Wind power forecast in Germany
General approach, practical applications and options for considering effects of wind turbine icing

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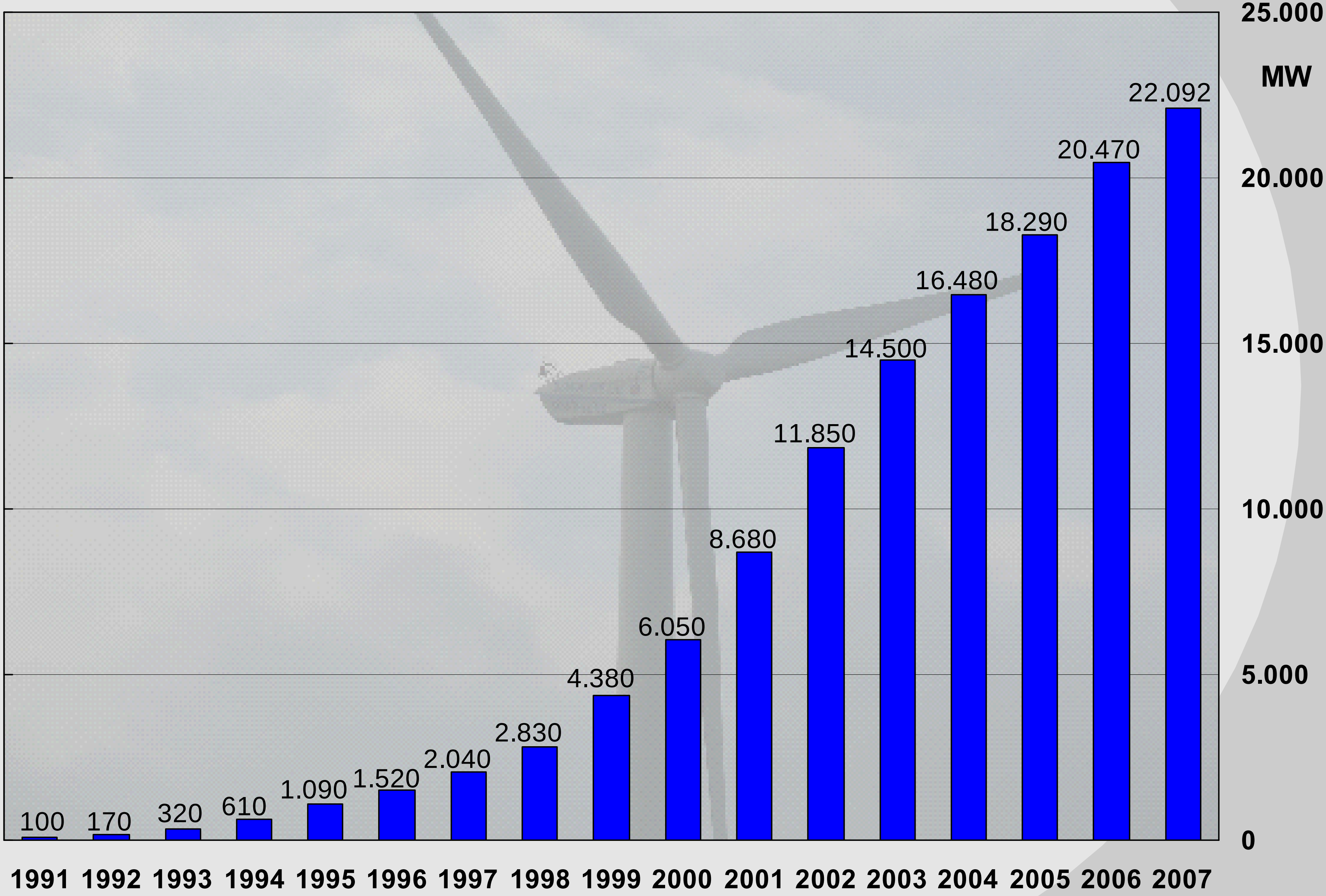
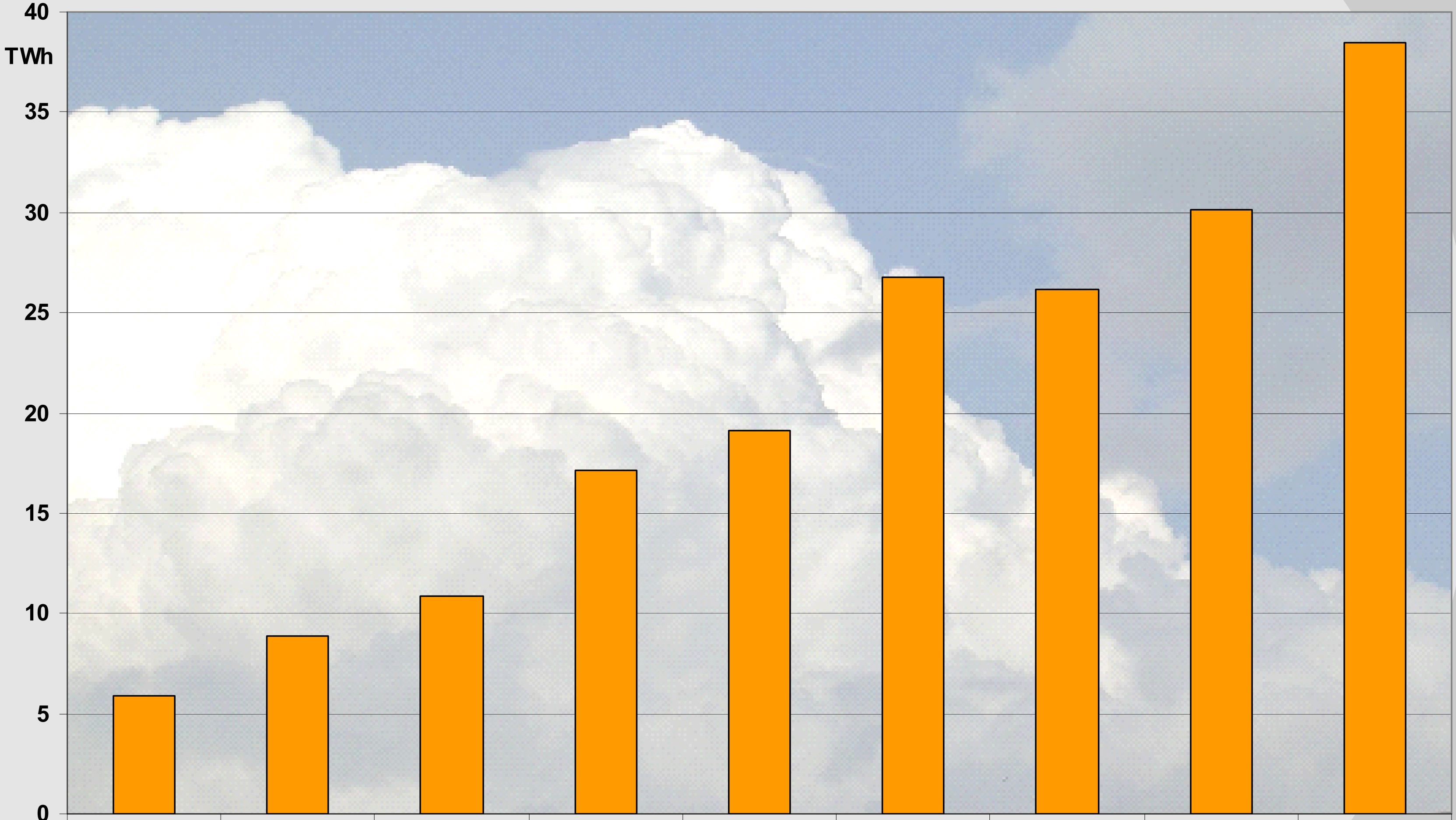
Wind power development in Germany

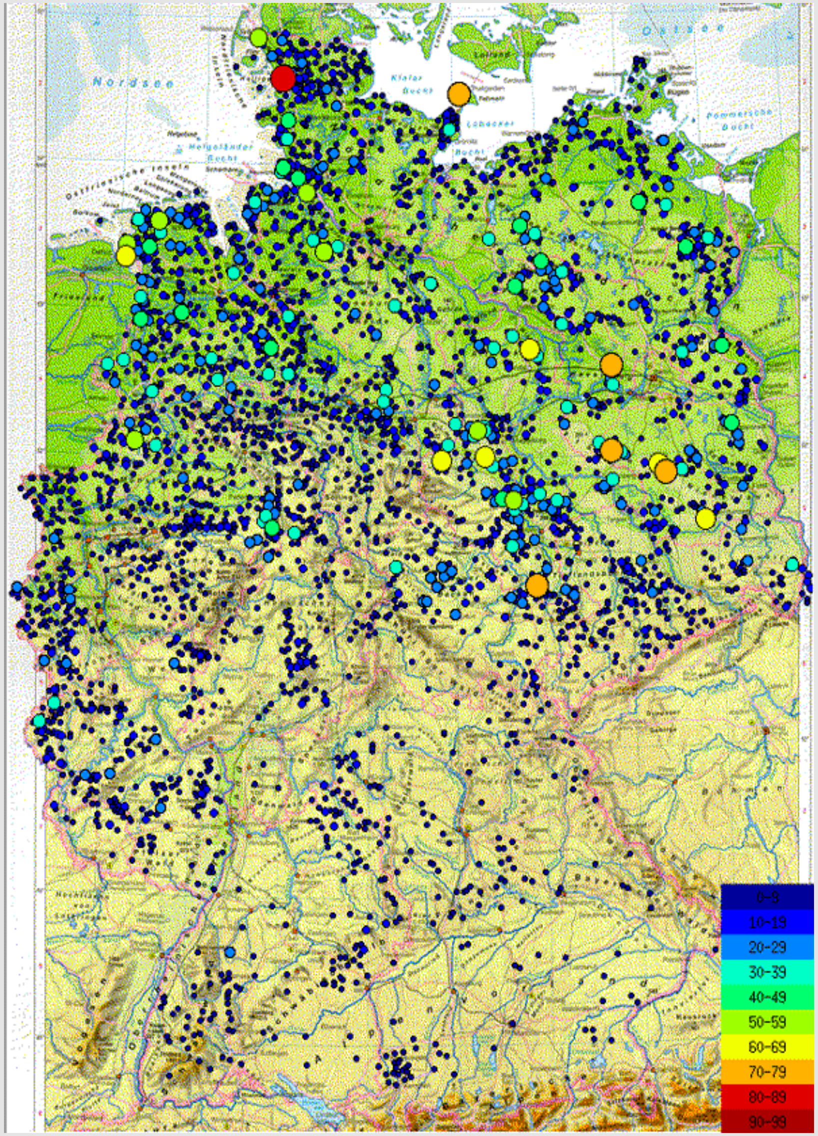


Electricity production by wind '99 – '07



	1999	2000	2001	2002	2003	2004	2005	2006	2007
gesamt	5,9 TWh	8,8 TWh	10,9 TWh	17,1 TWh	19,2 TWh	26,8 TWh	26,1 TWh	30,2 TWh	38,5 TWh

