Summary of Forecast Methodology of Previento

prepared by energy & meteo systems GmbH

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1 Technical description of forecast methodology

Previento is a physical wind power prediction system [Lange2005] and is based on a meteorological description of the atmosphere. Basically, Previento converts data from numerical weather prediction models (NWP) provided by Weather Services into power output (figure 1). The conversion from raw data of a weather model into power output of a specific wind farm is carried out in several steps with separate modules. This means that Previento's calculation of the correct wind speed at hub height and the transformation of this wind speed into power output can be provided as separate results.

The time horizons of the underlying numerical weather forecast determine Previento's timeframe. Usually, weather services cover 0-120 hours based on a sequence of different NWP models.

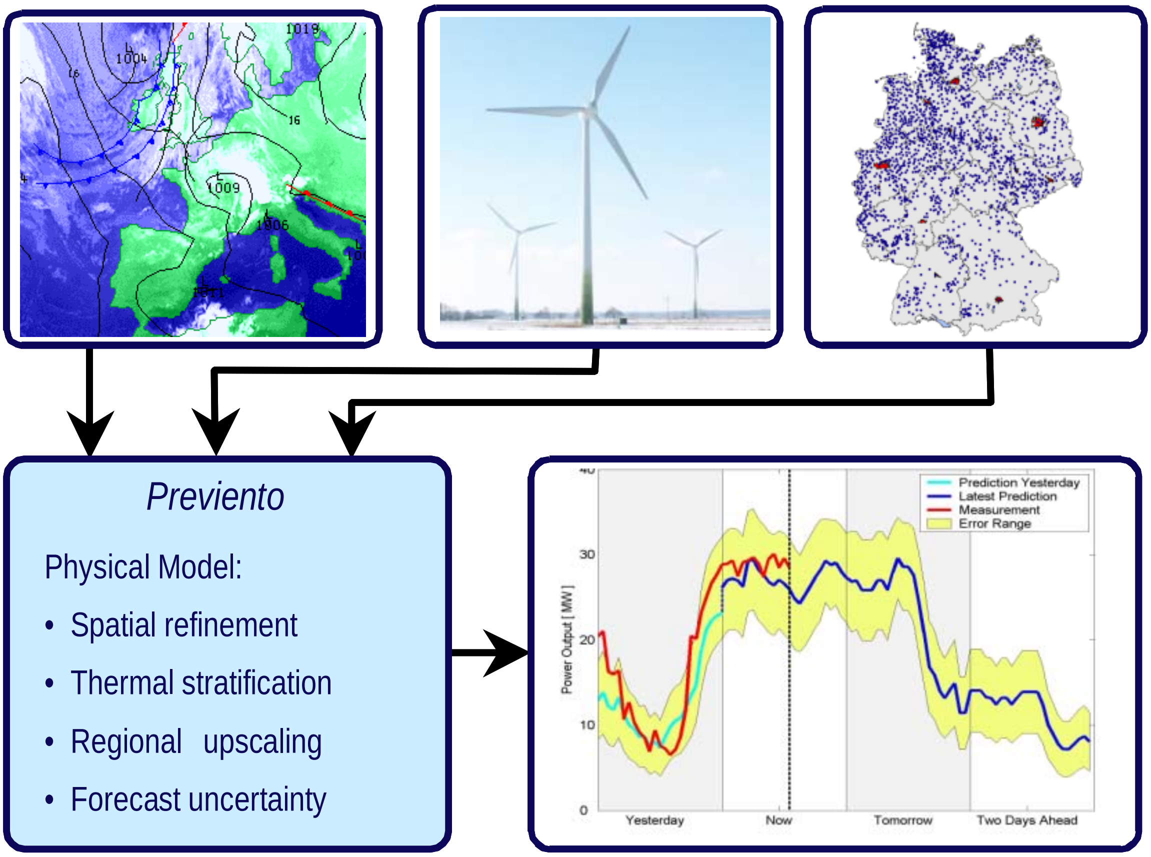


Figure 1: Basic scheme of the physical prediction system Previento. Based on weather data from several met services and information on the predicted wind farms the system uses physical methods to provide a wind power forecast.

In general, Previento does not require measurement data, neither wind speed nor power output, to produce a forecast and, thus, can deliver accurate predictions from the beginning of operation of each wind farm and for potential wind farm sites. However, measurement data can optionally be used to optimise the forecast in two important ways: the measured data can beneficially be used in the power conversion module and to obtain an optimal result for very short time horizons in the range 0 to 6 hours.

