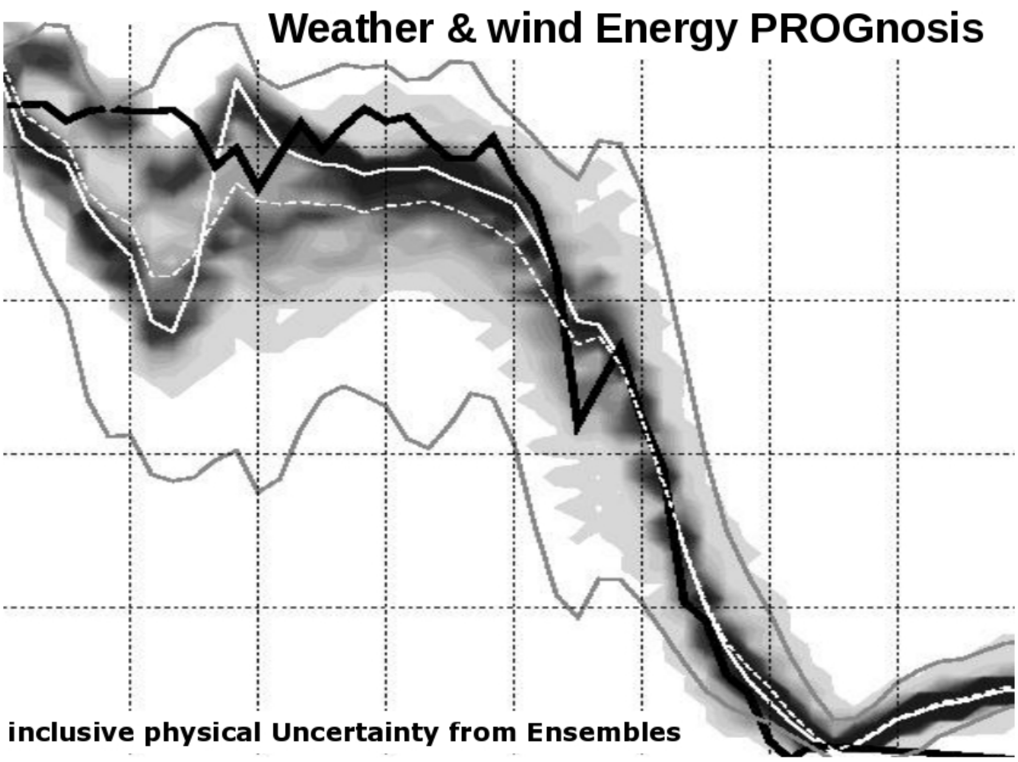
WEPROG
Technical Documentation
WP2010/01



January 2010

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1 Project Objectives

The increase in the oil price in spring of 2008 has caused that the electricity price exceeded the wind power production incentives in many areas in the world for the first time in history. The result of this increase is that commercial parties now offer higher prices for generated wind power than the support schemes managed by the TSO's offer. Consequently, wind farm owners started to contract the commercial traders where possible. The legislation in certain areas (e.g. Germany) does not yet support for this change, but changes are enforced by this development.

For the TSO's this means that the market bids will be out of the TSO's control and optimised for maximum revenue. Hence, the bids do no longer reflect necessarily the most accurate forecasts of wind power production, but minimum balancing costs. The TSO is therefore in a new situation that requires an objective algorithm to compute the amount of reserve required for secure operation of the grid.

Although the wind power prediction discipline has been used commercially for a number of years now, the upcoming challenges and the increasing amounts of wind power on the grid onshore and offshore require continued development and adaptation of methodologies to the new situations. Therefore, there is significant amount of research required in the next years to ensure reliable handling of wind power.

Especially, the planned work related to the description of the friction process in the NWP models in mountainous regions will bring value to the Danish and German wind energy community as the southern Norway has direct influence on approximately 20GW wind power today, taking into account that Denmark's and a major part of Germany's wind power generation is often under influence of low pressure systems located near Southern Norway.

In fact, the forecast errors due to the Southern Norway cause that 20GW of wind power are occasionally forecasted with a correlated error in the two countries, causing all available reserve to be activated and also wind power itself contributing as negative reserve. The occurrence rate of such events will increase with increasing installed wind power capacity in North Sea and Baltic Sea. Therefore, work dedicated to solve the very difficult events will add most value for energy systems in both countries.

This project is combining operational experiences gained by WEPROG over the past 5 years in Australia, Asia, North America and Europe and translates the needs for development into a number of clear research targets. That is,

- improvements of the description of the friction process in the NWP models, especially in mountainous regions
- investigations of the large errors and their impact on market prices
- wind power forecasting optimisation based on cost and risk based functions and use of a high resolution ensemble
- validation of the project's developments in a real-time demonstration period

These new developments and resulting tools will also be valuable for simulations of future scenarios, as they enable to estimate the cost efficiency and security aspects of a given wind power project with model results.

2 Status of project

There has been dramatic and unforeseen changes in the world since the project application was written in the late summer of 2008. The drop in energy prices is not in itself an important change in a research context, but secondary effects may have long term indirect impact:

- Market coupling between central Europe and the Nordic area
- Introduction of negative electricity prices on the spot market
- Several events have caused rather extreme negative prices in Germany
- Offshore wind power develops, but the finance crisis may change the view on the economic feasibility of large scale offshore wind power
- The unbundling process in Germany has been moving forward
- Direct marketing on wind power works despite currently difficult conditions
- A climate agreement with relaxed targets
- Some years with negative national budgets may change the view on the payback expectations from investments

The net result of all this is most likely that focus will be to develop and generate energy in a cost efficient manor regardless of whether it is renewable generation or not. It will be the economically most favourable solutions that will be prioritised. There, wind will have to act competitive regardless whether it is fair, political correct or intended. It will be real life for wind generators to not be price taker and not receive guaranteed fixed prices. To make this new world feasible for renewable energy is a challenge, but in light of the original project application WEPROG is now able to focus the work towards this target and thereby increase the value of the research:

The project aims to develop objective methods to allocate reserve and utilize the intra-day market in order to reduce the risk of system imbalance during periods of high uncertainty of the weather forecast. The methodology will be based on a multi/scheme ensemble prediction system for the combined Danish and German wind generation.