Introduction



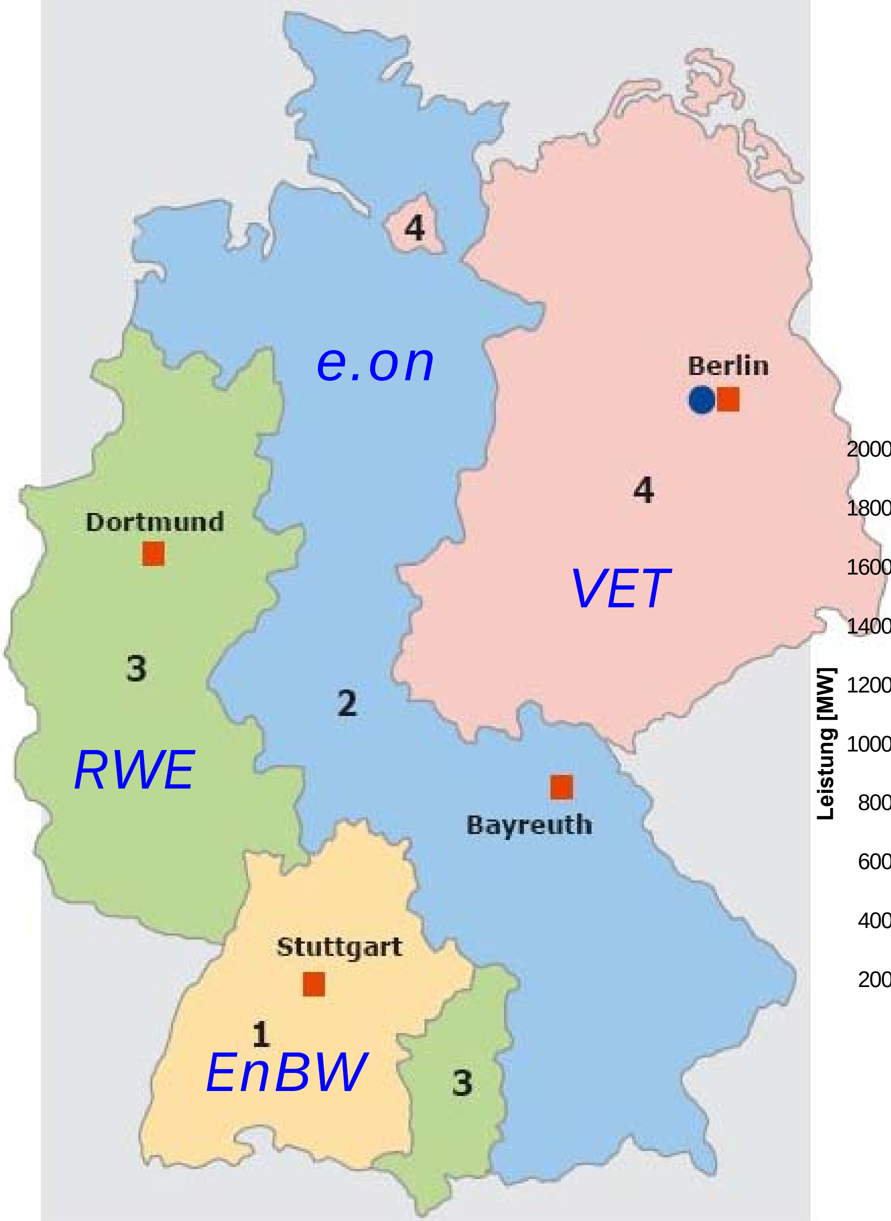
Wind Energy in Germany

Installations
22,100 MW
19,250 WT

as of 12 / 2007

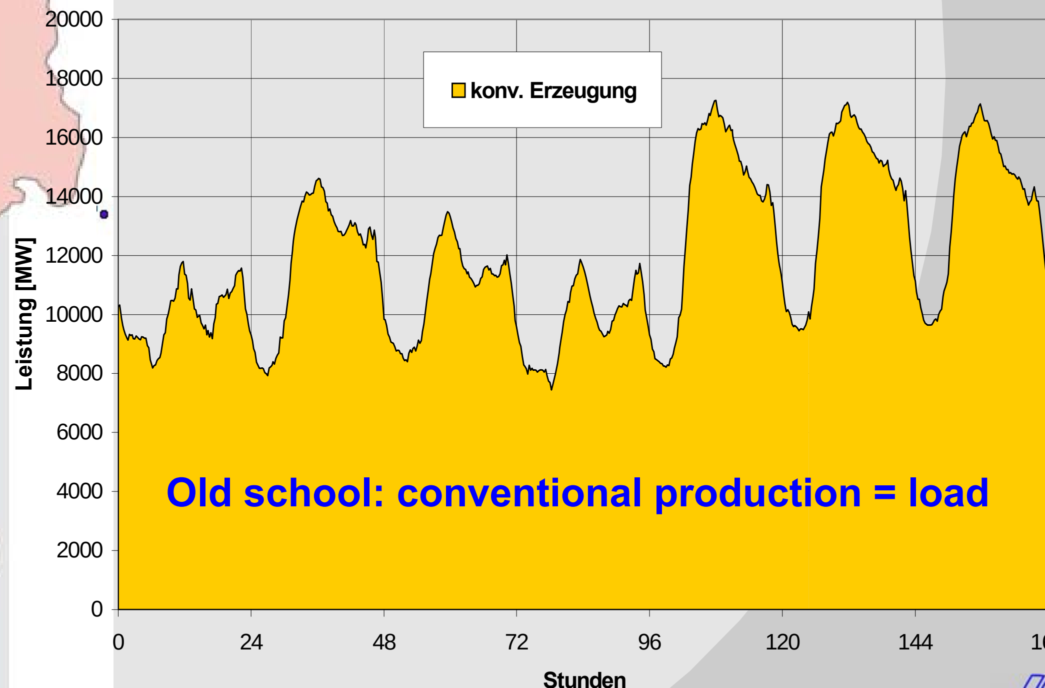
Energy Production
26.4 TWh in 2005
30.3 TWh in 2006
38,5 TWh in 2007

Wind power installations and TSO regions

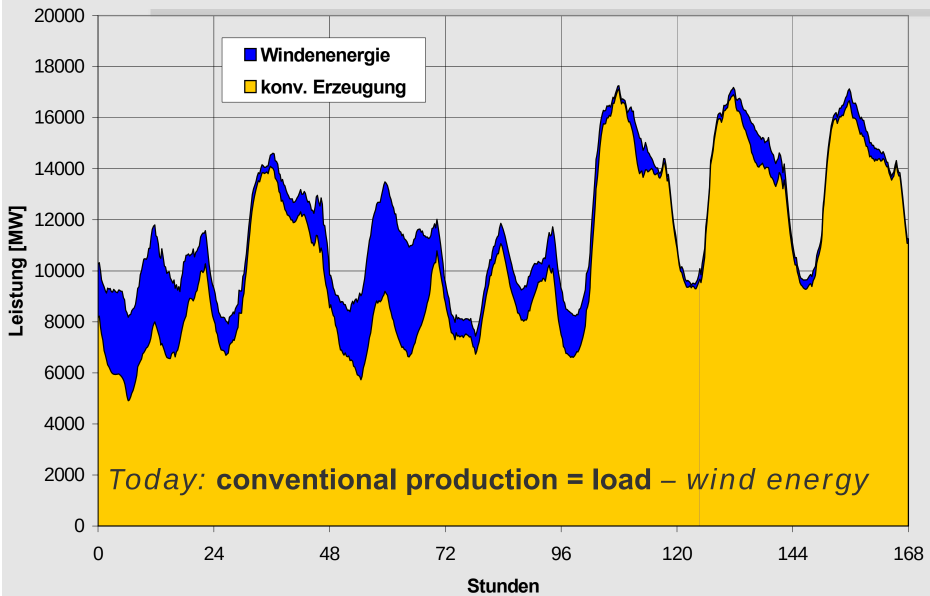


TSO mission

- *balancing of power generation and demand*
- *maintain grid stability voltage, frequency*
- *provide reserve power*
  (UCTE: 3000 MW primary control reserve)



Situation today

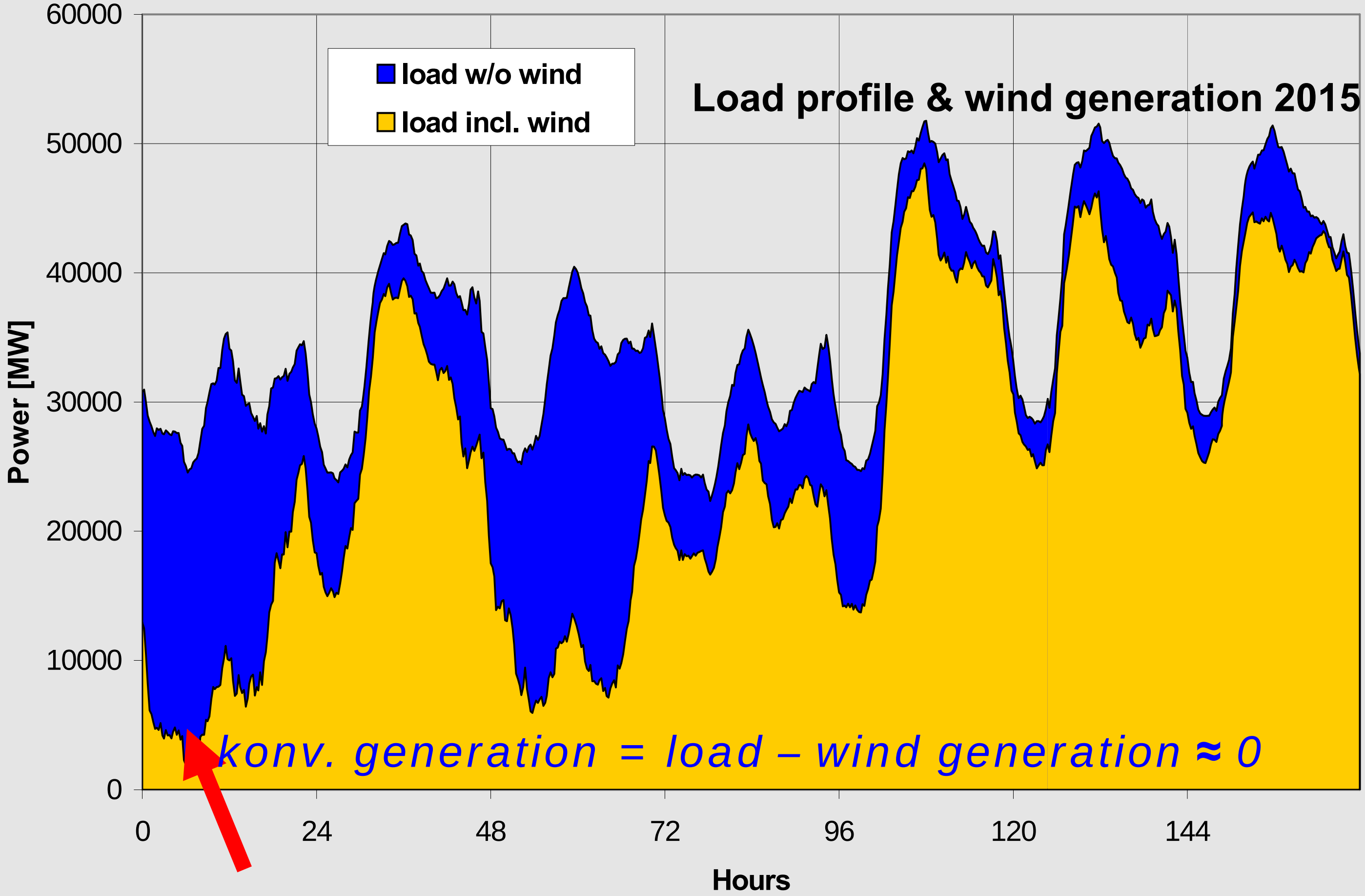


- Hundreds of wind farms and single turbines
- Fluctuating power generation
- Non-dispatchable generators
- Privileged production of RE
- Purchase commitment by utilities

→ consequences for stable and reliable grid operation

Information about
actual state of wind power feed-in
+ short & medium term forecast
is essential

