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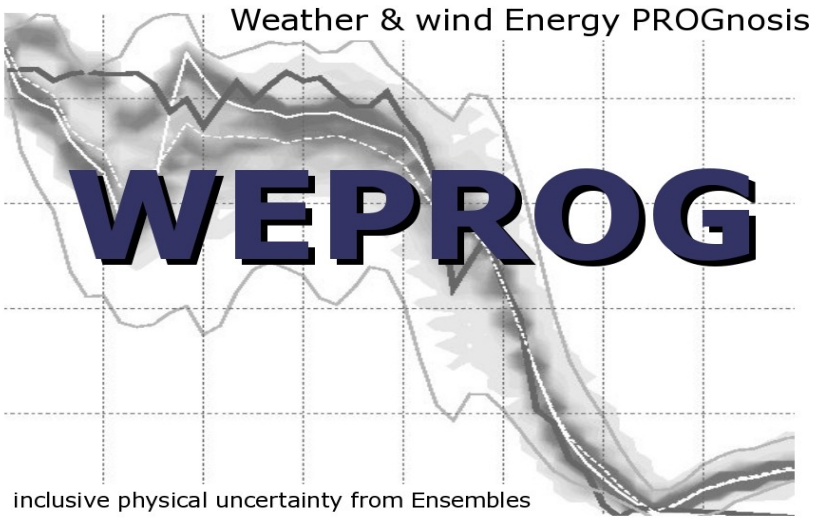

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1 Executive Summary

There is an ongoing trend of increased privatization in the handling of renewable energy. This trend has been started for a number of years in Denmark. Today, the privatized volume is growing in many other European countries and also in countries with traditionally high fixed price production incentives such as Germany. The trend is required to ensure an efficient energy system, where improvements that make economic sense are prioritised. The reason why centralized forecasting can be a challenge in that matter is that the TSO's tend to optimize on physical error rather than cost. Consequently, the market is likely to speculate against the TSO, which in turn increases the cost of balancing.

A privatized pool of wind and/or solar power is more difficult to speculate against, because the optimization criteria is unpredictable due to subjective risk considerations that may be taken into account at any time. Although there is an additional level of costs for the trading of the private volume, it can be argued that competition will accelerate efficiency from an economic perspective. Does this evolution imply that the physical balancing of renewable energy is changing to become more difficult in the future ? This is a valid concern to raise, because the amount of power put into the market will become less predictable, when the wind power spot market bid takes place on the basis of a risk consideration in addition to the forecast information itself. From an idealized scientific perspective there is a tendency to prefer that all wind power is sliced into fractions of the total produced power instead of separate smaller slices. That is, a fixed fraction of each turbine belongs to a given pool, which implies maximized spatial smoothing. Commercial sensitivity of the operating characteristics is however an obstacle for this approach, because stakeholders would probably with good reason object sharing of their sensitive, yet relevant information across many parties. Therefore, it is only possible to deploy centralized forecasting techniques under special conditions, where there is a common agreement upon the sharing of data necessary to optimise forecasts.

The scope of this summary is to demonstrate how the project developments are contributing to more efficient wind power integration targeted both to centralised and decentralised cost efficient IT solutions, which will complement each other in market based energy systems.

The detailed improvements from the DEWEPS project to the MSEPS system are shown in Figure 1 as grey text boxes. The blue text boxes show the basic components in the MSEPS production and dissemination system. All components have been updated with important enhancements using modern technology and standards contributing positive to the overall system performance and increasing the application range.