The precision of the project scope is giving most weight to the application of the ensemble, while the work on model improvements will be driven from what seems to cause the most problems for the power systems. This is the rough and inhomogeneous conditions like in the southern part of Norway. This report will demonstrate these problems with an event analysis. The originally proposed work on the Bergman theory is limited to stationary homogeneous conditions, which is of the opposite nature and therefore call for low priority.
The focus on the efficiency of wind power has over the years been evaluated centrally based on simple statistical methods of long time series of deterministic forecasts. As the wind power capacity develops the price volatility on primary power and reserve grows. This growth is to the disadvantage of the passive and weak parties. Unless these parties secure themselves via alternatives in an intelligent manor, these parties will loose some of their revenue to active and stronger parties. The prospect is that the weaker parties give up and are taken over by the stronger parties. The result is then less competition and most likely higher energy prices and consequently a poorer competitiveness of the community.

The daily price variability in DK1 has over the past decade shown that wind generators regardless of subsidy or not push down the spot market price. If the wind generation would be part of Dong and Vattenfall, then these parties would built online control systems on the build of the generation and play with the wind to keep the market clearing price as high as possible. Wind can therefore act as an important competitor on the energy market, but new tools are required to keep the present status.

There was an important lesson learned on the the handling of the German wind generation on the first weekend of October 2009. It appears that there was a loss in 2 hours of around 10 million Euro on the wind generation from extreme negative prices the night between Saturday and Sunday. The event happened although the forecasts were very good for the event. The reason seems to be that OTC (over the counter) sale of renewable energy is forbidden since the 1. October 2009. This made it impossible to trade large amounts of wind power in a low demand period on the day-ahead market. Possibly some wind generator had not bid in with a sufficiently negative price and as a result non wind generators were contracted.

2.1 Scientific work

September, October and November 2009 contained several events with higher forecasting errors than normally experienced at that time of the year. It was followed by half a year with generally quite modest forecast errors in the DK1 area. In fact, the weather in October 2009 started with a near-storm event and turned shortly thereafter into a cold weather period due to a strong flow from north over Denmark and Germany. This flow caused first very unstable conditions, and then strong wind and snowfall in Germany. The event also caused daytime frost in Denmark in October, which is in fact very unusual, because the climate is coastal and the sea surface is still warm at that time of the year. The strong northerly wind was part of a large scale flow driven by the pressure gradient between a low pressure system in Russia and a high pressure system west of Scotland. The northerly wind direction is unusual and in combination with the strength on the wind even more unusual.

2.1.1 Extreme case analysis

In order to study forecast quality regarding large forecast errors that can or are generating negative prices at the spot markets and that can become or are critical for the power system security, it is important to investigate extreme cases. We will therefore focus on a recent case and conduct the power analysis at the German power system in this case, also because the error was larger and more significant in Germany than in Denmark. We shall however see that the meteorological error actually took place over Norway, Sweden and Denmark, although it resulted in a wind power forecast error that was largest further south.

The left forecast on Figure 1 is our reference point, the operational forecast for the German day-ahead market.

As can be seen at Figure 1, there was a 6 hour phase error of the entire German power prediction. Later when settlement data became available, it became apparent that there could be a phase error of one hour of the up-scaled public data reducing the initial error to be 5 hours. Nevertheless, the error was approximately 7GW during a 6 hour period or equivalent to twice the permanent secondary reserve. The wind started to increase rapidly in the north-western Germany first. If there would be export of energy from Norway to Germany, then it would be relatively simple to balance the first 2GW error by changing from import to export from Germany to Norway. However, there is still 5GW to balance and the forecast error in Denmark was 700MW of the same sign corresponding to a 3 hour phase error in the ensemble average forecast.

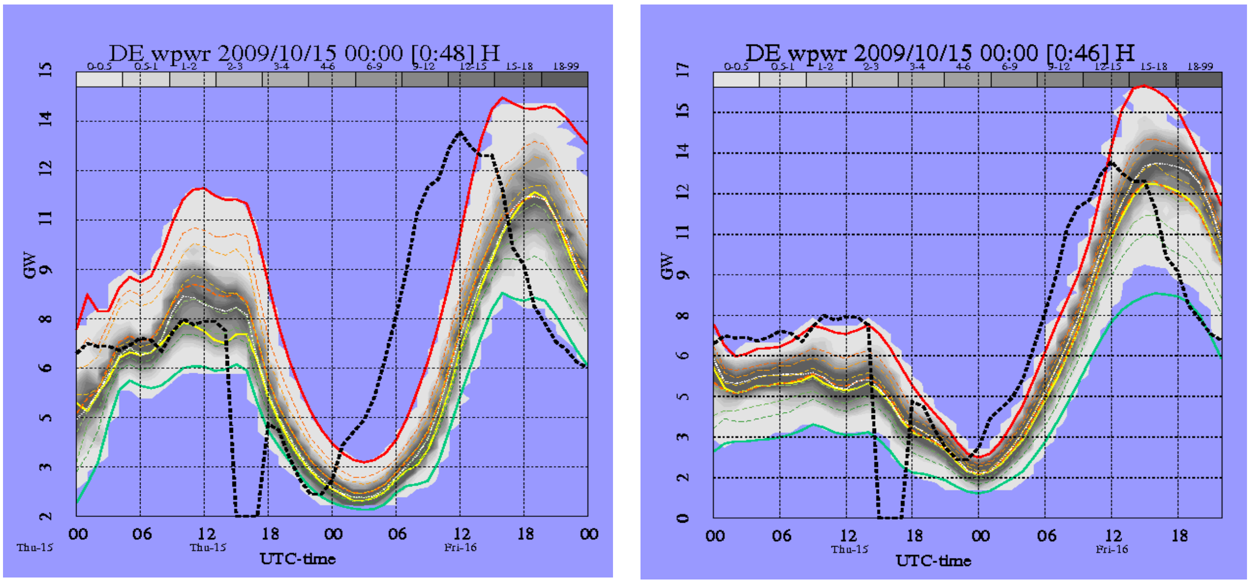

Figure 1: Probability plot of the forecast with large phase error of ca. 6 hours (left figure) and improved forecast with reduced phase error, where the orography has been changed in the model system (right figure). The published German up-scaled wind power is shown as a black dotted line and is unacceptable far outside the forecast uncertainty band.

Although the error was massive in terms of MW, the event took place at a time where the demand ramped up as well. This made the event technically easier to handle. The error started with low demand and ended with high demand. The imbalance was then almost only a matter of trading and to withhold some power plants from ramping up.