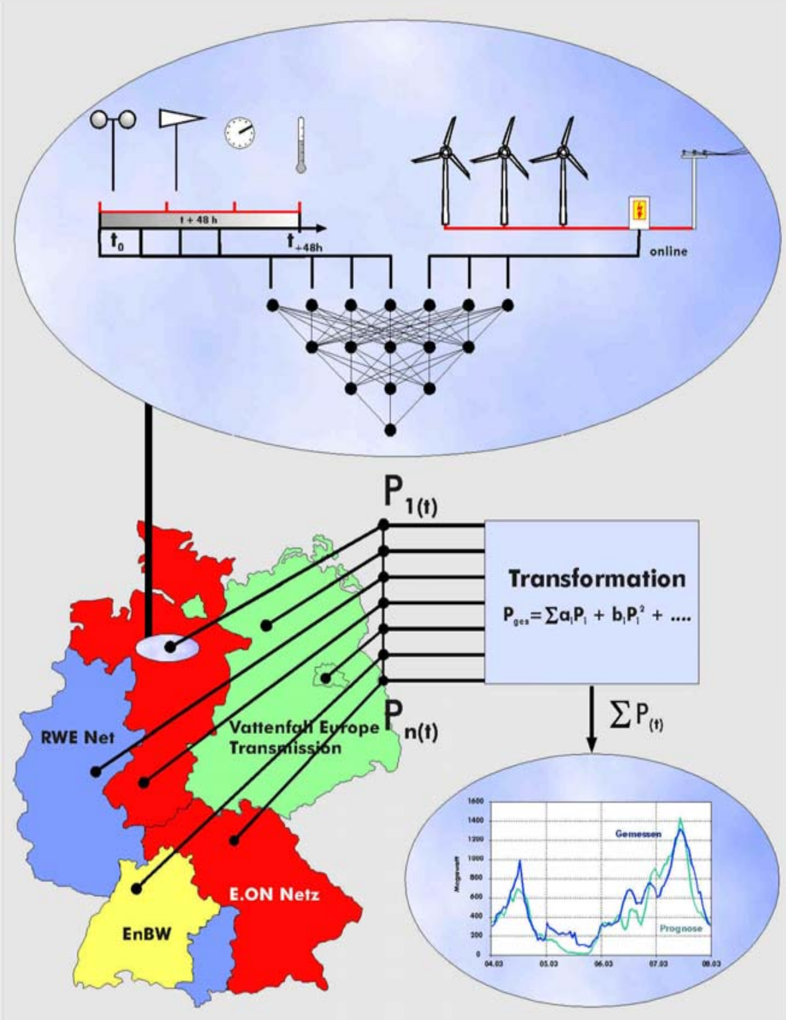
Situation tomorrow → results of DENA study



No conventional generation is running

=> Grid management (frequency, voltage control, ...) needed

Prediction Methods



Models and Tools for TSOs

Step 1:

Online model calculates from few measured windfarms the current power for all plants

Step 2:

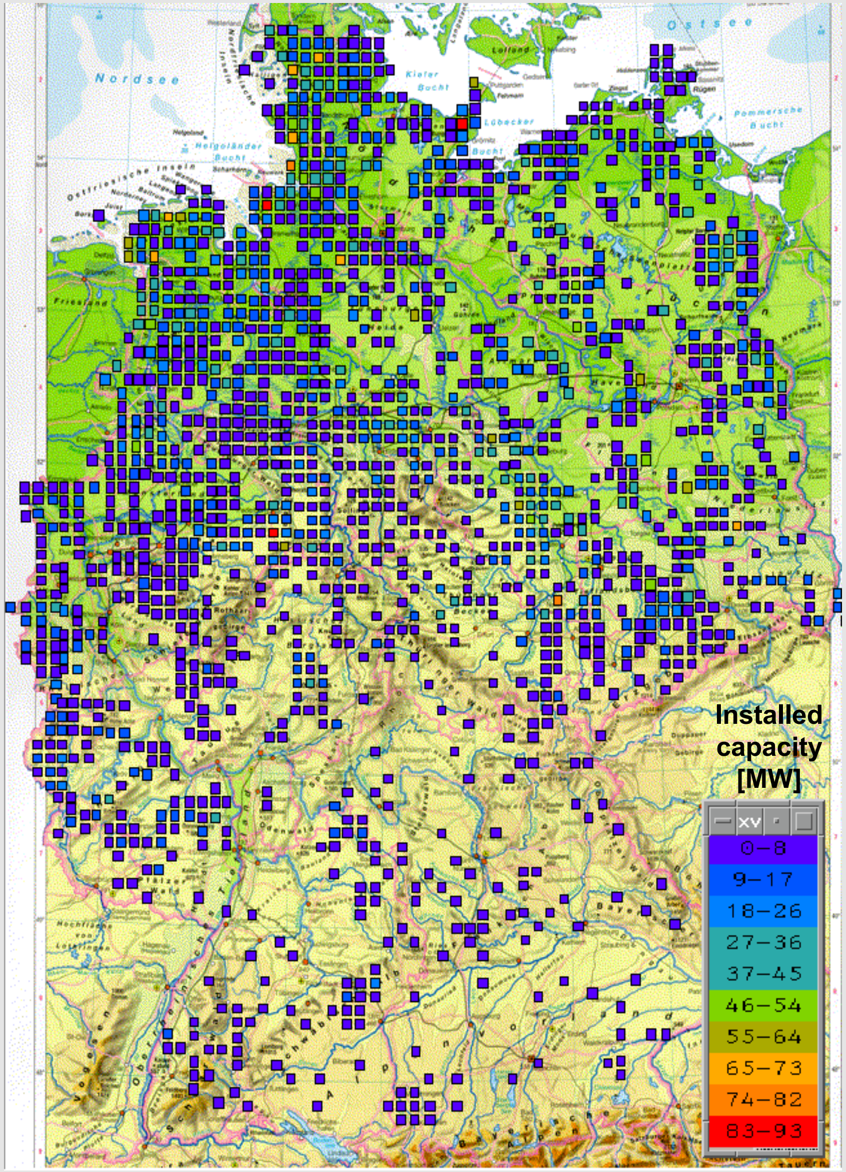
Prediction model calculates on the basis of the current power of all plants and the weather forecast the future wind power feed-in

Accuracy in the statistical average
> 94 % for the D+1 forecast
> 96 % for the 4 hours forecast

WPMS

Wind Power Management System

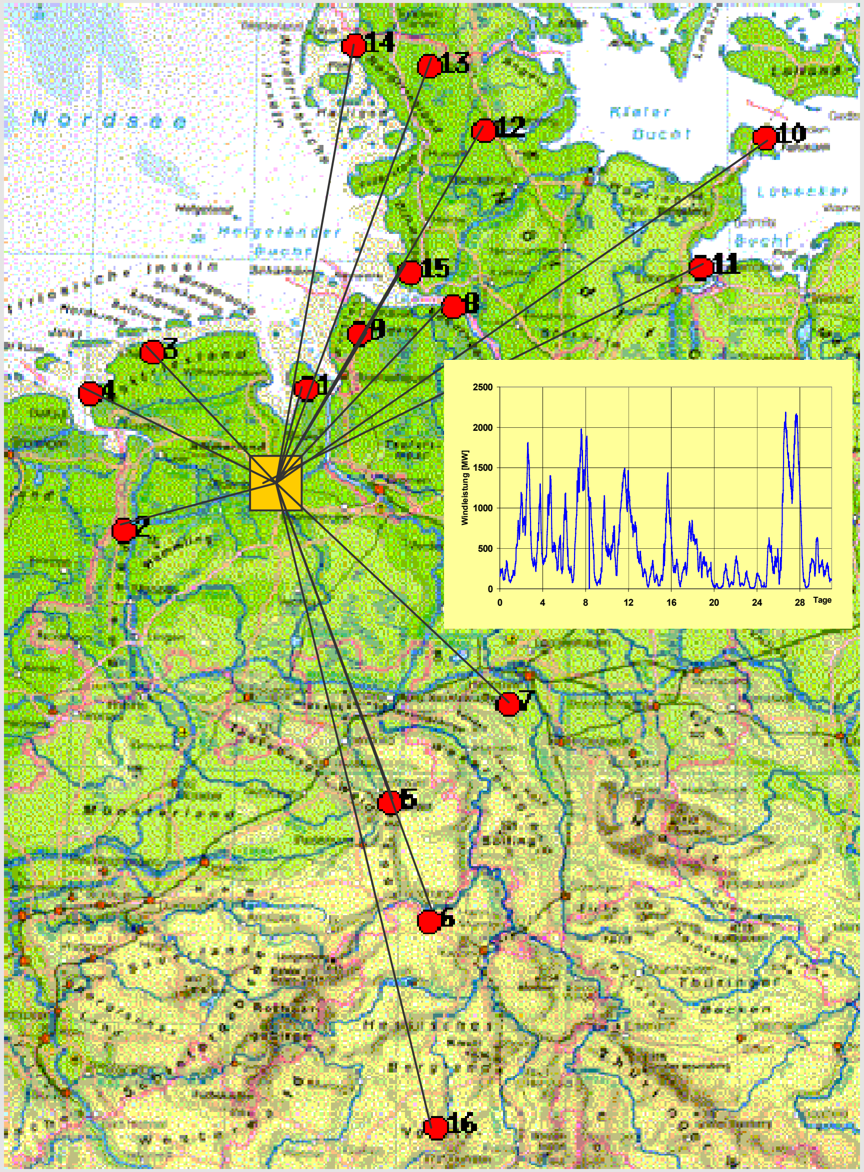
Prediction Methods



Sub-division of the control zones in small areas (like FEM)

8585 areas (on- and offshore)

Online calculation methods



Calculation of current power output of each grid square by evaluation of all representative power signals

$$P_{sum} = \sum_i P_i$$

considered parameters:

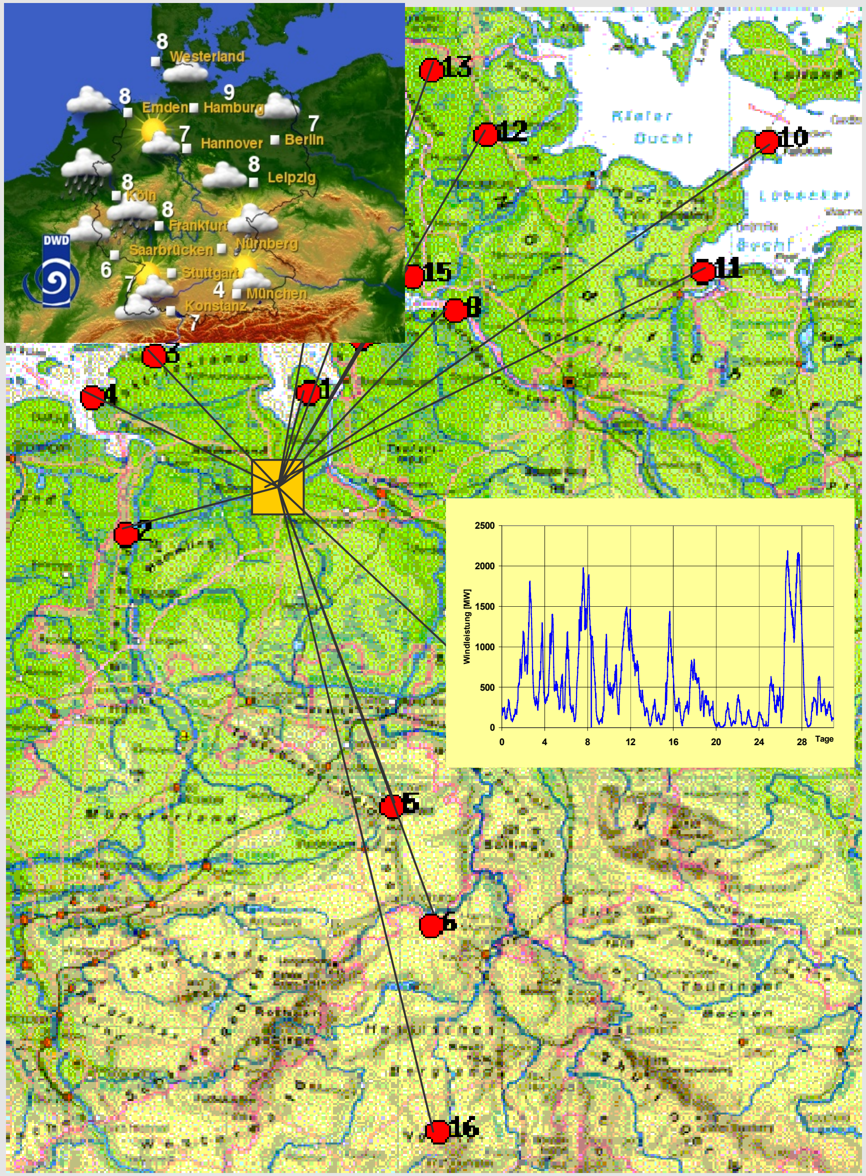
distance

roughness

control systems

$$P_i = P_{cap,i} k_i \sum_j s_j * A_{ij} * P_j$$

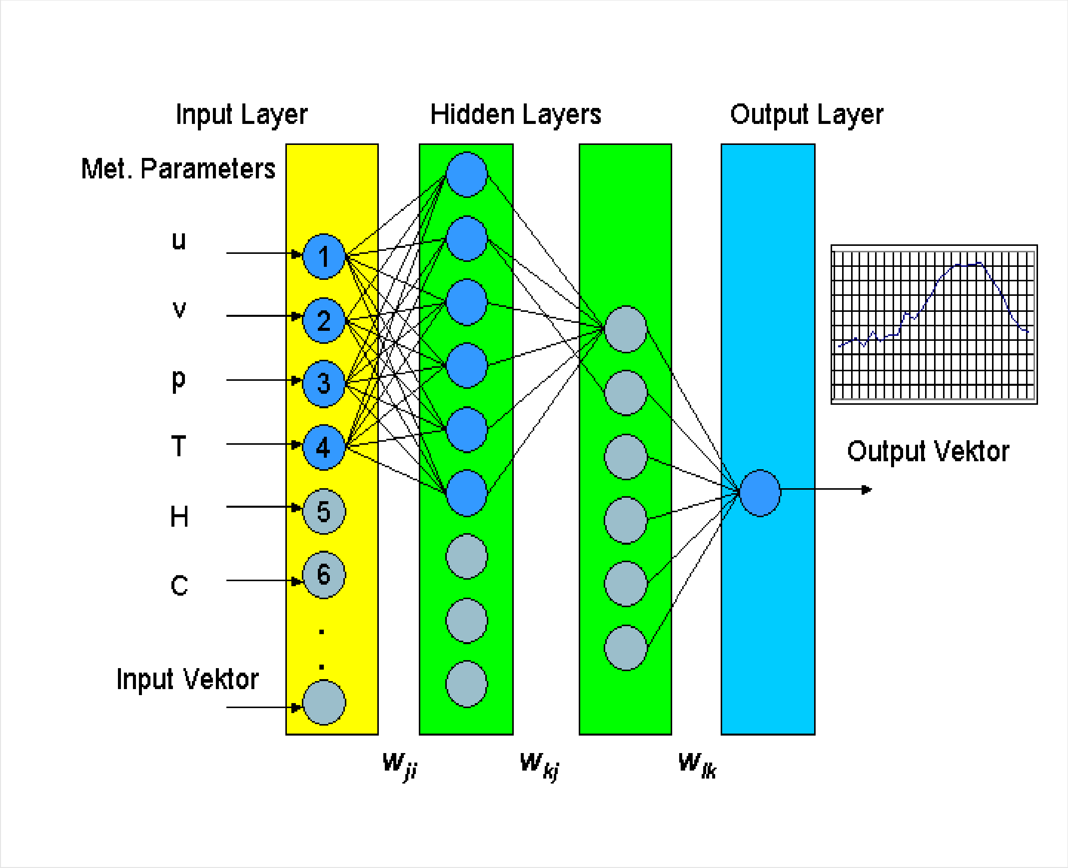
Prediction Methods



Calculation of **expected power output** of each grid square by evaluation of all representative wind farm power output predictions

using NWP models and Artificial Neural Networks

Prediction Methods



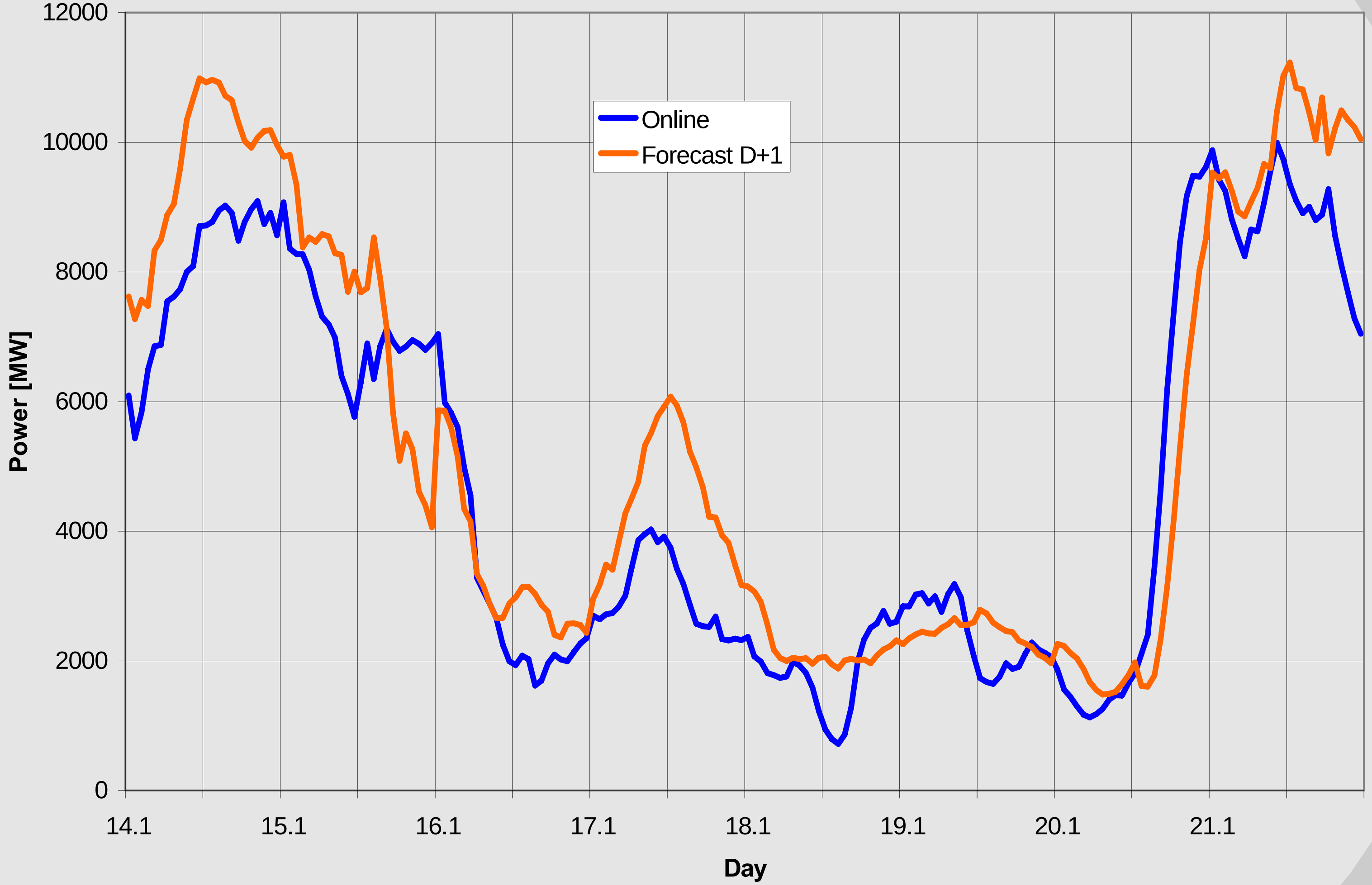
Artificial Neural Networks

$$\hat{P}(t) = g\left[\sum_{j=1}^{m} A_j g\left(\sum_{k=1}^{n} w_{jk} x_k(t)\right)\right]$$

Support Vector Machines

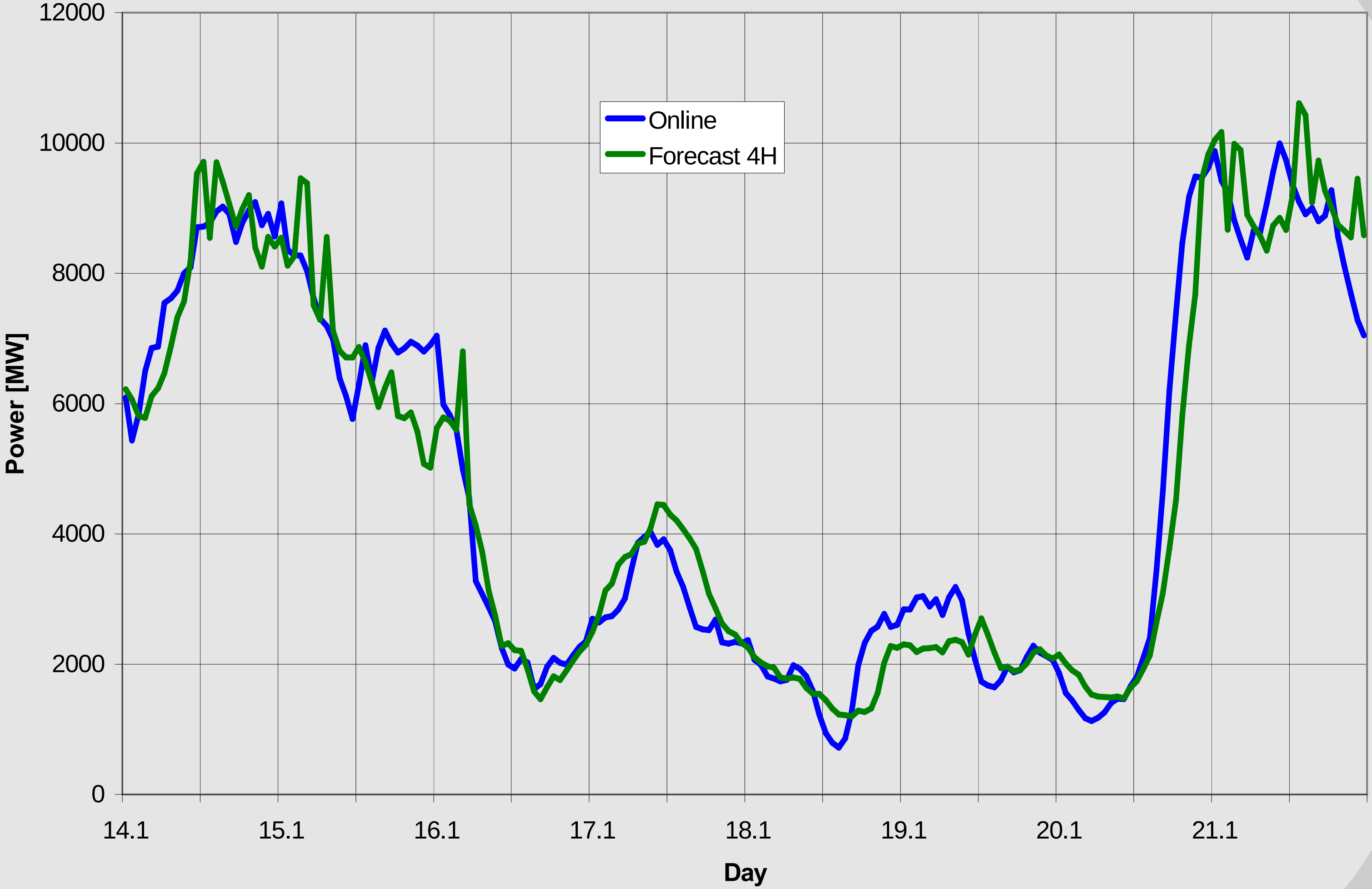
$$f(w_t) = sign\left[\sum_{\sup port\ \ vectors} P_i \alpha_i K(w_i, w_t) - b\right]$$

