Wind Power Prediction for Power System Operation

Arne Wessel, Jan Dobschinski, Bernhard Lange

GTZ-TERNA Expert Workshop 2009:
Grid and System Integration of Wind Energy

© Fraunhofer IWES

Fraunhofer IWES

OUTLINE

- Problems of integration of wind power
- Principles of wind power prediction methods
- Dayahead- and shortest term forecast
- Use of wind power prediction in Germany
- Importance of numerical weather predictions
- Spatial forecast error smoothing of wind power prediction
- Illustration and evaluation of forecast quality
- Confidence intervals of wind power forecast
- Wind park cluster management
- Research activities

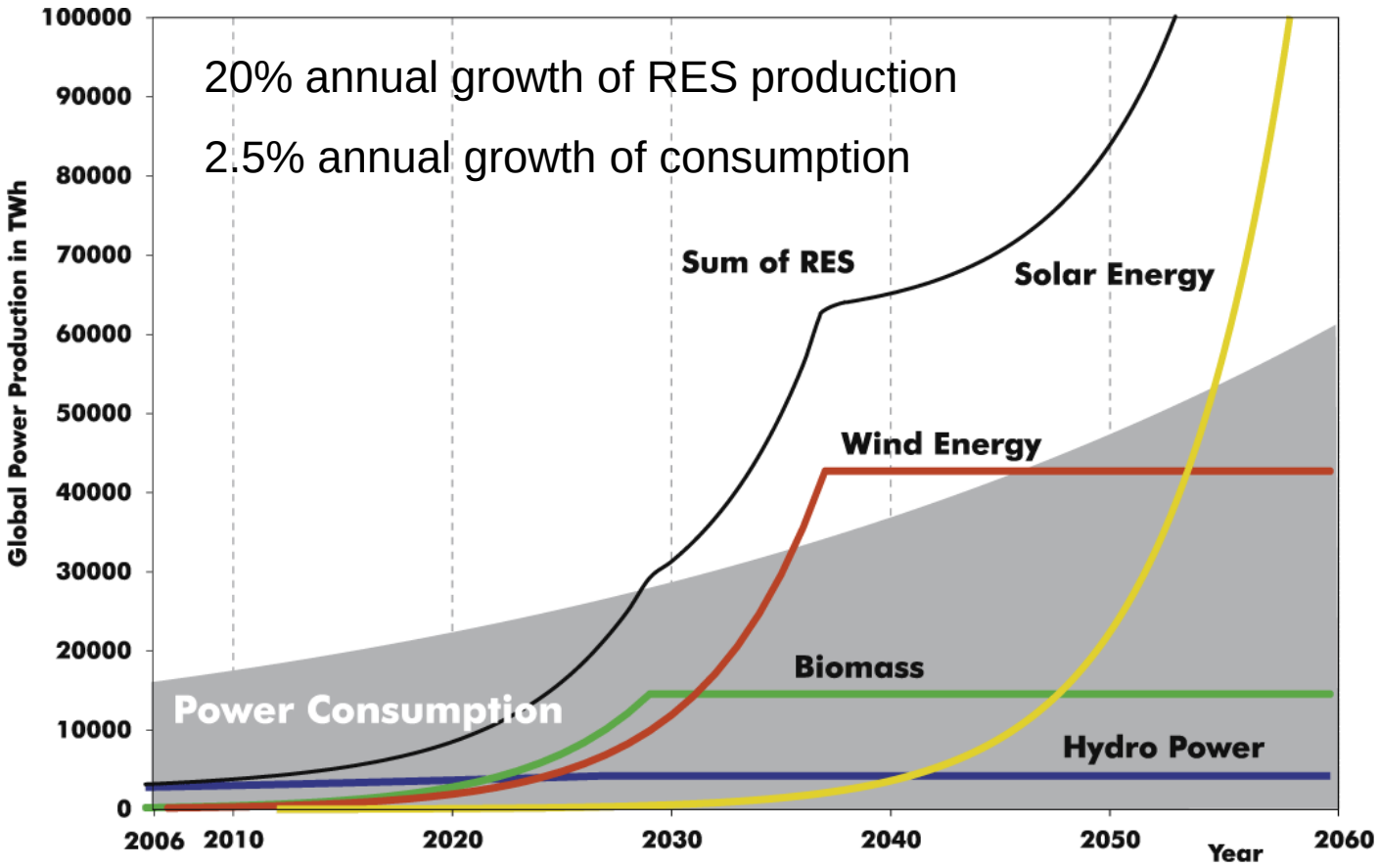
© Fraunhofer IWES

OUTLINE

- Problems of integration of wind power
- Principles of wind power prediction methods
- Dayahead- and shortest term forecast
- Use of wind power prediction in Germany
- Importance of numerical weather predictions
- Spatial forecast error smoothing of wind power prediction
- Illustration and evaluation of forecast quality
- Confidence intervals of wind power forecast
- Wind park cluster management
- Research activities

© Fraunhofer IWES

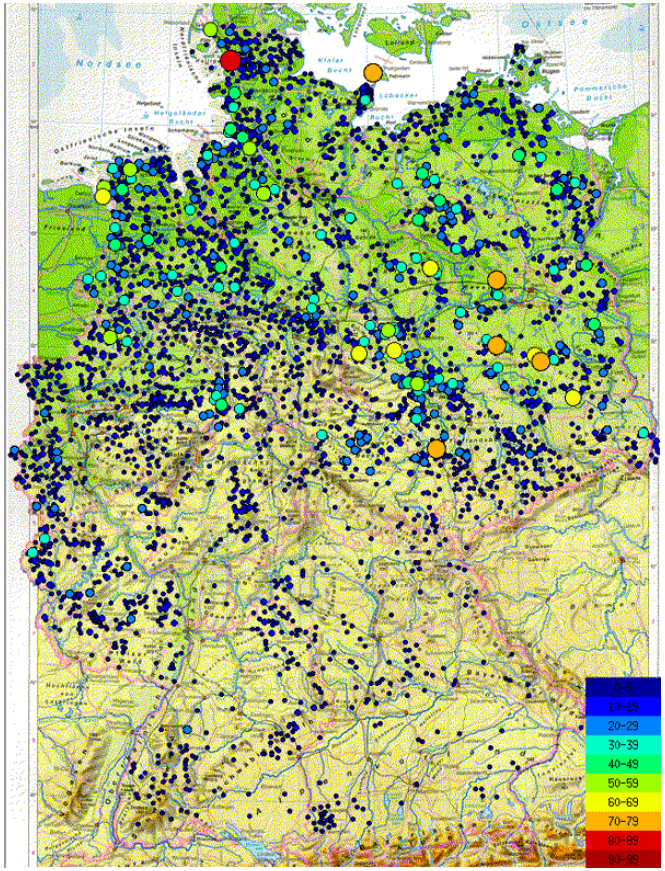
Problems of the integration of wind power



© Fraunhofer IWES

Fraunhofer IWES

Problems of the integration of wind power



Wind Energy Use
in Germany

23.500 MW
20.000 WT

as of 12/2008

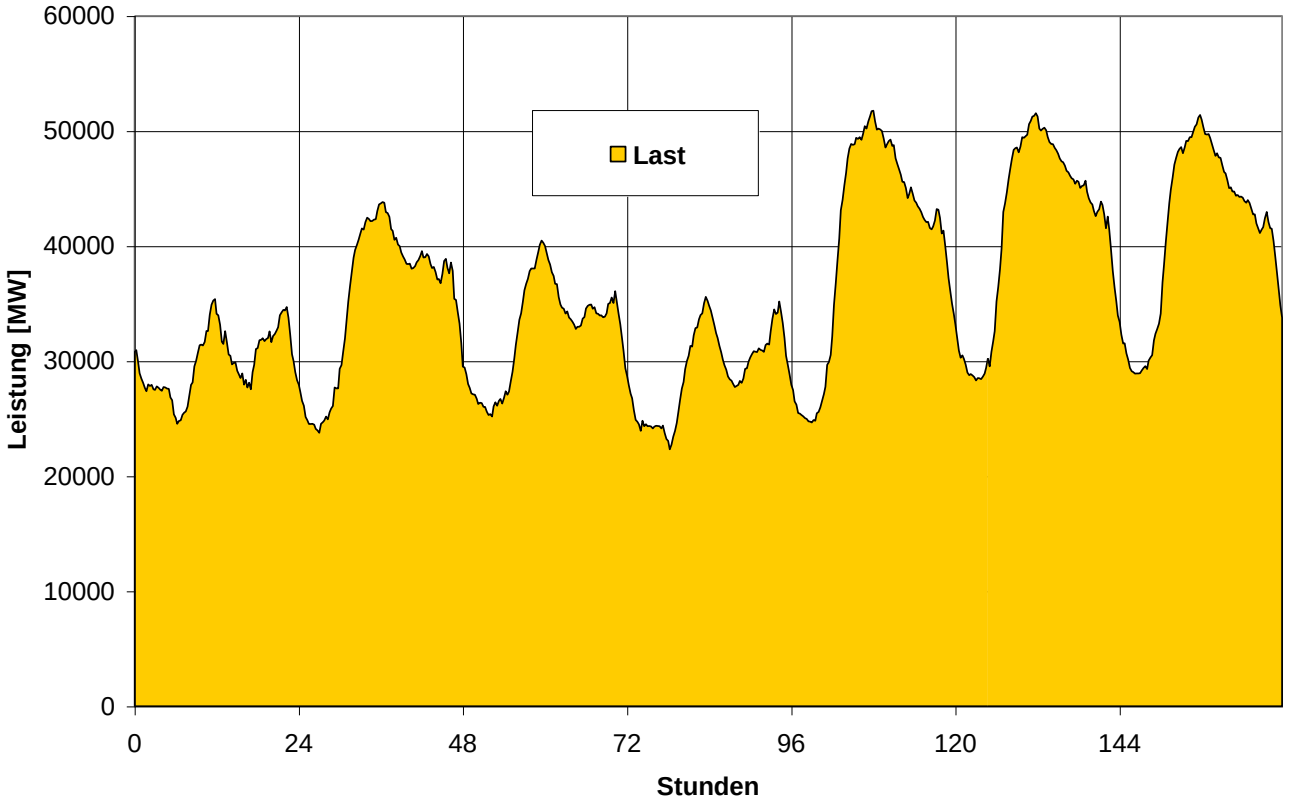
Energy Production

26.4 TWh in 2005 - Wind Index 89 %
30.3 TWh in 2006 - Wind Index 90%
39.0 TWh in 2007 - Wind Index 106%
40.5 TWh in 2008 - Wind Index 100%

© Fraunhofer IWES

Fraunhofer IWES

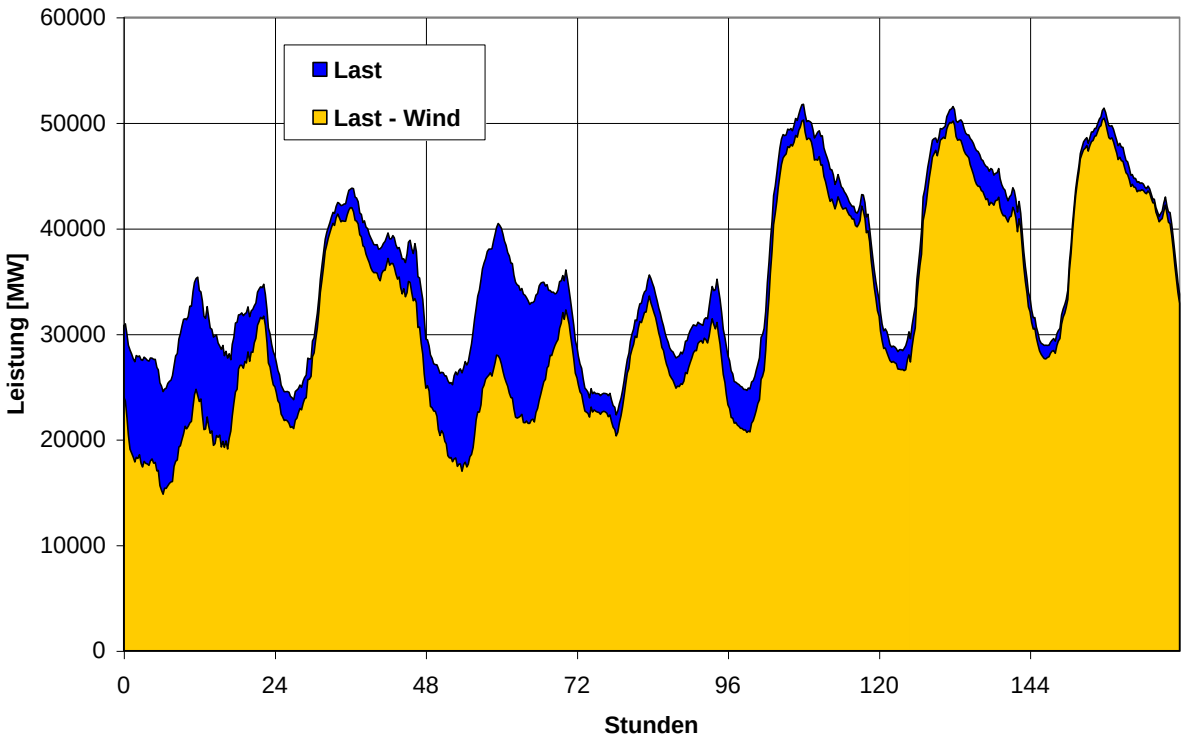
Problems of the integration of wind power