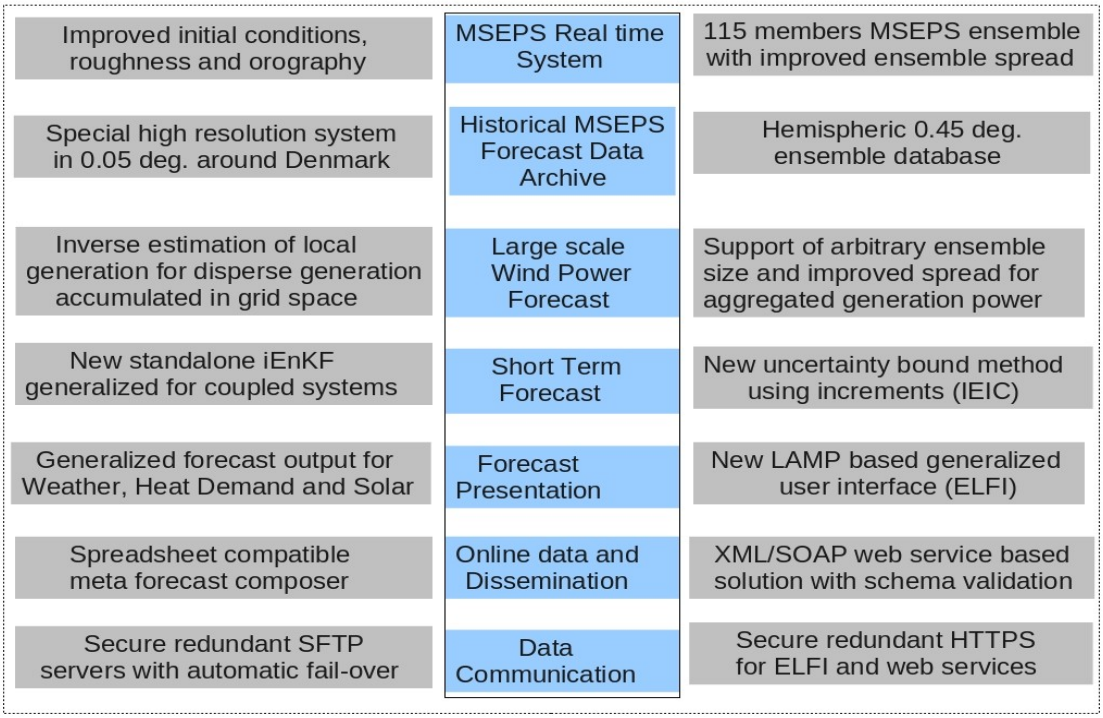

Figure 1: Details of the project developments and improvements and their integration in WEPROG's real-time system

1.1 Centralized Short-term Forecasting after Gate Closure

One application of centralized forecasting is large scale short-term forecasting after gate closure of the day-ahead market. Here, persistence in operating characteristics can be assumed constant with reasonable accuracy. This has been addressed in the project through a centralized short-term forecasting study based on the MSEPS ensemble, the iEnKF short-term forecast and a special implementation of an "*Incremental Ensemble-based Imbalance Correction*" (IEIC) update approach developed in the project.

The study included all Danish and German wind power and demonstrated a considerable gain by a shared centralized large scale forecasting. The potential value lies in improved scheduling of the required reserve and maximum usage of inter-connector balancing rather than concurrent counter regulation.
The study has turned out to be highly relevant, because the physical handling of reserve started to become more coordinated between Denmark, Germany and the Netherlands since late 2011. Although the study was based on public data, it was nevertheless possible to develop a new forecast and verification technique to increase the understanding of how forecast errors should be balanced to avoid costly counter regulation or too frequent semi-automatic regulations. The new technique essentially works with three types of expected imbalance:

1. the certain part of the aggregated imbalance
2. the uncertain part of the aggregated imbalance
3. the regional imbalance

The classification of imbalance takes place on the basis of an evaluation of the present generation schedule, the newest forecast and the forecast uncertainty through two simple equations that evaluate the sign of the terms in a third equation. By use of short-term forecasting 2 hours ahead every 5 minutes after gate closure, the approach allows for early detection of significant changes, although the algorithm will in normal conditions suggest to continue as planed.