Prediction Methods



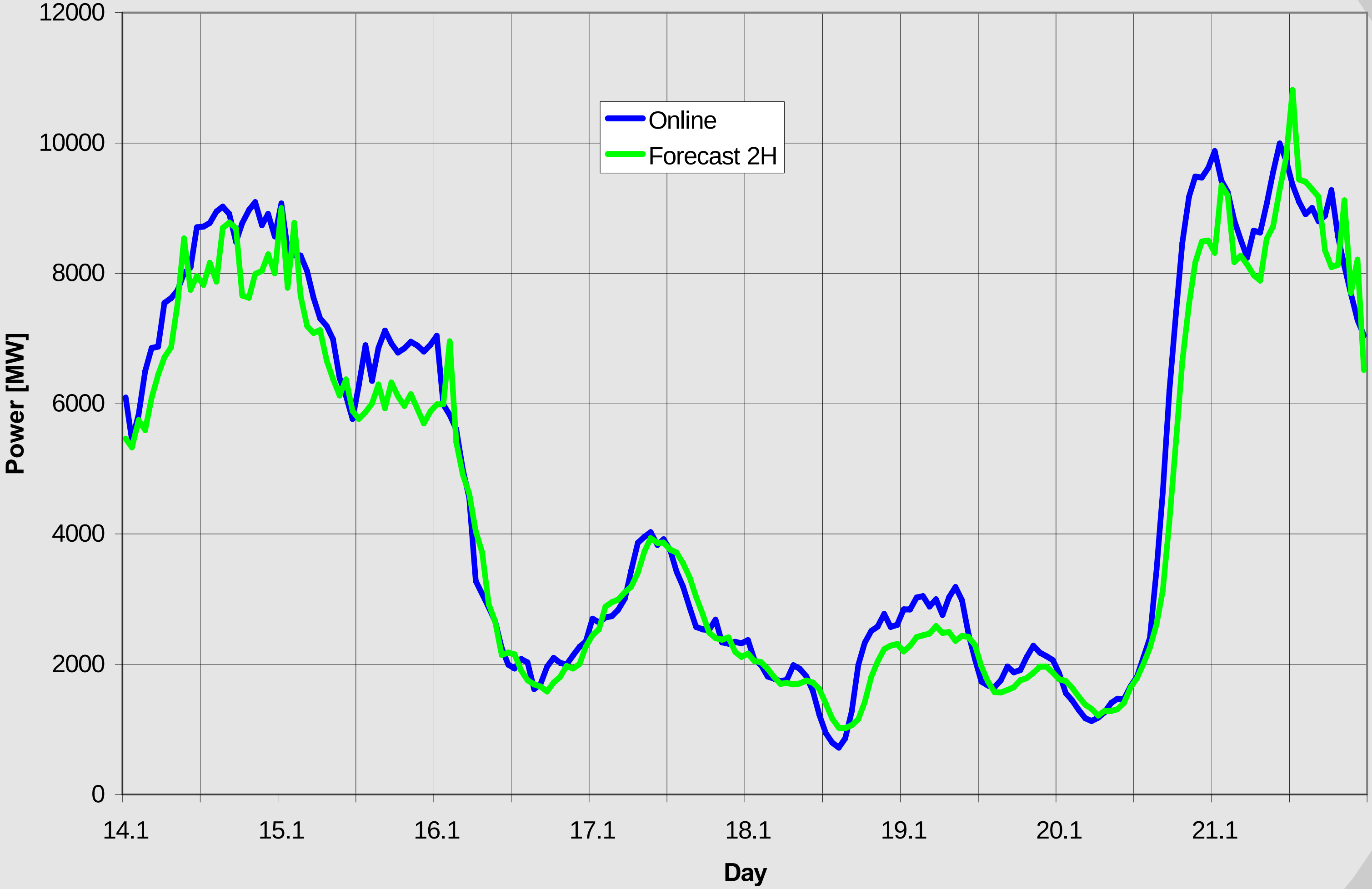
Wind generation – online, day-ahead forecast

Prediction Methods



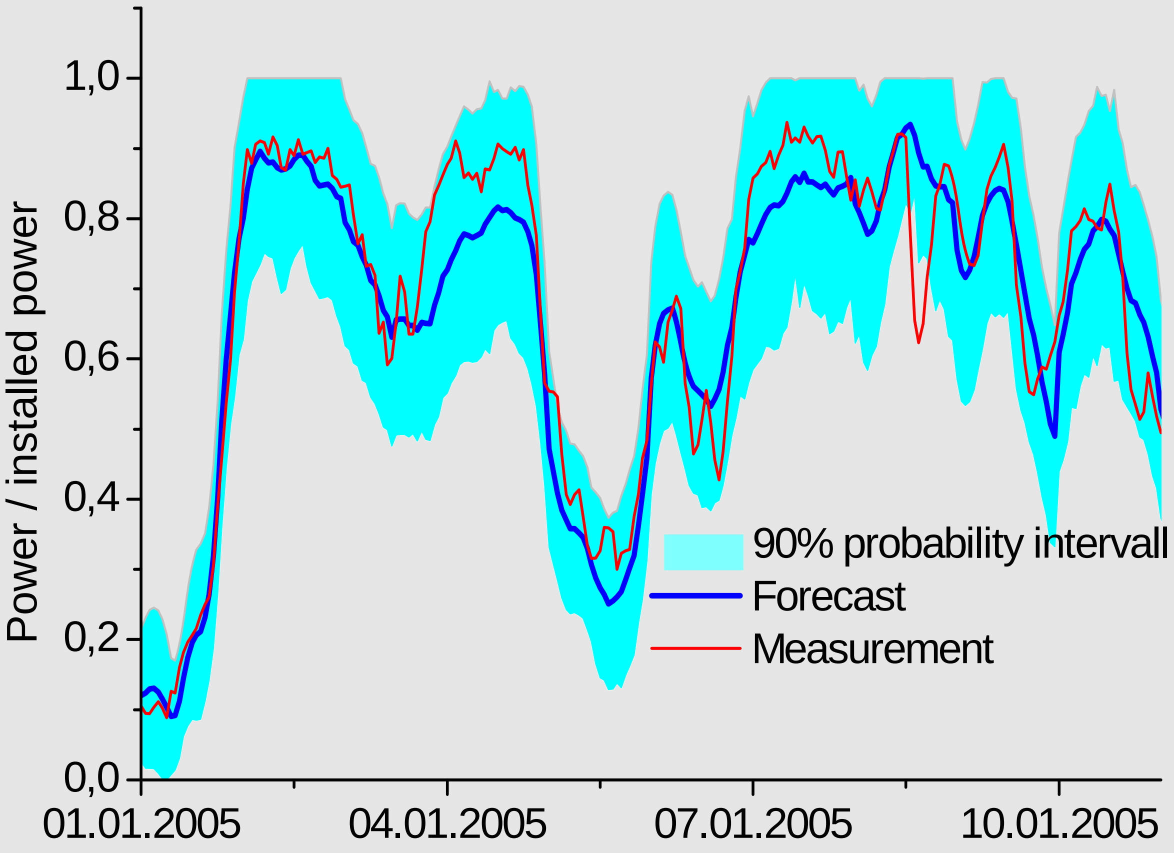
Wind generation – online, 4 hour forecast

Prediction Methods



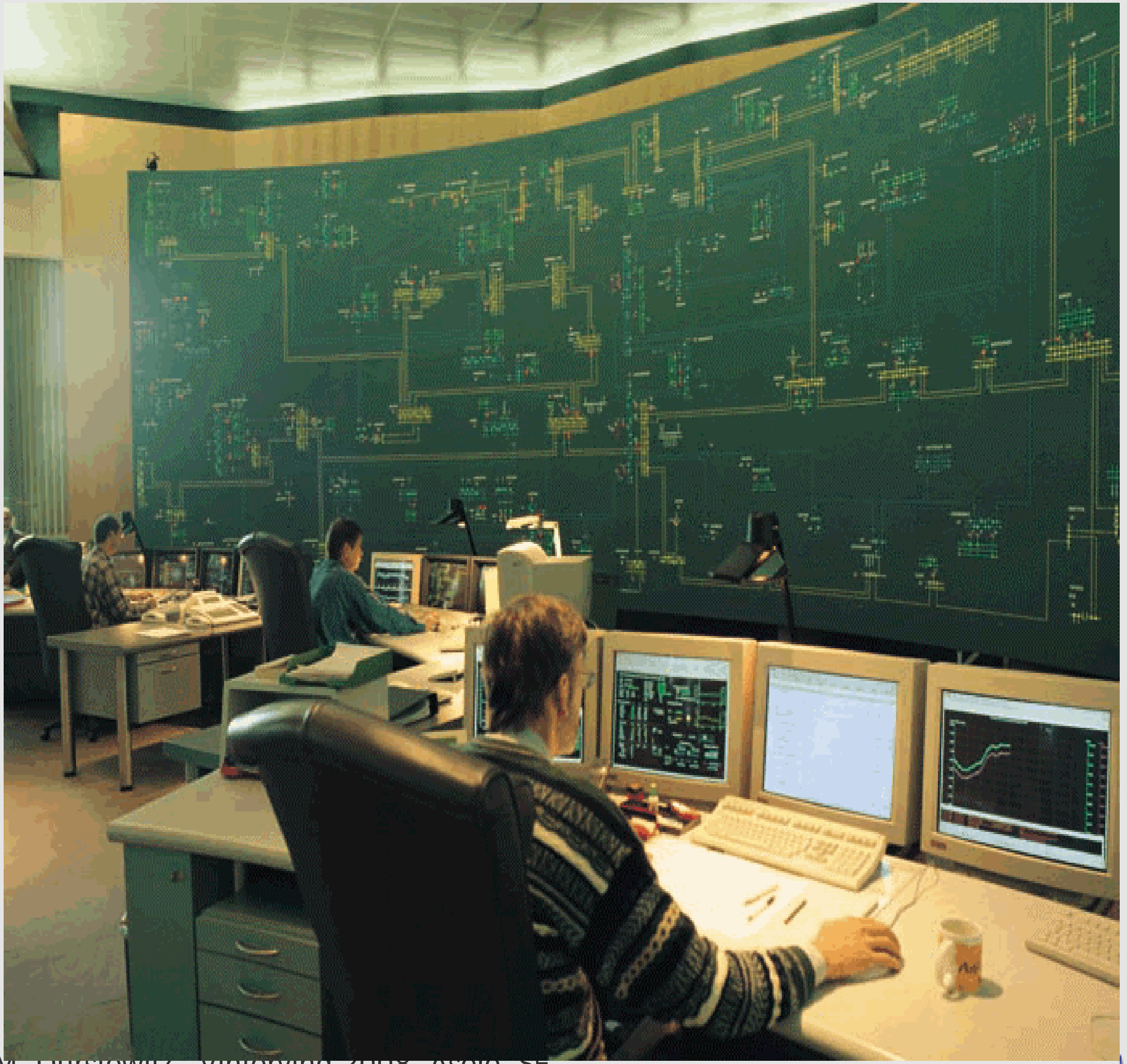
Wind generation – online, 2 hour forecast