© Fraunhofer IWES

Fraunhofer IWES

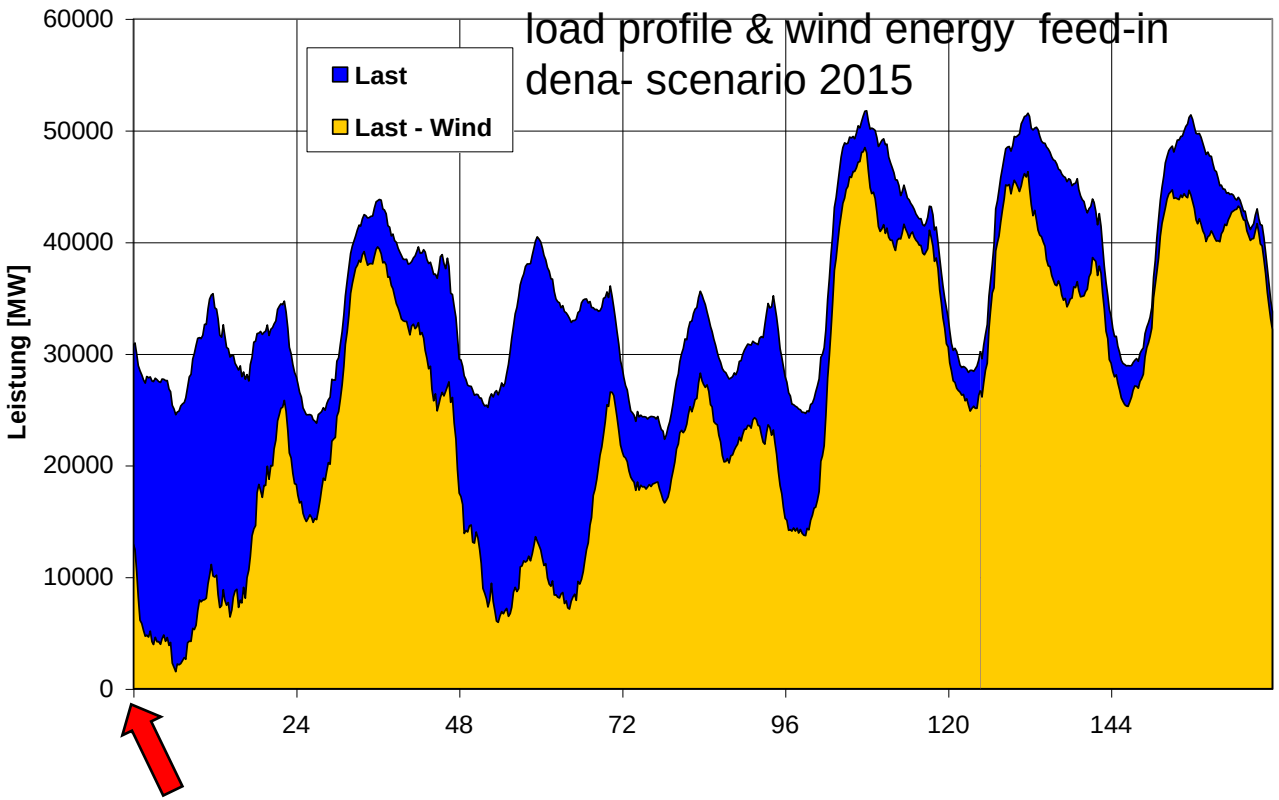
Problems of the integration of wind power



© Fraunhofer IWES

Fraunhofer IWES

Problems of the integration of wind power



Nearly no feed in of conventional power plants
=> Network control (frequency, voltage control, ...) is necessary

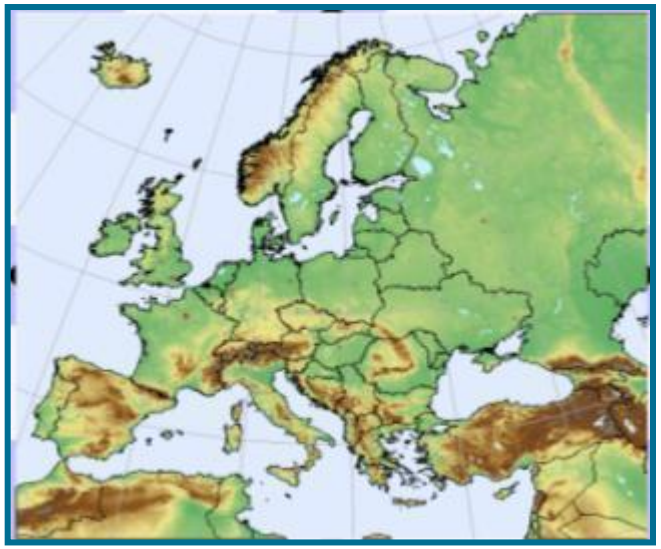
© Fraunhofer IWES

Fraunhofer IWES

Problems of the integration of wind power

A complete coverage of the power requirements by wind power will be expected in Germany for 2015-2020

Goal for Europe: 12%-14% wind power 2020, 25% in 2030

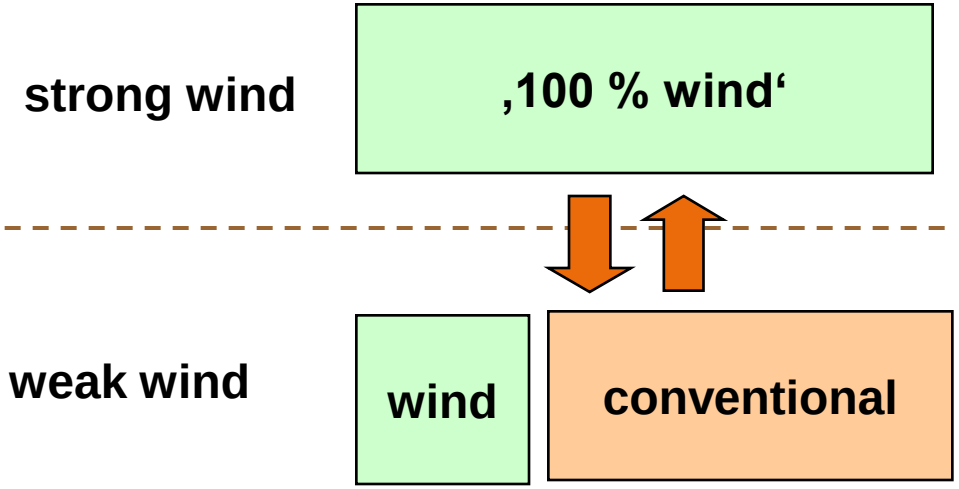


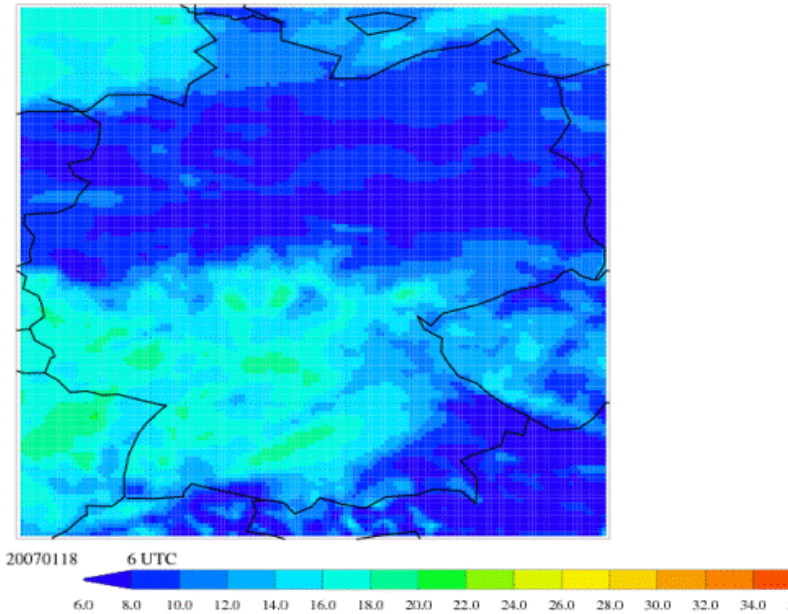
- High challenges for the network planning and system integration

© Fraunhofer IWES

Fraunhofer IWES

Problems of the integration of wind power





- For wind power a discrepancy between production in space and time exists
- The power plant ‚wind turbine‘ changes his capabilities depending on the weather situation

© Fraunhofer IWES

Fraunhofer IWES

Challenges in integration of wind energy in the electrical network

Integration of wind energy in the electrical networks needs a complete rethinking of the energy system technology

- Operation
  - **system management (backup power, reserve energy, power control, short circuit handling, …)**
  - **market integration (adaption of the generation planning and prediction of consumption)**

- Planning
  - **planning of the electrical network (transport capacities)**
  - **planning of energy system (power plants, storage, transport, load management, …)**

© Fraunhofer IWES

Energy meteorological methods and instruments

system management	online monitoring and (shortest-term)-forecast of wind power
market integration	forecast of wind power
power system planning	wind power feed-in for every single network node for future scenarios
energy system planning	characterization of the wind power modeling of the space-time variablility model calculation for future energy systems

© Fraunhofer IWES

Fraunhofer IWES

OUTLINE

- Problems of integration of wind power
- Principles of wind power prediction methods
- Dayahead- and shortest term forecast
- Use of wind power prediction in Germany
- Importance of numerical weather predictions
- Spatial forecast error smoothing of wind power prediction
- Illustration and evaluation of forecast quality
- Confidence intervals of wind power forecast
- Wind park cluster management
- Research activities

© Fraunhofer IWES

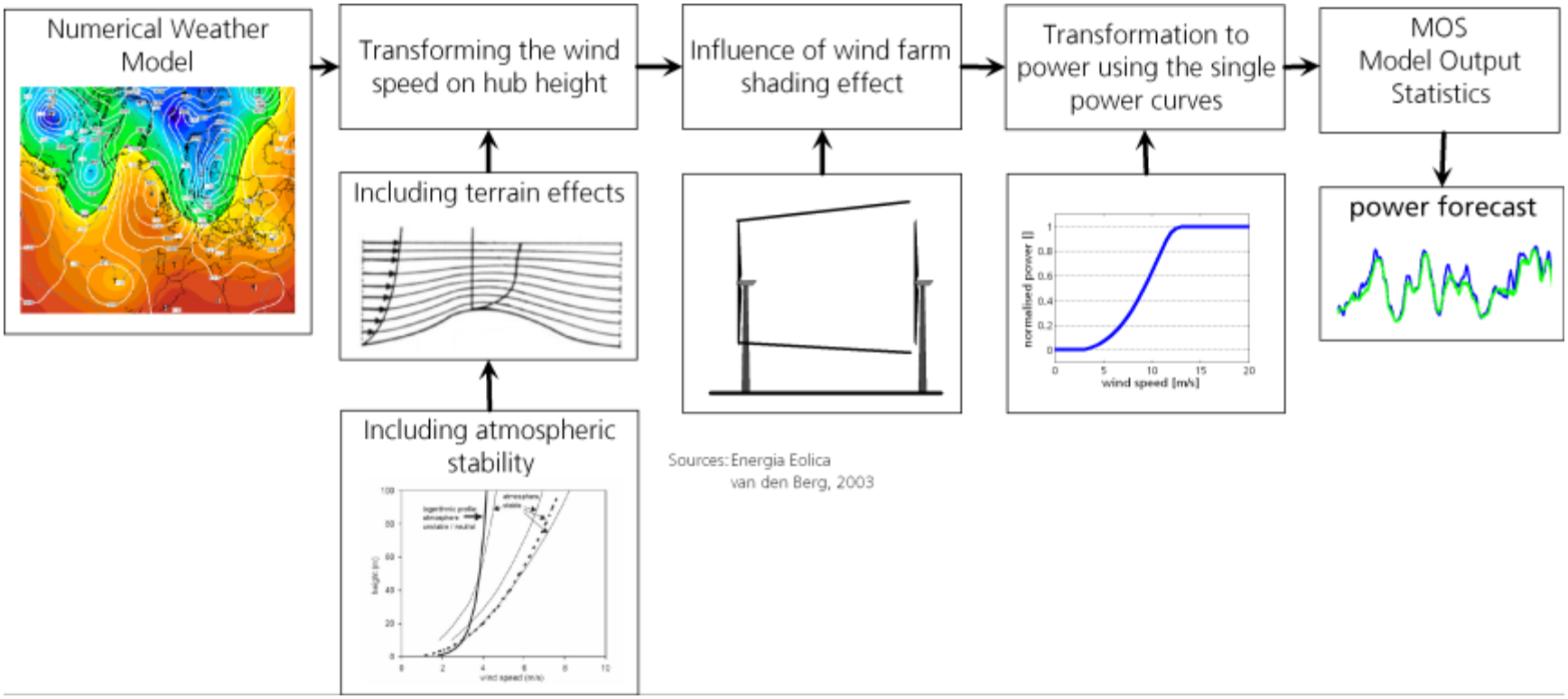
Approaches for Wind Power Forecast

- Modeling the interrelation between weather forecast and power production

- physical models use physical parameterizations
  - modeling of the wind farm
  - transformation of forecasted wind speed to hub height
- statistical models use historical measured data in combination with statistical approaches
  - methods of artificial intelligence (AI) ‘learn’ the relationship based on historical measured data