2 Methodology to provide the Forecasted meteorological data

2.1 NWP data

The numerical weather prediction is essential for the accuracy of the deterministic wind power prediction. For our solution we use input from different NWP models. Each NWP is basis for the calculation of a single wind power prediction. The optimal wind power prediction will be calculated using the combination tool described in the next section.
For Alberta we will use 3 different NWP inputs.

- GFS, National Center for Environmental Prediction,
  Resolution: ~33 km
  4 runs a day: 00, 06, 12, 18 UTC
  0 – 168 hours

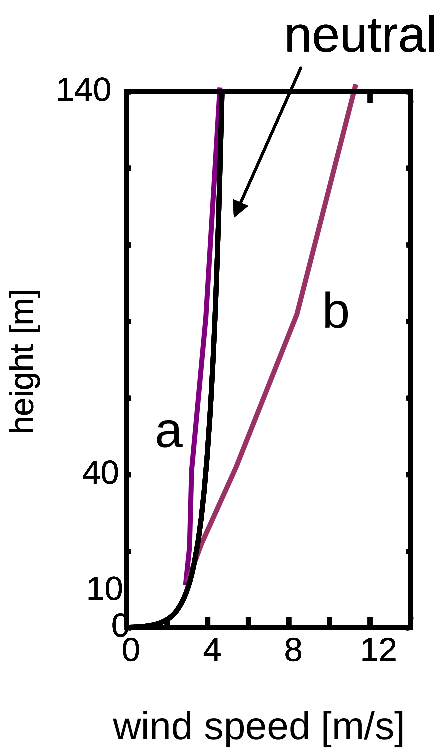
- ECMWF, European Center for Medium Range Forecasts
  Resolution: 0.25°
  2 runs a day: 00 ,12 UTC
  0 - 72 hours

- GEM, Environment Canada
  Resolution: 15 km
  2 runs a day: 00, 12 UTC
  0 – 48 hours

[netter plot der domain mit google maps/earth von ronny ??]

2.2 Calculation of local wind speed at hub height

Previento calculates the wind speed at hub height using physical parameterisations of the lower atmosphere based on NWP data. The coarse resolution of the numerical weather prediction is spatially refined to obtain the wind speed for given sites. For this purpose the local conditions in the area of the wind farms and the wind farm geometry into account.



For a correct transformation of the raw numerical weather data to hub height Previento considers the thermal stratification of the atmosphere (figure 2). This ensures that unstable situations with a high degree of thermally driven convection are treated differently from stable conditions leading to an individual wind profile for the prevailing weather conditions.

Figure 2: Previento calculates the wind speed at hub height for the specific meteorological situation. Due to the thermal stratification of the atmosphere the vertical profile can change significantly between unstable situations (a) and stable ones (b).

2.3 Situation-based combination module

The combination module is able to automatically classify weather situations which are relevant for wind power prediction. This allows for an optimal combination of different NWP inputs according to the individual strengths and weaknesses of each model in different forecast situations. This approach does not only lead to a strong reduction of the overall forecast error, it works particularly well in situations where extreme events occur (like storm fronts). For Alberta NWP data from Canada Environment, GFS and ECMWF is useds.