Prediction Methods



Short-term forecasts with associated confidence areas

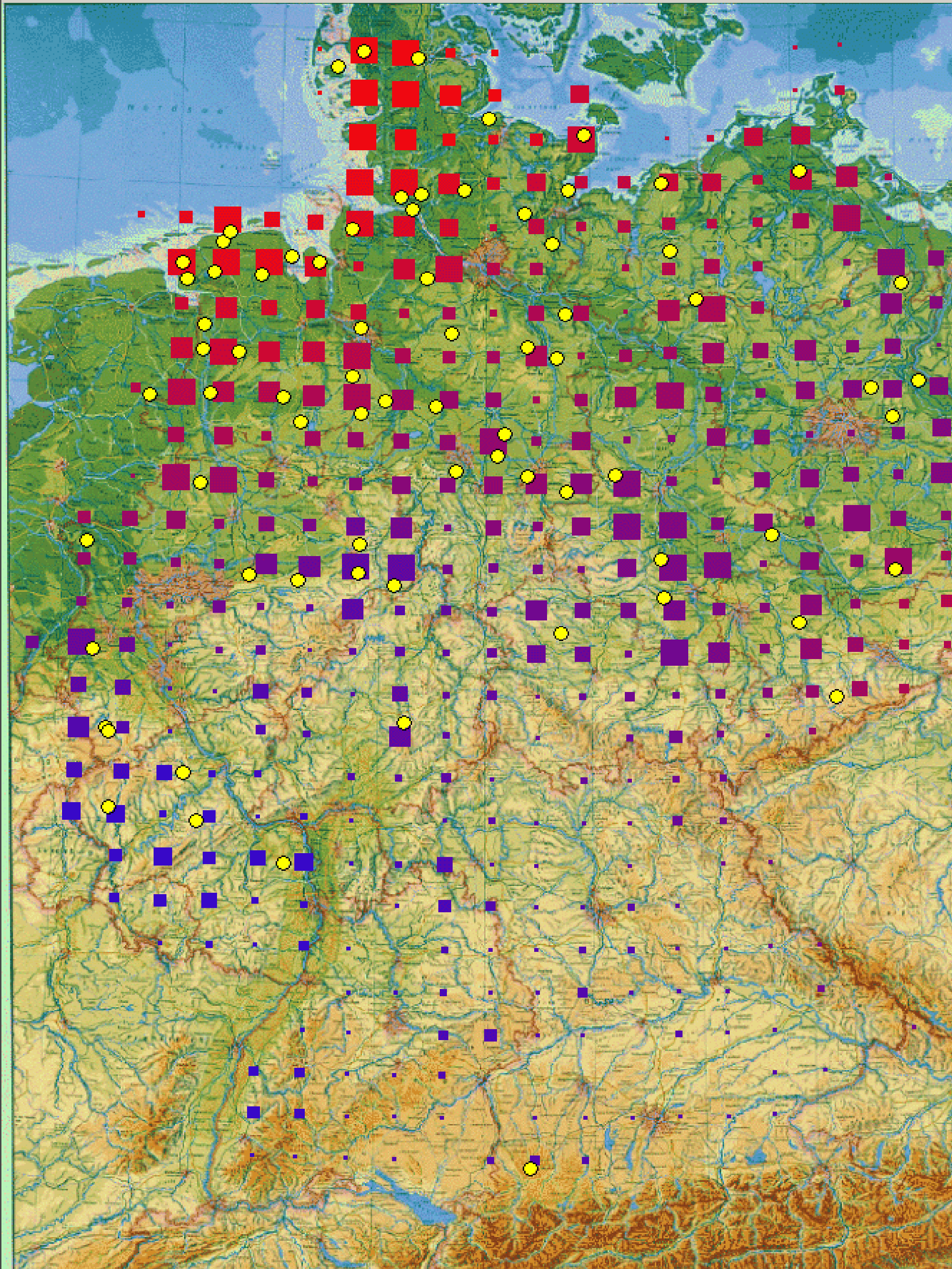
Integration of large quantities of wind power into the energy supply



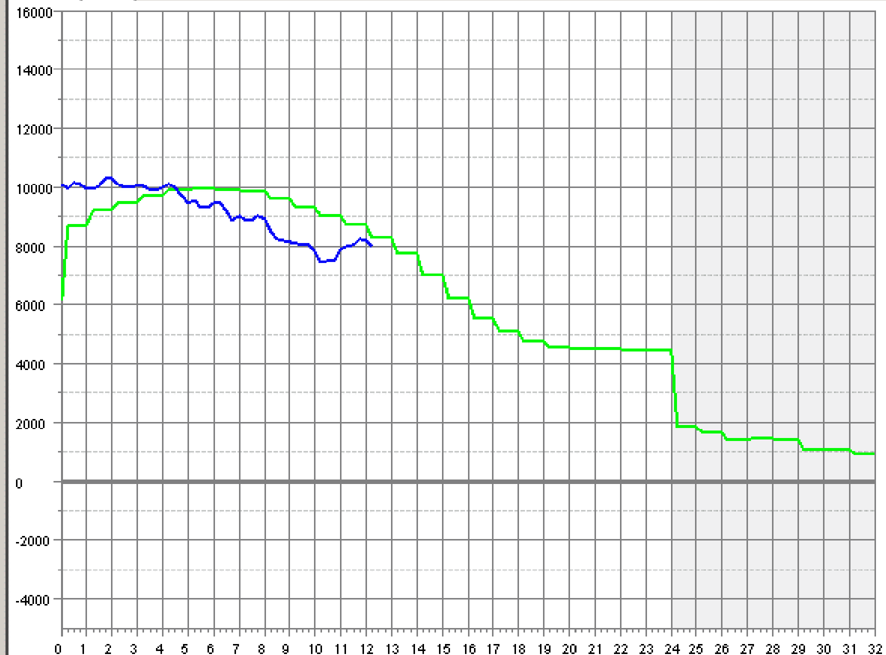
Dispatch centre TSO

WindPower-Management-System Germany

File View Help



Curves | Table



Measurement
DWD forecast
Short-term forecast
Reference curve
Deviation reference-measurement

Measurement from 25.12.2004 00:00
to 25.12.2004 12:15
DWD forecast of 24.12.2004 07:00

Total instantaneous power output: 7994 MW
Instantaneous capacity factor: 0,00 %

#	St...	On...	Name	Capacity	ICF	#	State	On...	Name	Capacity	ICF
1		☑	Nordenham	13.5 MW	83.5 %	2		☑	Niederlangen	93.0 MW	30.5 %
3		☑	Holtriem	52.5 MW	70.4 %	4		☑	Manslagt	29.1 MW	78.0 %
5		☑	Freiburg	40.6 MW	75.8 %	6		☑	Krempel	80.8 MW	58.4 %
7		☑	Travemuende	7.9 MW	45.9 %	8		☑	Lindewitt	34.0 MW	93.2 %
9		☑	Niebuell	24.21 MW	80.7 %	10		☑	Ulrichstein	10.3 MW	33.8 %
11		☑	Gettorf	13.5 MW	116.5 %	12		☑	Benhausen	33.275 MW	22.2 %
13		☑	Daseburg	32.0 MW	8.2 %	14		☑	Schwicheldt	31.3 MW	48.5 %
15		☑	Bleckenstedt	27.9 MW	61.4 %	16		☑	Wedehorn	33.9 MW	59.3 %
17		☑	Stadorf	38.75 MW	65.6 %	18		☑	Bueren	46.25 MW	28.5 %
19		☑	Emern	24.0 MW	76.1 %	20		☑	Pennigsehl	51.0 MW	38.8 %
21		☑	Katensen	31.5 MW	13.2 %	22		☑	Gestorf	16.0 MW	54.6 %
23		☑	Bentstreek	18.0 MW	80.2 %	24		☑	Damsum	26.4 MW	64.4 %
25		☑	Ihlow	49.8 MW	78.2 %	26		☑	Lorup	37.8 MW	74.3 %
27		☑	Oersdorf	46.7 MW	56.2 %	28		☑	Tewel	35.2 MW	31.4 %
29		☑	Rhede	77.4 MW	64.4 %	30		☑	Wybelsum	37.5 MW	68.7 %
31		☑	Wilhelmshav...	8.0 MW	78.7 %	32		☑	Wulfenau	39.6 MW	0.0 %

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Verein an der Universität Kassel e.V.

Wind Farm Control, Prediction Systems

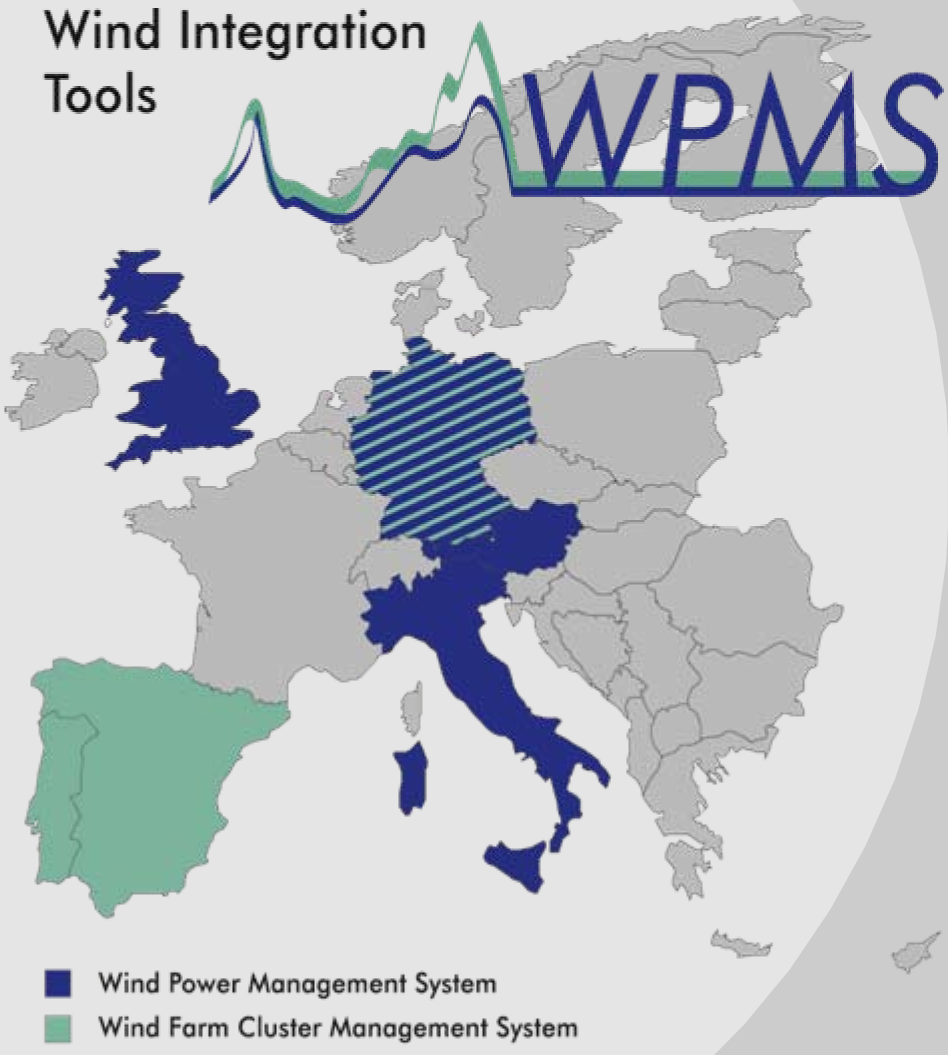
AI-based Prediction System
WPMS

E.ON Netz,
Vattenfall Europe Transmission,
RWE Transportnetz Strom,
EnBW Transportnetze