The focus has so far been on wind power, but in a future real-time application the focus should be on the basis of the residual of the demand minus wind and solar power in order to share the weather related uncertainties in a consistent manner and thereby reduce the total uncertainty and increase the predictability on the total system. This is so even though the total systems balance appears fairly unpredictable, because just a marginal improvement over many hours obtained via a more automated large-scale balancing process will add up to a considerable saving. As a consequence of the ongoing market coupling and international grid control corporation initiatives, two large-scale studies have been conducted in the project to investigate potential savings of cross-border handling of renewable energy (Möhrlen et al., 2010, Jørgensen et. al., 2011). Both day-ahead and intra-day aspects were considered.

From the results we can conclude that there is a benefit from an enlarged market also for the 24-hour operation, because this gives a potential to reduce the total amount of permanent reserve on a larger scale.

1.2 Enhancements to the Daily Dynamic Reserve Tendering

Another application of centralized forecasting lies in the day-ahead tendering of reserve. This is addressed in the project via a calculation of the required reserve allocation day- ahead or more precisely a dynamic calculation of the amount of reserve. It turned out that the MSEPS ensemble is predicting the reserve required to balance the 2-hour forecast error with a correlation of 0.43. This is not a prediction of the error of the day-ahead forecast, which is much easier to predict. Instead, this is a prediction of the actual error of the short-term forecast valid for the next day.

Although the correlation is below 0.5, it is still a very important result for the day-ahead allocation of reserve. This result is therefore rather impressing, because it is predicting the error of a running 2-hour short-term forecast generated 16-40 hours ahead in time. It is impressing because this forecast is driven by measurements and weather forecasts that do not exist at the generation time of the reserve forecast. Thus, the ensemble knows quite well 18-42 hours in advance, how the error pattern of the short-term forecast evolves even though the main input is unknown on the day-ahead horizon. Although real-life problems are again on a mixed portion of the "demand-wind power-solar power", the result nevertheless shows that a reserve allocation application can be developed based on the MSEPS ensemble in order to objectively justify how much reserve should be tendered by day and by hour.

The approach therefore reduces the required amount of reserve. The benefit is reduced grid operation costs without system security losses. The value of such daily tenders will increase in the future, because both the demand and a large portion of the generation side will have a strong weather dependency and will continue to increase further because of increasing penetration of wind power, solar power and heat pumps.

Finally, it should be noted that the approach is designed for automatic extreme event handling, where empirical or statistical estimates are most inaccurate.

1.3 Incremental Uncertainty Bounded Intra-day Balancing

A second target in this project has been to develop forecast methodologies designed for the bidding process of the privatized wind power pools. Although the emphasis in the project has been on how to handle wind power in the spot- and intraday market, the impact of this work is much wider and will help to increase the total system efficiency.

What is most important is that the wind power can be bid into spot market price optimized and strategic instead of optimized according to a predefined error measure in power, as it has been done traditionally. The reason why a strategic bidding is becoming possible is because the previously mentioned incremental ensemble-based IEIC trading scheme allows for more cost efficient intra-day incremental balancing. The incremental approach provides about 15-25 different possibilities to trade the expected imbalance up to gate closure of the rolling market and thereby reduces the risk of volatile prices caused by a low market volume or late detection of imbalance. The IEIC method is not worth much without market volume. However, IEIC is in itself stimulating market volume, because it is suitable for automated trading on any pool size. Therefore it can be expected that the market volume will increase, once the this method has been deployed sufficiently much to create a tipping point.

1.3.1 Long term Market Volume impacts of IEIC

The IEIC approach will be able to significantly increase the market volume during the the opening hours of the intra-day. An indirect benefit is that high inertia power generation can expect to get more opportunities to swap contracts and thereby get a more constant generation compared to what the day-ahead spot auction may have led to. This will reduce marginal costs and smooth out the sometimes volatile behaviour of the spot market prices. As the penetration of renewable grows, the day-ahead spot market auction will result in more frequent undesirable effects and the need of adjustments in the intra-day market will increase.

A likely pattern is that the spot market will develop to a platform which is used to set prices rather than a platform to sell power according to a schedule calculated by daily routine.