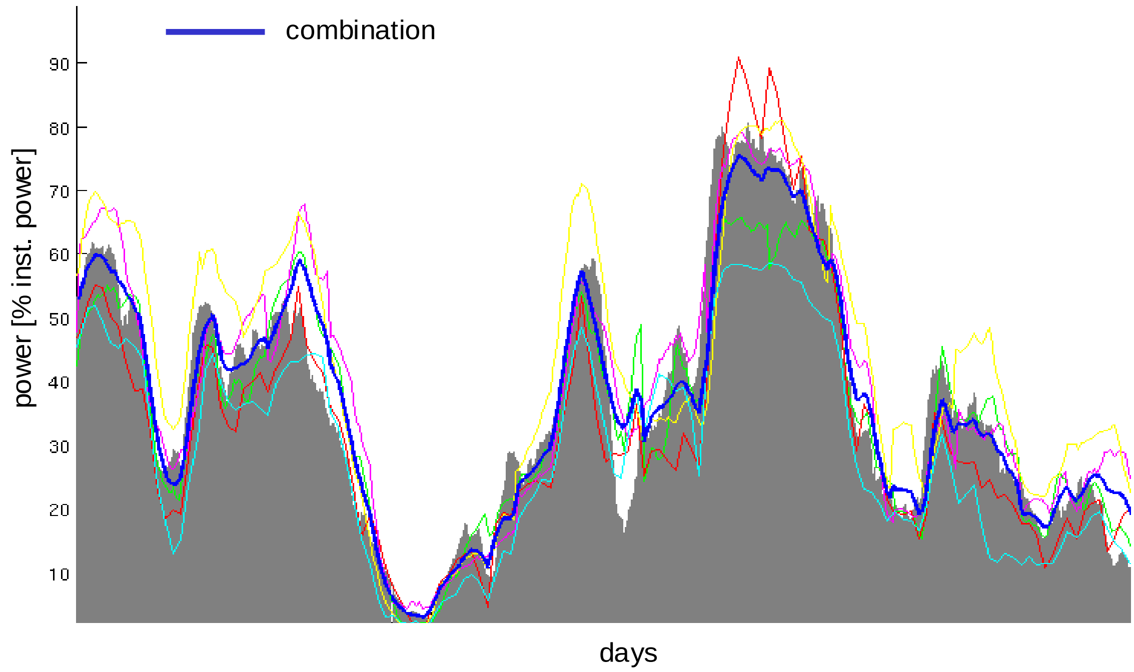


Figure 2: The weather dependent combination wind power forecasts (thick line) based on different NWP data (thin lines) strongly improves the accuracy and leads to better results in extreme events reducing the high risk of wrong predictions .The grey area represents the real-time measurement.

3 Methodology to perform power conversion

Previento provides a two-step approach to convert the wind speed at hub height into power output of a wind farm.

The first step is equation based and can be applied to any wind farm to obtain an accurate forecast and is based on the (certified) power curves of the individual wind turbines and a calculation of the direction dependent shadowing effects inside the wind farm based on its geometry.

The second step requires historical measurement data of the power output of the wind farm (not necessarily each turbine). This second step leads to an improved forecast by extracting a site-dependent and direction-dependent power curve of the specific wind farm from the historical data (figure 3). This procedure accounts more precisely for local effects and individual characteristics of the wind farm.

Hence, depending on the availability of historical measurements (at least half a year) the complexity of the power conversion method can be varied.

For the existing wind farms in Alberta where suitable measurements of the power output are available the direction-dependent power curves (second step) are used.