If the error would have taken place on a Saturday or Sunday evening ending at 02UTC, then the situation would have been very difficult to handle and would have required several nuclear power generators to stop generation. Additionally, the weather turned very cold and the demand increased. The opposite effect would have made the relative error more significant and export of energy northward even more difficult. We can therefore summarize that the event was expensive, but technically relatively easy to handle, because of the increasing demand in the up-ramping of wind power production.

However, the weather phenomena was not dependent on any diurnal cycle and could as well have taken place during a weekend evening. In this case the situation could have developed technically critical. For this reason it was considered a valuable case to study the reasons for such large forecast errors at times.

Although more than 300 independent NWP forecasts were started in real time at the 15th of October, it was found that not one single forecast of these had a satisfactory development of the event. All forecasts made after 18UTC on the 15th October were much more correct in magnitude and phase.

From this result, we can conclude that it is not the power prediction model that is the cause of the error, but the weather forecast. This is important to note, because the wind direction and speed was unusual, thus statistical models could easily generate wrong wind power forecasts. .

We conclude therefore that the error lies in the weather forecasts and apparently in all ensemble members. According to communication with German wind balance responsible parties all forecast providers had significant errors in the event, although of different size and structure, which indicates that the error is common in all model systems and therefore relevant for a detailed study.

EXP ID	Member	Analysis	Horiz. Resol. [km]	Description
24	1-75	NCEP	45	Europe reference forecast
23	1-75	CMC	45	Europe reference with Canadian MetCentre analysis
38	1-75	NCEP	22.5	Orography adopted to Europe 45km grid
39	1-75	NCEP	15	Europe 15km standard
40	1-75	CMC	22.5	Orography adopted to Europe 22.5km grid
50	1-75	NCEP	19	Europe 19km standard area
81	137	CMC	45	Tall orography in large Europe grid
82	137	CMC	22.5	Vertical diffusion test on TKE
83	137	NCEP	22.5	Extreme tall orography
84	142	NCEP	22.5	Tall orography
85	137	NCEP	22.5	N.Hemispheric grid boundary with tall orographgy
86	137	NCEP	22.5	Short-term 6hour forecasts, low orography

Table 1: List of experiments carried out for the analysis of the influence of improved orography to prevent high forecast errors

After a set of 11 sensitivity experiments (see Table 1), the right probability presentation in Figure 1 is the best achieved simulation from the 15th of October 00UTC so far. The error is reduced, but the uncertainty is still not large enough to cover the error as the black dotted line is clearly well outside the ensemble spread.

The probability figures show 300 power forecasts and have a vertical uncertainty of 5.5GW on the left figure and 4GW on the right figure. This is most likely also reflecting the uncertainty and different error pattern of the operational forecasts reported by the German balance responsible parties.

A number of the sensitivity experiments resulted in some improvement regarding the phase error. As can be seen in Table 1, twelve experiments have been carried out, including changes to the model's orography, model area variations, model resolution variations and input data (analysis) variations.

The reason for the changes in the model's orography this is that in the model mountains are often too smooth and hence there is too little blocking capacity of the air flow, as well as reduced generation of lee waves and lows at the lee side of the mountains. The difficulty in remodelling the mountainous regions in the model's orography to a more realistic shape and height lies in the model's capabilities to resolve steep terrain changes without reducing the dynamical time step in the model and hence increasing CPU requirements.

Because experiment 38 did not lead to significant changes in the error reduction of our case, a sensitivity study with tall and extreme tall orography changes was conducted (experiment 81 and 83). Such an extreme tall orography would not be a sustainable solution. However the experiment revealed an undesirable side effect that may reduce the positive effect of increased model orography. By increasing the orography, it was found that the roughness at the land surface increased so much that the air flow was decelerated too much in the 15th October case to produce enough wind power in the North of Germany.
This may explain, why the orography changes did not show the expected improvements yet and that this problem is not trivial, if changes should be applied in the entire model area (northern hemisphere) and be valid not only for the Norwgian Mountain ridge, but also for the Rocky Mountains, the Alpes and the Himalaya. The conclusion from these experiments are that more sensitivity studies are required to fully understand the impact of such changes on the entire model system.

Nevertheless, the most promising changes were combined in one setup, which is shown to the right on Figure 1. All in all four model changes were required to get from the left to the right forecast on Figure 1, although the error is still relatively high. Therefore, it became clear that there was a hidden error, which was not yet found by the 12 experiments.

A subjective analysis of the weather development in power space was therefore carried out. For this, a short-term forecast (0-6h) was compared with the day-ahead forecasts in horizontal graphs. The conclusion regarding a hidden error was confirmed by this analysis and consistent with the difference discovered in Figure 2 and Figure 3.
The first figure represents the failed forecast in 6-hourly steps (6,12,18,24,...48h) and the second figure shows the best model estimate of the wind power production using short-term forecasts (9 times a 6h forecast), which seems to be in much better correlation with the true weather development than what is shown on Figure 1.

We have all reason to believe that Figure 3 is a good approximation to the true development, because these short-term forecasts captured the event reasonably correct with errors well under the average error of 1GW.