© Fraunhofer IWES

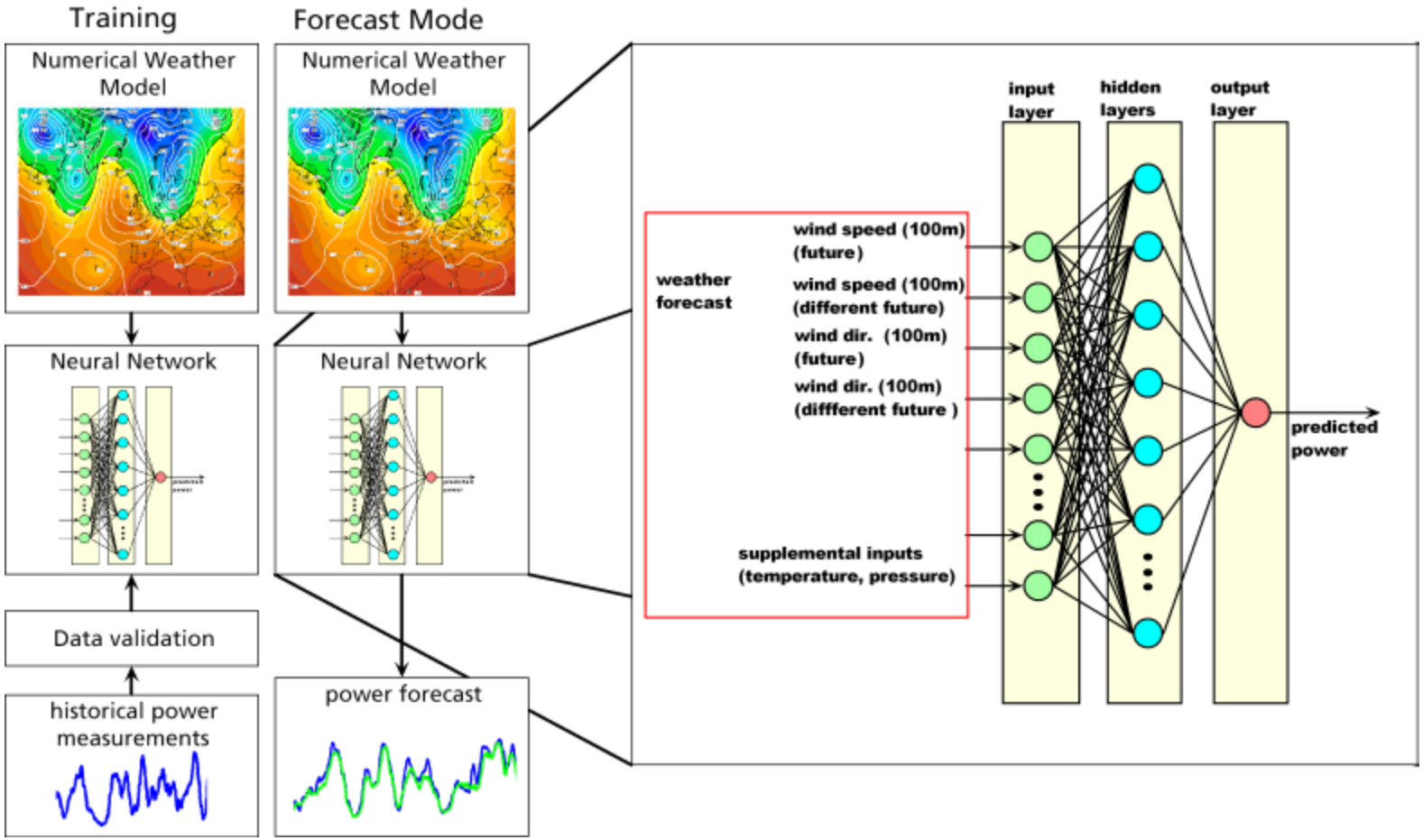
The physical approach



© Fraunhofer IWES

Fraunhofer IWES

The statistical approach – The Neural Network



© Fraunhofer IWES

Fraunhofer IWES

Ad- and Disadvantages of the Different Forecast Approaches

Statistical and AI-Methods

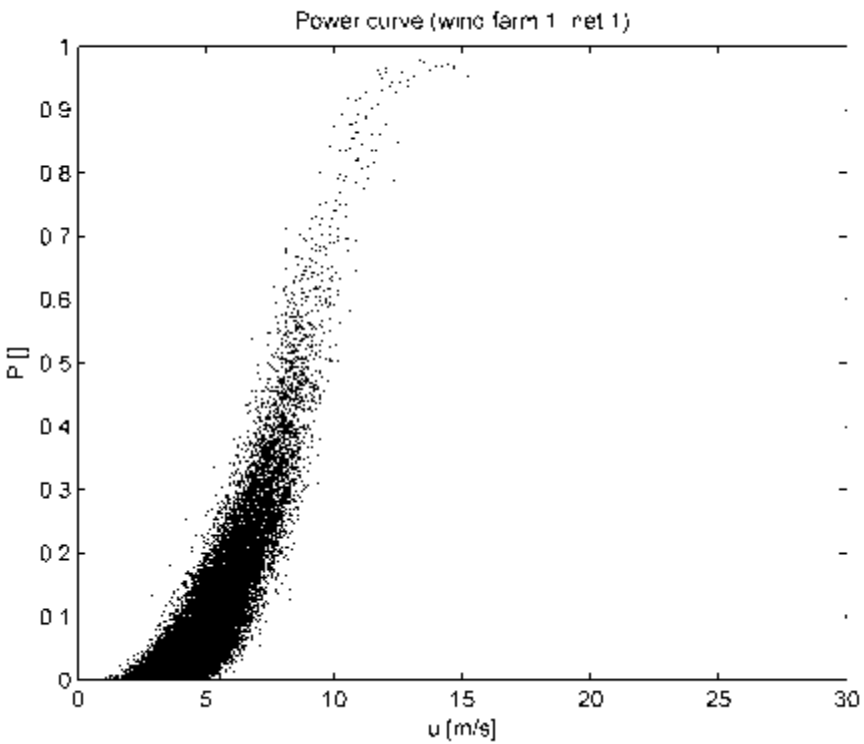
+	no detailed physical information needed
+	fast calculation
-	depends on premium historical power data
-	uncertainty at new or seldom situations

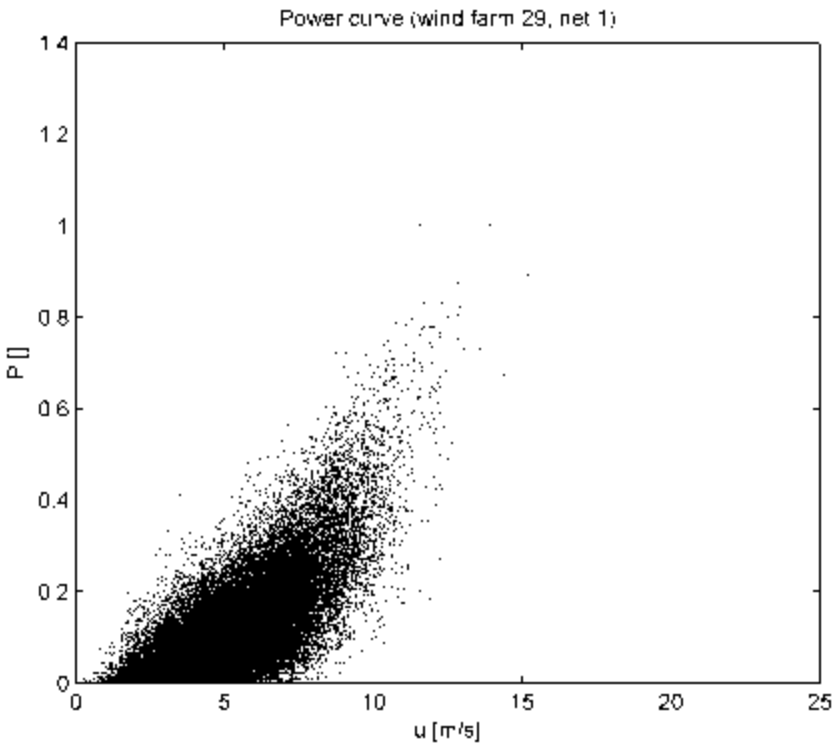
Physical Methods

+	Quality and amount of measured data a second order
-	Detailed information about wind farm and surrounding necessary
-	large efforts for building the model

© Fraunhofer IWES

Wind farm power curve

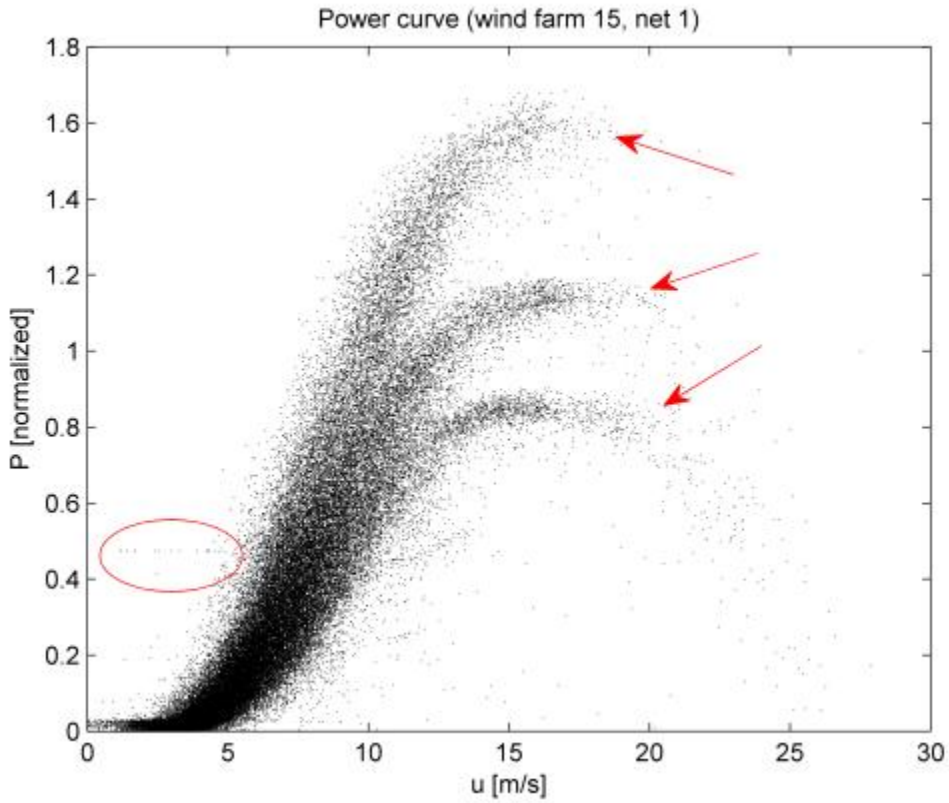




© Fraunhofer IWES

Fraunhofer IWES

Error interpretation – Wind farm power curve



© Fraunhofer IWES

Fraunhofer IWES

OUTLINE

- Problems of integration of wind power
- Principles of wind power prediction methods
- Dayahead- and shortest term forecast
- Use of wind power prediction in Germany
- Importance of numerical weather predictions
- Spatial forecast error smoothing of wind power prediction
- Illustration and evaluation of forecast quality
- Confidence intervals of wind power forecast
- Wind park cluster management
- Research activities

© Fraunhofer IWES

Day Ahead and Shortest Term Forecast

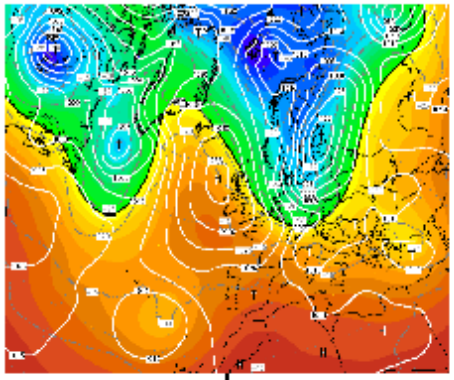
- **Day-Ahead Forecast (DAF)**
- Forecast horizon up to 96h
- Updated normally once or twice a day
- Using only Numerical Weather Prediction (NWP) as Input

- **Shortest Term Forecast (STF)**
- Forecast horizon from one to eight hours
- Updated every hour
- Using NWP and additional measurements as input

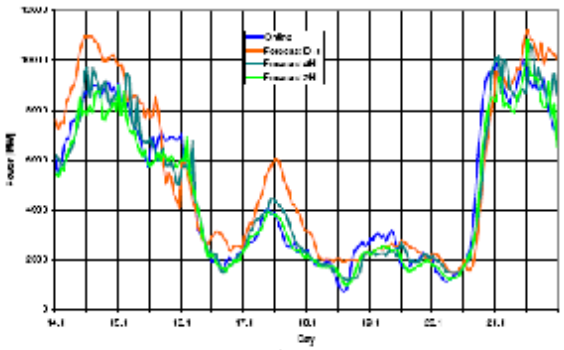
© Fraunhofer IWES

Day ahead forecast

Numerical weather model



Wind power prediction for TSO control zone



Weather prediction for the site of the repr. wind farm

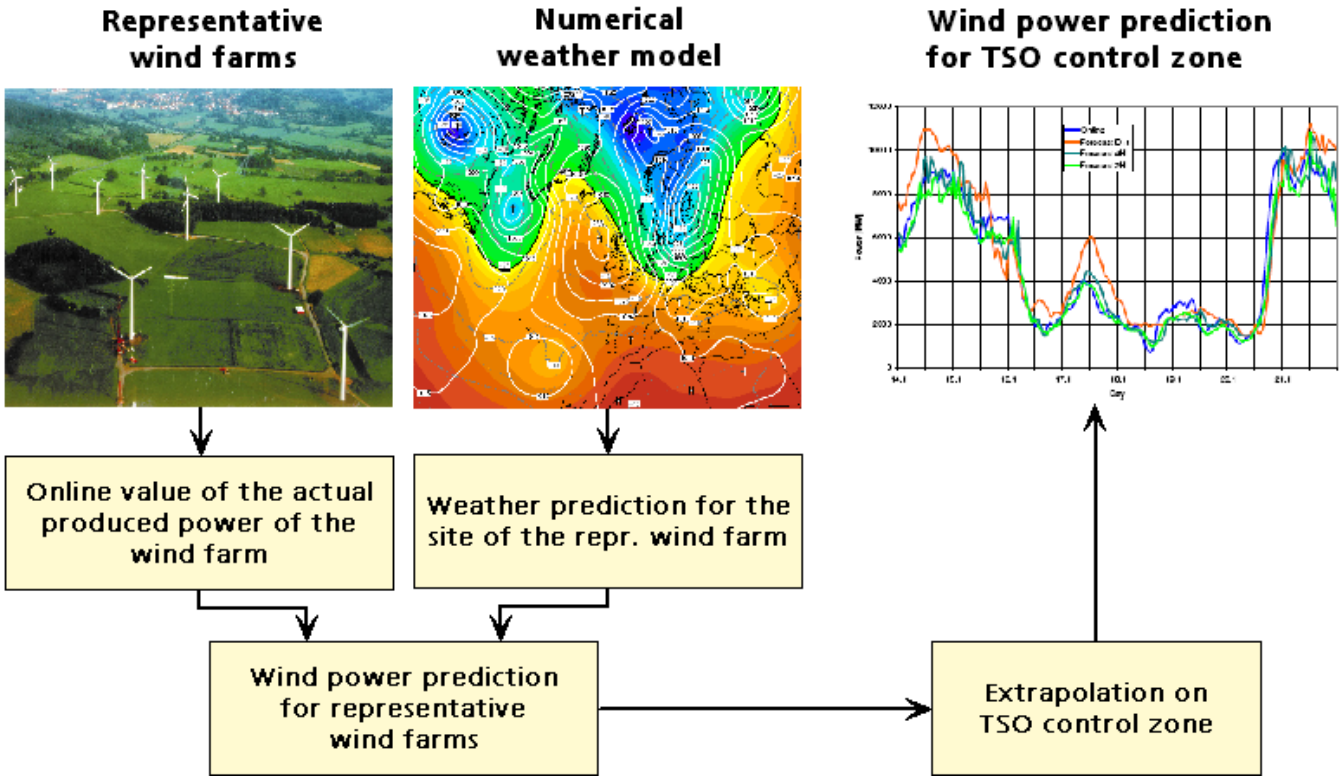
Wind power prediction for representative wind farms

