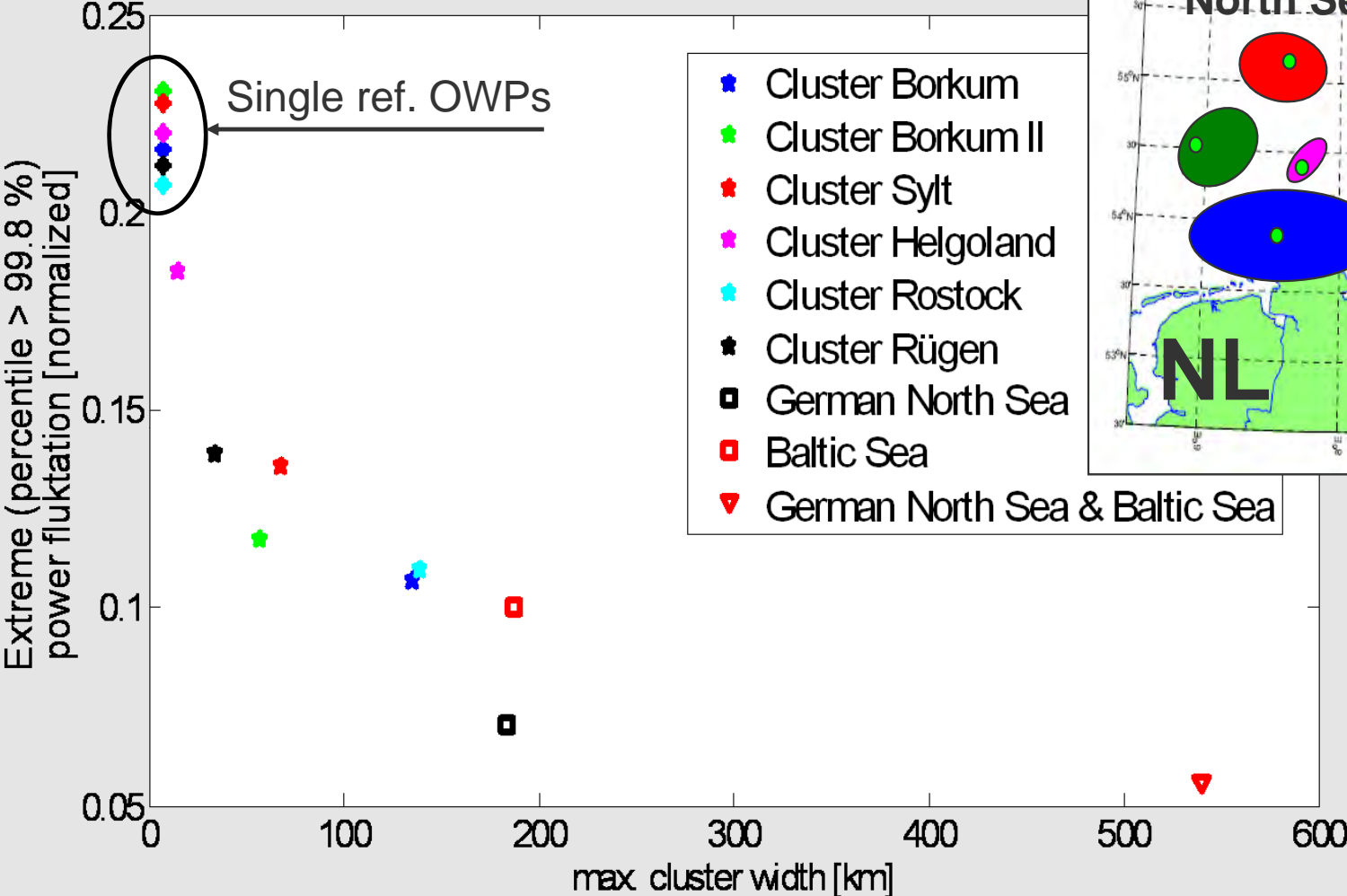
Smoothing effect clearly visible

Power fluctuations of clusters with different size

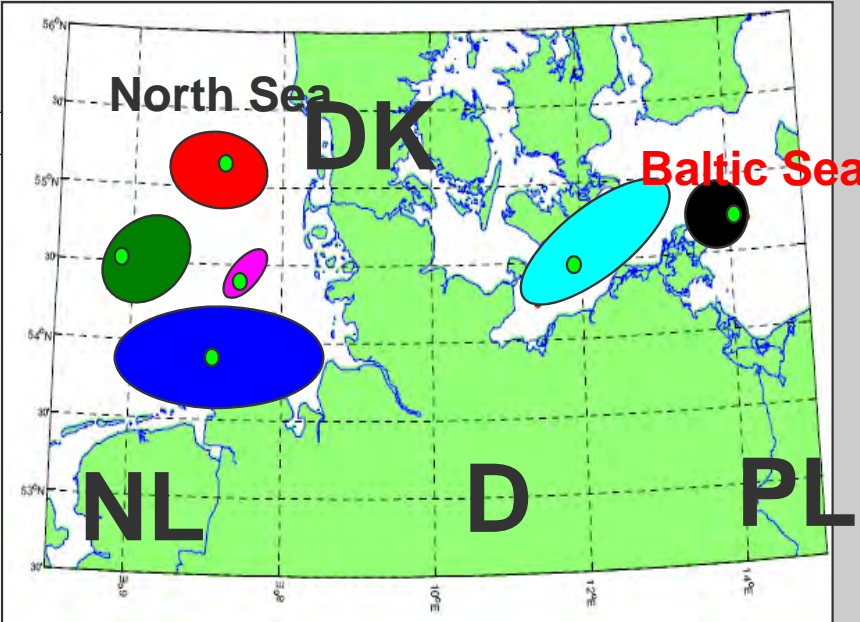


Power fluctuation decrease significantly with the cluster size

Extreme power fluctuations depending on the cluster size



- ★ Cluster Borkum
- ★ Cluster Borkum II
- ★ Cluster Sylt
- ★ Cluster Helgoland
- ★ Cluster Rostock
- ★ Cluster Rügen
- German North Sea
- Baltic Sea
- ▽ German North Sea & Baltic Sea



Conclusion & Outlook

- The whole model for the simulation of power time-series was validated and optimized using measured power time-series of large onshore wind farms.
 - Model performance is satisfactory but a final validation using offshore measurements has to be performed.

Statistics of regional power output:

- Grouping the wind farms in regional clusters up to the whole German North Sea leads to a minor change in statistics of power output.
- Grouping all OWPs in North Sea and Baltic Sea leads to a significant smoothing of the whole power distribution.

Short-term power fluctuations:

- Short term fluctuations were reduced drastically by the grouping of wind farms.



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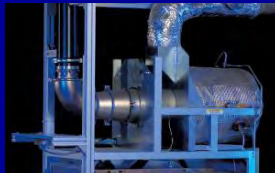
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Thank you for your attention