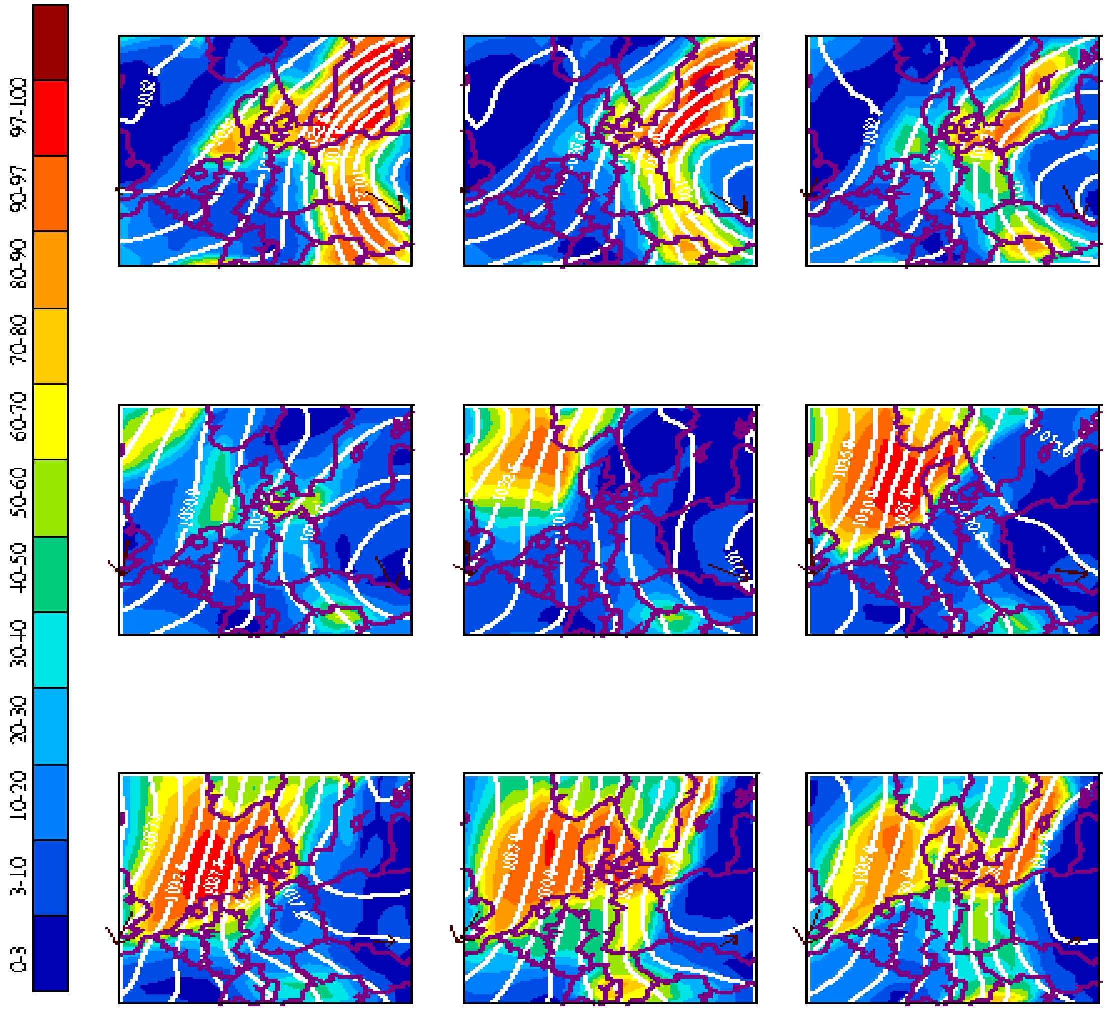

Figure 2: Potential wind power forecast every 6 hours of the forecast starting Oct 15 00UTC ending Oct 17 00UTC. Dark blue means no wind power generation and red means full generation. Isobars are shown as white contour lines.

The horizontal maps of wind power show the forecasted load factor in each model grid point. As shown at the legend. the dark blue indicates no generation (0% of inst. Cap.) and red colours indicate full generation (100% of inst. Cap.). This is computed for a 2MW turbine with hub height at 100m.

The figures start with the state valid at the 15th Oct 00 UTC on the top left. The next figure (top middle) is 6 hours later, the following (top,right) is valid at 12 UTC. The last figure (lower right) is ending the forecast on the 17th of Oct. 00 UTC. All four figures with 9 sub plots follow this order.
The white isolines represent the mean sea level pressure and are used to indicate the depth of the lee wave low pressure system from Norway. This low is for several reasons most visible in Sweden. First of all it connects to the lower pressure in eastern Europe, but the flow from north west onto Norway also tends to make the low more visible in Sweden.

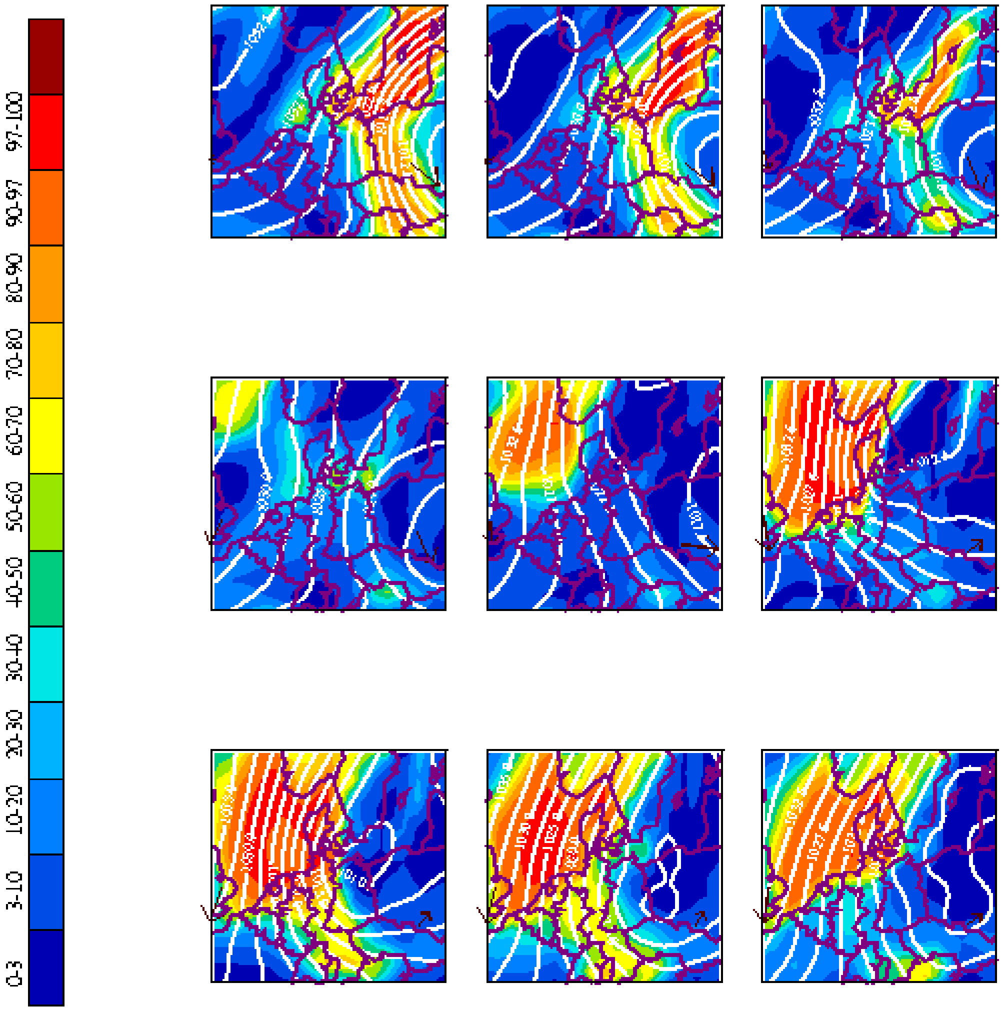

Figure 3: Wind power short-term forecast between the 15th and the 17th of October 2009 in 6-hourly steps over Denmark and Germany.