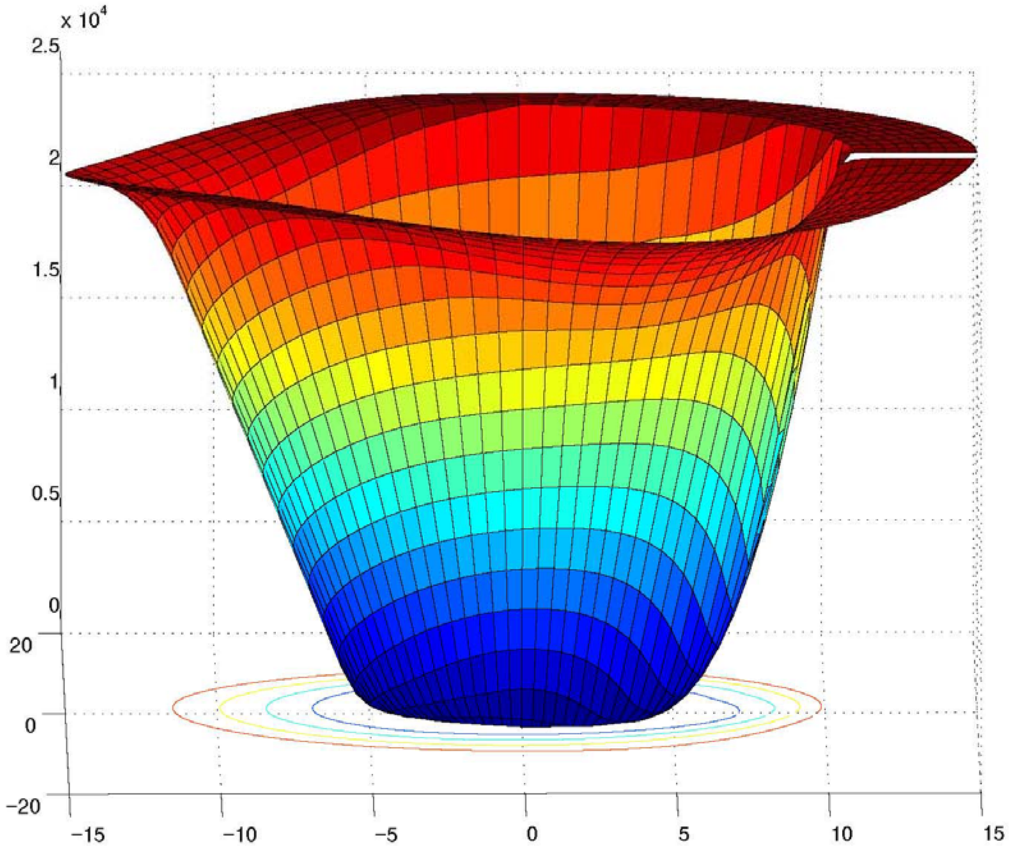


Figure 3: Direction-dependent power curve generated with second step of Previento*'s power conversion procedure. The plot shows the power curve function for 360 degrees.*

4 Uncertainty of prediction

In addition, the Previento supplies the uncertainty of the individual value of the power forecast or meteorological forecast depending on the weather situation. Hence, the lower and upper value of the confidence interval is not fixed but changes due to meteorological conditions.

The given uncertainty takes the underlying statistical error distribution of the predicted parameter into consideration. For deviations between predicted and measured wind speed the probability distribution is Gaussian while the equivalent distribution for power output is strongly non-Gaussian (figure 4). This effect is due to the non-linear power curve.

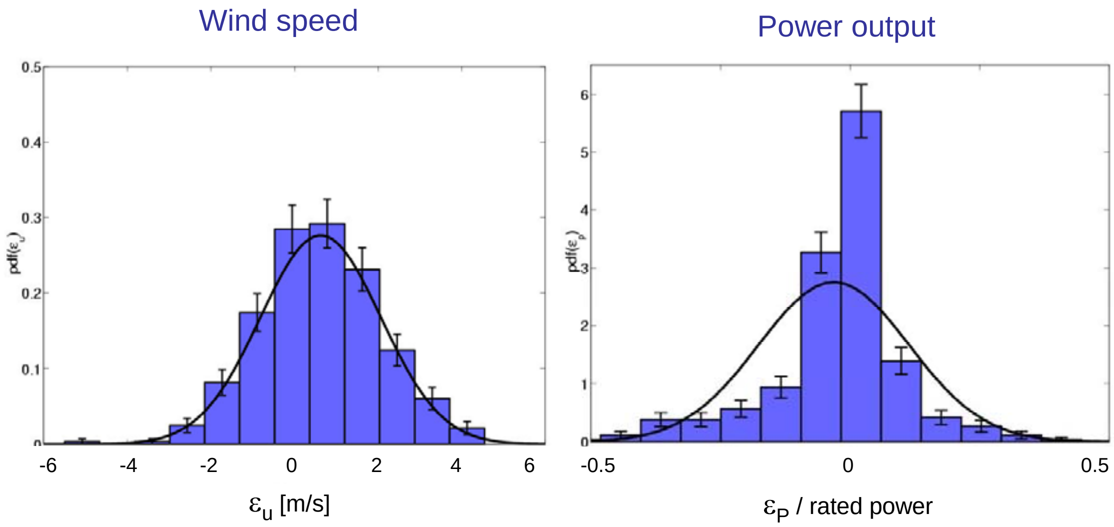


Figure 4: The uncertainty estimation in Previento considers the type of statistical distribution (pdf) of the forecast error. For wind speeds (left) the deviations between prediction and measurement follow a Gaussian distribution. For power output the corresponding distribution (right) is strongly non-Gaussian due to the power curve.

The uncertainty is given as a confidence interval at a pre-defined level of confidence. The level of confidence is usually 70%. Despite the fact that the underlying distribution of deviations between forcecast and measurement for the power output of wind farms is non-Gaussian, the 70% confidence interval approximately corresponds to the traditional σ-interval of normal distributions. The uncertainty interval provided by *Previento* is based on percentiles symmetric to 50% percentiles referring to the specific weather class.