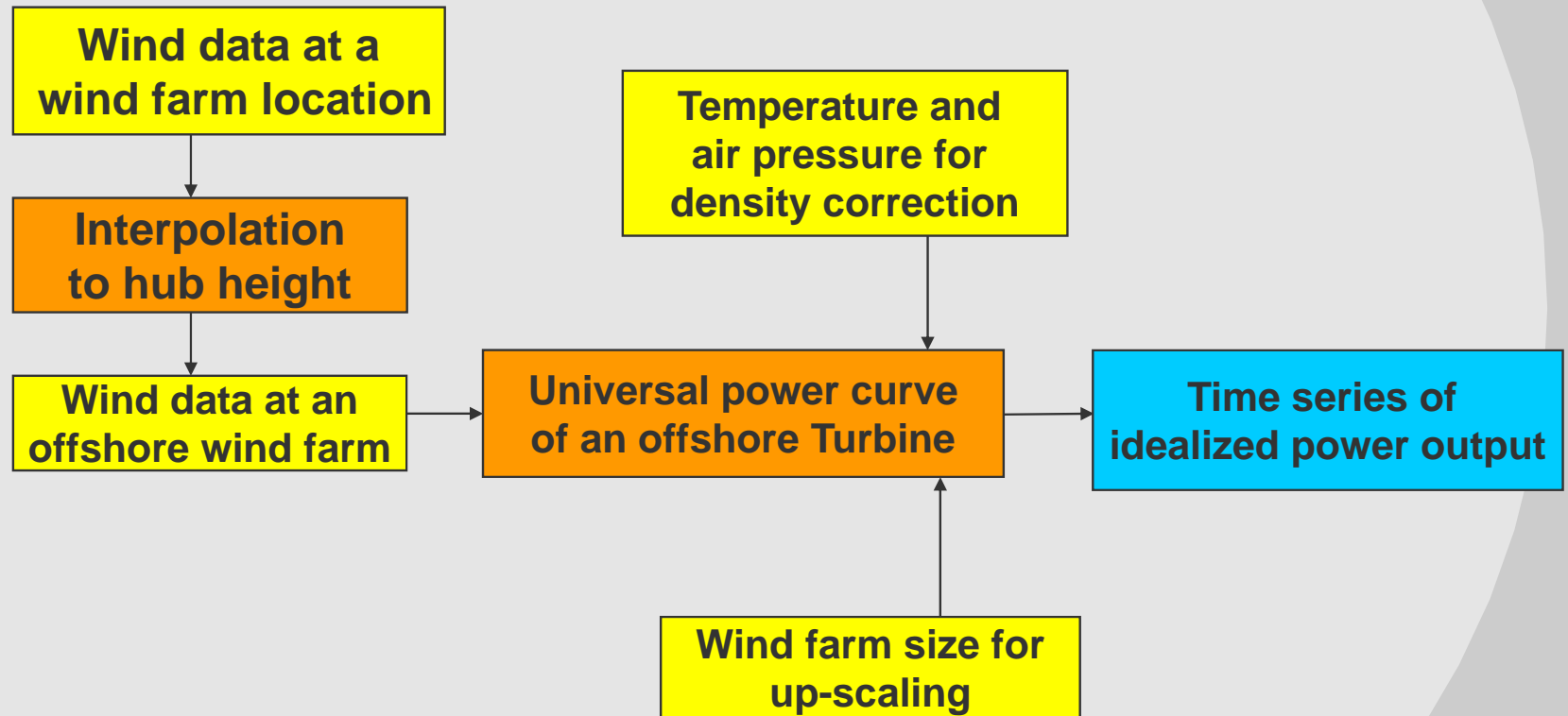
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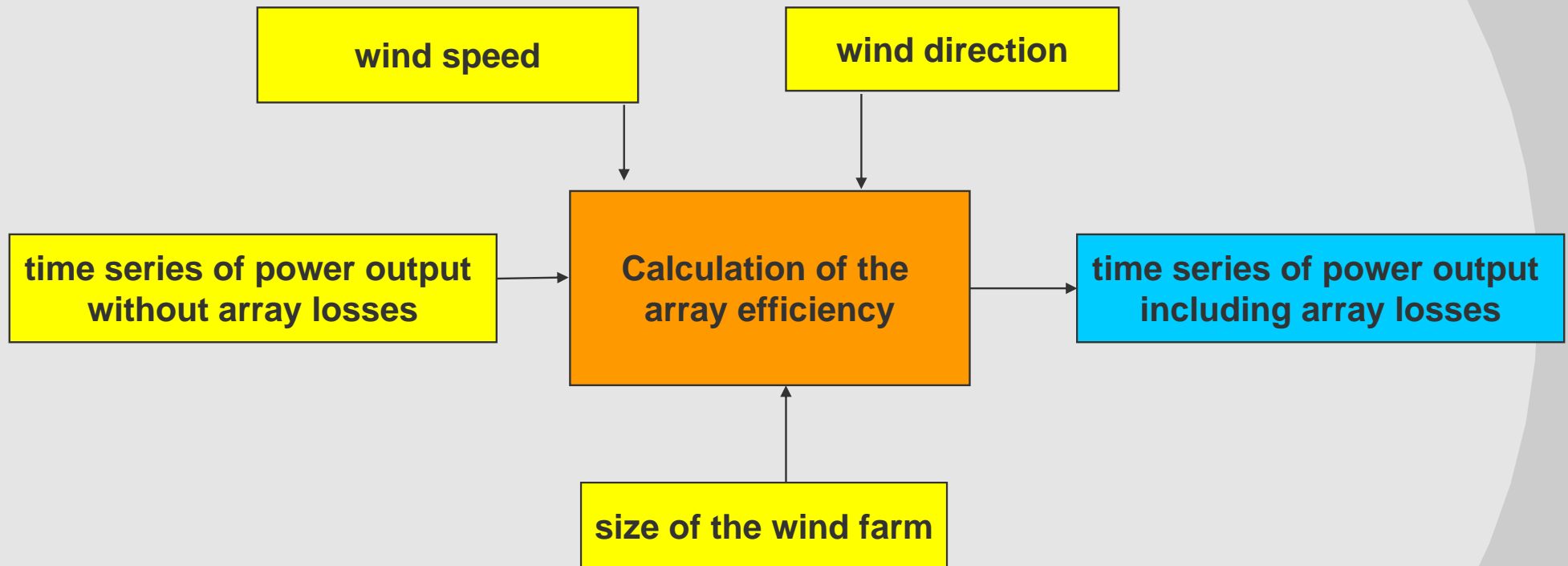