The difference between Figure 2 and Figure 3 is more important and visible at 00UTC and 06UTC on the 16th of October, as the development south east of Norway is more pronounced in the short-term forecasts. The wind speeds are also slightly stronger in the short-term forecast, although this difference is not enough to explain the error.
From the short-term forecasts it is apparent that a catalyst is required to start the development of a low pressure system. Once the evolution of the low picks up, the wind speed will automatically increase at the warm front on the southern side of the Norwegian mountain ridge , because the system will also move southward with the flow.
It is likely that the low pressure system would stay weak as lee wave south of Norway, i.e. as a result of blocking of the Norwegian mountains unless a catalyst would appear. We therefore started to search for what such a catalyst could be. We were looking for instability mechanisms that could explain this development.

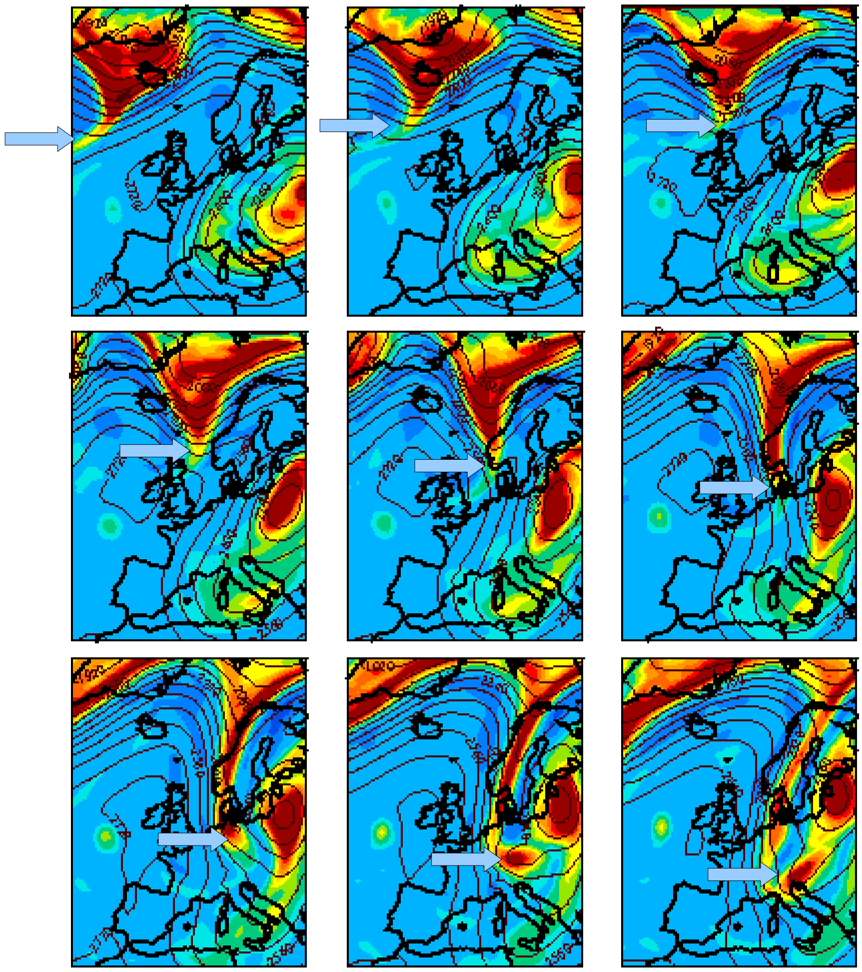

Figure 4: Analyzed IPV (isentropic potential vorticity) in 6-h steps from 15.-17. October. The upper level front "catalyst" (blue arrow) can be followed 4000km from the Atlantic over Scotland, Norway, Germany to Slowenia in these 48h.

In fact, we found an upper level front at the tropopause level moving from the Atlantic to Norway and then southward over Denmark and finally sweeping over Germany in the 48 hour period of the forecast. This movement is shown as a forecast on Figure 5 and as analysis (short-term forecast) on Figure 4, both as potential vorticity maps.
The time stamps are the same as on previous figures running from upper left to lower right. An isentropic potential vorticity (IPV) map is easy to understand, because it is shown in a plane that is a material surface in adiabatic conditions. This allows us to follow a conservative quantity over long distances. In this case it is illustrative to first focus on the position of the low south east of Norway.

All the contour lines on the IPV figures show the Montgomery stream function, which is an indicator of the pressure gradient force on the isentropic surfaces, thus the geostrophic wind blows parallel with the contours.
Where the colour is green, this corresponds to a tropopause level IPV. We now trace

this point back 6 hours and locate it north east of Scotland and further back until we reach the departure point at the 15th 00UTC.
It should be noted that the upper level front moves 2000-2500km in 24 hours. On Figure 4 we see the same structure and timing. This is a promising result, because we know that a catalyst is required for the forecast to develop reasonably correct. Note however, that the forecast is developing very different, when the front starts sweeping over Germany. This is no surprise, because the low pressure system triggered strong snowfall and therefore diabatic effects that had impact on the IPV values, i.e. the catalyst.

Nevertheless, the IPV presentation form provides a precise and useful information of the weather development and in particular when the development starts to go wrong. It is directly visible that the domain of dependence for the 48 hour forecast goes 4000km back from it's end position in Slowenia over Germany, Norway, Scotland and far out into the Atlantic. This would not be visible by looking at a low pressure system development only.