Non-scheduled generators will most likely use the spot market to hedge prices. As the intra-day volume grows we will see more and more attempts to oversell renewable energy in the day-ahead spot market and consequently lower spot market prices. This trend will result in more competitive prices in the spot market, which is an important goal, because this will mean that a bigger fraction of the produced energy is pushed through the markets as an alternative to "Over The Counter" sales of high inertia generation.

The traditional power optimized forecasts result in unfavourable balance costs, because high wind events tend to be moderately under-predicted from least square optimisation and low wind events vice versa. The unfavourable cost pattern lie in that high renewable energy generation results in higher competition level on up-regulation and vice versa at low generation. This pattern would become more and more dominant in the intra-day market unless proactive actions are taken to reduce the cost of physical balancing of wind power. Therefore, bidding on the spot market is and will most likely be much more percentile based in the future to ensure that non-scheduled intra-day offers match the actual scheduled market volume better.

There are already traders who use percentile forecasts today in the market to avoid corrections to the expensive side. However, the benefit is getting more significant with increasing intra-day volume. There is an indirect relation to the previously mentioned daily tender of reserve, because reduction of the static reserve frees capacity, which is then all indirectly encouraged to bid into the intra-day market, at least during events where these parties are not competitive in the day-ahead spot market.

The IEIC is therefore expected to be an important contributor to the competitiveness of the energy system. Changing something to be able to act more competitive with a new approach can be a challenge in a running system. Nevertheless, some renewable energy traders are in the process of getting IEIC into their system. A number of factors such as competition, more flexibility in the spot bid, reduced risk, simplicity and comprehensiveness for automatic systems will lead to a wider usage of IEIC. For ease of testing, we have therefore developed a range of web-services in this project that greatly enhance and accelerate the later implementation of IEIC in existing environments.

1.3.2 Moving flexible generation from Spot to Intra-day market

A growing renewable energy penetration will even without IEIC put the spot market price under pressure. This will encourage the renewable energy traders to act as price makers with block bids, where the basis for the price evaluation will be ensemble forecast based on "demand – wind - solar" and for the online controlled part of own generation. Absence of price makers during hours of high renewable energy penetration lower the market value of renewable energy and prevent a gradual transition to renewable energy on real market terms. So on the one hand scheduled generators should be put under pressure in the market, but the spot price should stay at a level where there is still economic feasibility of energy generation.

The importance of a more dynamic energy market is related to the impossible task of matching electricity generation based on a natural resource with a diurnal and weekly cycle. In earlier days, the match was simple, because the generation was determined by the clock and calendar. The fraction of energy generation following this pattern is shrinking day by day due to the huge expansion of solar energy generation and further expansion of wind power and to some extend also an increasing heat demand via heat pumps. The deficit between demand and non-scheduled generation is getting a more and more complex function, where the energy systems with storage facilities have the highest potential for optimisation. One can say that the more static the energy market is kept, the more expensive energy becomes, mainly because of the mismatch between natural generation and demand. Therefore, all initiatives facilitating conversion of static generation to dynamic generation lead to more competitiveness.

There are good physical explanations of why the energy production should not be planned exclusively from the daily spot market auction. The simple explanation is that we need to reserve flexible generation capacity to step in at higher prices in the intra-day market instead of letting the flexible generation run after fixed schedules out of convenience and at low price based on a day-ahead spot auction.

Local shared ownership without much market insight and local competition are major obstacles towards a dynamic market, where we rather need the renewable energy units to win as many contracts in the day-ahead spot market as possible.

This is mainly to ensure that lack of or over-production of renewable energy on short notice is not only compensated by reserve, because there was no volume in the intraday market.

Also, if we want to ensure that investments in fast reacting gas plants remain feasible in the future, these units have to be sure of enough production hours at a certain price level, which may no longer be achievable in the day-ahead spot market in the future.