- BACKUP -

Conversion of wind speed into power



Calculation of time series including the array efficiency



Calculation of the array efficiency using the Farm Layout Program

Calculation using Farm Layout Program (FLaP)

Universal wind farm layout for different wind farm sizes

Number and position of turbines (squared alignment with a distance of 7 rotor diameters)

All turbines have the same thrust curve

5 MW turbine

The number of turbines depend on nominal power

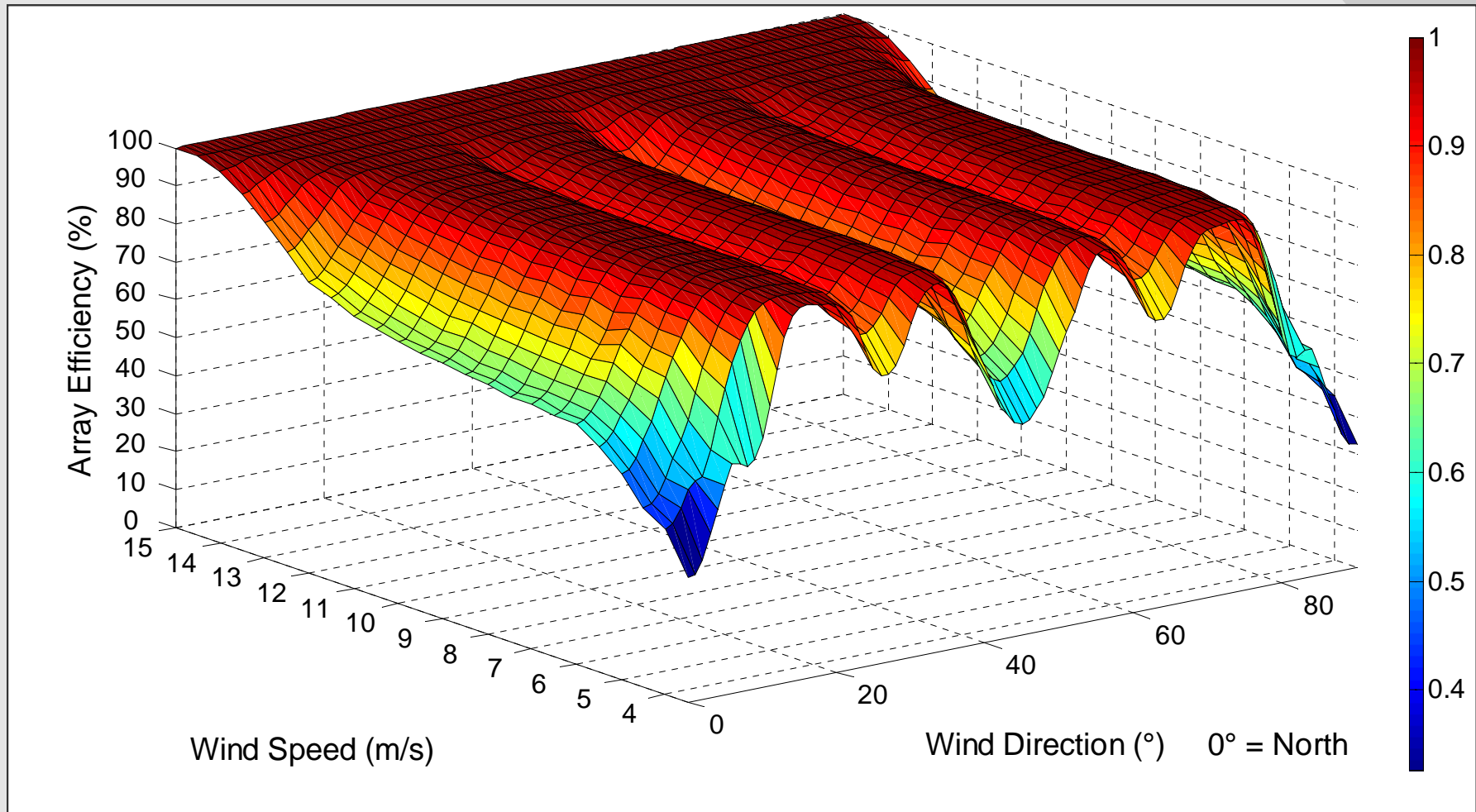
Ambient condition

Constant ambient turbulence of 4 %

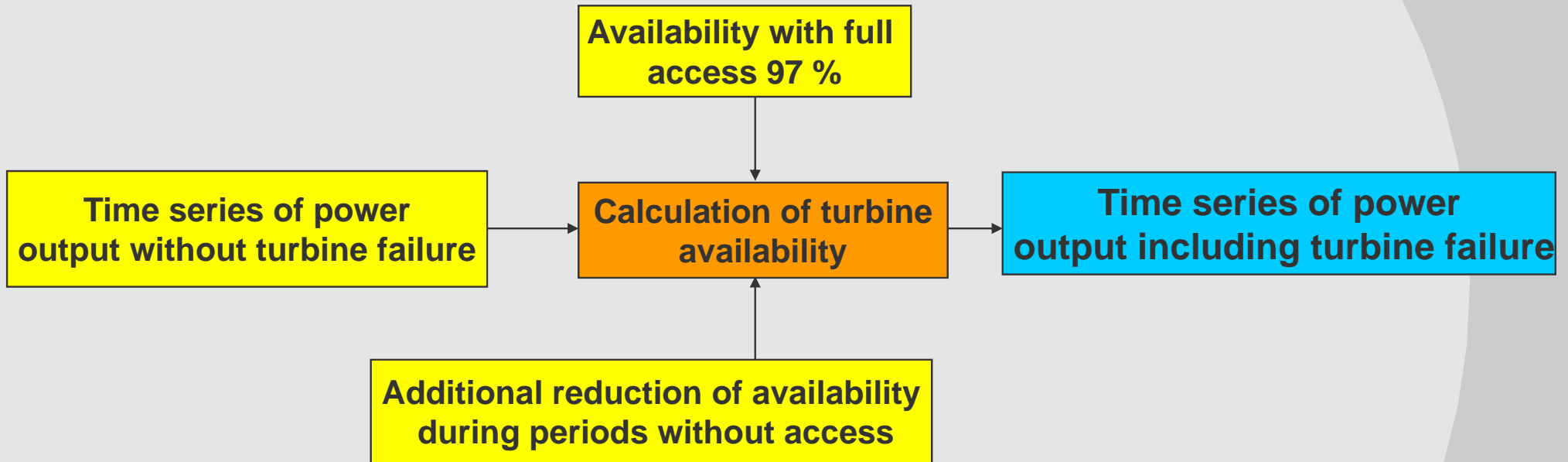
Output:

Array efficiency for different wind farm sizes depended of the wind speed and direction