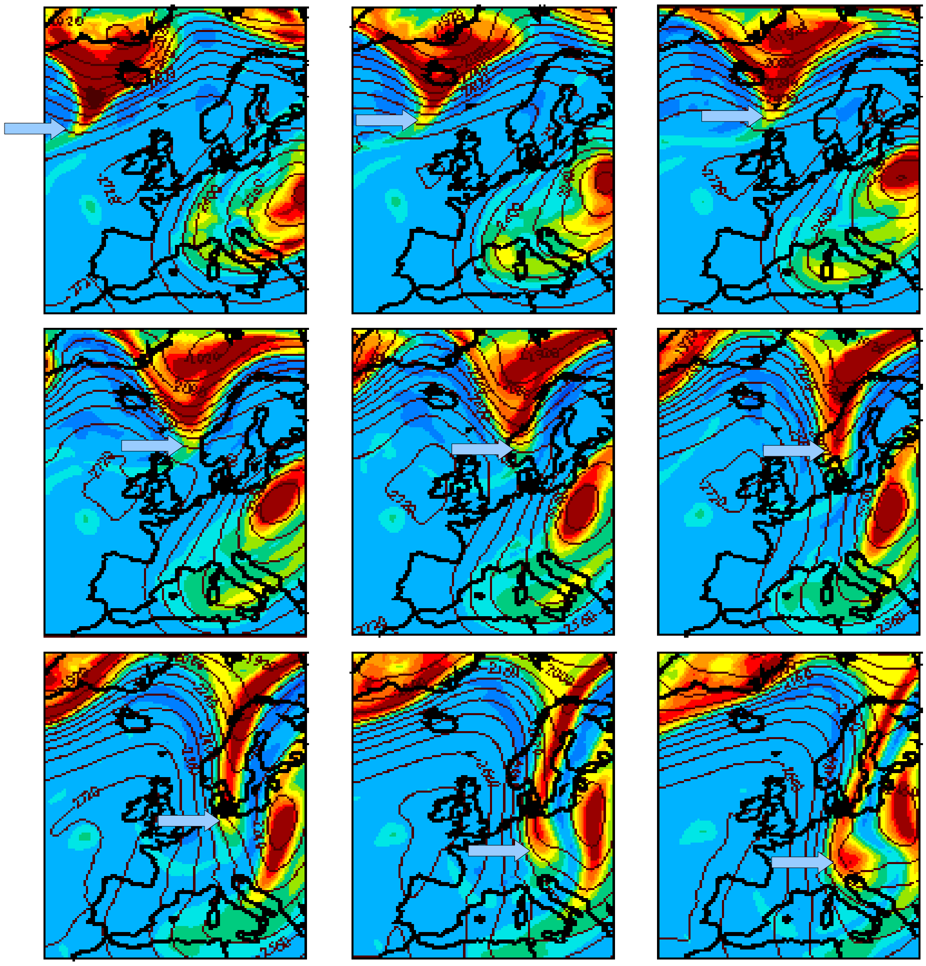

Figure 5: IPV (isentropic potential vorticity) in 6h steps from the 15.-17. October. he upper level front "catalyst" (blue arrow) can be followed 4000km from the Atlantic over Scotland, Norway, Germany to Slowenia in these 48h.

Apart from tracing back the origin of the catalyst (in terms of IPV) it is also possible to subjectively warn about the risk in forecast mode. That means an oral warning could be given that the forecast does or does not seem to react on a catalyst that is visible and known to have the potential of developing severe weather. The warning should definitely be given, if the event was about to take place while the demand is ramping down as this would require scheduled units to ramp double as fast down as normal, which can be critical during a weekend.

The fast movement of the upper level front also explains the 6 hour delay of power generation in the day-ahead forecast. If the low pressure system would have interacted and followed with the upper level front, then the surface winds would have been picking up timely.

For this reason the event is a very important lesson about what sudden evolutions in the weather can cause to the power system and how a warning system may be activated. It is not standard practise in forecasting centres to permanently watch out for such events. Attention is usually given to isobaric levels, where such effects may not be apparent. However, an upper level front may only be visible on an isentropic surface near the tropopause level. Therefore, it seems like subjective analysis is required, because the tropopause level changes constantly, especially when it is windy.

Subjective evaluation can however only be a fall-back solution for critical events or to study and improve the automatic solutions, because essentially all ensemble forecasts have to be checked. In real-time an automated solution which also computes probabilities is always to prefer, because it can send out warnings well in advance.
The configuration aim should therefore always be that some ensemble members react on "the" catalyst while other won't. This study is giving good hints regarding the configuration of the ensemble members. However, it has been shown that a lot of experiments are required to find the best strategy for the development of a catalyst to occur and be automatically detected by the system without producing too many false warnings.
Another important lesson from this event is that the model area size should not be compromised as the sharp fast moving upper level front extends from far north and down to approximately latitude 50.

The sensitivity to area size and timing of the upper front and the vertical mixing between the upper level front and the low level lee wave will therefore have to be further studied in order to find a strategy for such a warning system.

2.1.2 Optimisation of wind power forecasts

One of the targets of the cost optimisation in this project is to define and verify functions with the goal of reducing balancing costs from wind power forecasting errors. In other words, it is suggested that by using predicted uncertainty and present market prices for reserve, it is possible to change the role of wind power in the current market structure towards a more pro-active role than the way wind power is handled today in most jurisdiction.

Our target for the optimisation is lowest energy prices for the consumer and not highest prices for the wind generator. However, the proposed strategies should not comprise the value of wind power. The algorithm instead will contribute to decrease the market clearing price to avoid a situation where all generators will benefit and consumers will be in disadvantage.

This means, our target is to optimise on all parameters that reduce costs originating from wind generation to the consumer. This is a function of average market price of primary power including reserve and actual balancing costs. This optimisation target is expected to be in line with what a energy regulator would ideally try to promote.
There are two strategies to attack this problem:

- Construct solutions for the existing markets with workarounds
- Develop a new framework with capabilities to increase the renewable energy penetration

From a "here and now" perspective the first option is to prefer. However, considering that the political defined target in Europe and most parts of the world is increased renewable energy penetration, there is reason to prioritise the second strategy as well. There is work progress on both of these topics, which is summarised in the next sections .

2.1.2.1 Using existing market structures

The background for this work is that volatility natively develops to the disadvantage of small parties and especially those that are not doing anything to protect themselves against volatility.