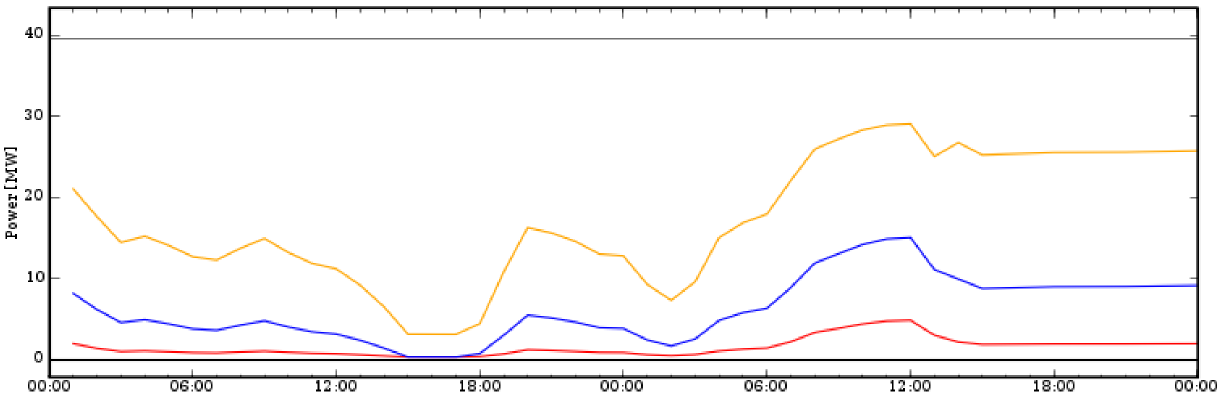


Figure 5: Uncertainty of prediction given as 70% confidence interval (red lines) around the predicted value (blue line). The level of uncertainty changes with the forecast situation.

5 Ramp rates

Strong gradients ("ramps") in the power output can occur due to different meteorological phenomena, such as fronts, local winds or thermal effects (see figure 6). Previento predicts the ramp rates as the anticipated gradients of the power production from one hour to the next hour. The ramp rates are derived from differentiating the prediction.

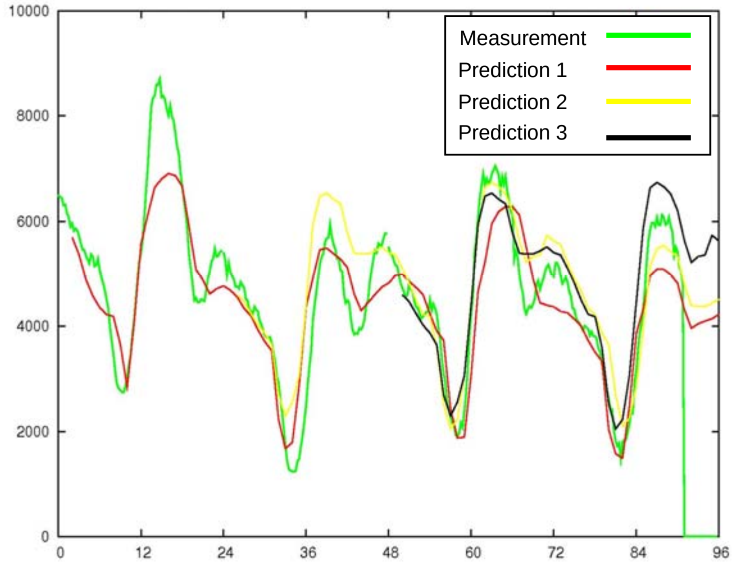


Figure 6: In certain meteorological situations the power output changes dramatically from one hour to the next. The plot shows strong gradients in the measured wind power (green line) due to changing thermal stratification. The corresponding predictions of consecutive forecast runs (red, yellow, black) capture these ramps very well.

6 Ultra-short term forecasting (0-6 hours forecast horizon)

For the very short prediction times energy & meteo systems developed a method that beneficially uses Artificial Neural Networks (ANN) to link online measurements of wind power production adequately to the deterministic forecast. The ANN are trained such that they consider the characteristic behaviour of the measured time series in specific forecast situations and smoothly fits those to the deterministic forecast.

This model is based on the deterministic forecast and the real-time measurements of the power output of the wind farms.

7 Visualisation of forecasts

Besides the delivery of forecasts to the AESO we also provide access to a web based browser interface to visualise the forecasting data for Alberta. All current and historical forecast for the AESO sites can be seen here (figure 7). The GUI can easily be configured for the specific needs of the user (size, choice of wind power predictions in one plot, time horizon of each plot, number of plots at each site etc.). Each user is able to design his own interface. It is possible to export current or historical forecast data through this interface in different formats like csv or xls.