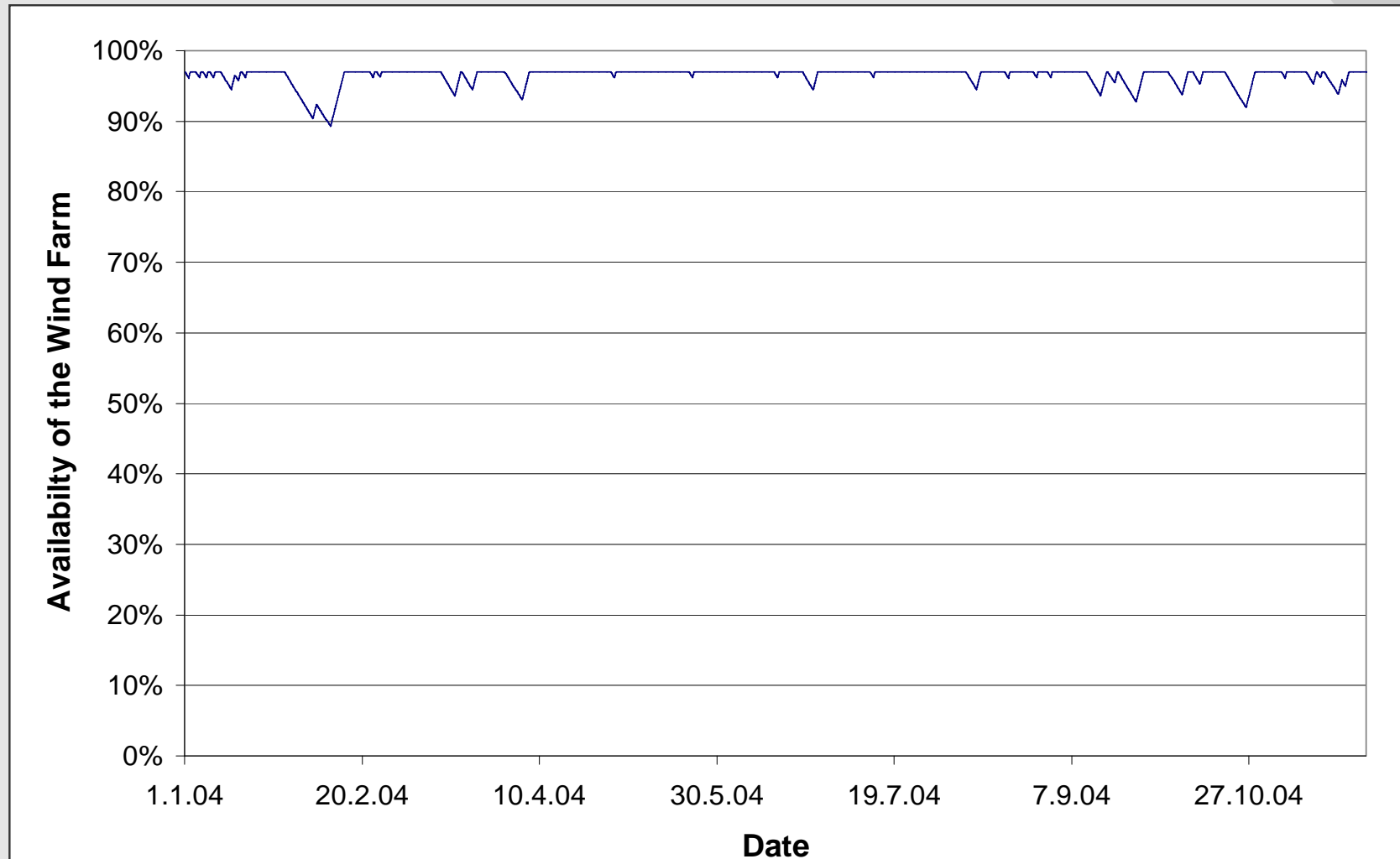
Example of array efficiency of an offshore wind farm (10 Turbines)



availability of turbines



Simulated time series of the availability of an offshore wind farm from January to November 2004