Extrapolation on TSO control zone

© Fraunhofer IWES

Fraunhofer IWES

Shortest Term Forecast

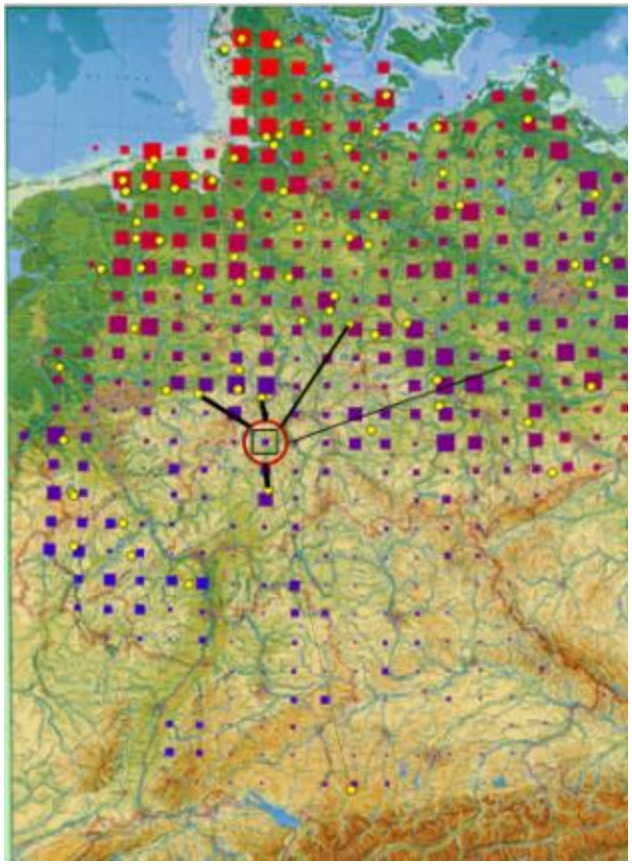


© Fraunhofer IWES

Fraunhofer IWES

Extrapolation to control zone

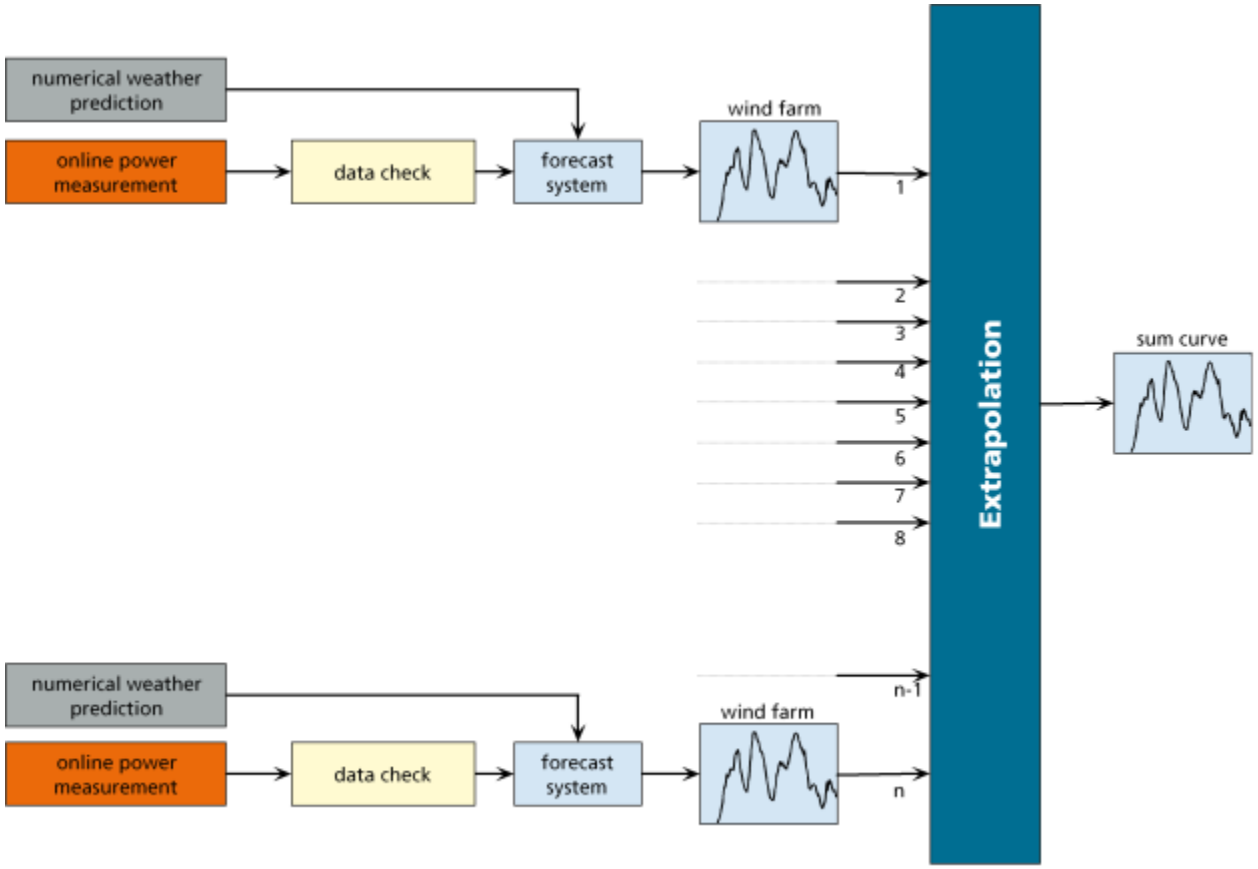
- Control zone is divided into grid squares
- The installed power in each grid square is known
- Forecast of each reference wind farm is extrapolated to grid square
- Extrapolation using inverse distance weighting
- All grid squares in control zone are summed up



© Fraunhofer IWES

Fraunhofer IWES

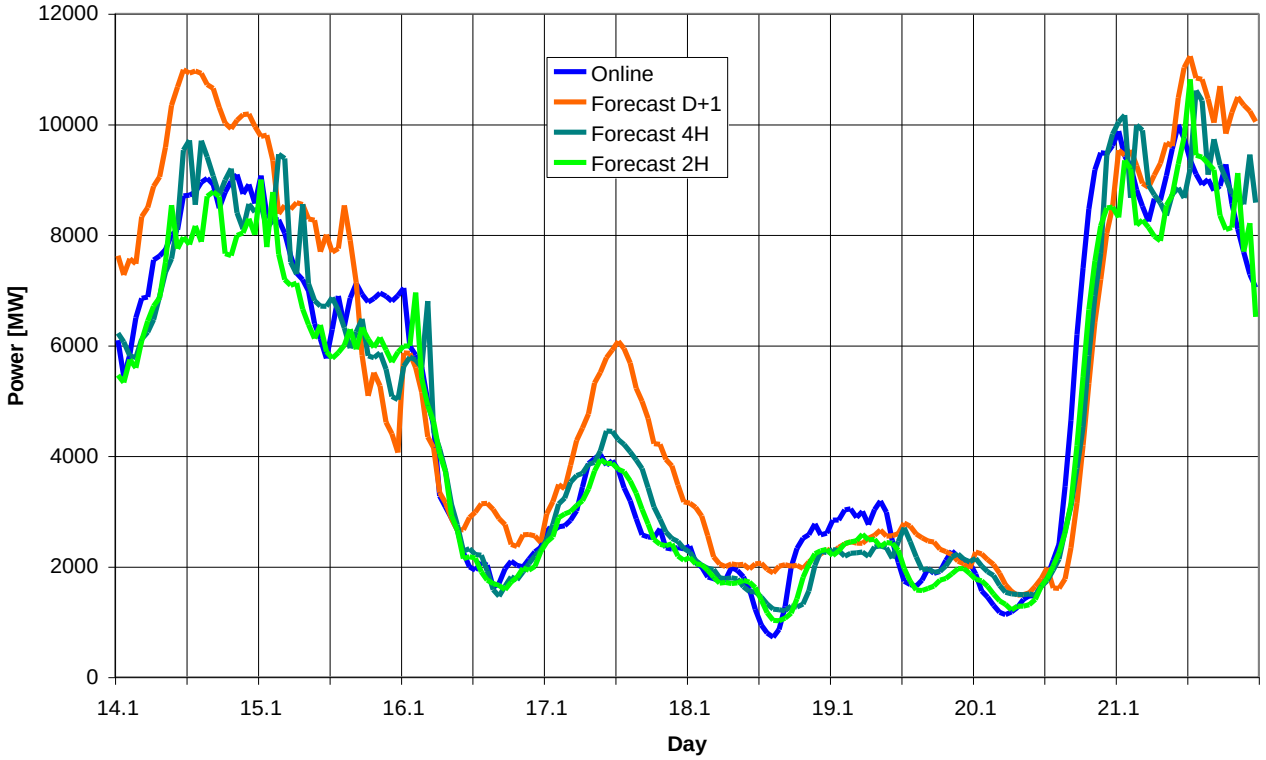
Extrapolation to control zone



© Fraunhofer IWES

Fraunhofer IWES

Example of Forecasts



© Fraunhofer IWES

Fraunhofer IWES

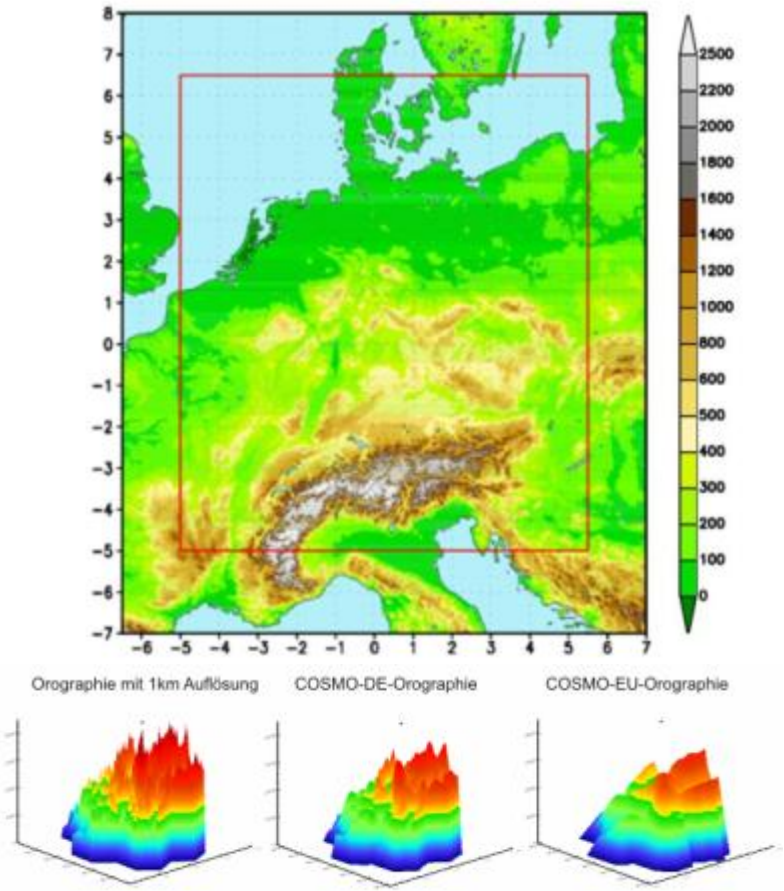
OUTLINE

- Problems of integration of wind power
- Principles of wind power prediction methods
- Dayahead- and shortest term forecast
- Use of wind power prediction in Germany
- Importance of numerical weather predictions
- Spatial forecast error smoothing of wind power prediction
- Illustration and evaluation of forecast quality
- Confidence intervals of wind power forecast
- Wind park cluster management
- Research activities

© Fraunhofer IWES

Importance of the numerical weather prediction

	Cosmo EU	Cosmo DE
Forecast Horizon	72h	18h
Spatial Resolution	2,8 km	~7km
Model Runs / Day	3	8
Calculation Time	7h	2h