Another reason for not using day-ahead spot markets only, is that an hourly auction over an enlarged area can not sustained deliver an optimal solution hour by hour. A small change in the competition level from one hour to the next may lead to rather different solutions. This means high inertia power generation cannot always expect a continuous operation and must account for stops and starts in their bid. The result is higher energy prices. In a dynamic trading schedule, they can be circumvented by using the afternoon volume in the intra-day market.

Although the development of the IEIC trading scheme seem at first glance targeted only for renewable energy handling, it's side effect of increased intra-day market volume will benefit all units and yet make sure that the prices of electricity follow sensible rules. In fact, with the incremental IEIC trading approach, it is possible to ensure enough generation hours for flexible gas based generation above the spot market price and prevent that high inertia generation is used inefficient. This is a key issue for the future of all European country's electricity generation asset planning, not only Denmark's.

1.3.3 Practical Application of IEIC

One very interesting aspect is that the users of the MSEPS+iEnKF+IEIC technique only need to focus on very few output parameters from the system and in fact do not even have to consider how the system works. With the condensed output that the IEIC tool generates, it is possible to work with a highly advanced and efficient forecast tool in the same way as we today drive cars with sophisticated electronics taking care of many aspects of driving without us understanding the details behind most of the features we use. Sometimes the driver may need to checkout on a detail in the control panel.

The same is required for a trader. For this purpose, we have developed ELFI (ELectricity Forecast Interface), which is a modern web interface based on LAMP technology. This is Linux, Apache, MySQL and PhP to view and inquire real-time and historic forecast and measurement data via a web-browser interface.

ELFI is operated with transaction times of 0.15 seconds for advanced on demand queries and provides access to a range of relevant probabilistic products related to the electrical system, raw weather variables as well in area integrated parameters. An example of the total sum of Danish and German wind and solar power can be seen in Figure 2.