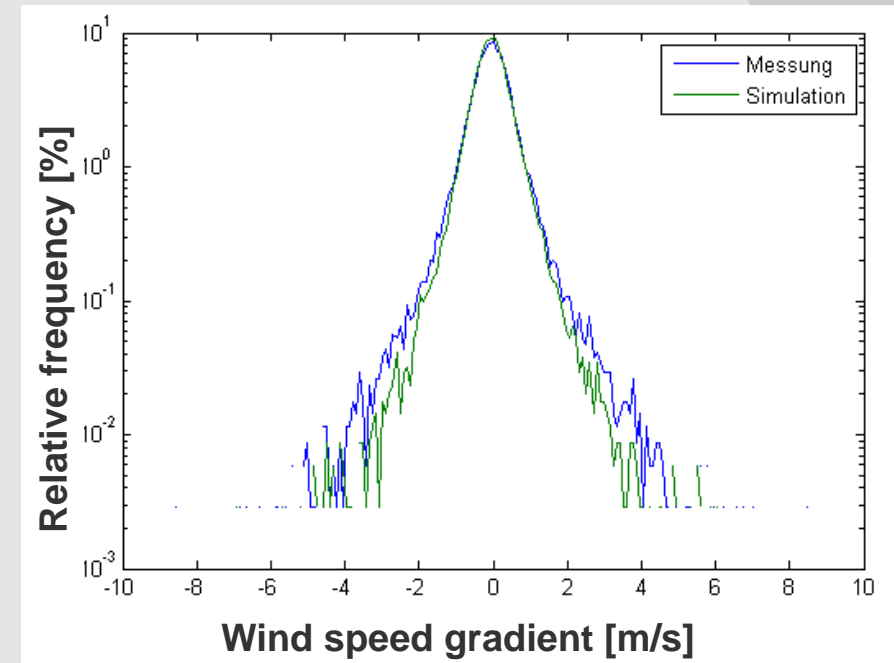
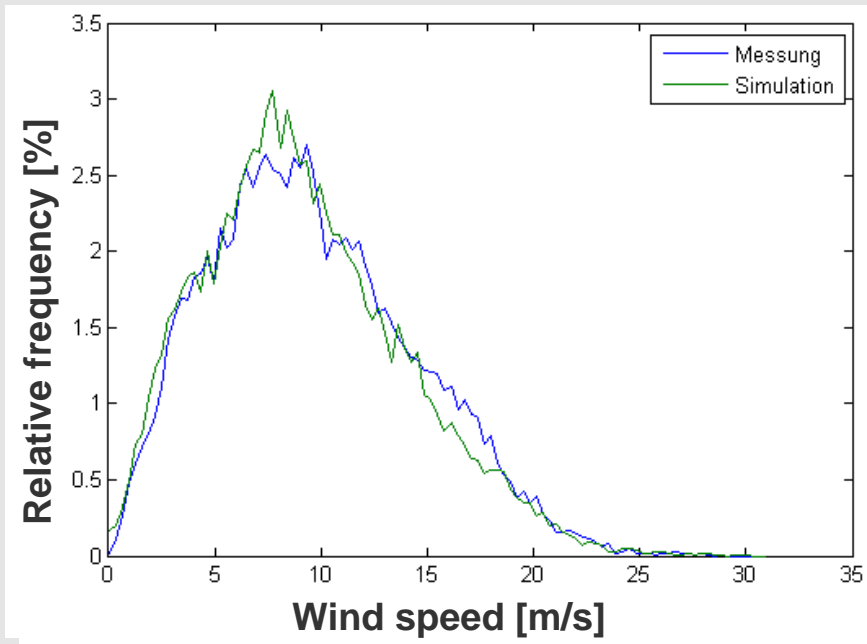
Calculation of the power output of a group of offshore wind farms

$$P_{group}(t) = \sum_{i=1}^n P_{wf,i}(t) \cdot c_{de,i}(t) \cdot c_{ar,i}(t) \cdot c_{av,i}(t) \cdot c_{el}$$

- P_{group}** = power output of a group of n wind farms
- P_{wf}** = idealized power output of one wind farm
- C_{de}** = correction factor for the air density
- C_{ar}** = correction factor for the array efficiency
- C_{av}** = correction factor for the unavailability of turbines
- C_{el}** = constant correction factor of 99.5 % for the electrical losses within the wind farm

Validation of the simulated 15-min. time-series

Comparison of FINO1 measurements with simulated time series at OWP alpha ventus



Simulated time-series include more times with lower wind speeds and also smaller fluctuations.

→ Underestimation of final wind power

But note: the procedure is based on DWD analysis data