Source: DWD

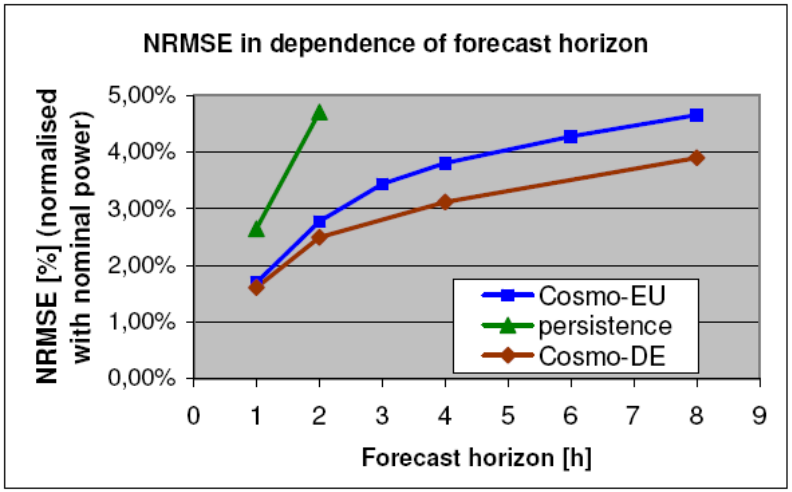
© Fraunhofer IWES

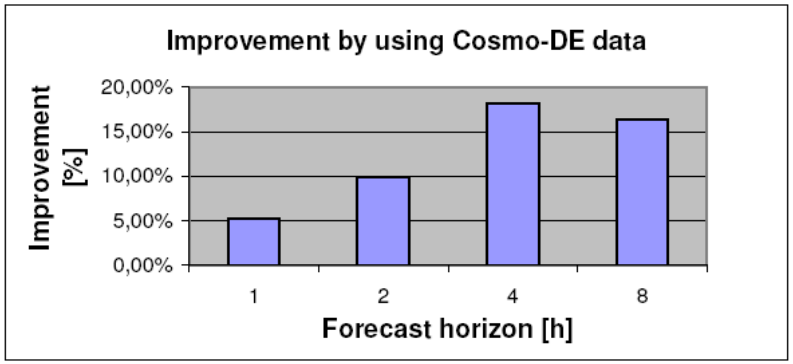
Fraunhofer IWES

Comparison between NWP-models

- **Forecasting whole Germany**
- Test range: 01.01.08-30.04.08
- NWP Models:
  - Cosmo-EU
  - Cosmo-DE
- Results:
  - Improvement at each forecast horizon
  - Highest improvement at forecast horizon of 4h

$$\mathrm{Imp} = \frac{NRMSE_{old} - NMRSE_{new}}{NRMSE_{old}}$$





© Fraunhofer IWES

Fraunhofer IWES

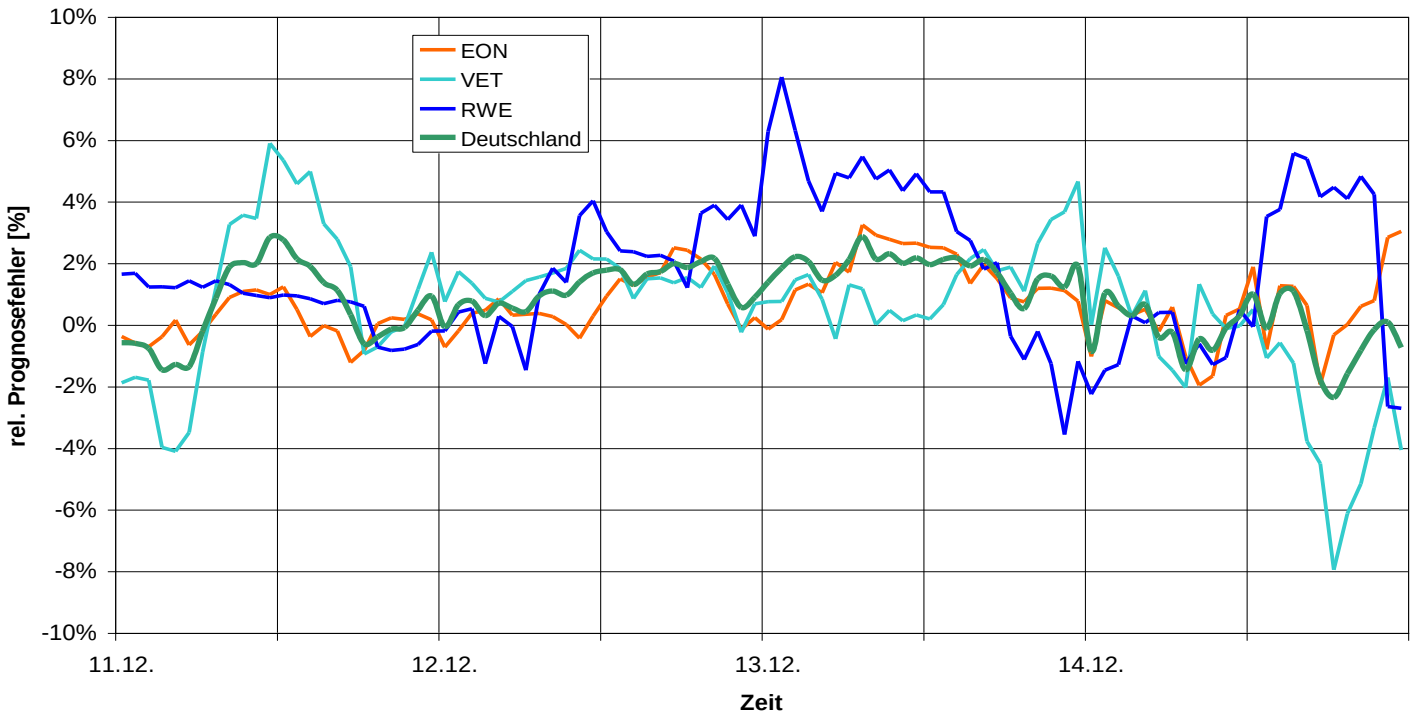
OUTLINE

- Problems of integration of wind power
- Principles of wind power prediction methods
- Dayahead- and shortest term forecast
- Use of wind power prediction in Germany
- Importance of numerical weather predictions
- Spatial forecast error smoothing of wind power prediction
- Illustration and evaluation of forecast quality
- Confidence intervals of wind power forecast
- Wind park cluster management
- Research activities

© Fraunhofer IWES

Spatial Forecast Error Smoothing

- **Reduction of forecast error by spatial smoothing**



© Fraunhofer IWES

Fraunhofer IWES

Spatial Forecast Error Smoothing

- **Reduction of forecast error by spatial smoothing**

Day ahead forecast		Germany	RWE
RMSE/installed capacity	[%]	5.72%	6.83%
correlation coefficient	[-]	0.955	0.933
RMSE/mean capacity	[%]	29.66%	37.67%
installed capacity	[MW]	15357	2760
mean capacity	[MW]	2973	503

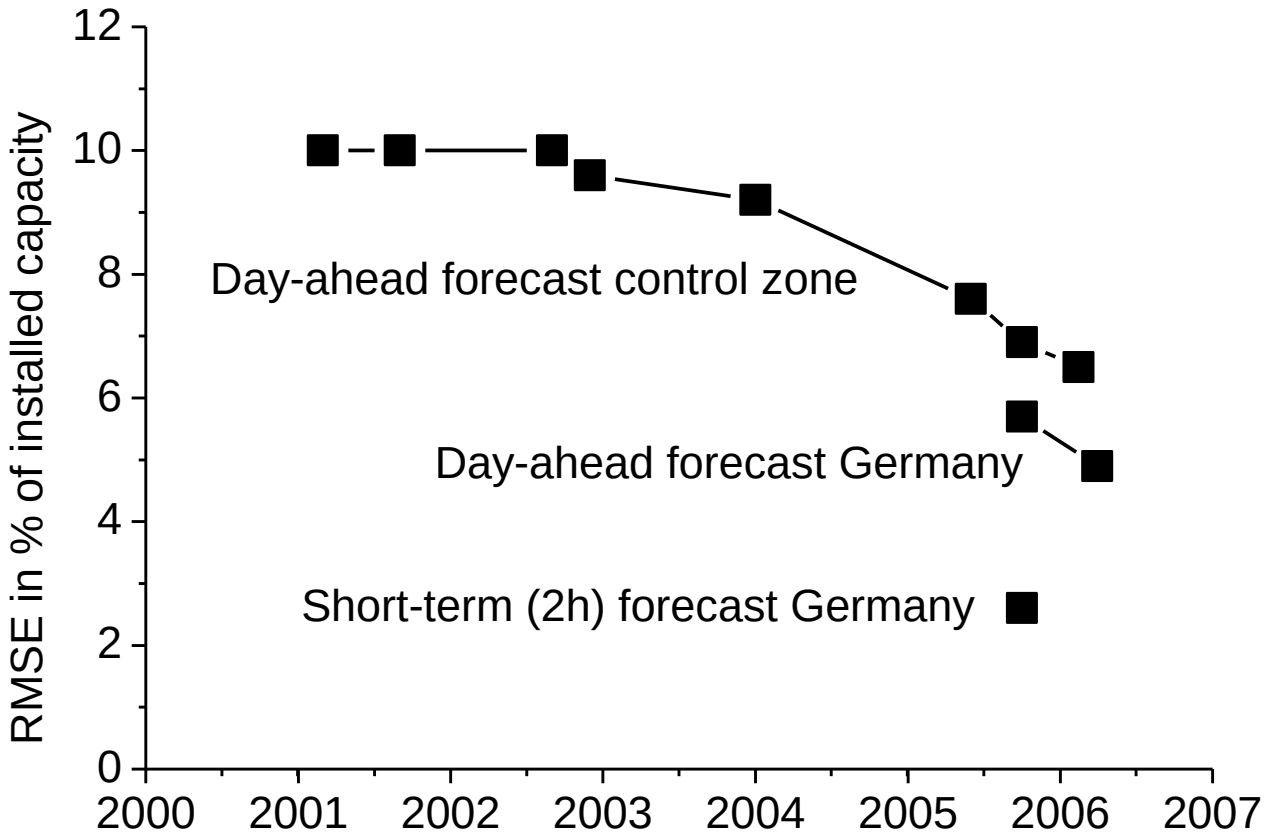
© Fraunhofer IWES

OUTLINE

- Problems of integration of wind power
- Principles of wind power prediction methods
- Dayahead- and shortest term forecast
- Use of wind power prediction in Germany
- Importance of numerical weather predictions
- Spatial forecast error smoothing of wind power prediction
- Illustration and evaluation of forecast quality
- Confidence intervals of wind power forecast
- Wind park cluster management
- Research activities

© Fraunhofer IWES

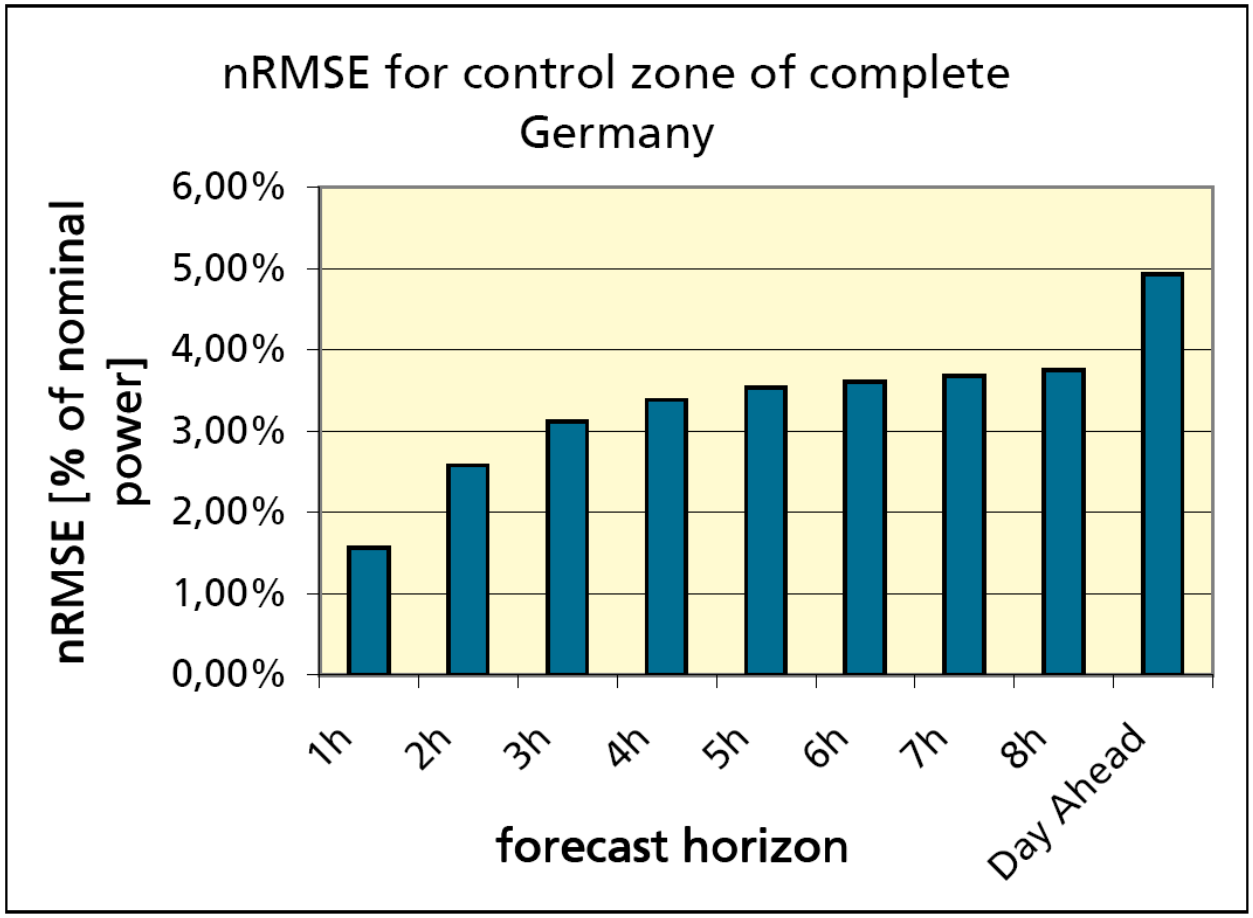
Illustration and Evaluation of Forecast Quality