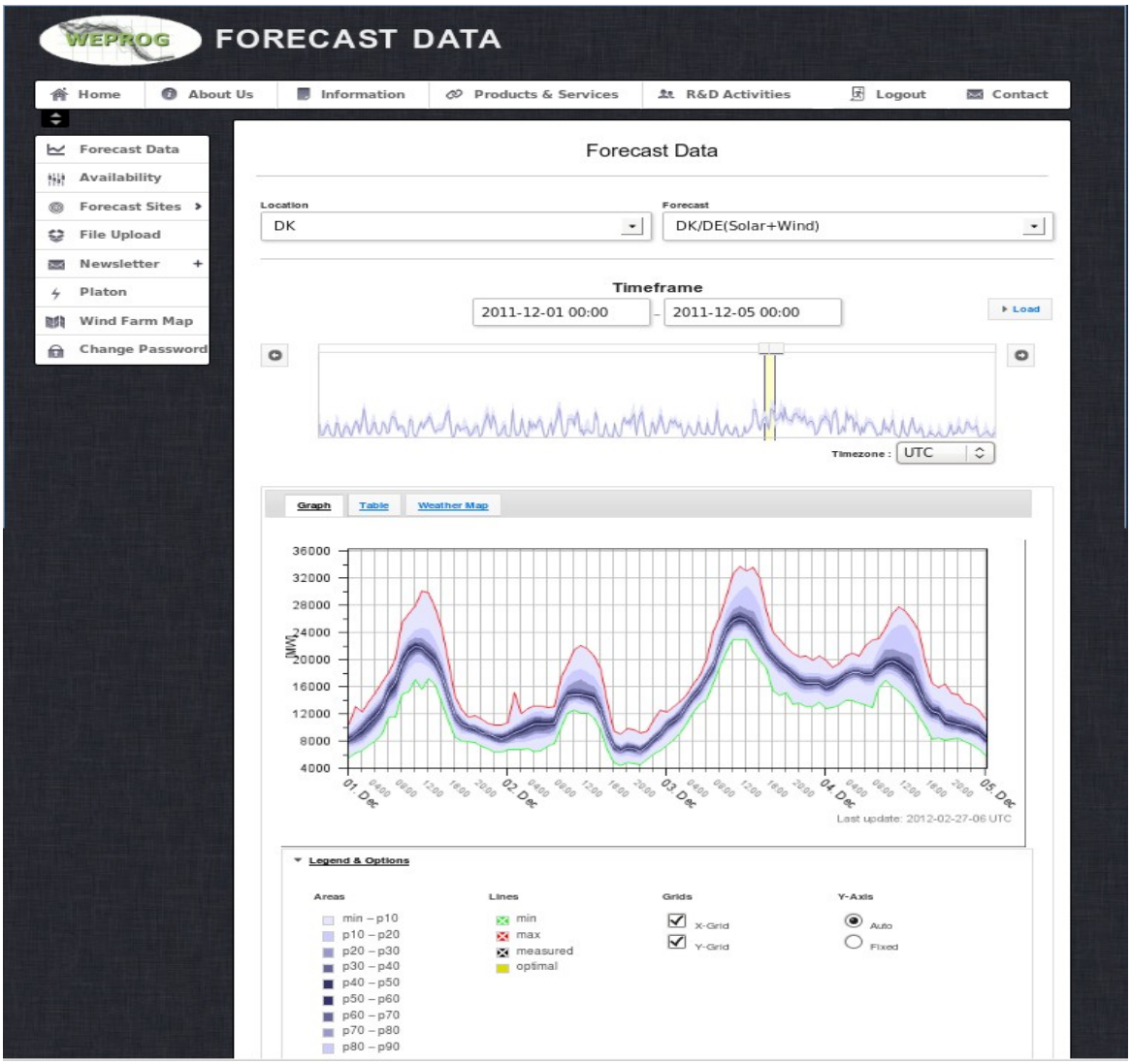

Figure 2: Example of a ELFI plot for the total wind and solar power in Denmark and Germany.

The design of the MySQL database allows for world wide dissemination of probabilistic forecasts of all weather- and power system forecasts. Dissemination is facilitated via the Hemispheric MSEPS setup and the historic forecast database generated during the project.

1.4 Development of an extended MSEPS ensemble

At the outset of the project, a number of case studies and a forecast sensitivity study were performed. The selected events were all characterised by large errors and/or extreme prices. The extreme events were selected, because it was found that relatively few hours often contribute considerable to the total balance costs. The lesson from these events were that the predictability was so poor that one cannot expect to hit right in a real-time environment. In both cases, we found that out of 1000 weather simulations either few or none of the models could generate a correct result.

This is an important realization, because this means that in the future energy system it will be more important to make realistic ensemble spread than trying to optimize on an average error target in power, if we cannot be sure that the forecasts can always give a realistic indication of the future. The forecasts that are required for minimum cost optimisation must therefore be able to show the uncertainty to the trader such that the cost of the sometimes inevitable error can be minimized by a defensive bid, evaluated in terms of expected costs.
In fact, it is also possible to argue for the defensive strategy in terms of physical imbalance. By looking at the error statistics of the plain average of a number of independent forecasts, we find lower imbalance for the averaged forecast than for each of the individual. This result indicates that focus on ensemble spread will not compromise the forecast error in power too much, because the defensive smooth forecast will catch up during low predictability anyway.
The defensive forecast approach is therefore a requirement seen from these two complementary perspectives. With this in mind, we developed an extended MSEPS system with emphasis on improved ensemble spread of the resulting super ensemble. The enhancements are a result of evaluating more than 1000 model simulations for the year 2009 and 2010.

The extended ensemble differs from the standard MSEPS on the use of:

1. Perturbed Planetary Boundary Layer analysis increments
2. Multiple spatial resolutions with one order of magnitude in difference
3. Multiple model domain sizes
4. Multiple definitions of roughness and orography
5. Coupling of variations of lateral boundary- and ensemble members
6. A 4-dimensional analysis increment technique
7. Independent statistical training data

The standard MSEPS uses a single model formulation of all of the above items, while the extended MSEPS has a minimum of three different formulations on each member. The potential for improvements has thereby increased both on the possibility to predict valid spread and also on the quality of the traditional single forecast.