Therefore, we use a market based model that deploys monthly tendered ancillary services. The idea behind the monthly tendering is to achieve a combination of security of supply and best price. Typically, blocks of power are provided for a fixed price in a certain time range of the day. The price increases with the amount of power requested and a base price for the service is paid for being available. The monthly tendering allows the price to adjust to the average market expectations and thereby allow for fairly competitive bidding.
The monthly tendering is attractive for many parties, because it is easier than participating in a 24 hour intra-day market, which is by nature to the benefit of those large parties that have most information available and use this information most intelligent. This is probably also the background for why there is little volume in the German intra-day market yet.

A German study of the annual cost of participating in the intra-day market suggests a minimum of 150MW generation capacity with approx. 1800 full load hours per participant to recover running costs and investments in the required IT infrastructure (Sensfuß, F., Ragwitz, M., Entwicklung eines Fördersystems für die Vermarktung von erneuerbarer Stromerzeugung, 6. Int. Energiewirtschaftstagung an der TU Wien, 2009.). The published information does unfortunately not provide a breakdown of the costs or even a list of what is required.

As a first study, published German spot market prices and generated wind power have been used as an example of how to use existing market structures. The work exploits that the reserve price profile is known over the month for every hour of the day for primary and secondary reserve. The so-called minute reserve is traded on a daily market.
The predefined price profile is required to optimize the bidding of wind power, because the optimization “speculates” in the skewness of the reserve prices, i.e. That negative reserve is cheaper than positive reserve. The skewness cannot be used unless the price is already secured, since market players would speculate against a party who bids into the market with a bias. As long as the forecast error is less than the pre-allocated reserve there is no possibility to speculate against a forecast bias, because the price has been secured.
Physically this means that the wind balance responsible party uses part of the reserve pooled together with the wind generation, because this gives price security and may give the possibility to achieve better revenue and a more constant generation following the demand.

A simple physical explanation of the benefit of the combined reserve and wind power can be given from a variability point of view. The highest frequencies and shortest waves in the weather system have low predictability, especially during the day ahead horizon. This variability is contained in the weather forecast and can therefore be expected to occupy some of the reserve the following day. An optimisation will adjust the forecast so that the cheapest reserve is used at any time of the day.

Suppose that a block of 100MW reserve is cheapest during 6 hours of the day. Then the forecast is adjusted in accordance with that range. Without this optimisation there would be more use of the second cheapest reserve block, which is typically the same amount of reserve with opposite sign. The operator would then need to continuously ask two reserve providers for adjustments instead of only one at a lower cost.
As a first order approximation one could add 50MW to the wind power forecast, but it is also possible to evaluate the uncertainty and look on the likelihood from a probabilistic forecast rather than asking for more reserve and pay higher prices. This simplistic approach of giving the forecast a bias can therefore become expensive, also if the bias will be correlated by another independent error covered by the same reserve pool.
It is complex to evaluate the approach against intra-day markets. Frequent usage of the reserve causes that the economic gain by participating in the intra day market is marginal and the volume in the market is then not increasing. Consequently prices may not be competitive and the reserve is a better alternative. Current experience says that wind should trade imbalance more than 6 hours ahead to not suffer from volatility.

However, the forecast error is considerable higher at hour +7 than +2 - +3. This means, if we can generalize the trading experience, then 7-12 hours ahead is a good window for the intra-day market and the shorter horizons are balanced via secondary reserve. The intra-day market can then be used to bring the error down to a level, which would be covered by the cheapest reserve blocks.

It should be noted that use of essentially different markets for balancing the wind causes that there is a bigger spill volume and therefore higher average prices in both markets.

For this optimisation example 3 years of forecasts have been applied. In every hour there was an optimal solution found in a 3-dimensional matrix. The superior matrix element was computed for each time interval of the day. Note, that the computation need to be redone whenever the reserve cost profile changes. This will normally be every day.

The computation takes the actual reserve cost profile for positive and negative reserve and uses this profile with 3 years of historical forecast data. The optimisation process computes 3 non-dimensional tunables giving relative weight to both a percentile forecast and a RMSE optimised forecast. The last tunable determines the mixture of the two forecasts. The solution is carried out by optimising on a cost function, where the target is to make minimum balance cost for wind during the 3 year training period. The optimisation does not need other prices than the actual reserve cost profile and the optimisation needs a best guess on what the spot market price will be in the hour to evaluate the cost of reserve against primary power. The historical prices of reserve have no influence of the result unless we consider the likelihood of a scheduled unit to fail and cause higher balancing costs. After the gate closure and the publication of the hourly prices a new optimisation can be performed to determine how to correct the forecast on the intra day market and thereby keep the forecast at the ideal level of the most favourable reserve block

The optimized forecast has the following capabilities compared to an RMSE optimized forecast:

1. The output forecast is smooth as it comprises a combination of two already smooth forecasts.
2. The variability of the resulting forecast has similar or less variability than a demand forecast for dispersed wind power, thus the dispatch is likely to be more efficient, because a “demand-wind” forecast should is a soft curve that does not cause anti-correlation on the unpredictable higher frequencies.
3. The diurnal cycle error is corrected in percentile space using the bias that is most favourable for the time of the day and the actual cost profile. Thus the ensemble forecast need not to be tuned for the time of the day.

The tuned forecast is at any time trying to make space in the market for possible generated wind power and thereby helps to set a lower market clearing price. This gives lower average prices, because the reserve provider may get more per Mwh, but only for the MWh he delivers as opposed to the market clearing price that applies to all primary power generation. Regardless of the applicable type of production incentive scheme also wind power will become more cost efficient for the consumer, because the balancing costs are reduced.

The benefit is though most significant for the market price + incentive model for the consumer for this optimisation rather than a fixed tariff for wind generated electricity. This means that we try with this optimisation scheme to simulate a TSO and consumer friendly scenario rather than optimising for highest generator revenue and it does protect wind power to be hit by volatility. However, the approach is not trying to increase the market clearing price like a generator would do. It seems more appropriate to bid in with price blocks between the ensemble minimum and the optimal bid, if a bid price can be computed from "demand-wind" and thereby make the wind generator more competitive in the market.

Note that so far, we have left out all assumptions in the optimisation. These assumptions relate to the influence of failed scheduled generation and the error of the demand versus wind power forecast. The following is a possible set of assumptions following the same principles as in out overall optimisation strategy.