© Fraunhofer IWES

Fraunhofer IWES

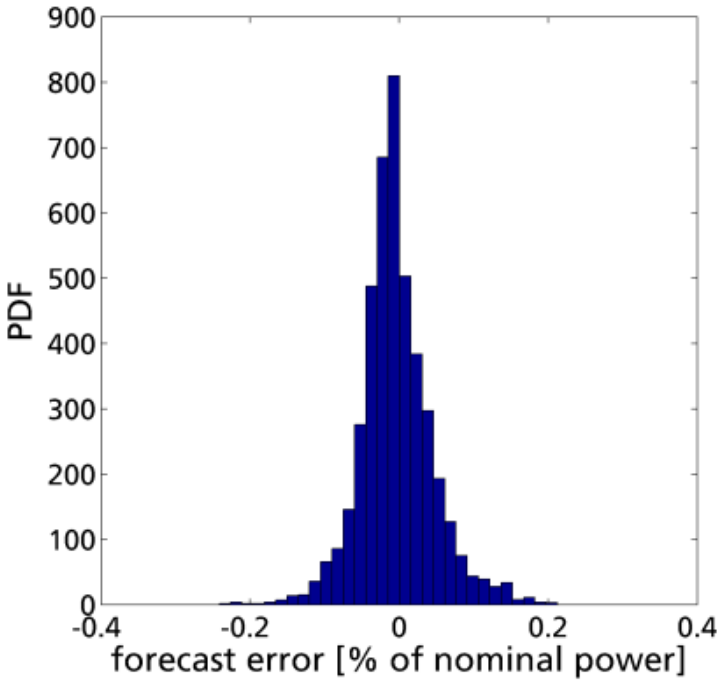
Forecast Error for complete Germany

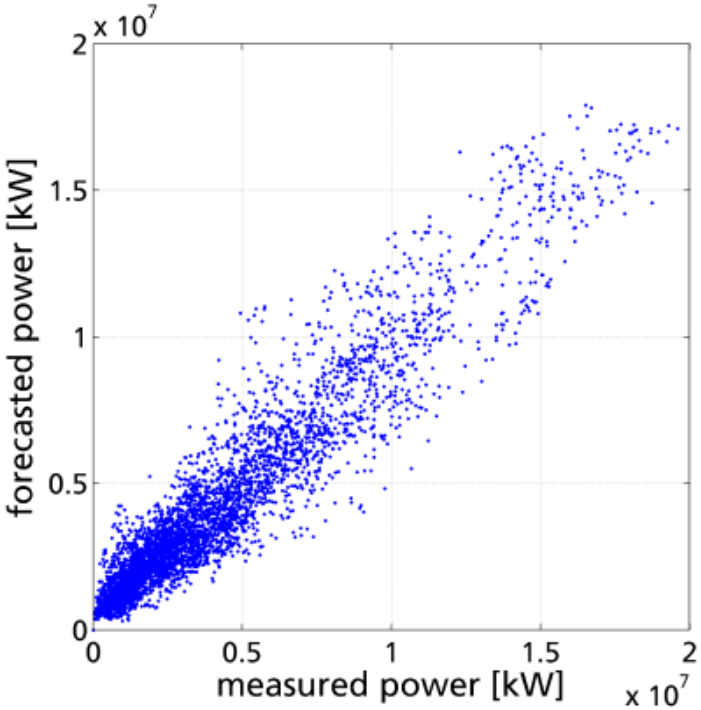


© Fraunhofer IWES

Fraunhofer IWES

Error Distribution and Scatter Plot for complete Germany



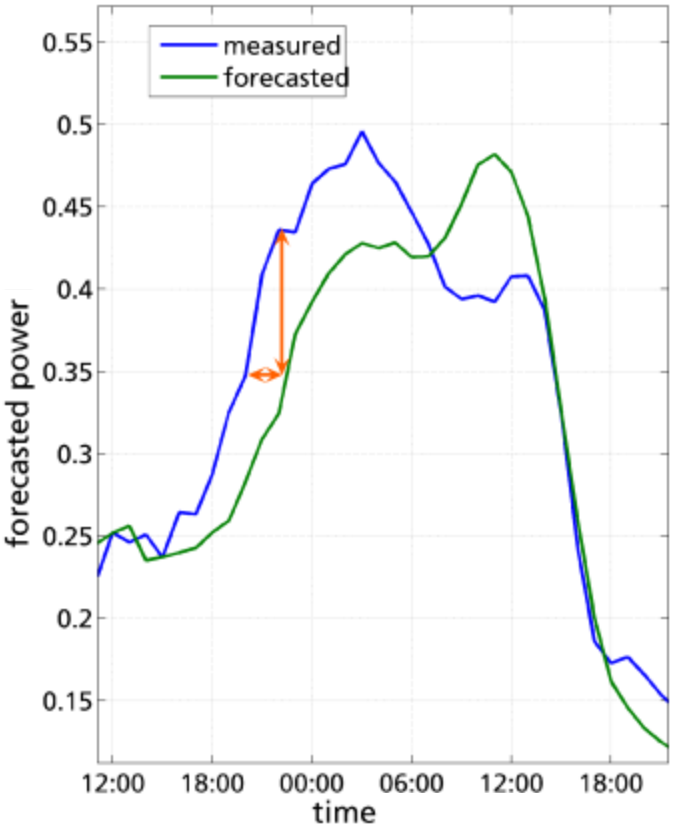


© Fraunhofer IWES

Fraunhofer IWES

Error interpretation

- Error Sources
- Overprediction
- Underprediction
- Phase / Timing Errors

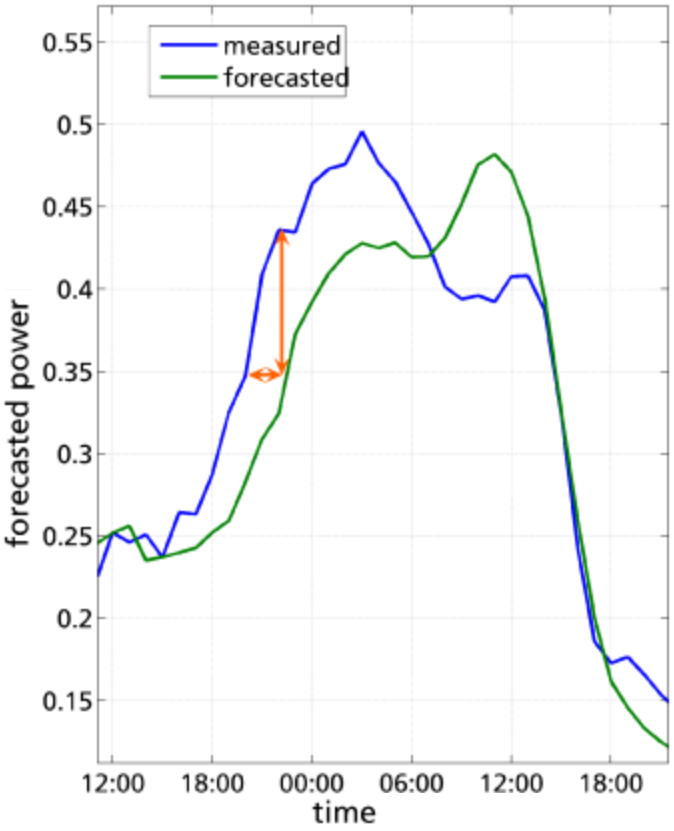


© Fraunhofer IWES

Fraunhofer IWES

Error scores

- RMSE
  - nRMSE
  - mRMSE
- MAE
  - nMAE
  - mMAE
- Bias
- Correlation



© Fraunhofer IWES

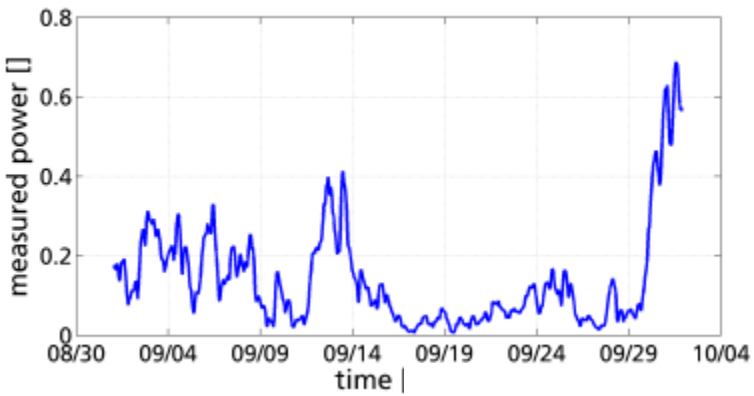
Fraunhofer IWES

Error interpretation - nRMSE

$$nRMSE = \sqrt{\frac{\sum Error / P_{nom}^{2}}{N}}$$

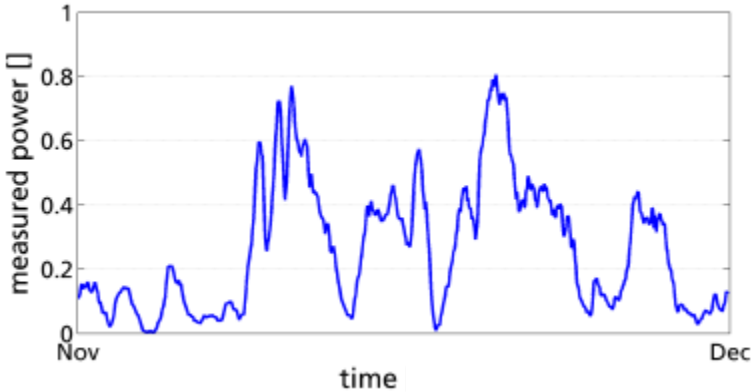
$$mRMSE = \sqrt{\frac{\sum Error / P_{mean}^{2}}{N}}$$

September 2008
nRMSE = 4,02 %
mRMSE = 28,78 %



- Error depends extreme on the variability of the wind in examined the time range.

Oktober 2008
nRMSE = 6,07 %
mRMSE = 23,11 %

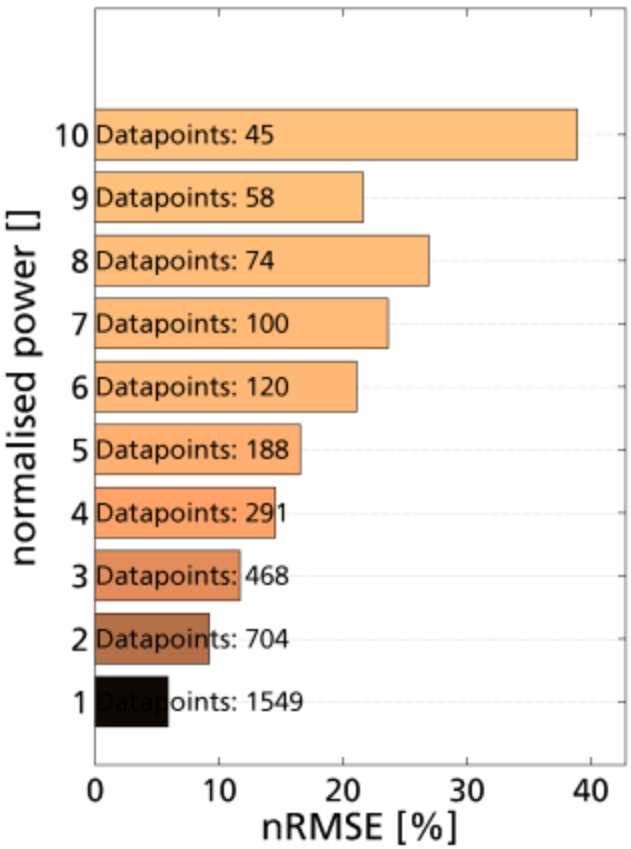


© Fraunhofer IWES

Fraunhofer IWES

Error interpretation – Error by power classes

- Error in dependence of the error classes can help to see the weakness of the forecast



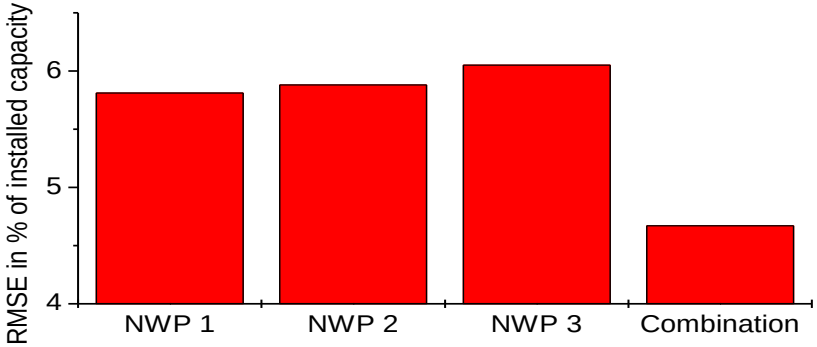
© Fraunhofer IWES

Fraunhofer IWES

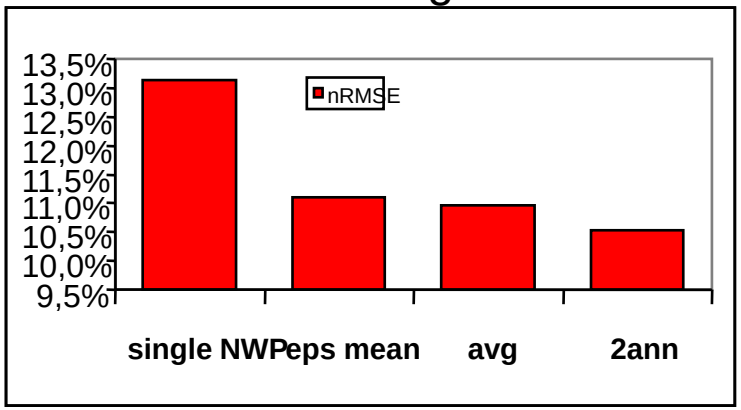
Combination of different weather services

- Combination of different weather models or Ensemble models can be used to reduce the forecast error
- Simple averaging already leads to promising results