2 Demonstration and Results

The extended MSEPS was run from the 1st July 2011 to the 15th of December 2011 in highly variable weather. There were very few calm and dry periods. There were hardly summer and winter conditions included due to abnormal climatic conditions in the beginning and end of the period.

Traditional statistical verification of almost 6 months demonstration resulted in 12% less error in both DK1 and DK2 on all tested error measures compared to a reference 75 member setup without the developed enhancements in the project. This is a significant improvement. From the study of these results, we identified two more enhancements that will be implemented in the next version of the extended MSEPS. One improvement is better utilization of the relative performance of the individual forecasts. Another improvement lies in reduced dependence of the ensemble mean in the statistical calibration. These changes are a required step forward, because of the increased ensemble spread in the enhanced system.

Although the enhanced system comprises 115 ensemble forecasts, it was found that the numerical stability was good and feasible to run as a real-time system. The winter 2011-2012 turned out to be rather of extreme weather in December.

The strong wind of nearly 400km/h at jet level over Denmark did have a negative impact on the numerical stability of some of the 24 members in the highest spatial resolution. The period was extreme, because of unusual high gust factors due to a very unstable troposphere under the jet. The conclusion was that a number of reruns are required to tune the frictional processes to withstand such extreme jet level wind speeds even though they are very rare.

The achieved improvement and the potential further improvement from deploying the two enhancements indicate that the extended MSEPS is an important milestone. The results indicate strongly that the standard MSEPS misses some important ensemble spread in certain weather situations.
This does not mean that the standard MSEPS is under-dispersive, but that the native spread sometimes does not occur for the correct reason and therefore may not correlate as well with the actual forecast error. The standard MSEPS can be understood as a 75 member ensemble where three different processes of the weather forecast are formulated with respectively 5 or 3 different numerical formulations (5x5x3). The members run independent, thus, their initial conditions also differ from each other. In the extended MSEPS ensemble, the differences between the members are still well defined. While the standard MSEPS members differ in at the most 3 ways from each other, the members in the extended MSEPS can have up to 7 static differences.

The potential application of the developments is shown in Figure 3 by use of coloured text and arrows. The upper right box elements indicate the DEWEPS developments on the MSEPS system. The lower right box show the impacted central services, while the left box focus on the impacted services at the typical market participant. The arrow and text colours are chosen to highlight the connection between the DEWEPS development and the utilization in WEPROG's real-time system.
The off-line data flow to the right represent data used for calibration of the tools. The physical location of IEIC is not restricted to stay within the MSEPS framework, because IEIC is tied closer to the market than the MSEPS system.