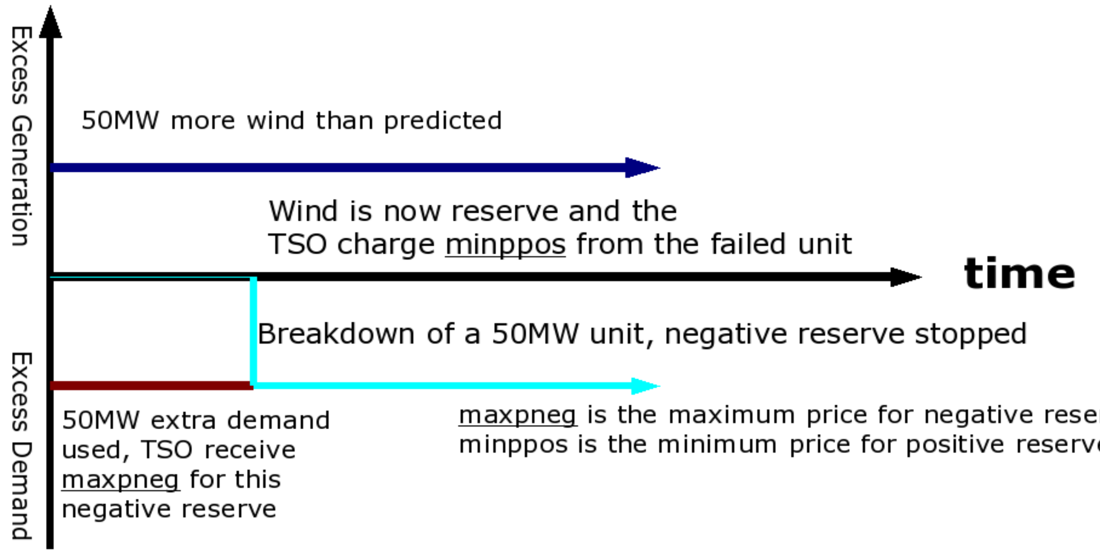

Figure 6: Example scenario of wind power being used to balance imbalance on the grid.

Inside the optimisation scheme there is a complicated handling of the compensation to wind whenever wind generates reserve for the system. An example is illustrated on Figure 7. To begin with we have 50MW too much wind. For this the TSO receives the price "maxpneg" which is a reserve price for negative reserve. This is essentially what the market is willing to pay for additional spill generation.
Later a power plant of 50MW breaks down. In this moment the wind helps the system to stay in balance. Under normal settlement calculation practise wind receives only the market clearing price, because imbalance generators are not supposed to earn on imbalance. In the Danish system there is a fixed compensation of 23DDK per MWh.

It is believed that this can be justified, because wind is not deliberately making imbalance to the correct side and thereby helps the system to be in balance. What is instead done in the optimisation is that wind starts acting as reserve and thereby gets the cheapest reserve price (minppos).

The intent is to make wind act as a full generator, participate in reserve and be also a prioritised energy source for reserve. It is fair for dispersed non-online controlled wind power that cannot speculate in creating imbalance to one side and gain on the other side. There is no operator behind and the system therefore every so often reacts as reserve provider as shown on Figure 7.

We have also built in the rule that wind is taken as the first reserve and gets the lowest block price for the amount of reserve delivered. Every time wind needs reserve it is also paying reserve, so the symmetry is fair.
It should be noted that the operator shall not care about cost or take any action on wind reserve. This change is only an implementation in the monthly settlement calculation. The operator is already using wind as reserve often even without knowing.
The reserve is built into the cost function and considered in every adjustment of the tunables. The cost function assumes that small imbalances on less than 50MW are handled at the prices for the first positive and negative 50MW block. The sign of errors is likely to change frequent for small error, because of a frequent sign change of the demand-forecast error.

2.1.2.2 Analysis of future compatible market structures

Existing market places have been under strong development over the past 2 years and it is clear that a number of workarounds have been implemented, because compromises had to be taken between stakeholders and authorities. The system has therefore not become less volatile and it has to be expected that volatility will further grow with increasing renewable energy penetration.

Regardless of which combination scheme of day-ahead, reserve and intra day markets one can imagine, there are potential disadvantages and it is obvious that we are not in the power of changing the weather and the weather is in no way conforming to restrictions implied by the traditional day-ahead market. A high penetration of renewable energy will sooner or later call for a break up with current concepts and there will be a transition to one running market. In this way all capacity is in one market and more competitive bids can be given for longer time slots of the required base load.

A single market increases competition and enhances also transparency. In a system with a mixture of production incentive financed energy systems and pure market systems it is imperative to implement barriers to prevent that commercial parties do not exploit the system to essentially cause double penalties for intermittent energy sources.

One of the lessons from the finance crisis is that there has to be regulation and solutions that prevent that the system is vulnerable to attacks and speculation. These lessons should also be adopted in the energy market systems.
Work is well under way on how to make a future compatible handling of intermittent renewable energy in a market without compromising security. The design will comprise best practises from all over the world combined with new software solutions.

2.2 Conclusion

This report demonstrates that the link between weather and energy is going to be a challenge with growing penetration of renewable energy. It is actually almost impossible to imagine that the system will work reliable unless some degree of simplification can be achieved in the near future. We need to focus our efforts on ways of solving the problems at hand in a conceptionally more simple form, both from a competition and security perspective.

The period from August 2008 and the entire year 2009 has been subject for major structural changes worldwide. Therefore, it is difficult at present to plan research towards improvements regarding the handling of wind power with the help of forecasts that would also be able to provide solutions to the challenges valid and important in 1-2 years. However, it has been possible to enhance the value and applicability of the current research tasks in the project by relatively small adjustments to the priority relative of the original plan.

Work on the friction process in the Planetary Boundary Layer is extended to include work on the vertical exchange through the entire Planetary Boundary Layer and troposphere for the purpose of addressing a common problem in apparently all NWP model formulations.

The work on cost optimisation is split into two parts. An approach that works with current market and ancillary service structures along with a parallel approach, which aims to develop more future compatible practises on how to handle more renewable energy in a market without compromising grid security. Both branches are targeted to reduce the costs of wind power generation in order to reduce the costs that are today mainly carried by the consumer. This is justified from that renewable energy today receives some kind of consumer paid incentive to cover the financial risk. The idea is that this improved handling makes wind power more competitive and will therefore contribute more to lower the average energy price in exchange for the incentive payment.

These tasks are essentially three independent tasks with different applications in different disciplines, but the combined effects of these tasks will contribute to make the energy system less vulnerable and more efficient at future levels of renewable energy penetrations.

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