Forecast for complete Germany



Forecast for a single wind farm



© Fraunhofer IWES

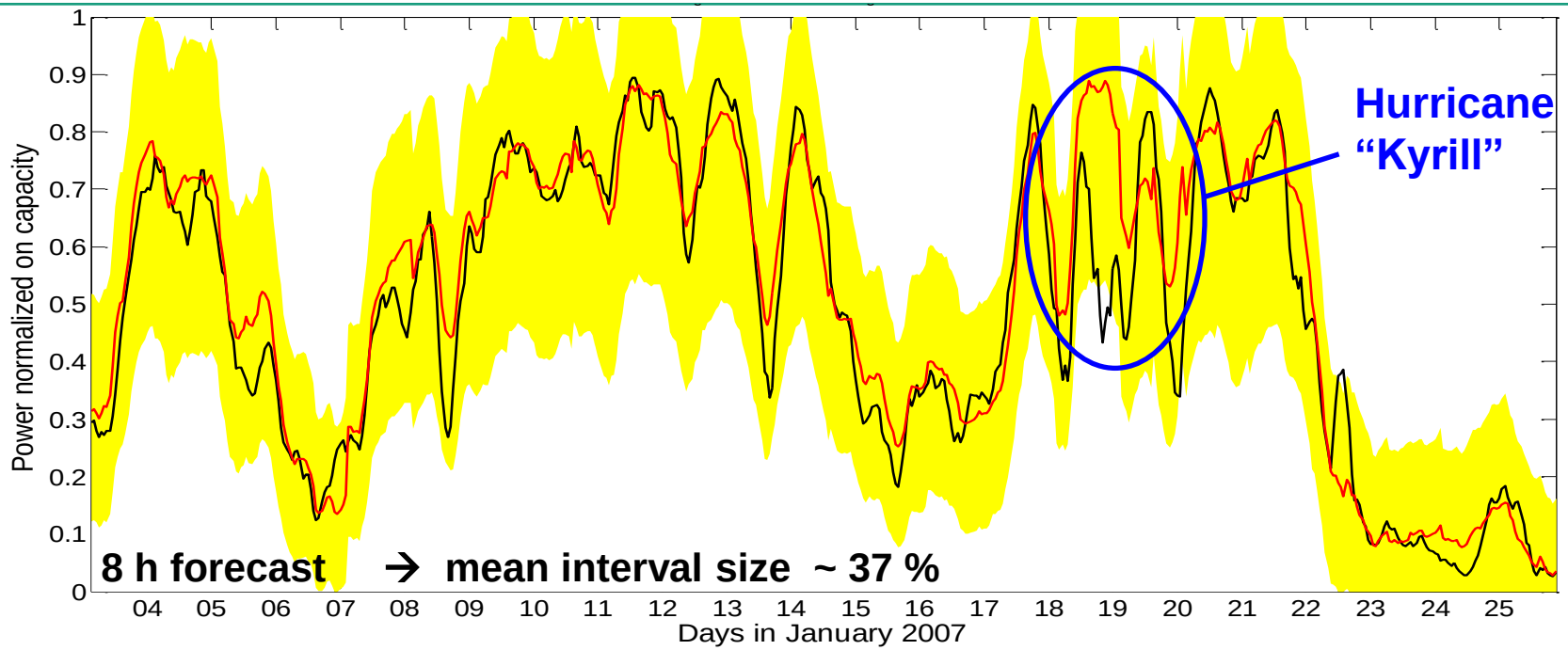
Fraunhofer IWES

OUTLINE

- Problems of integration of wind power
- Principles of wind power prediction methods
- Dayahead- and shortest term forecast
- Use of wind power prediction in Germany
- Importance of numerical weather predictions
- Spatial forecast error smoothing of wind power prediction
- Illustration and evaluation of forecast quality
- Confidence intervals of wind power forecast
- Wind park cluster management
- Research activities

© Fraunhofer IWES

Prediction intervals



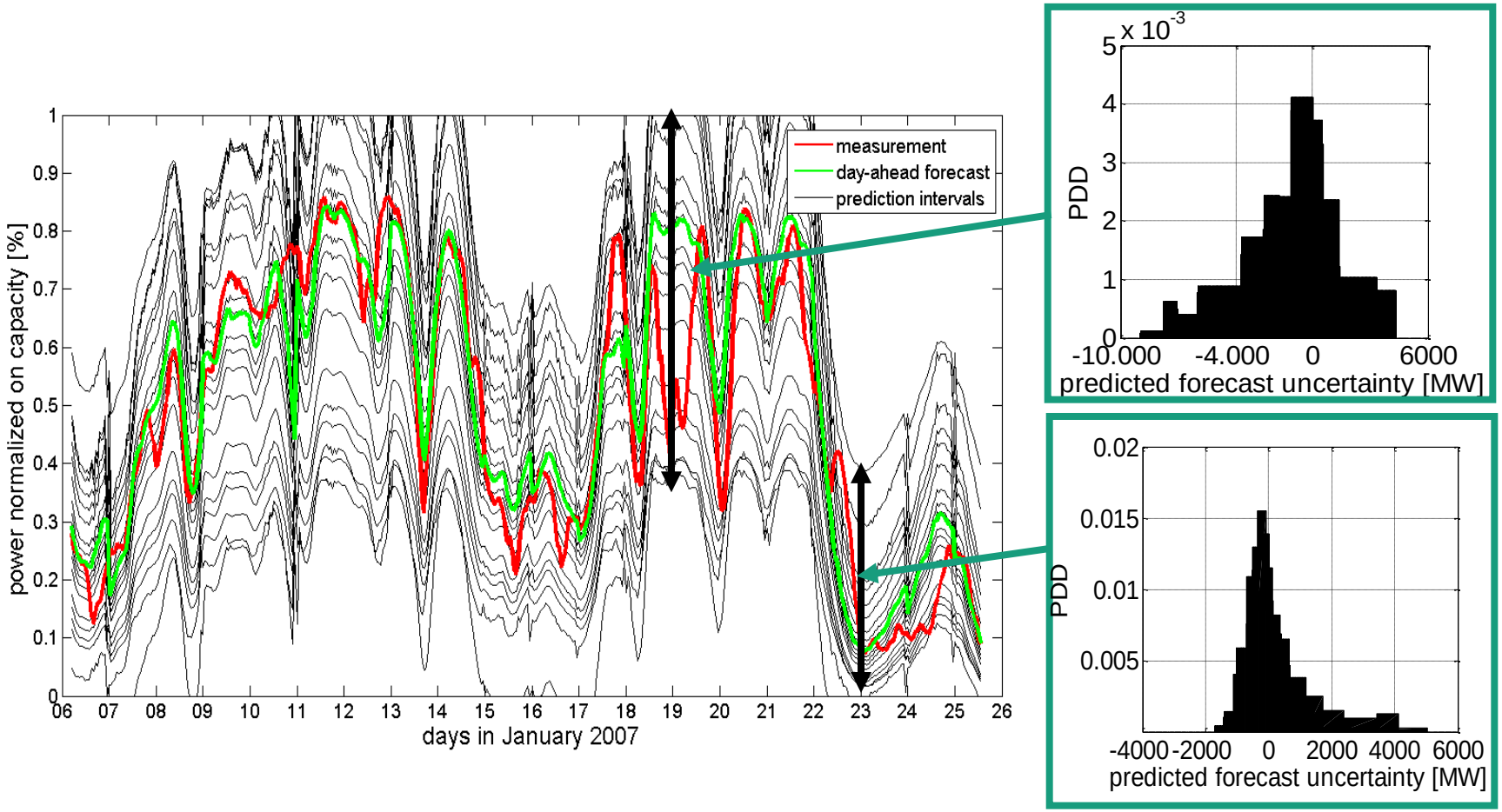
All observed reliabilities > 99.7 %

"The model cannot estimate the uncertainty for maximal 24 hours of one year. During the rest of the year, the fluctuating wind power can be controlled accurate."

© Fraunhofer IWES

Fraunhofer IWES

Distribution of forecast uncertainty



© Fraunhofer IWES

Fraunhofer IWES

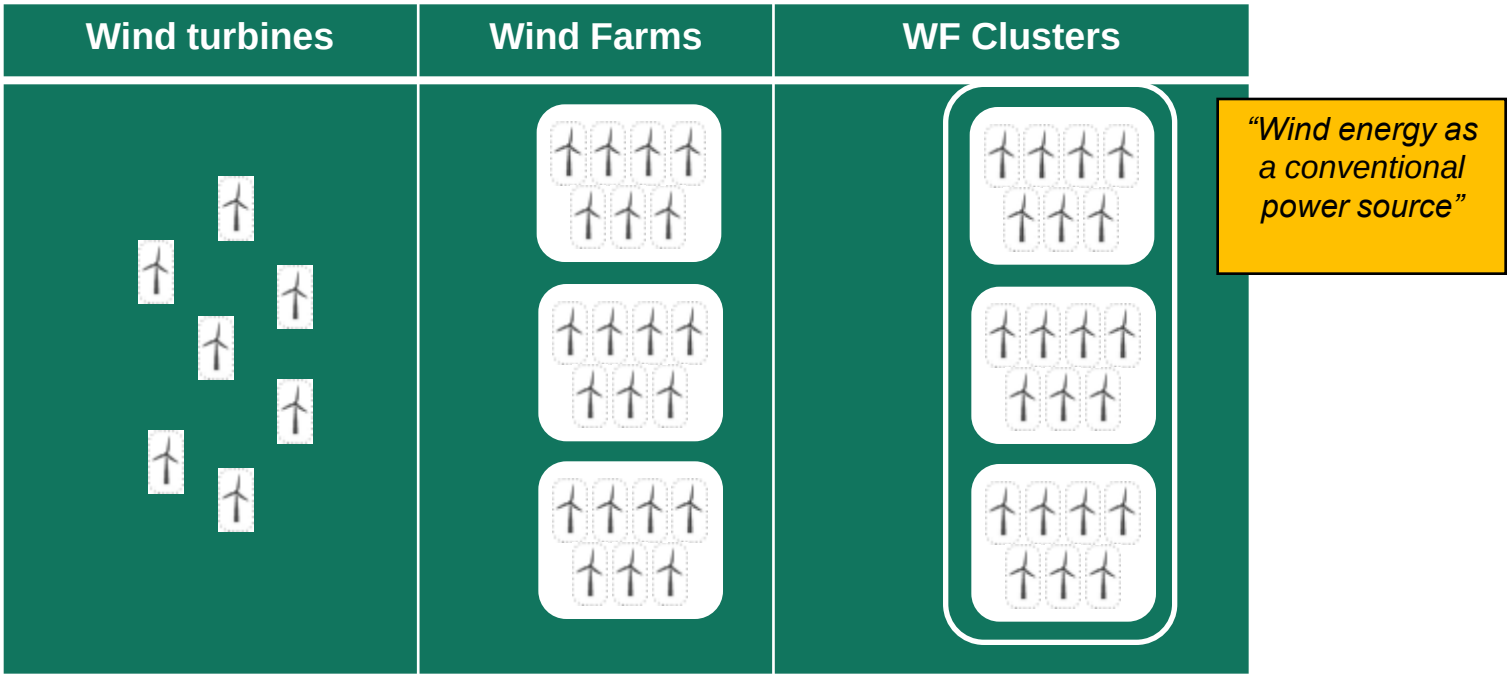
OUTLINE

- Problems of integration of wind power
- Principles of wind power prediction methods
- Dayahead- and shortest term forecast
- Use of wind power prediction in Germany
- Importance of numerical weather predictions
- Spatial forecast error smoothing of wind power prediction
- Illustration and evaluation of forecast quality
- Confidence intervals of wind power forecast
- Wind park cluster management
- Research activities

© Fraunhofer IWES

Wind Farm Cluster Management

"Logical aggregation of physical existing wind farms connected under the same grid node"



© Fraunhofer IWES

Fraunhofer IWES

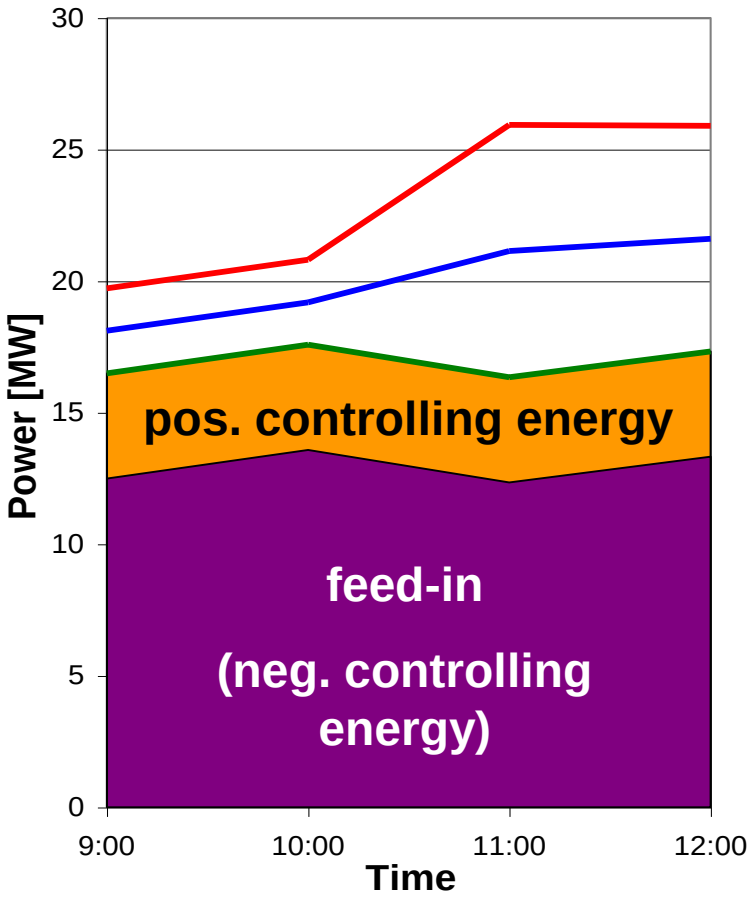
Power systems requirements for high wind penetration

- Balancing requirements.
  - Fluctuations of wind power injections represent one of the main factors of demand for controlling and balancing power.
  - Wind power prediction systems are highly required.
- Active Power control can be used in case of network shortages or for Frequency Regulation.
- Reactive Power control is required for Voltage Regulation.
  - Grid codes have already issued operational range for the voltage and power factor at the point of connection.