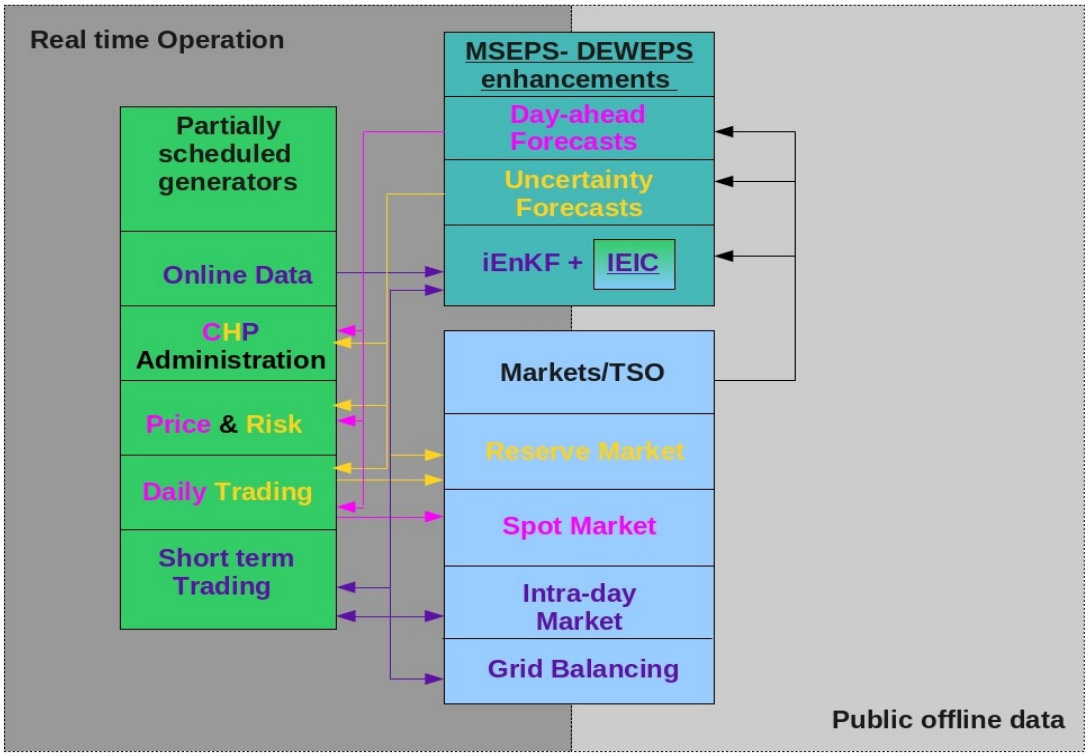

Figure 3: Schema of the applications in the forecasting process, where the project developments are deployed.

3 Outlook

The combined effects of the extended MSEPS, the incremental IEIC tool and the associated web-service technology plus access to detailed probabilistic forecasts via ELFI can be seen as a significant step forward in the deployment of probabilistic forecasting tools for the energy market.

There are three targets associated with these new tools: (1) generation of stronger competition from renewable energy in the spot market, (2) get more parties to understand the necessity to iterate the balance during the intra-day market in order to open for increased market volume and (3) encourage flexible units to participate in the 24 hour intra-day market in order to balance the renewable energy as a replacement of semi-automatic centralized reserve usage at higher prices.

To become an active participant in the intra-day market seems at first glance certainly a major change to the worse in terms of complexity and risk. As the efficiency grows, we will see less volume per offer, but many more offers generated by automatic processes. This will lead to much improved total system balance and reduced need of static reserve with additional benefits on total costs of electricity generation. From a long distance perspective it is obvious that flexibility has to be awarded by late contracts at higher prices and those units must operate with a short look-ahead time.

As part of the demonstration, we found out when meeting with some of the flexible CHP generators that they at this stage seem to be reluctant to centralize their operation and hand over to their balance responsible party. Considering our findings in this project, this evolution however seems inevitable. Renewable energy units will push them out of the spot market and dynamic prediction of reserve will in the long run mean less reserve allocation. Instead, the production possibilities will lie in the 24-hour operation in the intra-day market. From this perspective, the small units should be the first to change their operation and be managed remotely by their balance responsible party.

Successful evolution of the energy system requires that the fossil fuel generators adopt to market principles, so that increasing non-scheduled generators can act as an insurance mechanism against high average prices.

In this project, we have developed some important and crucial tools to assist in the market evolution towards a dynamic energy system based on large amounts of renewable energy generation in the future.

Acknowledgement

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Project Publications

Journal Publication:

Möhrlen,C., Pahlow, M., Jørgensen, J.U. (2012): Untersuchung verschiedener Handelsstrategien für Wind-und Solarenergie unter Berücksichtigung der EEG 2012 Novellierung, Zeitschrift f. Energiewirtschaft, No. 1/2012, Vol.36, No.1.

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Author's Version:http://download.weprog.com/WEPROG_Handelsstrategien_EEG2012_ZEFE_71-2012-01.pdf

ENGLISH TRANSLATION of full manuscript by Authors: Investigation of various trading strategies for wind and solar power developed for the new EEG 2012 rules.

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