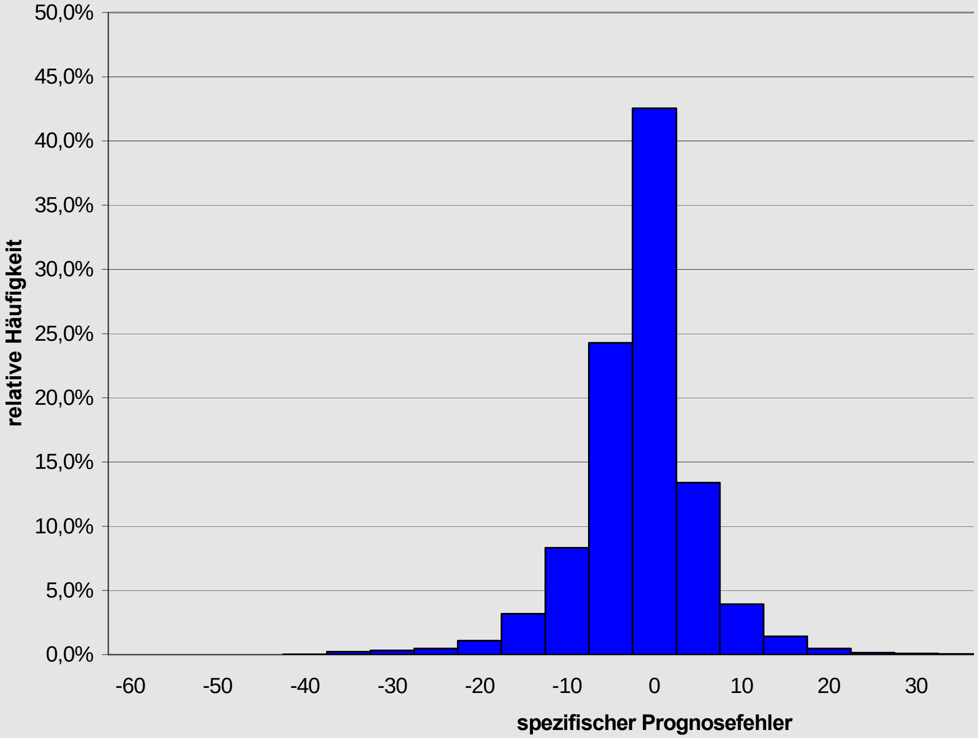
Verbund Austria
TERNA Italien
Egypt, Zafarana
UK, National Grid

Wind FarmCluster Management
WCMS

E.ON Netz
Vattenfall Europe Transmission
Red Electrica Espana
Redes Energeticias Nacionais



Forecast errors - statistics



Prediction error for TSO control zone

Forecast error reasons:

- weather forecasts storm: ATA ≠ ETA
- different trajectory of predicted storm
- other systematic errors
- Turbine response is utterly at variance with standard behaviours

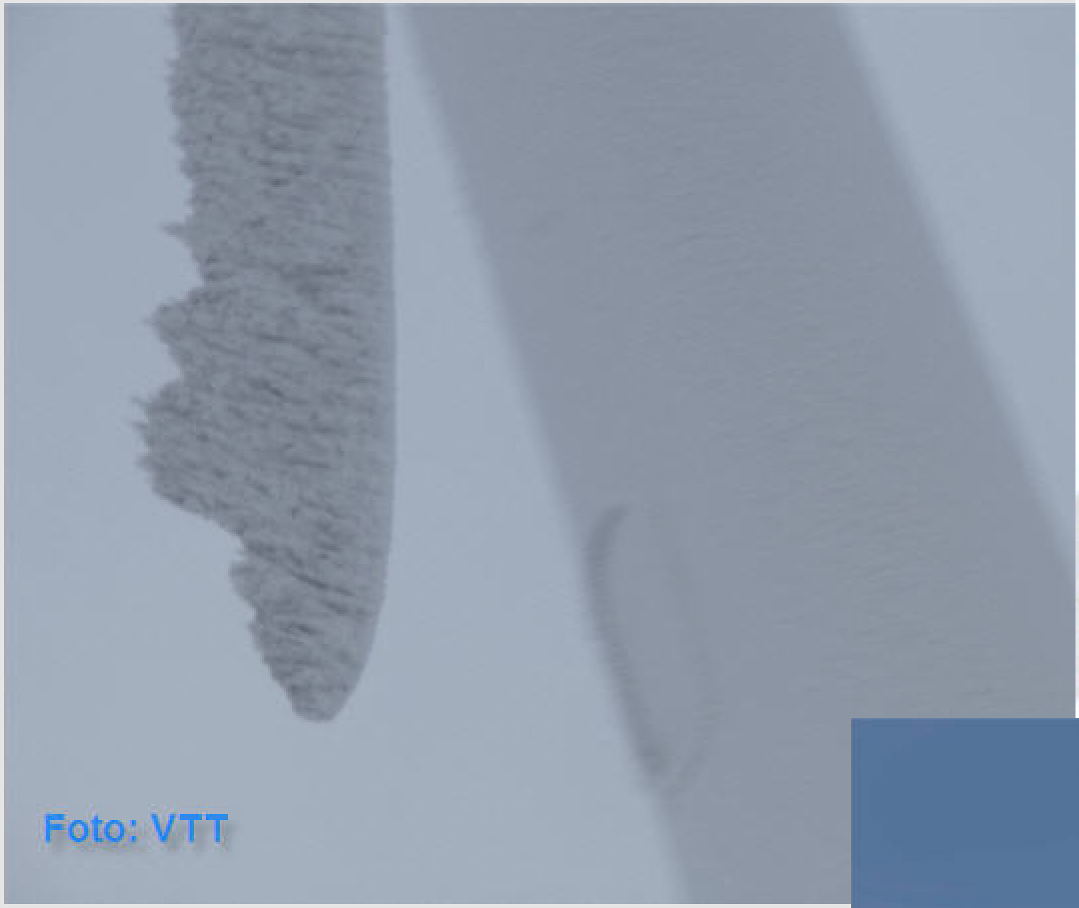
? → icing

Mean errors (2006)

< 6.0% RMS (24h forecast)

< 3.5% RMS (4h forecast)

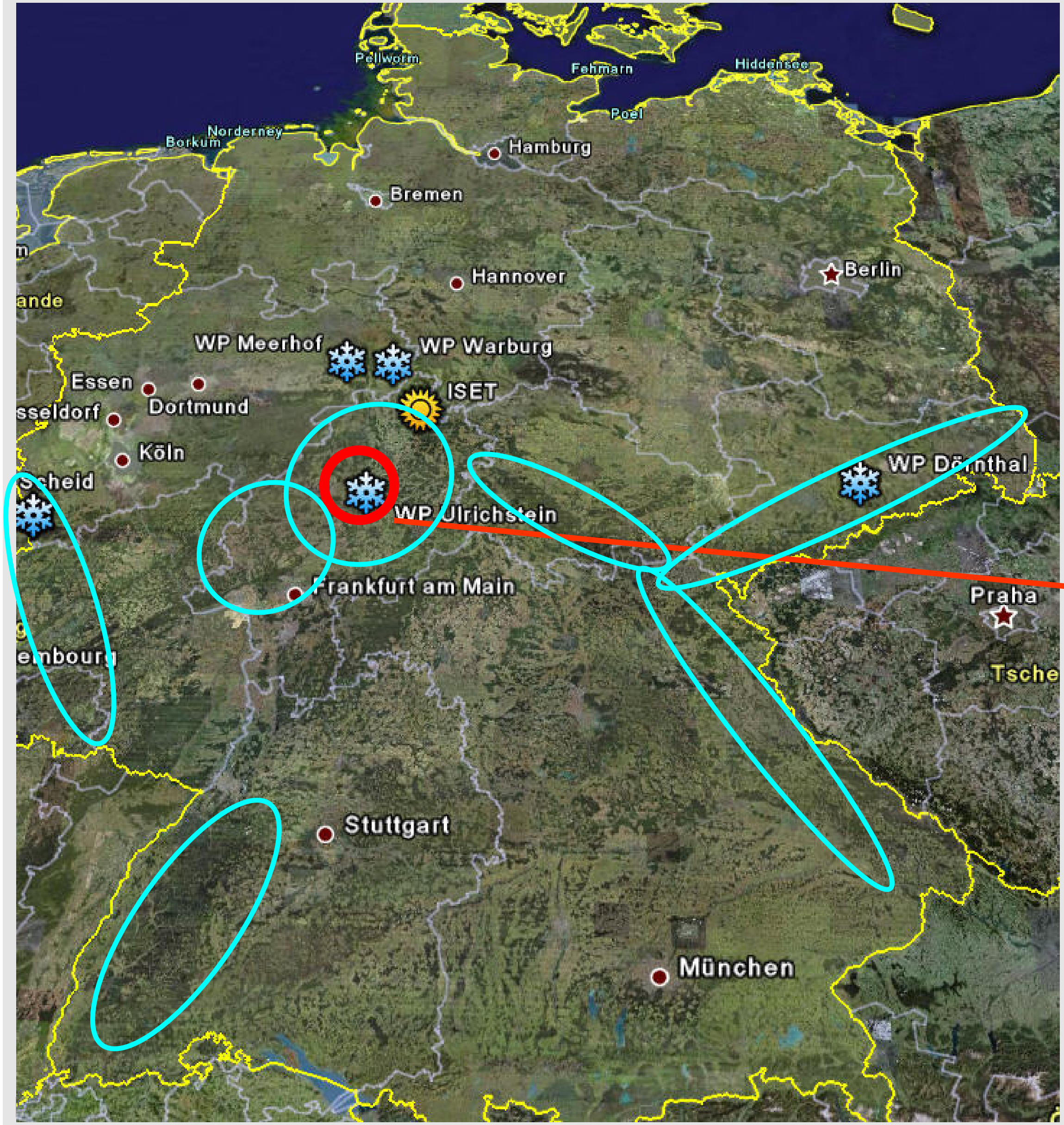
Wind & ice



Reduced aerodynamic efficiency

Faulty sensor signals

Forecast errors caused by icing ????



Task:

Analyse forecast quality with measured results

Selected sites:
Mountainous regions
Elev. 300 – 700 m asl

Example:

WP Ulrichstein/Vogelsberg
sev. types / ~ 11 MW_{tot}

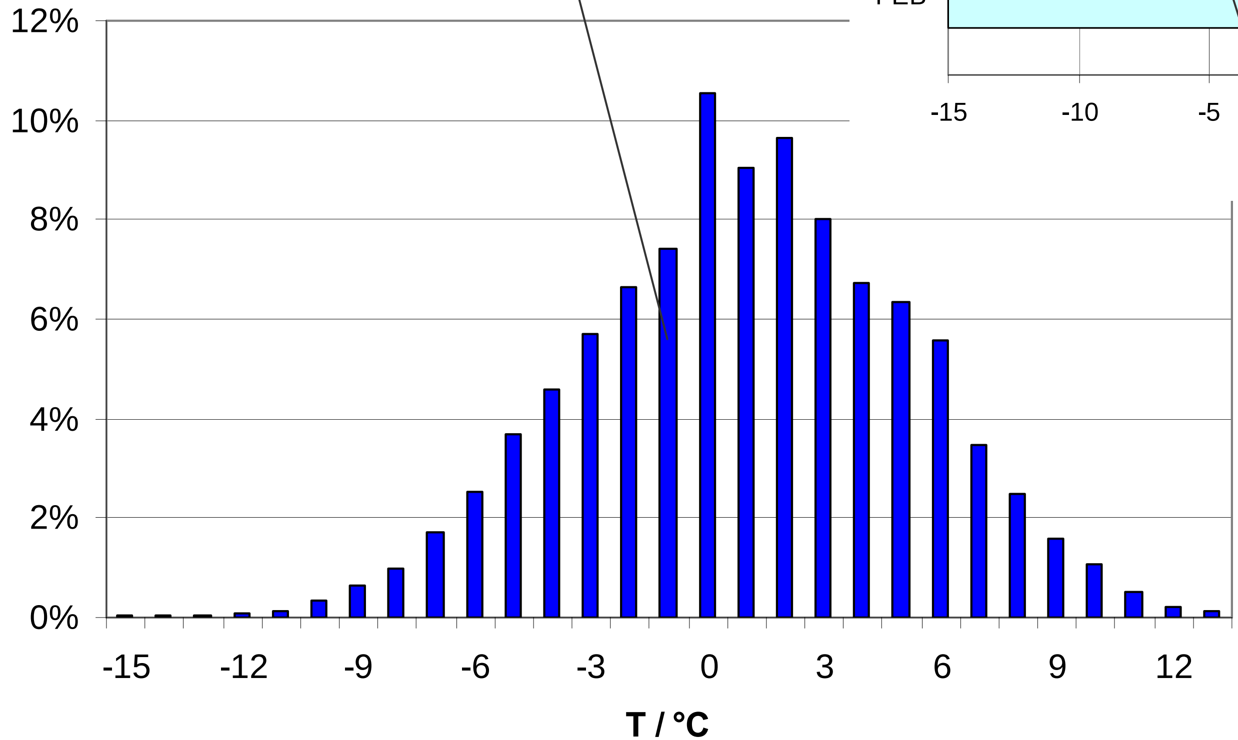
Elevation ~600 m asl

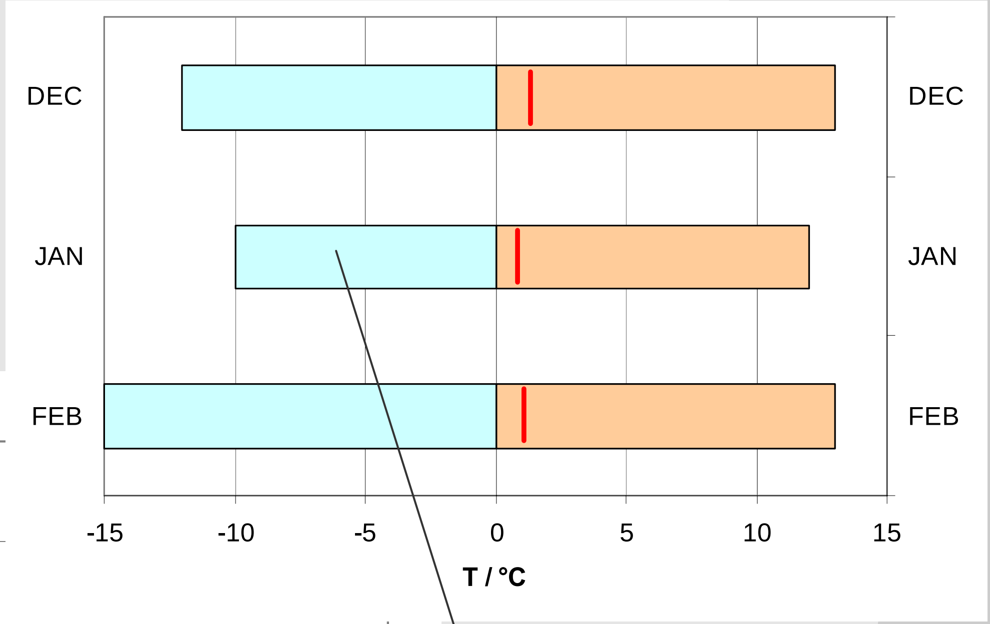
Low mountain range

Several icing reports

WP Ulrichstein / Temperatur profile (2004 – 2008 JAN, FEB, DEC)

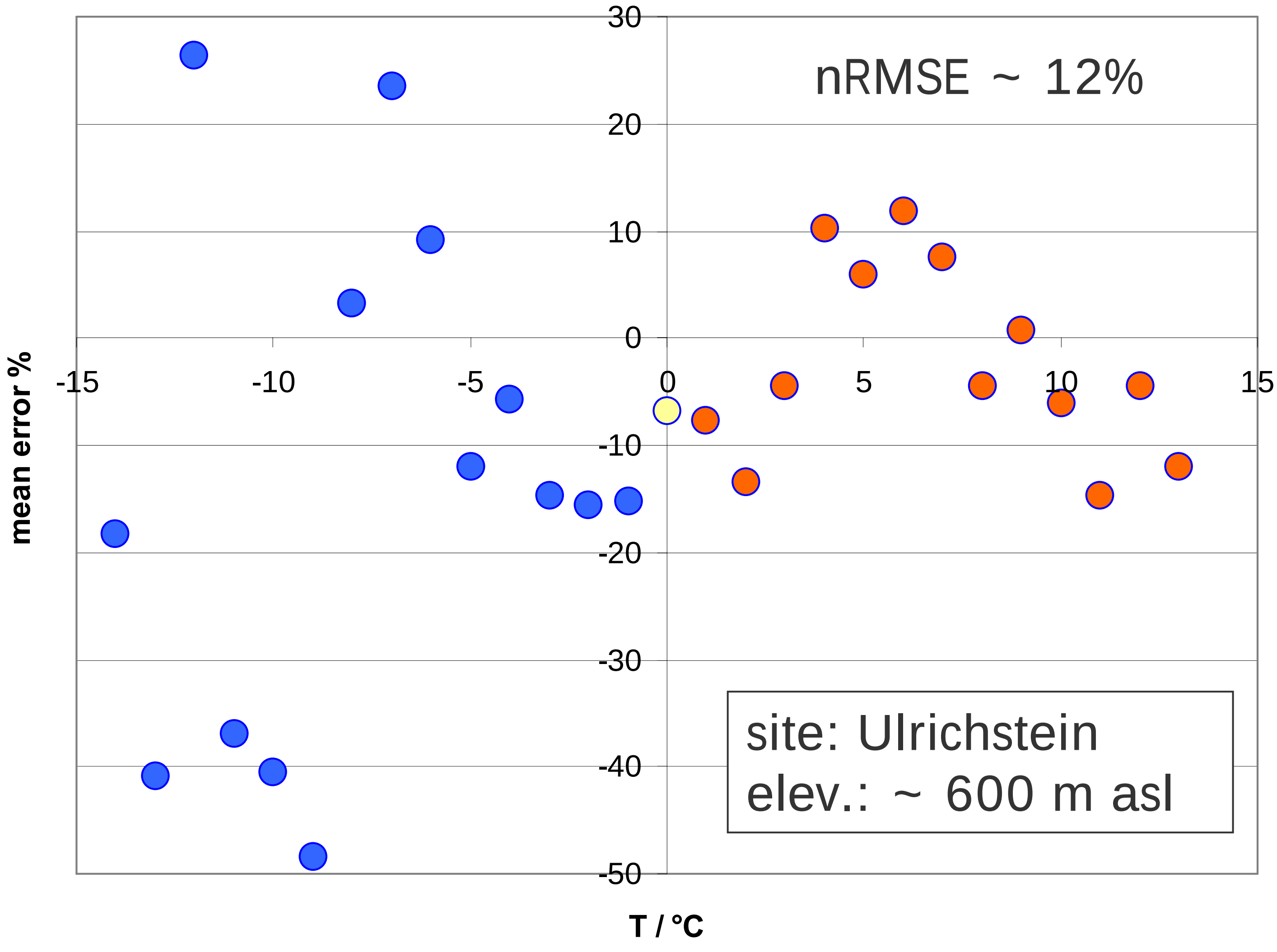
Frequency distribution of ambient temperature



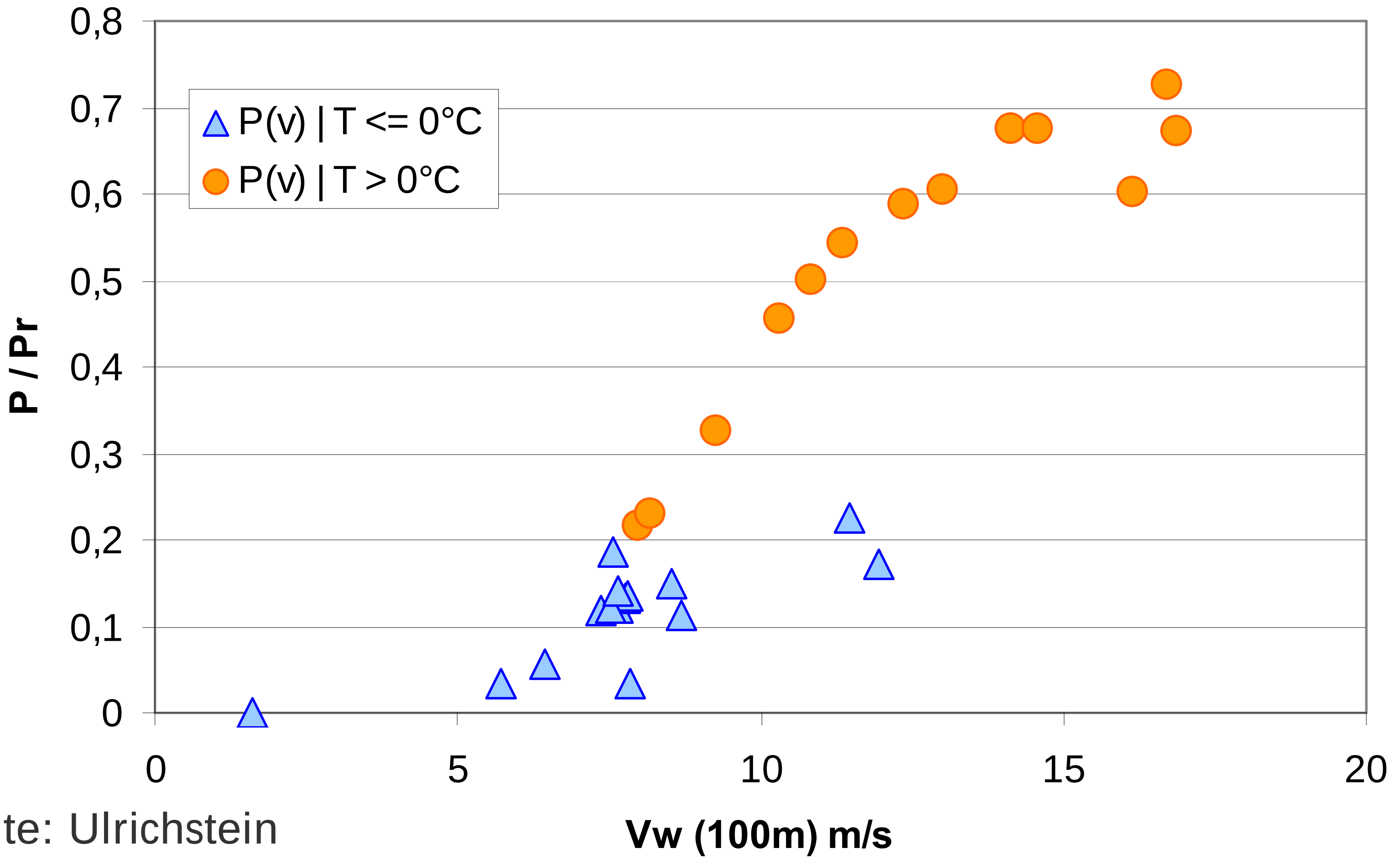


Span of T and avg temp. by months

Distribution of observed forecast errors vs. temperature



Power output vs. wind speed (WP Ulrichstein)



site: Ulrichstein
elev.: ~ 600 m asl

Conclusions / next steps

- *WPMS is a powerful tool for integrating wind power*
- *Reliability of results has to be checked for low temperatures*

Next steps:

- *Analysis of data from other sites*
- *Inclusion of further meteorological parameter*
- *Search for typical footprints*
- *Integration into ANN training procedure*
- *Verification of results*
- *...*
- *Implementation into update WPMS*