© Fraunhofer IWES

Fraunhofer IWES

Using wind power as reserve power



upper limit tolerance band

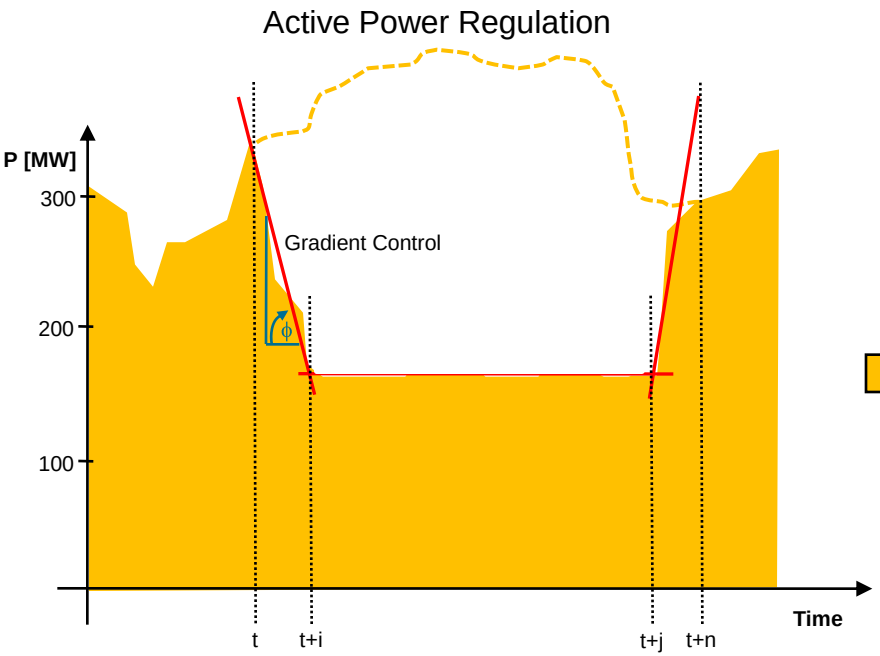
forecast

lower limit tolerance band

© Fraunhofer IWES

Fraunhofer IWES

Power systems requirements for high wind penetration



Reserve power

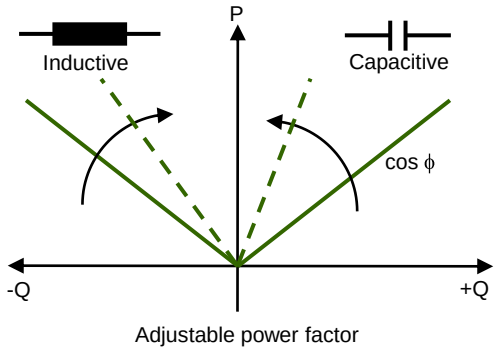
Congestion management

© Fraunhofer IWES

Fraunhofer IWES

Power systems requirements for high wind penetration

Reactive Power Regulation



Reactive power range determination

Control of reactive power according to TSO requirement

© Fraunhofer IWES

Fraunhofer IWES

Wind Farm Clusters R & D activities

- Reach acceptable controlability levels of wind power (P and Q).
- Continue validating and improving forecasting tools.
- Active power control.
  - Reserve power activation procedure:
    - Time response (primary, secondary and terciary power reserve).
    - Power stability.
- Reactive power control.
  - Voltage control.
  - Models to better assess the relation between: ΔU - ΔQ

© Fraunhofer IWES

Fraunhofer IWES

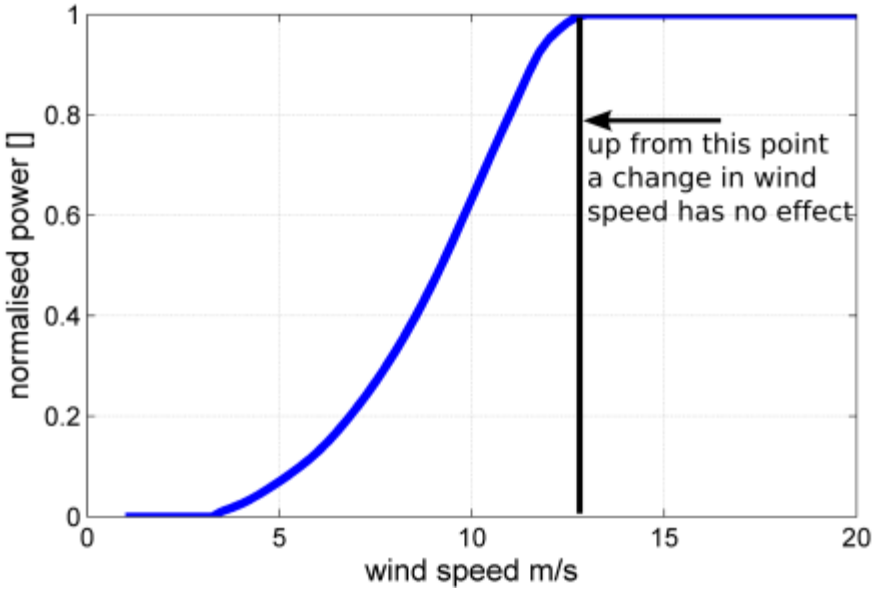
OUTLINE

- Problems of integration of wind power
- Principles of wind power prediction methods
- Dayahead- and shortest term forecast
- Use of wind power prediction in Germany
- Importance of numerical weather predictions
- Spatial forecast error smoothing of wind power prediction
- Illustration and evaluation of forecast quality
- Confidence intervals of wind power forecast
- Wind park cluster management
- Research activities

© Fraunhofer IWES

Research Activities

- At nominal power no change in wind speed is observable
- Informational content is limited by the power curve of the wind farm
- Online wind speed measurements can help to improve the forecast at high wind speeds

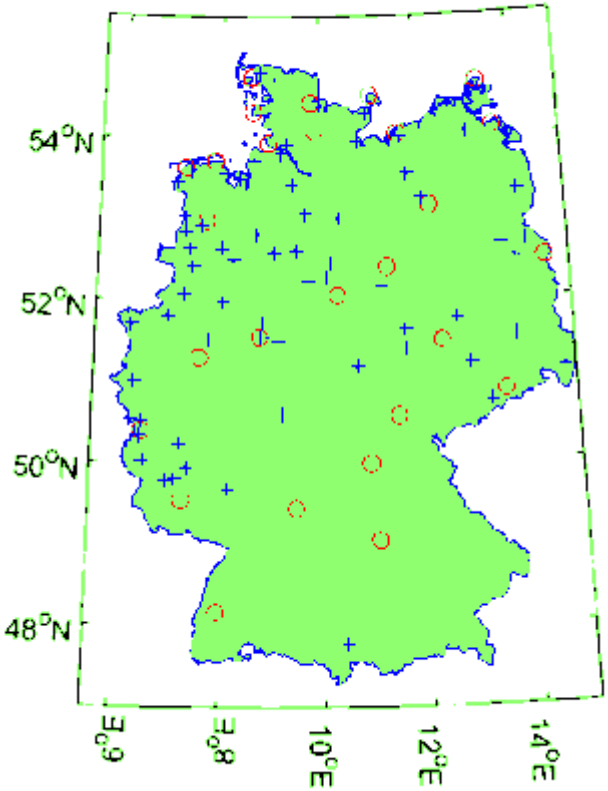


© Fraunhofer IWES

Fraunhofer IWES

Informational content in offsite wind measurements

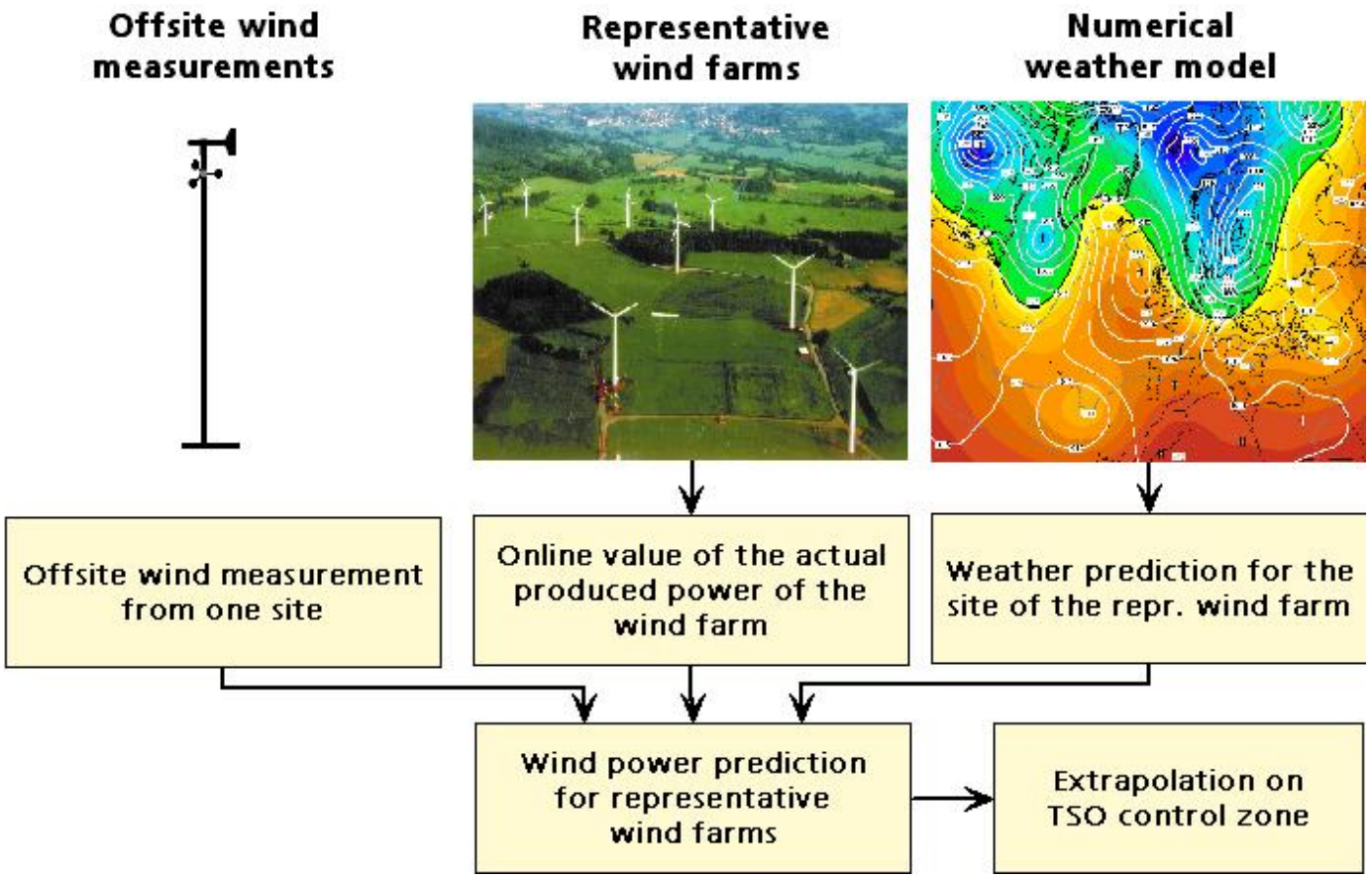
- Wind measurements are taken from the IWES wind measurement network.
- 30 wind measurement masts with anemometers in a height of 30m (red circles)
- 68 Reference wind farms are used for power forecast (blue crosses)



© Fraunhofer IWES

Fraunhofer IWES

Enhanced Forecast model



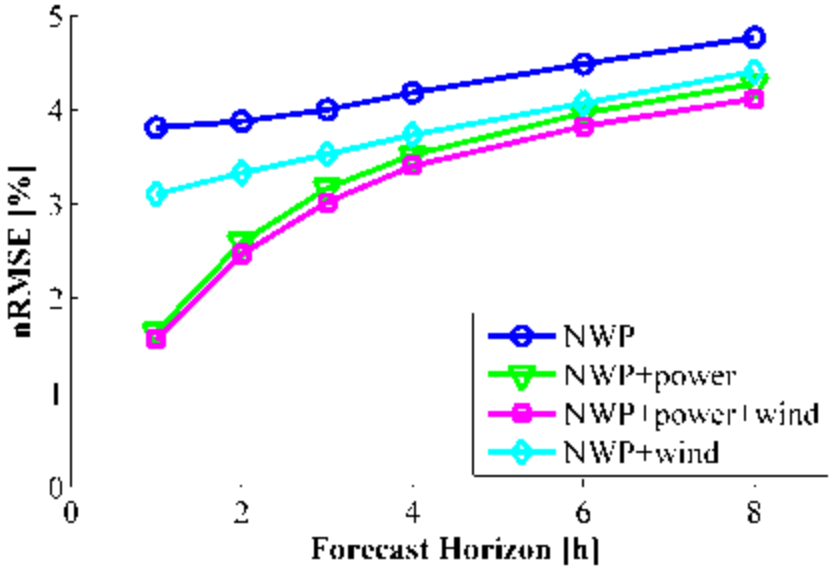
© Fraunhofer IWES

Fraunhofer IWES

Results of short term prediction for complete Germany

Four different scenarios are evaluated:

- Only NWP data
- NWP and actual measured power data (PW)
- NWP and actual measured wind data (Wind)
- NWP and actual measured power and wind data

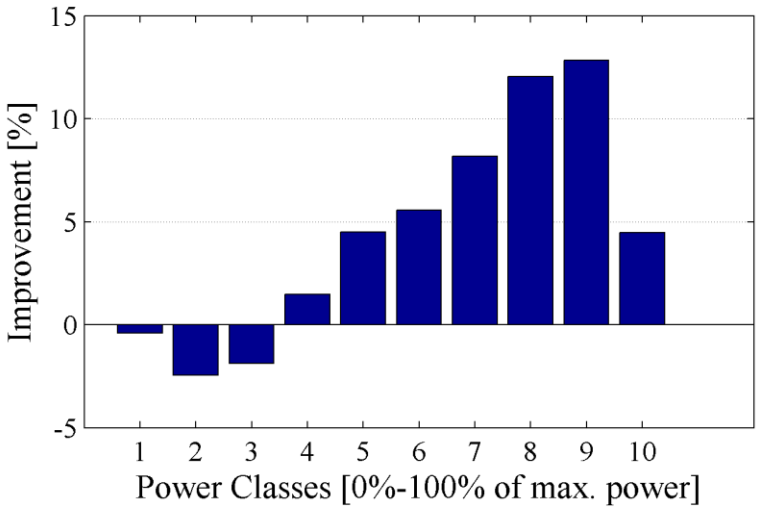


© Fraunhofer IWES

Fraunhofer IWES

Improvement in the single power classes

- Improvement in the higher power classes
- In highest power class a saturation is present
- Negative improvement in the lower power classses
- Overall improvement in the highest power classes for the forecast horizon from 1h – 4h



Forecast horizon	Improvement
1h	9,8 %
2h	12,6 %
3h	11,7 %
4h	9,38%

© Fraunhofer IWES

Fraunhofer IWES

Thank you for your attention

Arne Wessel
awessel@iset.uni-kassel.de

Energy Meteorology & Wind Power Management
R&D Division Energy Economy and Grid Operation

Fraunhofer Institute for Wind Energy and Energy System Technology IWES
(formerly ISET e.V.)
Königstor 59, 34119 Kassel

© Fraunhofer IWES

Fraunhofer IWES