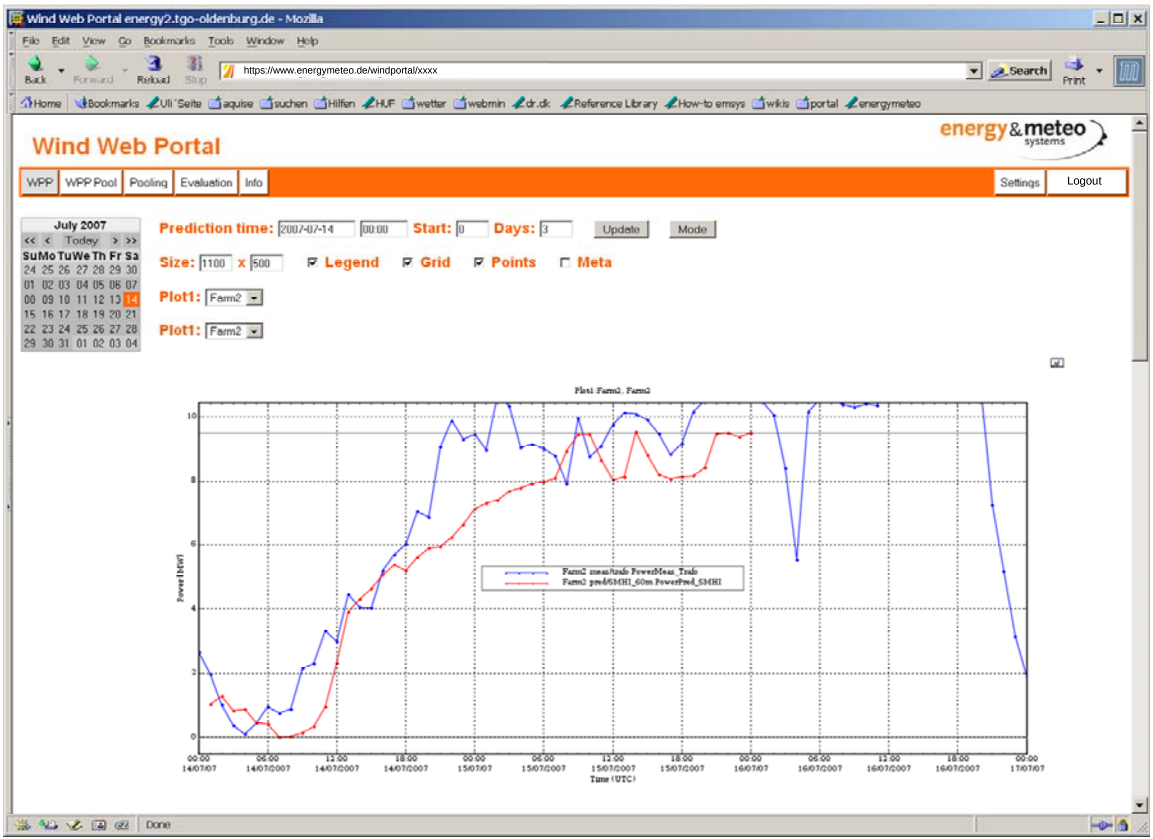


Figure 7: Example of the web based graphical user interface to visualise current and historical forecasts. The GUI can easily be configured by the user.

8 Recent publications

[Lange2005] M. Lange, U. Focken: Physical Approach to Short-Term Wind Power Prediction, Springer Berlin Heidelberg New York, 2005, ISBN 3-540-25662-8

[Krauss2006] C. Krauss, B. Graeber, M. Lange and U. Focken: Integration of 18 GW Wind Energy into the Energy Market - Practical Experiences in Germany, Proceedings of Sixth International Workshop on Large-Scale Integration of Wind Power and Transmission Networks for Offshore Wind Farms, Delft, 2006

[Lange2006] M. Lange, U. Focken, R. Meyer, M. Denhardt, B. Ernst, F. Berster: Optimal Combination of Different Numerical Weather Models for Improved Wind Power Predictions, Proceedings of Sixth International Workshop on Large-Scale Integration of Wind Power and Transmission Networks for Offshore Wind Farms, Delft, 2006